Green River Water Quality Model: Boundary Conditions and Model Setup

DRAFT

June 2003

King County
Department of Natural Resources and Parks
Water and Land Resources Division

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Prepared for:

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Table of Contents

Table of Contents iii
Table of Tables iv
Table of Figures v
Acknowledgements 14
Introduction 15
The Green-Duwamish Watershed 16
Prior Green River Models 17
Model Geometry 18
Bathymetry Data 18
Middle Green 18
Lower Green 18
Model Grid Development 19
Model Simulation Time Period 22
Water Quality 24
Model Boundary Conditions 26
Upstream Boundary 27
May 25, 1995 – November 1996 27
April 2001 –July 2002 34
Downstream Boundary 43
May 25, 1995 – November 1996 43
April 2001 – July 2002 49
Tributaries 55
Newaukum Creek 56
May 1995 – Nov 1996 56
April 2001 – July 2002 63
Crisp Creek 69
May 25, 1995 – November 1996 69
April 2001 – July 2002 75
Big Soos Creek 80
May 25, 1995 – Nov 1996 80
April 2001 – July 2002 86

Mill Creek 91
May 25, 1995 – November 1996 91
April 2001 – July 2002 96
Auburn Creek, Mullen Slough, and Midway Creek 101
May 25, 1995 – November 1996 101
April 2001 – Nov 2002 103
Groundwater 105
Distributed Tributaries 107
May 25, 1995 – Nov 1996 107
April 2001 - July 2002 110
Meteorological Data 112
May 25, 1995 - Nov 1996 113
April 2001 - July 2002 115
Shading 119
Summary 120
References 121
Appendix A: Upstream and Tributary Flow, Temperature, and Water Quality Data 123
Upstream Boundary Data 123
Downstream Boundary Data 127
Newaukum Creek Data 132
Crisp Creek Data 136
Big Soos Creek Data 140
Mill Creek Data 145
Mullen Slough, Midway Creek, and Auburn Creek 150
Appendix B: Water Quality Longitudinal Profiles 152
Appendix C: Travel Time Analysis 157
Appendix D: Water Quality Procedures 160
Appendix E: Data Gap Memo 163
Appendix F: Station and Gage Locations 168

Table of Tables

Table 1: Water Body Characteristics 21

Table 2: Temperature Data Summary 23
Table 3: Temperature gages at modeling locations 24
Table 4: Water Quality Monitoring Sites 25
Table 5: Water Quality Constituents sampled by King County 25
Table 6: Water Quality Constituents to be modeled 26
Table 7: Tributary River Miles and Segment Numbers 56
Table 8: Groundwater Inflows per Branch 106
Table 9: Basin MG1 Distributed Tributary 107
Table 10: Flow/Temperature/Water Quality Stations Used; May 1995 - Nov 1996 168
Table 11: Flow/Temperature/Water Quality Stations Used; April 2001 - July 2002 168

Table of Figures

Figure 1: Green River Vicinity Map 15
Figure 2: Green River and Major Tributaries 17
Figure 3: New River Channel Locations 19
Figure 4: Profile of Green River Channel Bottom 20
Figure 5: Model Grid Layout 21
Figure 6: Dissolved Oxygen Longitudinal Profile 26
Figure 7: Green River HSPF Basins 28
Figure 8: Green River Flow at Upstream Boundary: May 1995 to November 1996 28
Figure 9: Correlation between Stations WHI and 54a 29
Figure 10: Upstream Boundary: Station versus Correlated Data, 1995-1996 30
Figure 11: Green River Temperature at Upstream Boundary: May 1995 to November 1996 30
Figure 12: Ortho phosphorus at Upstream Boundary: May 1995 to November 1996 31
Figure 13: Ammonia at Upstream Boundary: May 1995 to November 1996 31
Figure 14: Nitrate-Nitrate at Upstream Boundary: May 1995 to November 1996 31
Figure 15: DO at Upstream Boundary: May 1995 to November 1996 31
Figure 16: ISS at Upstream Boundary: May 1995 to November 1996 32
Figure 17: Alkalinity at Upstream Boundary: May 1995 to November 1996 32
Figure 18: Conductivity at Upstream Boundary: May 1995 to November 1996 32
Figure 19: LDOM at Upstream Boundary: May 1995 to November 1996 32
Figure 20: RDOM at Upstream Boundary: May 1995 to November 1996 33

Figure 21: LPOM at Upstream Boundary: May 1995 to November 1996 33
Figure 22: RPOM at Upstream Boundary: May 1995 to November 1996 33
Figure 23: Algae at Upstream Boundary: May 1995 to November 1996 33
Figure 24: pH at Upstream Boundary: May 1995 to November 1996 34
Figure 25: TIC at Upstream Boundary: May 1995 to November 1996 34
Figure 26: Fecal Coliform at Upstream Boundary: May 1995 - Nov 1996 34
Figure 27: Green River Flow at Upstream Boundary: Apr 2001 – July 2002 35
Figure 28: Correlation between Stations GR5 and GR3-4 35
Figure 29: Upstream Boundary: Station Data versus Correlated Data, 2001-2002 36
Figure 30: Correlation between Stations GRT10 and GR3-4 37
Figure 31: Upstream Boundary: Station Data versus Correlated Data, 2001-2002 37
Figure 32: Correlation between Crisp Creek Temperature and U/S boundary stations 38
Figure 33: Upstream Boundary: Station versus correlated data, 2001-2002 38
Figure 34: Green River Temperature at Upstream Boundary: Apr 2001 – July 2002 39
Figure 35: Ortho phosphorus at Upstream Boundary: Apr 2001 – July 2002 39
Figure 36: Ammonia at Upstream Boundary: Apr 2001 – July 2002 39
Figure 37: Nitrate-Nitrite at Upstream Boundary: Apr 2001 – July 2002 40
Figure 38: DO at Upstream Boundary: Apr 2001 – July 2002 40
Figure 39: ISS at Upstream Boundary: Apr 2001 – July 2002 40
Figure 40: Alkalinity at Upstream Boundary: Apr 2001 – July 2002 40
Figure 41: Conductivity at Upstream Boundary: Apr 2001 - July 2002 41
Figure 42: LDOM at Upstream Boundary: Apr 2001 - July 2002 41
Figure 43: RDOM at Upstream Boundary: Apr 2001 – July 2002 41
Figure 44: LPOM at Upstream Boundary: Apr 2001 – July 2002 41
Figure 45: RPOM at Upstream Boundary: Apr 2001 - July 2002 42
Figure 46: Algae at Upstream Boundary: Apr 2001 – July 2002 42
Figure 47: pH at Upstream Boundary: Apr 2001 - July 2002 42
Figure 48: TIC at Upstream Boundary: Apr 2001 – July 2002 42
Figure 49: Fecal Coliform at Upstream Boundary: Apr 2001 - July 2002 43
Figure 50: Stage at downstream boundary 43
Figure 51: Correlation between Big Soos Temperature and D/S boundary station 44
Figure 52: Downstream Boundary: Station versus correlated data, 1995-1996 44
Figure 53: Green River Temperature at Downstream Boundary: May 25, 1995 – Nov 1996 45

Figure 54: Ortho phosphorus at Downstream Boundary: May 1995 to November 1996 45
Figure 55: Ammonia at Downstream Boundary: May 1995 to November 1996 46
Figure 56: Nitrate-Nitrite at Downstream Boundary: May 1995 to November 1996 46
Figure 57: DO at Downstream Boundary: May 1995 to November 1996 46
Figure 58: ISS at Downstream Boundary: May 1995 to November 1996 46
Figure 59: Alkalinity at Downstream Boundary: May 1995 to November 1996 47
Figure 60: Conductivity at Downstream Boundary: May 1995 to November 1996 47
Figure 61: LDOM at Downstream Boundary: May 1995 to November 1996 47
Figure 62: RDOM at Downstream Boundary: May 1995 to November 1996 47
Figure 63: LPOM at Downstream Boundary: May 1995 to November 1996 48
Figure 64: RPOM at Downstream Boundary: May 1995 to November 1996 48
Figure 65: Algae at Downstream Boundary: May 1995 to November 1996 48
Figure 66: pH at Downstream Boundary: May 1995 - November 1996 48
Figure 67: TIC at Downstream Boundary: May 1995 to November 1996 49
Figure 68: Fecal Coliform at Downstream Boundary: May 1995 to November 1996 49
Figure 69: Green River Stage at Downstream Boundary: May 25, 1995 – Nov 1996 50
Figure 70: Correlation between Station GR1 and D/S boundary station GRT18 50
Figure 71: Downstream Boundary: Station versus correlated data, 2001-2002 51
Figure 72: Green River Temperature at Downstream Boundary: Apr 2001 – July 2002 51
Figure 73: Ortho phosphorus at Downstream Boundary: Apr 2001 – July 2002 52
Figure 74: Ammonia at Downstream Boundary: Apr 2001 – July 2002 52
Figure 75: Nitrate-Nitrite at Downstream Boundary: Apr 2001 – July 2002 52
Figure 76: DO at Downstream Boundary: Apr 2001 – July 2002 52
Figure 77: ISS at Downstream Boundary: Apr 2001 – July 2002 53
Figure 78: Alkalinity at Downstream Boundary: Apr 2001 – July 2002 53
Figure 79: Conductivity at Downstream Boundary: Apr 2001 – July 2002 53
Figure 80: LDOM at Downstream Boundary: Apr 2001 – July 2002 53
Figure 81: RDOM at Downstream Boundary: Apr 2001 – July 2002 54
Figure 82: LPOM at Downstream Boundary: Apr 2001 – July 2002 54
Figure 83: RPOM at Downstream Boundary: Apr 2001 – July 2002 54
Figure 84: Algae at Downstream Boundary: Apr 2001 – July 2002 54
Figure 85: pH at Downstream Boundary: Apr 2001 - July 2002 55
Figure 86: TIC at Downstream Boundary: Apr 2001 – July 2002 55

Figure 87: Fecal Coliform at Downstream Boundary: Apr 2001 - July 2002 55
Figure 88: Modeled Tributaries to Green River 56
Figure 89: Newaukum Creek Flow: May 25, 1995 – Nov 1996 57
Figure 90: Correlation between Big Soos Temperature and Newaukum Creek station 58
Figure 91: Newaukum Creek: Station versus correlated data, 1995-1996 58
Figure 92: Newaukum Creek Temperature: May 25, 1995 – Nov 1996 59
Figure 93: Ortho phosphorus Newaukum Creek: May 25, 1995 – Nov 1996 59
Figure 94: Ammonia Newaukum Creek: May 25, 1995 – Nov 1996 59
Figure 95: Nitrate-Nitrite Newaukum Creek: May 25, 1995 – Nov 1996 60
Figure 96: DO Newaukum Creek: May 25, 1995 – Nov 1996 60
Figure 97: ISS Newaukum Creek: May 25, 1995 – Nov 1996 60
Figure 98: Alkalinity Newaukum Creek: May 25, 1995 – Nov 1996 60
Figure 99: Conductivity Newaukum Creek: May 25, 1995 – Nov 1996 61
Figure 100: LDOM Newaukum Creek: May 25, 1995 – Nov 1996 61
Figure 101: RDOM Newaukum Creek: May 25, 1995 – Nov 1996 61
Figure 102: LPOM Newaukum Creek: May 25, 1995 – Nov 1996 61
Figure 103: RPOM Newaukum Creek: May 25, 1995 – Nov 1996 62
Figure 104: Algae Newaukum Creek: May 25, 1995 – Nov 1996 62
Figure 105: pH Newaukum Creek: May 25, 1996 - Nov 1996 62
Figure 106: TIC Newaukum Creek: May 25, 1995 – Nov 1996 62
Figure 107: Fecal Coliform Newaukum Creek: May 25, 1995 - Nov 1996 63
Figure 108: Newaukum Creek Flow: Apr 2001 – July 2002 63
Figure 109: Correlation between Crisp Creek and Newaukum Creek Temperature 64
Figure 110: Station versus correlated data, 2001-2002 64
Figure 111: Newaukum Creek Temperature: Apr 2001 – July 2002 65
Figure 112: Ortho phosphorus Newaukum Creek: Apr 2001 – July 2002 65
Figure 113: Ammonia Newaukum Creek: Apr 2001 – July 2002 65
Figure 114: Nitrate-Nitrite Newaukum Creek: Apr 2001 – July 2002 66
Figure 115: DO Newaukum Creek: Apr 2001 – July 2002 66
Figure 116: ISS Newaukum Creek: Apr 2001 – July 2002 66
Figure 117: Alkalinity Newaukum Creek: Apr 2001 – July 2002 66
Figure 118: Conductivity Newaukum Creek: Apr 2001 – July 2002 67
Figure 119: LDOM Newaukum Creek: Apr 2001 – July 2002 67

Figure 120: RDOM Newaukum Creek: Apr 2001 – July 2002 67
Figure 121: LPOM Newaukum Creek: Apr 2001 – July 2002 67
Figure 122: RPOM Newaukum Creek: Apr 2001 – July 2002 68
Figure 123: Algae Newaukum Creek: Apr 2001 – July 2002 68
Figure 124: pH Newaukum Creek: Apr 2001 - July 2002 68
Figure 125: TIC Newaukum Creek: Apr 2001 – July 2002 68
Figure 126: Fecal Coliform Newaukum Creek: Apr 2001 - July 2002 69
Figure 127: Crisp Creek Flow: May 25, 1995 – Nov 1996 69
Figure 128: Correlation between Big Soos Temperature and Crisp Creek 70
Figure 129: Crisp Creek: Station versus correlated data, 1995-1996 70
Figure 130: Crisp Creek Temperature: May 25, 1995 – Nov 1996 71
Figure 131: Ortho phosphorus Crisp Creek: May 25, 1995 – Nov 1996 71
Figure 132: Ammonia Crisp Creek: May 25, 1995 – Nov 1996 72
Figure 133: Nitrate-Nitrite Crisp Creek: May 25, 1995 – Nov 1996 72
Figure 134: DO Crisp Creek: May 25, 1995 – Nov 1996 72
Figure 135: ISS Crisp Creek: May 25, 1995 – Nov 1996 72
Figure 136: Alkalinity Crisp Creek: May 25, 1995 - Nov 1996 72
Figure 137: Conductivity Crisp Creek: May 25, 1995 – Nov 1996 73
Figure 138: LDOM Crisp Creek: May 25, 1995 – Nov 1996 73
Figure 139: RDOM Crisp Creek: May 25, 1995 – Nov 1996 73
Figure 140: LPOM Crisp Creek: May 25, 1995 – Nov 1996 73
Figure 141: RPOM Crisp Creek: May 25, 1995 – Nov 1996 74
Figure 142: Algae Crisp Creek: May 25, 1995 – Nov 1996 74
Figure 143: pH Crisp Creek: May 25, 1995 - Nov 1996 74
Figure 144: TIC Crisp Creek: May 25, 1995 – Nov 1996 74
Figure 145: Fecal Coliform Crisp Creek: May 25, 1995 - Nov 1996 75
Figure 146: Crisp Creek Flow: Apr 2001 – July 2002 75
Figure 147: Crisp Creek Temperature: Apr 2001 – July 2002 76
Figure 148: Ortho phosphorus Crisp Creek: Apr 2001–July 2002 76
Figure 149: Ammonia Crisp Creek: Apr 2001–July 2002 77
Figure 150: Nitrate-Nitrite Crisp Creek: Apr 2001–July 2002 77
Figure 151: DO Crisp Creek: Apr 2001–July 2002 77
Figure 152: ISS Crisp Creek: Apr 2001–July 2002 77

Figure 153: Alkalinity Crisp Creek: Apr 2001–July 2002 77
Figure 154: Conductivity Crisp Creek: Apr 2001–July 2002 78
Figure 155: LDOM Crisp Creek: Apr 2001–July 2002 78
Figure 156: RDOM Crisp Creek: Apr 2001–July 2002 78
Figure 157: RPOM Crisp Creek: Apr 2001–July 2002 78
Figure 158: LPOM Crisp Creek: Apr 2001–July 2002 79
Figure 159: LDOM Crisp Creek: Apr 2001–July 2002 79
Figure 160: pH Crisp Creek: Apr 2001-July 2002 79
Figure 161: TIC Crisp Creek: Apr 2001–July 2002 79
Figure 162: Fecal Coliform Crisp Creek: Apr 2001 - July 2002 80
Figure 163: Big Soos Creek Flow: May 25, 1995 – Nov 1996 80
Figure 164: Correlation between Big Soos Creek and Station BIC 81
Figure 165: Big Soos Creek: Station data versus correlated values, 1995 - 1996 81
Figure 166: Big Soos Creek Temperature: May 25, 1995 – Nov 1996 82
Figure 167: Ortho phosphorus Big Soos Creek: May 25, 1995 – Nov 1996 82
Figure 168: Ammonia Big Soos Creek: May 25, 1995 – Nov 1996 82
Figure 169: Nitrate-Nitrite Big Soos Creek: May 25, 1995 – Nov 1996 83
Figure 170: ISS Big Soos Creek: May 25, 1995 – Nov 1996 83
Figure 171: Big Soos: DO Creek: May 25, 1995 – Nov 1996 83
Figure 172: Alkalinity Big Soos Creek: May 25, 1995 – Nov 1996 83
Figure 173: Conductivity Big Soos Creek: May 25, 1995 – Nov 1996 84
Figure 174: LDOM Big Soos Creek: May 25, 1995 – Nov 1996 84
Figure 175: RDOM Big Soos Creek: May 25, 1995 – Nov 1996 84
Figure 176: LPOM Big Soos Creek: May 25, 1995 – Nov 1996 84
Figure 177: RPOM Big Soos Creek: May 25, 1995 – Nov 1996 85
Figure 178: Algae Big Soos Creek: May 25, 1995 – Nov 1996 85
Figure 179: pH Big Soos Creek: May 25, 1995 - Nov 1996 85
Figure 180: TIC Big Soos Creek: May 25, 1995 – Nov 1996 85
Figure 181: Fecal Coliform: May 25, 1995 - Nov 1996 86
Figure 182: Big Soos Creek Flow: Apr 2001 – July 2002 86
Figure 183: Big Soos Temperature: Apr 2001 – July 2002 87
Figure 184: Ortho Phosphorus Big Soos: Apr 2001 – July 2002 87
Figure 185: Ammonia Big Soos: Apr 2001 – July 2002 87

Figure 186: Nitrate-Nitrite Big Soos: Apr 2001 – July 2002 88
Figure 187: DO Big Soos: Apr 2001 – July 2002 88
Figure 188: ISS Big Soos: Apr 2001 – July 2002 88
Figure 189: Alkalinity Big Soos: Apr 2001 – July 2002 88
Figure 190: Conductivity Big Soos: Apr 2001 – July 2002 89
Figure 191: LDOM Big Soos: Apr 2001 – July 2002 89
Figure 192: RDOM Big Soos: Apr 2001 – July 2002 89
Figure 193: LPOM Big Soos: Apr 2001 – July 2002 89
Figure 194: RPOM Big Soos: Apr 2001 – July 2002 90
Figure 195: Algae Big Soos: Apr 2001 – July 2002 90
Figure 196: pH Big Soos: Apr 2001 - July 2002 90
Figure 197: TIC Big Soos: Apr 2001 – July 2002 90
Figure 198: Fecal Coliform Big Soos: Apr 2001 - July 2002 91
Figure 199: Mill Creek Flow Comparison 92
Figure 200: Mill Creek Flow: May 25, 1995 – Nov 1996 92
Figure 201: Ortho phosphorus Mill Creek: May 25, 1995 – Nov 1996 93
Figure 202: Ammonia Mill Creek: May 25, 1995 – Nov 1996 93
Figure 203: Nitrate-Nitrite Mill Creek: May 25, 1995 – Nov 1996 93
Figure 204: DO Mill Creek: May 25, 1995 – Nov 1996 93
Figure 205: ISS Mill Creek: May 25, 1995 – Nov 1996 94
Figure 206: Alkalinity Mill Creek: May 25, 1995 – Nov 1996 94
Figure 207: Conductivity Mill Creek: May 25, 1995 – Nov 1996 94
Figure 208: LDOM Mill Creek: May 25, 1995 – Nov 1996 94
Figure 209: RDOM Mill Creek: May 25, 1995 – Nov 1996 95
Figure 210: LPOM Mill Creek: May 25, 1995 – Nov 1996 95
Figure 211: RPOM Mill Creek: May 25, 1995 – Nov 1996 95
Figure 212: Algae Mill Creek: May 25, 1995 – Nov 1996 95
Figure 213: pH Mill Creek: May 25, 1995 - Nov 1996 96
Figure 214: TIC Mill Creek: May 25, 1995 – Nov 1996 96
Figure 215: Fecal Coliform: May 25, 1995 - Nov 1996 96
Figure 216: Mill Creek Flow: Apr 2001 – July 2002 97
Figure 217: Mill Creek Temperature: Apr 2001 – July 2002 97
Figure 218: Ortho phosphorus Mill Creek: Apr 2001-July 2002 98

Figure 219: Ammonia Mill Creek: Apr 2001-July 2002 98
Figure 220: Nitrate-Nitrite Mill Creek: Apr 2001-July 2002 98
Figure 221: DO Mill Creek: Apr 2001-July 2002 98
Figure 222: ISS Mill Creek: Apr 2001-July 2002 99
Figure 223: Alkalinity Mill Creek: Apr 2001-July 2002 99
Figure 224: Conductivity Mill Creek: Apr 2001-July 2002 99
Figure 225: LDOM Mill Creek: Apr 2001-July 2002 99
Figure 226: RDOM Mill Creek: Apr 2001-July 2002 100
Figure 227: LPOM Mill Creek: Apr 2001-July 2002 100
Figure 228: RPOM Mill Creek: Apr 2001-July 2002 100
Figure 229: Algae Mill Creek: Apr 2001-July 2002 100
Figure 230: pH Mill Creek: Apr 2001 - July 2002 101
Figure 231: TIC Mill Creek: Apr 2001-July 2002 101
Figure 232: Fecal Coliform Mill Creek: Apr 2001 - July 2002 101
Figure 233: Auburn Creek Flow: May 25, 1995 – Nov 1996 (HSPF) 102
Figure 234: Mullen Slough Flow: May 25, 1995 – Nov 1996 (HSPF) 102
Figure 235: Midway Creek Flow: May 25, 1995 – Nov 1996 (HSPF) 103
Figure 236: Auburn Creek Flow: Apr 2001 – July 2002 104
Figure 237: Mullen Slough Flow: Apr 2001 – July 2002 104
Figure 238: Midway Creek Flow: Apr 2001 – July 2002 105
Figure 239: Groundwater Springs 106
Figure 240: Branch 2 Distributed Flow: May 25, 1995 – Nov 1996 107
Figure 241: Branch 3 Distributed Flow: May 25, 1995 – Nov 1996 108
Figure 242: Correlation between upstream boundary temperature and station “nee” 109
Figure 243: Distributed Tributary: Correlated versus station data 1995-1996 109
Figure 244: Distributed Tributary Temperature: May 25, 1995 – Nov 1996 110
Figure 245: Branch 2 Distributed Inflow: Apr 2001 – July 2002 110
Figure 246: Branch 3 Distributed Inflow: Apr 2001 – July 2002 111
Figure 247: Correlation between station Gr1 and station GRT04 111
Figure 248: Distributed tributary: Correlated versus station data 2001-2002 112
Figure 249: Distributed Tributary Temperature: Apr 2001 – July 2002 112
Figure 250: Air Temperature at Seattle-Tacoma International Airport 113
Figure 251: Dew Point Temperature at Seattle-Tacoma International Airport 113

Figure 252: Wind Speed at Seattle-Tacoma International Airport 114
Figure 253: Frequency of Wind Direction at Seattle-Tacoma International Airport..... 114
Figure 254: Cloud Cover at Seattle-Tacoma International Airport 115
Figure 255: Shortwave Solar Radiation for model calibration period..... 115
Figure 256: Air Temperature at Seattle-Tacoma International Airport 116
Figure 257: Dew Point Temperature at Seattle-Tacoma International Airport 116
Figure 258: Wind Speed at Seattle-Tacoma International Airport 116
Figure 259: Frequency of Wind Direction at Seattle-Tacoma International Airport..... 117
Figure 260: Cloud Cover at Seattle-Tacoma International Airport 117
Figure 261: Shortwave solar Radiation from Seattle ISIS Station 118
Figure 262: August 2002 flow data without travel time shift..... 157
Figure 263: August 2002 flow data shifted by 12 hours..... 158
Figure 264: May 2002 flow data without travel time shift 158
Figure 265: May 2002 flow data shifted by 12 hours..... 159
Figure 266: Data Monitoring Stations 169

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Introduction

The Green/Duwamish River is a major river system in King County, Washington. The watershed drains approximately 480 square miles (Green/Duwamish Ecosystem Restoration Study, 2003) as it travels from the Cascade Mountains and through the communities of Auburn, Kent, Tukwila, and Seattle.

The Green/Duwamish River system is unique in that it is located within a heavily urbanized and industrialized environment but still supports a large salmon population (Green/Duwamish Ecosystem Restoration Study, 2003). To protect the river and its prime salmon habitat (Green/Duwamish Ecosystem Restoration Study, 2003), King County and the US Army Corps of Engineers have joined together on a study to identify and implement strategies for restoring and protecting the Green/Duwamish River System and its tributaries (Green/Duwamish Ecosystem Restoration Study, 2003).

As part of the Green-Duwamish Watershed Water Quality Assessment Program, King County has contracted with Portland State University to develop a hydrodynamic and water quality model for the Lower and Middle Green Rivers. This model will be used in Total Maximum Daily Load (TMDL) development, in assessing current water quality conditions in the river, and as a planning tool for assessing future conditions. Figure 1 shows the upper and lower boundaries of the project.

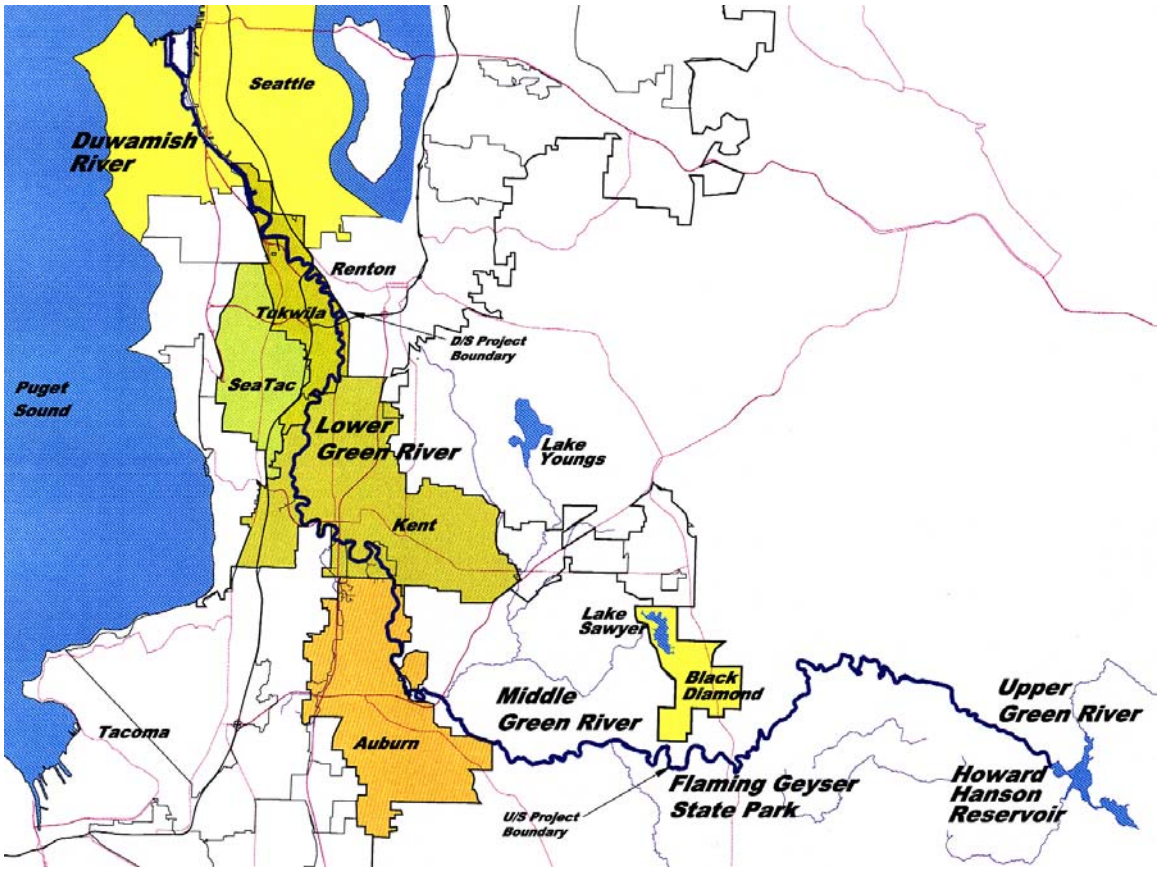

Figure 1: Green River Vicinity Map

The hydrodynamic and water quality model CE-QUAL-W2, Version 3.1 (Cole and Wells, 2002) will be applied to the river between Flaming Geyser State Park (RM 45.0) and the confluence with the Duwamish River, near Tukwila (RM 11.20).

In order to model the system, the following data are required:

- Bathymetry of the river
- In-stream flow, temperature, and water quality data
- Flow, temperature, and water quality characteristics for major tributaries and point sources
- Stage data and tidal information
- Meteorological conditions

Many local, state and federal agencies have been collecting data on the Green River. This report reviews the available data, provides an analysis of the data to determine model simulation periods, and documents procedures used in assembling model boundary conditions and tributary data.

The Green-Duwamish Watershed

The headwaters of the Green River are located in the Cascade Mountains east of Tacoma, WA. There are 2 reservoirs on the Upper Green River: Howard Hanson Reservoir, which was constructed by the Army Corps of Engineers in the early 1960's as flood control protection for communities on the lower flood plain, and a diversion dam, located 3 miles below Howard Hanson Reservoir, which diverts water for the city of Tacoma. The watershed above to this dam is protected, and entry is prohibited (U.S. Army Corps of Engineers, 2003).

The Middle Green River begins below the diversion dam and continues downstream to the city of Auburn, WA. Major tributaries include Newaukum Creek, Crisp Creek, and Big Soos Creek, which is the largest tributary to the Green River. The surrounding landscape is primarily farming, production forestry and state parks, but residential development is growing in the region. The tributary creeks to the Middle Green River continue to support prime salmon habitat (Middle Green River Sub-Watershed, 2003). See Figure 2 for the location of these tributaries.

The Lower Green River continues from Auburn to the confluence with the Duwamish River, in the town of Tukwila. The Lower Green River watershed is heavily urbanized with commercial and industrial development. There is an extensive dike and levee system on the Lower Green protecting the surrounding area from flooding. There are a number of smaller tributaries that contribute flow to the Lower Green, including Auburn, Mill, and Midway Creeks, and Mullen Slough. The Lower Green is tidally influenced up the Duwamish River from Elliot Bay.

The Lower Green suffers from habitat loss and stream degradation issues common with urbanized streams. Restoration efforts have begun in many places on the Lower Green and many programs, including the Green-Duwamish Water Quality Assessment Program of which this study is apart, are in place to plan and conduct restoration projects (Lower Green River Sub-Watershed, 2003; Green/Duwamish Early Action Habitat Projects, 2003; The Green/Duwamish Ecosystem Restoration Study, 2003).

The White River used to follow the current path of the Green River, and the Green River used to flow into the White River until 1906 when a debris jam blocked the White River and diverted it south. A permanent diversion structure replaced the log jam, and now the Green River flows north to the Duwamish without contributions from the White River (White River Watershed Facts, 2003).

The Black River used to flow out of Lake Washington, join with the Cedar River, and then flow into the Duwamish at the confluence with the White River. When Lake Washington was lowered in 1917, the river system was changed so the Cedar River flows into the lake, and the lake now discharges through Lake Union and the Lake Washington Shipping Canal. The Black River is now a small creek no longer connected to Lake Washington or Cedar River (EPA, 2002).

Today only the Green River feeds the Duwamish. The Duwamish River discharges into the southern tip of Elliot Bay, which is part of Puget Sound. The Duwamish River travels through a heavily industrialized section of Seattle before reaching the bay.

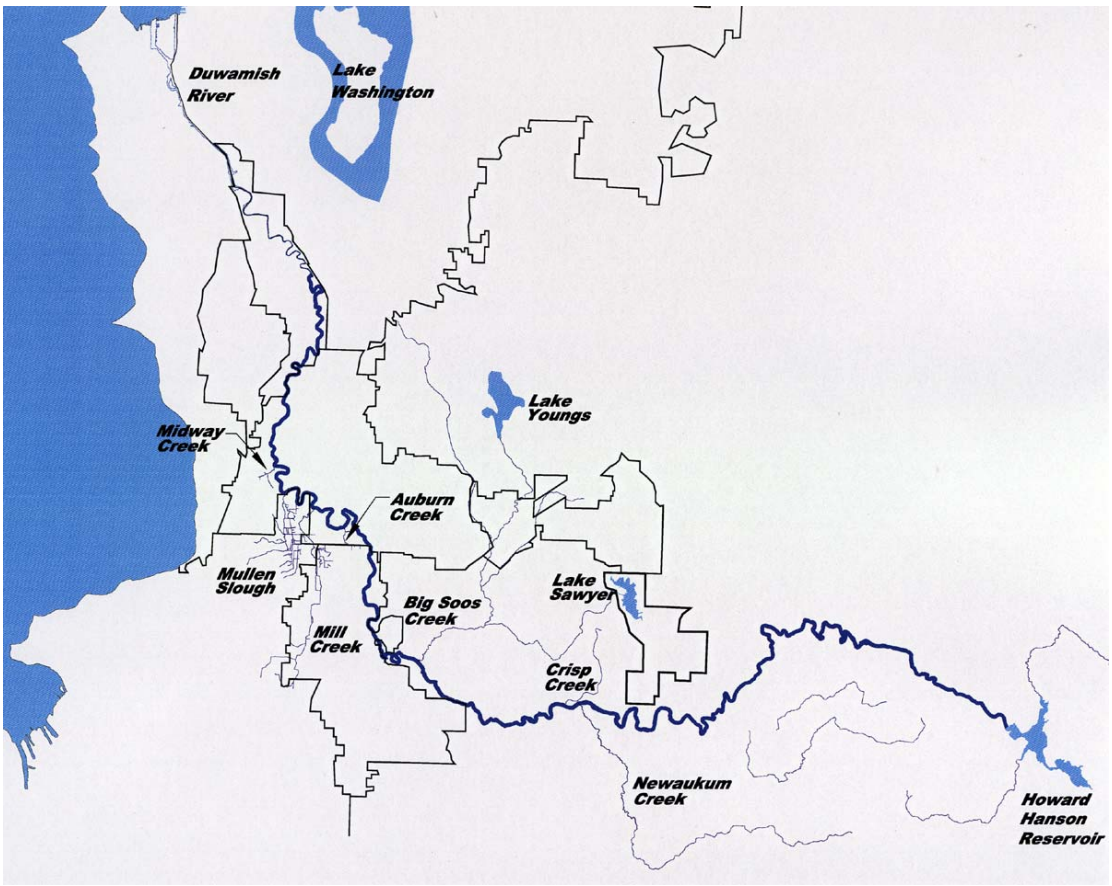

Figure 2: Green River and Major Tributaries

Prior Green River Models

Both the Middle and Lower Green River have been modeled with the Army Corps of Engineers program HEC-2. HEC-2 is a steady-state program that models one-dimensional river hydraulics and is commonly used for establishing flood plain elevations. King County modeled the Middle Green with HEC-2 in the middle 1990's, and in the late 1990's the Army Corps of Engineers converted both Lower and Middle Green River HEC-2 data to HEC-RAS, which is the Corp's Windows-based follow-up program to HEC-2.

The Duwamish River and Elliot Bay have been modeled using Environmental Fluids Dynamic Computer Code, a 3-dimensional hydrodynamic and transport model. This model was developed as part of a program to evaluate and simulate the impacts of combined sewer overflows on the river and bay (King County Combined Sewer Overflow Water Quality Assessment for Duwamish River and Elliot Bay, 1999).

Model Geometry

Bathymetry Data

Middle Green

For King County's 1990's HEC-2 study, aerial photogrammetry was used to obtain topography of the floodplain and surrounding area, and a standard field survey was used to obtain elevations of river cross sections. King County provided AutoCAD® files with the aerial photogrammetry points, and HEC-2 and HEC-RAS files from the previous floodplain work. Three-dimensional lines were connected between each HEC-2 river point and between each bank point. These lines were used to create a 3-D terrain model of the surface and river.

Lower Green

King County provided ground and channel elevations for each cross-section from the HEC-2 study. Bathymetric information between each cross-section was not available for this section of the river.

The HEC-2 cross-sections are shown on Federal Emergency Management Flood Insurance Rate Maps (FIRMs). To place the cross-sections in the correct location on the river, digital FIRMs (tiff files) were obtained from FEMA. These maps were placed over GIS linework of the Lower Green River. The cross-sections on the FIRMs were then digitized into the drawing, and the section elevations from the HEC-2 file were imported onto each cross-section. As with the Middle Green, 3-dimensional fault lines were connected between each HEC-2 river point and between each bank point. These 3-dimensional faults were used to generate a contoured 3-dimensional contoured surface of the river and banks.

Digital elevation models (DEMs) of USGS quadrangles were obtained and added to the 3-D surface of the river. With these DEMs, a full model of the river valley and surrounding terrain was created.

A grid of the river and floodplain was generated from the terrain model. This grid consisted of x, y, and z points at 3 meter intervals. This grid was then used to generate bathymetry files using SURFER®, a 3D mapping program.

King County also provided aerial photographs taken in 2000. These were used to compare cross-sectional data from the HEC models to river channel locations shown on the aerials. The river has changed significantly in three locations: at River Mile 32.40, downstream from the confluence with Big Soos Creek; near River Mile 36.00; and near River Mile 38.30. Figure 3 shows the locations of the revised channel locations. The revised channel at River Mile 32.40 will be incorporated into the model. The elevations in the new channel were estimated by interpolating between the available river elevations at each end of the channel. The channel changes at River Mile 36.00 and River Mile 38.30 are small and would not have much influence on river hydrodynamics.

When the consultant for the U.S. Army Corps of Engineers converted the HEC-2 files to HEC-RAS, there were data discrepancies noted between the Middle Green River data and the Lower Green River data (RAS Notes, 1998). One discrepancy is a difference in river bottom elevations where study data overlapped. There's a river bottom elevation discrepancy between the 2 studies that varies from 9' at River

Mile 33.83 to 0 at River Mile 33.55. The Middle Green River bathymetry was chosen for use in the model through this area for 2 reasons:

1. There was much more detailed information available on the Middle Green River bathymetry, including information on datum, when the data were obtained, and how the data were obtained. There was no information provided on the bathymetry information for the Lower Green River.
2. If the Lower Green River data were used up to River Mile 33.82, and Middle Green data were used above River Mile 33.82, there would be a 9' jump at this location. Using Middle Green data results in a uniform river slope when transferring from Middle Green River bathymetry data to Lower Green River bathymetry data.

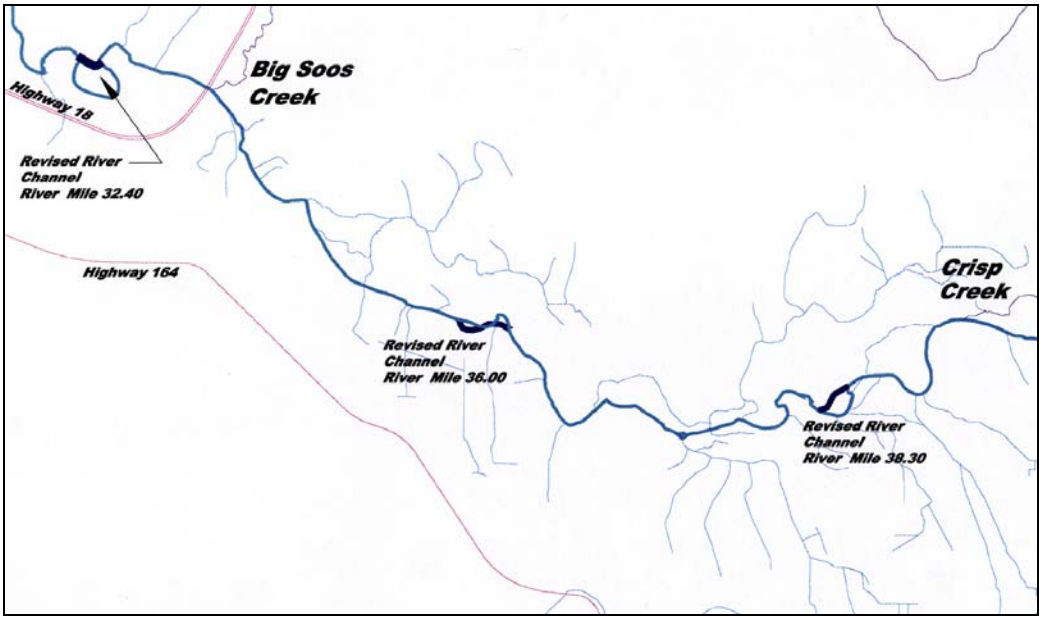

Figure 3: New River Channel Locations

Model Grid Development

The river will be modeled with 218 longitudinal segments, each approximately 250 meters long. Vertical grid layers are set at a thickness of 1.0 meter. The bypass created by the new channel at River Mile 32.40 will be a separate branch linking two river segments on the mainstem. This segment will be controlled by a gate during the 1995-1996 model run period, and the gate will be opened in February 1996.

Figure 4 shows a vertical profile of the river bottom created from the digital terrain model, and an average slope of the river bottom. As this figure shows, the river has 3 distinct slopes through the section being modeled. These reaches will be modeled as separate water bodies. Additionally, each water body will contain separate branches. The break point for each water body is shown in Figure 4, and Table 1 provides a breakdown of the branches in each water body. Note that the segment numbers in Table 1 include the "null" segments that divide each branch. Figure 5 shows the model segments and the branch locations.

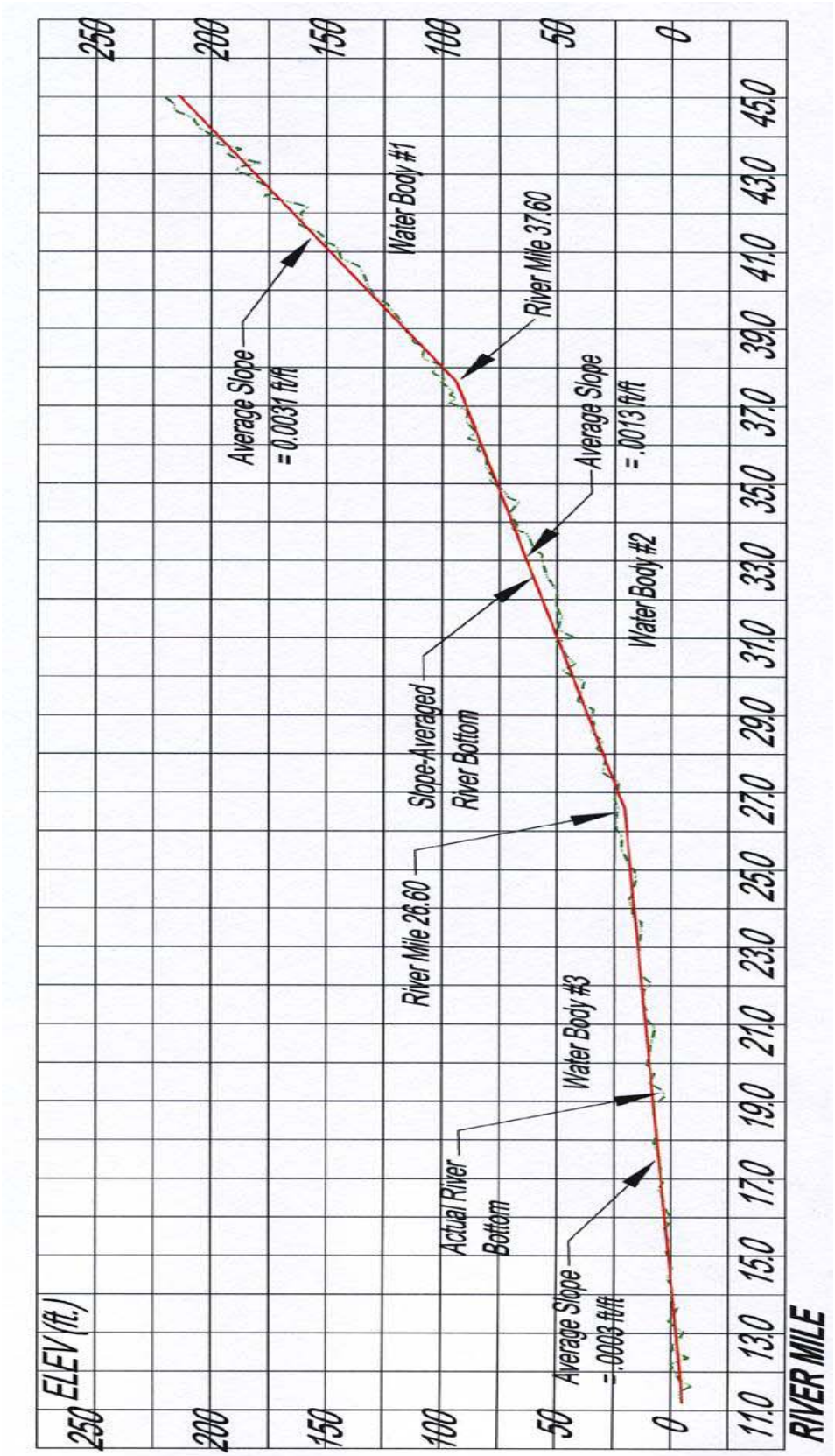

Figure 4: Profile of Green River Channel Bottom

Table 1: Water Body Characteristics						
Water Body	Description	Branch	Segment Start	Segment End	Number of Segments	Average Slope
1	Flaming Geyser Park to east boundary of Auburn	1	1	27	51	0.31%
		2	28	51		
2	East boundary of Auburn to south boundary of Kent	3	52	78	74	0.13%
		4	79	125		
2	New river channel at River Mile 32.40	6	228	230	3	0.53%
3	South Boundary of Kent to Tukwila	5	126	227	102	0.03%

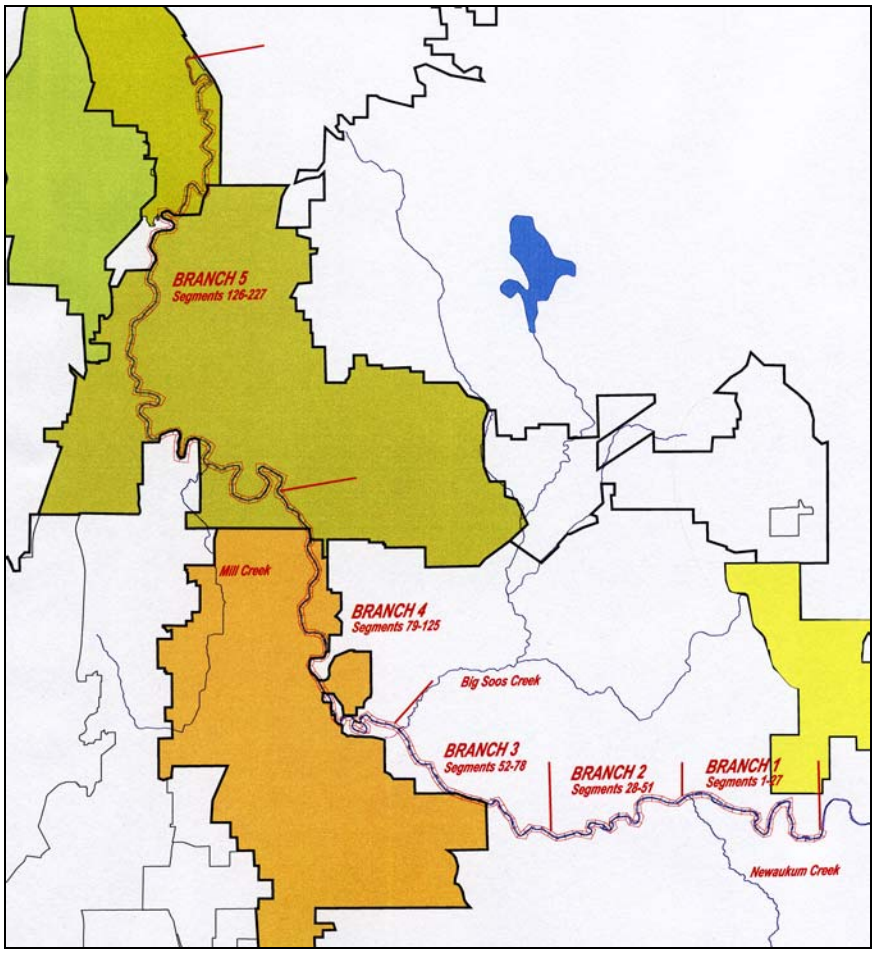

Figure 5: Model Grid Layout

Model Simulation Time Period

There are monitoring sites on the middle and lower reaches of the Green River, and many more on the various tributaries. King County and The United States Geological Survey (USGS) record flow on the river. King County, The Washington Department of Ecology, The University of Washington, and The United States Geological Survey have recorded temperature on the river, and King County, The Washington Department of Ecology, and USGS have sampled water quality constituents. Before beginning this project, King County reviewed all gages on the river and assembled data from the relevant gages in database files. They also compiled pertinent information in a document on bathymetry, meteorology, hydrology, shade, and water quality. This made data analysis and review much simpler.

According to the data compilation report, most data were recorded in Pacific Daylight Time, so all other data were converted to this time zone.

The data compilation report was used to evaluate time periods for running the model. There is a lot of water quality data between 1995 and 2001, and flow data can be obtained back to the late 1980's. Temperature data proved to be the limiting factor when determining model calibration periods.

Criteria for choosing model run times include:

- Availability of upstream and downstream boundary condition data
- Availability of data for larger tributaries, including Newaukum Creek, Big Soos Creek, Crisp Creek, and Mill Creek.
- Availability of data for the remaining tributaries.

Table 2 lists the temperature data available for the boundary locations and tributary streams between 1995 and 2001, and Table 3 lists the temperature gages for the same locations, along with the dates of available and missing data.

Based upon information in these 2 tables and the temperature data constraints, the model will be run from May 25, 1995 through November 1996, and from April 1, 2001 through July 2002. These time periods correspond to 2 major temperature studies by King County and have the most temperature data available. See Appendix F for a map showing the location of all stations and a table which shows the stations used for model data.

Table 2: Temperature Data Summary

Location	1995	1996	1997	1998	1999	2000	2001	2002
U/S Boundary	May - Nov	Jan - Nov	None	None	None	None	Apr - Dec	Jan- Sept
D/S Boundary	June - Dec	Jan - Dec	Jan - Dec	Jan - Dec	Jan - Dec	Jan	None	July - Sept.
Newaukum Creek	None	July - Dec	Jan - Dec	Jan - Oct	None	None	July - Dec	Jan - Sept
Crisp Creek	None	None	Oct - Dec	Jan - Dec	Jan - Dec	Jan - Dec	Jan - Dec	Jan - Aug
Big Soos Creek	Jan - Dec	Jan - Dec	Jan - Dec	Jan - Dec	Jan - Dec	Jan - Dec	Jan - Dec	Jan - Aug
Mill Creek	None	None	None	None	Oct - Dec	Jan - Dec	Jan - Dec	Jan - Aug
Mullen Slough	None	None	None	None	None	None	None	None
Auburn Creek	None	None	None	None	None	None	None	None
Midway Creek	None	None	None	None	None	None	None	None

Table 3: Temperature gages at modeling locations			
Location	Time Period of Data	Monitoring Station	Missing Data Periods
Green River Upstream Boundary	May 1995 –Nov. 1999	KC gage at Black Diamond (WHI)	Dec 1999 - April 2001
	July 24, 2001 – Aug. 2, 2002	GDWQA at Whitney Bridge (GRT10 and GRT10_2)	
	Apr 2001– Sept 2002	UW Gage (GR3-4)	
Downstream Boundary	June 1995 – Nov 1996 Jan 1996 – Jan 2000 July 2002 – Sept. 2002	KC Gage (BIC) USGS Gage (12113390) GDWQA gage (GRT18)	January – June 1995 February 2000 – June 2002
Crisp Creek	Oct 1997 – Aug 2002	KC gage at mouth (40d)	1995 to Sept. 1997
Newaukum Creek	July 1996 – Oct 1998 July 2001 – Sept 2002	USGS gage (12108500) GDWQA gage (GRT09)	Nov 1998 to June 2001
Big Soos Creek	Oct 1994 – Aug 2002	KC gage (54A)	Data set is complete
Mill Creek	Oct 1999 – Aug 2002	KC gage (41a)	1995 to Sept 1999
Mullen Slough	July 1996 – Nov 1996	KC gage (FRA)	Nov 1996 to Dec 2002
Midway Creek	None		1995-2002
Auburn Creek	None		1995-2002

Water Quality

King County has provided water quality samples on the Lower and Middle Green River from 1990 to 2002. Table 4 lists the water quality sites between the lower and upper boundaries of this project (including tributaries), Table 5 lists constituents of interest that have been sampled, and Table 6 lists the constituents to be modeled.

The Washington Department of Ecology (WDOE) also monitors data at various locations on the Middle and Lower Green River, however, the locations on the mainstem of the Green River are the same as where King County samples, and the constituents sampled are also the same, so these data were not used in the model.

Grab samples data were available at these locations on a monthly basis for both model periods. Longitudinal profiles were created using data from the four mainstem monitoring sites. Figure 6 shows a longitudinal profile for dissolved oxygen, and Appendix B contains longitudinal profiles for the remaining constituents listed in Table 5.

Table 4: Water Quality Monitoring Sites

Site ID	Description	RM	Agency
3106	Fort Dent Park	11.70	King County
0311	Interurban Avenue	12.40	King County
A319	Auburn-Black Diamond Road	33.80	King County
B319	Above Newaukum Creek	41.40	King County
G319	Below Mullen Slough	21.30	King County
Mullen1, Mullen2	Mouth of Mullen Slough	N/A	King County
A315	Mouth of Mill Creek	N/A	King County
A320	Big Soos	N/A	King County
0321	Crisp Creek	N/A	King County
0322	Newaukum Creek	N/A	King County

Table 5: Water Quality Constituents sampled by King County

Constituent Name	Constituent Name
Dissolved Oxygen	Temperature
Total Nitrogen	pH
Ammonia Nitrogen	Alkalinity
Nitrite-Nitrate	Conductivity
Total Phosphorus	Fecal Coliform
Ortho Phosphorus	Enterococcus
Turbidity	Escherichia coli.
Total Organic Carbon	Total Suspended Solids
Chlorophyll-A	Dissolved Organic Carbon
	Biochemical Oxygen Demand

Table 6: Water Quality Constituents to be modeled

Constituent	Constituent Name	Constituent	Constituent Name
DO	Dissolved Oxygen, mg/L	TEMP	Temperature, Celsius
NH_4	Ammonia Nitrogen	pH	pH
NO_2-NO_3	Nitrite-Nitrate, mg/L	ALK	Alkalinity, mg/L
L/R DOM and POM	Dissolved and Particulate Organic Matter, mg/L	COND	Conductivity, umhos/cm
PO_4	Ortho Phosphorus, mg/L	TIC	Total Inorganic Carbon, mg/L
ISS	Inorganic Suspended Solids, mg/L	ALG1	Algae, mg/L
		COLFRM	Fecal Coliform, ORG,100 ml

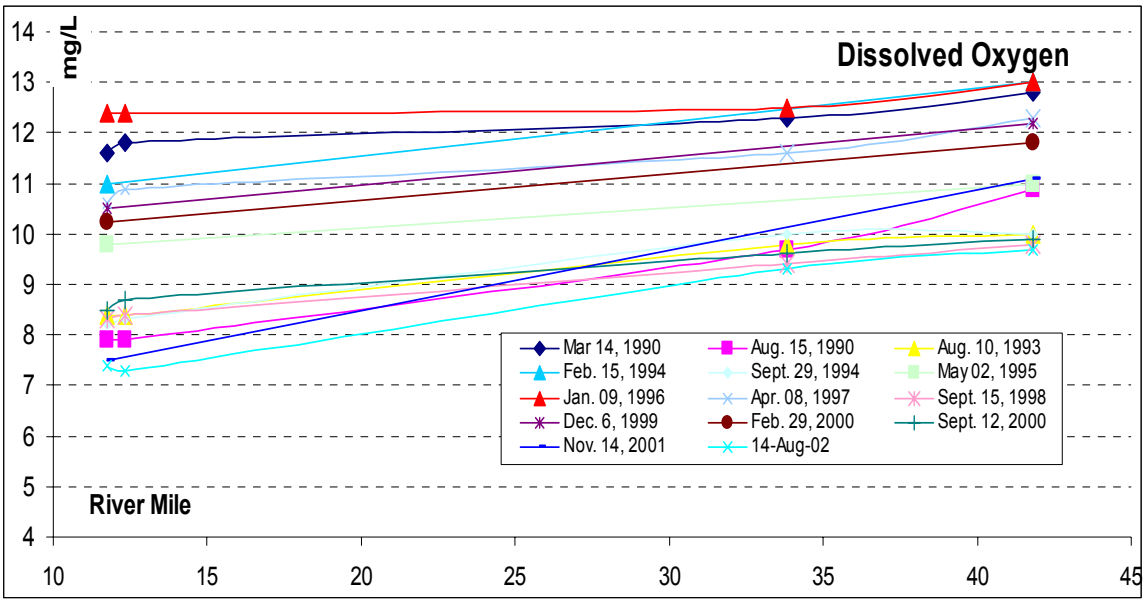

Figure 6: Dissolved Oxygen Longitudinal Profile

Model Boundary Conditions

The upstream boundary is at River Mile (RM) 45.0, in Flaming Geyser State Park, and the downstream boundary is at RM 11.20, downstream from Fort Dent Park. The upstream boundary condition is characterized by flow, temperature, and water quality, and the downstream boundary is characterized by water surface elevation, temperature, and water quality.

Upstream Boundary

May 25, 1995 – November 1996

Flow

The closest flow gage to the upstream boundary is a USGS gage (12106700) near Palmer, Washington, approximately 26 km upstream from Flaming Geyser State Park. Flow data were obtained for this gage in 15-minute intervals from October 1994 to December 2002.

Groundwater and surface water contribute flow to the river downstream of this gage. There are numerous springs in the Green River Gorge (Luzier 1969) and near Icy Creek (DeGasperi, 2003), and there are many small tributaries that flow into the river. To estimate surface water inflows for the area between the gage at Palmer and the upstream boundary, King County hydrologists used the hydrologic modeling program HSPF (Hydrologic Simulation Program-Fortran) to estimate surface runoff. They provided daily average flow rates of surface runoff from HSPF models for three basin tributaries to Green River. Figure 7 is a map of the 3 basins, with the location of the Palmer gage also shown.

All of Basin MG3 is upstream of the upstream project boundary. HSPF flow data for this basin were added to flow from the Palmer Gage. Basin MG2 includes the area tributary to Crisp Creek. This creek has gaged flow data available for input to the model, so it will be a separate tributary to the model. The size of Crisp Creek Basin is approximately 28% of Basin MG2, so 72% of the HSPF flow for Basin MG2 was added to the Palmer Gage. Daily average values were provided for the HSPF data, and data in 15-minute intervals were obtained for the Palmer Gage, so the daily averaged data were linearly interpolated to 15-minute intervals to match the Palmer Gage. A travel time analysis was performed to see how long it takes flow from the Palmer Gage to reach the downstream boundary of Basins MG2 and MG3. Flow from Basins MG3 and MG2 were shifted by 4 hours and 8 hours respectively to account for the travel time difference. Please see Appendix C for more information on establishing these times.

Deep Creek and Coal Creek Basins are closed drainages that do not discharge to any water body. King County hydrologists believe groundwater from these 2 streams makes its way to the Green River (DeGasperi, 2003; Green-Duwamish Watershed Water Quality Assessment, 2002). King County provided HSPF model approximations of surface runoff from these 2 basins. Although there's no information available indicating that all this flow makes to the Green River, all of the flow was added to flow from the Palmer Gage. Because daily average HSPF data were provided, linear interpolation was used to fill in the data for the 15 minute intervals for the Palmer gage. These flows will be re-examined once the hydrodynamic calibration is undertaken.

Groundwater is a major contributor to flows in the Green River between the USGS gage at Palmer and the upstream boundary of the model. Luzier (1969) estimated that as much as 1.26 cms summer flow and 6.30 cms winter flow contributions to the Middle Green come from springs in the Green River Gorge. These values were added to the flow data from the Palmer Gage, using 1.26 cms from April 1 to September 30, and 6.30 cms from October 1 to March 31. These flows will also be re-examined during model calibration.

Flow data from 1995 – 2002 is shown in Appendix A, and Figure 8 shows flow data for the model simulation period.

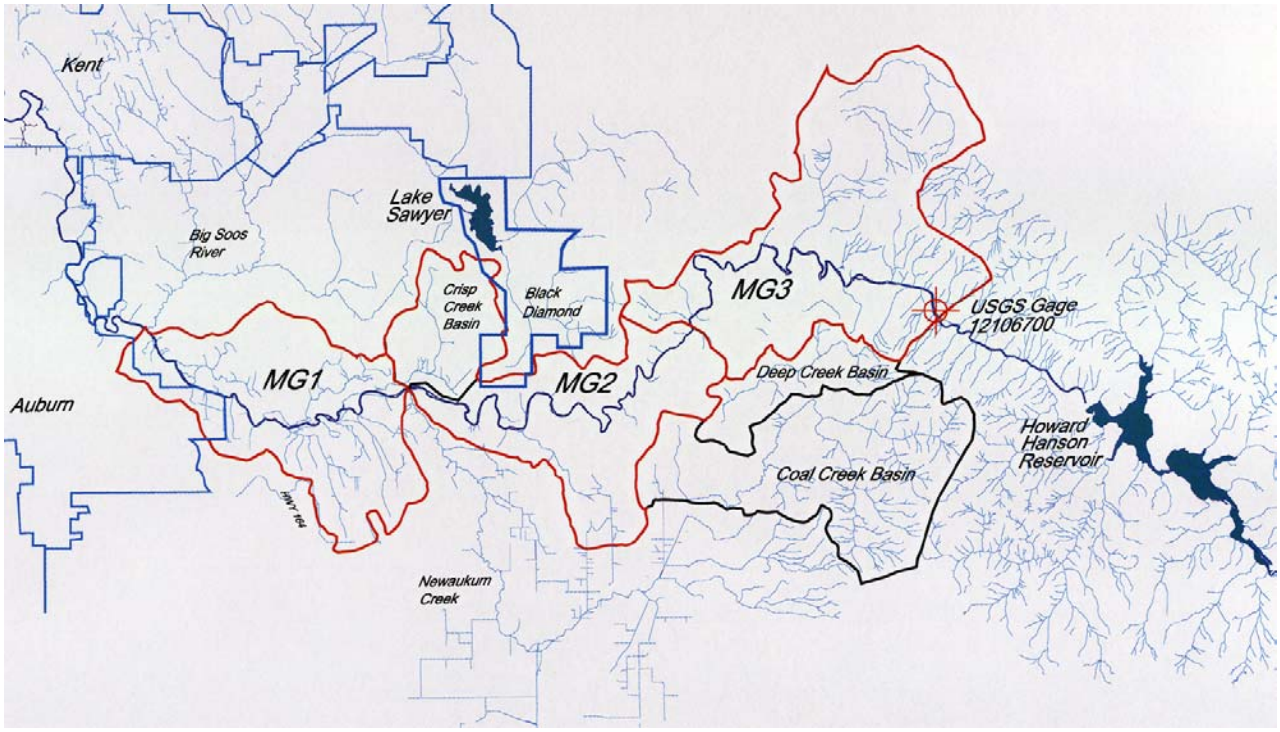

Figure 7: Green River HSPF Basins

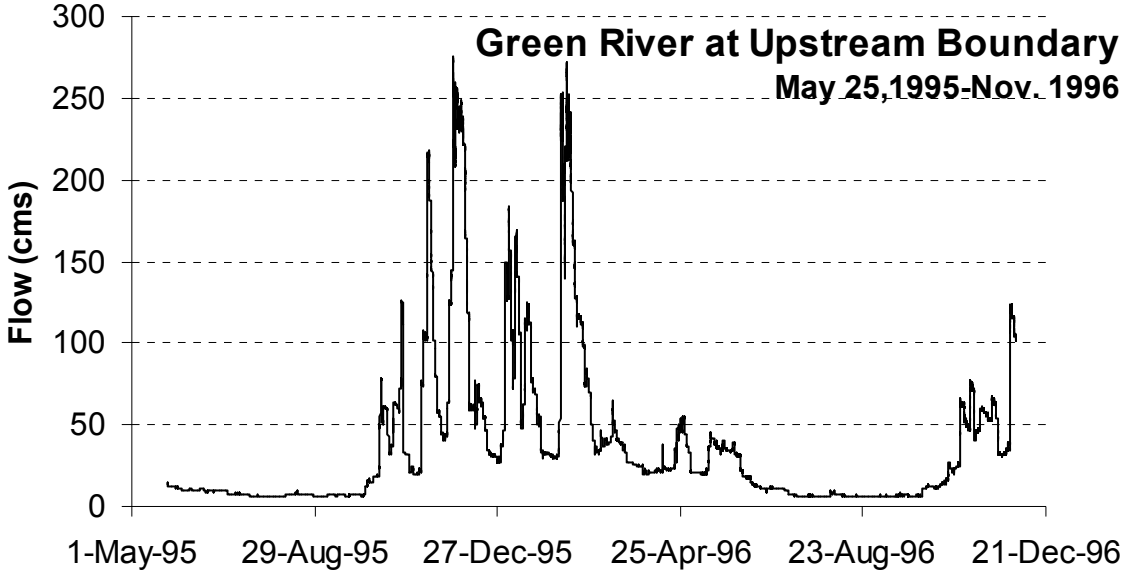

Figure 8: Green River Flow at Upstream Boundary: May 1995 to November 1996

Temperature

Monitoring station WHI is located about 4 km downstream of the first model segment. Temperature was recorded at this station in 1995 and 1996. This station has 2 data gaps for the model calibration period: from May 1, 1996 to June 7, 1996, and from July 26, 1996 to August 13, 1996. To fill these data gaps, data from monitoring station 54a, located at the mouth of Big Soos Creek, was correlated with station WHI from July 1995 through October 1995. The temperature relationship between the 2 stations is as follows:

$$\text{WHI Temp} = (\text{Sta 54a})(1.3412) - 3.1517$$

Figure 9 shows the data for the 2 stations, Figure 10 shows the correlated values and monitored data, and Figure 11 shows the temperature data for the model calibration period. Appendix A contains a graph of temperature for all gages used at the upstream boundary from 1995 through September 2002.

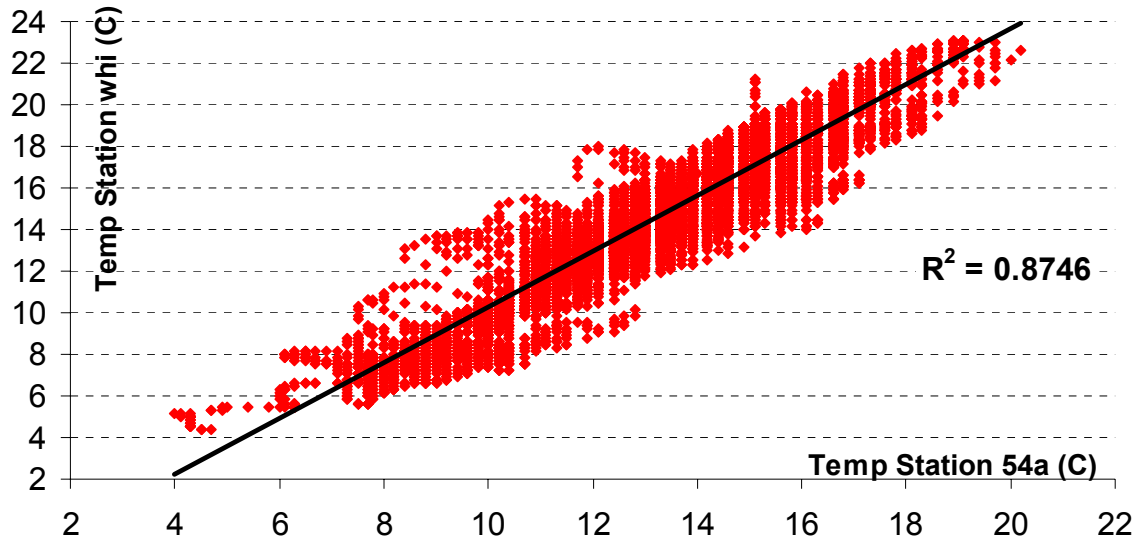

Figure 9: Correlation between Stations WHI and 54a

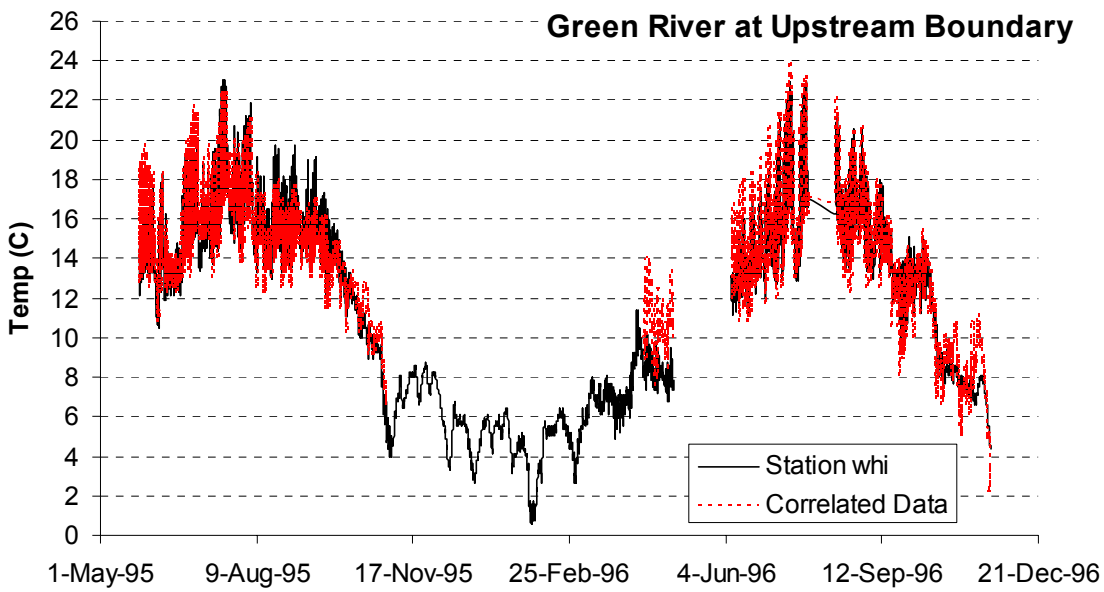

Figure 10: Upstream Boundary: Station versus Correlated Data, 1995-1996

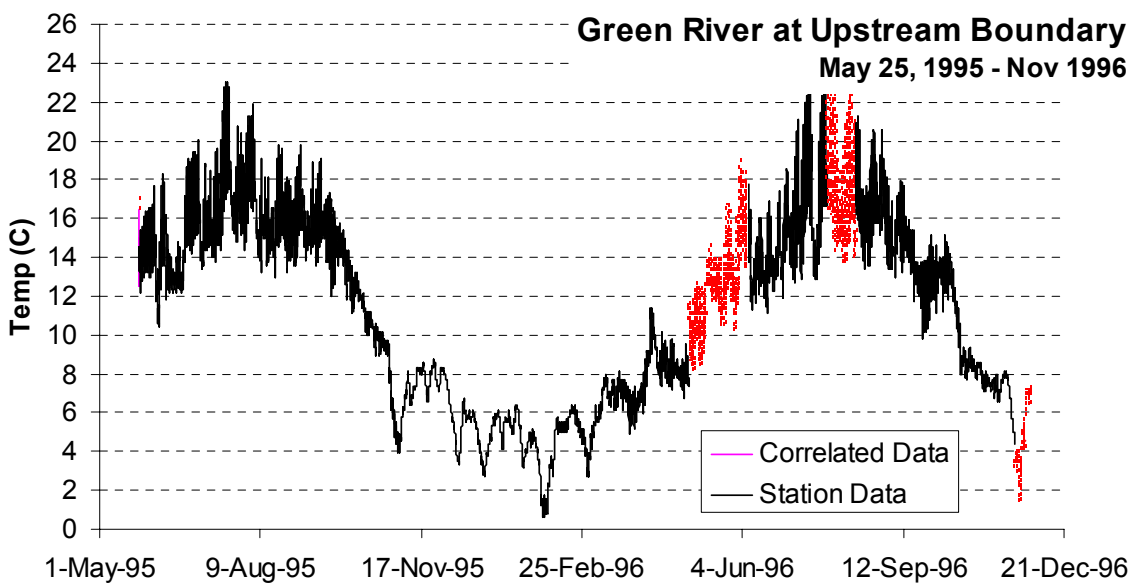

Figure 11: Green River Temperature at Upstream Boundary: May 1995 to November 1996

Water Quality

Data were available for all proposed constituents except alkalinity and chlorophyll a at the same location as the temperature monitoring station, 4 km downstream from the first model segment, under Locator Station B319. Figure 12 through Figure 25 plot the water quality constituents for the model calibration period for the upstream boundary condition. The procedure used for developing the water quality files, including filling data gaps, is in included in Appendix D. Appendix A contains water quality information from 1995 – 2002.

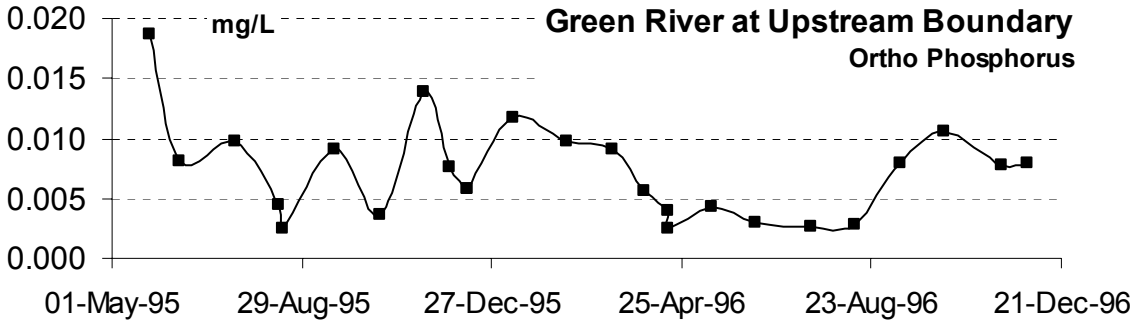

Figure 12: Ortho phosphorus at Upstream Boundary: May 1995 to November 1996

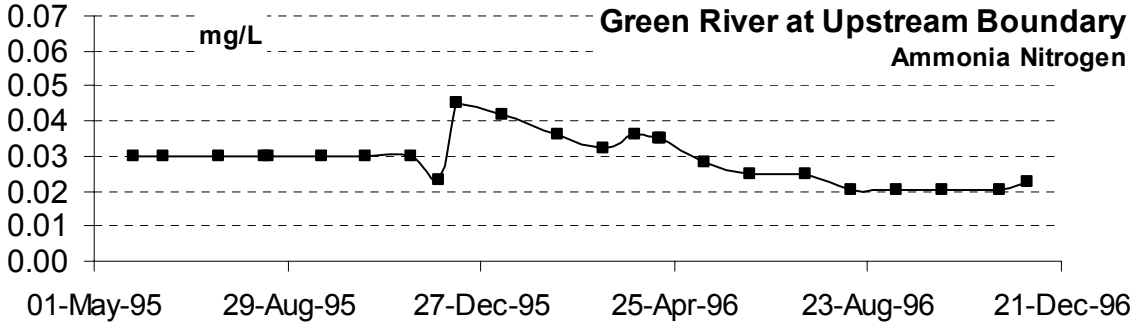

Figure 13: Ammonia at Upstream Boundary: May 1995 to November 1996

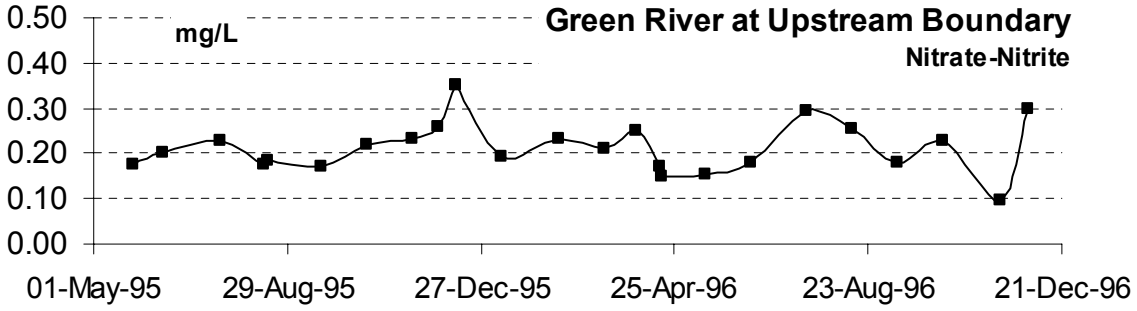

Figure 14: Nitrate-Nitrate at Upstream Boundary: May 1995 to November 1996

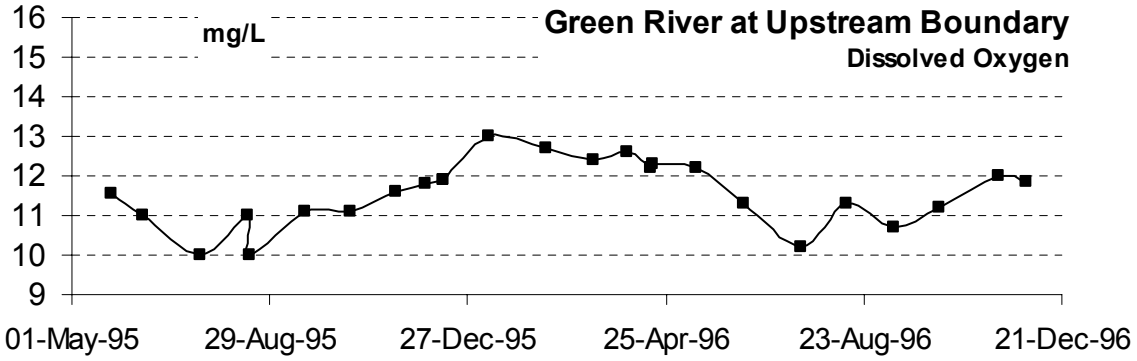

Figure 15: DO at Upstream Boundary: May 1995 to November 1996

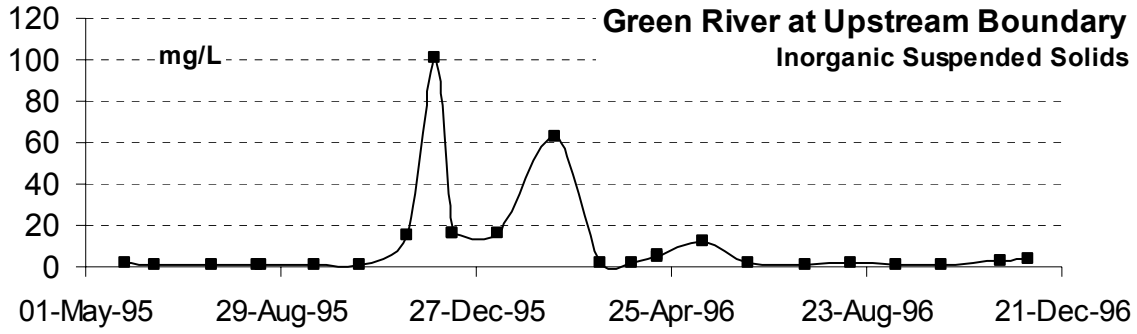

Figure 16: ISS at Upstream Boundary: May 1995 to November 1996

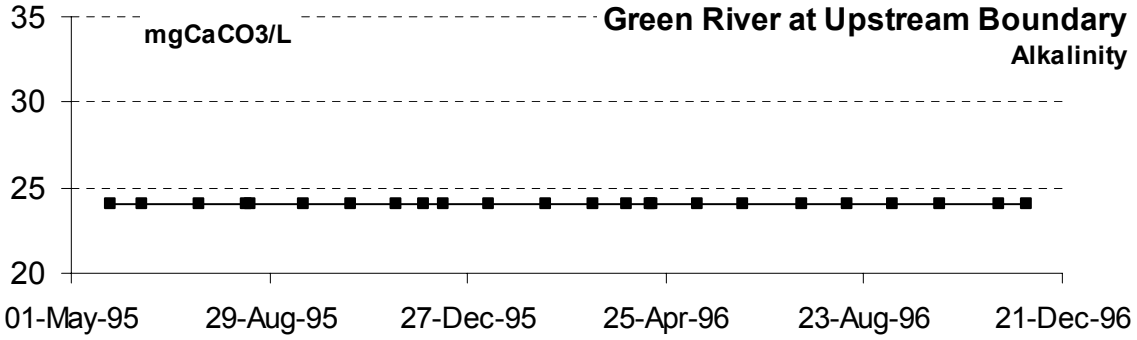

Figure 17: Alkalinity at Upstream Boundary: May 1995 to November 1996

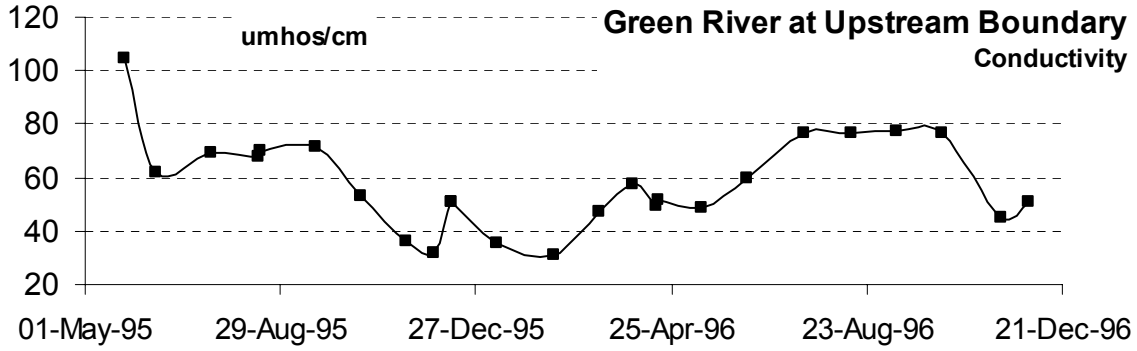

Figure 18: Conductivity at Upstream Boundary: May 1995 to November 1996

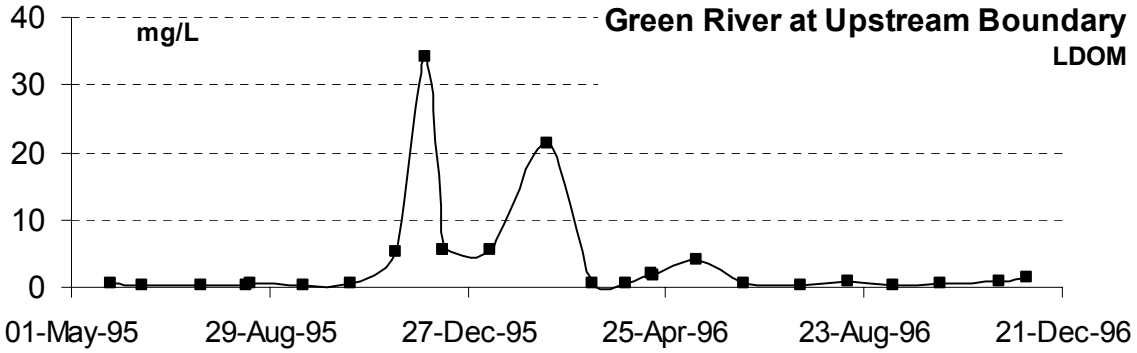

Figure 19: LDOM at Upstream Boundary: May 1995 to November 1996

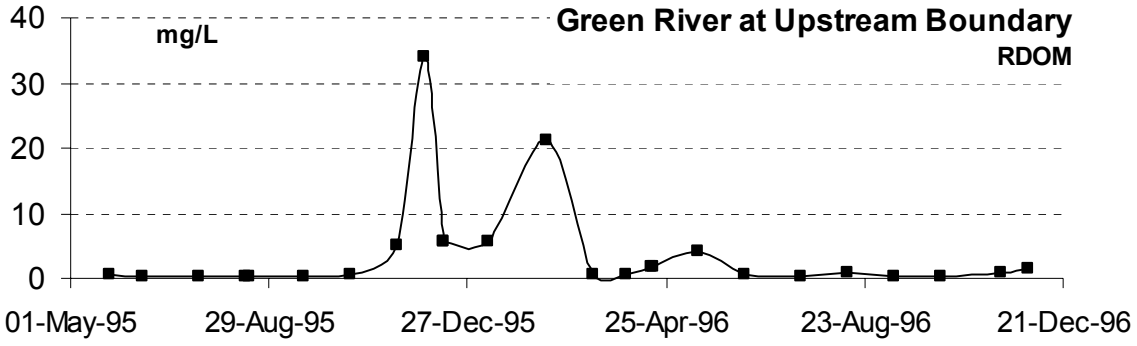

Figure 20: RDOM at Upstream Boundary: May 1995 to November 1996

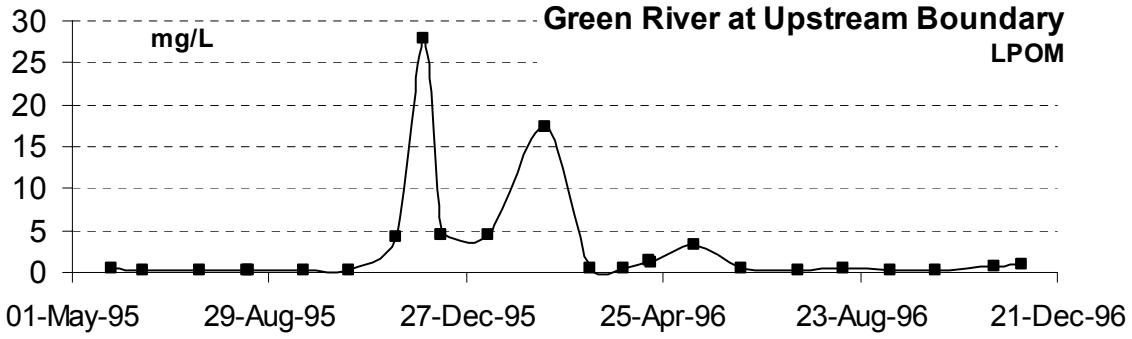

Figure 21: LPOM at Upstream Boundary: May 1995 to November 1996

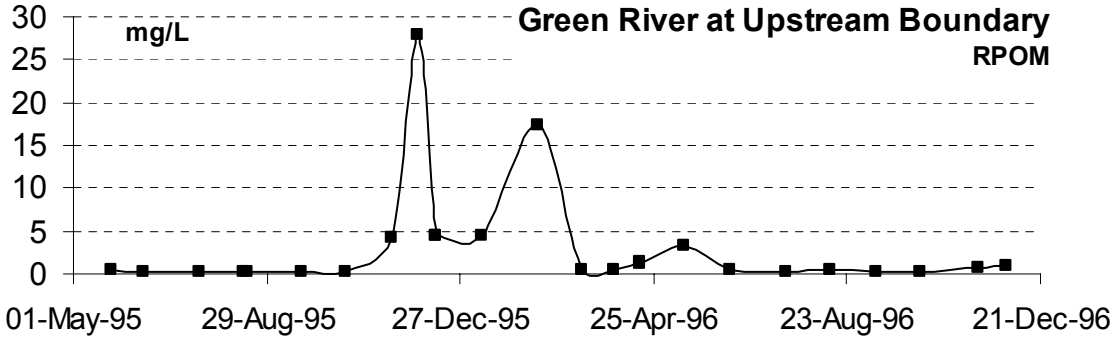

Figure 22: RPOM at Upstream Boundary: May 1995 to November 1996

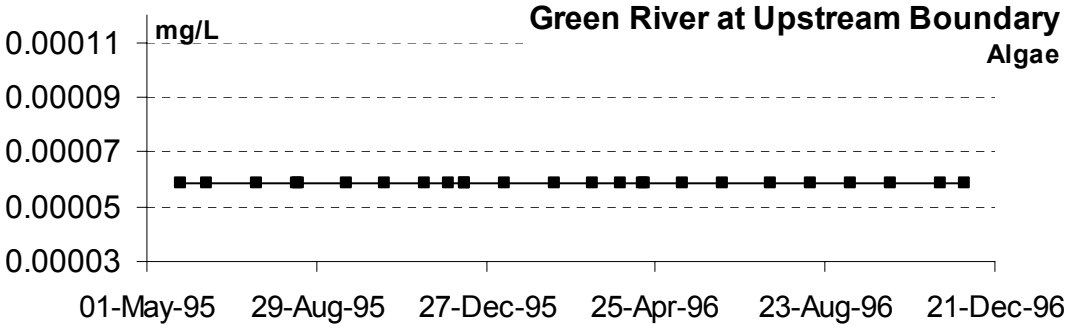

Figure 23: Algae at Upstream Boundary: May 1995 to November 1996

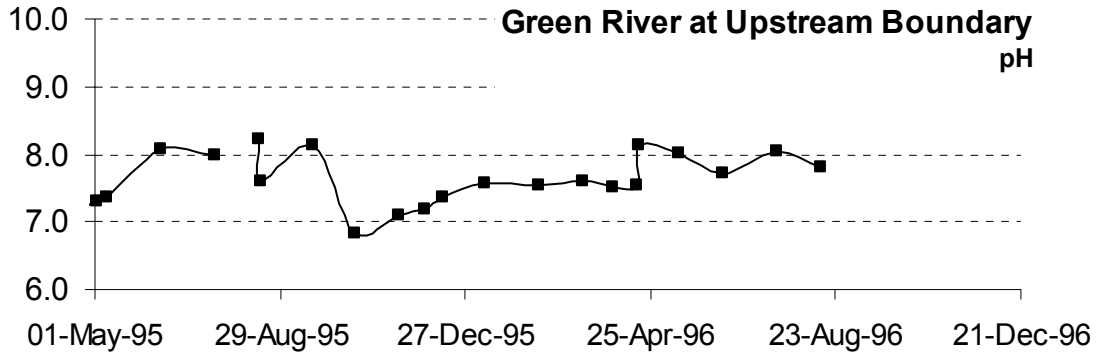

Figure 24: pH at Upstream Boundary: May 1995 to November 1996

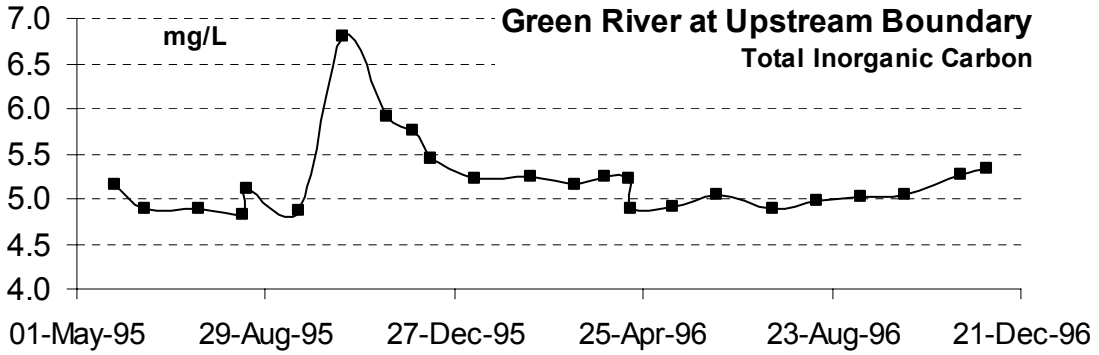

Figure 25: TIC at Upstream Boundary: May 1995 to November 1996

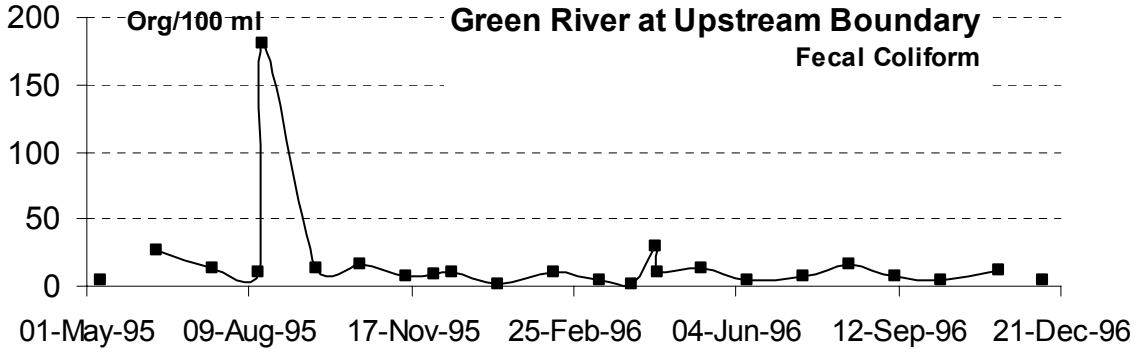

Figure 26: Fecal Coliform at Upstream Boundary: May 1995 - Nov 1996

April 2001 –July 2002

Flow

The same flow gage (USGS 12106700) was used for the upstream boundary condition for this model calibration period. As with the May 1995 – November 1996 calibration period, daily HSPF data were added to the Palmer gage with the same lag for travel time. Figure 27 shows the estimated flows for the model calibration period.

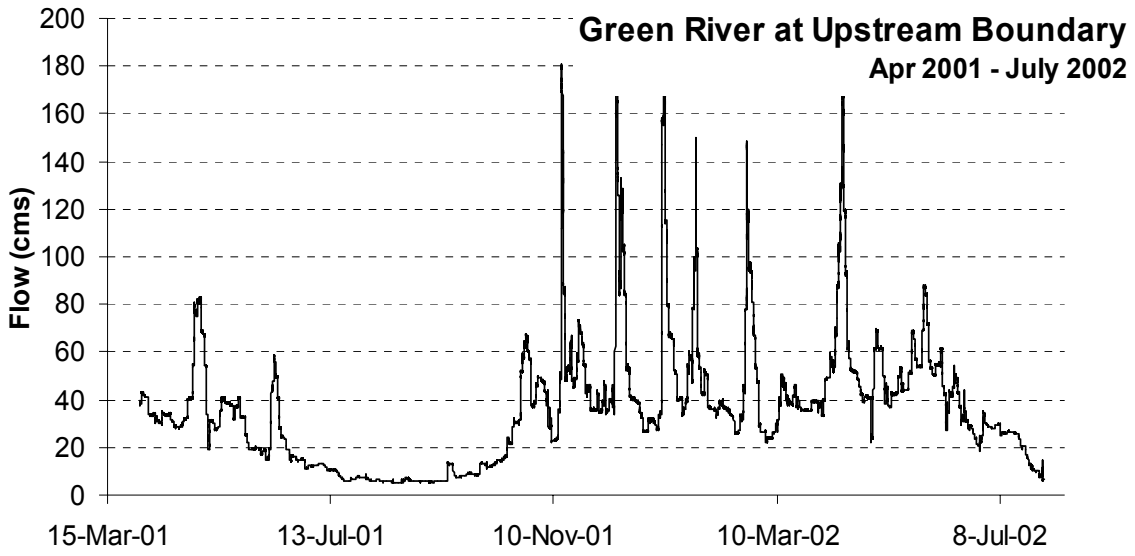

Figure 27: Green River Flow at Upstream Boundary: Apr 2001 – July 2002

Temperature

The University of Washington monitored temperature at Station GR5, which is located very close to the first model segment. Data are available at this location from July 24, 2001 to October 17, 2001. The University also monitored temperature at Station GR3-4, approximately 4 km downstream of GR5. Data are available at this station from March 30, 2001 to June 20, 2001, July 24, 2001 to October 17, 2001, and from July 29, 2002 to September 12, 2002. Data from the 2 stations were correlated with each other to fill from April 1, 2001 to June 20, 2001. The correlation equation is:

$$\text{GR5 Temp} = (\text{GR3-4 Temp})(0.8798) + 1.5465$$

Figure 28 shows the correlation between the 2 stations and Figure 29 shows temperature data and correlated values.

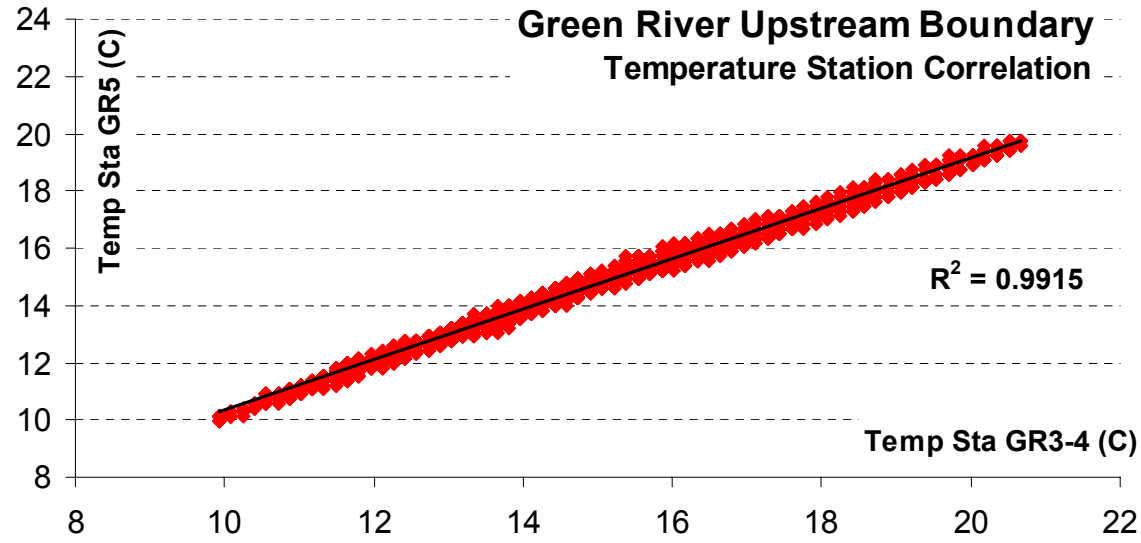

Figure 28: Correlation between Stations GR5 and GR3-4

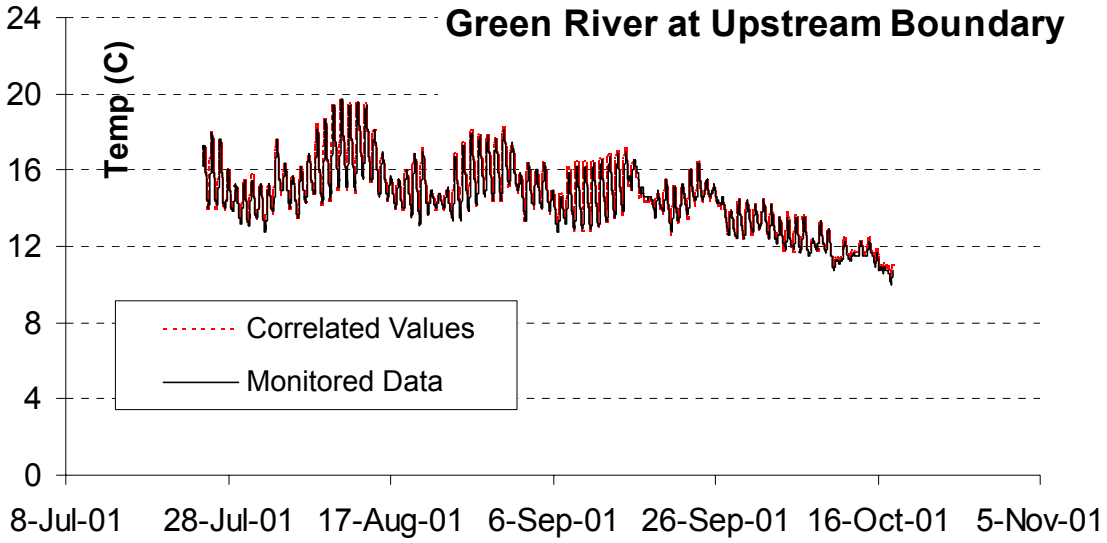

Figure 29: Upstream Boundary: Station Data versus Correlated Data, 2001-2002

According to King County, the University of Washington stations record in Coordinated Universal Time (UTC), so these data were converted to Pacific Daylight Time.

The King County Green-Duwamish Water Quality Assessment program recorded 2001 and 2002 temperatures at various locations along the Green River. Station GRT10 was located in the same place as the University's Station GR3-4. Station GRT10 collected temperature data from July 24, 2001 to September 6, 2001, from November 16, 2001 to February 22, 2002, and from March 14, 2002 to August 2, 2002. These data were correlated to data from Station GR3-4, then to Station GR5, using the relationship established above.

The relationship between GR3-4 and GRT10 is defined as follows:

$$GR3\text{-}4 = (GRT10)(0.8395) + 2.0076$$

These data will be used between November 16, 2001 and February 22, 2002, and between March 14, 2002 and July 31, 2002. Figure 30 shows the correlation between the 2 stations and Figure 31 shows temperature data and correlated values.

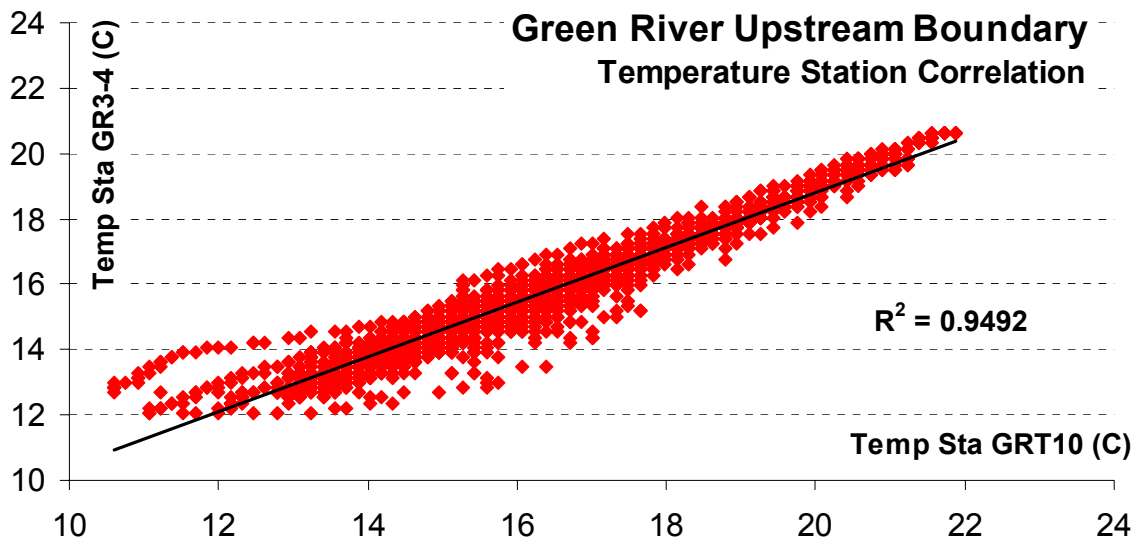

Figure 30: Correlation between Stations GRT10 and GR3-4

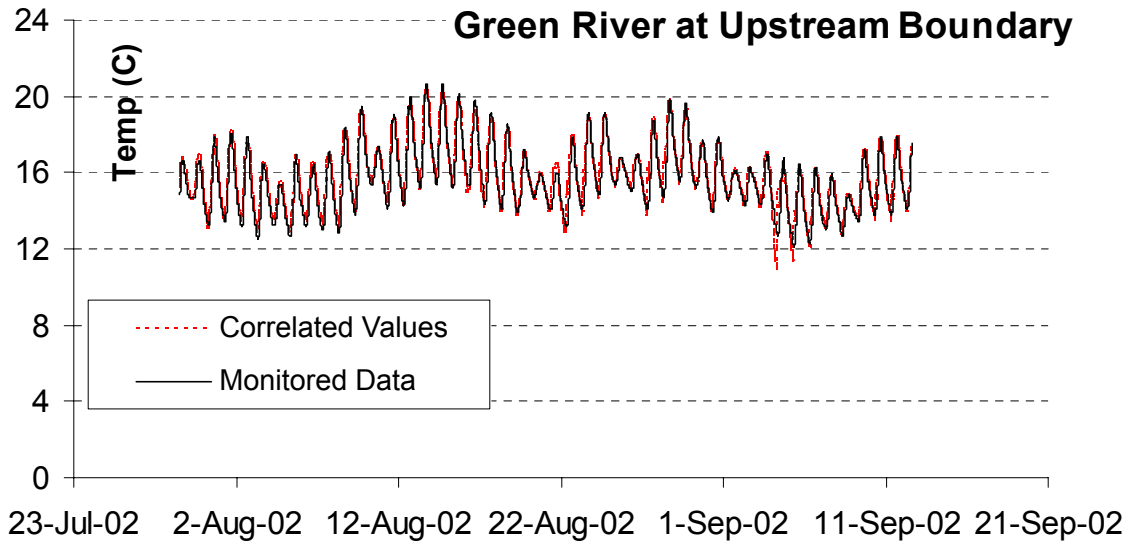

Figure 31: Upstream Boundary: Station Data versus Correlated Data, 2001-2002

With the available data there are still 3 data gaps to be filled:

- June 20, 2001 to July 24, 2001
- October 17, 2001 to November 16, 2001
- February 23, 2002 to March 14, 2002

To fill these data gaps, data from King County's monitoring station 40d on Crisp Creek provided the best correlation. The data from GR3-4 was compared with Station 40d from July 25, 2001 to August 2, 2002. The correlation equation is as follows:

U/S Temp = (Crisp Creek Temp)(2.0255) – 10.283

Figure 32 shows the data from the 2 stations, Figure 33 shows the station and correlated data, and Figure 34 shows the data for the model calibration period. Appendix A contains a graph of temperature stations near the upstream boundary from 1995 through September 2002.

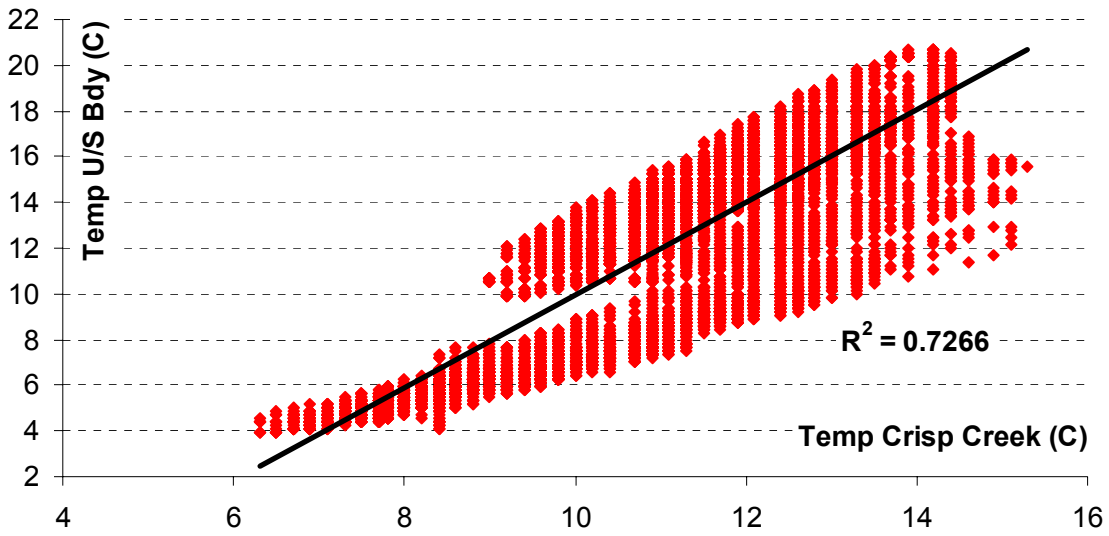

Figure 32: Correlation between Crisp Creek Temperature and U/S boundary stations

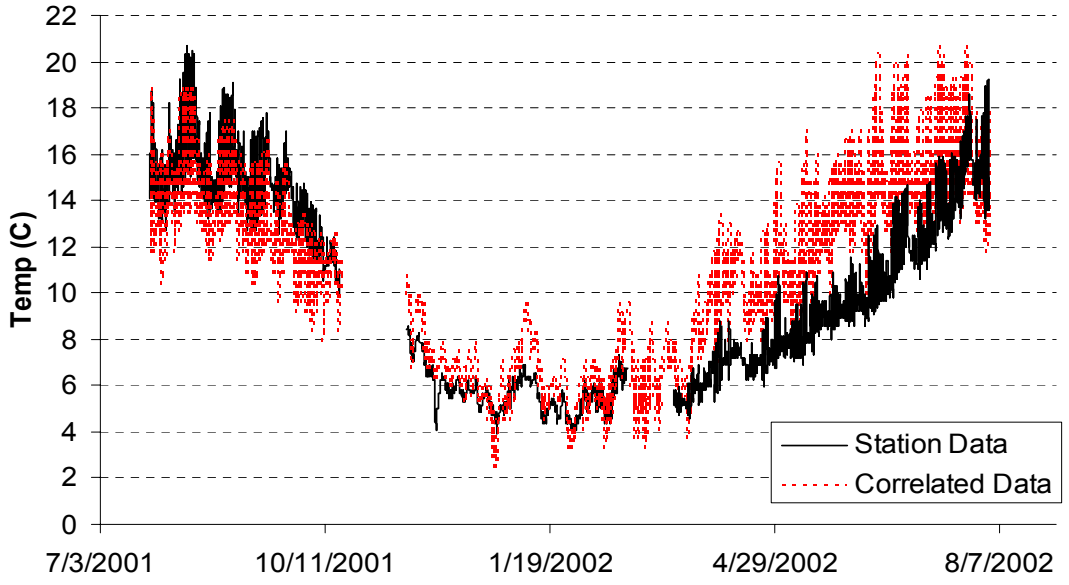

Figure 33: Upstream Boundary: Station versus correlated data, 2001-2002

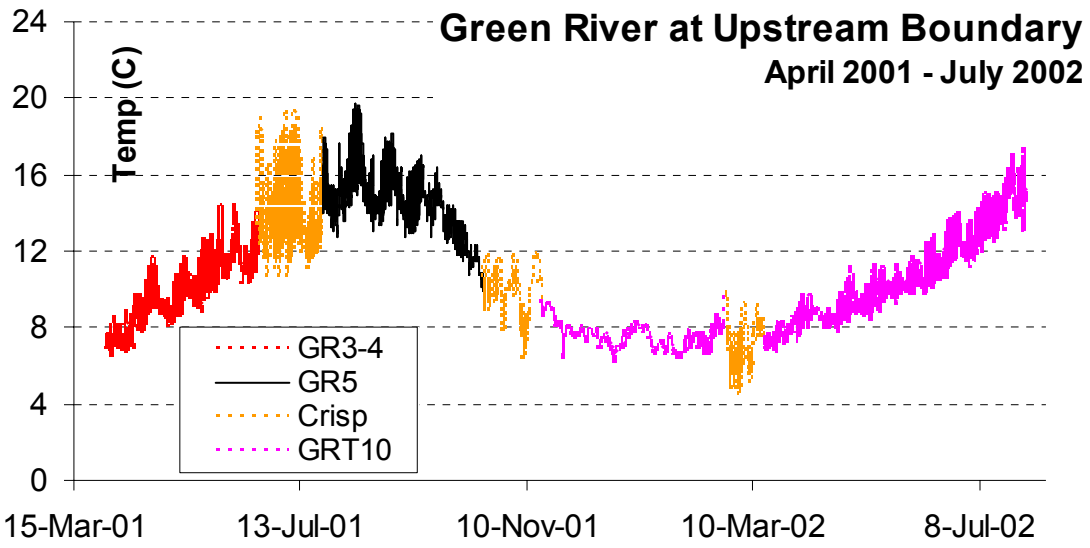

Figure 34: Green River Temperature at Upstream Boundary: Apr 2001 – July 2002

Water Quality

King County sampled water quality constituents downstream from Flaming Geyser State Park near the same location as the temperature stations GR3-4 and GRT10_2 (Locator Station B319). Data were available for all constituents. Figure 35 through Figure 48 show the constituents to be modeled for the model calibration period of April 2001 to June 2002.

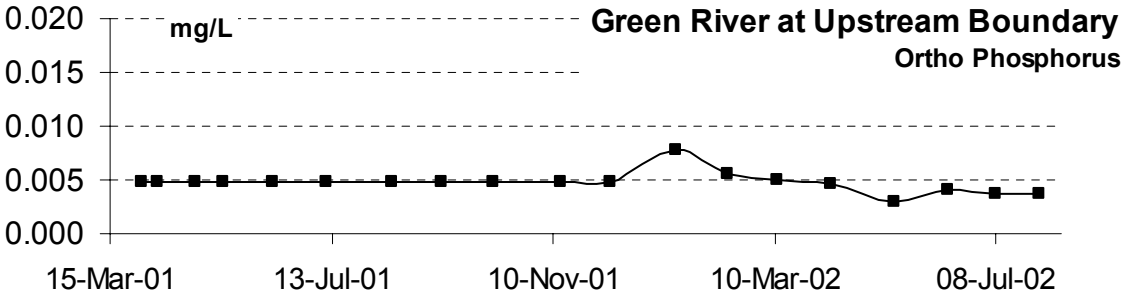

Figure 35: Ortho phosphorus at Upstream Boundary: Apr 2001 – July 2002

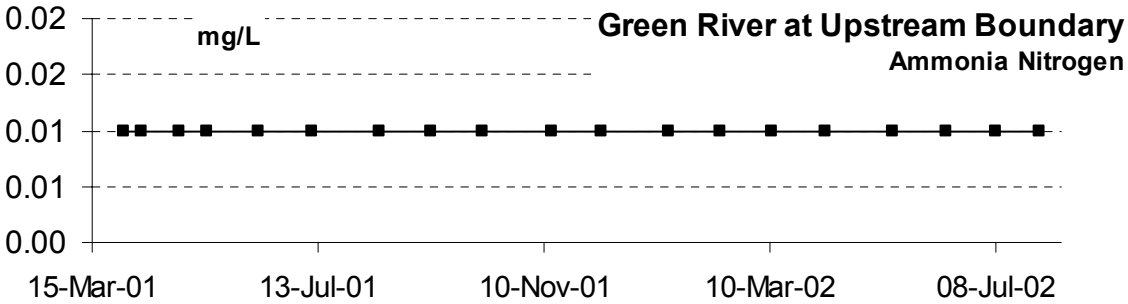

Figure 36: Ammonia at Upstream Boundary: Apr 2001 – July 2002

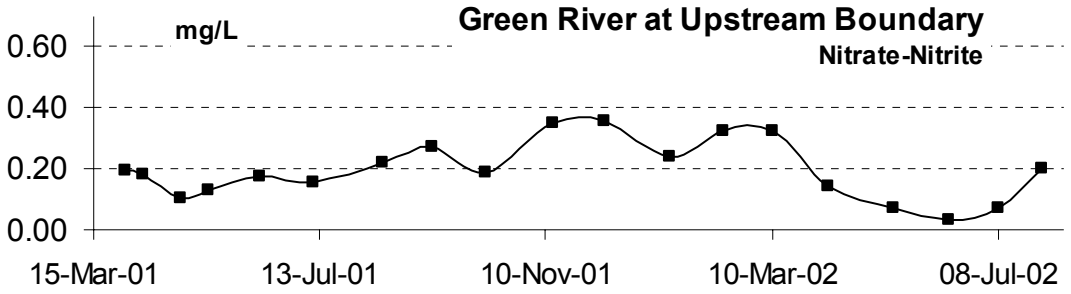

Figure 37: Nitrate-Nitrite at Upstream Boundary: Apr 2001 – July 2002

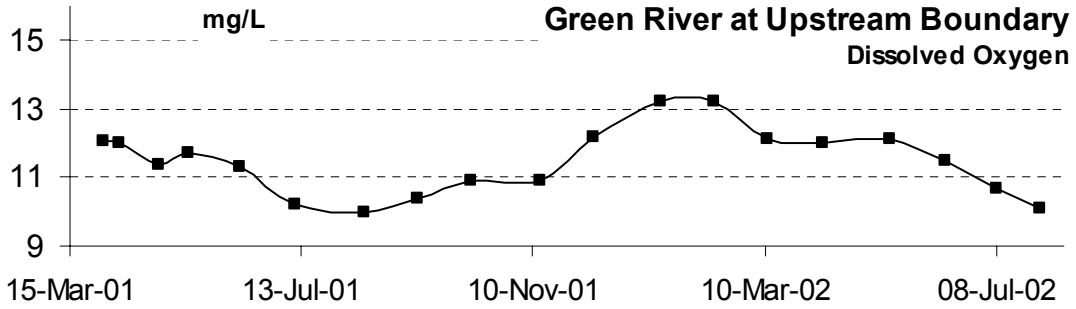

Figure 38: DO at Upstream Boundary: Apr 2001 – July 2002

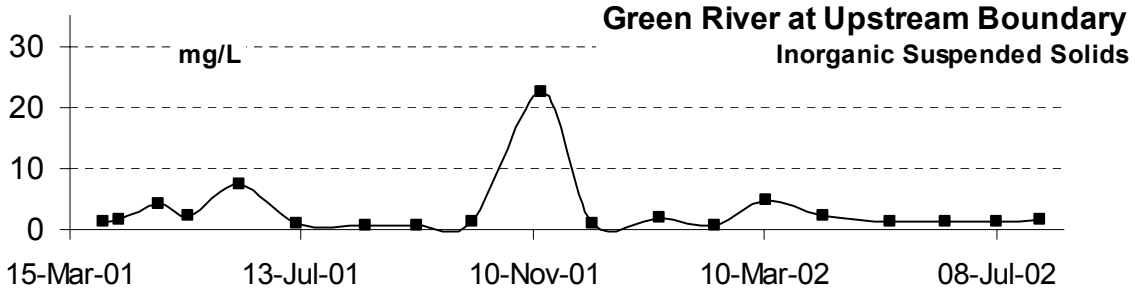

Figure 39: ISS at Upstream Boundary: Apr 2001 – July 2002

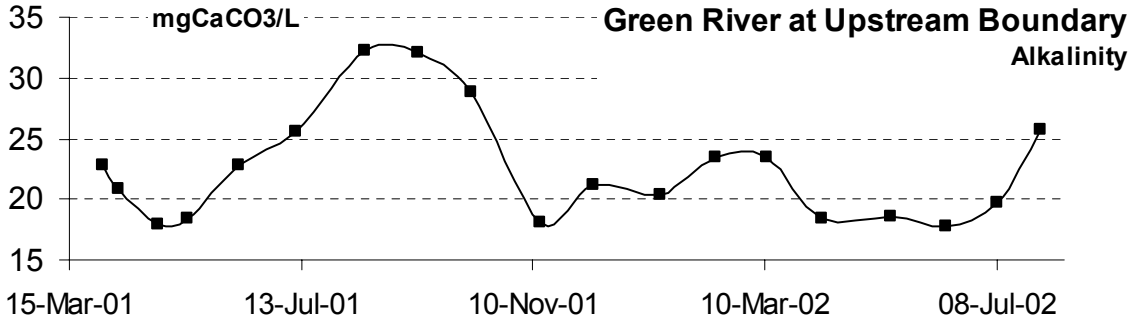

Figure 40: Alkalinity at Upstream Boundary: Apr 2001 – July 2002

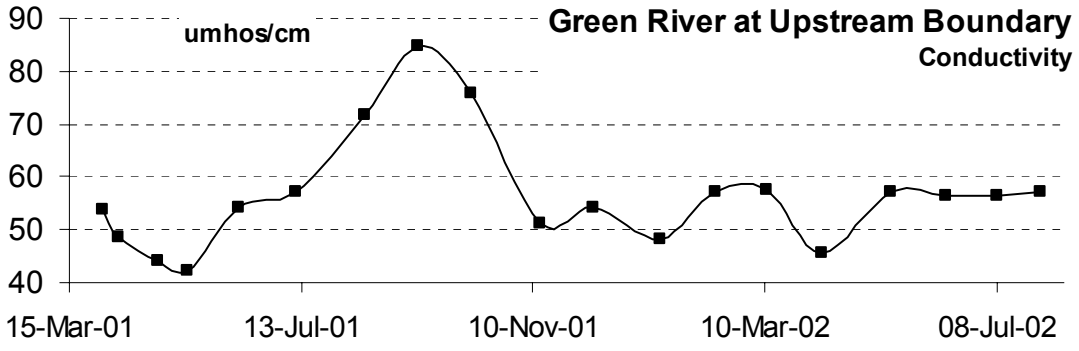

Figure 41: Conductivity at Upstream Boundary: Apr 2001 - July 2002

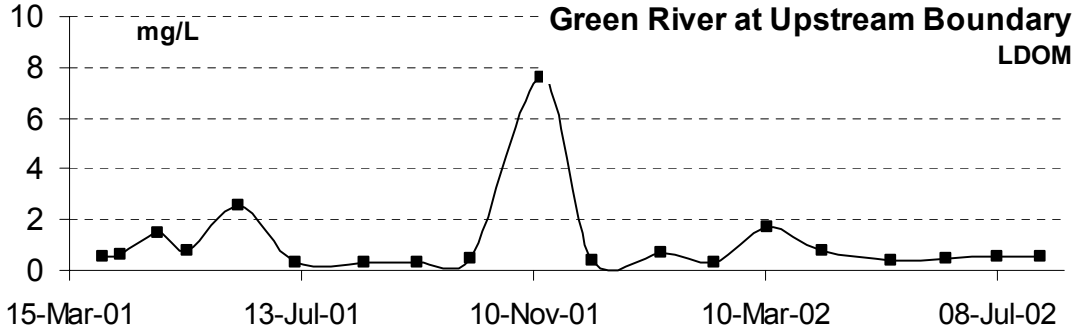

Figure 42: LDOM at Upstream Boundary: Apr 2001 - July 2002

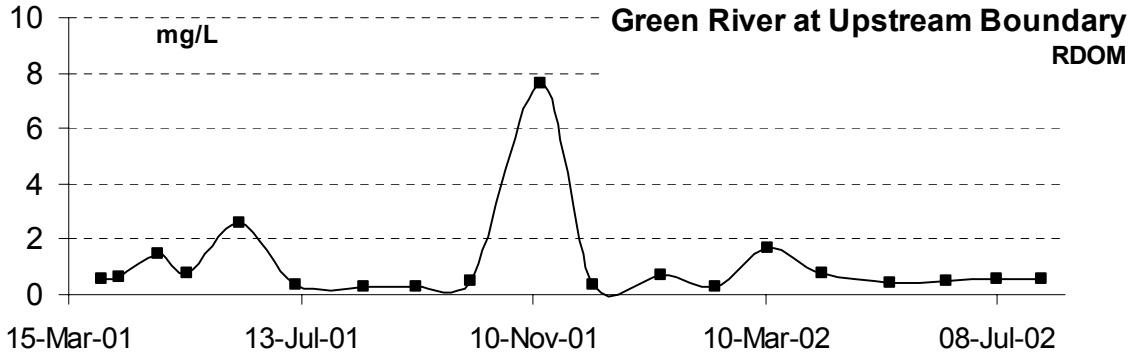

Figure 43: RDOM at Upstream Boundary: Apr 2001 – July 2002

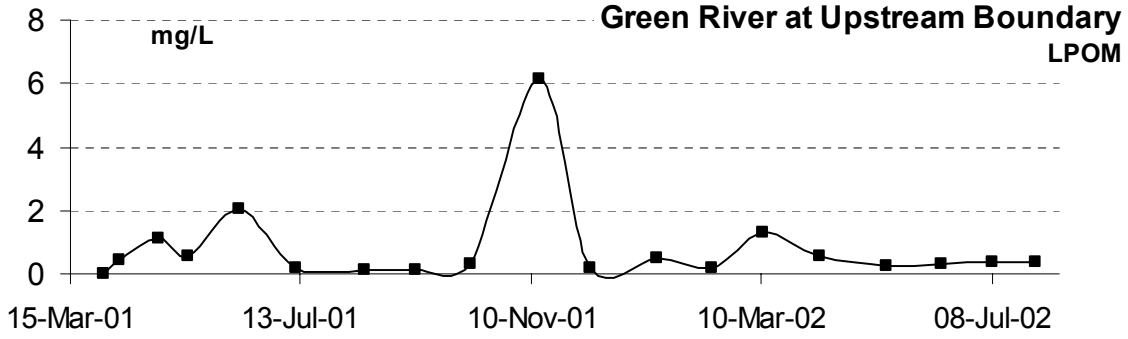

Figure 44: LPOM at Upstream Boundary: Apr 2001 – July 2002

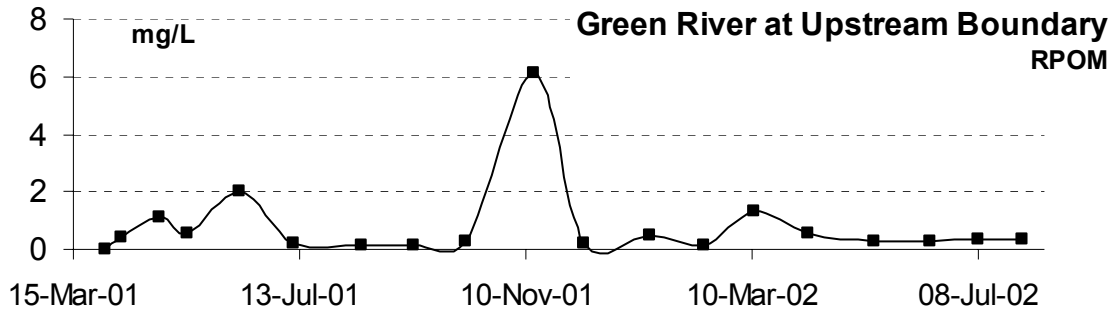

Figure 45: RPOM at Upstream Boundary: Apr 2001 - July 2002

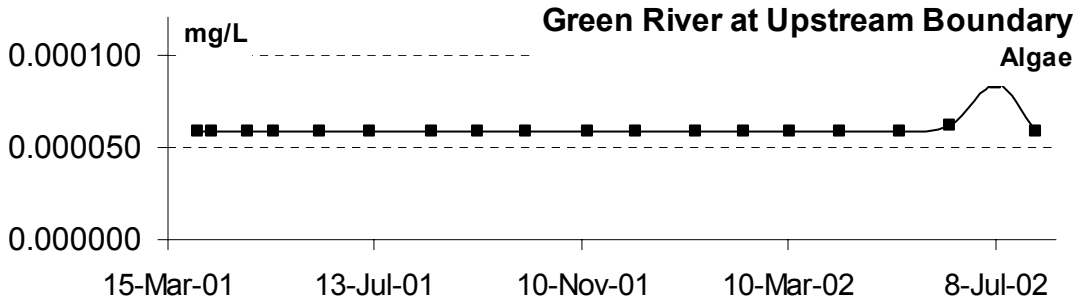

Figure 46: Algae at Upstream Boundary: Apr 2001 – July 2002

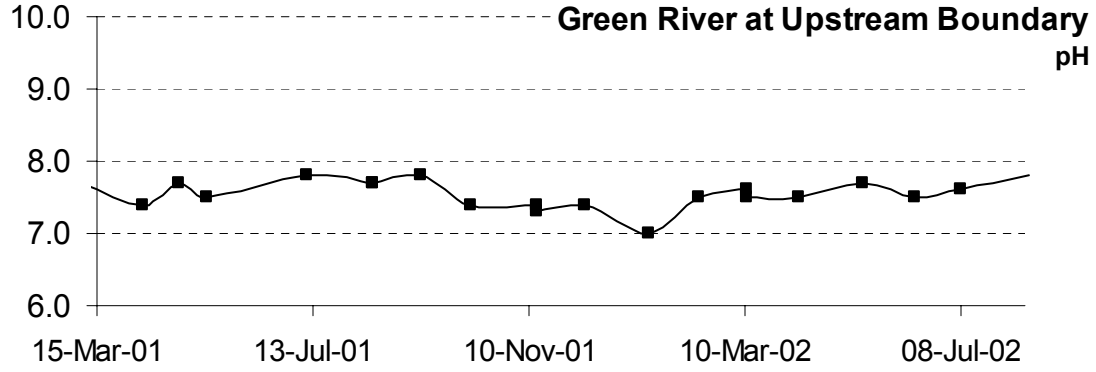

Figure 47: pH at Upstream Boundary: Apr 2001 - July 2002

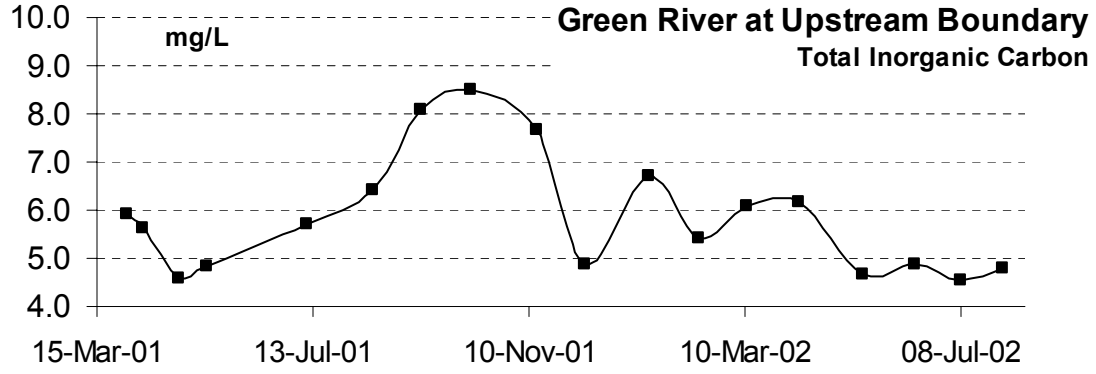

Figure 48: TIC at Upstream Boundary: Apr 2001 – July 2002

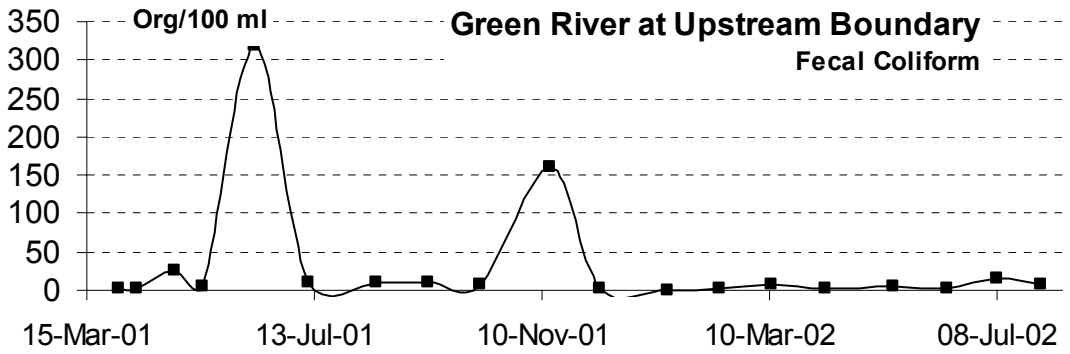

Figure 49: Fecal Coliform at Upstream Boundary: Apr 2001 - July 2002

Downstream Boundary

The downstream boundary is at Fort Dent, in Tukwila, where the Green River flows into the Duwamish River. The boundary condition here is characterized by water surface elevation, temperature, and water quality. This section of the river is tidally influenced, and flow data were recorded at this location until 1987. A review of this data indicates that the tide does not raise high enough to reverse flow in the river, but may influence flow velocities. A graph of flow from 1960 to 1987 is included in Appendix A.

May 25, 1995 – November 1996

Stage

Hourly stage data has been obtained from a USGS gage (12113350) at Fort Dent. These data will be used for an external downstream boundary condition. This gage has bad or missing data from May 24, 1995 to May 8, 1996. A good correlation with data from another source has not been found. Stage data from May 24, 1997 to May 8 1998 is currently being used. Figure 50 shows the stage data for the model calibration period.

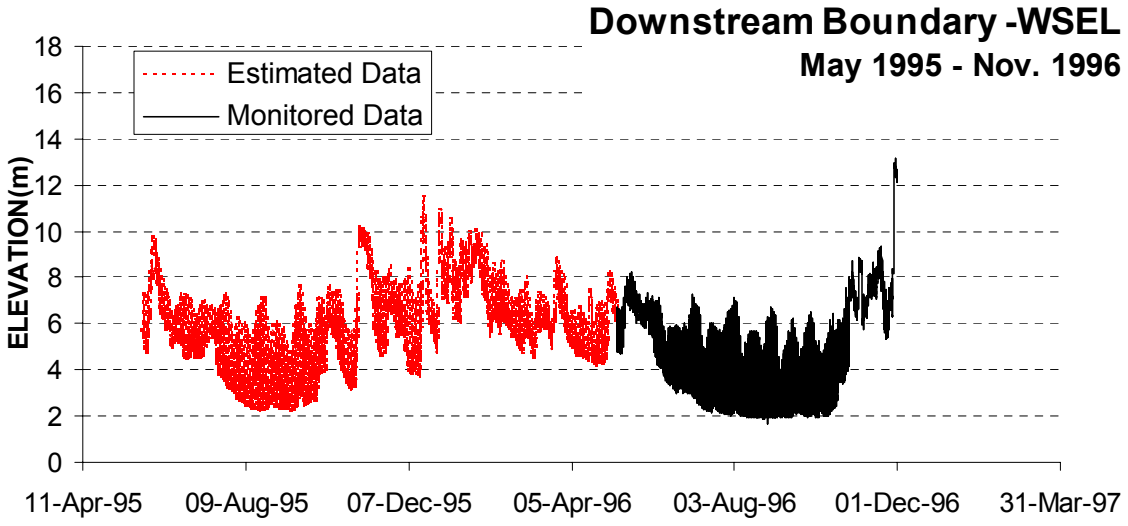

Figure 50: Stage at downstream boundary

Temperature

King County conducted a temperature study in 1995-1996 which monitored temperature approximately 2.0 km upstream of the downstream boundary (Station BIC). It is missing data from April 30, 1996 to June 7, 1996. Data from a temperature station on Big Soos Creek (Station 54a) was correlated with data from station BIC to fill this gap. The equation is:

$$BIC = 1.3147(\text{Big Soos Temp}) - 0.9051$$

Figure 51 shows the temperature correlation for the 2 stations, Figure 52 shows correlated values and monitored data for the correlation period, and Figure 53 shows the data for the model calibration period with correlated values included.

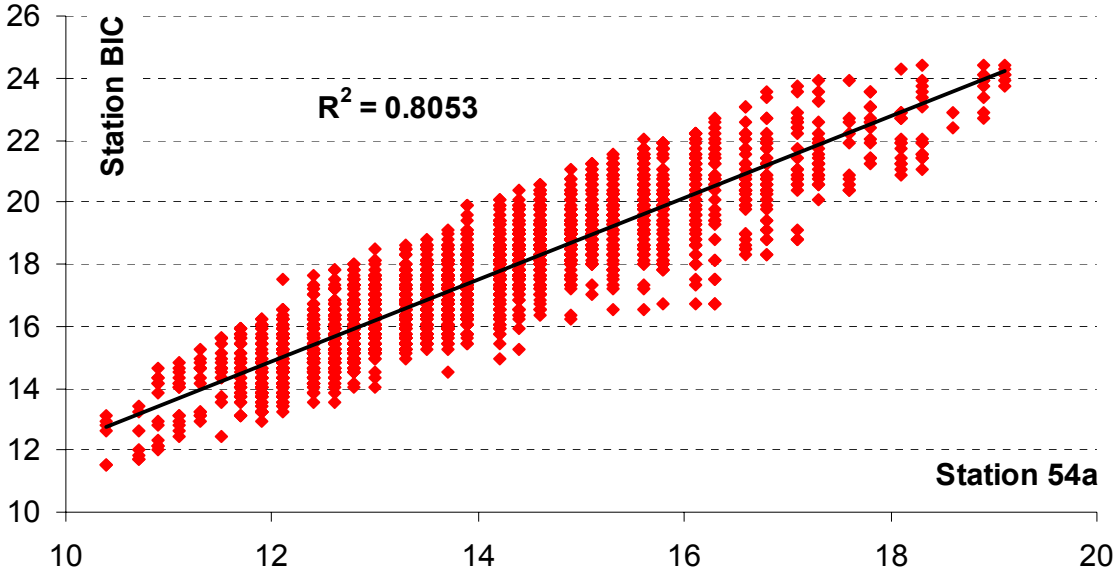

Figure 51: Correlation between Big Soos Temperature and D/S boundary station

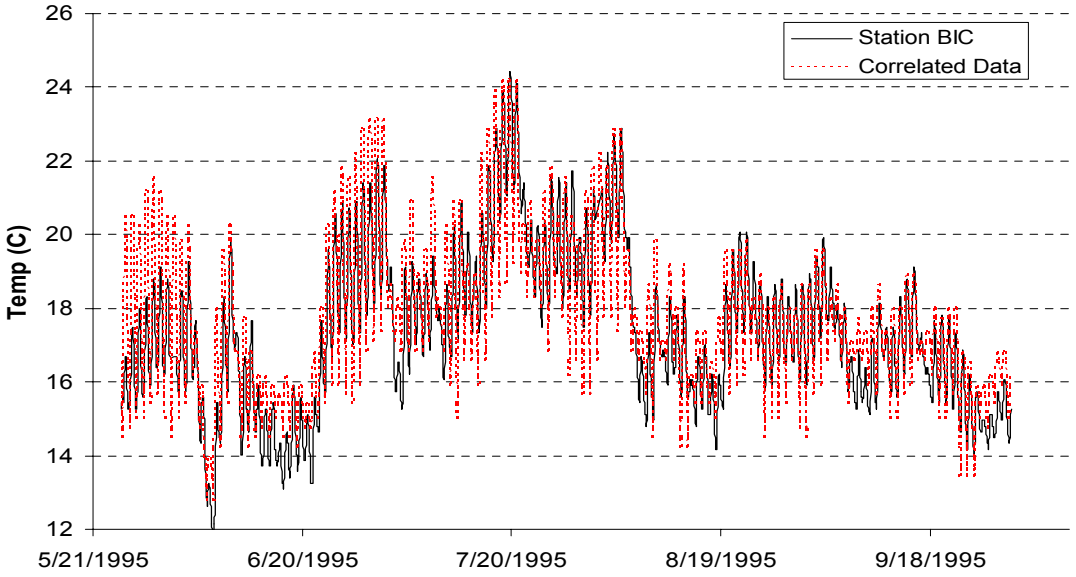

Figure 52: Downstream Boundary: Station versus correlated data, 1995-1996

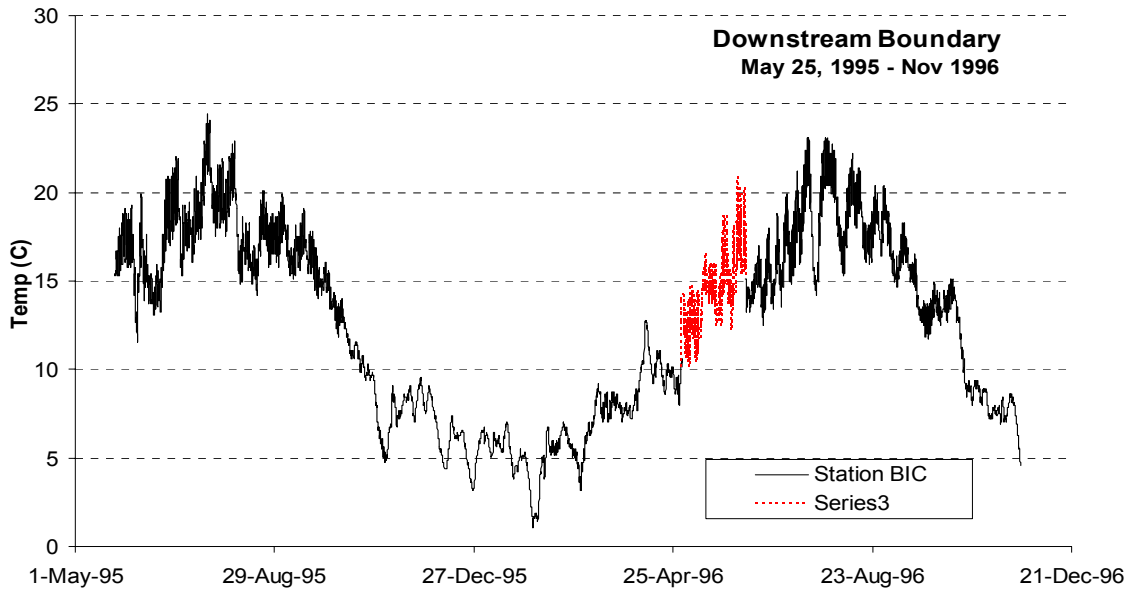

Figure 53: Green River Temperature at Downstream Boundary: May 25, 1995 – Nov 1996

Water Quality

King County has been collecting water quality at Monitoring Station 3106 which is located at the downstream boundary. Data are available for all constituents except chlorophyll a and alkalinity for the model calibration period. Figure 54 through Figure 67 shows the constituent data for the model calibration period. See Appendix D for procedures used in assembling the water quality data, including filling data gaps and estimating missing data.

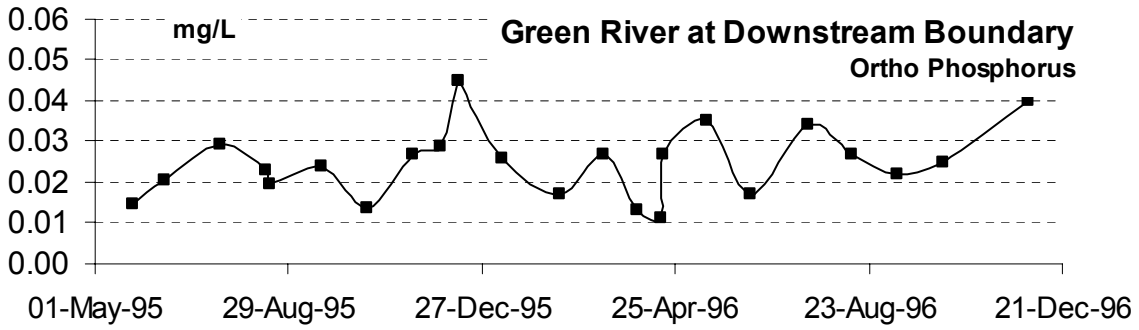

Figure 54: Ortho phosphorus at Downstream Boundary: May 1995 to November 1996

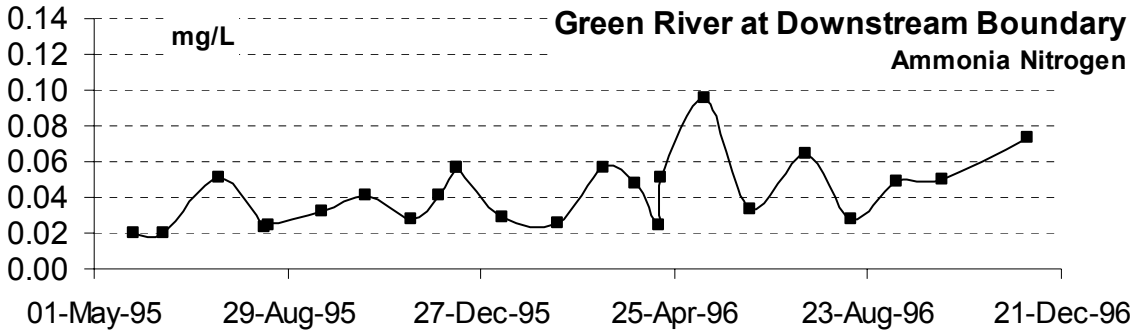

Figure 55: Ammonia at Downstream Boundary: May 1995 to November 1996

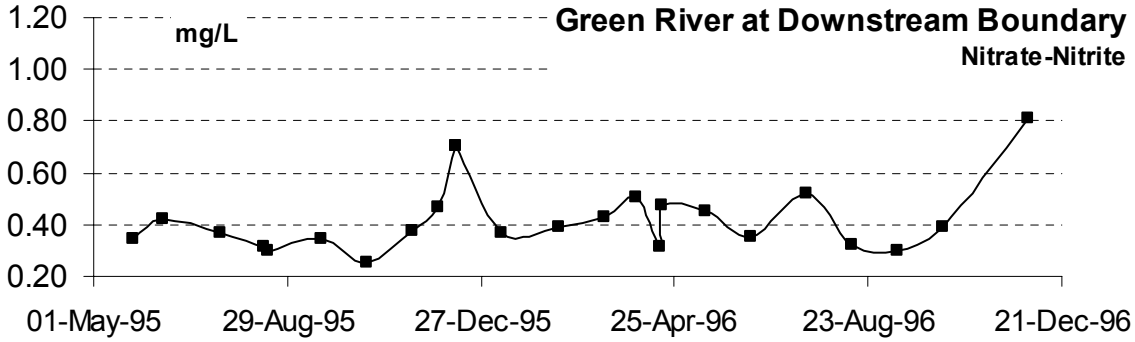

Figure 56: Nitrate-Nitrite at Downstream Boundary: May 1995 to November 1996

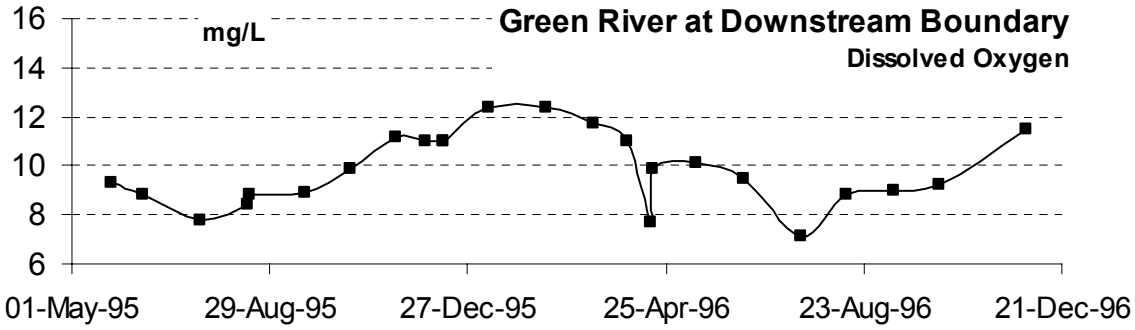

Figure 57: DO at Downstream Boundary: May 1995 to November 1996

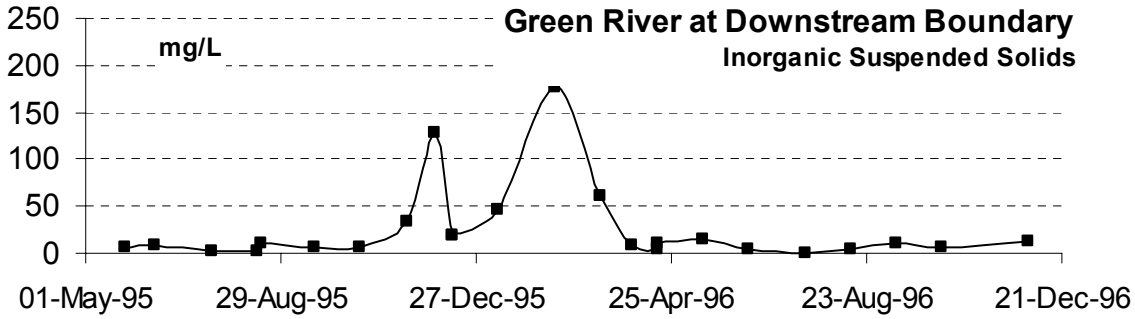

Figure 58: ISS at Downstream Boundary: May 1995 to November 1996

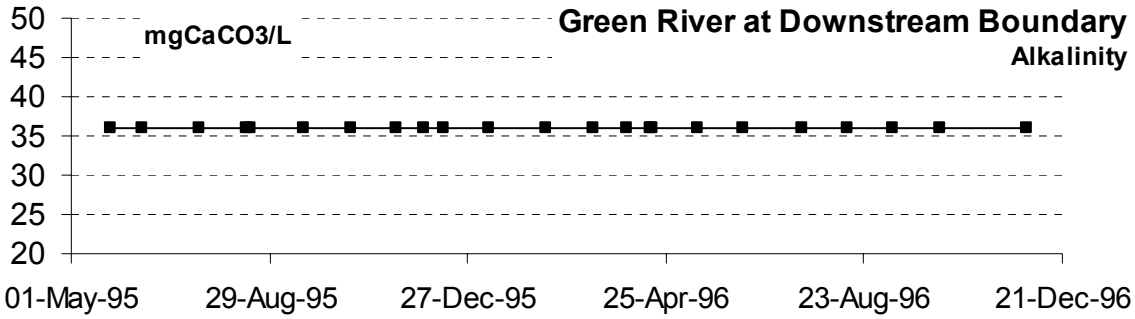

Figure 59: Alkalinity at Downstream Boundary: May 1995 to November 1996

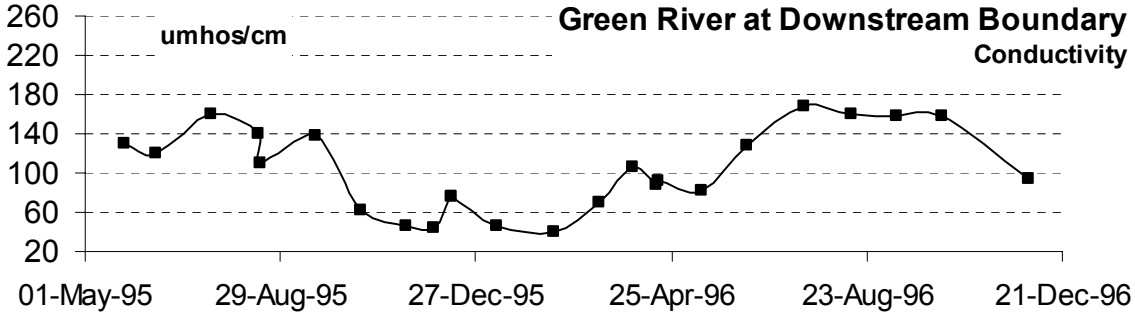

Figure 60: Conductivity at Downstream Boundary: May 1995 to November 1996

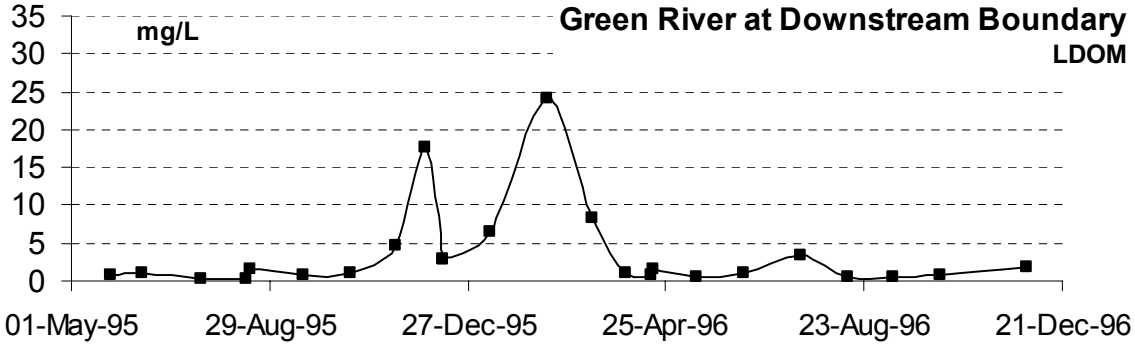

Figure 61: LDOM at Downstream Boundary: May 1995 to November 1996

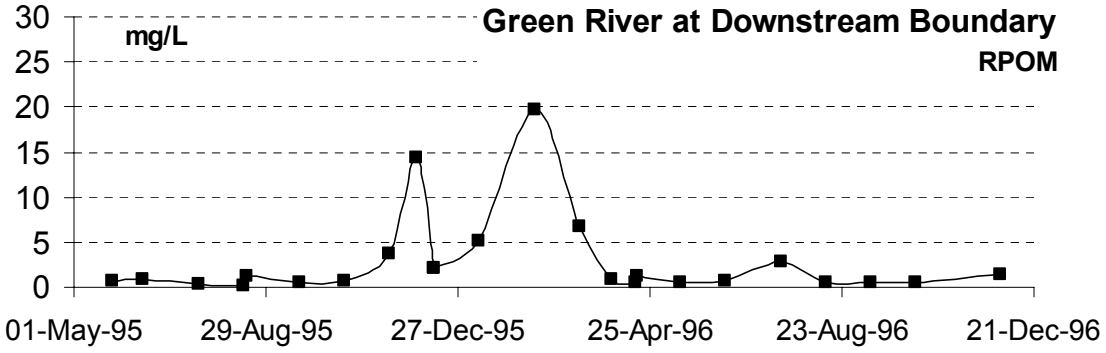

Figure 62: RDOM at Downstream Boundary: May 1995 to November 1996

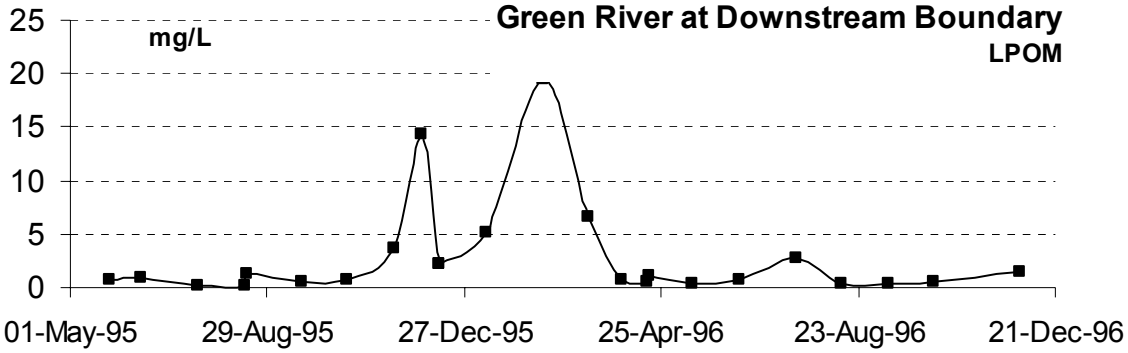

Figure 63: LPOM at Downstream Boundary: May 1995 to November 1996

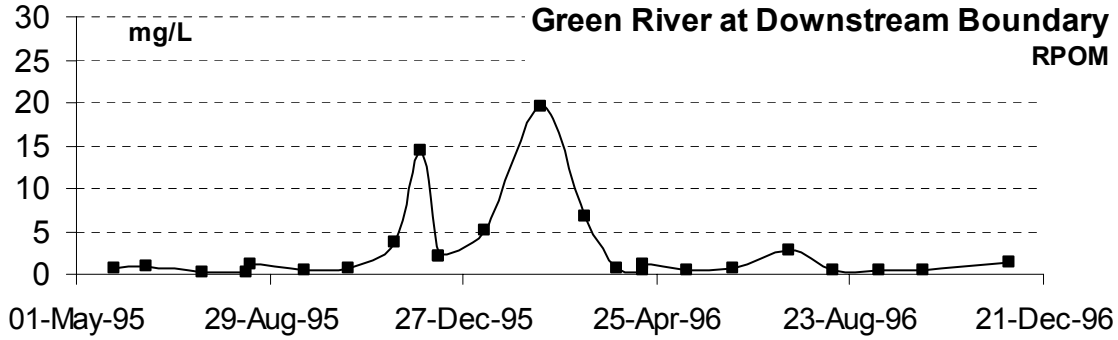

Figure 64: RPOM at Downstream Boundary: May 1995 to November 1996

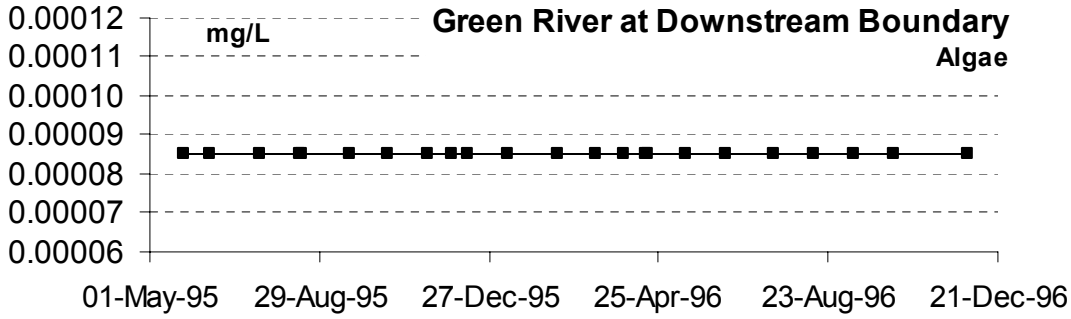

Figure 65: Algae at Downstream Boundary: May 1995 to November 1996

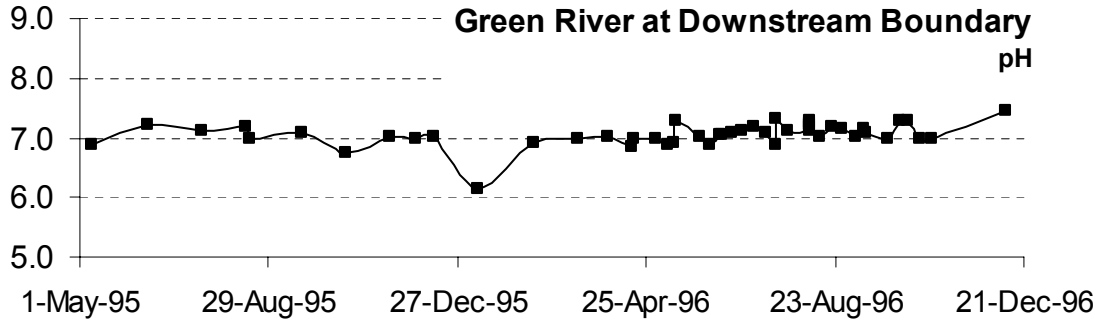

Figure 66: pH at Downstream Boundary: May 1995 - November 1996

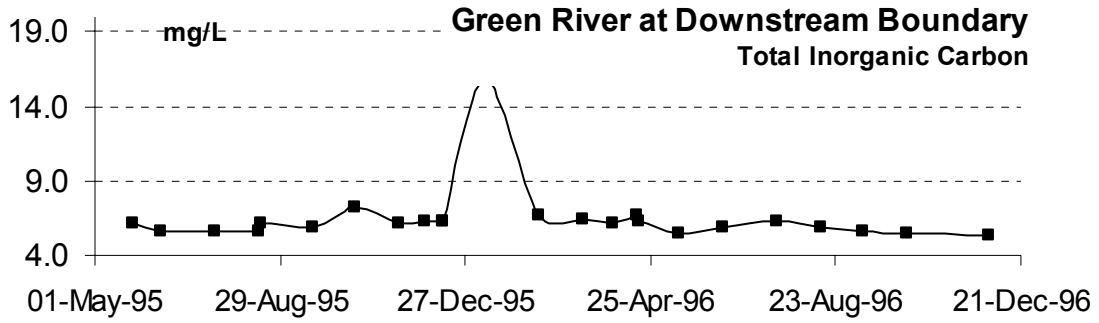

Figure 67: TIC at Downstream Boundary: May 1995 to November 1996

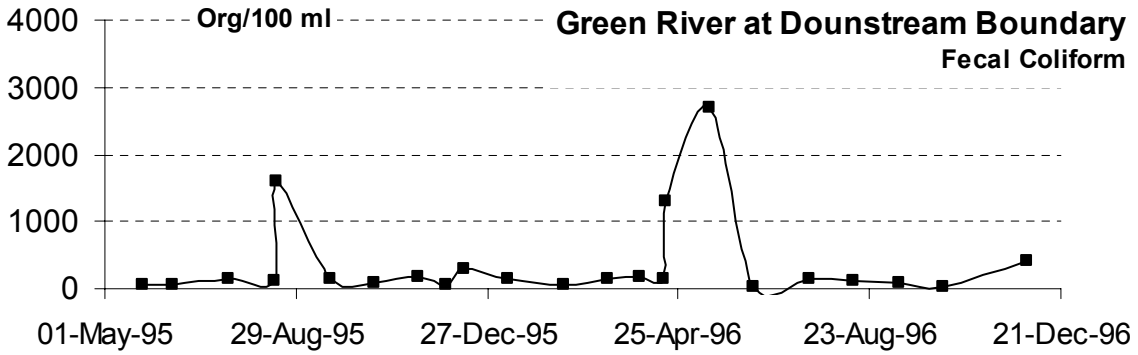

Figure 68: Fecal Coliform at Downstream Boundary: May 1995 to November 1996

April 2001 – July 2002

Stage

Stage data for USGS Gage 13113500 is available from April 2001 to June 18, 2002. To complete the data set through the end of July 2002, an average of the data from 1996 to 2001 for the same time period were used. The gage at Fort Dent was also missing data for 2 days in February 2002. Data from other years for the same 2 day time period was also used to fill in the missing time period. A graph of stage data from this gage from 1995 through June 18, 2002 is included in Appendix A. Figure 69 shows the stage data for the model period.

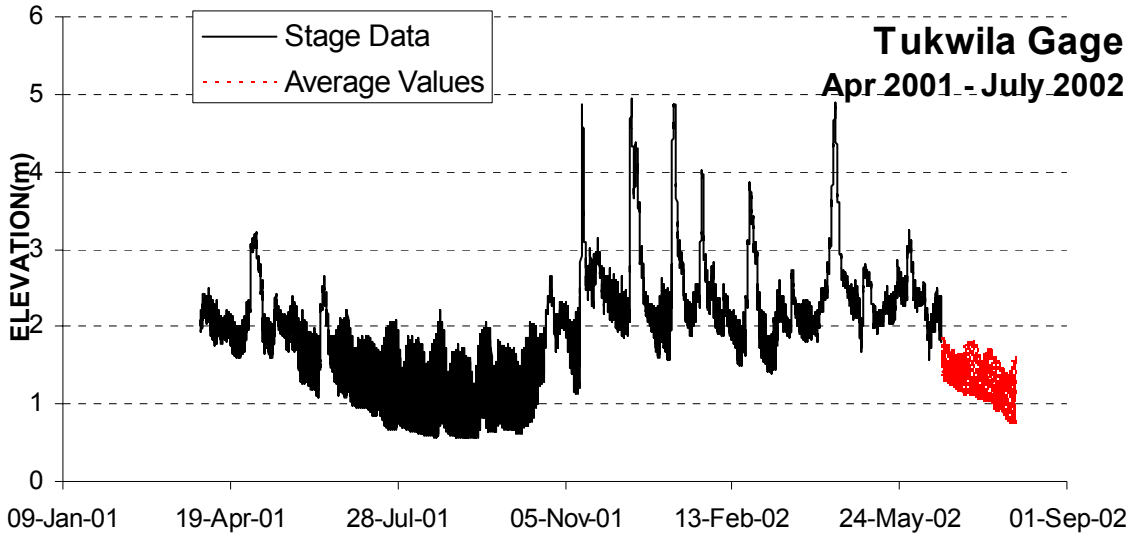

Figure 69: Green River Stage at Downstream Boundary: May 25, 1995 – Nov 1996

Temperature

King County began monitoring water temperature at this location in July 2002, and data were provided through September 2002 (Station GRT18). To provide data for April 2001 to July 2002, a correlation was used from temperature monitored by the University of Washington about 20 km upstream (Station GR1). The correlation period was between July 9, 2002 and September 12, 2002. The equation used to fill the data is as follows:

$$\text{D/S Temp} = 0.8632(\text{GR1}) + 3.5519$$

Figure 70 shows the graph of the 2 stations, Figure 71 shows a graph of data from GRT18 and the correlated data, and Figure 72 shows the data used for the model calibration period.

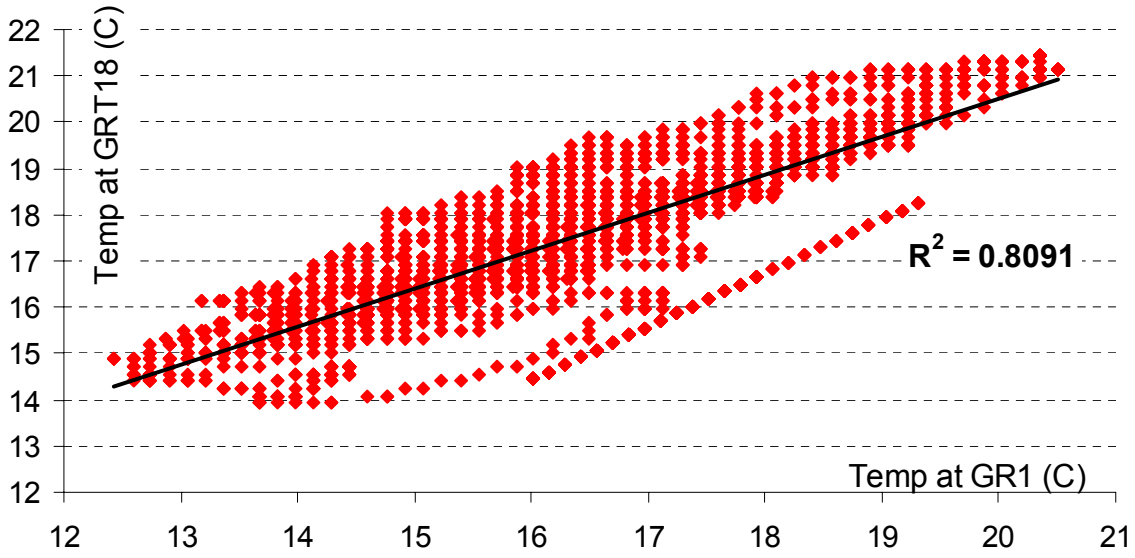

Figure 70: Correlation between Station GR1 and D/S boundary station GRT18

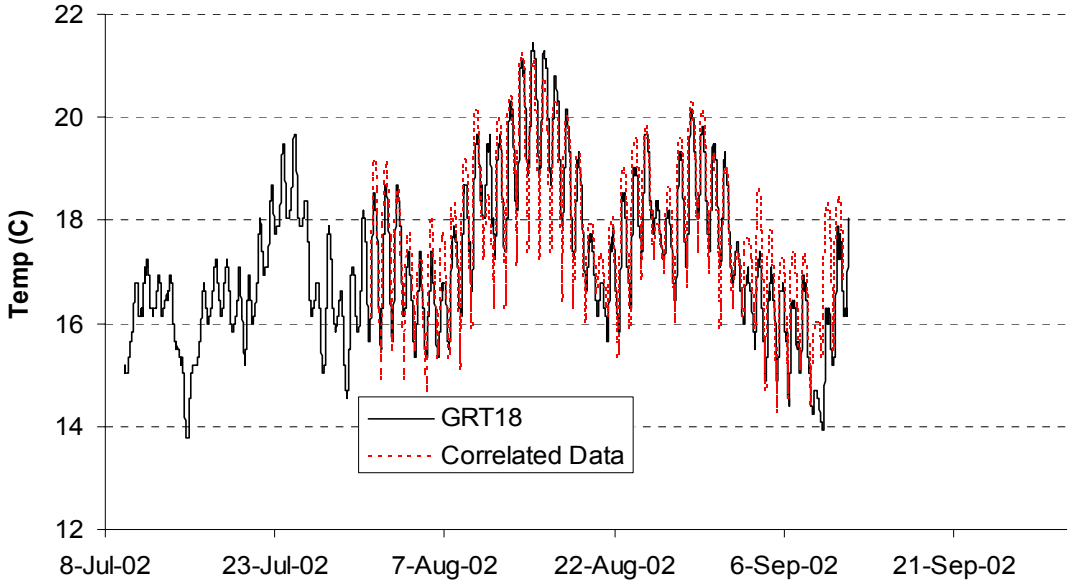

Figure 71: Downstream Boundary: Station versus correlated data, 2001-2002

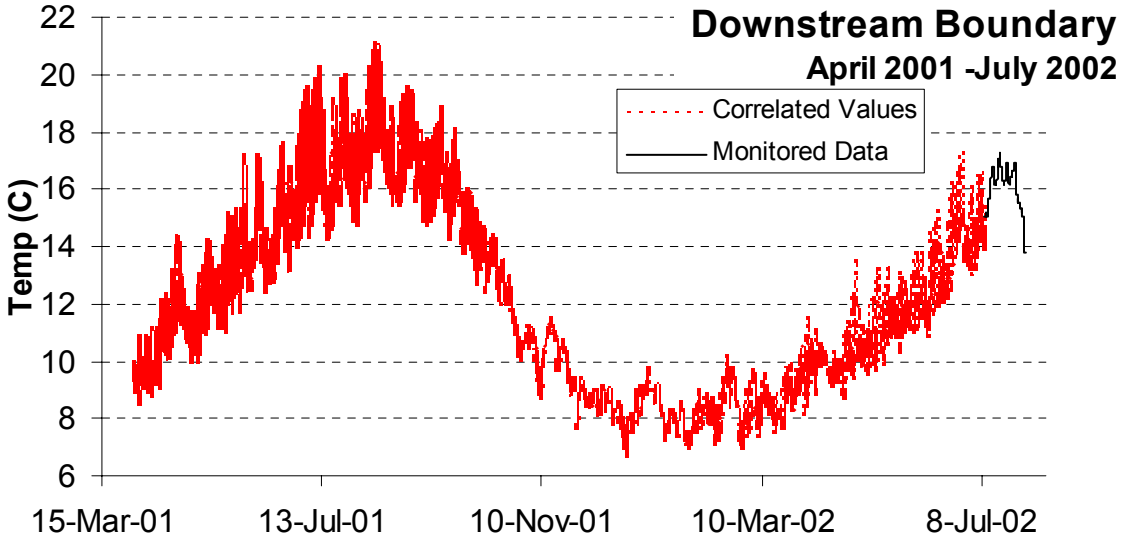

Figure 72: Green River Temperature at Downstream Boundary: Apr 2001 – July 2002

Water Quality

Water quality was monitored at this location for all constituents, with only minimal data available for chlorophyll a. These data are shown in Figure 73 through Figure 86. See Appendix D for procedures used in assembling the water quality data.

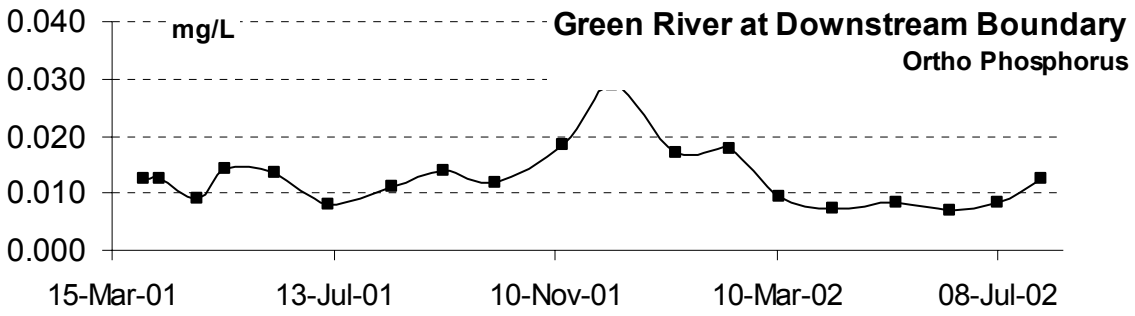

Figure 73: Ortho phosphorus at Downstream Boundary: Apr 2001 – July 2002

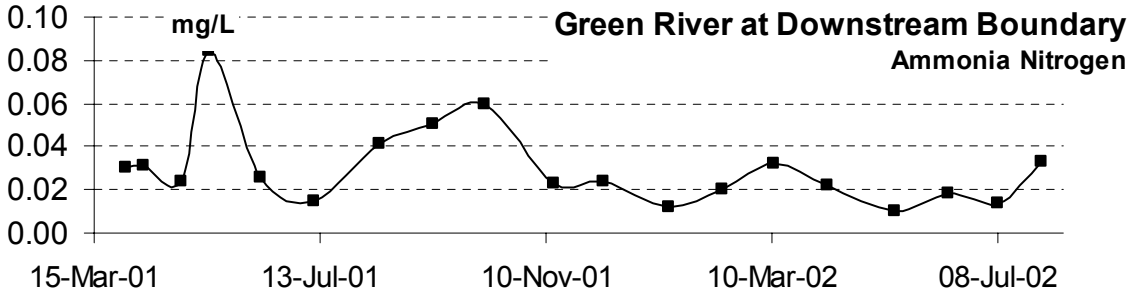

Figure 74: Ammonia at Downstream Boundary: Apr 2001 – July 2002

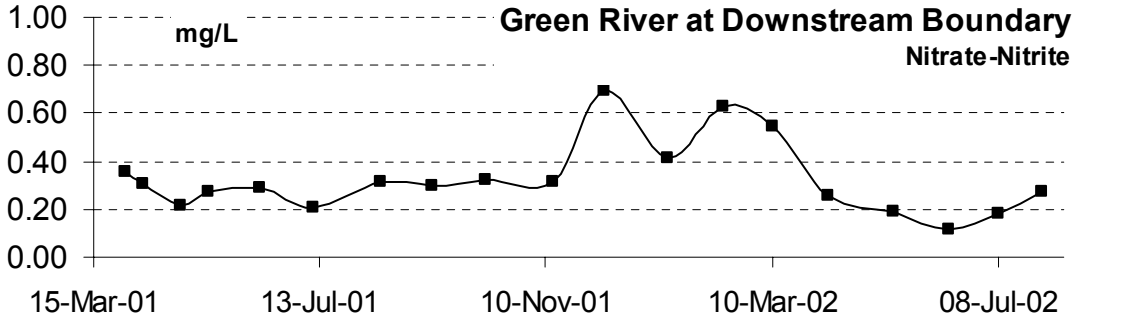

Figure 75: Nitrate-Nitrite at Downstream Boundary: Apr 2001 – July 2002

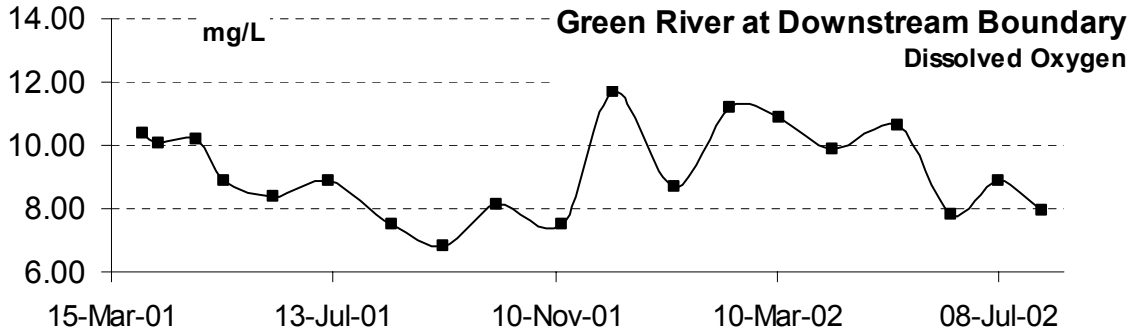

Figure 76: DO at Downstream Boundary: Apr 2001 – July 2002

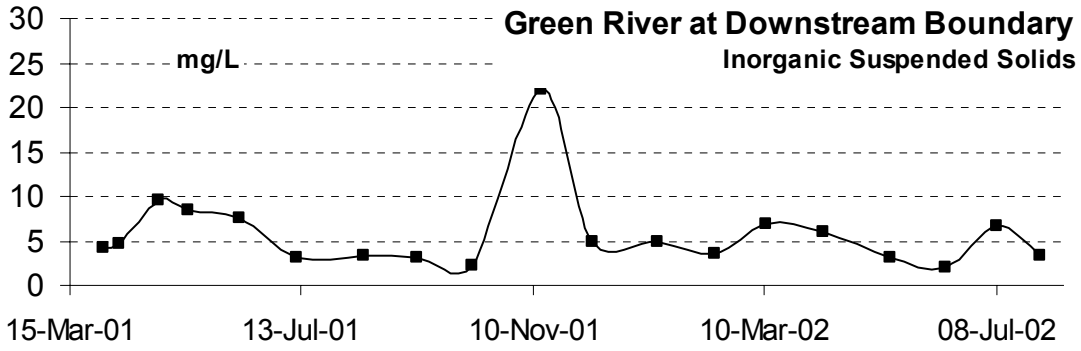

Figure 77: ISS at Downstream Boundary: Apr 2001 – July 2002

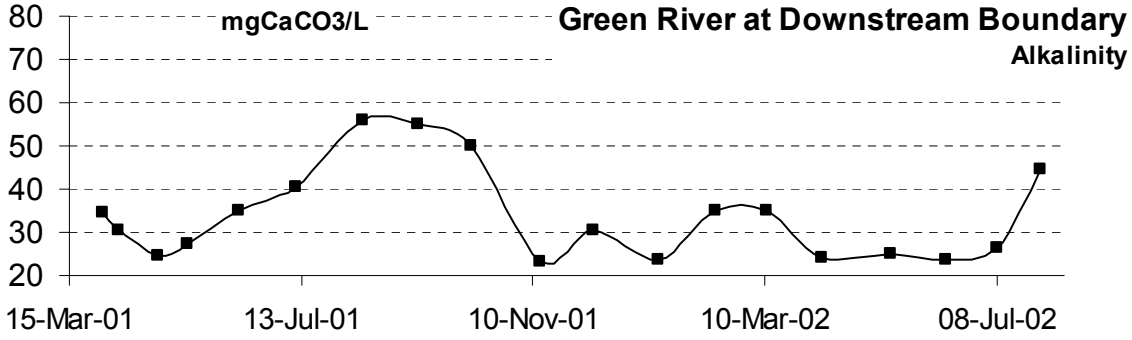

Figure 78: Alkalinity at Downstream Boundary: Apr 2001 – July 2002

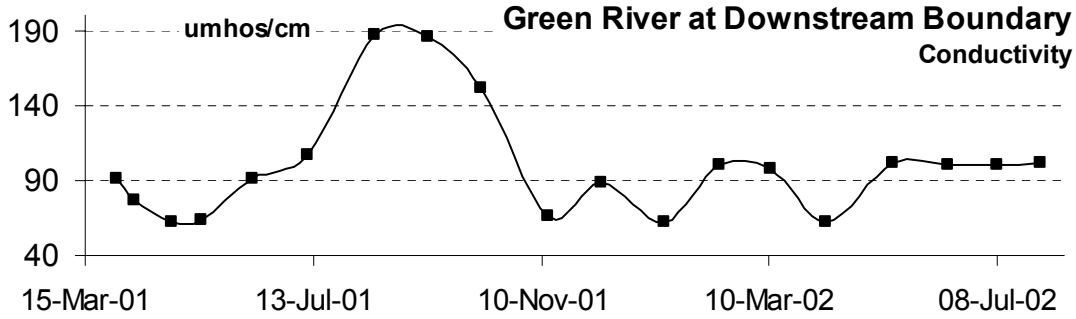

Figure 79: Conductivity at Downstream Boundary: Apr 2001 – July 2002

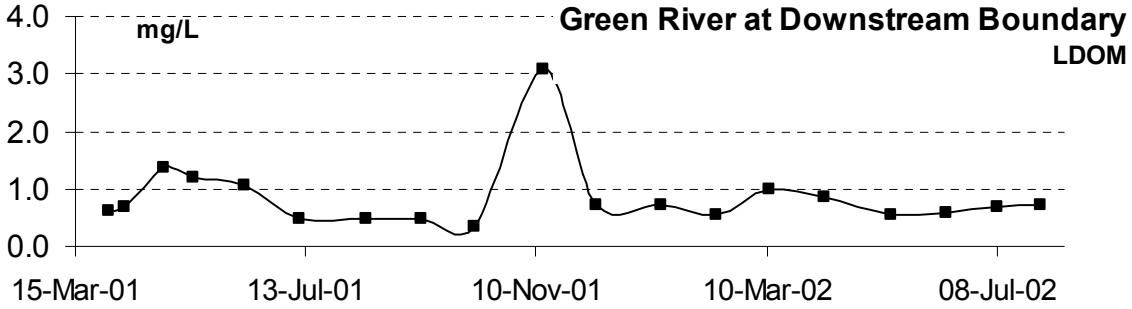

Figure 80: LDOM at Downstream Boundary: Apr 2001 – July 2002

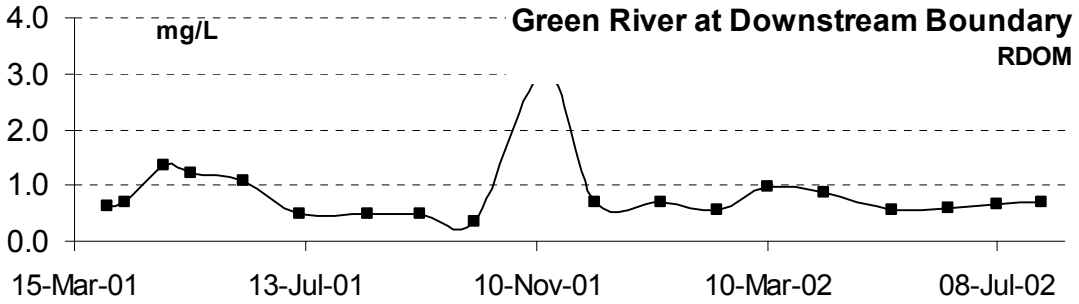

Figure 81: RDOM at Downstream Boundary: Apr 2001 – July 2002

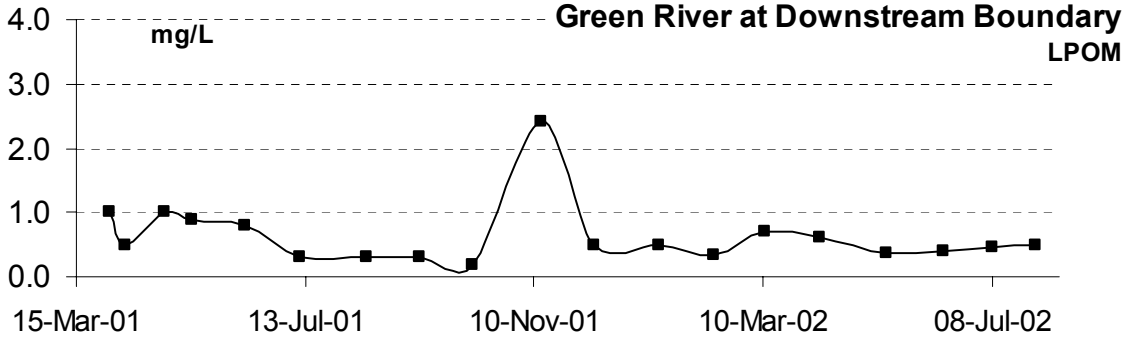

Figure 82: LPOM at Downstream Boundary: Apr 2001 – July 2002

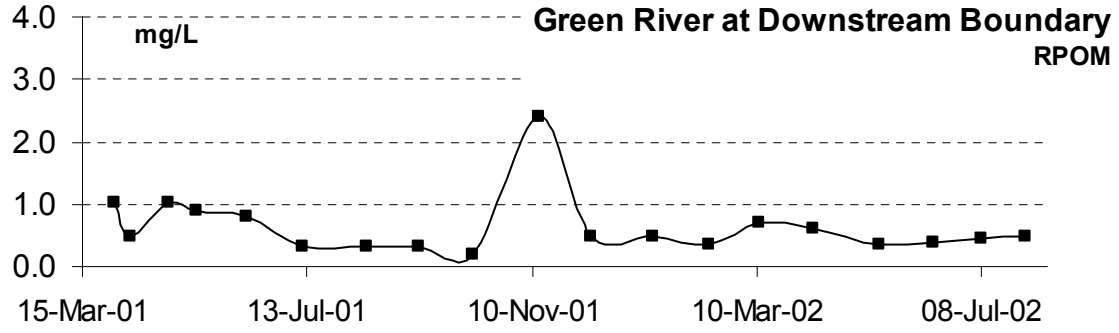

Figure 83: RPOM at Downstream Boundary: Apr 2001 – July 2002

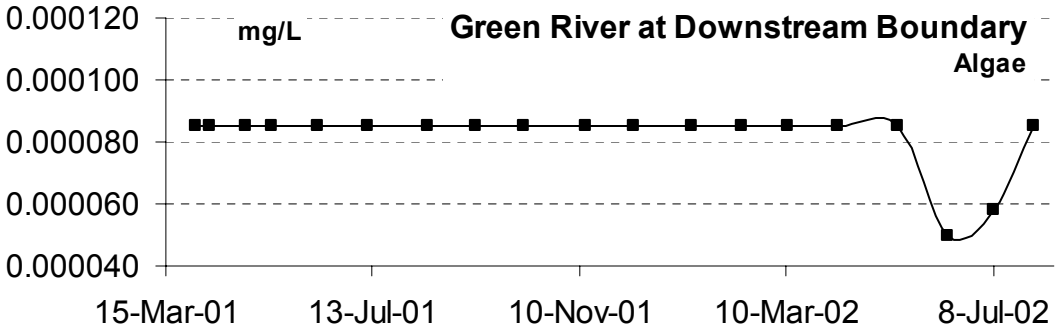

Figure 84: Algae at Downstream Boundary: Apr 2001 – July 2002

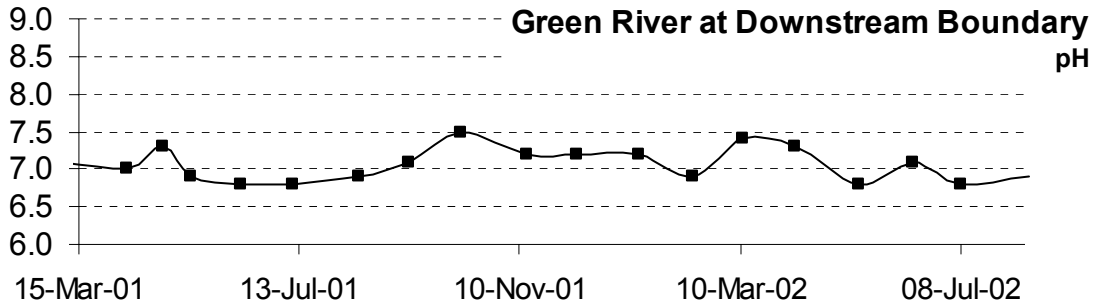

Figure 85: pH at Downstream Boundary: Apr 2001 - July 2002

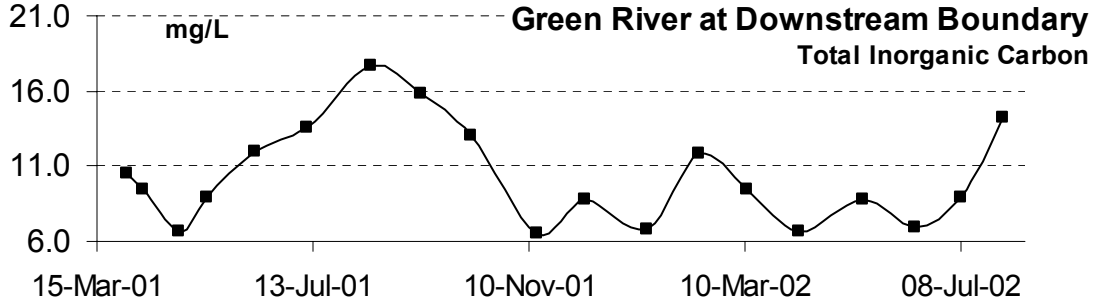

Figure 86: TIC at Downstream Boundary: Apr 2001 – July 2002

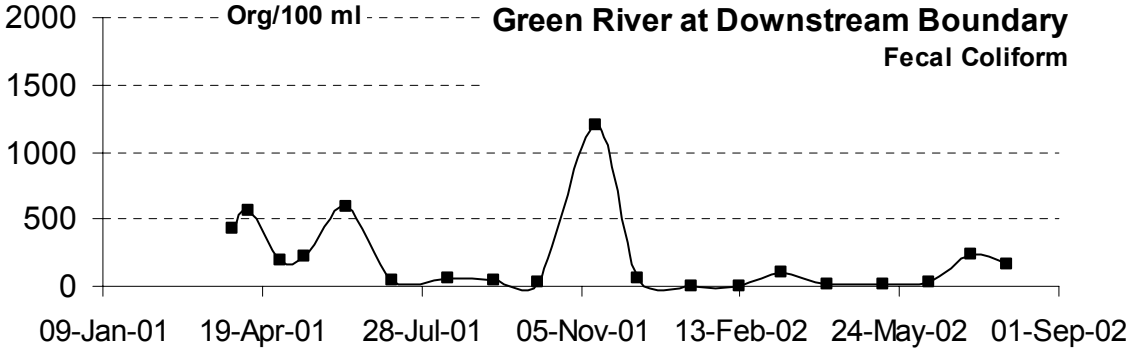

Figure 87: Fecal Coliform at Downstream Boundary: Apr 2001 - July 2002

Tributaries

The seven tributaries to be included in this model are Crisp Creek, Newaukum Creek, Big Soos Creek, Auburn Creek, Mill Creek, Mullen Slough, and Midway Creek. Table 7 lists the river mile and model segment number for each tributary, and Figure 88 shows the location of these tributaries on the river system.

Each tributary was characterized by flow, temperature, and water quality. The larger tributaries (Big Soos, Newaukum, Crisp, Mill) have some gaged or sampled data available. The 3 smaller tributaries (Midway, Mullen Slough, Auburn) have no gaged or sampled data available.

Table 7: Tributary River Miles and Segment Numbers		
Tributary	River Mile	Model Segment Number
Newaukum Creek	41.10	26
Crisp Creek	40.40	32
Big Soos Creek	33.80	77
Auburn Creek	25.50	135
Mill Creek	23.80	146
Mullen Slough	21.60	160
Midway Creek	19.60	172

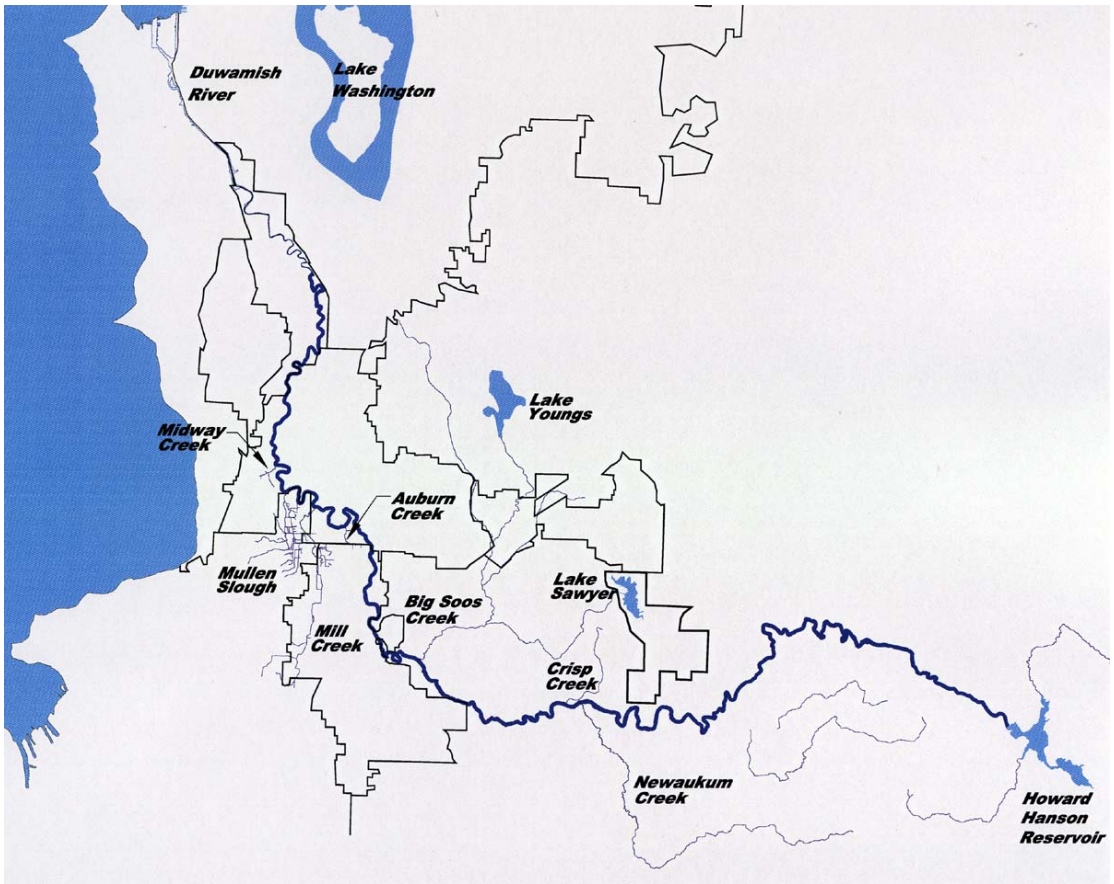

Figure 88: Modeled Tributaries to Green River

Newaukum Creek

Newaukum Creek is approximately 1.2 km upstream from Crisp Creek, at River Mile 26. It is a large tributary, with a basin size of approximately 7,200 hectares (17,800 acres).

May 1995 – Nov 1996

Flow

USGS has a flow gage (12108500) approximately 1.50 km upstream of the confluence with the Green River. Data were obtained in 15-minute intervals for this gage from October 1, 1994 to December 31, 2002. Flow data are available for the entire model run period. The complete data set is included in Appendix A, and Figure 89 shows the data for the model simulation period.

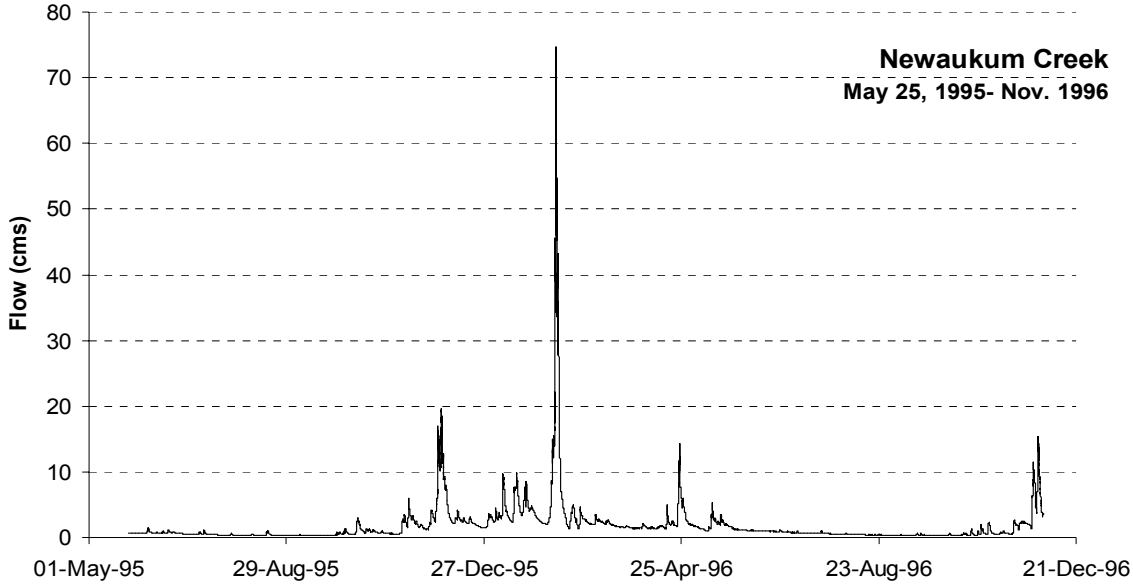

Figure 89: Newaukum Creek Flow: May 25, 1995 – Nov 1996

Temperature

USGS monitored hourly temperatures on Newaukum Creek from July 1996 to September 1998. Data are not available from May 25, 1995 to July 1996 during the model calibration period. To fill this gap, data from July 1996 to September 1998 were compared to data from Big Soos Creek for the same time period. The resulting correlation equation is:

$$\text{Newaukum Creek Temp} = 0.9529(\text{Big Soos Temp}) + 0.3982$$

Figure 90 shows the temperature correlation for the 2 stations, Figure 91 shows the correlated values with the data, and Figure 92 shows the data for the model calibration period.

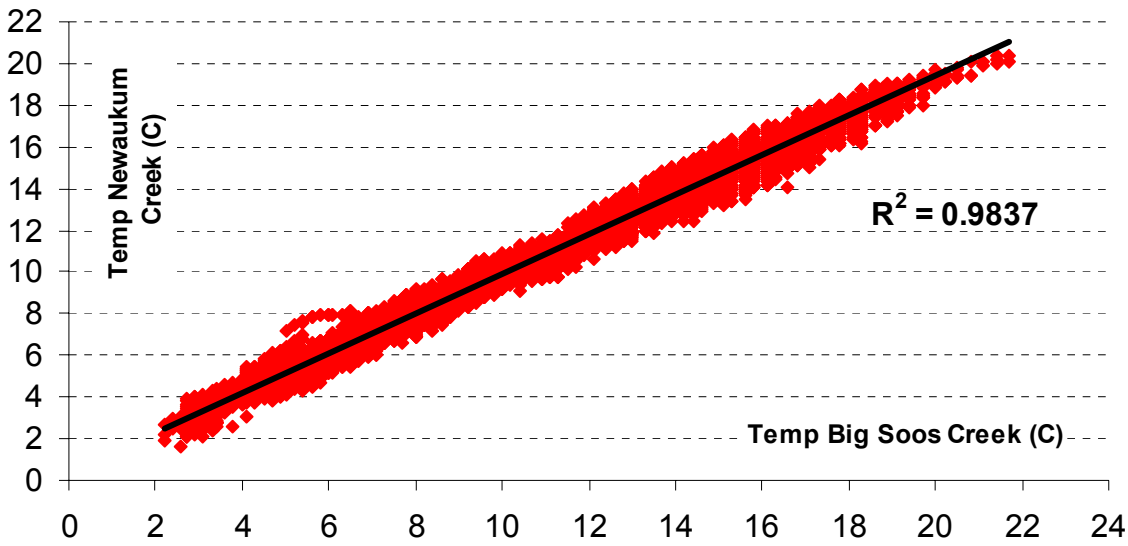

Figure 90: Correlation between Big Soos Temperature and Newaukum Creek station

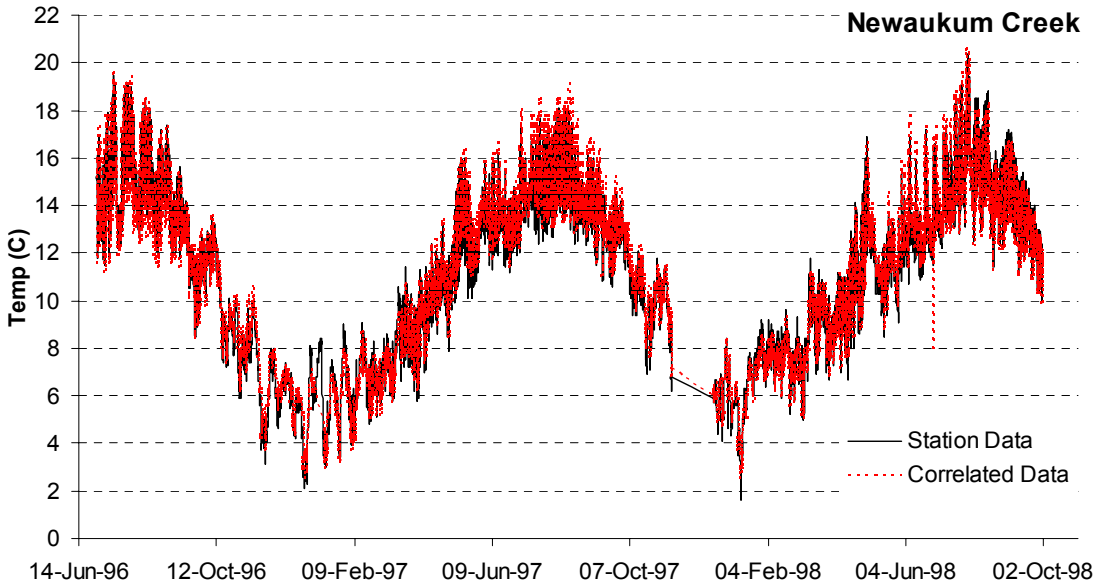

Figure 91: Newaukum Creek: Station versus correlated data, 1995-1996

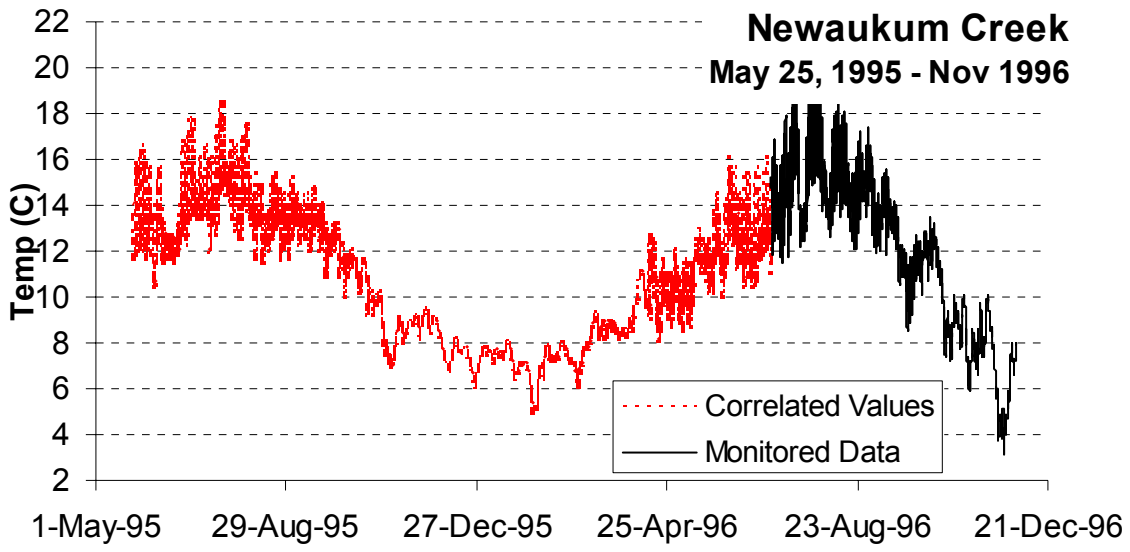

Figure 92: Newaukum Creek Temperature: May 25, 1995 – Nov 1996

Water Quality

King County monitored all the water quality constituents during the model calibration period except chlorophyll a and alkalinity (Locator 0322). Figure 93 through Figure 106 shows the water quality data for the model calibration period. See Appendix D for procedures used in assembling the water quality data, including estimates for missing data.

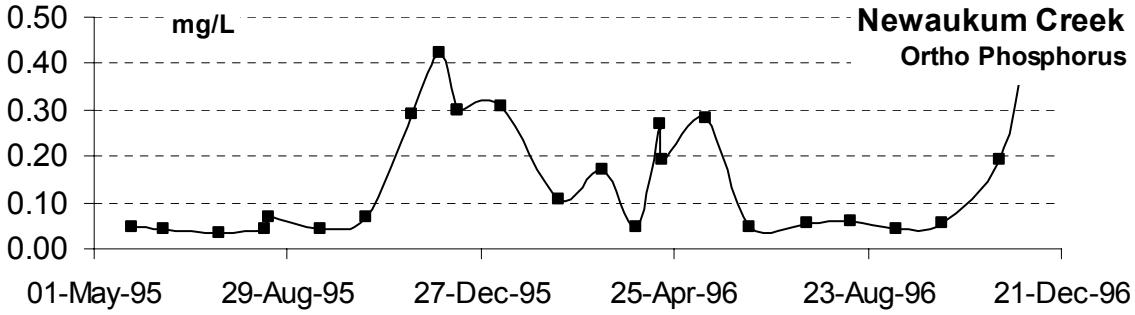

Figure 93: Ortho phosphorus Newaukum Creek: May 25, 1995 – Nov 1996

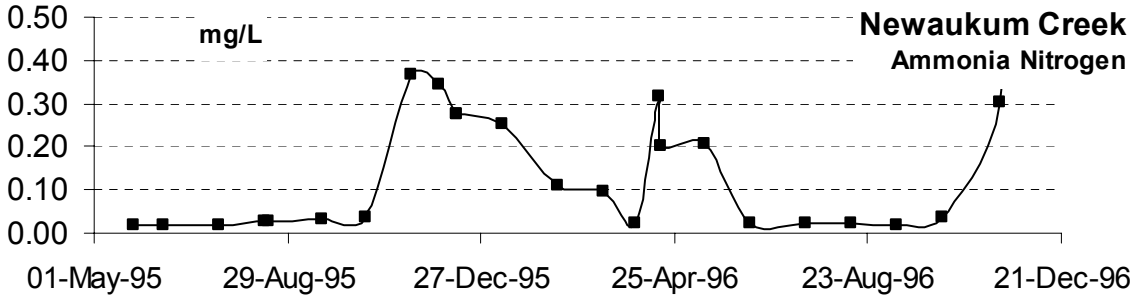

Figure 94: Ammonia Newaukum Creek: May 25, 1995 – Nov 1996

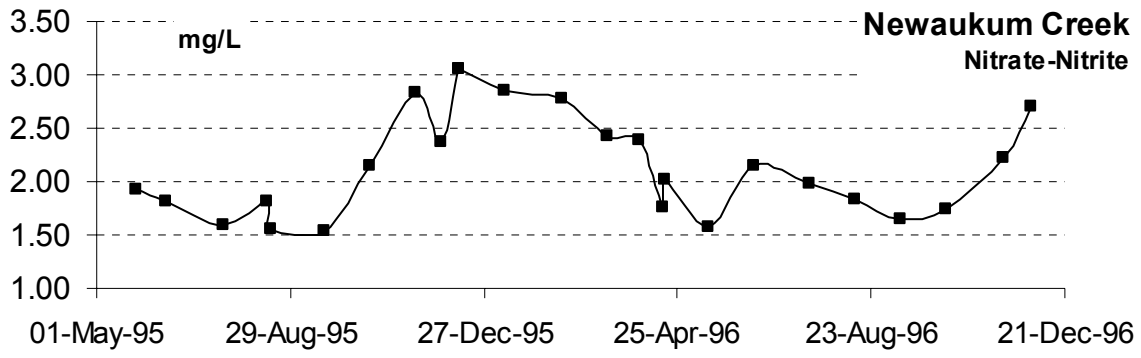

Figure 95: Nitrate-Nitrite Newaukum Creek: May 25, 1995 – Nov 1996

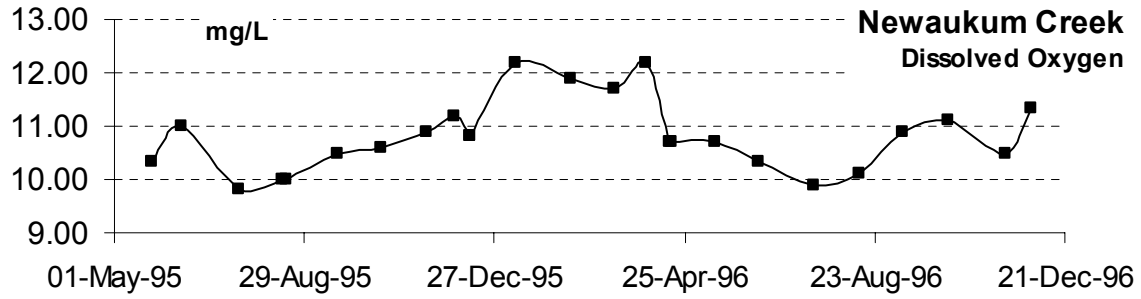

Figure 96: DO Newaukum Creek: May 25, 1995 – Nov 1996

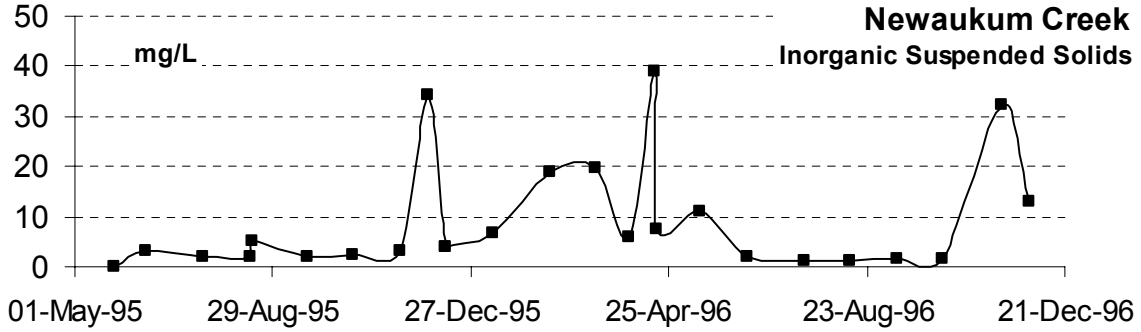

Figure 97: ISS Newaukum Creek: May 25, 1995 – Nov 1996

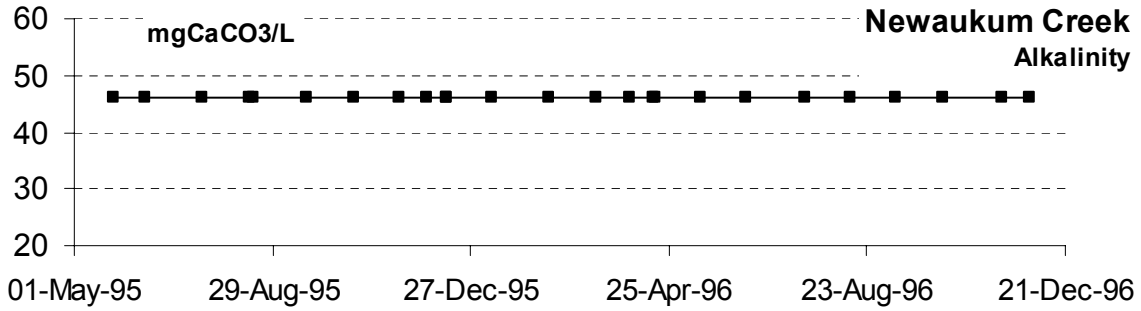

Figure 98: Alkalinity Newaukum Creek: May 25, 1995 – Nov 1996

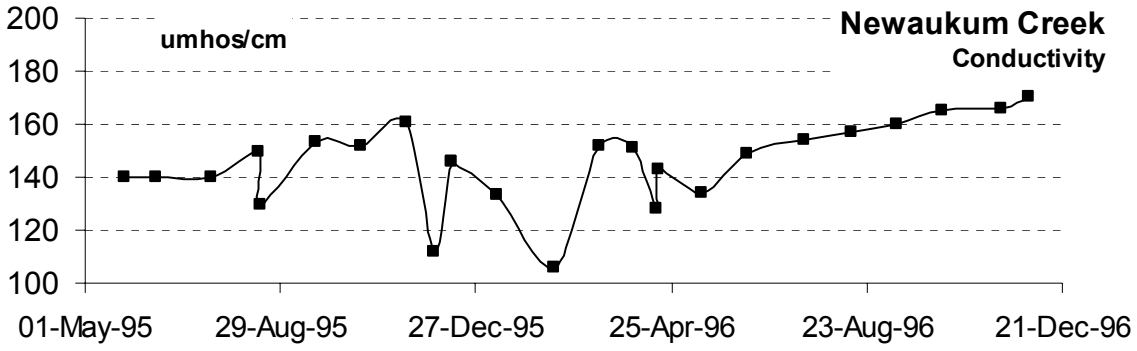

Figure 99: Conductivity Newaukum Creek: May 25, 1995 – Nov 1996

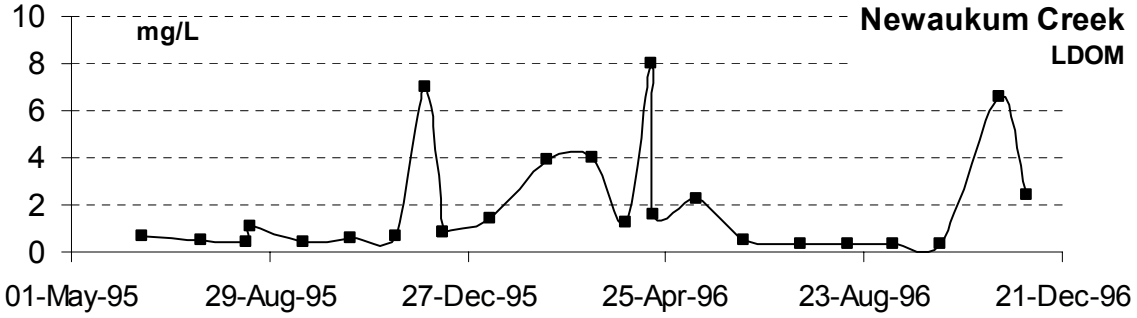

Figure 100: LDOM Newaukum Creek: May 25, 1995 – Nov 1996

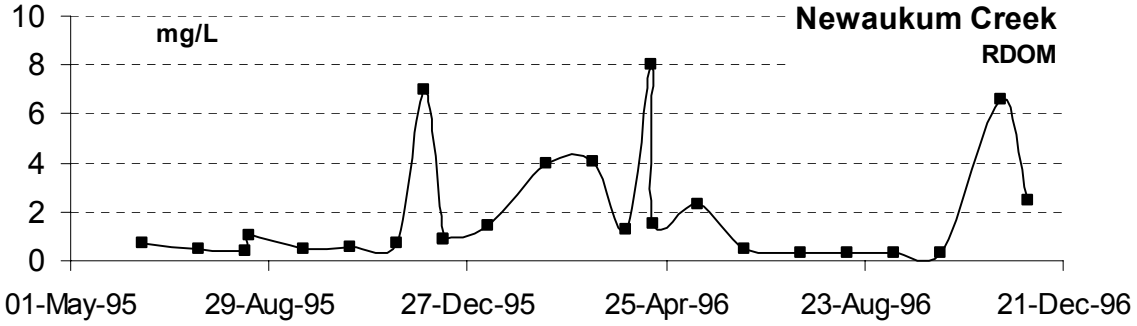

Figure 101: RDOM Newaukum Creek: May 25, 1995 – Nov 1996

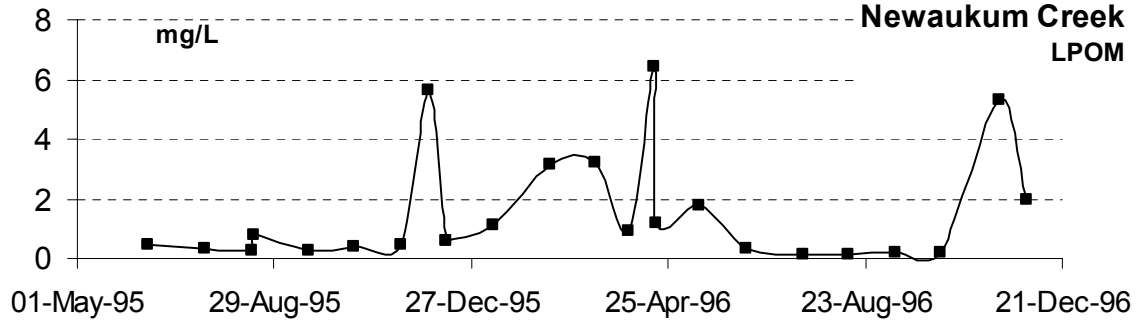

Figure 102: LPOM Newaukum Creek: May 25, 1995 – Nov 1996

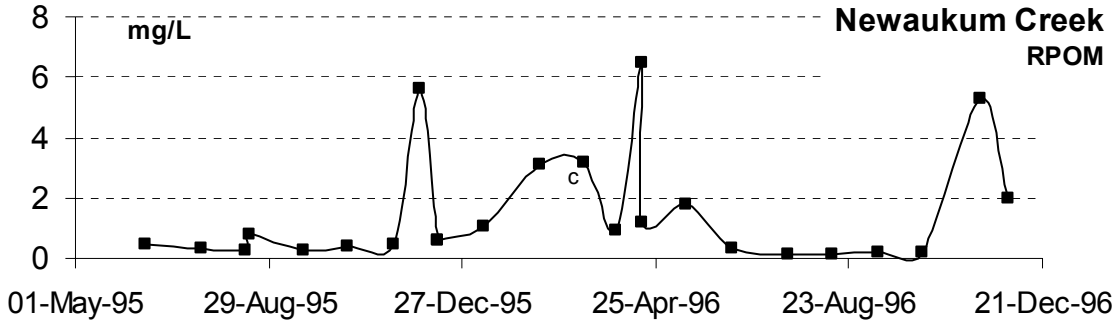

Figure 103: RPOM Newaukum Creek: May 25, 1995 – Nov 1996

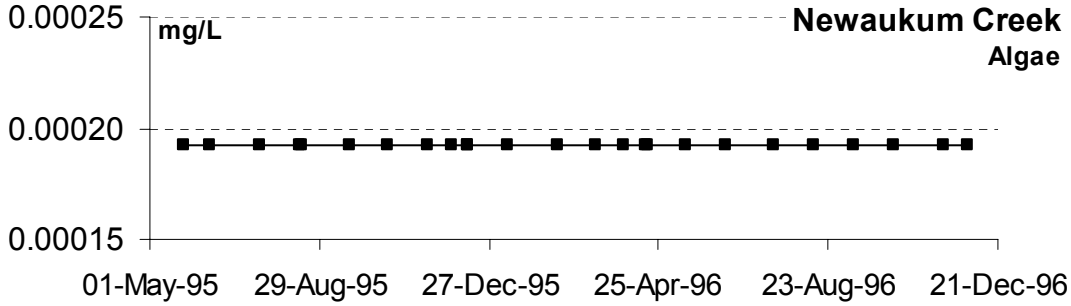

Figure 104: Algae Newaukum Creek: May 25, 1995 – Nov 1996

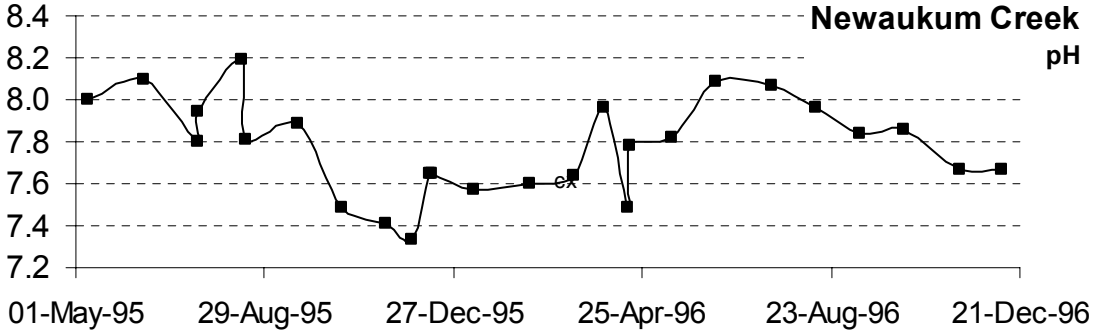

Figure 105: pH Newaukum Creek: May 25, 1996 - Nov 1996

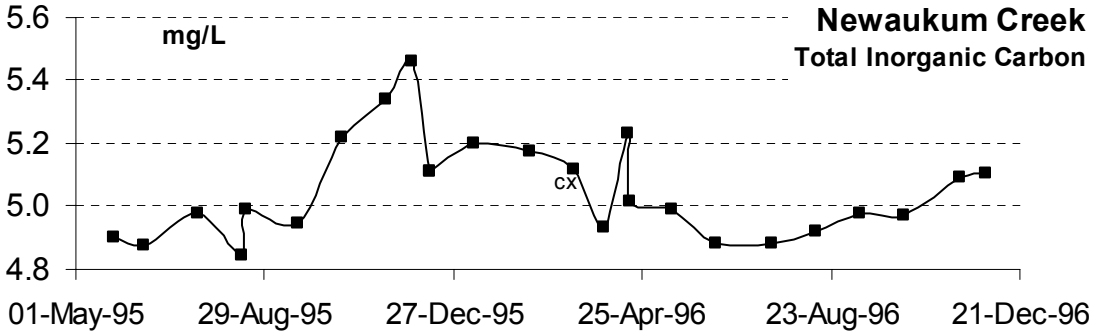

Figure 106: TIC Newaukum Creek: May 25, 1995 – Nov 1996

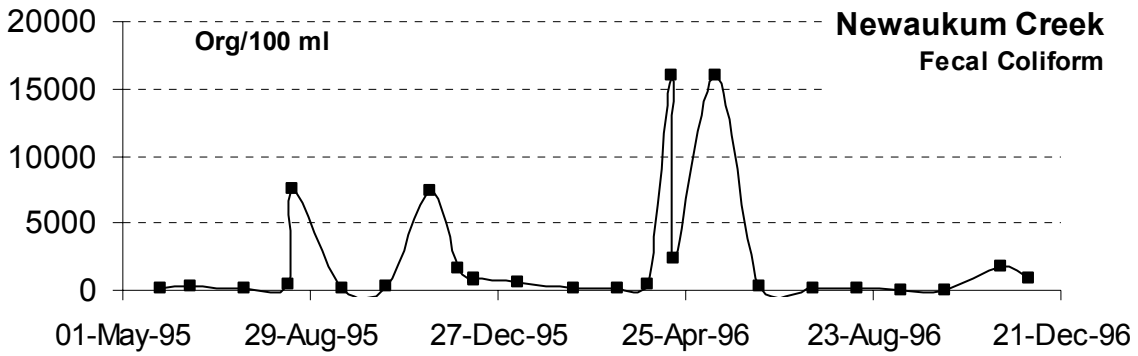

Figure 107: Fecal Coliform Newaukum Creek: May 25, 1995 - Nov 1996

April 2001 – July 2002

Flow

USGS gage (12108500) was used for this model calibration period. The complete data set is included in Appendix A, and Figure 108 shows the data for the model simulation period.

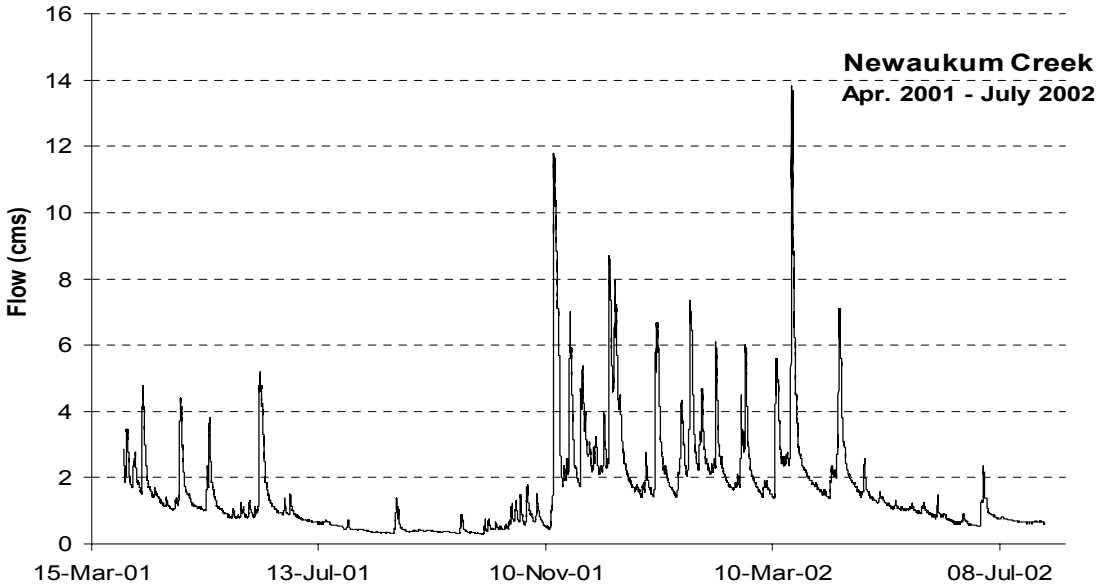

Figure 108: Newaukum Creek Flow: Apr 2001 – July 2002

Temperature

There are 2 temperature stations on Newaukum Creek that recorded data for different times. USGS Gage 1210855 has temperature data from June 29, 1996 to October 1, 1998, and the Green-Duwamish Water Quality Assessment study recorded temperatures in the same location from July 23, 2001 to October 25, 2001. The USGS temperatures are in hourly intervals, and the GDWQA temperatures are in 15-minute intervals.

For the model simulation period temperature data are not available for April through July 23, 2001 and from October 26, 2001 through March 14, 2002. To fill these missing gaps, Crisp Creek temperature data were correlated with temperature data from Newaukum Creek, using the following equation:

Newaukum Creek temperature = (1.63)(Crisp Creek) - 6.21

Figure 109 shows the temperature correlation between the sites with data, Figure 110 compares correlated data to actual data from Newaukum Creek, and Figure 111 shows the temperature data for this calibration period with correlated values included.

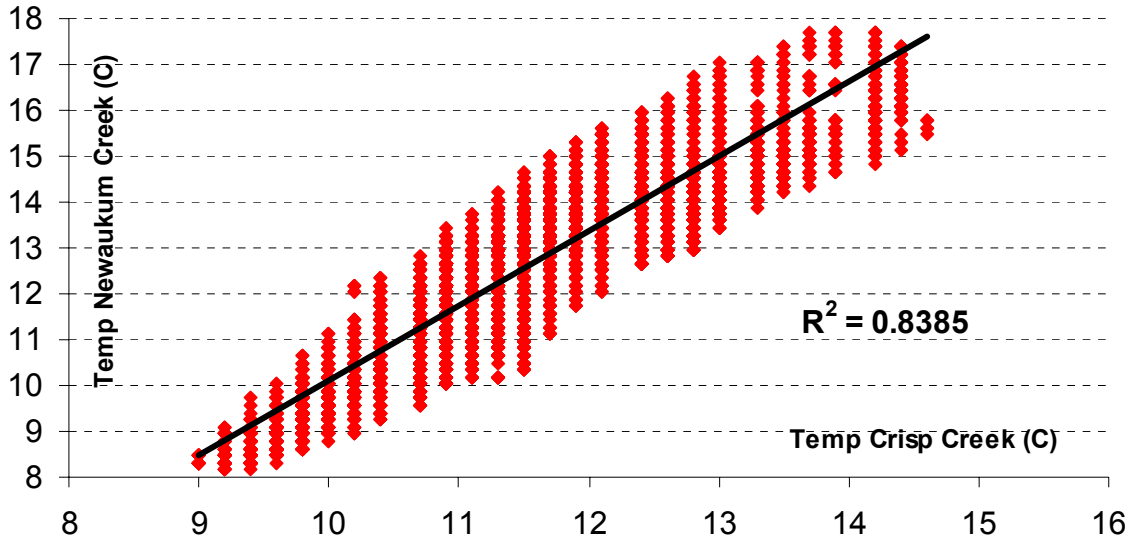

Figure 109: Correlation between Crisp Creek and Newaukum Creek Temperature

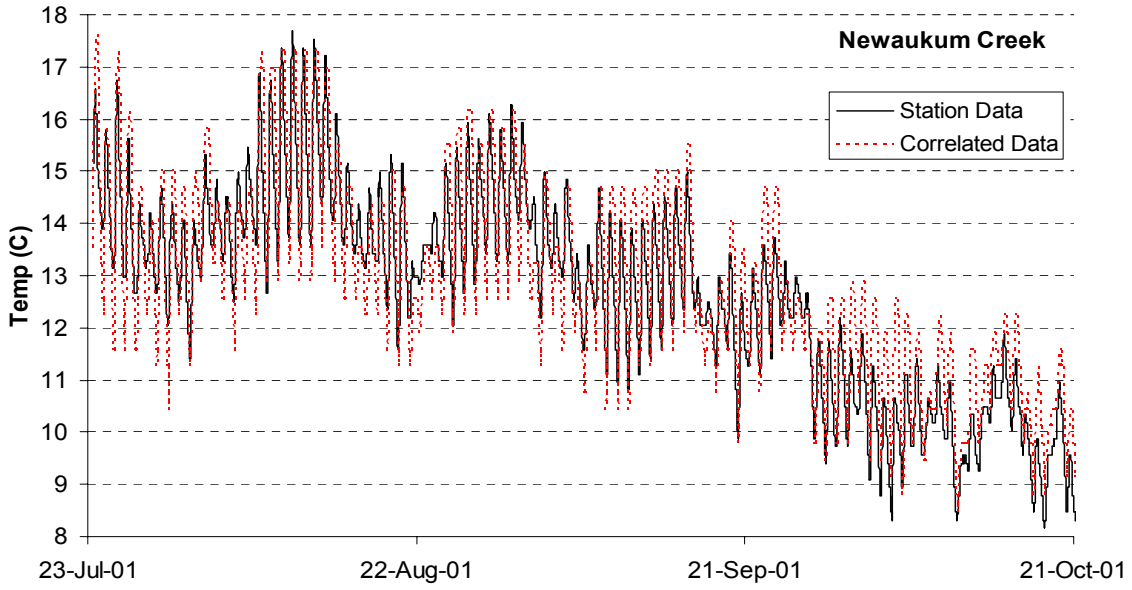

Figure 110: Station versus correlated data, 2001-2002

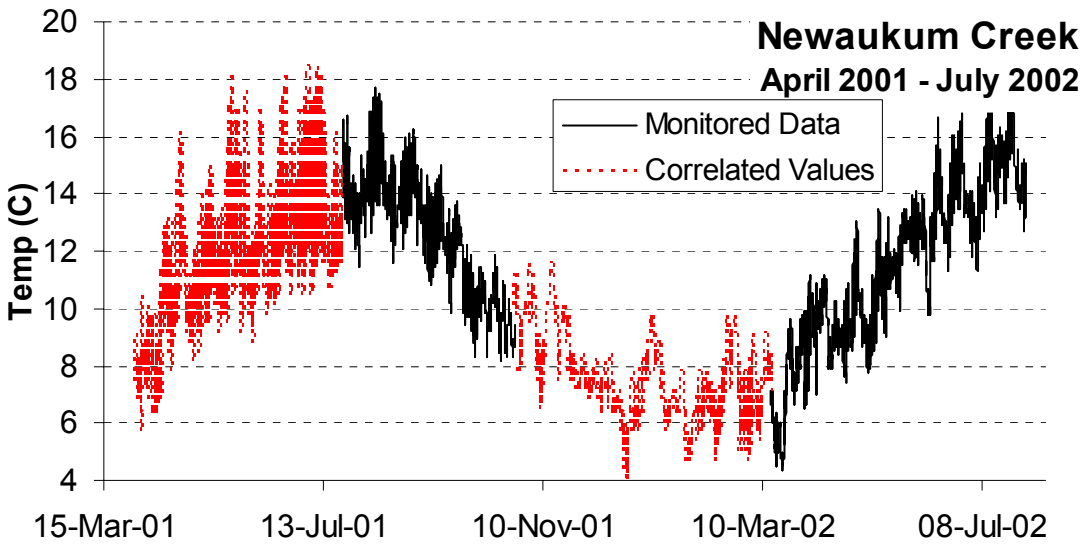

Figure 111: Newaukum Creek Temperature: Apr 2001 – July 2002

Water Quality

King County has provided water quality samples on Newaukum Creek from 1995 to 2002 (Locator 0322) for all data except chlorophyll a. Figure 112 through Figure 125 shows the data for the model calibration period. Data for the complete time period are included in Appendix A. See Appendix D for procedures used in assembling the water quality data, including estimating missing data.

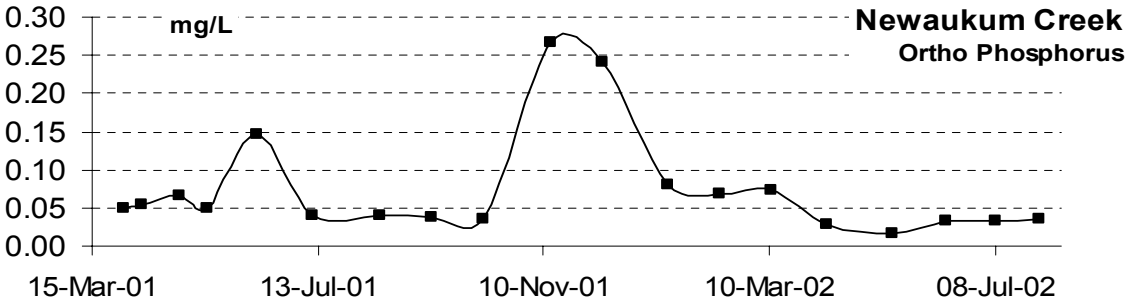

Figure 112: Ortho phosphorus Newaukum Creek: Apr 2001 – July 2002

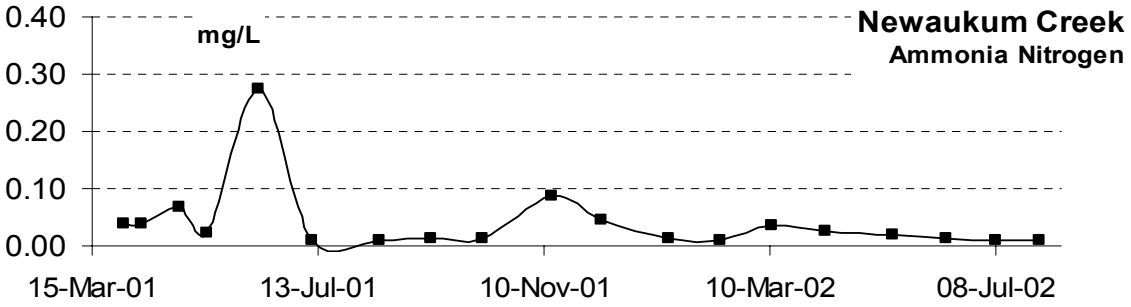

Figure 113: Ammonia Newaukum Creek: Apr 2001 – July 2002

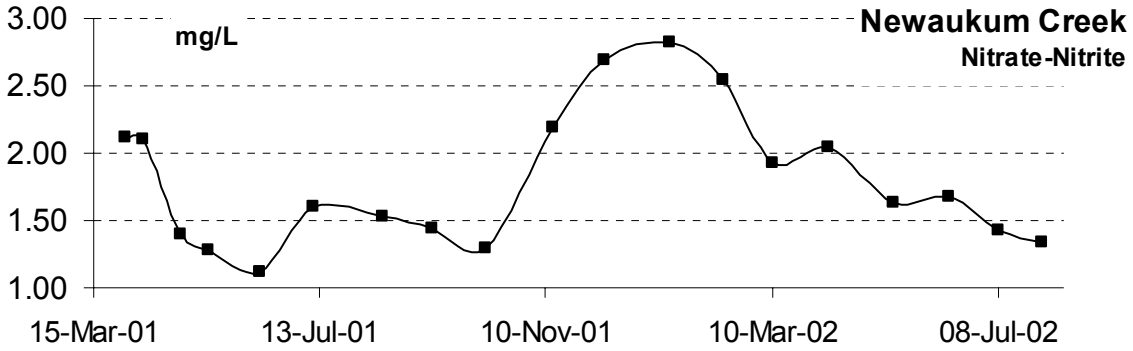

Figure 114: Nitrate-Nitrite Newaukum Creek: Apr 2001 – July 2002

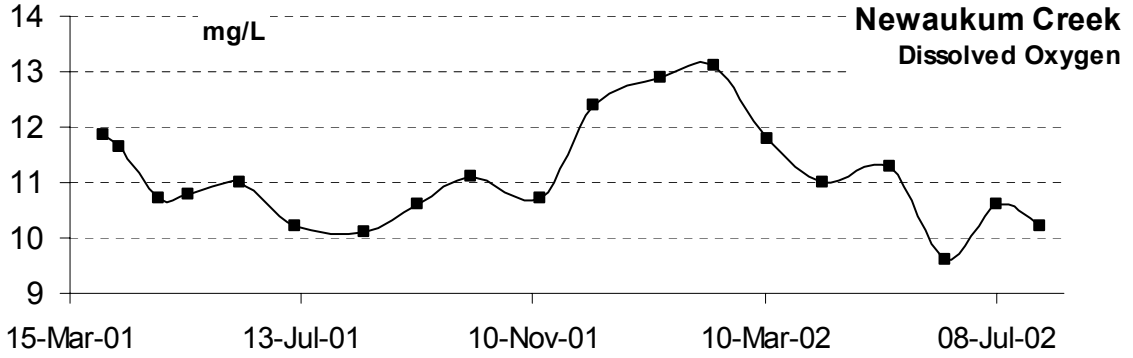

Figure 115: DO Newaukum Creek: Apr 2001 – July 2002

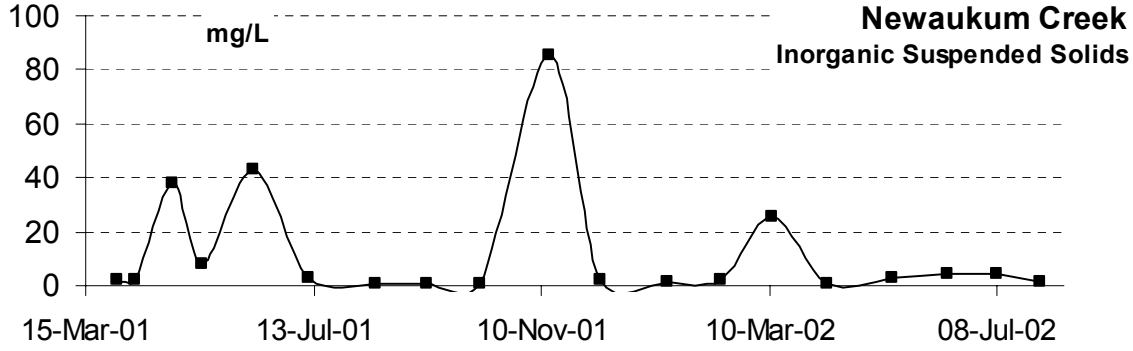

Figure 116: ISS Newaukum Creek: Apr 2001 – July 2002

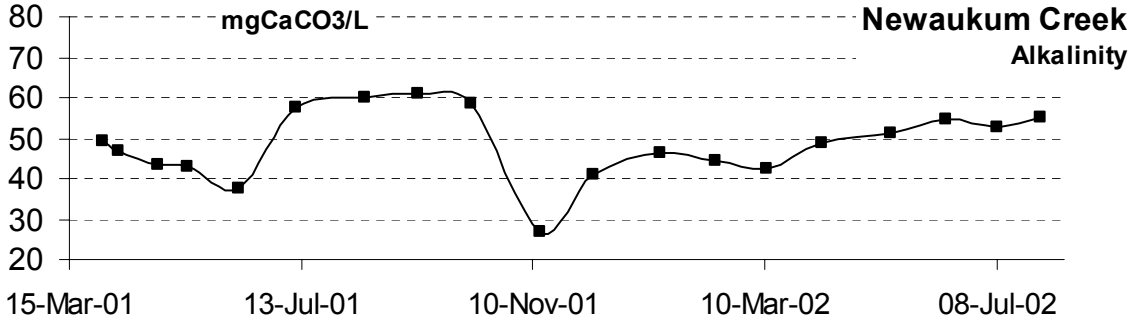

Figure 117: Alkalinity Newaukum Creek: Apr 2001 – July 2002

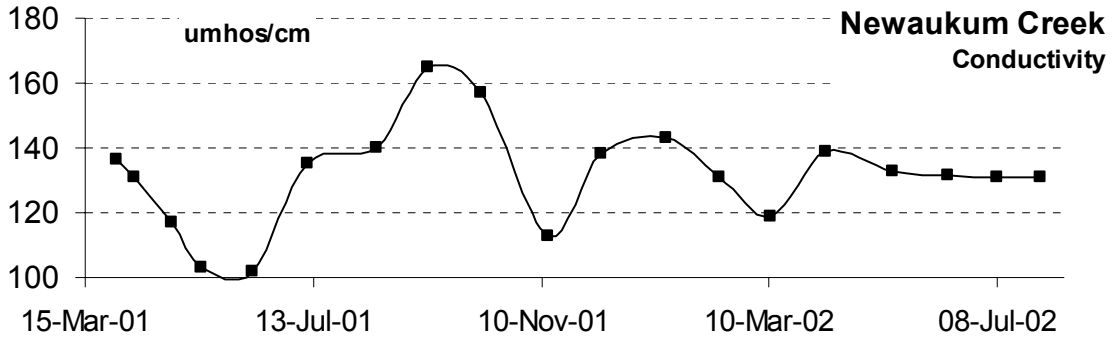

Figure 118: Conductivity Newaukum Creek: Apr 2001 – July 2002

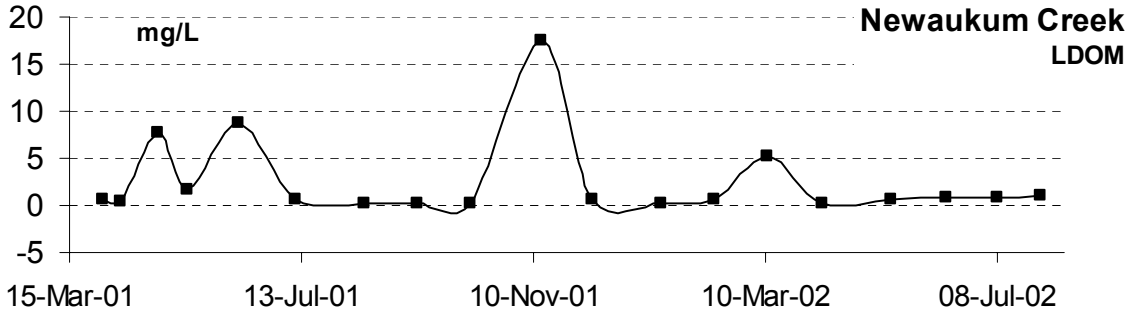

Figure 119: LDOM Newaukum Creek: Apr 2001 – July 2002

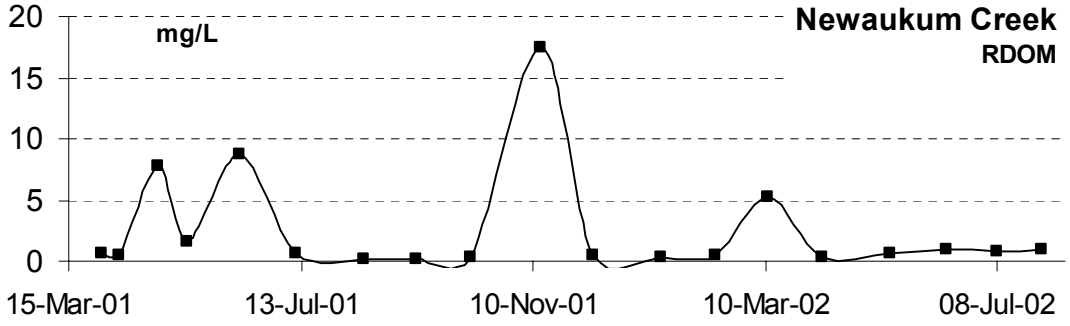

Figure 120: RDOM Newaukum Creek: Apr 2001 – July 2002

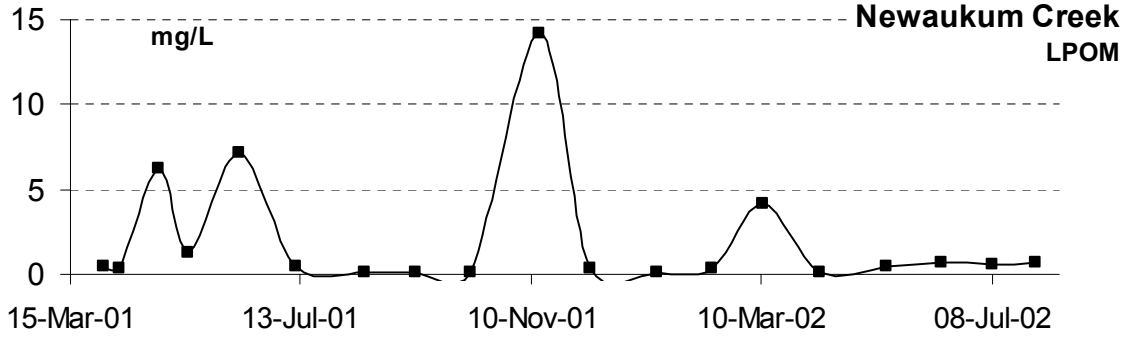

Figure 121: LPOM Newaukum Creek: Apr 2001 – July 2002

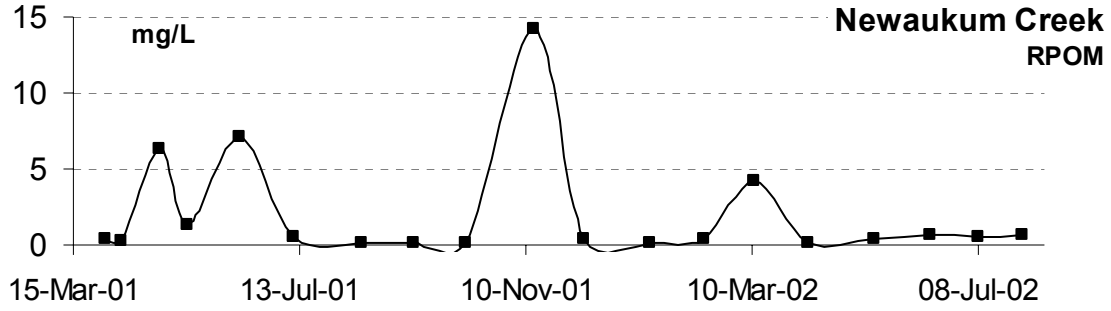

Figure 122: RPOM Newaukum Creek: Apr 2001 – July 2002

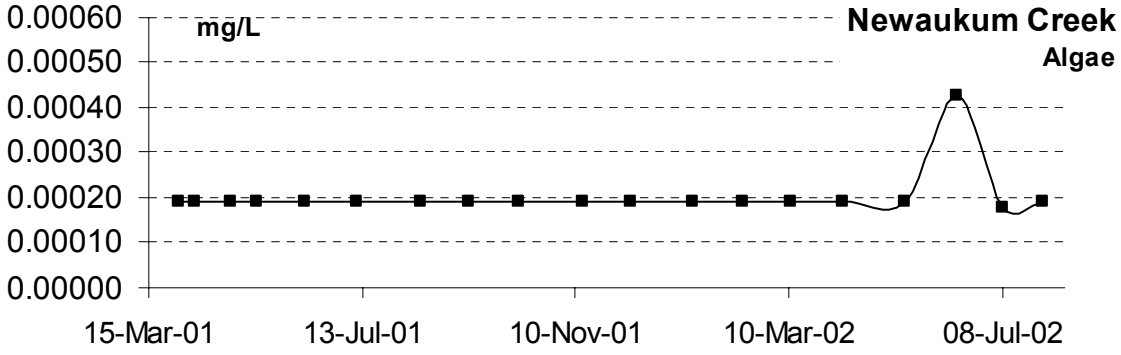

Figure 123: Algae Newaukum Creek: Apr 2001 – July 2002

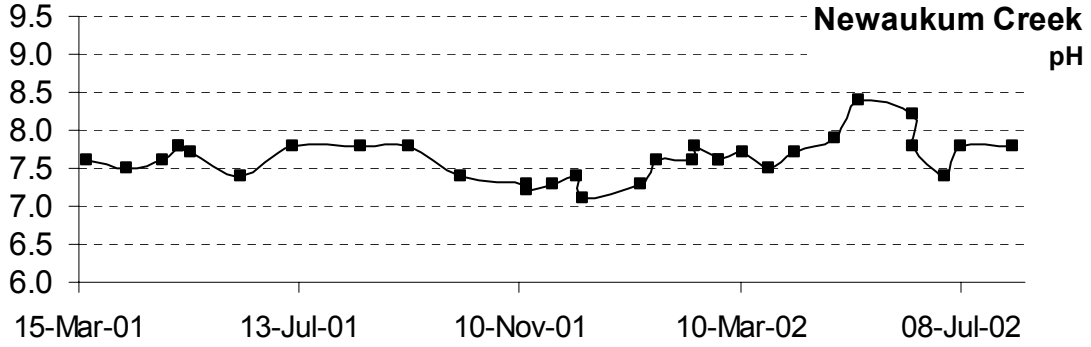

Figure 124: pH Newaukum Creek: Apr 2001 - July 2002

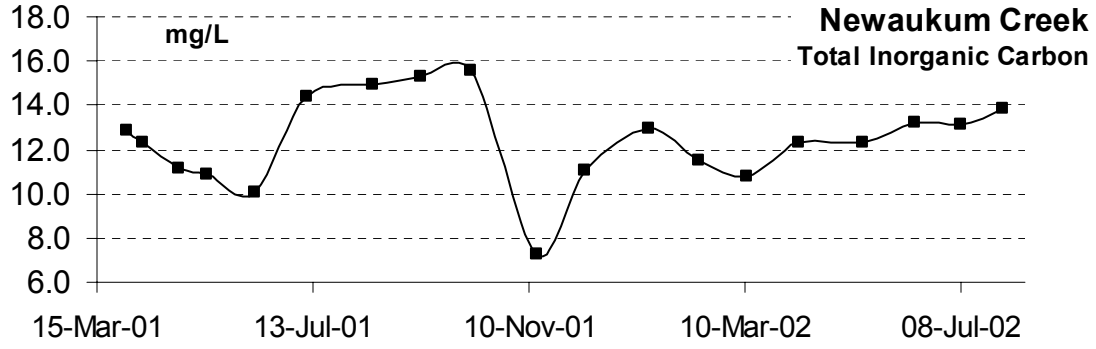

Figure 125: TIC Newaukum Creek: Apr 2001 – July 2002

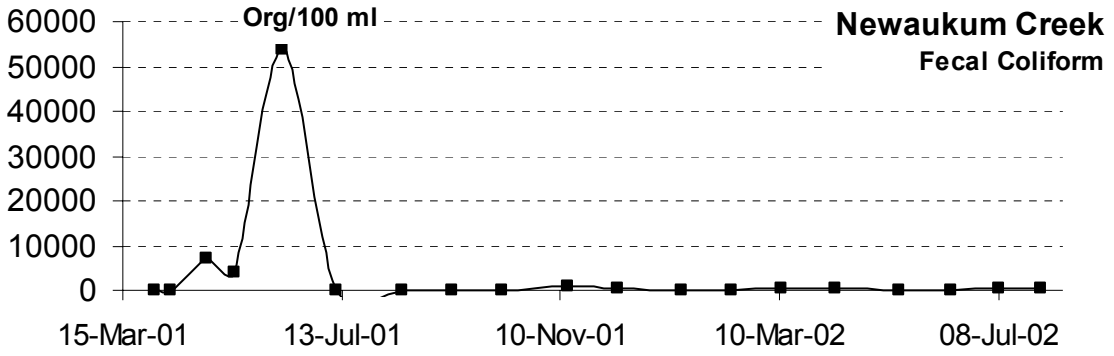

Figure 126: Fecal Coliform Newaukum Creek: Apr 2001 - July 2002

Crisp Creek

Crisp Creek flows into the Green River approximately 6.0 km downstream from Flaming Geyser State Park, at River Mile 32. King County monitors flow, temperature, and water quality at a fish hatchery approximately 3.0 km from the confluence with the Green River.

May 25, 1995 – November 1996

Flow

King County gage #40d records flow every 15-minutes. Flow data for this gage were provided by King County from August 25, 1994 to March 18, 2003. The entire data set is included in Appendix A. Figure 127 is a graph showing flow for the model period.

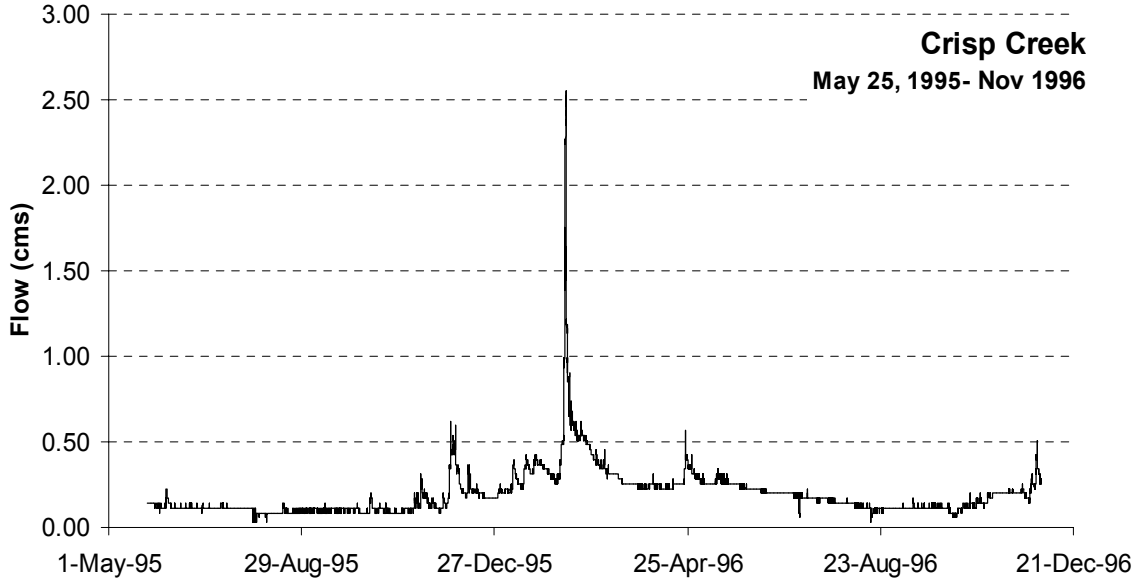

Figure 127: Crisp Creek Flow: May 25, 1995 – Nov 1996

Temperature

King County station #40d also records temperature at 15-minute intervals, but did not begin monitoring until October 10, 1997. Comparing temperatures recorded on Big Soos Creek with temperatures from Crisp Creek from October 1997 to June 1999, the following correlation was obtained:

Crisp Creek Temp = 0.5731(Big Soos Temp) + 3.7364

Figure 128 shows the temperature correlation between the sites with data, Figure 129 compares correlated values to monitored data from Crisp Creek, and Figure 130 shows the temperature data for this calibration period with correlated values included.

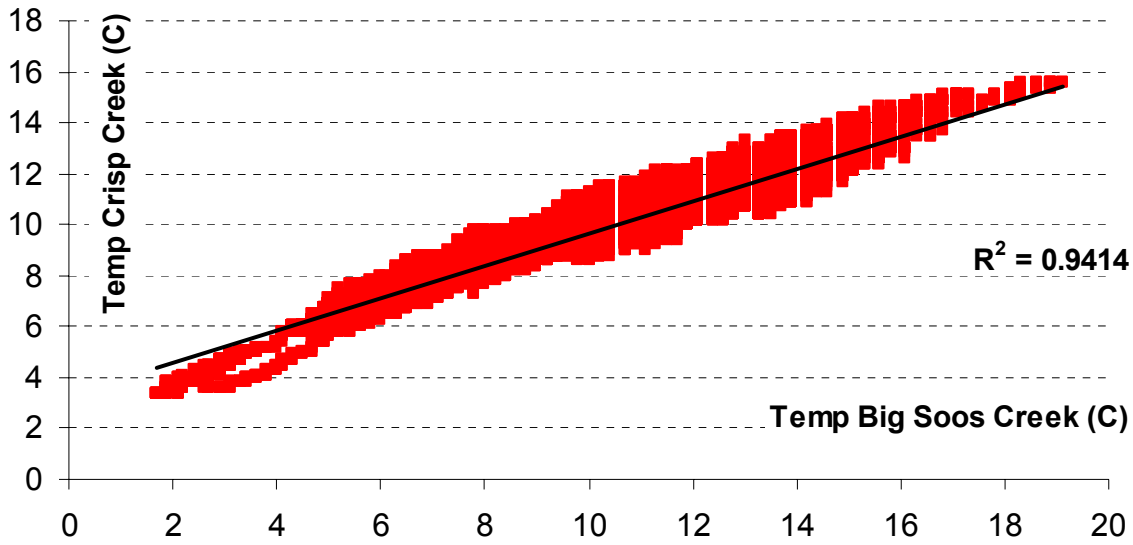

Figure 128: Correlation between Big Soos Temperature and Crisp Creek

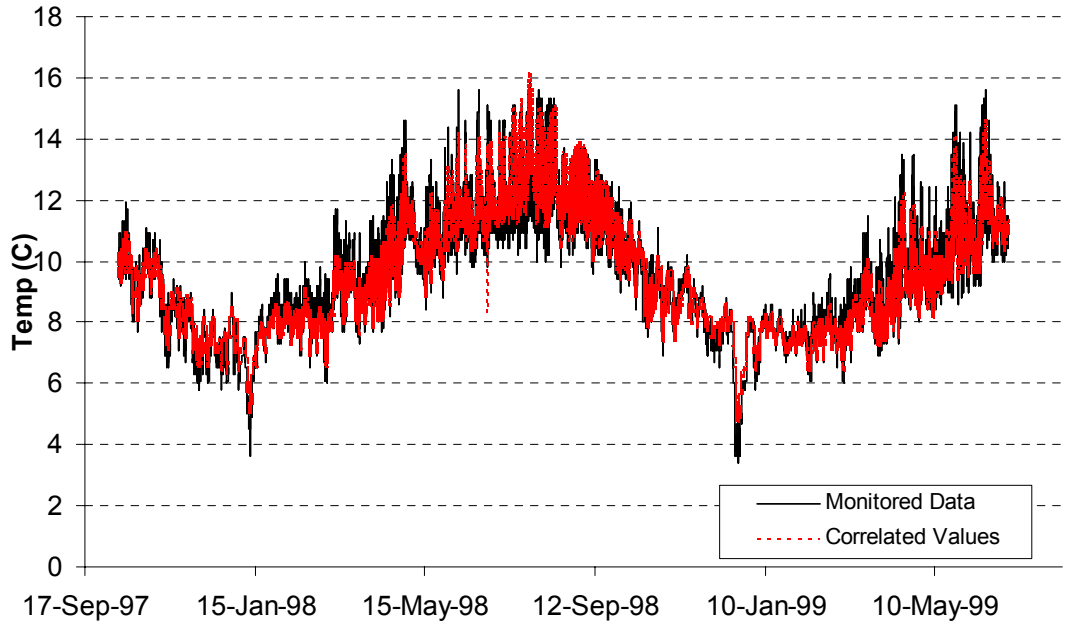

Figure 129: Crisp Creek: Station versus correlated data, 1995-1996

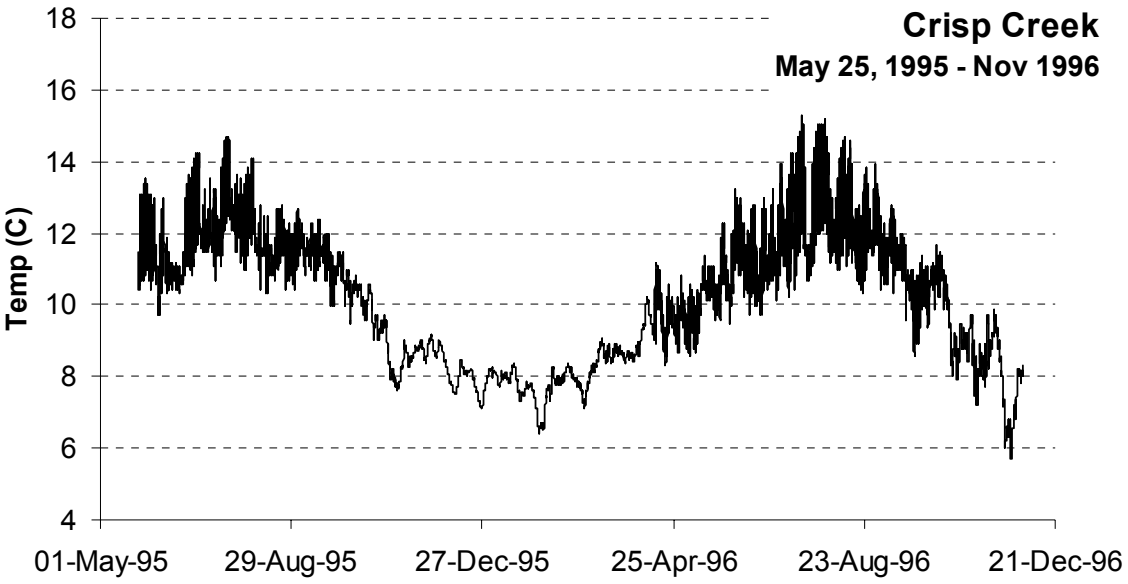

Figure 130: Crisp Creek Temperature: May 25, 1995 – Nov 1996

Water Quality

King County has provided water quality samples on Crisp Creek from 1995 to 2002 (Locator 0322). Monthly grab samples are available for the model calibration period for all constituents except chlorophyll a and alkalinity. See Appendix D for procedures used in assembling the water quality data, and Figure 131 through

Figure 144 for the constituents for the model calibration period.

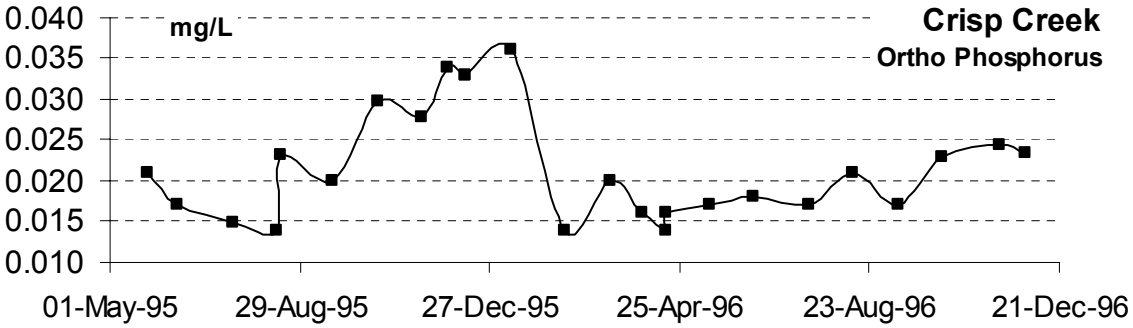

Figure 131: Ortho phosphorus Crisp Creek: May 25, 1995 – Nov 1996

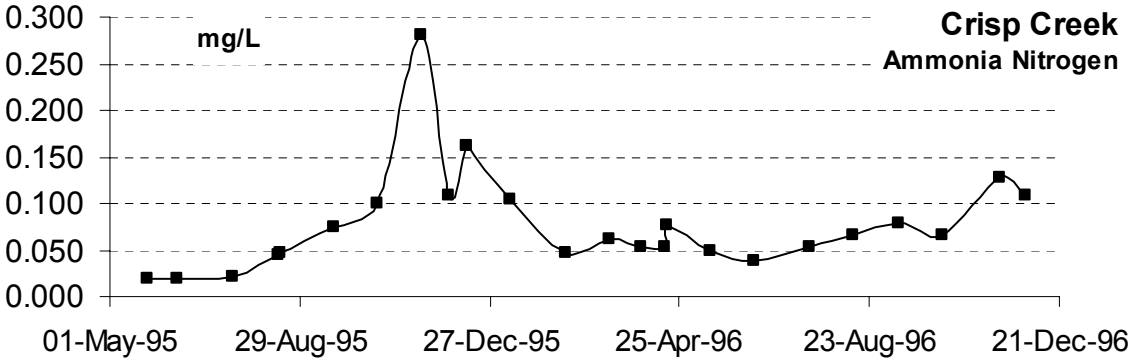

Figure 132: Ammonia Crisp Creek: May 25, 1995 – Nov 1996

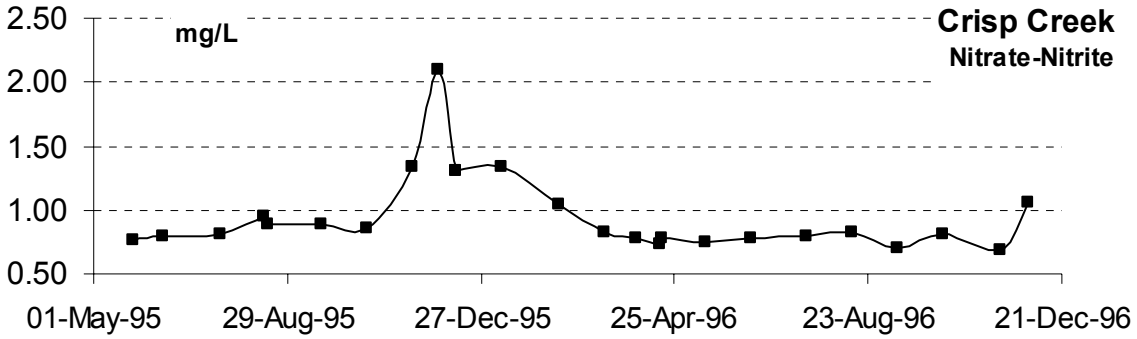

Figure 133: Nitrate-Nitrite Crisp Creek: May 25, 1995 – Nov 1996

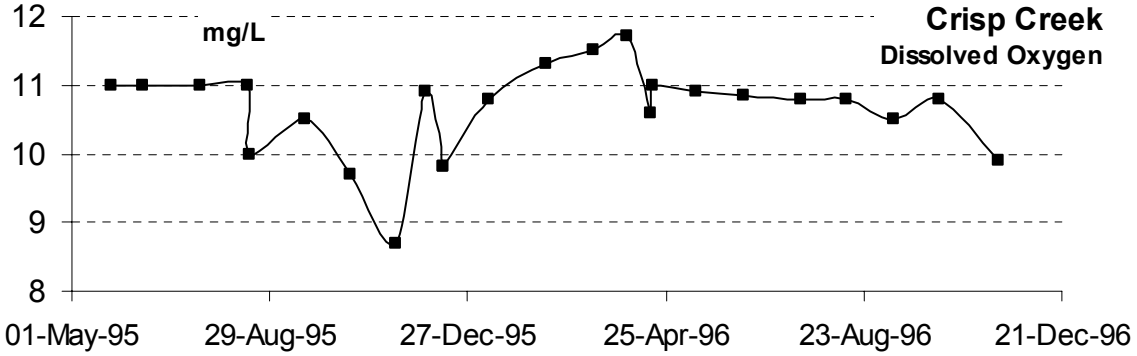

Figure 134: DO Crisp Creek: May 25, 1995 – Nov 1996

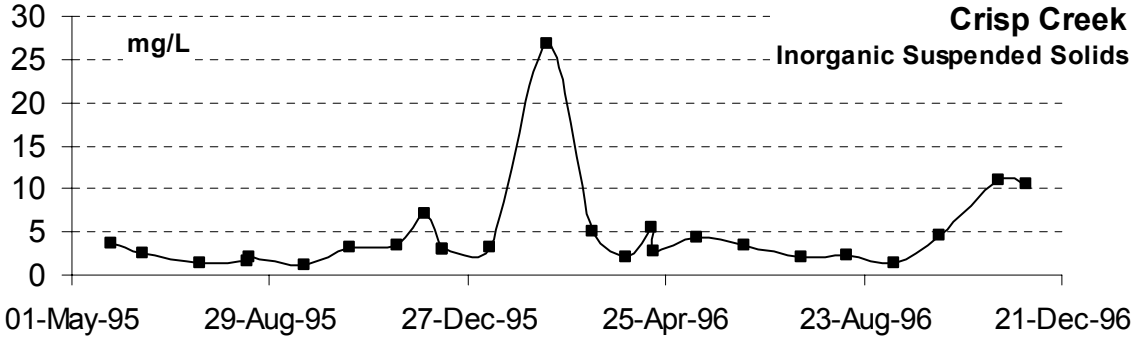

Figure 135: ISS Crisp Creek: May 25, 1995 – Nov 1996

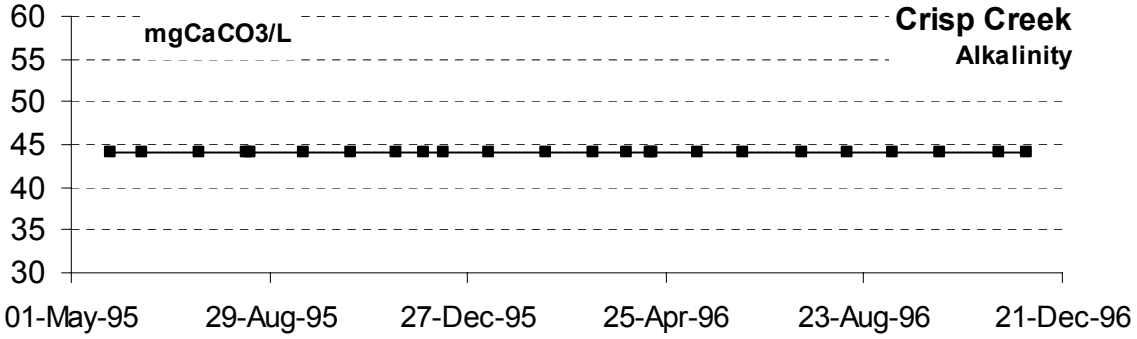

Figure 136: Alkalinity Crisp Creek: May 25, 1995 - Nov 1996

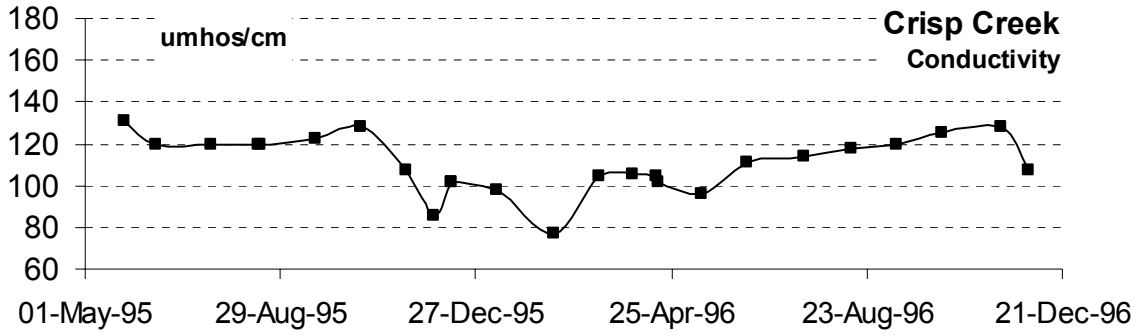

Figure 137: Conductivity Crisp Creek: May 25, 1995 – Nov 1996

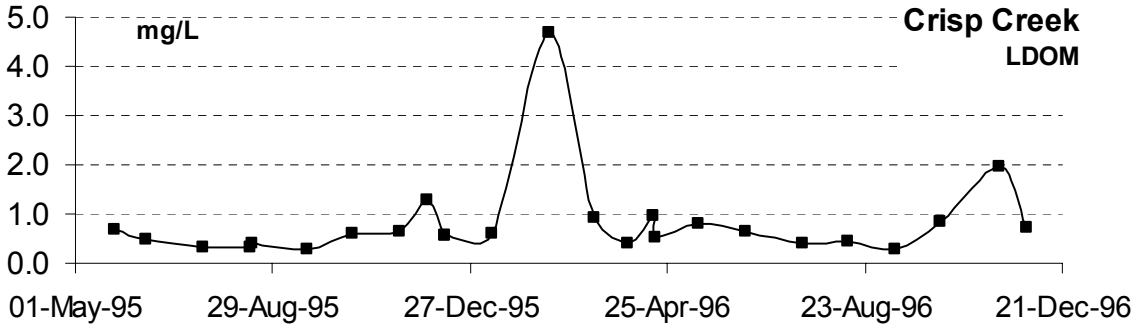

Figure 138: LDOM Crisp Creek: May 25, 1995 – Nov 1996

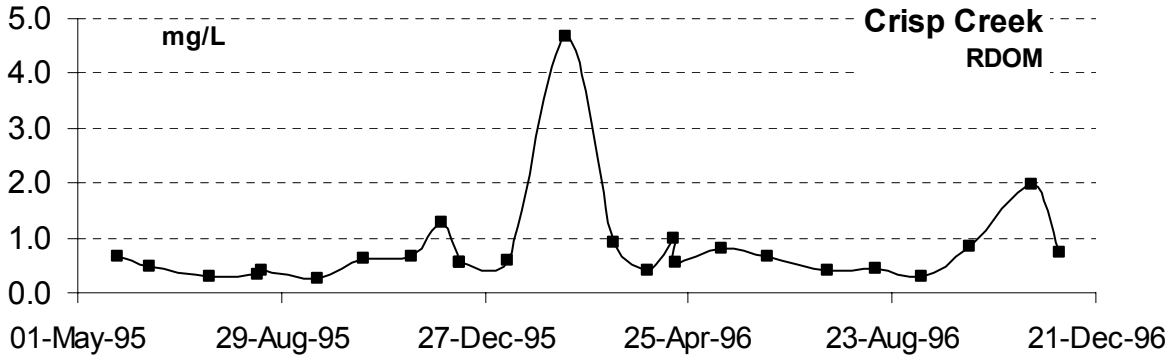

Figure 139: RDOM Crisp Creek: May 25, 1995 – Nov 1996

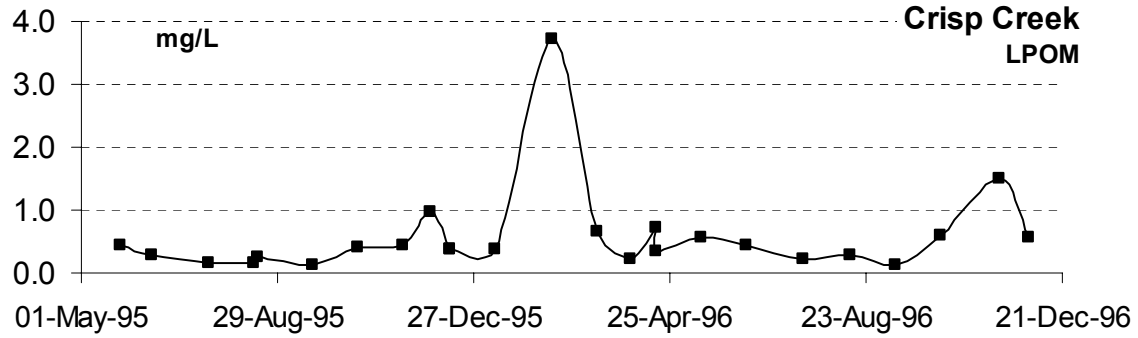

Figure 140: LPOM Crisp Creek: May 25, 1995 – Nov 1996

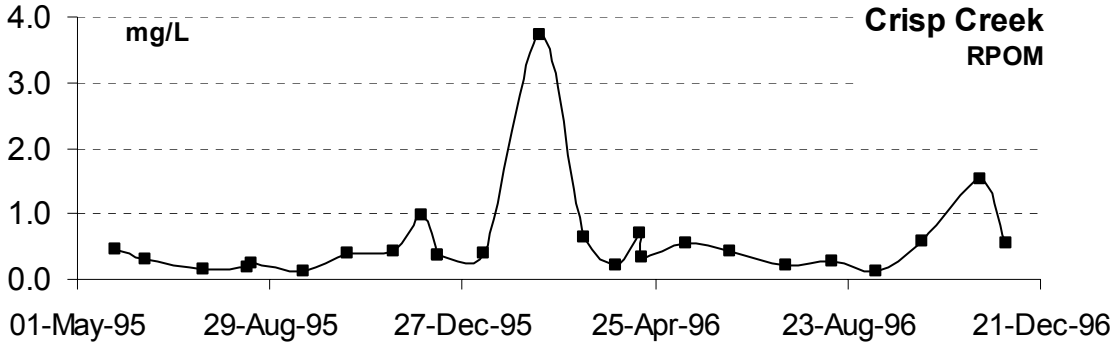

Figure 141: RPOM Crisp Creek: May 25, 1995 – Nov 1996

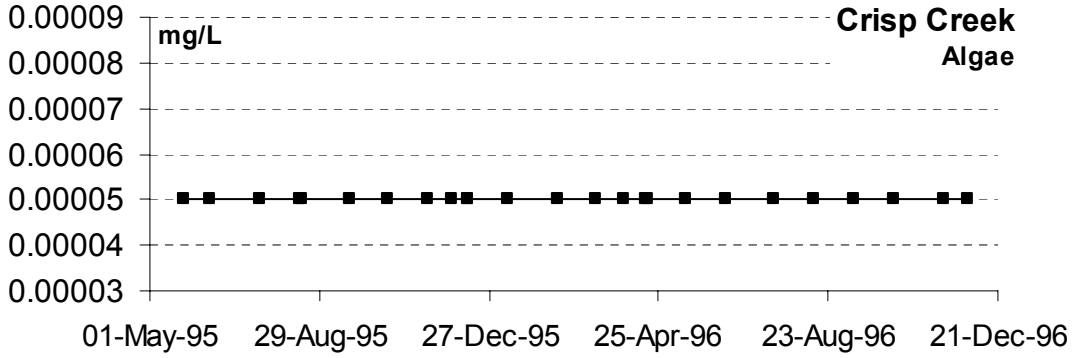

Figure 142: Algae Crisp Creek: May 25, 1995 – Nov 1996

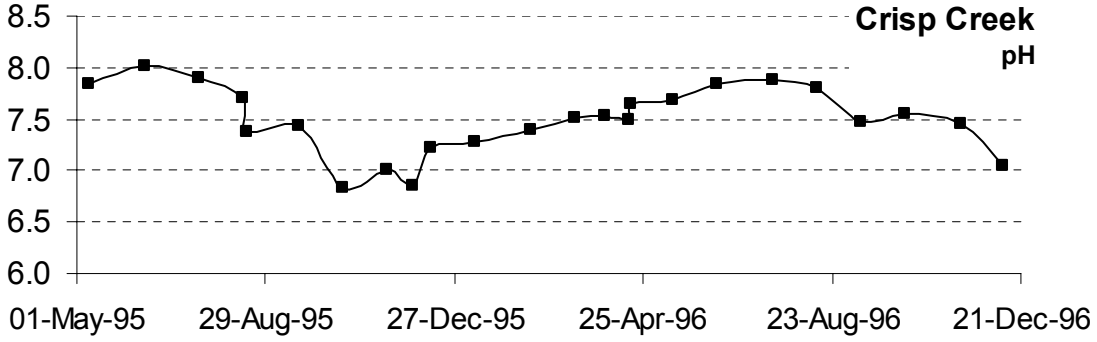

Figure 143: pH Crisp Creek: May 25, 1995 - Nov 1996

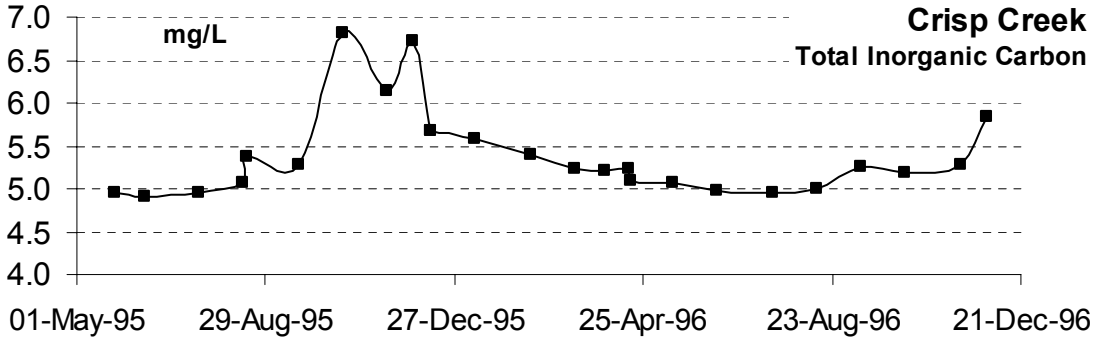

Figure 144: TIC Crisp Creek: May 25, 1995 – Nov 1996

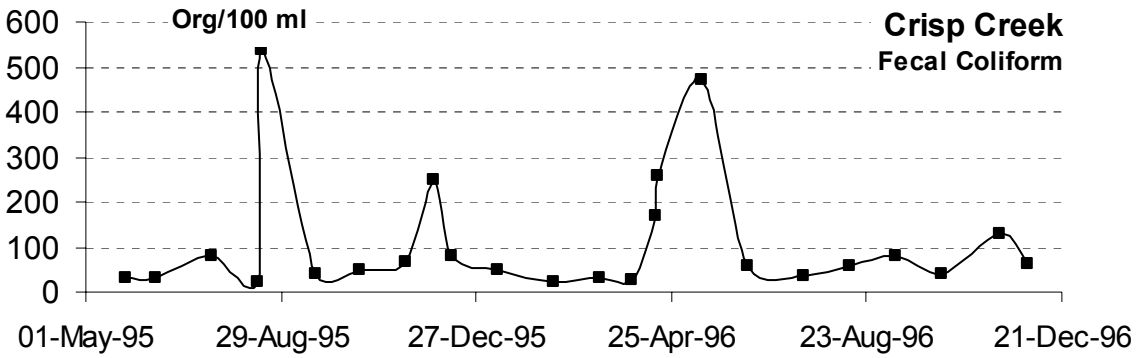

Figure 145: Fecal Coliform Crisp Creek: May 25, 1995 - Nov 1996

April 2001 – July 2002

Flow

King County gage #40d has flow data for this model calibration period in 15-minute intervals. The entire data set is included in Appendix A, and Figure 146 is a graph showing flow for the model calibration period.

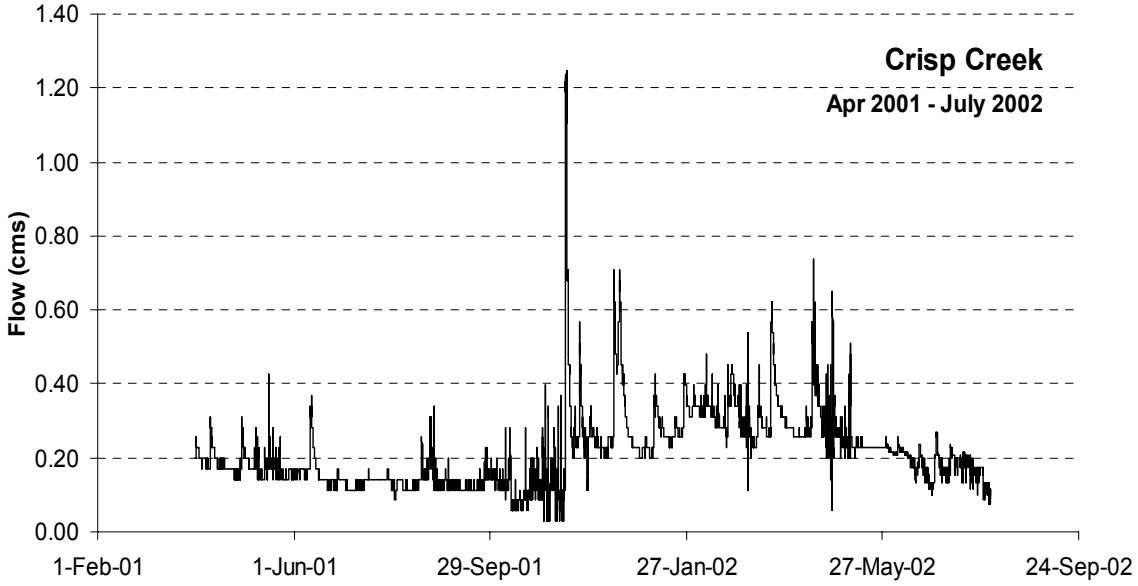

Figure 146: Crisp Creek Flow: Apr 2001 – July 2002

Temperature

Station #40d also had temperature for this model calibration period. Figure 147 shows the data for the model simulation period.

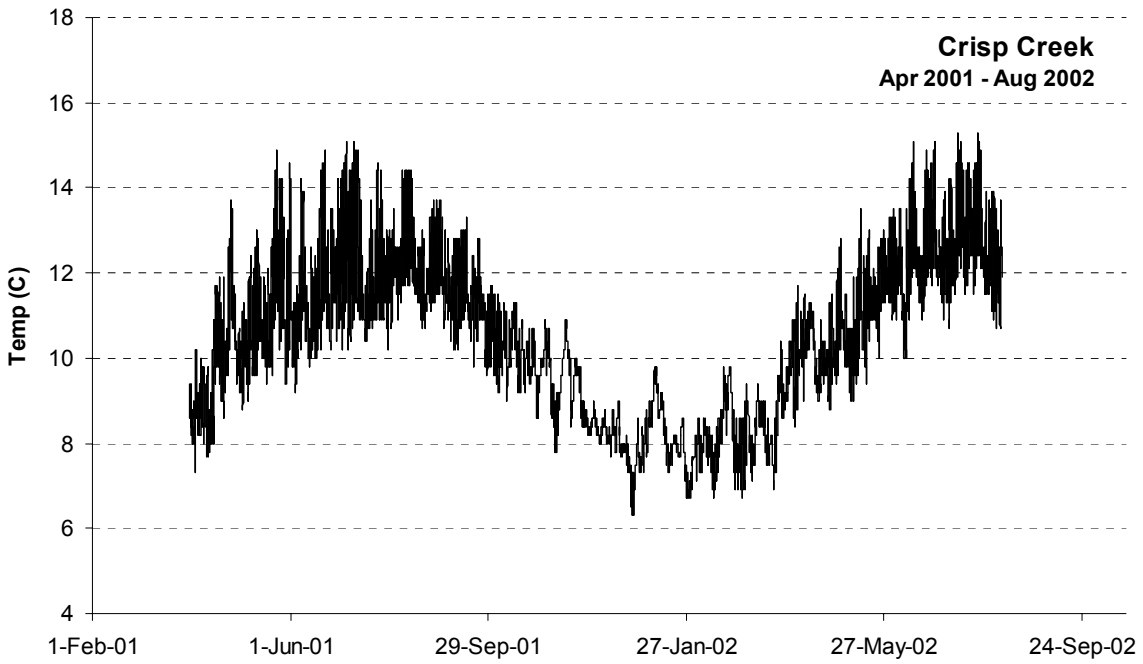

Figure 147: Crisp Creek Temperature: Apr 2001 – July 2002

Water Quality

King County has provided water quality samples on Crisp Creek from 1995 to 2002 (Locator 0321). Data are available for all constituents except chlorophyll a for the model calibration period. Figure 148 through Figure 161 shows data for the model calibration period. See Appendix D for procedures used in assembling the water quality data, including estimating missing data.

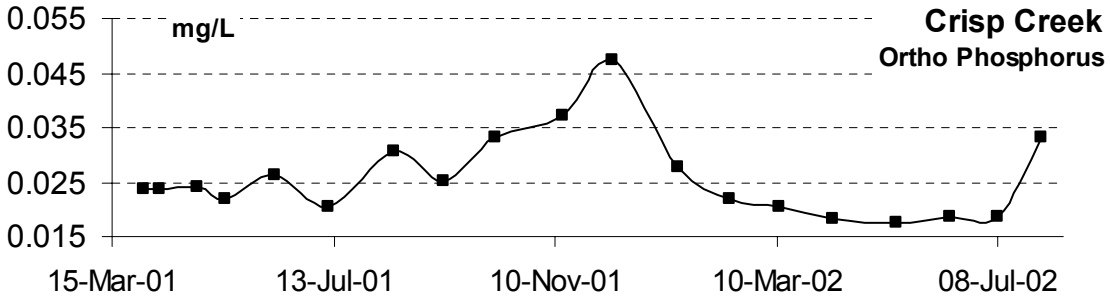

Figure 148: Ortho phosphorus Crisp Creek: Apr 2001–July 2002

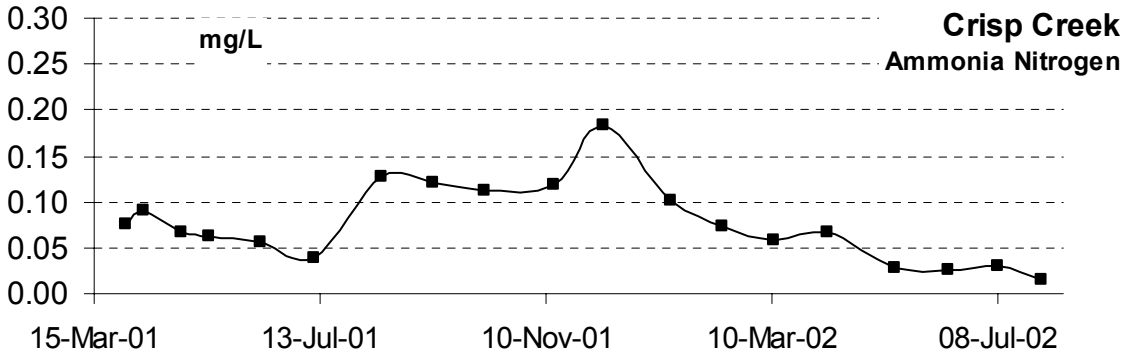

Figure 149: Ammonia Crisp Creek: Apr 2001–July 2002

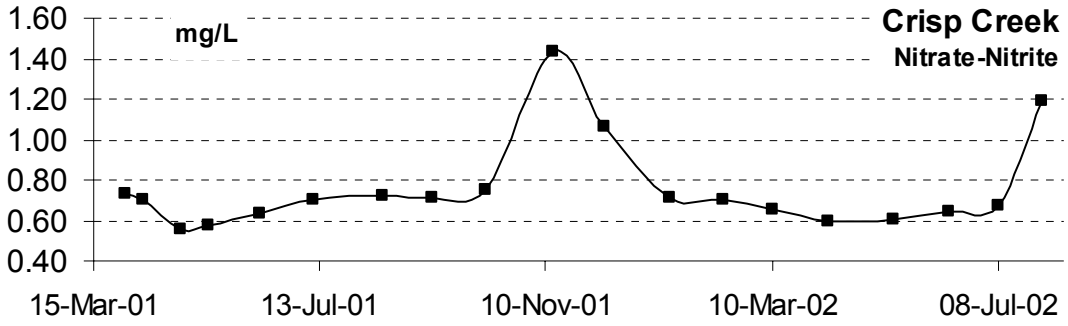

Figure 150: Nitrate-Nitrite Crisp Creek: Apr 2001–July 2002

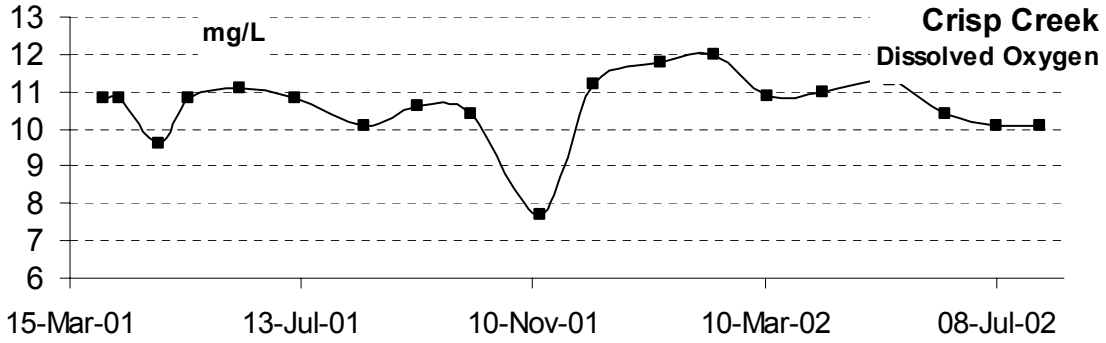

Figure 151: DO Crisp Creek: Apr 2001–July 2002

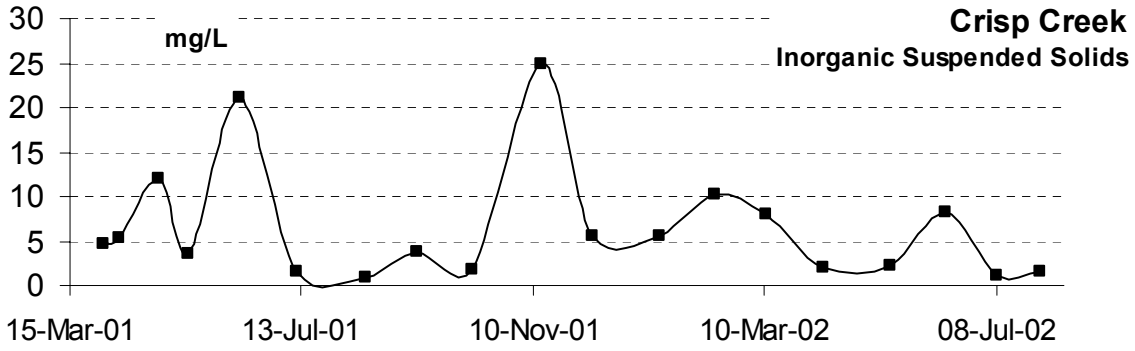

Figure 152: ISS Crisp Creek: Apr 2001–July 2002

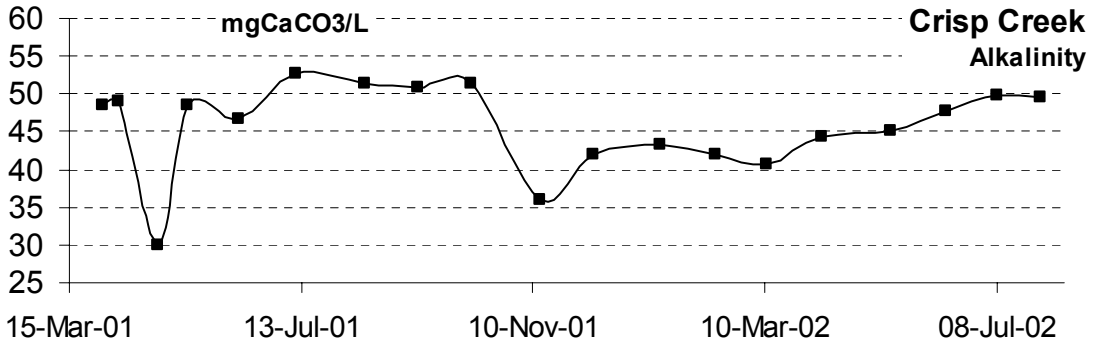

Figure 153: Alkalinity Crisp Creek: Apr 2001–July 2002

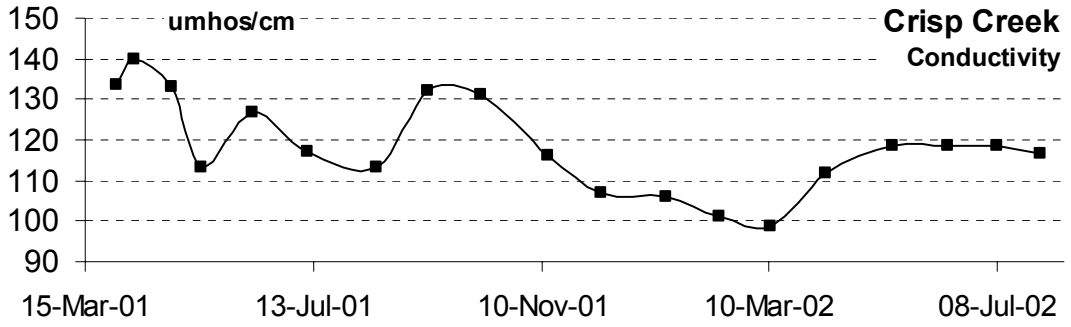

Figure 154: Conductivity Crisp Creek: Apr 2001–July 2002

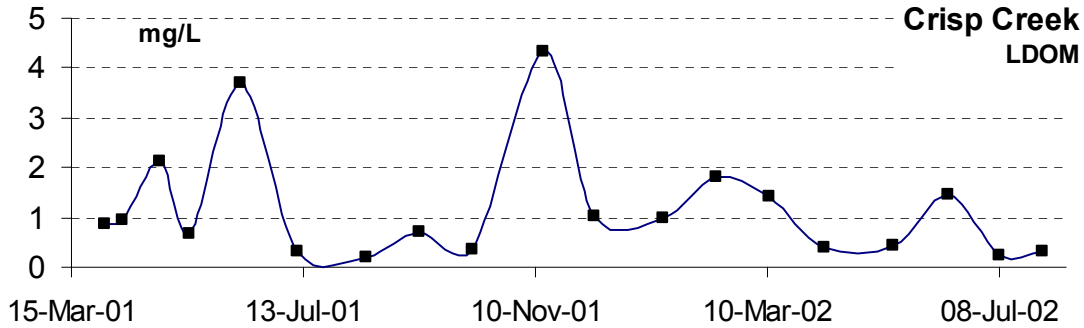

Figure 155: LDOM Crisp Creek: Apr 2001–July 2002

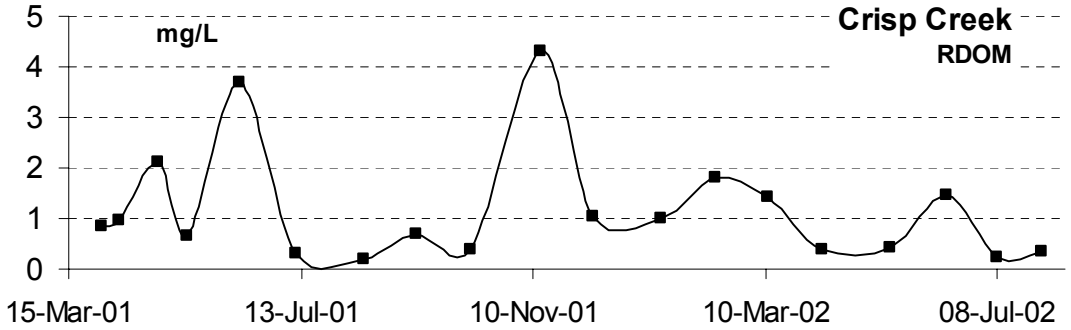

Figure 156: RDOM Crisp Creek: Apr 2001–July 2002

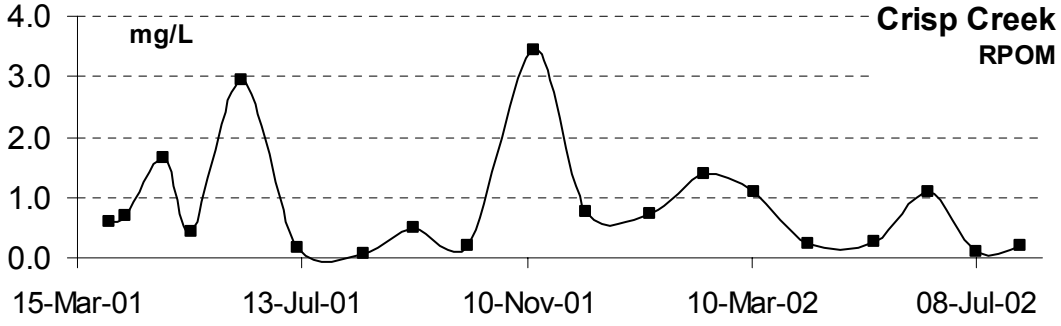

Figure 157: RPOM Crisp Creek: Apr 2001–July 2002

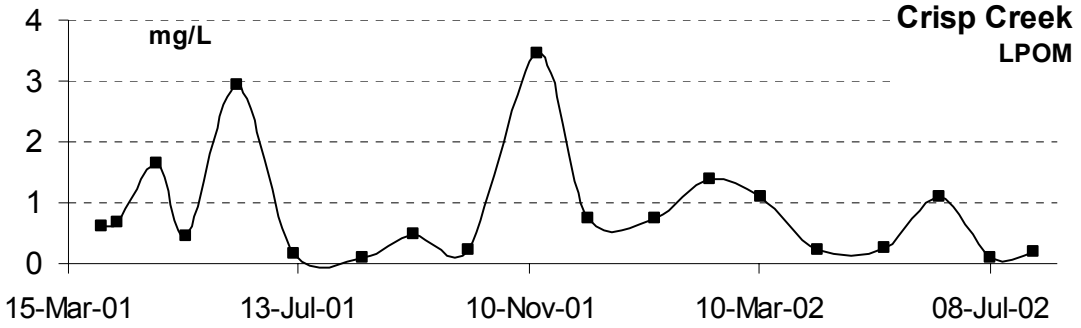

Figure 158: LPOM Crisp Creek: Apr 2001–July 2002

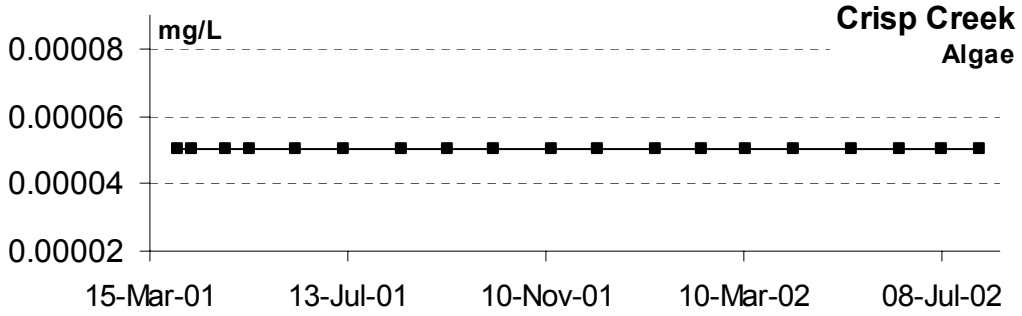

Figure 159: LDOM Crisp Creek: Apr 2001–July 2002

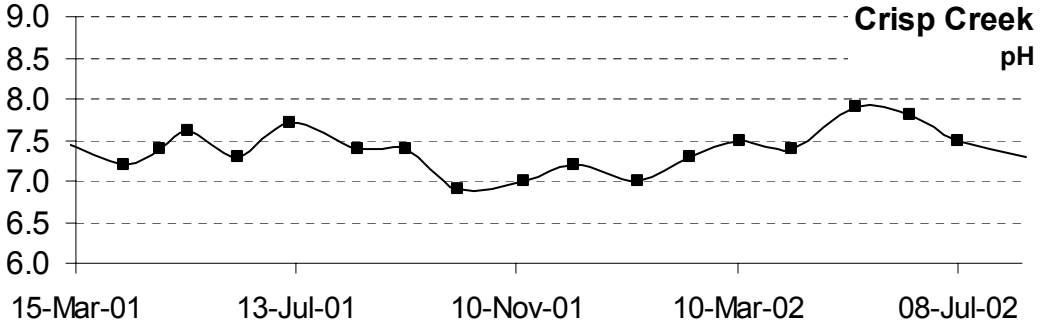

Figure 160: pH Crisp Creek: Apr 2001-July 2002

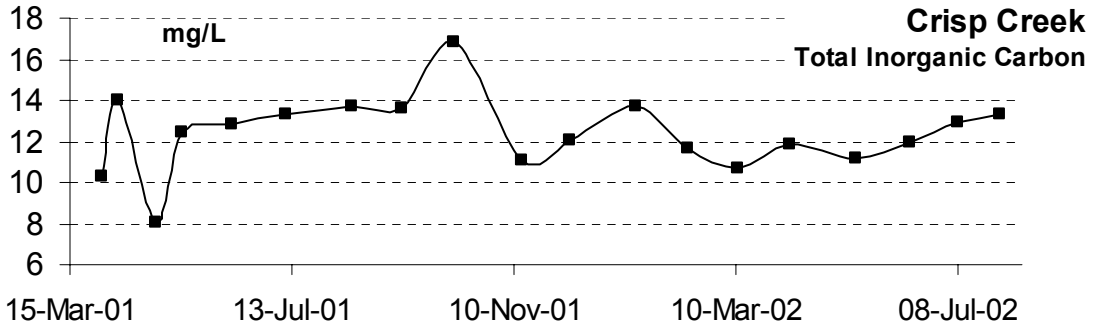

Figure 161: TIC Crisp Creek: Apr 2001–July 2002

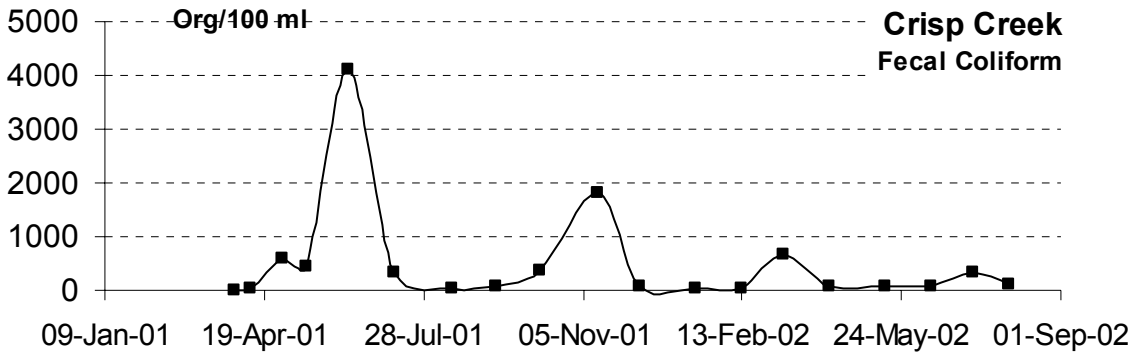

Figure 162: Fecal Coliform Crisp Creek: Apr 2001 - July 2002

Big Soos Creek

Big Soos Creek is the largest tributary contributing flow to the Green River. Big Soos Creek enters Green River at River Mile 33.80. The tributary basin is approximately 17,500 hectares (310,000 acres).

May 25, 1995 – Nov 1996

Flow

Flow data from USGS Gage 12112600 are available in 15-minute intervals from October 1, 1994, to December 31, 2002. The complete data set is included in Appendix A, and Figure 163 is the flow data for the model simulation period.

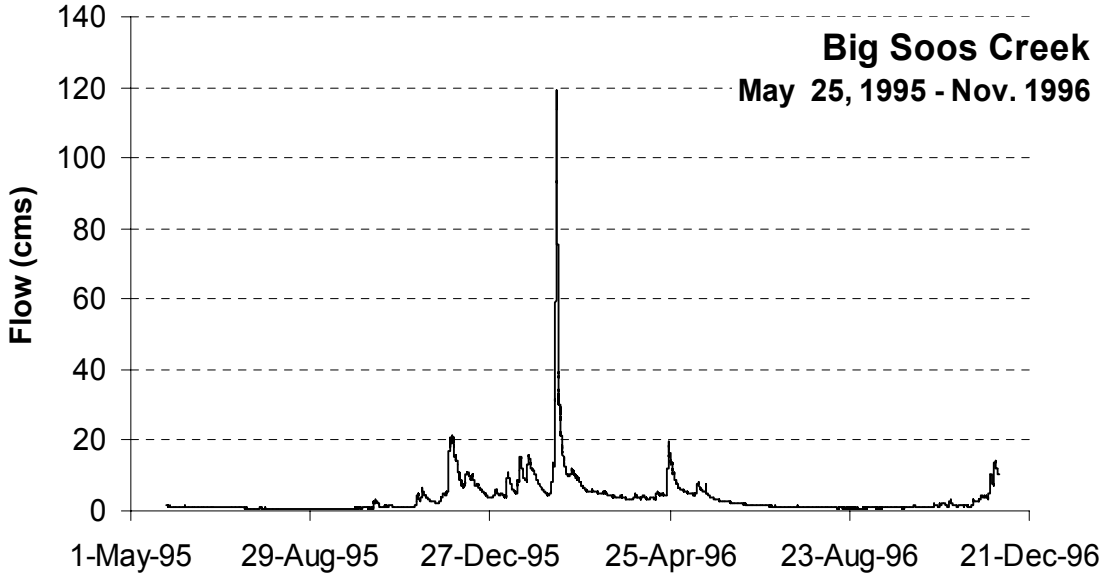

Figure 163: Big Soos Creek Flow: May 25, 1995 – Nov 1996

Temperature

There is one gap in temperature from October 30, 1995 to April 12, 1996. There is little temperature data available during this time period, so to fill this data gap Station BIC, on the Green River near Tukwila, was used. The correlation equation is as follows:

$$\text{Temp 54a} = (0.5682)(\text{Temp BIC}) + 4.0774$$

Figure 164 shows the temperature correlation between the 2 sites, Figure 165 compares correlated values to monitored data from Big Soos Creek, and Figure 166 shows the temperature data for this calibration period with correlated values included. Note that Station 54a records temperature in 15 minute intervals, and Station BIC recorded in half-hour intervals, so the correlated data are also in half-hour intervals.

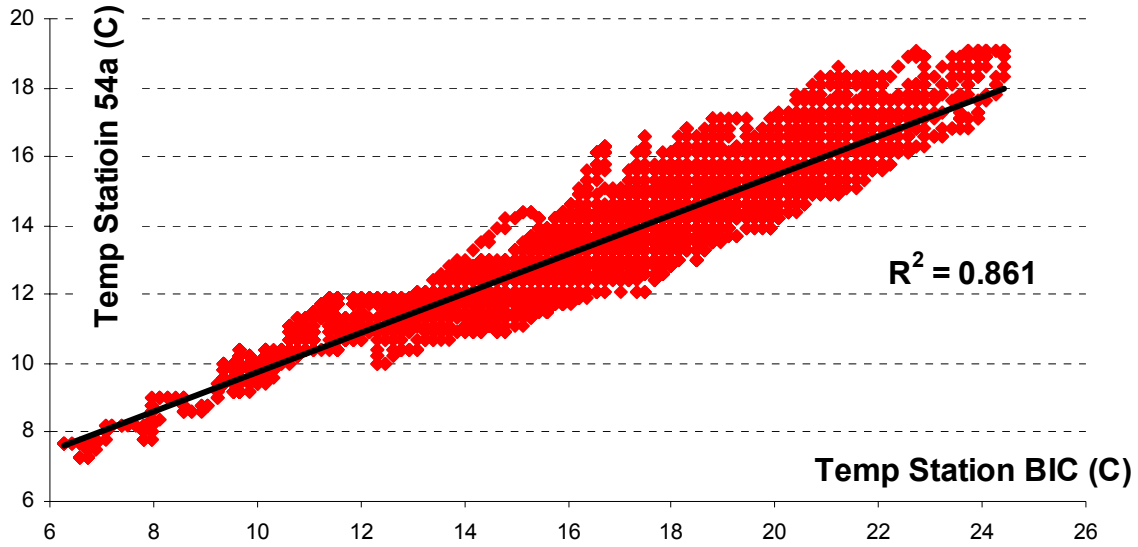

Figure 164: Correlation between Big Soos Creek and Station BIC

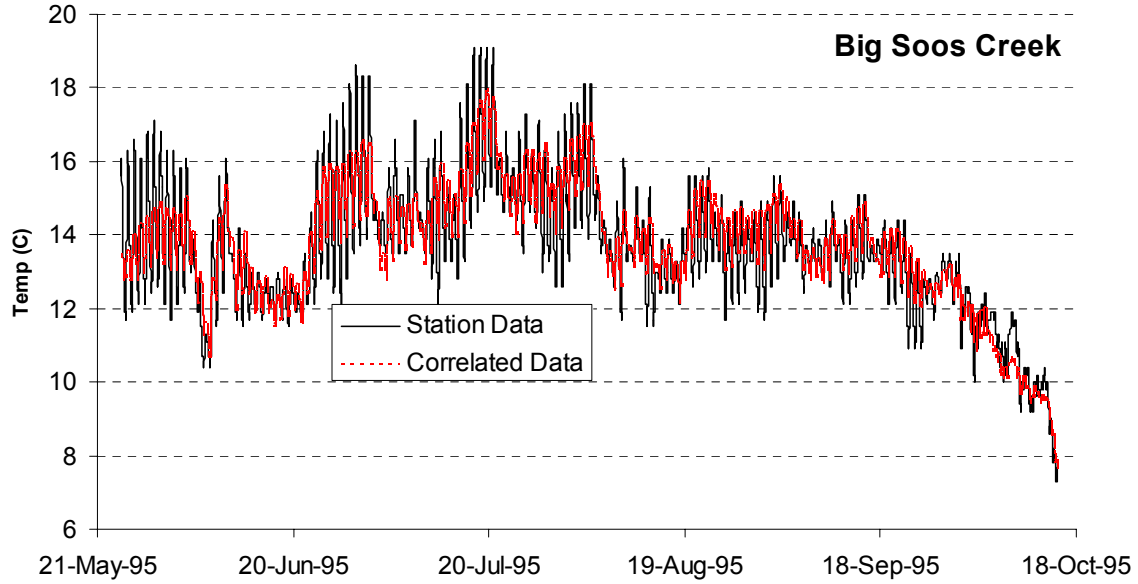

Figure 165: Big Soos Creek: Station data versus correlated values, 1995 - 1996

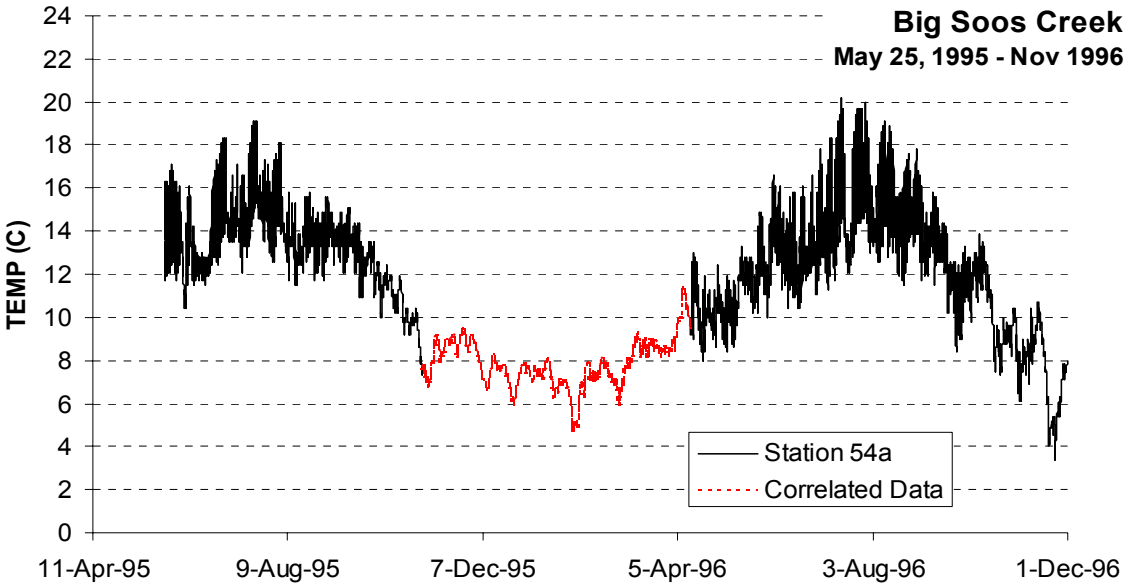

Figure 166: Big Soos Creek Temperature: May 25, 1995 – Nov 1996

Water Quality

King County has been collecting water quality samples at the mouth of Big Soos since 1995 (Locator A320). Data are available for all constituents except chlorophyll a and alkalinity. Figure 167 through Figure 180 shows graphs of the water quality constituents for the model calibration period. See Appendix D for procedures used in assembling the water quality data, including estimating missing data.

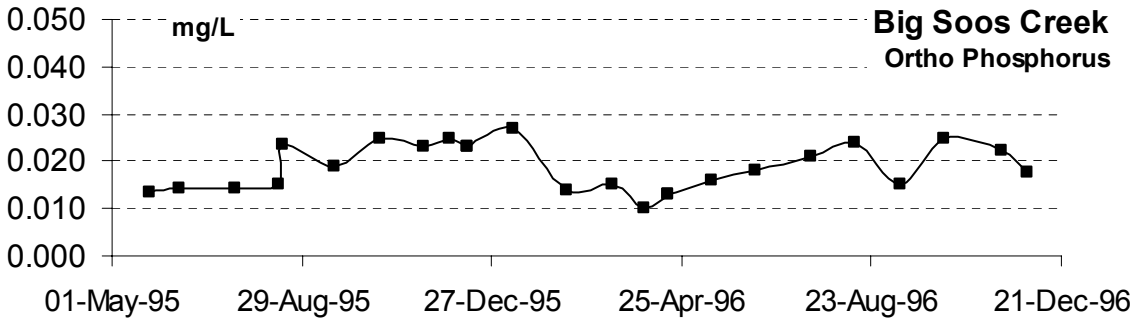

Figure 167: Ortho phosphorus Big Soos Creek: May 25, 1995 – Nov 1996

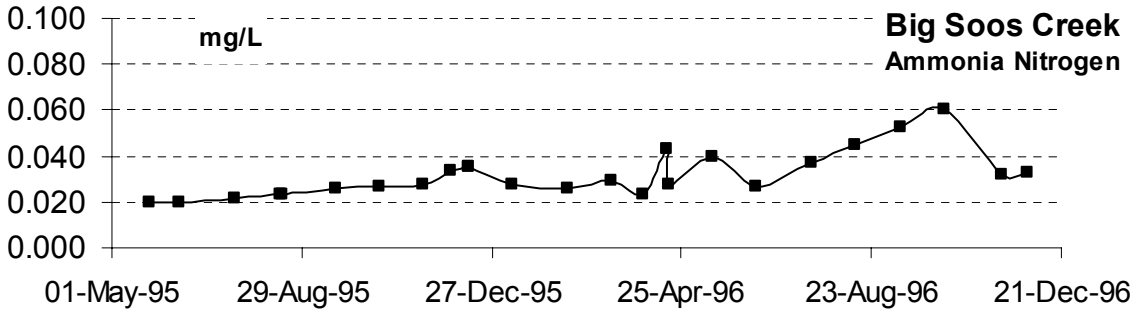

Figure 168: Ammonia Big Soos Creek: May 25, 1995 – Nov 1996

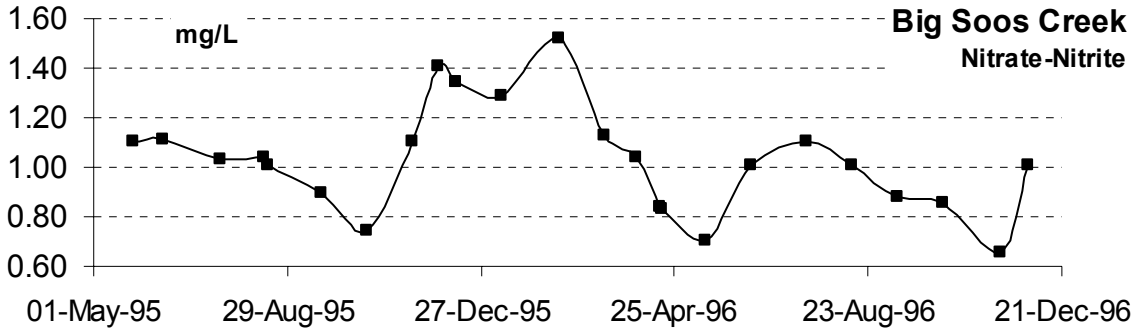

Figure 169: Nitrate-Nitrite Big Soos Creek: May 25, 1995 – Nov 1996

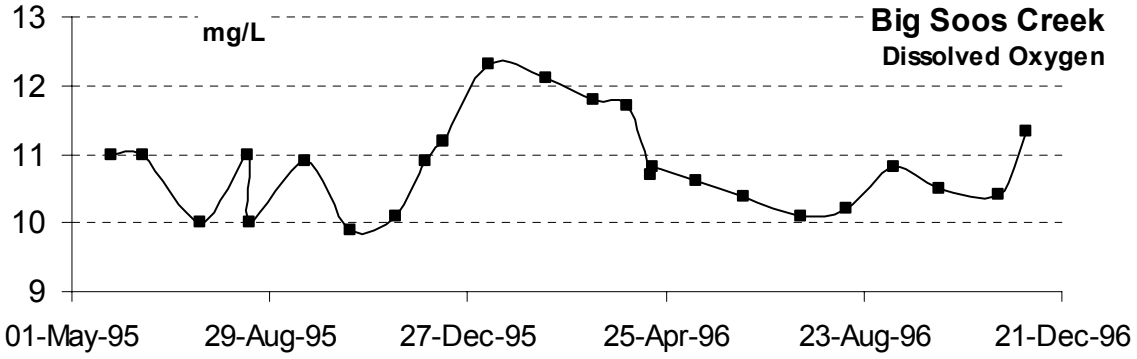

Figure 170: ISS Big Soos Creek: May 25, 1995 – Nov 1996

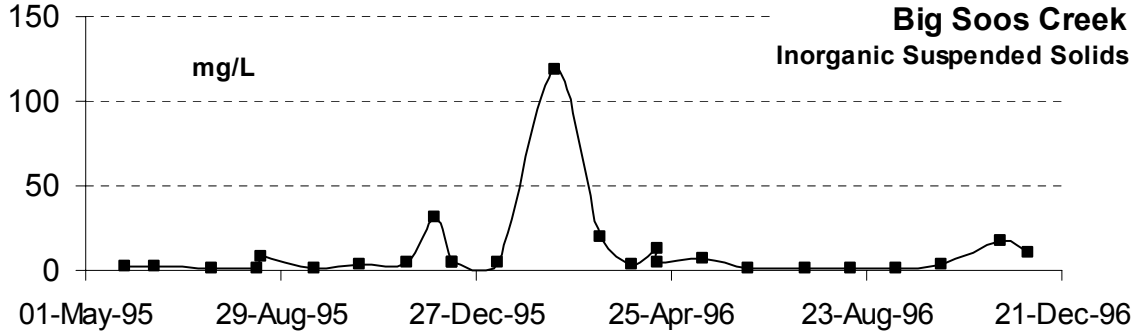

Figure 171: Big Soos: DO Creek: May 25, 1995 – Nov 1996

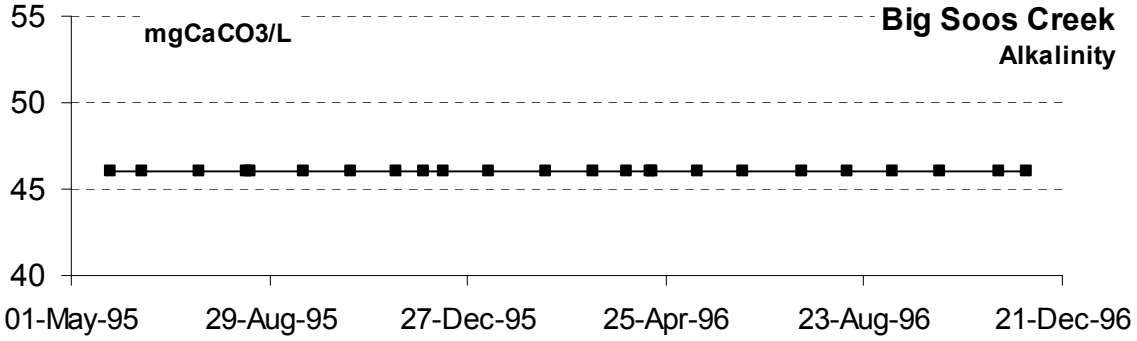

Figure 172: Alkalinity Big Soos Creek: May 25, 1995 – Nov 1996

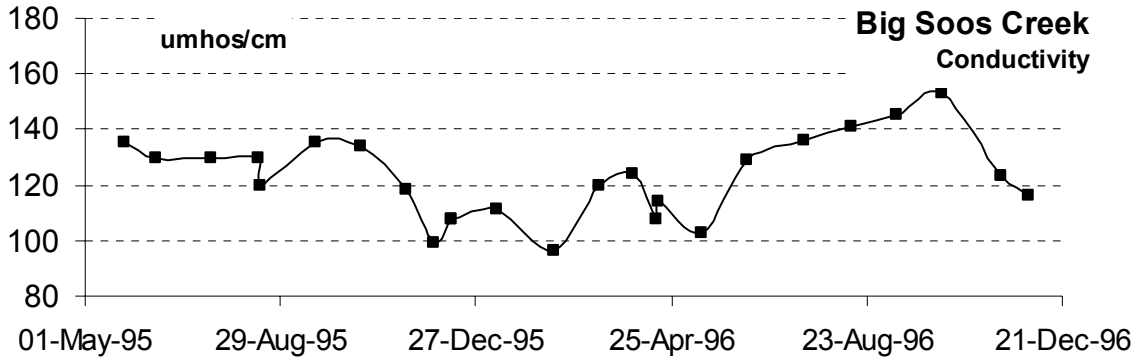

Figure 173: Conductivity Big Soos Creek: May 25, 1995 – Nov 1996

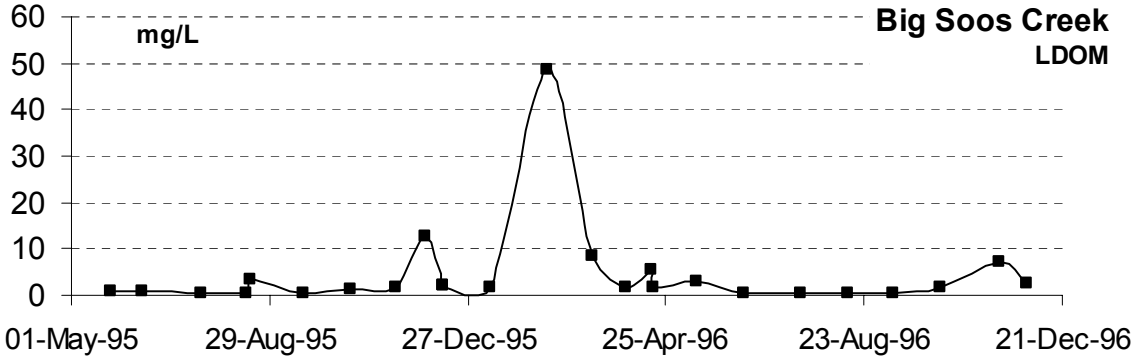

Figure 174: LDOM Big Soos Creek: May 25, 1995 – Nov 1996

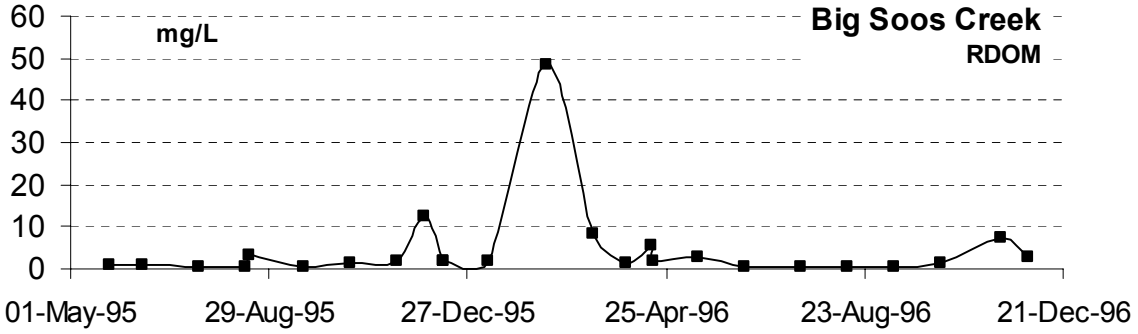

Figure 175: RDOM Big Soos Creek: May 25, 1995 – Nov 1996

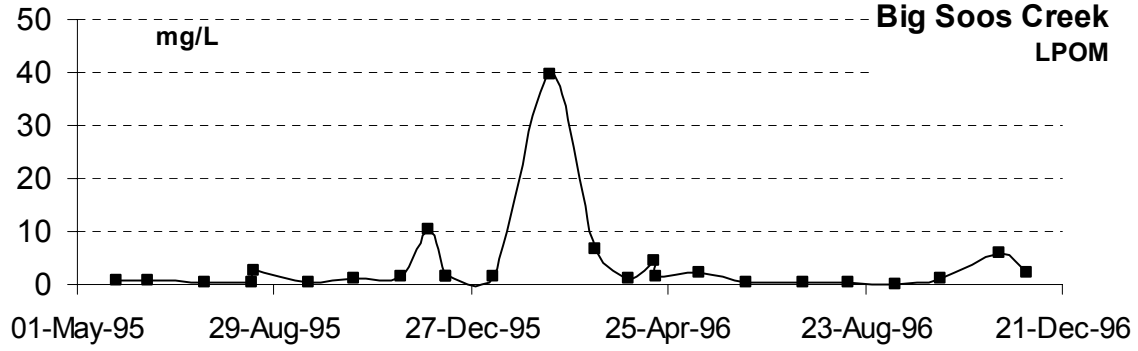

Figure 176: LPOM Big Soos Creek: May 25, 1995 – Nov 1996

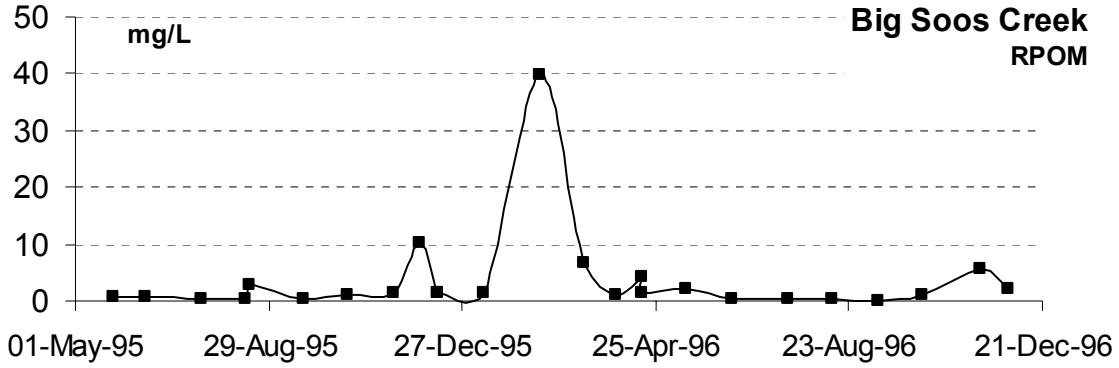

Figure 177: RPOM Big Soos Creek: May 25, 1995 – Nov 1996

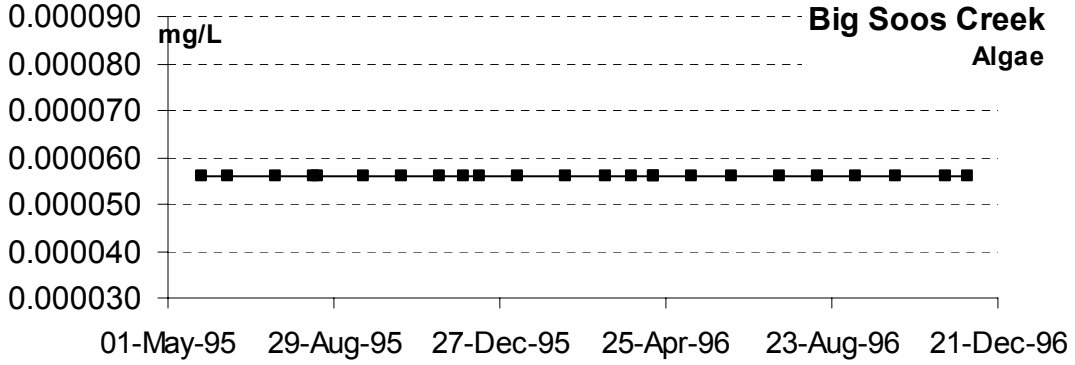

Figure 178: Algae Big Soos Creek: May 25, 1995 – Nov 1996

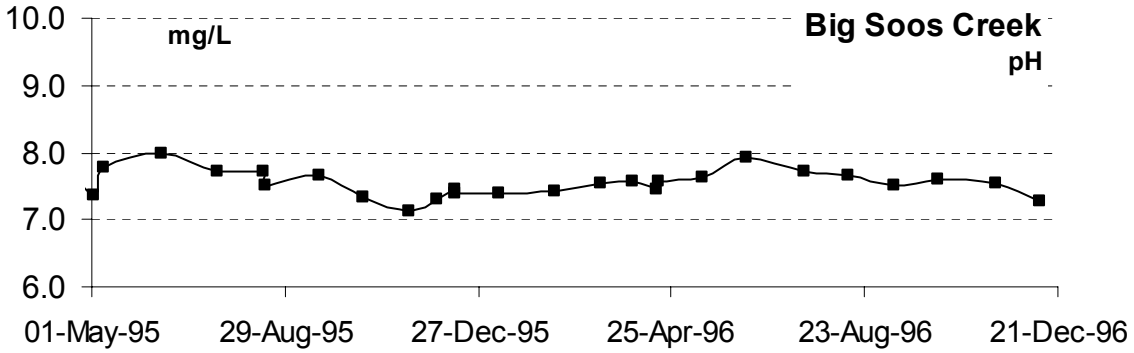

Figure 179: pH Big Soos Creek: May 25, 1995 - Nov 1996

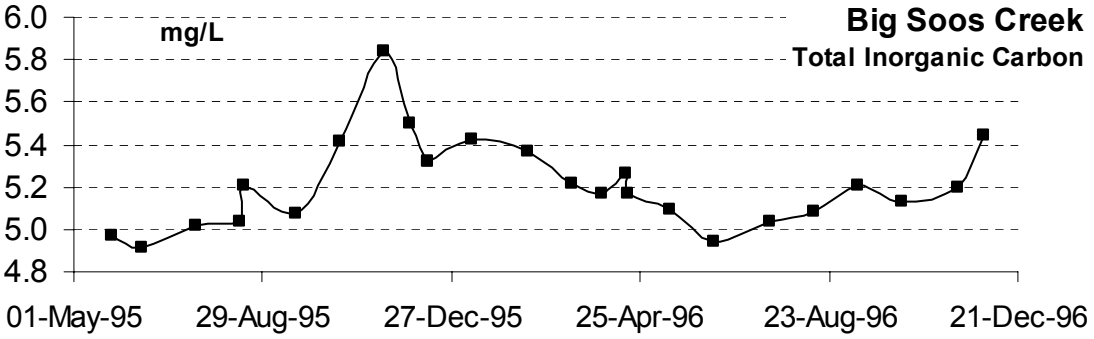

Figure 180: TIC Big Soos Creek: May 25, 1995 – Nov 1996

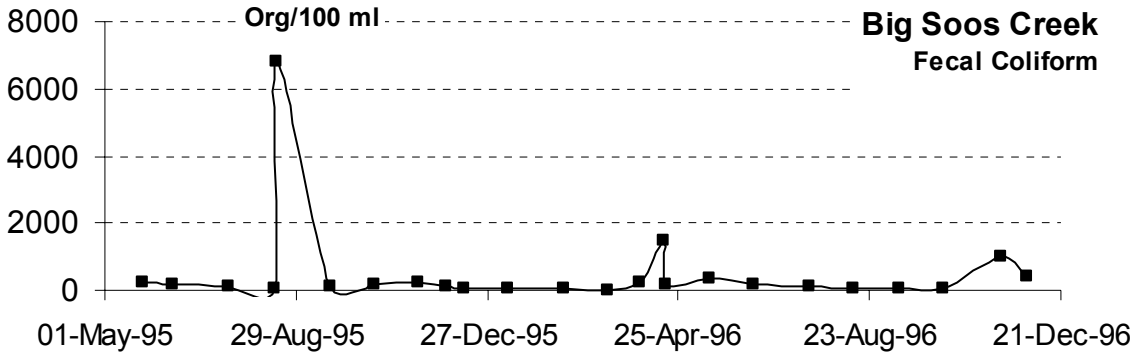

Figure 181: Fecal Coliform: May 25, 1995 - Nov 1996

April 2001 – July 2002

Flow

Flow data from USGS Gage 12112600 were also used for this model calibration period. The complete data set is included in Appendix A, and Figure 182 is the flow data for the model simulation period.

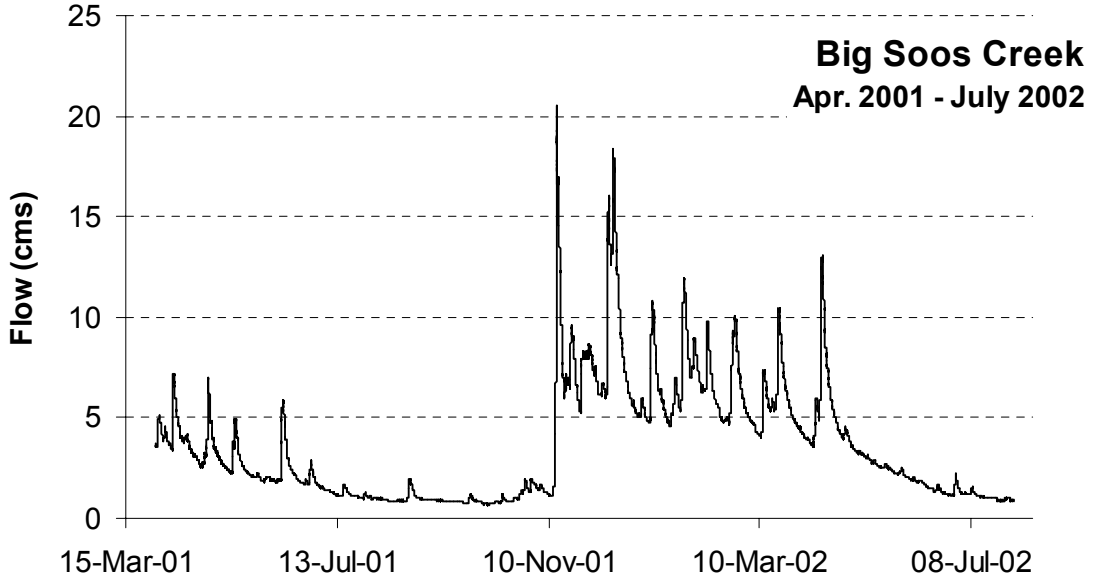

Figure 182: Big Soos Creek Flow: Apr 2001 – July 2002

Temperature

King County provided temperature data from a station at the mouth of Soos Creek from October 1, 1994 to August 1, 2002, in 15-minute intervals (Station 54a). Data from the model calibration period is shown in Figure 183.

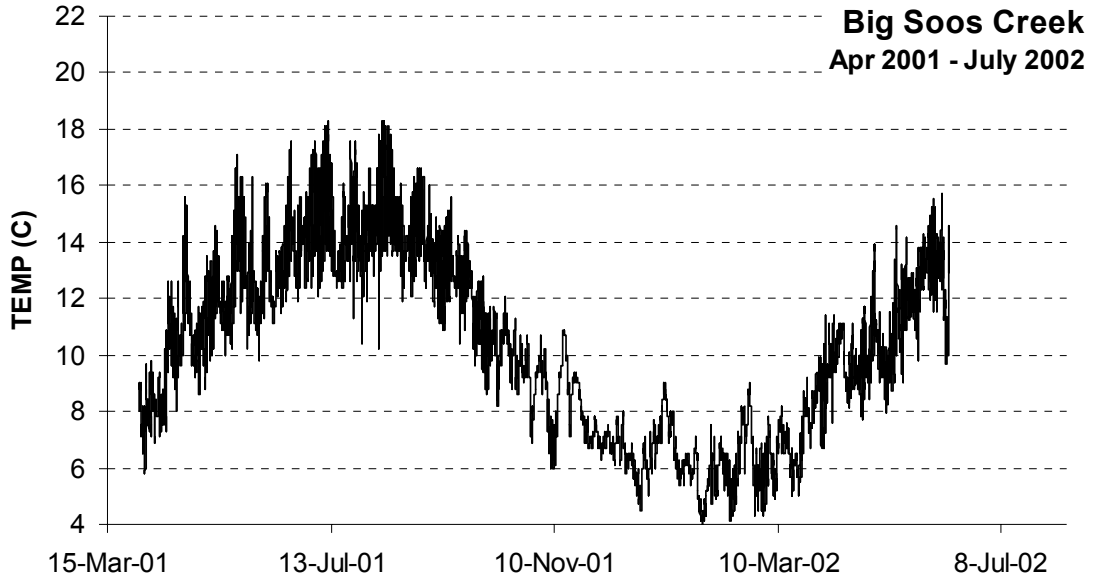

Figure 183: Big Soos Temperature: Apr 2001 – July 2002

Water Quality

King County has provided water quality data at the mouth of the Big Soos Creek from 1995 through 2002 (Station A320). Data are available for all constituents except chlorophyll a. Figure 184 through Figure 197 show graphs of the data for the model calibration period. Data from 1995-2002 are shown in Appendix A. See Appendix D for procedures used in assembling the water quality data, including estimates of missing data.

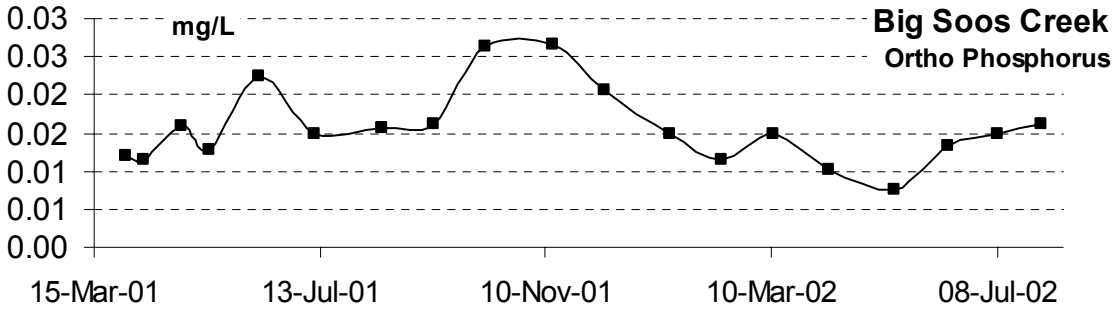

Figure 184: Ortho Phosphorus Big Soos: Apr 2001 – July 2002

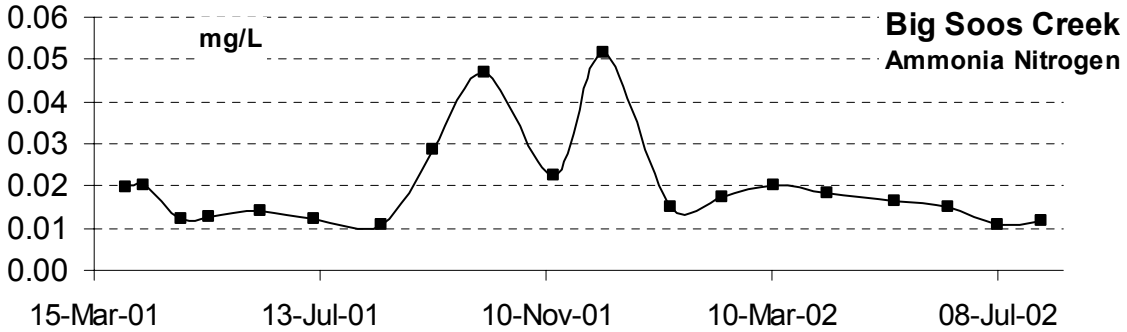

Figure 185: Ammonia Big Soos: Apr 2001 – July 2002

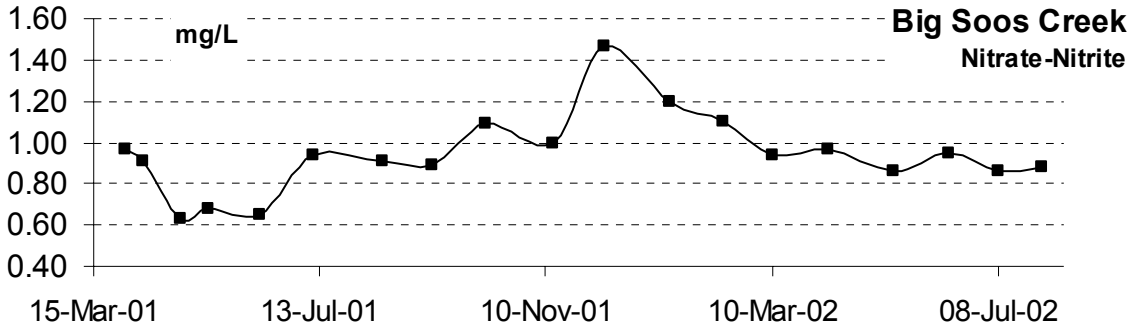

Figure 186: Nitrate-Nitrite Big Soos: Apr 2001 – July 2002

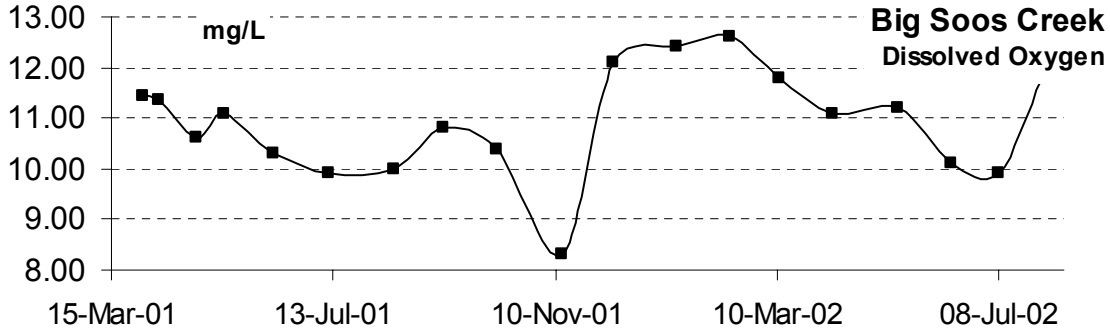

Figure 187: DO Big Soos: Apr 2001 – July 2002

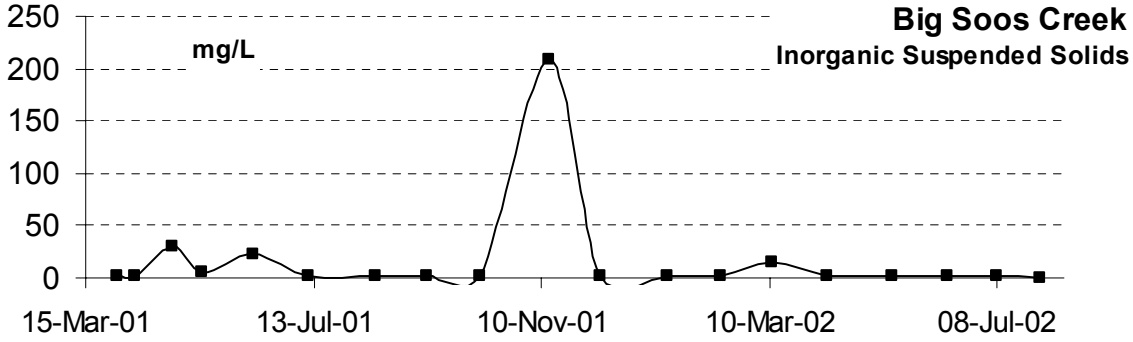

Figure 188: ISS Big Soos: Apr 2001 – July 2002

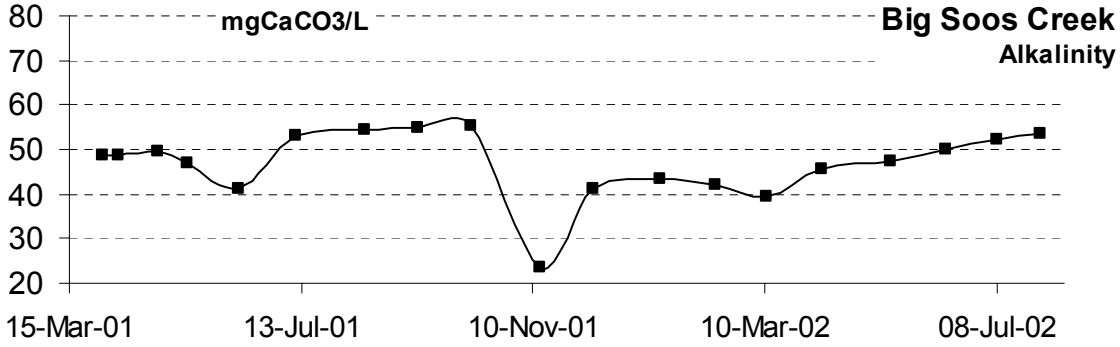

Figure 189: Alkalinity Big Soos: Apr 2001 – July 2002

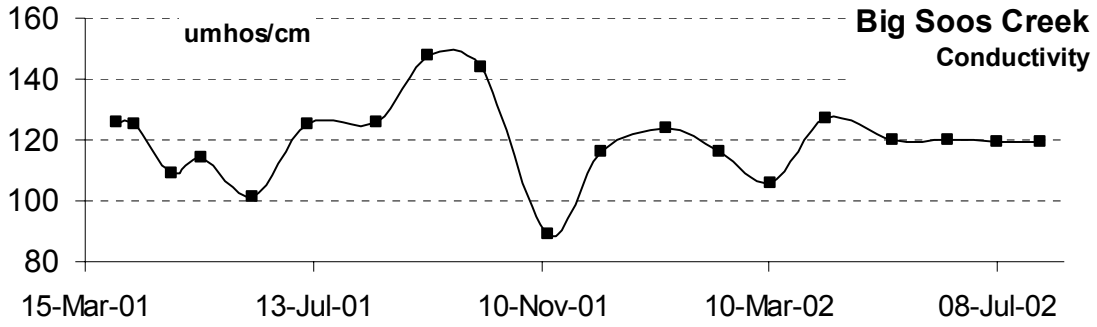

Figure 190: Conductivity Big Soos: Apr 2001 – July 2002

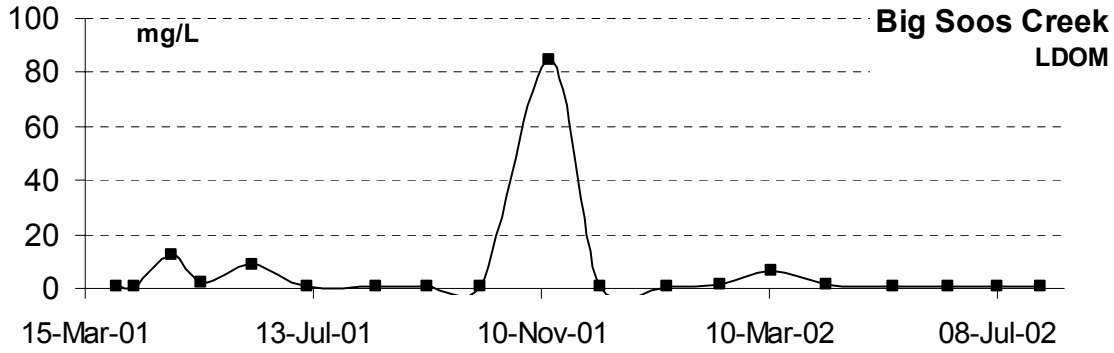

Figure 191: LDOM Big Soos: Apr 2001 – July 2002

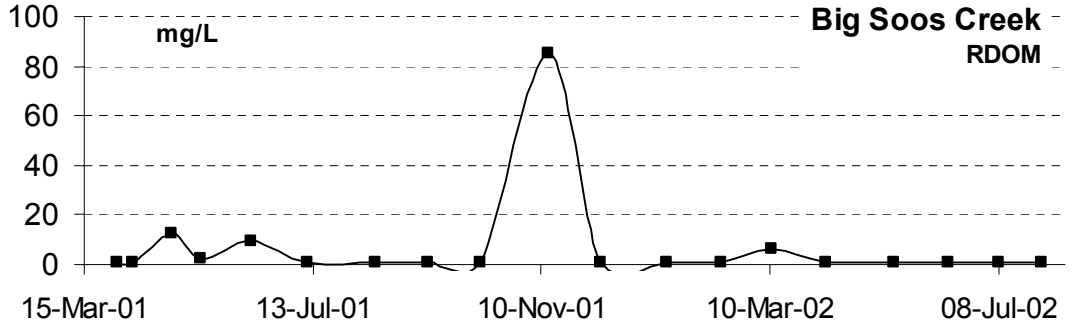

Figure 192: RDOM Big Soos: Apr 2001 – July 2002

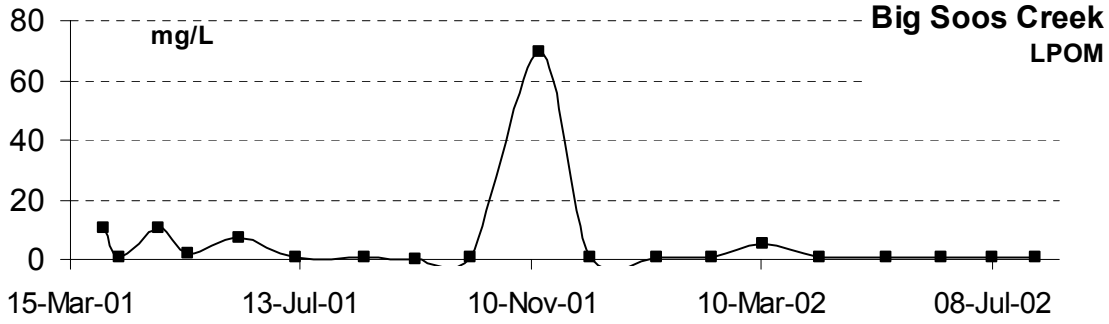

Figure 193: LPOM Big Soos: Apr 2001 – July 2002

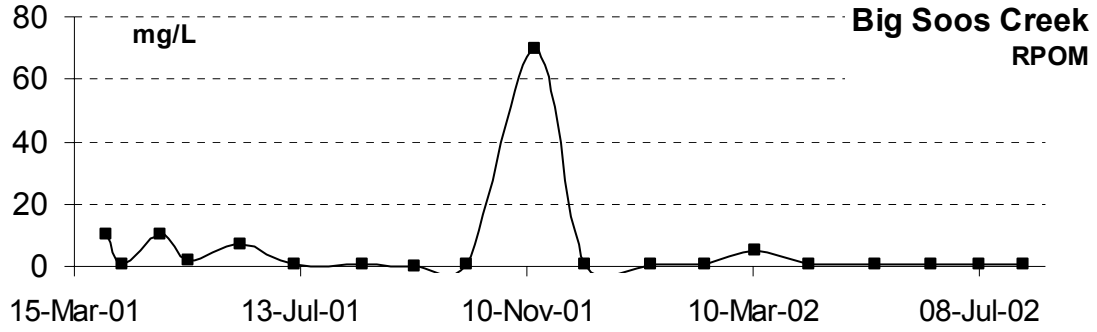

Figure 194: RPOM Big Soos: Apr 2001 – July 2002

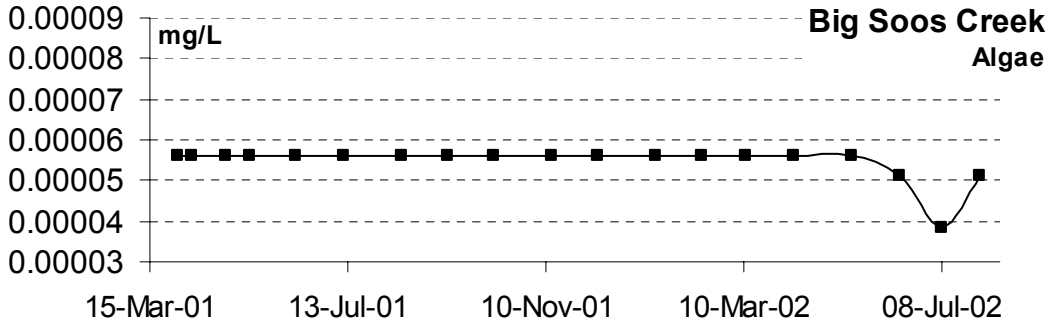

Figure 195: Algae Big Soos: Apr 2001 – July 2002

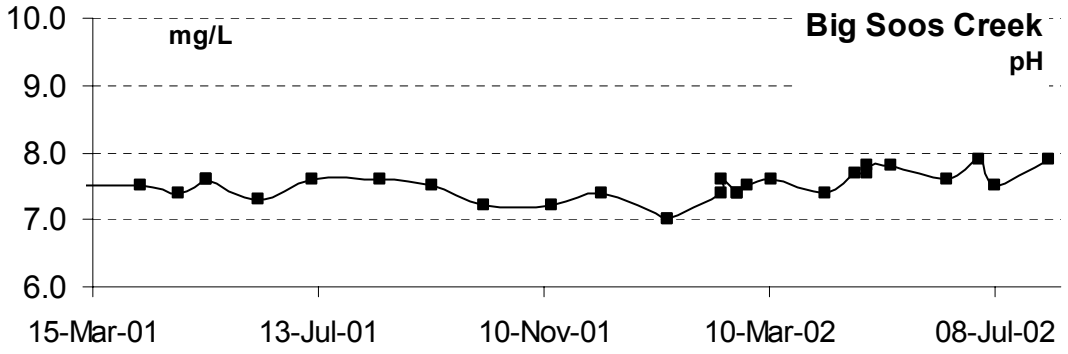

Figure 196: pH Big Soos: Apr 2001 - July 2002

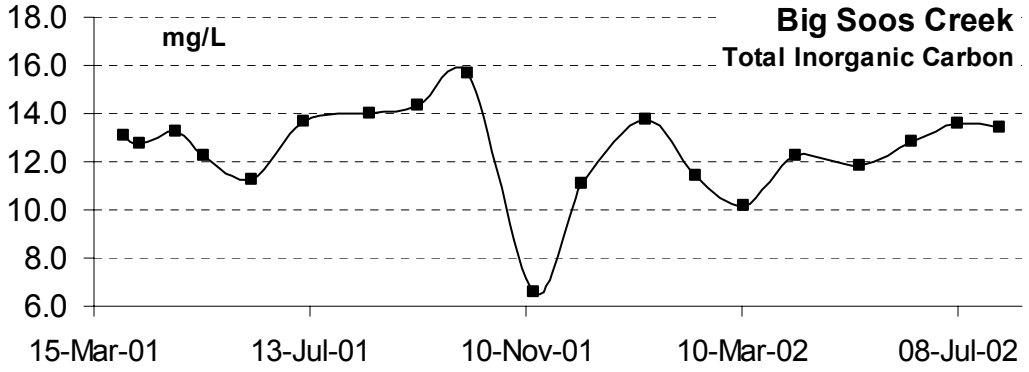

Figure 197: TIC Big Soos: Apr 2001 – July 2002

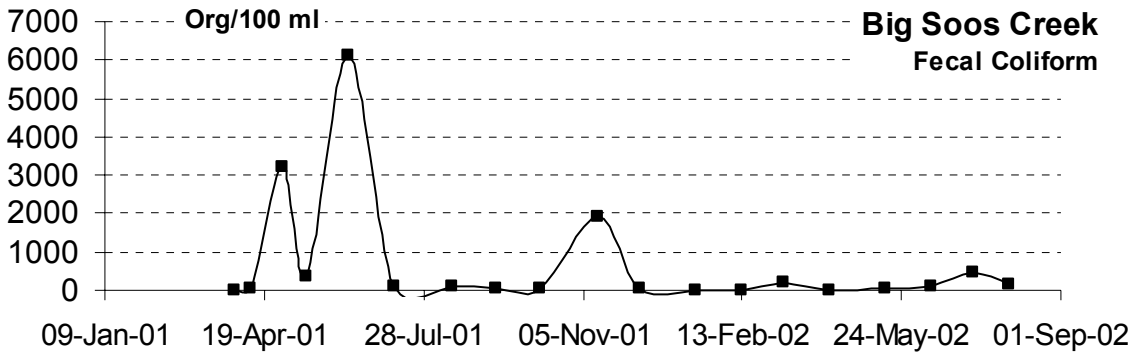

Figure 198: Fecal Coliform Big Soos: Apr 2001 - July 2002

Mill Creek

Mill Creek is another small tributary to Green River, with an approximate basin size of 3,950 hectares (9760 acres), which enters the Green River at River Mile 23.80.

May 25, 1995 – November 1996

Flow

King County maintained a flow gage on Mill Creek, but it was removed because the county believes backwater from the Green River made data from this gage unreliable (DeGasperi, 2003). Data were provided for this gage in 15-minute intervals from August 22, 1989 to April 6, 1996. These data are shown in Appendix A. Note the number of time periods where the gage data is at zero. These are time periods of "bad" data, possible where flow is reversed in the creek.

King County also "modeled" the Mill Creek basin using HSPF from October 1948 to December 2002. Daily average flow data were provided from this model. Flow data from Station 41a were graphed against the HSPF data. Figure 199 shows the comparison. The highs and lows occur at the same time, but the HSPF data are consistently larger in magnitude. Because there is a question of the reliability of data from Station 41, HSPF data will be used for both model calibration periods. Figure 200 shows the data for the model simulation period.

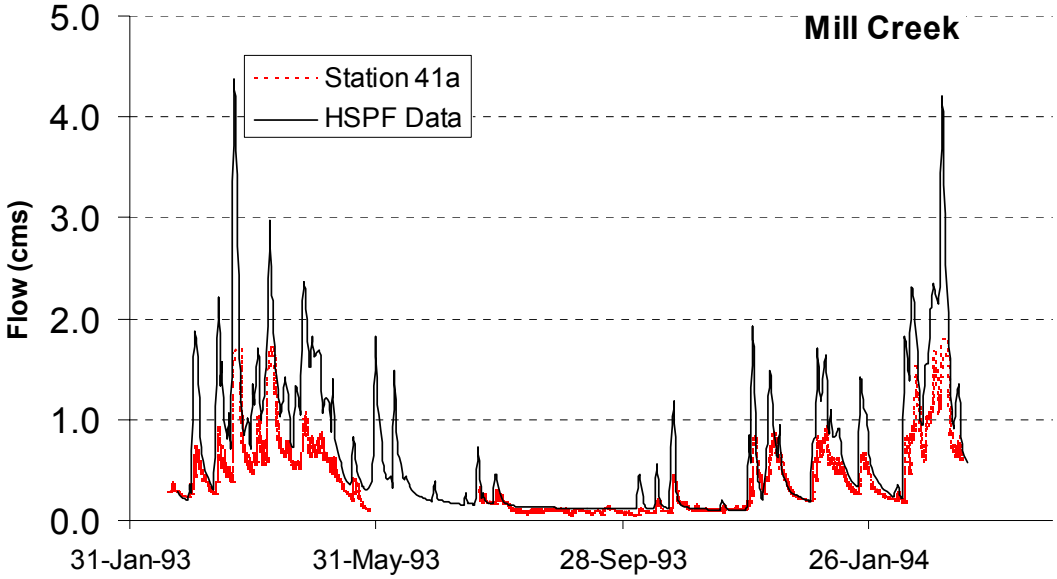

Figure 199: Mill Creek Flow Comparison

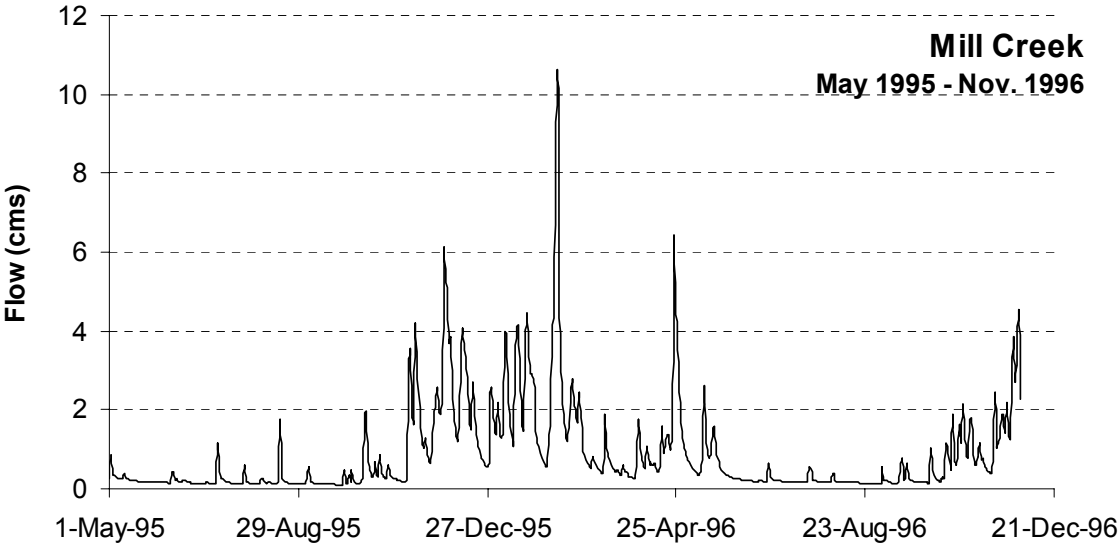

Figure 200: Mill Creek Flow: May 25, 1995 – Nov 1996

Temperature

Temperature monitoring data are not available until October 1999. Temperature data from Big Soos Creek will be used for this time period. Data from Big Soos Creek were chosen because it is the closest tributary to Mill Creek. See Figure 166 for temperature data.

Water Quality

King County has provided water quality data for the mouth of Mill Creek from 1990 to December 2002. Data are available for all constituents except chlorophyll a, and alkalinity. See Appendix A for water quality data for the entire time period, and Figure 201 through Figure 214 for data for the model

calibration period. See Appendix D for procedures used in assembling the water quality data, including estimating missing data.

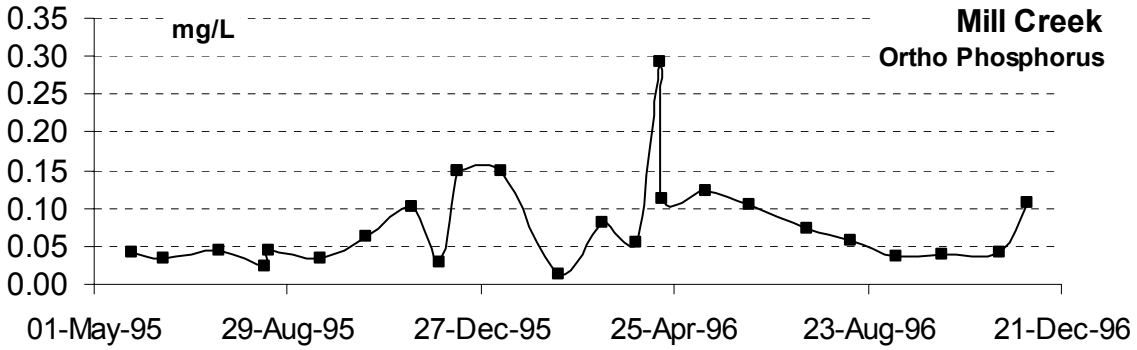

Figure 201: Ortho phosphorus Mill Creek: May 25, 1995 – Nov 1996

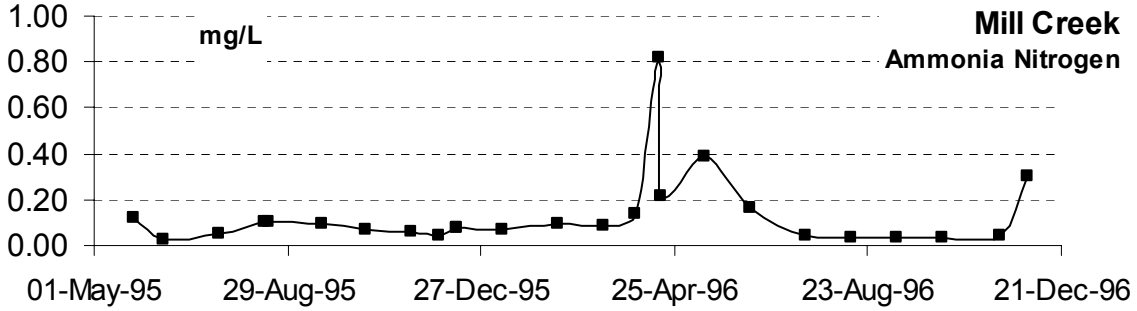

Figure 202: Ammonia Mill Creek: May 25, 1995 – Nov 1996

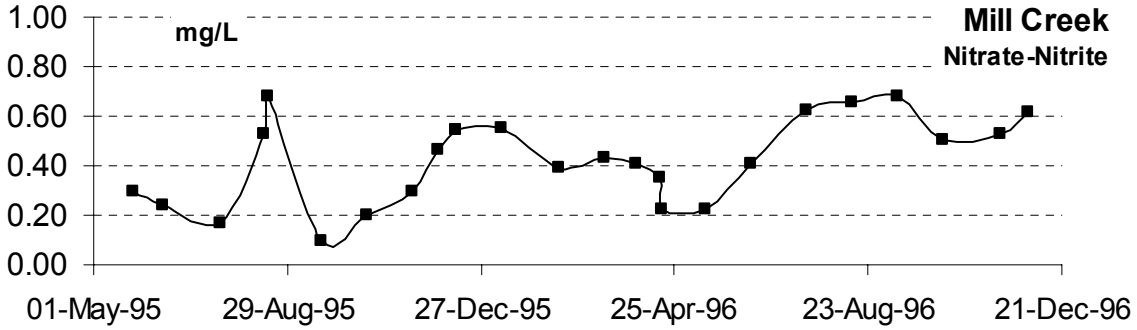

Figure 203: Nitrate-Nitrite Mill Creek: May 25, 1995 – Nov 1996

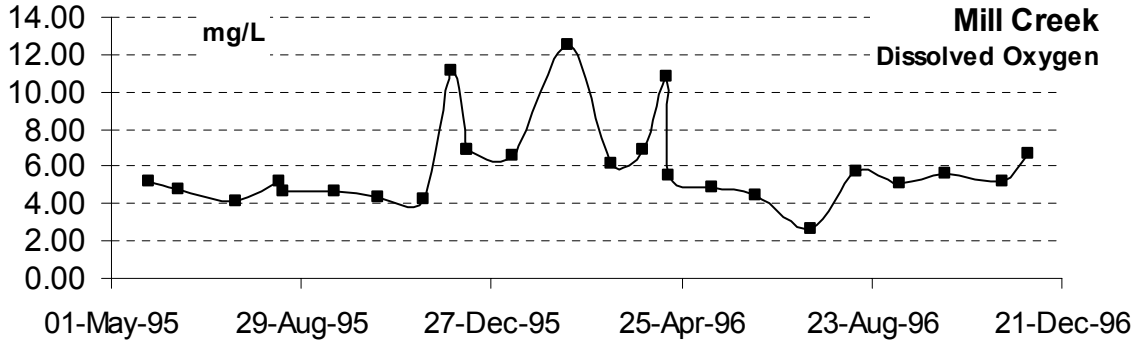

Figure 204: DO Mill Creek: May 25, 1995 – Nov 1996

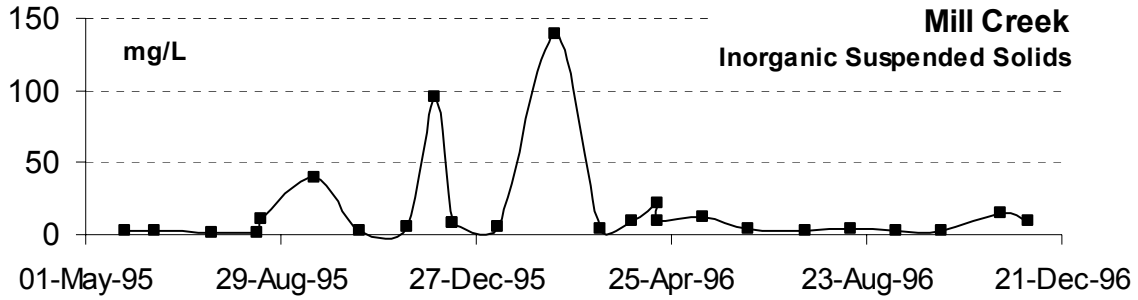

Figure 205: ISS Mill Creek: May 25, 1995 – Nov 1996

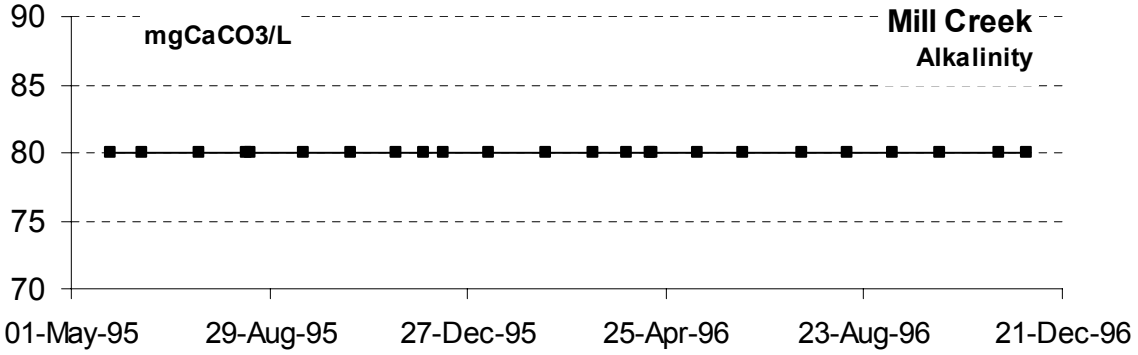

Figure 206: Alkalinity Mill Creek: May 25, 1995 – Nov 1996

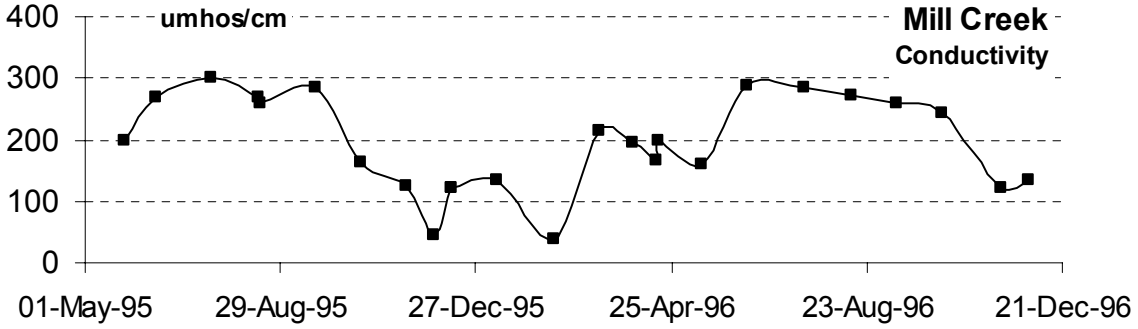

Figure 207: Conductivity Mill Creek: May 25, 1995 – Nov 1996

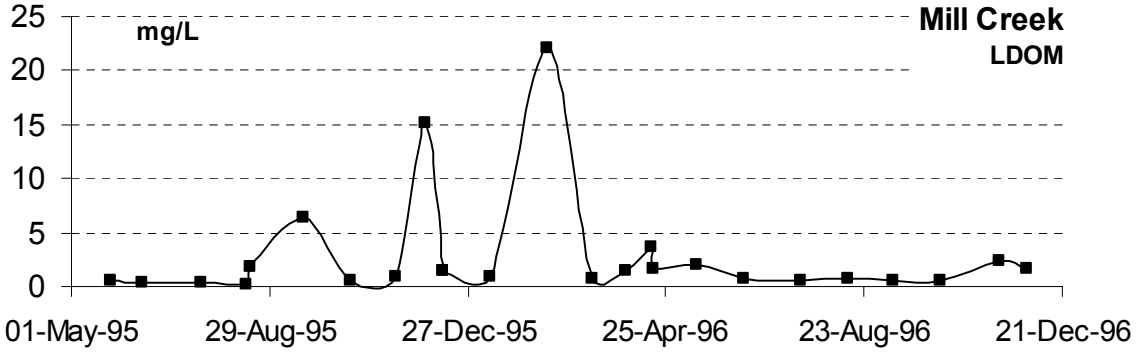

Figure 208: LDOM Mill Creek: May 25, 1995 – Nov 1996

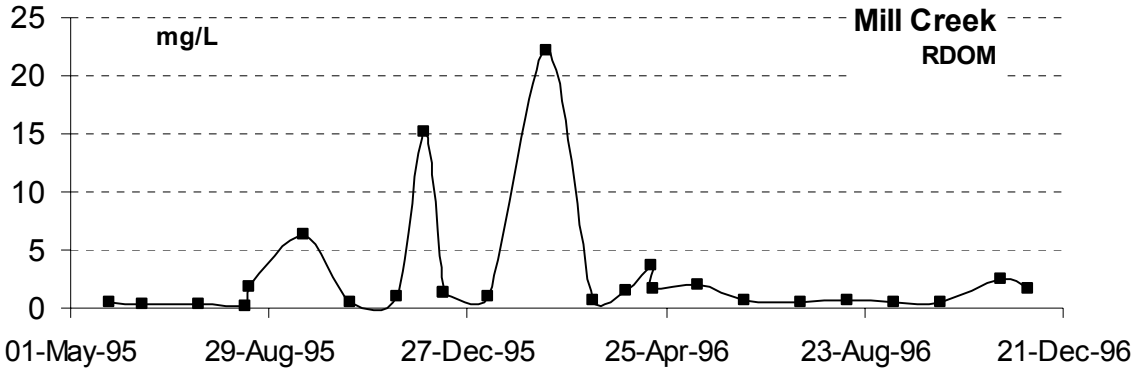

Figure 209: RDOM Mill Creek: May 25, 1995 – Nov 1996

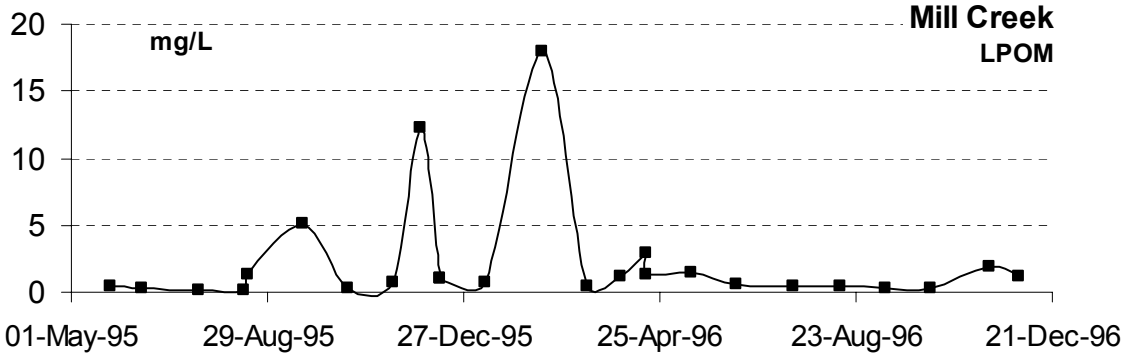

Figure 210: LPOM Mill Creek: May 25, 1995 – Nov 1996

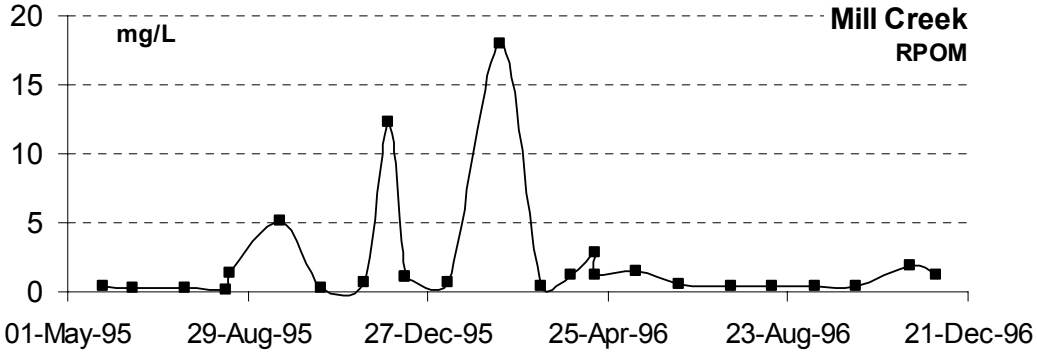

Figure 211: RPOM Mill Creek: May 25, 1995 – Nov 1996

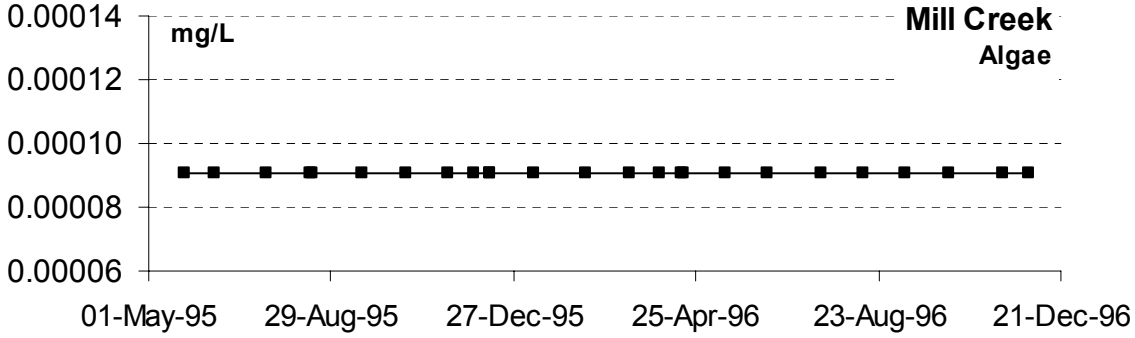

Figure 212: Algae Mill Creek: May 25, 1995 – Nov 1996

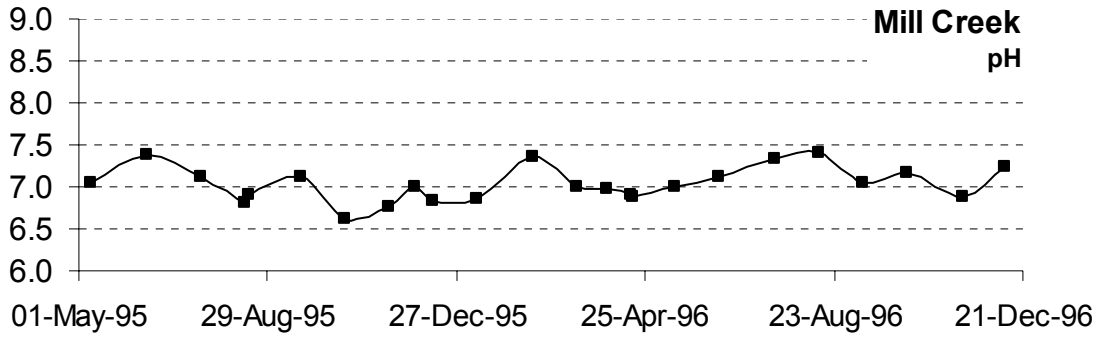

Figure 213: pH Mill Creek: May 25, 1995 - Nov 1996

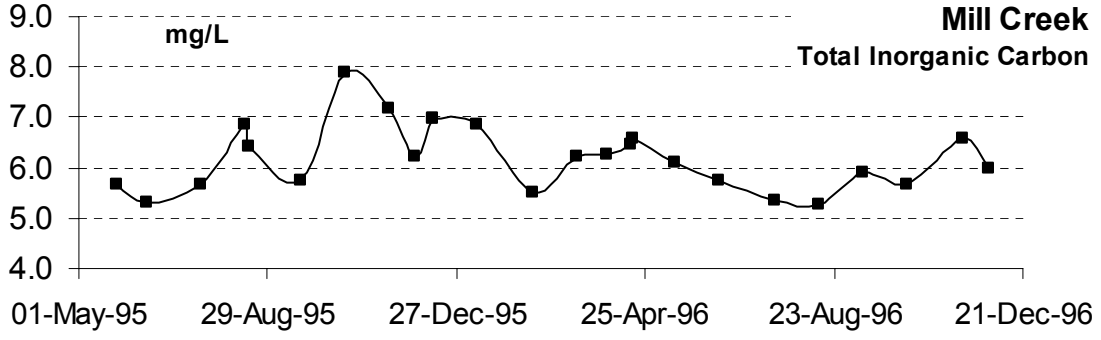

Figure 214: TIC Mill Creek: May 25, 1995 – Nov 1996

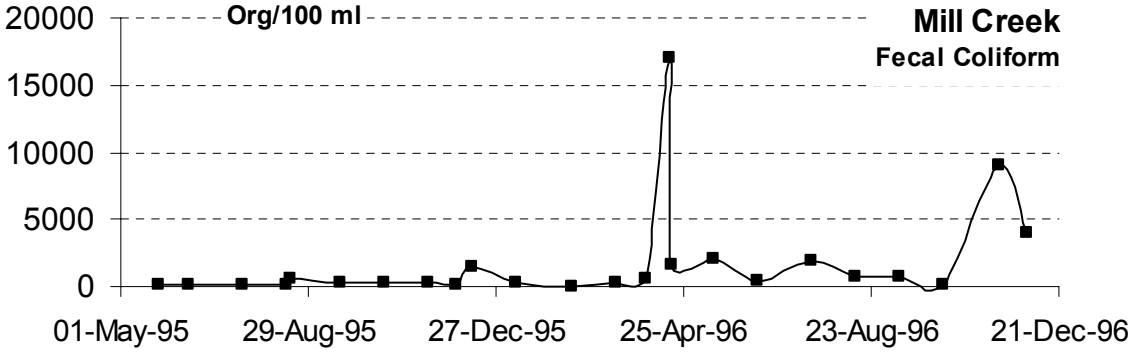

Figure 215: Fecal Coliform: May 25, 1995 - Nov 1996

April 2001 – July 2002

Flow

HSPF daily model output flows were used for this calibration period. Figure 216 shows the data for this model calibration period.

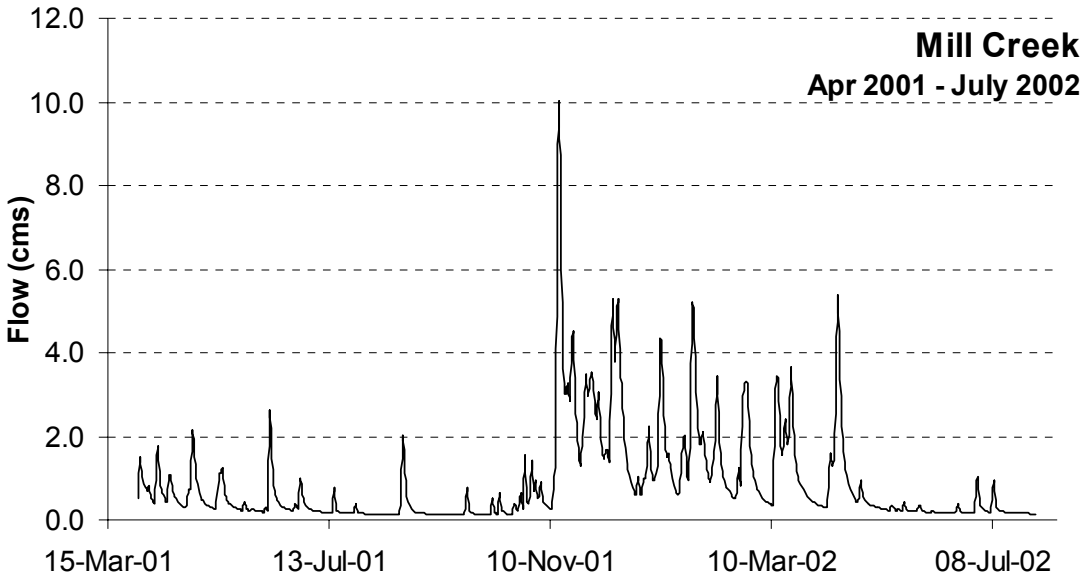

Figure 216: Mill Creek Flow: Apr 2001 – July 2002

Temperature

King County has also recorded temperature at the mouth of Mill Creek (Station 41a) beginning in October 1999 in 15 minute intervals. Figure 217 is a graph of temperature data for the model calibration period. Note that when backwater from the Green River enters Mill Creek the backwater would influence this temperature data also.

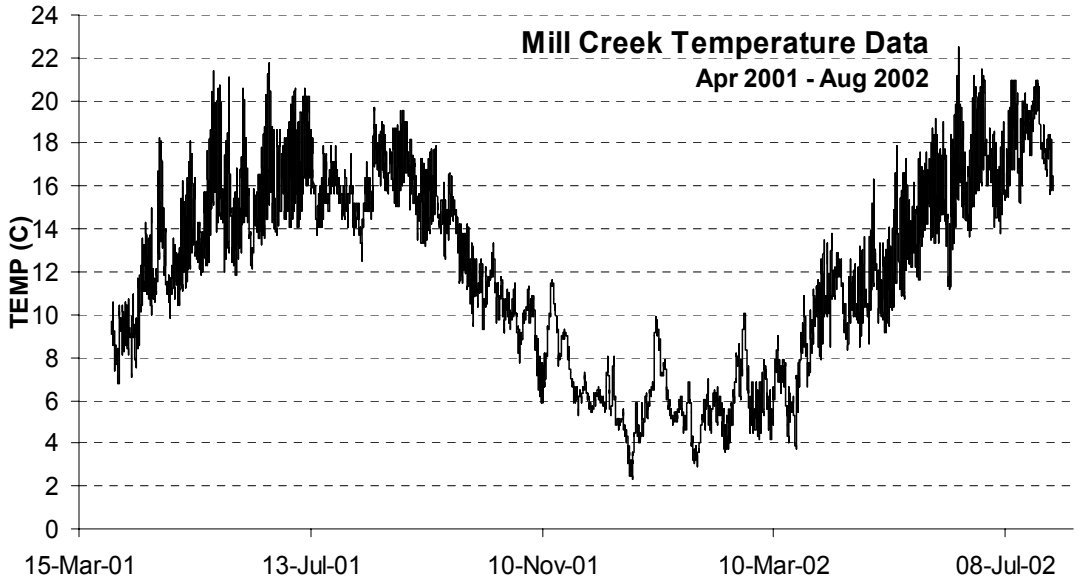

Figure 217: Mill Creek Temperature: Apr 2001 – July 2002

Water Quality

King County has provided water quality data at the mouth of Mill Creek from 1995 through 2002 (Station A315). Figure 218 through Figure 231 shows these data for the model calibration period. See Appendix D for procedures used in assembling the water quality data, including estimating missing data.

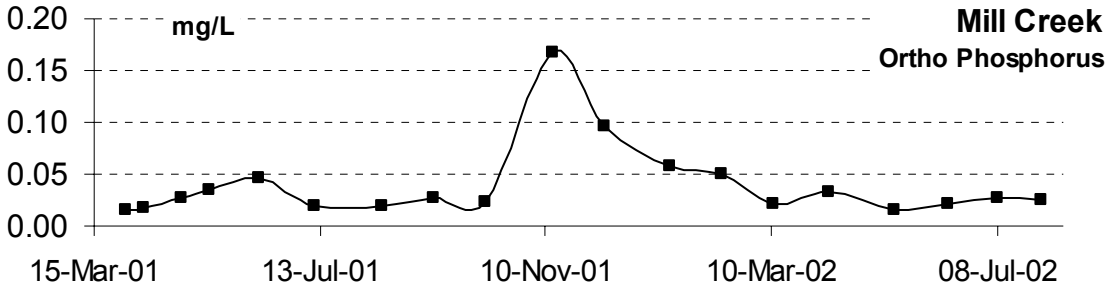

Figure 218: Ortho phosphorus Mill Creek: Apr 2001-July 2002

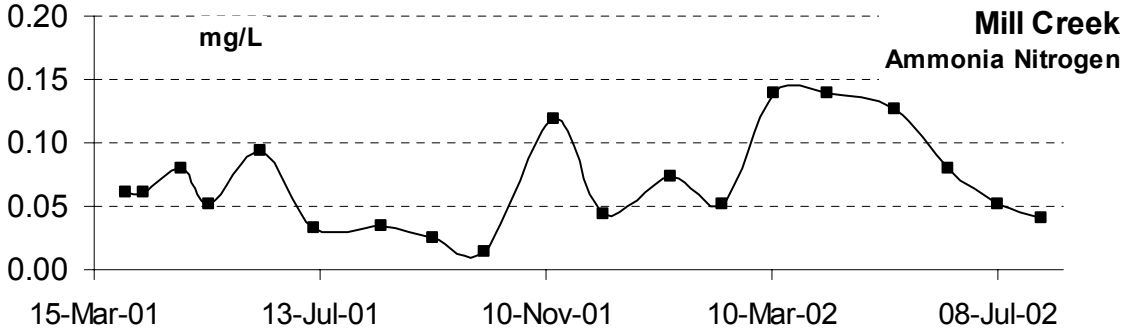

Figure 219: Ammonia Mill Creek: Apr 2001-July 2002

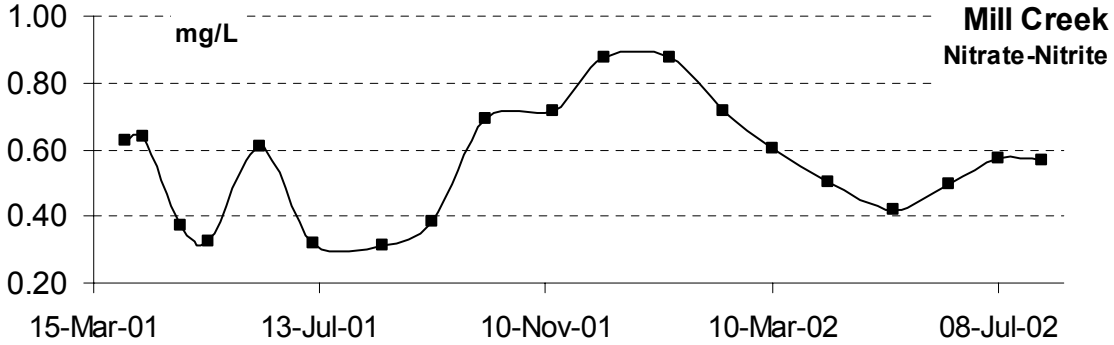

Figure 220: Nitrate-Nitrite Mill Creek: Apr 2001-July 2002

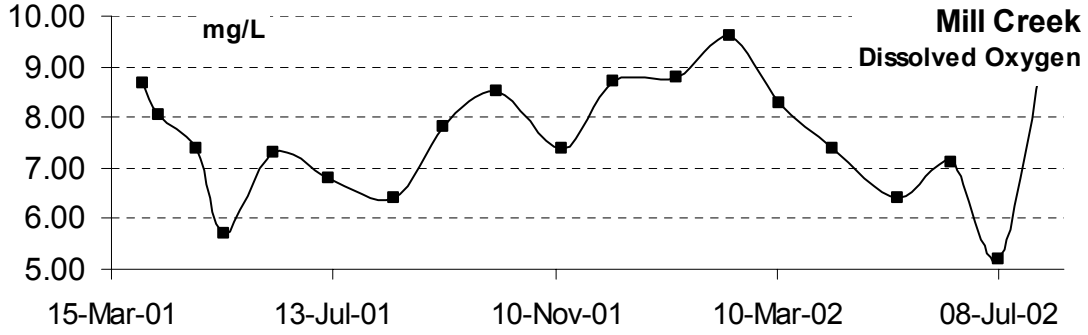

Figure 221: DO Mill Creek: Apr 2001-July 2002

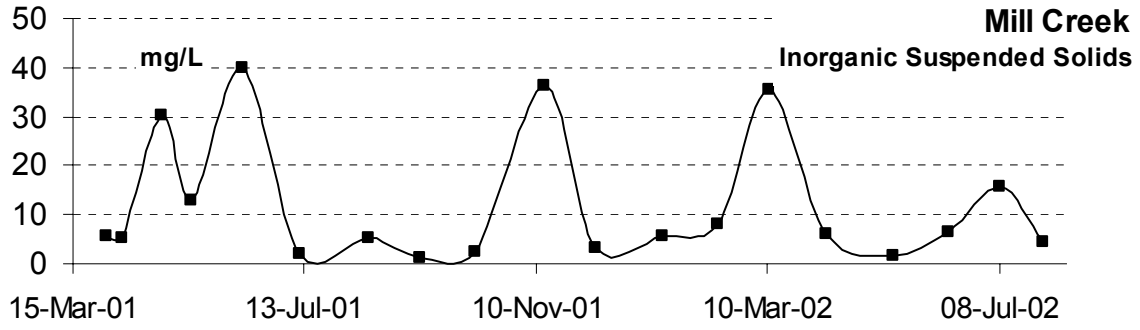

Figure 222: ISS Mill Creek: Apr 2001-July 2002

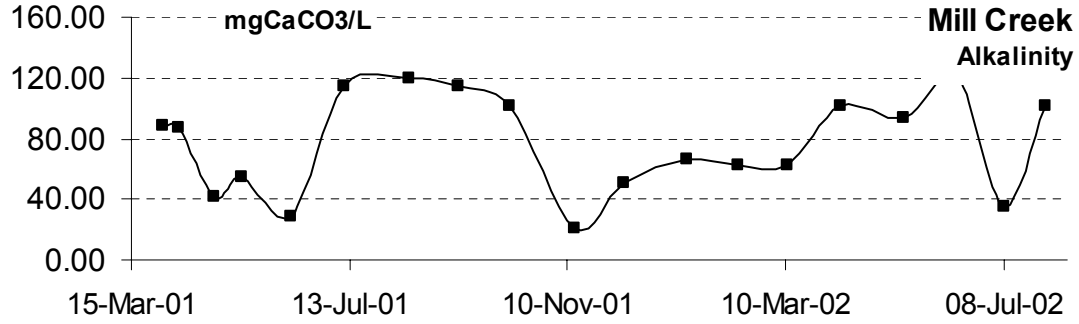

Figure 223: Alkalinity Mill Creek: Apr 2001-July 2002

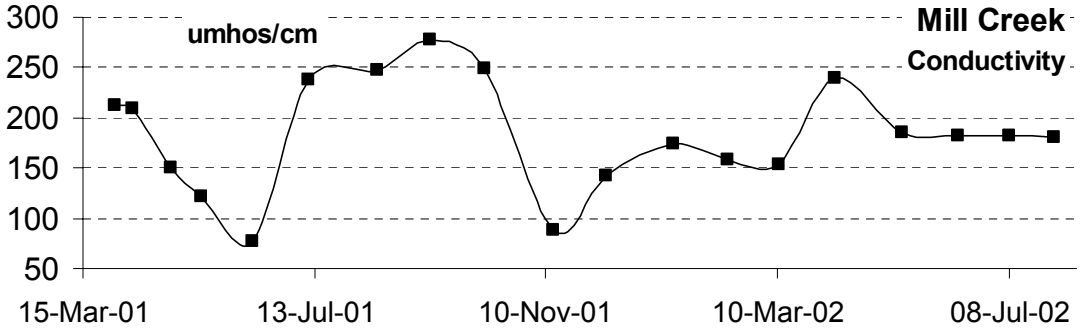

Figure 224: Conductivity Mill Creek: Apr 2001-July 2002

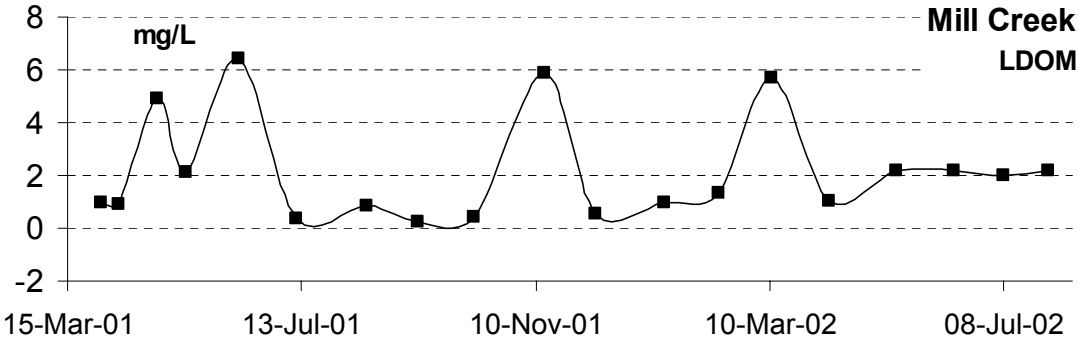

Figure 225: LDOM Mill Creek: Apr 2001-July 2002

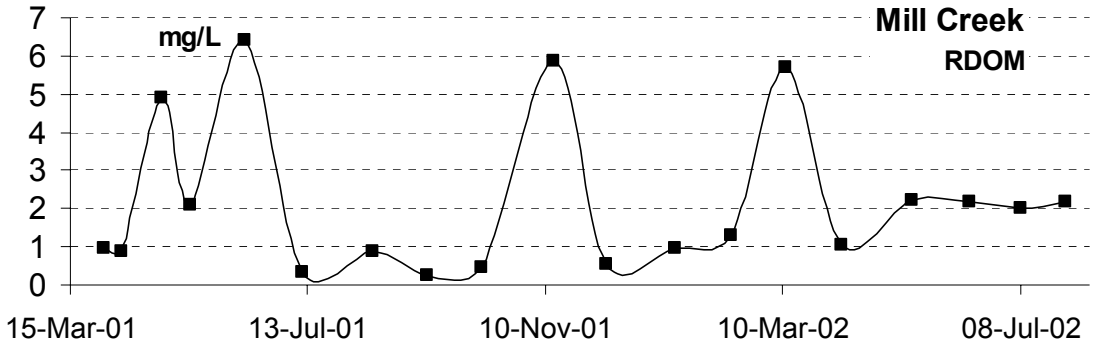

Figure 226: RDOM Mill Creek: Apr 2001-July 2002

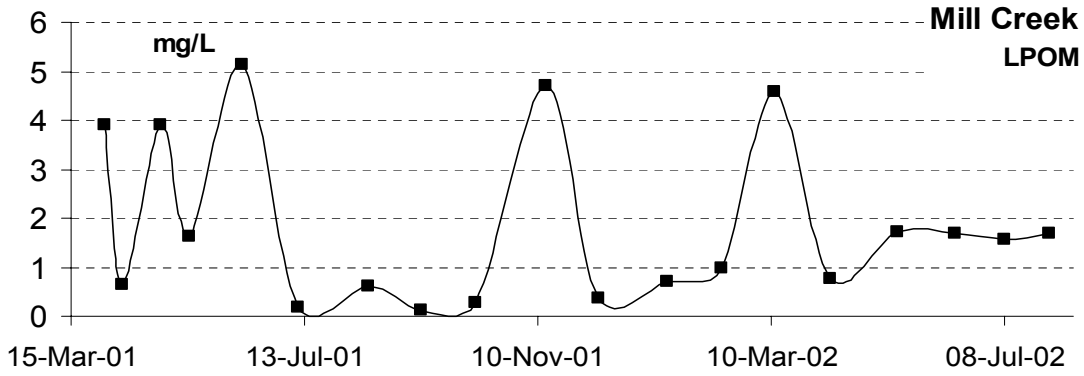

Figure 227: LPOM Mill Creek: Apr 2001-July 2002

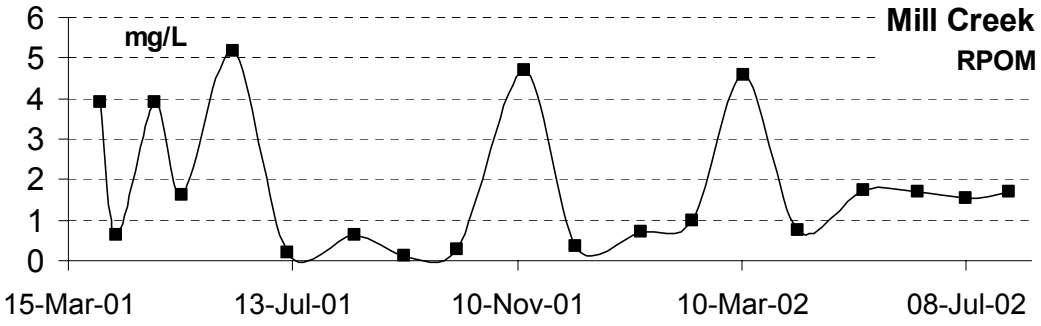

Figure 228: RPOM Mill Creek: Apr 2001-July 2002

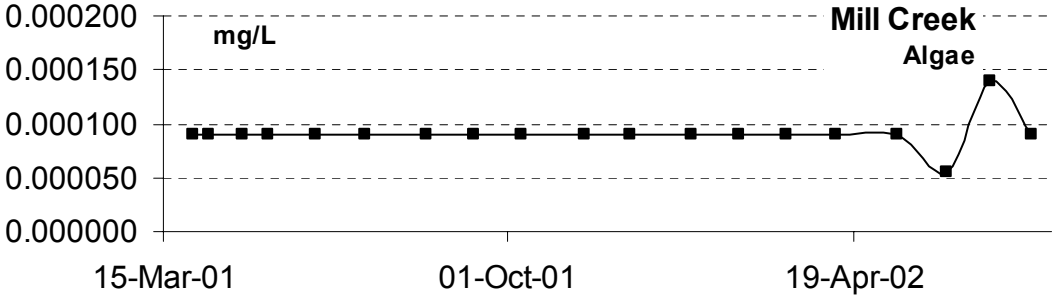

Figure 229: Algae Mill Creek: Apr 2001-July 2002

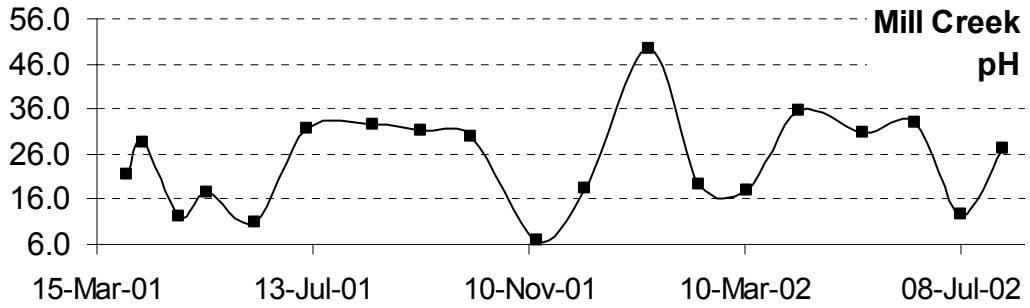

Figure 230: pH Mill Creek: Apr 2001 - July 2002

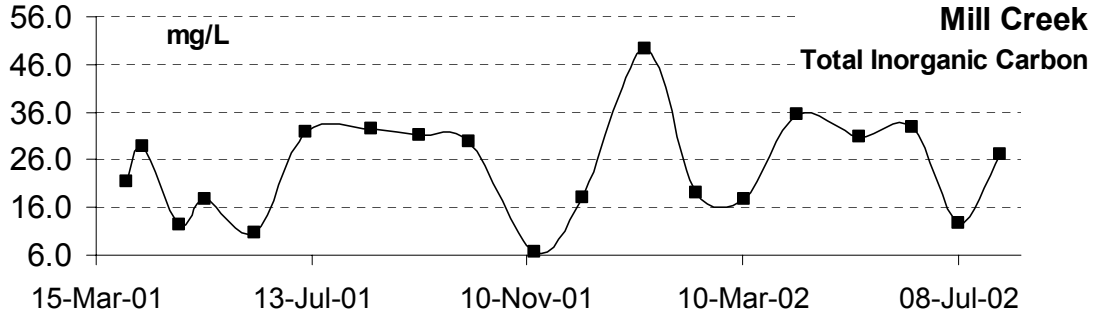

Figure 231: TIC Mill Creek: Apr 2001-July 2002

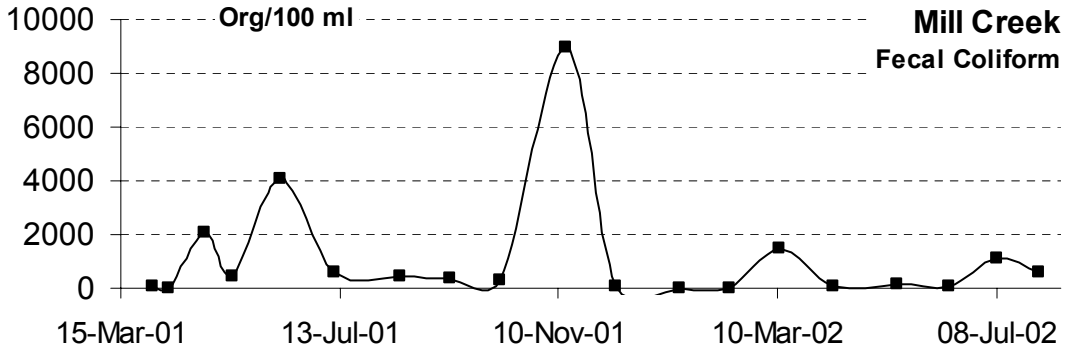

Figure 232: Fecal Coliform Mill Creek: Apr 2001 - July 2002

Auburn Creek, Mullen Slough, and Midway Creek

Auburn Creek, Mullen Slough, and Midway Creek are 3 of the smallest tributaries to the Green River. The only available data are a few water quality samples collected on Mullen Slough.

May 25, 1995 – November 1996

Flow

King County provided daily average flow from HSPF models of these 3 tributaries from 1948 to 2001. This information will be used in the model. Figure 233 through Figure 235 shows the flow data for the model simulation period.

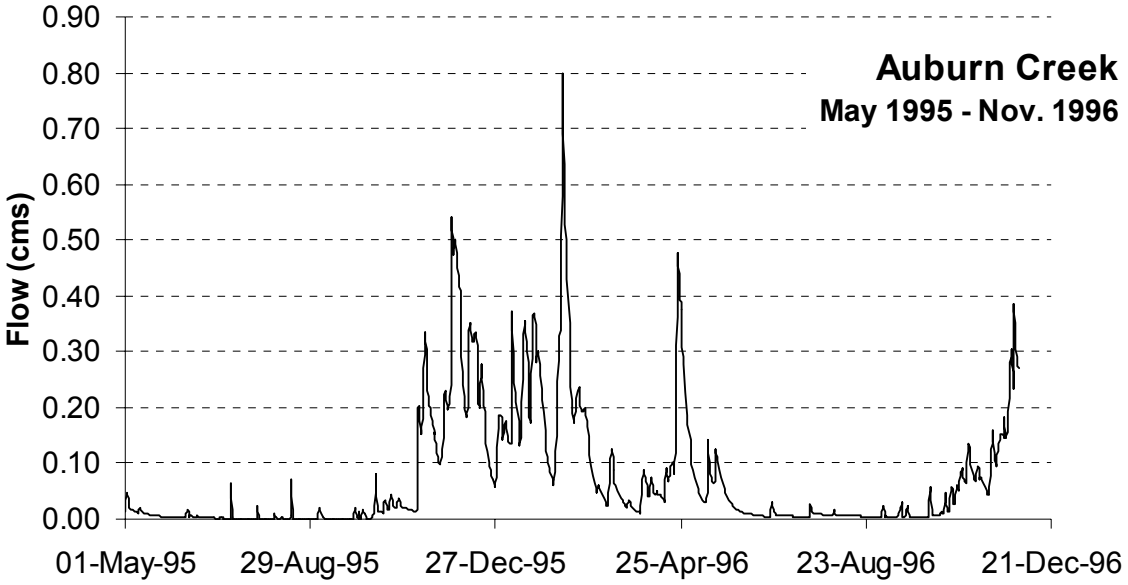

Figure 233: Auburn Creek Flow: May 25, 1995 – Nov 1996 (HSPF)

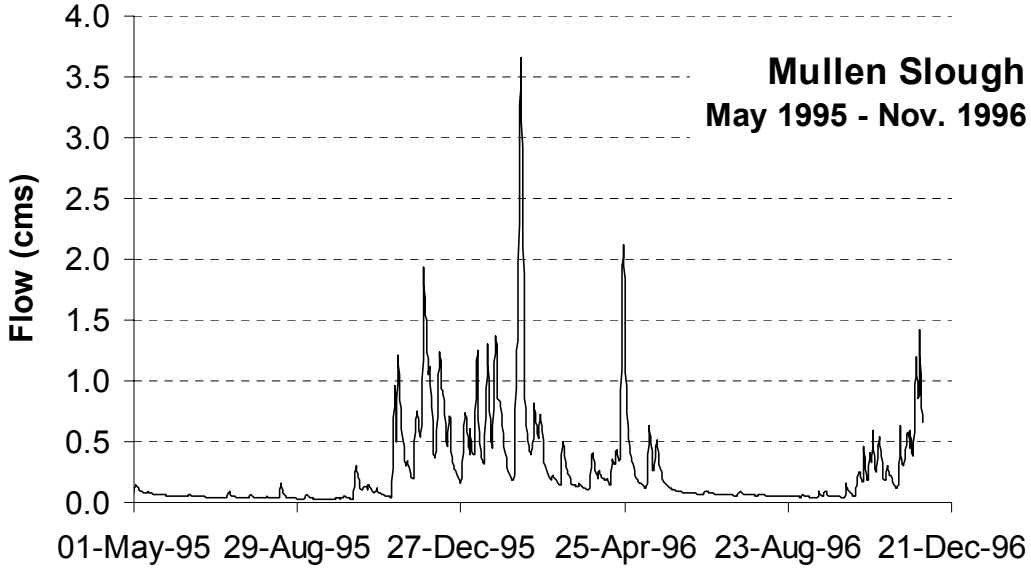

Figure 234: Mullen Slough Flow: May 25, 1995 – Nov 1996 (HSPF)

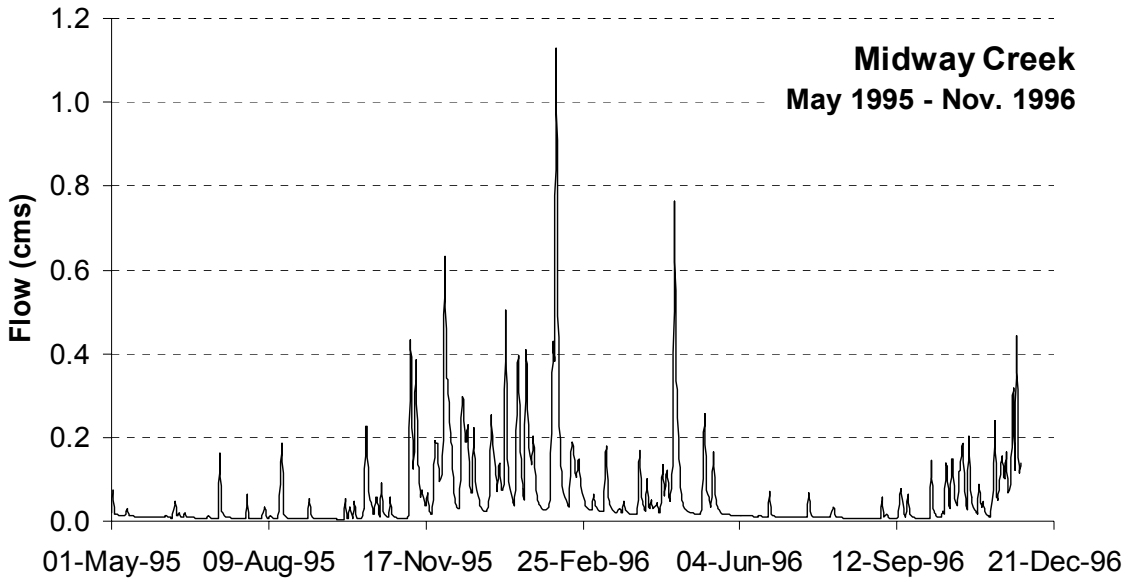

Figure 235: Midway Creek Flow: May 25, 1995 – Nov 1996 (HSPF)

Temperature

Water temperature has not been monitored on these creeks. Temperature data from Big Soos Creek will be used for this model calibration period. Figure 166 shows the temperature for the model simulation period. Big Soos Creek was chosen because it's the closest creek to these creeks with available data for this model run period.

Water Quality

Water quality constituents have not been sampled on these creeks for this model calibration period. Water quality data from Mill Creek will be used. See Figure 201 through Figure 214 for graphs of data for this model calibration period. Mill Creek was chosen because it's the closest creek with available data for this model run period.

April 2001 – Nov 2002

Flow

HSPF flow data will be used for these tributaries. Figure 236 through Figure 238 shows the flow data for the model calibration period.

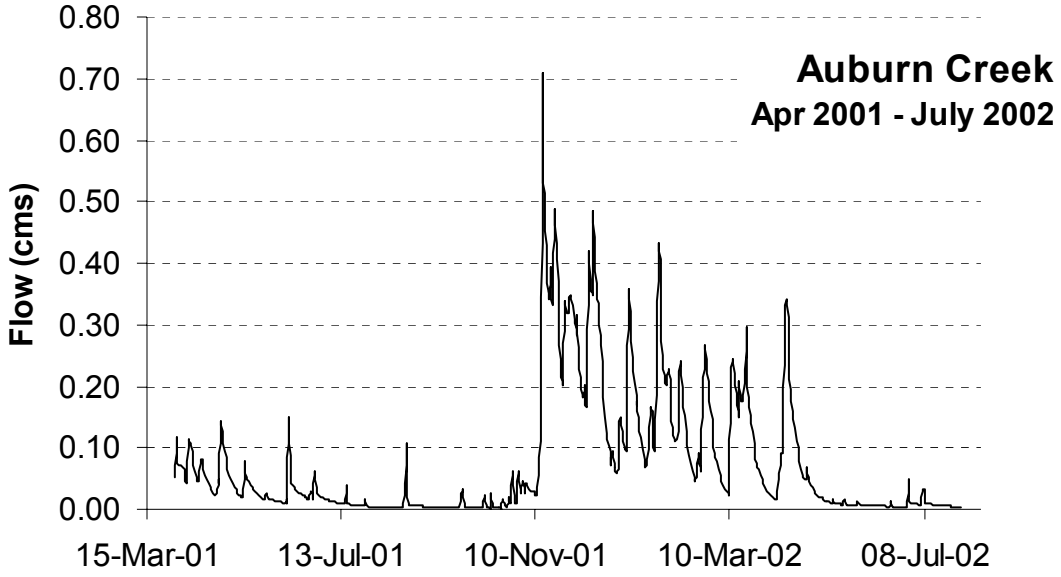

Figure 236: Auburn Creek Flow: Apr 2001 – July 2002

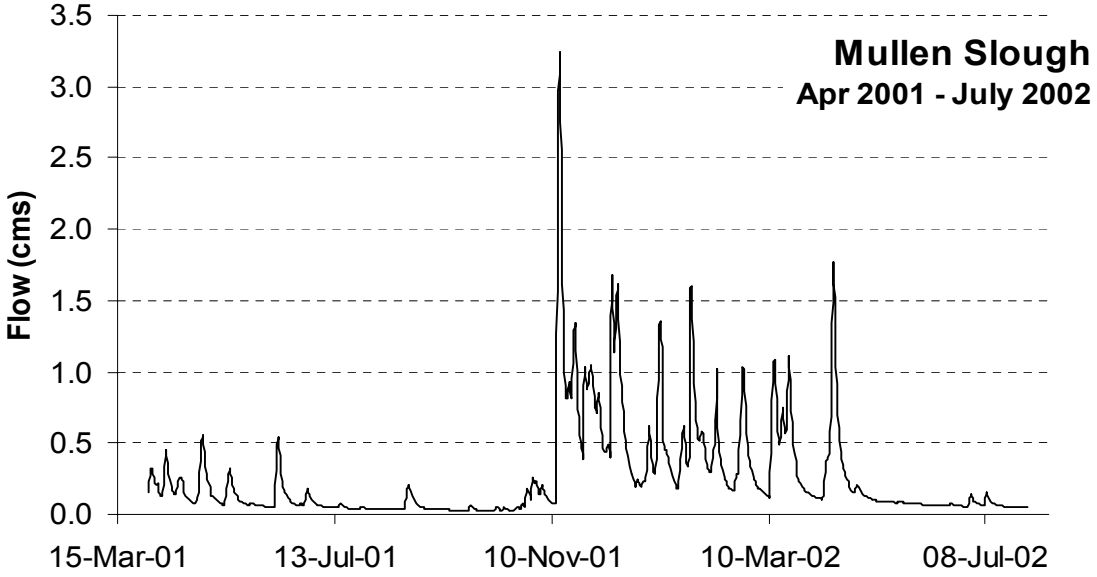

Figure 237: Mullen Slough Flow: Apr 2001 – July 2002

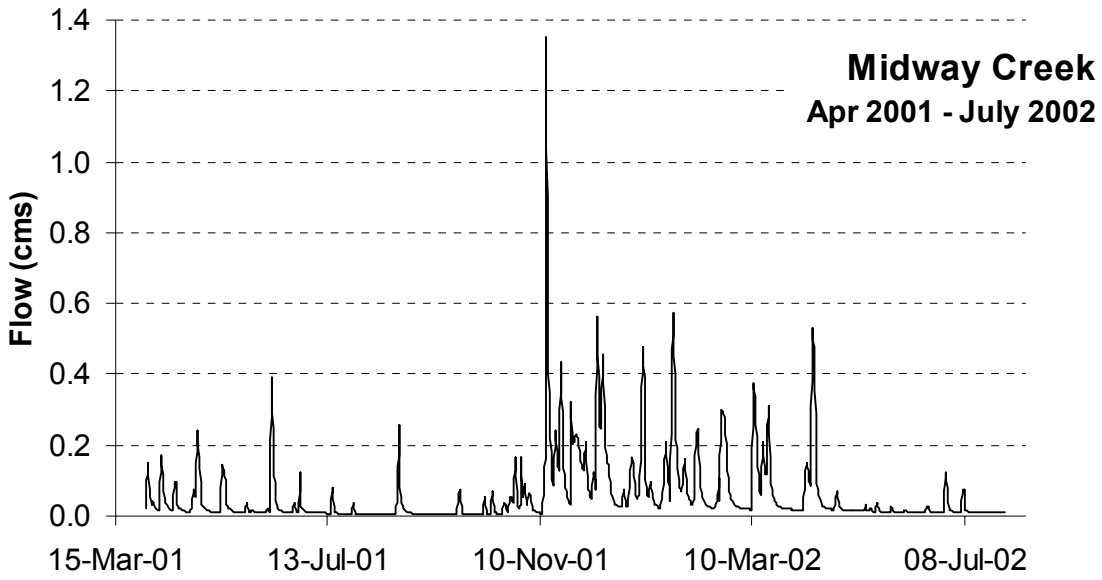

Figure 238: Midway Creek Flow: Apr 2001 – July 2002

Temperature

Water Temperature has not been monitored on these creeks. Temperature data from Mill Creek, the closest tributary to these creeks will be used. Figure 217 shows the temperature for the model simulation period.

Water Quality

Water quality constituents have not been sampled on these creeks for this model calibration period. Water quality data from Mill Creek will be used. Mill Creek was chosen because it is the closest tributary with sampled data. See Figure 218 through Figure 231 for data for the model calibration period.

Groundwater

Groundwater contributes flow to the river along most of its length, and except for a stretch near Auburn, Green River gains more water from groundwater than it loses (Luzier 1969, Woodward et al. 1995). Luzier (1969) believes there are significant groundwater inflows south of Kent where the river traverses the valley, and he also identifies numerous springs in the slopes of the Green River Gorge, which is east of Flaming Geyser State Park. Woodward et al. (1995) identifies 25 springs in the hill-slopes above the Green River between the upstream and downstream boundaries of this modeling project. The arrows in Figure 239 show the location of these springs.

There is little data available that quantifies inflow from groundwater, and Woodward et al., 1995 did not find adequate data to estimate baseflow in the Green River. Their report does include an estimate of discharge from springs in the bluffs above the river. Table 8 lists the discharge per mile from these springs as estimated in Woodward et al. The information is broken down into contributions to each branch of the model. The inflow rate from these springs is less than a tenth of a percent of the flow rate of the river.

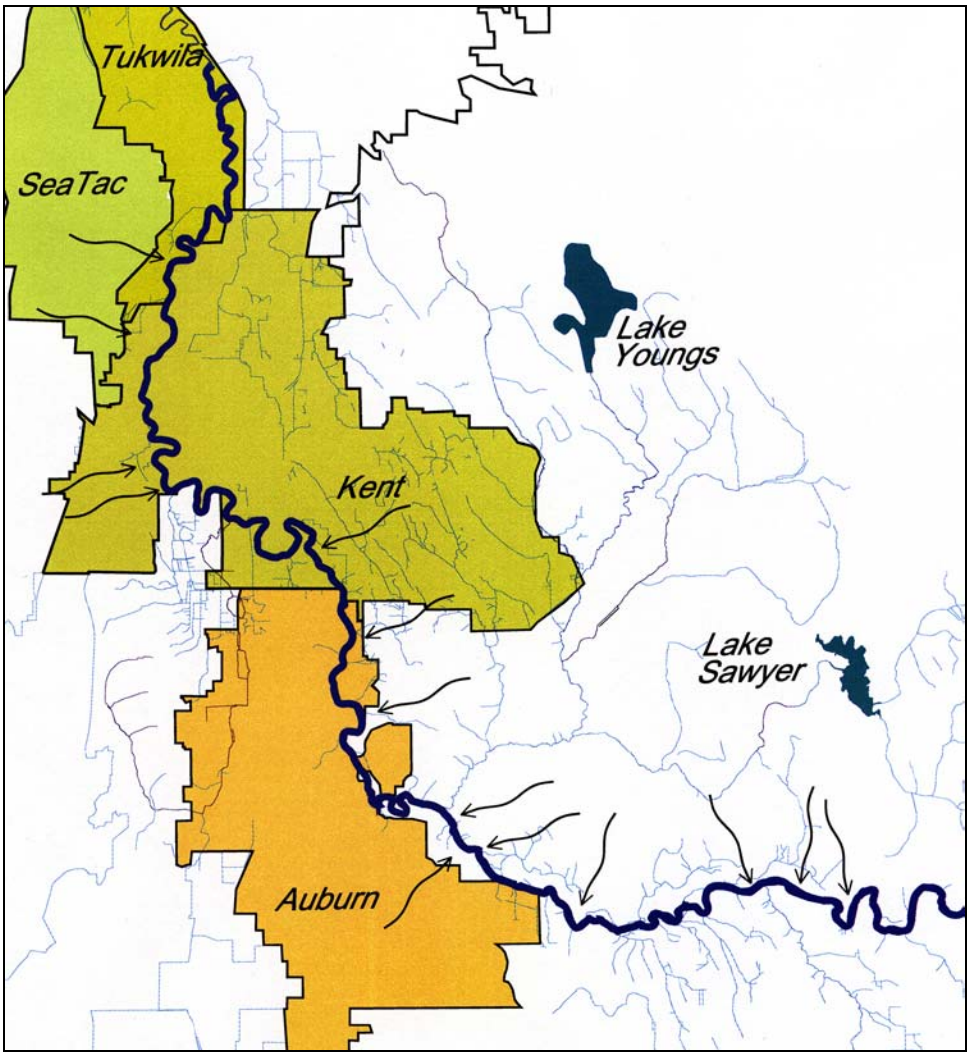

Figure 239: Groundwater Springs

Table 8: Groundwater Inflows per Branch

Branch	Discharge (cfs/mile)	Miles per branch	Discharge (cfs)
1	.01	3.90	.039
2	.01	3.40	.034
3	0.24	4.20	.042
4	0.24	7.0	1.0
5	0.27	15.50	4.20

Since the flow rates in Table 8 are not significant enough to be considered in the model, and no other reliable data are available for estimating groundwater and smaller tributaries downstream of Auburn, distributed inflows will not be used in these sections.

Distributed Tributaries

To address inflow from a series of smaller tributaries on the upper end of the Lower Green River and the lower end of the Middle Green River, King County hydrologists have simulated surface runoff using HSPF. Inflow from this basin will be added as a distributed tributary to Branches 2 and 3. Table 9 shows the segments and percentage of the flow attributed to each branch.

Table 9: Basin MG1 Distributed Tributary

Branch	Number of Segments	Area (hectare)	% of Basin MG1
2	22	1,920	52
3	27	1,767	48
TOTAL	49	3,687	100

May 25, 1995 – Nov 1996

Flow

Daily average flow was provided for this basin (HSPF data). It was divided evenly among the segments in each branch, and split between the 2 branches based upon the percentage of area within MG1 in each branch. The distributed discharges for each branch are shown in Figure 240 and Figure 241 for the proposed model period.

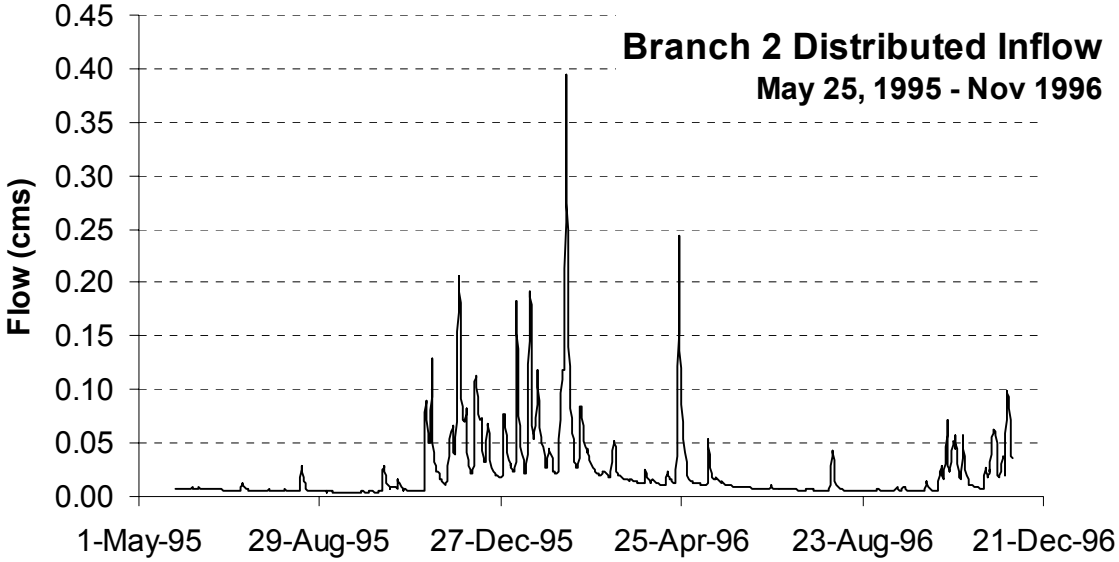

Figure 240: Branch 2 Distributed Flow: May 25, 1995 – Nov 1996

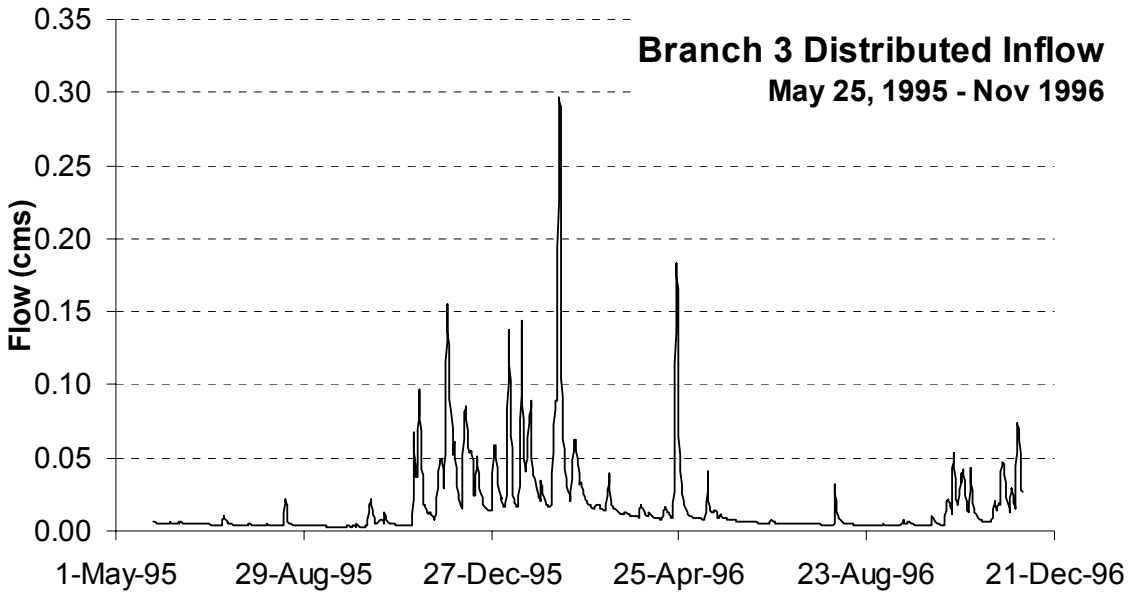

Figure 241: Branch 3 Distributed Flow: May 25, 1995 – Nov 1996

Temperature

A 1995-1996 temperature study conducted by King County recorded temperature at numerous locations at the downstream end of Basin MG1. None of these monitoring locations have complete data for the model calibration period. The station with the most complete data set, Station "NEE" was used for both distributed tributaries. There were 3 data gaps to be filled:

- The first 14 hours of May 25, 1995
- November 3, 1995 – June 7, 1996
- October 29, 1996 – November 30, 1996

To fill these data gaps, data from the upstream boundary was correlated with data from this monitoring location. Station "WHI" was used as the upstream temperature boundary for the May 25, 1995-November 1996 calibration period. Because it had missing data, the data from the upstream boundary, including filled gaps, was used in the correlation. The equation relating the 2 temperatures is as follows:

$$\text{NEE temp} = 0.923*(\text{WHI temp}) + 0.775$$

Figure 242 shows the correlation between the 2 stations, Figure 243 shows the correlated values and station data, and Figure 244 is the temperature data used in the model calibration period.

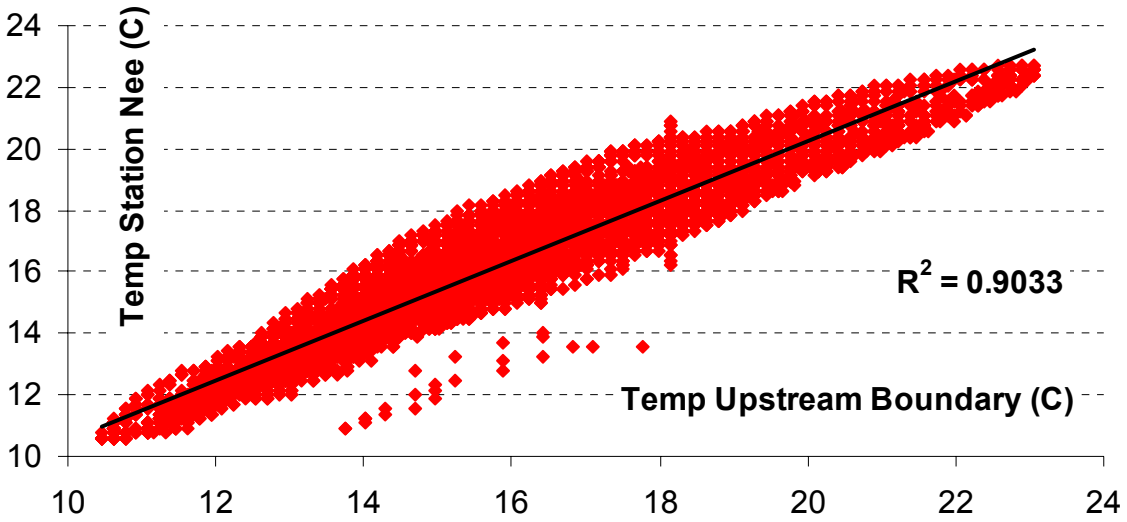

Figure 242: Correlation between upstream boundary temperature and station "nee"

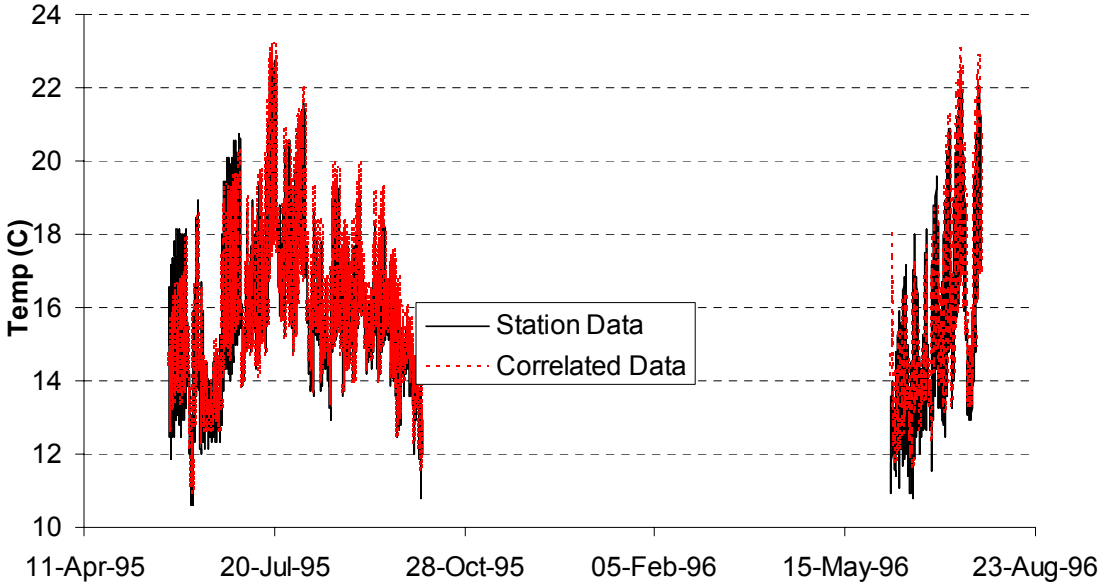

Figure 243: Distributed Tributary: Correlated versus station data 1995-1996

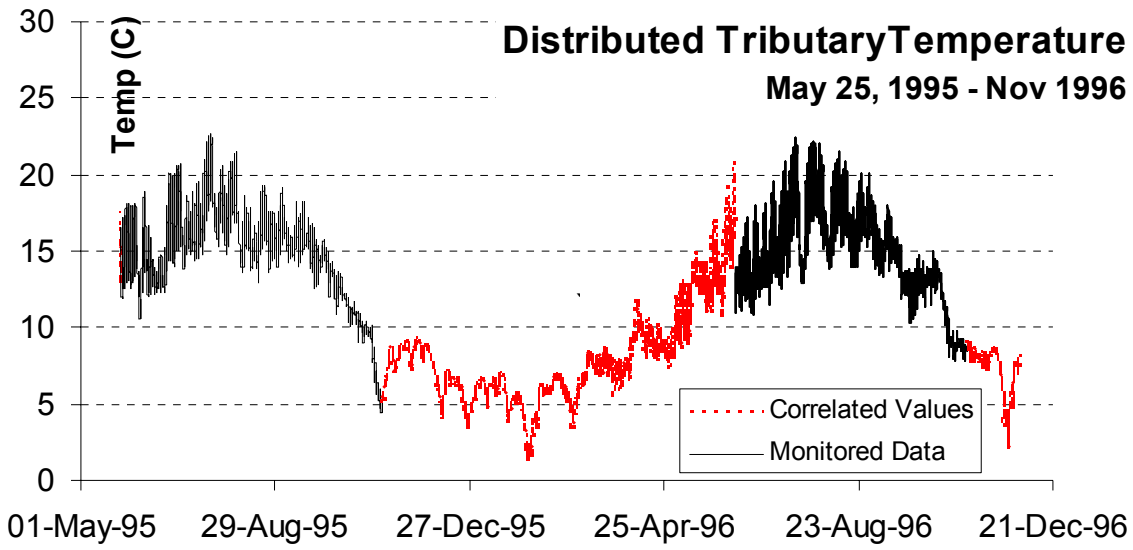

Figure 244: Distributed Tributary Temperature: May 25, 1995 – Nov 1996

Water Quality

Water quality data is not available for the distributed tributaries. Data from Big Soos Creek will be used. This is the closest tributary with monitored data. See Figure 167 through Figure 180.

April 2001 - July 2002

Flow

Daily average flow was provided for this basin (HSPF data). It was divided evenly among the segments in each branch, and split between the 2 branches based upon the percentage of area within MG1 in each branch. The distributed discharges for each branch are shown in Figure 245 and Figure 246 for the proposed model period.

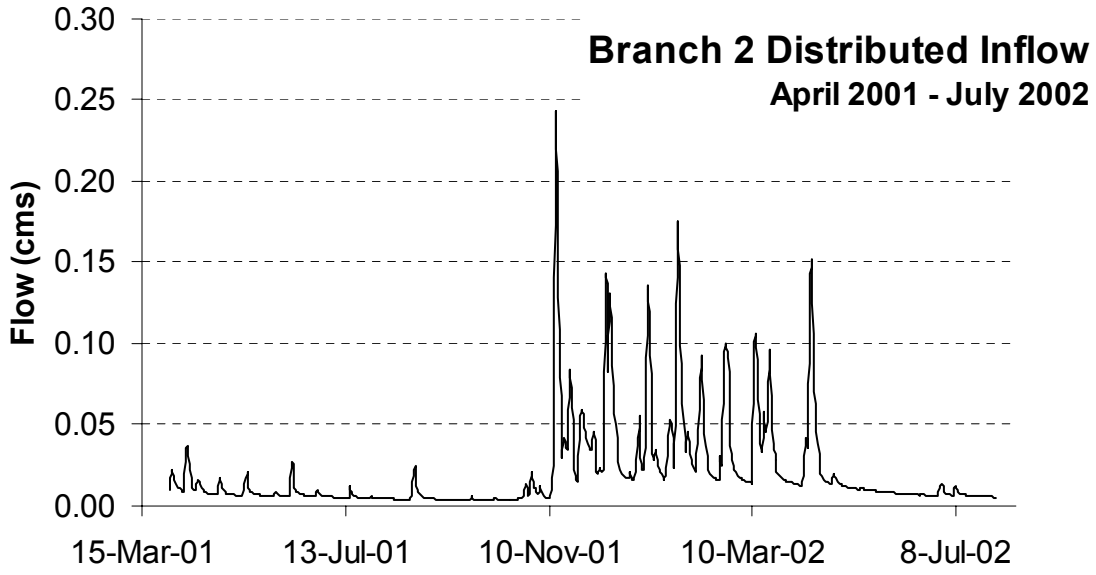

Figure 245: Branch 2 Distributed Inflow: Apr 2001 – July 2002

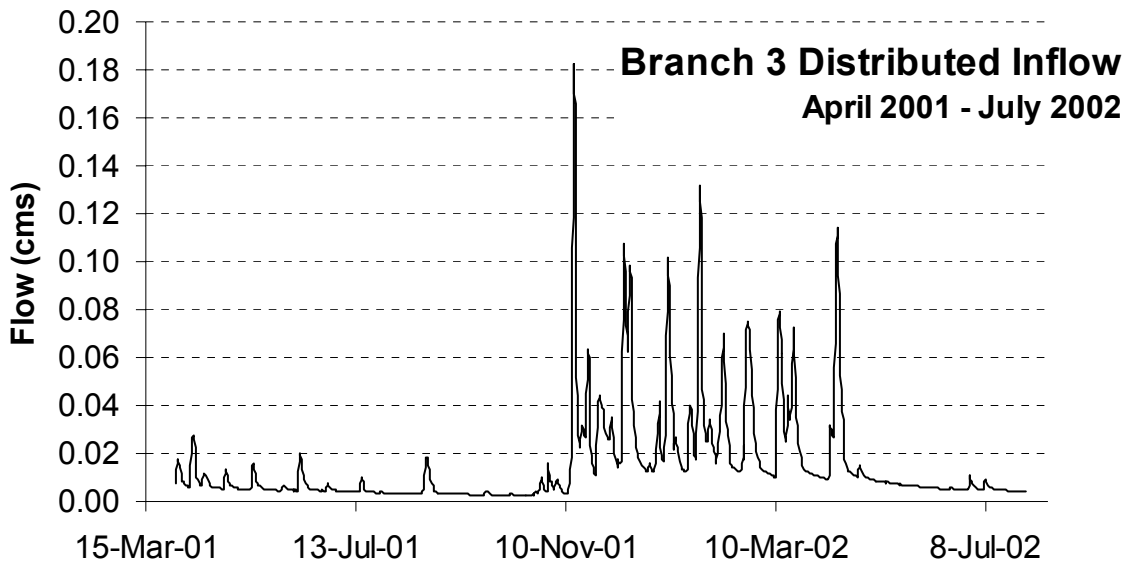

Figure 246: Branch 3 Distributed Inflow: Apr 2001 – July 2002

Temperature

King County monitors temperature on the Green River inside the downstream boundary of Branch 2. Locator GRT04 has temperature data from July 2001 to the end of this model calibration period. About 4 km downstream of GRT04, a University of Washington monitoring station (GR1) has temperature data from April 2001 to July 2001. These data were correlated with data from GRT04 to fill this time period. The correlation equation is as follows:

$$GRT04 = (GR1)(0.894) + 1.7154$$

Figure 247 graphs the 2 stations and shows the linear regression line, Figure 248 shows correlated values and station data, and Figure 249 shows the temperature data for the model calibration period. These data will be used for both distributed tributaries.

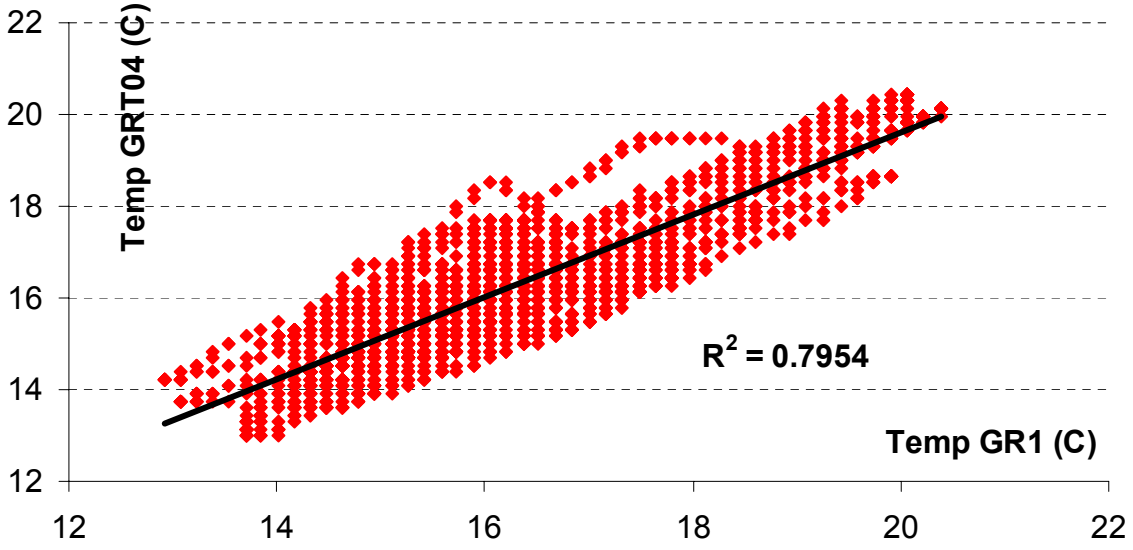

Figure 247: Correlation between station Gr1 and station GRT04

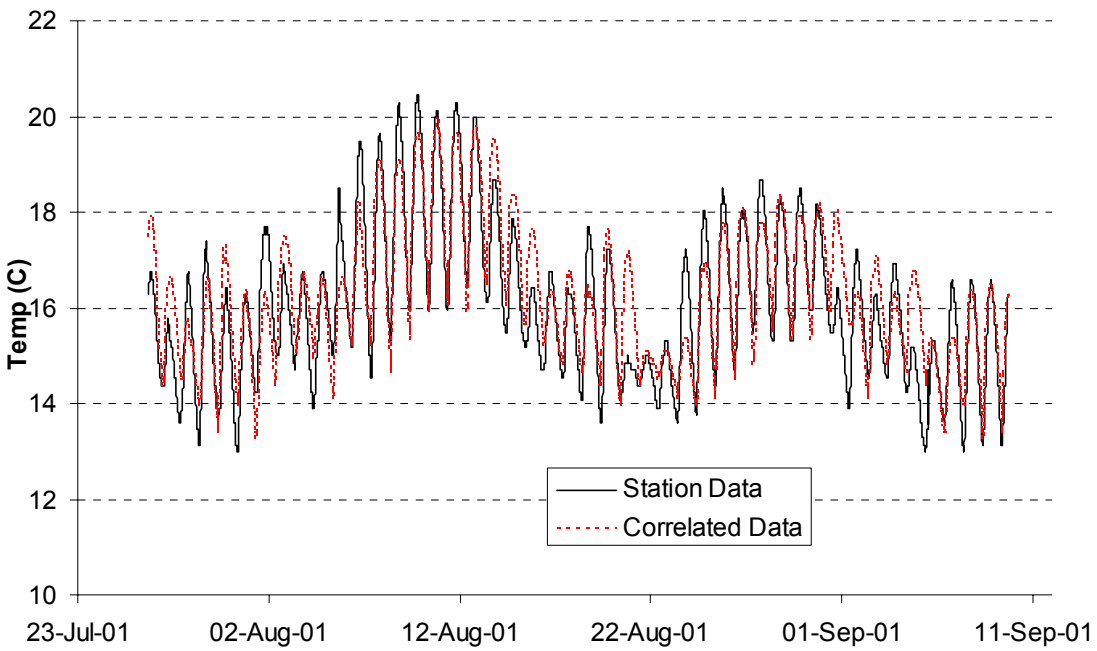

Figure 248: Distributed tributary: Correlated versus station data 2001-2002

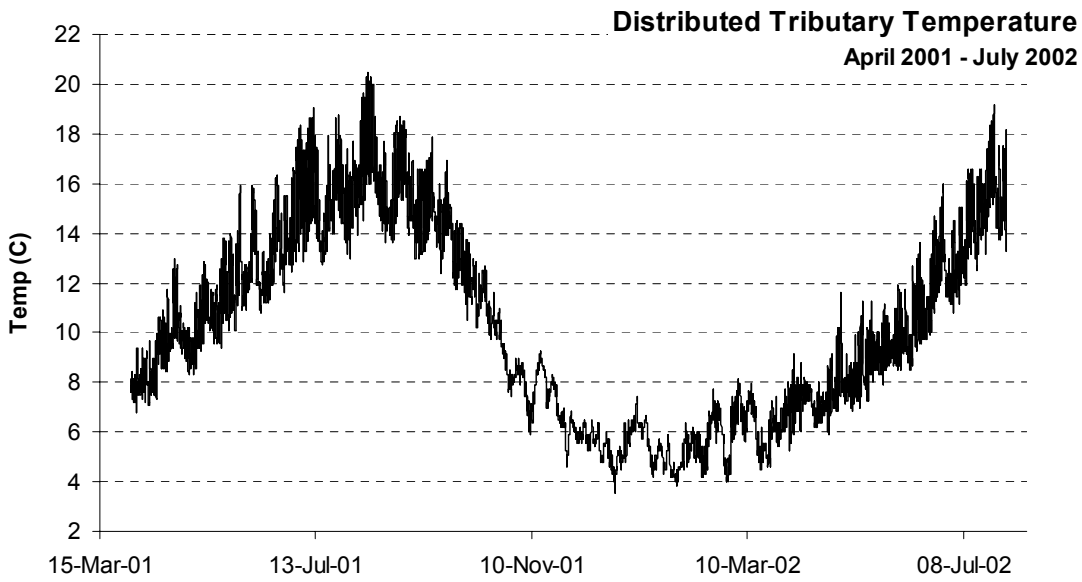

Figure 249: Distributed Tributary Temperature: Apr 2001 – July 2002

Water Quality

Water quality data are not available for the distributed tributaries. Data from Big Soos Creek will be used. See Figure 184 through Figure 197.

Meteorological Data

The Seattle-Tacoma (SeaTac) International Airport is less than a mile west of the downstream project boundary at Tukwila. The airport collects weather data including air temperature, dew point temperature, cloud cover, air pressure, wind speed, wind direction, and cloud cover. King County assembled this data

in a database file for years 1995 through March 2000. Additional data for the remainder of 2000 and for years 2001 and 2002 was collected for use in the model. Data were obtained in hourly intervals.

May 25, 1995 - Nov 1996

Figure 250 shows air temperature, Figure 251 shows dew point temperature, Figure 252 shows wind speed, and Figure 253 shows the frequency of the direction of the wind.

Note that in Figure 253 the number on the bottom axis of the bar graph refers to the angle of the wind direction, and the number on top of the bar refers to the number of times wind speed was recorded between that angle and the next angle left. For example, at 360 degrees there were 384 times the wind was recorded at an angle between 331 degrees and 360 degrees.

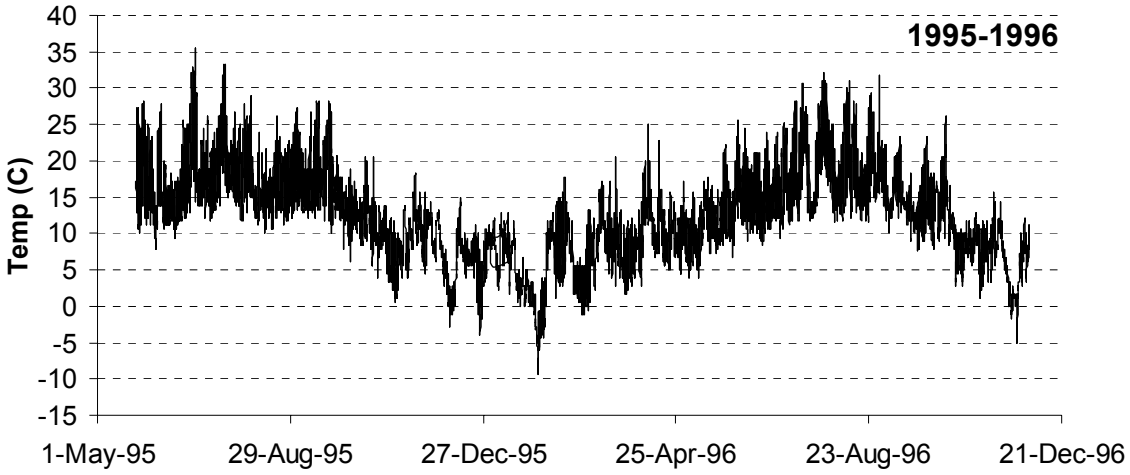

Figure 250: Air Temperature at Seattle-Tacoma International Airport

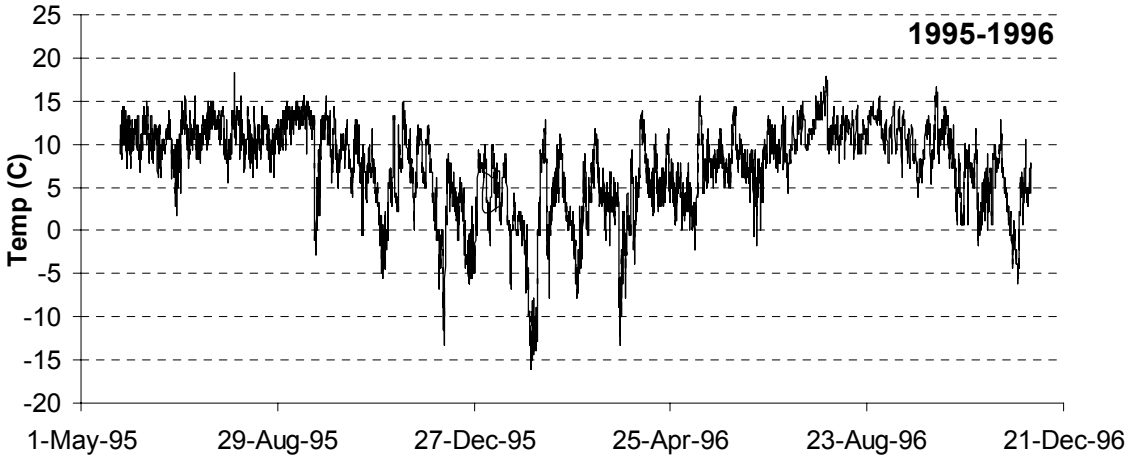

Figure 251: Dew Point Temperature at Seattle-Tacoma International Airport

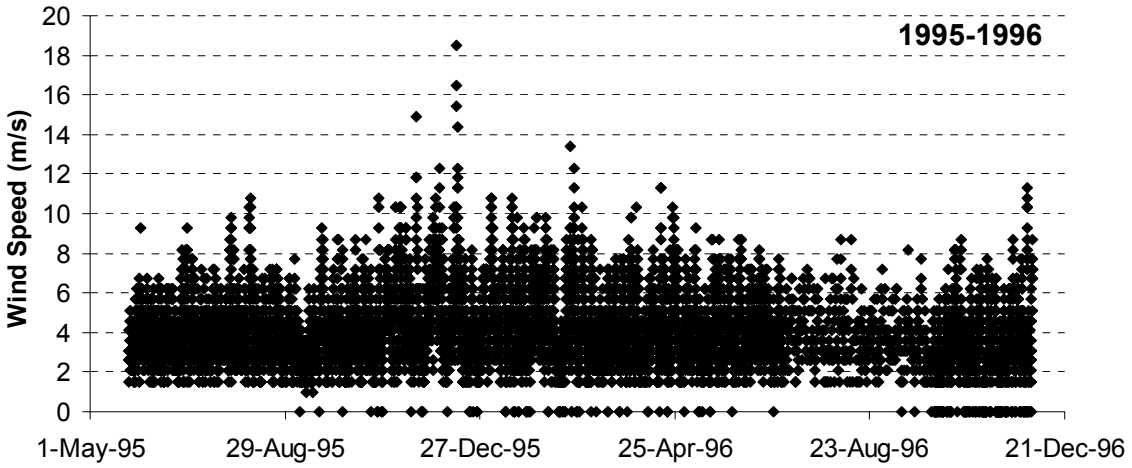

Figure 252: Wind Speed at Seattle-Tacoma International Airport

Note that in Figure 252 no wind values were recorded between 0 and 1.50 m/s.

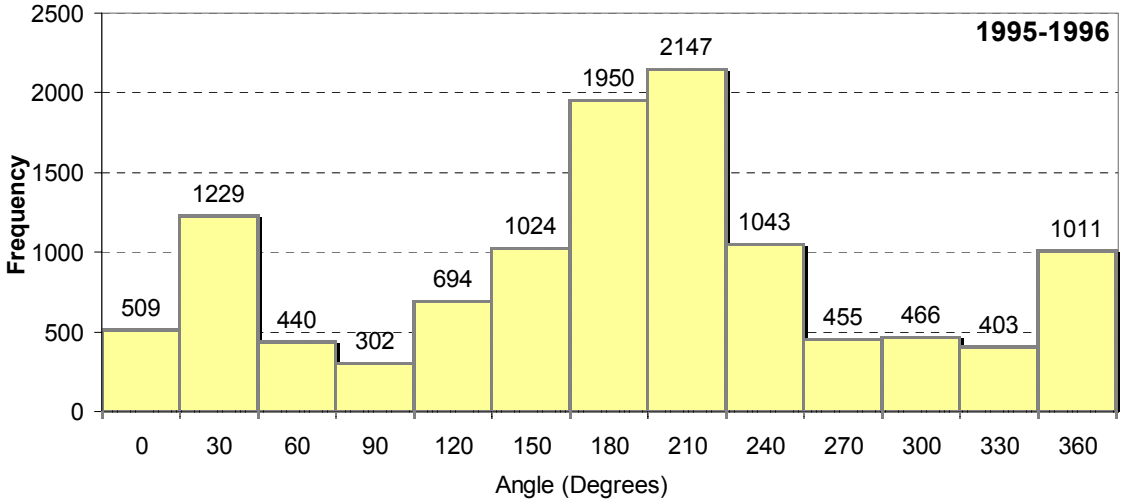

Figure 253: Frequency of Wind Direction at Seattle-Tacoma International Airport

In Figure 254 cloud cover varies on a scale of 0 to 10 with zero representing no cloud cover and ten representing full cloud cover.

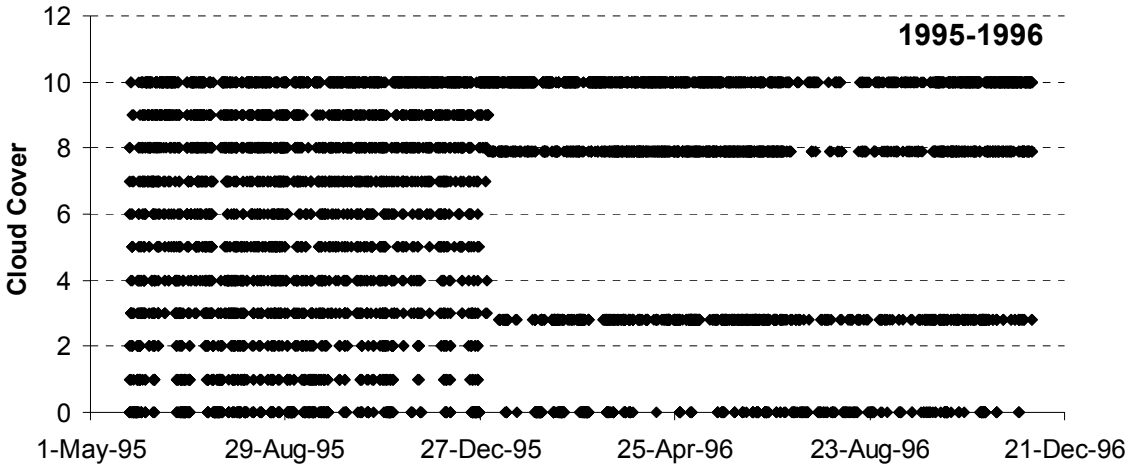

Figure 254: Cloud Cover at Seattle-Tacoma International Airport

The National Oceanic and Atmospheric Administration has a Level I ISIS (Integrated Surface Irradiance Study) station in Seattle which measures shortwave solar radiation data. These data are available from the NOAA web site in 15-minute intervals and was provided by King County for 1995 through 2000. Figure 255 is a graph of the shortwave solar radiation for the model simulation period.

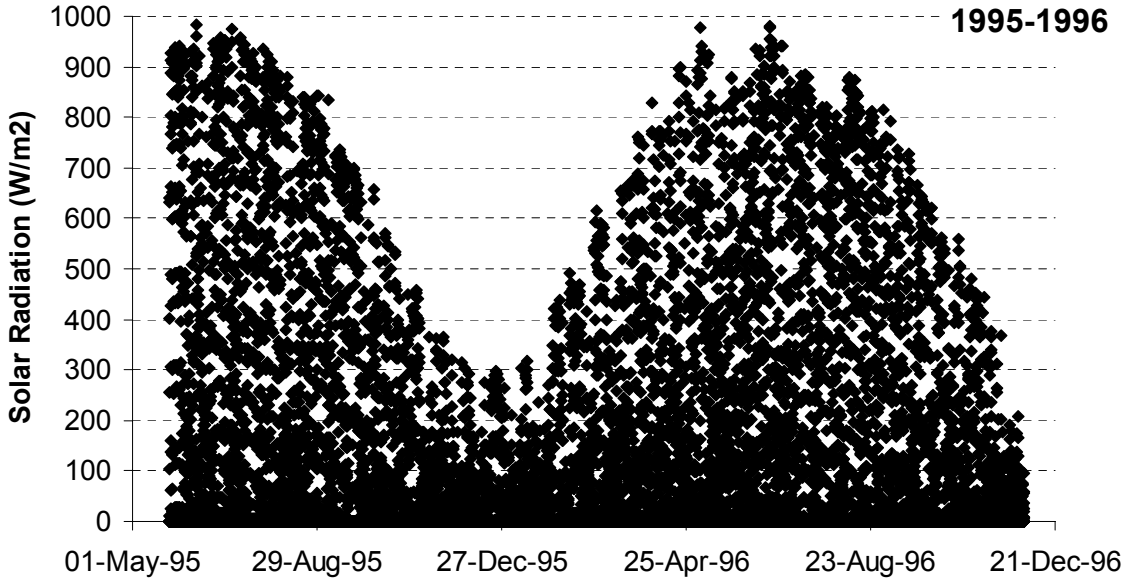

Figure 255: Shortwave Solar Radiation for model calibration period

April 2001 - July 2002

Figure 256 through Figure 261 are graphs of air temperature, dew point temperature, wind speed, wind direction, cloud cover, and shortwave solar radiation for this model calibration period.

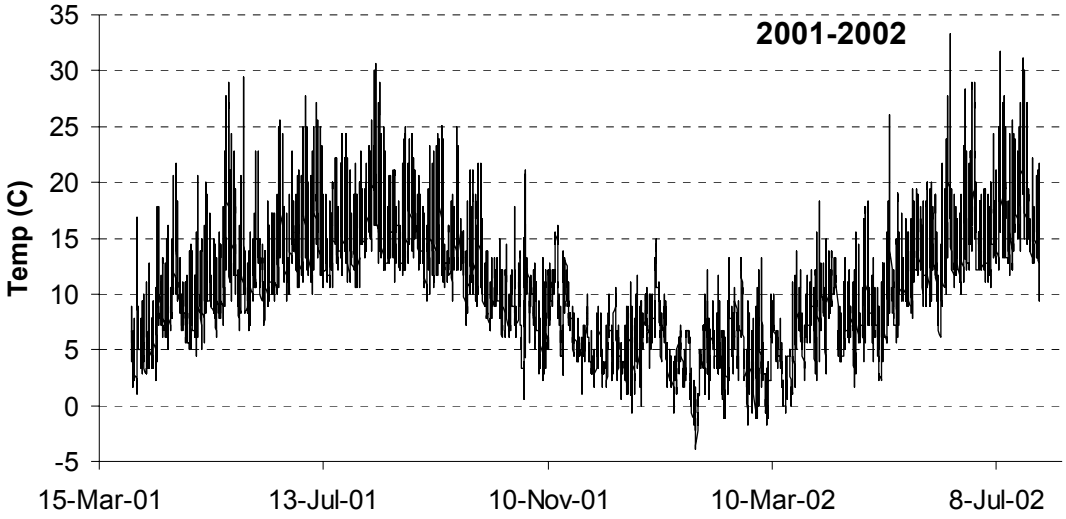

Figure 256: Air Temperature at Seattle-Tacoma International Airport

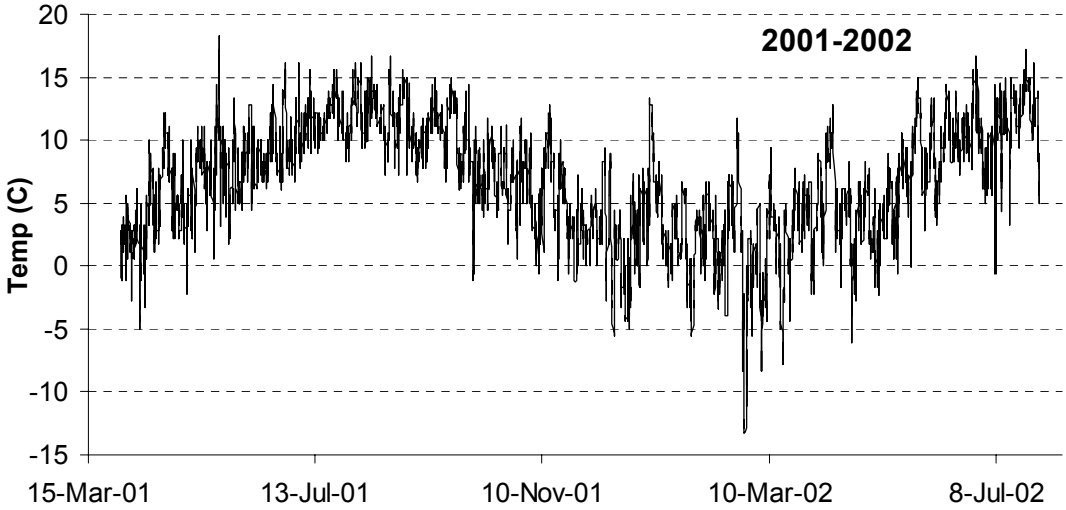

Figure 257: Dew Point Temperature at Seattle-Tacoma International Airport

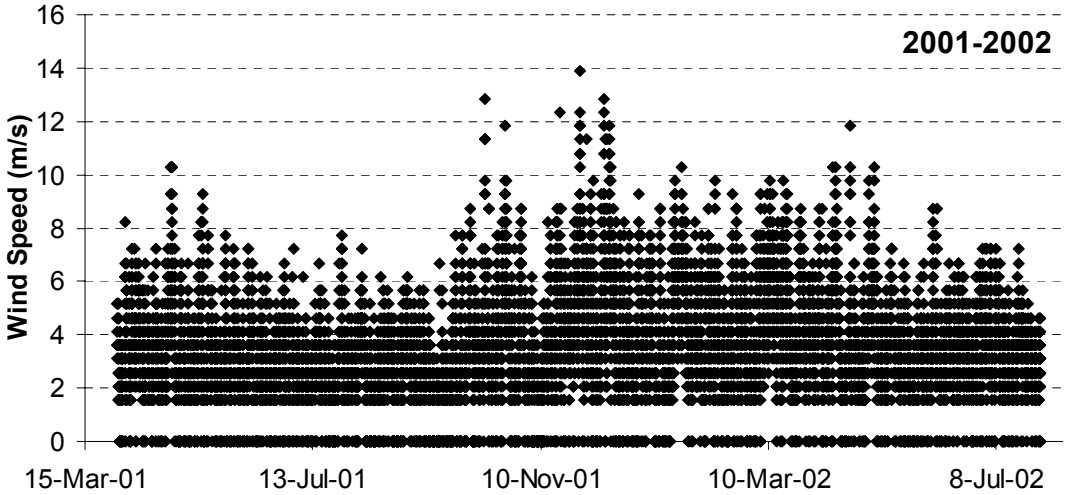

Figure 258: Wind Speed at Seattle-Tacoma International Airport

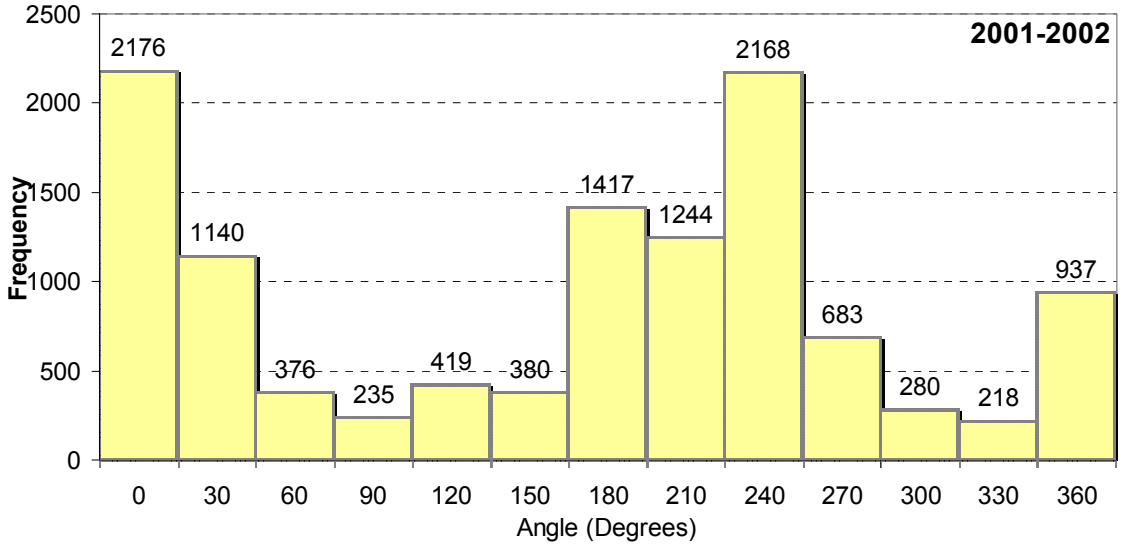

Figure 259: Frequency of Wind Direction at Seattle-Tacoma International Airport

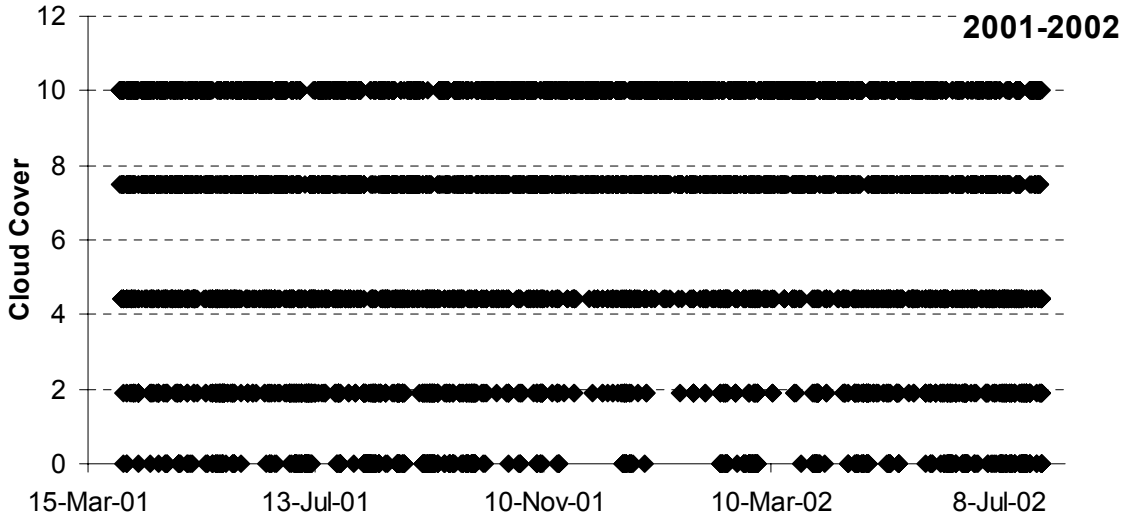

Figure 260: Cloud Cover at Seattle-Tacoma International Airport

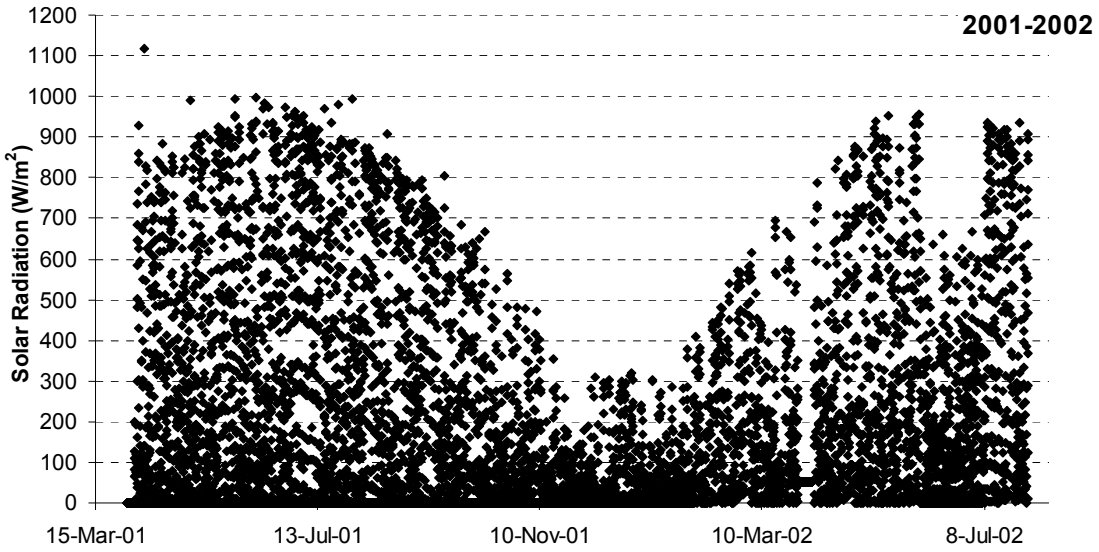

Figure 261: Shortwave solar Radiation from Seattle ISIS Station

The shortwave solar radiation for this model calibration period had a number of negative values during late evening and early morning hours. These values were changed to zero.

Shading

King County has assembled shade data and processed it using the Washington Department of Ecology's spreadsheet program. This program is a modification of the program developed by Oregon's Department of Ecology, and it uses the procedure developed by Y.D. Chen.

Summary

As part of the Green-Duwamish Watershed Quality Assessment program, King County has contracted with Portland State University to develop a hydrodynamic and water quality model of the middle and lower sections of the Green River. The Army Corps of Engineers program CE-QUAL-W2 (Cole and Wells, 2002) will be applied to the river from River Mile 11.20 to River Mile 45.0. This model will be used in TMDL studies, in assessing current water quality conditions in the river, and as a planning tool for assessing future conditions.

This report addresses the data assembled for use in the model including

- bathymetry,
- flow
- temperature
- meteorological
- water quality.

Model calibration periods were chosen based upon the availability of this data between 1995 and 2002. Two model simulation periods were chosen: May 25, 1995 to November 30, 1996, and April 1, 2001 to July 31, 2002.

Data were assembled for boundary conditions, tributary inflows, and distributed inflow due to groundwater and surface inflows (nonpoint sources). Water quality constituents to be modeled include dissolved and particulate non-living organic matter (both refractory and labile components), ammonia, nitrate, dissolved PO4, algae, TDS, pH, and dissolved oxygen. In many cases, boundary condition data were estimated using data correlations to fill in missing information for the model simulation periods.

The model grid consists of 3 water bodies and 6 branches, with a total of 218 model segments. Each segment has 22 vertical layers with a resolution of 1 meter.

A companion report will be developed detailing the model calibration.

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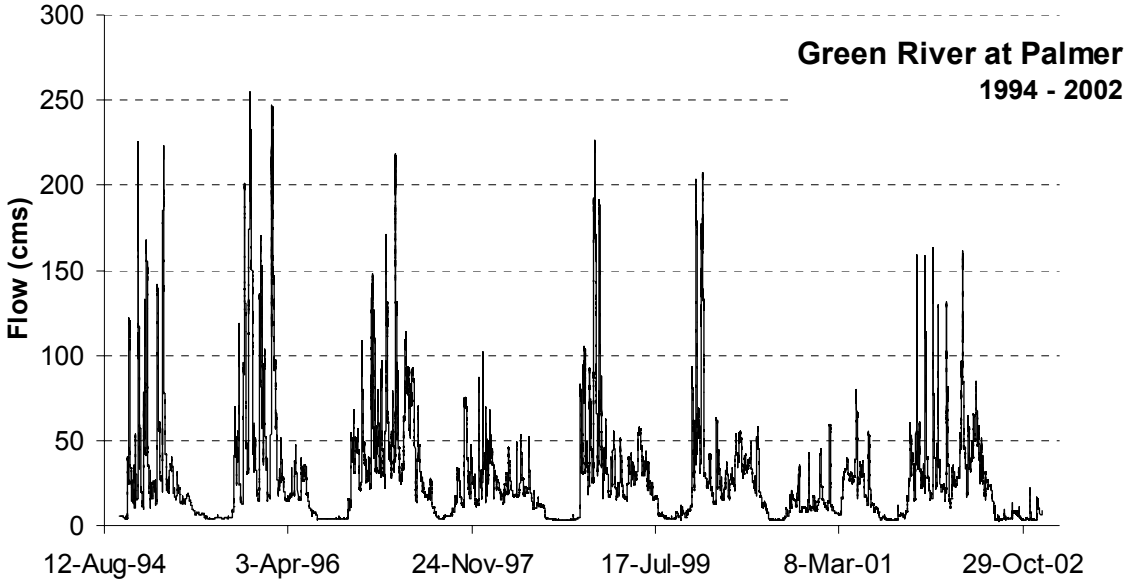
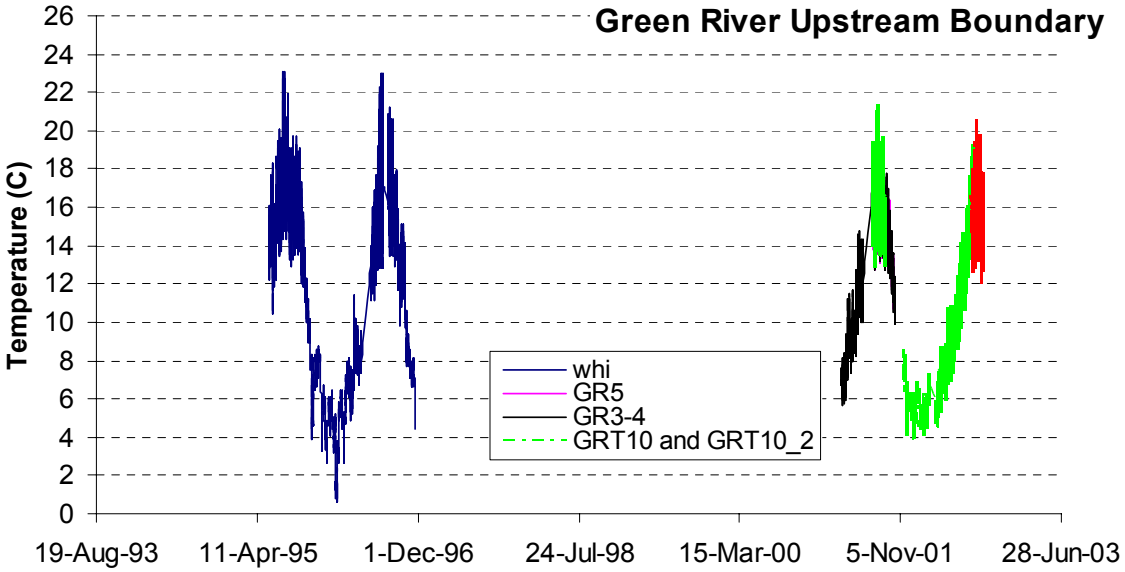
Appendix A: Upstream and Tributary Flow, Temperature, and Water Quality Data

Upstream Boundary Data

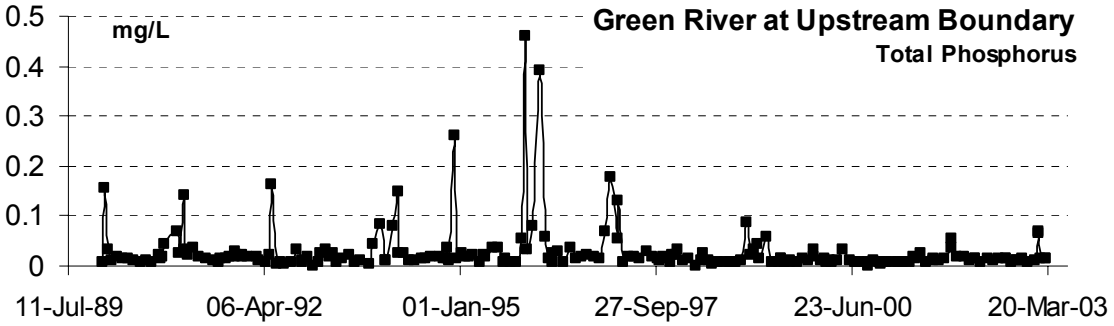
Flow data were obtained on the Green River near Palmer (USGS Gage 12106700) in 15 minute intervals from October 1994 through December 2002.

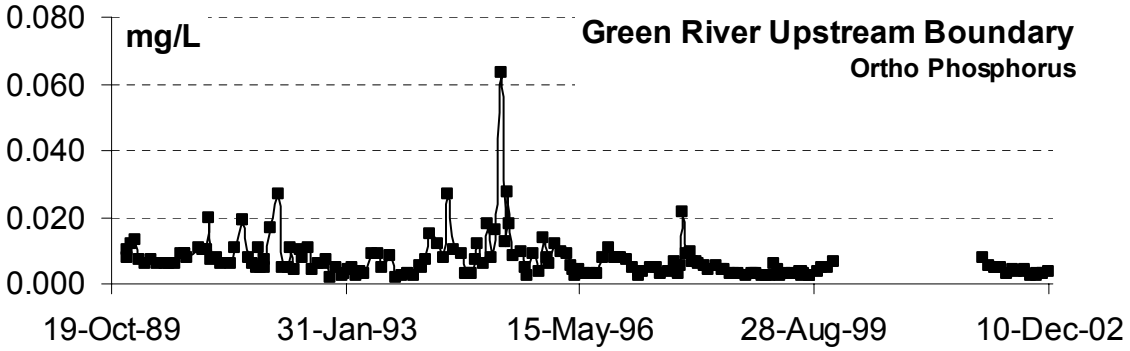


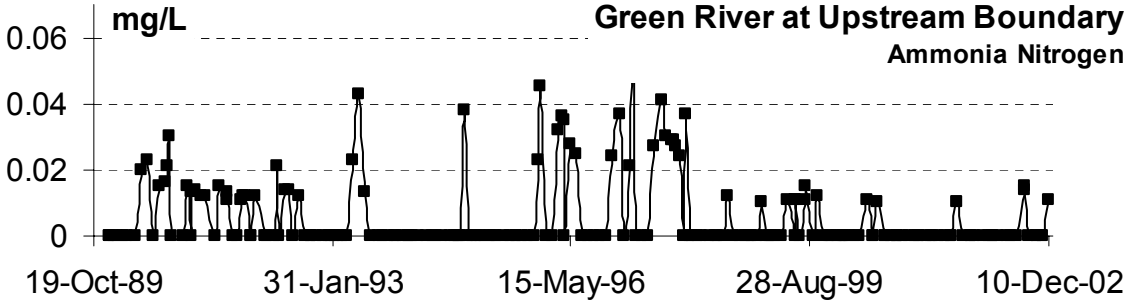
There have been a number of different temperature studies on the Green River near the upstream boundary - including 2 by the University of Washington (GR3-4 and GR5) and 3 by King County (WHI, GRT10, and GRT10_2). The data for all stations are shown below.

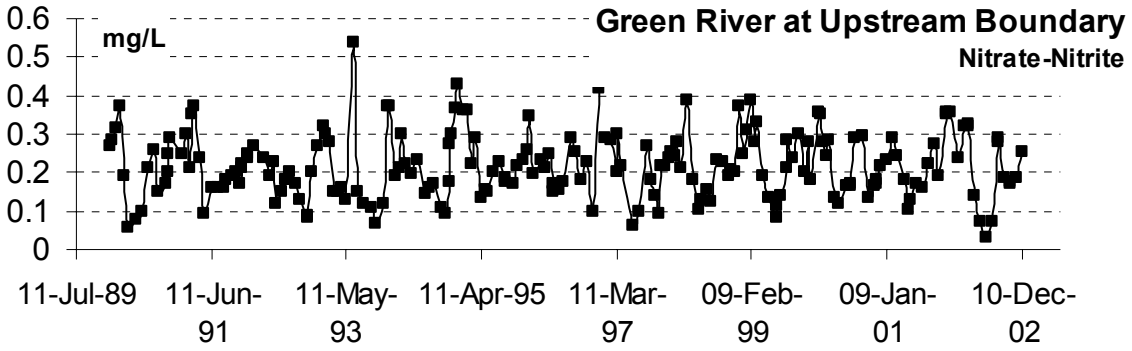


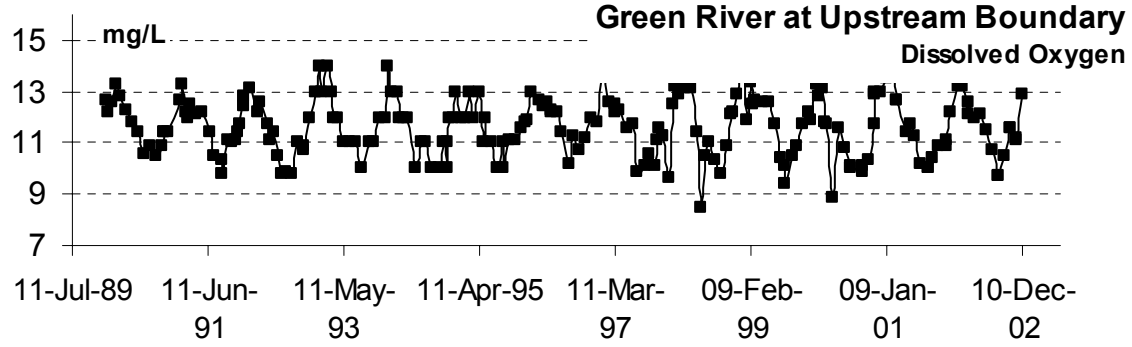
Monthly sampling of water quality constituents was provided from 1990 to 2002.

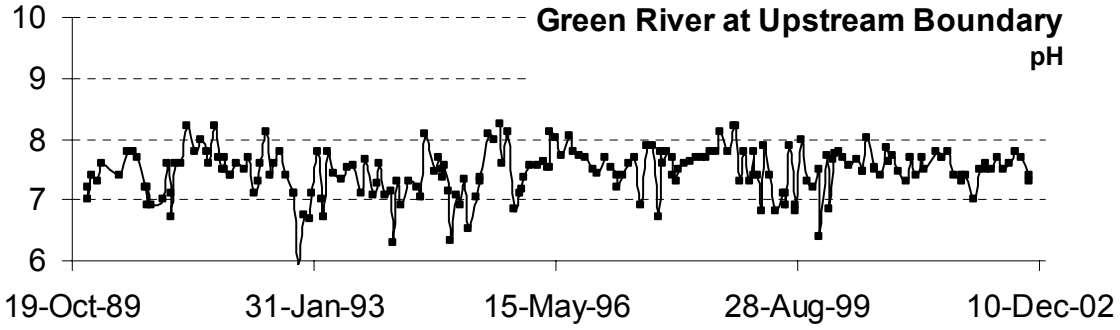


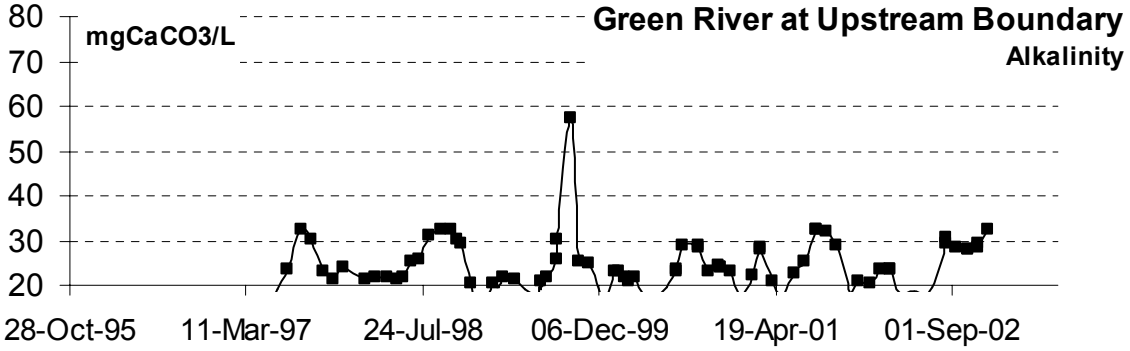


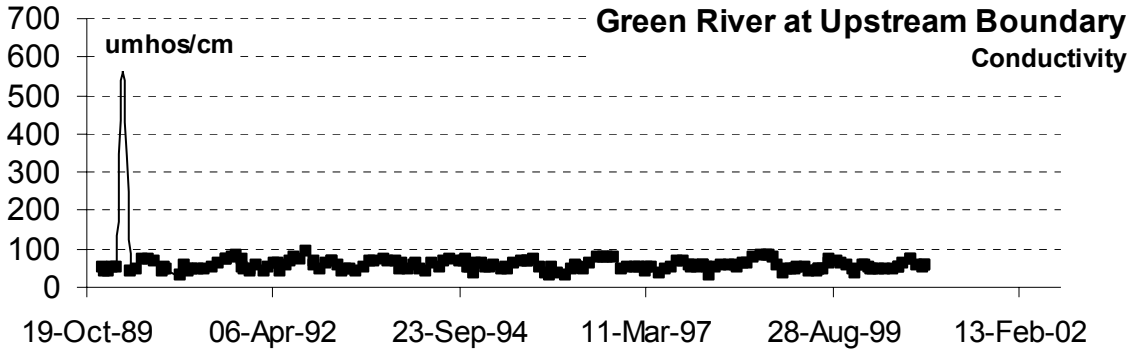


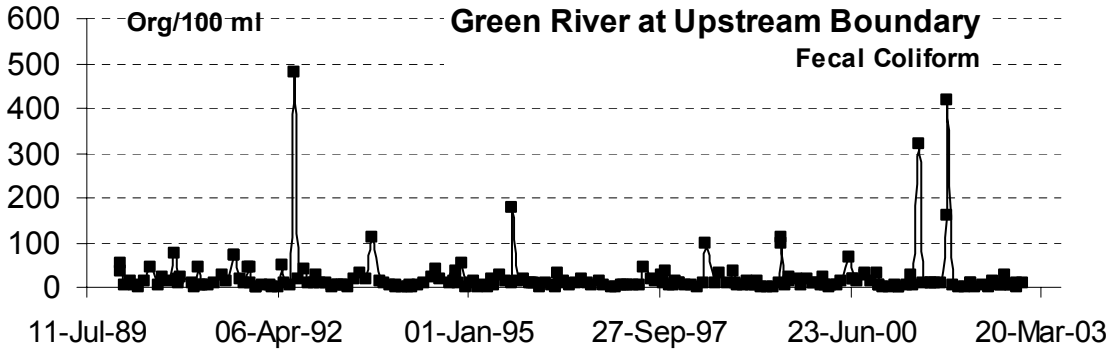

Green River at Upstream Boundary
Nitrate-Nitrite
mg/L
0.6
0.5
0.4
0.3
0.2
0.1
0
11-Jul-89
11-Jun-91
11-May-93
11-Apr-95
11-Mar-97
09-Feb-99
09-Jan-01
10-Dec-02

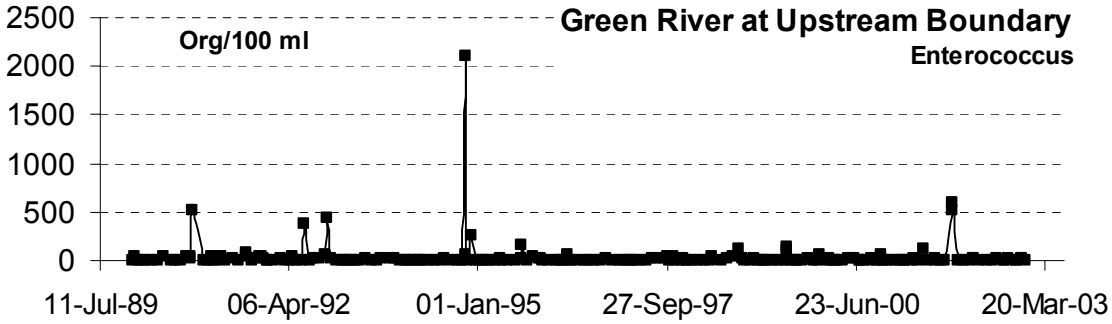

Green River at Upstream Boundary
Dissolved Oxygen
mg/L
15
13
11
9
7
11-Jul-89
11-Jun-91
11-May-93
11-Apr-95
11-Mar-97
09-Feb-99
09-Jan-01
10-Dec-02

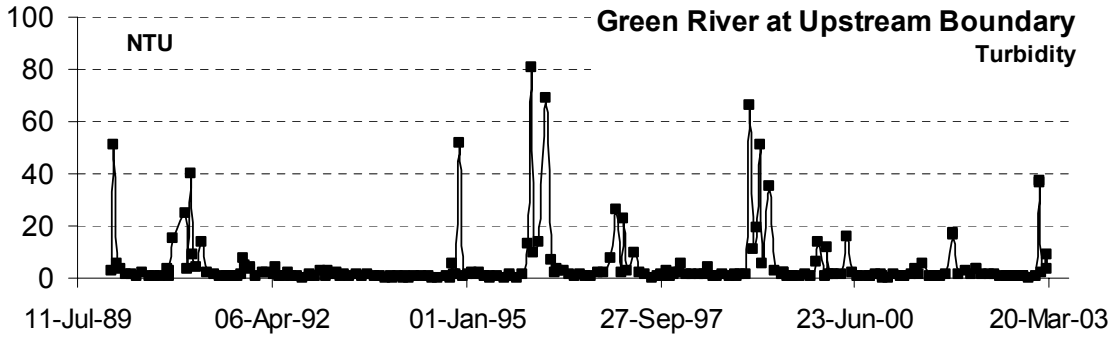

Green River at Upstream Boundary
pH
10
9
8
7
6
19-Oct-89
31-Jan-93
15-May-96
28-Aug-99
10-Dec-02

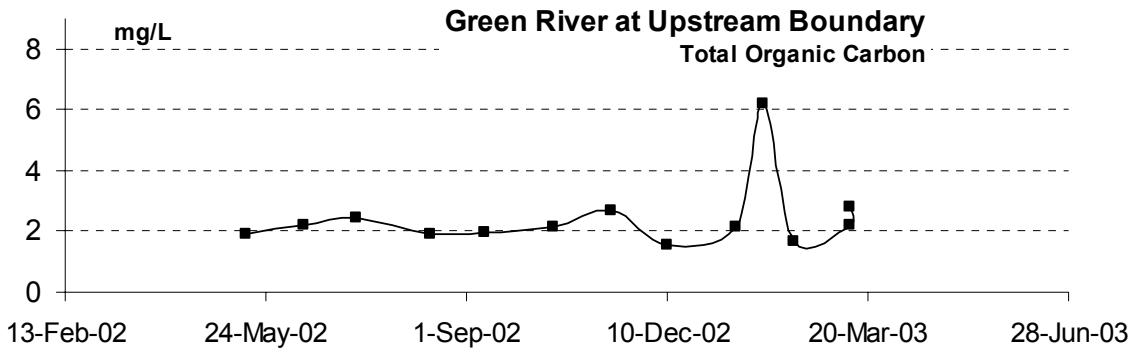

Green River at Upstream Boundary
Alkalinity
mgCaCO3/L
80
70
60
50
40
30
20
28-Oct-95
11-Mar-97
24-Jul-98
06-Dec-99
19-Apr-01
01-Sep-02

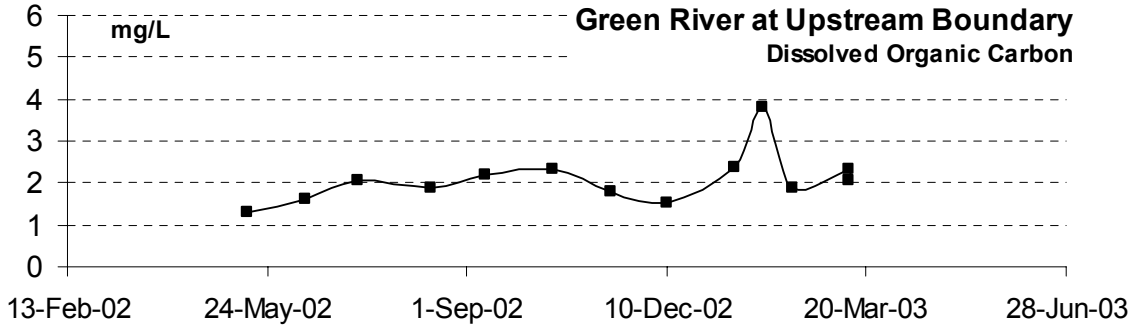

Green River at Upstream Boundary
Conductivity
umhos/cm
700
600
500
400
300
200
100
0
19-Oct-89
06-Apr-92
23-Sep-94
11-Mar-97
28-Aug-99
13-Feb-02

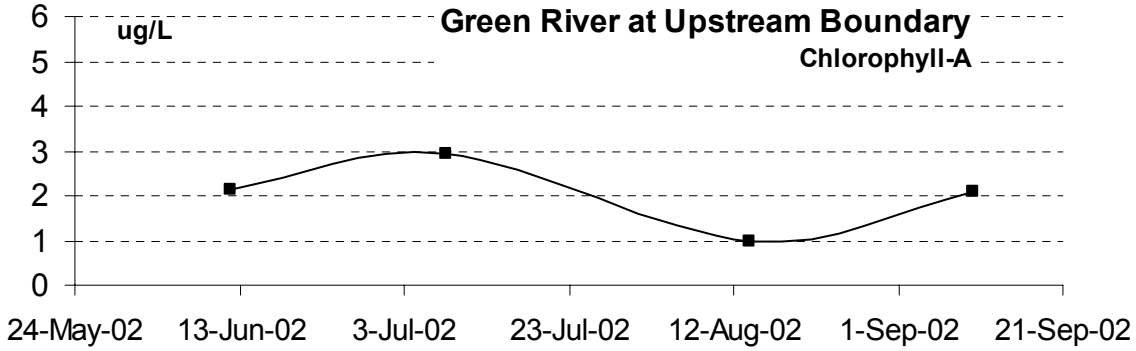

Green River at Upstream Boundary
Fecal Coliform
Org/100 ml
600
500
400
300
200
100
0
11-Jul-89
06-Apr-92
01-Jan-95
27-Sep-97
23-Jun-00
20-Mar-03


Green River at Upstream Boundary
Enterococcus
Org/100 ml
2500
2000
1500
1000
500
0
11-Jul-89
06-Apr-92
01-Jan-95
27-Sep-97
23-Jun-00
20-Mar-03


Green River at Upstream Boundary
Turbidity
NTU
100
80
60
40
20
0
11-Jul-89
06-Apr-92
01-Jan-95
27-Sep-97
23-Jun-00
20-Mar-03

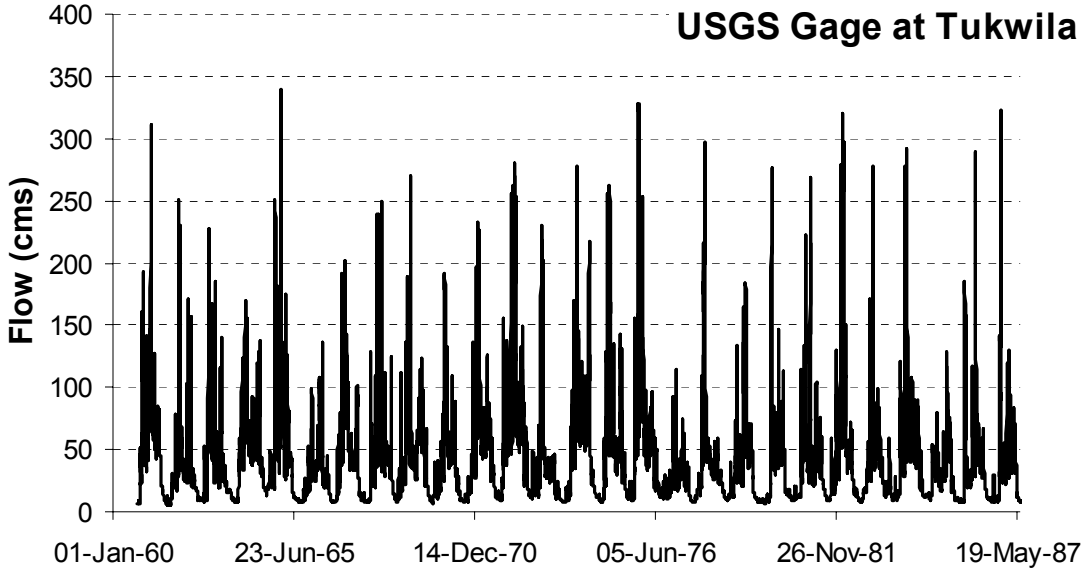




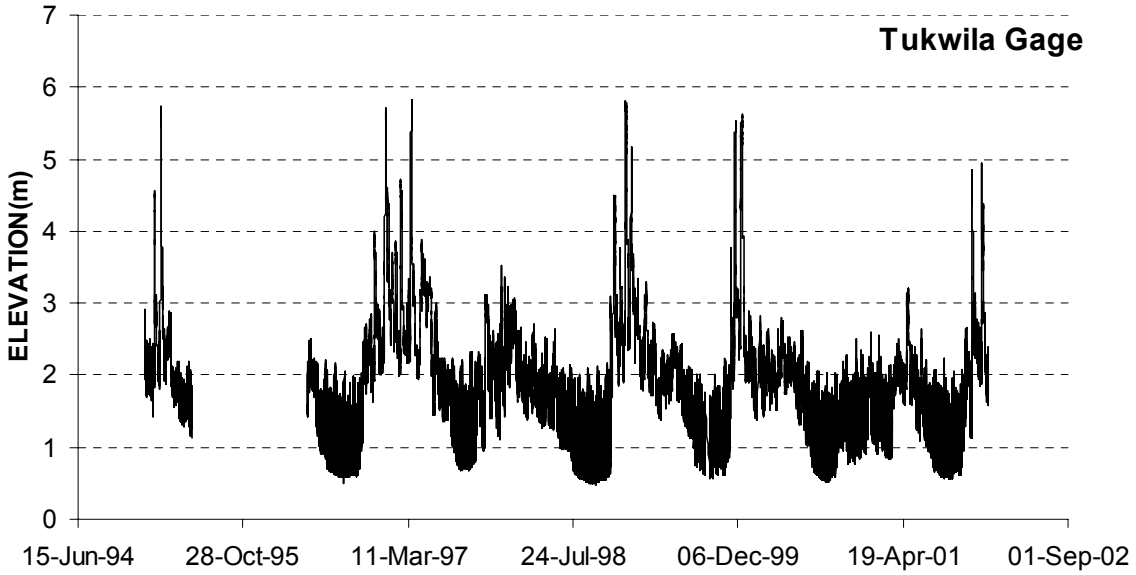


Downstream Boundary Data

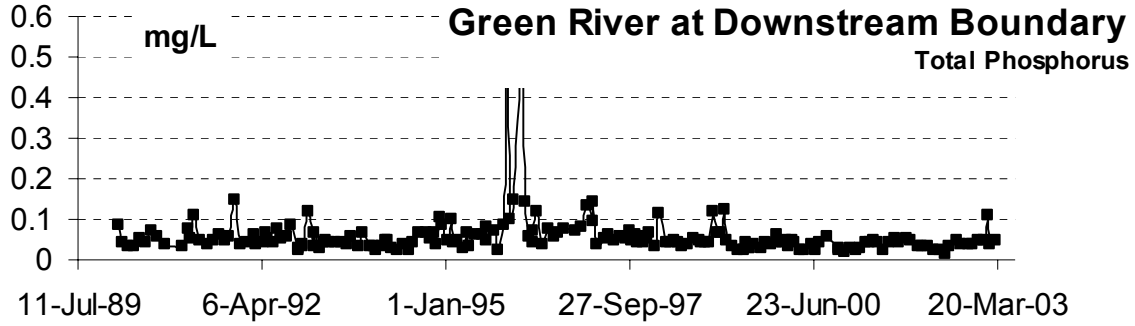
USGS (Gage No.12113350) recorded flow at Tukwila through 1987. Daily average data were provided by King County from 1960 through August 1987.

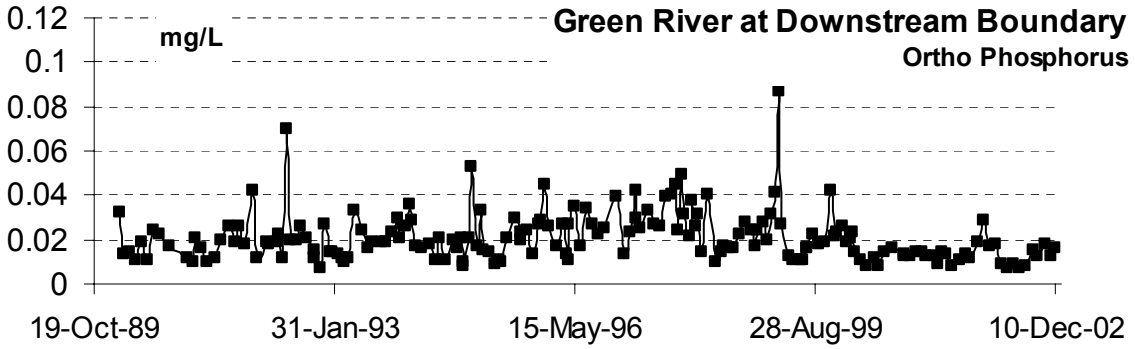


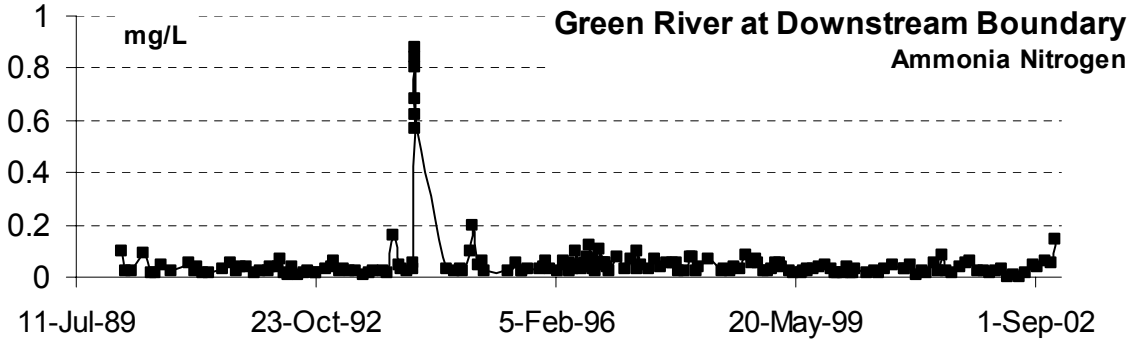
Stage data were obtained on the Green River at Tukwila (USGS Gage 12113500) in hourly intervals from 1995 through June of 2002.

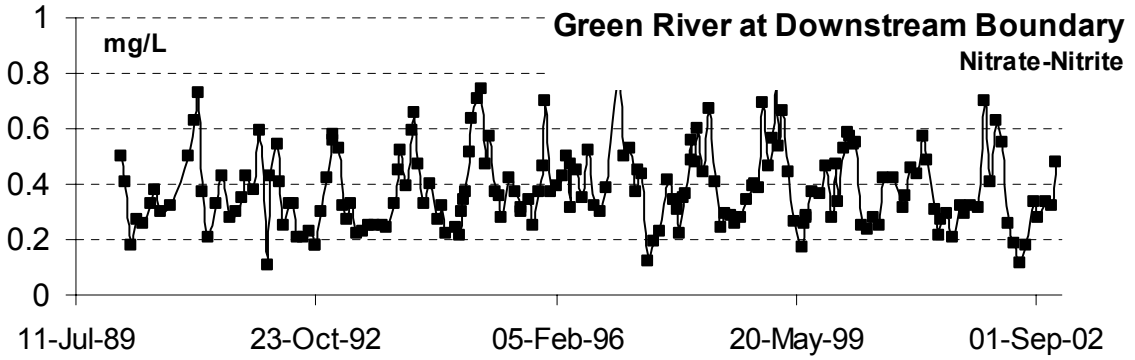


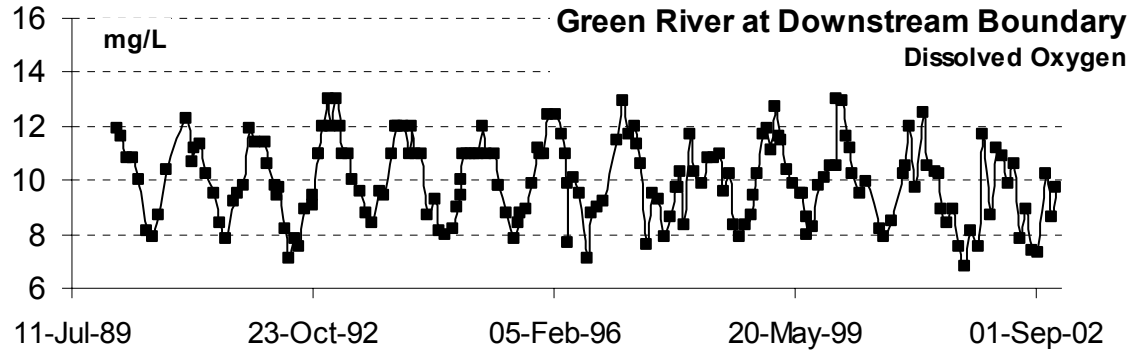
Water quality data were provided from 1990 to 2002.

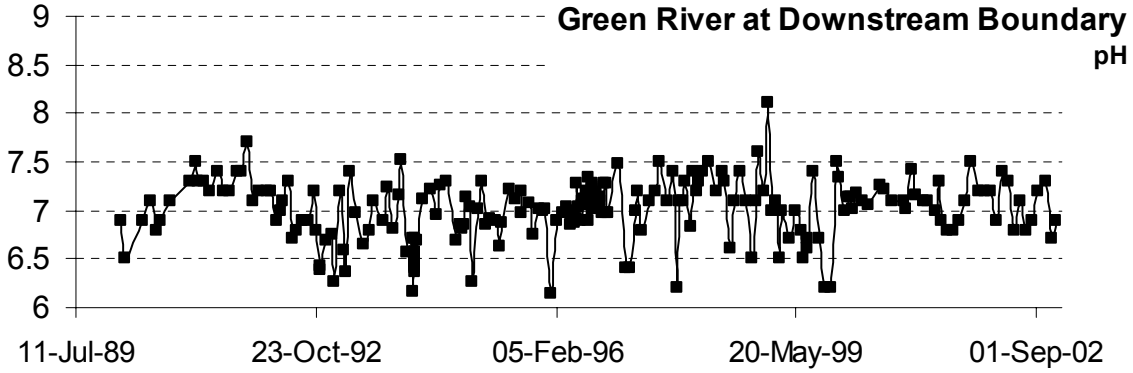


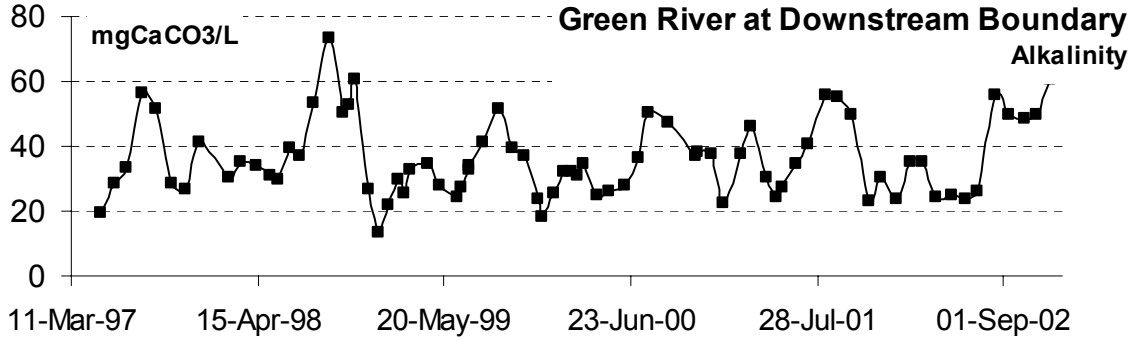


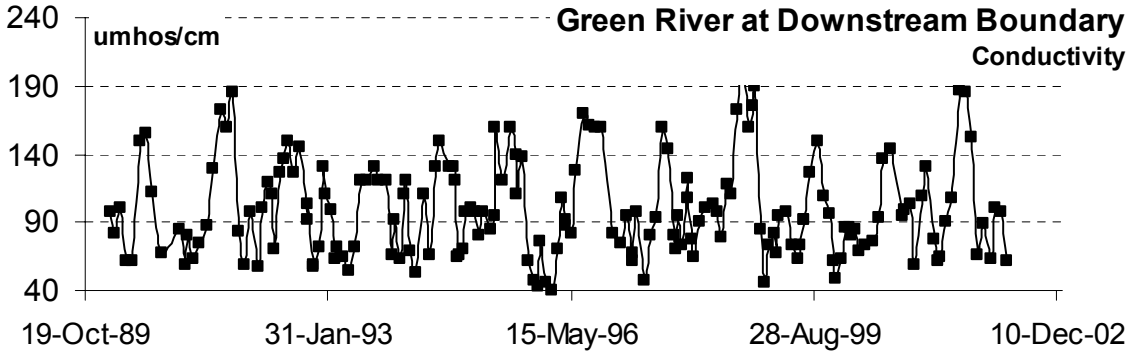


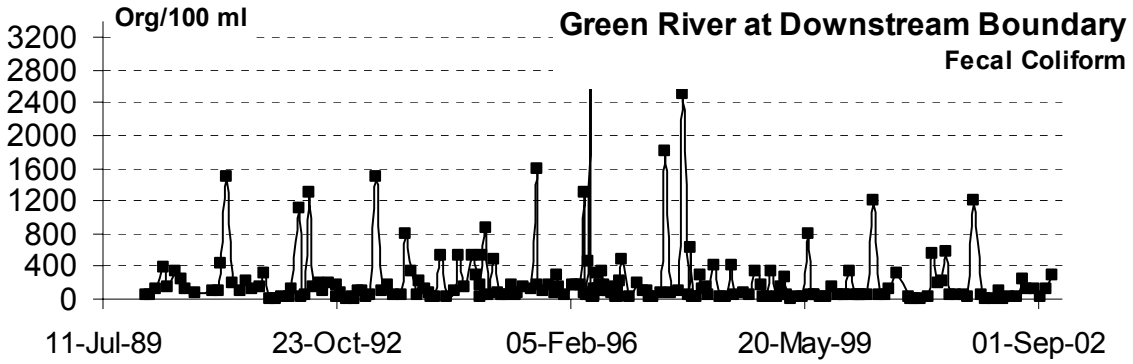


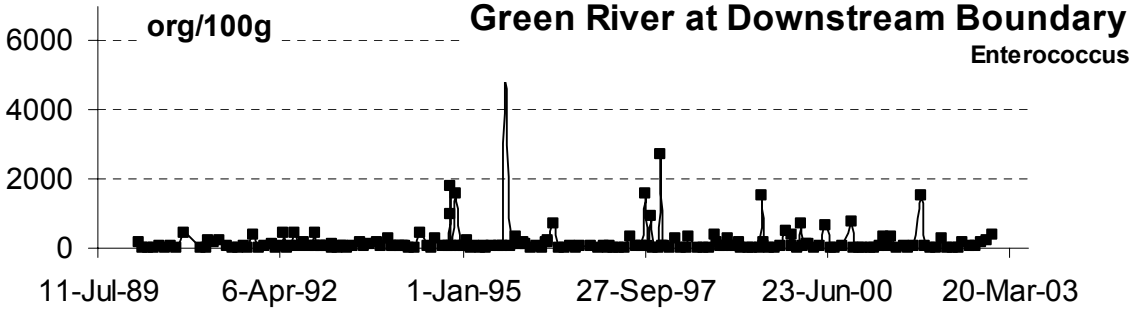

Green River at Downstream Boundary
Dissolved Oxygen
mg/L
16
14
12
10
8
6
11-Jul-89
23-Oct-92
05-Feb-96
20-May-99
01-Sep-02

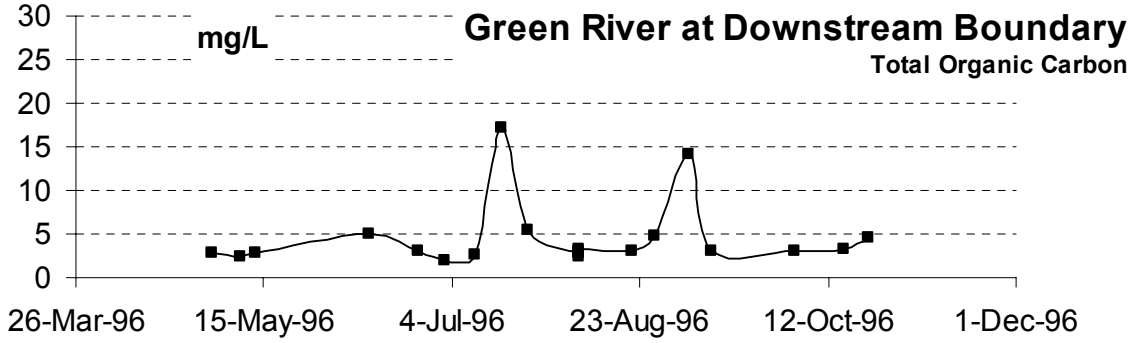

Green River at Downstream Boundary
pH
9
8.5
8
7.5
7
6.5
6
11-Jul-89
23-Oct-92
05-Feb-96
20-May-99
01-Sep-02

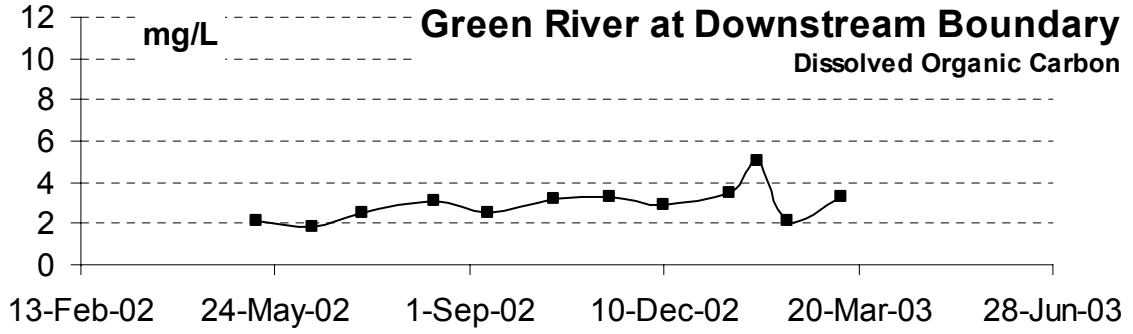

Green River at Downstream Boundary
Alkalinity
mgCaCO3/L
80
60
40
20
0
11-Mar-97
15-Apr-98
20-May-99
23-Jun-00
28-Jul-01
01-Sep-02

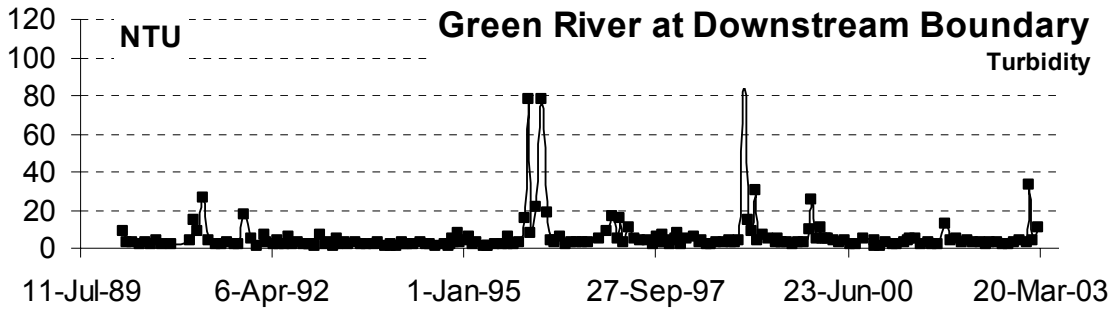

Green River at Downstream Boundary
Conductivity
umhos/cm
240
190
140
90
40
19-Oct-89
31-Jan-93
15-May-96
28-Aug-99
10-Dec-02


Org/100 ml
Green River at Downstream Boundary
Fecal Coliform
3200
2800
2400
2000
1600
1200
800
400
0
11-Jul-89
23-Oct-92
05-Feb-96
20-May-99
01-Sep-02


org/100g
Green River at Downstream Boundary
Enterococcus
6000
4000
2000
0
11-Jul-89
6-Apr-92
1-Jan-95
27-Sep-97
23-Jun-00
20-Mar-03

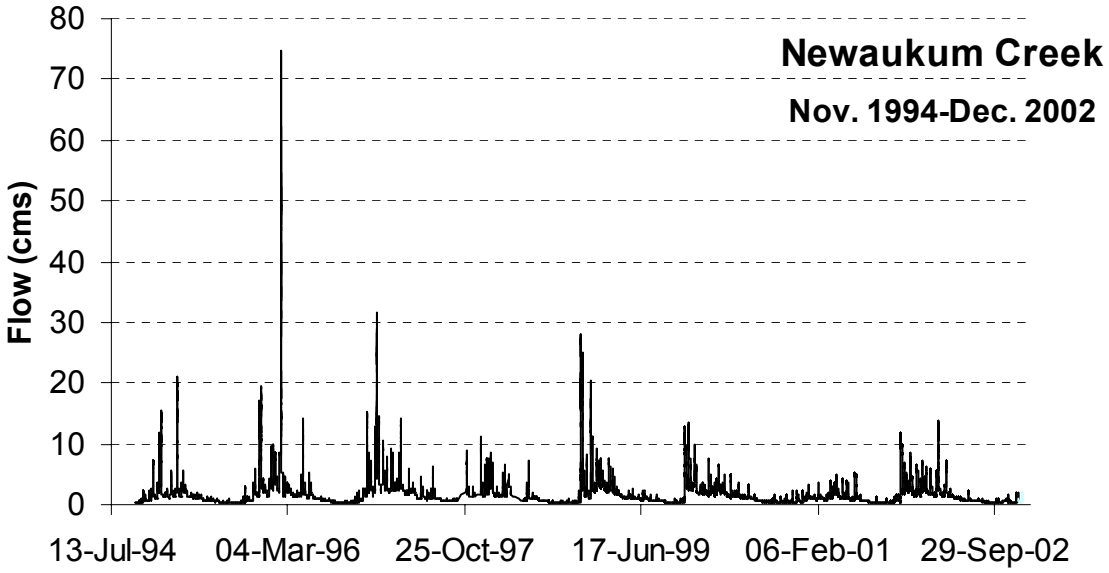

mg/L
Green River at Downstream Boundary
Total Organic Carbon
30
25
20
15
10
5
0
26-Mar-96
15-May-96
4-Jul-96
23-Aug-96
12-Oct-96
1-Dec-96


mg/L
Green River at Downstream Boundary
Dissolved Organic Carbon
12
10
8
6
4
2
0
13-Feb-02
24-May-02
1-Sep-02
10-Dec-02
20-Mar-03
28-Jun-03

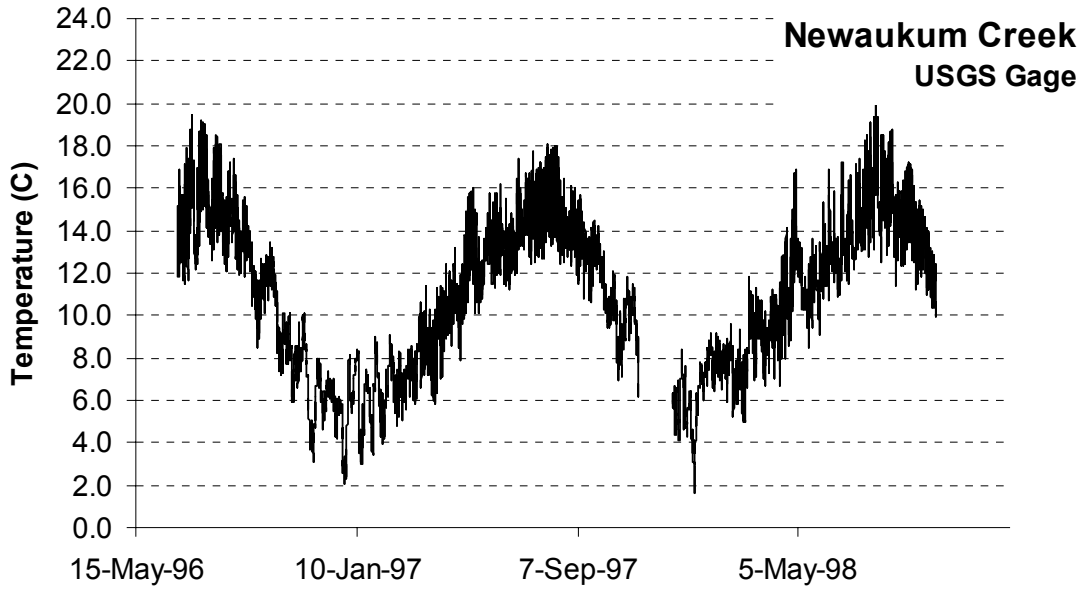


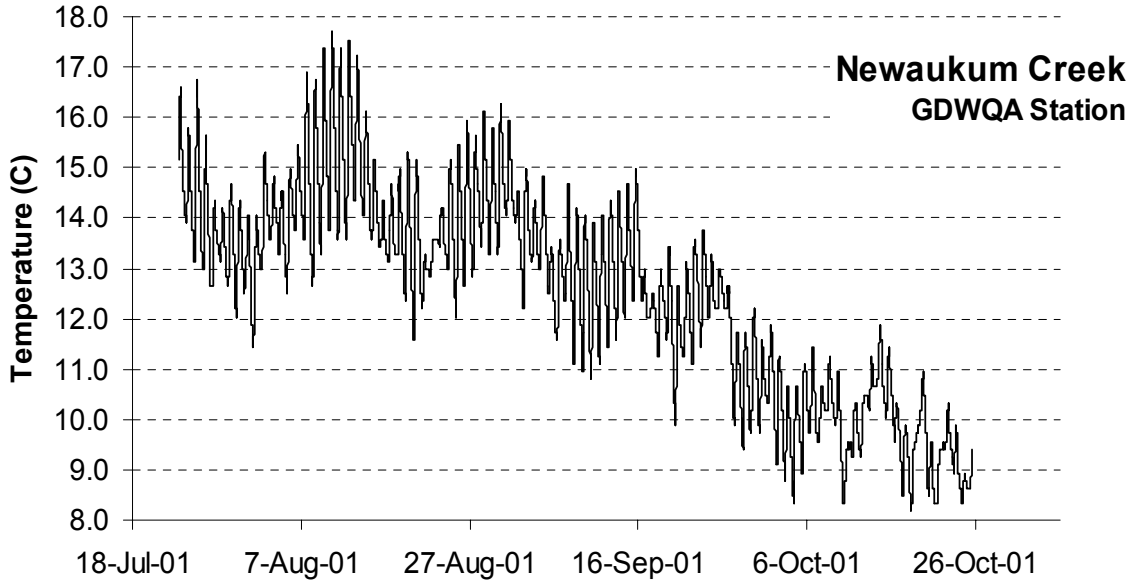
Newaukum Creek Data

Flow data were obtained on Newaukum Creek (USGS Gage 12108500) from November 1994 through December 2002.

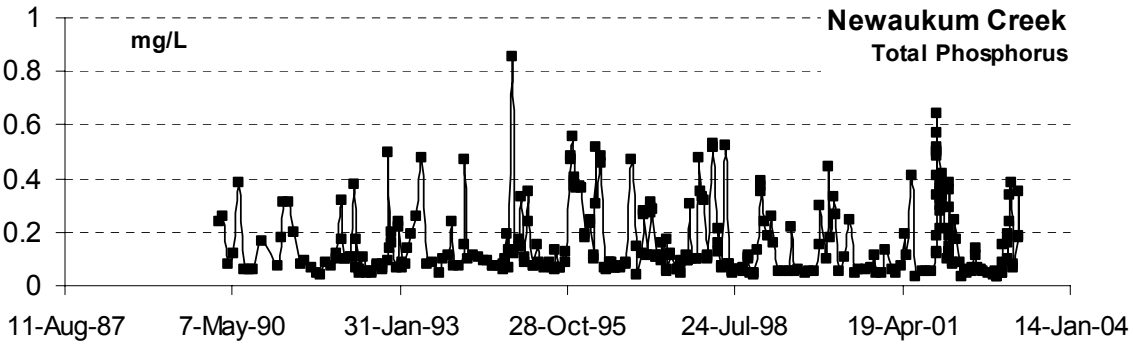


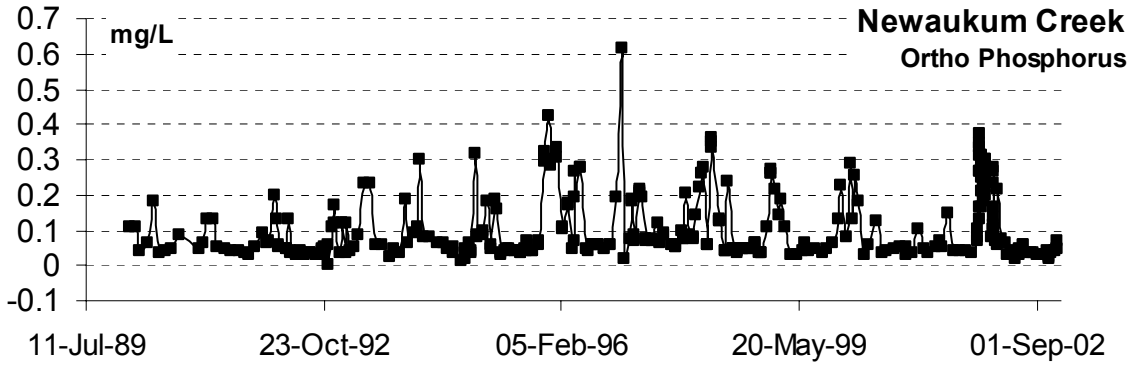
Both King County and the USGS recorded temperature on Newaukum Creek at different times. USGS recorded hourly temperature data from June 1996 to October 1998, and King County recorded temperature at the same location from July 2001 to the present. These data were provided in hourly intervals.

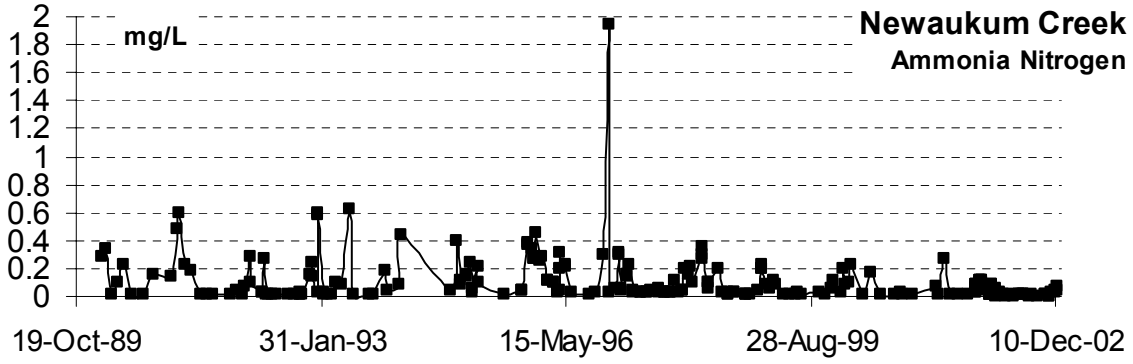


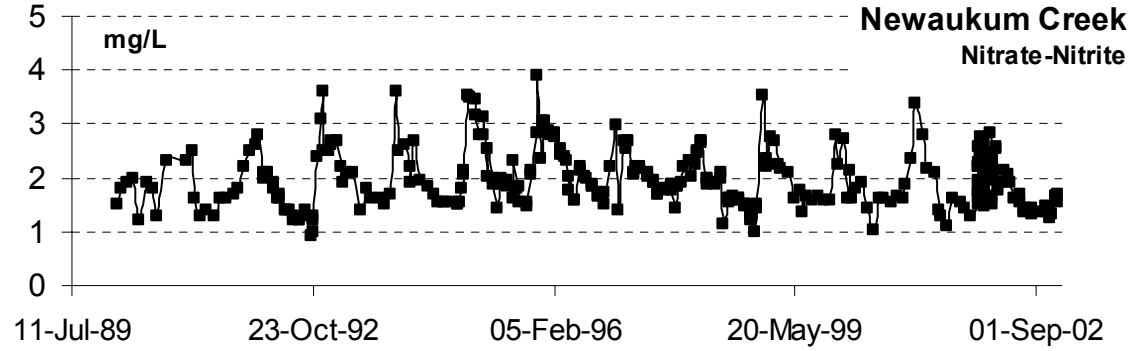


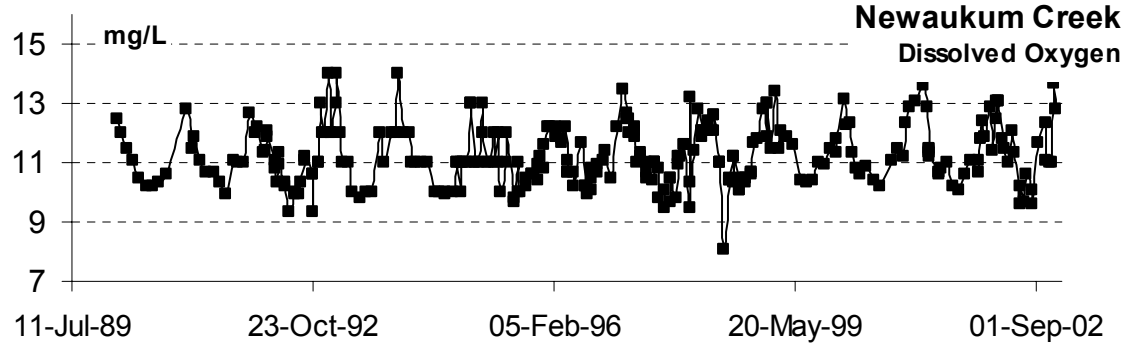
Water quality constituent data have been provided from 1990 to 2002.

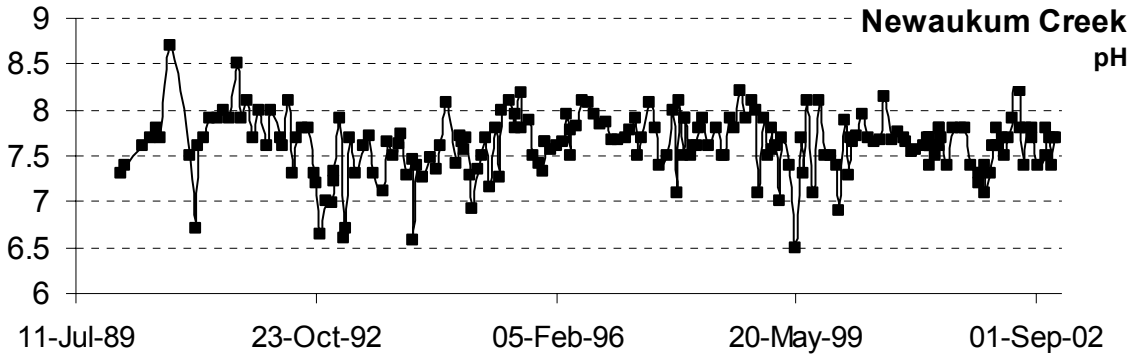


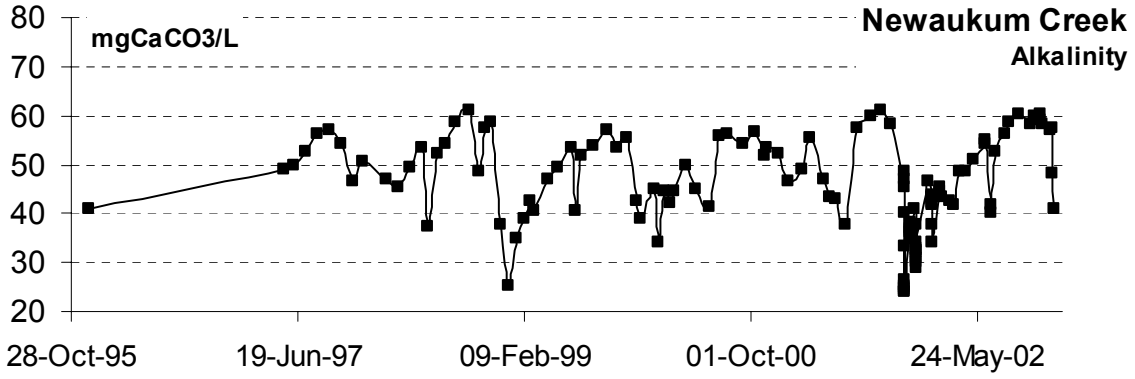

Newaukum Creek
Ortho Phosphorus
mg/L
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
11-Jul-89
23-Oct-92
05-Feb-96
20-May-99
01-Sep-02

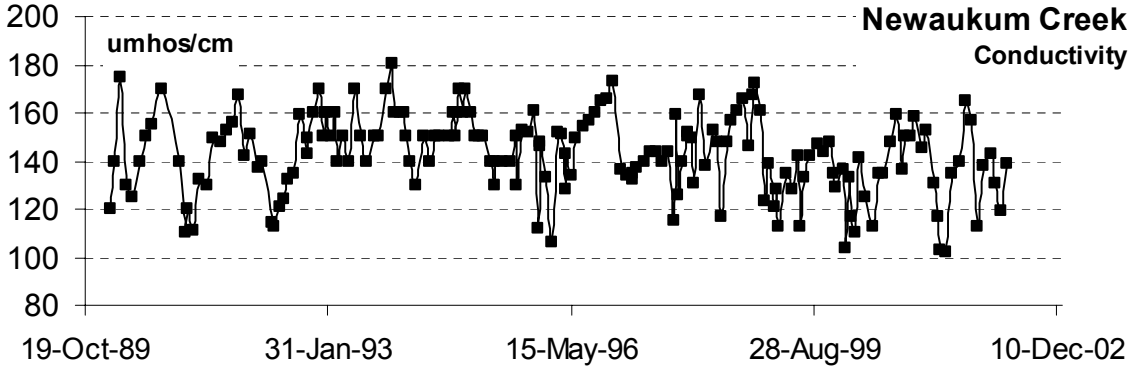

Newaukum Creek
Ammonia Nitrogen
mg/L
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
19-Oct-89
31-Jan-93
15-May-96
28-Aug-99
10-Dec-02

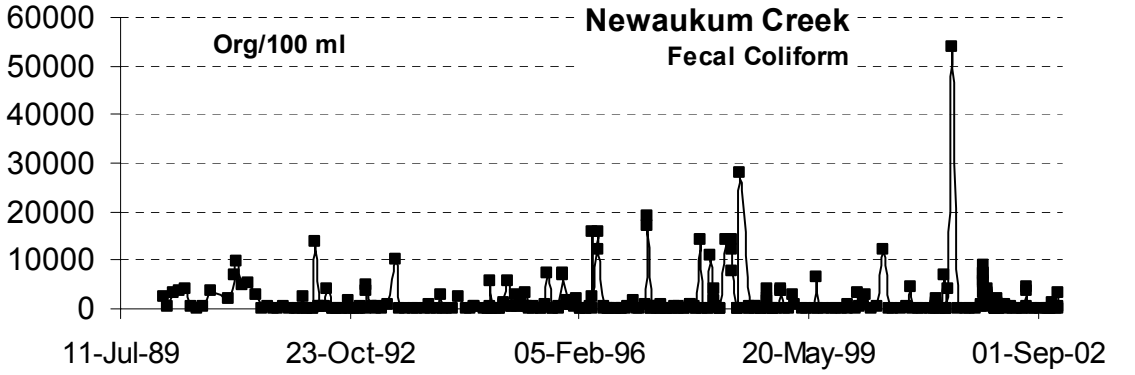

Newaukum Creek
Nitrate-Nitrite
mg/L
5
4
3
2
1
0
11-Jul-89
23-Oct-92
05-Feb-96
20-May-99
01-Sep-02

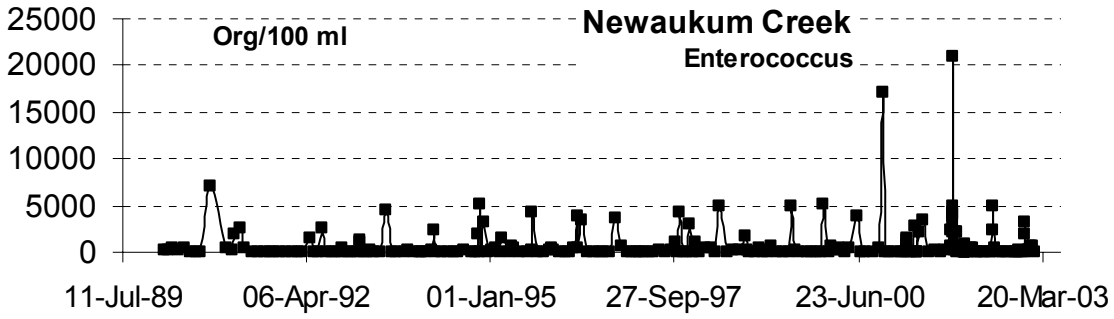

Newaukum Creek
Dissolved Oxygen
mg/L
15
13
11
9
7
11-Jul-89
23-Oct-92
05-Feb-96
20-May-99
01-Sep-02

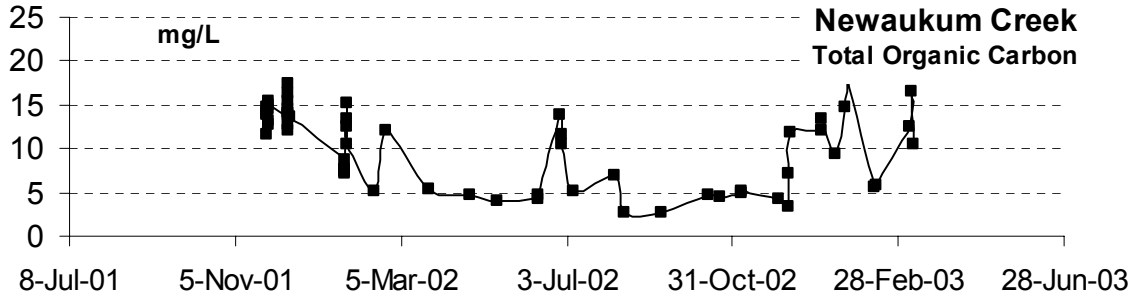

Newaukum Creek
pH
9
8.5
8
7.5
7
6.5
6
11-Jul-89
23-Oct-92
05-Feb-96
20-May-99
01-Sep-02

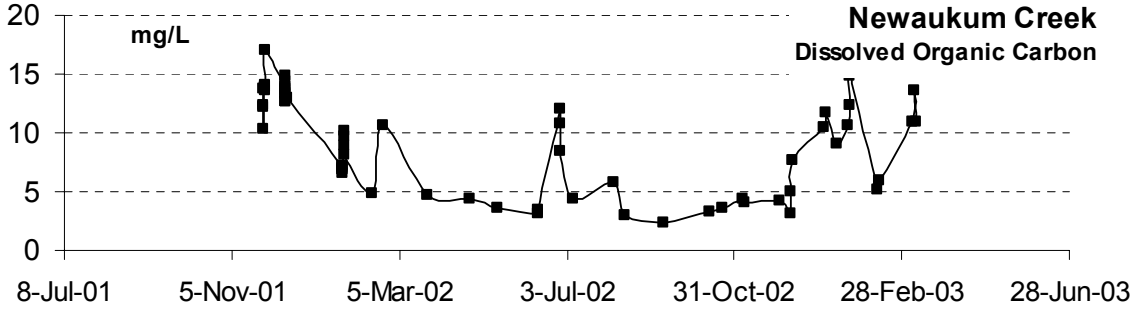

Newaukum Creek
Alkalinity
mgCaCO3/L
80
70
60
50
40
30
20
28-Oct-95
19-Jun-97
09-Feb-99
01-Oct-00
24-May-02

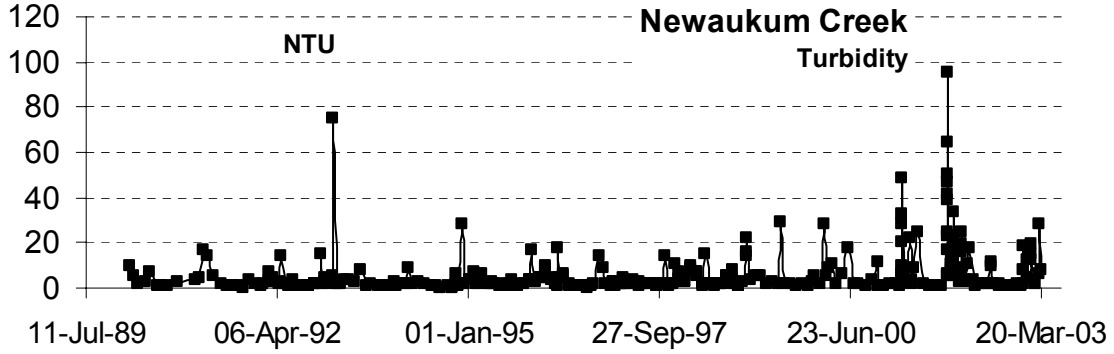

Newaukum Creek
Conductivity
umhos/cm
200
180
160
140
120
100
80
19-Oct-89
31-Jan-93
15-May-96
28-Aug-99
10-Dec-02


Newaukum Creek
Fecal Coliform
Org/100 ml
60000
50000
40000
30000
20000
10000
0
11-Jul-89
23-Oct-92
05-Feb-96
20-May-99
01-Sep-02



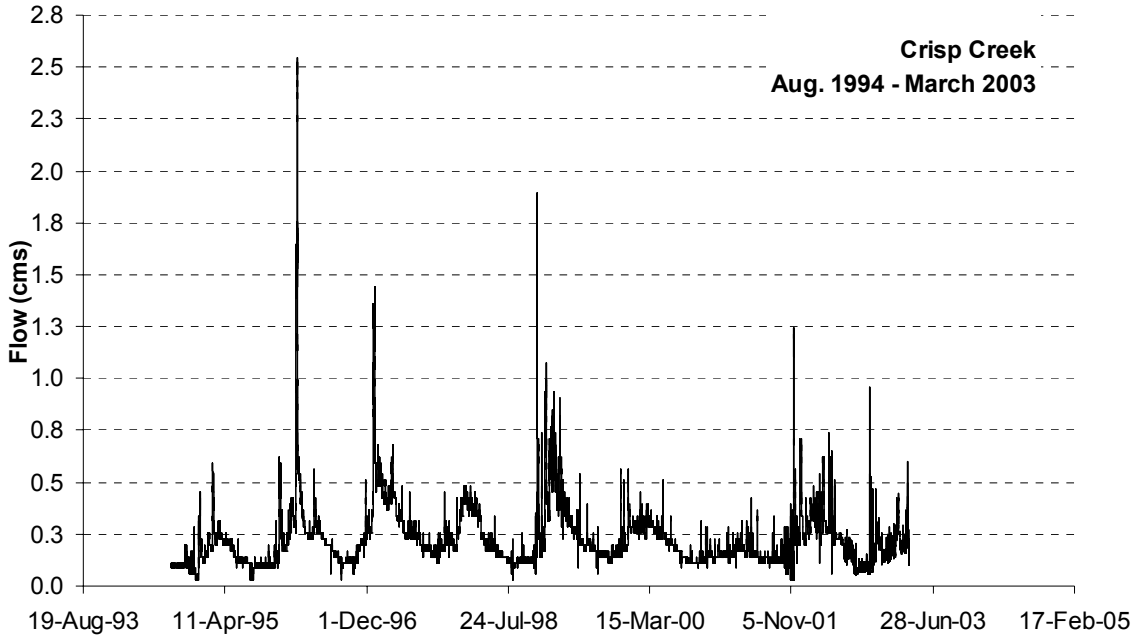




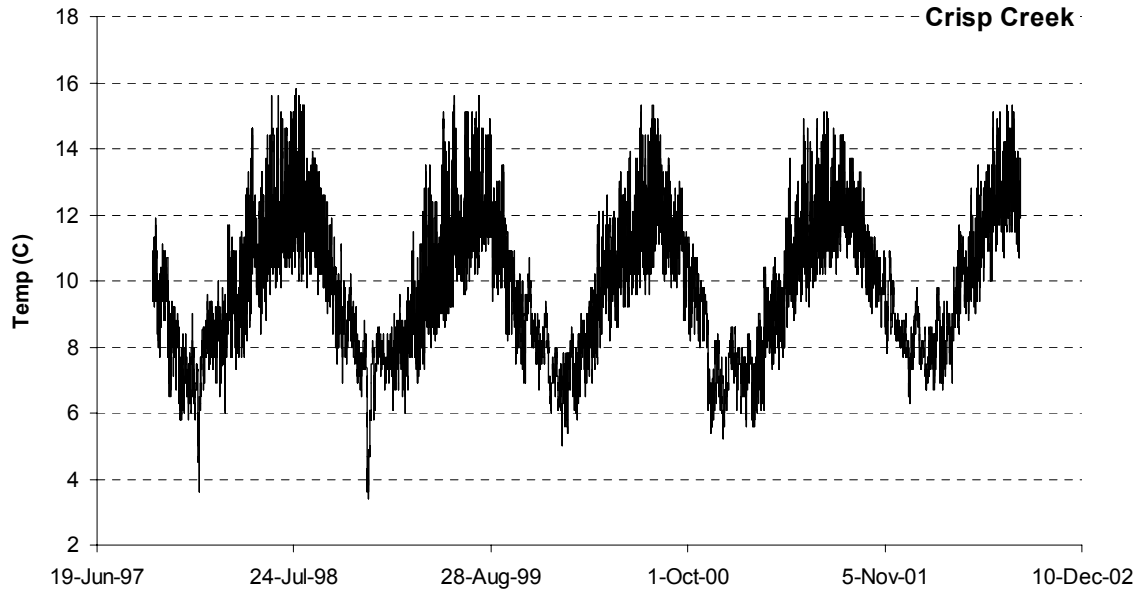


Crisp Creek Data

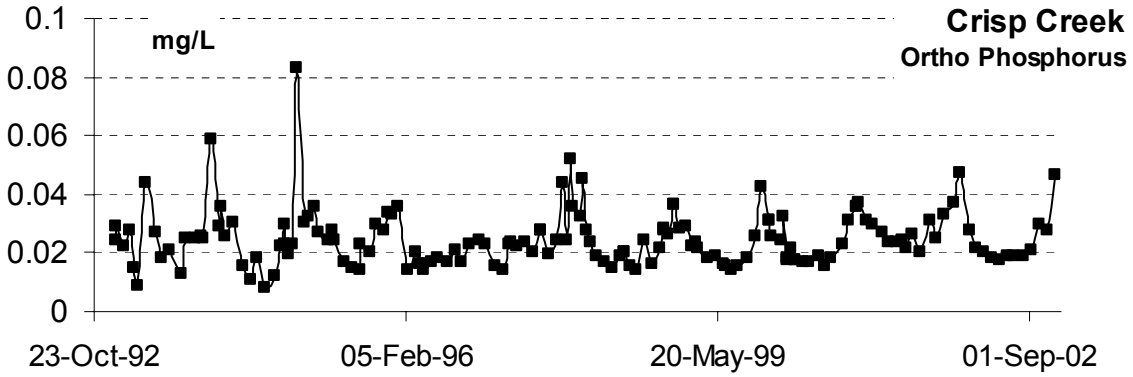
King County has a flow gage (#40d) on Crisp Creek. Data were obtained in 15 minute intervals from August 1994 through March 2003.

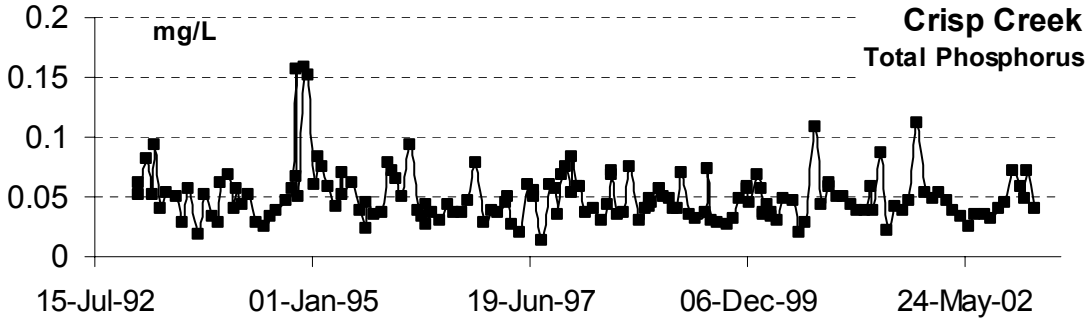


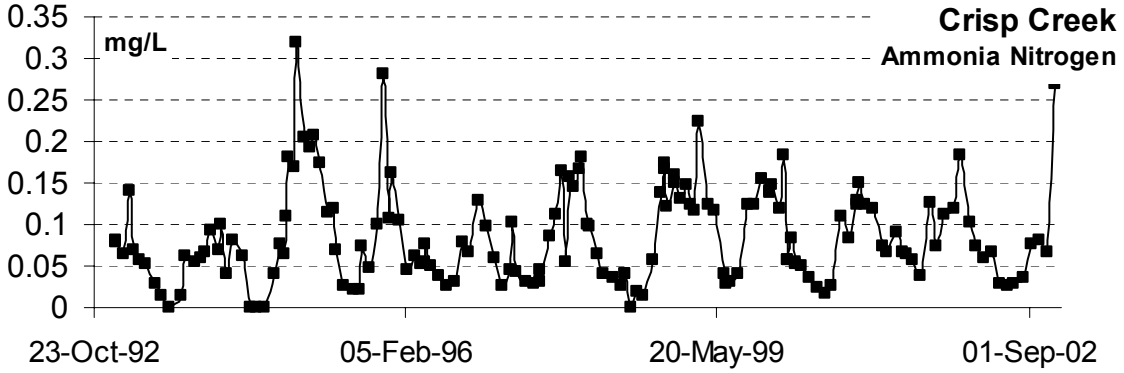
Temperature data for Crisp Creek was recorded by King County (#40d) in 15 minute intervals. Data were provided from October 1997 to August 2002.

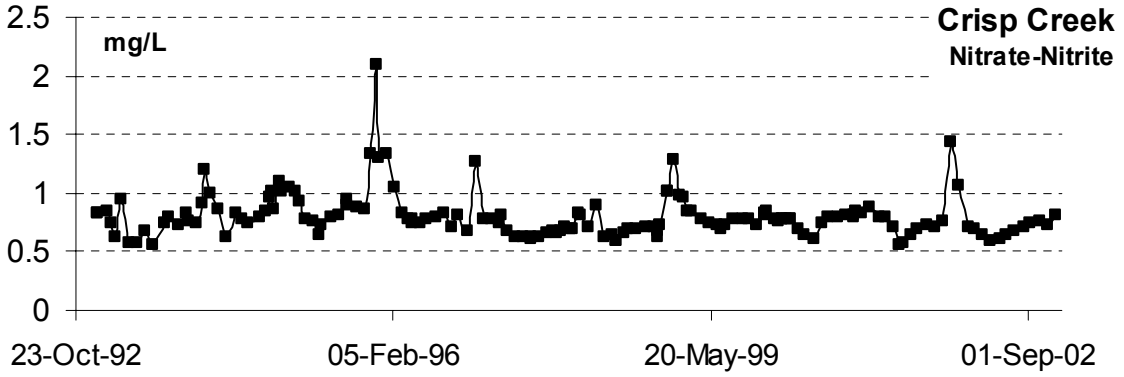


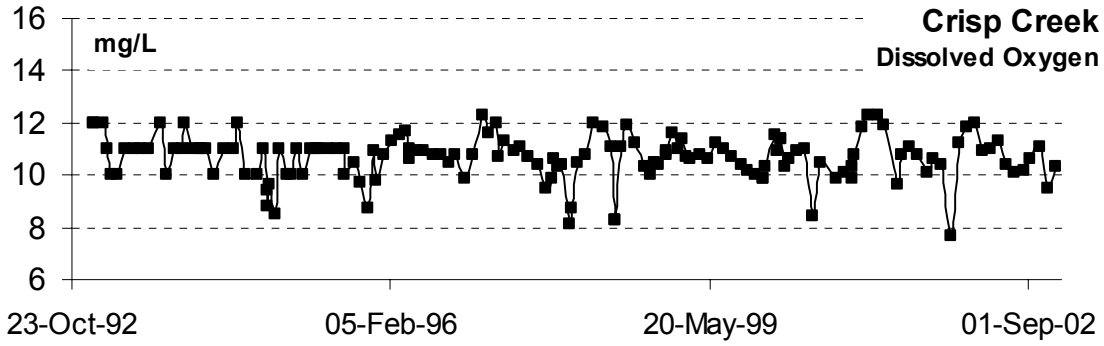
Water quality constituent data were provided from 1990 to 2002.

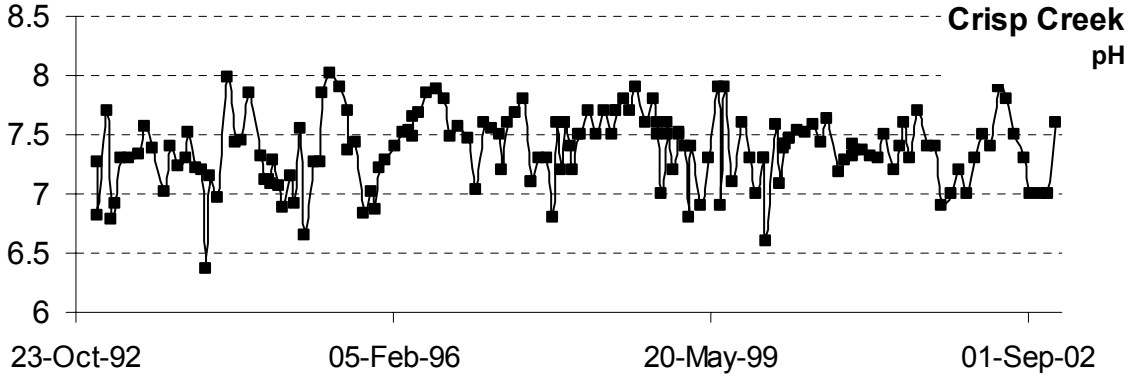

Crisp Creek
Ortho Phosphorus
mg/L
0.1
0.08
0.06
0.04
0.02
0
23-Oct-92
05-Feb-96
20-May-99
01-Sep-02

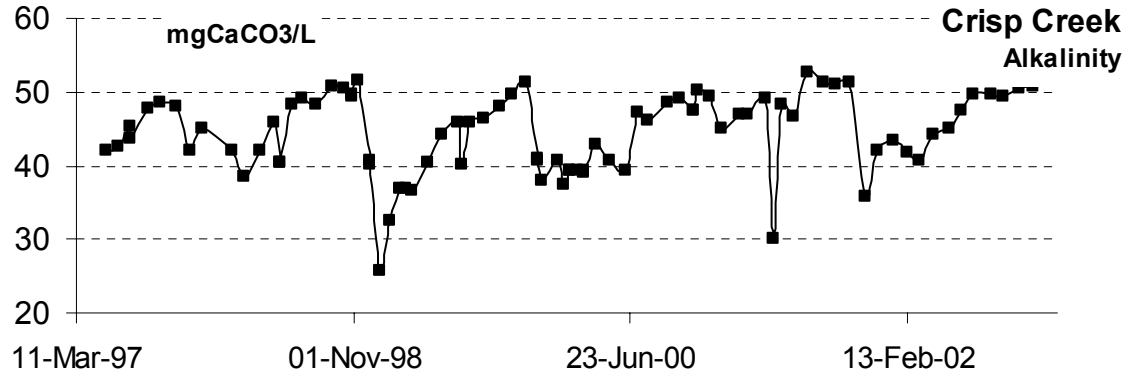

Crisp Creek
Total Phosphorus
mg/L
0.2
0.15
0.1
0.05
0
15-Jul-92
01-Jan-95
19-Jun-97
06-Dec-99
24-May-02

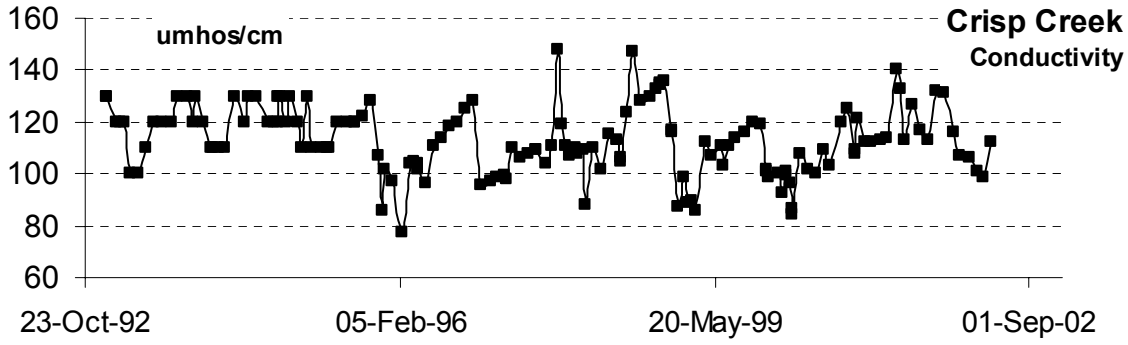

Crisp Creek
Ammonia Nitrogen
mg/L
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
23-Oct-92
05-Feb-96
20-May-99
01-Sep-02

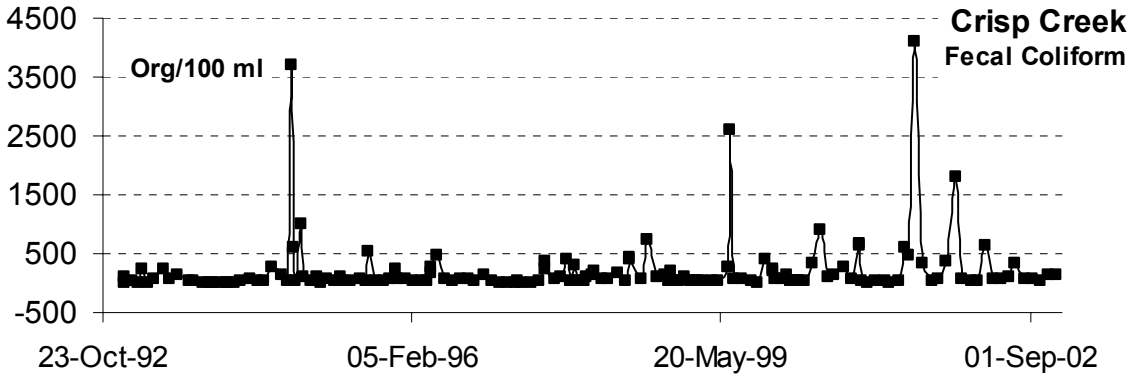

Crisp Creek
Nitrate-Nitrite
mg/L
2.5
2
1.5
1
0.5
0
23-Oct-92
05-Feb-96
20-May-99
01-Sep-02

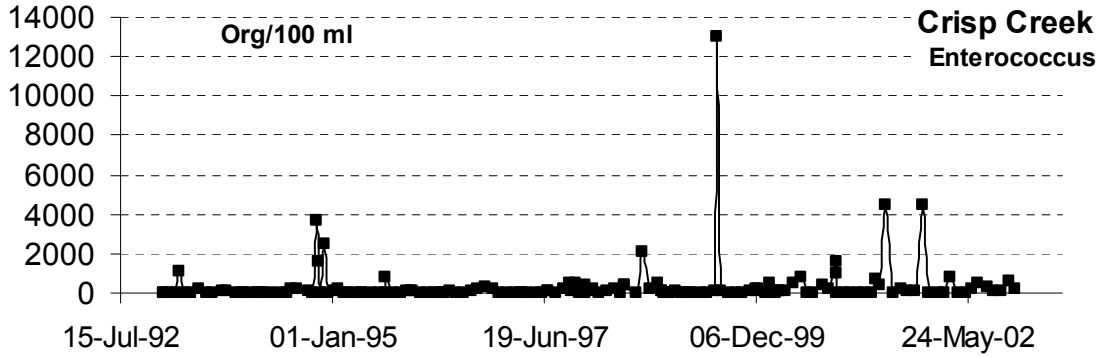

Crisp Creek
Dissolved Oxygen
mg/L
16
14
12
10
8
6
23-Oct-92
05-Feb-96
20-May-99
01-Sep-02

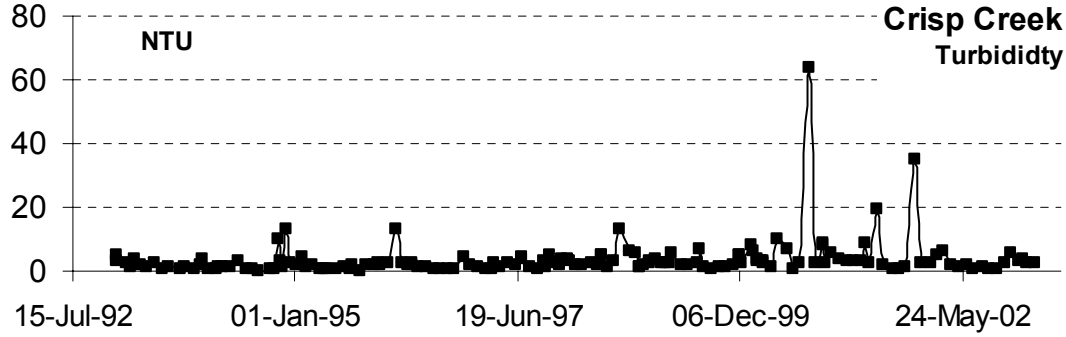

Crisp Creek
pH
8.5
8
7.5
7
6.5
6
23-Oct-92
05-Feb-96
20-May-99
01-Sep-02


Crisp Creek
Alkalinity
mgCaCO3/L
60
50
40
30
20
11-Mar-97
01-Nov-98
23-Jun-00
13-Feb-02


Crisp Creek
Conductivity
umhos/cm
160
140
120
100
80
60
23-Oct-92
05-Feb-96
20-May-99
01-Sep-02

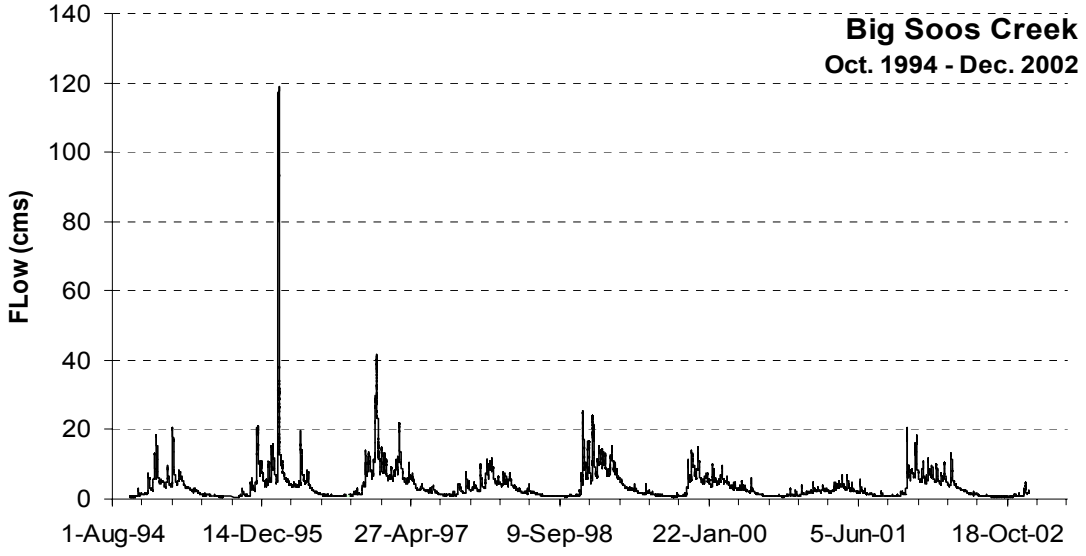




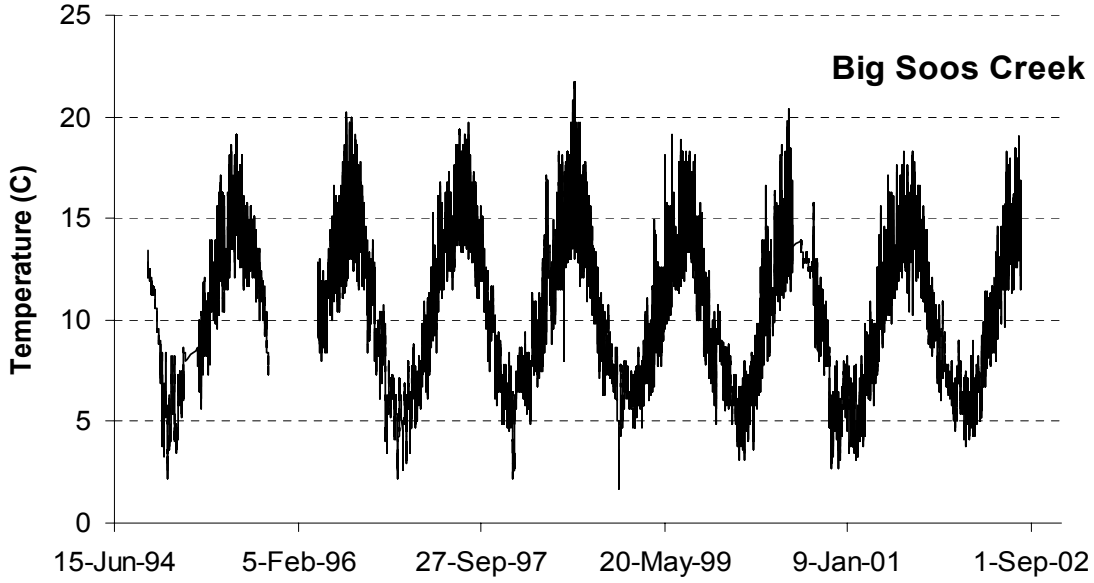


Big Soos Creek Data

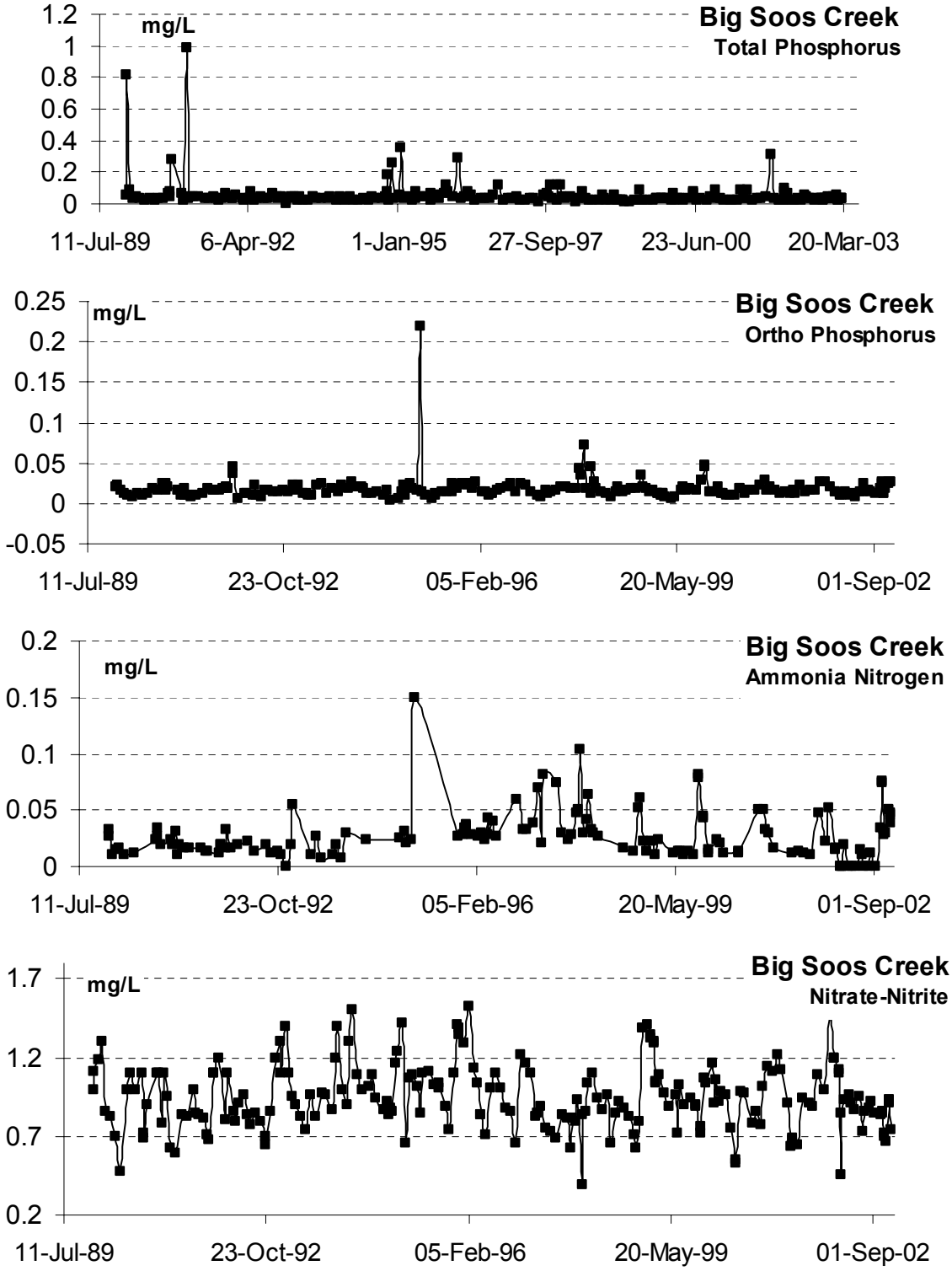
USGS has a flow gage (#12112600) on Big Soos Creek. Data were obtained in 15 minute intervals from October 1994 through December 2002.

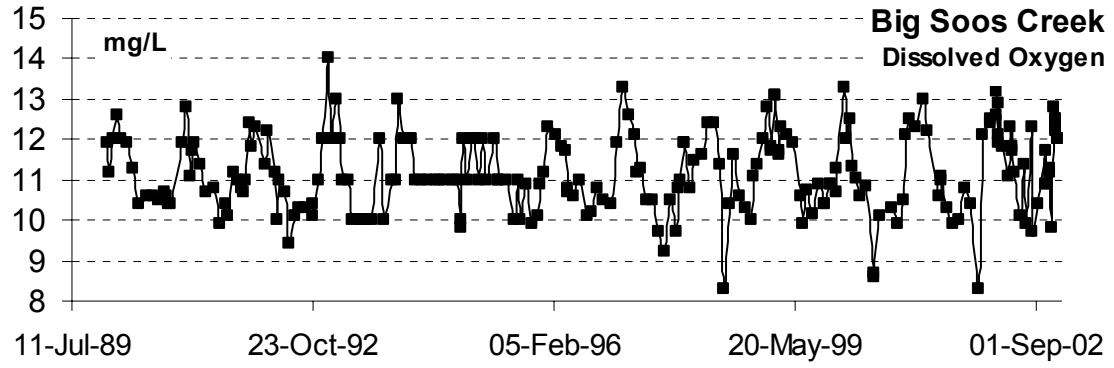


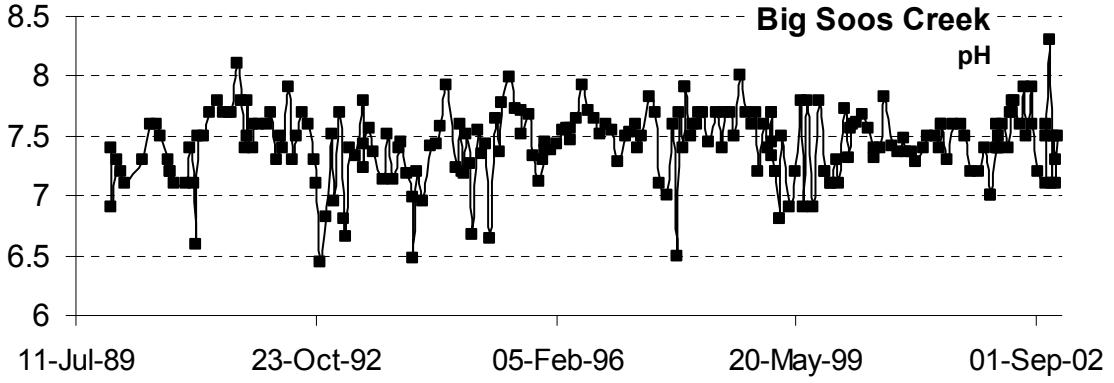
Temperature was recorded by King County (#54a) at the mouth of Big Soos Creek in 15 minute intervals. Data were provided from October 1994 to August 2002.

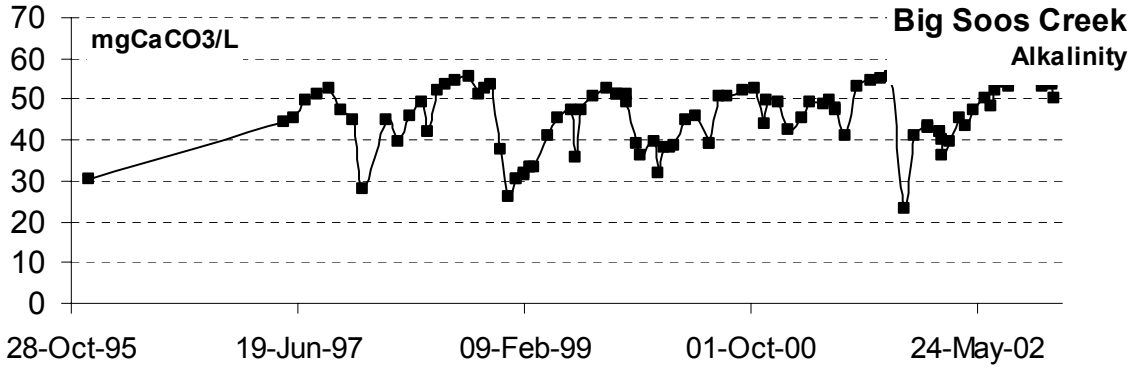


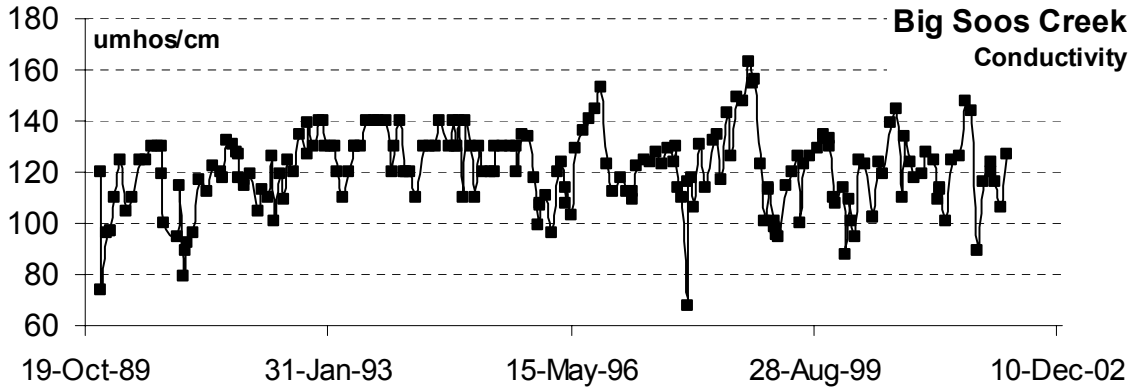
Water quality constituent data were provided from 1990 to 2002.

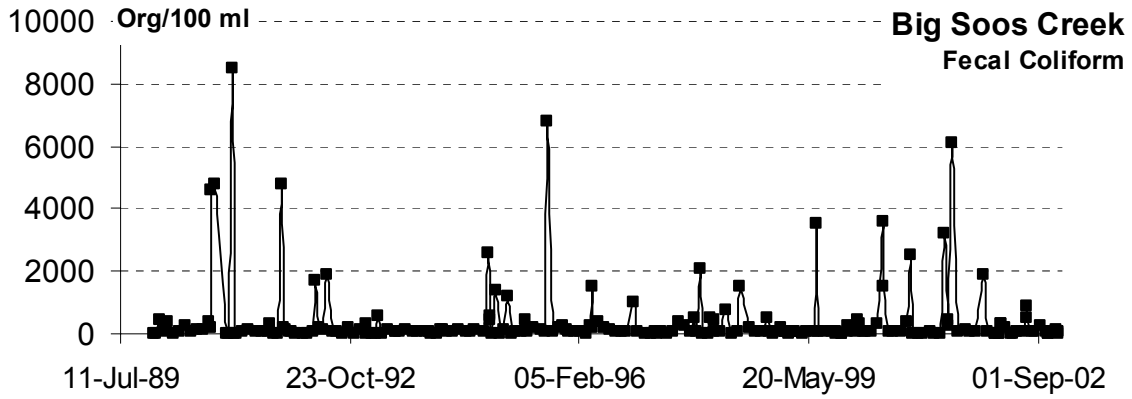


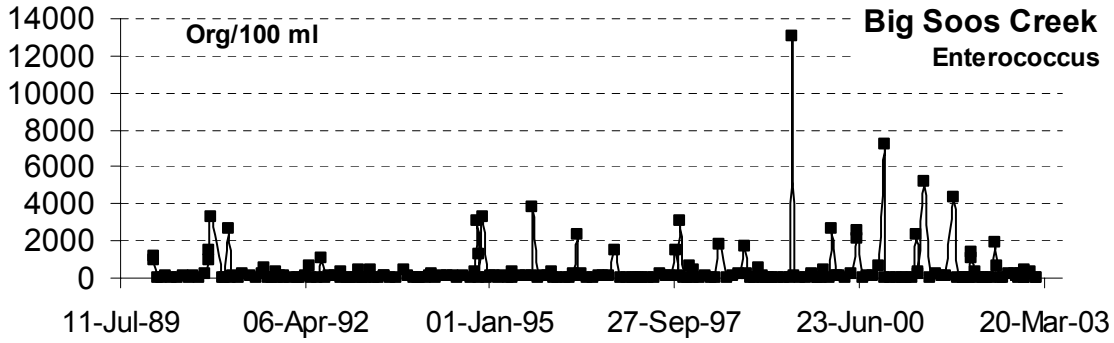

Big Soos Creek
Dissolved Oxygen
mg/L
15
14
13
12
11
10
9
8
11-Jul-89
23-Oct-92
05-Feb-96
20-May-99
01-Sep-02

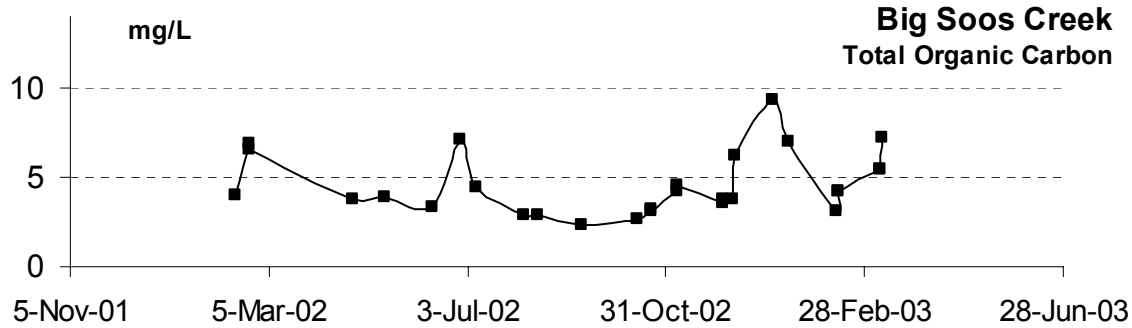

Big Soos Creek
pH
8.5
8
7.5
7
6.5
6
11-Jul-89
23-Oct-92
05-Feb-96
20-May-99
01-Sep-02

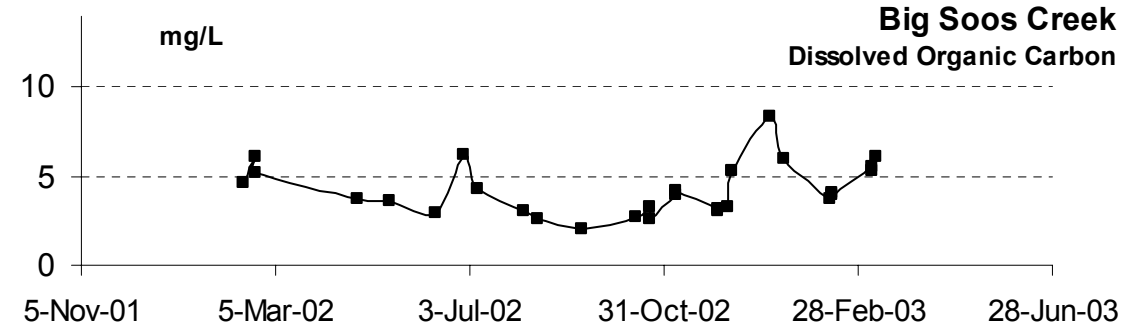

Big Soos Creek
Alkalinity
mgCaCO3/L
70
60
50
40
30
20
10
0
28-Oct-95
19-Jun-97
09-Feb-99
01-Oct-00
24-May-02

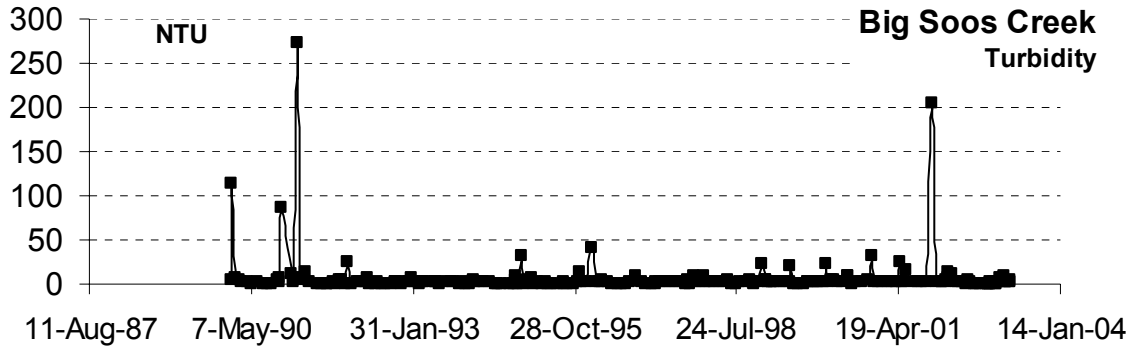

Big Soos Creek
Conductivity
umhos/cm
180
160
140
120
100
80
60
19-Oct-89
31-Jan-93
15-May-96
28-Aug-99
10-Dec-02


Big Soos Creek
Fecal Coliform
Org/100 ml
10000
8000
6000
4000
2000
0
11-Jul-89
23-Oct-92
05-Feb-96
20-May-99
01-Sep-02


Big Soos Creek
Enterococcus
Org/100 ml
14000
12000
10000
8000
6000
4000
2000
0
11-Jul-89
06-Apr-92
01-Jan-95
27-Sep-97
23-Jun-00
20-Mar-03

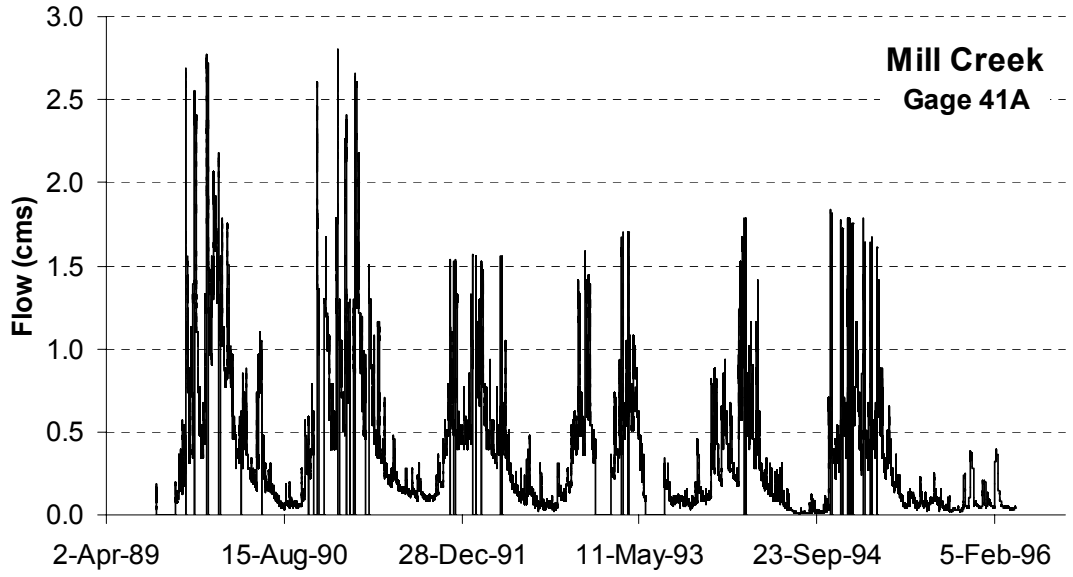

Big Soos Creek
Total Organic Carbon
mg/L
10
5
0
5-Nov-01
5-Mar-02
3-Jul-02
31-Oct-02
28-Feb-03
28-Jun-03


Big Soos Creek
Dissolved Organic Carbon
mg/L
10
5
0
5-Nov-01
5-Mar-02
3-Jul-02
31-Oct-02
28-Feb-03
28-Jun-03

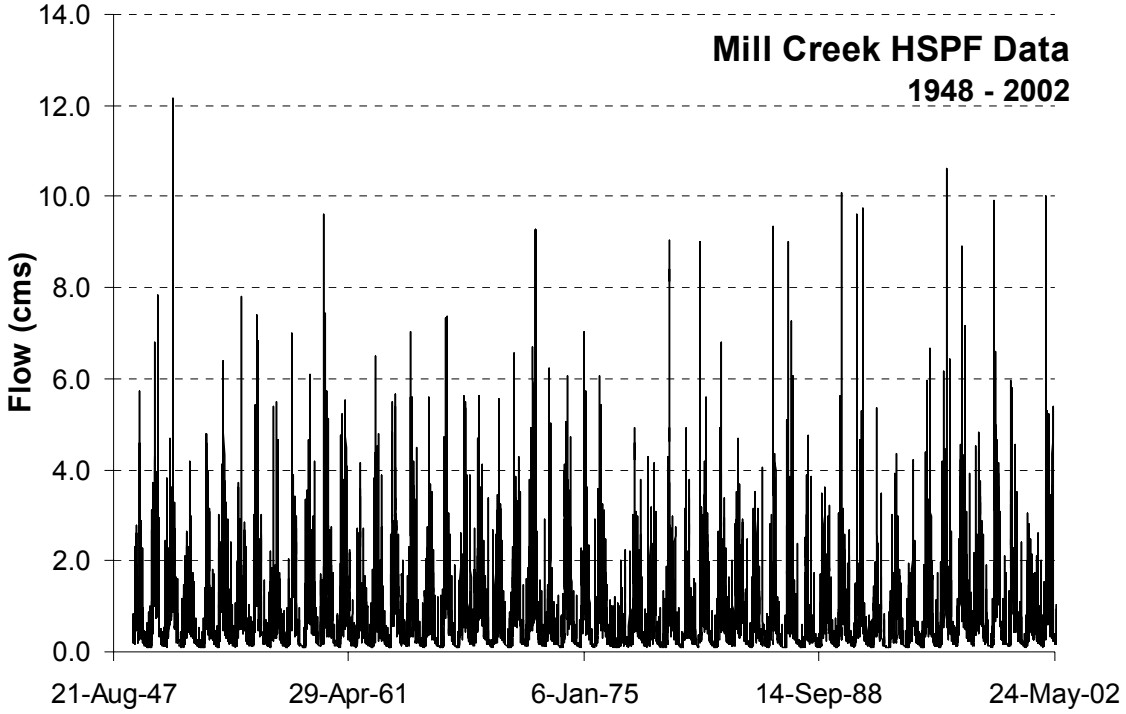


Mill Creek Data

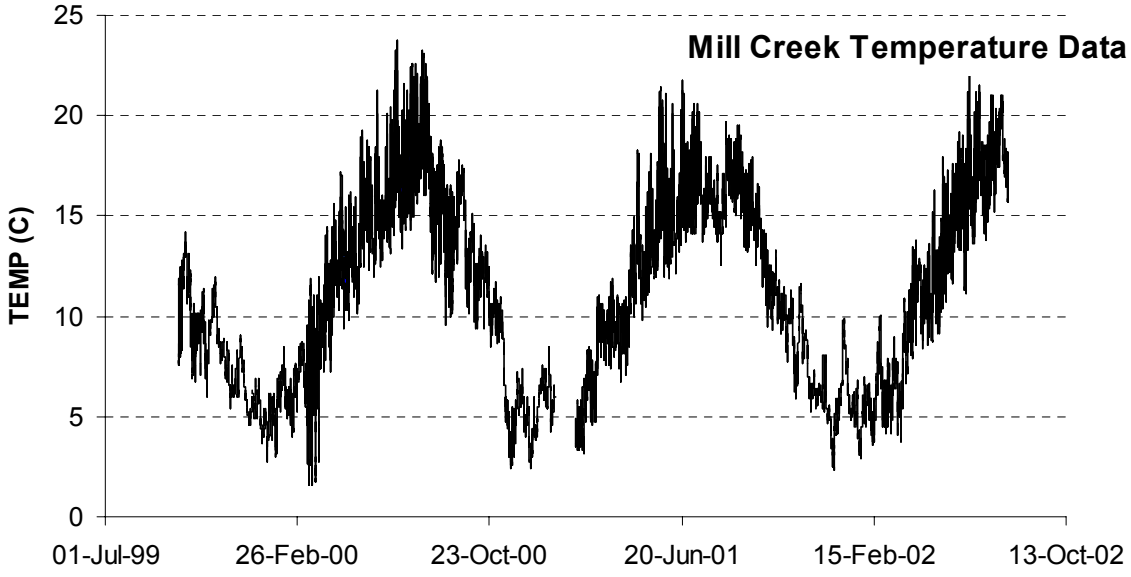
King County has a flow gage (#41a) on Mill Creek that recorded data through March 1996. Data from this gage has been determined to be unreliable because of backwater from Green River (DeGasperi 2003).



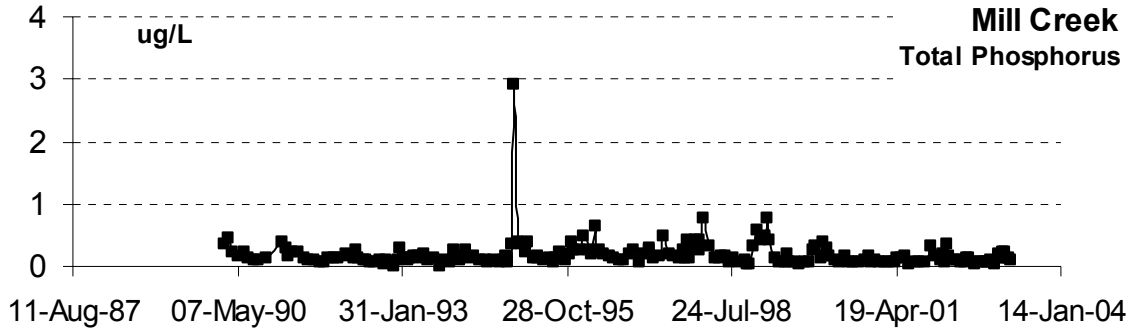
King County has modeled the Mill Creek drainage and provided daily average flow data from 1948 to 2002.

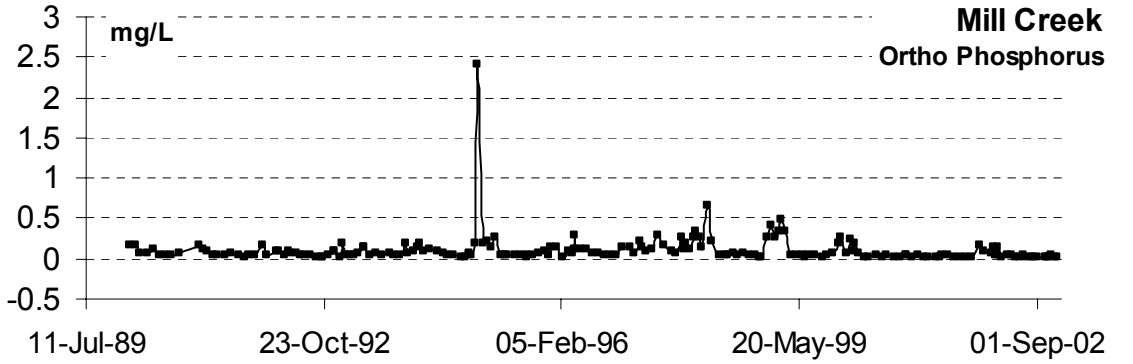


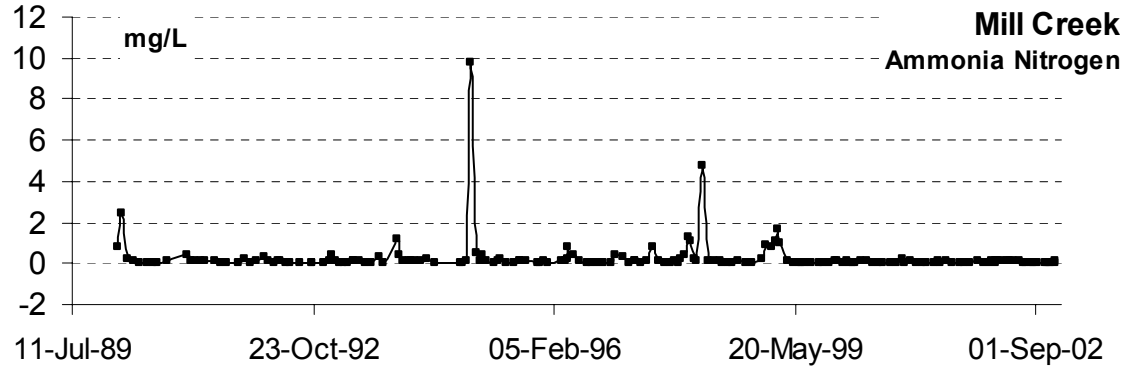
Mill Creek Temperature was recorded in 15 minute intervals by King County (41a), and data were provided from October 1999 to August 2002.

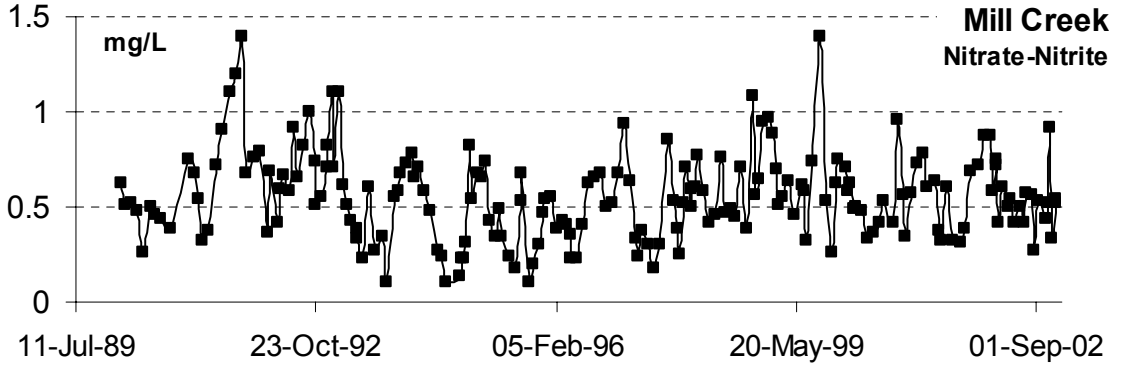


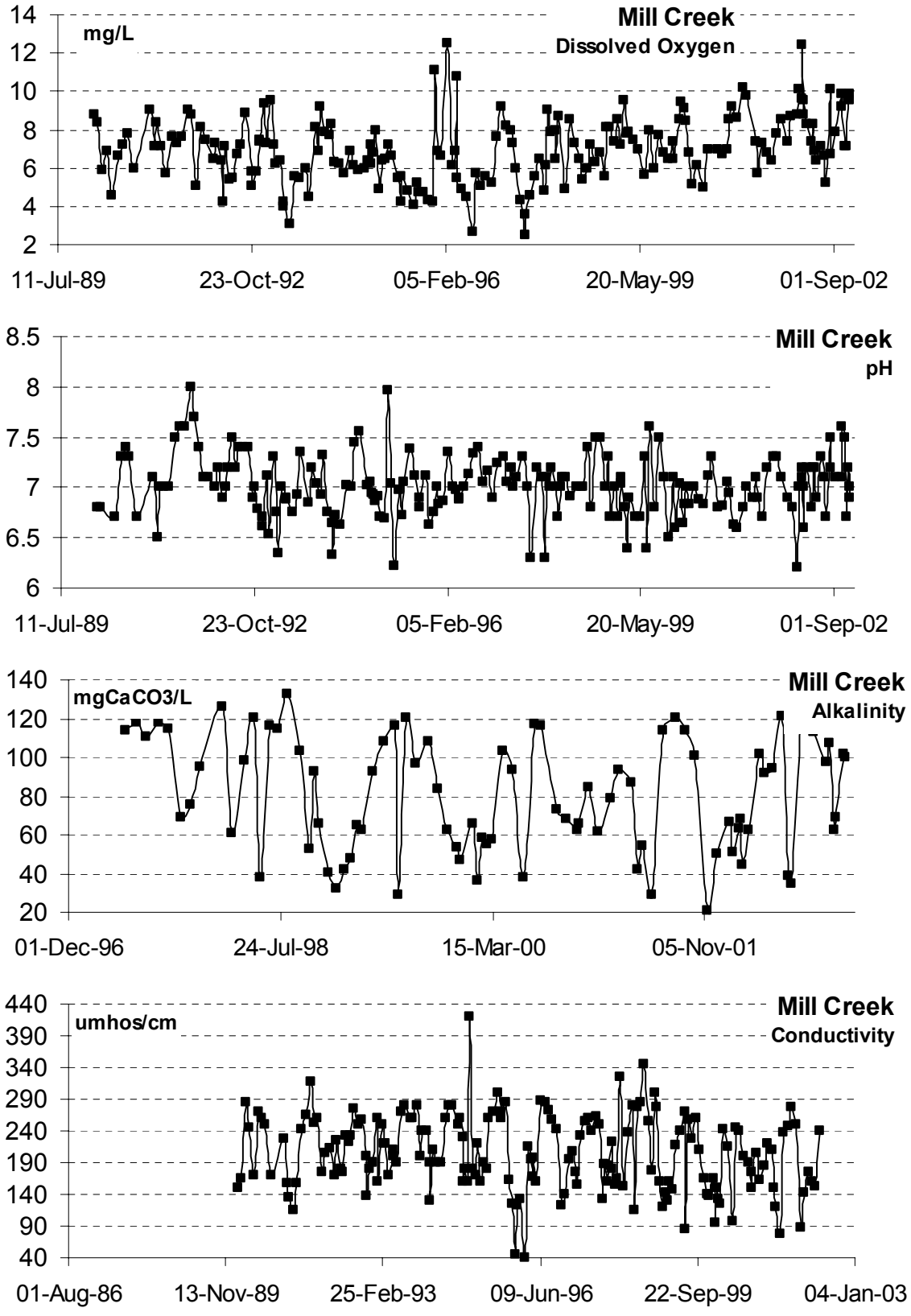
Water quality constituent data were provided from 1990 to 2002.

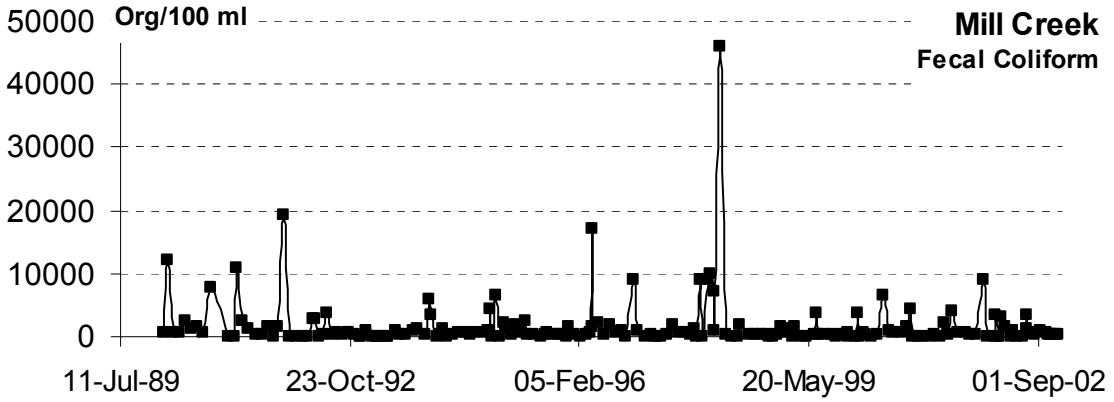

Mill Creek
Total Phosphorus
ug/L
4
3
2
1
0
11-Aug-87
07-May-90
31-Jan-93
28-Oct-95
24-Jul-98
19-Apr-01
14-Jan-04

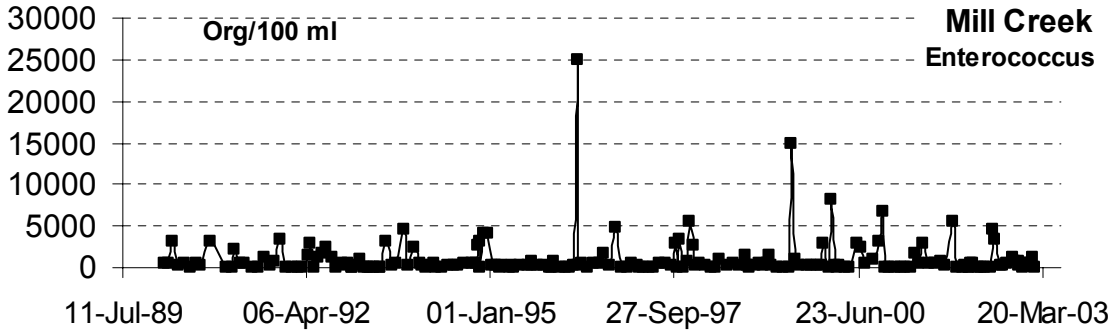

Mill Creek
Ortho Phosphorus
mg/L
3
2.5
2
1.5
1
0.5
0
-0.5
11-Jul-89
23-Oct-92
05-Feb-96
20-May-99
01-Sep-02

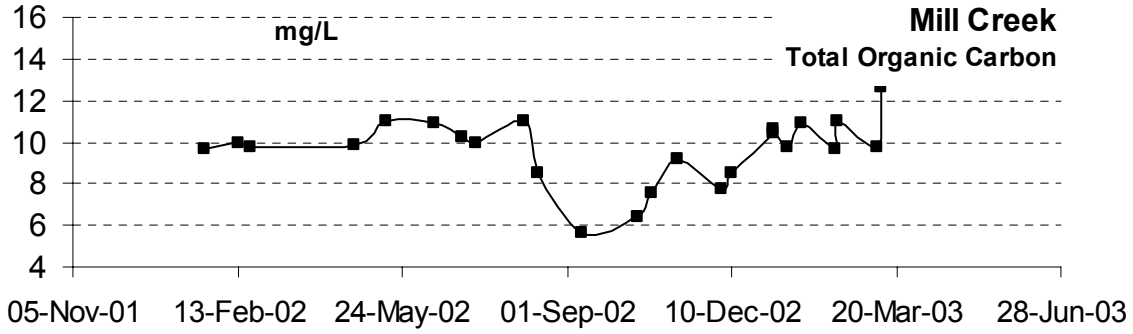

Mill Creek
Ammonia Nitrogen
mg/L
12
10
8
6
4
2
0
-2
11-Jul-89
23-Oct-92
05-Feb-96
20-May-99
01-Sep-02

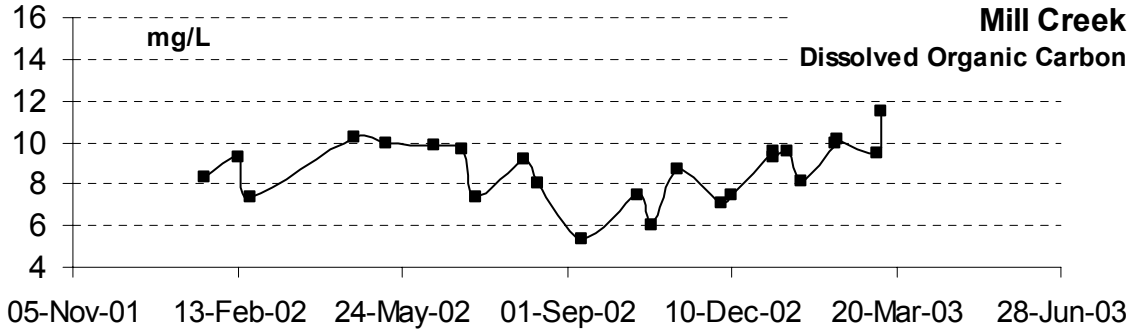

Mill Creek
Nitrate-Nitrite
mg/L
1.5
1
0.5
0
11-Jul-89
23-Oct-92
05-Feb-96
20-May-99
01-Sep-02

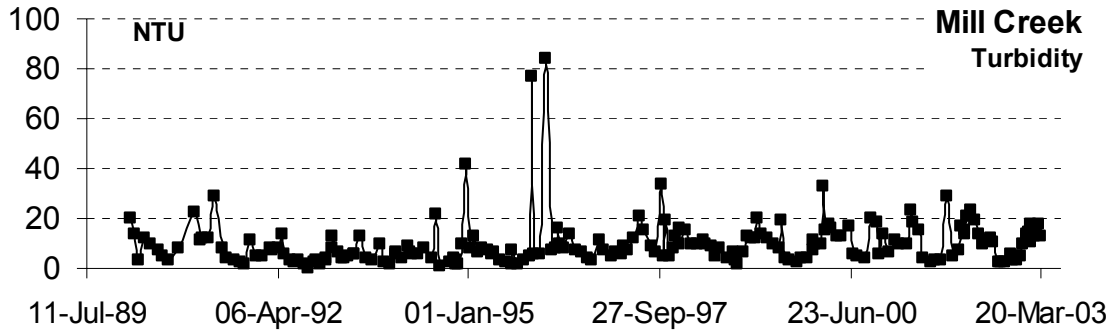

Mill Creek
Dissolved Oxygen
mg/L
14
12
10
8
6
4
2
11-Jul-89
23-Oct-92
05-Feb-96
20-May-99
01-Sep-02
Mill Creek
pH
8.5
8
7.5
7
6.5
6
11-Jul-89
23-Oct-92
05-Feb-96
20-May-99
01-Sep-02
Mill Creek
Alkalinity
mgCaCO3/L
140
120
100
80
60
40
20
01-Dec-96
24-Jul-98
15-Mar-00
05-Nov-01
Mill Creek
Conductivity
umhos/cm
440
390
340
290
240
190
140
90
40
01-Aug-86
13-Nov-89
25-Feb-93
09-Jun-96
22-Sep-99
04-Jan-03


Org/100 ml
Mill Creek
Fecal Coliform
50000
40000
30000
20000
10000
0
11-Jul-89
23-Oct-92
05-Feb-96
20-May-99
01-Sep-02


Org/100 ml
Mill Creek
Enterococcus
30000
25000
20000
15000
10000
5000
0
11-Jul-89
06-Apr-92
01-Jan-95
27-Sep-97
23-Jun-00
20-Mar-03

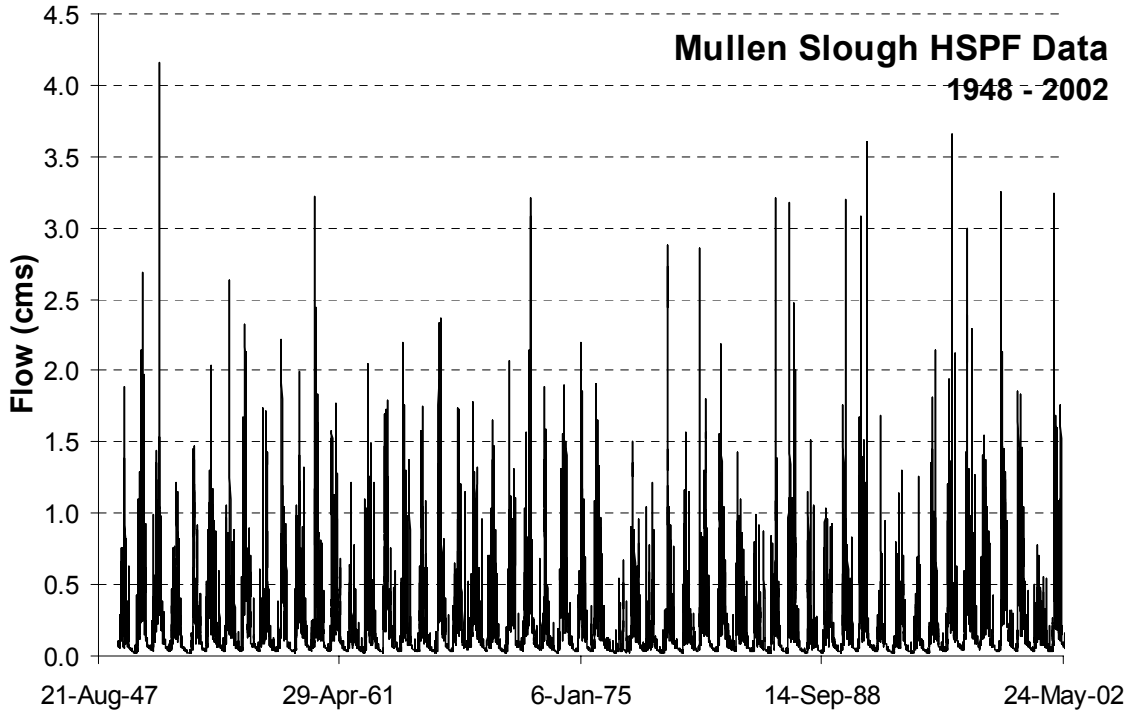

mg/L
Mill Creek
Total Organic Carbon
16
14
12
10
8
6
4
05-Nov-01
13-Feb-02
24-May-02
01-Sep-02
10-Dec-02
20-Mar-03
28-Jun-03

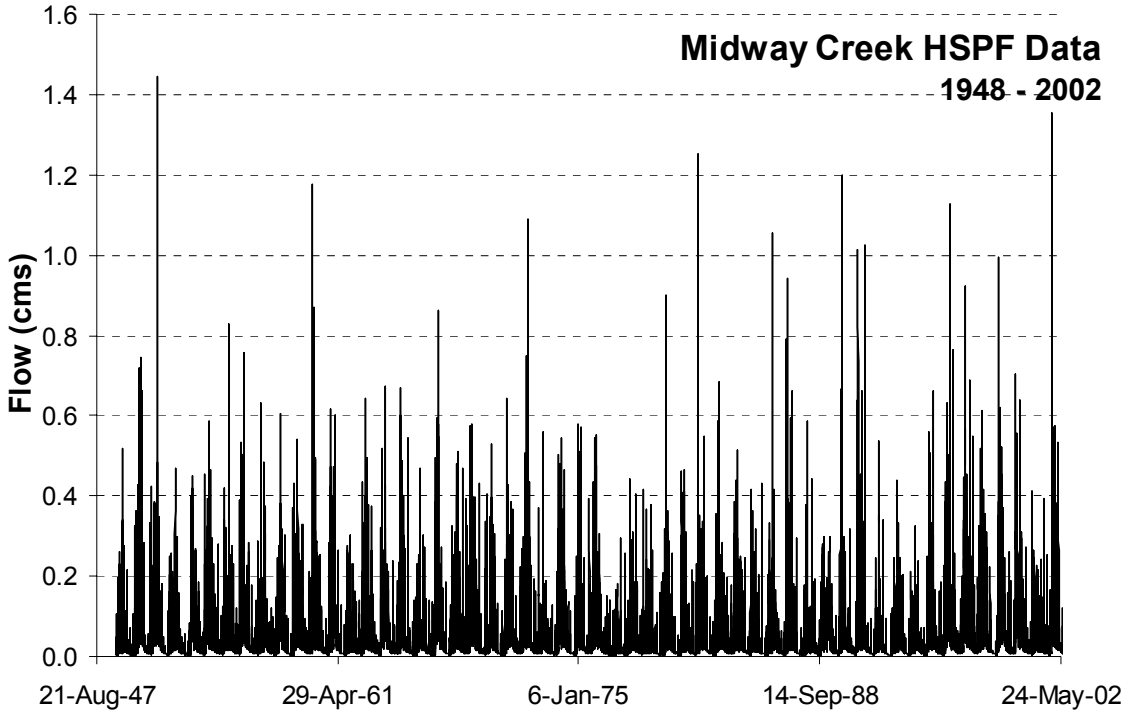

mg/L
Mill Creek
Dissolved Organic Carbon
16
14
12
10
8
6
4
05-Nov-01
13-Feb-02
24-May-02
01-Sep-02
10-Dec-02
20-Mar-03
28-Jun-03

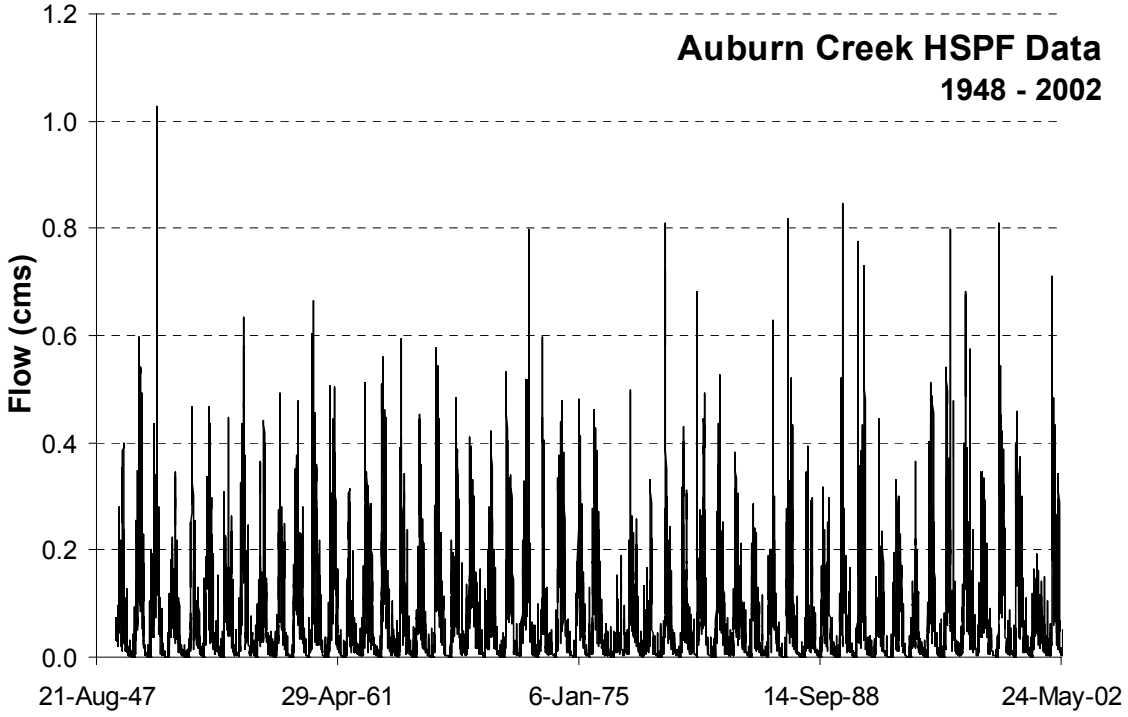


Mullen Slough, Midway Creek, and Auburn Creek

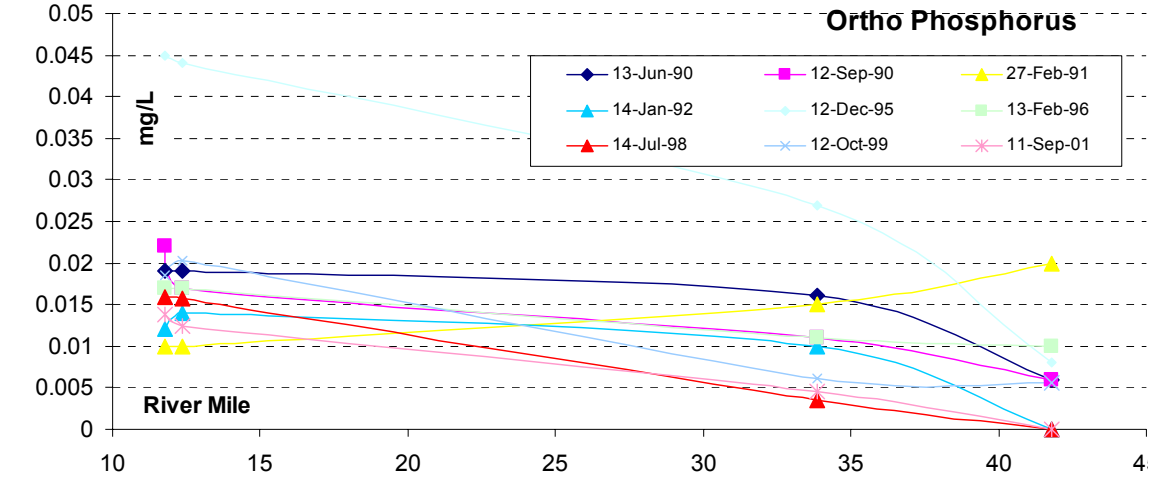
King County provided HSPF data for Mullen Slough, Midway Creek, and Auburn Creek from 1948 to 2002.

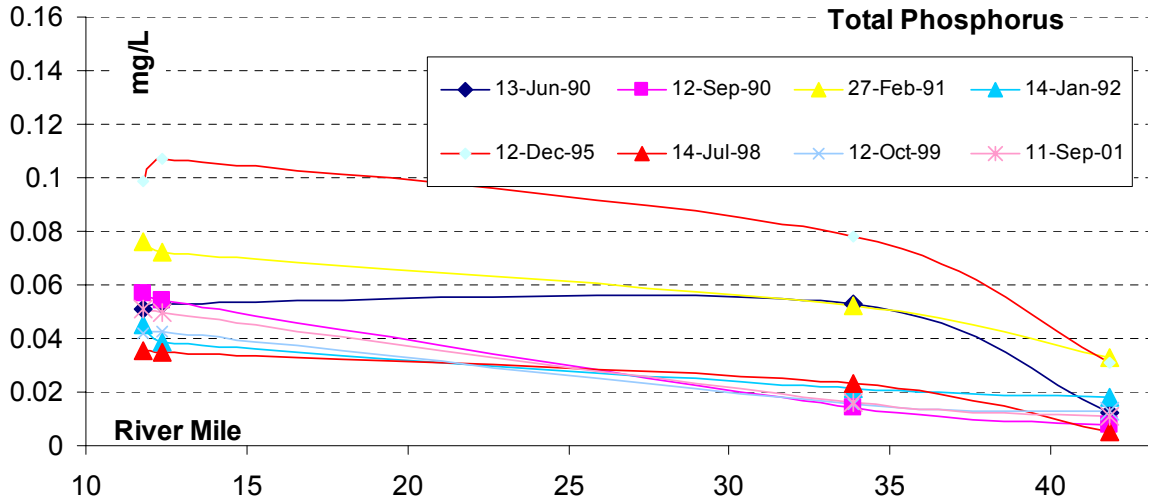


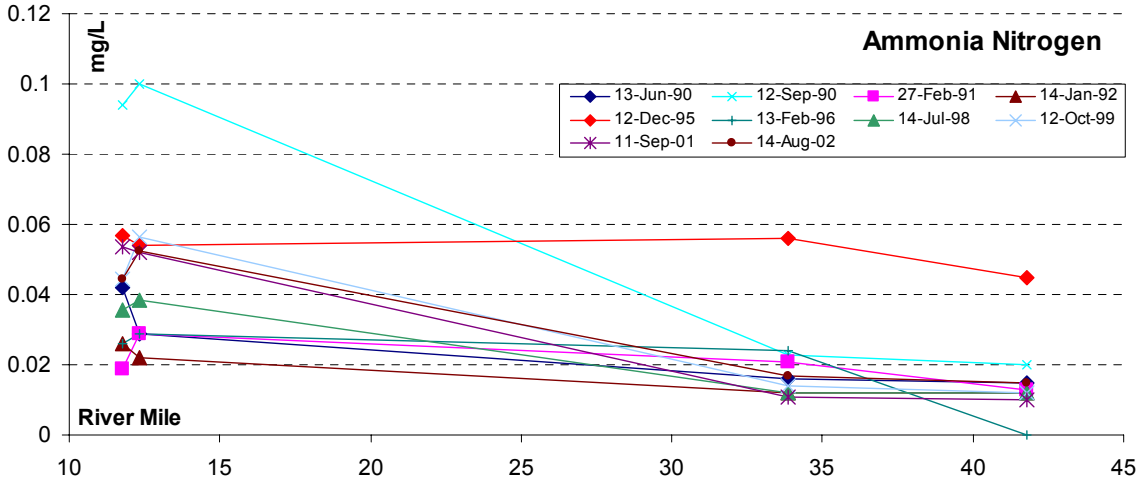

Midway Creek HSPF Data
1948 - 2002
Flow (cms)
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
21-Aug-47
29-Apr-61
6-Jan-75
14-Sep-88
24-May-02

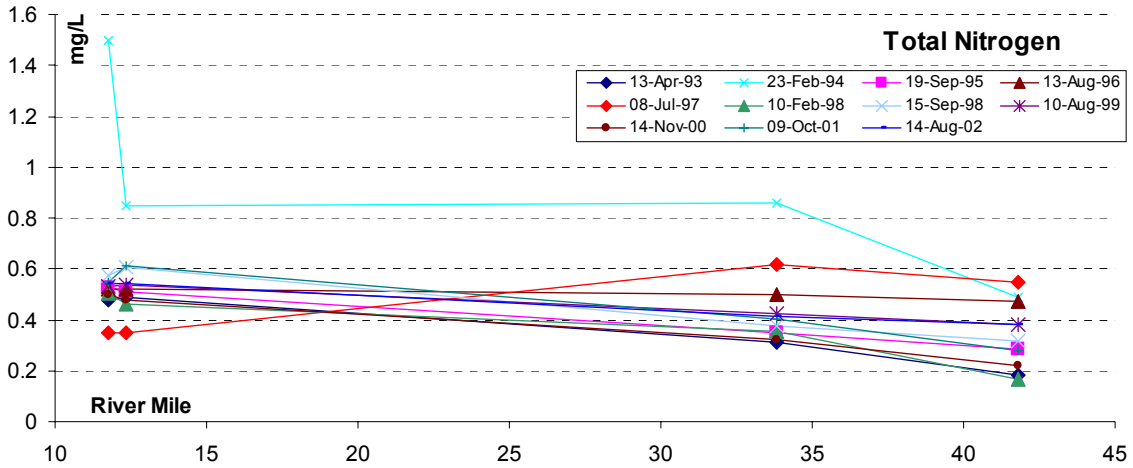

Auburn Creek HSPF Data
1948 - 2002
Flow (cms)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
21-Aug-47
29-Apr-61
6-Jan-75
14-Sep-88
24-May-02

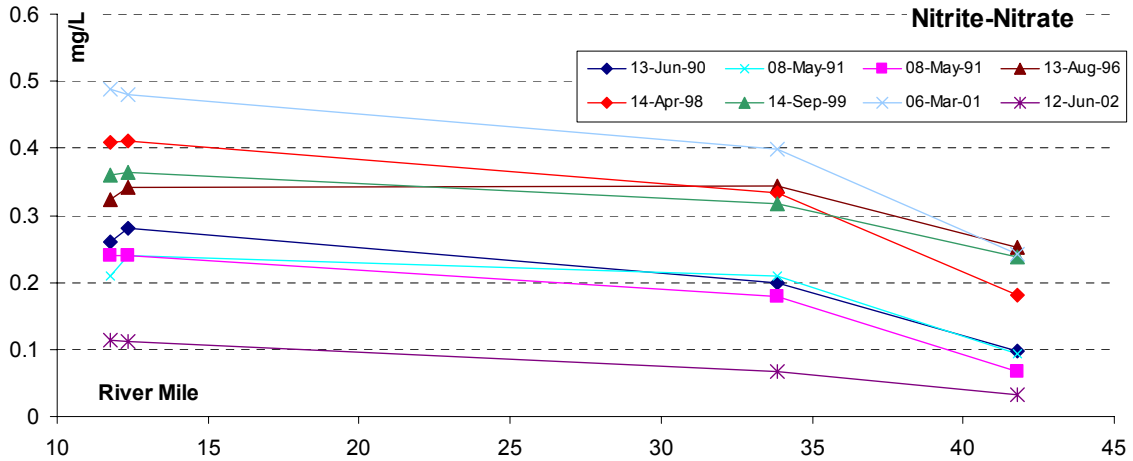
Appendix B: Water Quality Longitudinal Profiles

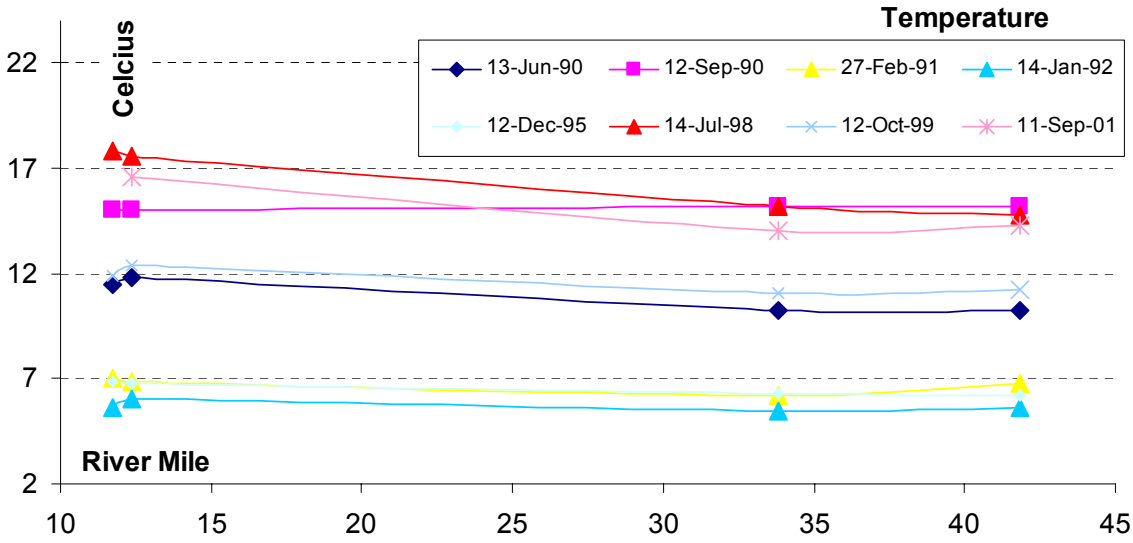


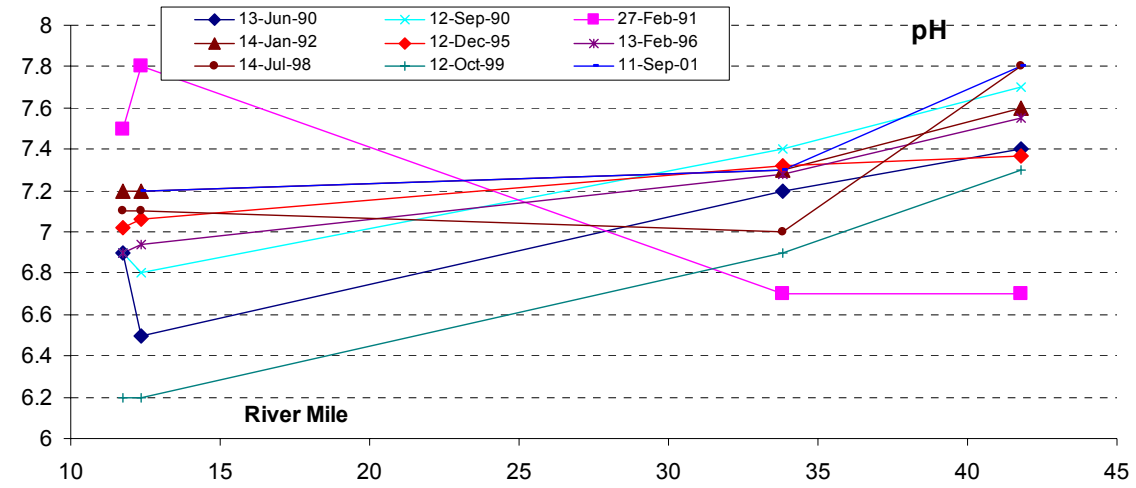


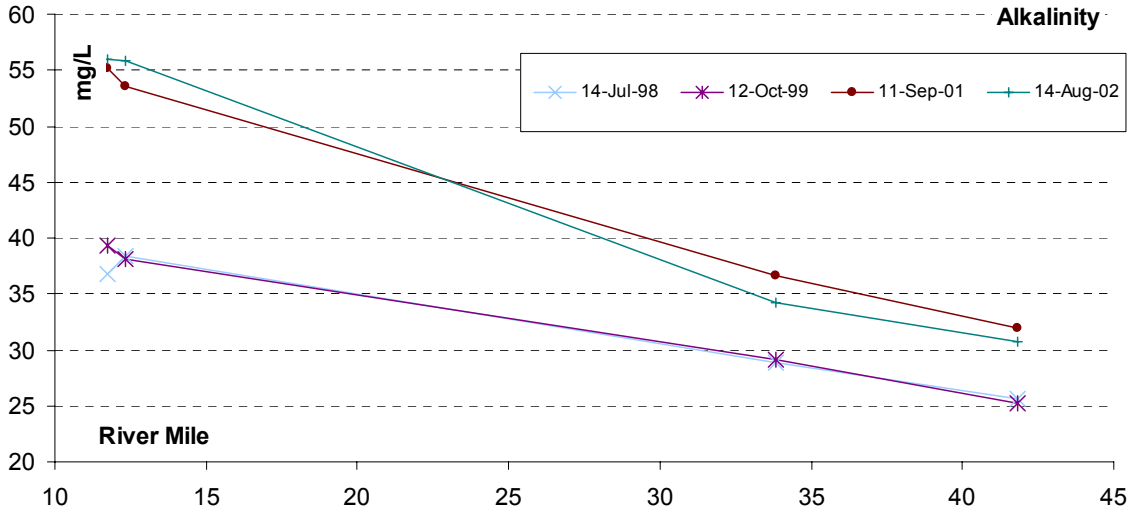


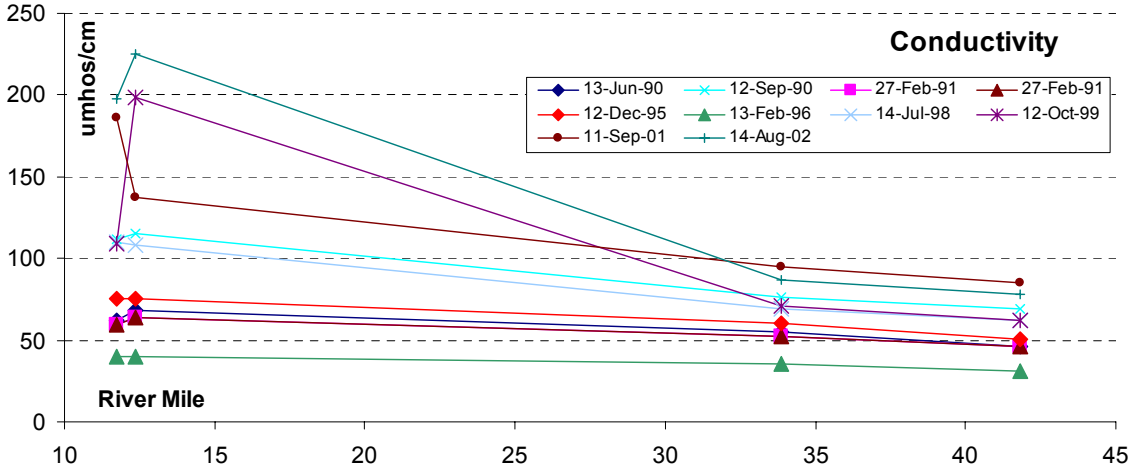

Total Nitrogen
mg/L
13-Apr-93
23-Feb-94
19-Sep-95
13-Aug-96
08-Jul-97
10-Feb-98
15-Sep-98
10-Aug-99
14-Nov-00
09-Oct-01
14-Aug-02
River Mile
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
10
15
20
25
30
35
40
45

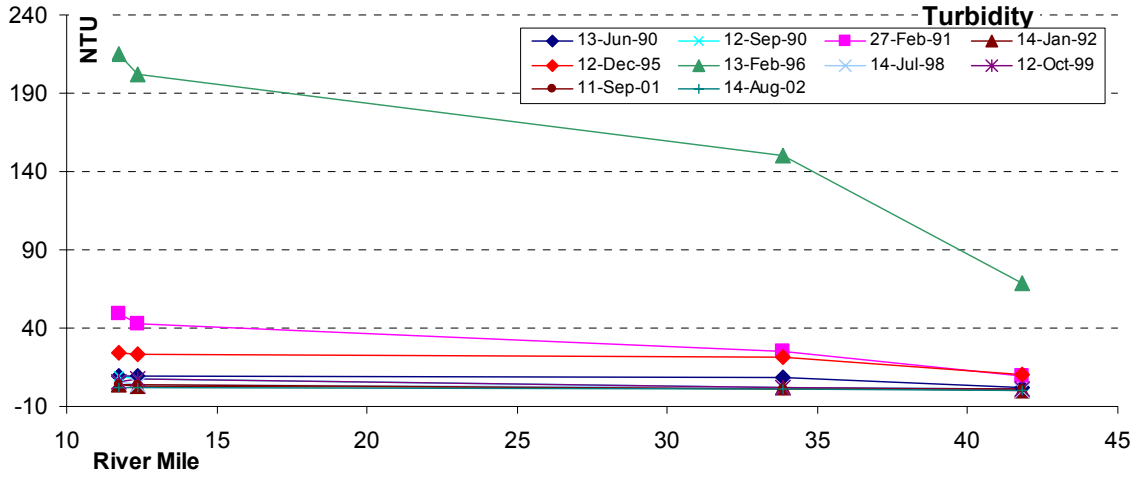

Nitrite-Nitrate
mg/L
13-Jun-90
08-May-91
08-May-91
13-Aug-96
14-Apr-98
14-Sep-99
06-Mar-01
12-Jun-02
River Mile
0.6
0.5
0.4
0.3
0.2
0.1
0
10
15
20
25
30
35
40
45

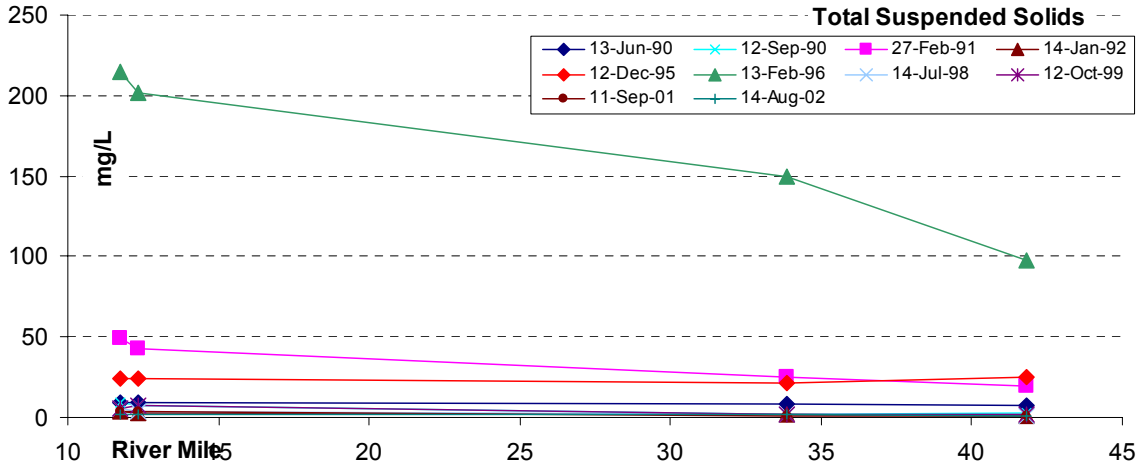

Temperature
Celcius
13-Jun-90
12-Sep-90
27-Feb-91
14-Jan-92
12-Dec-95
14-Jul-98
12-Oct-99
11-Sep-01
River Mile
22
17
12
7
2
10
15
20
25
30
35
40
45

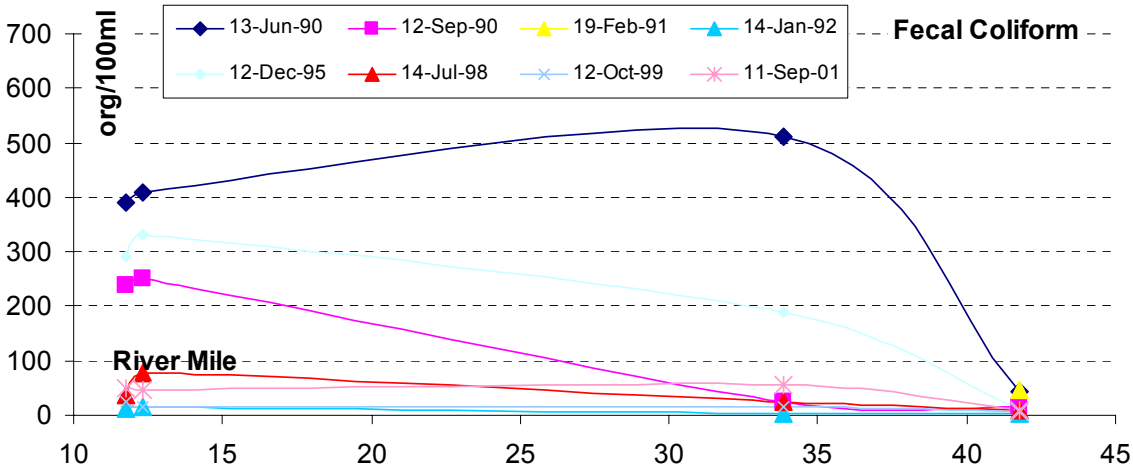

pH
13-Jun-90
12-Sep-90
27-Feb-91
14-Jan-92
12-Dec-95
13-Feb-96
14-Jul-98
12-Oct-99
11-Sep-01
River Mile
8
7.8
7.6
7.4
7.2
7
6.8
6.6
6.4
6.2
6
10
15
20
25
30
35
40
45

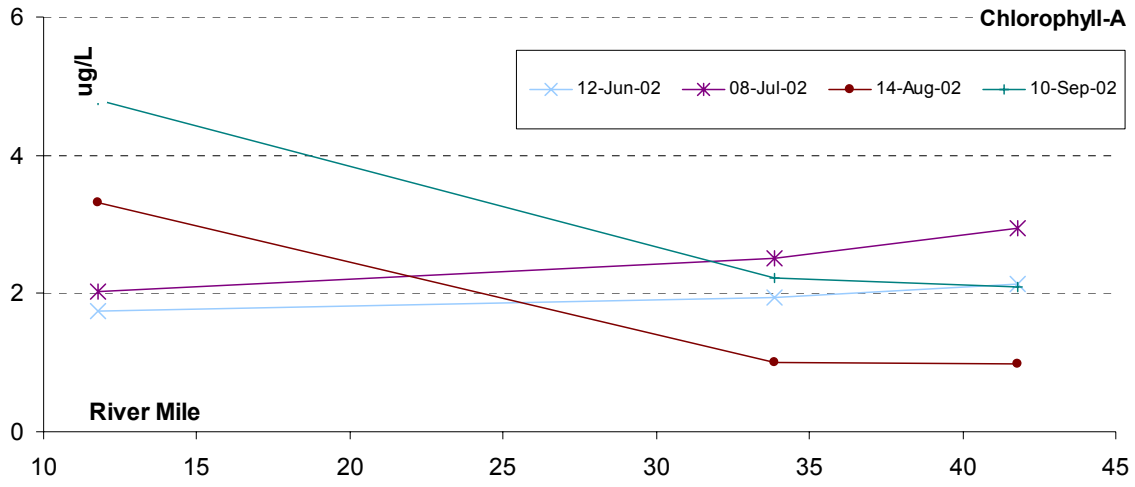

Alkalinity
mg/L
14-Jul-98
12-Oct-99
11-Sep-01
14-Aug-02
River Mile
60
55
50
45
40
35
30
25
20
10
15
20
25
30
35
40
45

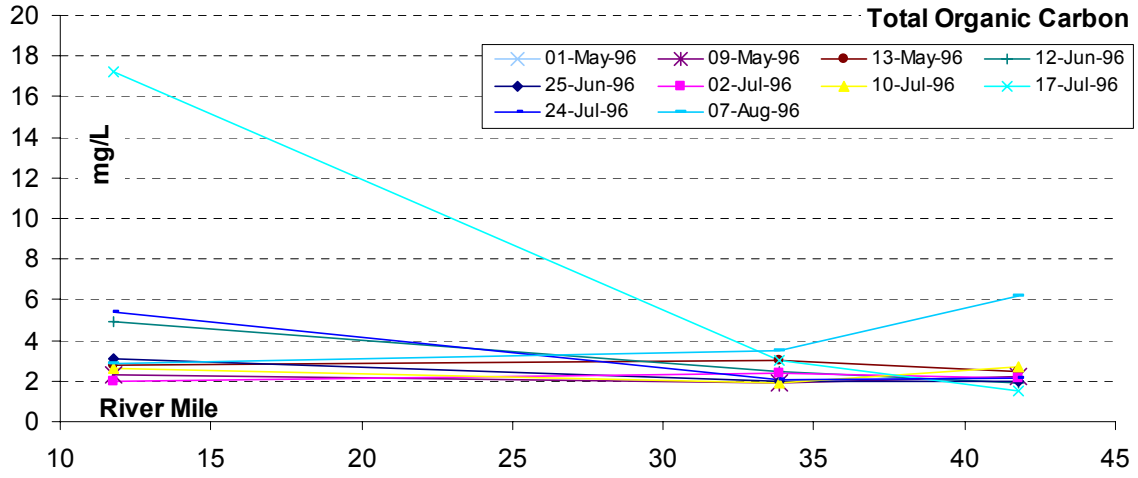

Conductivity
umhos/cm
13-Jun-90
12-Sep-90
27-Feb-91
27-Feb-91
12-Dec-95
13-Feb-96
14-Jul-98
12-Oct-99
11-Sep-01
14-Aug-02
River Mile
250
200
150
100
50
0
10
15
20
25
30
35
40
45

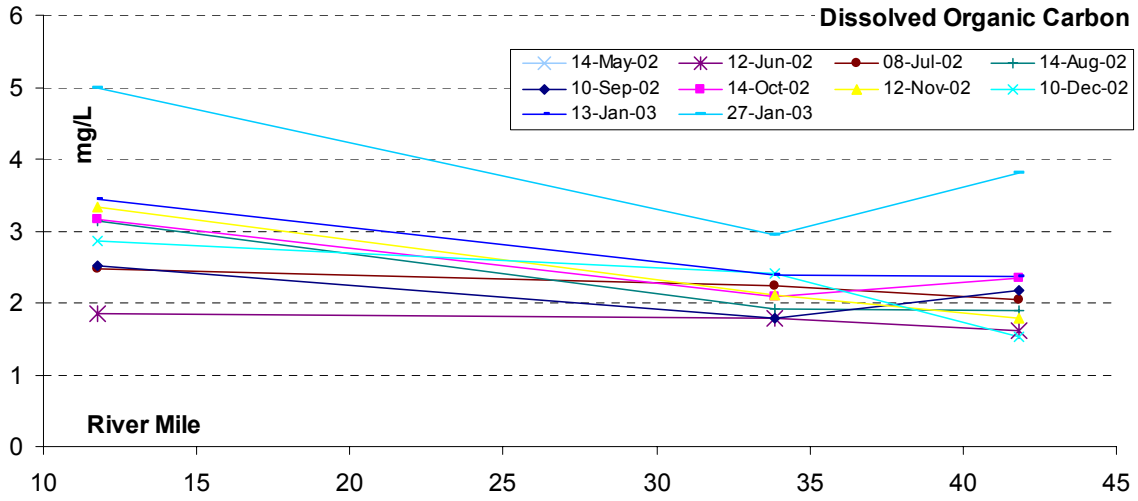

Turbidity
NTU
240
190
140
90
40
-10
10
15
20
25
30
35
40
45
River Mile
13-Jun-90
12-Sep-90
27-Feb-91
14-Jan-92
12-Dec-95
13-Feb-96
14-Jul-98
12-Oct-99
11-Sep-01
14-Aug-02


Total Suspended Solids
mg/L
250
200
150
100
50
0
10
15
20
25
30
35
40
45
River Mile
13-Jun-90
12-Sep-90
27-Feb-91
14-Jan-92
12-Dec-95
13-Feb-96
14-Jul-98
12-Oct-99
11-Sep-01
14-Aug-02


Fecal Coliform
org/100ml
700
600
500
400
300
200
100
0
10
15
20
25
30
35
40
45
River Mile
13-Jun-90
12-Sep-90
19-Feb-91
14-Jan-92
12-Dec-95
14-Jul-98
12-Oct-99
11-Sep-01


Chlorophyll-A
ug/L
12-Jun-02
08-Jul-02
14-Aug-02
10-Sep-02
River Mile
0
2
4
6
10
15
20
25
30
35
40
45


Total Organic Carbon
mg/L
01-May-96
09-May-96
13-May-96
12-Jun-96
25-Jun-96
02-Jul-96
10-Jul-96
17-Jul-96
24-Jul-96
07-Aug-96
River Mile
0
2
4
6
8
10
12
14
16
18
20
10
15
20
25
30
35
40
45


Dissolved Organic Carbon
mg/L
14-May-02
12-Jun-02
08-Jul-02
14-Aug-02
10-Sep-02
14-Oct-02
12-Nov-02
10-Dec-02
13-Jan-03
27-Jan-03
River Mile
0
1
2
3
4
5
6
10
15
20
25
30
35
40
45

Appendix C: Travel Time Analysis

Flow data for the upstream boundary comes from a gage located 26 km upstream (USGS Gage 126700, near Palmer). To account for flow between the gage at Palmer and the upstream project boundary, King County hydrologists have prepared HSPF simulations of runoff from the basin area between the Palmer gage and the upstream boundary. Basin MG3 and a portion of MG2 will be added to flow from the Palmer gage for a better estimate of the flow at the upstream boundary. Also, because groundwater

The flow from the Palmer gage takes time to travel down to the downstream boundary of the 2 HSPF basins. To estimate this time period, flow data were compared at Palmer Gage and at a USGS gage at Auburn (Gage 12113300) for 2 separate time periods. Figure 262 shows data from the 2 gages for the month of August, 2002, and Figure 263 shows data for the same month, with the Palmer gage shifted ahead by 12 hours. Figure 264 and Figure 265 compares data from the same time and data shifted 12 hours for May, 2002.

The distance from the Palmer gage to the Auburn gage is 47 km, and the distance from the Palmer gage to the downstream end of Basin MG3 is 15 km, one-third of the distance to the Auburn gage. Therefore, when adding flows from Basin MG3, Flow from MG3 will be shifted back 4 hours.

The distance from the Palmer gage to Basin MG2 is 32 km, so when adding flow from MG2 the data will be shifted back 8 hours.

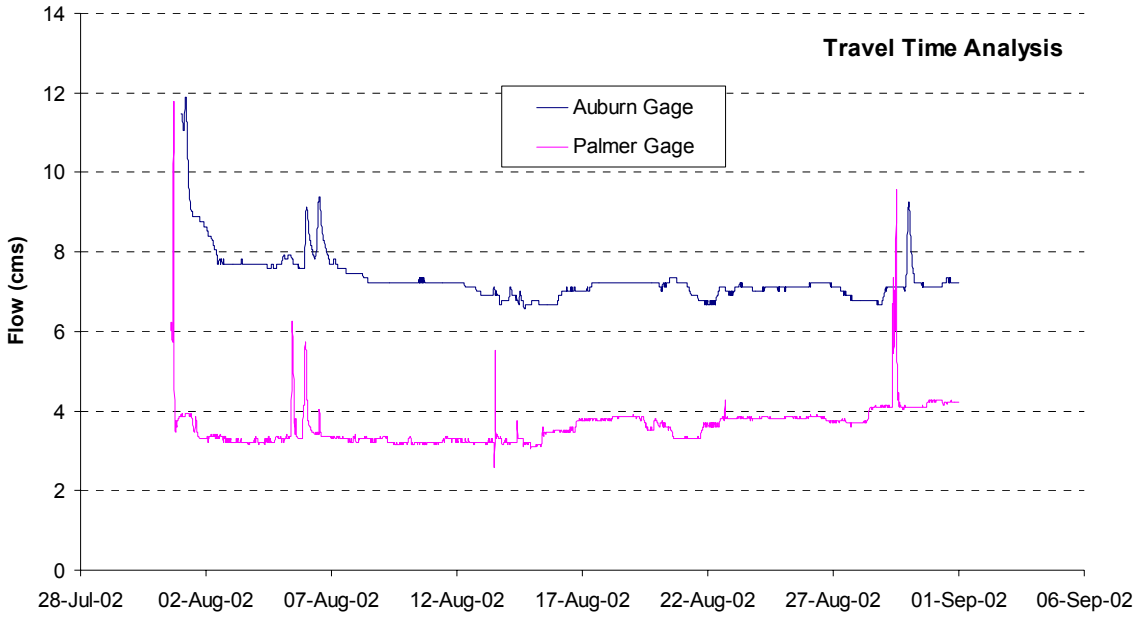


Figure 262: August 2002 flow data without travel time shift

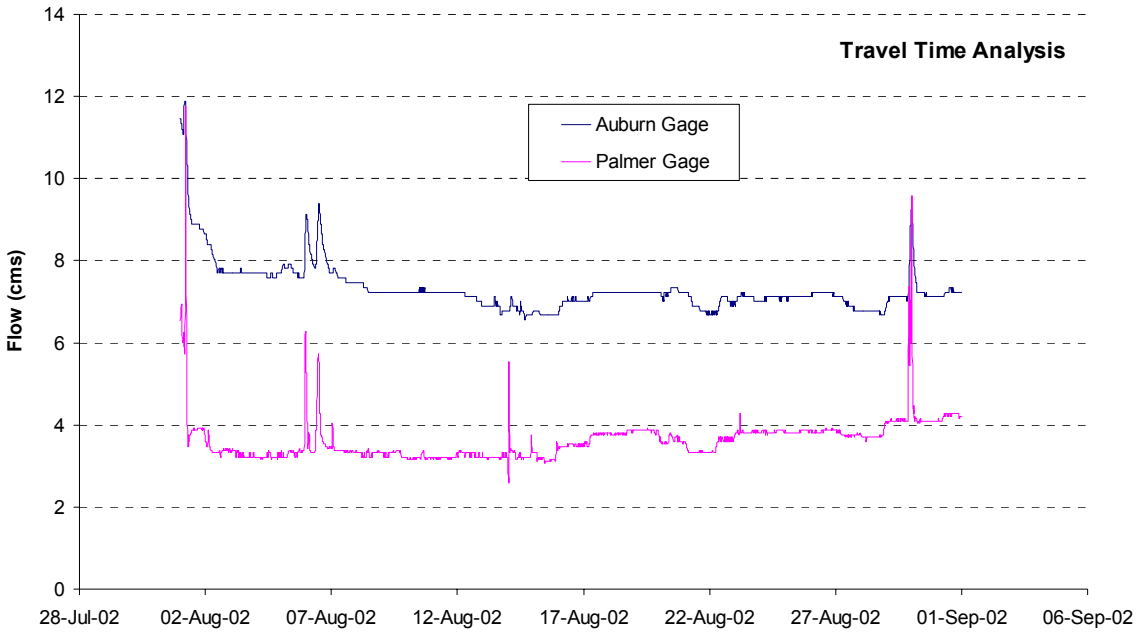


Figure 263: August 2002 flow data shifted by 12 hours

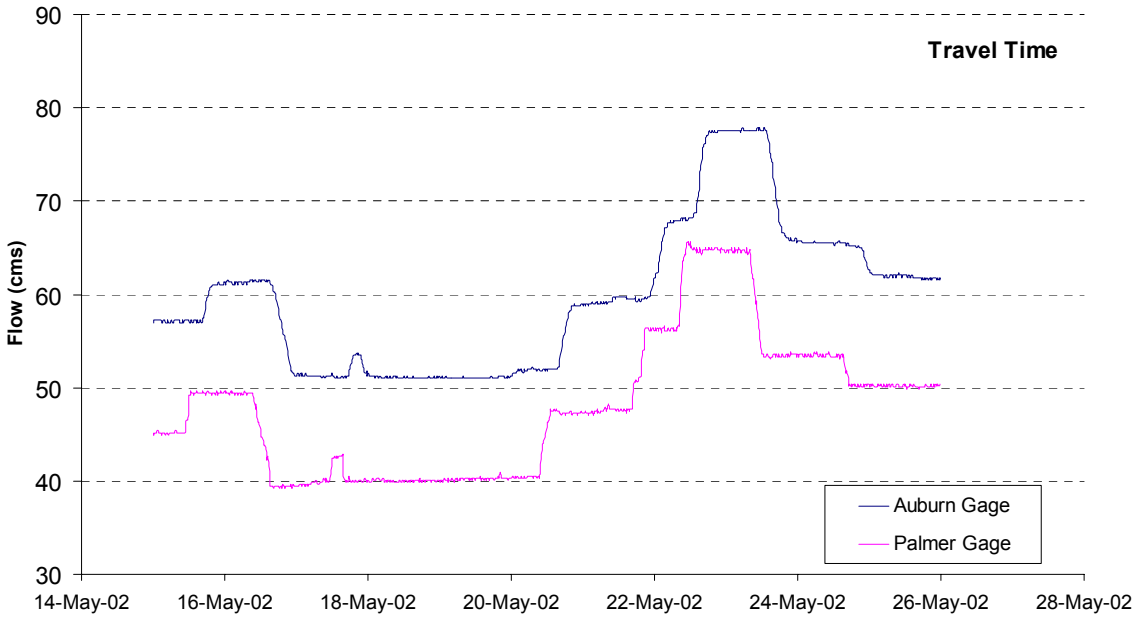


Figure 264: May 2002 flow data without travel time shift

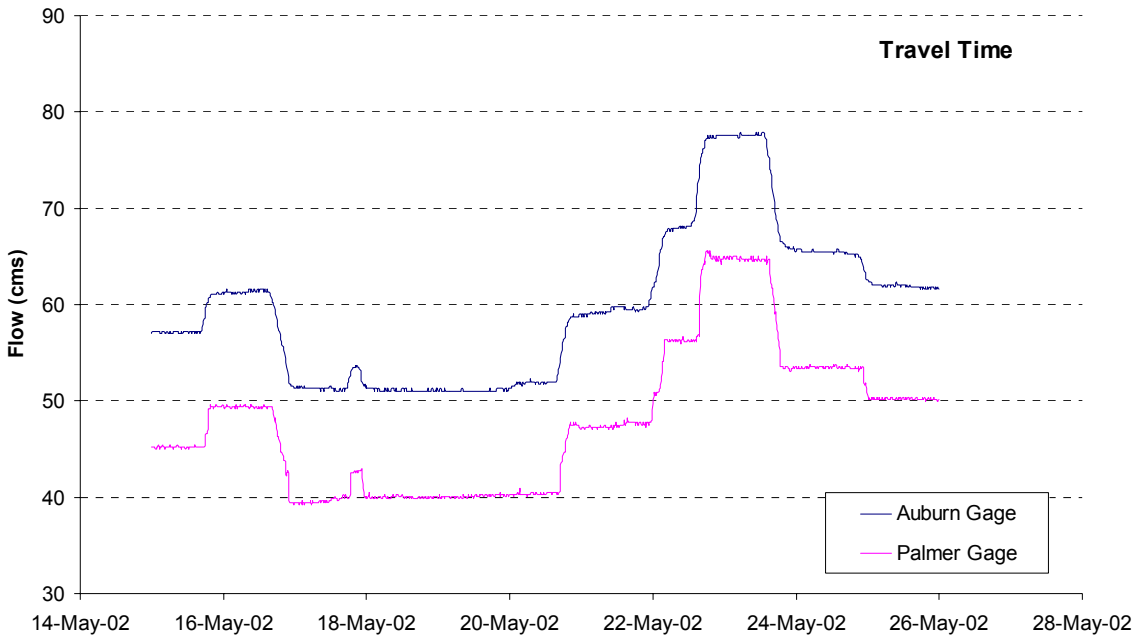


Figure 265: May 2002 flow data shifted by 12 hours

Appendix D: Water Quality Procedures

Algae:

If data are available:

$$\sum \Phi_{algae} = \Phi_{algae(total)} = \Phi_{Chl_a(total)} \Big/ Chla_to_Algae_ratio \quad (1)$$

Chla_to_Algae_Ratio = 35 and $\Phi_{Chl_a(total)} = data$ If missing data for both model run periods, use 0.00005 (Average from other stations). If some data are available, use average to fill missing data.

Total Organic Matter

If Total Organic Carbon (TOC) data were available, then:

$$\Phi_{TOM} = \frac{\Phi_{TOC}}{\delta_O} \quad (1)$$

$$\delta_O = 1.4$$

If no TOC then:

$$\Phi_{TOM} = \frac{\Phi_{POM} + \Phi_{algae}}{fraction} \quad (2)$$

Where fraction = 0.45

Detritus:

If Total Organic Carbon (TOC) data were available, then:

$$\Phi_{POM} = frac(\Phi_{TOM}) - \sum \Phi_{algae} \quad (3)$$

If no TOC then:

$$\Phi_{POM} = f(\Phi_{TSS}) - \sum \Phi_{algae} \quad (4)$$

$$f = \frac{\Phi_{POM} + \sum \Phi_{algae}}{\Phi_{TSS}} \quad (5)$$

Where TOC was not available, an average *f* was used from dates where TOC was available.

ISS:

$$\Phi_{ISS} = \left(\Phi_{TSS} - \sum \Phi_{algae} - \Phi_{POM}\right) \text{ or } \Phi_{ISS} = (1-f)(\Phi_{TSS}) \quad (2)$$

Dissolved Organic Matter (DOM)

$$\Phi_{DOM} = \Phi_{TOM} - \Phi_{POM} \quad (3)$$

Labile DOM

$$\Phi_{LDOM} = f_{LDOM}\Phi_{DOM} \quad (4)$$

$$f_{LDOM} = 0.50$$

Refractory DOM

$$\Phi_{RDOM} = (1 - f_{LDOM})\Phi_{DOM} \quad (5)$$

Labile POM

$$\Phi_{LPOM} = f_{LPOM}\Phi_{POM} \quad (6)$$

$$f_{LPOM} = 0.5$$

Refractory POM

$$\Phi_{RPOM} = (1 - f_{LPOM})\Phi_{POM} \quad (7)$$

Total Organic Phosphorus

$$\Phi_{PO4-P} = \Phi_{PO4} \quad (8)$$

If no data then $\Phi_{PO4} = \frac{\sum_{j=1}^{n} \Phi_{PO4-data}}{n}$ for all n data points. PO4 represents Dissolved Ortho Phosphorus. If not available then Ortho Phosphorus.

Nitrogen

$$\Phi_{TKN} = \Phi_{NH4} \quad (9)$$

If no data exists for that time then $\Phi_{NH4} = \frac{\sum_{j=1}^{n} \Phi_{NH4-data}}{n}$ for all n data points. NH4 represents NH3-N Dissolved, if available, if not then NH3-N total.

Nitrite-Nitrate

$\Phi_{NO3+NO2} = data$, if missing interpolate with nearest two points

Total Inorganic Carbon

$\Phi_{TIC} = function(\Phi_{alk} + pH + Temp)$ and is solved from the following equation:

$\Phi_{Alk} = TIC(\alpha_1 + 2\alpha_2) + [OH^-] - [H^+]$

where α_1 =2000 and α_2 =

Alkalinity

$\Phi_{alk} = data$, if missing interpolate with nearest two points. No data was available for 1995-1996 model run period, so the average from the 2001-2002 run period was used.

Dissolved Oxygen

$\Phi_{DO} = data$, if missing interpolate with nearest two points

Conductivity

$\Phi_{arbitray_constituent} = Conductivity = data$, if missing interpolate with nearest two points

Fecal Coliform

$\Phi_{arbitray_constituent} = FecalColiform = data$, if missing interpolate with nearest two points

Appendix E: Data Gap Memo

Memorandum

May 8, 2003

To: Curtis DeGasperi
King County Department of Natural Resources and Parks

From: Tim Kraft, Rob Annear, and Scott Wells
Civil and Environmental Engineering Department, Portland State University

RE: Green River Model Simulation; Data Gap Identification

King County provided a large majority of the data used in this project in database files. These data have been reviewed to determine data gaps during the model calibration period, and to determine how complete the data are for running the model between 1995 and 2002. This memo summarizes the available data, identifies data gaps, and identifies the model calibration period determined from this data analysis. This data gap analysis will also be provided in the Data Report.

1. Flow and Stage Data

Flow data has been obtained in 15-minute intervals for Green River at Palmer (the upstream boundary condition), Crisp Creek, Newaukum Creek, and Big Soos Creek. These data are complete, except for small periods, which can be filled in by CE-QUAL-W2 using interpolation.

HSPF model output has been provided for Mill Creek, Auburn Creek, Mullen Slough, and Midway Creek. This information set is complete between 1995 and 2002.

Stage data at USGS gage 13113500, near Tukwila, are available in hourly time intervals for the entire period, except for a period of missing or bad data from May 24, 1995 to May 8, 1996. Methods of estimating data for this time period are still being reviewed.

2. Temperature

Temperature is the limiting factor in determining the model calibration period. Table 1 shows the temperature monitoring done between 1995 and 2002, and Table 2 shows the monitoring stations used at each boundary and tributary location, along with the time period temperature was monitored for that station. Note that Table 2 does not address individual gaps within those time periods.

Table 1: Temperature data summary								
Location	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**
U/S Boundary	May - Nov	Jan - Nov	None	None	None	None	Apr - Dec	Jan- Sept
D/S Boundary	June - Dec	Jan - Dec	Jan - Dec	Jan - Dec	Jan - Dec	Jan	None	None
Newaukum Creek	None	July - Dec	Jan - Dec	Jan - Oct	None	None	July - Dec	Jan - Sept
Crisp Creek	None	None	Oct - Dec	Jan - Dec	Jan - Dec	Jan - Dec	Jan - Dec	Jan - Aug
Big Soos Creek	Jan - Dec	Jan - Dec	Jan - Dec	Jan - Dec	Jan - Dec	Jan - Dec	Jan - Dec	Jan - Aug
Mill Creek	None	None	None	None	Oct - Dec	Jan - Dec	Jan - Dec	Jan - Aug
Mullen Slough	None	None	None	None	None	None	None	None
Auburn Creek	None	None	None	None	None	None	None	None
Midway Creek	None	None	None	None	None	None	None	None

Table 2. Temperature gages at modeling locations			
Location	**Time Period of Data**	**Monitoring Station**	**Missing Data Periods**
Green River Upstream Boundary	May 1995 – Nov. 1999	KC gage at Black Diamond (WHI)	Dec 1999 - April 2001
	July 24, 2001 – Aug. 2, 2002	GDWQA at Whitney Bridge (GRT10 and GRT10_2)	
	Apr 2001 – Sept 2002	UW Gage (GR3-4)	
Downstream Boundary	June 1995 – Nov 1996 Jan 1996 – Jan 2000	KC Gage (BIC) USGS Gage (12113390)	January – June 1995 February 2000 – Dec 200
Crisp Creek	Oct 1997 – Aug 2002	KC gage at mouth (40d)	1995 to Sept. 1997
Newaukum Creek	July 1996 – Oct 1998 July 2001 – Sept 2002	USGS gage (12108500) GDWQA gage (GRT09)	Nov 1998 to June 2001
Big Soos Creek	Oct 1994 – Aug 2002	KC gage (54A)	Data set is complete
Mill Creek	Oct 1999 – Aug 2002	KC gage (41a)	1995 to Sept 1999
Mullen Slough	July 1996 – Nov 1996	KC gage (FRA)	Nov 1996 to Dec 2002

Based upon information in these 2 tables and the temperature data constraints, the model will be calibrated for 2 different time periods: May 1995 through November 1996, and April 2001 through July 2002.

To calibrate the model for November 1996 through April 2001, temperature data are needed for the upstream boundary and for Mill Creek.

Table 3 summarizes the temperature data gaps for each model calibration period. It's important to note the difference between the missing data listed in Table 2, and the data listed in Table 3. The missing data in Table 2 are where temperature was not monitored; the data gaps in Table 3 are when either temperature was not monitored, or there is bad or missing data within the monitoring period. Table 3 lists data for the model calibration periods, where Table 2 lists missing data between 1995 and 2002.

Table 3. Temperature data gaps for model calibration periods

Location	May 1995 - Nov 1999	April 2001 - July 2002
Green River Upstre Boundary	May 1, 1996 - June 7, 1996 July 26, 1996 - Aug 13, 1996	June 20, 2001 - July 24, 2001 Oct 17, 2001 - Nov 16, 2001 Feb 22, 2002 - March 14, 2002
Downstream Boundary	May 1, 1995 - May 24, 1995 Nov 21 1996 - Nov 30, 1996	No data available
Crisp Creek	No data available	Data set is complete
Newaukum Creek	May 1995 - July 1996	April 1, 2001 - July 23, 2001 Oct 25, 2001 - Mar 14, 2002
Big Soos Creek	Data set is complete	Data set is complete
Mill Creek	No data available	Data set is complete
Mullen Slough	July 1996 – Nov 1996	No data available
Midway Creek	No data available	No data available
Auburn Creek	No data available	No data available

Temperature data gaps in Table 3 will be filled by establishing a correlation with data from the same time period in other years, or with data from the same year from nearby tributaries. Mill Creek temperature data will be used for Mullen Slough, Auburn Creek, and Midway Creek for the 2001-2002 data period. For the downstream boundary in the April 2001 - July 2002 calibration period other gages will be looked at, including GRT01, GRT30, and GRT31, which are farther downstream on the Duwamish River.

3. Water Quality

Table 4 lists the water quality constituents to be modeled. Monthly samples are available for all constituents except chlorophyll A, used for modeling nutrients and eutrophication processes. For the rest of the constituents monthly samples are available for 1995 through 2002 for the boundary conditions and all tributaries except Mullen Slough, Mill Creek, and Auburn Creek.

Table 4. Water Quality Constituents	
DO, Dissolved Oxygen	Residence time
NH3, Ammonia	Inorganic Carbon
NO2-NO3, Nitrite-Nitrate	Conductivity
PO4, Ortho-phosphorus	pH
Organic Matter - LDOM, RDO LPOM, RDOM	Alkalinity

4. Recommendations for additional data collection

Flow data are readily available for boundary conditions and tributaries, but the only available calibration location is the USGS gage at Auburn (1211300). Having additional flow information downstream, while staying above the tidal affects, would be helpful.

Temperature data are the limiting factor in available model data. King County has begun a more aggressive temperature collection study, and this is helpful for calibrating the model in years 2001 and 2002. Temperature data at the downstream boundary was discontinued in January 2000. Additional data would be useful at this location. Monitoring temperature farther downstream from Auburn (but still upstream from tidal affects) would be helpful for model calibration.

For the future, to improve the model calibration the upstream boundary condition of the model should be moved upstream to the gage station just below the Howard Hanson Reservoir (USGS: 12106700). This location will provide a more accurate boundary condition with flow, temperature and water quality data. Additionally it would allow model development and calibration to better characterize groundwater inflows to the river. Additional gage stations measuring stage and discharge along the Green River would provide more model calibration points and further identify where groundwater is entering the system and would provide a better understanding of the flows and tidal influences at the downstream model boundary. Moving the upstream boundary condition to below Hanson Reservoir would require additional bathymetric data to develop the model grid.

There are limited data on dissolved organic carbon, total organic carbon, BOD_5, CBOD and chlorophyll a. Characterizing the organic matter and algal production is important in modeling the nutrients and eutrophication processes. Periodic grab samples of organic matter compartments and chlorophyll a in the Green River and major tributaries would be useful for the modeling effort.

Since flow data are minimal within the model domain, a dye study would be necessary to verify model travel times and dispersion characteristics. This would allow a much better check on the model predictive ability than currently exists. This is a very important part of river model development and should be performed at high and low flows.

To summarize, we recommend that the following additional data be developed to improve our understanding of the Green River system:

- Hydraulic and travel time data – provide another location for checking the flow rate within the model boundary or at the end of the model at the tidal boundary; perform a dye study to verify model hydraulics/travel time
- Temperature data – need to provide temperature data at lower tidal boundary. This may though not be important if flow does not reverse at the tidal boundary.
- Model development – extend the model to Hanson Reservoir
- Organic data – take systematic BOD_5/COD/TOC data to determine of this is an important source of oxygen depletion in the system
- Algae data - take systematic algae data to assess importance of algal blooms in the lower river

Appendix F: Station and Gage Locations

Table 10 and Table 11 list the stations used in the model calibration periods. Figure 266, on the following page, shows where each of these stations is located.

Table 10: Flow/Temperature/Water Quality Stations Used; May 1995 - Nov 1996

Boundary Condition/Tributary	Flow/ Stage	Temperature	Water Quality
Upstream Boundary	USGS 12106700	GR3-4, GR10_2	B319
Downstream Boundary	USGS 12113350	BIC	3106
Newaukum Creek	USGS 12108500	GDWQA GRT-09	322
Crisp Creek	KC 40d	KC 40d	321
Big Soos Creek	USGS 12112600	KC 54a	A320
Auburn Creek	HSPF	Mill Creek	Mill Creek
Mill Creek	HSPF	KC 41a	A315
Mullen Slough	HSPF	Mill Creek	Mill Creek
Midway Creek	HSPF	Mill Creek	Mill Creek
Distributed Inflows	HSPF	NEE	Big Soos Creek

Table 11: Flow/Temperature/Water Quality Stations Used; April 2001 - July 2002

Boundary Condition/Tributary	Flow/ Stage	Temperature	Water Quality
Upstream Boundary	USGS 12106700	GR3-4, GR10_2	B319
Downstream Boundary	USGS 12113350	GRT10	3106
Newaukum Creek	USGS 12108500	GDWQA GRT-09	322
Crisp Creek	KC 40d	KC 40d	321
Big Soos Creek	USGS 12112600	KC 54a	A320
Auburn Creek	HSPF	Mill Creek	Mill Creek
Mill Creek	HSPF	KC 41a	A315
Mullen Slough	HSPF	Mill Creek	Mill Creek
Midway Creek	HSPF	Mill Creek	Mill Creek
Distributed Inflows	HSPF	GRT04	Big Soos Creek

Figure 266: Data Monitoring Stations