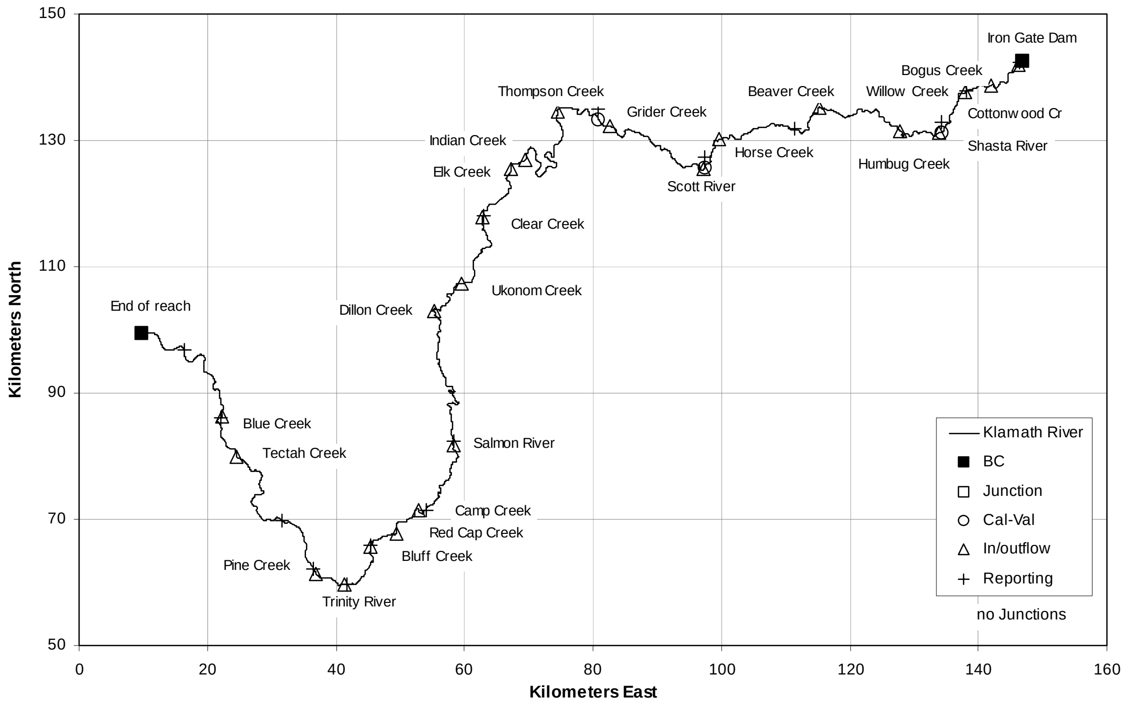
# Klamath River Modeling Framework to Support the PacifiCorp Federal Energy Regulatory Commission Hydropower Relicensing Application




Prepared for PacifiCorp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Napa, CA 94559


March 9, 2004

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## Unit Abbreviations

| | |
|---|---|
| Acre-feet | ac-ft |
| Cubic feet per second | cfs |
| Day | d |
| Degree Celsius | °C |
| Degree Fahrenheit | °F |
| Degree Kelvin | K |
| Feet | ft |
| Fluid ounce | fl oz |
| Gallon | gal |
| Gram | g |
| Hectare | ha |
| Hour | hr |
| Inch | in |
| Joule | J |
| Kilogram | kg |
| Kilometer | km |
| Liter | L |
| Meter | m |
| Microgram | µg |
| Micromhos | µmhos |
| Mile | mi |
| Millibar | mb |
| Milliliter | ml |
| Microgram | µg |
| Milligram | mg |
| Millimeter | mm |
| Ounce | oz |
| Parts per billion | ppb |
| Parts per million | ppm |
| Parts per thousand | ppt |
| Pascal | Pa |
| Pounds per square inch | psi |
| Second | s |
| Watt | W |
| Yard | yd |

# Unit Conversions

| Class | Multiply | By | To Obtain |
|---|---|---|---|
| Area | acre | 4047.0 | $m^2$ |
| | acre | 0.4047 | ha (10 000 $m^2$) |
| | $ft^2$ | 0.0929 | $m^2$ |
| | $yd^2$ | 0.8361 | $m^2$ |
| | $mi^2$ | 2.590 | $km^2$ |
| Length | ft | 0.3048 | m |
| | in | 25.4 | mm |
| | mi | 1.6093 | km |
| | yd | 0.9144 | m |
| Volume | $ft^3$ | 0.0283 | $m^3$ |
| | gal | 3.785 | L |
| | fl oz | 29.575 | mL |
| | $yd^3$ | 0.7646 | $m^3$ |
| | acre-feet | 1233.49 | $m^3$ |
| Mass | oz | 28.35 | g |
| | lb | 0.4536 | kg |
| Concentration | g/l | 1.0 | ppb |
| | g/l | 1.0 | $mg/m^3$ |
| | g/l | 0.001 | mg/l |
| | mg/l | 1.0 | ppm |
| | mg/l | 1.0 | $g/m^3$ |
| | mg/l | 0.001 | g/L |
| | g/l | 1.0 | ppt |
| | g/l | 1.0 | $kg/m^3$ |
| Density | $lb/ft^3$ | 6894.7 | $kg/m^3$ |
| Velocity | ft/s | 0.3048 | m/s |
| | mi/hr | 0.4470 | m/s |
| | mi/hr | 1.6093 | km/h |
| Flow Rate | cfs | 0.0283 | cms |
| Temperature | °F | $T_{°C} = (T_{°F} – 32.0)/1.8$ | °C |

# Temperature Conversion Table

| Temperature °C | Temperature °F | Temperature °C | Temperature °F |
|---|---|---|---|
| 0.0 | 32.0 | 25.0 | 77.0 |
| 1.0 | 33.8 | 26.0 | 78.8 |
| 2.0 | 35.6 | 27.0 | 80.6 |
| 3.0 | 37.4 | 28.0 | 82.4 |
| 4.0 | 39.2 | 29.0 | 84.2 |
| 5.0 | 41.0 | 30.0 | 86.0 |
| 6.0 | 42.8 | 31.0 | 87.8 |
| 7.0 | 44.6 | 32.0 | 89.6 |
| 8.0 | 46.4 | 33.0 | 91.4 |
| 9.0 | 48.2 | 34.0 | 93.2 |
| 10.0 | 50.0 | 35.0 | 95.0 |
| 11.0 | 51.8 | 36.0 | 96.8 |
| 12.0 | 53.6 | 37.0 | 98.6 |
| 13.0 | 55.4 | 38.0 | 100.4 |
| 14.0 | 57.2 | 39.0 | 102.2 |
| 15.0 | 59.0 | 40.0 | 104.0 |
| 16.0 | 60.8 | 41.0 | 105.8 |
| 17.0 | 62.6 | 42.0 | 107.6 |
| 18.0 | 64.4 | 43.0 | 109.4 |
| 19.0 | 66.2 | 44.0 | 111.2 |
| 20.0 | 68.0 | 45.0 | 113.0 |
| 21.0 | 69.8 | 46.0 | 114.8 |
| 22.0 | 71.6 | 47.0 | 116.6 |
| 23.0 | 73.4 | 48.0 | 118.4 |
| 24.0 | 75.2 | 49.0 | 120.2 |

# Julian Days (2000 Leap Year)

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1-Jan-00** | 1 | **1-Mar-00** | 61 | **1-May-00** | 122 | **1-Jul-00** | 183 | **1-Sep-00** | 245 | **1-Nov-00** | **306** |
| 2-Jan-00 | 2 | 2-Mar-00 | 62 | 2-May-00 | 123 | 2-Jul-00 | 184 | 2-Sep-00 | 246 | 2-Nov-00 | 307 |
| 3-Jan-00 | 3 | 3-Mar-00 | 63 | 3-May-00 | 124 | 3-Jul-00 | 185 | 3-Sep-00 | 247 | 3-Nov-00 | 308 |
| 4-Jan-00 | 4 | 4-Mar-00 | 64 | 4-May-00 | 125 | 4-Jul-00 | 186 | 4-Sep-00 | 248 | 4-Nov-00 | 309 |
| 5-Jan-00 | 5 | 5-Mar-00 | 65 | 5-May-00 | 126 | 5-Jul-00 | 187 | 5-Sep-00 | 249 | 5-Nov-00 | 310 |
| 6-Jan-00 | 6 | 6-Mar-00 | 66 | 6-May-00 | 127 | 6-Jul-00 | 188 | 6-Sep-00 | 250 | 6-Nov-00 | 311 |
| 7-Jan-00 | 7 | 7-Mar-00 | 67 | 7-May-00 | 128 | 7-Jul-00 | 189 | 7-Sep-00 | 251 | 7-Nov-00 | 312 |
| 8-Jan-00 | 8 | 8-Mar-00 | 68 | 8-May-00 | 129 | 8-Jul-00 | 190 | 8-Sep-00 | 252 | 8-Nov-00 | 313 |
| 9-Jan-00 | 9 | 9-Mar-00 | 69 | 9-May-00 | 130 | 9-Jul-00 | 191 | 9-Sep-00 | 253 | 9-Nov-00 | 314 |
| 10-Jan-00 | 10 | 10-Mar-00 | 70 | 10-May-00 | 131 | 10-Jul-00 | 192 | 10-Sep-00 | 254 | 10-Nov-00 | 315 |
| 11-Jan-00 | 11 | 11-Mar-00 | 71 | 11-May-00 | 132 | 11-Jul-00 | 193 | 11-Sep-00 | 255 | 11-Nov-00 | 316 |
| 12-Jan-00 | 12 | 12-Mar-00 | 72 | 12-May-00 | 133 | 12-Jul-00 | 194 | 12-Sep-00 | 256 | 12-Nov-00 | 317 |
| 13-Jan-00 | 13 | 13-Mar-00 | 73 | 13-May-00 | 134 | 13-Jul-00 | 195 | 13-Sep-00 | 257 | 13-Nov-00 | 318 |
| 14-Jan-00 | 14 | 14-Mar-00 | 74 | 14-May-00 | 135 | 14-Jul-00 | 196 | 14-Sep-00 | 258 | 14-Nov-00 | 319 |
| 15-Jan-00 | 15 | 15-Mar-00 | 75 | 15-May-00 | 136 | 15-Jul-00 | 197 | 15-Sep-00 | 259 | 15-Nov-00 | 320 |
| 16-Jan-00 | 16 | 16-Mar-00 | 76 | 16-May-00 | 137 | 16-Jul-00 | 198 | 16-Sep-00 | 260 | 16-Nov-00 | 321 |
| 17-Jan-00 | 17 | 17-Mar-00 | 77 | 17-May-00 | 138 | 17-Jul-00 | 199 | 17-Sep-00 | 261 | 17-Nov-00 | 322 |
| 18-Jan-00 | 18 | 18-Mar-00 | 78 | 18-May-00 | 139 | 18-Jul-00 | 200 | 18-Sep-00 | 262 | 18-Nov-00 | 323 |
| 19-Jan-00 | 19 | 19-Mar-00 | 79 | 19-May-00 | 140 | 19-Jul-00 | 201 | 19-Sep-00 | 263 | 19-Nov-00 | 324 |
| 20-Jan-00 | 20 | 20-Mar-00 | 80 | 20-May-00 | 141 | 20-Jul-00 | 202 | 20-Sep-00 | 264 | 20-Nov-00 | 325 |
| 21-Jan-00 | 21 | 21-Mar-00 | 81 | 21-May-00 | 142 | 21-Jul-00 | 203 | 21-Sep-00 | 265 | 21-Nov-00 | 326 |
| 22-Jan-00 | 22 | 22-Mar-00 | 82 | 22-May-00 | 143 | 22-Jul-00 | 204 | 22-Sep-00 | 266 | 22-Nov-00 | 327 |
| 23-Jan-00 | 23 | 23-Mar-00 | 83 | 23-May-00 | 144 | 23-Jul-00 | 205 | 23-Sep-00 | 267 | 23-Nov-00 | 328 |
| 24-Jan-00 | 24 | 24-Mar-00 | 84 | 24-May-00 | 145 | 24-Jul-00 | 206 | 24-Sep-00 | 268 | 24-Nov-00 | 329 |
| 25-Jan-00 | 25 | 25-Mar-00 | 85 | 25-May-00 | 146 | 25-Jul-00 | 207 | 25-Sep-00 | 269 | 25-Nov-00 | 330 |
| 26-Jan-00 | 26 | 26-Mar-00 | 86 | 26-May-00 | 147 | 26-Jul-00 | 208 | 26-Sep-00 | 270 | 26-Nov-00 | 331 |
| 27-Jan-00 | 27 | 27-Mar-00 | 87 | 27-May-00 | 148 | 27-Jul-00 | 209 | 27-Sep-00 | 271 | 27-Nov-00 | 332 |
| 28-Jan-00 | 28 | 28-Mar-00 | 88 | 28-May-00 | 149 | 28-Jul-00 | 210 | 28-Sep-00 | 272 | 28-Nov-00 | 333 |
| 29-Jan-00 | 29 | 29-Mar-00 | 89 | 29-May-00 | 150 | 29-Jul-00 | 211 | 29-Sep-00 | 273 | 29-Nov-00 | 334 |
| 30-Jan-00 | 30 | 30-Mar-00 | 90 | 30-May-00 | 151 | 30-Jul-00 | 212 | 30-Sep-00 | 274 | 30-Nov-00 | 335 |
| 31-Jan-00 | 31 | 31-Mar-00 | 91 | 31-May-00 | 152 | 31-Jul-00 | 213 | **1-Oct-00** | 275 | **1-Dec-00** | 336 |
| **1-Feb-00** | 32 | **1-Apr-00** | 92 | **1-Jun-00** | 153 | **1-Aug-00** | 214 | 2-Oct-00 | 276 | 2-Dec-00 | 337 |
| 2-Feb-00 | 33 | 2-Apr-00 | 93 | 2-Jun-00 | 154 | 2-Aug-00 | 215 | 3-Oct-00 | 277 | 3-Dec-00 | 338 |
| 3-Feb-00 | 34 | 3-Apr-00 | 94 | 3-Jun-00 | 155 | 3-Aug-00 | 216 | 4-Oct-00 | 278 | 4-Dec-00 | 339 |
| 4-Feb-00 | 35 | 4-Apr-00 | 95 | 4-Jun-00 | 156 | 4-Aug-00 | 217 | 5-Oct-00 | 279 | 5-Dec-00 | 340 |
| 5-Feb-00 | 36 | 5-Apr-00 | 96 | 5-Jun-00 | 157 | 5-Aug-00 | 218 | 6-Oct-00 | 280 | 6-Dec-00 | 341 |
| 6-Feb-00 | 37 | 6-Apr-00 | 97 | 6-Jun-00 | 158 | 6-Aug-00 | 219 | 7-Oct-00 | 281 | 7-Dec-00 | 342 |
| 7-Feb-00 | 38 | 7-Apr-00 | 98 | 7-Jun-00 | 159 | 7-Aug-00 | 220 | 8-Oct-00 | 282 | 8-Dec-00 | 343 |
| 8-Feb-00 | 39 | 8-Apr-00 | 99 | 8-Jun-00 | 160 | 8-Aug-00 | 221 | 9-Oct-00 | 283 | 9-Dec-00 | 344 |
| 9-Feb-00 | 40 | 9-Apr-00 | 100 | 9-Jun-00 | 161 | 9-Aug-00 | 222 | 10-Oct-00 | 284 | 10-Dec-00 | 345 |
| 10-Feb-00 | 41 | 10-Apr-00 | 101 | 10-Jun-00 | 162 | 10-Aug-00 | 223 | 11-Oct-00 | 285 | 11-Dec-00 | 346 |
| 11-Feb-00 | 42 | 11-Apr-00 | 102 | 11-Jun-00 | 163 | 11-Aug-00 | 224 | 12-Oct-00 | 286 | 12-Dec-00 | 347 |
| 12-Feb-00 | 43 | 12-Apr-00 | 103 | 12-Jun-00 | 164 | 12-Aug-00 | 225 | 13-Oct-00 | 287 | 13-Dec-00 | 348 |
| 13-Feb-00 | 44 | 13-Apr-00 | 104 | 13-Jun-00 | 165 | 13-Aug-00 | 226 | 14-Oct-00 | 288 | 14-Dec-00 | 349 |
| 14-Feb-00 | 45 | 14-Apr-00 | 105 | 14-Jun-00 | 166 | 14-Aug-00 | 227 | 15-Oct-00 | 289 | 15-Dec-00 | 350 |
| 15-Feb-00 | 46 | 15-Apr-00 | 106 | 15-Jun-00 | 167 | 15-Aug-00 | 228 | 16-Oct-00 | 290 | 16-Dec-00 | 351 |
| 16-Feb-00 | 47 | 16-Apr-00 | 107 | 16-Jun-00 | 168 | 16-Aug-00 | 229 | 17-Oct-00 | 291 | 17-Dec-00 | 352 |
| 17-Feb-00 | 48 | 17-Apr-00 | 108 | 17-Jun-00 | 169 | 17-Aug-00 | 230 | 18-Oct-00 | 292 | 18-Dec-00 | 353 |
| 18-Feb-00 | 49 | 18-Apr-00 | 109 | 18-Jun-00 | 170 | 18-Aug-00 | 231 | 19-Oct-00 | 293 | 19-Dec-00 | 354 |
| 19-Feb-00 | 50 | 19-Apr-00 | 110 | 19-Jun-00 | 171 | 19-Aug-00 | 232 | 20-Oct-00 | 294 | 20-Dec-00 | 355 |
| 20-Feb-00 | 51 | 20-Apr-00 | 111 | 20-Jun-00 | 172 | 20-Aug-00 | 233 | 21-Oct-00 | 295 | 21-Dec-00 | 356 |
| 21-Feb-00 | 52 | 21-Apr-00 | 112 | 21-Jun-00 | 173 | 21-Aug-00 | 234 | 22-Oct-00 | 296 | 22-Dec-00 | 357 |
| 22-Feb-00 | 53 | 22-Apr-00 | 113 | 22-Jun-00 | 174 | 22-Aug-00 | 235 | 23-Oct-00 | 297 | 23-Dec-00 | 358 |
| 23-Feb-00 | 54 | 23-Apr-00 | 114 | 23-Jun-00 | 175 | 23-Aug-00 | 236 | 24-Oct-00 | 298 | 24-Dec-00 | 359 |
| 24-Feb-00 | 55 | 24-Apr-00 | 115 | 24-Jun-00 | 176 | 24-Aug-00 | 237 | 25-Oct-00 | 299 | 25-Dec-00 | 360 |
| 25-Feb-00 | 56 | 25-Apr-00 | 116 | 25-Jun-00 | 177 | 25-Aug-00 | 238 | 26-Oct-00 | 300 | 26-Dec-00 | 361 |
| 26-Feb-00 | 57 | 26-Apr-00 | 117 | 26-Jun-00 | 178 | 26-Aug-00 | 239 | 27-Oct-00 | 301 | 27-Dec-00 | 362 |
| 27-Feb-00 | 58 | 27-Apr-00 | 118 | 27-Jun-00 | 179 | 27-Aug-00 | 240 | 28-Oct-00 | 302 | 28-Dec-00 | 363 |
| 28-Feb-00 | 59 | 28-Apr-00 | 119 | 28-Jun-00 | 180 | 28-Aug-00 | 241 | 29-Oct-00 | 303 | 29-Dec-00 | 364 |
| 29-Feb-00 | 60 | 29-Apr-00 | 120 | 29-Jun-00 | 181 | 29-Aug-00 | 242 | 30-Oct-00 | 304 | 30-Dec-00 | 365 |
| | | 30-Apr-00 | 121 | 30-Jun-00 | 182 | 30-Aug-00 | 243 | 31-Oct-00 | 305 | 31-Dec-00 | 366 |
| | | | | | | 31-Aug-00 | 244 | | | | |

# Julian Days (2001)

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1-Jan-01** | 1 | **1-Mar-01** | 60 | **1-May-01** | 121 | **1-Jul-01** | 182 | **1-Sep-01** | 244 | **1-Nov-01** | **305** |
| 2-Jan-01 | 2 | 2-Mar-01 | 61 | 2-May-01 | 122 | 2-Jul-01 | 183 | 2-Sep-01 | 245 | 2-Nov-01 | 306 |
| 3-Jan-01 | 3 | 3-Mar-01 | 62 | 3-May-01 | 123 | 3-Jul-01 | 184 | 3-Sep-01 | 246 | 3-Nov-01 | 307 |
| 4-Jan-01 | 4 | 4-Mar-01 | 63 | 4-May-01 | 124 | 4-Jul-01 | 185 | 4-Sep-01 | 247 | 4-Nov-01 | 308 |
| 5-Jan-01 | 5 | 5-Mar-01 | 64 | 5-May-01 | 125 | 5-Jul-01 | 186 | 5-Sep-01 | 248 | 5-Nov-01 | 309 |
| 6-Jan-01 | 6 | 6-Mar-01 | 65 | 6-May-01 | 126 | 6-Jul-01 | 187 | 6-Sep-01 | 249 | 6-Nov-01 | 310 |
| 7-Jan-01 | 7 | 7-Mar-01 | 66 | 7-May-01 | 127 | 7-Jul-01 | 188 | 7-Sep-01 | 250 | 7-Nov-01 | 311 |
| 8-Jan-01 | 8 | 8-Mar-01 | 67 | 8-May-01 | 128 | 8-Jul-01 | 189 | 8-Sep-01 | 251 | 8-Nov-01 | 312 |
| 9-Jan-01 | 9 | 9-Mar-01 | 68 | 9-May-01 | 129 | 9-Jul-01 | 190 | 9-Sep-01 | 252 | 9-Nov-01 | 313 |
| 10-Jan-01 | 10 | 10-Mar-01 | 69 | 10-May-01 | 130 | 10-Jul-01 | 191 | 10-Sep-01 | 253 | 10-Nov-01 | 314 |
| 11-Jan-01 | 11 | 11-Mar-01 | 70 | 11-May-01 | 131 | 11-Jul-01 | 192 | 11-Sep-01 | 254 | 11-Nov-01 | 315 |
| 12-Jan-01 | 12 | 12-Mar-01 | 71 | 12-May-01 | 132 | 12-Jul-01 | 193 | 12-Sep-01 | 255 | 12-Nov-01 | 316 |
| 13-Jan-01 | 13 | 13-Mar-01 | 72 | 13-May-01 | 133 | 13-Jul-01 | 194 | 13-Sep-01 | 256 | 13-Nov-01 | 317 |
| 14-Jan-01 | 14 | 14-Mar-01 | 73 | 14-May-01 | 134 | 14-Jul-01 | 195 | 14-Sep-01 | 257 | 14-Nov-01 | 318 |
| 15-Jan-01 | 15 | 15-Mar-01 | 74 | 15-May-01 | 135 | 15-Jul-01 | 196 | 15-Sep-01 | 258 | 15-Nov-01 | 319 |
| 16-Jan-01 | 16 | 16-Mar-01 | 75 | 16-May-01 | 136 | 16-Jul-01 | 197 | 16-Sep-01 | 259 | 16-Nov-01 | 320 |
| 17-Jan-01 | 17 | 17-Mar-01 | 76 | 17-May-01 | 137 | 17-Jul-01 | 198 | 17-Sep-01 | 260 | 17-Nov-01 | 321 |
| 18-Jan-01 | 18 | 18-Mar-01 | 77 | 18-May-01 | 138 | 18-Jul-01 | 199 | 18-Sep-01 | 261 | 18-Nov-01 | 322 |
| 19-Jan-01 | 19 | 19-Mar-01 | 78 | 19-May-01 | 139 | 19-Jul-01 | 200 | 19-Sep-01 | 262 | 19-Nov-01 | 323 |
| 20-Jan-01 | 20 | 20-Mar-01 | 79 | 20-May-01 | 140 | 20-Jul-01 | 201 | 20-Sep-01 | 263 | 20-Nov-01 | 324 |
| 21-Jan-01 | 21 | 21-Mar-01 | 80 | 21-May-01 | 141 | 21-Jul-01 | 202 | 21-Sep-01 | 264 | 21-Nov-01 | 325 |
| 22-Jan-01 | 22 | 22-Mar-01 | 81 | 22-May-01 | 142 | 22-Jul-01 | 203 | 22-Sep-01 | 265 | 22-Nov-01 | 326 |
| 23-Jan-01 | 23 | 23-Mar-01 | 82 | 23-May-01 | 143 | 23-Jul-01 | 204 | 23-Sep-01 | 266 | 23-Nov-01 | 327 |
| 24-Jan-01 | 24 | 24-Mar-01 | 83 | 24-May-01 | 144 | 24-Jul-01 | 205 | 24-Sep-01 | 267 | 24-Nov-01 | 328 |
| 25-Jan-01 | 25 | 25-Mar-01 | 84 | 25-May-01 | 145 | 25-Jul-01 | 206 | 25-Sep-01 | 268 | 25-Nov-01 | 329 |
| 26-Jan-01 | 26 | 26-Mar-01 | 85 | 26-May-01 | 146 | 26-Jul-01 | 207 | 26-Sep-01 | 269 | 26-Nov-01 | 330 |
| 27-Jan-01 | 27 | 27-Mar-01 | 86 | 27-May-01 | 147 | 27-Jul-01 | 208 | 27-Sep-01 | 270 | 27-Nov-01 | 331 |
| 28-Jan-01 | 28 | 28-Mar-01 | 87 | 28-May-01 | 148 | 28-Jul-01 | 209 | 28-Sep-01 | 271 | 28-Nov-01 | 332 |
| 29-Jan-01 | 29 | 29-Mar-01 | 88 | 29-May-01 | 149 | 29-Jul-01 | 210 | 29-Sep-01 | 272 | 29-Nov-01 | 333 |
| 30-Jan-01 | 30 | 30-Mar-01 | 89 | 30-May-01 | 150 | 30-Jul-01 | 211 | 30-Sep-01 | 273 | 30-Nov-01 | 334 |
| 31-Jan-01 | 31 | 31-Mar-01 | 90 | 31-May-01 | 151 | 31-Jul-01 | 212 | **1-Oct-01** | 274 | **1-Dec-01** | 335 |
| **1-Feb-01** | 32 | **1-Apr-01** | 91 | **1-Jun-01** | 152 | **1-Aug-01** | 213 | 2-Oct-01 | 275 | 2-Dec-01 | 336 |
| 2-Feb-01 | 33 | 2-Apr-01 | 92 | 2-Jun-01 | 153 | 2-Aug-01 | 214 | 3-Oct-01 | 276 | 3-Dec-01 | 337 |
| 3-Feb-01 | 34 | 3-Apr-01 | 93 | 3-Jun-01 | 154 | 3-Aug-01 | 215 | 4-Oct-01 | 277 | 4-Dec-01 | 338 |
| 4-Feb-01 | 35 | 4-Apr-01 | 94 | 4-Jun-01 | 155 | 4-Aug-01 | 216 | 5-Oct-01 | 278 | 5-Dec-01 | 339 |
| 5-Feb-01 | 36 | 5-Apr-01 | 95 | 5-Jun-01 | 156 | 5-Aug-01 | 217 | 6-Oct-01 | 279 | 6-Dec-01 | 340 |
| 6-Feb-01 | 37 | 6-Apr-01 | 96 | 6-Jun-01 | 157 | 6-Aug-01 | 218 | 7-Oct-01 | 280 | 7-Dec-01 | 341 |
| 7-Feb-01 | 38 | 7-Apr-01 | 97 | 7-Jun-01 | 158 | 7-Aug-01 | 219 | 8-Oct-01 | 281 | 8-Dec-01 | 342 |
| 8-Feb-01 | 39 | 8-Apr-01 | 98 | 8-Jun-01 | 159 | 8-Aug-01 | 220 | 9-Oct-01 | 282 | 9-Dec-01 | 343 |
| 9-Feb-01 | 40 | 9-Apr-01 | 99 | 9-Jun-01 | 160 | 9-Aug-01 | 221 | 10-Oct-01 | 283 | 10-Dec-01 | 344 |
| 10-Feb-01 | 41 | 10-Apr-01 | 100 | 10-Jun-01 | 161 | 10-Aug-01 | 222 | 11-Oct-01 | 284 | 11-Dec-01 | 345 |
| 11-Feb-01 | 42 | 11-Apr-01 | 101 | 11-Jun-01 | 162 | 11-Aug-01 | 223 | 12-Oct-01 | 285 | 12-Dec-01 | 346 |
| 12-Feb-01 | 43 | 12-Apr-01 | 102 | 12-Jun-01 | 163 | 12-Aug-01 | 224 | 13-Oct-01 | 286 | 13-Dec-01 | 347 |
| 13-Feb-01 | 44 | 13-Apr-01 | 103 | 13-Jun-01 | 164 | 13-Aug-01 | 225 | 14-Oct-01 | 287 | 14-Dec-01 | 348 |
| 14-Feb-01 | 45 | 14-Apr-01 | 104 | 14-Jun-01 | 165 | 14-Aug-01 | 226 | 15-Oct-01 | 288 | 15-Dec-01 | 349 |
| 15-Feb-01 | 46 | 15-Apr-01 | 105 | 15-Jun-01 | 166 | 15-Aug-01 | 227 | 16-Oct-01 | 289 | 16-Dec-01 | 350 |
| 16-Feb-01 | 47 | 16-Apr-01 | 106 | 16-Jun-01 | 167 | 16-Aug-01 | 228 | 17-Oct-01 | 290 | 17-Dec-01 | 351 |
| 17-Feb-01 | 48 | 17-Apr-01 | 107 | 17-Jun-01 | 168 | 17-Aug-01 | 229 | 18-Oct-01 | 291 | 18-Dec-01 | 352 |
| 18-Feb-01 | 49 | 18-Apr-01 | 108 | 18-Jun-01 | 169 | 18-Aug-01 | 230 | 19-Oct-01 | 292 | 19-Dec-01 | 353 |
| 19-Feb-01 | 50 | 19-Apr-01 | 109 | 19-Jun-01 | 170 | 19-Aug-01 | 231 | 20-Oct-01 | 293 | 20-Dec-01 | 354 |
| 20-Feb-01 | 51 | 20-Apr-01 | 110 | 20-Jun-01 | 171 | 20-Aug-01 | 232 | 21-Oct-01 | 294 | 21-Dec-01 | 355 |
| 21-Feb-01 | 52 | 21-Apr-01 | 111 | 21-Jun-01 | 172 | 21-Aug-01 | 233 | 22-Oct-01 | 295 | 22-Dec-01 | 356 |
| 22-Feb-01 | 53 | 22-Apr-01 | 112 | 22-Jun-01 | 173 | 22-Aug-01 | 234 | 23-Oct-01 | 296 | 23-Dec-01 | 357 |
| 23-Feb-01 | 54 | 23-Apr-01 | 113 | 23-Jun-01 | 174 | 23-Aug-01 | 235 | 24-Oct-01 | 297 | 24-Dec-01 | 358 |
| 24-Feb-01 | 55 | 24-Apr-01 | 114 | 24-Jun-01 | 175 | 24-Aug-01 | 236 | 25-Oct-01 | 298 | 25-Dec-01 | 359 |
| 25-Feb-01 | 56 | 25-Apr-01 | 115 | 25-Jun-01 | 176 | 25-Aug-01 | 237 | 26-Oct-01 | 299 | 26-Dec-01 | 360 |
| 26-Feb-01 | 57 | 26-Apr-01 | 116 | 26-Jun-01 | 177 | 26-Aug-01 | 238 | 27-Oct-01 | 300 | 27-Dec-01 | 361 |
| 27-Feb-01 | 58 | 27-Apr-01 | 117 | 27-Jun-01 | 178 | 27-Aug-01 | 239 | 28-Oct-01 | 301 | 28-Dec-01 | 362 |
| 28-Feb-01 | 59 | 28-Apr-01 | 118 | 28-Jun-01 | 179 | 28-Aug-01 | 240 | 29-Oct-01 | 302 | 29-Dec-01 | 363 |
| | | 29-Apr-01 | 119 | 29-Jun-01 | 180 | 29-Aug-01 | 241 | 30-Oct-01 | 303 | 30-Dec-01 | 364 |
| | | 30-Apr-01 | 120 | 30-Jun-01 | 181 | 30-Aug-01 | 242 | 31-Oct-01 | 304 | 31-Dec-01 | 365 |
| | | | | | | 31-Aug-01 | 243 | | | | |

# 1 Introduction

Watercourse Engineering, Inc. (Watercourse) has undertaken the design and implementation of a flow and water quality modeling framework for the Klamath River from Link Dam to Turwar to support studies for the Federal Energy Regulatory Commission Hydropower relicensing process. Link Dam is located at Klamath River Mile (RM) 255 and Turwar at RM 5. The original framework and supporting documentation are found in attached appendices. Outlined herein are three specific tasks:

1) Model Implementation
2) Calibration and Validation
3) Model Application

Model implementation is the process of gathering appropriate data (including geometry, flow, water quality, and meteorology) and formatting it for input into numerical models. Also included in this step is selection of default model parameters and general model testing. The end result of model implementation is a running, but uncalibrated model. Model calibration and validation is the stage wherein model parameters are modified to fit the model to field observations – calibration. The model is then tested on an independent set of data (validation) to illustrate that the model can replicate field conditions with parameter values determined in calibration. The final stage of implementation is model application, wherein the calibrated models are applied to selected management strategies or scenarios. Such scenarios may represent varied flow or water quality conditions and may include the addition or removal of project facilities to identify potential impacts and outcomes. Data sets for model implementation, calibration and application are described in the text.

This report is arranged as per the three specific modeling tasks outlined above, with supporting information presented in appendices. Appendices includes the modeling framework proposed with additions and changes included, as well as other supporting information.

# 2 Model Implementation

## 2.1 Model Selection

Flow and water quality conditions in the Klamath River basin vary dramatically along the approximately 250 river miles from Link Dam (RM 255), near Klamath Falls Oregon, to Turwar (RM 5), California. There are a wide range of natural and anthropogenic influences affecting water quality along this extended stretch of river: inflows to the system at Link Dam originate in hypereutrophic Upper Klamath Lake; there are four major reservoirs on the main stem Klamath River; diversions and return flows for agriculture, as well as municipal and industrial use, occur in the reach between Link Dam and Keno Dam; and the river receives considerable inflow from tributaries as it flows towards the Pacific Ocean..

A combination of discrete river models and reservoir models were selected to address these diverse system characteristics. Selected river models were produced by Resource Management Associates (RMA). Flow is represented with RMA-2, a finite element hydrodynamic model capable of modeling highly dynamic flow regimes in short space and time steps. Output from the model (including velocity, depth, and representative surface and bed areas) is passed to the water quality model RMA-11. RMA-11 is a finite element water quality model simulating the fate and transport of a wide range of physical, chemical, and biological constituents. These two linked river models are applied on hourly or sub-hourly time steps to capture the short-term response of state variables such as temperature and dissolved oxygen. For this application the RMA models are applied in one-dimension, representing variations along the longitudinal axis of the river while vertical and lateral details are averaged.

System reservoirs are represented by the two-dimensional, longitudinal/vertical hydrodynamic and water quality model CE-QUAL-W2. Because the model assumes lateral homogeneity, it is well suited for relatively long and narrow water bodies exhibiting longitudinal and vertical water quality gradients. The CE-QUAL-W2 model is capable of representing a wide range physical, chemical, and biological processes affecting water quality. The model can simulate selective withdrawal, sediment nutrient release dynamics, nitrogen inhibition under anoxic conditions, internal weirs and curtains, and other options useful in assessing a wide range of existing and possible future conditions of the system. To interface with the river model, time steps on the same scale as the river models are employed.

## 2.2 Model Implementation

The river and reservoir models were implemented for nine discrete river reaches. These reaches are presented in Table 1 and shown on a map of the river in Figure 1. Model implementation includes constructing appropriate system geometry, flow and water quality conditions (boundary conditions, initial conditions), calibration/validation datasets, meteorological data, and other model parameters.

- Geometry data include a description of the river location (i.e., latitude and longitude, UTM, or similar coordinate system), bed slope, and cross section data. For reservoirs, bathymetric information and facilities information (such as stage-volume relationships, intake structure configurations, elevations, locations of diversion structures, and return points) are required.
- Flow and water quality information include system inflow (main stem system headwater, tributaries, return flows, etc.), outflow (diversions), reservoir storage change, and facilities operations. Water quality data for all inflows, as well as in-river and reservoir conditions, are required.
- Meteorological data include standard parameters for heat budget calculation within the numerical models, e.g., air temperature, wet bulb temperature (or dew point temperature), solar radiation, cloud cover, wind speed, and/or barometric pressure.
- Other model parameters include selection of time step, spatial resolution, identified periods of analysis, and selection of default model constants and coefficients.

**Table 1. River reaches and representation in the modeling framework**

| Reach | Existing Representation | Model(s) |
|---|---|---|
| Link River | River | RMA-2/RMA-11 |
| Lake Ewauna-Keno Dam | Reservoir | CE-QUAL-W2 |
| Keno Dam to J.C. Boyle Reservoir | River | RMA-2/RMA-11 |
| J.C. Boyle Reservoir | Reservoir | CE-QUAL-W2 |
| Bypass Reach[a] | River | RMA-2/RMA-11 |
| Peaking Reach[a] | River | RMA-2/RMA-11 |
| Copco Reservoir[b] | Reservoir | CE-QUAL-W2 |
| Iron Gate Reservoir | Reservoir | CE-QUAL-W2 |
| IG Dam to Turwar | River | RMA-2/RMA-11 |

[a] The Bypass and Peaking sections are modeled as a single reach
[b] Copco 2 is not represented in the framework

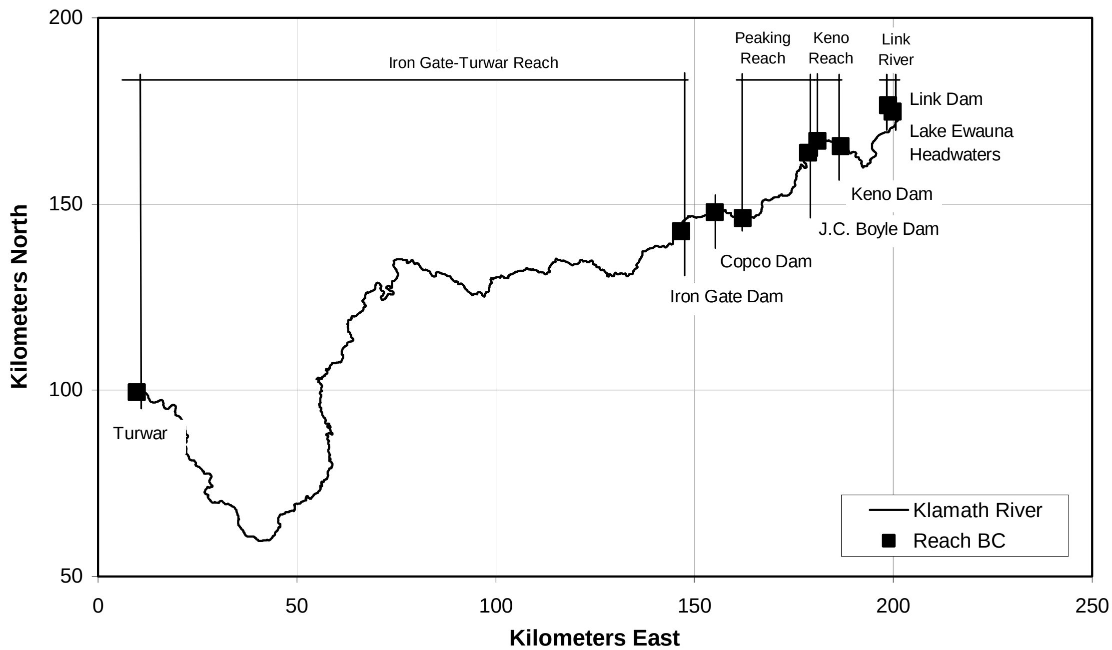



**Figure 1. Designated river reaches and reservoirs**

To create a system-wide simulation, the models are applied in series, starting with upper most reach – Link River – and passing output from one reach to the next. Thus output from the Link River (simulated with RMA models) forms the upstream boundary condition for the CE-QUAL-W2 representation of Lake Ewauna/Keno Reservoir. Similarly, output from CE-QUAL-W2 forms the headwater boundary condition for the river models representing the Keno River reach, the Klamath River from Keno Dam to J.C. Boyle Dam, and so on down the river. Flow conditions are generally not passed from reservoir to river reaches. Instead, historical flows (typically reported near the top of each river reach) are used as headwater boundary conditions for most river reaches. Further details of the flow records used in each reach are outlined later in this section.

Water quality is passed downstream between both reservoir and river reaches. But the river models (RMA) and the reservoir model (CE-QUAL-W2) do not represent all water quality parameters in the same fashion. The river models represent organic matter as organic nitrogen and organic phosphorous, while the reservoir model represents organic matter as refractory and labile dissolved and particulate organic matter. Stoichiometric equivalents are used to convert the appropriate information for passing from one model to the next. Details of these conversions are addressed in Model Application.

## 2.3 River-Reservoir Reaches

Model implementation for each reach is outlined in this section. Each reach is presented, in upsteam to downstream order, with a description of geometric data, flow and water quality conditions, and meteorological conditions.

## 2.3.1 Link River

The Link River reach starts at Link Dam and terminates at Lake Ewauna. There are two powerhouses which discharge into this reach. Geometry, flow, water quality, meteorological conditions, and other model parameters are outlined below. Flow is modeled with RMA-2 and water quality with RMA-11.

### 2.3.1.1 River Geometry

***River Location***

Coordinates describing river location and path were determined using a digitized version of 1:24,000 USGS topographic quadrangles provided by CH2MHill, as discussed in Appendix C. This information was translated into a network of nodes and elements for use by the numerical model. The Link River reach and important locations within the reach are shown in Figure 2 and presented in Table 2. All coordinates presented in this report are referenced to UTM 400000E 4500000N, NAD27 (typical).

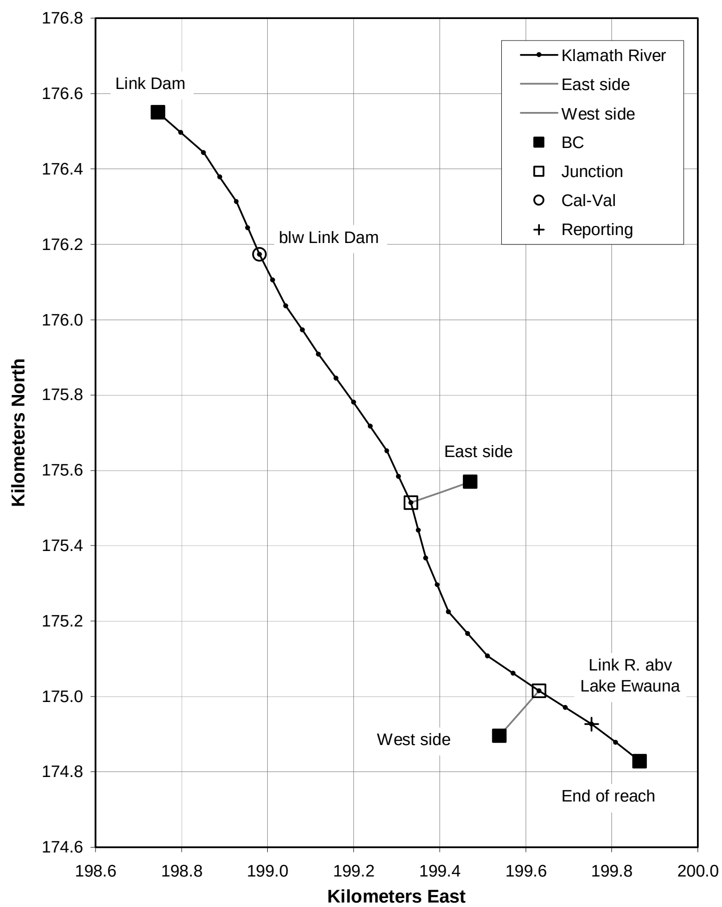



**Figure 2. Map of Link River representation**

**Table 2. Geometry information for Link River**

| Location | Node | Element | x-coord | y-coord | Site type |
|---|---|---|---|---|---|
| Link Dam | 1 | 1 | 198.8 | 176.6 | BC |
| East Side | 17 | 9 | 199.9 | 174.8 | BC |
| West Side | 25 | 13 | 199.5 | 175.6 | BC |
| End Link R reach | 29 | 14 | 199.5 | 174.9 | BC |
| East Side | 30 | 15 | 199.3 | 175.54 | Junction, inflow |
| West Side | 34 | 16 | 199.6 | 175.0 | Junction, inflow |
| Link River above Lake Ewauna | 27 | - | 199.8 | 174.9 | Reporting Point |

### *River Width*

Link River widths were obtained from 1:7,500-scale aerial photos taken July 21, 1988.Daily average flow for that day was 920 cfs. Width measurements were taken at six locations within this relatively short river reach. Cross sections are represented by trapezoids with twenty-to-one side slopes on the main stem and one-to-one side slopes in the tributaries.

### *Bed Elevations/Slope*

Bed slope for the reach was estimated from USGS topographic maps and estimated Lake Ewauna elevations. Upstream reach elevation was set at 4130.5 ft msl (1259 m) and the downstream reach elevation was set at 4084.6 ft msl (1245 m). Elevations were estimated from topographic contours to preserve the genral slope of the river. Because of uncertainty in these estimates, actual river bed elevations may differ. Link River reach geometry is summarized in Table 3.

### *Junctions and side flow*

Tributaries and inflows can be represented in several fashions in RMA-2. When such inflows form a large percentage of the baseflow in the main stem, a junction is added to the model as a small branch. This type of inflow is placed at a single point in the model – a node. When inflows to the main stem are relatively modest, they are included in the model as element side flows. In this case the inflow is placed into simulated reach over the length of a single element. The Link River reach is simulated with two junctions and no element side flows.

**Table 3. Link River Geometry Summary**

| | |
|---|---|
| Node spacing | 75 meters |
| Number of nodes | 29 nodes in length; 37 nodes total including junctions |
| Length | 1.31 miles from RM 252.57-253.88 |
| Elevations | Range: 1245-1259 meters |
| Widths | Constant widths: 5 meters main stem; 20 meters junction elements |
| Side slopes | 20:1 main stem; 1:1 junctions |
| Data sources | UTM coordinates from CH2MHill; Elevations estimated from USGS topographic maps. |
| Notes | 2 junctions: East side, West side; Nodes 30-33 at East side; 34-37 at West side |

#### 2.3.1.2 Flow Data

***Inflows and Outflows***

Water enters the Link River reach via releases from Link Dam. Two diversions are made from Upper Klamath Lake at Link Dam: one takes water along the west side of the river through a canal and short penstock to the West Side power house and the other takes water along the East Side of the River to the East Side power house. The East Side powerhouse returns to the river above the West Side powerhouse return. Between the East Side and West Side powerhouses lies the USGS Gage (11507500 Link River at Klamath Falls, OR). No outflows are represented in this reach.

Flow entering the reach at the upstream-most element (Link Dam) is termed the Link Bypass flow. East Side Turbine flows were calculated as the difference between the Link River USGS gage 11507500 and the Link Bypass flow. West Side Turbine flows are reported by PacifiCorp. East Side and West Side powerhouses are represented by junction elements in the model. There are no tributaries or accretions included as element side flows in the Link River reach.

***Downstream Boundary Condition***

The hydrodynamic downstream boundary condition for the Link River reach is determined by Lake Ewauna water surface elevation. This approach resulted in a variable stage downstream boundary condition, replicating backwater conditions at the lower end of the reach. Elevations measured by PacifiCorp in the vicinity of Highway 97 are assumed to represent stage at the headwaters of Lake Ewauna. Because river elevations were approximated from topographic maps and stage measurements are accurate, elevation discrepancies arise where rivers meet reservoirs. This discrepancy was estimated to be around 3 meters at Lake Ewauna headwaters, so the downstream boundary conditions for the Link River reach was defined as Keno Reservoir elevations plus 3 meters (9.84 feet).

#### 2.3.1.3 Water Quality Data

Water quality data for the Link River reach was derived from multiple sources. Little data exists at Link Dam prior to 2001. Grab samples collected at Fremont Bridge from

1994 to 2001 and provided by the Klamath Tribes were used to describe seasonal water quality conditions at the upstream boundary of the reach. The East Side and West Side Turbines were assumed to have the same water source as the flows at Link Dam (the upstream boundary), so the same water quality was used for all three water sources in the Link River reach.. Data sources for Link River water quality boundary conditions are outlined in Table 4.

**Table 4. Data sources for boundary conditions to the Link River reach**

| Data | Source | Type |
|---|---|---|
| Water quality parameters[1] | Klamath Tribes | Seasonal estimates |
| Temperature | U.S. Bureau of Reclamation | Hourly, seasonal estimates |
| Dissolved Oxygen | U.S. Bureau of Reclamation | Hourly, seasonal estimates |

[1] Water quality parameters include pH, conductivity, total phosphorus, orthophosphates, total nitrogen, nitrate + nitrite, ammonia, chlorophyll-a and phaeophytin.

### *Temperature*

Water temperatures reported from USBR monitoring of A-Canal during 2000-2001 were used to construct a composite of hourly inflow temperatures for the Link River. Calendar year 2000 temperatures were available from Julian Day (JD) 133 though JD 333. Calendar year 2001 temperatures were used from JD 26 through JD 133. Temperatures from JD 1 through 26 and from JD 333 through 367 were estimated by assuming that the temperature on JD 1 and JD 367 was 2 ºC and linearly interpolating. The East Side and West Side Turbines were assumed to have the same water source as the flows at Link Dam, so the same temperatures were used for all three water sources in the Link River reach.

### *Constituent Concentrations*

Dissolved Oxygen: Limited field data are available to describe Link Dam dissolved oxygen. Hourly dissolved oxygen saturation concentrations were calculated from USBR water quality probe temperatures for A-Canal during 2000-2001. In a method analogous to that used for temperature, calculated dissolved oxygen concentrations were used to construct a composite of hourly inflow for the Link River reach. Calendar year 2000 dissolved oxygen saturation values were available from JD 133 though JD 333. Calendar year 2001 temperatures were used from JD 26 through JD 133. Dissolved oxygen concentrations from JD 1 through 26 and from JD 333 through 367 were estimated as the saturation values of the inflow temperatures. The East Side and West Side Turbines have the same water source as the flows at Link Dam, therefore the same dissolved oxygen were used for all three water sources in the Link River reach.

BOD: There was no biochemical oxygen demand data available for 2000. BOD levels were estimated based on available data from the 2002 sampling program completed by USBR. Samples were collected at two-week intervals from late April through September, 2002. BOD concentrations for Link Dam prior to April were assumed to be 2.0 mg/l. The USBR sampling effort suggests that BOD levels remain elevated through the end of September. BOD was assumed to be 10 mg/l on October 15th, 3 mg/l on November 15th, and 2 mg/l after December 15th.

Nutrients and Algae: Water quality boundary conditions for the Link River were calculated from Upper Klamath Lake grab sample data collected by the Klamath Tribes from 1994-2001 at the Fremont Bridge (Kann, 2001). The Fremont Bridge location in Upper Klamath Lake was selected because of the proximity to the Link Dam.

Between 1994 and 2001 there were approximately 60 grab samples with nutrient concentrations (at multiple depths). Because there were insufficient samples in 2000 to identify a boundary condition for the Link River reach, a composite of all data were used to create monthly average concentrations that represented general seasonal conditions.

Comparison of field data suggested that conditions in the Fremont Bridge area were generally well mixed (i.e., minimal vertical variation for the selected water quality constituents). Thus all samples were used in the determination of monthly average concentrations. Data were sorted by Julian day and averaged. Monthly averages were calculated from the daily data. The first and last days of the year were given concentrations that were the average of the January and December monthly average concentrations. Organic nitrogen and phosphorus were calculated as the total forms minus the inorganic forms of each nutrient.

#### 2.3.1.4 Meteorological Data

Required hourly information for a meteorological input file consisted of: air temperature (°C), wet bulb temperature (°C), wind speed (m/s), cloud cover (scale 0-1.0) and atmospheric pressure.

Meteorological data for the Link River reach were derived from meteorological observations near Klamath Falls, OR. This meteorological station (KFLO) is operated by the Pacific Northwest Cooperative Agricultural Weather Network, and provides the following necessary information: dry bulb temperature, dew point temperature, relative humidity, cumulative solar radiation, and wind speed, as well as many other parameters.

Air temperature and wind speed were readily available from the weather station. Cloud cover was calculated from the daily summation of solar radiation provided by the station, using the ideal sine wave representation of the maximum possible solar radiation throughout the year to determine the ratio of measured radiation to total radiation. Atmospheric pressure was calculated based on elevation (4100 ft (1250 m)) and assumed constant throughout the simulation period (870 mb). Wet bulb temperature was calculated based on relative humidity, atmospheric pressure, and air temperature. These methods of determination and calculations are outlined in Appendix E.

All times within the modeling effort are Pacific Standard Time. Daylight Saving Time is not used.

### 2.3.2 Lake Ewauna to Keno Dam

The Lake Ewauna to Keno Dam reach extends from the headwaters of Lake Ewauna (RM 253) to Keno Dam (RM 233). The impoundment is generally a broad, shallow body of water. System width ranges from several hundred to over 1000 feet (over 300 meters), and a depths range to a maximum of roughly 20 feet (approximately 6 meters). There are several discharges and withdrawals in this reach. Physical characteristics (e.g., geometry), flow, water quality, meteorological conditions, and other model parameters are outlined below. The reach is modeled with CE-QUAL-W2.

#### 2.3.2.1 Reservoir Physical Data

The primary purpose of Keno Dam operations is to provide a regulated water surface for irrigation project diversions within this reservoir reach. A total of eighteen discharges and seven withdrawals were represented in the model.

***Keno Dam Features***

The Keno Dam spillway, with an invert elevation of 4070 feet, contains six Taintor gates. Three additional outlets include a sluice conduit, the fish attraction outlet, and the fish ladder exit to the reservoir. The details of these outlets are summarized in Table 5.

**Table 5. Keno Dam outlet features**

| Outlet | Invert Elevation | Dimension | Operation |
|---|---|---|---|
| Sluice Conduit | 4,073.0 ft | 36 inch diameter | Manual gate |
| Fish Attraction Outlet | 4,075.0 ft | 30 inch diameter | Manual gate |
| Fish Ladder | 4,078.5 ft | 60 inch width | Stop logs |
| Spillway | 4,070.0 ft | 6 gates @ 40 ft width each | Remote control on three gates |
| Sources: | PacifiCorp (2002), PacifiCorp (2000) | | |

***Reservoir Bathymetry for CE-QUAL-W2***

The model was originally implemented with the bathymetry for the Lake Ewauna to Keno Dam section of the Klamath River derived from existing bathymetry created by Dr. Scott Wells (ODEQ, 1995). This representation was replaced using the results of a recent bathymetrc survey of the entire reservoir (MaxDepth Aquatics, Inc., 2004).

The number of segments, number of layers, segment lengths, layer widths per segment and water surface elevation from the Wells (ODEQ, 1995) work largely retained, but were supplemented by new segment orientations calculated from the x-y coordinates provided by CH2MHill. Orientation of individual river segments was updated because the original file orientations contained discrepancies when applied to the newer versions of CE-QUAL-W2. Model representation is shown in Figure 3.

In addition to segment and layer specifications, bottom roughness was represented by a Manning coefficient of 0.04 for each segment. The volume generated by model representation was consistent with the volume calculated from reservoir bathymetry available from PacifiCorp.

The CE-QUAL-W2 representation of Lake Ewauna to Keno reach has two branches. Branch 1 has 106 active segments, all 1000 ft (304.8 m) in length. Branch 2 has three active segments, each 800 ft (243.8 m) in length. There are fifteen active layers in Lake Ewauna all 2.00 ft (0.61 m) thick. Branch 2 starts at Branch 1, Segment 14, and ends at Branch 1, Segment 18. A total of eighteen discharges and seven withdrawals were represented in the model (see Table 6). Branch 2 has no external inflows or outflows. The modeled and observed stage-volume curve is shown in Figure 4.

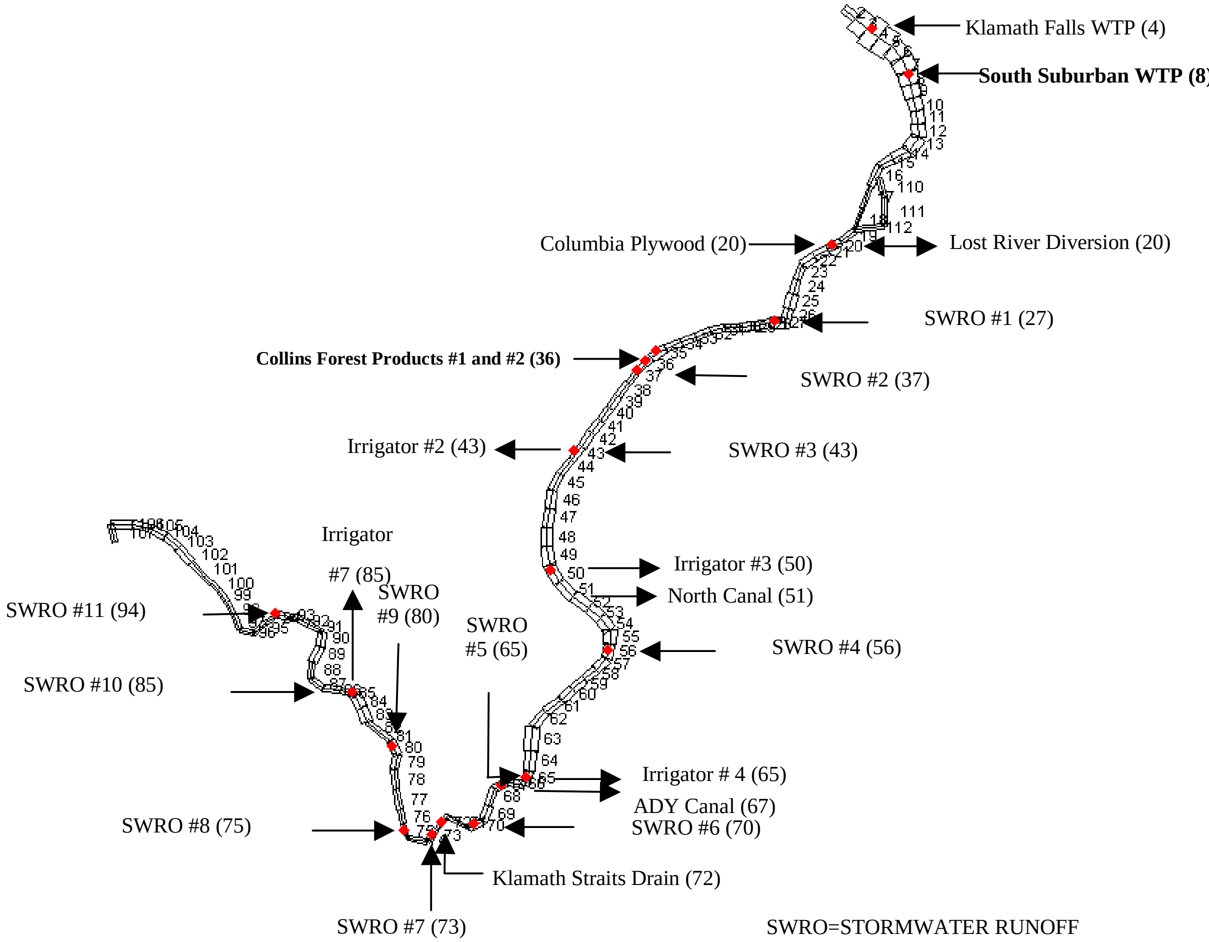



**Figure 3. Map of Lake Ewauna to Keno Dam CE-QUAL-W2 representation, identifying inputs and withdrawals**

**Table 6. Modeled inflows and outflows in the Lake Ewauna to Keno Dam reach**

| Name | Type | River Bank [a] | Approximate RM [b] | Model Segment |
|---|---|---|---|---|
| Klamath Falls Wastewater Treatment Plant | Inflow | Left | 253 | 4 |
| South Suburban Sanitation District | Inflow | Left | 252 | 8 |
| Columbia Plywood | Inflow | Right | 250 | 20 |
| Lost River Diversion | Inflow / Outflow | Left | 250 | 20 |
| Collins Forest Products #1 | Inflow | Right | 247 | 36 |
| Collins Forest Products #2 | Inflow | Right | 247 | 36 |
| Klamath Straits Drain | Inflow | Left | 240 | 72 |
| Stormwater Runoff #1 | Inflow | NA | 249 | 27 |
| Stormwater Runoff #2 | Inflow | NA | 247 | 37 |
| Stormwater Runoff #3 | Inflow | NA | 246 | 43 |
| Stormwater Runoff #4 | Inflow | NA | 243 | 56 |
| Stormwater Runoff #5 | Inflow | NA | 242 | 65 |
| Stormwater Runoff #6 | Inflow | NA | 241 | 70 |
| Stormwater Runoff #7 | Inflow | NA | 240 | 73 |
| Stormwater Runoff #8 | Inflow | NA | 240 | 75 |
| Stormwater Runoff #9 | Inflow | NA | 239 | 80 |
| Stormwater Runoff #10 | Inflow | NA | 238 | 85 |
| Stormwater Runoff #11 | Inflow | NA | 236 | 94 |
| North Canal | Outflow | Left | 247 | 35 |
| ADY Canal | Outflow | Left | 241 | 67 |
| Irrigator #1 | Inflow / Outflow | NA | 246 | 43 |
| Irrigator #2 | Inflow / Outflow | NA | 244 | 50 |
| Irrigator #3 | Inflow / Outflow | NA | 242 | 65 |
| Irrigator #4 | Inflow / Outflow | NA | 238 | 85 |

[a] : The river bank is given for reference only. The model does not discriminate between river bank when simulating flows.

[b] : The river miles are approximate as each model segment is 1000 ft in length.

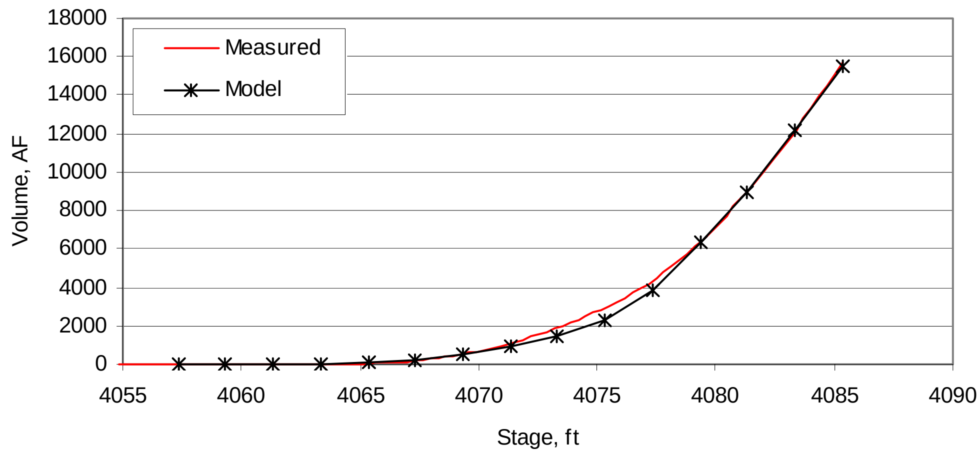



**Figure 4. Comparison of measured and model representation of Lake Ewauna stage-volume (S-V) relationships**

#### 2.3.2.2 Flow Data

Flow data required for the model application includes the upstream boundary condition representing water flowing into Lake Ewauna from Link River. In addition there are a series of discrete withdrawals and inflows along the reach. Accretion/depletion flow, representing un-quantified losses and gains within the reach, is distributed evenly among the four irrigator locations. Typically flow data are recorded in cubic feet per second or million gallons per day – all flows were converted to cubic meters per second for model input. Each flow component is addressed below.

***Link River Inflow***

The USGS Gage at Link River is upstream of the Westside Powerhouse return. Thus, the branch inflow flow rates for the Lake Ewauna to Keno reach were determined by subtracting the PacifiCorp West Turbine Gage from the USGS Gage 11507500.

***Tributary Inflows***

***Storm water Runoff***

Storm water runoff flow from the Wells 1992 simulation (ODEQ, 1995) was compared to 1992 rainfall data recorded at the KFLO meteorological station. A relationship for the 1992 data was determined between total storm water runoff flow rate and daily precipitation using linear regression.

$$SWRO = 12.129 \times R \qquad (r^2=1)$$

Where: SWRO = Total stormwater runoff, cms

R = precipitation, inches

An average percent of total stormwater runoff flow for each of the eleven locations was determined for each rainfall event in 1992. Calendar year 2000 daily precipitation from KFLO and the relationships determined from the 1992 data were used to calculate each of the eleven storm water runoff flow rates for 2000. The placement of stormwater runoff flows is as per Wells (ODEQ, 1995).

### *Columbia Plywood*

An average monthly flow for Columbia Plywood discharge was calculated from the maximum monthly flows recorded on the plant's monthly monitoring reports submitted to ODEQ. The average for calendar year 2000 was 0.01 cfs (0.0004 cms) and was applied throughout the year.

### *Klamath Falls Water Treatment Plant*

Daily flows for the Klamath Falls Wastewater Treatment Plant were provided by daily flows recorded in monthly monitoring reports submitted to ODEQ. These flows are typically variable, ranging from 5-12 cfs, until May when variability diminishes significantly and flows average a little over 4 cfs. Daily flow from the Klamath Falls Wastewater Treatment Plant was input into the model after being converted to the appropriate units.

### *South Suburban Sanitation District*

Daily flows from South Suburban Sanitation District were derived from flows recorded five times a week in the monthly monitoring reports the District submitted to the ODEQ. Because plant discharge varied little from day to day and were relatively small, input flows for 2000 were monthly averages based on measured data. These monthly averages range from a little over 2 cfs to just over 4 cfs.

### *Collins Forest Products #1 and #2*

Daily inflows from Collins Forest Products discharge #1 and #2 were taken from monthly monitoring reports submitted to ODEQ. These flows average about 1.4 cfs and 0.1 cfs for discharge #1 and #2, respectively. Daily measured data was directly input into the model.

### *Lost River Diversion Channel*

The daily inflows into Lake Ewauna from the Lost River Diversion Channel are gauged by USBR. These records were used to define both the Lost River discharge to, and withdrawal from, Lake Ewauna to Keno Reach (for diversion from Lake Ewauna to Keno reach see the withdrawal section below).

### *Klamath Straits Drain*

Inflow to Lake Ewauna from the Klamath Straits Drain is gauged by USBR. Daily input flows range from a minimum of 0.0 to a maximum of nearly 350 cfs, depending on the season. High monthly variability occurs between February and September. Flows used in the simulations were taken directly from the recorded information.

## *Withdrawals*

#### *Klamath Reclamation Project Diversions*

There are three withdrawals within Lake Ewauna for the Klamath Reclamation Project: the Lost River, North Canal and ADY Canal. All three withdrawals were daily flows, gauged by USBR. Lost River withdrawals range dramatically in summer months to a maximum withdrawal of over 600 cfs. North Canal withdrawals are less variable and peak in summer and winter months at about 150-200 cfs. ADY Canal withdrawals follow the same pattern as those at North Canal but are of greater magnitude, reaching maxima of 400-500 cfs.

#### *Non-Reclamation Irrigation Diversions*

Due to a lack of available records describing non-USBR irrigation, daily withdrawal rates from the Wells 1992 simulation (ODEQ, 1995) were applied for 2000. The irrigation season was assumed to extend from May 30, 2000 JD 152) to September 30, 2000 (JD 274). Withdrawals peaked at a steady 60 cfs for Irrigator #7 and at a steady 14 cfs for Irrigators #2, #3, and #4. Prior to and after the irrigation season flows were assumed to be zero for all four irrigation withdrawals.

#### *Keno Dam Outflow*

The hourly flow rate at Keno Dam was taken from data recorded at USGS Gage 11509500, Klamath River near Keno, Oregon. The flows, ranging from a maximum of over 4000 cfs in spring to a minimum of just under 500 cfs in summer.

### *Accretion / Depletion (Distributed Tributary) Inflow*

Flow representing net un-gauged accretions and depletions from the system was determined using a water balance based on the aforementioned inflows and outflows and the change in storage recorded at Keno Dam (provided by PacifiCorp). This flow was represented in CE-QUAL-W2 by four point sources located at irrigator withdrawal points.

### 2.3.2.3 Water Quality Data

Water quality data for the main inflow to the Lake Ewauna to Keno Dam reach model implementation is described below. However, during calibration and application, Link River reach simulation output was used to provide all water quality data for the main inflow to the Lake Ewauna to Keno Dam reach.

### ***Temperature***

In CE-QUAL-W2, only model inflows are required to have assigned water quality data. All withdrawals from the system assume the temperature or water quality at the point of withdrawal. Inflow locations, data sources, and data and model resolution are summarized in Table 7, followed by descriptions of each data set.

**Table 7. Temperature data for inflow locations, including data source, and data and model resolution**

| Location | Source | Data Resolution | Model Input Resolution |
|---|---|---|---|
| Link River | USBR | Hourly, other | Hourly, other [a] |
| Distributed tributary | Estimated | n/a | Annual |
| Stormwater | Estimated | n/a | Annual |
| Columbia Plywood | ODEQ | monthly | Monthly |
| KFWTP | ODEQ / estimated | Daily | Daily |
| South Suburban Sanitation District | ODEQ | Daily | Monthly |
| Collins Forest Products #1, 2 | ODEQ | Daily | Daily |
| Lost River | USBR | Semi-monthly | Semi-monthly |
| Klamath Straits Drain | USBR | hourly | daily, other [a] |

[a] : Hourly data was not available for all periods.

### *Link River Temperature*

For model implementation, hourly temperatures from Link Dam (A-Canal) recorded by USBR were used as input temperatures. For calibration and application, simulated hourly temperatures from the Link River reach simulation were used as hourly input temperatures for the Lake Ewauna reach simulation.

### *Distributed Tributary Accretion/Depletion Temperature*

Accretions and depletions to the Lake Ewauna reach were assumed to represent groundwater exchange within the reach. A constant inflow temperature of 12.0$^{o}$C was assumed for the entire 2000 simulation.

### *Tributary Temperatures*

#### *Storm water Runoff*

Temperatures for storm water runoff in 2000 were assumed constant at 12.0$^{o}$C for the entire year, which is the same as the temperature assigned to storm water runoff in the 1992 Wells simulation (ODEQ, 1995).

#### *Columbia Plywood*

Monthly values provided in the Columbia Plywood monitoring reports to ODEQ were used as model input. These temperatures range from 13.3 °C in winter to 21.1 °C in summer.

#### *Klamath Falls Wastewater Treatment Plant*

Klamath Falls Wastewater Treatment Plant (KFWTP) was not required to report effluent temperature prior to July 2001. However, after 2001, daily effluent temperature was reported as well as daily blowdown temperature and daily combined effluent and blowdown temperature. Blowdown is the water used as coolant at the cogeneration plant. Blowdown temperatures were not available prior to July 2001, because effluent was not being used at the cogeneration plant as cooling water. Using the existing data set, a linear regression relationship between the daily influent and effluent temperatures was determined based on data from July 2001 through February 2002. All temperatures in the relationship are in Fahrenheit.

$$T_{effluent} = 0.8952(T_{influent}) + 8.1293 \qquad (r^2 = 0.89)$$

This relationship was used to calculate the effluent temperatures for 2000 for the KFWTP, which were then converted to degrees Celsius. Resulting temperatures range from a low of about 15°C, to a high of about 23°C. A brief spike in late summer reaches temperatures over 25°C.

***South Suburban Sanitation District***

average monthly water temperature for the South Suburban Sanitation District were calculated from measured data gathered five times a week and reported in monthly monitoring reports submitted to ODEQ. These temperatures range from 2.5°C in winter to below 21°C in summer.

***Collins Forest Products #1 and #2***

Daily measured temperatures for the #1 and #2 discharges from Collins Forest Products were reported in the monthly monitoring reports submitted to ODEQ and were used directly in model input. These temperatures, similar for both discharges, range from about 3 °C in winter to over 25 °C in summer.

***Lost River Diversion***

Temperatures for the Lost River Diversion input were estimated from bimonthly measurements taken in the Lost River at Wilson Reservoir by USBR between December 28, 1999 and December 18, 2000. These temperatures range from a low of 2.2°C in winter to a high of 30°C in summer.

***Klamath Straits Drain***

The temperature record for the Klamath Straits Drain (KSD) is a composite of hourly temperatures measured by USBR at both the mouth of KSD and KSD at Stateline for 2000, averaged to daily temperatures. First, daily temperatures were calculated for each location. Data was available at the mouth from 1/15/00 to 3/16/00, 4/6/00 to 4/19/00 and 5/2/00 to 11/22/00. Data from the Stateline location was used to fill the data gaps for 3/20/00 to 4/5/00. Daily air temperatures from KFLO 2000 were used to fill the data gaps from 1/1/00 to 1/14/00 and from 11/23/00 to 12/31/00. If daily average air temperature was less than 0.0 ºC, a water temperature of 0.0 ºC was used. The composite temperature record for KSD ramges from 0 ºC in winter to over 25 0 ºC in summer.

***<u>Constituent Concentrations</u>***

***Link River Concentrations***

For model implementation, outflow from Link River simulations was used to define inflow concentrations to the Lake Ewauna to Keno reach. Not all parameters modeled in CE-QUAL-W2 are modeled in RMA-11. Total dissolved solids, suspended solids, total inorganic carbon, and alkalinity are not represented in the river reach models as implemented in this study. Values from Wells (ODEQ, 1995) were used for these parameters. Labile dissolved organic matter (LDOM) was estimated from organic nitrogen and phosphorous concentrations output by RMA-11 by using the stoichiometric equivalence for the nitrogen and phosphorous partitioning in the CE-QUAL-W2 model parameter set. Calibration – validation and model application simulations also used Link River simulated results to represent headwater quality boundary conditions.

***Accretion/Depletion Concentrations***

Constituent concentrations from the 1992 Wells simulation (ODEQ, 1995) were used in the 2000 simulation. The simulation period for the Wells simulation covered only part of the calendar year, from JD 152 to JD 274, so prior to JD 152, concentrations in 2000 were assumed to be equal to concentrations on JD 152 in 1992. After JD 274, concentrations in 2000 were assumed to be equal to those on JD 274 in 1992.

***Tributary Concentrations***

***Storm water Runoff***

Stormwater runoff concentrations from the Wells 1992 simulation (ODEQ, 1995ODEQ, 1995) were applied directly to the 2000 simulation. These concentrations were constant for each constituent throughout entire year.

***Columbia Plywood***

The monthly monitoring reports submitted by Columbia Plywood to ODEQ generally provide average monthly pH, biological oxygen demand (BOD) and total suspended solids (TSS). Results for a single sample were reported for 2000 (December) and eight samples were taken in 2001. An average of the nine reported concentrations reported in the December 2000 through December 2001 period was used to represent a constant annual input value of 8 mg/l of BOD. TSS was similarly estimated to be 16 mg/l. Inputs for the other water quality parameters were taken from the 1992 Wells simulation (ODEQ, 1995) for Columbia Plywood.

***Klamath Falls Water Treatment Plant***

Constituent concentrations for the Klamath Falls Water Treatment Plant were based on both monthly ODEQ reports and the 1992 Wells simulation (ODEQ, 1995).

Because reported daily dissolved oxygen and suspended solids values showed modest variation, monthly average values were calculated for model input. Monthly BOD concentrations were estimated from samples collected at biweekly intervals. All other data are monthly estimates based on the 1992 Wells simulation (ODEQ, 1995).

***South Suburban Sanitation District***

South Suburban Sanitation District reports dissolved oxygen, BOD, TSS, total phosphorus, ammonia, nitrate and pH to ODEQ. The frequency of reporting varied for each parameter, with dissolved oxygen and pH reported 5 times a week, BOD and TSS reported twice a week, and all nutrients reported once a month. All data was converted to monthly averages. Orthophosphate was estimated as 50 percent of total phosphorous concentrations because no data were available. The pH and temperature monthly averages were used to estimate alkalinity and TIC monthly values (Snoeyink and Jenkins, 1980). TDS was estimated to be 200 mg/l (same as 1992 simulation (ODEQ, 1995)). Several parameters were set to zero because there was no available information. These parameters included iron, refractory and labile particulate organic matter, and algae concentration.

***Collins Forest Products (Weyerhauser #1 and #3)***

Constituent concentrations for Collins Forest Products #1 and #2 were estimated from the monthly water quality reports submitted to ODEQ. These reports provided daily flows and temperatures. BOD and TSS were reported twice a week. Other constituent concentrations were estimated from the 1992 Wells simulation (ODEQ, 1995) input files for Weyerhauser #1 and #3 (Collins Forest Products is the current owner of the same facilities that Weyerhauser owned in 1992).

***Lost River Diversion***

Lost River Diversion constituent concentrations were estimated from bimonthly data collected by USBR at Wilson Reservoir in 2000, Klamath Straits data from 2000 (for dissolved oxygen), Link Dam 2002 grab samples, and from the 1992 Wells simulation (ODEQ, 1995). Wilson Reservoir data were used only during periods when the Lost River diversion channel was flowing into the Klamath River.

***Klamath Straits Drain***

Monthly model input values were identified for all water quality constituents at the Klamath Straits Drain. Dissolved oxygen and total dissolved solids values were calculated from USBR datasonde data collected from Klamath Straits Drain during 2000. This sonde was deployed from January through November, and the record shows several periods of missing data (the largest data gaps are from March 16, 2000 through April 6, 2000 and April 19, 2000 through May 2, 2000). Monthly estimates for ammonia, nitrate, orthophosphate, algae, and alkalinity concentrations were based on USBR grab samples collected in 2000. All other constituent concentrations were estimated from the 1992 Wells simulation (ODEQ, 1995).

#### 2.3.2.4 Meteorological Data

Hourly information required for the meteorological input file consisted of air temperature (°C), wet bulb temperature (°C), wind speed (m/s), cloud cover (scale 0-10), and atmospheric pressure.

Meteorological data for the Lake Ewauna to Keno Dam reach of the Klamath River were derived from meteorological observations near Klamath Falls, OR. The meteorological station at this site (KFLO) is operated by the Pacific Northwest Cooperative Agricultural Weather Network, and provides the following necessary information: dry bulb temperature, dew point temperature, relative humidity, cumulative solar radiation, and wind speed, as well as many other parameters.

Air temperature and wind speed were readily available from reported KFLO data. Cloud cover was calculated from the daily summation of solar radiation provided by the station, using the ideal sine wave representation of the maximum possible solar radiation throughout the year to determine the ratio of measured radiation to total radiation. Atmospheric pressure was calculated within CE-QUAL-W2 (elevation of Keno Reservoir: 4085 ft (1245 m)). Dew point temperature was calculated based on relative humidity, atmospheric pressure, and air temperature. These methods of determination and calculations are outlined in Appendix E.

### 2.3.3 Keno Reach

The Keno reach extends from Keno Dam to the headwaters of J.C. Boyle Reservoir. There are no appreciable streams tributary to this reach. Physical description (e.g., geometry), flow, water quality, meteorological conditions, and other model parameters describing this reach are outlined below. This study uses RMA-2 to represent flow and RMA-11 to represent water quality.

#### 2.3.3.1 River Physical Description

***River Location and Path***

Coordinates describing river location and path were defined using a digitized version of 1:24,000 USGS topographic quadrangles provided by CH2M Hill, as discussed in Appendix C. Key locations in the reach are presented in Table 8 and a model representation of the reach is shown in Figure 5.

**Table 8. Klamath River, Keno reach geometry information for the RMA-2 and RMA-11 models**

| Location | Node | Element | x-coord | y-coord | Site type |
|---|---|---|---|---|---|
| Keno Dam | 1 | 1 | 186.8 | 165.4 | BC, upper |
| End Keno R reach | 117 | 58 | 181.0 | 166.9 | BC, lower |
| A/D Keno reach | 73 | 37 | 183.7 | 167.0 | A/D |
| 1/4 mi abv J.C. Boyle | 110 | 56 | 181.4 | 166.9 | Cal/Val and Reporting |

BC – boundary condition (flow, constituent concentration, stage)
A/D – accretion/depletion location
Reporting – model output location

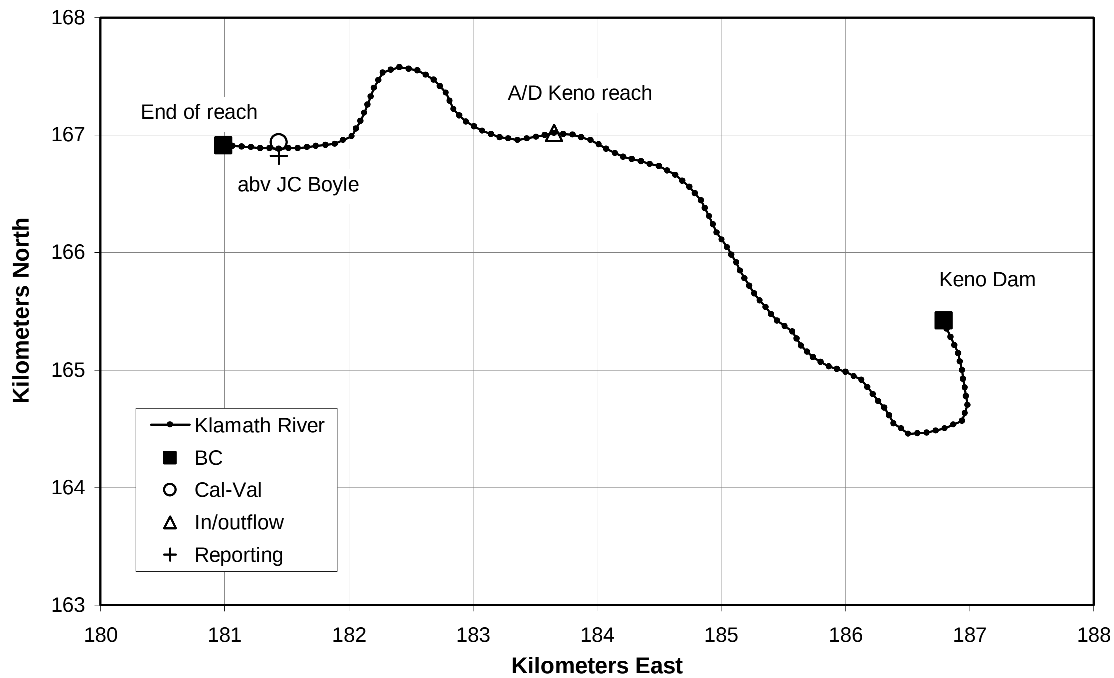



**Figure 5. Klamath River, Keno reach representation**

### *River Width*

Keno reach widths were obtained from habitat surveys conducted by Tom Payne and Associates. Measurements were completed at roughly eight locations per mile. These measurements were not necessarily uniformly spaced. Because measurement locations did not always coincide with the 1:24,000 x-y coordinates, field data were assigned to the nearest x-y coordinate. Trapezoidal river cross sections were constructed at evenly spaced intervals of 75 meters. Side slopes were assumed to be 1:1 and river width was based on a seven times running average of measured widths.

### *Bed Elevation/Slope*

Bed slope for the reach was estimated from USGS topographic maps and known elevations at Keno Dam and J.C. Boyle water surface elevations. Reach elevations range from approximately 3796 ft MSL (1157 m) to 4019 ft MSL (1225 m). Elevations were estimated from topographic contours and do not represent the river bed elevations.

**Table 9. Klamath River, Keno reach geometry summary**

| | |
|---|---|
| Node spacing | 75 meters |
| Number of nodes | 117 nodes in length |
| Length | 5.37 miles from RM228.69-234.06 |
| Elevations | Range: 1157-1225 meters |
| Widths | Range: 21-57 meters |
| Side slopes | 1:1 |
| Data sources | UTM coordinates from CH2MHill; Elevations estimated from USGS topographic maps. |
| Notes | n/a |

#### 2.3.3.2 Flow Data

***Inflows and Outflows***

Inflow to the Keno reach was based on daily flows measured by the USGS gage near Keno (No. 11509500. No appreciable tributary contributions or diversions have been identified for this relatively short reach and accretions/depletions between Keno Dam and J.C. Boyle Dam were assigned to the J.C. Boyle Reservoir reach. However, an element inflow location and small inflow (0.1 cms) has been included at element 37.

***Downstream Boundary Condition***

The measured elevations at J.C. Boyle dam were used to calculate the downstream elevations for the Keno reach simulation. This approach resulted in a variable stage downstream boundary condition and replicated backwater conditions within the reach. Because river elevations were approximated from topographic maps with twenty-foot contours and stage measurements are accurate, elevation discrepancies arise where rivers meet reservoirs. This discrepancy was estimated to be around 3.1 meters at J.C. Boyle headwaters, so the downstream boundary conditions for the Keno River reach was defined as J.C. Boyle Reservoir elevations plus 3.1 meters (10.2 feet).

#### 2.3.3.3 Water Quality Data

***Temperature***

Hourly simulated temperatures from the Lake Ewauna CE-QUAL-W2 simulation were used as the temperatures in the Keno reach.

***Constituent Concentrations***

Hourly simulated constituent concentrations from the Lake Ewauna CE-QUAL-W2 simulation were used as the constituent concentrations in the Keno reach. CE-QUAL-W2 provides total organic and dissolved organic forms of nitrogen and phosphorous as derived output values. To maintain the total mass of organic nitrogen and phosphorous in the system, total organic nitrogen and total organic phosphorous are passed to the downstream river model (RMA-11). Because CE-QUAL-W2 includes the algae fraction in organic nitrogen and organic phosphorus, the algal component of each nutrient was subtracted from the total.

#### 2.3.3.4 Meteorological Data

Required hourly information for meteorological input consisted of: air temperature (°C), wet bulb temperature (°C), wind speed (m/s), cloud cover (scale 0-1.0) and atmospheric pressure.

Meteorological data for the Klamath River Keno reach were derived from meteorological observations near Klamath Falls, OR. This meteorological station (KFLO) is operated by the Pacific Northwest Cooperative Agricultural Weather Network, and provides the following necessary information: dry bulb temperature, dew point temperature, relative humidity, cumulative solar radiation, and wind speed, as well as many other parameters.

Air temperature and wind speed were readily available from the weather station. Cloud cover was calculated from the daily summation of solar radiation provided by the station, using the ideal sine wave representation of the maximum possible solar radiation throughout the year to determine the ratio of measured radiation to total radiation. Atmospheric pressure was calculated based on a J.C. Boyle elevation of 3800 ft (1158 m) and assumed constant throughout the simulation period at 880 mb. Wet bulb temperature was calculated based on relative humidity, atmospheric pressure, and air temperature. These methods of determination and calculations are outlined in Appendix E.

### 2.3.4 J.C. Boyle Reservoir

J.C. Boyle Reservoir primarily serves to regulate peaking flows for the J.C. Boyle Powerhouse (RM 220.4). This reservoir reach extends from the J.C. Boyle headwaters (the end of the Keno reach at RM 227.6) to J.C. Boyle Dam (RM 224.7). There is one tributary represented in the model, located at Spencer Creek. Physical characteristics, flow, water quality, meteorological conditions, and other model parameters are outlined below.

#### 2.3.4.1 Reservoir Physical Data

***J.C. Boyle Dam Features***

J.C. Boyle Dam has four primary outlets: a spillway, fish ladder, and two outlets into the waterway intake (fish screen bypass and waterway pipeline). There are two additional low level culverts that were used during dam construction – these have been filled with concrete. The details of these outlets are summarized in Table 10.

**Table 10. J.C. Boyle Dam outlet features**

| Outlet | Invert Elevation | Dimension | Operation |
|---|---|---|---|
| Fish ladder | 3780.0 ft | 24 inch diameter | Manual |
| Fish Screen Bypass | 3757.0 ft | 24 inch diameter | Manual |
| Waterway pipeline | 3775.0 ft | 14 foot diameter | ** |
| Spillway | 3782.0 ft | 3 radial gates @ 35 ft width each | Remote control on one gate |
| Sources: PacifiCorp (2002), PacifiCorp (2000), PacifiCorp drawing: Exhibit L-4 | | | |

### *Reservoir Bathymetry Representation*

Unlike the Lake Ewauna to Keno Dam Reservoir reach, there has been no previous modeling effort of J.C. Boyle using CE-QUAL-W2. Reservoir geometry was derived from bathymetric data provided by J.C. Headwaters (Figure 6). Segment length, segment orientation, layer thickness and width were required for the reservoir model. Segments were identified based on changes in the reservoir morphology and widths. The reservoir was divided into sixteen active segments. Segments varied in length from approximately 135 ft (roughly 40 m) to 1600 ft (roughly 490 m). While capturing the general shape of J.C. Boyle Reservoir, the chosen segments also captured pertinent features of the reservoir such as the deep hole in the northwest corner of the reservoir and the discontinuity in the reservoir bed near the dam (Figure 7).

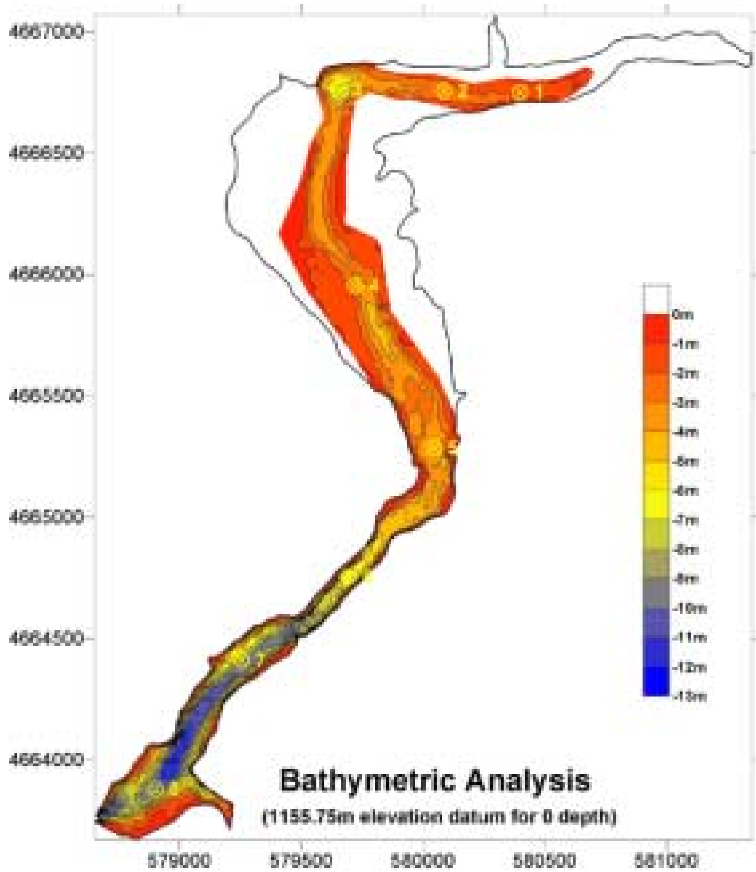



**Figure 6. J.C. Boyle Reservoir Bathymetry (J.C. Headwaters)**

Cross sections were defined by roughly bisecting each segment and determining the depths as measured from river left to river right (looking downstream). These measurements were used to determine the number of active layers and the layer widths for each segment. Layer thickness was set to one meter. Twelve active layers of varying widths were determined from this method. Although a finer resolution representation was attempted, peaking hydropower operations produced a dynamic water surface elevation and simulations times were long (on the order of a day) because the model was continually adding and subtracting both layers and segments. The 1 meter layer thickness produced reasonable results and the simulation time was approximately 10 minutes, while smaller layer thicknesses resulted in long run times (e.g., greater than 20 hours) due to the continual addition and removal of layers and segments in this small peaking power reservoir.

Manning's friction factor for each segment was assumed to be 0.04. A stage-volume curve was generated from the bathymetry data and compared to the measured stage-volume curve of the reservoir. Adjustments were made as necessary to ensure the simulated reservoir stage-volume relationship was consistent with the observed stage-volume relationship. The second active segment (segment 3) layer widths were increased slightly to increase the volume within that segment because the model experienced solution difficulties due to the characteristics of the accretion/depletion at Spencer Creek. A comparison of modeled and measured stage-volume relationships is shown in Figure 8.

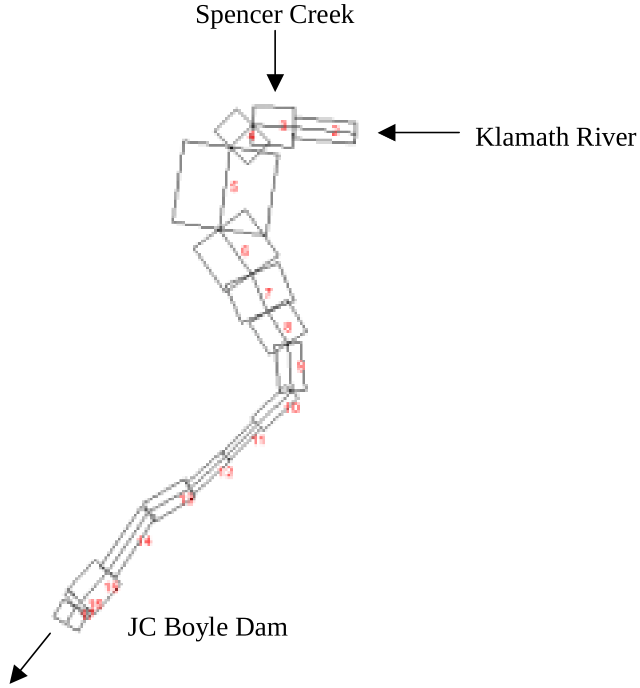



**Figure 7. Representation of J.C. Boyle Reservoir in CE-QUAL-W2**

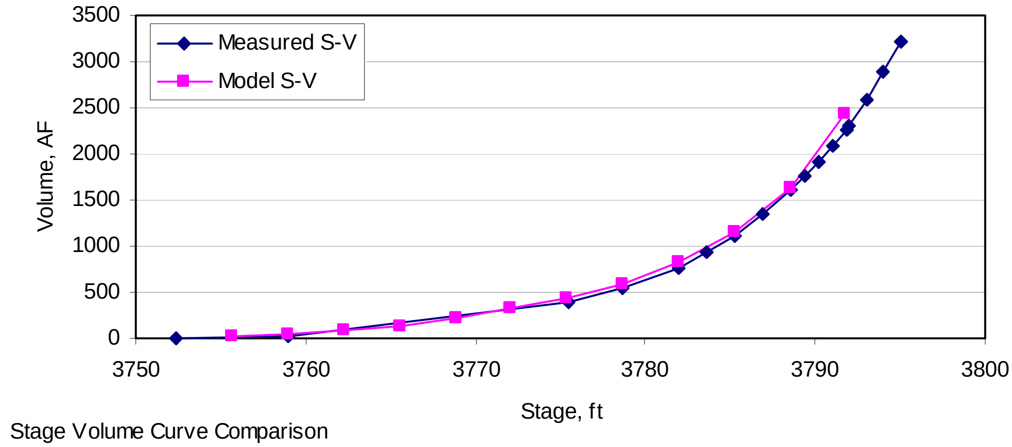



**Figure 8. Comparison of measured and model representation of J.C. Boyle Reservoir stage-volume (S-V) relationships**

#### 2.3.4.2 Flow Data

***Klamath River Inflow***

Klamath River inflow to J.C. Boyle Reservoir is not directly measured. A water balance between Keno Dam and J.C. Boyle Dam suggest that accretions within this reach are generally modest. Thus, daily flow rates from the Klamath River near Keno USGS gage 11509500 were used as inflow into J.C. Boyle Reservoir.

***Spencer Creek Inflow***

Limited Spencer Creek inflow information was available. Net reservoir accretion/depletion was calculated as the difference between the daily average outflow from J.C. Boyle Dam and the daily average inflow (which was derived from the USGS Gage "Klamath River near Keno"). This accretion/depletion for the reservoir, with daily fluctuations ranging from a maximum withdrawal rate of 600 cfs to a maximum accretion rate of about 600 cfs, was located at Spencer Creek.

***J.C. Boyle Dam Outflow***

The outflow from the J.C. Boyle Reservoir was calculated as the sum of recorded releases to the powerhouse canal, spill from the dam, bypass releases, and fish ladder releases. Hourly data for power canal flows and spill were derived from PacifiCorp records. Fish ladder and bypass releases were assumed constant at 80 cfs and 20 cfs, respectively.

#### 2.3.4.3 Water Quality Data

***Temperature***

***Klamath River Inflow***

Inflow temperatures to J.C. Boyle Reservoir are derived from hourly temperatures simulated by RMA-11 (Keno Reach simulation at Node 110).

***Spencer Creek Inflow (Accretion/Depletion)***

A temperature record for inflow at Spencer Creek was composed from hourly field data recorded by PacifiCorp using Onset Computer Corporation Tidbits® remote logging temperature sensors (Tidbits) in 2001 and 2002. Data was available for 2001 from 5/11 to 12/31 and for 2002 from 1/1 to 5/5. Missing data was linearly interpolated.

***Constituent Concentrations***

***Klamath River Inflow***

Hourly constituent concentrations used in model implementation are from CE-QUAL-W2 Lake Ewauna implementation simulation. This input data stream was only used to implement the model (to test the model). For calibration and application, hourly constituent concentrations from Keno River reach simulations (using RMA11) were used and are presented in the calibration and application sections of this document.

***Spencer Creek Inflow Water Quality***

Concentrations for required constituents at Spencer Creek were estimated from 2002 grab samples. Nine dates were input into the model, representing the seven available grab samples and the first and last day of the year. Labile dissolved organic matter (LDOM) was estimated from total phosphorus and phosphate concentrations using the calculation:

$$LDOM = \frac{TotalPhosphorus - Phosphate}{0.005}$$

The value of 0.005 is a stoichiometric equivalence between phosphate and organic matter.

#### 2.3.4.4 Meteorological Data

Required hourly information for the meteorological input file consisted of: air temperature (°C), wet bulb temperature (°C), wind speed (m/s), cloud cover (scale 0-10) and atmospheric pressure.

Meteorological data for the J.C. Boyle Reservoir reach were derived from meteorological observations near Klamath Falls, OR. This meteorological station (KFLO) is operated by the Pacific Northwest Cooperative Agricultural Weather Network, and provides the following necessary information: dry bulb temperature, dew point temperature, relative humidity, cumulative solar radiation, and wind speed, as well as many other parameters.

Air temperature and wind speed were readily available from the weather station. Cloud cover was calculated from the daily summation of solar radiation provided by the station, using the ideal sine wave representation of the maximum possible solar radiation throughout the year to determine the ratio of measured radiation to total radiation. Atmospheric pressure is calculated within CE-QUAL-W2 using the elevation of J.C.

Boyle Reservoir: 3793 ft (1156 m). Dew point temperature was calculated based on relative humidity, atmospheric pressure, and air temperature. These methods of determination and calculations are outlined in Appendix E.

## 2.3.5 Bypass and Peaking Reach

The Bypass and Peaking reach extends from J.C. Boyle Dam to the headwaters of Copco Reservoir. Noteworthy features of the reach include diversion of main stem flows at J.C. Boyle Dam for hydropower production, the powerhouse penstock return roughly five miles downstream from J.C. Boyle Dam, a large springs complex in the bypass section, and hydropower peaking operations downstream of the powerhouse. There are a few small streams entering the reach, the most significant being Shovel Creek. The geometry, flow and water quality data, meteorological conditions and other model parameters are outlined below.

### 2.3.5.1 River Physical Description

***River Location and Path***

Coordinates describing river location and path were defined using a digitized version of the 1:24,000 USGS topographic quadrangles provided by CH2M Hill, as discussed in Appendix C. This information was translated into a network of nodes and elements for use by the numerical model (see Figure 9). Important locations within the reach, i.e., those of boundary conditions, are presented in Table 11.

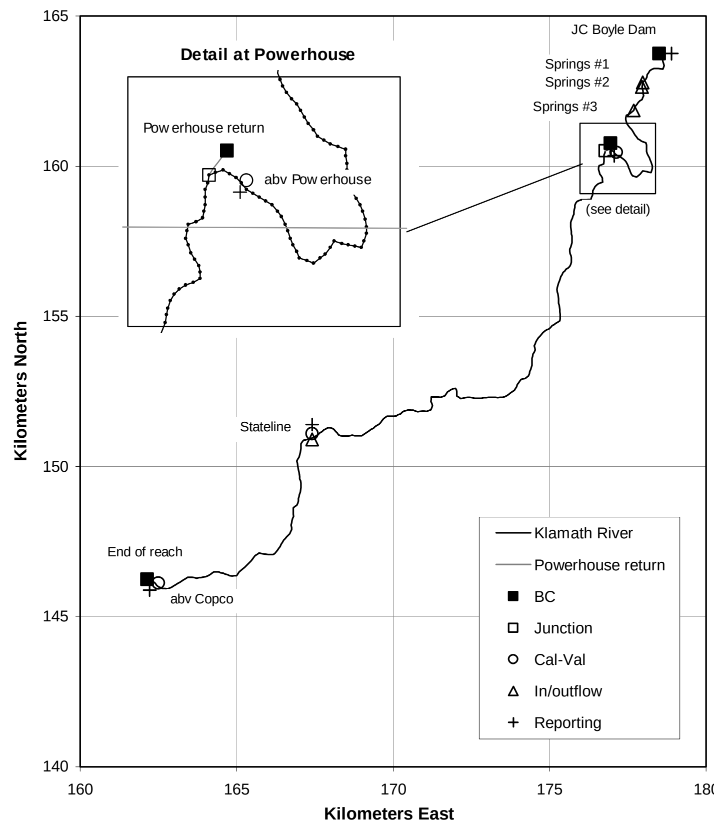



**Figure 9. Bypass - Peaking reach representation**

**Table 11. Geometry information for the Bypass - Peaking reach EC simulation**

| Location | Node | Element | x-coord | y-coord | Site type |
|---|---|---|---|---|---|
| J.C. Boyle Dam | 1 | 1 | 178.7 | 163.7 | BC, upper |
| End Peaking reach | 453 | 226 | 162.2 | 146.2 | BC, lower |
| J.C. Boyle Powerhouse | 95 | 48 | 176.9 | 160.8 | BC |
| Simulated Powerhouse Return | 97 | 49 | 176.8 | 160.5 | Junction, inflow |
| 1/4 mi abv Powerhouse | 91 | 46 | 177.1 | 160.4 | Cal-Val |
| 1/4 mi abv Shovel Cr | 389 | 195 | 166.3 | 147.2 | Cal-Val |
| 1/4 mi abv Copco | 447 | 224 | 162.5 | 146.00 | Cal-Val |
| CA-OR Stateline | 331 | 166 | 167.4 | 151.1 | Cal-Val, A/D |
| Springs #1 | 21 | 11 | 178.0 | 162.8 | A/D |
| Springs #2 | 23 | 12 | 178.0 | 162.6 | A/D |
| Springs #4 | 35 | 18 | 177.7 | 161.9 | A/D |

BC – boundary condition
A/D – accretion/depletion location
Cal-Val – calibration and validation location

## *River Width*

Bypass and Peaking reach widths were obtained from habitat surveys completed by Tom Payne and Associates. Measurements were completed at roughly eight locations per mile. These measurements were not necessarily uniformly spaced. Because measurement locations did not always coincide with the 1:24,000 x-y coordinates, field data were assigned to the nearest x-y coordinate. Trapezoidal river cross sections were constructed at evenly spaced intervals of 75 meters. Side slopes were assumed to be 1:1 and river width was based on a seven times running average of measured widths. Widths and other geometric characteristics of the Bypass and Peaking reach are summarized in Table 12.

***Bed Elevation/Slope***

Bed slope for the reach was estimated from USGS topographic maps and known elevations at J.C. Boyle Dam and Copco Reservoir water surface elevations. Reach elevations range from approximately 2565 ft MSL (782 m) to 3760 ft MSL (1146 m). Elevations were estimated from topographic contours and do not represent the river bed elevations.

**Table 12. Klamath River, Bypass-Peaking Reach geometry summary**

| | |
|---|---|
| Node spacing | 75 meters |
| Number of nodes | 459 nodes in length |
| Length | 20.81 miles from RM204.72-225.53 |
| Elevations | Range: 782-1146 meters |
| Widths | Range: 19-64 meters |
| Side slopes | 1:1 |
| Data sources | UTM coordinates from CH2MHill; Elevations estimated from USGS topographic maps. |
| Notes | 1 junction: J.C.B Powerhouse; Nodes 97, 458, 459 |

### 2.3.5.2 Flow Data

***Inflows and Outflows***

The Bypass-Peaking reach has two inflows: releases from J.C. Boyle Dam directly to the Klamath River (Bypass flow) and inflow at the J.C. Boyle Powerhouse tailrace. Measured releases from J.C. Boyle Dam during the 2000 calendar year were obtained from PacifiCorp and used to designate both flows. The springs, located in the bypass reach are represented by three element inflows at elements 11, 12 and 18. These springs were assigned a constant flow of 75 cfs (2.12 cms) each for the entire simulation resulting in a total inflow of 225 cfs (6.36 cms) for that section of the reach. A single accretion/depletion is located at Stateline in the Peaking portion of the reach (element 168). This accretion/depletion was placed at Stateline because there are several inflows in this vicinity, as well as diversions for agriculture. The accretion/depletion was calculated using seven day average values to smooth day to day variations in operations in the peaking reach

### *Downstream Boundary Condition*

The downstream boundary condition for the Bypass and Peaking reach is located at Copco Reservoir and was represented by reservoir elevation. This approach resulted in a variable stage downstream boundary condition and replicated backwater conditions within the reach. Elevations were determined by subtracting 39.21 ft (11.95 m) from the measured Copco Dam water surface elevations, to match the Peaking reach datum and the Copco Reservoir datum.

#### 2.3.5.3 Water Quality Data

### *Temperature*

Both the J.C. Boyle Dam release to the Bypass reach and via the Powerhouse were assigned the simulated hourly temperature releases at J.C. Boyle Dam (from CE-QUAL-W2). It was assumed that the transit time between J.C. Boyle Dam and the powerhouse tailrace, roughly three miles, was approximately twenty minutes at Peaking (T. Olson personal communication). Thus, Powerhouse release temperatures were not lagged.

The springs were assigned constant temperatures of 11.0°C. Accretion/depletions at Stateline were not assigned a temperature.

### *Constituent Concentrations*

Both the J.C. Boyle Dam release to the Bypass and the Powerhouse were assigned the simulated hourly constituent concentrations releases at J.C. Boyle Dam (from CE-QUAL-W2). It was assumed that the transit time between J.C. Boyle Dam and the powerhouse tailrace, roughly three miles, was approximately twenty minutes. Thus, Powerhouse release constituent concentrations were not lagged.

The springs were assigned constant concentrations of 9.7 mg/l estimated as dissolved oxygen saturation at elevation 3600 ft and water temperature of 11°C. All constituent concentrations were assumed zero except nitrate and orthophosphate, which were assumed at 0.15 mg/l. The A/D at Stateline was not assigned water quality characteristics.

#### 2.3.5.4 Meteorological Data

Required hourly information for meteorological input to the models consisted of: air temperature (°C), wet bulb temperature (°C), wind speed (m/s), cloud cover (scale 0-1.0) and atmospheric pressure.

Meteorological data for the Bypass and Peaking reach of the Klamath River were derived from meteorological observations near Klamath Falls, OR. This meteorological station (KFLO) is operated by the Pacific Northwest Cooperative Agricultural Weather Network, and provides the following necessary information: dry bulb temperature, dew point temperature, relative humidity, cumulative solar radiation, and wind speed, as well as many other parameters.

Barometric pressure was calculated based on mean reach elevation of approximately 3160 ft (963 m) and was assumed constant at 904 mb. The methods of determination and calculation of necessary model parameters are outlined in Appendix E.

## 2.3.6 Copco Reservoir

The Copco Reservoir reach extends from Copco Reservoir headwaters (RM 203.1) to Copco Dam (RM 198.6). There are no tributaries represented in the model: the only inflow represented is Klamath River inflow to the reservoir. The physical data, flow and water quality data, meteorological conditions and other model parameters are outlined below.

### 2.3.6.1 Reservoir Physical Data

#### *Copco Dam Features*

Copco Dam has two primary outlets: a spillway and two waterway intakes that feed Unit 1 and Unit 2 at Copco No. 1 powerhouse. The two penstock intakes are treated as a single outlet in CE-QUAL-W2. The details of these outlets are summarized in Table 13.

**Table 13. Copco Dam outlet features**

| Outlet | Invert Elevation | Dimension | Operation |
|---|---|---|---|
| Penstock Intake (Unit 1) | 2575 ft | Two, 10-foot diameter | Remote Operation |
| Penstock Intake (Unit 2) | 2575 ft | 14 foot diameter | Remote Operation |
| Spillway | 2594 ft | 3 radial gates @ 35 ft width each | Remote control on one gate, others by motorized hoist |
| Sources: PacifiCorp (2002), PacifiCorp (2000) | | | |

#### *Reservoir Bathymetry*

Reservoir geometry was derived from bathymetric data of Copco Reservoir provided by J.C. Headwaters (Figure 10). Segment length, segment orientation, layer thickness and width were required for the reservoir model. Segments were identified based on changes in the reservoir morphology and widths. The reservoir was divided into twenty active segments. Segments varied in length from approximately 470 ft (roughly 140 m) to 2340 ft (roughly 715 m). While capturing the general shape of Copco Reservoir, the segment layout also captured the some of the pertinent features of the reservoir such as the deep hole near the dam.

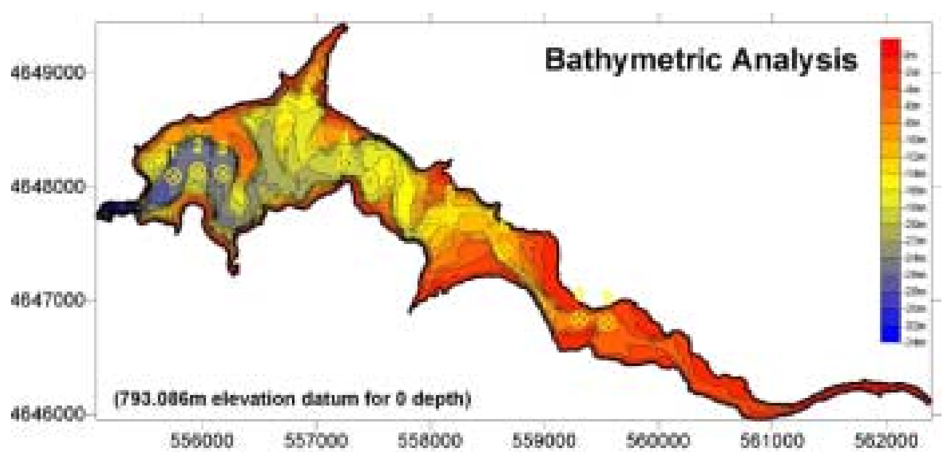



**Figure 10. Copco Reservoir bathymetry (J.C. Headwaters)**

Cross sections were defined by roughly bisecting each segment and determining the depths as measured from river left to river right (looking downstream). These measurements were used to determine the number of active layers and the layer widths for each segment. The layer thickness used was 6.6 ft (2.0 m). There were sixteen active layers of varying widths determined from this method.  The 6.6 ft (2.0 m) layer thickness produced reasonable results and the simulation time was approximately 15 minutes. The final CE-QUAL-W2 representation is shown in Figure 11, and the computed versus measured stage-volume relationships are compared in Figure 12.

The Manning's friction factor for each segment was assumed to be 0.04.  A stage-volume curve was generated from the bathymetry data and compared to the measured stage-volume curve of the reservoir to ensure proper volume and storage representation.

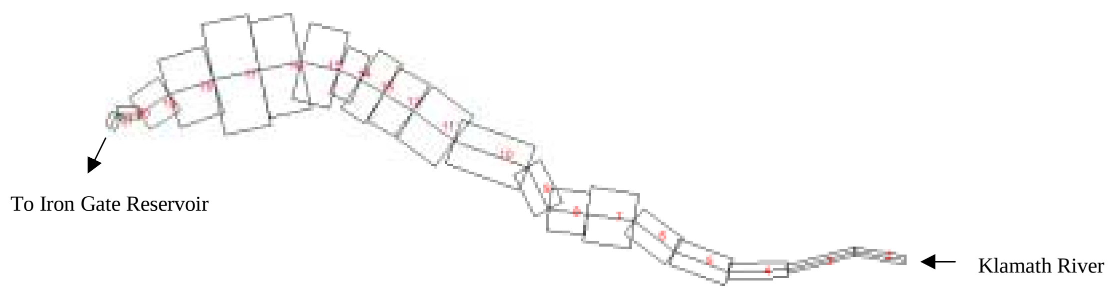



**Figure 11. Representation of Copco Reservoir in CE-QUAL-W2**

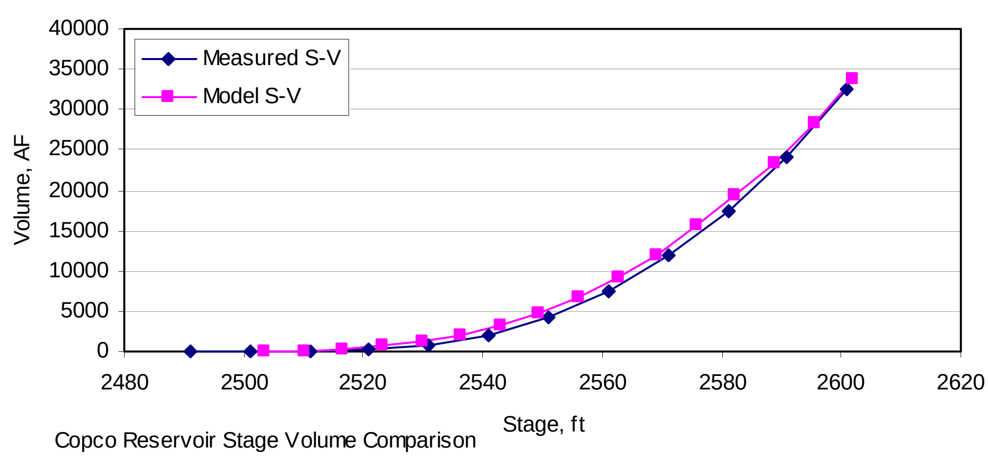



**Figure 12. Comparison of measured and model representation of Copco Reservoir stage-volume (S-V) relationships**

### 2.3.6.2 Flow Data

#### *Klamath River Inflow and Accretion/Depletion*

The hourly inflows for Copco Reservoir are represented as the sum of the inflow into the reservoir and the estimated accretion /depletion for the reservoir. The inflow into the reservoir used was the hourly flows from the Bypass-Peaking reach simulation (RMA-2 output: Node 453): there is no flow measurement station immediately above Copco Reservoir. The hourly accretion / depletion was calculated as sum of the daily change in storage in Copco and the daily average outflow from Copco, subtracting the daily average inflows from the Peaking Reach. Then a 7-day average accretion/depletion was calculated. This 7-day average accretion/depletion was expanded to hourly flows as a step function (no linear interpolation was used) and added Klamath River inflows.

***Copco Dam Outflow***

Hourly outflow for both the Copco powerhouse and the spillway were available from PacifiCorp and were used as the Copco Reservoir outflow flows for model implementation. The two powerhouse units were treated as a single outlet, with a single elevation (2581.04 feet (786.70 meters)).

#### 2.3.6.3 Water Quality Data

***Temperature***

***Klamath River Inflow***

Inflow temperatures for Copco Reservoir were the hourly temperatures from the Bypass-Peaking reach (RMA-11: Node 453).

***Constituent Concentrations***

***Klamath River Inflow***

For model implementation and application, the hourly constituent concentrations from the RMA-11 output file are used. Not all parameters modeled in CE-QUAL-W2 are modeled in RMA-11. Total dissolved solids, suspended solids, total inorganic carbon, and alkalinity are not explicitly represented in the river model at this time. Labile dissolved organic matter (LDOM) was estimated from organic nitrogen and phosphorous concentrations output by RMA-11 by using the stoichiometric equivalence for the nitrogen and phosphorous partitioning in the CE-QUAL-W2 model parameter set and accounting for the algal component of organic nitrogen and phosphorus. Suspended solids, iron, and tracer concentrations were set to reference levels (these parameters are included in the simulation, but not directly used, except to check issues such as conservation of mass (tracer)).

#### 2.3.6.4 Meteorological Data

The required hourly information for the meteorological input file consisted of: air temperature (°C), wet bulb temperature (°C), wind speed (m/s), cloud cover (scale 0-10) and atmospheric pressure.

The meteorological data for the Copco Reservoir reach was derived from meteorological observations near Klamath Falls, OR. The meteorological station (KFLO) is operated by the Pacific Northwest Cooperative Agricultural Weather Network, and provides the following necessary information: dry bulb temperature, dew point temperature, relative humidity, cumulative solar radiation, and wind speed, as well as many other parameters.

Air temperature and wind speed were readily available from the weather station. Cloud cover was calculated from the daily summation of solar radiation provided by the station, using the ideal sine wave representation of the maximum possible solar radiation throughout the year to determine the ratio of measured radiation to total radiation. Atmospheric pressure is calculated within CE-QUAL-W2 (elevation of Copco Reservoir: 2607 ft (765 m)). Dew point temperature was calculated based on relative humidity, atmospheric pressure, and air temperature. These methods of determination and calculations are outlined in Appendix E.

Because Copco Reservoir is roughly 1500 feet lower than Klamath Falls, the air temperature was adjusted to accommodate for the change in elevation. A lapse rate of 3.0°C, based on data from Klamath Falls and a meteorological station at Iron Gate Dam (see Appendix E). Air temperature was adjusted according to the following formula, based on Linacre (1992).

$$T_1 = T_2 + 0.003h$$

Where: T1 = temperature at site 1

T2 = temperature at site 2

h = $E_2 - E_1$, meters

$E_1$ = Elevation of site 1

$E_2$ = Elevation of site 2

For the purposes of this study an average elevation of Copco and Iron Gate Reservoirs was applied (2450 ft (746.8 m)). Based on a meteorological station at Copco Village, it was apparent that wind speed was moderated near the headwaters of Copco Reservoir. A second field season of data is being collected to better understand local conditions. For this effort the remaining meteorological parameters from the KFLO station were not modified.

### 2.3.7 Iron Gate Reservoir

The Iron Gate Reservoir reach extends from the headwaters of Iron Gate Reservoir to Iron Gate Dam. The small Copco #2 Reservoir and river reach between Copco and Iron Gate reservoirs are not represented in the modeling framework (the exception is the Without Project scenario, discussed in the application section). There are three tributaries represented in the Iron Gate Reservoir CE-QUAL-W2 applications: Camp Creek, Jenny Creek, and Fall Creek. The spillway for the dam is modeled as a withdrawal in the last active segment because the spillway structure draws water to the side of the dam, not over or through the dam. Also, due to the shape of the reservoir, two branches were included in the representation. Branch one is the main branch, and receives water from Klamath River (i.e., releases from Copco Reservoir). The Camp Creek arm of Iron Gate Reservoir is represented with a separate branch. The geometry, flow and water quality data, meteorological conditions and other model parameters are outlined below.

### 2.3.7.1 Reservoir Physical Data

***Iron Gate Dam Features***

Iron Gate Dam has four primary outlets: a spillway, penstock, and two fish hatchery intakes. The details of these outlets are summarized in Table 14.

**Table 14. Iron Gate Dam outlet features**

| Outlet | Invert Elevation | Dimension | Operation |
|---|---|---|---|
| Upper Fish Hatchery | 2293 ft | 24 inch diameter | Manual |
| Penstock Intake | 2309 ft | 12 foot diameter | Remote operation |
| Lower Fish Hatchery | 2253 ft | 24 inch diameter | Manual |
| Spillway | 2328 ft | Side channel (727 feet in length) | Overflow |
| Sources: PacifiCorp (2002), PacifiCorp (2000) | | | |

***Reservoir Bathymetry***

Reservoir geometry was derived from bathymetric data of Iron Gate Reservoir provided by J.C. Headwaters (Figure 13). Segments were identified based on changes in the reservoir orientations and widths. Using this method, two branches were created. Branch 1 had twenty-six active segments and Branch 2 had four active segments. The segment length for the entire reservoir varies from approximately 121 ft (roughly 40 m) to approximately 1680 ft (roughly 510 m). Branch 2 had an external upstream boundary and ended at Branch 1, Segment 20.

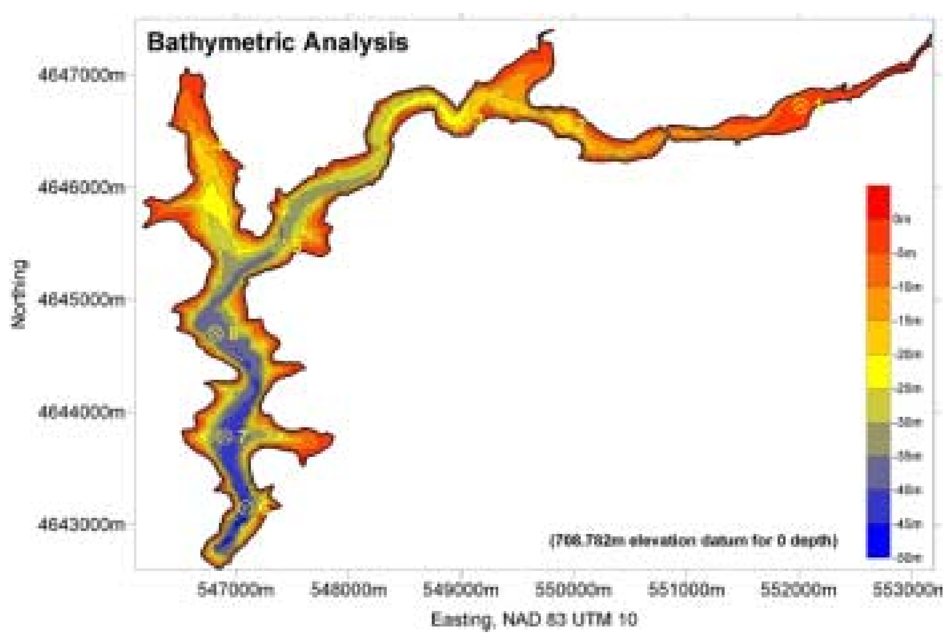



**Figure 13. Iron Gate bathymetry (J.C. Headwaters)**

Once the segments were determined, each segment was roughly bisected and the changes in depth across each segment were measured from river left to river right (looking downstream). These measurements were used to determine the number of active layers and the layer widths for each segment. The layer thickness was 8.2 ft (2.5 m) and there were 18 active layers.

Also determined from the bathymetric map of Iron Gate Reservoir were the orientations of each segment. Segment length, segment orientation, layer thickness and width were all used to construct the bathymetry file. The Manning's friction factor for each segment was assumed to be 0.04. A stage-volume curve was generated from the bathymetry data and adjusted to match the measured stage-volume curve of the reservoir (Figure 14).

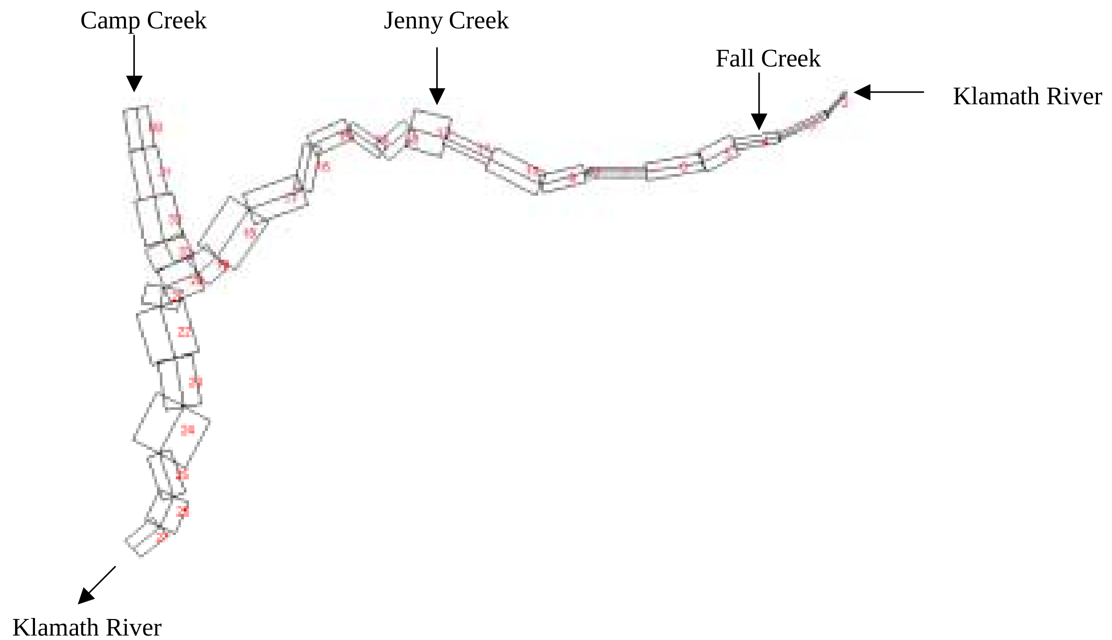



**Figure 14. Representation of Iron Gate Reservoir for CE-QUAL-W2**

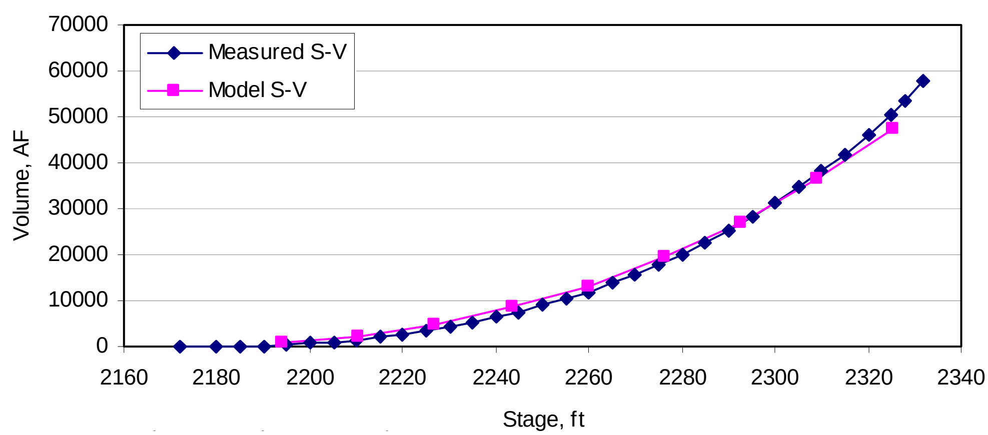



**Figure 15. Comparison of measured and model representation of Iron Gate Reservoir stage-volume (S-V) relationships**

### 2.3.7.2 Flow Data

***Iron Gate Reservoir Inflow***

There is no gage to measure flow into Iron Gate Reservoir; however, hourly flows from the Copco Reservoir were used as representative inflows. Hydropower peaking at Copco No. 1 and No. 2 results in periods when releases to the Klamath River downstream are insignificant. During these periods a flow of 0.035 cfs (0.001 cms) was assumed.

***Accretion/Depletion and Tributary Inflow***

The hourly accretion/depletion was calculated as sum of the daily inflow to, outflow from, and change in storage in Iron Gate Reservoir. A 7-day running average accretion/depletion was determined from the daily values.

Because limited flow information was available for any of the creeks (Camp, Jenny, and Fall Creeks) flowing into Iron Gate Reservoir, the accretion/depletion was placed at Jenny Creek inflow location (Segment 12). Camp Creek (segment 10) and Fall Creek (segment 4) are active in the model, but flows are set to small numbers or zero, effectively rendering them insignificant. Camp Creek, because it is a branch inflow, was assigned a value of 0.0035 cfs (0.0001 cms) for the entire year. Fall Creek inflow was set to zero.

***Iron Gate Dam Outflow***

Outflow from Iron Gate Reservoir was determined from PacifiCorp daily flow records for the Powerhouse release and spill, and estimates of fish hatchery releases. A constant flow of 50 cfs (1.42 cms) was assumed for the lower fish hatchery release. The upper fish hatchery release was assumed zero.

#### 2.3.7.3 Water Quality Data

***Temperature***

***Copco Dam Inflow***

Hourly Iron Gate Reservoir inflow temperatures were assigned based on simulated Copco Reservoir outflow values produced by CE-QUAL-W2. During off peak hours, the small inflow (0.035 cfs or 0.001 cms) was assigned the water quality of the last time step there was a release from Copco.

***Accretion/Depletion and Tributary Inflow Quality***

The accretion/depletion for this reach was located at Jenny Creek. However, Jenny Creek has not been monitored for temperature historically. Water temperatures assigned to Jenny Creek flows were monthly estimated temperatures for Bogus Creek (located in the Iron Gate to Turwar reach). The same water temperature is assigned at Fall and Camp Creeks; however, because there are very small or no flows assigned at these tributaries, the impact is negligible.

***Constituent Concentrations***

***Copco Dam Inflow***

Hourly Iron Gate Reservoir inflow quality was assigned based on simulated Copco Reservoir outflow values produced by CE-QUAL-W2. During off peak hours, the small inflow was assigned the water quality of the last time step there was a release from Copco.

***Accretion/Depletion and Tributary Inflow Quality***

The accretion/depletion for this reach was located at Jenny Creek. Bogus Creek monthly estimated water quality was assigned to the accretion/depletion at Jenny Creek. The same water quality is assigned at Fall and Camp Creeks; however, because there are very small or no flows assigned at these tributaries, the impact is negligible.

#### 2.3.7.4 Meteorological Data

The required hourly information for the meteorological input file consisted of: air temperature (°C), wet bulb temperature (°C), wind speed (m/s), cloud cover (scale 0-10) and atmospheric pressure.

The meteorological data for the Iron Gate Reservoir reach was derived from meteorological observations near Klamath Falls, OR. The meteorological station (KFLO) is operated by the Pacific Northwest Cooperative Agricultural Weather Network, and provides the following necessary information: dry bulb temperature, dew point temperature, relative humidity, cumulative solar radiation, and wind speed, as well as many other parameters.

Air temperature and wind speed were readily available from the weather station. Cloud cover was calculated from the daily summation of solar radiation provided by the station, using the ideal sine wave representation of the maximum possible solar radiation throughout the year to determine the ratio of measured radiation to total radiation. Atmospheric pressure is calculated within CE-QUAL-W2 (elevation of Iron Gate Reservoir: 2,328 ft (710 m)). Dew point temperature was calculated based on relative humidity, atmospheric pressure, and air temperature. These methods of determination and calculations are outlined in Appendix E.

Because Iron Gate Reservoir is roughly 1700 feet lower than Klamath Falls, the air temperature was adjusted to accommodate for the change in elevation. A lapse rate of 3.0 °C, based on data from Klamath Falls and a meteorological station at Iron Gate Dam (see Appendix E). Air temperature was adjusted according to the following formula, based on Linacre (1992).

$$T_1 = T_2 + 0.003h$$

Where: T1 = temperature at site 1

T2 = temperature at site 2

h = $E_2 - E_1$, meters

$E_1$ = Elevation of site 1

$E_2$ = Elevation of site 2

For the purposes of this study an average elevation of Copco and Iron Gate Reservoirs was applied (2450 ft (746.77 m)). Field data did not suggest any additional relationships between the Klamath Falls and Iron Gate Reservoir site. Thus, the remaining meteorological parameters from the KFLO station were not modified.

### 2.3.8 Iron Gate Dam to Turwar

The Iron Gate Dam to Turwar reach extends from Iron Gate Dam to the mouth of the Klamath River. There are several main tributaries flowing into the reach: Shasta River, Scott River, Salmon River, and Trinity River. Several creeks are also included within the simulation. The geometry, flow and water quality data, meteorological conditions and other model parameters are outlined below.

#### 2.3.8.1 River Physical Description

***River Location***

The x-y coordinates describing the river location were defined using a digitized version of the 1:24,000 USGS topographic quadrangles provided by CH2M Hill, as discussed in Appendix C. This information was translated into a network of nodes and elements for use by the numerical model (Figure 16). Important locations within the reach, i.e., those of boundary conditions or reporting / output locations, are presented in Table 15. Two model grids were developed for the reach, one with roughly 245-foot (75 meter) node spacing and one with 490 foot (150 meter) node spacing. The more refined model grid was constructed first and used for calibration and validation. When longer simulation periods were identified (e.g., months versus days), a coarser grid was constructed to reduce simulation times. Results from the two grids were compared and differences were negligible.

**Table 15. Geometry information for the IG-Turwar reach (150 meter grid)**

| Location | Node | Element | x-coord | y-coord | Site type | Inflow Angle, Radians [a] |
|---|---|---|---|---|---|---|
| Iron Gate Dam | 1 | 1 | 146.747 | 142.634 | BC, upper | 4.040 |
| End IG-Turwar reach | 2081 | 1040 | 9.821 | 99.506 | BC, lower | - |
| Bogus Creek | 7 | 4 | 146.141 | 142.022 | A/D | - |
| Willow Creek | 55 | 28 | 142.035 | 138.739 | A/D | - |
| Cottonwood Creek | 86 | 43 | 137.904 | 137.535 | A/D | - |
| Shasta River | 144 | 72 | 133.963 | 131.178 | A/D | - |
| Humbug Creek | 204 | 102 | 127.848 | 131.402 | A/D | - |
| Beaver Creek | 319 | 160 | 115.190 | 135.232 | A/D | - |
| Horse Creek | 468 | 234 | 99.597 | 130.180 | A/D | - |
| Scott River | 513 | 257 | 97.299 | 125.428 | A/D | - |
| Grider Creek (A/D Scott to Seiad) | 656 | 328 | 82.714 | 132.246 | A/D | - |
| Thompson Creek | 735 | 368 | 74.440 | 134.626 | A/D | - |
| Indian Creek | 906 | 453 | 69.371 | 126.831 | A/D | - |
| Elk Creek | 925 | 463 | 67.209 | 125.507 | A/D | - |
| Clear Creek | 1000 | 500 | 62.733 | 117.818 | A/D | - |
| Ukonom Creek | 1098 | 549 | 59.559 | 107.347 | A/D | - |
| Dillon Creek | 1162 | 581 | 55.209 | 102.905 | A/D | - |
| Salmon River | 1357 | 679 | 58.333 | 81.788 | A/D | - |
| Camp Creek | 1466 | 733 | 52.865 | 71.474 | A/D | - |
| Red Cap Creek | 1511 | 756 | 49.403 | 67.773 | A/D | - |
| Bluff Creek | 1547 | 774 | 45.339 | 65.584 | A/D | - |
| Trinity River | 1609 | 805 | 41.415 | 59.672 | A/D | - |
| Pine Creek | 1644 | 822 | 36.954 | 61.269 | A/D | - |
| Tectah Creek | 1850 | 925 | 24.557 | 79.833 | A/D | - |
| Blue Creek | 1908 | 954 | 22.306 | 86.220 | A/D | - |
| 1/4 mi bl Iron Gate | 4 | 2 | 146.419 | 142.345 | reporting | - |
| 1/4 mi ab Cottonwood | 84 | 42 | 138.117 | 137.743 | reporting | - |
| 1/4 mi ab Shasta | 142 | 71 | 134.262 | 131.198 | reporting | - |
| Walker Bridge | 369 | 185 | 111.329 | 131.759 | reporting | - |
| 1/4 mi ab Scott | 511 | 256 | 97.348 | 125.720 | reporting | - |
| USGS Gage at Seiad Valley | 672 | 336 | 80.887 | 133.289 | reporting | - |
| 1/4 mi ab Clear Cr. | 998 | 499 | 62.908 | 118.058 | reporting | - |
| 1/2 mi ab Salmon (Ishi Pishi) | 1352 | 676 | 58.231 | 82.372 | reporting | - |
| USGS Gage at Orleans | 1454 | 727 | 54.016 | 71.457 | reporting | - |
| 1/4 mi ab Bluff Cr. | 1545 | 773 | 45.357 | 65.876 | reporting | - |
| 1/4 mi ab Trinity | 1607 | 804 | 41.692 | 59.692 | reporting | - |
| Martin's Ferry | 1651 | 826 | 36.505 | 62.187 | reporting | - |
| Young's Bar | 1722 | 861 | 31.541 | 69.894 | reporting | - |
| 1/4 mi ab Blue Cr. | 1906 | 953 | 22.177 | 85.992 | reporting | - |
| USGS Gage nr Turwar | 2024 | 1012 | 16.341 | 96.868 | reporting | - |

[a] : Radians are measured counter-clockwise from due east

### *River Width*

Klamath River widths from Iron Gate Dam to Turwar were estimated from Meso-habitat surveys completed by US Fish and Wildlife Service. This data set included a reach by reach description of habitat unit type, width, and maximum depth (a total of 1741 units). These measurements were not uniformly spaced. Because measurement locations did not always coincide with the 1:24,000 x-y coordinates, field data were assigned to the nearest x-y coordinate. Trapezoidal river cross sections were constructed at evenly spaced intervals of 75 meters. Side slopes were assumed to be 1:1 and river width was based on a seven times running average of measured widths.

### *River Bed Elevation*

Bed slope for the reach was estimated from USGS topographic maps and known elevations at Iron Gate Dam. Reach elevations range from approximately sea level to roughly 2200 ft msl (671 m). Elevations were estimated from land surface topographic contours and do not represent the river bed elevations.

**Table 16. Klamath River, Iron Gate Dam to Turwar Reach geometry summary**

| | |
|---|---|
| Node spacing | 75 meters/150 meters |
| Number of nodes | 2082 nodes/4161 nodes in length |
| Length | 190.54 miles from RM0.00-190.54 |
| Elevations | Range: 0-671 meters |
| Widths | Range: 29- meters |
| Side slopes | 1:1 |
| Data sources | UTM coordinates from CH2MHill; Elevations estimated from USGS topographic maps. |
| Notes | n/a |

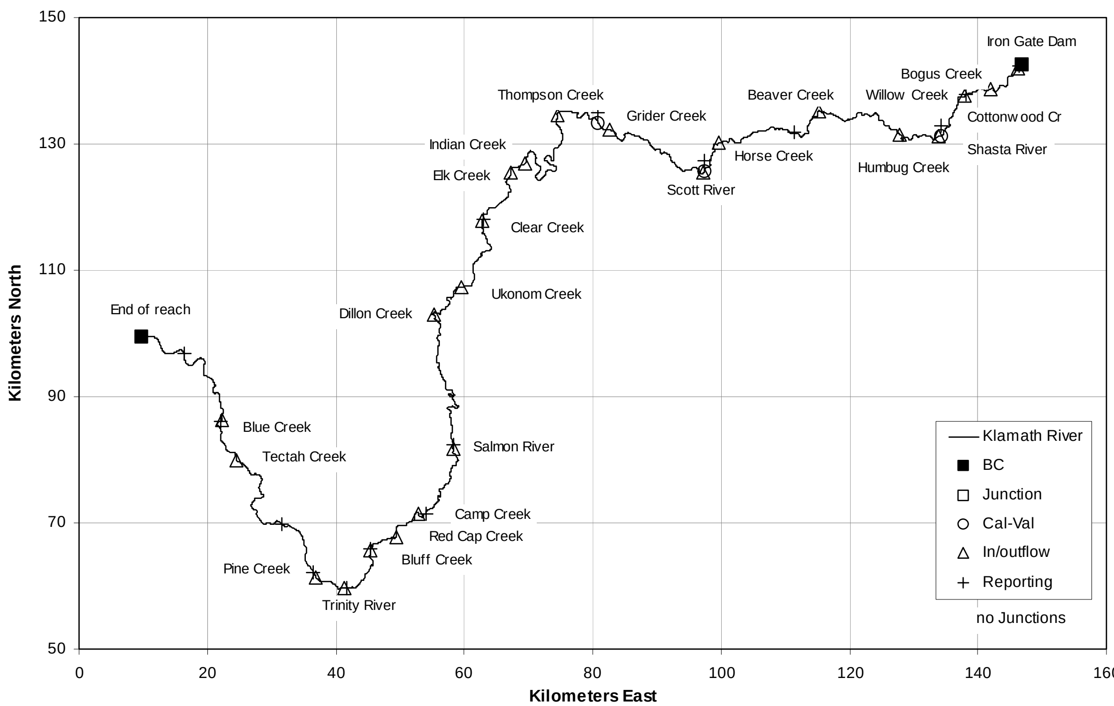



**Figure 16. Iron Gate Dam to Turwar reach representation showing tributary names**

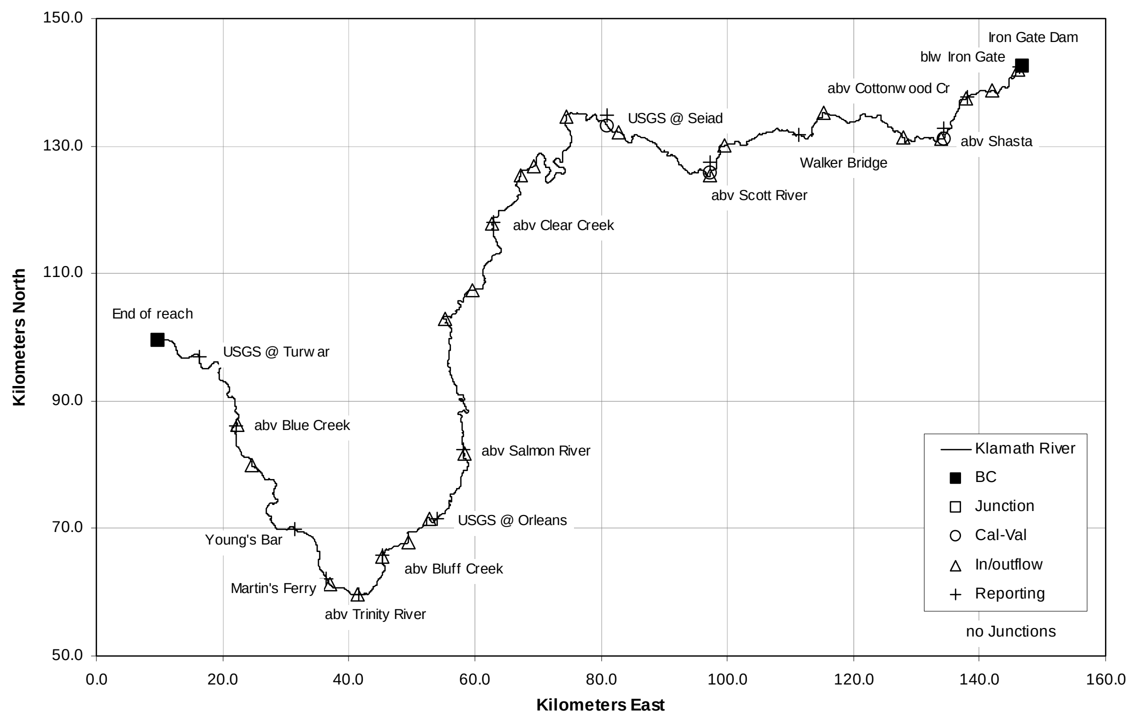



**Figure 17. Iron Gate Dam to Turwar reach representation showing reporting location names**

#### 2.3.8.2 Flow Data

***Inflows***

The Iron Gate Dam to Turwar reach includes 23 inflows in addition to the headwater boundary condition at Iron Gate Dam. Measured releases from Iron Gate during the 2000 calendar year as provided by PacifiCorp were used to designate operations.

Observed field data were used for those tributaries that are actively gauged, including the Shasta, Scott, Salmon, and Trinity Rivers, and Indian Creek. The inflows for minor tributaries were defined and quantified based on USGS (1995). The details of the USGS methodology are included in Appendix D. All tributaries in this reach are treated as element inflows.

***Element flows (ELM)***

There are 23 element flows in the IG-Turwar reach. Tributary contributions were assigned daily data based on USGS gages or 7-day average flows based on accretion calculations. Table 17 summarizes the locations, model node and element information, and type of record employed.

**Table 17. Element flow information for the IG-Turwar EC simulation**

| Location | Node | Element | Flow Type |
|---|---|---|---|
| Bogus Creek | 7 | 4 | 7 day average |
| Willow Creek | 55 | 28 | 7 day average |
| Cottonwood Creek | 86 | 43 | 7 day average |
| Shasta River | 144 | 72 | Daily measured |
| Humbug Creek | 204 | 102 | 7 day average |
| Beaver Creek | 319 | 160 | 7 day average |
| Horse Creek | 468 | 234 | 7 day average |
| Scott River (+ A/D Ft. Jones to Klamath) | 513 | 257 | Daily calculated |
| Grider Creek (A/D Scott to Seiad) | 656 | 328 | 7 day average |
| Thompson Creek | 735 | 368 | 7 day average |
| Indian Creek | 906 | 453 | Daily measured |
| Elk Creek | 925 | 463 | 7 day average |
| Clear Creek | 1000 | 500 | 7 day average |
| Ukonom Creek | 1098 | 549 | 7 day average |
| Dillon Creek | 1162 | 581 | 7 day average |
| Salmon River | 1357 | 679 | Daily measured |
| Camp Creek | 1466 | 733 | 7 day average |
| Red Cap Creek | 1511 | 756 | 7 day average |
| Bluff Creek | 1547 | 774 | 7 day average |
| Trinity River ( + A/D Hoopa to Klamath) | 1609 | 805 | Daily calculated |
| Pine Creek | 1644 | 822 | 7 day average |
| Tectah Creek | 1850 | 925 | 7 day average |
| Blue Creek | 1908 | 954 | 7 day average |

The Shasta River daily flows were from USGS gage 11517500. The Scott + A/D daily flows were calculated from USGS gage 11519500 (Scott River daily flows) and A/D described in Appendix D. The daily Indian Creek flows were from USGS gage 11521500. The Salmon River daily flows were from USGS gage 11522500. The Trinity + A/D daily flows were calculated from USGS gage 11530000 (Trinity River daily flows) and the A/D described below.

The 7 day accretion / depletion calculations are described in Appendix D. Daily A/D flows were calculated and then averaged over 7 days, except for the Scott River and Trinity River A/D, which were added to their respective river daily flows.

***Downstream Boundary Condition***

The downstream boundary for the model is placed at River Mile (RM) 0. There is tidal influence at Turwar (RM 5), but this dynamic condition is neglected in the model application. Instead a stage-discharge boundary condition of the form

$$Q = A_1 + A_2(E - E_o)^C$$

is applied, where

$Q$ = flow rate ($m^3/s$)

$A_1$ = 0.0

$A_2$ = 39.481

$E$ = simulated water surface elevation (representing depth) (m)

$E_o$ = water surface elevation datum (m)

$C$ = 2.2974

The coefficients for the stage discharge relationship were derived from the rating curve available for the Klamath River at Turwar USGS gage (15530500) corrected for tidal influence.

#### 2.3.8.3 Water Quality Data

***Temperature***

Tributary water temperature data for calendar year 2000 and 2001 in the Iron Gate Dam to Turwar reach were largely unavailable, with the exception of major tributaries, including the Shasta, Scott, Salmon, and Trinity Rivers. However, even these records exhibited significant data gaps. Inflow temperatures for the upstream boundary condition include simulated hourly temperatures in the Iron Gate Reservoir. The source of records and final model inputs for major and minor tributaries are outlined below.

<u>Major Tributaries</u>

A complete water temperature record for the Shasta River during 2000 was not available. Thus, hourly temperatures were represented with a composite records constructed from multiple sources. Data from USBR (2003) was used from 3/22/00 – through 11/6/00, while California Department of Fish and Game (Shasta River at Mouth temperatures) data was used from 1/1/01 to 3/23/01 and 11/6/00 to 12/31/00. Water temperature data were largely complete for 2001.

Scott River hourly temperatures were derived primarily from a datasonde deployed at the mouth of the Scott River from March through November 2000 by USBR. However, there were some gaps in that data. These data gaps were filled with data from the Shasta River composite temperatures that was corrected to match the existing Scott River temperatures. Water temperature data were largely complete for 2001.

Salmon River was assigned hourly temperatures from a composite. Some 2000 data was available for the Salmon River from USBR. The composite was made of 3/22/00 - 4/13/00, 5/2/00 - 5/22/00, and 5/30/00 - 11/13/00 Salmon River temperatures and 1/1/00 - 3/22/00, 5/22/00 - 5/30/00 and 11/13/00 - 12/31/00 Trinity River temperatures. Water temperature data were largely complete for 2001.

The Trinity River hourly water temperatures were obtained from the California Department of Water Resources, California Data Exchange Center (CDEC): site name for Trinity River at Hoopa (HPA). Water temperature data were largely complete for 2000 and 2001.

<u>Minor Tributaries</u>

The tributary water temperatures for 2000 and 2001 were based on hourly (typically) data collected by U.S. Forest Service (USFS) between 1994 and 2001. The exception was Blue Creek data which was supplied by the Yurok Tribe. The USFS temperature database contains all of the stream temperature records available in the Klamath National Forest stream temperature database, as of Oct. 17, 2002. This includes almost 650,000 individual stream records total. Generally, the USFS monitoring efforts did not provide long-term data sets at any one location, but rather several locations were monitored for intermittent periods. To provide representative temperature for the various tributaries composite hourly temperature traces were identified for each creek. These composite data sets were used to calculate monthly average temperatures for each tributary. Certain tributaries lacked data or provided little summer time flow volume and thus were not assigned a water temperature at this time. A brief discussion of each inflow temperature for tributary is outlined below and the monthly temperatures are presented in Table 18.

Bogus Creek had no temperature data available. Shovel Creek composite monthly temperatures were used for Bogus Creek. Shovel Creek composite monthly temperatures were estimated as follows. No winter data for Shovel Creek was available. No 2000 data was available. Observed 2001 hourly temperatures (available for 5/9/01 to 10/15/01) were filled with composite Spencer Creek hourly data. Composite Shovel Creek hourly data was then aggregated to daily and then to monthly averages.

Willow, Cottonwood, and Humbug Creeks were not assigned temperatures because they only minor flows during the summer.

<u>Beaver Creek</u>: No 2000 data was available. A composite temperature record was made of 6/30/99 - 9/13/99 Beaver Creek daily temperatures, and 1/1 - 6/29 and 9/14 - 12/31 composite Elk Creek daily temperatures, and then aggregated to monthly average temperatures.

<u>Horse Creek</u>: No 2000 data was available. A composite temperature record was made of 7/1/99 - 9/14/99 Horse Creek daily temperatures and 1/1 - 6/30 and 9/15 - 12/31 composite Elk Creek daily temperatures, and then aggregated to monthly average temperatures.

<u>Grider Creek:</u> Only summer 2000 temperatures were available for Grider Creek. A composite temperature record was made of 7/1/00 - 10/13/00 Grider Creek daily temperatures, and 1/1 - 6/29 and 10/14 - 12/31 composite Elk Creek daily temperatures. Elk Creek temperatures were used because both creeks had sources in the Marble Mountains. The daily composite Grider Creek temperature record was aggregated to monthly average temperatures.

<u>Thompson Creek:</u> No 2000 data was available. An incomplete record available was for 2001. After comparing the existing Thompson Creek data to other creeks' records, Blue Creek 2000 temperatures were chosen because the small amount of existing Thompson Creek temperature record matched the 2000 Blue Creek temperatures. The composite Thompson Creek temperatures were aggregated to monthly average temperatures.

<u>Blue Creek:</u> Only summer 2000 temperatures were available for Indian Creek. A composite temperature record was made up of 7/1/00 - 9/27/00 Indian Creek daily temperatures, and 1/1 - 6/30 and 9/28 - 12/31 composite Clear Creek daily temperatures. Clear Creek temperatures were used because the sources for both creeks are adjacent to each other in the Siskiyou Mountains. The composite Indian creek daily temperatures were aggregated to monthly average temperatures.

<u>Elk Creek:</u> Only summer 2000 temperatures were available for Elk Creek. However, there were other years available. A composite temperature record was made up of 1/1/93 - 6/30/93, 7/1/00 - 10/3/00 and 10/4/93 - 12/31/93 Elk Creek daily temperatures. The composite Elk Creek data was aggregated to monthly average temperatures.

<u>Clear Creek:</u> No 2000 temperature data was available for Clear Creek near the mouth. A composite temperature record was made of 1993 Clear Creek daily temperatures, which were aggregated to monthly average temperatures.

<u>Ukonom Creek:</u> No 2000 temperature data was available. A composite temperature record was made of 1993 Ukomon Creek daily temperatures, which were aggregated to monthly average temperatures.

<u>Dillon Creek:</u> No 2000 temperature data was available. A composite temperature record was made of 1/1/94 - 9/30/94 and 10/1/92 - 12/31/92 Dillon Creek daily temperatures, which were aggregated to monthly average temperatures.

<u>Camp Creek:</u> No 2000 temperature data was available. A composite temperature record was made up of 2000 Blue Creek daily temperatures. Blue Creek temperatures were chosen because the existing record for Camp Creek matched the 2000 record for Blue Creek. The composite Camp creek daily temperatures were aggregated to monthly average temperatures.

<u>Red Cap Creek:</u> No 2000 temperature data was available. A composite temperature record was made of 1/1 - 7/30 composite Dillon Creek daily temperatures, and 7/31/92 - 12/31/92 Red Cap Creek daily temperatures. Dillon Creek temperatures were chosen because the two creeks are somewhat adjacent to each other and their sources share the

same approximate elevation. The composite Red Cap Creek daily temperatures were aggregated to monthly average temperatures.

Bluff Creek: There was no temperature data available for Bluff Creek. A composite temperature record for Bluff Creek was created using Blue Creek daily temperatures. Blue Creek temperatures were chosen because they were a complete record. The composite daily Bluff Creek temperatures were aggregated to monthly average temperatures.

Pine Creek: There was no temperature data available for Pine Creek. A composite temperature record for Pine Creek was created using Blue Creek daily temperatures. Blue Creek temperatures were chosen because they were a complete record. The composite daily Pine Creek temperatures were aggregated to monthly average temperatures.

Tectah Creek: Some 2000 data was available. A composite temperature record was made of 4/29/00 - 9/15/00 Tectah Creek daily temperatures and 1/1 - 4/28 and 9/16 - 12/31 Blue Creek daily temperatures. The composite daily Tectah Creek temperatures were aggregated to monthly average temperatures.

Blue Creek: Blue Creek had daily temperatures available for 2000. No composite record was necessary. The daily Blue Creek temperatures were aggregated to monthly average temperatures.

**Table 18. Minor tributary inflow temperatures for Iron Gate to Turwar reach model**

| | Temperature, ºC | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| JDAY | 1 | 15 | 46 | 75 | 106 | 136 | 167 | 197 | 228 | 259 | 289 | 320 | 350 | 366 | 367 |
| Bogus Creek | 0.13 | 0.19 | 0.52 | 3.39 | 7.79 | 12.43 | 12.76 | 14.06 | 14.50 | 12.43 | 8.31 | 2.87 | 0.06 | 0.13 | 0.13 |
| Beaver Creek | 4.00 | 4.25 | 4.85 | 6.98 | 7.79 | 8.68 | 11.16 | 14.03 | 15.55 | 14.31 | 11.09 | 4.79 | 4.04 | 4.00 | 4.00 |
| Horse Creek | 4.00 | 4.25 | 4.85 | 6.98 | 7.79 | 8.68 | 11.09 | 13.13 | 14.08 | 13.64 | 11.09 | 4.79 | 4.04 | 4.00 | 4.00 |
| Grider Creek | 4.00 | 4.25 | 4.85 | 6.98 | 7.79 | 8.68 | 11.09 | 16.31 | 16.82 | 13.95 | 10.80 | 4.79 | 4.04 | 4.00 | 4.00 |
| Thompson Creek | 7.89 | 7.76 | 8.25 | 8.23 | 10.00 | 10.96 | 14.10 | 15.37 | 16.79 | 15.79 | 13.35 | 9.91 | 8.01 | 7.89 | 7.89 |
| Indian Creek | 5.00 | 5.11 | 5.55 | 6.76 | 7.33 | 8.74 | 11.61 | 16.88 | 18.41 | 15.69 | 12.08 | 5.74 | 4.60 | 5.00 | 5.00 |
| Elk Creek | 4.00 | 4.25 | 4.85 | 6.98 | 7.79 | 8.68 | 11.09 | 17.62 | 18.15 | 14.95 | 11.09 | 4.79 | 4.04 | 4.00 | 4.00 |
| Clear Creek | 5.00 | 5.13 | 5.50 | 6.95 | 7.39 | 8.76 | 11.96 | 15.78 | 17.29 | 15.06 | 11.83 | 5.45 | 4.56 | 5.00 | 5.00 |
| Ukonom Creek | 5.00 | 5.05 | 5.26 | 6.74 | 7.38 | 8.17 | 10.71 | 13.05 | 13.95 | 12.37 | 10.66 | 5.52 | 4.88 | 5.00 | 5.00 |
| Dillon Creek | 5.00 | 6.93 | 6.19 | 7.67 | 9.52 | 12.46 | 15.49 | 20.21 | 18.58 | 16.92 | 11.80 | 7.63 | 4.93 | 5.00 | 5.00 |
| Camp Creek | 7.89 | 7.76 | 8.25 | 8.23 | 10.00 | 10.96 | 14.10 | 15.37 | 16.79 | 15.79 | 13.35 | 9.91 | 8.01 | 7.89 | 7.89 |
| Red Cap Creek | 6.50 | 6.93 | 6.19 | 7.67 | 9.52 | 12.46 | 15.49 | 20.30 | 19.37 | 16.62 | 13.06 | 9.22 | 6.23 | 6.50 | 6.50 |
| Bluff Creek | 7.89 | 7.76 | 8.25 | 8.23 | 10.00 | 10.96 | 14.10 | 15.37 | 16.79 | 15.79 | 13.35 | 9.91 | 8.01 | 7.89 | 7.89 |
| Pine Creek | 7.89 | 7.76 | 8.25 | 8.23 | 10.00 | 10.96 | 14.10 | 15.37 | 16.79 | 15.79 | 13.35 | 9.91 | 8.01 | 7.89 | 7.89 |
| Tectah Creek | 7.90 | 7.76 | 8.26 | 8.18 | 9.94 | 10.02 | 12.51 | 13.73 | 14.10 | 14.48 | 13.50 | 9.98 | 8.03 | 7.90 | 7.90 |
| Blue Creek | 7.89 | 7.76 | 8.25 | 8.23 | 10.00 | 10.96 | 14.10 | 15.37 | 16.79 | 15.79 | 13.35 | 9.91 | 8.01 | 7.89 | 7.89 |

### *Constituent Concentrations*

Constituent concentrations for the tributary inflows between Iron Gate Dam and the Pacific Ocean were assigned for all streams identified in Table 17 with the exception of Willow, Cottonwood, and Humbug Creeks. There was no data available for these tributaries and they contribute only minor flow in the summer months.

Constituent concentrations for the upstream boundary condition were provided by the Iron Gate Reservoir CE-QUAL-W2 simulation, and passed to the Iron Gate to Turwar reach in the manner described for the Keno reach.

Dissolved oxygen at all minor tributaries was estimated assuming 100 percent saturated conditions. This assumption is based on most of these streams reach the Klamath River after flowing

- through step canyon reaches that are several miles long
- through watersheds that have little or no water resources development and/or
- through watersheds where organic loads and other oxygen demanding processes are modest.

Review of available data (USBR, 2003) indicates this is a reasonable assumption for modeling applications. However, any diurnal variations due to primary production are not represented.

Dissolved oxygen concentrations were based on the hourly (Shasta, Scott, Salmon, and Trinity Rivers) or monthly (all remaining tributaries) temperature data identified above and atmospheric pressure corrected for elevation. Because the atmospheric correction through the study reach was small, average elevations for three sub-reaches were used in the calculation. The average elevation from Iron Gate Dam to the USGS Gage at Seiad Valley (1759.9 ft (536.4 m)) was used to correct atmospheric pressure for all tributaries within that reach. Likewise, the average elevation for USGS Gage at Seiad Valley to Trinity River reach (810.0 ft (246.9 m)) and from the Trinity River to the end of the IG-Turwar reach (150.0 ft (45.7 m)) were used to correct atmospheric pressure for all tributaries within those reaches. The methodology for dissolved oxygen saturation calculation and atmospheric pressure correction are included in Appendix F.

Representation of chemical constituents (e.g., nutrients, BOD, and algae) was based largely on USFWS (1999), USBR (2003), and EPA (1997). Overall, there was little data available for most tributaries, and the minor tributaries generally had no available water quality data of this type. The Shasta and Scott Rivers had sufficient data from USBR (2003) to represent seasonal variations. Table 19 summarizes the estimated water quality boundary conditions for the Shasta and Scott Rivers, as well as other major and minor tributaries. As noted above, many of these tributary watersheds are lightly populated, have minimal water resources development, and although several areas reside within active timber management areas, the water quality out of most tributaries is of good quality.

**Table 19. Water quality boundary conditions for constituent concentrations for Klamath River tributaries between Iron Gate Dam and Turwar**

| Parameter | | Shasta R. | | Scott R [a] | | All Other Tributaries [b] |
|---|---|---|---|---|---|---|
| | | 1/1- 7/15 | 7/16-12/31 | 1/1- 7/15 | 7/16-12/31 | 1/1-12/31 |
| Organic N (D [c]) | (mg/l) | 0.45 | 0.45 | 0.20 | 0.20 | 0.15 |
| $NH_4^+$ | (mg/l) | 0.15 | 0.05 | 0.15 | 0.05 | 0.05 |
| $NO_2^-$ | (mg/l) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| $NO_3^-$ | (mg/l) | 0.05 | 0.05 | 0.15 | 0.05 | 0.05 |
| Organic P (D [c]) | (mg/l) | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |
| $PO_4^{3-}$ | (mg/l) | 0.45 | 0.15 | 0.10 | 0.05 | 0.05 |
| BOD | (mg/l) | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| Algae | (mg/l) | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Dissolved Oxygen | (mg/l) | Based on saturation dissolved oxygen | | | | |

[a] based on synoptic at mouth

[b] Including Salmon River, Trinity River and all minor tributaries

[c] D – Dissolved

### 2.3.8.4 Meteorological Data

The required hourly information for the meteorological input file consisted of: air temperature (°C), wet bulb temperature (°C), wind speed (m/s), cloud cover (scale 0-1.0) and atmospheric pressure.

The meteorological data for the Klamath River Iron Gate to Turwar reach was derived from meteorological observations near Klamath Falls, OR; however, it is clear that atmospheric conditions vary appreciably throughout the study reach due to elevation, orographic features, proximity to the Pacific Ocean, and the shear size of the study area. To more effectively address local meteorological conditions with data collected at a distance location, an assessment of available observations at several locations throughout the reach was completed to determine meteorological variability throughout the basin and, to the extent feasible, adjust parameters to more fully represent local conditions.

Air temperature, dew point (for wet bulb), and wind speed were examined at several locations and lapse rates for air temperature and dew point identified. No clear relationship was identified for relating wind speed at different locations. Adjustments to air temperature and dew point for the Iron Gate Dam to Turwar reach are shown in Table 20 and Table 21. Appendix E contains additional details on comparison of meteorological conditions throughout the study area.

**Table 20. Air temperature corrections, based on month for Klamath River temperature modeling**

| Month | Correction: Klamath Falls (°C) | Correction: Iron Gate to Orleans (°C) | Correction: Orleans to Turwar (°C) |
|---|---|---|---|
| January | 0.0 | 0.0 | 3.5 |
| February | 0.0 | 0.0 | 3.5 |
| March | 0.0 | 0.0 | 2.5 |
| April | 0.0 | 2.5 | 1.5 |
| May | 0.0 | 2.5 | 0.5 |
| June | 0.0 | 2.5 | 0.0 |
| July | 0.0 | 2.5 | 0.0 |
| August | 0.0 | 2.5 | 0.5 |
| September | 0.0 | 2.5 | 1.5 |
| October | 0.0 | 2.5 | 2.5 |
| November | 0.0 | 2.5 | 3.5 |
| December | 0.0 | 0.0 | 3.5 |

Positive corrections are added to the KFLO data to arrive at local conditions

**Table 21. Dew point temperature corrections, based on month for Klamath River temperature modeling**

| Month | Correction: Klamath Falls (°C) | Correction: Iron Gate to Orleans (°C) | Correction: Orleans to Turwar (°C) |
|---|---|---|---|
| January | 0.0 | 0.0 | 8.0 |
| February | 0.0 | 0.0 | 8.0 |
| March | 0.0 | 0.0 | 8.0 |
| April | 0.0 | 0.0 | 8.0 |
| May | 0.0 | 0.0 | 5.5 |
| June | 0.0 | 0.0 | 4.0 |
| July | 0.0 | 0.0 | 4.0 |
| August | 0.0 | 0.0 | 5.5 |
| September | 0.0 | 0.0 | 5.5 |
| October | 0.0 | 0.0 | 8.0 |
| November | 0.0 | 0.0 | 8.0 |
| December | 0.0 | 0.0 | 8.0 |

Positive corrections are added to the KFLO data to arrive at local conditions

# 3 Model Calibration and Validation

Model calibration and validation is the stage wherein model parameters are adjusted to fit model results to field observations (calibration), and then the model is tested on an independent set of data (often termed validation). This process provides a means to test the model and quantify its ability to replicate field conditions for the selected parameter values. The results of model calibration and validation, as well as the final set of model parameters are presented for each river reach.

The reservoir reaches were not formally calibrated for flow. Inflows and outflows are specified as input values in CE-QUAL-W2 and these were determined based on changes in observed or assumed storage. Existing data are insufficient to test the actual hydrodynamic performance of these models. Probably the most useful method of assessing hydrodynamic performance would be the implementation of a dye study, but this is beyond the scope of this project. The river reaches were calibrated for flow. The specific approach is outlined in the Flow Calibration section included below.

All river and reservoirs reaches were formally calibrated for water temperature and dissolved oxygen. The models were not specifically calibrated for nutrients, phytoplankton, or benthic algae. There was insufficient data in most cases (the exception is the Klamath River below Iron Gate Dam) to test the models rigorously for simulation of nutrient concentrations. However, these data were not discounted. Available nutrient data were plotted versus simulation results to ensure the model produced realistic response to system conditions. Temperature, dissolved oxygen, nutrients and algae data are all presented herein.

Although the reservoir models were all applied over a calendar year during calibration, there was generally little or no data between late fall and mid spring. Model results are presented for the entire year, but late fall to mid spring calibration and validation was not completed for this analysis.

## *3.1 Flow Calibration*

Hydrodynamic calibration typically requires varying channel roughness (e.g., Manning coefficient, n) through a range of values while comparing simulated transit time and river stage with measured data. Transit time can be estimated from stream velocity measurements or tracking changes in river stage under varying flow conditions. Although USGS gages are located near Seiad Valley (RM 129), Orleans (RM 56), and Turwar (RM5), travel time was difficult to ascertain accurately due to the long distance and uncertainty in ungaged tributary flows and other accretions.

To overcome limitations of independent calibration of flow, Deas and Orlob (1997) present a method for iterative calibration wherein both the hydrodynamic and water quality models were used jointly. Application requires modeling on a sub-daily time step and availability of associated sub-daily water temperature data (e.g., hourly). Both criteria were fulfilled for this project. The method is outlined below in the context of the Klamath River.

### 3.1.1 Iterative Calibration: Background

Iterative calibration of flow and temperature was completed for the Keno, J.C. Boyle to Copco Reservoir, and Iron Gate Dam to Turwar Reaches. The Link River reach was deemed too short for effective application of the methodology. The upstream boundary conditions for these three reaches (Keno Dam, J.C. Boyle Dam and powerhouse release, and Iron Gate Dam) provide unique temperature signals that can be identified in downstream reaches. Because the heat budget is driven primarily by solar energy, river temperature downstream of the reservoir responds to daily cycles of heating and cooling. In response to this cycle, a characteristic diurnal temperature pattern is produced, the advective transport of which serves as a "tracer" of the flow. Thus, diurnal variations in water temperature provide a signal similar to that of a conservative tracer that is superimposed on the mean daily thermal profile. This signal is effectively reproduced in model results, and can be "fit" to measured data in the process of model calibration. This approach is not generally applicable to unregulated rivers.

Calibration parameters for the hydrodynamic model include bed roughness (Manning coefficient) and turbulent exchange coefficients, although in this exercise longitudinal mixing was assumed minimal (i.e., turbulent exchange coefficients were not varied). In the water quality model, temperature calibration parameters include evaporative cooling coefficients, where evaporation, E, is represented by

$$E = (a+bW)(e_s-e_a) \qquad (6.1)$$

where $a$ and $b$ are empirical evaporation coefficients, W is wind velocity, $e_s$ is saturation vapor pressure, and $e_a$ is actual atmospheric vapor pressure.

The calibration technique requires that the hydrodynamic model initially be applied to simulate a flow field that is then used as input to the water quality model. Computed hourly water temperature data are then compared to measured field data. Three possible relationships between phase and amplitude of computed and measured values may occur: (1) both phase and amplitude are correct; (2) phase is correct, but amplitude is incorrect; and, (3) phase is incorrect. The calibration technique is represented schematically in Figure 18.

Phase of the diurnal temperature variation is directly related to travel time. Travel time, in turn, is determined by water velocity, and is thus a function of bed roughness. The amplitude of diurnal temperature variations is affected by two processes: travel time (i.e., exposure time), and evaporation coefficients. The possible outcomes and model steps of the calibration process are described below.

*Case 1: Phase correct, amplitude correct* - If the simulated phase and amplitude of the diurnal variation in water temperature match measured data, the calibration is complete.

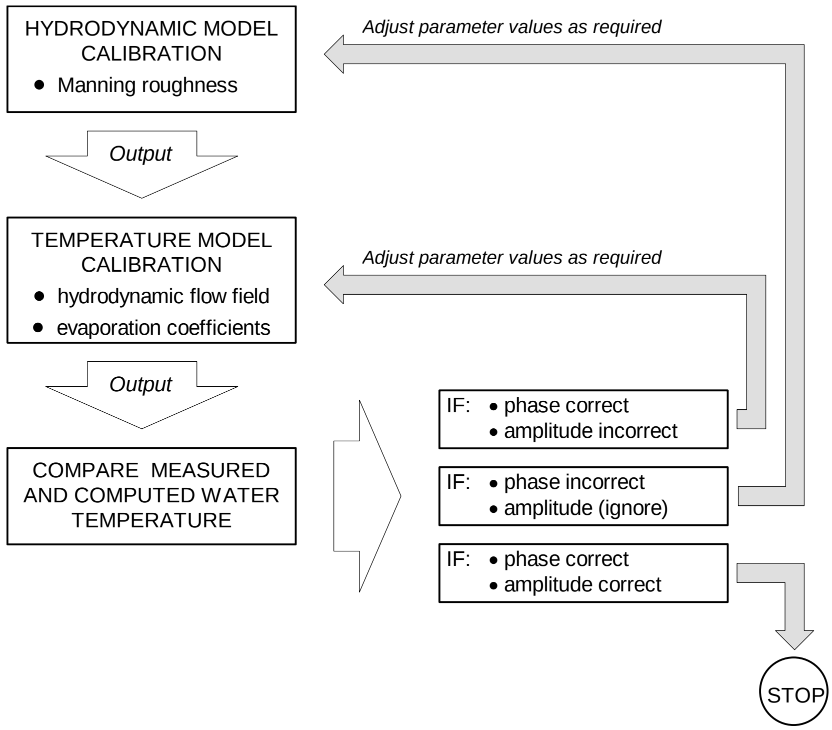



**Figure 18. Schematic of iterative hydrodynamic and water temperature model calibration process**

*Case 2: Phase correct, amplitude incorrect* - If the phase of simulated diurnal temperature variation matches measured data, but amplitude is incorrect, the applied Manning roughness coefficient is representative and hydrodynamic calibration is complete. Subsequently, evaporation coefficients (*a* and *b*) may be adjusted to improve/calibrate diurnal temperature amplitude.

*Case 3: Phase incorrect* - If the phase of simulated diurnal temperature variation does not coincide with measured field data, transit time in the river has been compromised. For excessive roughness values, average river velocities are reduced and transit time is increased; the converse is true for roughness values that are too small. The result is a temperature tracer signal that is displaced upstream or downstream, respectively. Amplitude of the signal is ignored because replication of the phase is necessary prior to assessing the amplitude, i.e., increased or decreased travel time will lead to greater or lesser heating of river water, directly affecting amplitude. Under these conditions, the Manning coefficient must be modified appropriately and both the hydrodynamic and water quality models re-run. Water quality model calibration coefficients remain unchanged because amplitude calibration cannot be completed until the phase of the tracer signal is correctly determined.

The steps of calibrating for phase and subsequently calibrating for amplitude are illustrated for an idealized example in Figure 19. The initial simulated temperatures illustrate both a phase shift and amplitude error. Calibration of channel roughness corrects for phase and, because travel time has been changed, also affects amplitude error. Subsequently, the amplitude is calibrated with evaporation coefficients. In practice, simulated phase and amplitude may not consistently match measured data due to short-term variations in upstream operations, local meteorology, and tributary influences.

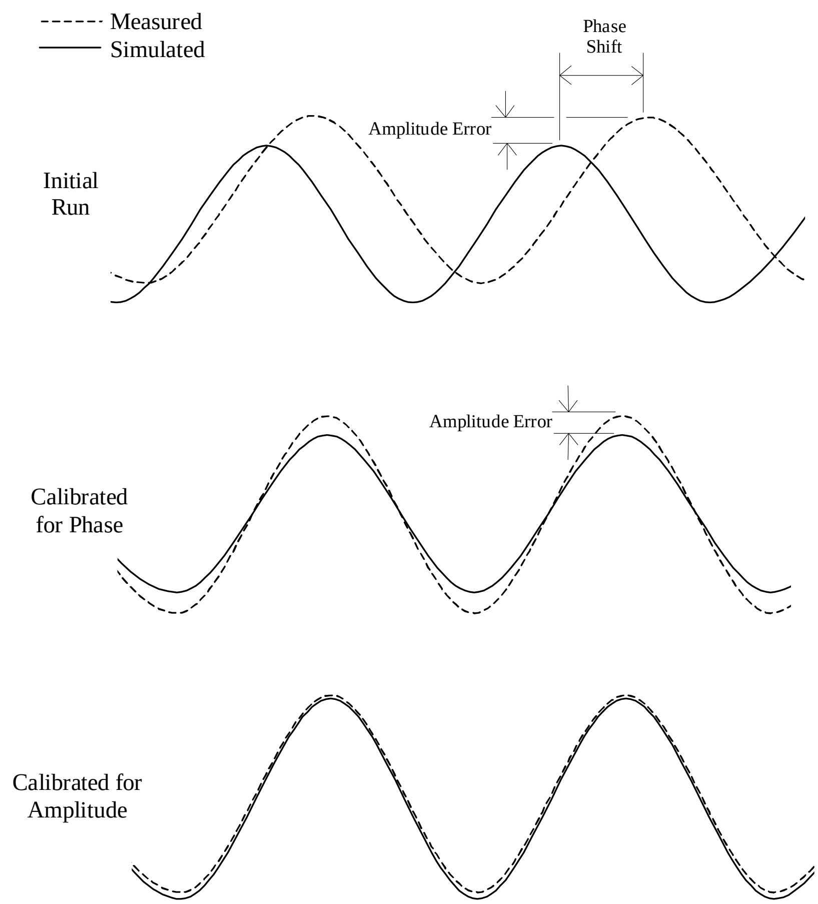



**Figure 19. Example calibration of phase and amplitude for diurnal temperature trace**

The final values for Manning roughness and evaporative heat flux coefficients are included for each reach in the summary table at the end of the calibration presentation.

### 3.1.2 Slope Factor

Preliminary runs, with a water surface slope based on the elevation of the upstream and downstream end of each reach (gross slope), showed that model results in the steep river reaches were not effectively represented. The water surface slope of steep rivers is generally significantly less than the overall gross slope of the river profile. Further, steep rivers are typically not uniform in slope, but consist of short cascades or riffles, combined with intermediate pools and runs. RMA-2 includes a slope factor (SF) and associated logic that reduces the effective bed slope of the stream and assumes travel time through the short cascade sections is negligible compared to the transit time through runs or pools. Figure 20 shows a schematic of initial model application (Case 1; SF = 0) and model application with slope factor applied (Case 2: 1>SF>0). For cases 1 and 2 the stream reaches have equivalent vertical elevation change (z) and horizontal distance. But, by neglecting the short cascade reach the transit time in the river is more closely simulated.

To estimate slope factor, uniform flow was assumed and Manning's equation applied.

$$Q = [1.49AR^{2/3}S^{1/2}] / n \qquad (4.2)$$

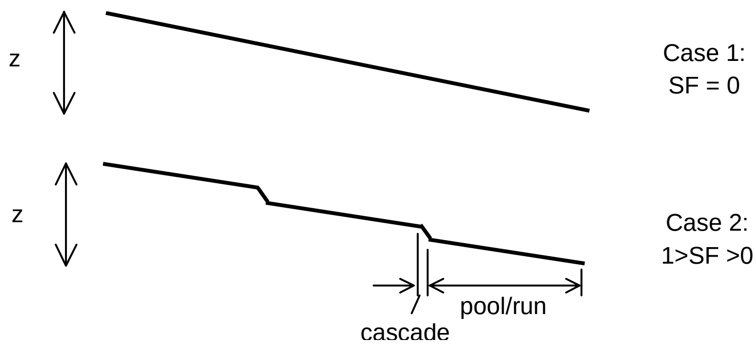



**Figure 20. Slope factor application for a representative river reach**

Where Q is flow rate, A is cross sectional area, R is hydraulic radius, S is bed slope (or water surface slope), and n is a channel roughness coefficient. Using this equation for a known cross sectional area, hydraulic radius, and an estimated value of Manning n, the slope required to deliver a known flow rate can be determined.

Based on typical summer flow rates the slope factor for the Link and Keno reaches was set at 0.90, the bypass and peaking reaches slope factor was 0.95, and the factor for the Klamath River from Iron Gate Dam to Turwar was set at 0.80. These value were not changed throughout calibration. The assumption is that small discrepancies in the slope factor can be accommodated in selection of an appropriate Manning coefficient. For this reason, use of the Manning coefficient determined herein for application in other flow models should be done with great consideration and care.

### 3.1.3 Calibration Measures and Methods

Calibration required comparison of several alternative parameter sets. Selecting final parameter values may include professional judgment, graphical comparisons of simulated versus measured data, and statistical analysis of simulated and measured data, to name a few. Though each measure has merits and demerits, statistical analyses were used as the primary method to select final calibration parameters for the flow and temperature models. Graphical comparisons and professional judgment were used to assess general model performance and provided significant insight, but proved difficult to quantify differences over long time periods and at multiple locations along the river. Thus, several basic statistics were applied to the simulated temperature data and associated error to provide additional insight into model performance and to quantify model uncertainty: bias, mean absolute error, and root mean squared error.

These summary statistics are presented in the temperature calibration section for each river reach. The final values of channel roughness and other hydrodynamic parameters are included in the summary table that concludes each calibration section.

## 3.2 Link River

The RMA suite of models for Link River was calibrated and validated for May 21-23, 2002 and July 16-18, 2002, respectively. Water temperature, dissolved oxygen, and nutrient (phosphorous and nitrogen) data were collected during field season 2002 to support the modeling task.

### 3.2.1 Data

Water quality conditions of water flowing into the reach (boundary conditions), initial status of the system (initial conditions), and intermediate points within the main stem (calibration/validation points) were required.

#### 3.2.1.1 Boundary Conditions

The boundary condition data was derived from samples collected at Link Dam. Water temperature and dissolved oxygen data were available from water quality probes at hourly intervals. Grab samples were collected once per day for three days. Due to the inherent variability and infrequent sampling interval of the grab data, the boundary condition values for nutrients, BOD, and algae were assumed to be a constant value for the calibration and validation period, based on the grab sample data from 2002 (Appendix F).

The water quality boundary conditions derived for Link Dam were also applied to the return flows at East Side and West Side powerhouse. The water quality values for the calibration and validation period are shown in Table 22 and Figure 21 and Figure 22.

**Table 22. Link River reach calibration and validation water quality boundary conditions**

| Parameter | Units | Dates | |
|---|---|---|---|
| | | 5/21/02 - 5/23/02 | 7/16/02 - 7/18/02 |
| BOD | mg/l | 3.0 | 5.0 |
| DO | mg/l | variable | Variable |
| Org N | mg/l | 0.70 | 1.80 |
| $NH_4^+$ | mg/l | 0.10 | 0.25 |
| $NO_2^-$ | mg/l | 0.00 | 0.00 |
| $NO_3^-$ | mg/l | 0.05 | 0.10 |
| Org P | mg/l | 0.25 | 0.40 |
| $PO_4^{3-}$ | mg/l | 0.10 | 0.10 |
| Algae | mg/l | 2.0 | 22.0 |
| Tw | °C | variable | variable |

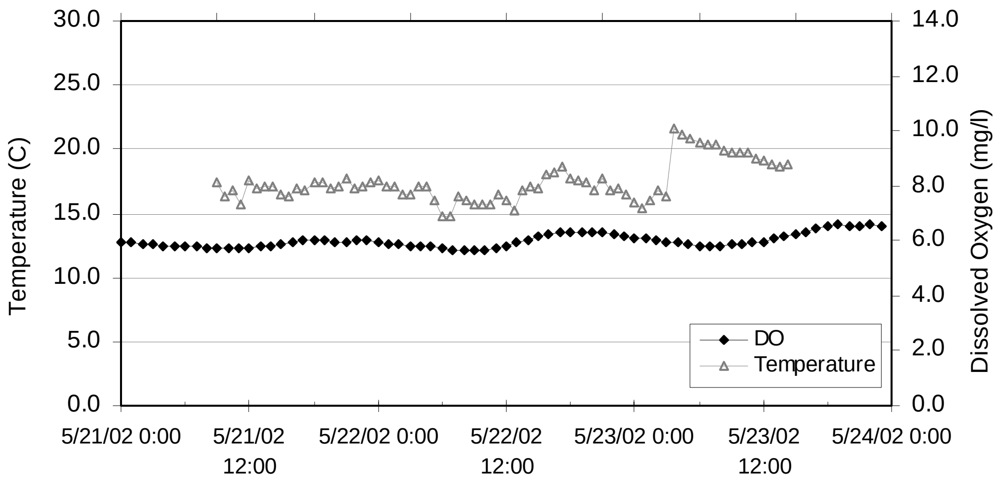



**Figure 21. Link River reach temperature and dissolved oxygen calibration boundary conditions**

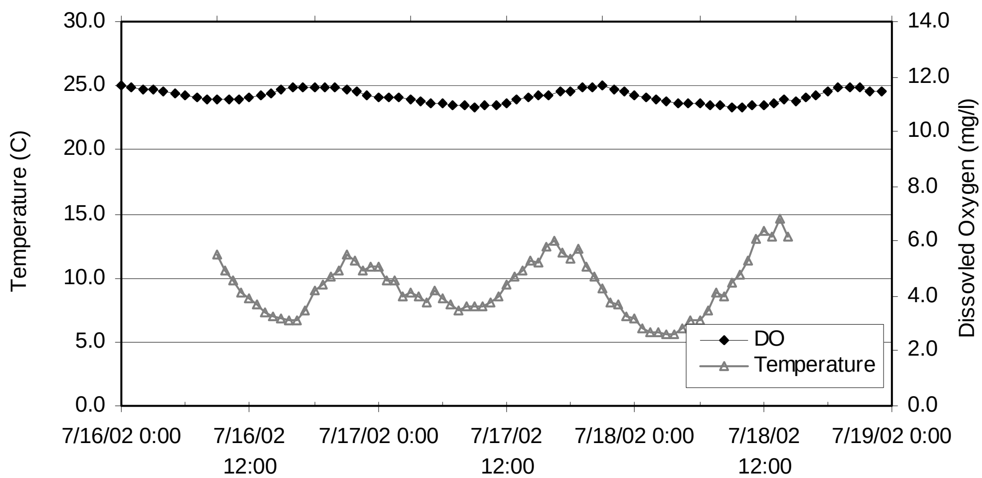



**Figure 22. Link River reach temperature and dissolved oxygen validation boundary conditions**

#### 3.2.1.2 Initial conditions

The model was run for three days prior to both the calibration and validation periods to provide an initial condition for simulation. The initial bed algae mass was estimated at 5 $g/m^2$.

#### 3.2.1.3 Calibration and Validation Points

The calibration and validation point for the Link River reach was Link River at Lake Ewauna. These data are displayed in the following section with model results.

### 3.2.2 Results

Calibration and validation were completed for temperature and dissolved oxygen as primary constituents and inorganic nutrient forms (ammonia, nitrate, orthophosphate) as secondary constituents. Field observations for temperature and dissolved oxygen were typically available from water quality probes on an hourly interval, allowing for summary statistics to be calculated both on an hourly and daily basis. The nutrient data were primarily derived from field data, which were typically sampled once per day, resulting in sparse data that are not readily amenable for such statistical analysis. All model parameters for the Link River reach are summarized in Table 25 at the end of this section.

#### 3.2.2.1 Water Temperature

Water temperature calibration required varying evaporation heat flux coefficients (presented in Table 25) that govern the mass transfer formulation represented in the numerical model heat budget. No other parameters were varied. The hourly results are presented graphically in Figure 23 and Figure 24. The diurnal range and phase is well represented for spring temperatures in the neighborhood of 12°C-14°C, as well as in the summer period, when temperatures reach almost 25°C. Tabulated statistics (Table 23) illustrate that simulated results on an hourly and daily basis are within about 0.2°C of observations. These results are not unexpected given the short river reach.

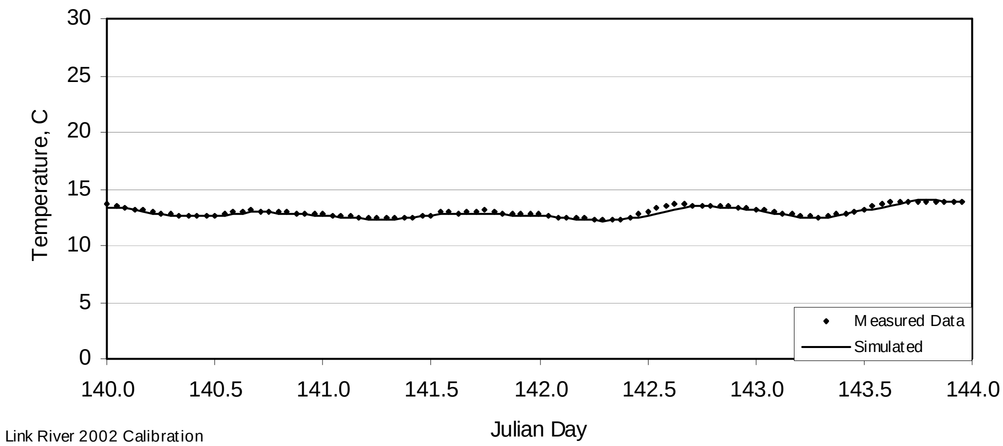



**Figure 23. Link River simulated versus measured water temperature, May 20-23, 2002**

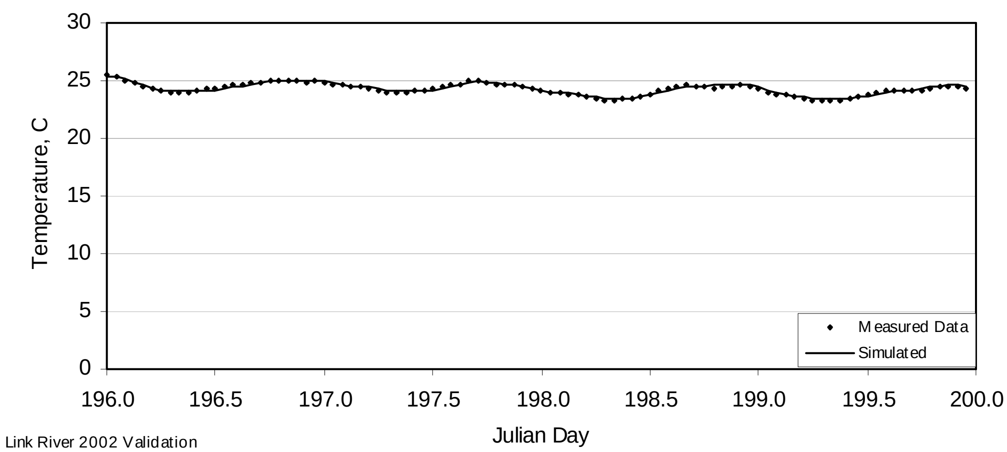



**Figure 24. Link River simulated versus measured water temperature, July 15-18, 2002**

**Table 23. Link River hourly and daily calibration and validation period statistics for water temperature**

| Calibration / Validation Statistics | | Hourly | | Daily | |
|---|---|---|---|---|---|
| | Unit | Calib. | Valid. | Calib. | Valid. |
| Mean Bias[a] | °C | -0.11 | 0.02 | -0.11 | 0.02 |
| Mean absolute error (MAE) | °C | 0.13 | 0.11 | 0.11 | 0.03 |
| Root mean squared error (RMSE) | °C | 0.16 | 0.12 | 0.12 | 0.03 |
| n | - | 95 | 96 | 4 | 4 |

[a] Mean bias = simulated – measured

### 3.2.2.2 Dissolved Oxygen

Dissolved oxygen calibration required varying several parameters, including but not limited to algal growth rates, and respiration rates, organic and inorganic nutrient decay rates, and temperature constants for rate reactions. Both phytoplankton and benthic algae were modeled in river reaches. To represent the adverse environment a river imposes on phytoplankton that are washed in from Upper Klamath Lake, growth rates were set to very low numbers in river reaches.

The hourly results are presented graphically in Figure 25 and Figure 26. The diurnal range and phase is well represented for spring dissolved oxygen (DO) conditions in the neighborhood of 8-10 mg/l, as well as in the summer period, when DO concentrations vary from about 4 to 6 mg/l. Tabulated statistics (Table 24) illustrate that simulated results on an hourly and daily basis are within about 1 mg/l of observed values. Some of the disparity between simulated and observed values is probably due to Link Dam dissolved oxygen conditions being imposed as boundary conditions at East and West Side powerhouses.

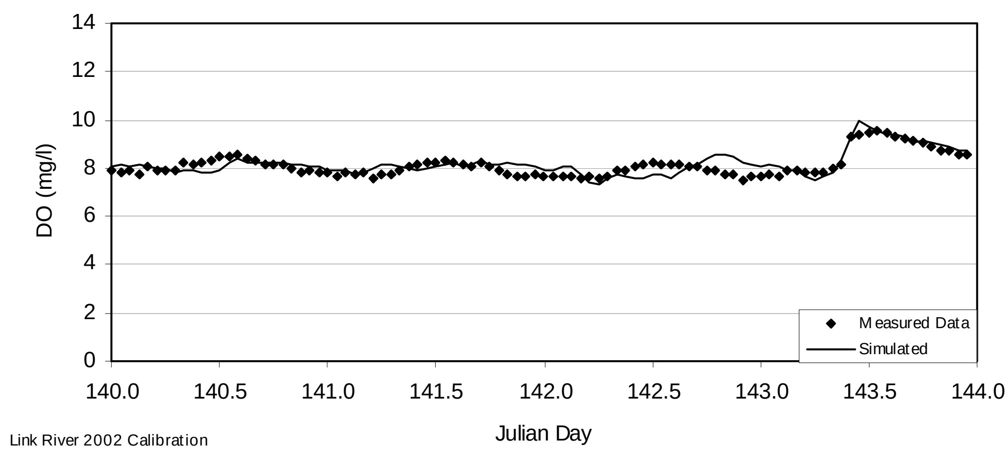



**Figure 25. Link River simulated versus measured dissolved oxygen, May 20-23, 2002**

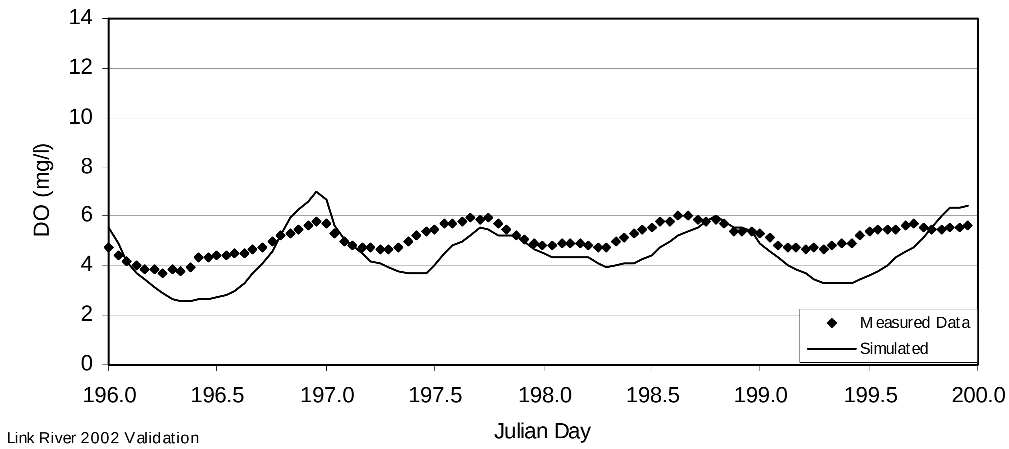



**Figure 26. Link River simulated versus measured dissolved oxygen, July 15-18, 2002**

**Table 24. Link River hourly and daily calibration and validation period statistics for dissolved oxygen**

| Calibration / Validation Statistics | | Hourly | | Daily | |
|---|---|---|---|---|---|
| | Unit | Calib. | Valid. | Calib. | Valid. |
| Mean Bias | mg/l | 0.08 | -0.60 | 0.08 | -0.60 |
| Mean absolute error (MAE) | mg/l | 0.25 | 0.80 | 0.08 | 0.60 |
| Root mean squared error (RMSE) | mg/l | 0.31 | 0.95 | 0.10 | 0.61 |
| n | - | 95 | 95 | 4 | 4 |

[a] Mean bias = simulated – measured

### 3.2.2.3 Nutrients

Nutrient concentrations were not formally calibrated in the Link River reach. That is, values for nutrient interactions (e.g., stoichiometric equivalence with regard to primary production, decay rates and temperature rate constants) identified in the dissolved oxygen calibration were not modified further, and other parameters were set at default values. The results are presented graphically in Figure 27 through Figure 32. Simulated concentrations for ammonia, nitrate, and orthophosphate were consistent with field observations.

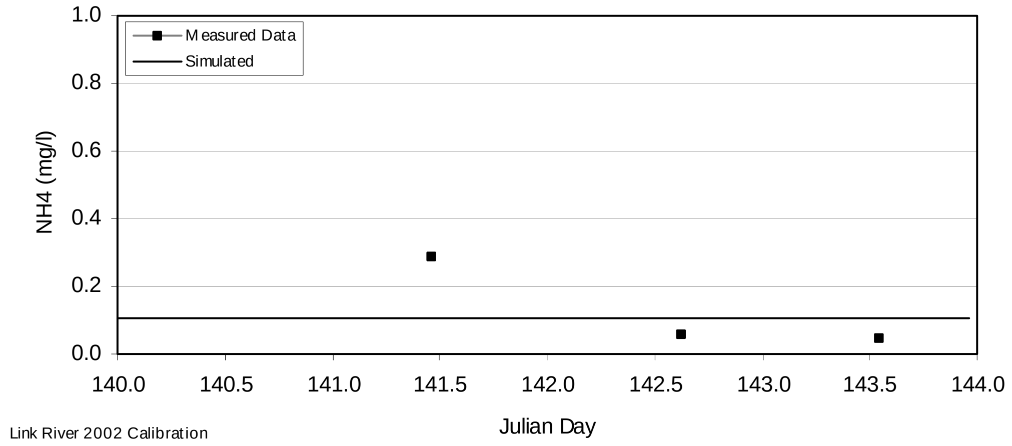



**Figure 27. Link River simulated versus measured ammonia, May 20-23, 2002**

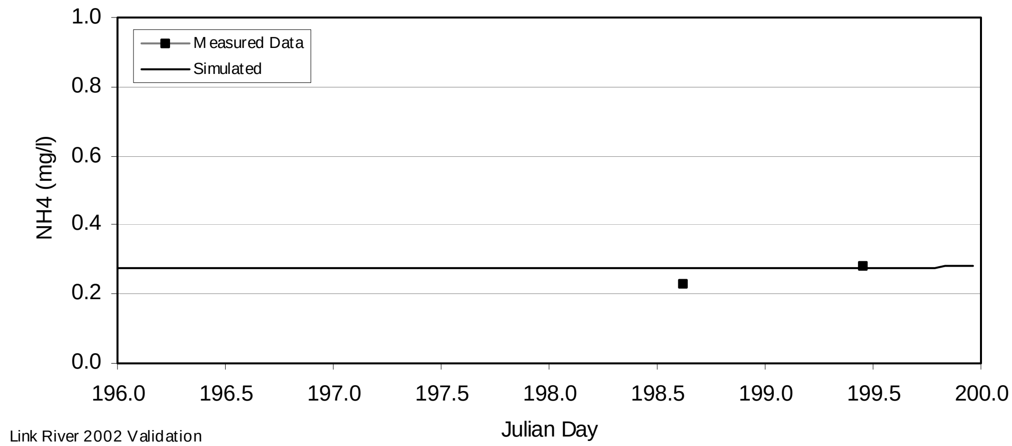



**Figure 28. Link River simulated versus measured ammonia, July 15-18, 2002**

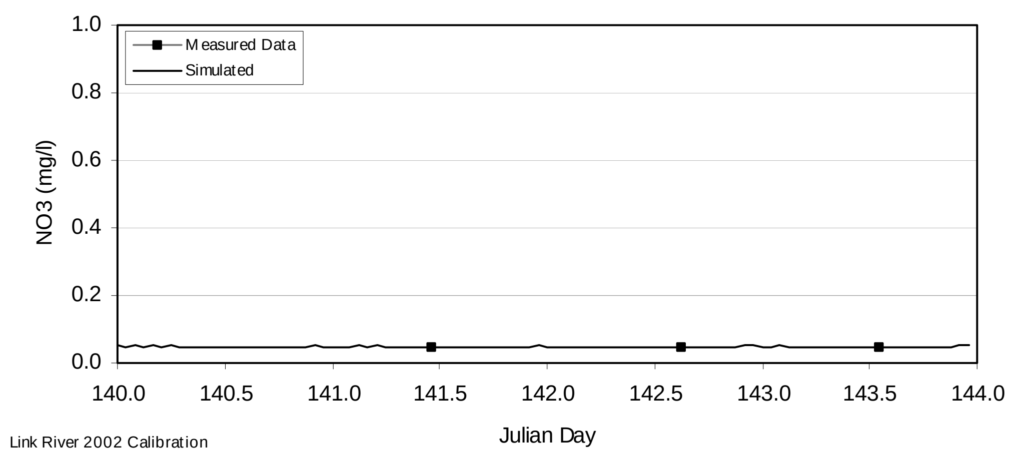



**Figure 29. Link River simulated versus measured nitrate, May 20-23, 2002**

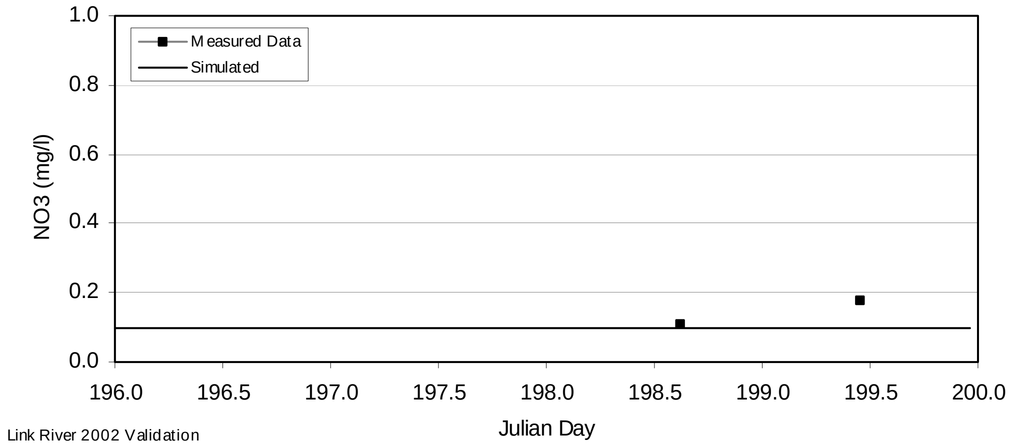



**Figure 30. Link River simulated versus measured nitrate, July 15-18, 2002**

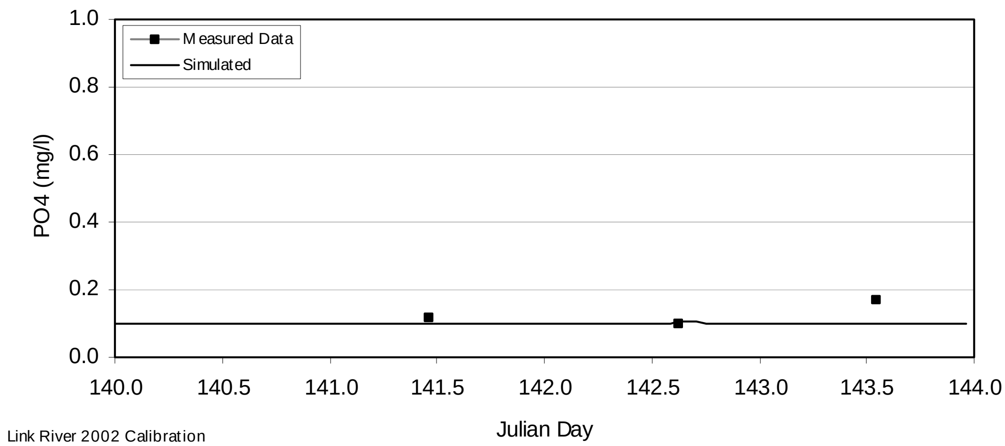



**Figure 31. Link River simulated versus measured orthophosphate, May 20-23, 2002**

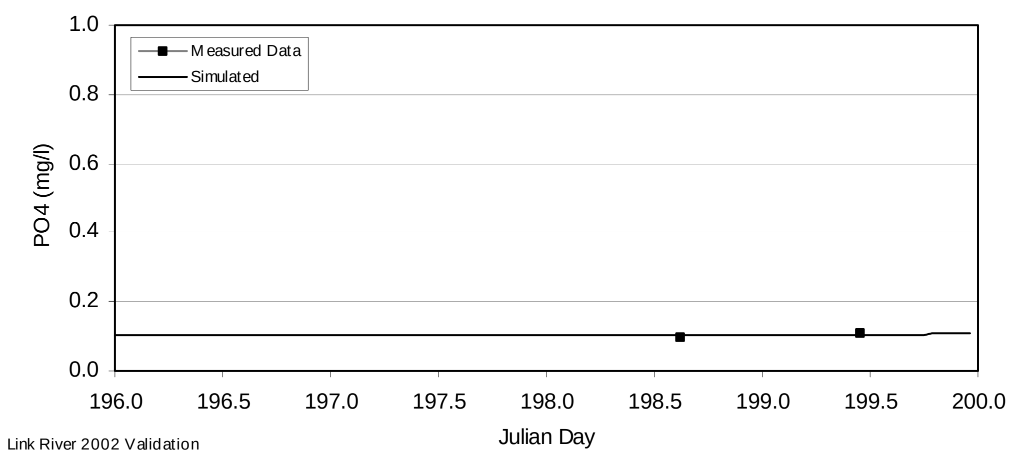



**Figure 32. Link River simulated versus measured orthophosphate, July 15-18, 2002**

### 3.2.2.4 Summary of Parameters

**Table 25. RMA-2 and RMA-11 Model, rates, coefficients, constants for the Link River reach**

| Variable Name | Description, units | Value |
|---|---|---|
| | Time step, hr | 1.0 |
| | Space step, m | 75 |
| | Manning roughness coefficient | 0.04 |
| | Turbulence factor, Pascal-sec | 100 |
| | Longitudinal diffusion scale factor | 0.10 |
| | Slope Factor | 0.80 |
| ELEV | Elevation of site, m | 1192.0 |
| LAT | Latitude of site, degrees | 41.5 |
| LONG | Longitude of site, degrees | 122.45 |
| EVAPA | Evaporative heat flux coefficient a, m $hr^{-1}$ $mb^{-1}$ | 0.000015 |
| EVAPB | Evaporative heat flux coefficient b, m $hr^{-1}$ $mb^{-1}$ $(m/h)^{-1}$ | 0.000005 |
| EXTINC | Light Extinction coefficient, used when algae is not simulated, 1/m | 1.5 |
| ALP0 | Chl *a* to algal biomass conversion factor, phytoplankton, mgChl_a to mg-A | 67 |
| ALP1 | Fraction of algal biomass that is nitrogen, phytoplankton, mg-N/mg A | 0.072 |
| ALP2 | Fraction of algal biomass that is phosphorous, phytoplankton, mg-P/mg A | 0.010 |
| LAMB1 | Linear algal self-shading coefficient, phytoplankton, 1/m | n/a |
| LAMB2 | Non-linear algal self shading coefficient, phytoplankton, 1/m | n/a |
| MUMAX | Maximum specific growth rate, phytoplankton, 1/d | 0.01 |
| RESP | Local respiration rate of algae, phytoplankton, 1/d | 0.05 |
| SIG1 | Settling rate of algae, phytoplankton, 1/d | 0.0 |
| KLIGHT | Half saturation coefficient for light, phytoplankton, KJ $m^{-2}$ $s^{-1}$ | 0.01 |
| KNITR | Michaelis-Menton half saturation constant: nitrogen, phytoplankton, mg/l | 0.01 |
| KPHOS | Michaelis-Menton half saturation constant: phosphorous, phytoplankton, mg/l | 0.001 |
| PREFN | Preference factor for NH3-N, phytoplankton | 0.6 |
| ABLP0 | Chl a to algal biomass conversion factor, bed algae, mgChl_a to mg-A | 50 |
| ABLP1 | Fraction of algal biomass that is nitrogen, bed algae, mg/l | 0.07 |
| ABLP2 | Fraction of algal biomass that is phosphorus, bed algae, mg/l | 0.01 |
| LAMB1 | Linear algal self shading coefficient, bed algae, 1/m | n/a |
| LAMB2 | Non-linear self shading coefficient, bed algae, 1/m | n/a |
| MUMAX | Maximum specific growth rate, bed algae, 1/d | 1.0 |
| RESP | Local respiration rate of algae, bed algae, 1/d | 0.60 |
| MORT | Mortality, bed algae, 1/d | 0.0 |
| KBNITR | Half-saturation coefficient for nitrogen, bed algae, mg/l | 0.01 |
| KBPHOS | Half-saturation coefficient for phosphorus, bed algae, mg/l | 0.002 |
| KBLIGHT | Half-saturation coefficient for light, bed algae, KJ $m^{-2}$ $s^{-1}$ | 0.01 |
| PBREFN | Preference factor for NH3-N, bed algae | 0.75 |
| BET1 | Rate constant: biological oxidation NH3-N, 1/d | 0.3 |
| BET2 | Rate constant: biological oxidation NO2-N, 1/d | 0.5 |
| BET3 | Rate constant: hydrolysis Org N to NH3-N, 1/d | 0.3 |
| BET4 | Rate constant: transformation Org P to P-D, 1/d | 0.3 |
| KNINH | First order nitrification inhibition coefficient, $mg^{-1}$ | n/a |
| ALP3 | Rate $O_2$ production per unit of algal photosynthesis, phytoplankton, mg-O/mg-A | 1.6 |
| ALP4 | Rate $O_2$ uptake per unit of algae respired, phytoplankton, mg-O/mg-A | 1.6 |
| ABLP3 | Rate $O_2$ production per unit of algal photosynthesis, bed algae, mg-O/mg-A | 1.6 |
| ABLP4 | Rate $O_2$ uptake per unit of algae respired, bed algae, mg-O/mg-A | 1.6 |
| ALP5 | Rate $O_2$ uptake per unit NH3-N oxidation, mg-O/mg-N | 3.43 |
| ALP6 | Rate $O_2$ uptake per unit NO2-N oxidation, mg-O/mg-N | 1.14 |
| K1 | Deoxygenation rate constant: BOD, 1/d | 0.3 |
| - | Minimum reaeration rate constant (Churchill formula applied), 1/d | 3.0 |
| SIG6 | BOD settling rate constant, 1/d | 0.0 |

n/a – not applicable

**Table 26. RMA-11 model temperature factors for the Link River reach**

| Variable Name | Description | Value |
|---|---|---|
| Water Column | | |
| THET1 | Algal growth rate temperature factor | 1.047 |
| THET2 | Algal respiration rate temperature factor | 1.047 |
| THET3 | Algal settling rate temperature factor | 1.047 |
| THET4 | Organic nitrogen decay rate temperature factor | 1.047 |
| THET5 | Organic nitrogen settling rate temperature factor | 1.024 |
| THET6 | Ammonia nitrogen decay rate temperature factor | 1.083 |
| THET7 | Ammonia nitrogen benthic sources rate temperature factor | 1.074 |
| THET8 | Nitrite nitrogen decay rate temperature factor | 1.047 |
| THET9 | Organic phosphorous decay rate temperature factor | 1.047 |
| THET10 | Organic phosphorous settling rate temperature factor | 1.024 |
| THET11 | Orthophosphate benthic sources rate temperature factor | 1.074 |
| THET12 | BOD decay rate temperature factor | 1.047 |
| THET13 | BOD settling rate temperature factor | 1.024 |
| THET14 | DO benthic demand rate temperature factor | 1.000 |
| THET15 | DO reaeration rate temperature factor | 1.024 |
| Bed | | |
| BTHET1 | Bed algae growth rate temperature factor | 1.047 |
| BTHET2 | Bed algae respiration rate temperature factor | 1.047 |
| BTHET3 | Bed algae settling rate temperature factor | 1.000 |
| BTHET4 | Bed organic nitrogen decay rate temperature factor | 1.000 |
| BTHET5 | Bed organic nitrogen settling rate temperature factor | 1.000 |
| BTHET6 | Bed ammonia nitrogen decay rate temperature factor | 1.000 |
| BTHET7 | Bed ammonia nitrogen benthic sources rate temperature factor | 1.000 |
| BTHET8 | Bed nitrite nitrogen decay | 1.000 |
| BTHET9 | Bed organic phosphorous decay rate temperature factor | 1.000 |
| BTHET12 | Bed BOD decay rate temperature factor | n/a |

## 3.3 Lake Ewauna-Keno Dam Reach

The CE-QUAL-W2 model for the Lake Ewauna to Keno Dam reach was calibrated for 2001 and tested using 2000 data. Water temperature, dissolved oxygen, and nutrient (phosphorous and nitrogen) data were collected at multiple locations during the 2001 field season and at three locations (Klamath River at Miller Island, Klamath River at Highway 66 bridge, and Klamath Straits Drain at Highway 97) during the 2000 field season by the U.S. Bureau of Reclamation.

The Lake Ewauna-Keno Reach is a complex reach with multiple inputs and outputs. The headwater boundary condition is Link River, which essentially represents Upper Klamath Lake – a highly dynamic hyper-eutrophic body of water. Other inputs include municipal waste water treatment plant effluent, industrial (primarily wood processing) discharges, agricultural discharges, and stormwater runoff. Although variable in size, the persistence and long-term nature of these discharges into this impoundment have created a water quality condition that is wholly uncommon in rivers of this size in the western United States. Namely, persistent and extreme anoxia, elevated nutrient levels, highly variable (in space and time) algal standing crop, appreciable BOD, and SOD demands. Available data have lead to a preliminary characterization of pertinent system processes.

Additional field work and model testing completed during the summer of 2003 has identified that this reach is dominated by the inflow quantity and quality at Upper Klamath Lake. Further, this boundary condition is highly variable in time, presumably in response to conditions in Upper Klamath Lake during late spring through fall periods, including but not limited to primary production (algal standing crop, blooms and die-offs), storage, flow conditions, and meteorological conditions (incident solar radiation, wind conditions). Because there is a measurable current throughout much of Keno Reservoir, the inputs from Upper Klamath Lake are actively transported downstream, impacting water quality throughout the reservoir length. This current, coupled with the shallow nature of the impoundment and intermittent winds, preclude strong thermal stratification of the system. The reservoir does stratify on a diurnal basis under calm conditions. The water velocity is not sufficient to preclude the development of large densities of phytoplankton, which actively colonize the top few feet of the water body. The high level of primary production, coupled with the large load of organic matter (living and dead algal tissue), creates a system that is almost wholly anoxic in the aphotic zone and experiences large diurnal variation in dissolved oxygen concentration in the photic zone. At certain locations there have been periods where the entire water column experiences dissolved oxygen concentrations less than 1 mg/l.

The large load of nutrients and organic matter from Upper Klamath Lake, imparts an appreciable oxygen demand on the system, wherein the system experiences a severe and persistent dissolved oxygen sag in the region from Lake Ewauna to below the Klamath Straits drain. The river system tends to recover somewhat by the time it reaches the Keno area, but concentrations often remain well below saturation in summer months. The role of sediment oxygen demand has been briefly explored with the CE-QUAL-W2 model and appears to play a modest role compared to the impacts of Upper Klamath Lake inflows.

U.S. Bureau of Reclamation operations occasionally have a dramatic affect on the water quality of the reservoir. Namely, there are periods where Link Dam releases are reduced and Lost River diversion channel inputs are increased. For example, in the fall of 2000 Link Dam releases were reduced to about 100 cfs and the Lost River diversion channel flows increased to around 700 cfs. During these operations the reservoir water quality was dominated by Lost River diversion channel water inflow. Another conditions that can affect water quality in the Klamath River downstream of the Lost River Diversion Channel is when diversions to the Reclamation project occur. If large amounts of water are diverted the residence time downstream of this point can potentially increase depending on the operations of the other withdrawal points and the Klamath Straits Drain. These may be short term events, but they can have impacts on water quality. The Klamath Straits Drain rarely exceeds 200 cfs in discharge and plays a lesser role; however, the drain is experiences a more persistent flow regime, while the Lost River diversion channel is often off line or diverting water from the river to the Reclamation Project.

Lake Ewauna/Keno Reservoir is a complex system and although significant improvements in characterizing the system have been identified, more studies will be required to improve the water quality simulation of the system. Probably the most important issue is characterizing the boundary conditions (primarily Link Dam, but also Lost River diversion channel and Klamath Straits Drain) on a timescale sufficiently short to capture the dynamics of the system – probably on the order of several days to a week.

## 3.3.1 Data

Water quality conditions of water flowing into the reach (boundary conditions), initial status of the system (initial conditions), and intermediate points within the main stem (calibration/validation points) were required.

### 3.3.1.1 Boundary Conditions

The upstream and downstream flow boundary conditions utilized 2000 and 2001 existing conditions. The upstream boundary conditions for temperature and constituent concentrations were passed from the calibrated Link River model simulation. All other boundary conditions were derived as documented in the model implementation section. (Note: selected boundary condition data for 2001 and presented in Appendix H in graphical or tabular form.)

### 3.3.1.2 Initial conditions

The residence time in the reach is approximately 10 days, thus the first half of January is used to "warmed up" the model and results from this period are not applicable to analysis for both 2000 and 2001.

### 3.3.1.3 Calibration Points

There are two calibration and validation points within the Lake Ewauna to Keno Dam reach for the simulated years. The first is located at the Miller Island boat ramp. The second is located in the Keno Reservoir at the Highway 66 Bridge. These data are displayed in the following section with model results.

## 3.3.2 Results

Calibration and validation were completed for temperature and dissolved oxygen as primary constituents and inorganic nutrient forms (ammonia, nitrate, orthophosphate) as secondary constituents. The model was run for the entire calendar year (2000 and 2001). Model performance was evaluated for the first week of the months of June through October to cover a wide range of seasons. Graphical presentation of these weekly periods also includes the 10 days prior to and 10 days following the selected week. This information, although not included in the statistical summary, provides insight into any trends the model is or is not representing in this dynamic and complex reach.

Field observations for temperature and dissolved oxygen were available from water quality probes on an hourly interval, allowing for summary statistics to be calculated on an hourly and daily basis. The nutrient data were primarily derived from field data, which were typically sampled monthly or semimonthly; resulting in sparse data that are not readily amenable for such statistical analysis. All model parameters for the Lake Ewauna to Keno Dam reach are summarized in Table 35 at the end of this section.

#### 3.3.2.1 Water Temperature

Water temperature calibration included varying the three wind speed evaporation coefficients specified by the user in CE-QUAL-W2. CE-QUAL-W2 simulated seasonal variations in water temperature effectively at both Miller Island (approximate river mile and Highway 66 near Keno. CE-QUAL W-2 was applied to this reach for the entire year. Residence time ranges from a few days to roughly two weeks and the system does not seasonally stratify.

***Miller Island***

The entire calendar year was simulated and temperature results for the first week of the months June through October 2000 and 2001 are shown in Figure 34 and Figure 35 and Figure 36 and Figure 37, respectively. Seasonal trends and short-term meteorological conditions are reflected in the model simulations. Summary statistics for the first week of each month for 2000 and 2001 are provided in Table 27 and Table 28, respectively.

The simulated hourly and mean daily temperature is represented to within about 1°C for 2000, and generally well under 1°C for 2001. The model matched short term variations as well as seasonal trends. However, simulated results did not reproduce a component of the diurnal variation evident in field observations. It is important to note that in 2000 the US Bureau of Reclamation datasonde was deployed at the Miller Island boat ramp dock in approximately 4 feet of water. This location did not represent actual mid-channel conditions. Further, the location was subject to mixing due to boat launching activities. Close examination of the trace shows increases in water temperatures on the order of 7°C within an hour (see Julian Day 173), which is highly unlikely. Thus attempting to calibrate to the peak daily temperatures was not appropriate. Associated dissolved oxygen data, pH and electrical conductivity also suggest that this location was not desirable. During the 2001 field season, the Bureau of Reclamation moved the sampling location to mid-channel, suspending the sonde from a buoy. The 2001 data, while still illustrating mid- to late-afternoon peaks, do not exhibit such drastic deviations.

Upon close examination, the daily temperature peaks are actually deviations from a smother sinusoidal temperature trace. Figure 33 illustrates the observed temperature at Miller Island (at a depth of approximately 1 meter) with an estimated sinusoidal signal sketched in on Julian days 207, 208, and 212. These deviations occur in the late afternoon, and after observing conditions at Miller Island and Keno, as well as other locations, in the summer of 2003 it is postulated that this upward deviation is due to late afternoon wind mixing. Local meteorological data suggest that during summer periods afternoon winds are typical, especially in the vicinity of Keno where the river cuts through the Cascades. During these afternoon wind events, the mixing energy is presumed to be sufficient to overcome at least a portion of the diurnal stratification wherein surface waters are mixed downward by wind, possibly aided by local velocities (current) within the reservoir. Field data from August 2003 suggest there are considerable temperature differences in the top meter: in the vicinity of Miller Island surface waters (depth of 0.1 m) were 28°C, while at 0.5 and 1.0 meters water temperatures were 25.1°C and 22.5°C, respectively. Towards sunset the thermal loading drastically diminishes and winds die down and water temperatures return to the typical smooth sinusoidal pattern. Examination of the observed data at Highway 66 suggests this occurs at Keno as well. Attempts to refine the model to address these afternoon deviations were not attempted.

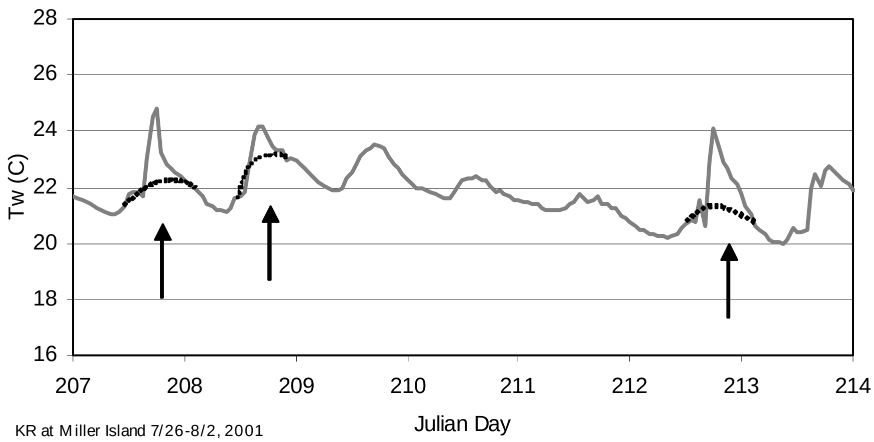
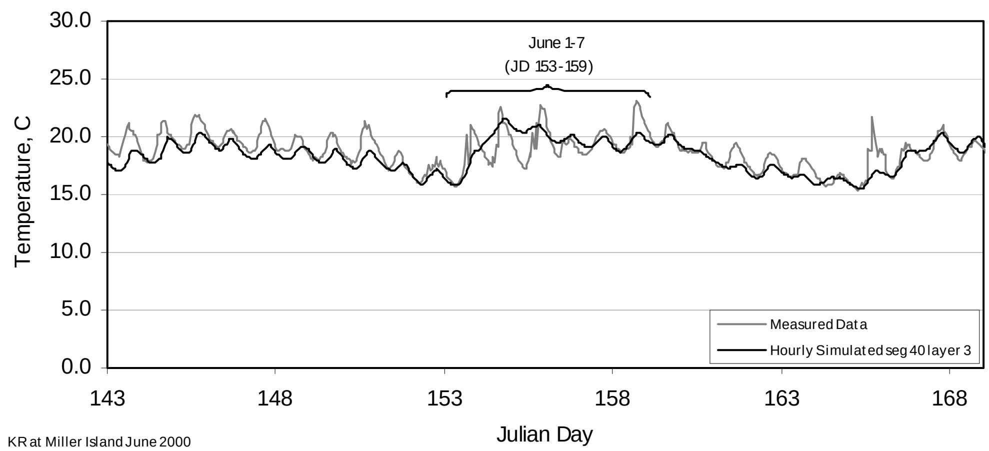
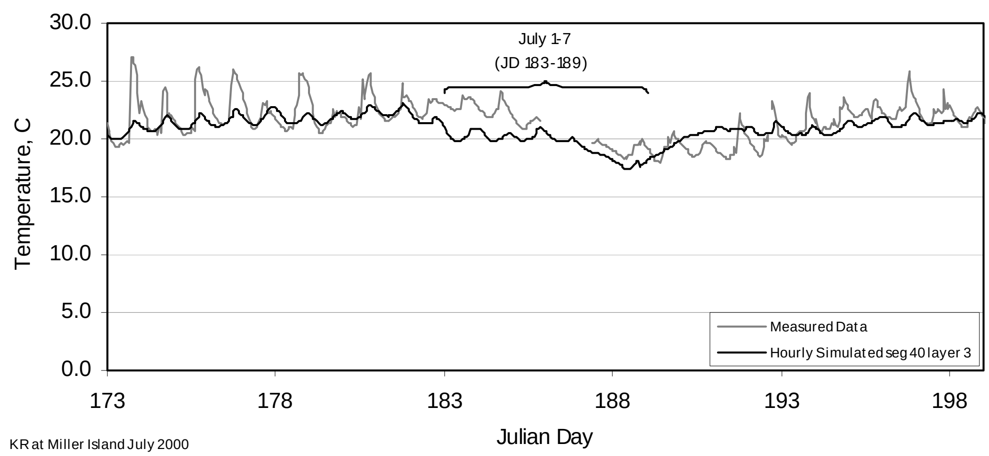


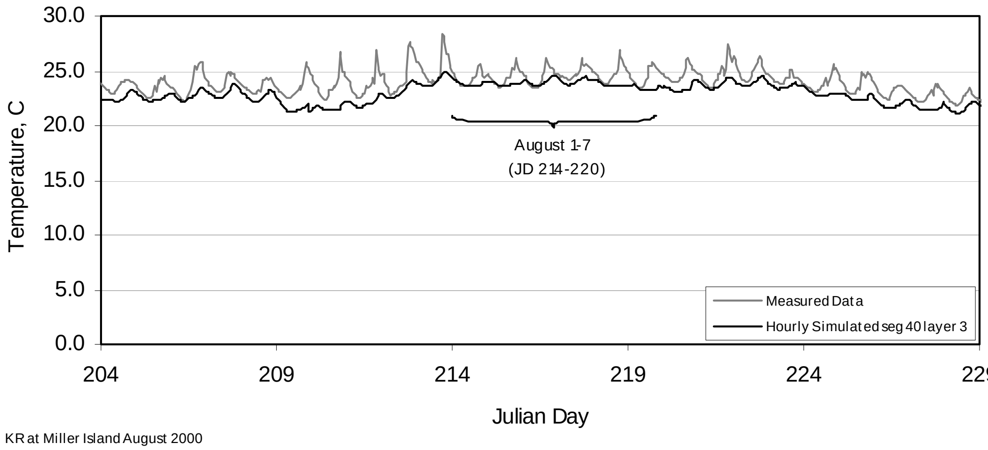

**Figure 33. Observed water temperature at Miller Island (2001) showing afternoon deviations from the typical sinusoidal pattern of water temperatures (estimated with the dashed line and marked by arrows)**




(a)

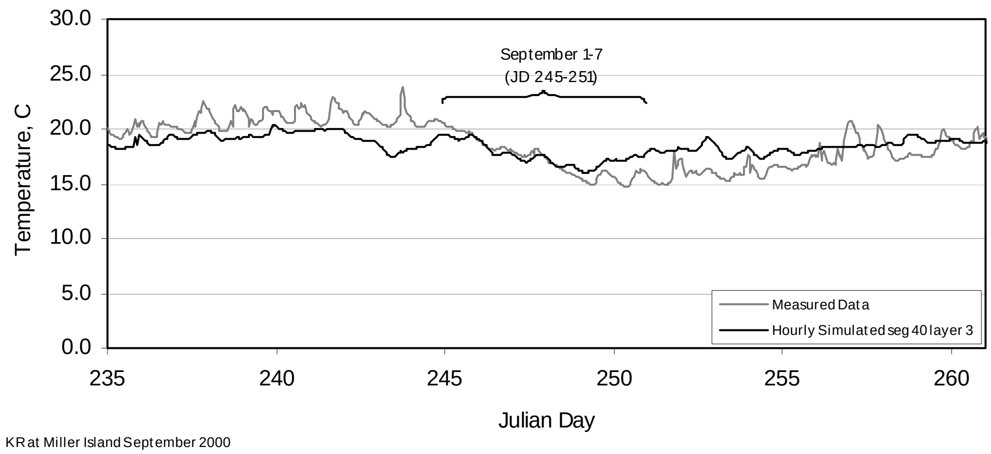


(b)

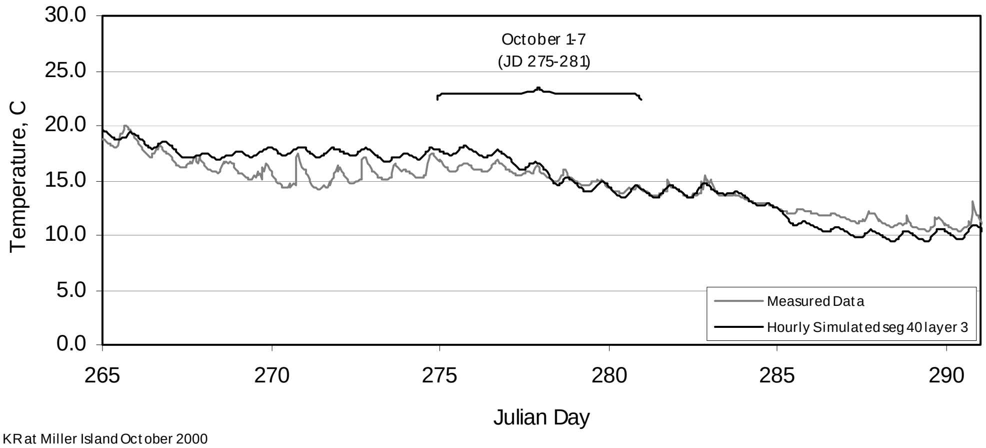



(c)

**Figure 34. Simulated versus measured temperatures for Lake Ewauna to Keno for Klamath River at Miller Island (a) June 1-7, (b) July 1-7, (c) August 1-7, 2000**




(a)

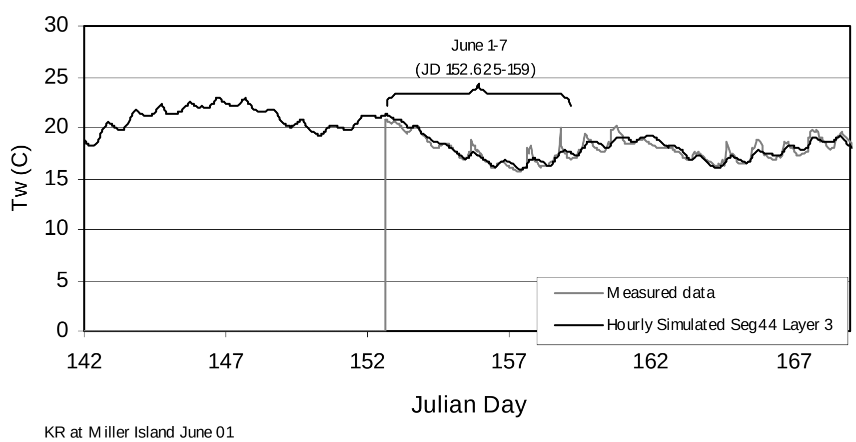



(b)

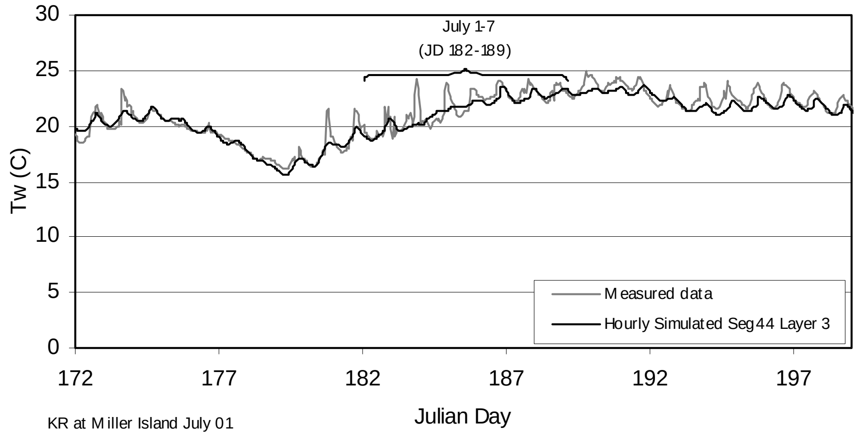
**Figure 35. Simulated versus measured temperatures for Lake Ewauna to Keno for Klamath River at Miller Island (a) September 1-7, (b) October 1-7, 2000**

**Table 27. Lake Ewauna-Keno Reach hourly and daily calibration period statistics for temperature at Miller Island 2000**

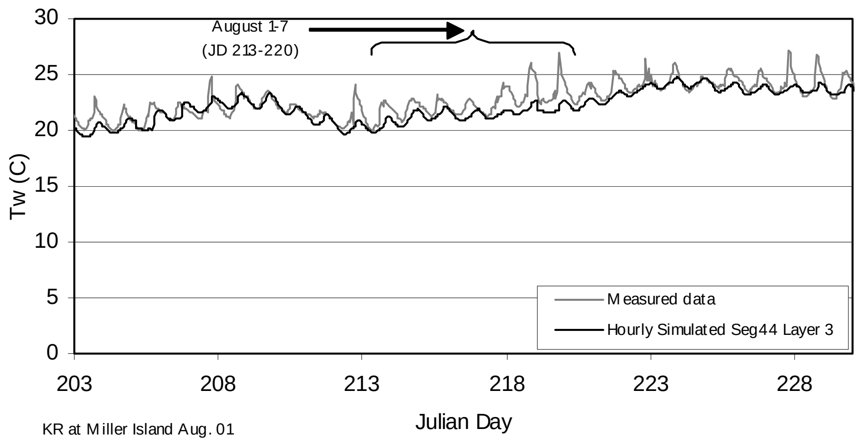
| Statistic | Unit | Jun 1-7 | Jul 1-7 | Aug 1-7 | Sept 1-7 | Oct 1-7 |
|---|---|---|---|---|---|---|
| **Hourly** | | | | | | |
| Mean Bias | C | 0.09 | -1.48 | -0.80 | 0.65 | 0.39 |
| Mean absolute error (MAE) | C | 0.94 | 1.53 | 0.83 | 1.01 | 0.63 |
| Root mean squared error (RMSE) | C | 1.26 | 1.78 | 1.08 | 1.34 | 0.82 |
| N | - | 168 | 131 | 168 | 168 | 168 |
| **Daily** | | | | | | |
| Mean Bias | C | 0.09 | -1.62 | -0.80 | 0.65 | 0.91 |
| Mean absolute error (MAE) | C | 0.66 | 1.62 | 0.80 | 0.99 | 0.56 |
| Root mean squared error (RMSE) | C | 0.78 | 1.88 | 0.85 | 1.69 | 0.77 |
| N | - | 7 | 4 | 7 | 7 | 7 |




(a)

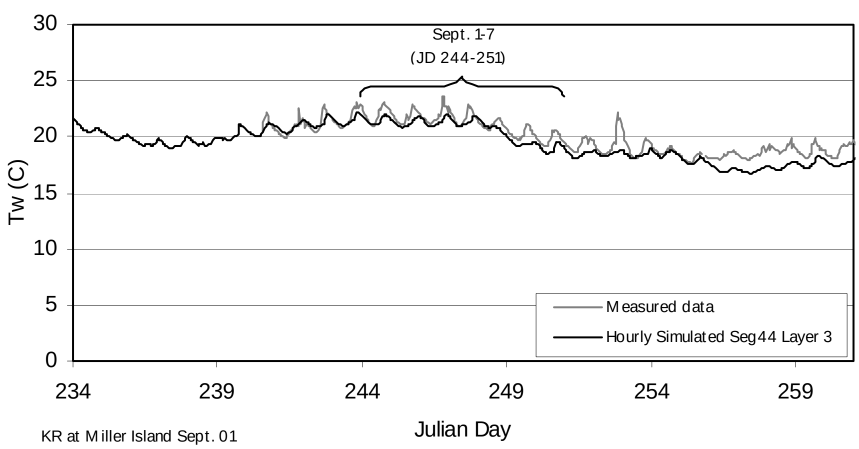



(b)

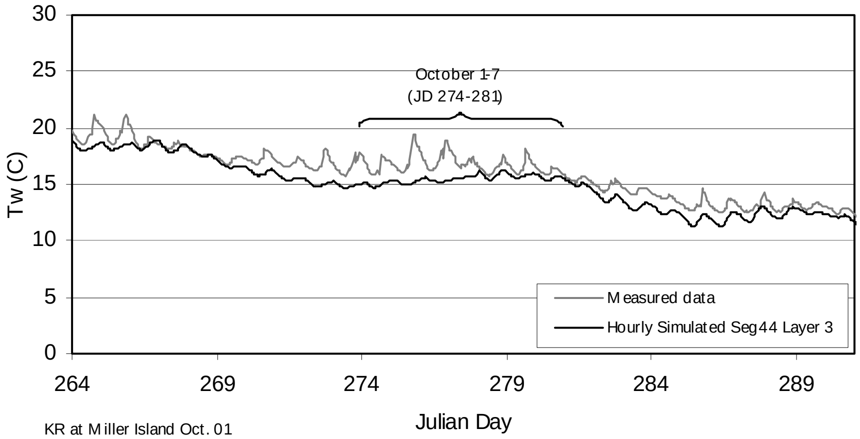



(c)

**Figure 36. Simulated versus measured temperatures for Lake Ewauna to Keno for Klamath River at Miller Island (a) June 1-7, (b) July 1-7, (c) August 1-7, 2001**




(a)




(b)

**Figure 37. Simulated versus measured temperatures for Lake Ewauna to Keno for Klamath River at Miller Island (a) September 1-7, (b) October 1-7, 2001**

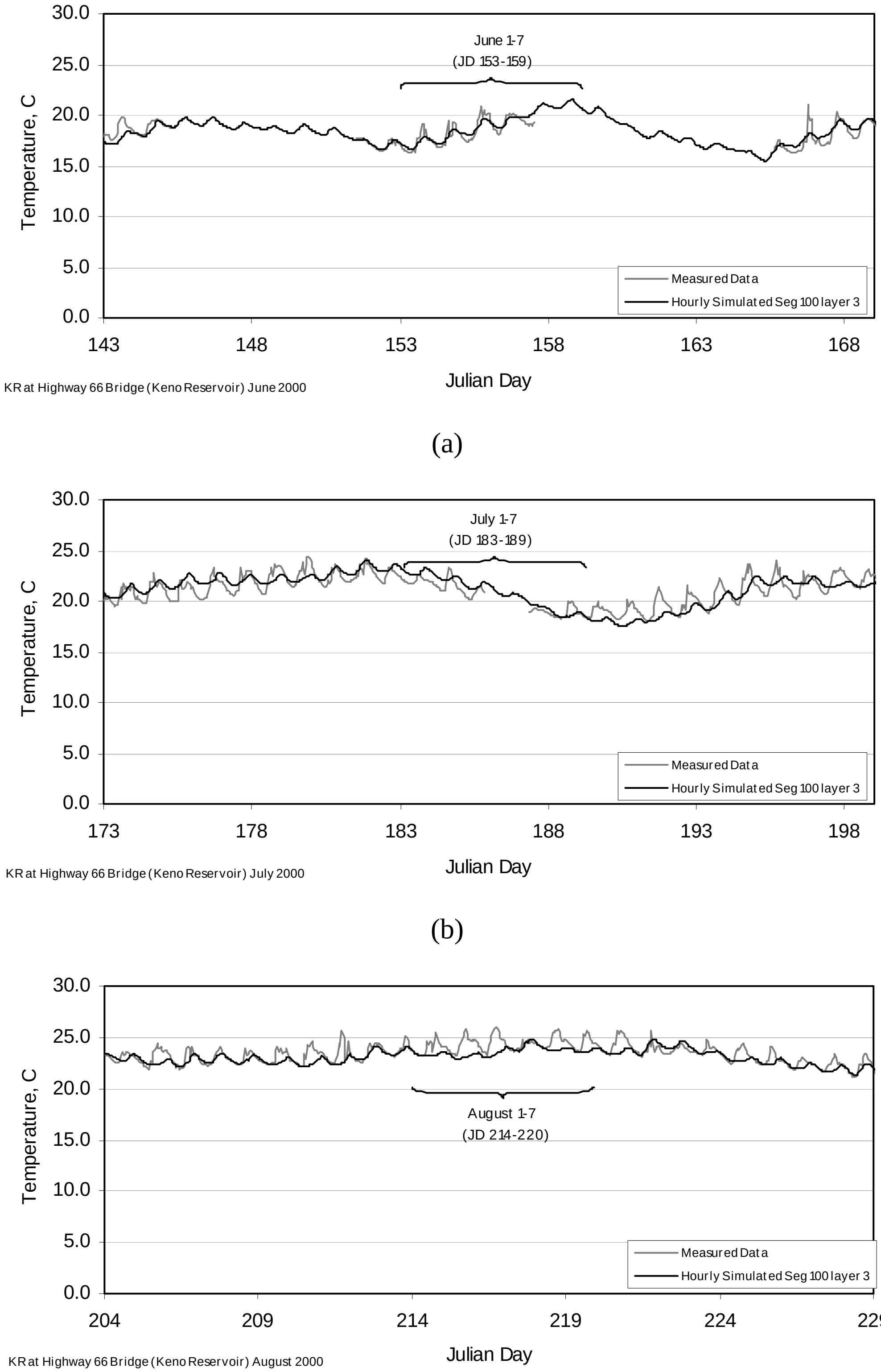
**Table 28. Lake Ewauna-Keno Reach hourly and daily calibration period statistics for temperature at Miller Island 2001**

| Statistic | Unit | Jun 1-7 | Jul 1-7 | Aug 1-7 | Sept 1-7 | Oct 1-7 |
|---|---|---|---|---|---|---|
| Hourly | | | | | | |
| Mean Bias | C | 0.08 | -0.29 | -1.06 | -0.56 | -1.31 |
| Mean absolute error (MAE) | C | 0.32 | 0.61 | 1.06 | 0.61 | 1.31 |
| Root mean squared error (RMSE) | C | 0.45 | 0.86 | 1.35 | 0.75 | 1.56 |
| N | - | 153 | 168 | 168 | 168 | 168 |
| Daily | | | | | | |
| Mean Bias | C | 0.05 | -0.32 | -1.07 | -0.56 | -1.31 |
| Mean absolute error (MAE) | C | 0.15 | 0.33 | 1.07 | 0.56 | 1.31 |
| Root mean squared error (RMSE) | C | 0.19 | 0.39 | 1.15 | 0.60 | 1.43 |
| N | - | 6 | 7 | 7 | 7 | 7 |

### *Highway 66 Bridge near Keno*

Both 2000 and 2001 were simulated for the calendar year and results shown in Figure 38 through Figure 41. Hourly and daily summary statistics are included in Table 29 and Table 30 for 2000 and 2001, respectively. Seasonal trends and short-term meteorological conditions are clearly reflected in the model results and the models are within 1°C if observed values for all calibration periods. The US Bureau of Reclamation data sonde at Highway 66 has was suspended from a buoy in both 2000 and 2001. Windy conditions, similar to Miller Island are also present in the Keno area.

In general the models perform well over a wide range of conditions at both Miller Island and at Highway 66 near Keno.




(a)

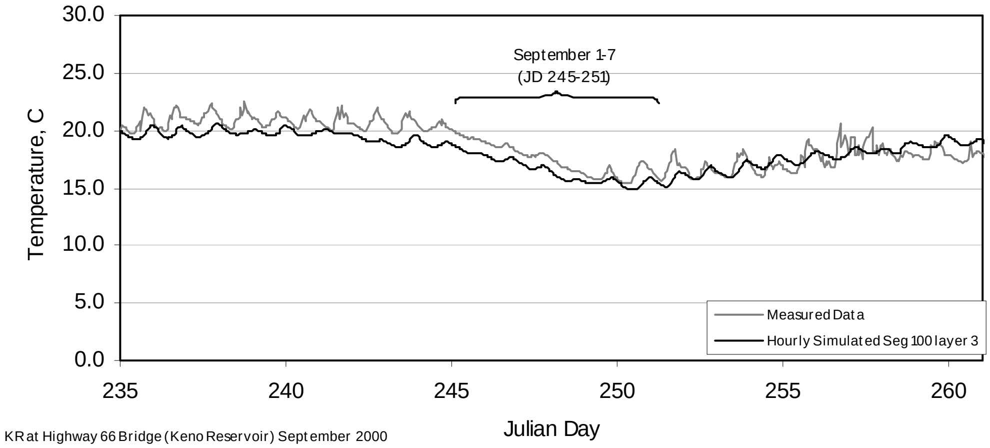


(b)

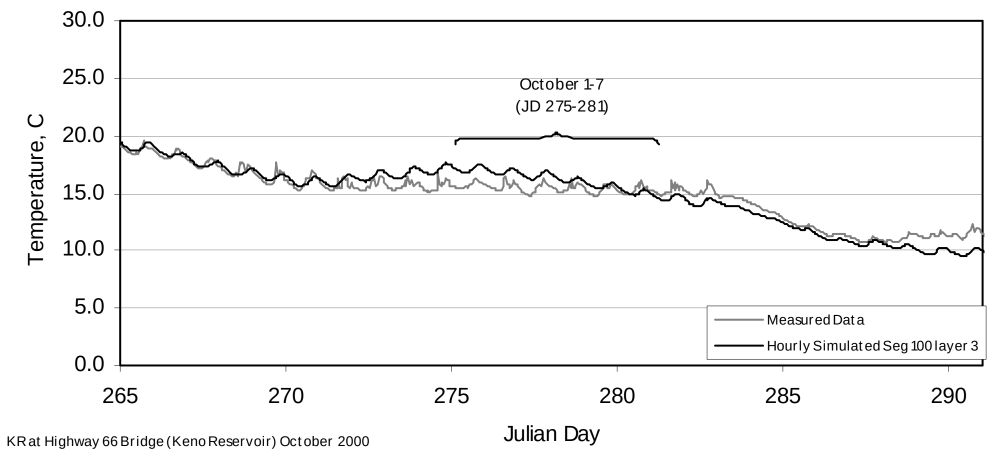


(c)

**Figure 38. Temperature simulation results for Lake Ewauna to Keno Reach for Klamath River at Highway 66 bridge (a) June 1-7, (b) July 1-7, (c) August 1-7, 2000**




(a)

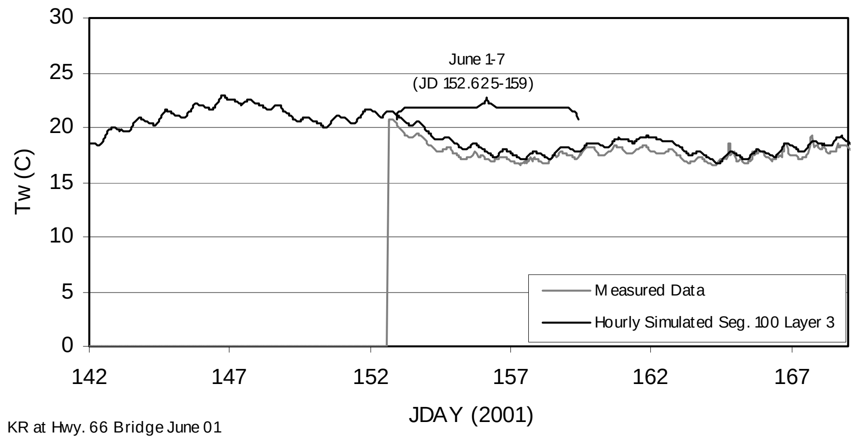



(b)

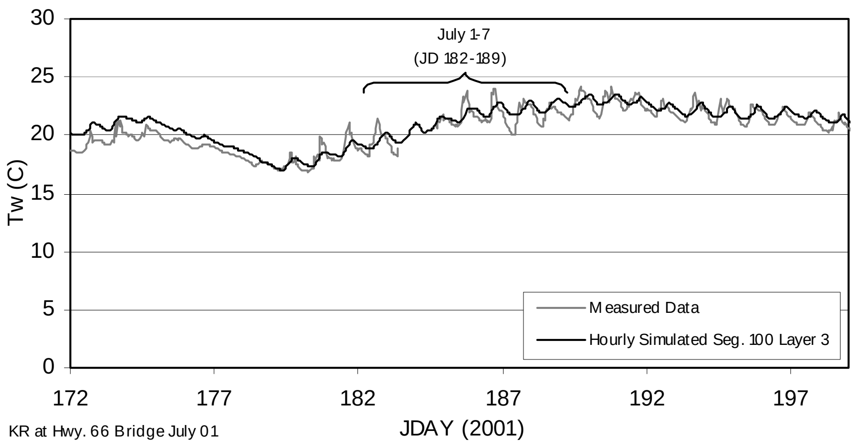
**Figure 39. Temperature simulation results for Lake Ewauna to Keno for Klamath River at Highway 66 (a) September 1-7 and (b) October 1-7, 2000**

**Table 29. Lake Ewauna-Keno Reach hourly and daily period statistics for temperature at Highway 66, 2000**

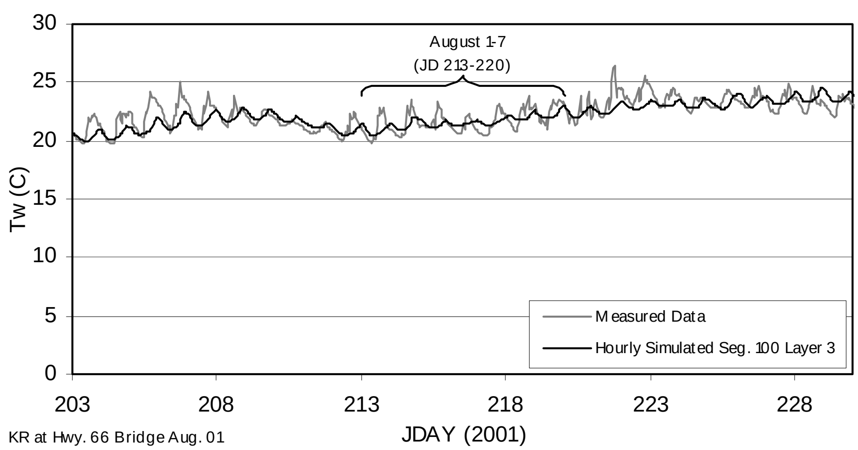
| Statistic | Unit | June 1-7 | July 1-7 | Aug 1-7 | Sept 1-7 | Oct 1-7 |
|---|---|---|---|---|---|---|
| Hourly | | | | | | |
| Mean Bias | C | 0.06 | 0.27 | -0.75 | -0.97 | 0.60 |
| Mean absolute error (MAE) | C | 0.46 | 0.70 | 0.79 | 0.97 | 0.85 |
| Root mean squared error (RMSE) | C | 0.56 | 0.83 | 1.08 | 1.07 | 0.98 |
| N | - | 110 | 132 | 168 | 168 | 168 |
| Daily | | | | | | |
| Mean Bias | C | -0.03 | 0.14 | -0.75 | -0.97 | 0.29 |
| Mean absolute error (MAE) | C | 0.03 | 0.58 | 0.75 | 0.97 | 0.82 |
| Root mean squared error (RMSE) | C | 0.03 | 0.61 | 0.83 | 1.32 | 0.93 |
| N | - | 4 | 4 | 7 | 7 | 7 |




(a)

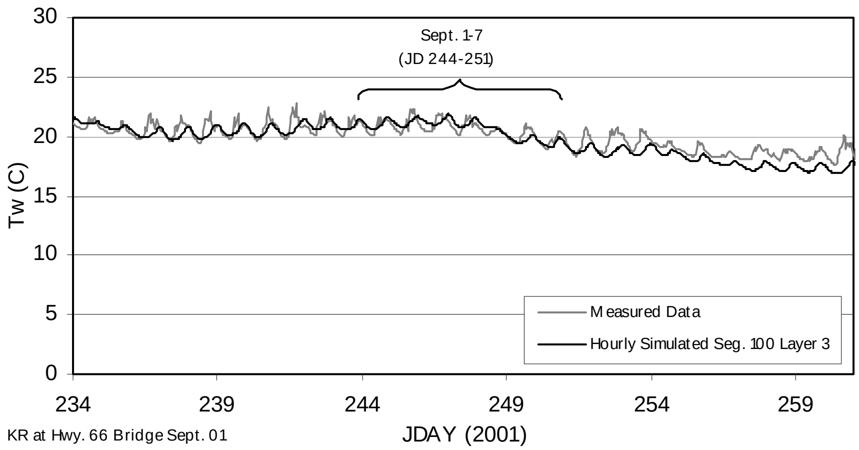



(b)

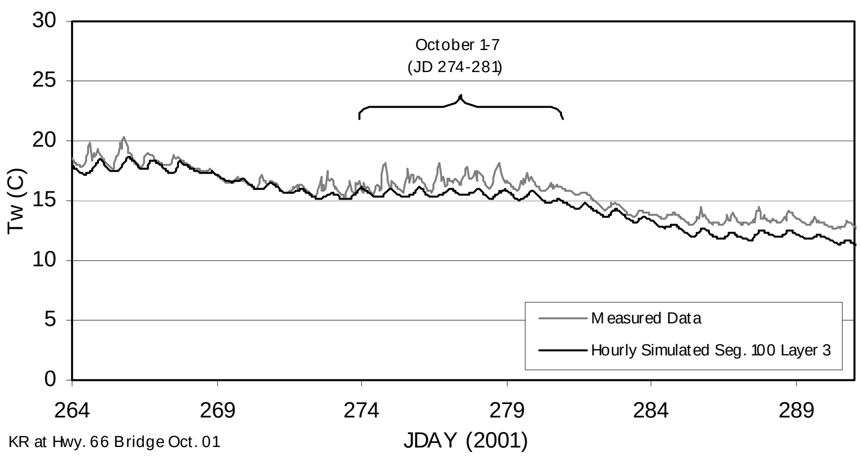



(c)

**Figure 40. Temperature simulation results for Lake Ewauna to Keno Reach for Klamath River at Highway 66 bridge (a) June 1-7, (b) July 1-7, (c) August 1-7, 2001**




(a)




(b)

**Figure 41. Temperature simulation results for Lake Ewauna to Keno for Klamath River at Highway 66 (a) September 1-7 and (b) October 1-7, 2001**

**Table 30. Lake Ewauna-Keno Reach hourly and daily period statistics for temperature at Highway 66, 2001**

| Statistic | Unit | June 1-7 | July 1-7 | Aug 1-7 | Sept 1-7 | Oct 1-7 |
|---|---|---|---|---|---|---|
| Hourly | | | | | | |
| Mean Bias | C | 0.76 | 0.27 | -0.09 | 0.06 | -1.03 |
| Mean absolute error (MAE) | C | 0.76 | 0.66 | 0.65 | 0.41 | 1.04 |
| Root mean squared error (RMSE) | C | 0.81 | 0.80 | 0.80 | 0.49 | 1.17 |
| N | - | 153 | 138 | 168 | 168 | 168 |
| Daily | | | | | | |
| Mean Bias | C | 0.76 | 0.19 | -0.10 | 0.06 | -1.04 |
| Mean absolute error (MAE) | C | 0.76 | 0.34 | 0.19 | 0.21 | 1.04 |
| Root mean squared error (RMSE) | C | 0.81 | 0.40 | 0.21 | 0.22 | 1.05 |
| N | - | 6 | 5 | 7 | 7 | 7 |

### 3.3.2.2 Dissolved Oxygen

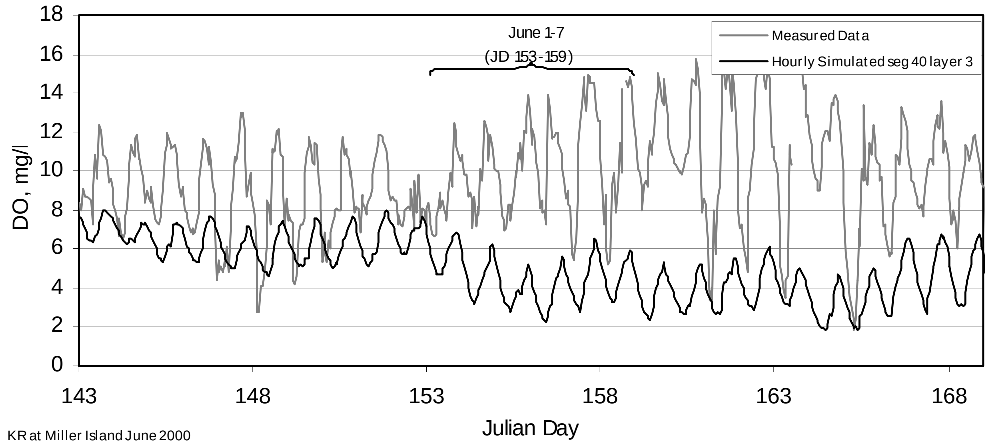
Dissolved oxygen response of Lake Ewauna to Keno Dam is unique for a river system of this size and morphology. The system receives appreciable organic loads from Upper Klamath Lake as well as small, but low quality return flows from municipal, industrial, and agricultural sources. However, an overriding system condition is the severe, persistent anoxia that develops within the system from near the bottom of Lake Ewauna proper to near Keno Dam. Although there are a suite of parameters available for model calibration, including algal growth, respiration and mortality rates, nutrient decay rates, organic matter decay rates, and SOD (zero order), the critical factor is the considerable organic load from Upper Klamath Lake – and the characterization of that boundary condition at Link Dam.

Initial model calibration identified the need for additional field information and year 2001 was added to the analysis. Results for both 2000 and 2001 suggest that general seasonal trends are represented, as are diurnal variations and periods of anoxia. Further, trends in dissolved oxygen concentration for many of the multi-week periods shown in the figures are well represented. However, the model performance is spotty with certain periods not well represented. Simulated results at Highway 66 are notably better than those at Miller Island. Based on field data and model simulations, it is postulated that the region of extreme water quality conditions originates in the stretch from Lake Ewauna to somewhere in the vicinity of Miller Island – a reach of roughly seven or eight miles. Thus results at the upper site – Miller Island – are more directly impacted than those at the lower River site near Keno Dam. The dynamic nature of the Lake Ewauna/Keno reach is primarily driven by the organic load originating in Upper Klamath Lake. The long, narrow aspect of Keno Reservoir results in a much reduced surface area for primary production to occur versus the broad aspect of Upper Klamath Lake. Given the large organic load (dead algae, as well as living algae that flows into the narrow Lake Ewauna/Keno reach and resides below the photic zone and subsequently dies) and the measurable current, it appears that the reservoir experiences an oxygen sag with the largest oxygen deficits occurring between Lake Ewauna to downstream of Miller Island and then showing modest recovery by the time waters reach Keno.

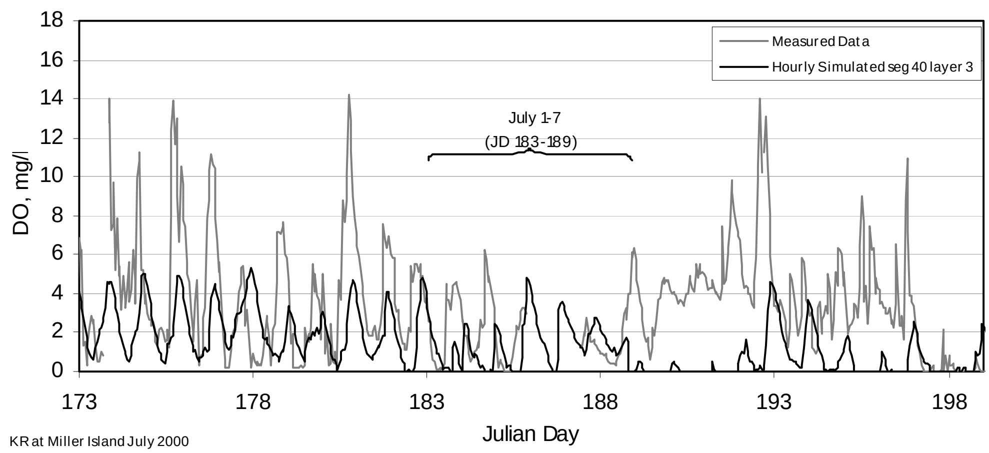
A limited amount of model testing was completed with CE-QUAL-W2 to determine the sensitivity of dissolved oxygen to influent algae and BOD concentrations from Link Dam and the model is quite sensitive to short term variations in these parameters at the upstream boundary conditions. It is estimated that improved results could be obtained if water quality information were collected on a more frequent basis (e.g. twice weekly) to more completely represent water quality conditions of waters leaving Upper Klamath Lake.

Additional model simulations were completed to determine if algal populations, and thus dissolved oxygen, would be affected if respiratory requirements were not met during anoxic periods. The model was modified to limit algal growth based on respiratory needs of phytoplankton. Specifically, if there was insufficient dissolved oxygen in the water column to support respiration of algae, algal mortality was increased

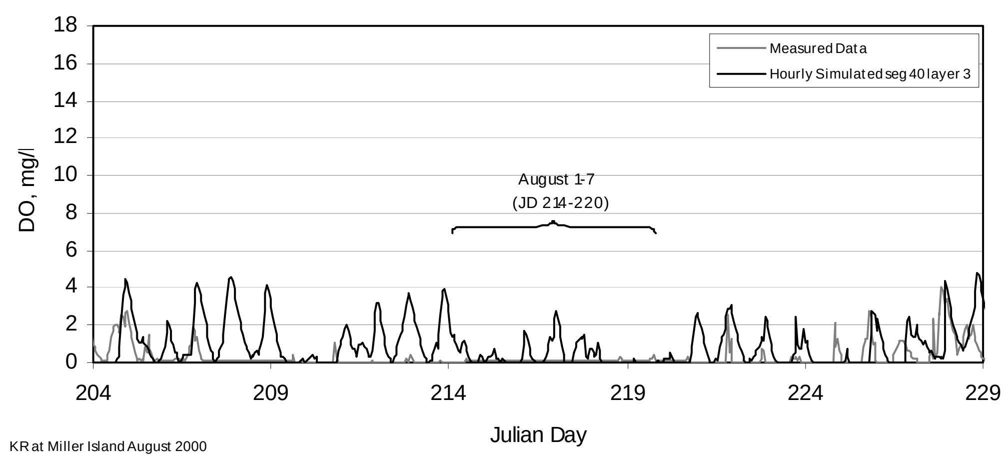
While there was no field data to test the model logic, but sensitivity testing of the model parameters while assessing phytoplankton, DO, and nutrient level responses indicated that algal respiratory requirements is probably not the primary factor behind the persistent anoxia, elevated nutrients and low algal counts that are prone to occur in this reach. Advection from upstream reaches tends to re-colonize downstream reaches on the order of days Further research into this issue has focused on algal inhibition by one of several factors, potentially including impacts of pharmaceutical/human health and personal care products in municipal treated effluent, phenolic compounds associated with organic matter – including that within the sediments (source: tannins, humic substances, lignin), production of hydrogen peroxide, other chemical constituents or reactions that may lead to inhibition or toxicity. Additional analyses and field studies have been completed in 2003 to refine model representation of dissolved oxygen, as well as other factors, in this reach; however, additional studies are needed to more fully characterize the complex dynamics of this reach and its relationship with Upper Klamath Lake.




(a)

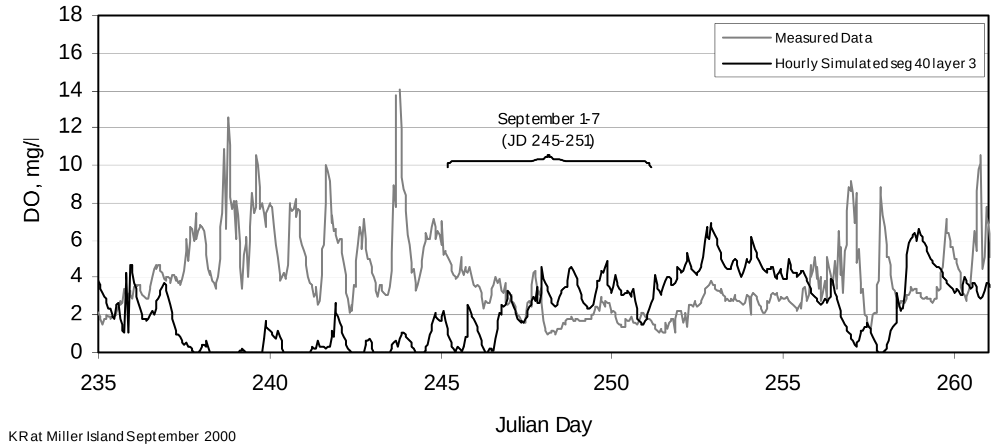



(b)

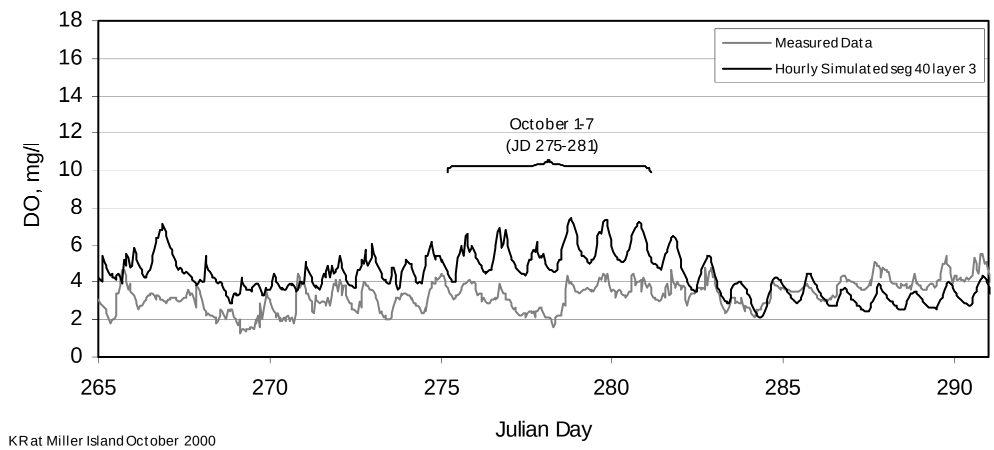



(c)

**Figure 42. Dissolved oxygen simulation for Lake Ewauna to Keno Dam reach: Klamath River at Miller Island (a) June 1-7, (b) July 1-7, (c) August 1-7, 2000**




(a)




(b)

**Figure 43. Dissolved oxygen simulation for Lake Ewauna to Keno Dam reach: Klamath River at Miller Island (a) September 1-7, (b) October 1-7, 2000**

**Table 31. Lake Ewauna-Keno Reach hourly and daily period statistics for dissolved oxygen at Miller Island, 2000**

| Statistic | Unit | Jun 1-7 | Jul 1-7 | Aug 1-7 | Sept 1-7 | Oct 1-7 |
|---|---|---|---|---|---|---|
| Hourly | | | | | | |
| Mean Bias | mg/l | -5.94 | -1.41 | 0.20 | 0.05 | 2.25 |
| Mean absolute error (MAE) | mg/l | 5.94 | 1.95 | 0.33 | 1.79 | 2.25 |
| Root mean squared error (RMSE) | mg/l | 6.40 | 2.56 | 0.57 | 2.13 | 2.36 |
| N | - | 168 | 126 | 152 | 168 | 168 |
| Daily | | | | | | |
| Mean Bias | mg/l | -5.89 | -1.80 | 0.30 | 0.05 | 2.25 |
| Mean absolute error (MAE) | mg/l | 5.89 | 1.80 | 0.34 | 1.72 | 2.25 |
| Root mean squared error (RMSE) | mg/l | 6.07 | 1.99 | 0.43 | 1.98 | 2.30 |
| N | - | 7 | 4 | 7 | 7 | 7 |

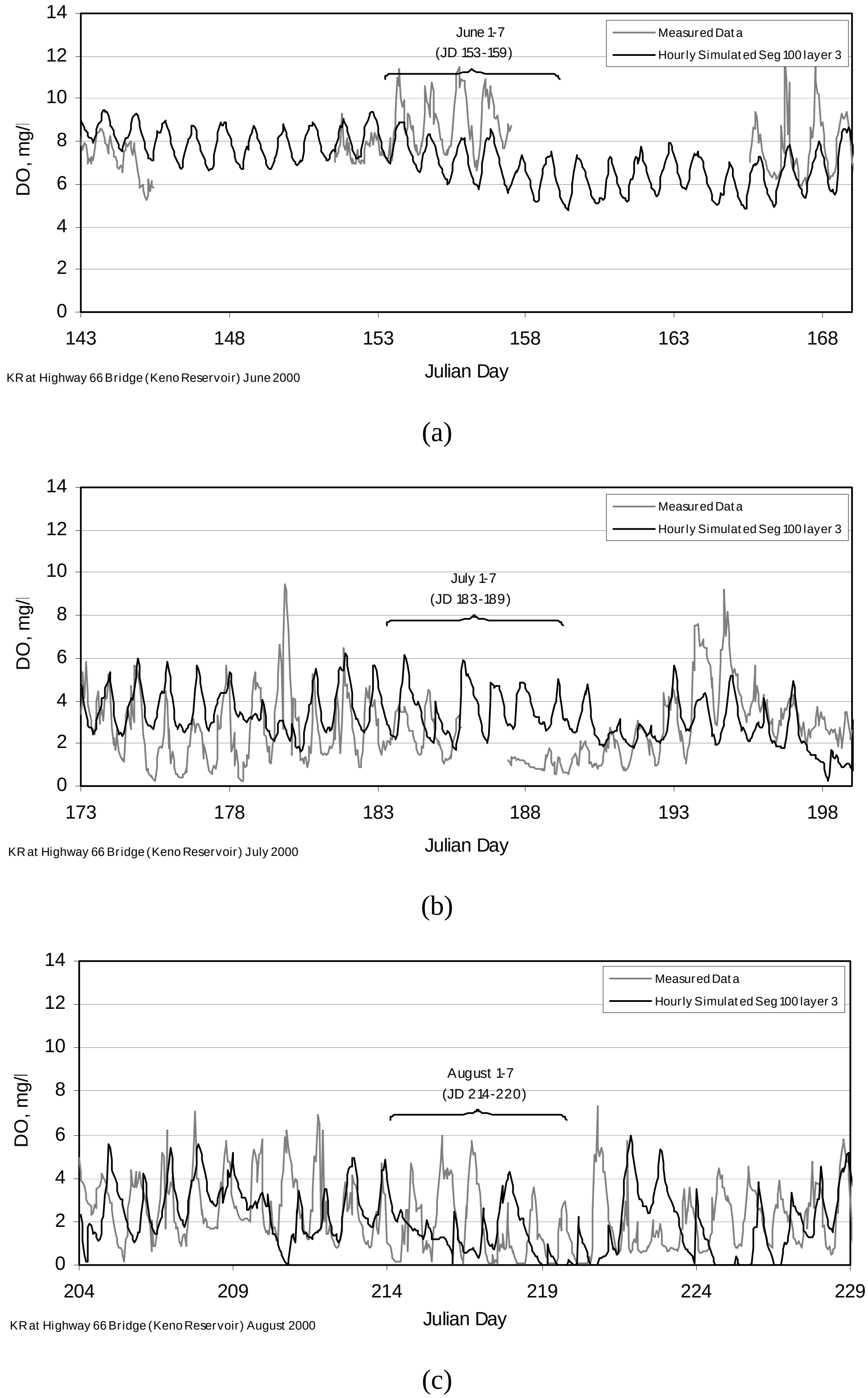
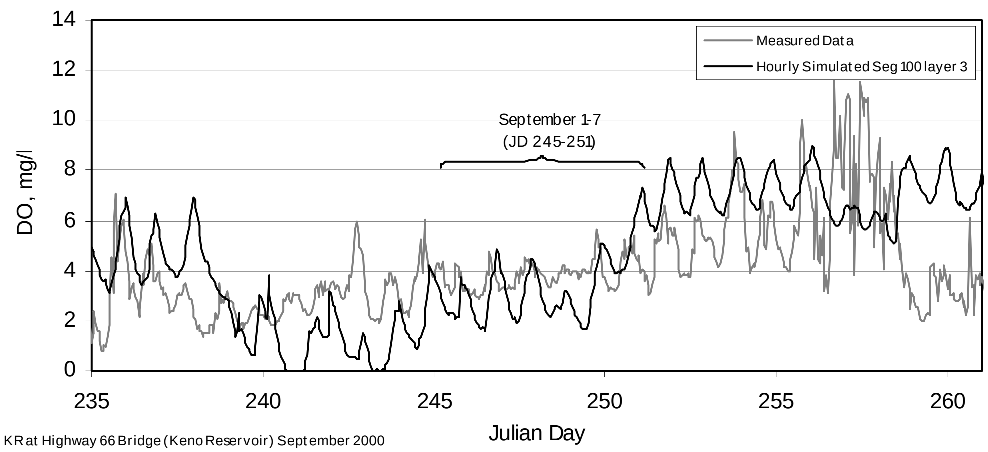
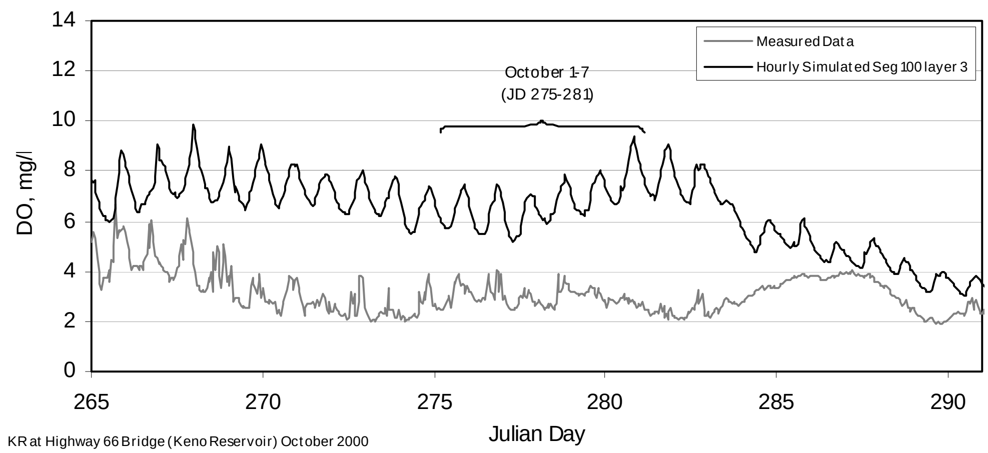



**Figure 44. Dissolved oxygen simulation for Lake Ewauna to Keno Dam reach: Klamath River at Highway 66 (a) June 1-7, (b) July 1-7, (c) August 1-7, 2000**




(a)

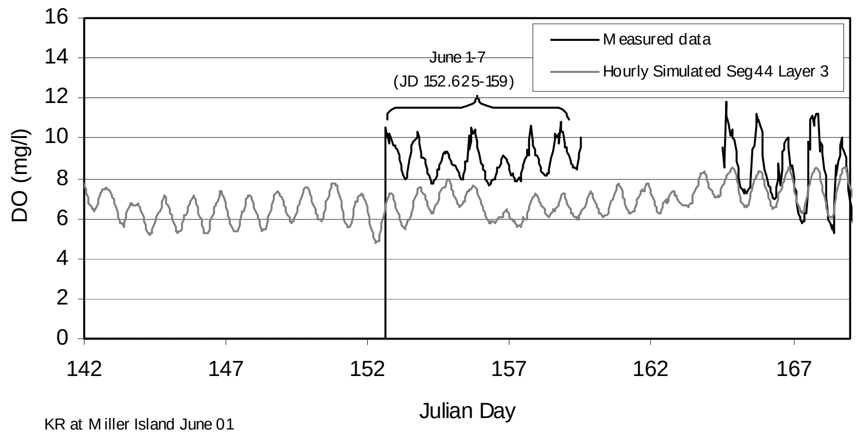



(b)

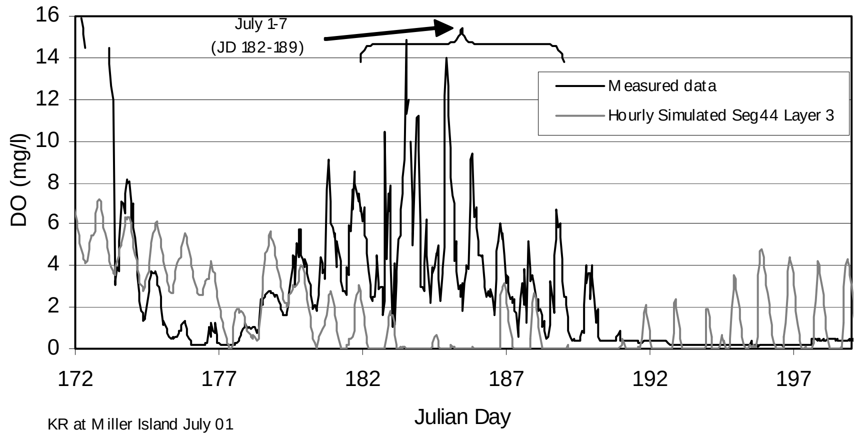
**Figure 45. Dissolved oxygen simulation for Lake Ewauna to Keno Dam reach: Klamath River at Highway 66 (a) September 1-7, (b) October 1-7, 2000**

**Table 32. Lake Ewauna-Keno Reach hourly and daily period statistics for dissolved oxygen at Highway 66, 2000**

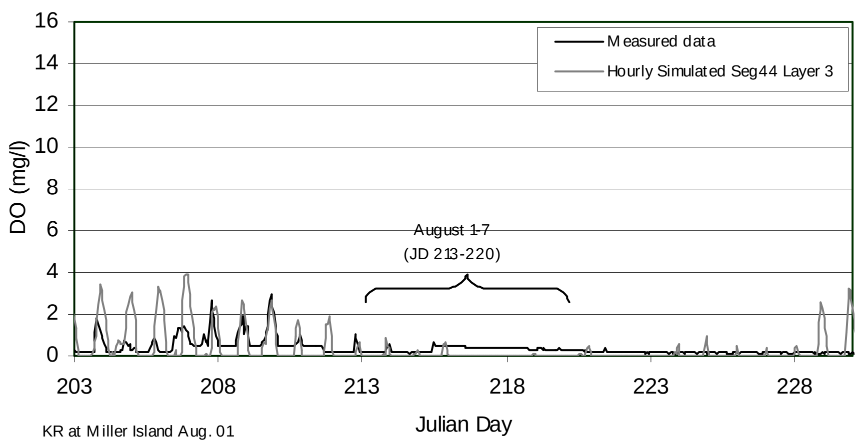
| Statistic | Unit | June 1-7 | July 1-7 | Aug 1-7 | Sept 1-7 | Oct 1-7 |
|---|---|---|---|---|---|---|
| Hourly | | | | | | |
| Mean Bias | mg/l | -1.50 | 1.54 | -0.48 | -0.24 | 3.96 |
| Mean absolute error (MAE) | mg/l | 1.55 | 1.86 | 1.80 | 1.15 | 3.96 |
| Root mean squared error (RMSE) | mg/l | 1.78 | 2.06 | 2.26 | 1.38 | 4.09 |
| N | - | 110 | 132 | 168 | 168 | 168 |
| Daily | | | | | | |
| Mean Bias | mg/l | -1.42 | 1.55 | -0.48 | -0.24 | 3.96 |
| Mean absolute error (MAE) | mg/l | 1.42 | 1.55 | 1.15 | 1.00 | 3.96 |
| Root mean squared error (RMSE) | mg/l | 1.56 | 1.72 | 1.27 | 1.11 | 4.05 |
| N | - | 4 | 4 | 7 | 7 | 7 |




(a)

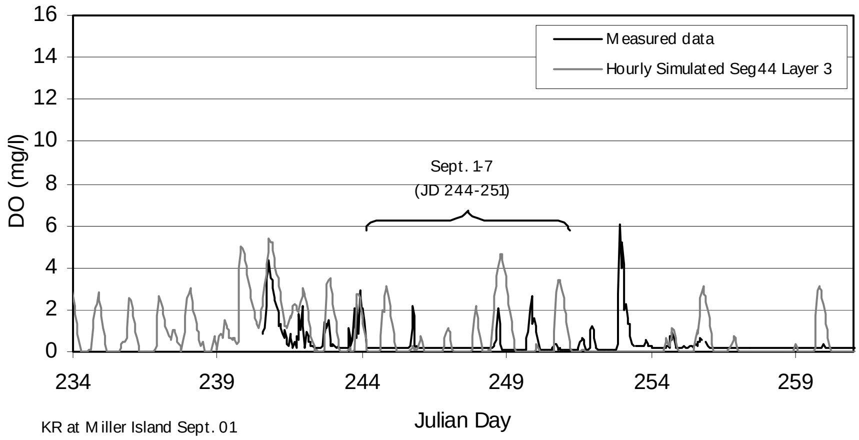



(b)

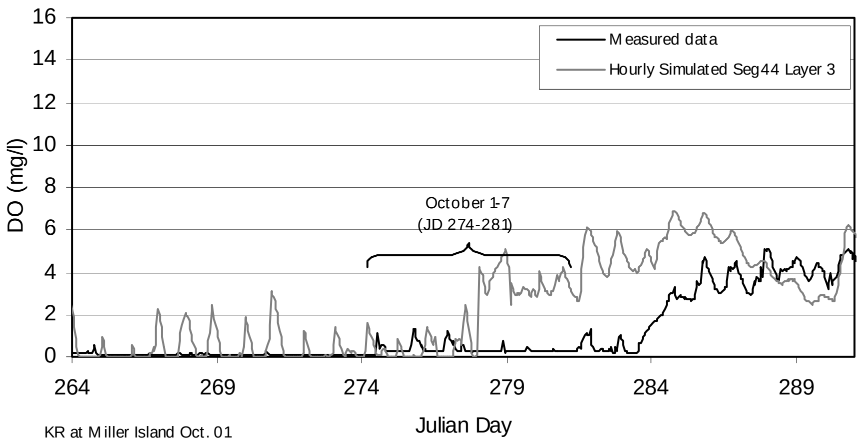



(c)

**Figure 46. Dissolved oxygen simulation for Lake Ewauna to Keno Dam reach: Klamath River at Miller Island (a) June 1-7, (b) July 1-7, (c) August 1-7, 2001**




(a)

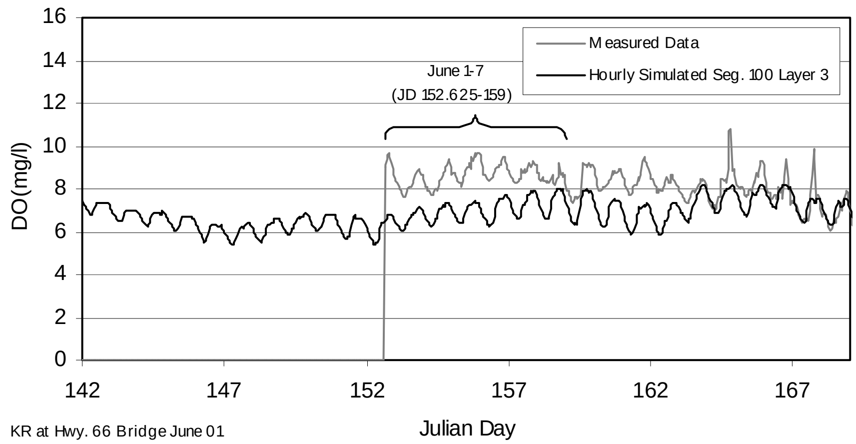



(b)

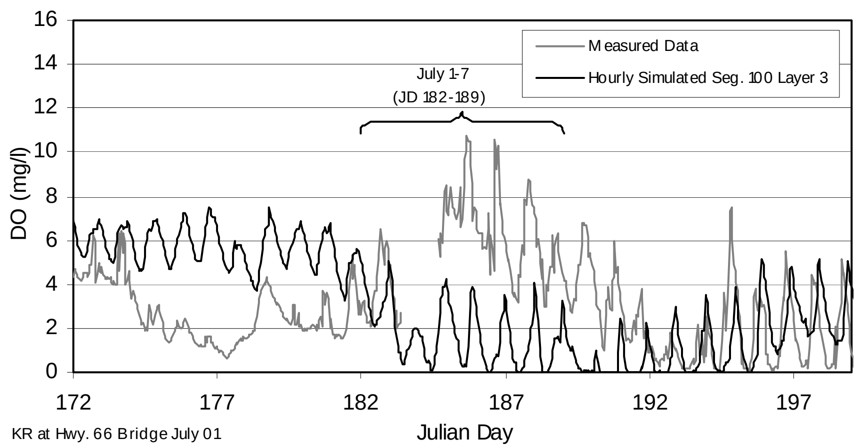
**Figure 47. Dissolved oxygen simulation for Lake Ewauna to Keno Dam reach: Klamath River at Miller Island (a) September 1-7, (b) October 1-7, 2001**

**Table 33. Lake Ewauna-Keno Reach hourly and daily period statistics for dissolved oxygen at Miller Island, 2001**

| Statistic | Unit | Jun 1-7 | Jul 1-7 | Aug 1-7 | Sept 1-7 | Oct 1-7 |
|---|---|---|---|---|---|---|
| Hourly | | | | | | |
| Mean Bias | mg/l | -2.26 | -4.19 | -0.29 | 0.42 | 1.41 |
| Mean absolute error (MAE) | mg/l | 2.26 | 4.20 | 0.30 | 0.82 | 1.70 |
| Root mean squared error (RMSE) | mg/l | 2.34 | 5.13 | 0.32 | 1.33 | 2.24 |
| N | - | 144 | 167 | 168 | 168 | 168 |
| Daily | | | | | | |
| Mean Bias | mg/l | -2.26 | -4.21 | -0.29 | 0.42 | 1.41 |
| Mean absolute error (MAE) | mg/l | 2.26 | 4.21 | 0.29 | 0.46 | 1.51 |
| Root mean squared error (RMSE) | mg/l | 2.29 | 4.53 | 0.30 | 0.68 | 2.14 |
| N | - | 6 | 7 | 7 | 7 | 7 |




(a)

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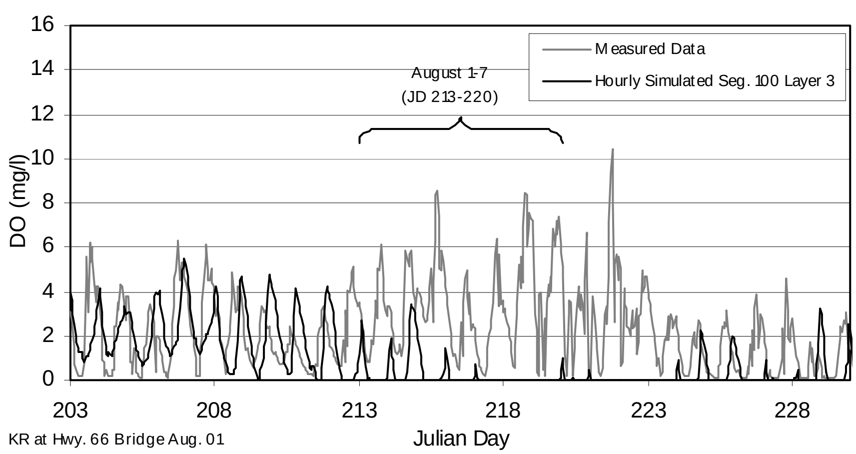
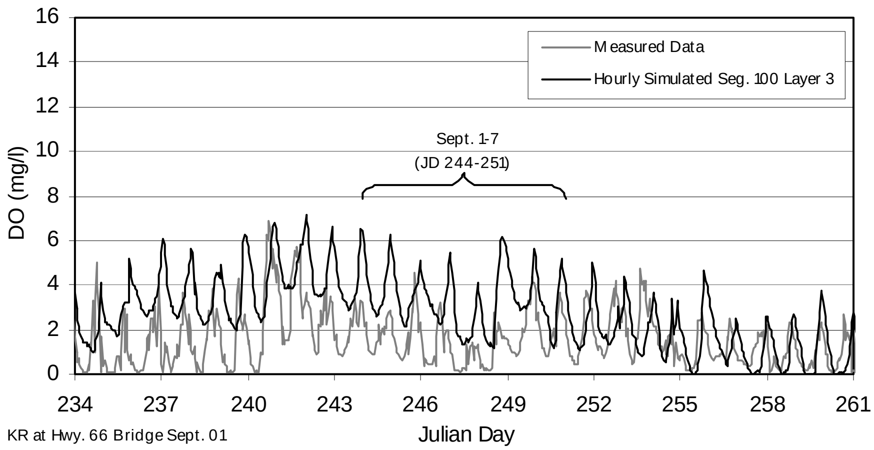
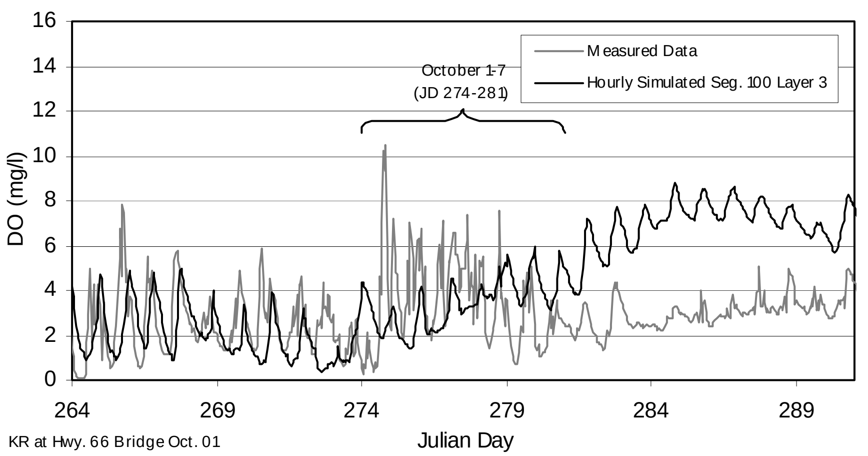



(c)

**Figure 48. Dissolved oxygen simulation for Lake Ewauna to Keno Dam reach: Klamath River at Highway 66 (a) June 1-7, (b) July 1-7, (c) August 1-7, 2001**




(a)




(b)

**Figure 49. Dissolved oxygen simulation for Lake Ewauna to Keno Dam reach: Klamath River at Highway 66 (a) September 1-7, (b) October 1-7, 2001**

**Table 34. Lake Ewauna-Keno Reach hourly and daily period statistics for dissolved oxygen at Highway 66, 2001**

| Statistic | Unit | June 1-7 | July 1-7 | Aug 1-7 | Sept 1-7 | Oct 1-7 |
|---|---|---|---|---|---|---|
| Hourly | | | | | | |
| Mean Bias | mg/l | -1.50 | 1.54 | -0.48 | -0.24 | 3.96 |
| Mean absolute error (MAE) | mg/l | 1.55 | 1.86 | 1.80 | 1.15 | 3.96 |
| Root mean squared error (RMSE) | mg/l | 1.78 | 2.06 | 2.26 | 1.38 | 4.09 |
| N | - | 110 | 132 | 168 | 168 | 168 |
| Daily | | | | | | |
| Mean Bias | mg/l | -1.42 | 1.55 | -0.48 | -0.24 | 3.96 |
| Mean absolute error (MAE) | mg/l | 1.42 | 1.55 | 1.15 | 1.00 | 3.96 |
| Root mean squared error (RMSE) | mg/l | 1.56 | 1.72 | 1.27 | 1.11 | 4.05 |
| N | - | 4 | 4 | 7 | 7 | 7 |

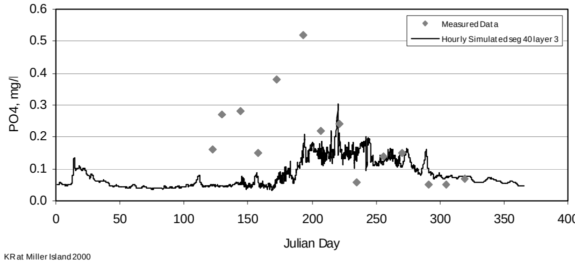
### 3.3.2.3 Nutrients and Phytoplankton

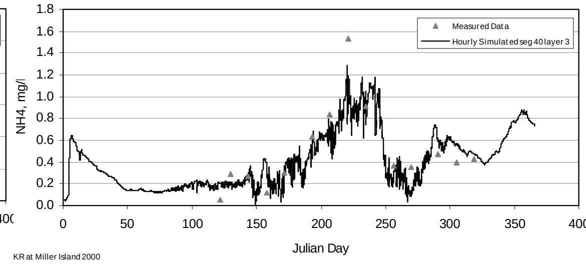
Nutrient concentrations were not formally calibrated in the Lake Ewauna to Keno Dam reach; however, examination of model performance was compared with limited available field data.

As noted previously, the upstream boundary condition at Link Dam plays a critical role in the water quality response of Lake Ewauna/Keno Reservoir during spring through fall periods. Most sampling programs to date have either collected data infrequently (e.g., semi-monthly, monthly, quarterly). A limited amount of daily monitoring was done in 2002 (two periods of three days each). However, observations of data sonde data at Link Dam, Link River at Lake Ewauna, and other downstream locations, as well as the infrequent grab sample data suggest that past monitoring efforts do not sufficiently represent the dynamic water quality conditions present at Link Dam. The transit time through the reservoir during summer periods ranges from approximately 7 to 14 days depending on time of year, local operations, and water year type. Thus monitoring programs that span either a few days or multiple weeks are insufficient to fully characterize the spatial and temporal conditions between Link River and Keno Dam. The monitoring and modeling effort has provided critical insight into the temporal and spatial variability and response of system processes, including thermal, dissolved oxygen, and nutrient conditions. The model has been used to assess variable boundary conditions at Link Dam, Lost River, and Klamath Straits drain and has identified the need for more detailed Link Dam and Lost River inflow water quality conditions.

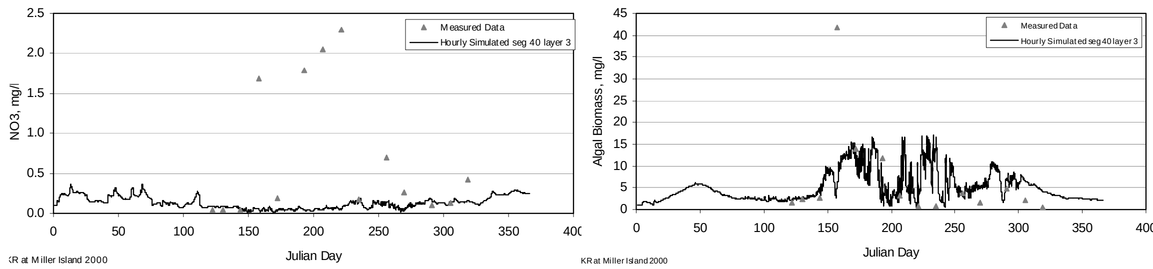
When anoxia occurs within this reach, algal concentrations decline, and a corresponding increase in nutrients occurs. It is apparent from field observations that under anoxia there is decreased phytoplankton present reducing the opportunity of increase oxygen levels through photosynthesis, as well as elevated nutrient levels. Field observations also indicate that pH falls from a range of 8.5 to 9.5 under aerobic conditions to around 7 during periods of severe anoxia (Watercourse, 2003), further indicating the absence of algal production in this weakly buffered system.

The model generally under-predicted orthophosphate during the first part of the season, but was in general agreement after July. Ammonia was well represented throughout the simulation, while nitrate was systematically under predicted. The model over predicted algal biomass, especially in the Keno region. Further model and field studies are planned for 2003 to refine model representation of system conditions in this reach.



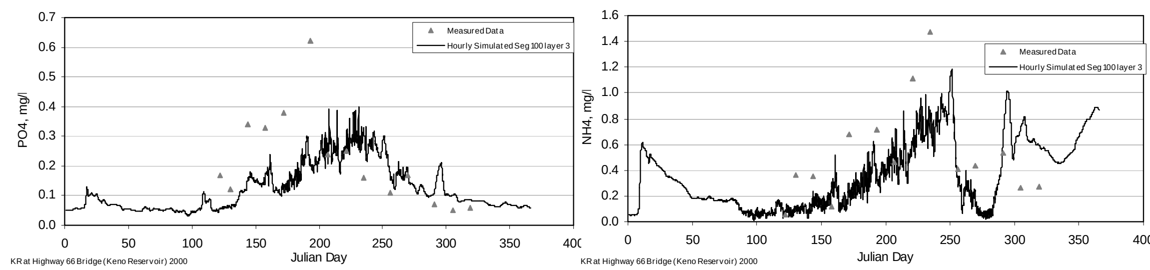



(a) (b)

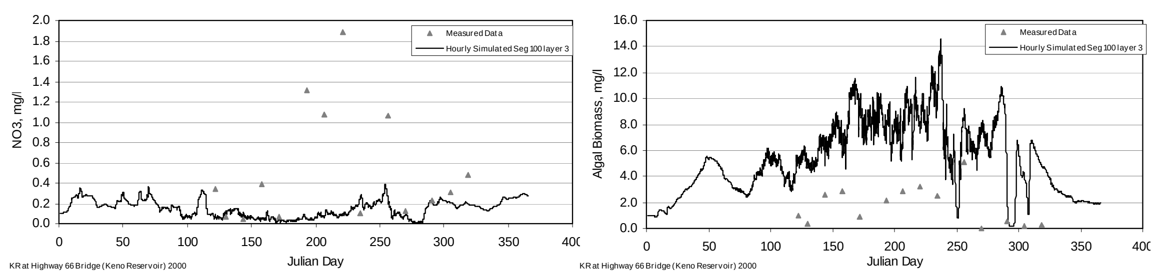



(c) (d)

**Figure 50. Simulated (line) and observed (triangles) nutrients and algal biomass for Klamath River at Miller Island in the Lake Ewauna to Keno Dam reach. (a) phosphate; (b) ammonia; (c) nitrate; (d) algal biomass**




(a) (b)




(c) (d)

**Figure 51. Simulated (line) and observed (triangles) nutrient and algal biomass for Klamath River at Highway 66 bridge in the Lake Ewauna to Keno Dam reach. (a) phosphate; (b) ammonia; (c) nitrate; (d) algal biomass.**

### 3.3.2.4 Summary of Parameters

**Table 35. Significant control file parameters for the Lake Ewauna to Keno Dam reach calibration**

| Parameter Name | Description | EC Lake Ewauna Value | Default Value |
|---|---|---|---|
| DLT MIN | Minimum timestep, sec | 5.0 | N/A |
| DLT MAX | Maximum timestep, sec | 500 | N/A |
| SLOPE | Waterbody bottom slope | 0.0 | N/A |
| LAT | Latitude, degrees | 42.13 | N/A |
| LONG | Longitude, degrees | 121.95 | N/A |
| EBOT | Bottom elevation of waterbody, m | 1236.25 | N/A |
| CFW | C coefficient in the wind speed formulation | 1.0 | 2.0 |
| WINDH | Wind speed measurement height, m | 2.0 | N/A |
| TSED | Sediment (ground) Temperature, C | 12.0 | N/A |
| FI | Interfacial friction factor | 0.04 | N/A |
| TSEDF | Heat lost to sediments that is added back to water column, fraction | 0.01 | N/A |
| EXH2O | Extinction for pure water, $m^{-1}$ | 0.25 | 0.25 (for full WQ sim) |
| CGQ10 (Tracer) | Arhennius temperature rate multiplier | 0 | 0 |
| CG0DK (Tracer) | 0-order decay rate, 1/day | 0 | 0 |
| CG1DK (Tracer) | $1^{st}$-order decay rate, 1/day | 0 | 0 |
| CGS (Tracer) | Settling rate, m/day | 0 | 0 |
| CGQ10 (Age) | Arhennius temperature rate multiplier | 0 | 0 |
| CG0DK (Age) | 0-order decay rate, 1/day | -1.0 | -1.0 |
| CG1DK (Age) | $1^{st}$-order decay rate, 1/day | 0 | 0 |
| CGS (Age) | Settling rate, m/day | 0 | 0 |
| CGQ10 (Coliform) | Arhennius temperature rate multiplier | 1.04 | N/A |
| CG0DK (Coliform) | 0-order decay rate, 1/day | 0 | N/A |
| CG1DK (Coliform) | $1^{st}$-order decay rate, 1/day | 1.4 | N/A |
| CGS (Coliform) | Settling rate, m/day | 1.0 | N/A |
| AG | Maximum algal growth rate, 1/day | 3.0 | 2.0 |
| AR | Maximum algal respiration rate, 1/day | 0.05 | 0.04 |
| ASAT | Light saturation intensity at a maximum photosynthetic rate, $W/m^2$ | 100.0 | 75.0 |
| AT1 | Lower temperature for algal growth, C | 5.0 | 5.0 |
| PO4R | Sediment release rate of phosphorus, fraction of SOD | 0.03 | 0.001 |
| PARTP | Phosphorus partitioning coefficient for suspended solids | 0.001 | 0.0 |
| NH4REL | Sediment release rate of ammonium, fraction of SOD | 0.07 | 0.001 |
| NH4DK | Ammonium decay rate, 1/day | 0.1 | 0.12 |
| NO3DK | Nitrate decay rate, 1/day | 0.1 | 0.03 |
| NO3S | De-nitrification rate from sediments, m/day | 0 | 1.0 |
| CO2REL | Sediment carbon dioxide release rate, fraction of SOD | 0.01 | 0.1 |
| O2AR | Oxygen stoichiometry for algal respiration | 1.4 | 1.1 |
| O2AG | Oxygen stoichiometry for algal primary production | 1.5 | 1.4 |
| SOD | Zero-order sediment oxygen demand for each segment, $g\ O_2 / m^2 day$ | 2.0 (for each segment) | N/A |

# *3.4 Keno Reach*

The Keno reach extends from Keno Dam to the headwaters of J.C. Boyle Reservoir, a distance of about 5.4 miles. The RMA suite of models for the Klamath River Keno reach was calibrated and validated using data from the periods of May 21-23, 2002 and September 10-12, 2002, respectively.

## 3.4.1 Data

Water quality conditions of water flowing into the reach (boundary conditions), initial status of the system (initial conditions), and observations in the Klamath River above J.C. Boyle were required (calibration/validation points). There were no intermediate locations within this short reach that required inflow for outflow boundary condition or that were used for calibration and validation.

### 3.4.1.1 Boundary Conditions

The boundary condition data was derived from samples collected at Keno Dam and Highway 66. Hourly water temperature and dissolved oxygen data were available from water quality probes deployed by the US Bureau of Reclamation at Highway 66 near Keno. Grab samples were collected once per day for three days below Keno Dam. Due to the inherent variability and infrequent sampling interval of the grab data, the boundary condition values for nutrients, BOD, and algae were assumed to be a constant value for the calibration and validation period, based on the grab sample data from 2002 (Appendix F). The water quality values for the calibration and validation period are shown in Table 22 and Figure 21 and Figure 22.

**Table 36. Keno Dam to J.C. Boyle Reservoir, Klamath River reach calibration and validation water quality boundary conditions**

| Parameter | Units | Dates | |
|---|---|---|---|
| | | 5/21/02 - 5/23/02 | 9/10/02 – 9/12/02 |
| BOD | mg/l | 3.0 | 5.0 |
| DO | mg/l | variable | variable |
| Org N | mg/l | 0.80 | 1.50 |
| $NH_4^+$ | mg/l | 0.10 | 0.15 |
| $NO_2^-$ | mg/l | 0.00 | 0.00 |
| $NO_3^-$ | mg/l | 0.10 | 0.20 |
| Org P | mg/l | 0.30 | 0.05 |
| $PO_4^{3-}$ | mg/l | 0.20 | 0.20 |
| Algae | mg/l | 2.0 | 4.2 |
| Tw | °C | variable | variable |

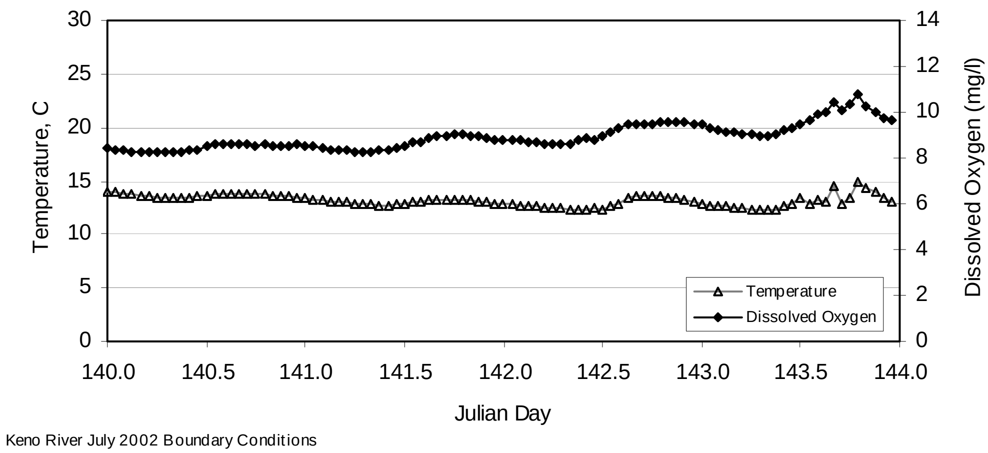



**Figure 52. Keno Dam temperature and dissolved oxygen calibration boundary conditions**

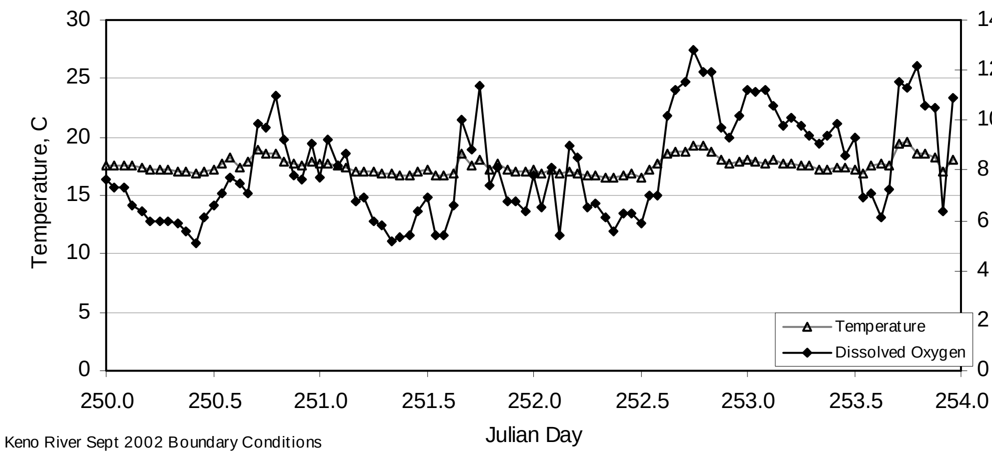



**Figure 53. Keno Dam temperature and dissolved oxygen validation boundary conditions**

### 3.4.1.2 Initial conditions

The model was run for one day prior to both the calibration and validation periods to provide an initial condition for simulation. The initial bed algae mass was estimated at 5 $g/m^2$.

### 3.4.1.3 Calibration and Validation Points

The calibration and validation point for the Keno reach was Klamath River above J.C. Boyle Reservoir. During May and July water quality probes and tidbit temperature devices were employed to represent conditions above J.C. Boyle Reservoir. These data are displayed in the following section with model results.

## 3.4.2 Results

Calibration and validation were completed for temperature and dissolved oxygen as primary constituents and inorganic nutrient forms (ammonia, nitrate, orthophosphate) as secondary constituents. Field observations for temperature and dissolved oxygen were typically available from water quality probes on an hourly interval, allowing for summary statistics to be calculated both on an hourly and daily basis. The exception is validation during the September period: grab sample temperatures and dissolved oxygen data were available, but the sonde deployed during the data gathering effort malfunctioned and hourly data were not available. The nutrient data were primarily derived from field data, which were sampled once per day. All model parameters for the Keno reach are summarized in Table 39 at the end of this section.

#### 3.4.2.1 Water Temperature

Water temperature calibration required varying evaporation heat flux coefficients (presented in Table 39) that govern the mass transfer formulation represented in the numerical model heat budget. No other parameters were varied. The hourly results are presented graphically in Figure 54 through Figure 56. Summary statistics are included in Table 37. The diurnal range and phase is well represented for spring temperatures in the neighborhood of 12°C-15°C. Limited data for the September period late summer period was available for temperature. To further test the model available data from mid-July were used to test the model. Phase and diurnal range are well represented under conditions when observations conditions exceeded 25°C. Hourly bias for the July simulation was –0.19°C with a mean absolute error of 0.54°C. Tabulated statistics (Table 37) illustrate that simulated results on an hourly and daily basis are within 1°C of observations.

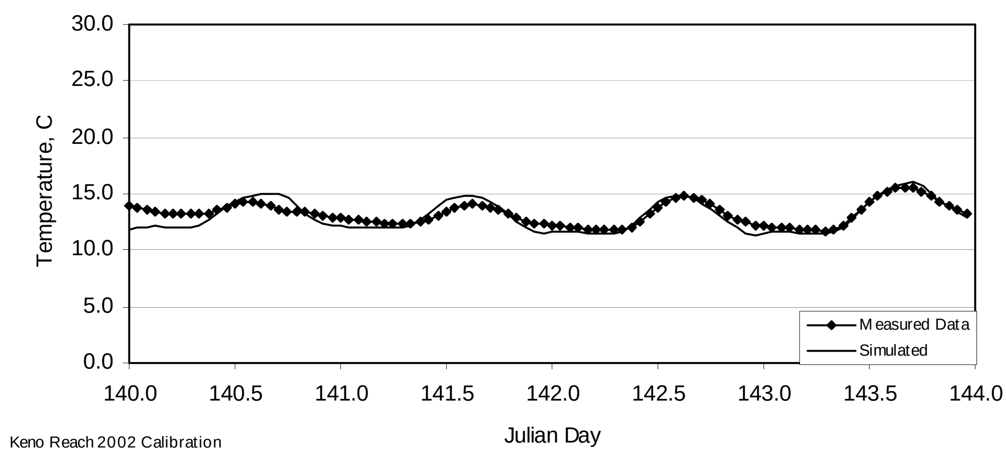



**Figure 54. Klamath River, Keno to J.C. Boyle, simulated versus measured water temperature, May 20-23, 2002**

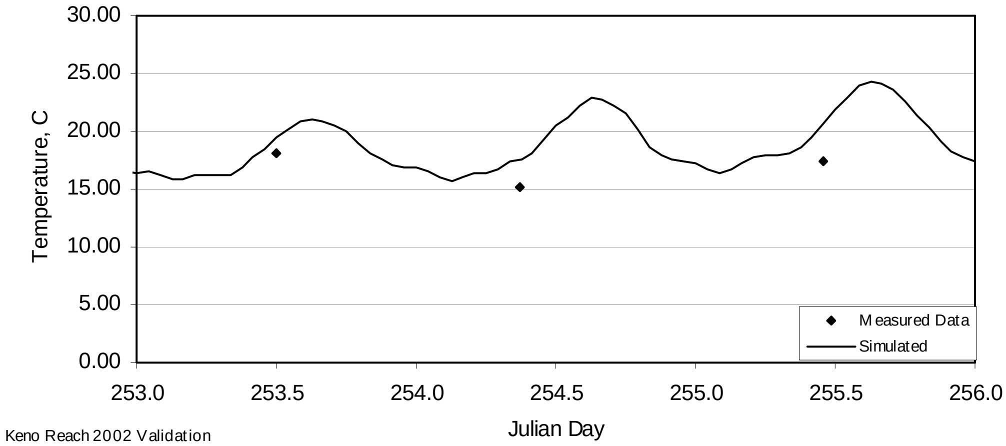



**Figure 55. Klamath River, Keno to J.C. Boyle, simulated versus measured water temperature, September 10-12, 2002**

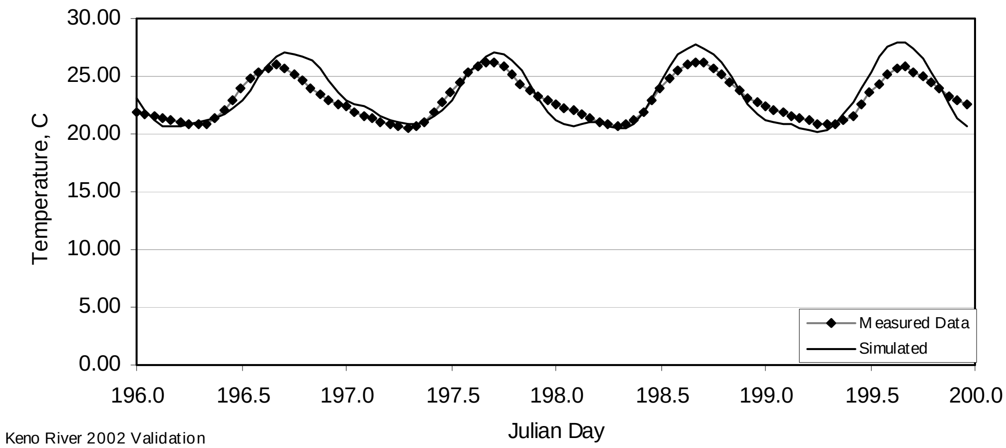



**Figure 56. Klamath River, Keno to J.C. Boyle, simulated versus measured water temperature, July 14-17, 2002**

**Table 37. Klamath River, Keno to J.C. Boyle, hourly and daily calibration and validation period statistics for temperature**

| Calibration / Validation Statistics | | Hourly | | Daily | |
|---|---|---|---|---|---|
| | Unit | Calib. | Valid. | Calib. | Valid. |
| Mean Bias[a] | °C | -0.19 | n/a | -0.17 | n/a |
| Mean absolute error (MAE) | °C | 0.54 | n/a | 0.17 | n/a |
| Root mean squared error (RMSE) | °C | 0.68 | n/a | 0.23 | n/a |
| n | - | 96 | n/a | 4 | n/a |

[a] Mean bias = simulated – measured

### 3.4.2.2 Dissolved Oxygen

Dissolved oxygen calibration required varying several parameters, including but not limited to algal growth rates, and respiration rates, organic and inorganic nutrient decay rates, and temperature constants for rate reactions. Both phytoplankton and benthic algae were modeled in river reaches. To represent the adverse environment a river imposes on phytoplankton that are washed in from upstream of Keno Dam, growth rates for plankton were set to very low numbers in river reaches.

The hourly results are presented graphically in Figure 57 and Figure 58. Field observations suggest a moderated diurnal range in this reach, and the model replicates these conditions as well as overall magnitude of dissolved oxygen concentrations. The hourly bias of –0.46 mg/l and the mean absolute error of 0.50 mg/l presented in Table 38 illustrate that simulated results on an hourly and daily basis are within about 1 mg/l of observed values.

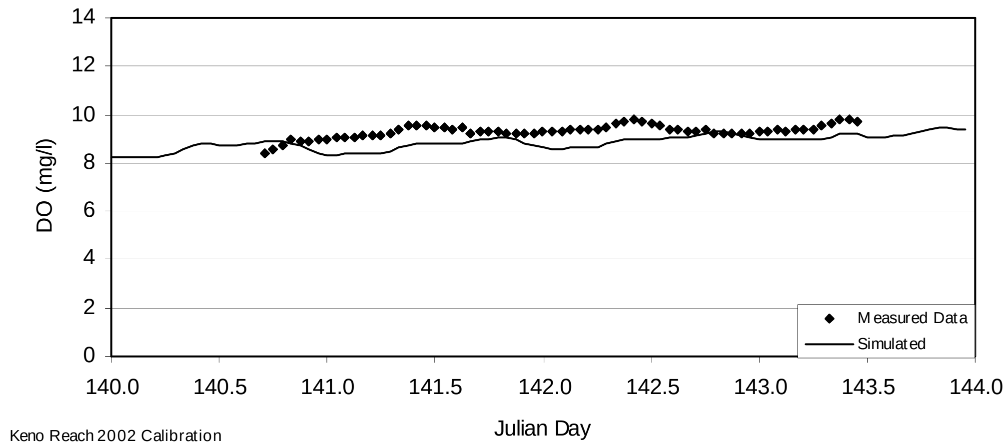



**Figure 57. Klamath River, Keno to J.C. Boyle, simulated versus measured dissolved oxygen, May 20-23, 2002**

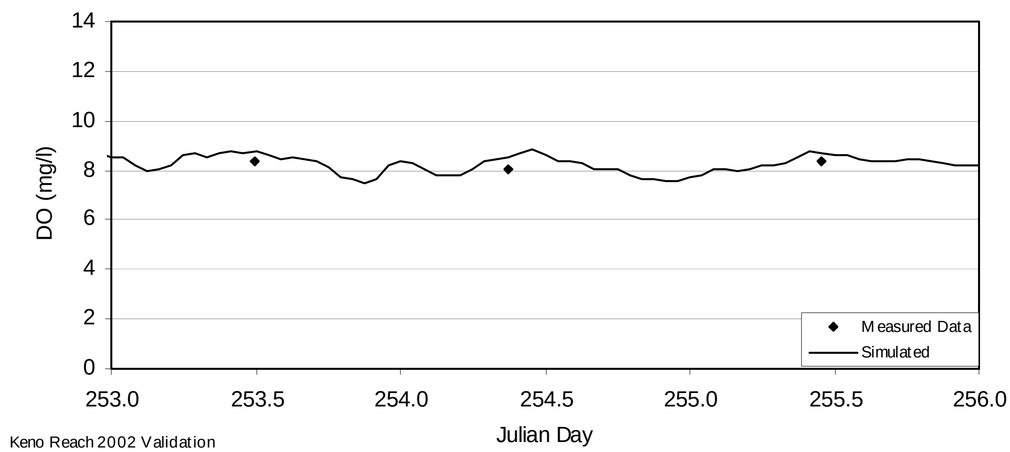



**Figure 58. Klamath River, Keno to J.C. Boyle, simulated versus measured dissolved oxygen, September 10-12, 2002**

**Table 38. Klamath River, Keno to J.C. Boyle, hourly and daily calibration and validation period statistics for dissolved oxygen**

| Calibration / Validation Statistics | Unit | Hourly Calib. | Hourly Valid. | Daily Calib. | Daily Valid. |
|---|---|---|---|---|---|
| Mean Bias[a] | mg/l | -0.46 | n/a | -0.47 | n/a |
| Mean absolute error (MAE) | mg/l | 0.50 | n/a | 0.47 | n/a |
| Root mean squared error (RMSE) | mg/l | 0.55 | n/a | 0.48 | n/a |
| n | - | 67 | n/a | 3 | n/a |

[a] Mean bias = simulated – measured

### 3.4.2.3 Nutrients

Nutrient concentrations were not formally calibrated in the Keno reach. That is, values for nutrient interactions (e.g., stoichiometric equivalence with regard to primary production, decay rates and temperature rate constants) identified in the dissolved oxygen calibration were not modified further, and other parameters were set at default values. The results are presented graphically in Figure 59 through Figure 64. Simulated concentrations for ammonia, nitrate, and orthophosphate were consistent with field observations. There is some scatter in the observed data that is not replicated within the model. Because upstream boundary conditions were maintained at constant values for these simulations, such results in a short reach are not unexpected.

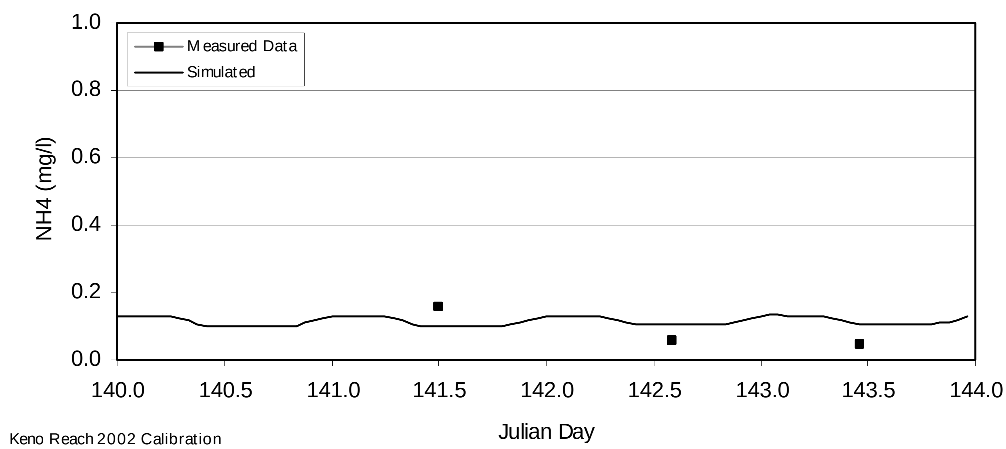



**Figure 59. Klamath River, Keno to J.C. Boyle, simulated versus measured ammonia, May 20-23, 2002**

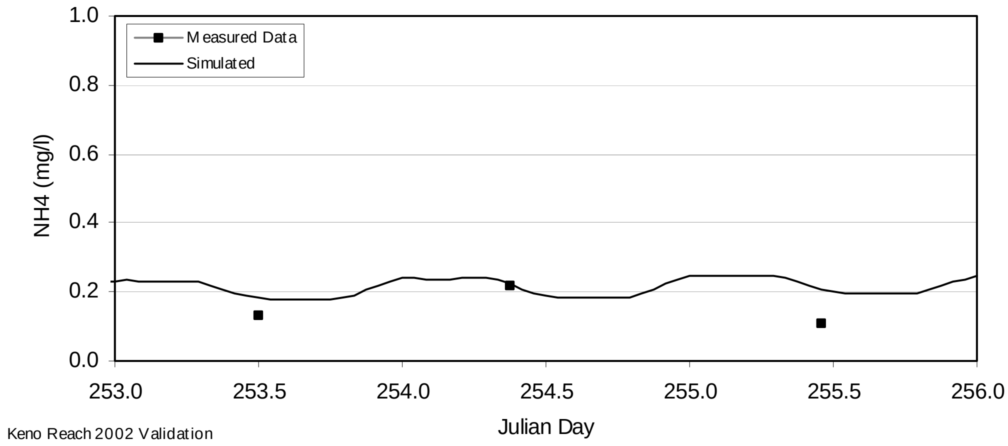



**Figure 60. Klamath River, Keno to J.C. Boyle, simulated versus measured ammonia, September 10-12, 2002**

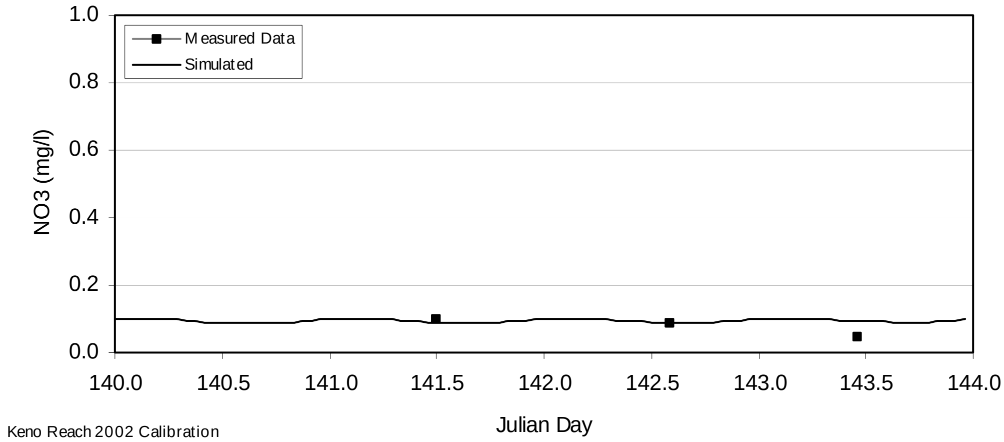



**Figure 61. Klamath River, Keno to J.C. Boyle, simulated versus measured nitrate, May 20-23, 2002**

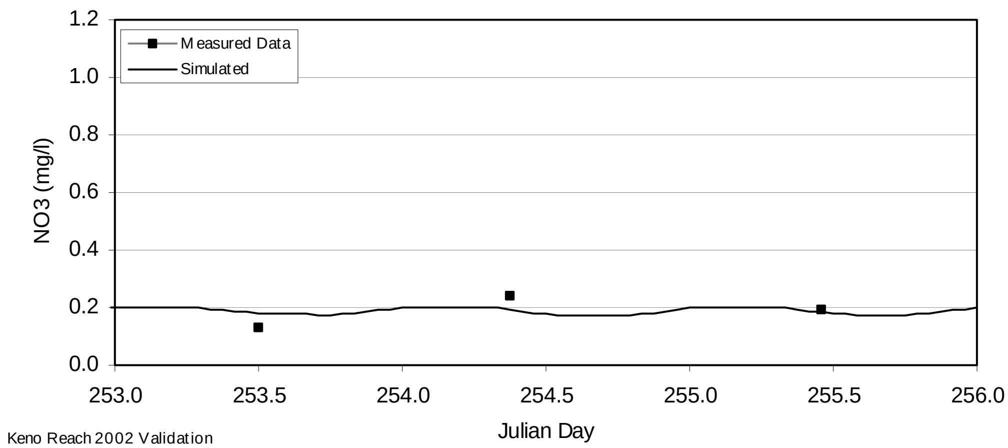


**Figure 62. Klamath River, Keno to J.C. Boyle, simulated versus measured nitrate, September 10-12, 2002**

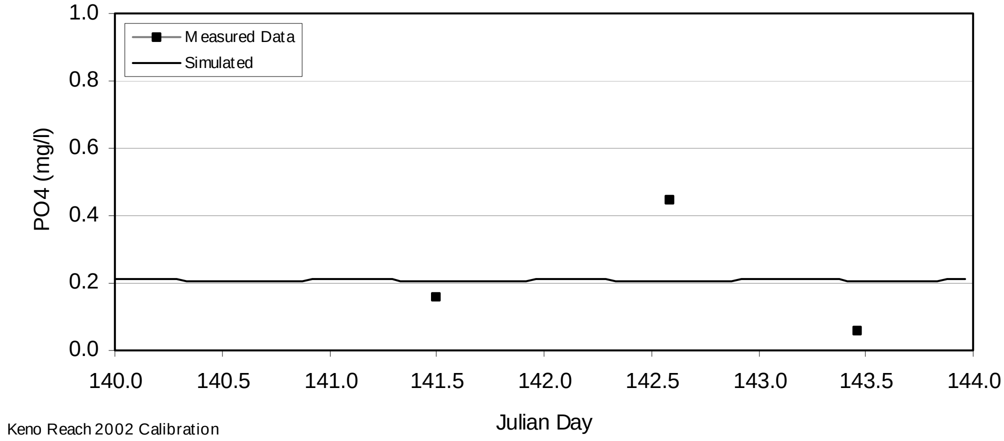



**Figure 63. Klamath River, Keno to J.C. Boyle, simulated versus measured orthophosphate, May 20-23, 2002**

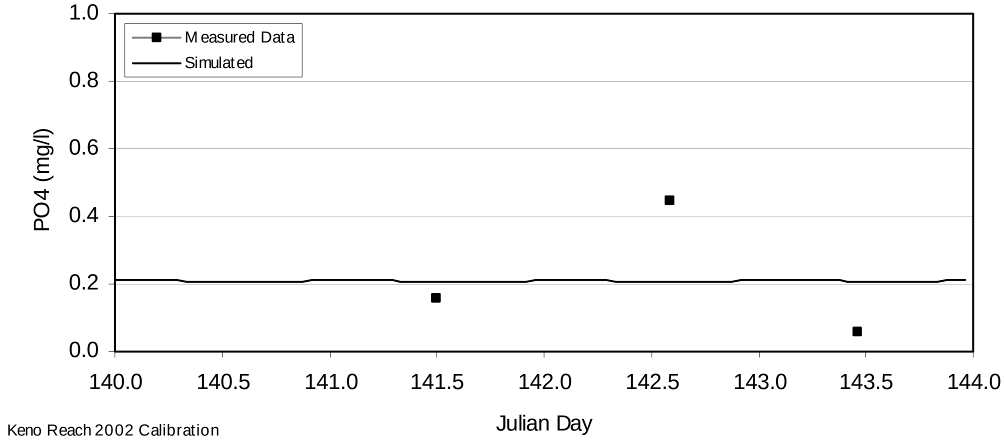



**Figure 64. Klamath River, Keno to J.C. Boyle, simulated versus measured orthophosphate, September 10-12, 2002**

### 3.4.2.4 Summary of Parameters

**Table 39. RMA-2 and RMA-11 Model , rates, coefficients, constants for the Keno reach**

| Variable Name | Description, units | Value |
|---|---|---|
| | Time step, hr | 1.0 |
| | Space step, m | 75 |
| | Manning roughness coefficient | 0.04 |
| | Turbulence factor, Pascal-sec | 100 |
| | Longitudinal diffusion scale factor | 0.10 |
| | Slope Factor | 0.90 |
| ELEV | Elevation of site, m | 1192 |
| LAT | Latitude of site, degrees | 41.5 |
| LONG | Longitude of site, degrees | 122.45 |
| EVAPA | Evaporative heat flux coefficient a, m $hr^{-1}$ $mb^{-1}$ | 0.000015 |
| EVAPB | Evaporative heat flux coefficient b, m $hr^{-1}$ $mb^{-1}$ $(m/h)^{-1}$ | 0.000010 |
| EXTINC | Light Extinction coefficient, used when algae is not simulated, 1/m | 1.5 |
| ALP0 | Chl *a* to algal biomass conversion factor, phytoplankton, mgChl_a to mg-A | 67 |
| ALP1 | Fraction of algal biomass that is nitrogen, phytoplankton, mg-N/mg A | 0.072 |
| ALP2 | Fraction of algal biomass that is phosphorous, phytoplankton, mg-P/mg A | 0.010 |
| LAMB1 | Linear algal self-shading coefficient, phytoplankton, 1/m | n/a |
| LAMB2 | Non-linear algal self shading coefficient, phytoplankton, 1/m | n/a |
| MUMAX | Maximum specific growth rate, phytoplankton, 1/d | 0.01 |
| RESP | Local respiration rate of algae, phytoplankton, 1/d | 0.05 |
| SIG1 | Settling rate of algae, phytoplankton, 1/d | 0.0 |
| KLIGHT | Half saturation coefficient for light, phytoplankton, KJ $m^{-2}$ $s^{-1}$ | 0.01 |
| KNITR | Michaelis-Menton half saturation constant: nitrogen, phytoplankton, mg/l | 0.01 |
| KPHOS | Michaelis-Menton half saturation constant: phosphorous, phytoplankton, mg/l | 0.001 |
| PREFN | Preference factor for NH3-N, phytoplankton | 0.6 |
| ABLP0 | Chl a to algal biomass conversion factor, bed algae, mgChl_a to mg-A | 50 |
| ABLP1 | Fraction of algal biomass that is nitrogen, bed algae, mg/l | 0.07 |
| ABLP2 | Fraction of algal biomass that is phosphorus, bed algae, mg/l | 0.01 |
| LAMB1 | Linear algal self shading coefficient, bed algae, 1/m | n/a |
| LAMB2 | Non-linear self shading coefficient, bed algae, 1/m | n/a |
| MUMAX | Maximum specific growth rate, bed algae, 1/d | 1.0 |
| RESP | Local respiration rate of algae, bed algae, 1/d | 0.60 |
| MORT | Mortality, bed algae, 1/d | 0.0 |
| KBNITR | Half-saturation coefficient for nitrogen, bed algae, mg/l | 0.01 |
| KBPHOS | Half-saturation coefficient for phosphorus, bed algae, mg/l | 0.002 |
| KBLIGHT | Half-saturation coefficient for light, bed algae, KJ $m^{-2}$ $s^{-1}$ | 0.01 |
| PBREFN | Preference factor for NH3-N, bed algae | 0.75 |
| BET1 | Rate constant: biological oxidation NH3-N, 1/d | 0.3 |
| BET2 | Rate constant: biological oxidation NO2-N, 1/d | 0.5 |
| BET3 | Rate constant: hydrolysis Org N to NH3-N, 1/d | 0.3 |
| BET4 | Rate constant: transformation Org P to P-D, 1/d | 0.3 |
| KNINH | First order nitrification inhibition coefficient, $mg^{-1}$ | n/a |
| ALP3 | Rate $O_2$ production per unit of algal photosynthesis, phytoplankton, mg-O/mg-A | 1.6 |
| ALP4 | Rate $O_2$ uptake per unit of algae respired, phytoplankton, mg-O/mg-A | 1.6 |
| ABLP3 | Rate $O_2$ production per unit of algal photosynthesis, bed algae, mg-O/mg-A | 1.6 |
| ABLP4 | Rate $O_2$ uptake per unit of algae respired, bed algae, mg-O/mg-A | 1.6 |
| ALP5 | Rate $O_2$ uptake per unit NH3-N oxidation, mg-O/mg-N | 3.43 |
| ALP6 | Rate $O_2$ uptake per unit NO2-N oxidation, mg-O/mg-N | 1.14 |
| K1 | Deoxygenation rate constant: BOD, 1/d | 0.3 |
| - | Minimum reaeration rate constant (Churchill formula applied), 1/d | 3.0 |
| SIG6 | BOD settling rate constant, 1/d | 0.0 |

n/a – not applicable

## 3.5 J.C. Boyle Reservoir

The CE-QUAL-W2 model of J.C. Boyle Reservoir was calibrated for 2000. Although the reservoir has a relatively short residence time and could be calibrated and validated using two periods within a single year, it is proposed to continue testing the model on an independent year for validation. The primary calibration data are monthly profiles and a second year of analysis will provide additional data. Although this reach has not been formally validated, it has been represented under various levels of spatial discretization in CE-QUAL-W2 and results compared with the application of the one-dimensional model WQRRS. Thus, although it is a work in progress, there is a good level of confidence in model results.

Water temperature, dissolved oxygen, and nutrient (phosphorous and nitrogen) data were collected during field season 2000 just upstream from the dam to support the modeling task (additional profiles were collected in the vicinity of the Highway 66 bridge and conditions were found to be similar to those near the dam).

### 3.5.1 Data

Water quality conditions of water flowing into the reach (boundary conditions), initial status of the system (initial conditions), and intermediate points within the main stem (calibration/validation points) were required.

#### 3.5.1.1 Boundary Conditions

Because no upstream data were available, the upstream boundary conditions were derived from simulated output using the calibrated Keno reach model. Hourly inflow and outflow from J.C. Boyle Reservoir were used, thus peaking operations at J.C. Boyle Powerhouse were reflected in the operations. The accretion / depletion boundary conditions were those defined in model implementation of J.C. Boyle Reservoir.

#### 3.5.1.2 Initial conditions

Initial conditions for the J.C. Boyle Reservoir were assumed to wash out within the first few days of January, due to the short residence time and isothermal conditions of the reservoir.

### 3.5.2 Results

Calibration was completed for temperature and dissolved oxygen as primary constituents and inorganic nutrient forms (ammonia, nitrate, orthophosphate) as secondary constituents. Field observations for temperature and dissolved oxygen were typically available from monthly profiles. The nutrient data were primarily derived from field data, which were typically sampled once per month at two depths within the reservoir. All model parameters for the J.C. Boyle Reservoir reach are summarized in Table 42 at the end of this section.

#### 3.5.2.1 Water Temperature

The water temperature was calibrated using the three user specified wind evaporation coefficients available in CE-QUAL-W2. Results are shown in Figure 65 and summary statistics are included in Table 40. J.C. Boyle Reservoir experiences weak, intermittent stratification. The model does replicate this to some degree. The profile bias ranged from 0.03°C to –1.46°C and the mean absolute error ranged from 0.21°C to 1.46°C. Overall the model is within about 1.5°C of observations. Because J.C. Boyle Reservoir residence time is on the order of a day or two, water temperature is strongly influenced by the temperature of river inflows.

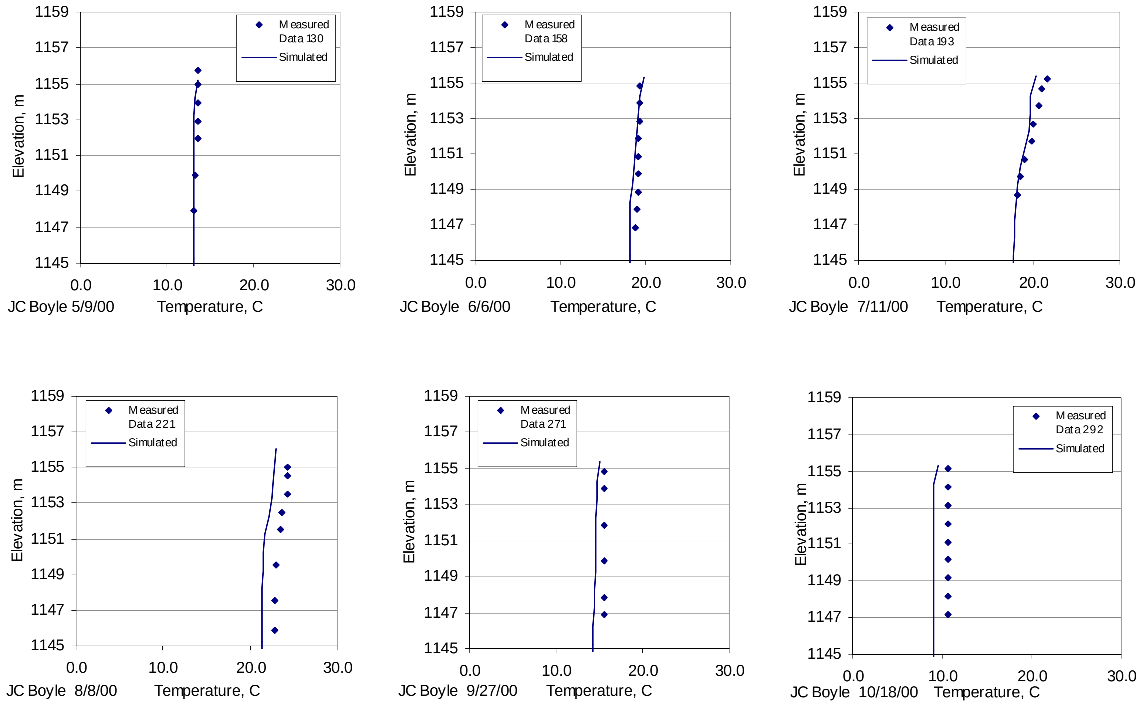



**Figure 65. J.C. Boyle Reservoir thermal profiles, simulated versus measured monthly values: 2000**

**Table 40. J.C. Boyle Reservoir thermal profile summary statistics: simulated versus measured**

| Date | Mean Bias[a] (˚C) | Mean Absolute Error (˚C) | Root Mean Squared Error (˚C) | n |
|---|---|---|---|---|
| April 12, 2000 | -2.44 | 2.44 | 2.45 | 8 |
| May 9, 2000 | -0.29 | 0.29 | 0.34 | 6 |
| June 6, 2000 | -0.41 | 0.47 | 0.54 | 9 |
| July 11, 2000 | -0.63 | 0.63 | 0.79 | 8 |
| August 8, 2000 | -1.53 | 1.53 | 1.54 | 8 |
| September 28, 2000 | -0.94 | 0.94 | 0.97 | 6 |
| October 18, 2000 | -1.55 | 1.55 | 1.56 | 9 |

[a] Mean bias = simulated – measured

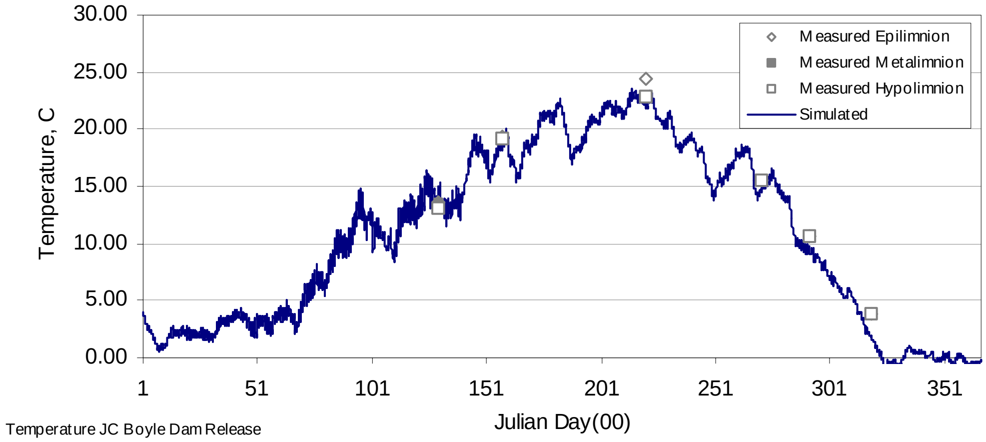



**Figure 66. J.C. Boyle Reservoir simulated release temperatures compared with in-pool grab samples near J.C. Boyle Dam**

### 3.5.2.2 Dissolved Oxygen

The dissolved oxygen was calibrated by varying several different parameters, including algal rates, organic matter decay rates and nutrient decay rates. Also zero order SOD was employed in calibrating dissolved oxygen.

Results are shown in Figure 67 and summary statistics are included in Table 41. The profile bias ranged from –1.87 mg/l to 3.75 mg/l while the mean absolute error ranged from 0.30 mg/l to 3.75 mg/l. The model performed well through about mid-June. Thereafter, dissolved oxygen concentrations were over predicted in surface waters. Simulated dissolved oxygen concentration in J.C. Boyle release is compared with in-pool grab samples in Figure 68. Because the reservoir is only weakly stratified and has a short residence time, boundary conditions can play an important role in model performance. Additional simulations using data from subsequent years are planned to improve model representation and to provide a validation step.

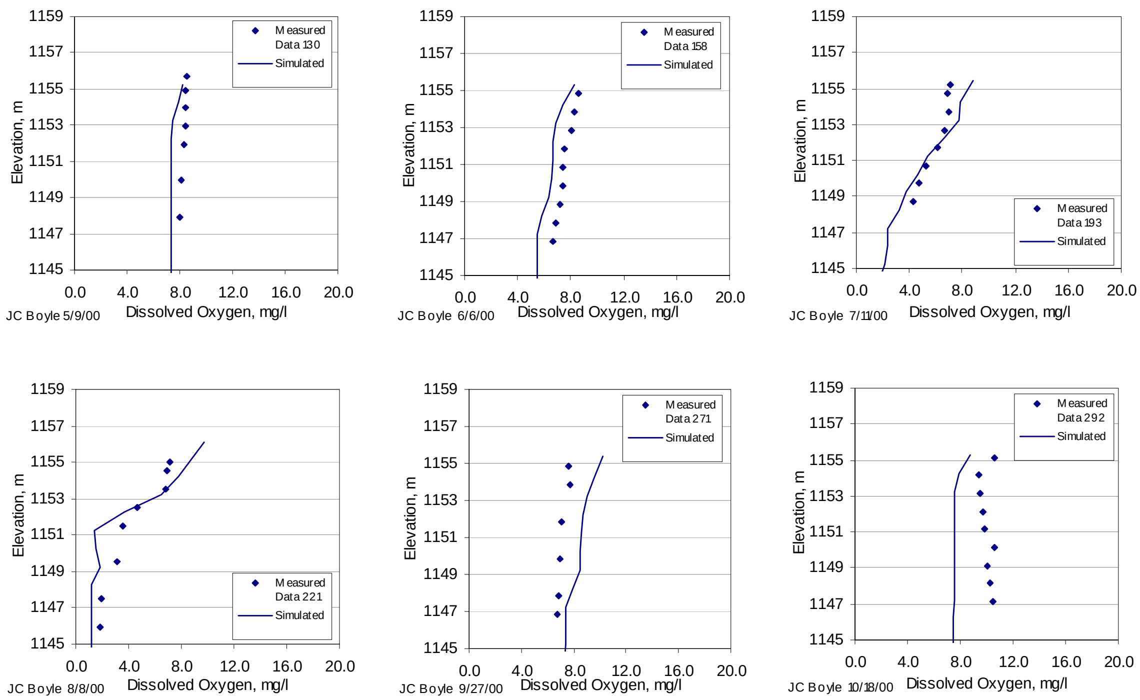



**Figure 67. J.C. Boyle Reservoir dissolved oxygen profiles, simulated versus measured monthly values: 2000**

**Table 41. J.C. Boyle Reservoir dissolved oxygen profile summary statistics: simulated versus measured.**

| Date | Mean Bias[a] (mg/l) | Mean Absolute Error (mg/l) | Root Mean Squared Error (mg/l) | n |
|---|---|---|---|---|
| April 12, 2000 | 0.54 | 0.54 | 0.57 | 8 |
| May 9, 2000 | -0.74 | 0.74 | 0.78 | 6 |
| June 6, 2000 | -1.01 | 1.01 | 1.03 | 9 |
| July 11, 2000 | 0.29 | 0.74 | 0.88 | 8 |
| August 8, 2000 | -0.27 | 0.90 | 1.06 | 8 |
| September 28, 2000 | 1.47 | 1.47 | 1.57 | 6 |
| October 18, 2000 | -2.33 | 2.33 | 2.38 | 9 |

[a] Mean bias = simulated – measured

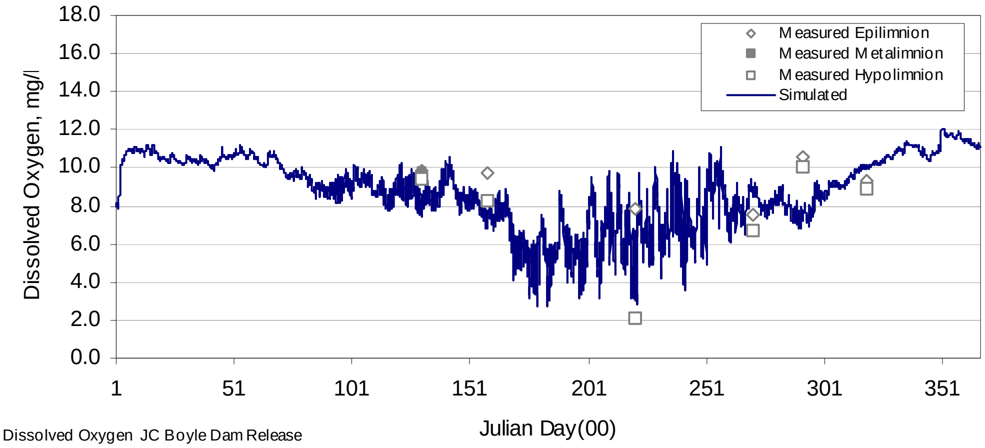



**Figure 68. J.C. Boyle Reservoir simulated release dissolved oxygen concentration compared with in-pool grab samples near J.C. Boyle Dam**

### 3.5.2.3 Nutrients

Nutrient concentrations were not actively calibrated in the J.C. Boyle Reservoir reach. That is, values for nutrient interactions (e.g., stoichiometric equivalence with regard to primary production, decay rates and temperature rate constants) identified in the DO calibration were not modified, and other parameters were set at default values. Results are presented for orthophosphate, ammonia, nitrate, and chlorophyll a (algae) in Figure 69 through Figure 71, respectively. These results, similar to dissolved oxygen, are impacted by the assumed upstream boundary condition. Additional simulations planned using data from subsequent years to improve model representation.

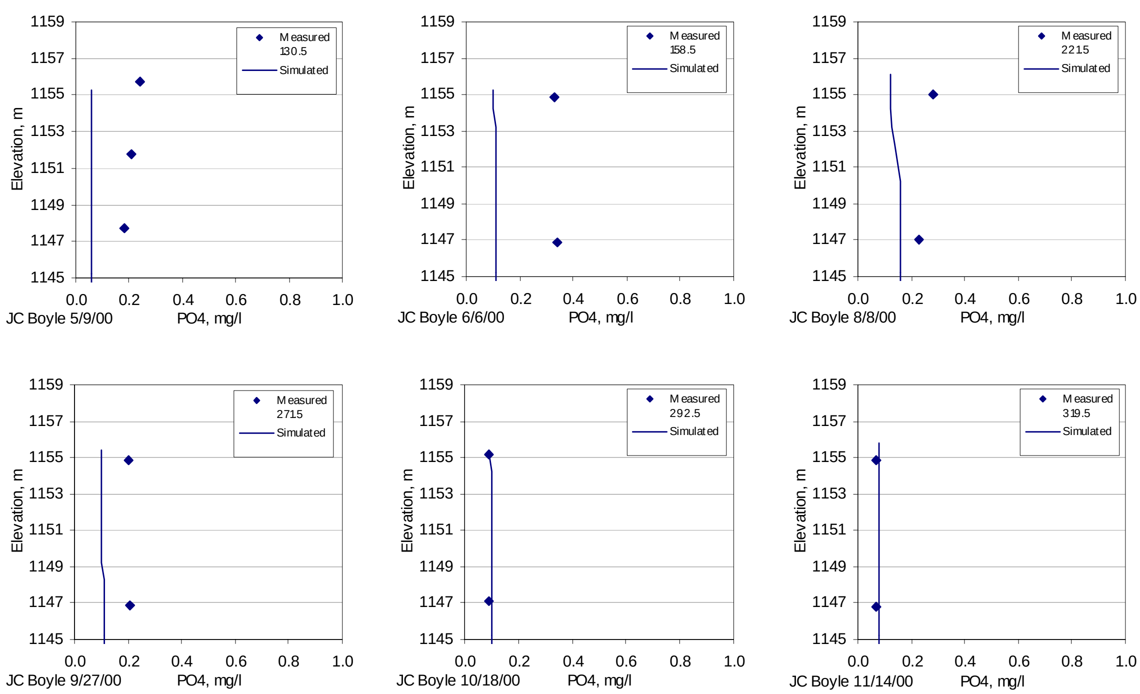


**Figure 69. J.C. Boyle Reservoir orthophosphate profiles, simulated versus measured monthly values: 2000**

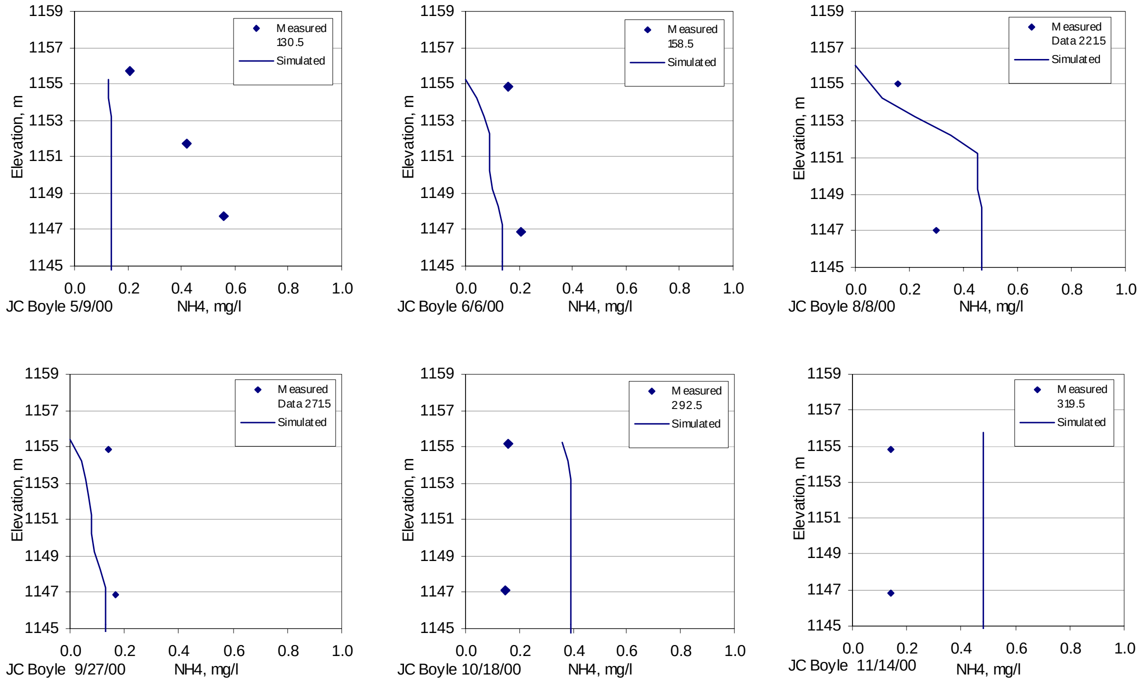



**Figure 70. J.C. Boyle Reservoir ammonia profiles, simulated versus measured monthly values: 2000**

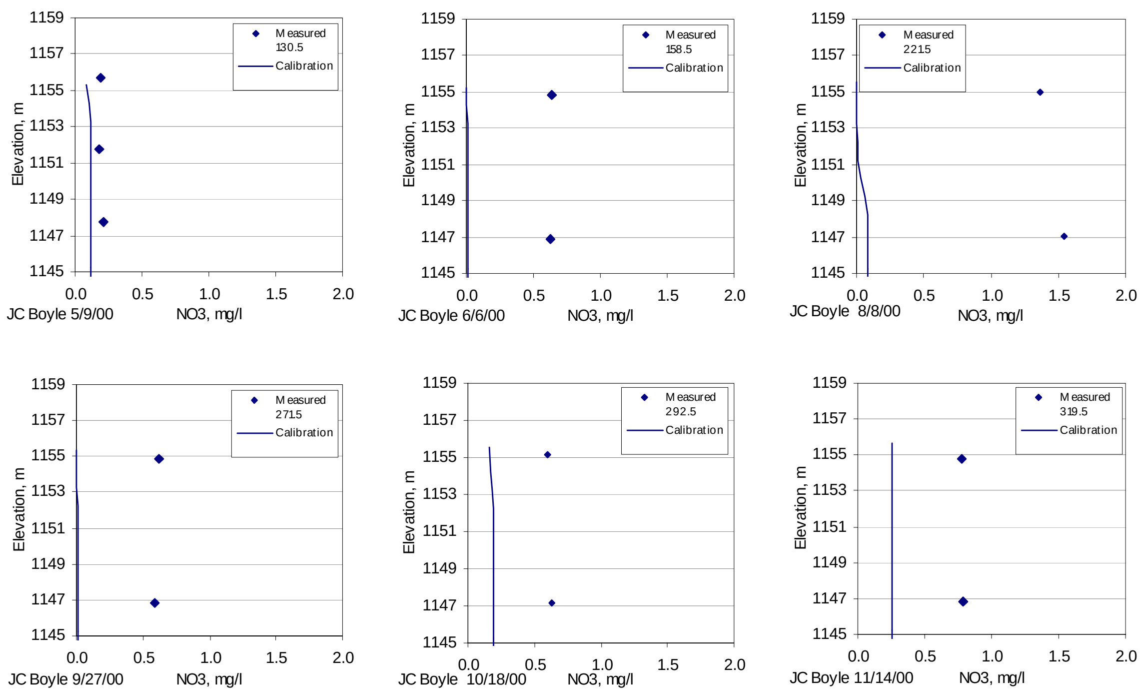



**Figure 71. J.C. Boyle Reservoir nitrate profiles, simulated versus measured monthly values: 2000**

### 3.5.2.4 Summary of Parameters

**Table 42. Significant control file parameter values for the J.C. Boyle Reservoir EC simulation**

| Parameter Name | Description | EC J.C. Boyle Value | Default Values |
|---|---|---|---|
| DLT MIN | Minimum timestep, sec | 5.0 | N/A |
| DLT MAX | Maximum timestep, sec | 500 | N/A |
| SLOPE | Waterbody bottom slope | 0.0 | N/A |
| LAT | Latitude, degrees | 42.12 | N/A |
| LONG | Longitude, degrees | 122.05 | N/A |
| EBOT | Bottom elevation of waterbody, m | 1143.75 | N/A |
| AFW | A coefficient in the wind speed formulation | 18.0 | 9.2 |
| WINDH | Wind speed measurement height, m | 2.0 | N/A |
| TSED | Sediment (ground) temperature, C | 12.0 | N/A |
| FI | Interfacial friction factor | 0.04 | N/A |
| TSEDF | Heat lost to sediments that is added back to water column, fraction | 0.01 | N/A |
| EXH20 | Extinction for pure water, $m^{-1}$ | 0.25 | 0.25 (for full WQ sim) |
| CGQ10 (Tracer) | Arhennius temperature rate multiplier | 0 | 0 |
| CG0DK (Tracer) | 0-order decay rate, 1/day | 0 | 0 |
| CG1DK (Tracer) | $1^{st}$-order decay rate, 1/day | 0 | 0 |
| CGS (Tracer) | Settling rate, m/day | 0 | 0 |
| CGQ10 (Age) | Arhennius temperature rate multiplier | 0 | 0 |
| CG0DK (Age) | 0-order decay rate, 1/day | -1.0 | -1.0 |
| CG1DK (Age) | $1^{st}$-order decay rate, 1/day | 0 | 0 |
| CGS (Age) | Settling rate, m/day | 0 | 0 |
| CGQ10 (Coliform) | Arhennius temperature rate multiplier | 1.04 | N/A |
| CG0DK (Coliform) | 0-order decay rate, 1/day | 0 | N/A |
| CG1DK (Coliform) | $1^{st}$-order decay rate, 1/day | 1.4 | N/A |
| CGS (Coliform) | Settling rate, m/day | 1.0 | N/A |
| AG | Maximum algal growth rate, 1/day | 3.0 | 2.0 |
| AT1 | Lower temperature for algal growth, C | 5.0 | 5.0 |
| PO4R | Sediment release rate of phosphorus, fraction of SOD | 0.03 | 0.001 |
| PARTP | Phosphorus partitioning coefficient for suspended solids | 0.001 | 0.0 |
| NH4REL | Sediment release rate of ammonium, fraction of SOD | 0.07 | 0.001 |
| NH4DK | Ammonium decay rate, 1/day | 0.1 | 0.12 |
| NO3DK | Nitrate decay rate, 1/day | 0.1 | 0.03 |
| NO3S | De-nitrification rate from sediments, m/day | 0.0 | 1.0 |
| CO2REL | Sediment carbon dioxide release rate, fraction of sediment oxygen demand | 0.01 | 0.1 |
| O2AR | Oxygen stoichiometry for algal respiration | 1.4 | 1.1 |
| O2AG | Oxygen stoichiometry for algal primary production | 1.5 | 1.4 |
| SOD | Zero-order sediment oxygen demand for each segment, g $O_2$ / $m^2$ day | 3.0<br>(for each segment) | N/A |

## 3.6 Bypass Reach and Peaking Reach

The RMA suite of models for the Klamath River Bypass and Peaking reach was calibrated and validated during May 20 – 23, 2003 and July 15 – 18, 2003 respectively. The Bypass and Peaking Reach extends from J.C. Boyle Dam to the headwaters of Copco Reservoir and encompasses the J.C. Boyle Powerhouse tailrace.

## 3.6.1 Data

Water quality conditions of water flowing into the reach (boundary conditions at J.C. Boyle Dam and J.C. Boyle Powerhouse return), initial status of the system (initial conditions), and observations in the Klamath River (calibration/validation points at Klamath River above J.C. Boyle Powerhouse tailrace, Stateline and above Copco Reservoir) were required.

### 3.6.1.1 Boundary Conditions

The boundary condition data was derived from samples collected at J.C. Boyle Dam Reservoir. Water temperature and dissolved oxygen data were available from water quality probes and water temperature loggers at hourly intervals. Grab samples were collected once per day for three days. Due to the inherent variability and infrequent sampling interval of the grab data, the boundary condition values for nutrients, BOD, and algae were assumed to be a constant value for the calibration and validation period, based on the grab sample data from 2002 (Appendix F).

The upstream boundary condition for temperature and dissolved oxygen were obtained from water quality probes during the May and July calibration and validation periods. Sondes were deployed above the J.C. Boyle Dam, but were used to represent temperature and dissolved oxygen in both the direct J.C. Boyle Dam release into the river and the J.C. Boyle Powerhouse tailrace release into the river. Grab samples were also collected above the dam, providing concentrations of nutrients at J.C. Boyle Dam, as well as the boundary condition for the J.C. Boyle Powerhouse tailrace. These boundary conditions were assumed equivalent because they are both drawn from J.C. Boyle Reservoir.

There is a lag time from J.C. Boyle Dam to the powerhouse, but it is well under one hour (approximately 15 minutes at 600 cfs, 8 minutes at 3000 cfs; pers. comm. T. Olson) and is thus neglected.

The water quality values for the calibration and validation period are shown in Table 43, Table 44, Figure 72 and Figure 73.

**Table 43. Bypass/Peaking Klamath River reach calibration and validation water quality boundary conditions for J.C. Boyle Dam and J.C. Boyle Powerhouse return**

| Parameter | Units | Dates | |
|---|---|---|---|
| | | 5/21/02 - 5/23/02 | 7/16/02 - 7/18/02 |
| BOD | mg/l | 3.0 | 3.0 |
| DO | mg/l | variable | Variable |
| Org N | mg/l | 0.60 | 1.30 |
| $NH_4^+$ | mg/l | 0.10 | 0.20 |
| $NO_2^-$ | mg/l | 0.00 | 0.00 |
| $NO_3^-$ | mg/l | 0.10 | 0.80 |
| Org P | mg/l | 0.20 | 0.10 |
| $PO_4^{3-}$ | mg/l | 0.20 | 0.30 |
| Algae | mg/l | 2.0 | 22.0 |
| Tw | °C | variable | variable |

**Table 44. Bypass/Peaking Klamath River reach calibration and validation water quality boundary conditions for the Bypass Reach spring inflow**

| Parameter | Units | Dates | |
|---|---|---|---|
| | | 5/21/02 - 5/23/02 | 7/16/02 - 7/18/02 |
| BOD | mg/l | 0.0 | 0.0 |
| DO | mg/l | 9.7 | 9.7 |
| Org N | mg/l | 0.00 | 0.00 |
| $NH_4^+$ | mg/l | 0.00 | 0.00 |
| $NO_2^-$ | mg/l | 0.00 | 0.00 |
| $NO_3^-$ | mg/l | 0.15 | 0.15 |
| Org P | mg/l | 0.00 | 0.00 |
| $PO_4^{3-}$ | mg/l | 0.15 | 0.15 |
| Algae | mg/l | 0.0 | 0.0 |
| $T_w$ | °C | 11.0 | 11.0 |

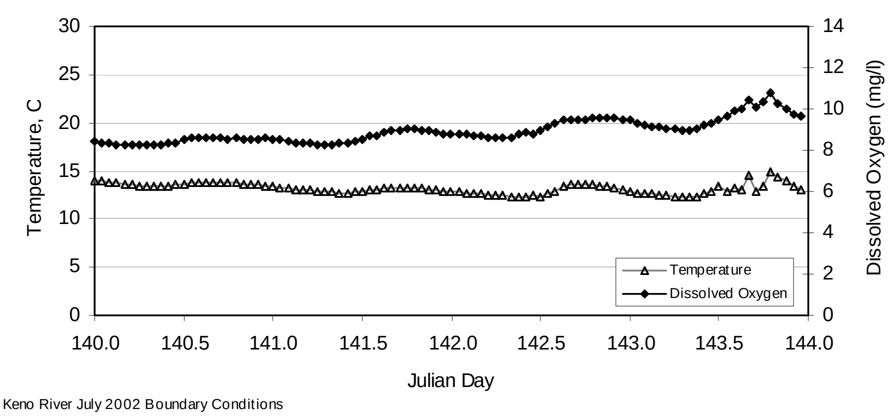


**Figure 72. Temperature and dissolved oxygen calibration boundary conditions at both J.C. Boyle Dam and J.C. Boyle Powerhouse**

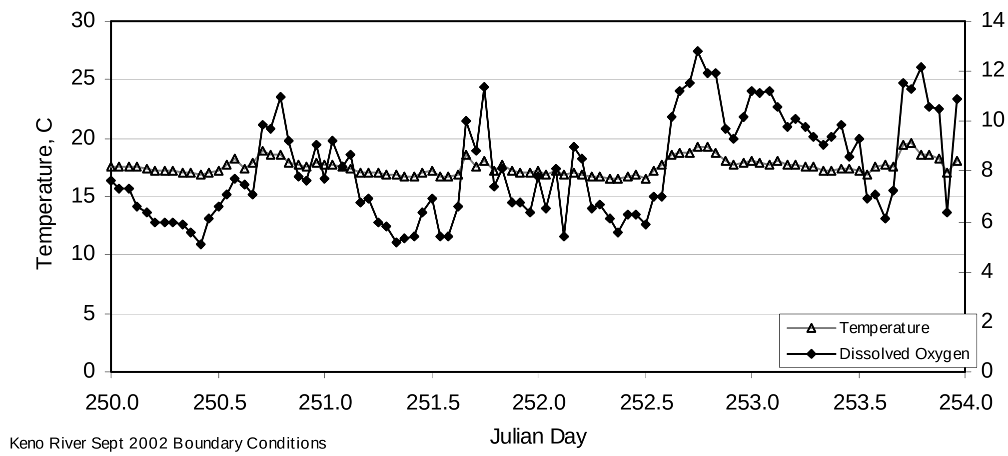



**Figure 73. Temperature and dissolved oxygen validation boundary conditions at both J.C. Boyle Dam and J.C. Boyle Powerhouse**

#### 3.6.1.2 Initial conditions

The model was run for three days prior to both the calibration and validation periods to provide an initial condition for simulation. The initial bed algae mass was estimated at 5 $g/m^2$.

#### 3.6.1.3 Calibration and Validation Points

The calibration and validation points for the Bypass / Peaking reach were Klamath River above J.C. Boyle Powerhouse tailrace, Klamath River at Stateline and Klamath River above Copco Reservoir. These data are displayed in the following section with model results.

### 3.6.2 Results

Calibration and validation were completed for temperature and dissolved oxygen as primary constituents and inorganic nutrient forms (ammonia, nitrate, orthophosphate) as secondary constituents. Field observations for temperature and dissolved oxygen were available from water quality probes on an hourly interval, allowing for summary statistics to be calculated both on an hourly and daily basis. An exception was at Klamath River above the J.C. Boyle Powerhouse tailrace site during the July (validation) period only temperature was available on an hourly interval. Dissolved oxygen was only available from field data collected once a day, and thus dissolved oxygen summary statistics are not available for that location in July. The nutrient data were primarily derived from field data, which were sampled once per day. All model parameters for the Bypass / Peaking reach are summarized in Table 51 at the end of this section.

#### 3.6.2.1 Water Temperature

Water temperature calibration required varying evaporation heat flux coefficients (presented in Table 51) that govern the mass transfer formulation represented in the numerical model heat budget. No other parameters were varied. The hourly results are presented graphically in Figure 74 through Figure 79 . Summary statistics for both calibration and validation periods (May 20-23, 2002 and July 15-18, 2002, respectively) are included in Table 45 through Table 47.

At Klamath River above J.C. Boyle Powerhouse tailrace, the phase was well represented while the range was moderated slightly. Hourly bias for the May period (calibration) was 0.14 °C and the mean absolute error was 0.87 °C. Hourly bias for the July period (validation) was –0.23 °C and the mean absolute error was 0.91 °C. Both the calibration and validation simulation results were within 1 °C of observations.

At Klamath River at Stateline, the diurnal phase was approximately reproduced while the diurnal range was well represented. Hourly bias for the May period (calibration) was –0.39 °C and the mean absolute error was 0.67 °C. Hourly bias for the July period (validation) was –0.48 °C and the mean absolute error was 1.11 °C. Both the calibration and validation simulation results were within approximately 1.5 °C of observations.

At Klamath River above Copco Reservoir, the diurnal phase was approximately represented in May, but not represented well in July, while the diurnal range for both periods was well represented. Hourly bias for the May period (calibration) was –0.35 °C and the mean absolute error was 0.61 °C. Hourly bias for the July period (validation) was –0.05 °C and the mean absolute error was 1.10 °C. Both the calibration and validation simulation results were generally within 1.5 °C of observations.

Apparent in both the observed and simulated temperature time series is the influence of peaking operations. During off peak hours, water of a significantly different quality (from the bypass reach) markedly alters water temperature. The timing and magnitude of peaking operations create unique temperature traces at downstream locations. Figure 79 illustrates the thermal response of the Klamath River above Copco and, although shifted slightly in phase, the model replicates such conditions.

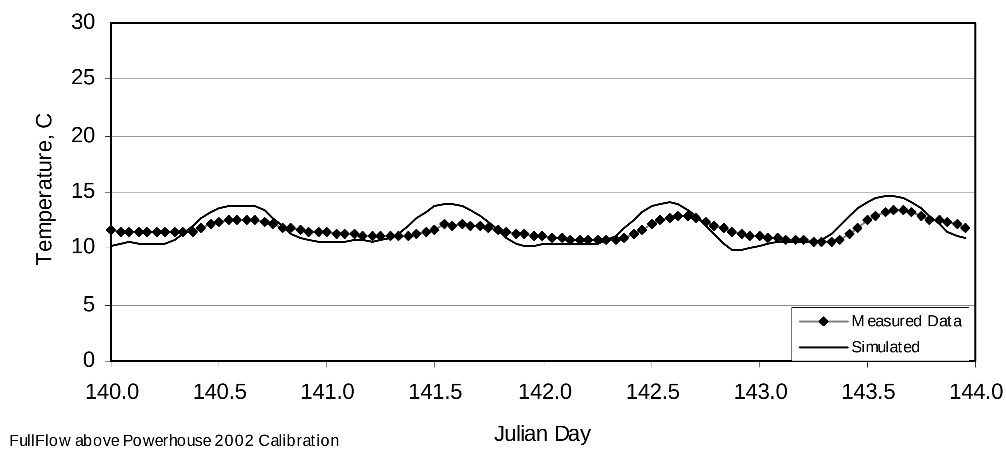



**Figure 74. Klamath River, above J.C. Boyle PH tailrace, simulated versus measured water temperature, May 20-23, 2002**

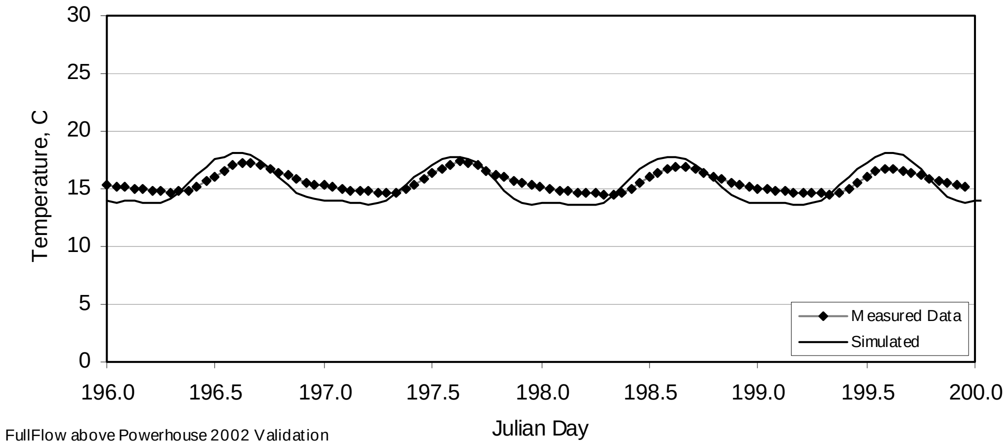



**Figure 75. Klamath River, above J.C. Boyle PH tailrace, simulated versus measured water temperature, July 15-18, 2002**

**Table 45. Klamath River, above J.C. Boyle PH tailrace, hourly and daily calibration and validation period statistics for temperature**

| Calibration / Validation Statistics | | Hourly | | Daily | |
|---|---|---|---|---|---|
| | Unit | Calib. | Valid. | Calib. | Valid. |
| Mean Bias[a] | mg/l | 0.14 | -0.23 | 0.14 | -0.23 |
| Mean absolute error (MAE) | mg/l | 0.87 | 0.91 | 0.18 | 0.23 |
| Root mean squared error (RMSE) | mg/l | 0.99 | 1.01 | 0.22 | 0.27 |
| N | - | 96 | 96 | 4 | 4 |

[a] Mean bias = simulated – measured

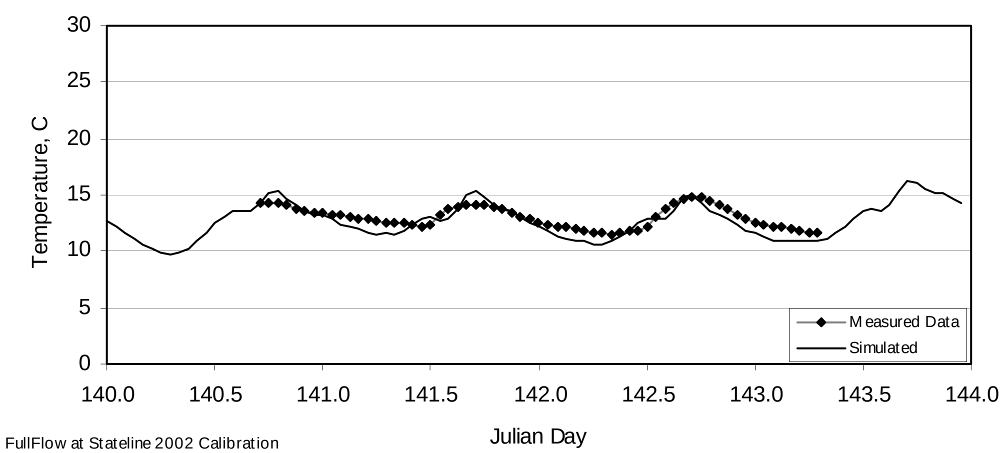



**Figure 76. Klamath River, at Stateline, simulated versus measured water temperature, May 20-23, 2002**

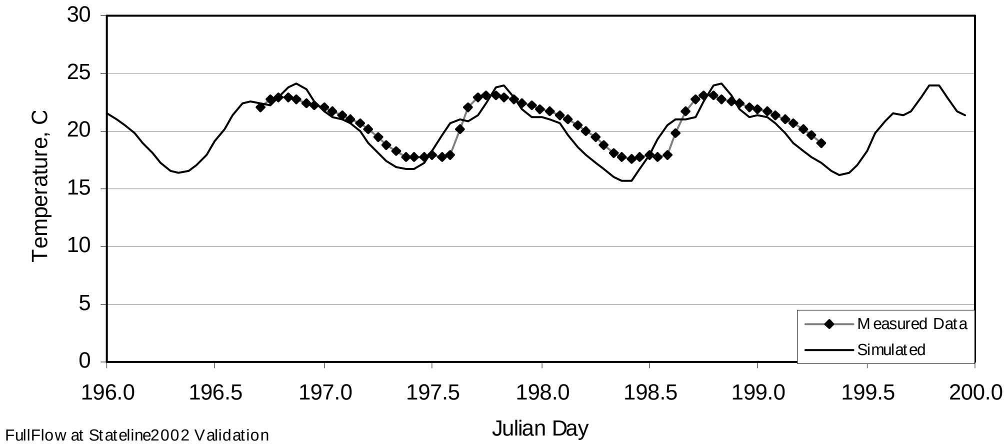



**Figure 77. Klamath River, at Stateline, simulated versus measured water temperature, July 15-18, 2002**

**Table 46. Klamath River, at Stateline, hourly and daily calibration and validation period statistics for temperature**

| Calibration / Validation Statistics | | Hourly | | Daily | |
|---|---|---|---|---|---|
| | Unit | Calib. | Valid. | Calib. | Valid. |
| Mean Bias[a] | mg/l | -0.39 | -0.48 | -0.40 | -0.49 |
| Mean absolute error (MAE) | mg/l | 0.67 | 1.11 | 0.40 | 0.49 |
| Root mean squared error (RMSE) | mg/l | 0.77 | 1.29 | 0.42 | 0.51 |
| n | - | 63 | 63 | 2 | 2 |

[a] Mean bias = simulated – measured

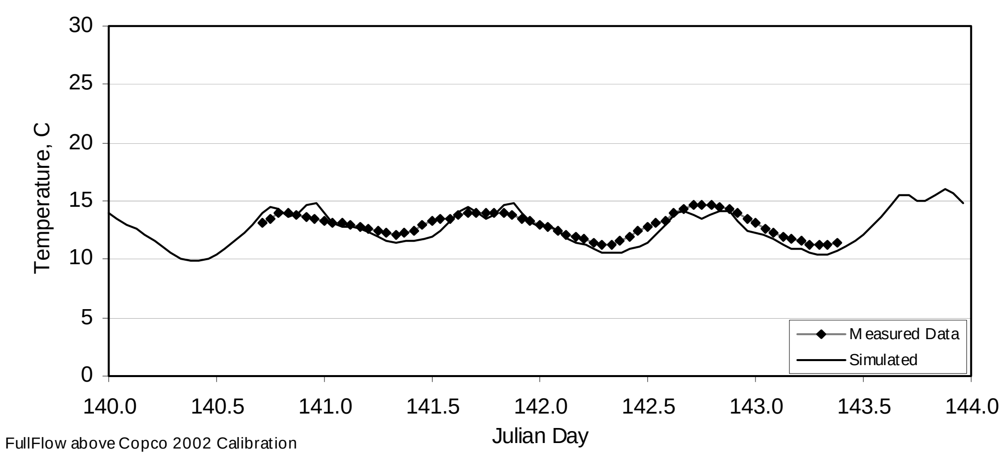



**Figure 78. Klamath River, above Copco Reservoir, simulated versus measured water temperature, May 20-23, 2002**

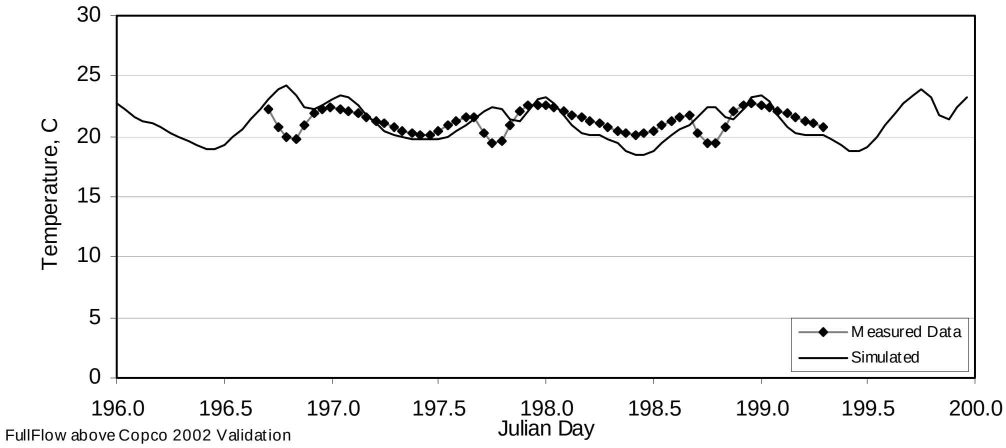



**Figure 79. Klamath River, above Copco Reservoir, simulated versus measured water temperature, July 15-18, 2002**

**Table 47. Klamath River, above Copco Reservoir, hourly and daily calibration and validation period statistics for temperature**

| Calibration / Validation Statistics | | Hourly | | Daily | |
|---|---|---|---|---|---|
| | Unit | Calib. | Valid. | Calib. | Valid. |
| Mean Bias[a] | mg/l | -0.35 | 0.05 | -0.41 | -0.12 |
| Mean absolute error (MAE) | mg/l | 0.61 | 1.10 | 0.41 | 0.29 |
| Root mean squared error (RMSE) | mg/l | 0.71 | 1.39 | 0.46 | 0.31 |
| n | - | 65 | 63 | 2 | 2 |

[a] Mean bias = simulated – measured

### 3.6.2.2 Dissolved Oxygen

Dissolved oxygen calibration required varying several parameters, including but not limited to algal growth rates and respiration rates, organic and inorganic nutrient decay rates, and temperature constants for rate reactions. Both phytoplankton and benthic algae were modeling in river reaches. To represent the adverse environment a river imposes on phytoplankton that are washed in from upstream of Keno Dam, growth rates were set to very low numbers in river reaches. The results are presented both graphically, in Figure 80 through Figure 85, and using summary statistics, in Table 48 through

Table 50.

At Klamath River above J.C. Boyle Powerhouse tailrace, the model reproduced dissolved oxygen concentrations and the moderated diurnal signal. For July, the simulated concentrations are very similar to the field data. Hourly bias for the May period (calibration) was –0.07 mg/l and the mean absolute error was 0.28 mg/l. Hourly bias and mean absolute error for the July period (validation) were not available. The calibration and simulation results were within 1 mg/l of observations.

At Klamath River at Stateline, the May phase and range were approximately represented. For July the phase and range were well represented, but the magnitude was over-represented. Hourly bias for the May period (calibration) was 0.37 mg/l and the mean absolute error was 0.39 mg/l. Hourly bias for the July period (validation) was 1.17 mg/l and the mean absolute error was 1.17 mg/l. Both the calibration and validation simulation results were within 1.5 mg/l of observations.

At Klamath River above Copco Reservoir, the overall magnitude was well represented, but the diurnal range was not. In July, both the diurnal phase and range were well represented, as was the magnitude. Hourly bias for the May period (calibration) was 0.00 mg/l and the mean absolute error was 0.59 mg/l. Hourly bias for the July period (validation) was 0.56 mg/l and the mean absolute error was 0.56 mg/l. While the summary statistics of both the calibration and validation indicate the simulation results were within 1 mg/l of observations, a visual inspection of the May graph indicates that the simulation results for that period were within 2 mg/l.

Uncertainty in organic matter and algae inputs may be the cause for elevated simulation values in July at Klamath River at Stateline. Additionally, the distribution of benthic algae and biomass is largely unknown, as are the temporal and spatial variability of light extinction, and could impact model results.

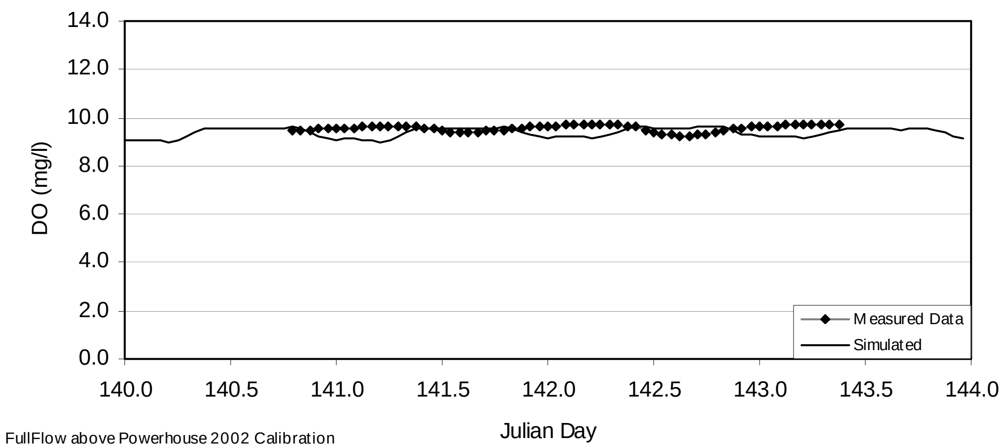


**Figure 80. Klamath River, above J.C. Boyle PH tailrace, simulated versus measured dissolved oxygen, May 20-23, 2002**

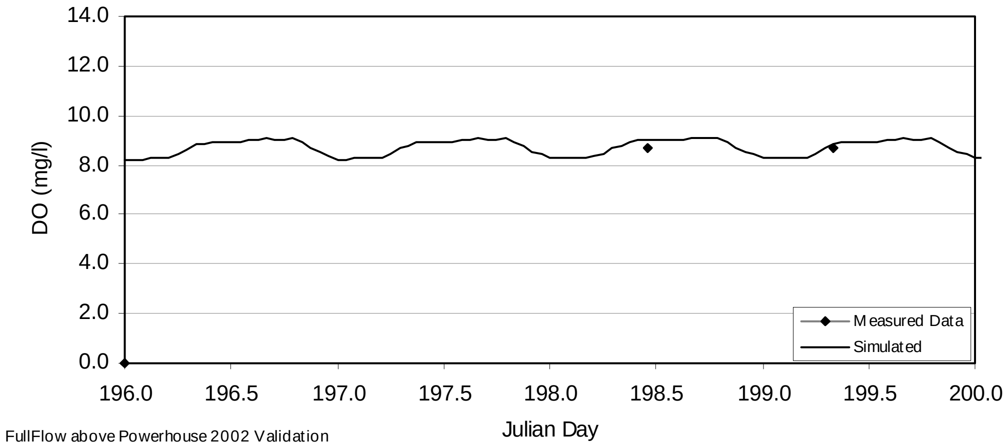



**Figure 81. Klamath River, above J.C. Boyle PH tailrace, simulated versus measured dissolved oxygen, July 15-18, 2002**

**Table 48. Klamath River, above J.C. Boyle PH tailrace, hourly and daily calibration and validation period statistics for dissolved oxygen**

| Calibration / Validation Statistics | | Hourly | | Daily | |
|---|---|---|---|---|---|
| | Unit | Calib. | Valid. | Calib. | Valid. |
| Mean Bias[a] | mg/l | -0.07 | n/a | -0.02 | n/a |
| Mean absolute error (MAE) | mg/l | 0.28 | n/a | 0.04 | n/a |
| Root mean squared error (RMSE) | mg/l | 0.30 | n/a | 0.04 | n/a |
| N | - | 63 | n/a | 2 | n/a |

[a] Mean bias = simulated – measured

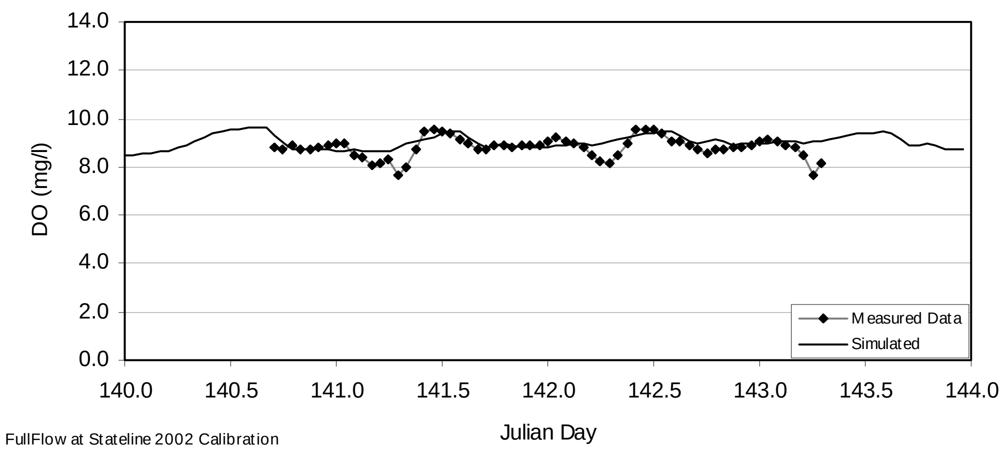



**Figure 82. Klamath River, at Stateline, simulated versus measured dissolved oxygen, May 20-23, 2002**

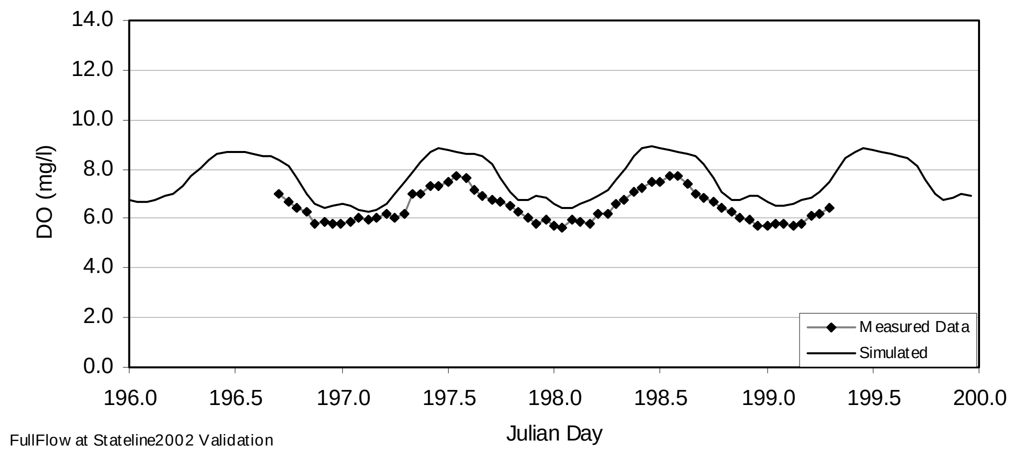



**Figure 83. Klamath River, at Stateline, simulated versus measured dissolved oxygen, July 15-18, 2002**

**Table 49. Klamath River, at Stateline, hourly and daily calibration and validation period statistics for dissolved oxygen**

| Calibration / Validation Statistics | | Hourly | | Daily | |
|---|---|---|---|---|---|
| | Unit | Calib. | Valid. | Calib. | Valid. |
| Mean Bias[a] | mg/l | 0.37 | 1.17 | 0.36 | 1.19 |
| Mean absolute error (MAE) | mg/l | 0.39 | 1.17 | 0.36 | 1.19 |
| Root mean squared error (RMSE) | mg/l | 0.51 | 1.22 | 0.36 | 1.19 |
| n | - | 63 | 63 | 2 | 2 |

[a] Mean bias = simulated – measured

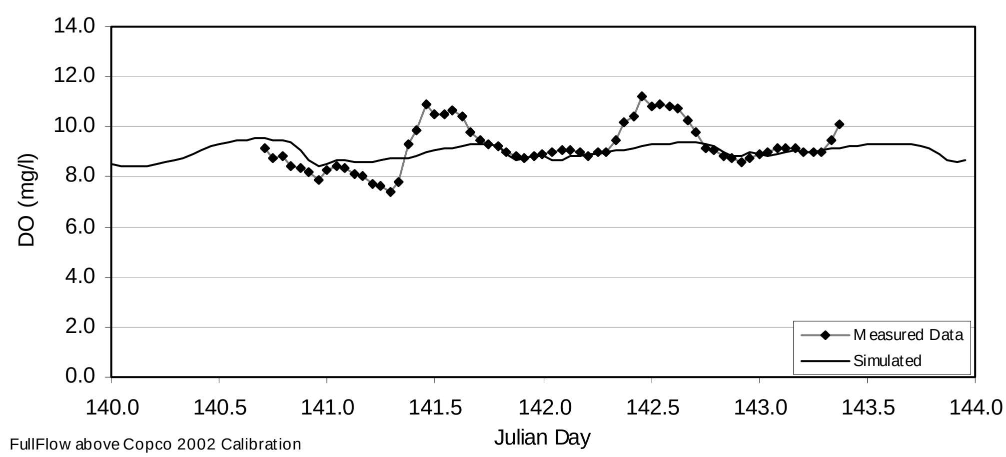



**Figure 84. Klamath River, above Copco Reservoir, simulated versus measured dissolved oxygen, May 20-23, 2002**

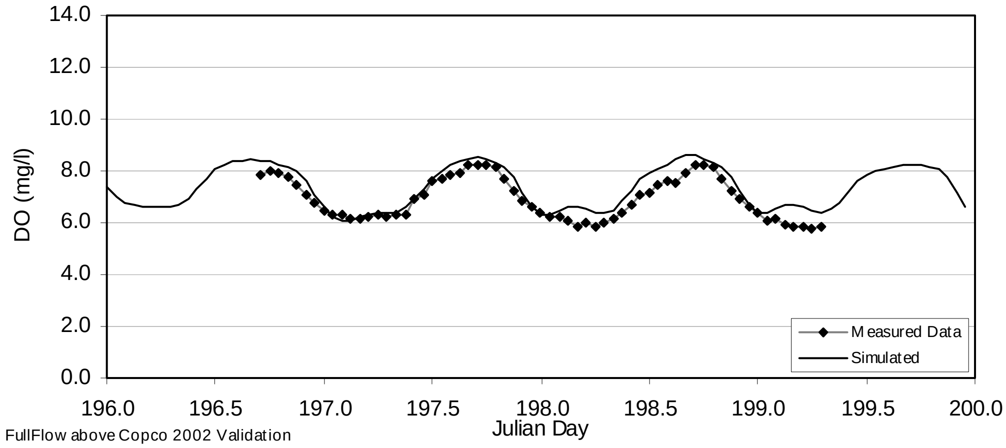



**Figure 85. Klamath River, above Copco Reservoir, simulated versus measured dissolved oxygen, July 15-18, 2002**

**Table 50. Klamath River, above Copco Reservoir, hourly and daily calibration and validation period statistics for dissolved oxygen**

| **Calibration / Validation Statistics** | | **Hourly** | | **Daily** | |
|---|---|---|---|---|---|
| | Unit | Calib. | Valid. | Calib. | Valid. |
| Mean Bias[a] | mg/l | 0.00 | 0.56 | -0.13 | 0.52 |
| Mean absolute error (MAE) | mg/l | 0.59 | 0.56 | 0.18 | 0.52 |
| Root mean squared error (RMSE) | mg/l | 0.75 | 0.62 | 0.22 | 0.54 |
| n | - | 65 | 63 | 2 | 2 |

[a] Mean bias = simulated – measured

### 3.6.2.3 Nutrients

Nutrient concentrations were not formally calibrated in the Bypass / Peaking reach. That is, values for nutrient interactions (e.g. stoichiometric equivalence with regard to primary production, decay rates and temperature rate constants) identified in the dissolved oxygen calibration were not modified further, and other parameters were set at default values. The results are presented graphically in Figure 86 through Figure 103. Simulated concentrations for ammonia, nitrate and orthophosphate were consistent with field observations. Although there is some scatter in the observed data that is not replicated within the model, the variations in water quality in response to peaking operations are well represented for certain constituents (e.g. nitrate, Figure 95 and Figure 101).

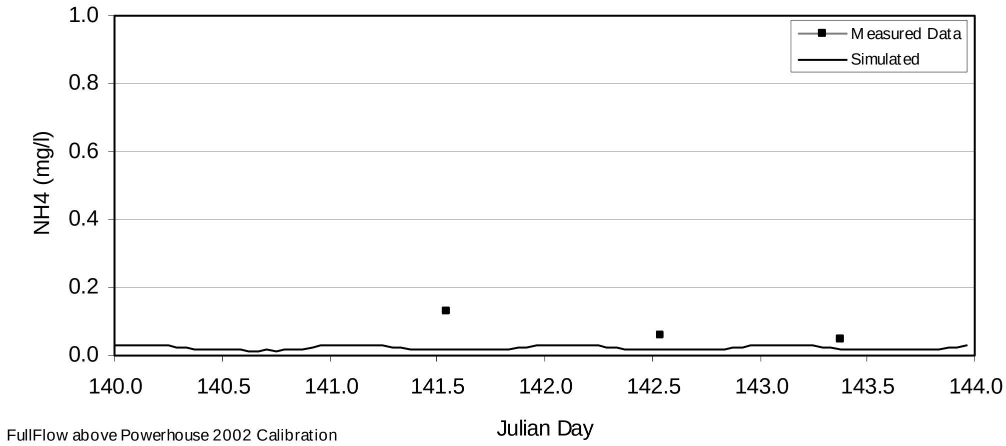



**Figure 86. Klamath River, above J.C. Boyle PH tailrace, simulated versus measured ammonia, May 20-23, 2002**

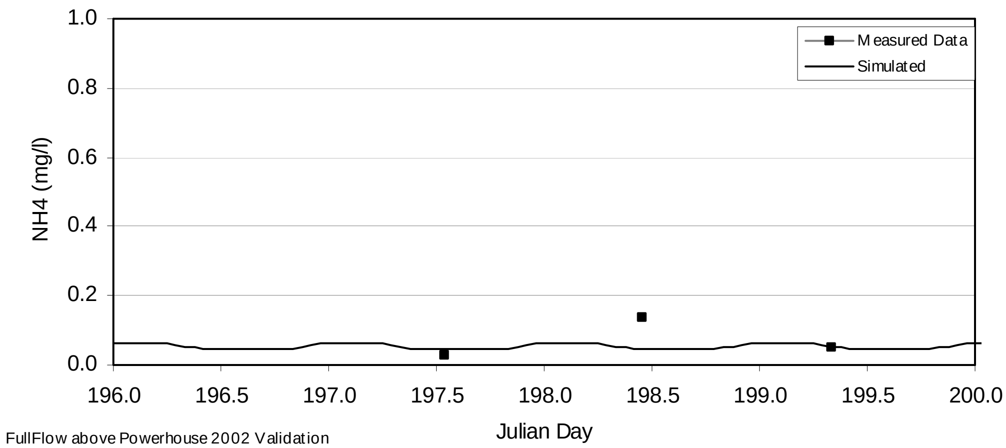



**Figure 87. Klamath River, above J.C. Boyle PH tailrace, simulated versus measured ammonia, July 15-18, 2002**

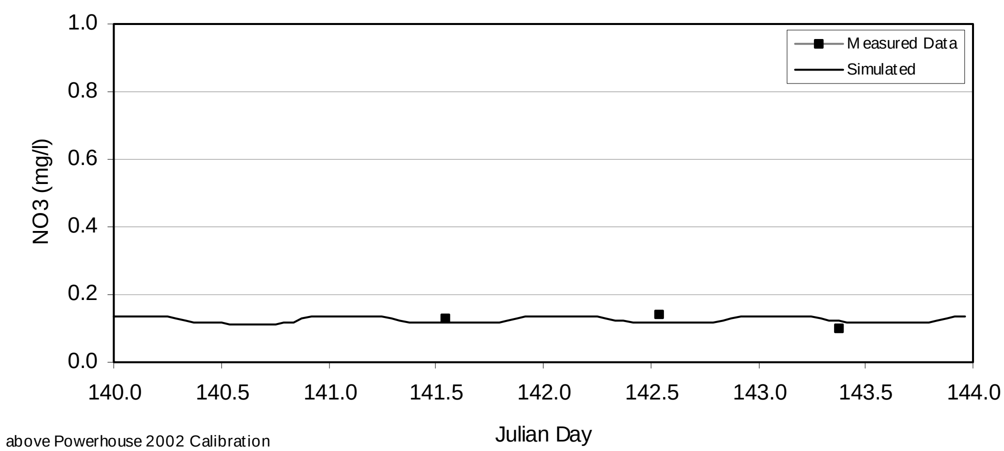


**Figure 88. Klamath River, above J.C. Boyle PH tailrace, simulated versus measured nitrate, May 20-23, 2002**

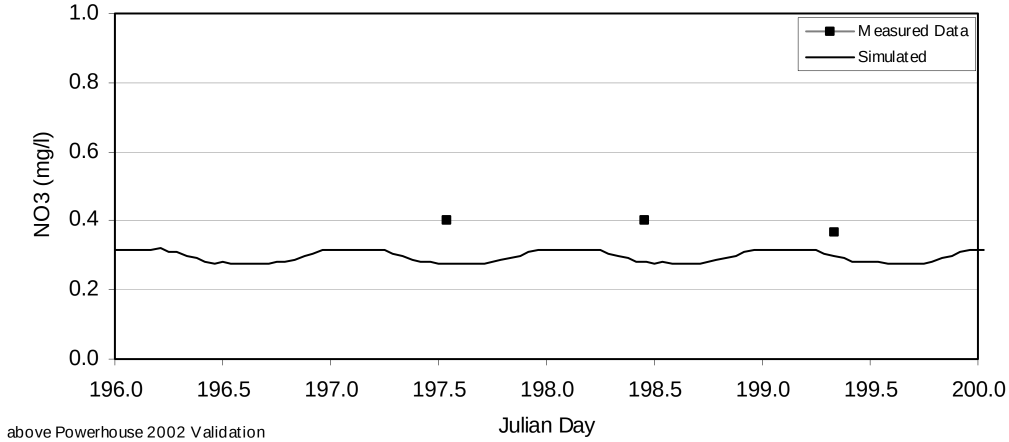



**Figure 89. Klamath River, above J.C. Boyle PH tailrace, simulated versus measured nitrate, July 15-18, 2002**

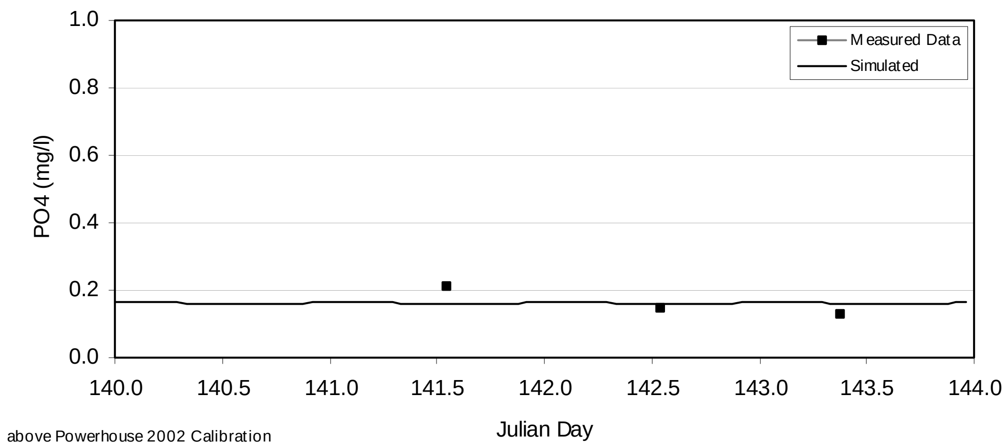



**Figure 90. Klamath River, above J.C. Boyle PH tailrace, simulated versus measured orthophosphate, May 20-23, 2002**

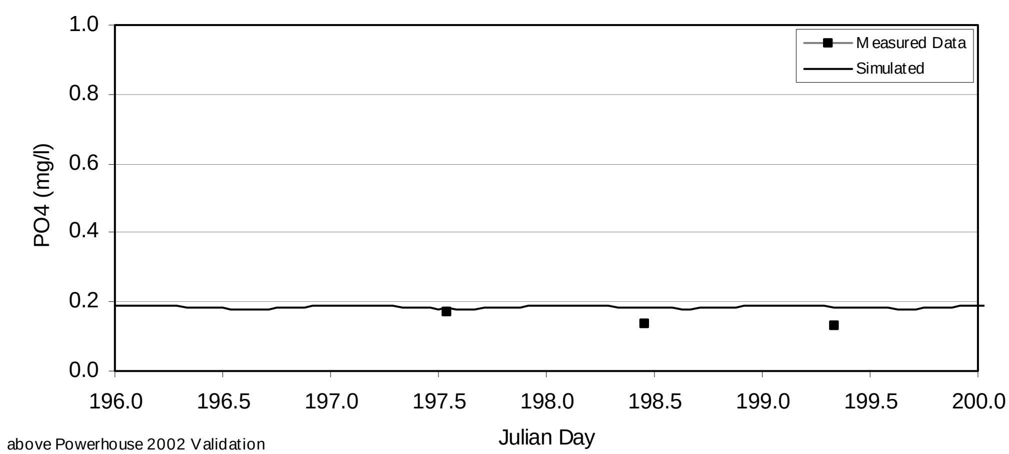


**Figure 91. Klamath River, above J.C. Boyle PH tailrace, simulated versus measured orthophosphate, July 15-18, 2002**

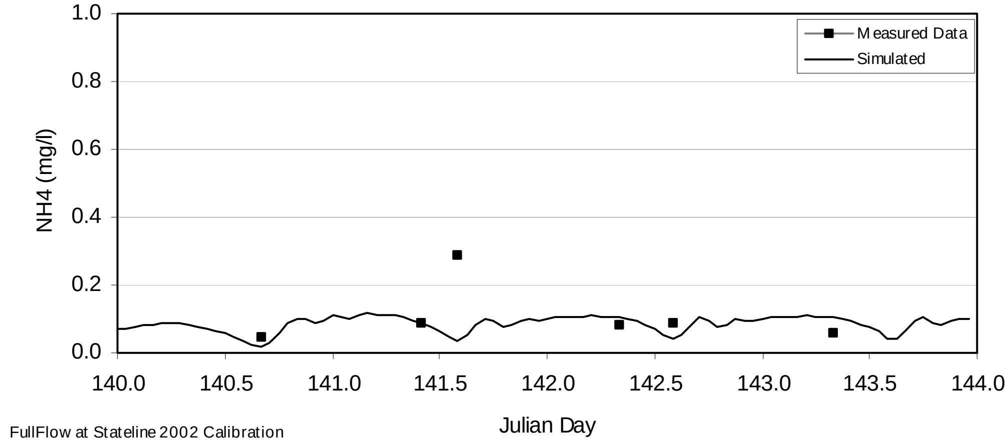



**Figure 92. Klamath River, at Stateline, simulated versus measured ammonia, May 20-23, 2002**

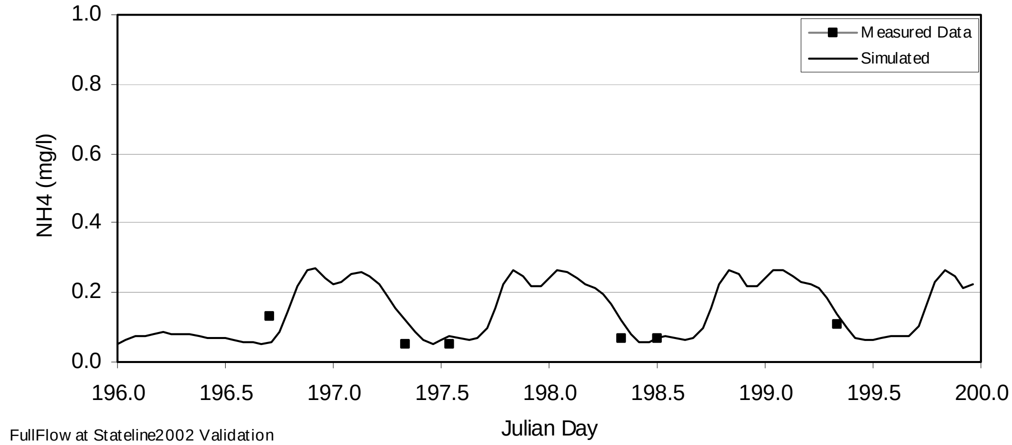



**Figure 93. Klamath River, at Stateline, simulated versus measured ammonia, July 15-18, 2002**

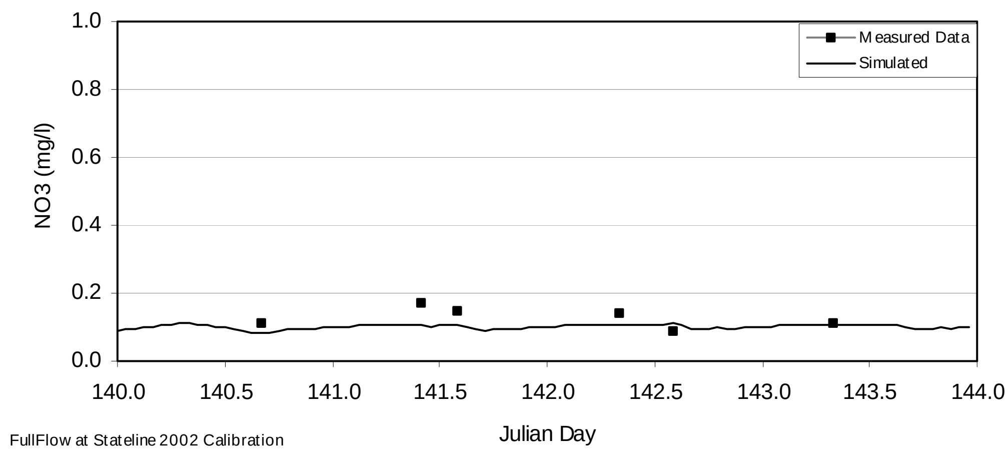


**Figure 94. Klamath River, at Stateline, simulated versus measured nitrate, May 20-23, 2002**

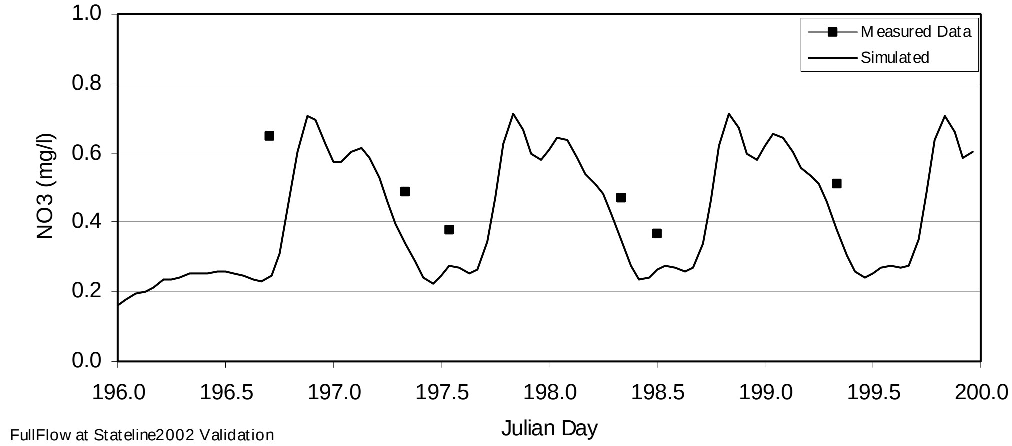



**Figure 95. Klamath River, at Stateline, simulated versus measured nitrate, July 15-18, 2002**

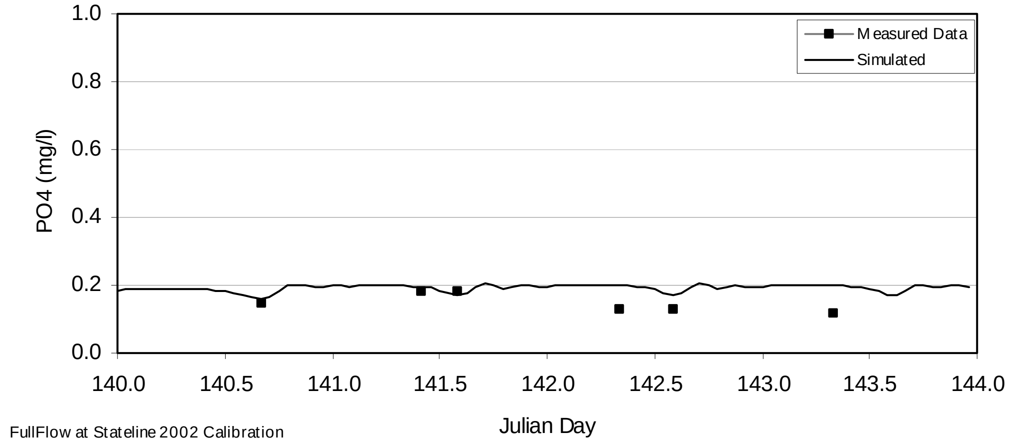



**Figure 96. Klamath River, at Stateline, simulated versus measured orthophosphate, May 20-23, 2002**

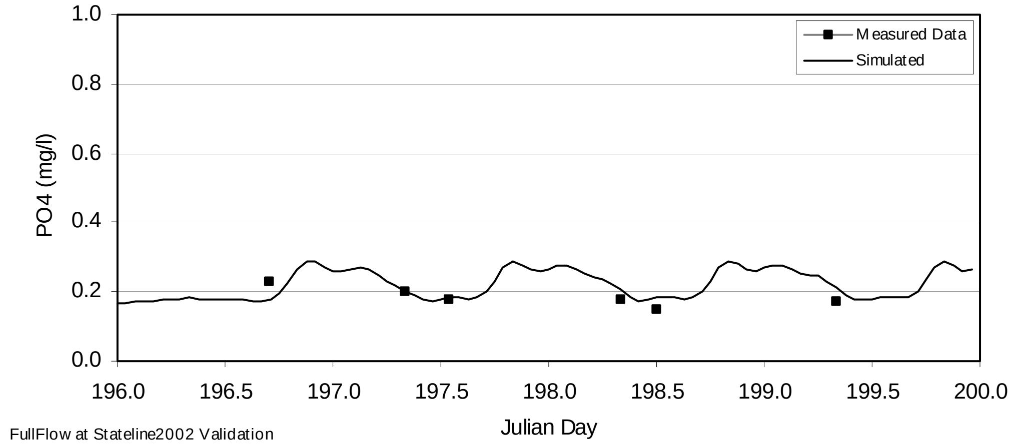


**Figure 97. Klamath River, at Stateline, simulated versus measured orthophosphate, July 15-18, 2002**

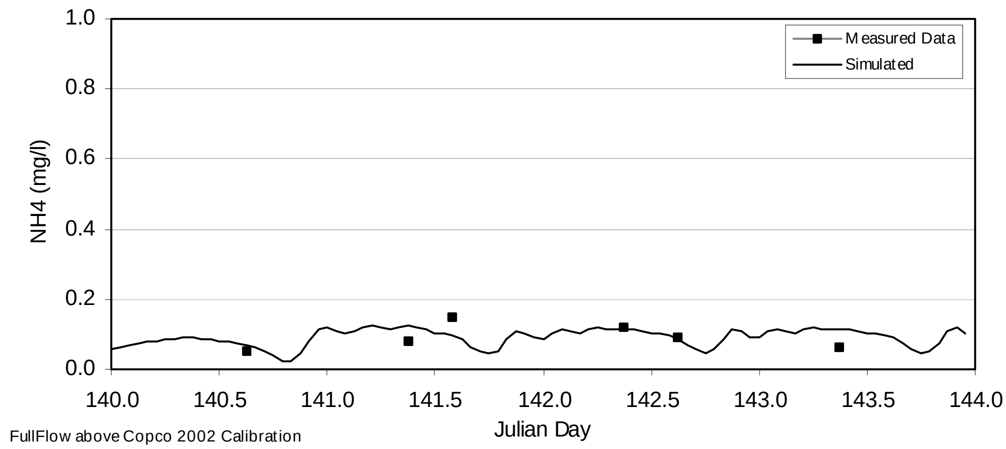



**Figure 98. Klamath River, above Copco Reservoir, simulated versus measured ammonia, May 20-23, 2002**

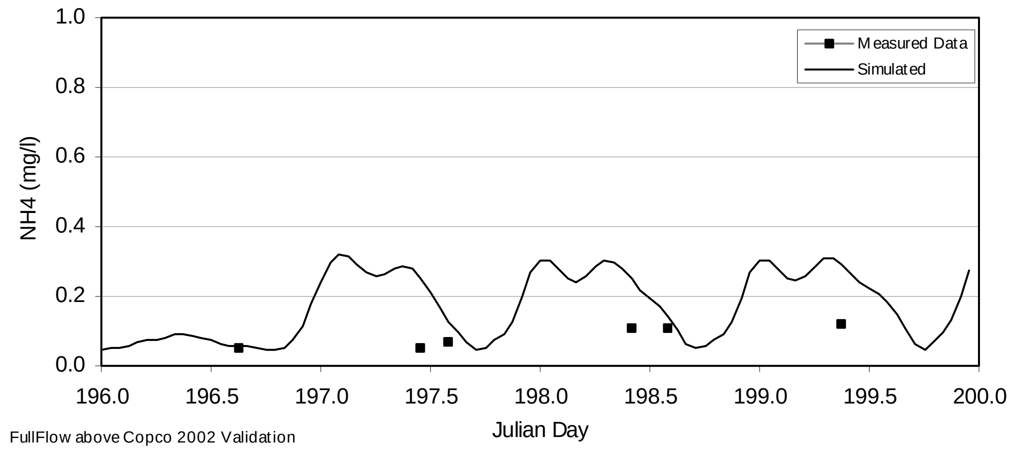



**Figure 99. Klamath River, above Copco Reservoir, simulated versus measured ammonia, July 15-18, 2002**

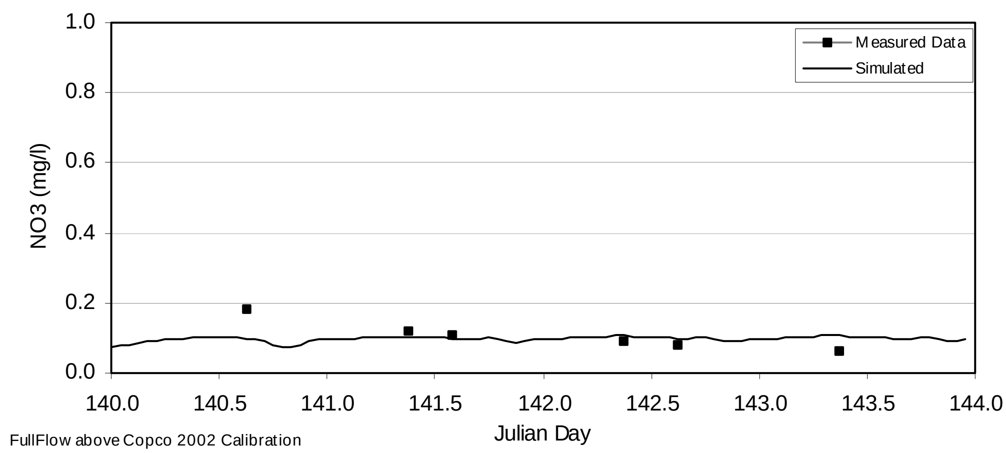


**Figure 100. Klamath River, above Copco Reservoir, simulated versus measured nitrate, May 20-23, 2002**

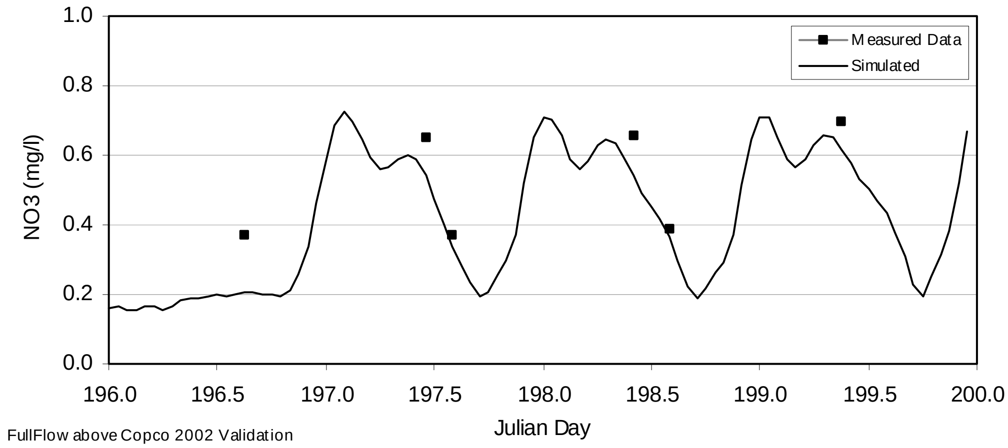



**Figure 101. Klamath River, above Copco Reservoir, simulated versus measured nitrate, July 15-18, 2002**

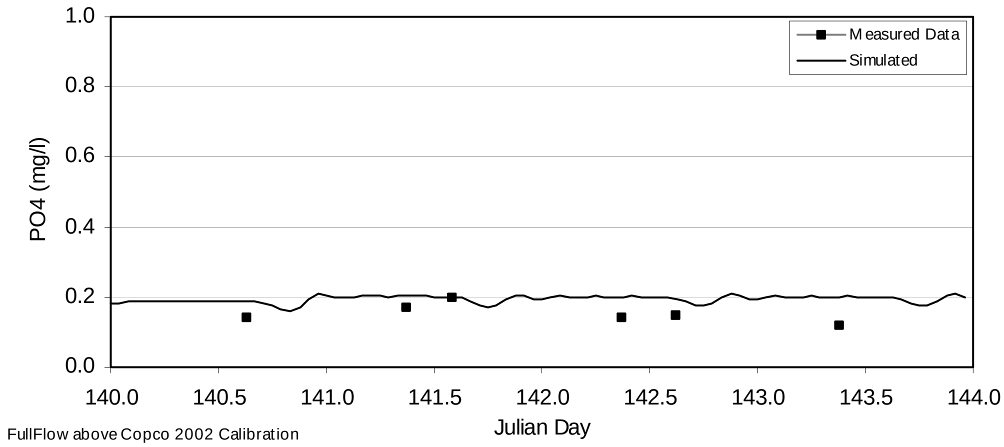



**Figure 102. Klamath River, above Copco Reservoir, simulated versus measured orthophosphate, May 20-23, 2002**

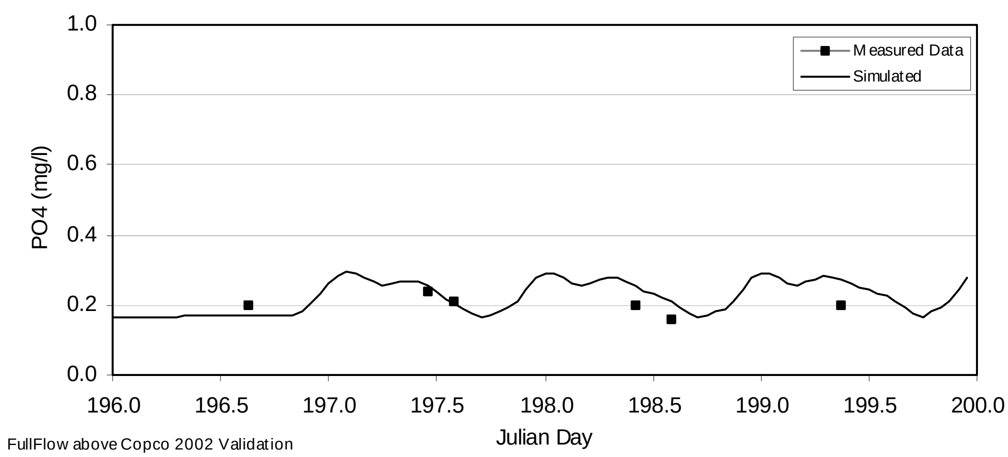


**Figure 103. Klamath River, above Copco Reservoir, simulated versus measured orthophosphate, July 15-18, 2002**

### 3.6.2.4 Summary of Parameters

**Table 51. RMA-2 and RMA-11 Model rates, coefficients and constants for the Bypass / Peaking reach**

| Variable Name | Description, units | Value |
|---|---|---|
| | Time step, hr | 0.25 (RMA-2)<br>1.0 (RMA-11) |
| | Space step, m | 75 |
| | Manning roughness coefficient | 0.04 |
| | Turbulence factor, Pascal-sec | 100 |
| | Longitudinal diffusion scale factor | 0.10 |
| | Slope Factor | 0.95 |
| ELEV | Elevation of site, m | 964.00 |
| LAT | Latitude of site, degrees | 41.5 |
| LONG | Longitude of site, degrees | 122.45 |
| EVAPA | Evaporative heat flux coefficient a, m $hr^{-1}$ $mb^{-1}$ | 0.000010 |
| EVAPB | Evaporative heat flux coefficient b, m $hr^{-1}$ $mb^{-1}$ $(m/h)^{-1}$ | 0.000010 |
| EXTINC | Light Extinction coefficient, used when algae is not simulated, 1/m | 1.5 |
| ALP0 | Chl *a* to algal biomass conversion factor, phytoplankton, mgChl_a to mg-A | 67 |
| ALP1 | Fraction of algal biomass that is nitrogen, phytoplankton, mg-N/mg A | 0.072 |
| ALP2 | Fraction of algal biomass that is phosphorous, phytoplankton, mg-P/mg A | 0.010 |
| LAMB1 | Linear algal self-shading coefficient, phytoplankton, 1/m | n/a |
| LAMB2 | Non-linear algal self shading coefficient, phytoplankton, 1/m | n/a |
| MUMAX | Maximum specific growth rate, phytoplankton, 1/d | 0.01 |
| RESP | Local respiration rate of algae, phytoplankton, 1/d | 0.05 |
| SIG1 | Settling rate of algae, phytoplankton, 1/d | 0.0 |
| KLIGHT | Half saturation coefficient for light, phytoplankton, KJ $m^{-2}$ $s^{-1}$ | 0.01 |
| KNITR | Michaelis-Menton half saturation constant: nitrogen, phytoplankton, mg/l | 0.01 |
| KPHOS | Michaelis-Menton half saturation constant: phosphorous, phytoplankton, mg/l | 0.001 |
| PREFN | Preference factor for NH3-N, phytoplankton | 0.6 |
| ABLP0 | Chl a to algal biomass conversion factor, bed algae, mgChl_a to mg-A | 50 |
| ABLP1 | Fraction of algal biomass that is nitrogen, bed algae, mg/l | 0.07 |
| ABLP2 | Fraction of algal biomass that is phosphorus, bed algae, mg/l | 0.01 |
| LAMB1 | Linear algal self shading coefficient, bed algae, 1/m | n/a |
| LAMB2 | Non-linear self shading coefficient, bed algae, 1/m | n/a |
| MUMAX | Maximum specific growth rate, bed algae, 1/d | 1.0 |
| RESP | Local respiration rate of algae, bed algae, 1/d | 0.60 |
| MORT | Mortality, bed algae, 1/d | 0.0 |
| KBNITR | Half-saturation coefficient for nitrogen, bed algae, mg/l | 0.01 |
| KBPHOS | Half-saturation coefficient for phosphorus, bed algae, mg/l | 0.002 |
| KBLIGHT | Half-saturation coefficient for light, bed algae, KJ $m^{-2}$ $s^{-1}$ | 0.01 |
| PBREFN | Preference factor for NH3-N, bed algae | 0.75 |
| BET1 | Rate constant: biological oxidation NH3-N, 1/d | 0.3 |
| BET2 | Rate constant: biological oxidation NO2-N, 1/d | 0.5 |
| BET3 | Rate constant: hydrolysis Org N to NH3-N, 1/d | 0.3 |
| BET4 | Rate constant: transformation Org P to P-D, 1/d | 0.3 |
| KNINH | First order nitrification inhibition coefficient, $mg^{-1}$ | n/a |
| ALP3 | Rate $O_2$ production per unit of algal photosynthesis, phytoplankton, mg-O/mg-A | 1.6 |
| ALP4 | Rate $O_2$ uptake per unit of algae respired, phytoplankton, mg-O/mg-A | 1.6 |
| ABLP3 | Rate $O_2$ production per unit of algal photosynthesis, bed algae, mg-O/mg-A | 1.6 |
| ABLP4 | Rate $O_2$ uptake per unit of algae respired, bed algae, mg-O/mg-A | 1.6 |
| ALP5 | Rate $O_2$ uptake per unit NH3-N oxidation, mg-O/mg-N | 3.43 |
| ALP6 | Rate $O_2$ uptake per unit NO2-N oxidation, mg-O/mg-N | 1.14 |
| K1 | Deoxygenation rate constant: BOD, 1/d | 0.3 |
| - | Minimum reaeration rate constant (Churchill formula applied), 1/d | 3.0 |
| SIG6 | BOD settling rate constant, 1/d | 0.0 |

n/a – not applicable

## 3.7 Copco Reservoir

Copco Reservoir reach extends from the headwaters of Copco Reservoir to Copco Dam. Copco Reservoir was modeled using CE-QUAL-W2 and was calibrated at selected dates for 2000.

### 3.7.1 Data

Water quality conditions of water flowing into the reach (boundary conditions), initial status of the system (initial conditions), and intermediate points within the main stem (calibration/validation points) were required.

#### 3.7.1.1 Boundary Conditions

The flow and temperature boundary conditions for the main inflow both passed from the Peaking reach and constituent concentrations were estimated from field data. The accretion / depletion flow for the Copco Reservoir reach is included in the river inflow, and therefore is assumed to have the same temperature and constituent concentrations as the main inflow.

#### 3.7.1.2 Initial conditions

During the winter the Copco Reservoir Can have a residence time of less than 10 days. Thus initial conditions under this short residence time and isothermal conditions are presumed to wash out of the system in a few weeks.

### 3.7.2 Results

Calibration was completed for temperature and dissolved oxygen as primary constituents and inorganic nutrient forms (ammonia, nitrate, orthophosphate) as secondary constituents. Field observations for temperature and dissolved oxygen were typically available from water quality probes on an hourly interval, allowing for summary statistics to be calculated both on an hourly and daily basis. The nutrient data were primarily derived from field data, which were typically sampled once per day. All model parameters for the Copco Reservoir reach are summarized in Table 54, at the end of this section.

#### 3.7.2.1 Water Temperature

The water temperature was calibrated using the three user specified wind evaporation coefficients available in CE-QUAL-W2. Results are shown in Figure 104 and summary statistics are included in Table 52. Copco Reservoir experiences seasonal stratification, and the model replicates these conditions. The profile bias ranged from 0.44°C to –1.11°C and the mean absolute error ranged from 0.45°C to 1.15°C. Overall the model is within about 1.5°C of observations, except at the bottom of the reservoir where simulated data indicate the presence of a cold water pocket not shown in the observations.

**Table 52. Copco Reservoir thermal profile summary statistics: simulated versus measured**

| Date | Mean Bias[a] (˚C) | Mean Absolute Error (˚C) | Root Mean Squared Error (˚C) | n |
|---|---|---|---|---|
| April 12, 2000 | 0.32 | 1.06 | 1.20 | 18 |
| May 9, 2000 | 0.44 | 0.47 | 0.66 | 18 |
| June 6, 2000 | 0.23 | 0.46 | 0.52 | 18 |
| July 11, 2000 | 0.10 | 0.52 | 0.65 | 18 |
| August 8, 2000 | -0.50 | 0.83 | 1.00 | 17 |
| September 10, 2000 | -0.08 | 0.46 | 0.62 | 9 |
| September 27, 2000 | -1.11 | 1.15 | 1.77 | 9 |
| October 18, 2000 | 0.28 | 0.45 | 0.54 | 18 |

[a] Mean bias = simulated – measured

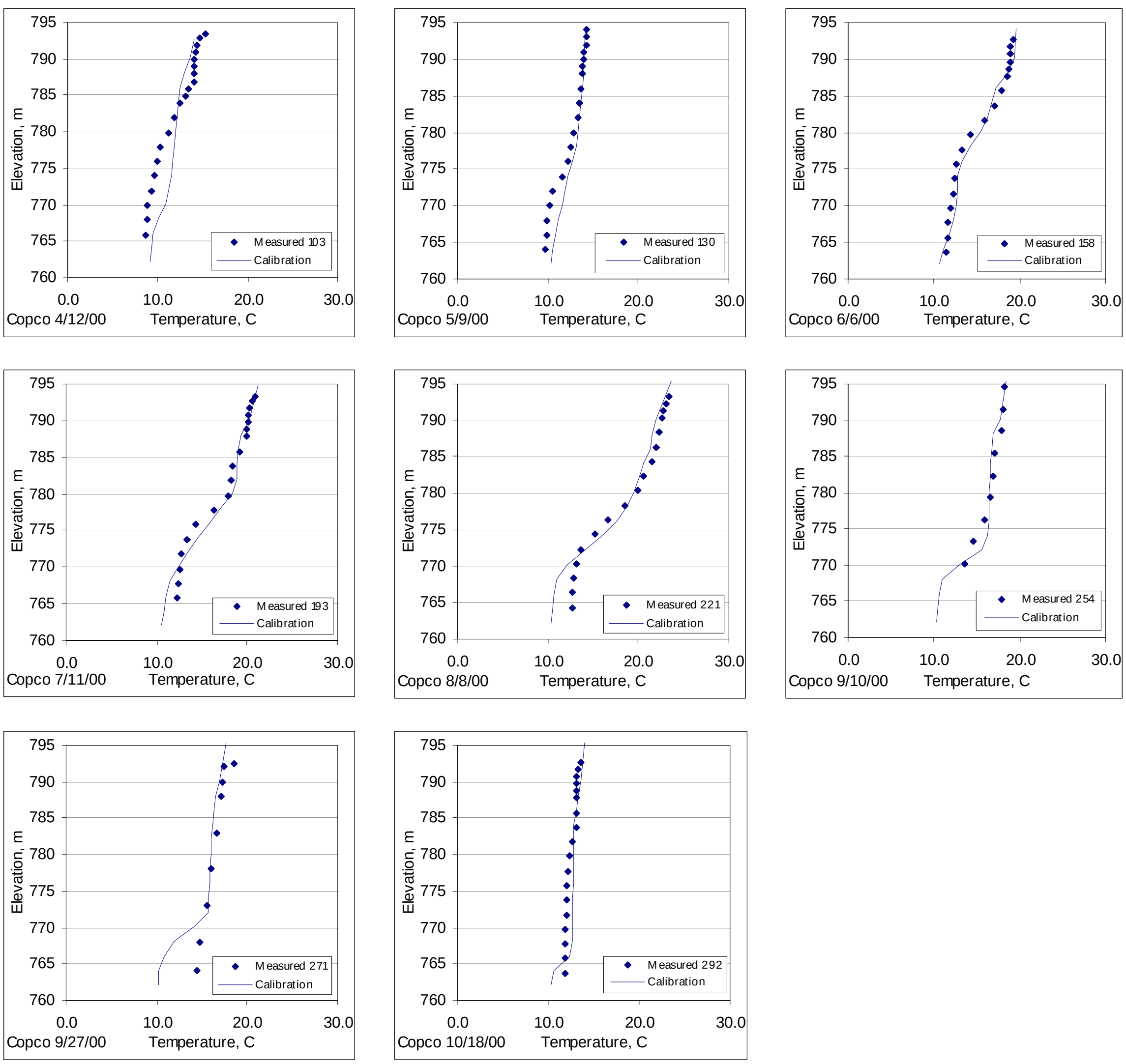


**Figure 104. Copco Reservoir thermal profiles, simulated versus measured monthly values: 2000**

#### 3.7.2.2 Dissolved Oxygen

The dissolved oxygen was calibrated using several different parameters, including algal rates, organic matter decay rates and nutrient decay rates. Also, zero order SOD was employed in calibrating dissolved oxygen. Results are shown in Figure 105 and summary statistics are included in Table 53. The profile bias ranged from –3.00 mg/l to 5.73 mg/l while the mean absolute error ranged from 0.44 mg/l to 3.00 mg/l.

Conditions are generally well represented, with spring and fall conditions most variable. The October 18 simulated profile suggests that the lake had not attained isothermal condition, while observed data presented in Figure 104 identifies that the lake had turned over.

**Table 53. Copco Reservoir dissolved oxygen profile summary statistics: simulated versus measured**

| Date | Mean Bias[a] (mg/l) | Mean Absolute Error (mg/l) | Root Mean Squared Error (mg/l) | n |
|---|---|---|---|---|
| April 12, 2000 | 0.09 | 0.53 | 0.64 | 18 |
| May 9, 2000 | 1.39 | 1.40 | 2.10 | 18 |
| June 6, 2000 | -0.11 | 0.44 | 0.61 | 18 |
| July 11, 2000 | -0.61 | 0.78 | 1.13 | 18 |
| August 8, 2000 | -1.62 | 1.62 | 2.16 | 17 |
| September 27, 2000 | -1.87 | 1.87 | 2.29 | 9 |
| October 18, 2000 | -3.00 | 3.00 | 4.32 | 18 |

[a] Mean bias = simulated – measured

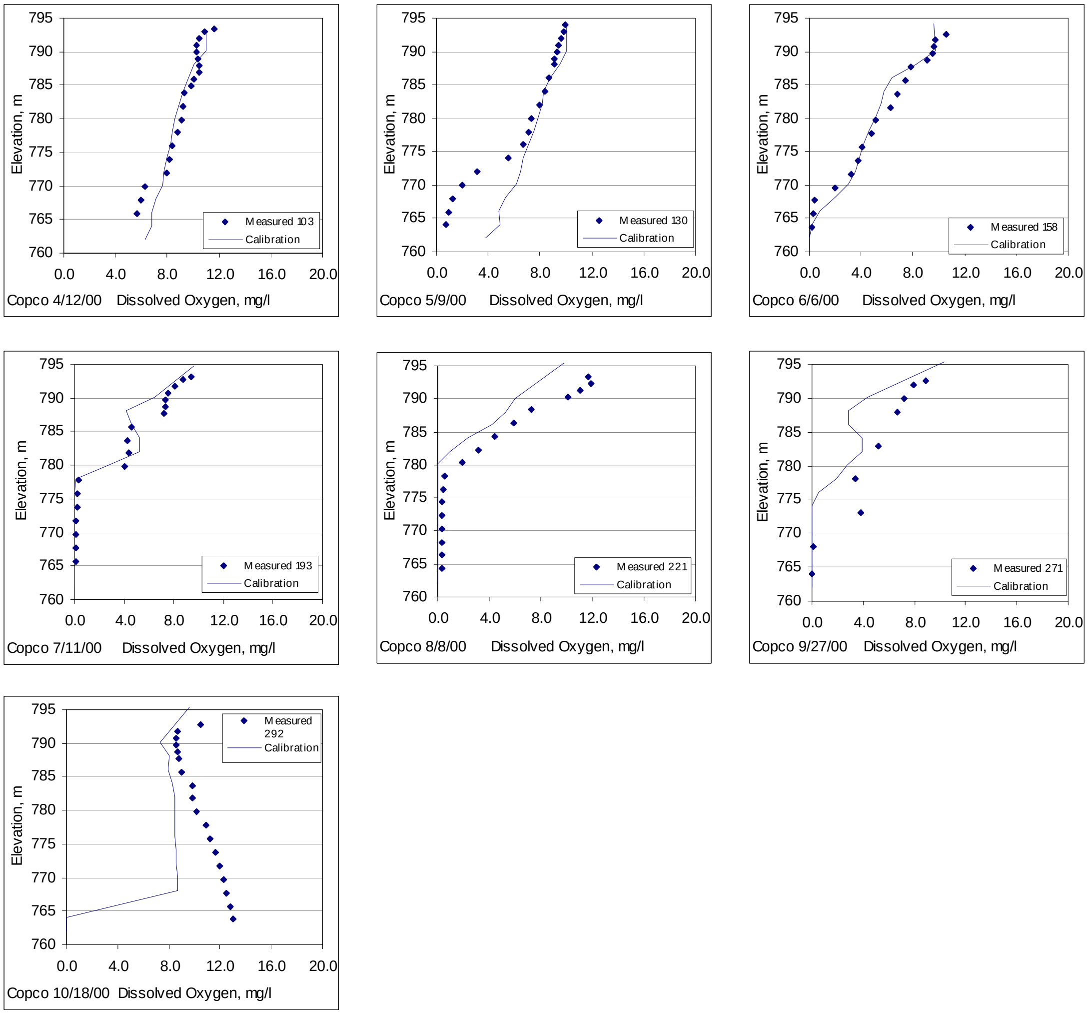



**Figure 105. Copco Reservoir dissolved oxygen profiles, simulated versus measured monthly values: 2000**

### 3.7.2.3 Nutrients

Nutrient concentrations were not formally calibrated in the Copco Reservoir reach. That is, values for nutrient interactions (e.g., stoichiometric equivalence with regard to primary production, decay rates and temperature rate constants) identified in the DO calibration were not modified, and other parameters were set at default values. Graphical results are presented in Figure 106 through Figure 109. Simulated coditions generally follow seasonal trends.

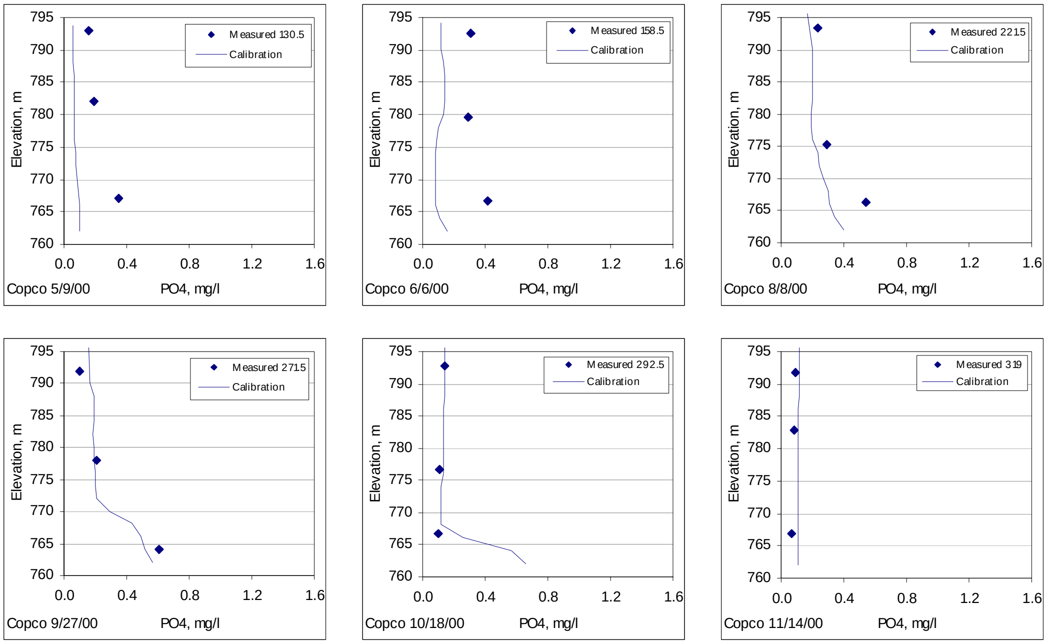



**Figure 106. Copco Reservoir phosphate profiles, simulated versus measured monthly values: 2000**

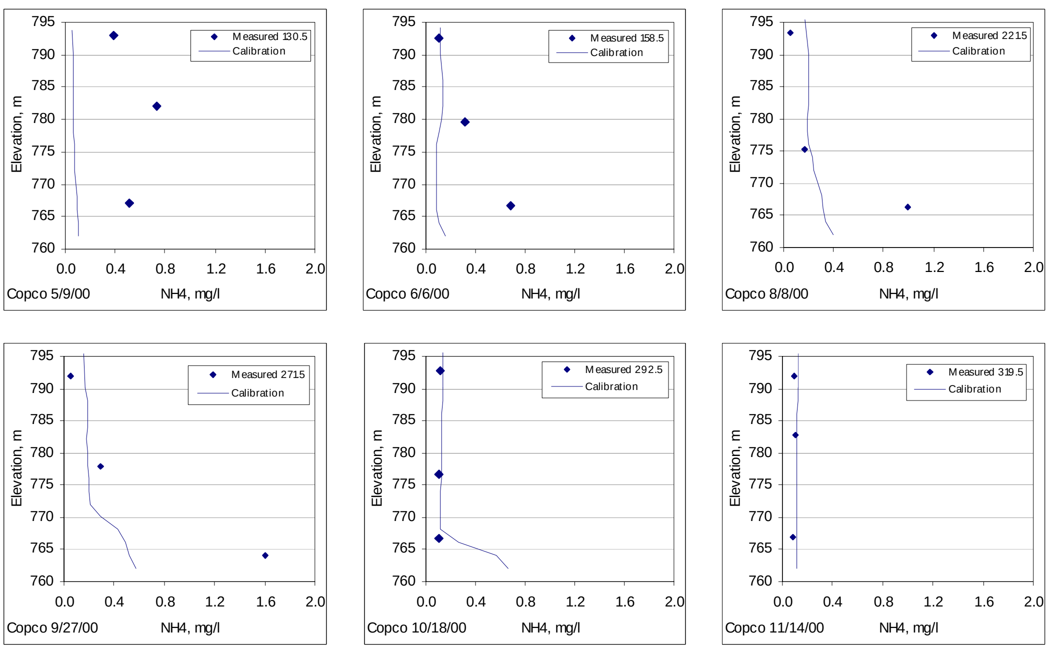



**Figure 107. Copco Reservoir ammonia profiles, simulated versus measured monthly values: 2000**

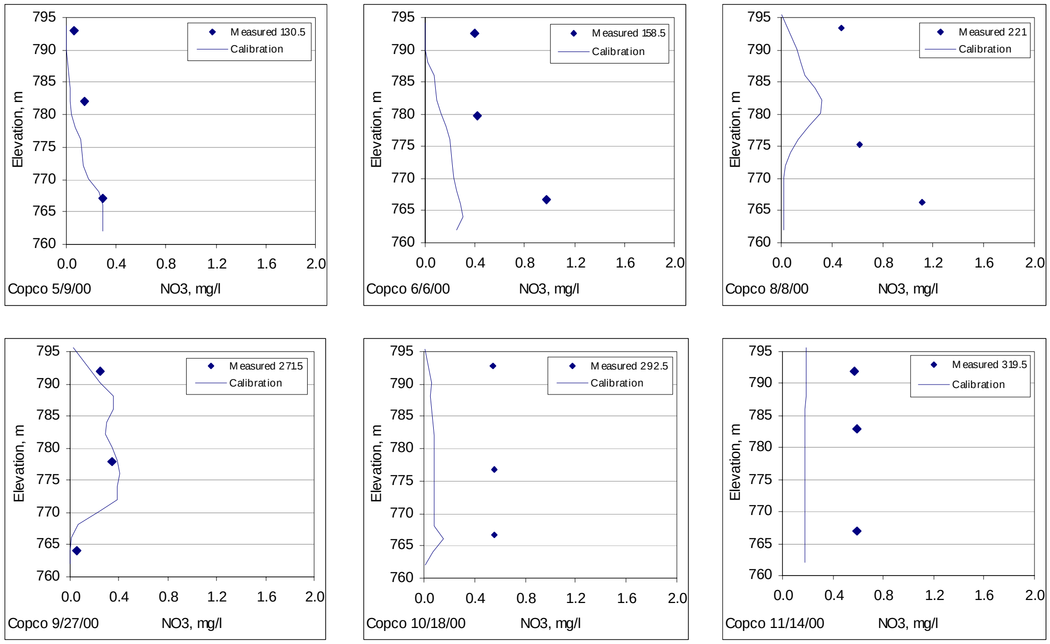



**Figure 108. Copco Reservoir nitrate profiles, simulated versus measured monthly values: 2000**

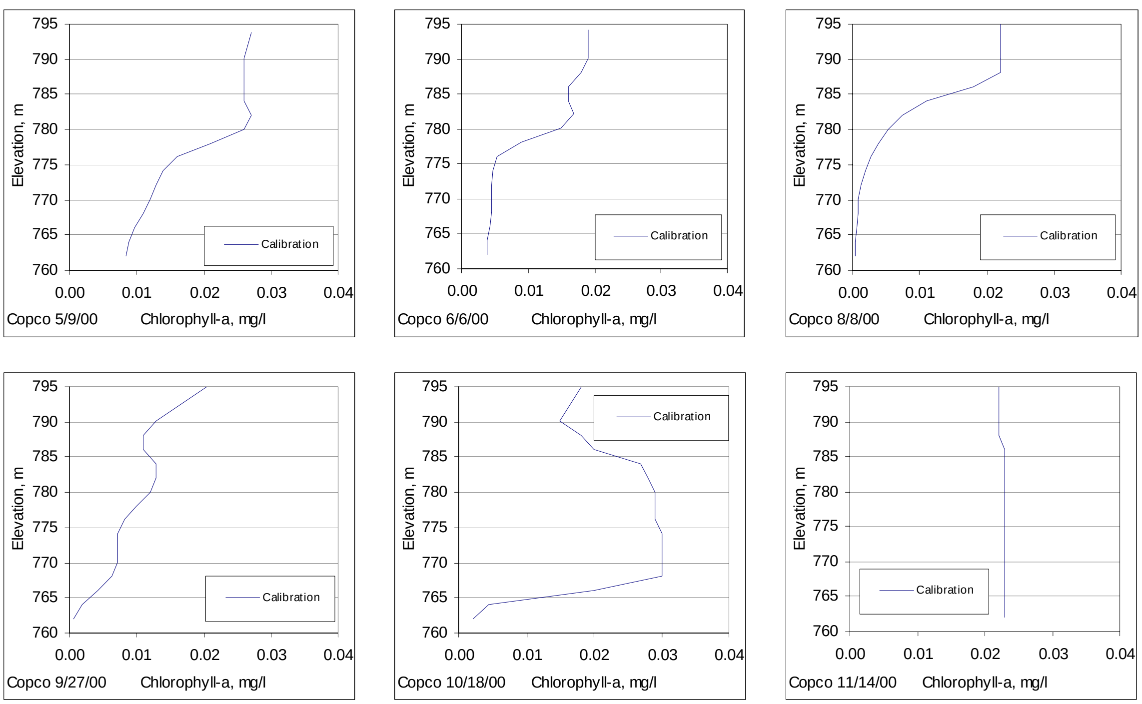



**Figure 109. Copco Reservoir chlorophyll-a profiles, simulated concentrations only: 2000**

### 3.7.2.4 Summary of Parameters

**Table 54. Significant control file parameters for the Copco Reservoir reach calibration**

| Parameter Name | Description | EC Copco Value | Default Values |
|---|---|---|---|
| DLT MIN | Minimum timestep, sec | 5.0 | N/A |
| DLT MAX | Maximum timestep, sec | 500 | N/A |
| SLOPE | Waterbody bottom slope | 0.0 | N/A |
| LAT | Latitude, degrees | 42.12 | N/A |
| LONG | Longitude, degrees | 122.33 | N/A |
| EBOT | Bottom elevation of waterbody, m | 761.09 | N/A |
| CFW | C coefficient in the wind speed formulation | 1.0 | 2.0 |
| WINDH | Wind speed measurement height, m | 2.0 | N/A |
| CBHE | Coefficient of bottom heat exchange, $W/m^2 sec$ | 3.0 | 7.0E-8 |
| TSED | Sediment (ground) Temperature, C | 10.0 | N/A |
| FI | Interfacial friction factor | 0.04 | N/A |
| TSEDF | Heat lost to sediments that is added back to water column, fraction | 0.01 | N/A |
| EXH20 | Extinction for pure water, $m^{-1}$ | 0.25 | 0.25 (Full WQ sim) |
| CGQ10 (Tracer) | Arhennius temperature rate multiplier | 0 | 0 |
| CG0DK (Tracer) | 0-order decay rate, 1/day | 0 | 0 |
| CG1DK (Tracer) | 1$^{st}$-order decay rate, 1/day | 0 | 0 |
| CGS (Tracer) | Settling rate, m/day | 0 | 0 |
| CGQ10 (Age) | Arhennius temperature rate multiplier | 0 | 0 |
| CG0DK (Age) | 0-order decay rate, 1/day | -1.0 | -1.0 |
| CG1DK (Age) | 1$^{st}$-order decay rate, 1/day | 0 | 0 |
| CGS (Age) | Settling rate, m/day | 0 | 0 |
| CGQ10 (Coliform) | Arhennius temperature rate multiplier | 1.04 | N/A |
| CG0DK (Coliform) | 0-order decay rate, 1/day | 0 | N/A |
| CG1DK (Coliform) | 1$^{st}$-order decay rate, 1/day | 1.4 | N/A |
| CGS (Coliform) | Settling rate, m/day | 1.0 | N/A |
| AG | Maximum algal growth rate, 1/day | 3.0 | 2.0 |
| AT1 | Lower temperature for algal growth, C | 5.0 | 5.0 |
| PO4R | Sediment release rate of phosphorus, fraction of SOD | 0.03 | 0.001 |
| PARTP | Phosphorus partitioning coefficient for suspended solids | 0.001 | 0.0 |
| NH4REL | Sediment release rate of ammonium, fraction of SOD | 0.07 | 0.001 |
| NH4DK | Ammonium decay rate, 1/day | 0.1 | 0.12 |
| NO3DK | Nitrate decay rate, 1/day | 0.1 | 0.03 |
| NO3S | De-nitrification rate from sediments, m/day | 0.0 | 1.0 |
| CO2REL | Sediment carbon dioxide release rate, fraction of sediment oxygen demand | 0.01 | 0.1 |
| O2AR | Oxygen stoichiometry for algal respiration | 1.4 | 1.1 |
| O2AG | Oxygen stoichiometry for algal primary production | 1.5 | 1.4 |
| SOD | Zero-order sediment oxygen demand for each segment, $g\ O_2 / m^2$ day | 2.0 (for each segment) | N/A |

## *3.8 Iron Gate Reservoir*

Iron Gate Reservoir was modeled using CE-QUAL-W2. Calibration occurred at selected dates in 2000. Validation has not occurred. Iron Gate Reservoir reach extends from the headwaters of Iron Gate Reservoir to Iron Gate Dam.

## 3.8.1 Data

Water quality conditions of water flowing into the reach (boundary conditions), initial status of the system (initial conditions), and intermediate points within the main stem (calibration/validation points) were required.

### 3.8.1.1 Boundary Conditions

The boundary condition information for Iron Gate Reservoir is passed from the Copco Reservoir reach simulation. The accretion / depletion, located at Jenny Creek, has the same concentrations as presented in the model implementation section.

### 3.8.1.2 Initial conditions

The residence time for Iron Gate Reservoir is approximately 10 days in the winter. Thus initial conditions under this short residence time and isothermal conditions are presumed to wash out of the system in a few weeks.

## 3.8.2 Results

Calibration and validation were completed for temperature and dissolved oxygen as primary constituents and inorganic nutrient forms (ammonia, nitrate, orthophosphate) as secondary constituents. Field observations for temperature and dissolved oxygen were typically available from water quality probes on an hourly interval, allowing for summary statistics to be calculated both on an hourly and daily basis. The nutrient data were primarily derived from field data, which were typically sampled once per day. All model parameters for the Iron Gate Reservoir reach are summarized in Table 57, at the end of this section.

### 3.8.2.1 Water Temperature

The water temperature was calibrated using the three user specified wind evaporation coefficients available in CE-QUAL-W2. Results are shown in Figure 110 and summary statistics are included in Table 55. Iron Gate Reservoir experiences seasonal stratification and the model replicates this stratification. The profile bias ranged from –1.06°C to 1.42°C and the mean absolute error ranged from 0.46°C to 1.42°C. Overall the model is within about 2°C of observations.

**Table 55. Iron Gate Reservoir thermal profile summary statistics: simulated versus measured**

| Date | Mean Bias[a] (˚C) | Mean Absolute Error (˚C) | Root Mean Squared Error (˚C) | n |
|---|---|---|---|---|
| April 12, 2000 | 0.24 | 1.16 | 1.28 | 26 |
| May 9, 2000 | 1.06 | 1.06 | 1.22 | 24 |
| June 6, 2000 | 1.42 | 1.42 | 1.70 | 23 |
| July 11, 2000 | 0.26 | 0.46 | 0.50 | 23 |
| August 8, 2000 | 0.53 | 0.75 | 0.91 | 23 |
| September 10, 2000 | 0.34 | 0.93 | 1.21 | 12 |
| September 27, 2000 | -0.80 | 0.91 | 1.26 | 19 |
| October 18, 2000 | -1.06 | 1.06 | 1.31 | 22 |

[a] Mean bias = simulated – measured

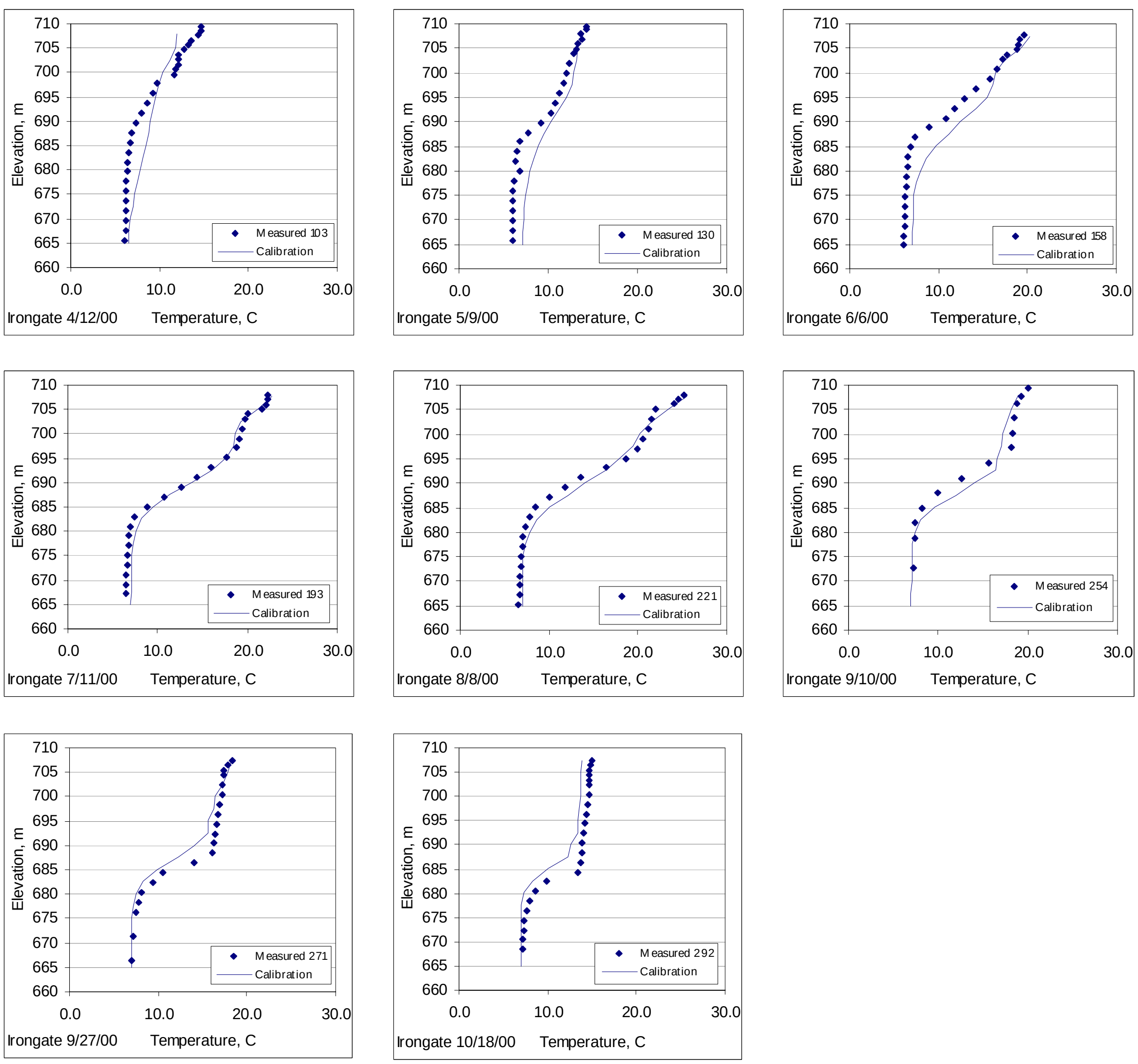


**Figure 110. Iron Gate Reservoir thermal profiles, simulated versus measured monthly values: 2000**

### 3.8.2.2 Dissolved Oxygen

The dissolved oxygen was calibrated using several different parameters, including algal rates, organic matter decay rates and nutrient decay rates. A zero order SOD representation was employed in calibrating dissolved oxygen. Results are shown in Figure 111 and summary statistics are included in Table 56. Iron Gate Reservoir dissolved oxygen concentrations experience significant seasonal deviations from saturated conditions. The seasonal anoxia in timing and extent is well represented in simulated results, with the exception of October when anoxia persists longer than the last observed data suggest. The profile bias ranged from –1.12 mg/l to 3.20 mg/l and the mean absolute error ranged from 0.94 mg/l to 3.20 mg/l. Overall the model is within about 5 mg/l of observations.

**Table 56. Iron Gate Reservoir dissolved oxygen profile summary statistics: simulated versus measured**

| Date | Mean Bias[a] (mg/l) | Mean Absolute Error (mg/l) | Root Mean Squared Error (mg/l) | n |
|---|---|---|---|---|
| April 12, 2000 | -1.12 | 1.51 | 1.74 | 26 |
| May 9, 2000 | 0.54 | 0.94 | 1.07 | 24 |
| June 6, 2000 | 0.17 | 0.94 | 1.09 | 23 |
| July 11, 2000 | 0.02 | 1.00 | 1.26 | 23 |
| August 8, 2000 | 0.25 | 1.77 | 2.38 | 23 |
| September 10, 2000 | 3.20 | 3.20 | 4.61 | 12 |
| September 27, 2000 | 1.00 | 1.40 | 2.15 | 19 |
| October 18, 2000 | 0.66 | 2.53 | 2.81 | 22 |

[a] Mean bias = simulated – measured

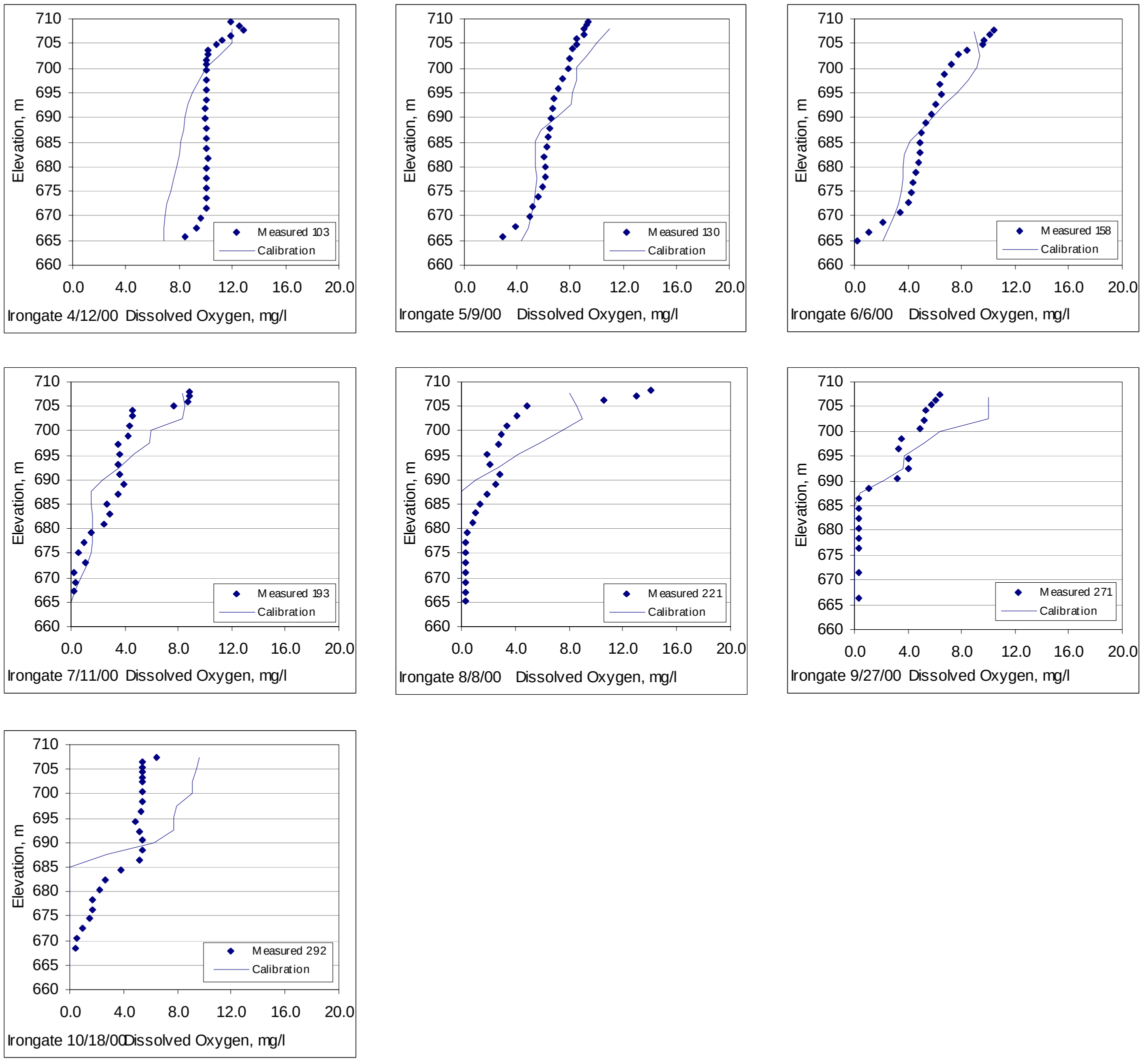



**Figure 111. Iron Gate Reservoir dissolved oxygen profiles, simulated versus measured monthly values: 2000**

### 3.8.2.3 Nutrients

Nutrient concentrations were not actively calibrated in the Iron Gate Reservoir reach. That is, values for nutrient interactions (e.g., stoichiometric equivalence with regard to primary production, decay rates and temperature rate constants) identified in the DO calibration were not modified, and other parameters were set at default values.

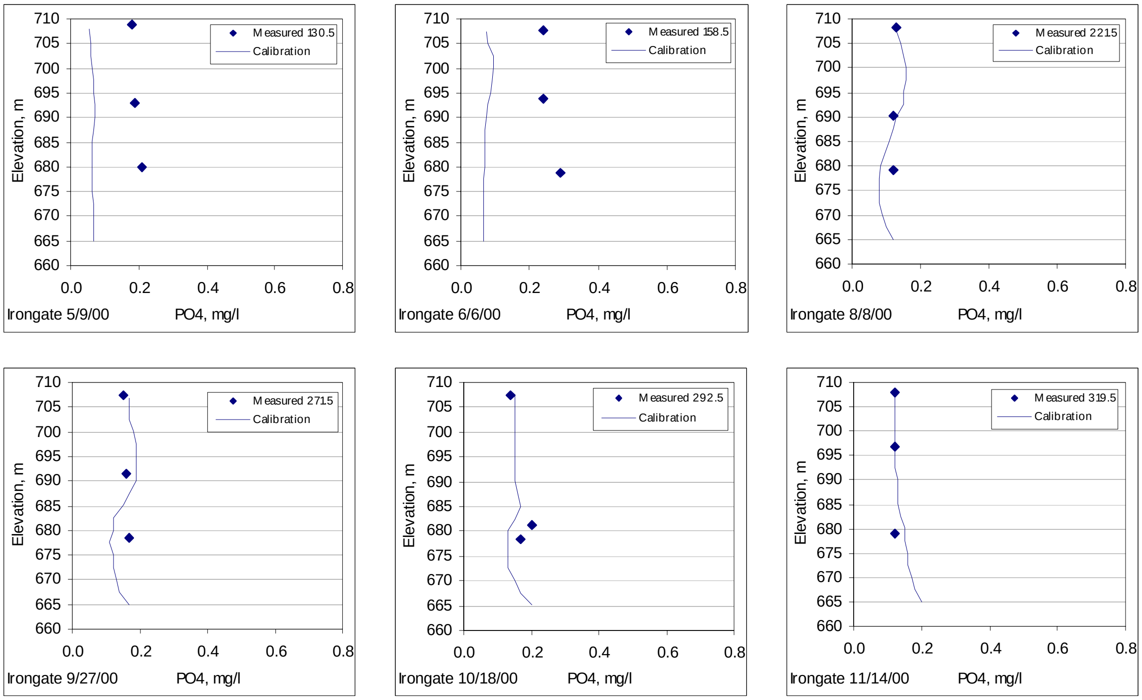



**Figure 112. Iron Gate Reservoir phosphate profiles, simulated versus measured monthly values: 2000**

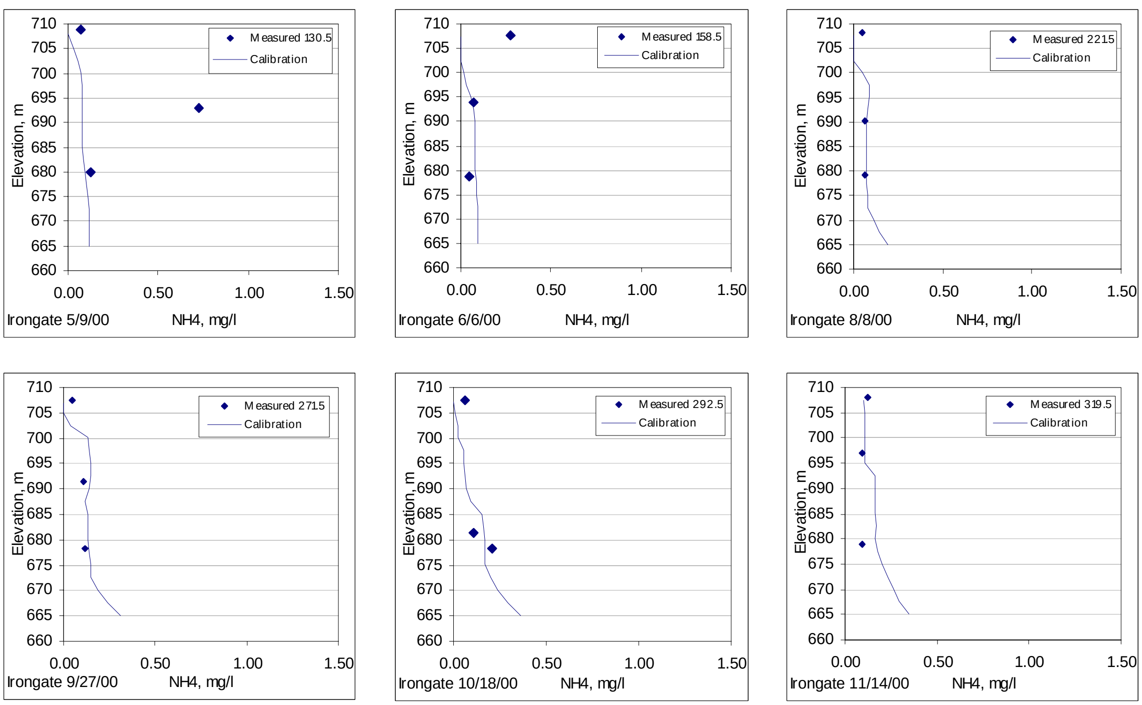



**Figure 113. Iron Gate Reservoir ammonia profiles, simulated versus measured monthly values: 2000**

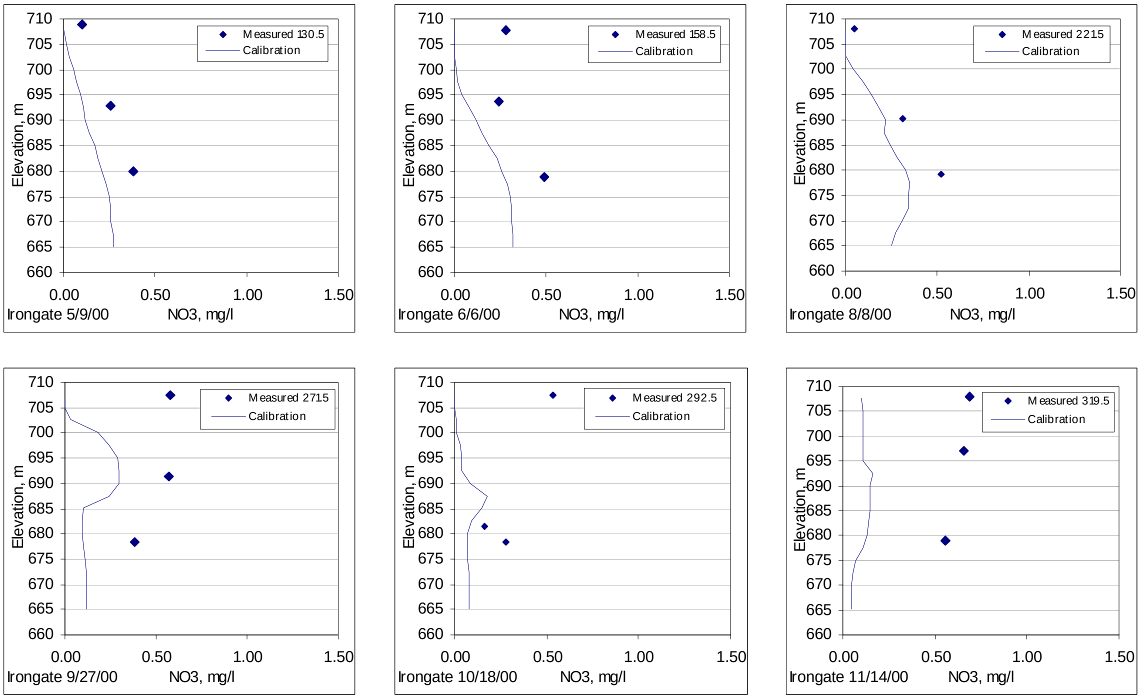



**Figure 114. Iron Gate Reservoir nitrate profiles, simulated versus measured monthly values: 2000**

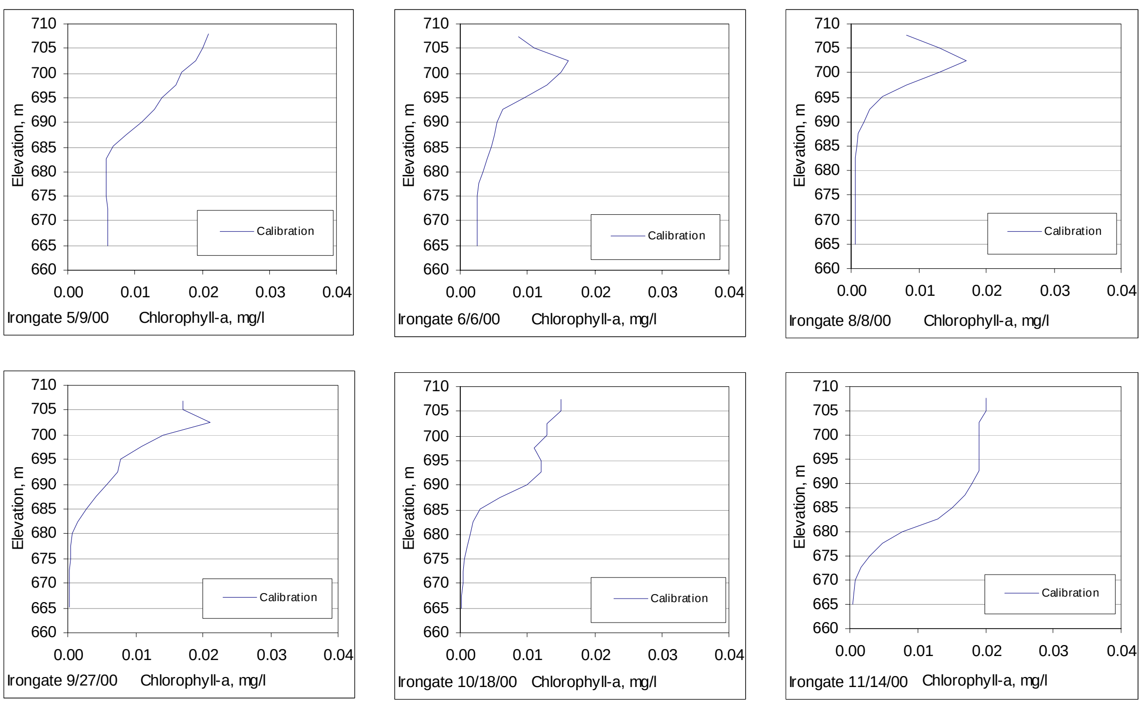



**Figure 115. Iron Gate Reservoir chlorophyll-a profiles, simulated concentrations only: 2000**

### 3.8.2.4 Summary of Parameters

**Table 57. Significant control file parameters in the Iron Gate Reservoir calibration**

| Parameter Name | Description | EC Iron Gate Value | Default Value |
|---|---|---|---|
| DLT MIN | Minimum timestep, sec | 5.0 | N/A |
| DLT MAX | Maximum timestep, sec | 500 | N/A |
| SLOPE | Waterbody bottom slope | 0.0 | N/A |
| LAT | Latitude, degrees | 42.97 | N/A |
| LONG | Longitude, degrees | 122.42 | N/A |
| EBOT | Bottom elevation of waterbody, m | 663.78 | N/A |
| AFW | A coefficient in the wind speed formulation | 6.0 | |
| CFW | C coefficient in the wind speed formulation | 1.0 | 2.0 |
| WINDH | Wind speed measurement height, m | 2.0 | N/A |
| CBHE | Coefficient of bottom heat exchange, $W/m^2 sec$ | 17.14 | 7.0-8 |
| TSED | Sediment (ground) Temperature, C | 7.0 | N/A |
| FI | Interfacial friction factor | 0.04 | N/A |
| TSEDF | Heat lost to sediments that is added back to water column, fraction | 0.01 | N/A |
| EXH20 | Extinction for pure water, $m^{-1}$ | 0.25 | 0.25 (for Full WQ sim) |
| CGQ10 (CG1) | Arhennius temperature rate multiplier | 0 | 0 |
| CG0DK (CG1) | 0-order decay rate, 1/day | 0 | 0 |
| CG1DK (CG1) | $1^{st}$-order decay rate, 1/day | 0 | 0 |
| CGS (CG1) | Settling rate, m/day | 0 | 0 |
| CGQ10 (CG2) | Arhennius temperature rate multiplier | 0 | 0 |
| CG0DK (CG2) | 0-order decay rate, 1/day | -1.0 | -1.0 |
| CG1DK (CG2) | $1^{st}$-order decay rate, 1/day | 0 | 0 |
| CGS (CG2) | Settling rate, m/day | 0 | 0 |
| CGQ10 (CG3) | Arhennius temperature rate multiplier | 1.04 | N/A |
| CG0DK (CG3) | 0-order decay rate, 1/day | 0 | N/A |
| CG1DK (CG3) | $1^{st}$-order decay rate, 1/day | 1.4 | N/A |
| CGS (CG3) | Settling rate, m/day | 1.0 | N/A |
| AG | Maximum algal growth rate, 1/day | 3.0 | 2.0 |
| AT1 | Lower temperature for algal growth, C | 5.0 | 5.0 |
| PO4R | Sediment release rate of phosphorus, fraction of SOD | 0.03 | 0.001 |
| PARTP | Phosphorus partitioning coefficient for suspended solids | 0.001 | 0.0 |
| NH4REL | Sediment release rate of ammonium, fraction of SOD | 0.07 | 0.001 |
| NH4DK | Ammonium decay rate, 1/day | 0.1 | 0.12 |
| NO3DK | Nitrate decay rate, 1/day | 0.1 | 0.03 |
| NO3S | De-nitrification rate from sediments, m/day | 0.0 | 1.0 |
| CO2REL | Sediment carbon dioxide release rate, fraction of sediment oxygen demand | 0.01 | 0.1 |
| O2AR | Oxygen stoichiometry for algal respiration | 1.4 | 1.1 |
| O2AG | Oxygen stoichiometry for algal primary production | 1.5 | 1.4 |
| SOD | Zero-order sediment oxygen demand for each segment, g $O_2$ / $m^2$ day | 3.0 (for each segment) | N/A |

## 3.9 Iron Gate Dam to Turwar

The RMA suite of models for the Klamath River from Iron Gate Dam (RM 190) to Seiad Valley (RM 129) was initially calibrated for June 5-7, 2000 (Julian Day 157-159) and August 7-9, 2000 (JD 220-222), respectively. To calibrate the lower river and further test the model, field data was collected from 12 locations between Iron Gate Dam and Turwar, including major tributaries, in 2003. Field data was collected June 9-12, 2003 (JD 160-164) and August 18-21, 2003 (JD 230-234). The 2003 period was used as the final calibration data set; however, 2000 results are included to illustrate model performance over a wider range of conditions. The 2000 data are presented in less detail following the 2003 results.

### 3.9.1 Data: 2003

Water quality conditions of water flowing into the reach (boundary conditions), initial status of the system (initial conditions), and observations in the Klamath River at several points were required (calibration / validation points).

#### 3.9.1.1 Boundary Conditions: 2003

Boundary conditions were required for all inflows into the reach, including the main inflow from Iron Gate Dam and twenty of the twenty-three tributaries modeled in the reach (three tributaries were not assigned temperature, dissolved oxygen or constituent concentrations due to their relatively small size, especially in summer: Willow, Cottonwood, and Humbug Creeks). Flow, temperature, dissolved oxygen and other water quality conditions for the 2003 period are presented below.

**Flow**

The Iron Gate Dam to Turwar reach includes 23 inflows in addition to the headwater boundary condition at Iron Gate Dam. Measured gage flow at Klamath River below Iron Gate Dam (USGS gage 11516530) during the 2003 recalibration periods was used to designate flow from Iron Gate Dam (presented in Figure 116).

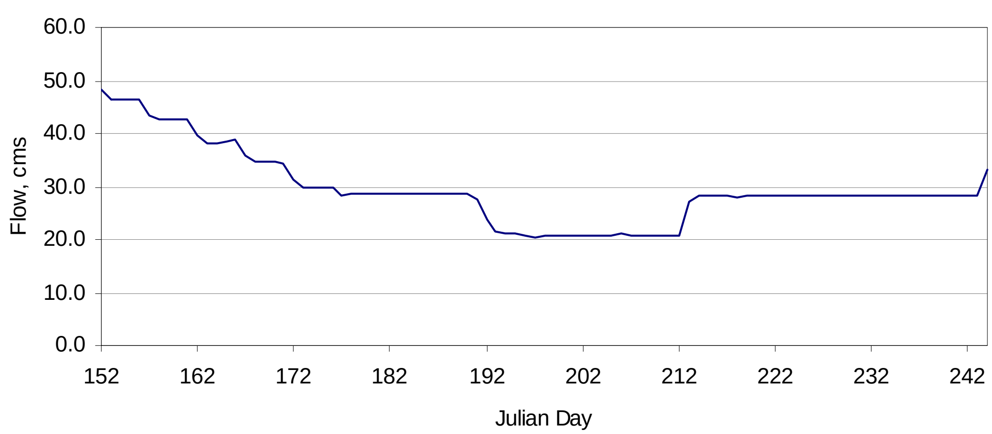


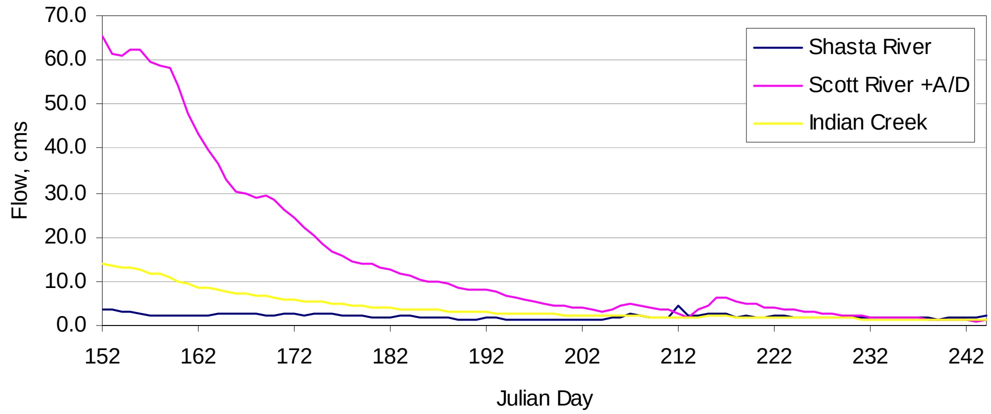

**Figure 116. Gauged flow at Klamath River below Iron Gate Dam for Iron Gate to Turwar reach model 2003 calibration**

There are 23 tributary flows in the IG-Turwar reach. Tributary contributions were assigned daily data based on USGS gages or daily average calculated flows based on accretion calculations. Table 17 summarizes the locations, model node and element information, and type of record employed.

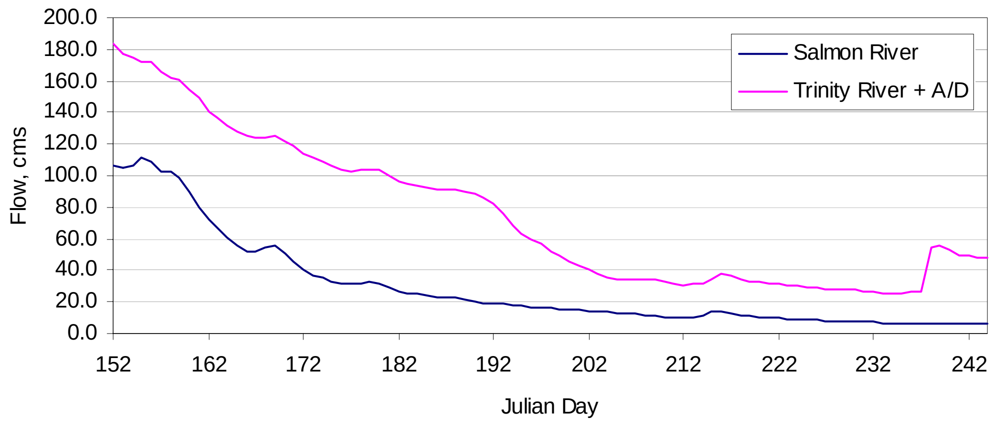
**Table 58. Element flow information for the IG-Turwar EC simulation**

| Location | Node | Element | Flow Type |
|---|---|---|---|
| Bogus Creek | 7 | 4 | Daily average |
| Willow Creek | 55 | 28 | Daily average |
| Cottonwood Creek | 86 | 43 | Daily average |
| Shasta River | 144 | 72 | Daily measured |
| Humbug Creek | 204 | 102 | Daily average |
| Beaver Creek | 319 | 160 | Daily average |
| Horse Creek | 468 | 234 | Daily average |
| Scott River (+ A/D) | 513 | 257 | Daily calculated |
| Grider Creek | 656 | 328 | Daily average |
| Thompson Creek | 735 | 368 | Daily average |
| Indian Creek | 906 | 453 | Daily measured |
| Elk Creek | 925 | 463 | Daily average |
| Clear Creek | 1000 | 500 | Daily average |
| Ukonom Creek | 1098 | 549 | Daily average |
| Dillon Creek | 1162 | 581 | Daily average |
| Salmon River | 1357 | 679 | Daily measured |
| Camp Creek | 1466 | 733 | Daily average |
| Red Cap Creek | 1511 | 756 | Daily average |
| Bluff Creek | 1547 | 774 | Daily average |
| Trinity River ( + A/D) | 1609 | 805 | Daily calculated |
| Pine Creek | 1644 | 822 | Daily average |
| Tectah Creek | 1850 | 925 | Daily average |
| Blue Creek | 1908 | 954 | Daily average |

The Shasta River daily flows were from USGS gage 11517500. The Scott + A/D daily flows were calculated from USGS gage 11519500 (Scott River daily flows) and A/D described below. The daily Indian Creek flows were from USGS gage 11521500. The Salmon River daily flows were from USGS gage 11522500. The Trinity + A/D daily flows were calculated from USGS gage 11530000 (Trinity River daily flows) and the A/D described below. For input into the water quality input file for RMA-11, the daily average flows were disaggregated to hourly flows using linear interpolation. Daily A/D flows were calculated as those for implementation of the reach, but were not averaged over 7 days. Weekly A/D flows were also calculated for use in the water quality input file for RMA-11. The daily inflows for the gauged tributaries are presented in Figure 117. The daily inflows for the minor tributaries are presented in Figure 118. The weekly inflows for the minor tributaries are presented in Table 59.

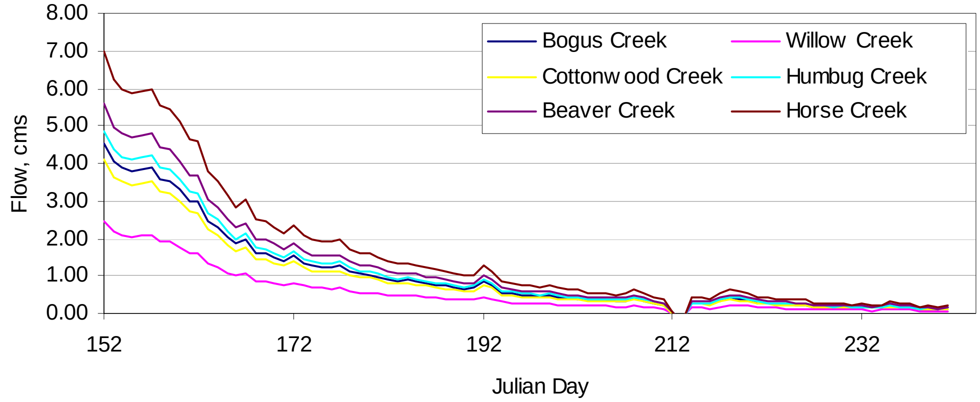



(a)

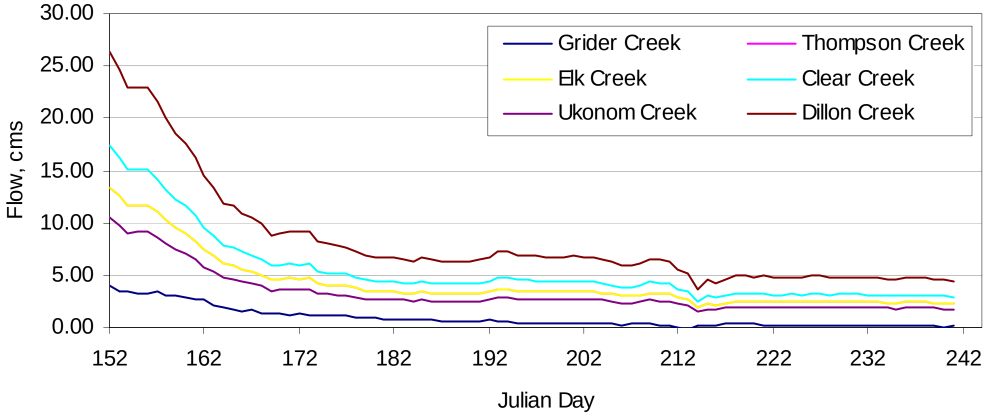



(b)

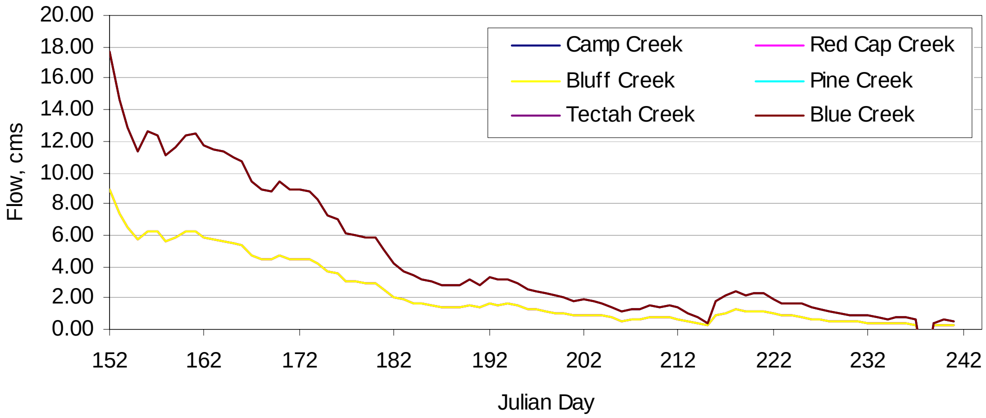
**Figure 117. Gauged tributary inflows for Iron Gate to Turwar reach model 2003 calibration: (a) Shasta River, Scott River and Indian Creek; (b) Salmon River and Trinity River**




(a)




(b)




(c)

**Figure 118. Minor tributary inflows for Iron Gate to Turwar 2003 calibration: (a) above Scott River; (b) between the Scott and the Salmon Rivers; (c) between the Salmon River and the mouth of the Klamath River.**

**Table 59. Weekly average minor tributary inflows for Iron Gate to Turwar reach model, for use in the water quality input files for RMA-11**

| | Flow, cms | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Julian Day** | **152** | **158** | **165** | **172** | **179** | **186** | **193** | **200** | **207** | **214** | **221** | **228** | **235** |
| Bogus Creek | 3.94 | 3.94 | 2.80 | 1.64 | 1.22 | 0.90 | 0.73 | 0.49 | 0.36 | 0.19 | 0.32 | 0.23 | 0.17 |
| Beaver Creek | 4.85 | 4.85 | 3.45 | 2.02 | 1.50 | 1.11 | 0.90 | 0.60 | 0.45 | 0.24 | 0.40 | 0.28 | 0.21 |
| Horse Creek | 6.07 | 6.07 | 4.32 | 2.52 | 1.88 | 1.39 | 1.12 | 0.75 | 0.56 | 0.30 | 0.50 | 0.35 | 0.26 |
| Grider Creek | 3.42 | 3.42 | 2.43 | 1.42 | 1.06 | 0.78 | 0.63 | 0.42 | 0.31 | 0.17 | 0.28 | 0.20 | 0.14 |
| Thompson Creek | 11.77 | 11.77 | 7.57 | 4.94 | 4.02 | 3.37 | 3.34 | 3.49 | 3.27 | 2.91 | 2.41 | 2.44 | 2.42 |
| Indian Creek | 12.78 | 12.78 | 9.03 | 6.62 | 5.06 | 3.84 | 3.16 | 2.67 | 2.22 | 1.93 | 2.05 | 1.76 | 1.55 |
| Elk Creek | 11.77 | 11.77 | 7.57 | 4.94 | 4.02 | 3.37 | 3.34 | 3.49 | 3.27 | 2.91 | 2.41 | 2.44 | 2.42 |
| Clear Creek | 15.18 | 15.18 | 9.76 | 6.37 | 5.18 | 4.34 | 4.31 | 4.50 | 4.21 | 3.75 | 3.10 | 3.15 | 3.12 |
| Ukonom Creek | 9.15 | 9.15 | 5.89 | 3.84 | 3.12 | 2.62 | 2.60 | 2.71 | 2.54 | 2.26 | 1.87 | 1.90 | 1.88 |
| Dillon Creek | 23.05 | 23.05 | 14.83 | 9.67 | 7.86 | 6.59 | 6.54 | 6.83 | 6.40 | 5.69 | 4.71 | 4.79 | 4.74 |
| Camp Creek | 6.63 | 6.63 | 5.86 | 4.67 | 3.54 | 2.05 | 1.49 | 1.27 | 0.79 | 0.63 | 0.97 | 0.76 | 0.41 |
| Red Cap Creek | 6.63 | 6.63 | 5.86 | 4.67 | 3.54 | 2.05 | 1.49 | 1.27 | 0.79 | 0.63 | 0.97 | 0.76 | 0.41 |
| Bluff Creek | 6.63 | 6.63 | 5.86 | 4.67 | 3.54 | 2.05 | 1.49 | 1.27 | 0.79 | 0.63 | 0.97 | 0.76 | 0.41 |
| Pine Creek | 13.22 | 13.22 | 11.67 | 9.30 | 7.06 | 4.09 | 2.97 | 2.53 | 1.57 | 1.26 | 1.94 | 1.51 | 0.83 |
| Tectah Creek | 13.22 | 13.22 | 11.67 | 9.30 | 7.06 | 4.09 | 2.97 | 2.53 | 1.57 | 1.26 | 1.94 | 1.51 | 0.83 |
| Blue Creek | 13.22 | 13.22 | 11.67 | 9.30 | 7.06 | 4.09 | 2.97 | 2.53 | 1.57 | 1.26 | 1.94 | 1.51 | 0.83 |

The downstream boundary for the Iron Gate to Turwar reach was not altered from the downstream boundary used in implementation of the reach.

## Temperature

Inflow temperatures for the upstream boundary condition were the hourly and half-hourly temperatures recorded by sondes deployed below Iron Gate Dam in June and August (shown in Figure 119 and Figure 120). The first full day of data is repeated for the four days previous to deployment to provide main inflow temperatures for the “warm up” period of the model. The source of records and final model inputs for major and minor tributaries are outlined below.

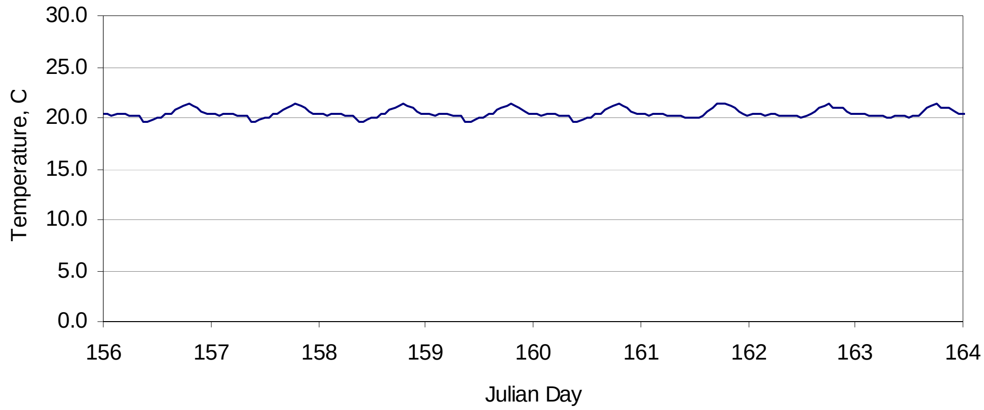



**Figure 119. Main inflow temperatures for Iron Gate to Turwar reach model (June 2003)**

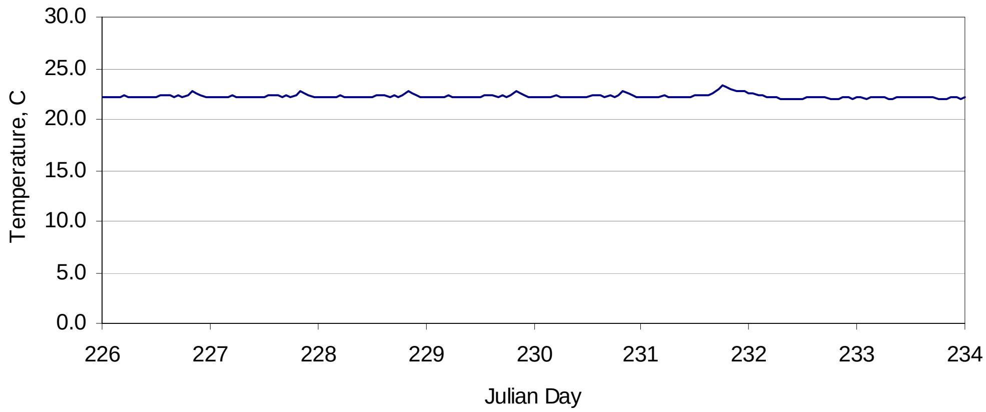



**Figure 120. Main inflow temperatures for Iron Gate to Turwar reach model (August 2003)**

## Major Tributaries

Sonde data collected in June and August in the Shasta River, Scott River, Salmon River and Trinity River provided hourly temperatures for recalibration of the Iron Gate Dam to Turwar reach (presented in Figure 121 through Figure 122). To provide data for the four days of model simulation that occur prior to the deployment of the sondes, the first day temperatures are repeated until the time of deployment for all major tributaries. The Scott River had some missing data due to deployment difficulties in June. The following day's temperatures were used to fill in the missing temperatures. The simulation periods last until midnight of the last day of deployment, although many of the sondes were not deployed at that point in time. If there was missing data, the temperatures were filled in with the last recorded temperature for the particular hour of the day until midnight was reached.

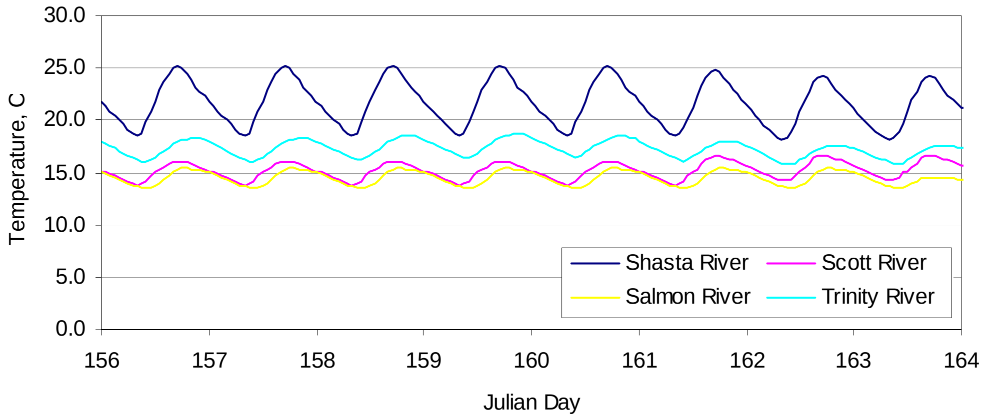



**Figure 121. Major tributary inflow temperatures for Iron Gate to Turwar reach model 2003 calibration (June 2003)**

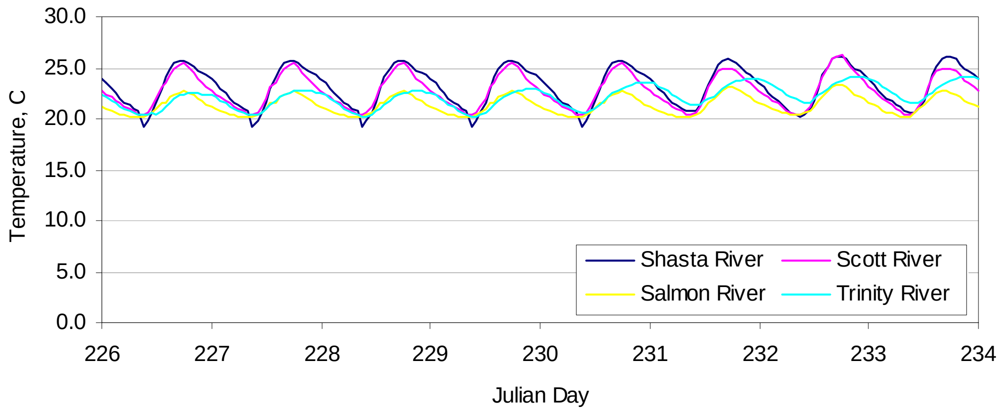



**Figure 122. Major tributary inflow temperatures for Iron Gate to Turwar reach model 2003 calibration (August 2003)**

## Minor Tributaries

The minor tributary temperatures used for the 2003 calibration of the Iron Gate to Turwar reach were those used for the 2000 calibration and are presented in the main model documentation. The monthly average temperatures used in the previous calibration were disaggregated to weekly averages using linear interpolation for use in the 2003 calibration. The weekly average temperatures are presented in Table 60.

**Table 60. Minor tributary inflow temperatures for Iron Gate to Turwar reach 2003 model calibration**

| | Temperature, °C | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Julian Day** | **152** | **158** | **165** | **172** | **179** | **186** | **193** | **200** | **207** | **214** | **221** | **228** | **235** |
| Bogus Creek | 12.60 | 12.66 | 12.74 | 12.98 | 13.28 | 13.58 | 13.89 | 14.10 | 14.20 | 14.30 | 14.40 | 14.50 | 14.03 |
| Beaver Creek | 9.96 | 10.44 | 11.00 | 11.64 | 12.31 | 12.98 | 13.65 | 14.18 | 14.52 | 14.86 | 15.21 | 15.55 | 15.27 |
| Horse Creek | 9.92 | 10.39 | 10.93 | 11.43 | 11.91 | 12.38 | 12.86 | 13.22 | 13.44 | 13.65 | 13.87 | 14.08 | 13.98 |
| Grider Creek | 9.92 | 10.39 | 10.93 | 11.96 | 13.18 | 14.40 | 15.61 | 16.36 | 16.47 | 16.59 | 16.70 | 16.82 | 16.17 |
| Thompson Creek | 12.58 | 13.19 | 13.90 | 14.31 | 14.61 | 14.90 | 15.20 | 15.51 | 15.83 | 16.15 | 16.47 | 16.79 | 16.56 |
| Indian Creek | 10.22 | 10.78 | 11.42 | 12.49 | 13.72 | 14.95 | 16.18 | 17.03 | 17.37 | 17.72 | 18.06 | 18.41 | 17.80 |
| Elk Creek | 9.92 | 10.39 | 10.93 | 12.18 | 13.70 | 15.23 | 16.75 | 17.67 | 17.79 | 17.91 | 18.03 | 18.15 | 17.43 |
| Clear Creek | 10.41 | 11.03 | 11.75 | 12.60 | 13.49 | 14.38 | 15.27 | 15.93 | 16.27 | 16.61 | 16.95 | 17.29 | 16.79 |
| Ukonom Creek | 9.48 | 9.97 | 10.55 | 11.10 | 11.65 | 12.19 | 12.74 | 13.14 | 13.34 | 13.54 | 13.75 | 13.95 | 13.59 |
| Dillon Creek | 14.02 | 14.61 | 15.29 | 16.28 | 17.38 | 18.48 | 19.58 | 20.05 | 19.68 | 19.32 | 18.95 | 18.58 | 18.21 |
| Camp Creek | 12.58 | 13.19 | 13.90 | 14.31 | 14.61 | 14.90 | 15.20 | 15.51 | 15.83 | 16.15 | 16.47 | 16.79 | 16.56 |
| Red Cap Creek | 14.02 | 14.61 | 15.29 | 16.29 | 17.41 | 18.54 | 19.66 | 20.21 | 20.00 | 19.79 | 19.58 | 19.37 | 18.75 |
| Bluff Creek | 12.58 | 13.19 | 13.90 | 14.31 | 14.61 | 14.90 | 15.20 | 15.51 | 15.83 | 16.15 | 16.47 | 16.79 | 16.56 |
| Pine Creek | 12.58 | 13.19 | 13.90 | 14.31 | 14.61 | 14.90 | 15.20 | 15.51 | 15.83 | 16.15 | 16.47 | 16.79 | 16.56 |
| Tectah Creek | 11.31 | 11.79 | 12.35 | 12.71 | 13.00 | 13.28 | 13.57 | 13.77 | 13.85 | 13.93 | 14.02 | 14.10 | 14.19 |
| Blue Creek | 12.58 | 13.19 | 13.90 | 14.31 | 14.61 | 14.90 | 15.20 | 15.51 | 15.83 | 16.15 | 16.47 | 16.79 | 16.56 |

## Constituent Concentrations

Constituent concentrations for the tributary inflows between Iron Gate Dam and the Pacific Ocean were assigned for all streams identified in Table 17 with the exception of Willow, Cottonwood, and Humbug Creeks.  There was no data available for these tributaries and they contribute only minor flow in the summer months.

Dissolved oxygen concentrations were recorded by sonde below Iron Gate Dam. The first four days of model data are the first day of recorded data repeated to provide dissolved oxygen concentrations for the main inflow during the “warm up” period of the model. The model input dissolved oxygen concentrations are presented in Figure 123.

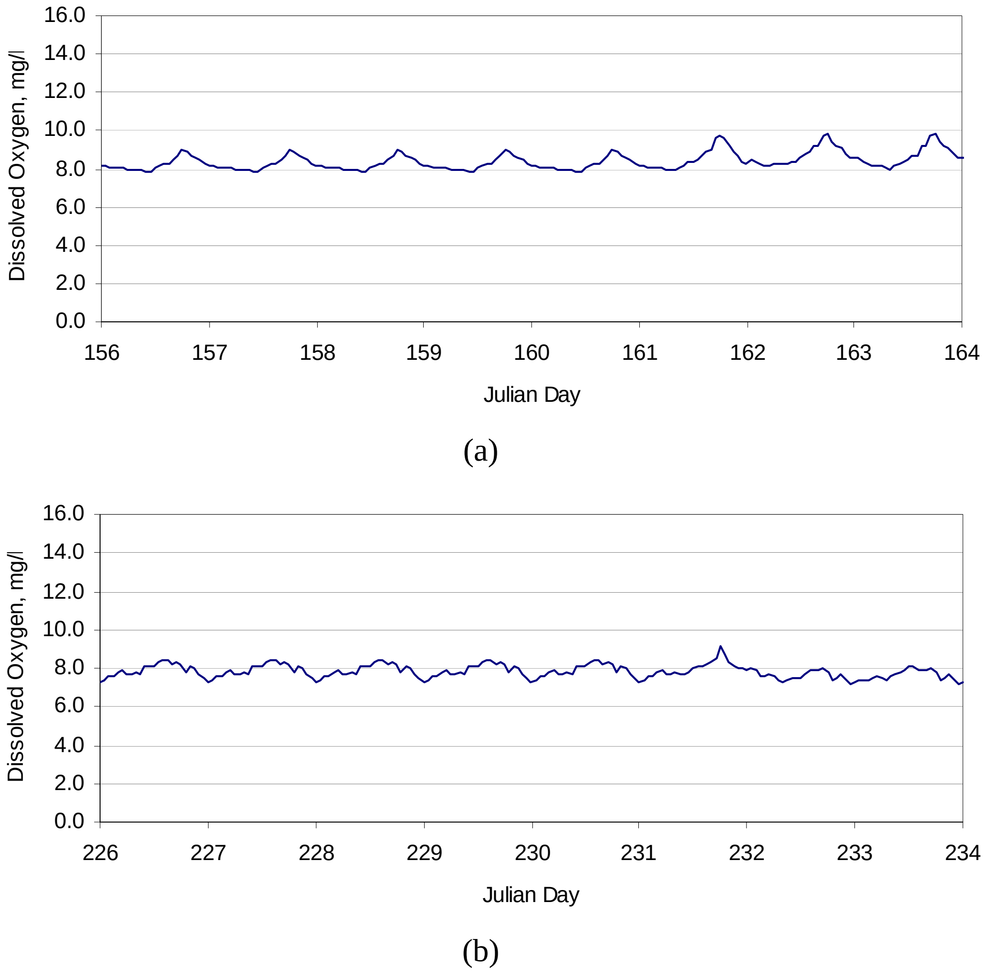
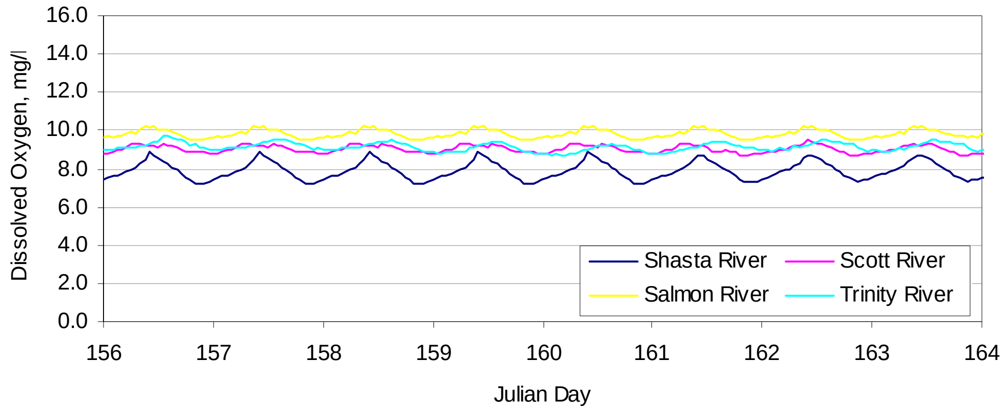
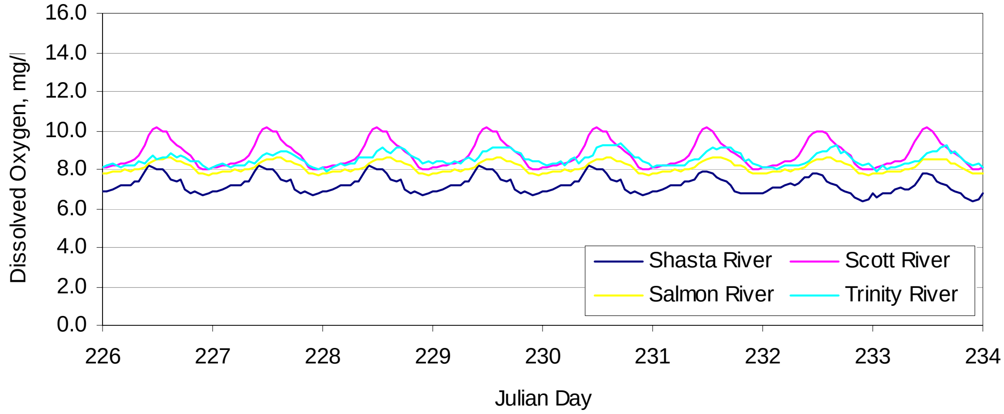



**Figure 123. Klamath River below Iron Gate Dam dissolved oxygen concentrations for: (a) June 2003; (b) August 2003**

Dissolved oxygen concentrations for the 2003 were those recorded by sondes for the major tributaries on the hourly (Shasta, Scott, Salmon, and Trinity Rivers) or those calculated in model implementation for the minor tributaries (all remaining tributaries). The dissolved oxygen concentrations recorded by sonde were adjusted for biofouling when appropriate (as discussed in Technical Memorandum 6). The calculated monthly average dissolved oxygen concentrations were disaggregated to weekly averages by linear interpolation. Hourly dissolved oxygen concentrations are presented in Figure 124. Weekly average dissolved oxygen concentrations are presented in Table 61.




(a)




(b)

**Figure 124. Major tributary dissolved oxygen concentrations for Iron Gate to Turwar reach model calibration: (a) June 2003; (b) August 2003**

**Table 61. Minor tributary inflow dissolved oxygen concentrations for Iron Gate to Turwar reach model**

| | Dissolved Oxygen, mg/l | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Julian Day** | **152** | **158** | **165** | **172** | **179** | **186** | **193** | **200** | **207** | **214** | **221** | **228** | **235** |
| Bogus Creek | 10.02 | 10.01 | 9.99 | 9.94 | 9.87 | 9.81 | 9.74 | 9.69 | 9.67 | 9.65 | 9.63 | 9.61 | 9.71 |
| Beaver Creek | 10.66 | 10.54 | 10.40 | 10.25 | 10.10 | 9.95 | 9.80 | 9.68 | 9.61 | 9.53 | 9.46 | 9.39 | 9.45 |
| Horse Creek | 10.68 | 10.56 | 10.42 | 10.30 | 10.19 | 10.08 | 9.97 | 9.89 | 9.84 | 9.79 | 9.75 | 9.70 | 9.72 |
| Grider Creek | 10.68 | 10.56 | 10.42 | 10.19 | 9.92 | 9.66 | 9.39 | 9.23 | 9.21 | 9.19 | 9.16 | 9.14 | 9.27 |
| Thompson Creek | 10.39 | 10.24 | 10.08 | 9.99 | 9.92 | 9.86 | 9.80 | 9.73 | 9.67 | 9.60 | 9.54 | 9.47 | 9.52 |
| Indian Creek | 10.97 | 10.82 | 10.66 | 10.42 | 10.15 | 9.88 | 9.60 | 9.42 | 9.35 | 9.29 | 9.22 | 9.15 | 9.27 |
| Elk Creek | 11.04 | 10.92 | 10.78 | 10.50 | 10.16 | 9.83 | 9.49 | 9.29 | 9.27 | 9.25 | 9.22 | 9.20 | 9.35 |
| Clear Creek | 10.92 | 10.76 | 10.57 | 10.38 | 10.18 | 9.98 | 9.78 | 9.64 | 9.57 | 9.51 | 9.44 | 9.37 | 9.47 |
| Ukonom Creek | 11.16 | 11.03 | 10.87 | 10.74 | 10.61 | 10.48 | 10.34 | 10.25 | 10.20 | 10.15 | 10.11 | 10.06 | 10.14 |
| Dillon Creek | 10.05 | 9.92 | 9.77 | 9.58 | 9.37 | 9.16 | 8.95 | 8.86 | 8.92 | 8.99 | 9.05 | 9.12 | 9.19 |
| Camp Creek | 10.39 | 10.24 | 10.08 | 9.99 | 9.92 | 9.86 | 9.80 | 9.73 | 9.67 | 9.60 | 9.54 | 9.47 | 9.52 |
| Red Cap Creek | 10.05 | 9.92 | 9.77 | 9.58 | 9.36 | 9.15 | 8.93 | 8.83 | 8.86 | 8.90 | 8.94 | 8.98 | 9.10 |
| Bluff Creek | 10.39 | 10.24 | 10.08 | 9.99 | 9.92 | 9.86 | 9.80 | 9.73 | 9.67 | 9.60 | 9.54 | 9.47 | 9.52 |
| Pine Creek | 10.63 | 10.48 | 10.31 | 10.21 | 10.15 | 10.08 | 10.02 | 9.95 | 9.89 | 9.82 | 9.76 | 9.69 | 9.74 |
| Tectah Creek | 10.93 | 10.81 | 10.67 | 10.58 | 10.52 | 10.45 | 10.39 | 10.34 | 10.32 | 10.30 | 10.28 | 10.26 | 10.24 |
| Blue Creek | 10.63 | 10.48 | 10.31 | 10.21 | 10.15 | 10.08 | 10.02 | 9.95 | 9.89 | 9.82 | 9.76 | 9.69 | 9.74 |

Other constituent concentrations for the main inflow and major tributaries were either based on grab samples taken during the summer of 2003 or were those concentrations used in the previous calibration effort. Concentrations based on 2003 grab samples are presented in Table 62 and Table 63.

**Table 62. Main inflow and major tributary constituent concentrations based on 2003 grab sample data, June 2003**

| | **Ammonia as N** | **Nitrate as N** | **Ortho Phosphate as P** | **Organic Nitrogen** | **Organic Phosphorus** | **Algae** | **BOD** |
|---|---|---|---|---|---|---|---|
| **Site Name** | **mg/L** | **mg/L** | **mg/L** | **mg/l** | **mg/l** | **mg/l** | **mg/l** |
| KR below Iron Gate Dam | 0.10 | 0.15 | 0.08 | 0.93 | 0.06 | 0.28 | 2 |
| Shasta River | 0.10 | 0.01 | 0.17 | 1.01 | 0.04 | 0.02 | 2 |
| Scott River | 0.10 | 0.11 | 0.05 | 0.79 | 0.00 | 0.03 | 2 |
| Salmon River | 0.10 | 0.01 | 0.05 | 0.86 | 0.00 | 0.00 | 2 |
| Trinity River | 0.10 | 0.01 | 0.05 | 0.84 | 0.00 | 0.02 | 2 |

**Table 63. Main inflow and major tributary constituent concentrations based on 2003 grab sample data, August 2003**

| Site Name | Ammonia as N mg/L | Nitrate as N mg/L | Ortho Phosphate as P mg/L | Organic Nitrogen mg/l | Organic Phosphorus mg/l | Algae mg/l | BOD mg/l |
|---|---|---|---|---|---|---|---|
| KR below Iron Gate Dam | 0.10 | 0.27 | 0.12 | 0.65 | 0.02 | 0.30 | 5 |
| Shasta River | 0.10 | 0.01 | 0.20 | 0.45 | 0.00 | 0.02 | 2 |
| Scott River | 0.10 | 0.14 | 0.05 | 0.40 | 0.00 | 0.03 | 2 |
| Salmon River | 0.10 | 0.01 | 0.05 | 0.40 | 0.00 | 0.00 | 2 |
| Trinity River | 0.10 | 0.01 | 0.05 | 0.40 | 0.00 | 0.02 | 2 |

Other constituent concentrations for minor tributaries were those used for model implementation and the previous calibration effort and are presented in the main model documentation.

#### 3.9.1.2 Initial Conditions

The model was run for four days prior for the 2003 period (approximate travel time to mouth) to provide an initial condition for simulations. The initial bed algae mass was estimated at 5 $g/m^2$. Where field data were unavailable, the conditions of the first day of available field data were applied.

#### 3.9.1.3 Meteorological Data

The meteorological data for the 2003 calibration was processed in the same manner as identified above under model implementation, using 2003 meteorological data from the KLFO station in Klamath Falls, Oregon.

### 3.9.2 Model Output Locations: 2003

The calibration locations for the Iron Gate to Turwar reach are presented in Table 64. There was additional temperature and dissolved oxygen collected from deployed sondes during June at Klamath River at Aikens Hole, but that data was not used for formal calibration of the reach. The recorded data are presented in the following section with model results.

All water quality probes and grab samples were collected from near-shore areas and although all efforts were made to identify locations that were deemed consistent with overall main stem conditions (e.g., areas that readily exchanged water with main flow in the river), several factors could result in potential deviation main stem conditions. The primary factor is probably the rapidly descending hydrographs in the June sampling periods which changed local conditions at some sampling locations and required successive re-deployment of water quality probes as water levels fell.

**Table 64. Calibration and other data gathering locations in the Klamath River for 2003**

| Site | River Mile | Elevation, ft | Node | Location Type |
|---|---|---|---|---|
| Klamath River above Shasta River | 177.46 | 2002.0 | 141 | Cal / Val |
| Klamath River above Scott River | 143.61 | 1560.0 | 369 | Cal / Val |
| Klamath River at Seiad Valley | 129.04 | 1320.0 | 672 | Cal / Val |
| Klamath River at Clear Creek | 99.00 | 937.0 | 994 | Cal / Val |
| Klamath River above Salmon River | 67.05 | 491.2 | 1354 | Cal / Val |
| Klamath River at Aikens Hole | 50.00 | 310.0 | 1545 | Additional Information |
| Klamath River above Trinity River | 43.50 | 302.0 | 1609 | Cal / Val |
| Klamath River at Martins Ferry / Tully Creek | 39.50 | 273.0 | 1649 | Cal / Val |
| Klamath River at Blue Creek | 16.95 | 100.0 | 1901 | Cal / Val |
| Klamath River at Turwar | 5.63 | 6.0 | 1974 | Cal / Val |

## 3.9.3 Results 2003

### 3.9.3.1 Water Temperature

Mean absolute error was less than 1.0°C for all sites for both June and August conditions with the exception of Klamath River above Salmon River in June (MAE = 1.44°C). Tabulated statistics illustrate that simulated results on a daily basis were within 1.0°C of observations, with the exception of the above noted site. Further, observation of the diurnal phase and amplitude were generally well represented at the individual locations.

Summary statistics include bias (average error), mean absolute error, and root mean square error. The error is computed as simulated values minus measured values, and the summary statistics are determined based on the period of available data. Daily statistics are calculated based on whole days, while hourly statistics utilize portions of days when data is available. The statistics represent performance over the period observed data.

The hourly results are presented graphically in Figure 125 through Figure 140. Summary statistics are included in Table 69. Representation of diurnal phase as well as diurnal range was a calibration objective.

At Klamath River above Shasta River, the diurnal phase for both June and August was well represented, as well as the shape of the diurnal temperature trace. The maximum and minimum daily temperatures closely matched observed temperatures. Hourly bias for the June period was –0.40°C with a mean absolute error of 0.47 °C. Hourly bias for the August period was 0.81°C with a mean absolute error of 0.81°C.

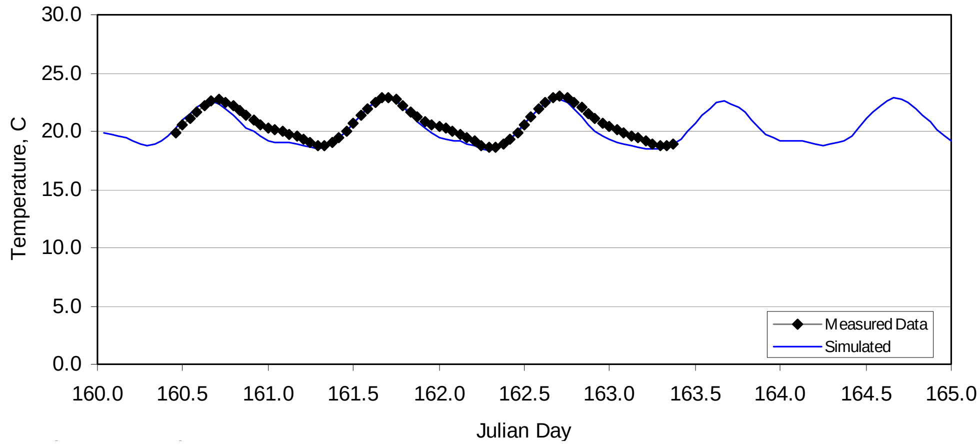



**Figure 125. Klamath River ab Shasta River simulated versus measured water temperature, June 9-12, 2003**

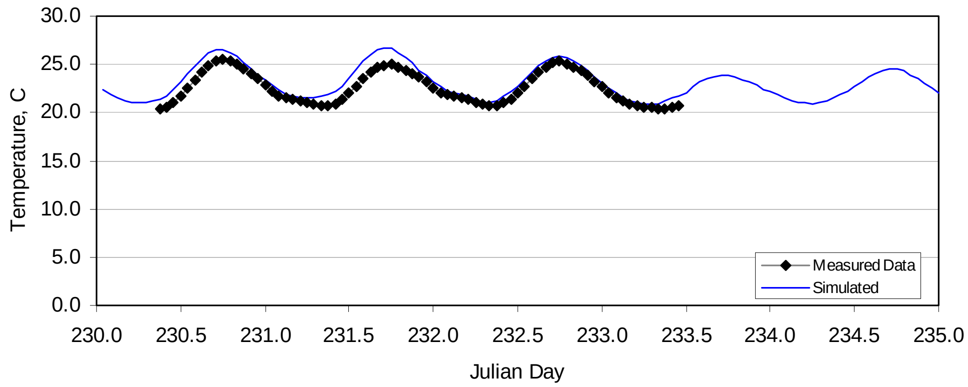



**Figure 126. Klamath River ab Shasta River simulated versus measured water temperature, August 18-21, 2003**

At Klamath River above Scott River, the diurnal phase and range for both June and August periods was well represented. Hourly bias for the June period was -0.11°C with a mean absolute error of 0.51°C. Hourly bias for the August period was 0.91°C with a mean absolute error of 0.91°C.

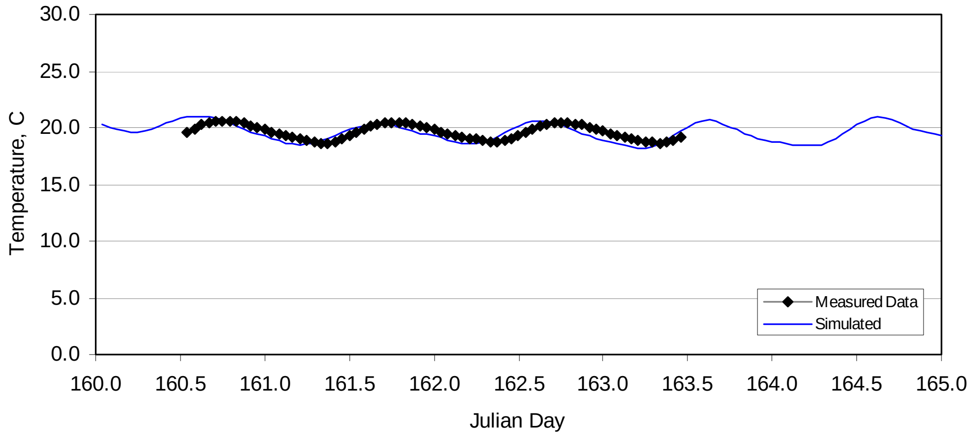



**Figure 127. Klamath River above Scott River versus measured water temperature, June 9-12, 2003**

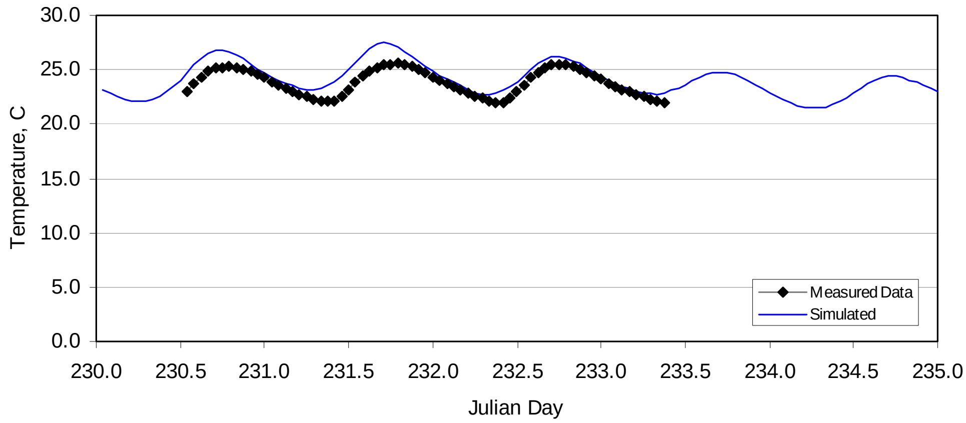



**Figure 128. Klamath River above Scott River simulated versus measured water temperature, August 18-21, 2003**

At Klamath River near Seiad Valley, the diurnal phase was well represented in both June and August periods. The diurnal range was adequately represented in both periods, with the maximum simulated temperatures slightly higher than observed temperatures. Hourly bias for the June period was 0.05°C with a mean absolute error of 0.13°C, and the shape of the diurnal signal is well represented. Hourly bias for the August period was 0.92°C with a mean absolute error of 0.92°C.

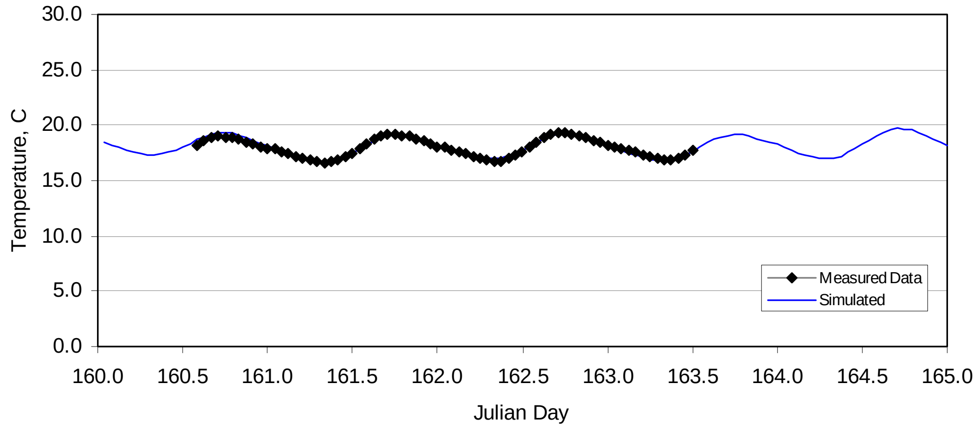



**Figure 129. Klamath River near Seiad Valley simulated versus measured water temperature, June 9-12, 2003**

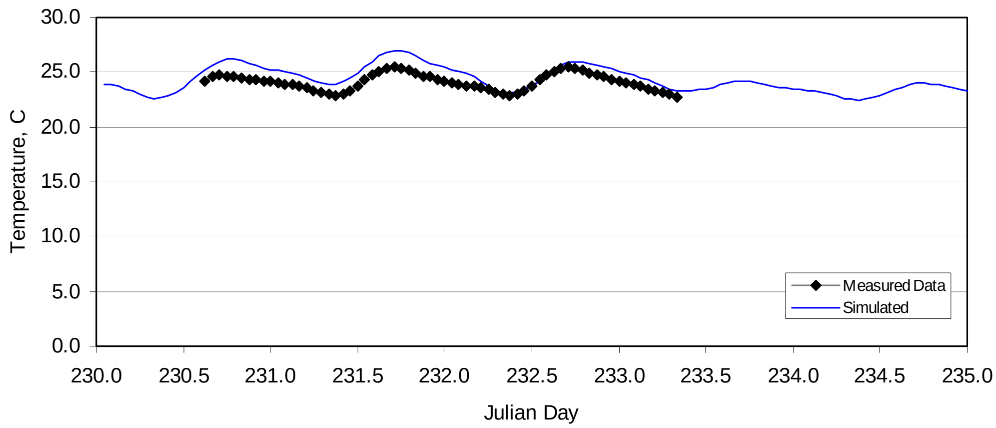



**Figure 130. Klamath River near Seiad Valley simulated versus measured water temperature, August 18-21, 2003**

At Klamath River above Clear Creek, observations for June were unavailable. The diurnal range for August was well represented. The hourly bias for August was 0.13°C with a mean absolute error of 0.47°C.

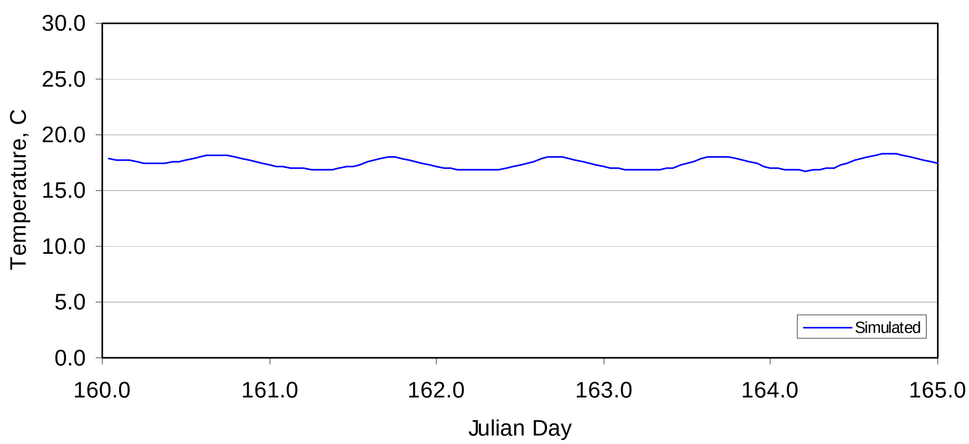



**Figure 131. Klamath River ab Clear Creek simulated water temperature, June 9-12, 2003**

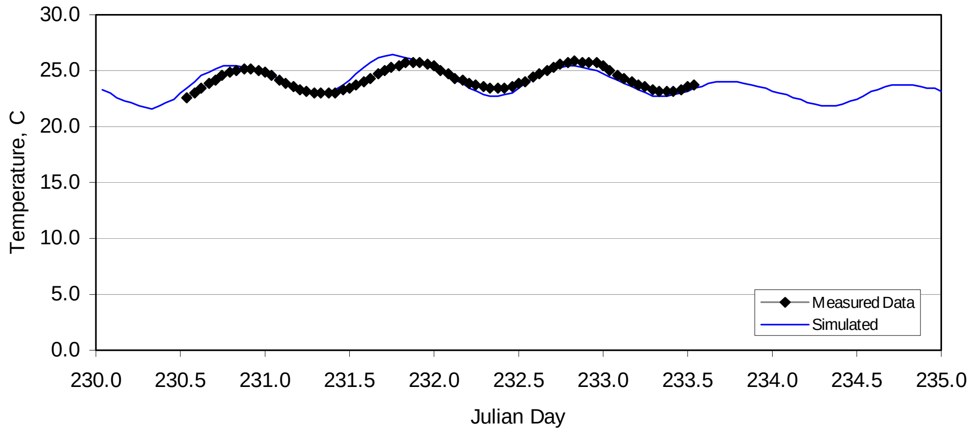



**Figure 132. Klamath River ab Clear Creek simulated versus measured water temperature, August 18-21, 2003**

At Klamath River above the Salmon River, the diurnal phase was well represented in both June and August periods; however June period simulated temperatures were under predicted. The diurnal range was well represented in both periods. Hourly bias for the June period was -1.44°C with a mean absolute error of 1.44°C. Hourly bias for the August period was 0.15°C with a mean absolute error of 0.43°C.

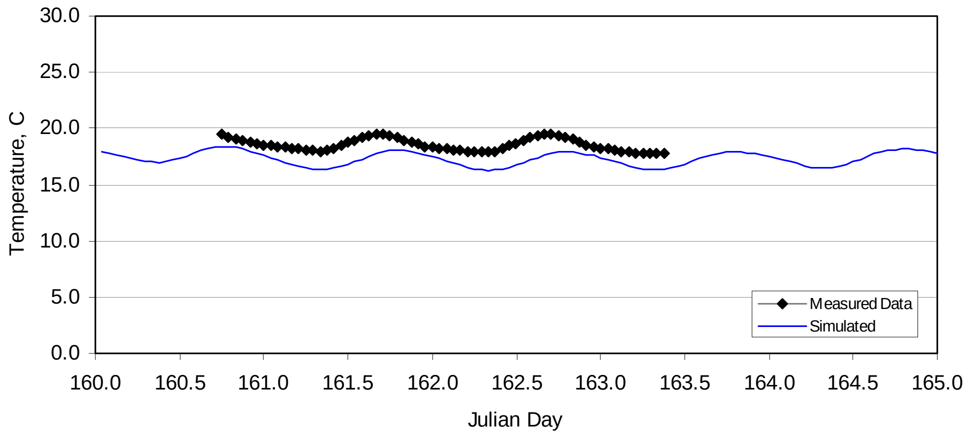



**Figure 133. Klamath River ab Salmon River simulated versus measured water temperature, June 9-12, 2003**

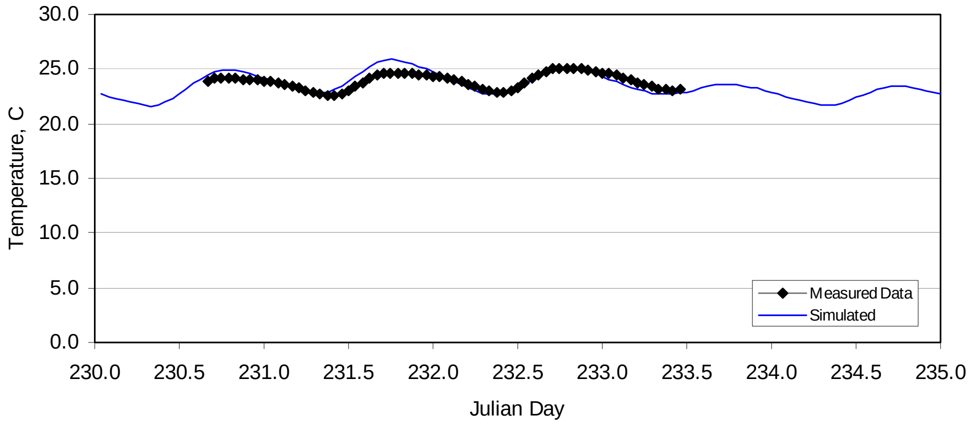



**Figure 134. Klamath River ab Salmon River simulated versus measured water temperature, August 18-21, 2003**

At Klamath River above the Trinity River the diurnal range was under represented in June, but matched well in August. The diurnal phase for August was generally well represented. Hourly bias for the June period was -0.98°C with a mean absolute error of 0.98°C. Hourly bias for the August period was 0.55°C with a mean absolute error of 0.67°C.

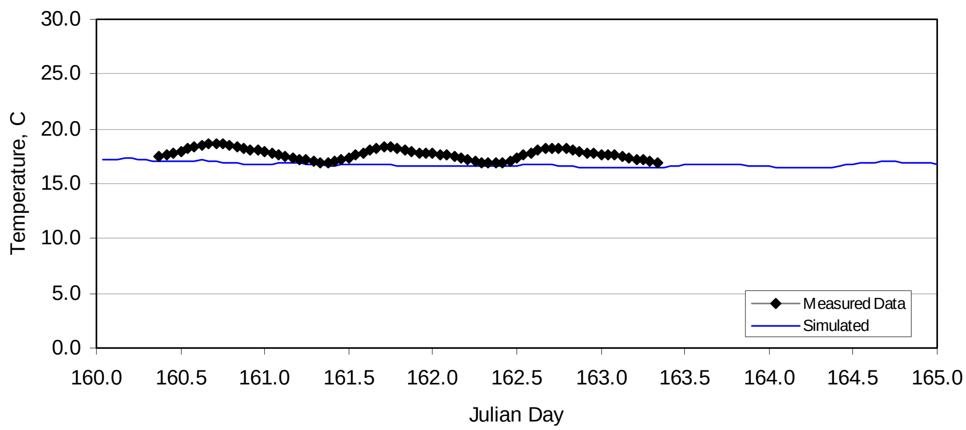



**Figure 135. Klamath River ab Trinity River simulated versus measured water temperature, June 9-12, 2003**

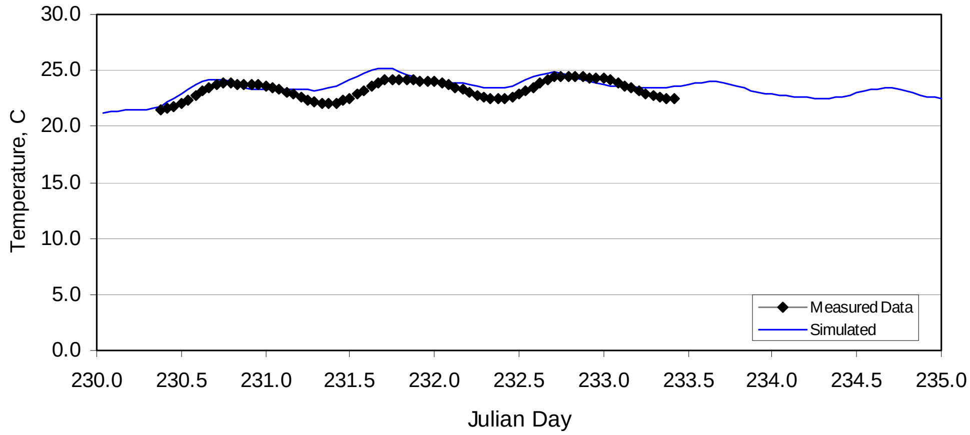



**Figure 136. Klamath River ab Trinity River simulated versus measured water temperature, August 18-21, 2003**

At Klamath River below the Trinity River in the vicinity of Martins Ferry was assessed at two locations due to movement of the sampling location: Martins Ferry in June and Tully Creek in August. Similar to the site above the Trinity, the simulated diurnal range was largely absent in the June results; however, the mean daily temperature was well represented (MAE = 0.63°C). The moderated diurnal range and phase was replicated in August. Hourly bias for the June period was -0.63°C with a mean absolute error of 0.63°C. Hourly bias for the August period was 0.43°C with a mean absolute error of 0.47°C.

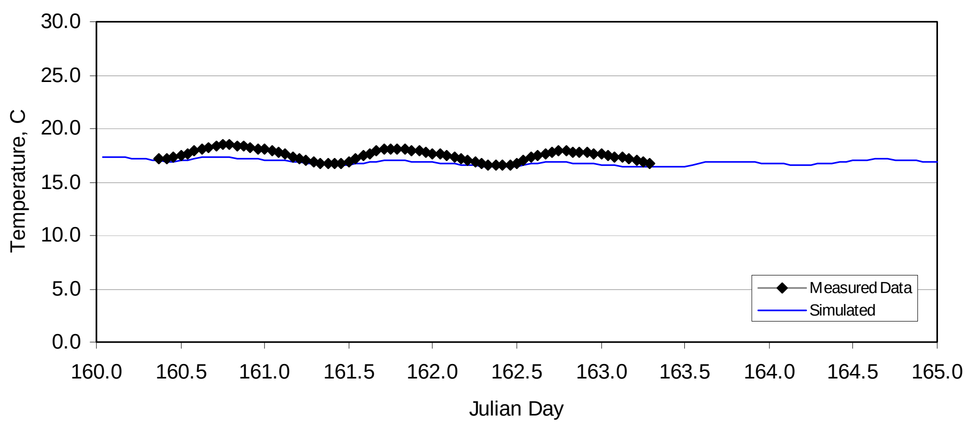



**Figure 137. Klamath River ab Martins Ferry simulated versus measured water temperature, June 9-12, 2003**

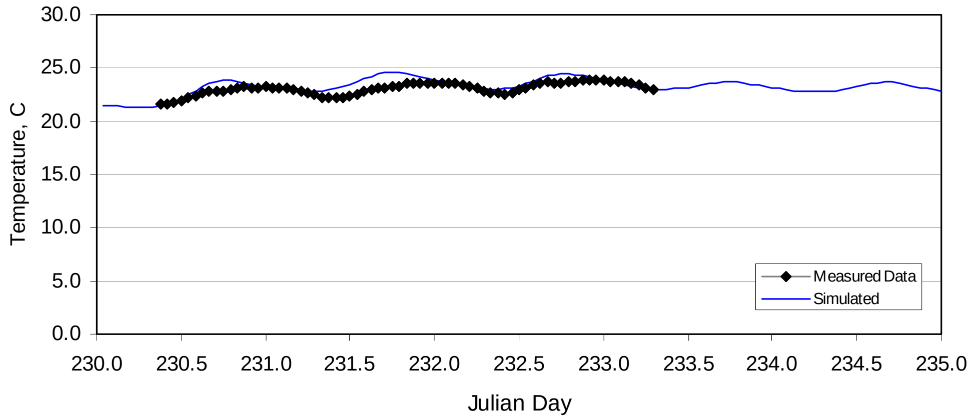



**Figure 138. Klamath River ab Tully Creek simulated versus measured water temperature, August 18-21, 2003**

At Klamath River below in the lowest reaches was assessed at two locations due to lack of data at Turwar in August: Turwar in June and Blue Creek in August. The June diurnal range was under represented in June, while the diurnal range and phase was generally replicated in August at Blue Creek. Hourly bias for the June period was -0.57°C with a mean absolute error of 0.68°C. Hourly bias for the August period was 0.86°C with a mean absolute error of 0.86°C.

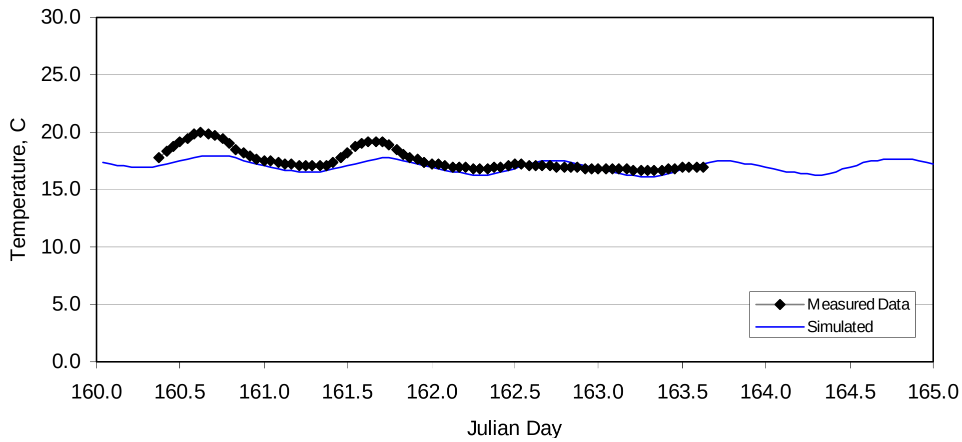



**Figure 139. Klamath River at Turwar simulated versus measured water temperature, June 9-12, 2003**

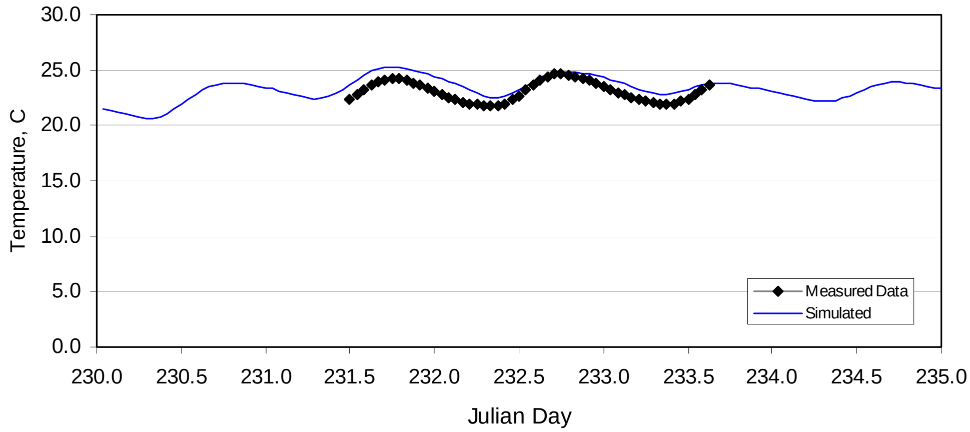



**Figure 140. Klamath River ab Blue Creek simulated versus measured water temperature, August 18-21, 2003**

**Table 65. Klamath River hourly and daily calibration statistics for water temperature 2003**

| Calibration / Validation Statistics | | Hourly | | Daily | |
|---|---|---|---|---|---|
| | Unit | June | August | June | August |
| Klamath River ab Shasta River | | | | | |
| Mean Bias[a] | °C | -0.40 | 0.81 | -0.39 | 0.80 |
| Mean absolute error (MAE) | °C | 0.47 | 0.81 | 0.39 | 0.80 |
| Root mean squared error (RMSE) | °C | 0.59 | 0.93 | 0.39 | 0.84 |
| n | - | 71 | 75 | 2 | 2 |
| Klamath River ab Scott River | | | | | |
| Mean Bias[a] | °C | -0.11 | 0.91 | -0.12 | 0.92 |
| Mean absolute error (MAE) | °C | 0.51 | 0.91 | 0.12 | 0.92 |
| Root mean squared error (RMSE) | °C | 0.57 | 1.08 | 0.12 | 0.98 |
| n | - | 71 | 69 | 2 | 2 |
| Klamath River near Seiad Valley | | | | | |
| Mean Bias[a] | °C | 0.05 | 0.92 | 0.04 | 0.88 |
| Mean absolute error (MAE) | °C | 0.13 | 0.92 | 0.04 | 0.88 |
| Root mean squared error (RMSE) | °C | 0.17 | 1.02 | 0.04 | 0.94 |
| n | - | 71 | 66 | 2 | 2 |
| Klamath River above Clear Creek | | | | | |
| Mean Bias[a] | °C | na | 0.03 | na | 0.03 |
| Mean absolute error (MAE) | °C | na | 0.47 | na | 0.41 |
| Root mean squared error (RMSE) | °C | na | 0.59 | na | 0.41 |
| n | - | na | 73 | na | 2 |
| Klamath River above Salmon River | | | | | |
| Mean Bias[a] | °C | -1.44 | 0.15 | -1.44 | 0.23 |
| Mean absolute error (MAE) | °C | 1.44 | 0.43 | 1.44 | 0.33 |
| Root mean squared error (RMSE) | °C | 1.49 | 0.56 | 1.44 | 0.40 |
| n | - | 48 | 68 | 2 | 2 |
| Klamath River above Trinity River | | | | | |
| Mean Bias[a] | °C | -0.98 | 0.55 | -0.93 | 0.66 |
| Mean absolute error (MAE) | °C | 0.98 | 0.67 | 0.93 | 0.66 |
| Root mean squared error (RMSE) | °C | 1.08 | 0.80 | 0.93 | 0.69 |
| n | - | 72 | 74 | 2 | 2 |
| Klamath River at Martins Ferry/Tully Ck[b] | | | | | |
| Mean Bias[a] | °C | -0.67 | 0.43 | -0.63 | 0.53 |
| Mean absolute error (MAE) | °C | 0.67 | 0.47 | 0.63 | 0.53 |
| Root mean squared error (RMSE) | °C | 0.75 | 0.61 | 0.63 | 0.55 |
| N | - | 71 | 71 | 2 | 2 |
| Klamath River at Blue Creek/Turwar[c] | | | | | |
| Mean Bias[a] | °C | -0.57 | 0.86 | -0.46 | 0.71 |
| Mean absolute error (MAE) | °C | 0.68 | 0.86 | 0.46 | 0.71 |
| Root mean squared error (RMSE) | °C | 0.84 | 0.94 | 0.57 | 0.71 |
| n | - | 79 | 52 | 2 | 1 |

[a] Mean bias = simulated – measured
[b] June, Martins Ferry; August, Tully Creek
[c] June, Turwar; August, Blue Creek
na – not available

### 3.9.3.2 Dissolved Oxygen

Mean absolute error was within 1.0 mg/l for all sites for both June and August conditions with the exception of Klamath River above Salmon River in August, which was just over 1.0 mg/l. Tabulated statistics illustrate that simulated results on a daily basis were also within approximately 1.0 mg/l of observations, with the exception of the above noted site. Further, observation of the diurnal phase and amplitude were generally well represented at the individual locations. The hourly results are presented graphically in Figure 141 through Figure 156. Summary statistics are included in Table 69.

At Klamath River above Shasta River, the diurnal phase is well represented; however, in June the amplitude is moderated in model simulations. The maximum and minimum daily temperatures closely matched observed temperatures. Hourly bias for the June period was 0.64 mg/l with a mean absolute error of 0.84 mg/l. Hourly bias for the August period was 0.69 mg/l with a mean absolute error of 0.69 mg/l.

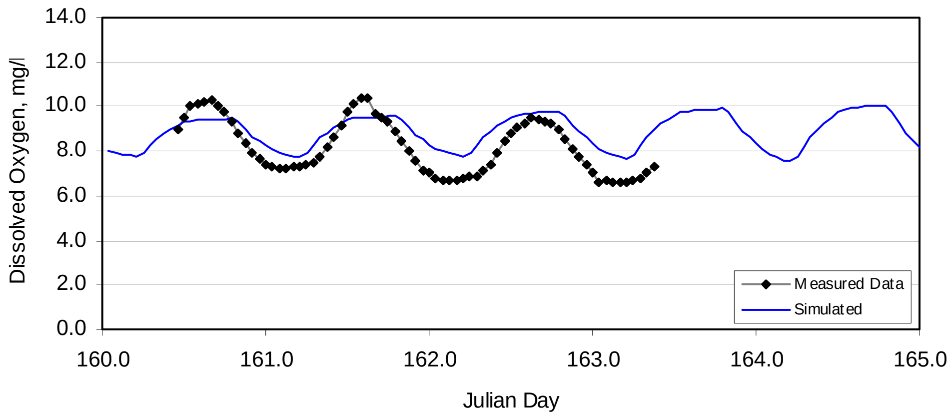



**Figure 141. Klamath River above Shasta River simulated versus measured dissolved oxygen, June 9-12, 2003**

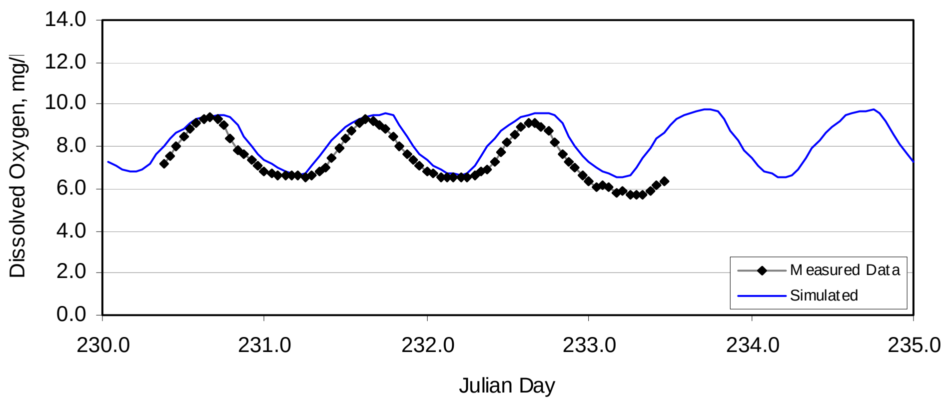



**Figure 142. Klamath River above Shasta River simulated versus measured dissolved oxygen, August 18-21, 2003**

At Klamath River above Scott River, the diurnal phase is well represented. The diurnal range is replicated in June, with the model over predicting daily minimum values. In August the maximum values are under represented. Hourly bias for the June period was 0.63 mg/l with a mean absolute error of 0.64 mg/l. Hourly bias for the August period was -0.26 mg/l with a mean absolute error of 0.36 mg/l.

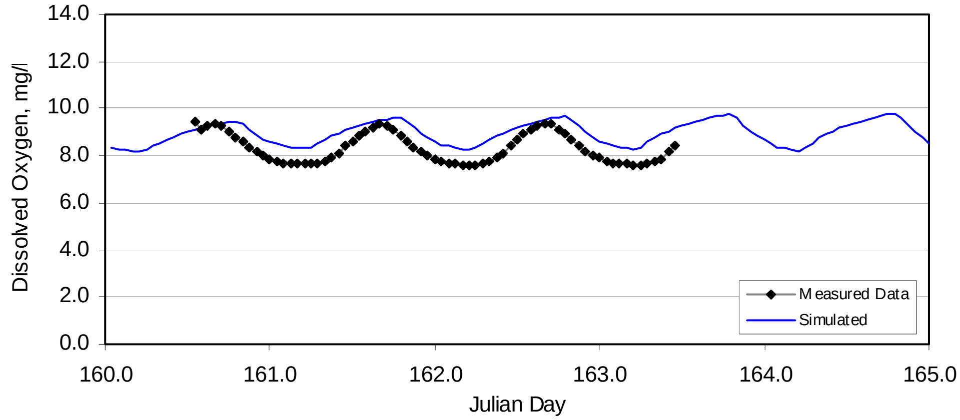



**Figure 143. Klamath River above Scott River simulated versus measured dissolved oxygen, June 9-12, 2003**

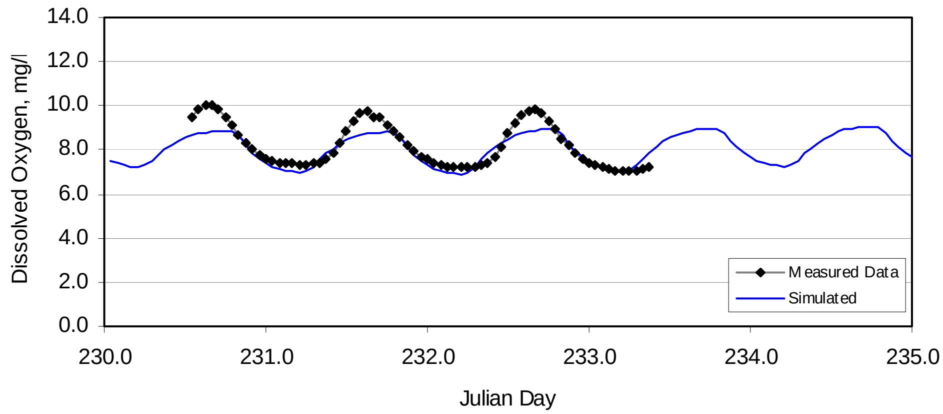



**Figure 144. Klamath River above Scott River simulated versus measured dissolved oxygen, August 18-21, 2003**

At Klamath River near Seiad Valley, the diurnal phase is shifted by approximately an our, but the amplitude is well represented in June. In August the maximum values are under represented. Hourly bias for the June period was 0.13 mg/l with a mean absolute error of 0.18 mg/l. Hourly bias for the August period was -0.42 mg/l with a mean absolute error of 0.52 mg/l.

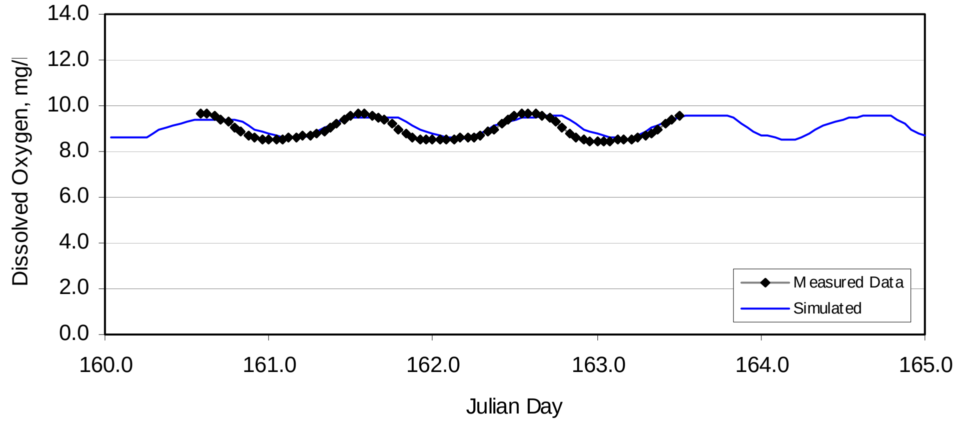



**Figure 145. Klamath River near Seiad Valley simulated versus measured dissolved oxygen, June 9-12, 2003**

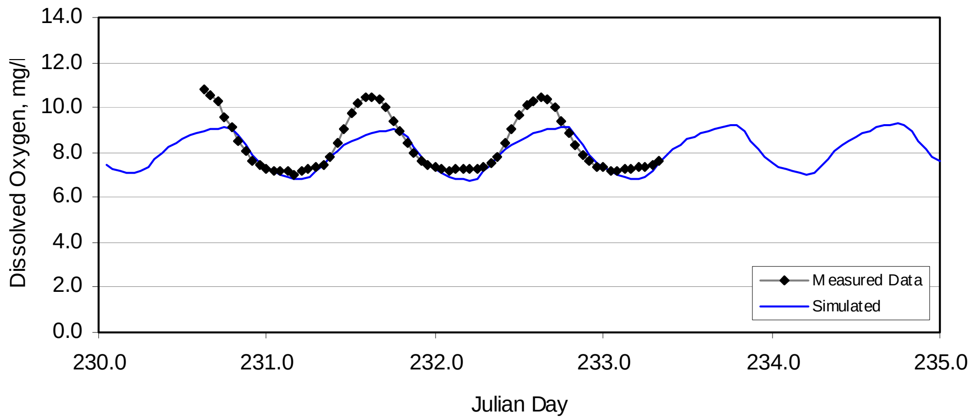



**Figure 146. Klamath River near Seiad Valley simulated versus measured dissolved oxygen, August 18-21, 2003**

At Klamath River above Clear Creek, no data were available for June and August phase and diurnal range are generally well represented; however, the model results are overall lower than the observed values. Hourly bias for the August period was -0.73 mg/l with a mean absolute error of 0.73 mg/l.

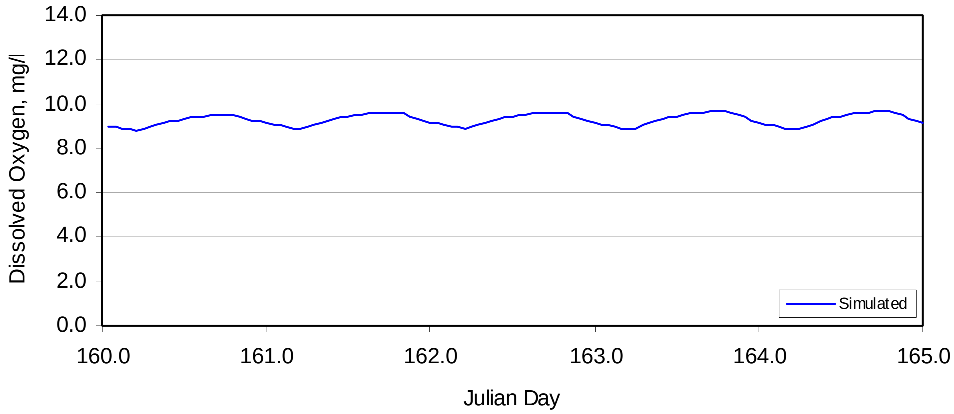



**Figure 147. Klamath River above Clear Creek simulated versus measured dissolved oxygen, June 9-12, 2003**

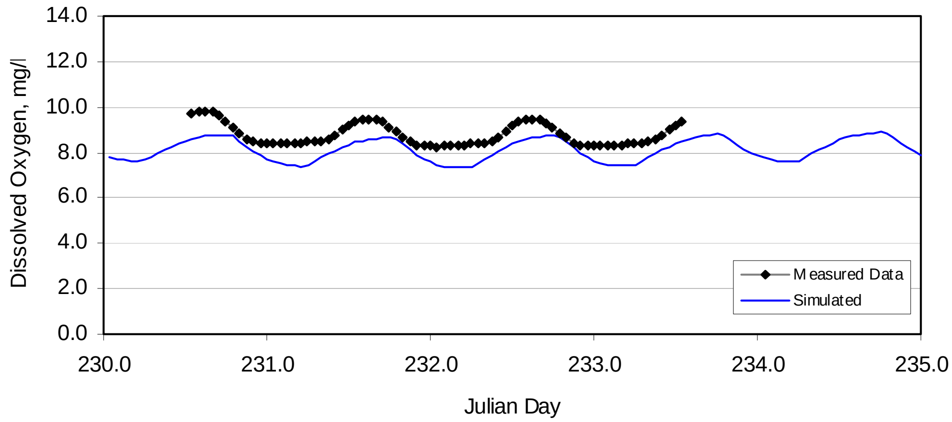



**Figure 148. Klamath River above Clear Creek simulated versus measured dissolved oxygen, August 18-21, 2003**

At Klamath River above Salmon River, both the moderated June diurnal signal and larger August diurnal range is replicated by the model; however the model results are lower than the observed values by about 1.0 mg/l.  Hourly bias for the June period was 0.13 mg/l with a mean absolute error of 0.18 mg/l. Hourly bias for the August period was -0.42 mg/l with a mean absolute error of 0.52 mg/l.

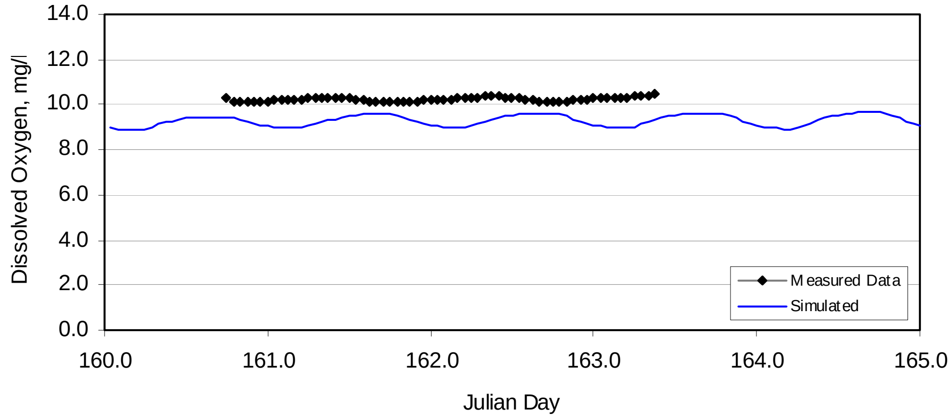



**Figure 149. Klamath River above Salmon River simulated versus measured dissolved oxygen, June 9-12, 2003**

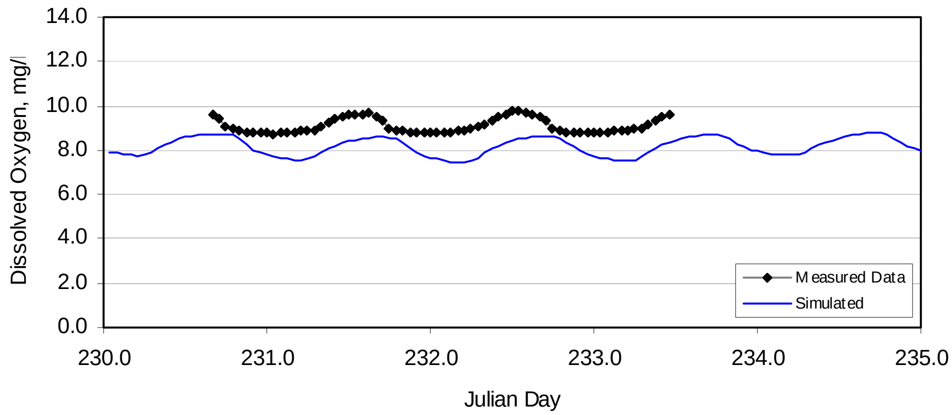



**Figure 150. Klamath River above Salmon River simulated versus measured dissolved oxygen, August 18-21, 2003**

At Klamath River above Trinity River, both the moderated June diurnal signal and larger August diurnal range is replicated by the model; however the model results are higher than observations in June and the August diurnal signal is smaller than observed values. Hourly bias for the June period was 0.67 mg/l with a mean absolute error of 0.67 mg/l. Hourly bias for the August period was 0.29 mg/l with a mean absolute error of 0.50 mg/l.

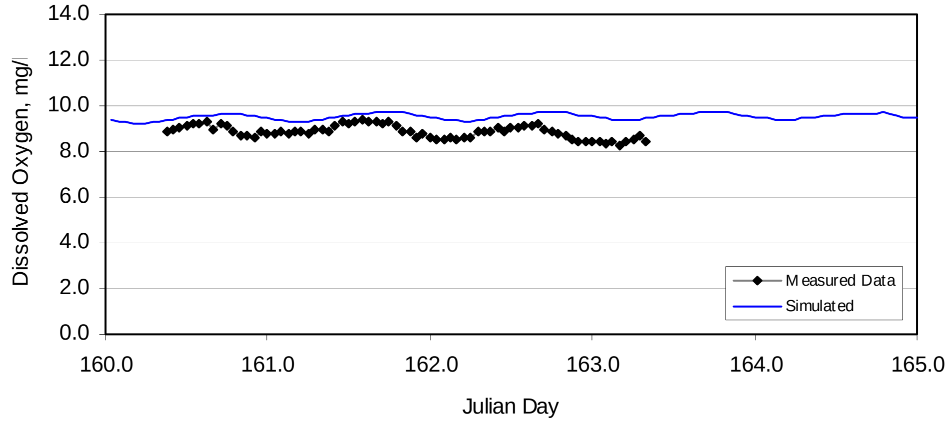



**Figure 151. Klamath River above Trinity River simulated versus measured dissolved oxygen, June 9-12, 2003**

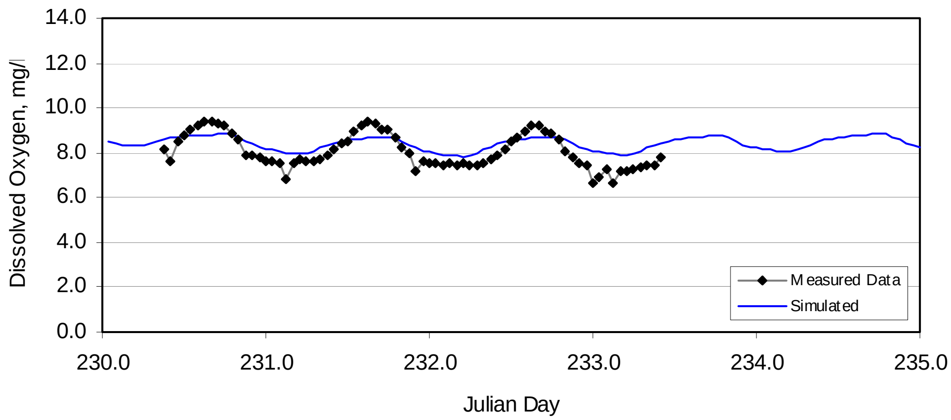



**Figure 152. Klamath River above Trinity River simulated versus measured dissolved oxygen, August 18-21, 2003**

At Klamath River nears Martins Ferry as represented by Martins Ferry and Tully Creek, both the moderated June diurnal signal and larger August diurnal range is replicated by the model; however the model results are slightly higher than observations in June and the August diurnal signal is smaller than observed values. Hourly bias for the June period was 0.51 mg/l with a mean absolute error of 0.51 mg/l. Hourly bias for the August period was 0.02 mg/l with a mean absolute error of 0.29 mg/l.

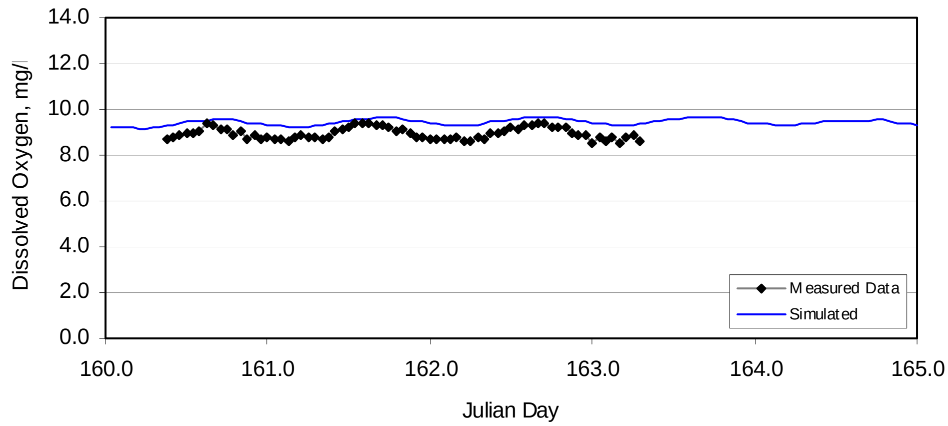



**Figure 153. Klamath River at Martins Ferry simulated versus measured dissolved oxygen, June 9-12, 2003**

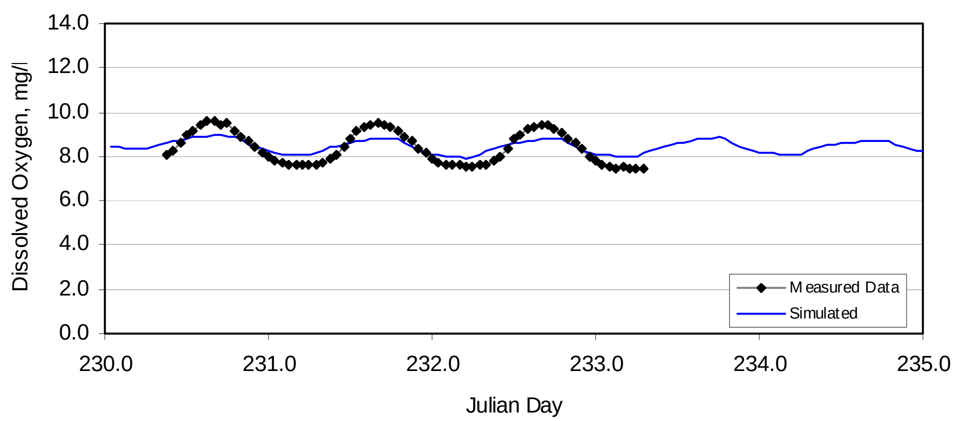



**Figure 154. Klamath River at Tully Creek simulated versus measured dissolved oxygen, August 18-21, 2003**

At Klamath River in the extreme lower river as represented by Turwar and Blue Creek the Turwar site has a wider diurnal range than the model (this may be due to deployment location), while the August phase and range are generally well represented at Blue Creek. Hourly bias for the June period was -0.27 mg/l with a mean absolute error of 0.41 mg/l. Hourly bias for the August period was 0.25 mg/l with a mean absolute error of 0.47 mg/l.

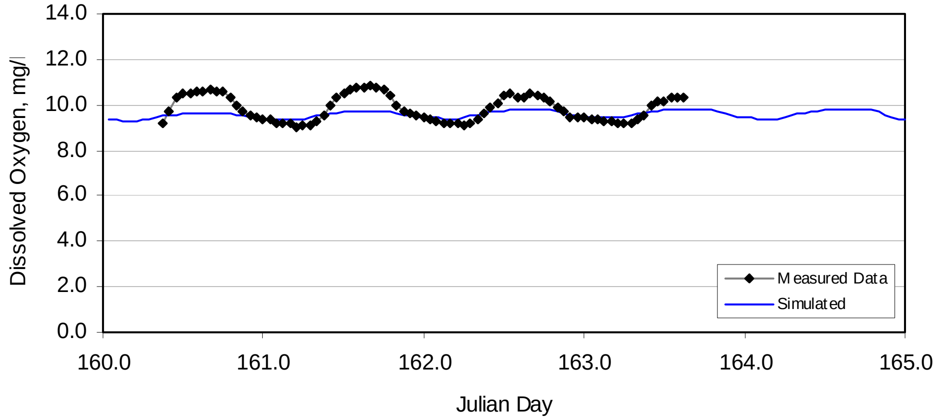



**Figure 155. Klamath River at Turwar simulated versus measured dissolved oxygen, June 9-12, 2003**

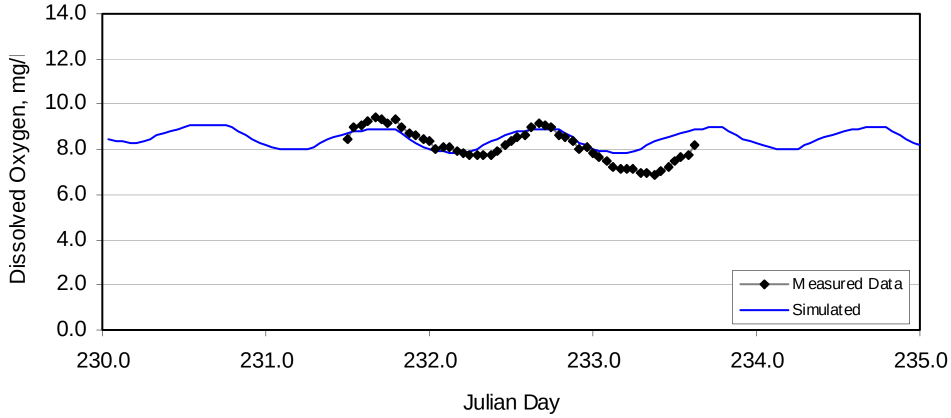



**Figure 156. Klamath River at Blue Creek River simulated versus measured dissolved oxygen, August 18-21, 2003**

**Table 66. Klamath River hourly and daily calibration statistics for dissolved oxygen 2003**

| Calibration / Validation Statistics | | Hourly | | Daily | |
|---|---|---|---|---|---|
| | Unit | June | August | June | August |
| Klamath River ab Shasta River | | | | | |
| Mean Bias[a] | °C | 0.64 | 0.69 | 0.69 | 0.60 |
| Mean absolute error (MAE) | °C | 0.84 | 0.69 | 0.69 | 0.60 |
| Root mean squared error (RMSE) | °C | 0.94 | 0.84 | 0.75 | 0.60 |
| n | - | 71 | 75 | 2 | 2 |
| Klamath River ab Scott River | | | | | |
| Mean Bias[a] | °C | 0.63 | -0.26 | 0.65 | -0.25 |
| Mean absolute error (MAE) | °C | 0.64 | 0.36 | 0.65 | 0.25 |
| Root mean squared error (RMSE) | °C | 0.68 | 0.49 | 0.65 | 0.25 |
| n | - | 71 | 69 | 2 | 2 |
| Klamath River near Seiad Valley | | | | | |
| Mean Bias[a] | °C | 0.13 | -0.42 | 0.13 | -0.44 |
| Mean absolute error (MAE) | °C | 0.18 | 0.52 | 0.13 | 0.44 |
| Root mean squared error (RMSE) | °C | 0.24 | 0.73 | 0.13 | 0.44 |
| n | - | 71 | 66 | 2 | 2 |
| Klamath River above Clear Creek | | | | | |
| Mean Bias[a] | °C | na | -0.73 | na | -0.71 |
| Mean absolute error (MAE) | °C | na | 0.73 | na | 0.71 |
| Root mean squared error (RMSE) | °C | na | 0.77 | na | 0.71 |
| n | - | na | 73 | na | 2 |
| Klamath River above Salmon River | | | | | |
| Mean Bias[a] | °C | -0.96 | -1.03 | -0.91 | -1.05 |
| Mean absolute error (MAE) | °C | 0.96 | 1.03 | 0.91 | 1.05 |
| Root mean squared error (RMSE) | °C | 1.00 | 1.08 | 0.91 | 1.05 |
| n | - | 64 | 68 | 2 | 2 |
| Klamath River above Trinity River | | | | | |
| Mean Bias[a] | °C | 0.67 | 0.29 | 0.64 | 0.23 |
| Mean absolute error (MAE) | °C | 0.67 | 0.50 | 0.64 | 0.23 |
| Root mean squared error (RMSE) | °C | 0.71 | 0.57 | 0.65 | 0.23 |
| n | - | 72 | 74 | 2 | 2 |
| Klamath River at Martins Ferry/Tully Ck[b] | | | | | |
| Mean Bias[a] | °C | 0.51 | 0.02 | 0.50 | 0.00 |
| Mean absolute error (MAE) | °C | 0.51 | 0.39 | 0.50 | 0.01 |
| Root mean squared error (RMSE) | °C | 0.54 | 0.43 | 0.50 | 0.01 |
| N | - | 71 | 71 | 2 | 2 |
| Klamath River at Blue Creek/Turwar[c] | | | | | |
| Mean Bias[a] | °C | -0.27 | 0.25 | -0.24 | 0.50 |
| Mean absolute error (MAE) | °C | 0.41 | 0.47 | 0.24 | 0.50 |
| Root mean squared error (RMSE) | °C | 0.53 | 0.60 | 0.26 | 0.67 |
| n | - | 79 | 52 | 2 | 2 |

[a] Mean bias = simulated – measured
[b] June, Martins Ferry; August, Tully Creek
[c] June, Turwar; August, Blue Creek
na – not available

### 3.9.3.3 Nutrients

Inorganic forms of nitrogen (ammonia, $NH_4^+$; nitrate, $NO_3^-$) and phosphorous (orthophosphate, $PO_4^{3-}$) were sampled once per day during the June and August 2003 monitoring program at the identified sampling sites for calibration. The sites at Blue Creek and at Turwar were not sampled for nutrients and are not included herein. The model results indicate that for all nutrients the bias is within ±0.10 mg/l and the MAE is les than 0.10 mg/l. These values are close to the reporting limits for these nutrients. Results are presented graphically in Figure 157 to Figure 198 and tabulated in Table 67.

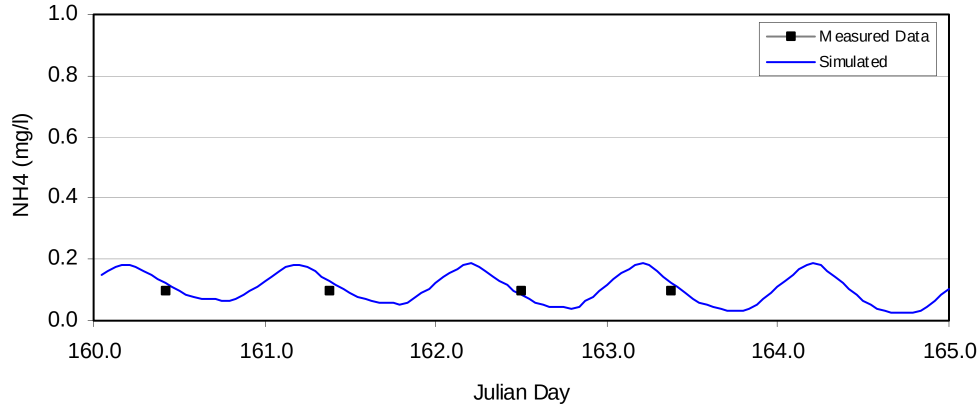



**Figure 157. Klamath River above Shasta River simulated versus measured ammonia, June 9-12, 2003**

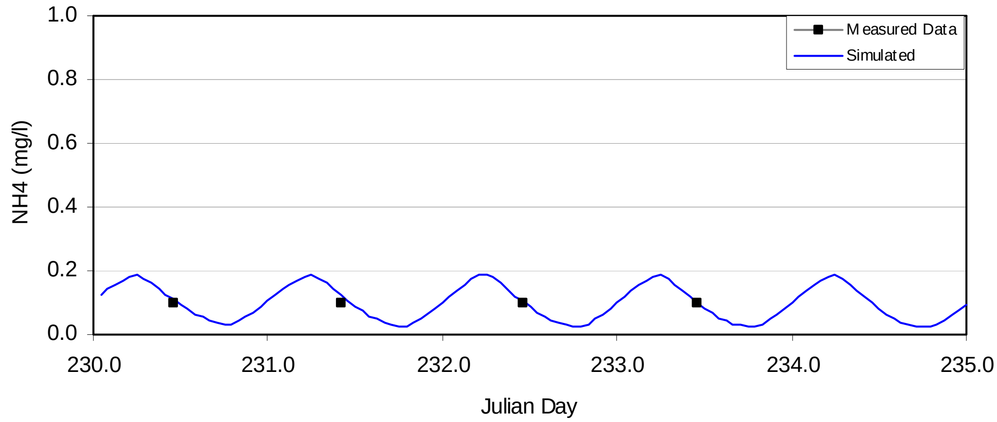



**Figure 158. Klamath River above Shasta River simulated versus measured ammonia, August 18-21, 2003**

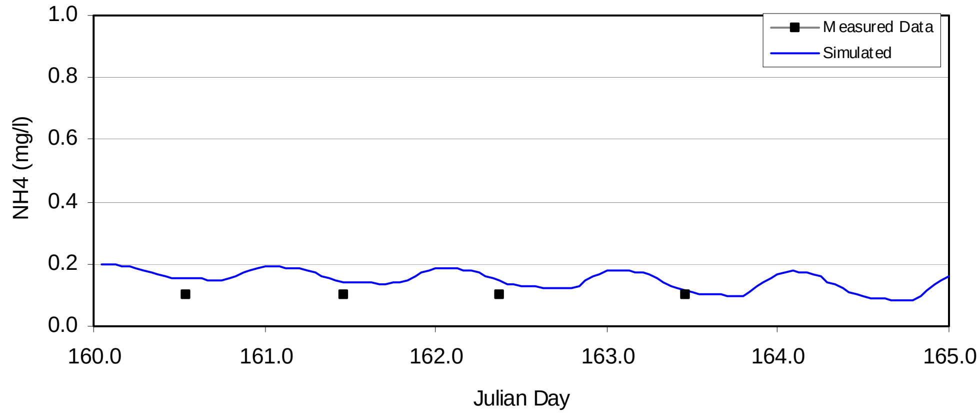



**Figure 159. Klamath River above Scott River simulated versus measured ammonia, June 9-12, 2003**

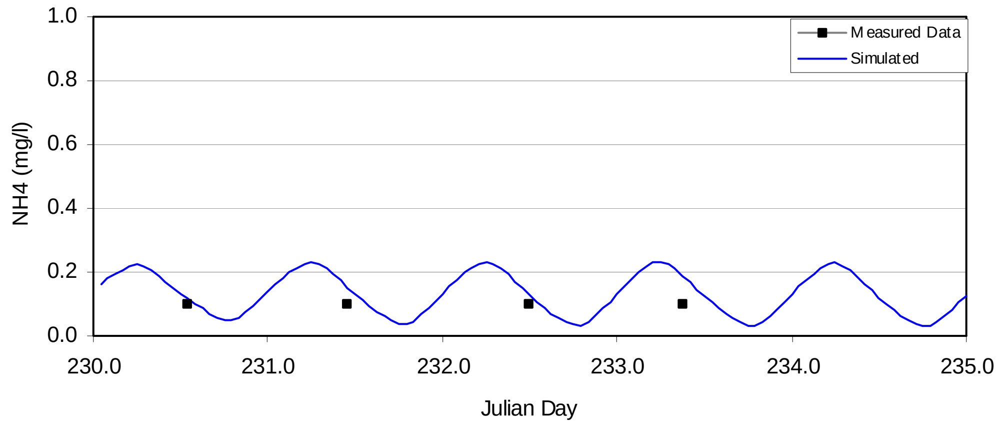



**Figure 160. Klamath River above Scott River simulated versus measured ammonia, August 18-21, 2003**

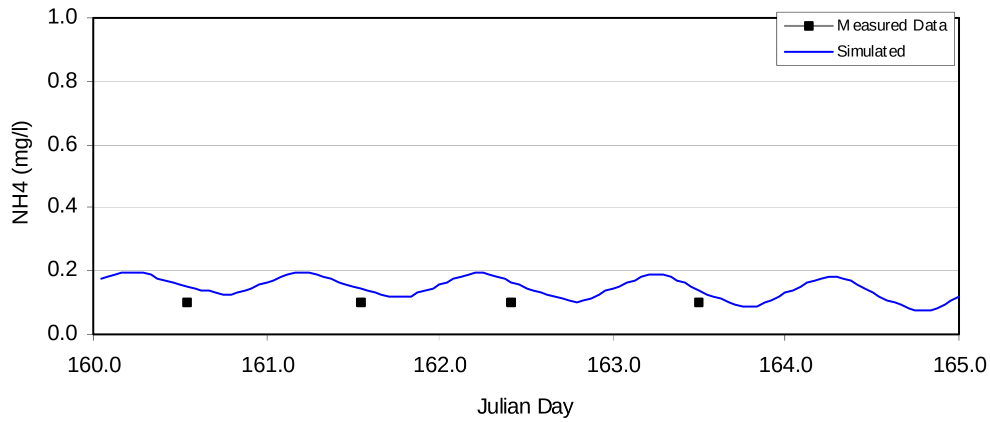



**Figure 161. Klamath River near Seiad Valley simulated versus measured ammonia, June 9-12, 2003**

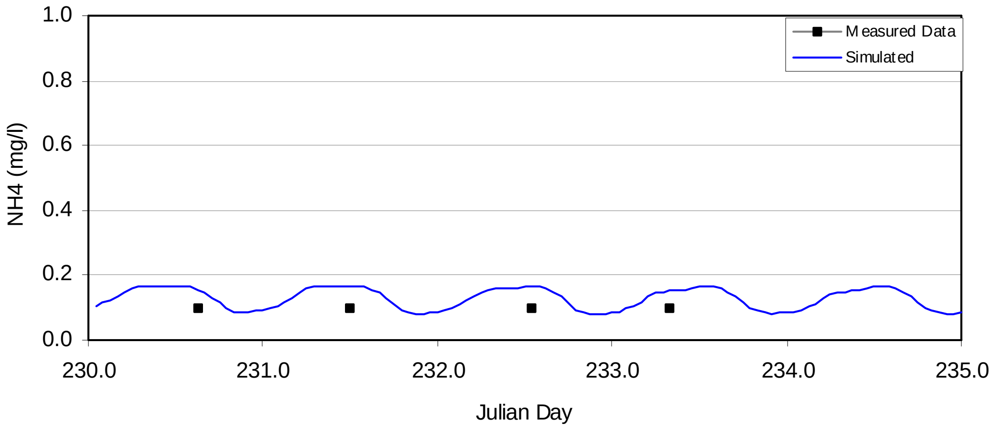



**Figure 162. Klamath River near Seiad Valley simulated versus measured ammonia, August 18-21, 2003**

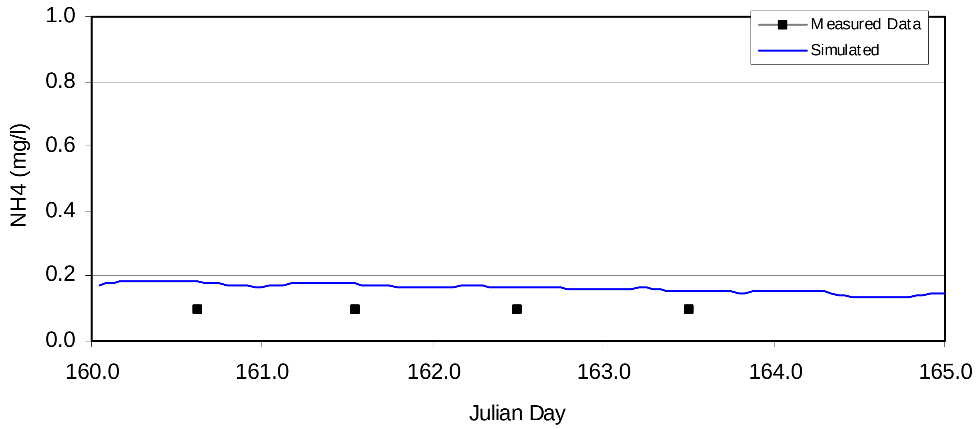



**Figure 163. Klamath River above Clear Creek simulated versus measured ammonia, June 9-12, 2003**

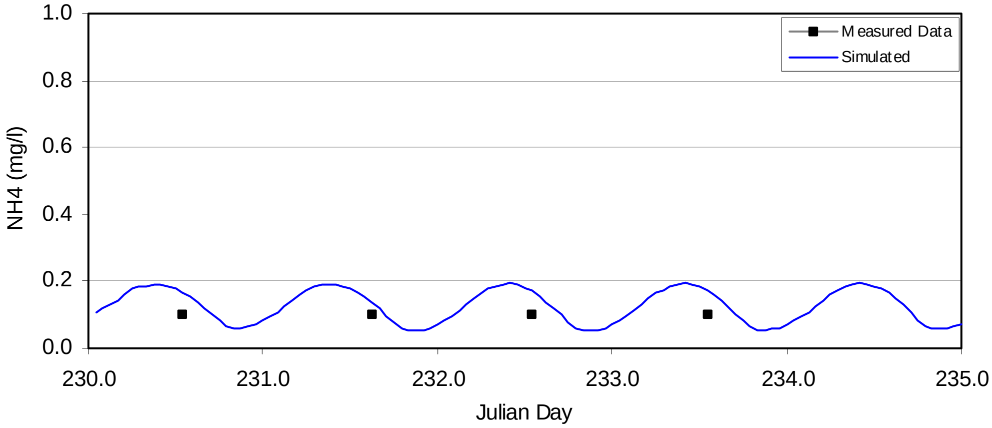



**Figure 164. Klamath River above Clear Creek simulated versus measured ammonia, August 18-21, 2003**

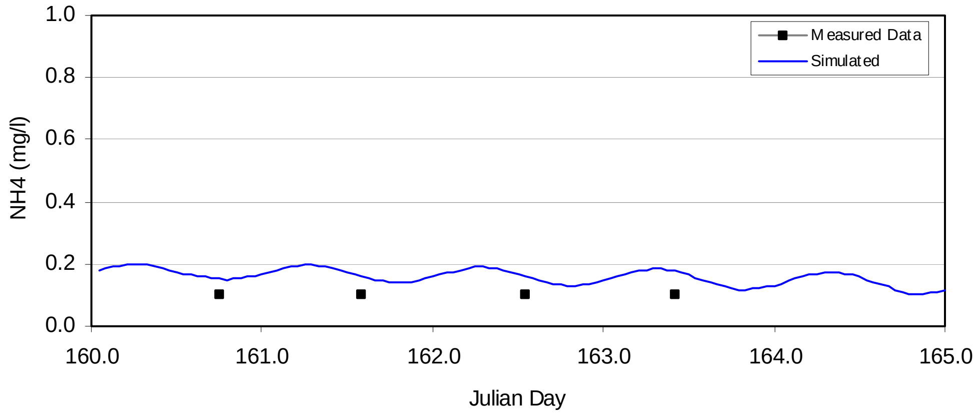



**Figure 165. Klamath River above Salmon River simulated versus measured ammonia, June 9-12, 2003**

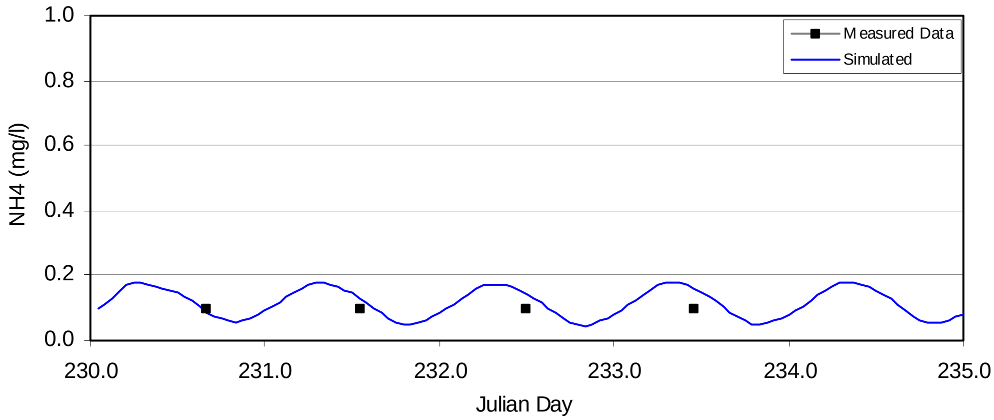



**Figure 166. Klamath River above Salmon River simulated versus measured ammonia, August 18-21, 2003**

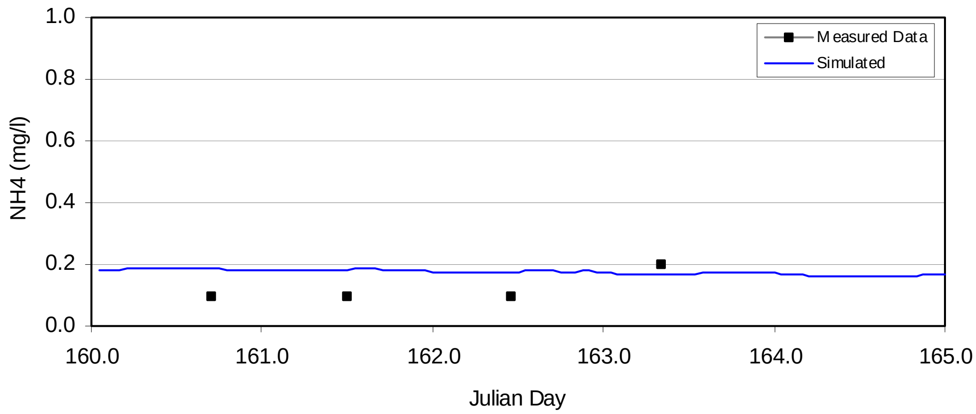



**Figure 167. Klamath River above Trinity River simulated versus measured ammonia, June 9-12, 2003**

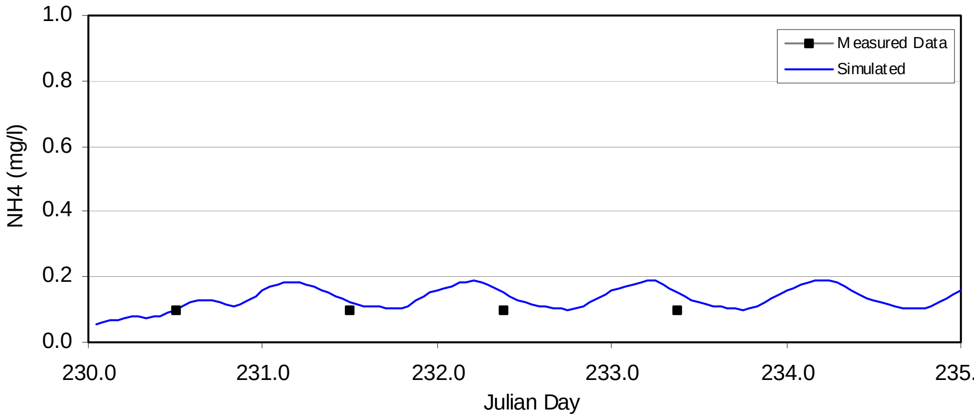



**Figure 168. Klamath River above Trinity River simulated versus measured ammonia, August 18-21, 2003**

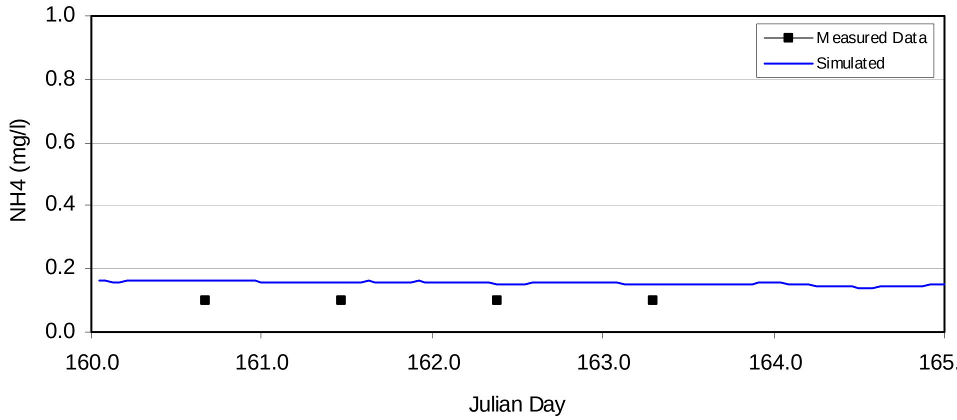



**Figure 169. Klamath River at Martins Ferry simulated versus measured ammonia, June 9-12, 2003**

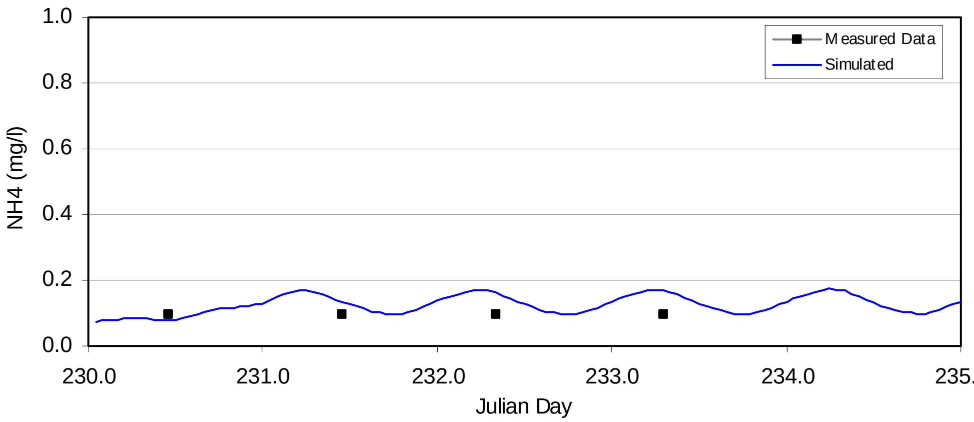



**Figure 170. Klamath River at Tully Creek simulated versus measured ammonia, August 18-21, 2003**

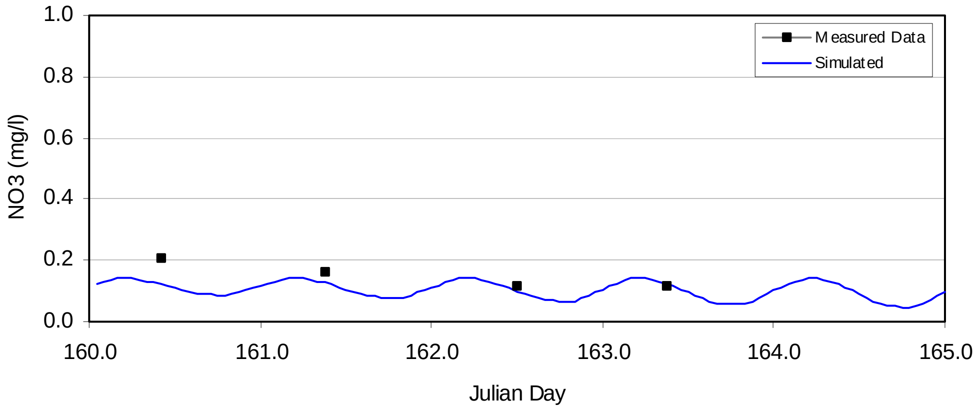



**Figure 171. Klamath River above Shasta River simulated versus measured nitrate, June 9-12, 2003**

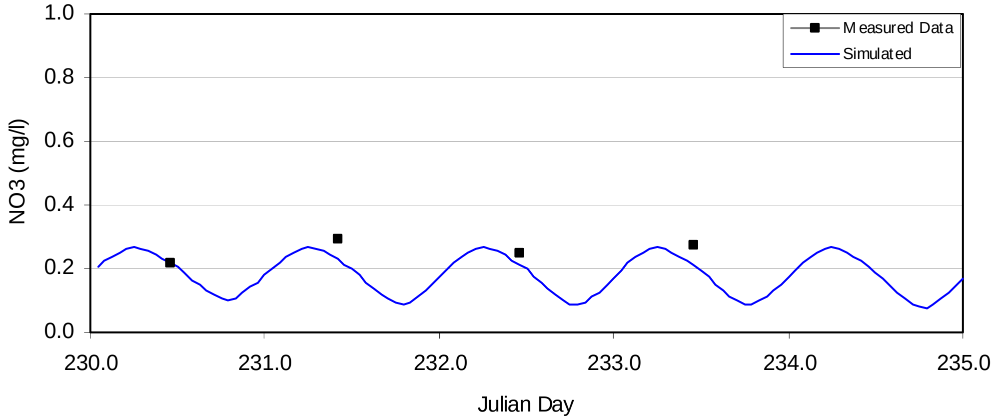



**Figure 172. Klamath River above Shasta River simulated versus measured nitrate, August 18-21, 2003**

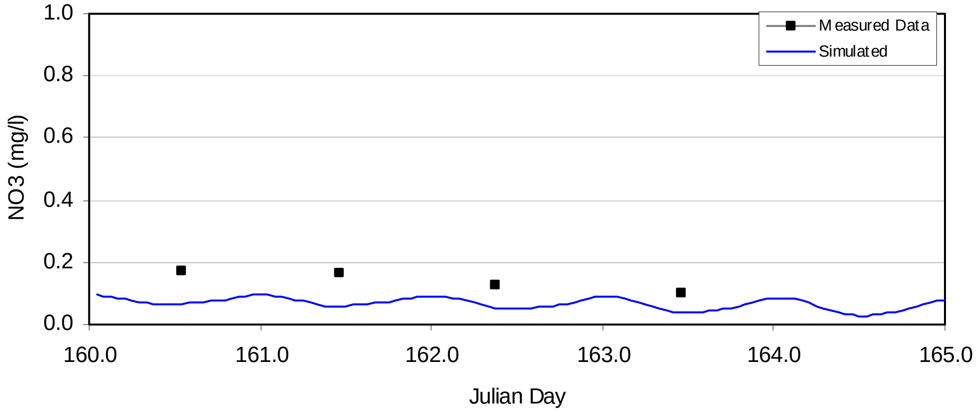



**Figure 173. Klamath River above Scott River simulated versus measured nitrate, June 9-12, 2003**

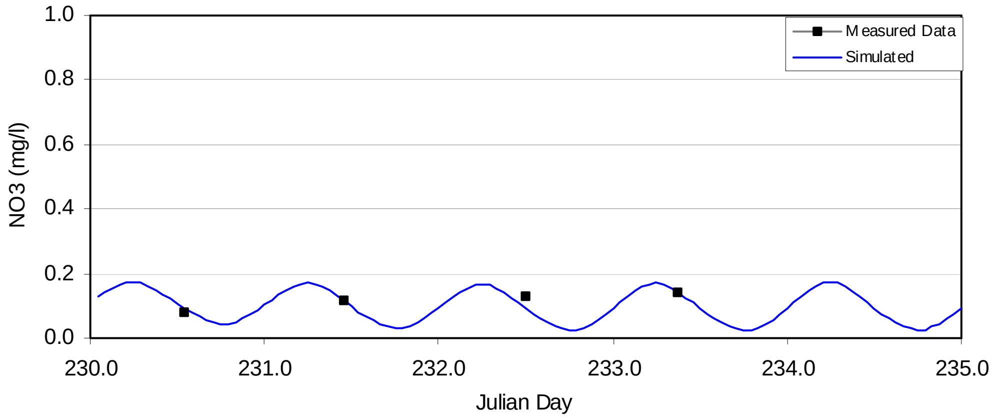



**Figure 174. Klamath River above Scott River simulated versus measured nitrate, August 18-21, 2003**

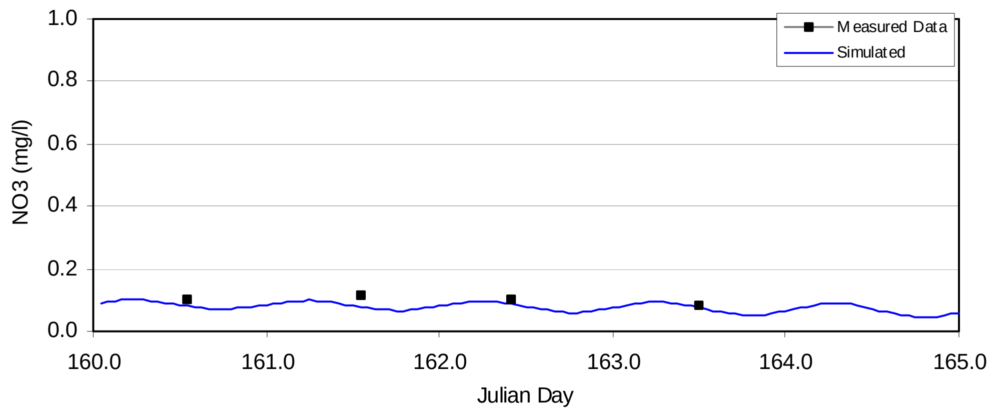



**Figure 175. Klamath River near Seiad Valley simulated versus measured nitrate, June 9-12, 2003**

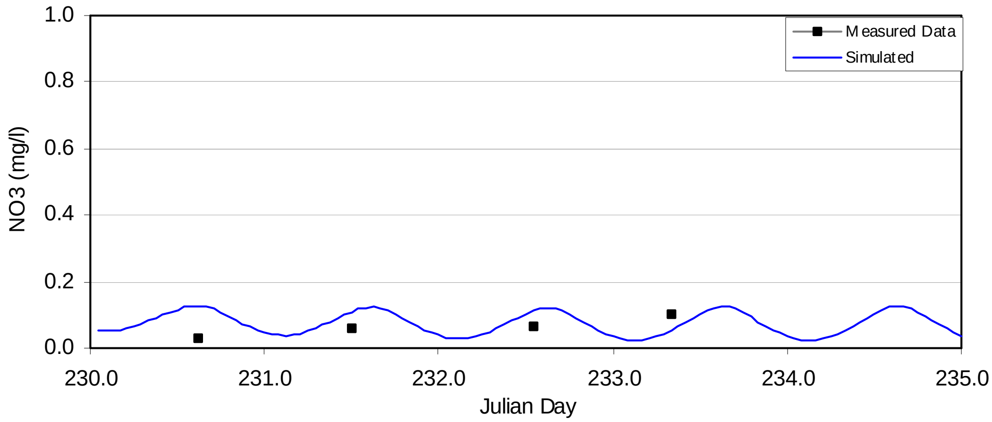



**Figure 176. Klamath River near Seiad Valley simulated versus measured nitrate, August 18-21, 2003**

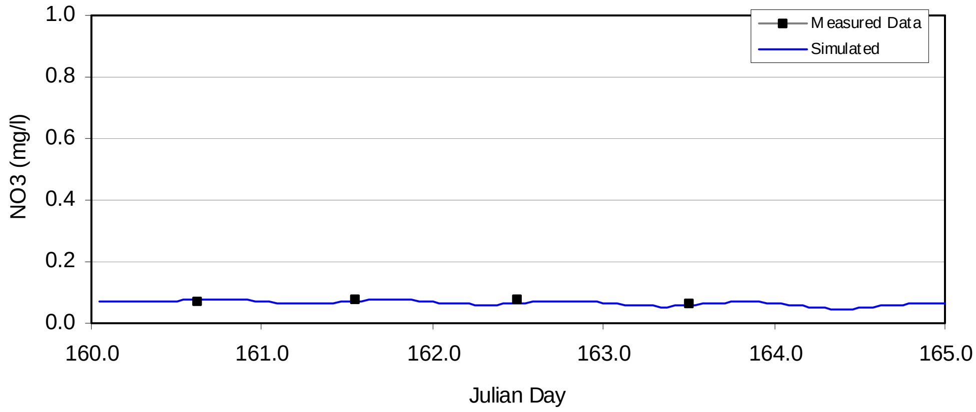



**Figure 177. Klamath River above Clear Creek simulated versus measured nitrate, June 9-12, 2003**

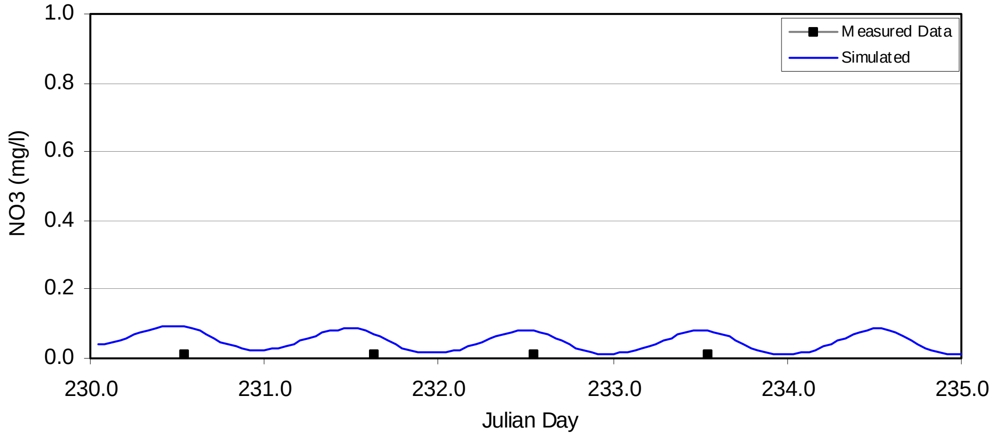



**Figure 178. Klamath River above Clear Creek simulated versus measured nitrate, August 18-21, 2003**

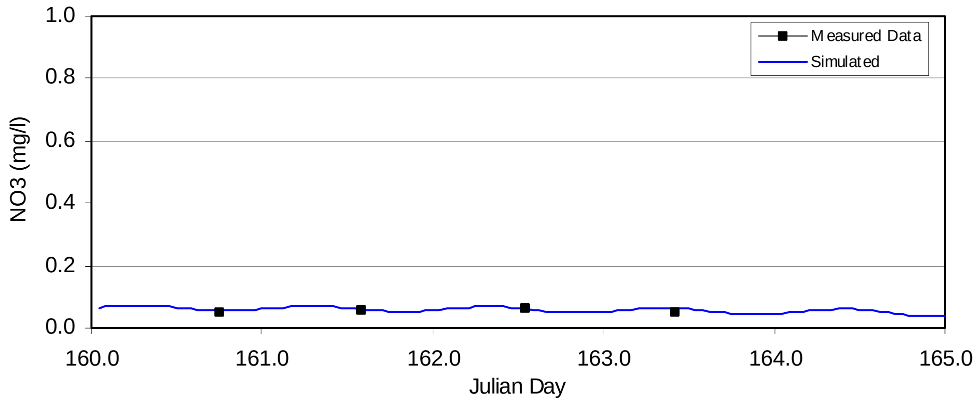



**Figure 179. Klamath River above Salmon River simulated versus measured nitrate, June 9-12, 2003**

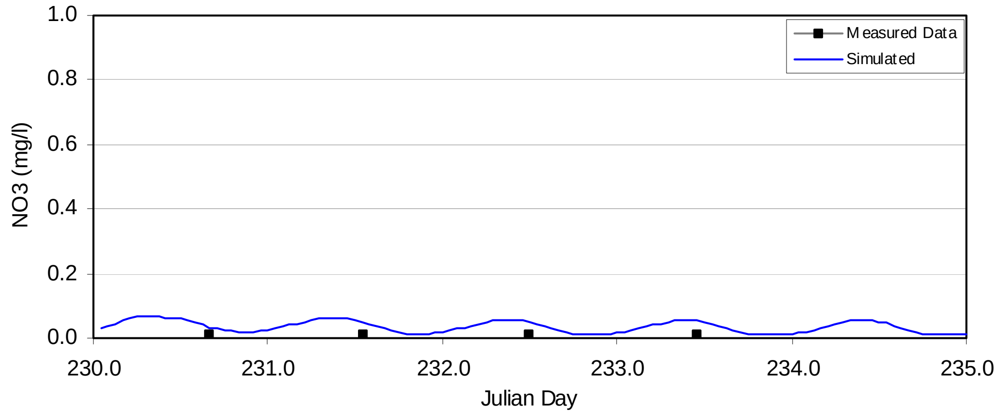



**Figure 180. Klamath River above Salmon River simulated versus measured nitrate, August 18-21, 2003**

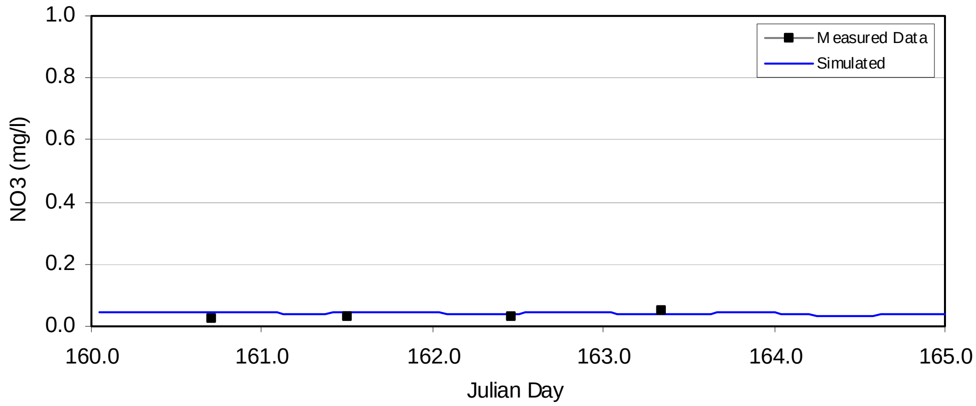



**Figure 181. Klamath River above Trinity River simulated versus measured nitrate, June 9-12, 2003**

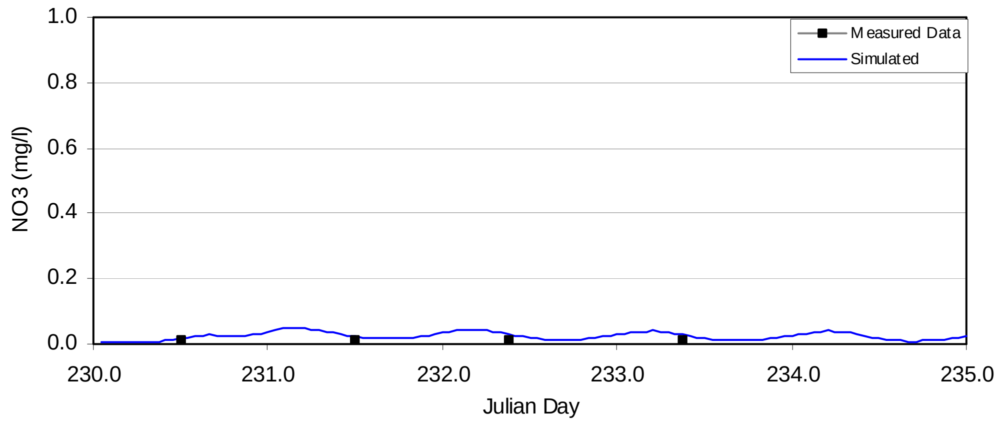



**Figure 182. Klamath River above Trinity River simulated versus measured nitrate, August 18-21, 2003**

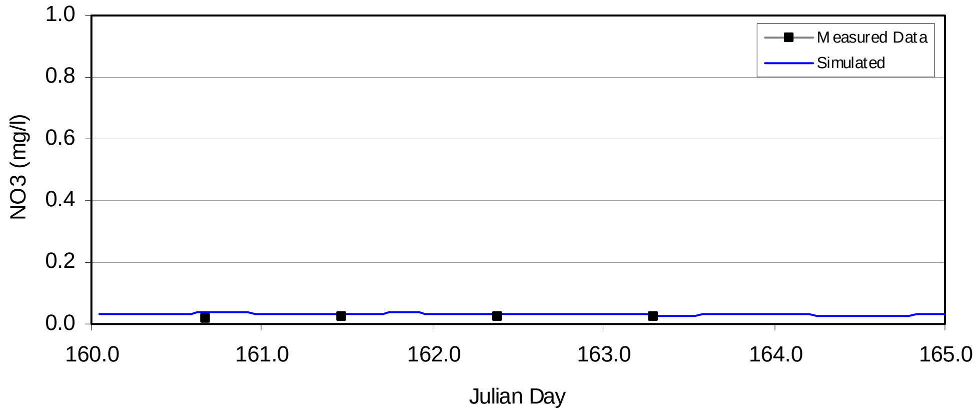



**Figure 183. Klamath River at Martins Ferry simulated versus measured nitrate, June 9-12, 2003**

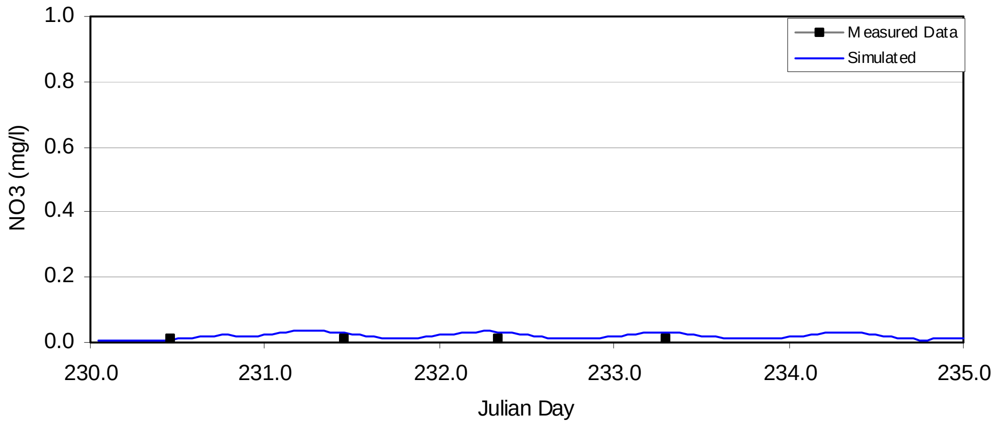



**Figure 184. Klamath River at Tully Creek simulated versus measured nitrate, August 18-21, 2003**

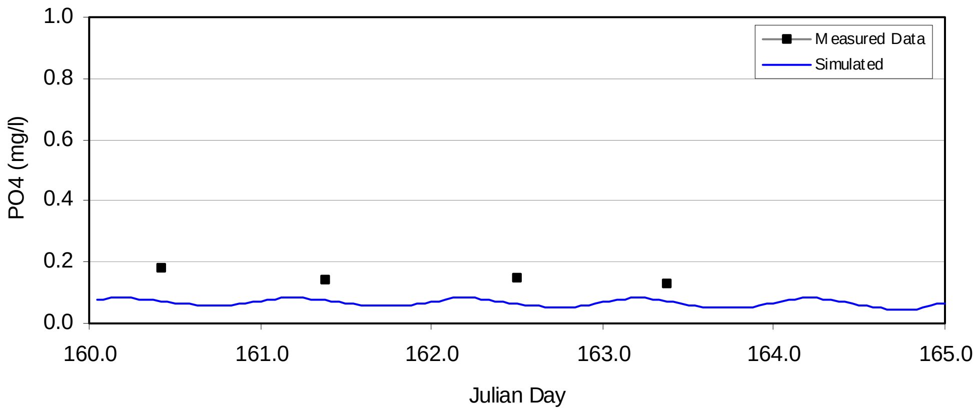



**Figure 185. Klamath River above Shasta River simulated versus measured orthophosphate, June 9-12, 2003**

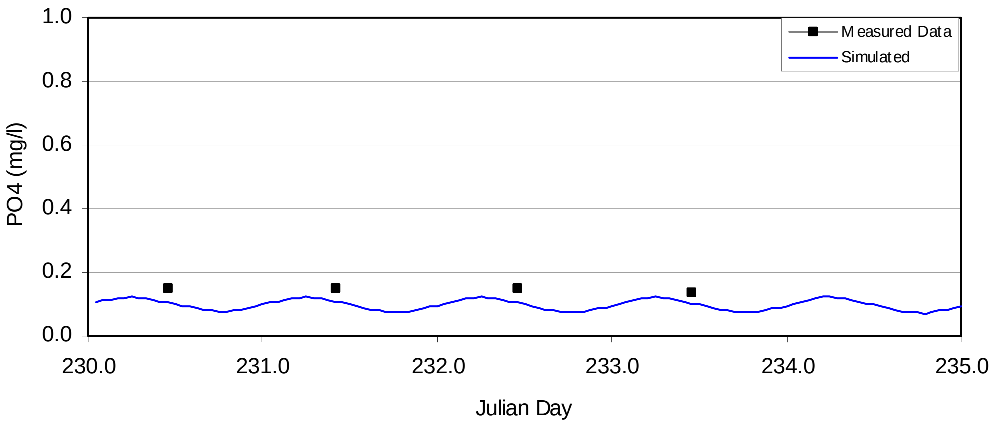



**Figure 186. Klamath River above Shasta River simulated versus measured orthophosphate, August 18-21, 2003**

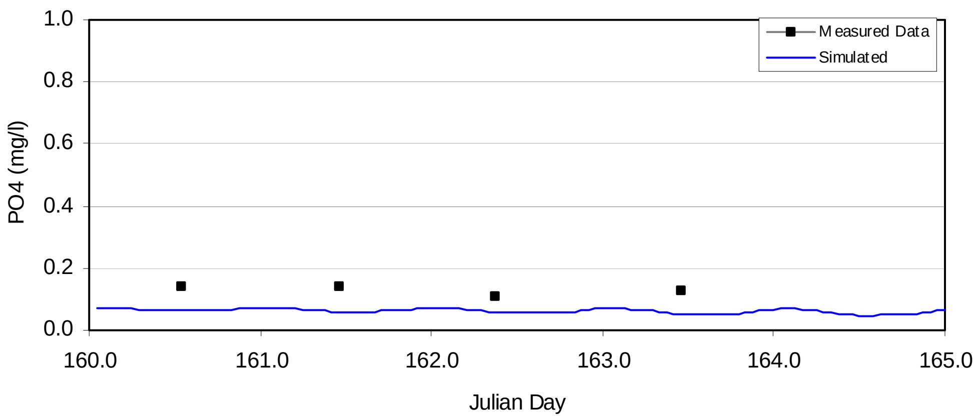



**Figure 187. Klamath River above Scott River simulated versus measured orthophosphate, June 9-12, 2003**

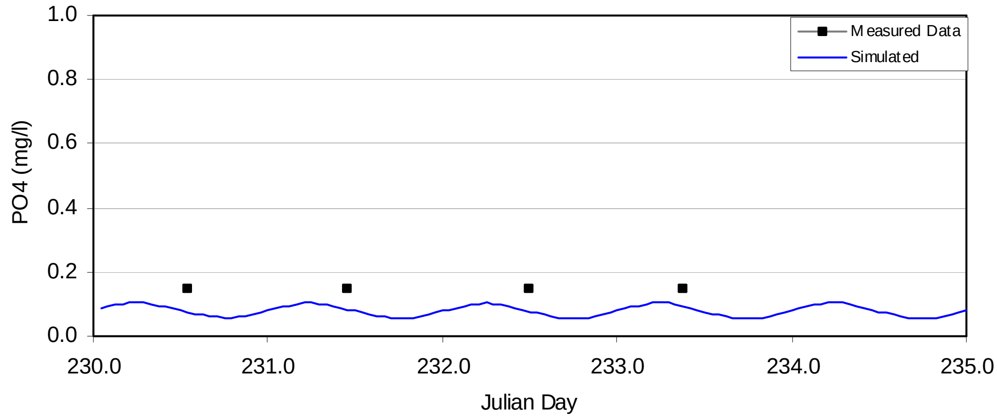



**Figure 188. Klamath River above Scott River simulated versus measured orthophosphate, August 18-21, 2003**

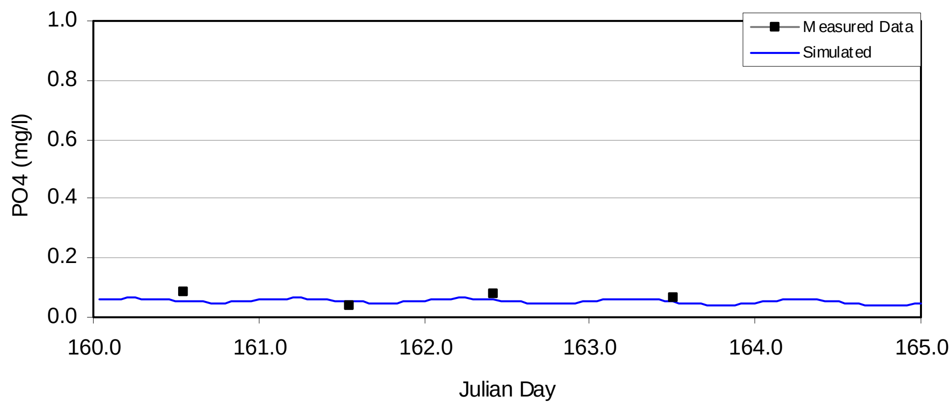



**Figure 189. Klamath River near Seiad Valley simulated versus measured orthophosphate, June 9-12, 2003**

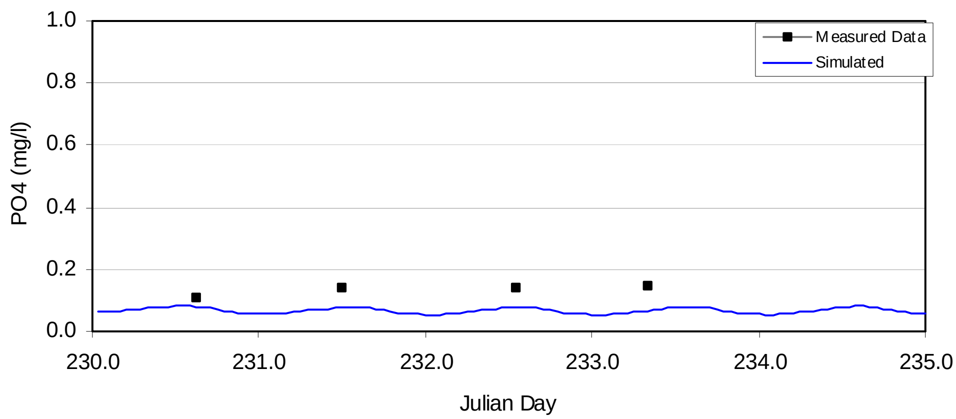


**Figure 190. Klamath River near Seiad Valley simulated versus measured orthophosphate, August 18-21, 2003**

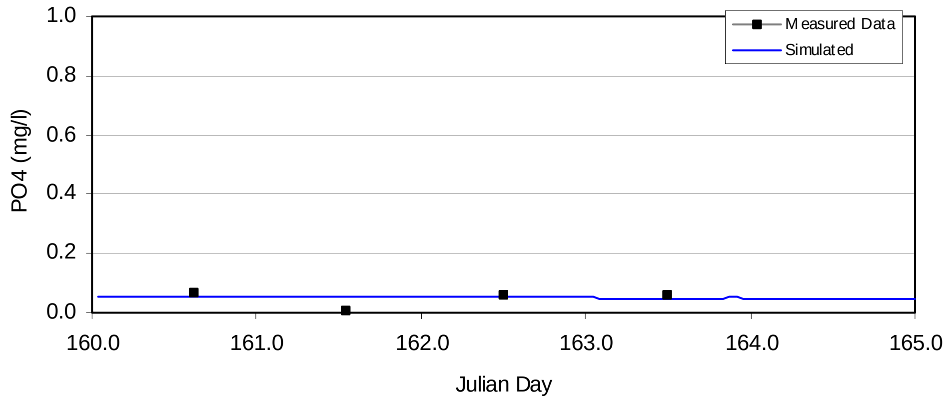



**Figure 191. Klamath River above Clear Creek simulated versus measured orthophosphate, June 9-12, 2003**

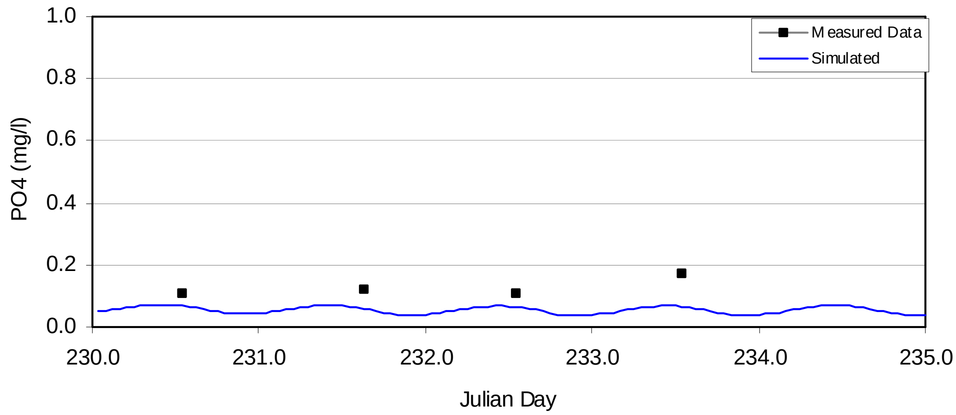



**Figure 192. Klamath River above Clear Creek simulated versus measured orthophosphate, August 18-21, 2003**

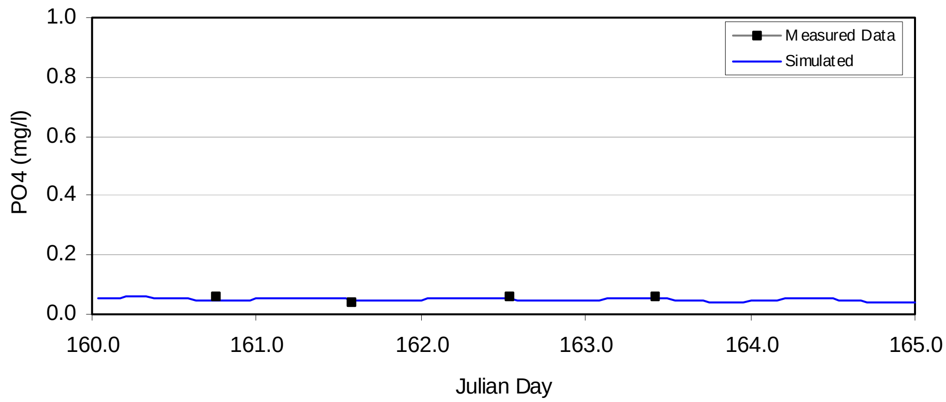


**Figure 193. Klamath River above Salmon River simulated versus measured orthophosphate, June 9-12, 2003**

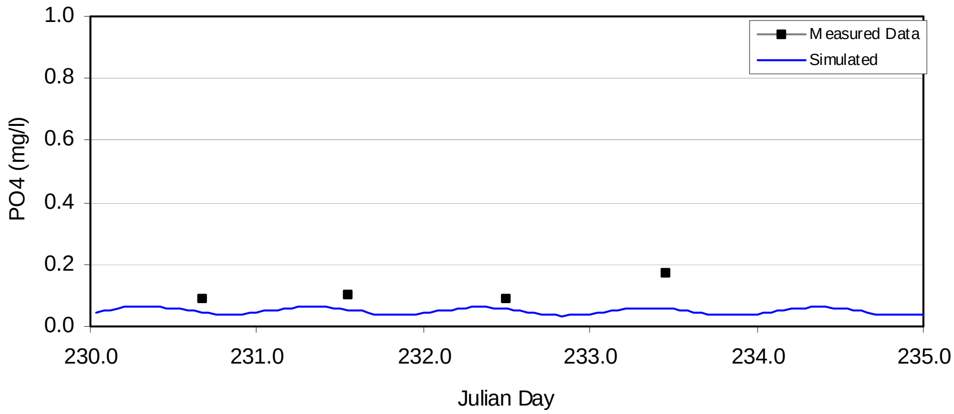



**Figure 194. Klamath River above Salmon River simulated versus measured orthophosphate, August 18-21, 2003**

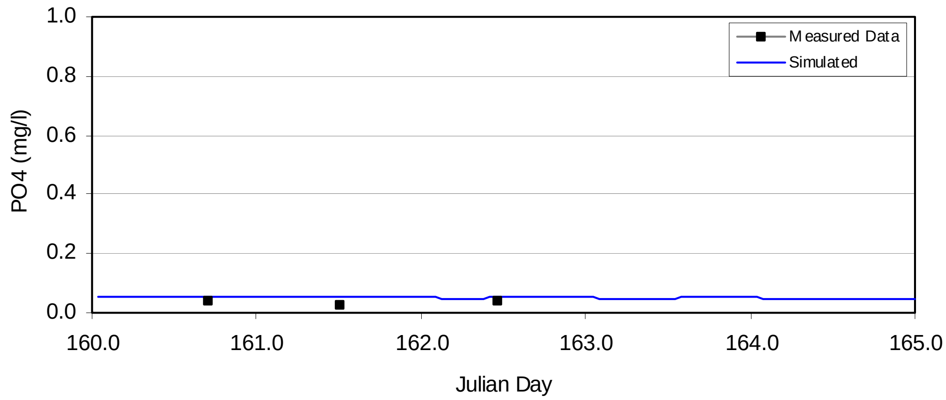



**Figure 195. Klamath River above Trinity River simulated versus measured orthophosphate, June 9-12, 2003**

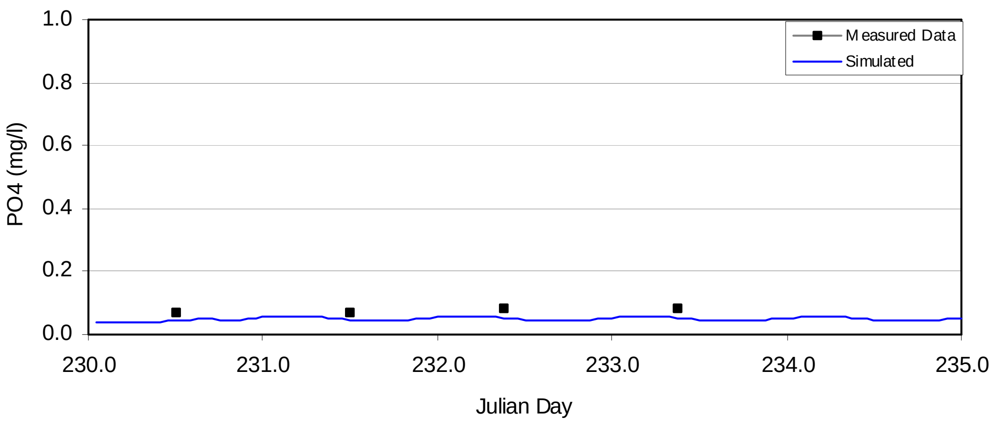



**Figure 196. Klamath River above Trinity River simulated versus measured orthophosphate, August 18-21, 2003**

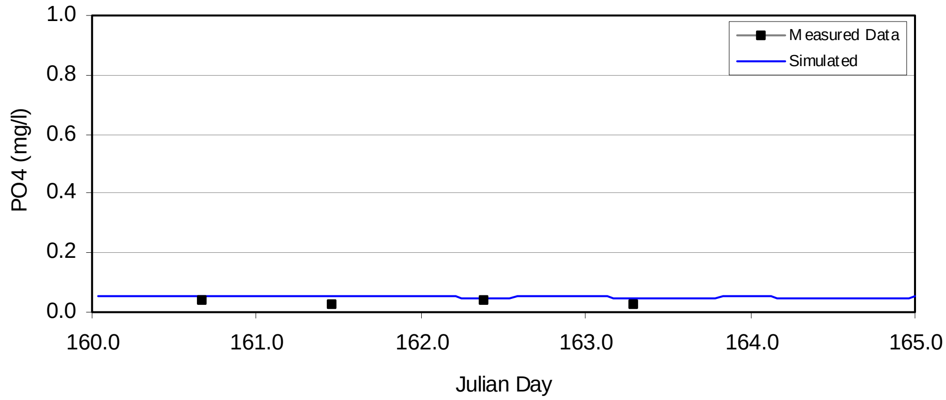



**Figure 197. Klamath River at Martins Ferry simulated versus measured orthophosphate, June 9-12, 2003**

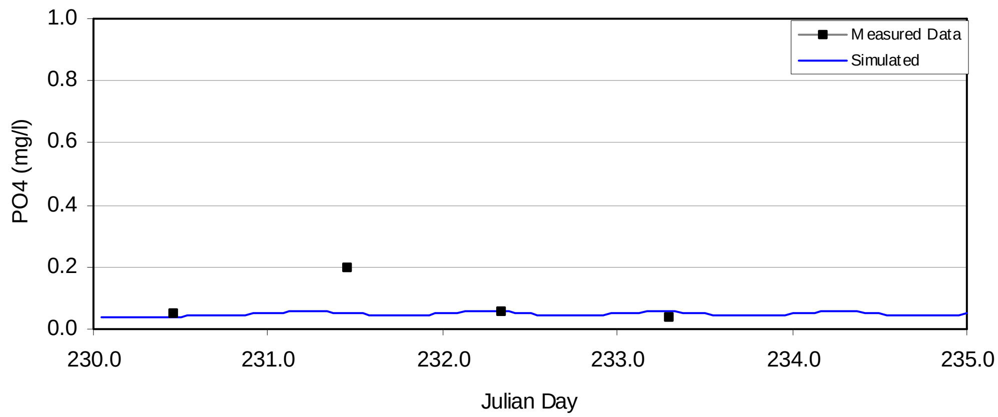



**Figure 198. Klamath River at Tully Creek simulated versus measured orthophosphate, August 18-21, 2003**

**Table 67. Klamath River hourly and daily calibration statistics for nutrients 2003**

**Ammonia, $NH_4^+$**

| JUNE | Above Shasta | Above Scott | Near Seiad | Above Clear Ck | Above Salmon R | Above Trinity R | Near Martins Ferry |
|---|---|---|---|---|---|---|---|
| Bias | 0.02 | 0.04 | 0.05 | 0.07 | 0.06 | 0.05 | 0.06 |
| MAE | 0.02 | 0.04 | 0.05 | 0.07 | 0.06 | 0.07 | 0.06 |
| RMSE | 0.03 | 0.05 | 0.05 | 0.07 | 0.06 | 0.07 | 0.06 |
| n | 4 | 4 | 4 | 4 | 4 | 4 | 4 |

| AUGUST | Above Shasta | Above Scott | Near Seiad | Above Clear Ck | Above Salmon R | Above Trinity R | At Tully Ck |
|---|---|---|---|---|---|---|---|
| Bias | 0.01 | 0.05 | 0.06 | 0.06 | 0.03 | 0.03 | 0.04 |
| MAE | 0.01 | 0.05 | 0.06 | 0.06 | 0.04 | 0.03 | 0.05 |
| RMSE | 0.01 | 0.06 | 0.06 | 0.06 | 0.03 | 0.04 | 0.05 |
| n | 4 | 4 | 4 | 4 | 4 | 4 | 4 |

**Nitrate, $NO_3^-$**

| JUNE | Above Shasta | Above Scott | Near Seiad | Above Clear Ck | Above Salmon R | Above Trinity R | Near Martins Ferry |
|---|---|---|---|---|---|---|---|
| Bias | -0.03 | -0.09 | -0.02 | -0.01 | 0.01 | 0.01 | 0.01 |
| MAE | 0.04 | 0.09 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 |
| RMSE | 0.05 | 0.10 | 0.03 | 0.01 | 0.00 | 0.02 | 0.01 |
| n | 4 | 4 | 4 | 4 | 4 | 4 | 4 |

| AUGUST | Above Shasta | Above Scott | Near Seiad | Above Clear Ck | Above Salmon R | Above Trinity R | At Tully Ck |
|---|---|---|---|---|---|---|---|
| Bias | -0.04 | 0.00 | 0.04 | 0.07 | 0.04 | 0.01 | 0.02 |
| MAE | 0.04 | 0.01 | 0.06 | 0.07 | 0.04 | 0.01 | 0.02 |
| RMSE | 0.04 | 0.01 | 0.06 | 0.07 | 0.03 | 0.02 | 0.02 |
| n | 4 | 4 | 4 | 4 | 4 | 4 | 4 |

**Orthophosphate, $PO_4^{3-}$**

| JUNE | Above Shasta | Above Scott | Near Seiad | Above Clear Ck | Above Salmon R | Above Trinity R | Near Martins Ferry |
|---|---|---|---|---|---|---|---|
| Bias | -0.08 | -0.07 | -0.02 | 0.00 | 0.00 | 0.02 | 0.02 |
| MAE | 0.08 | 0.07 | 0.02 | 0.02 | 0.01 | 0.02 | 0.02 |
| RMSE | 0.08 | 0.07 | 0.03 | 0.03 | 0.01 | 0.02 | 0.02 |
| n | 4 | 4 | 4 | 4 | 4 | 3 | 4 |

| AUGUST | Above Shasta | Above Scott | Near Seiad | Above Clear Ck | Above Salmon R | Above Trinity R | At Tully Ck |
|---|---|---|---|---|---|---|---|
| Bias | -0.04 | -0.07 | -0.06 | -0.06 | -0.06 | -0.03 | -0.04 |
| MAE | 0.04 | 0.07 | 0.06 | 0.06 | 0.06 | 0.03 | 0.04 |
| RMSE | 0.04 | 0.07 | 0.06 | 0.05 | 0.04 | 0.03 | 0.07 |
| n | 4 | 4 | 4 | 4 | 4 | 4 | 4 |

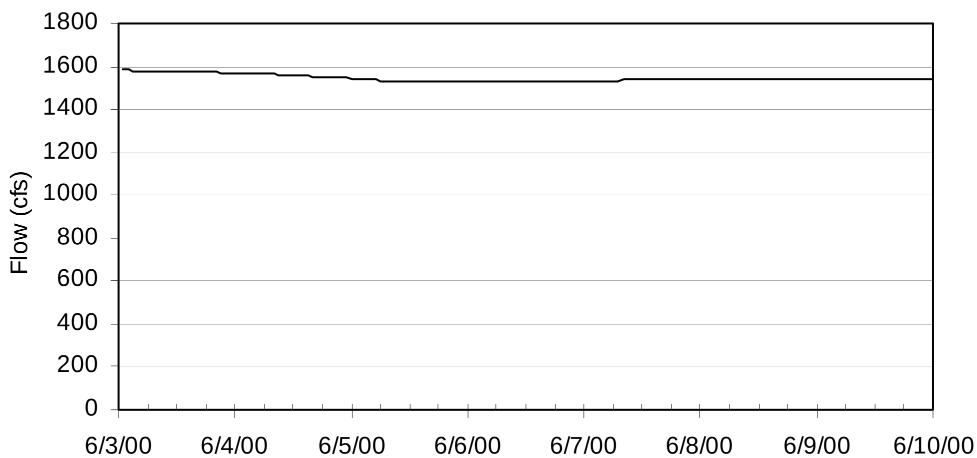
## 3.9.4 Model Application for 2000

The model was applied to the 2000 period and compared with available data: June 5-7, 2000 (Julian Day 157-159) and August 7-9, 2000 (JD 220-222). The process of identifying initial conditions, boundary conditions, and calibration data were the same as in 2003. These data are briefly discussed below, but the graphical and tabular presentation is not presented for sake of brevity.

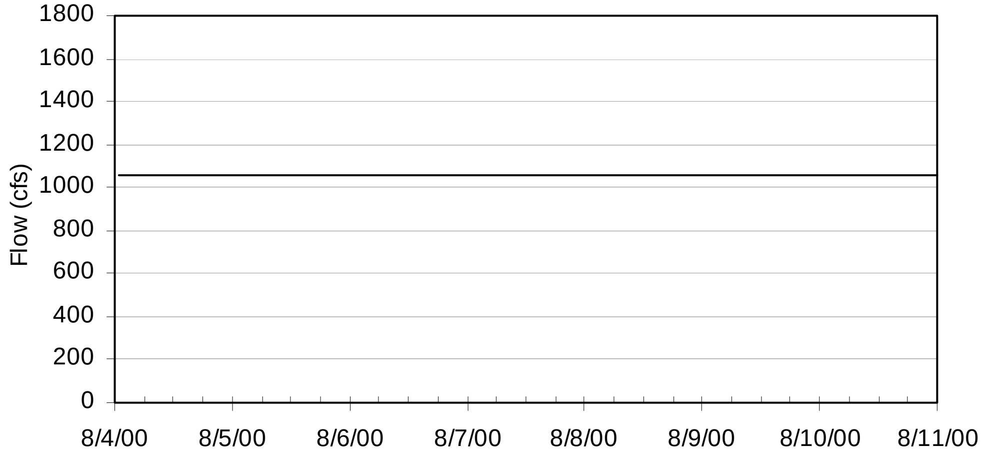
### 3.9.4.1 Data: 2000

**Boundary Conditions at Iron Gate Dam**

Flow data were derived in a similar fashion to 2003. The temperature and dissolved oxygen boundary conditions data for Iron Gate Dam were derived from hourly data recorded by sondes deployed in 2000 by USBR at Klamath River below Iron Gate Dam. The constituent concentration boundary condition data for the Iron Gate Dam was derived from 2000 grab samples (USBR, 2003), which were collected three times per day during the June and August periods. The concentrations were averaged for each period and the average was applied to the calibration or validation period as a constant boundary condition (Table 68). All boundary conditions for the tributaries were those used in model implementation, as described in section 2.3.8, and are not revisited herein.




(a)




(b)

**Figure 199. Gauged flow at Klamath River below Iron Gate Dam for Iron Gate to Turwar reach model 2000: (a) June, (b) August**

**Table 68. Water quality constituent boundary conditions for the Klamath River below Iron Gate Dam: June and August 2000**

| Constituent | Unit | June | August |
|---|---|---|---|
| Temp | C | hourly | hourly |
| DO | mg/l | hourly | hourly |
| BOD | mg/l | 2.00 | 2.00 |
| OrgN | mg/l | 0.70 | 0.55 |
| NH4 | mg/l | 0.10 | 0.10 |
| NO2 | mg/l | 0.00 | 0.00 |
| NO3 | mg/l | 0.06 | 0.30 |
| OrgP | mg/l | 0.05 | 0.00 |
| PO4 | mg/l | 0.25 | 0.15 |
| Chlor_a | mg/m^3 | 10.00 | 10.00 |

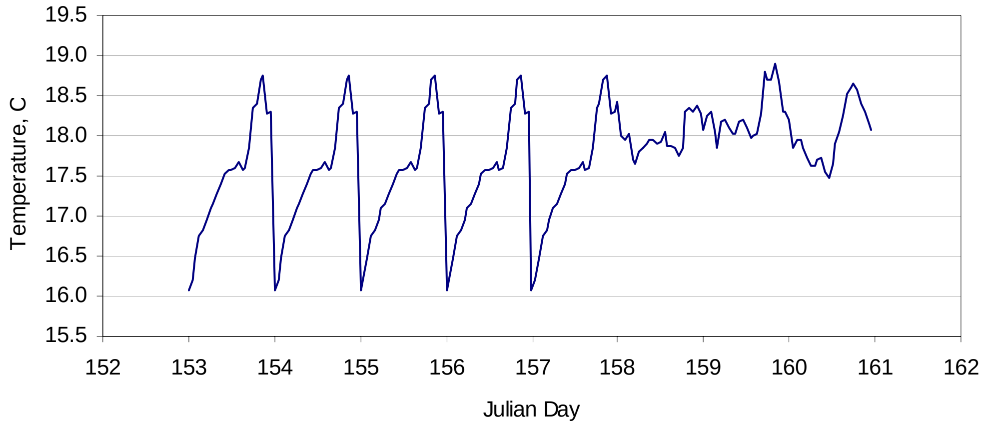



**Figure 200. Klamath River below Iron Gate water temperature: June 1-9, 2000 (JD 153-161)**

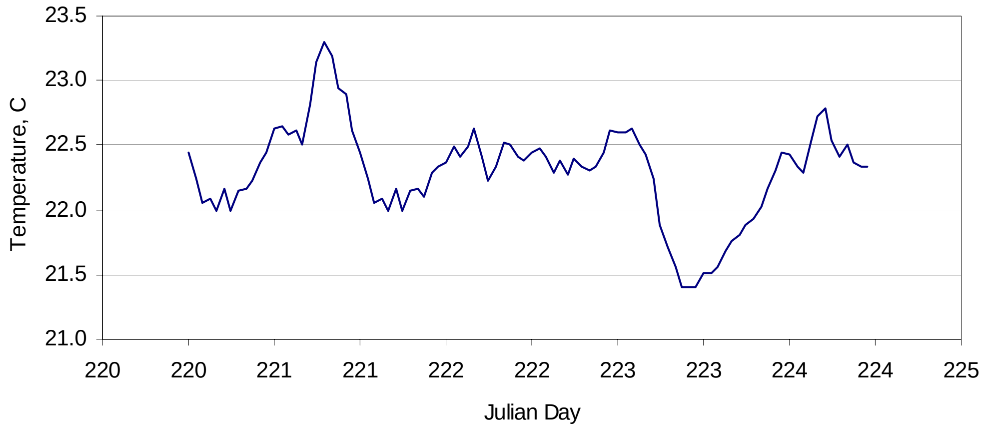



**Figure 201. Klamath River below Iron Gate water temperature : August 7-15, 2000 (JD 220-224)**

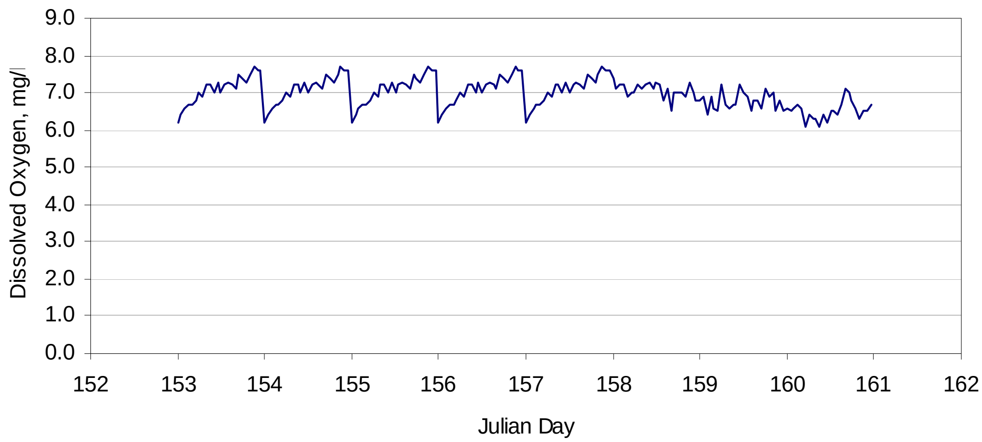



**Figure 202. Klamath River below Iron Gate dissolved oxygen: June 1-9, 2000 (JD 153-161)**

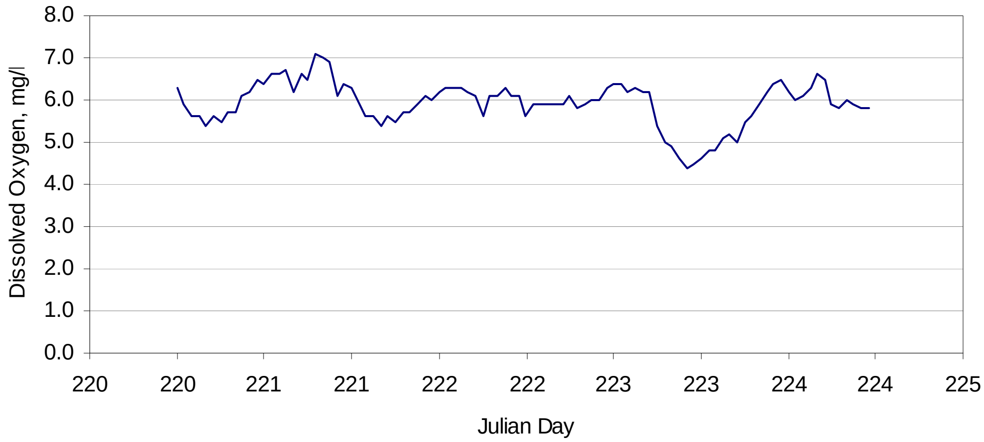



**Figure 203. Klamath River below Iron Gate dissolved oxygen: August 7-15, 2000 (JD 220-224)**

### Initial Conditions

The model was run for two days prior to the 2000 calibration period (approximate travel time from Iron Gate to Seiad Valley) to provide an initial condition for simulations. The initial bed algae mass was estimated at 5 $g/m^2$. Where field data were unavailable, the conditions of the first day of available field data were applied.

### Model Output Locations

For the 2000 simulation, model output was compared with observations at: Klamath River above Shasta River, above Walker Road Bridge, above Scott River, and near Seiad Valley. For dissolved oxygen there was only sufficient data for the Klamath River above the Shasta River and near Seiad Valley. Water quality probes and/or temperature loggers were employed to record conditions at the identified locations, and grab samples were available from USBR (2003). These data are displayed in the following section with model results.

All water quality probes and grab samples were collected from near-shore areas and although all efforts were made to identify locations that were deemed consistent with overall main stem conditions (e.g., areas that readily exchanged water with main flow in the river), several factors could result in potential deviation main stem conditions. The primary factor is probably the rapidly descending hydrographs in the June sampling periods which changed local conditions at some sampling locations and required successive re-deployment of water quality probes as water levels fell.

## 3.9.5 Results 2000

Results of year 2000 simulations were complete for temperature and dissolved oxygen as primary constituents and inorganic nutrient forms (ammonia, nitrate, orthophosphate) as secondary constituents (i.e., summary statistics were not computed). Field observations for temperature and dissolved oxygen were available from water quality probes on an hourly interval for June and August 2000 at multiple sites from Iron Gate Dam to Seiad Valley allowing for summary statistics to be calculated both on hourly and daily basis.

### 3.9.5.1 Water Temperature

Overall simulated results indicate that phase and amplitude were well represented during the 2000 periods and the mean absolute error between hourly simulated and observed value was less than 1.2°C at all locations. The mean absolute error in daily averaged values was 1.0°C or less at all locations. Simulated and observed temperatures results for each location are presented below.

At Klamath River above Shasta River, the diurnal range and phase were well represented in both periods of examination. Hourly bias for the June period was –0.17°C with a mean absolute error of 1.19°C. Hourly bias for the August period was 0.54°C with a mean absolute error of 0.70°C.

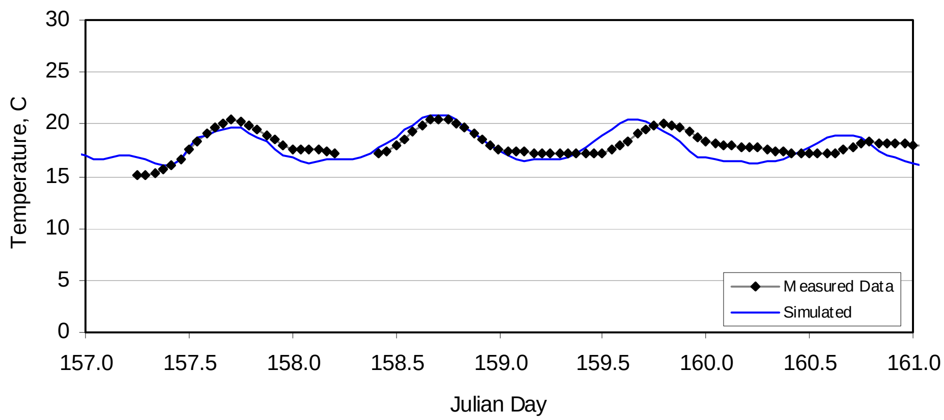



**Figure 204. Klamath River above Shasta River simulated versus measured water temperature, June 5-7, 2000**

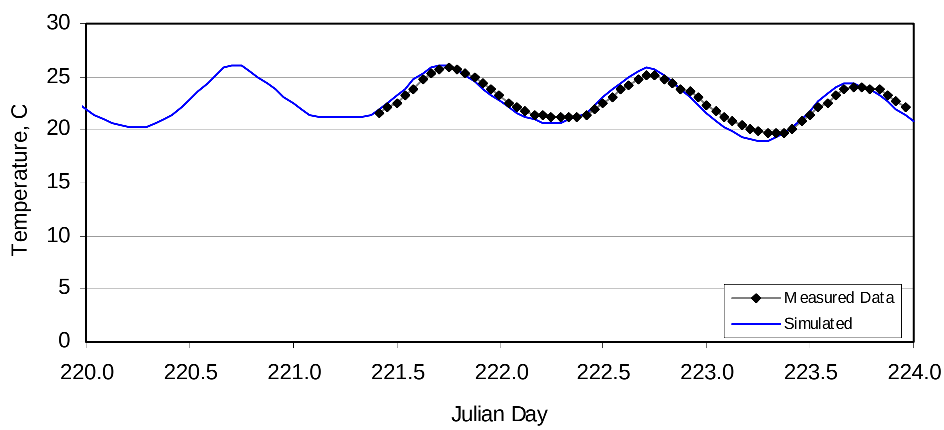



**Figure 205. Klamath River above Shasta River simulated versus measured water temperature, August 7-9, 2000**

At Klamath River at Walker Road Bridge, the moderated diurnal phase associated with the node of minimum diurnal variation due to Iron Gate Dam operations was well represented for both June and August periods. Hourly bias for the June period was 0.26°C with a mean absolute error of 0.47°C. Hourly bias for the August period was -0.25°C with a mean absolute error of 0.75°C.

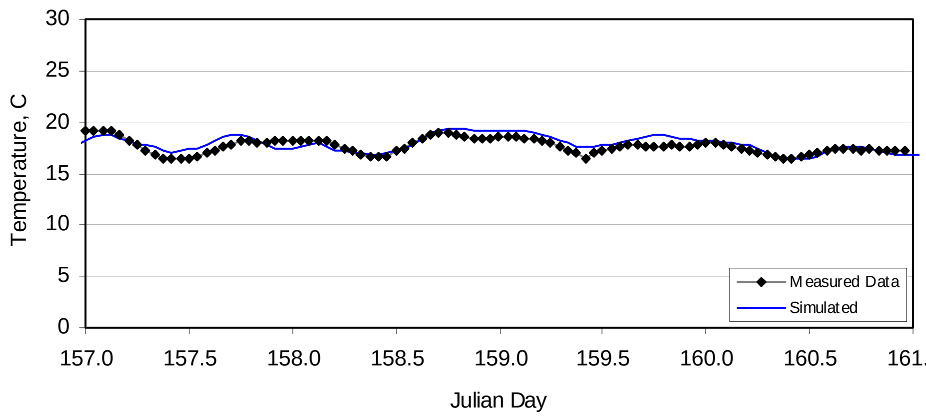



**Figure 206. Klamath River above Walker Road Bridge (RM 156) simulated versus measured water temperature, June 5-7, 2000**

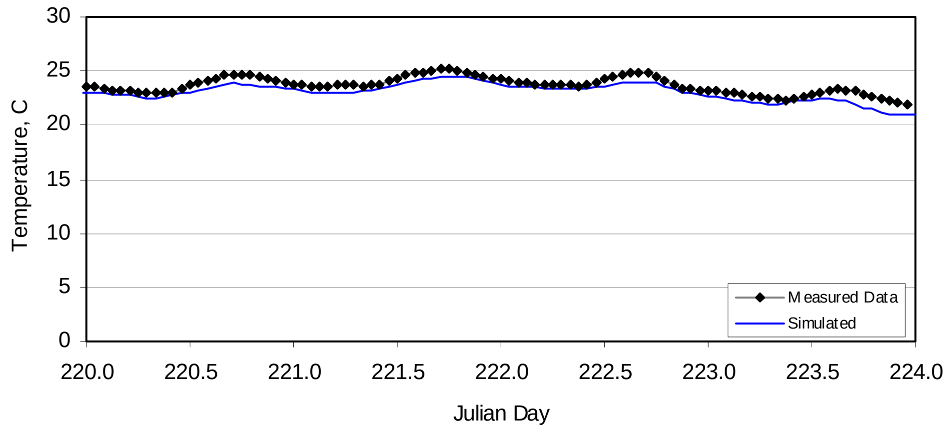



**Figure 207. Klamath River above Walker Road Bridge (RM 156) simulated versus measured water temperature, August 7-9, 2000**

At Klamath River above Scott River, the diurnal range and phase were generally well represented in both periods of examination. Hourly bias for the June period was 0.02°C with a mean absolute error of 0.51°C.  Hourly bias for the August period was -0.53°C with a mean absolute error of 0.98°C.

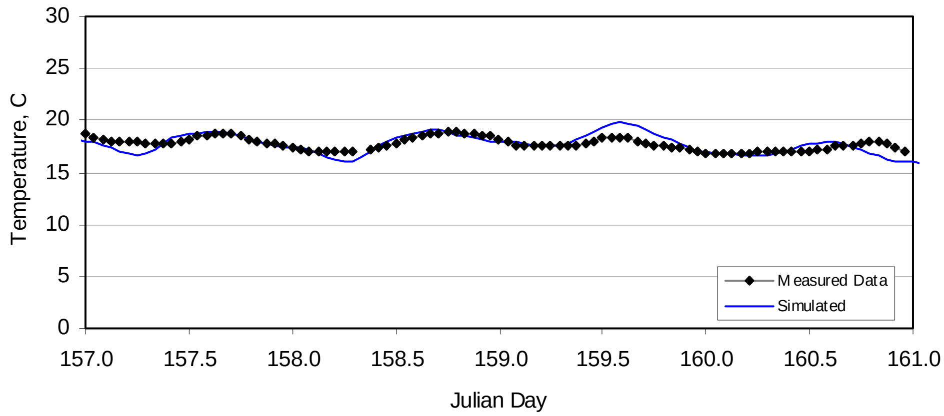



**Figure 208. Klamath River above Scott River versus measured water temperature, June 5-7, 2000**

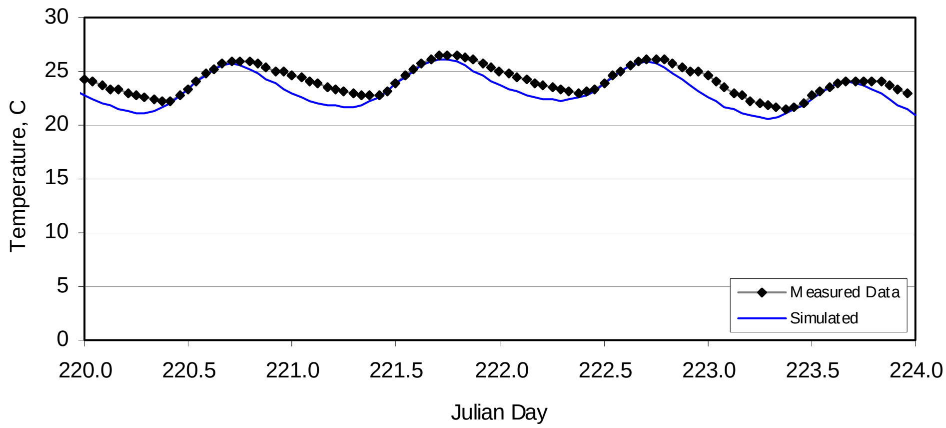



**Figure 209. Klamath River above Scott River simulated versus measured water temperature, August 7-9, 2000**

At Klamath River near Seiad Valley, the diurnal range and phase were well represented in both periods of examination; however, the model systematically under predicts in August. Hourly bias for the June period was -0.04°C with a mean absolute error of 0.38°C. Hourly bias for the August period was -0.78°C with a mean absolute error of 1.06°C.

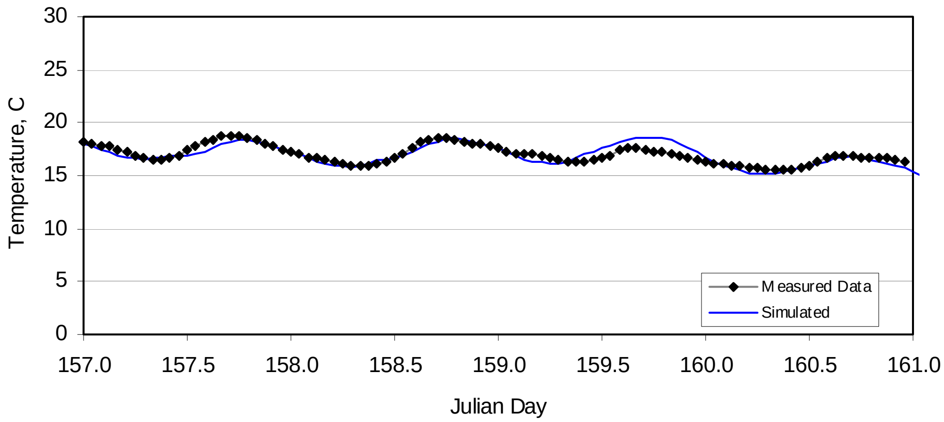



**Figure 210. Klamath River near Seiad Valley versus measured water temperature, June 5-7, 2000**

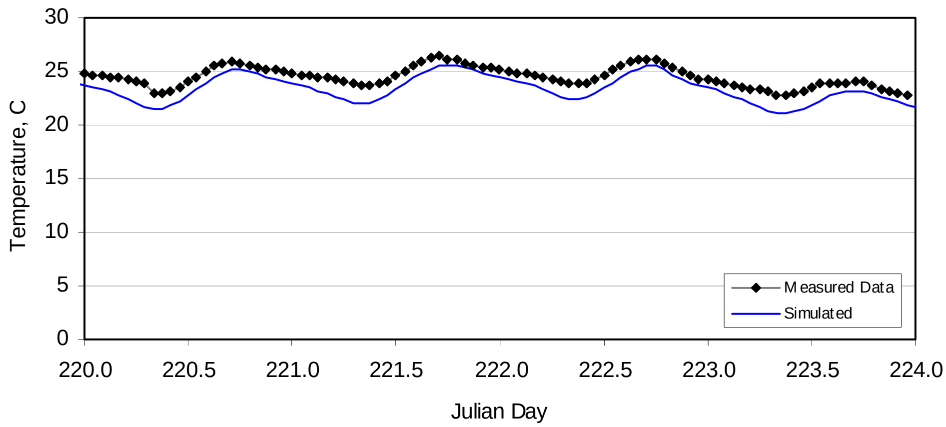



**Figure 211. Klamath River near Seiad Valley versus measured water temperature, August 7-9, 2000**

**Table 69. Klamath River hourly and daily calibration and validation period statistics for water temperature 2000**

| Calibration / Validation Statistics | | Hourly | | Daily | |
|---|---|---|---|---|---|
| | Unit | June | August | June | August |
| Klamath River ab Shasta River | | | | | |
| Mean Bias[a] | °C | -0.17 | 0.54 | -0.25 | 0.68 |
| Mean absolute error (MAE) | °C | 1.19 | 0.70 | 0.25 | 0.68 |
| Root mean squared error (RMSE) | °C | 1.48 | 0.87 | 0.26 | 0.77 |
| n | - | 92 | 62 | 3 | 2 |
| Klamath River at Walker Road Bridge | | | | | |
| Mean Bias[a] | °C | 0.26 | -0.25 | 0.26 | -0.25 |
| Mean absolute error (MAE) | °C | 0.47 | 0.75 | 0.26 | 0.67 |
| Root mean squared error (RMSE) | °C | 0.56 | 0.84 | 0.36 | 0.74 |
| n | - | 96 | 96 | 4 | 4 |
| Klamath River ab Scott River | | | | | |
| Mean Bias[a] | °C | 0.02 | -0.53 | 0.01 | -0.53 |
| Mean absolute error (MAE) | °C | 0.51 | 0.98 | 0.31 | 0.87 |
| Root mean squared error (RMSE) | °C | 0.67 | 1.19 | 0.36 | 0.92 |
| n | - | 95 | 96 | 4 | 4 |
| Klamath River near Seiad Valley | | | | | |
| Mean Bias[a] | °C | -0.04 | -0.78 | -0.04 | -0.78 |
| Mean absolute error (MAE) | °C | 0.38 | 1.06 | 0.26 | 1.00 |
| Root mean squared error (RMSE) | °C | 0.50 | 1.21 | 0.30 | 1.08 |
| n | - | 96 | 96 | 4 | 4 |

[a] Mean bias = simulated – measured

### 3.9.5.2 Dissolved Oxygen

Dissolved oxygen calibration required varying several parameters, including but not limited to algal growth rates, and respiration rates, organic and inorganic nutrient decay rates, and temperature constants for rate reactions. Both phytoplankton and benthic algae were modeled in river reaches. To represent the adverse environment a river imposes on phytoplankton that are washed in from upstream Iron Gate Reservoir, growth rates were set to very low numbers in river reaches.

The hourly results are presented graphically in Figure 212 through Figure 216. Tabulated statistics are presented in Table 70.

At Klamath River above Shasta River, the diurnal phase is well represented during both June and August periods. However, the diurnal range in June is under represented and the shape of the daily cycle deviates from observed data. Hourly bias for the June period was 0.29 mg/l with a mean absolute error of 0.46 mg/l. Hourly bias for the August period was 0.48 mg/l with a mean absolute error of 0.56 mg/l.

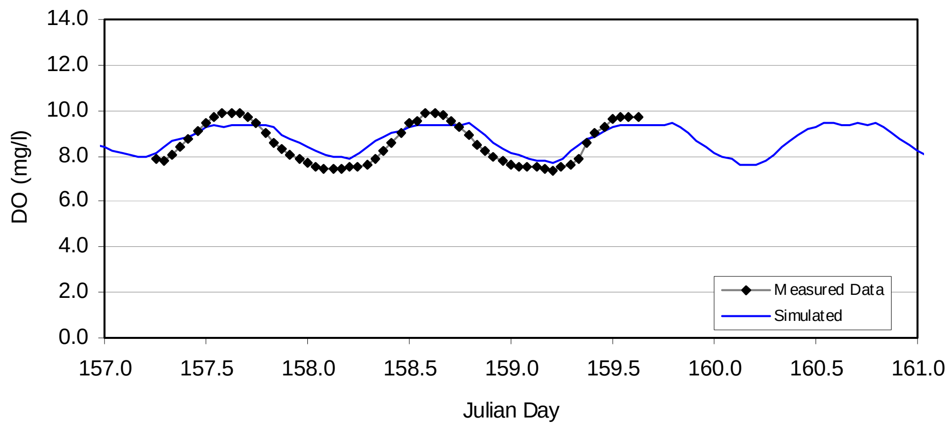



**Figure 212. Klamath River above Shasta River simulated versus measured dissolved oxygen, June 5-7, 2000**

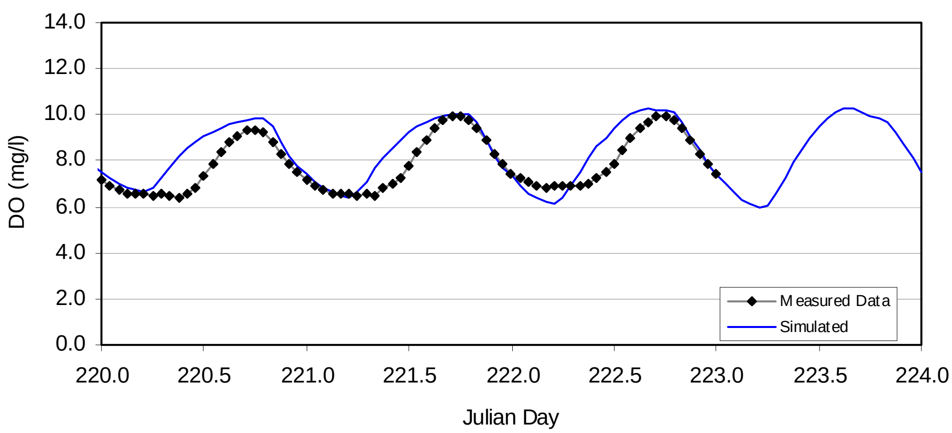



**Figure 213. Klamath River above Shasta River simulated versus measured dissolved oxygen, August 7-9, 2000**

There were no dissolved oxygen observations at Klamath River at Walker Road Bridge.

At Klamath River above Scott River, dissolved oxygen observations were only available during the August period (June data were unavailable). While the diurnal phase and range were well represented, the simulated values were offset approximately 1.5 mg/l higher than observations. Saturated dissolved oxygen concentration, included in the figure, suggest that the observed data were well below saturation, while model results are much more consistent with saturation dissolved oxygen values on a daily basis. Hourly bias for the August period was 1.50 mg/l with a mean absolute error of 1.50 mg/l.

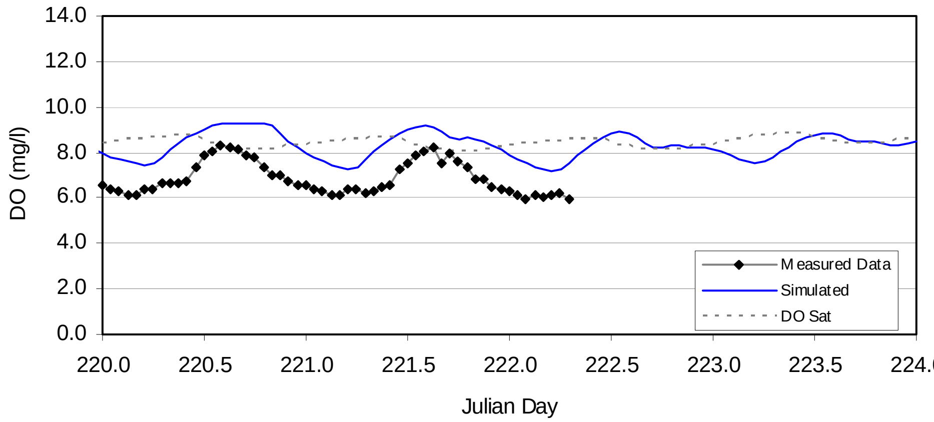



**Figure 214. Klamath River above Scott River simulated versus measured dissolved oxygen, August 7-9, 2000**

At Klamath River near Seiad Valley, during both June and August the diurnal phase and range were well represented; however, the simulated August values were offset by over 1.0 mg/l higher than observations. Saturated dissolved oxygen concentration, included in the figure, suggest that the observed data were well below saturation, while model results are much more consistent with saturation dissolved oxygen values on a daily basis. Hourly bias for the June period (calibration) was 0.19 mg/l with a mean absolute error of 0.27 mg/l. Hourly bias for the August period (validation) was 1.19 mg/l with a mean absolute error of 1.19 mg/l.

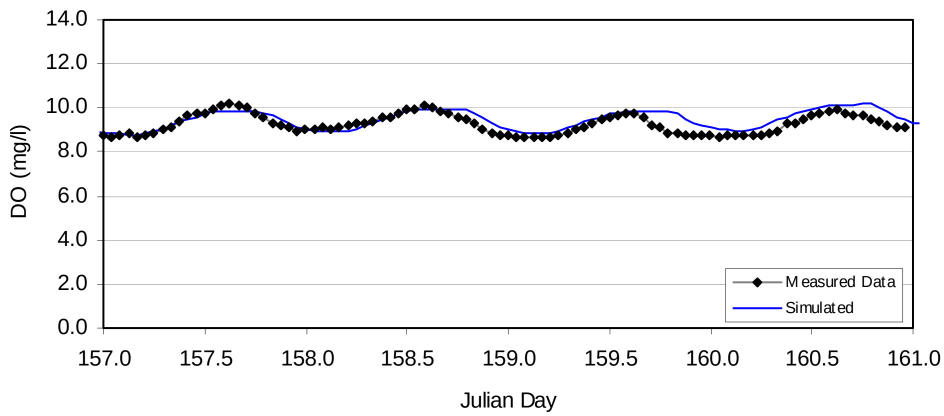



**Figure 215. Klamath River near Seiad Valley simulated versus measured dissolved oxygen, June 5-7, 2000**

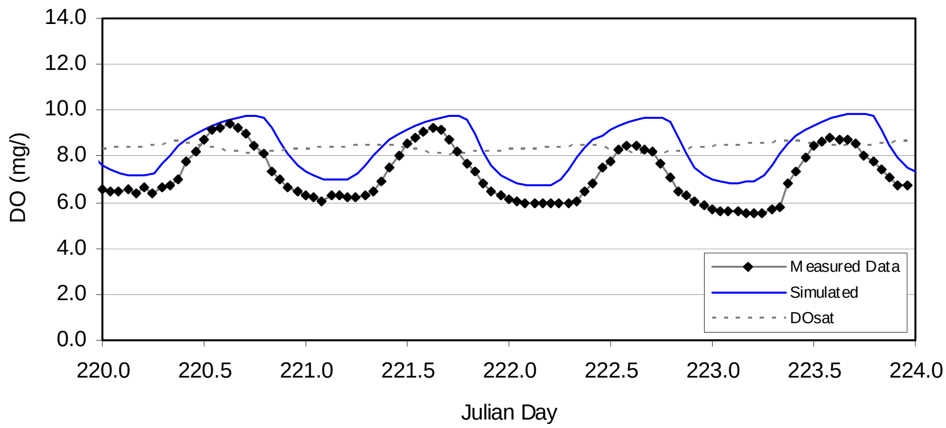



**Figure 216. Klamath River near Seiad Valley simulated versus measured dissolved oxygen, August 7-9, 2000**

**Table 70. Klamath River hourly and daily calibration and validation period statistics for dissolved oxygen**

| Calibration / Validation Statistics | | Hourly | | Daily | |
|---|---|---|---|---|---|
| | Unit | Calib. | Valid. | Calib. | Valid. |
| Klamath River ab Shasta River | | | | | |
| Mean Bias[a] | mg/l | 0.29 | 0.48 | 0.35 | 0.49 |
| Mean absolute error (MAE) | mg/l | 0.46 | 0.56 | 0.35 | 0.49 |
| Root mean squared error (RMSE) | mg/l | 0.51 | 0.76 | 0.35 | 0.52 |
| n | - | 52 | 73 | 1 | 3 |
| Klamath River ab Scott River | | | | | |
| Mean Bias[a] | mg/l | n/a | 1.50 | n/a | 1.51 |
| Mean absolute error (MAE) | mg/l | n/a | 1.50 | n/a | 1.51 |
| Root mean squared error (RMSE) | mg/l | n/a | 1.54 | n/a | 1.51 |
| n | - | n/a | 56 | n/a | 2 |
| Klamath River near Seiad Valley | | | | | |
| Mean Bias[a] | mg/l | 0.19 | 1.19 | 0.19 | 1.19 |
| Mean absolute error (MAE) | mg/l | 0.27 | 1.19 | 0.19 | 1.19 |
| Root mean squared error (RMSE) | mg/l | 0.34 | 1.29 | 0.26 | 1.21 |
| n | - | 96 | 96 | 4 | 4 |

[a] Mean bias = simulated – measured

### 3.9.5.3 Nutrients

Nutrient concentrations were not formally calibration in the Iron Gate to Turwar reach. That is, values for nutrient interactions (e.g. stoichiometric equivalence with regard to primary production, decay rates and temperature rate constants) identified in the dissolved oxygen calibration were not modified further, and other parameters were set at default values. The results are presented graphically in Figure 217 through Figure 234. Simulated concentrations for ammonia, nitrate, and orthophosphate were consistent with field observations. There is some scatter in the observed data that is not replicated within the model.

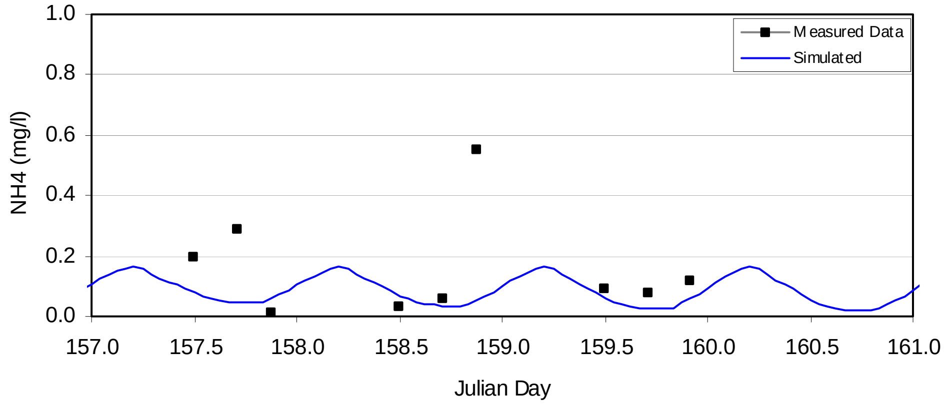



**Figure 217. Klamath River above Shasta River simulated versus measured ammonia, June 5-7, 2000**

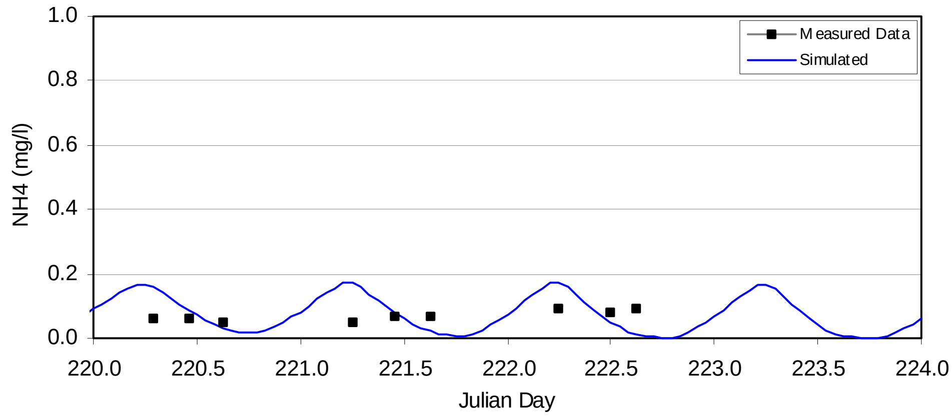



**Figure 218. Klamath River above Shasta River simulated versus measured ammonia, August 7-9, 2000**

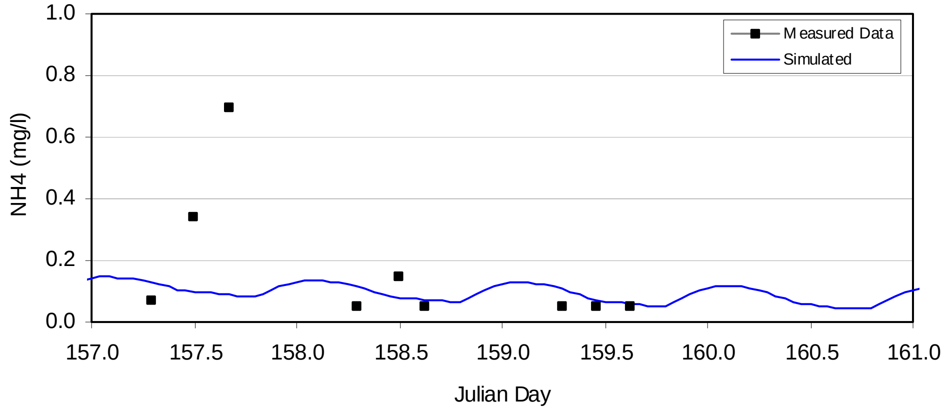


**Figure 219. Klamath River above Scott River simulated versus measured ammonia, June 5-7, 2000**

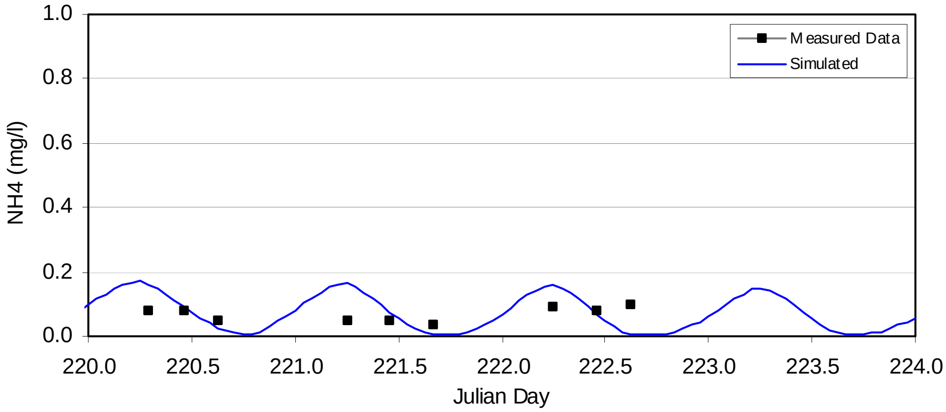



**Figure 220. Klamath River above Scott River simulated versus measured ammonia, August 7-9, 2000**

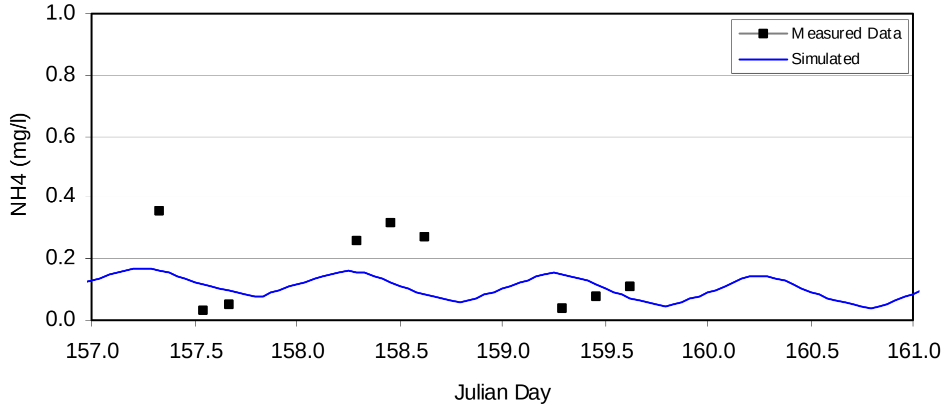



**Figure 221. Klamath River near Seiad Valley simulated versus measured ammonia, June 5-7, 2000**

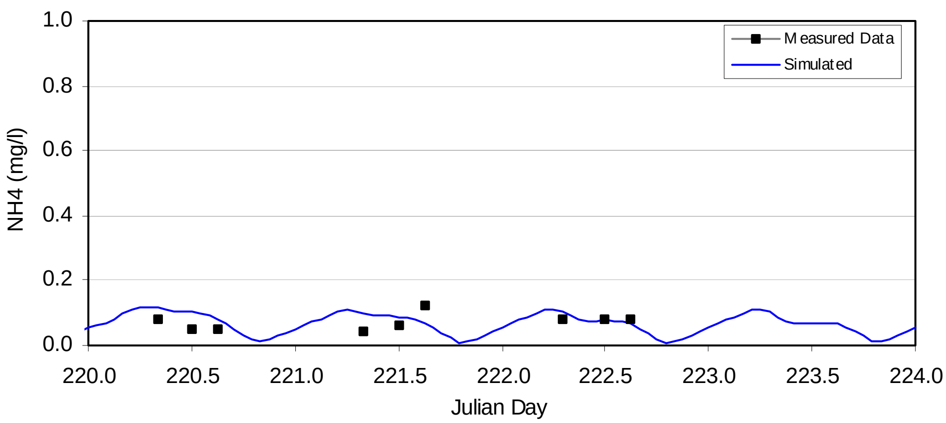


**Figure 222. Klamath River near Seiad Valley River simulated versus measured ammonia, August 7-9, 2000**

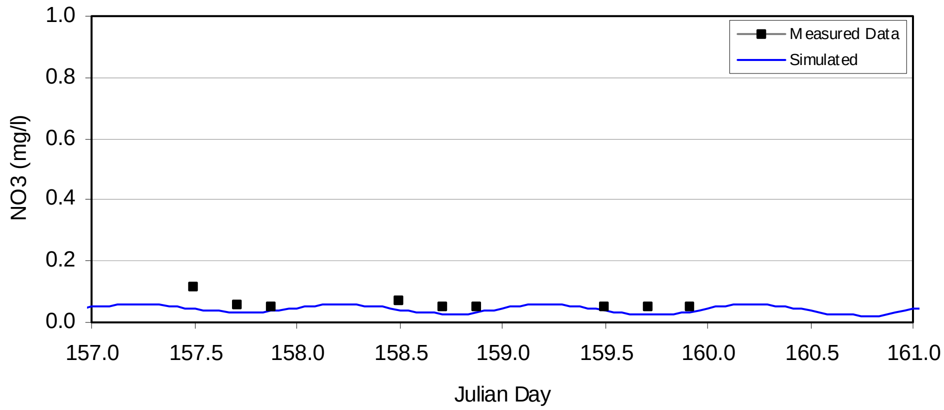



**Figure 223. Klamath River above Shasta River simulated versus measured nitrate, June 5-7, 2000**

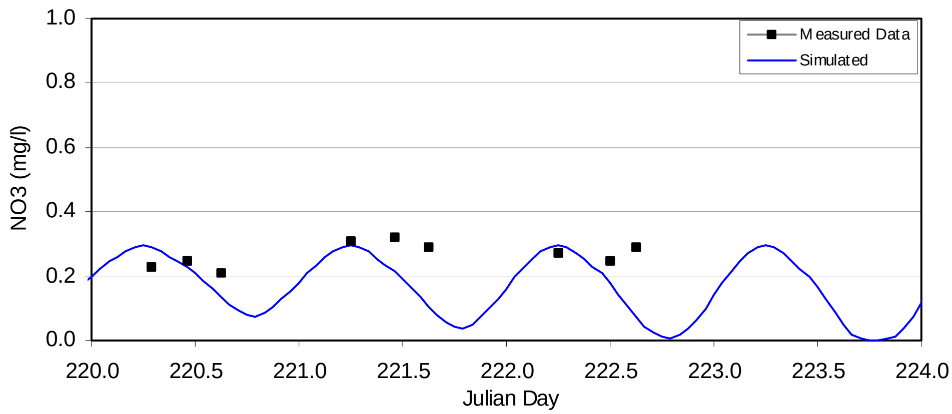



**Figure 224. Klamath River above Shasta River simulated versus measured nitrate, August 7-9, 2000**

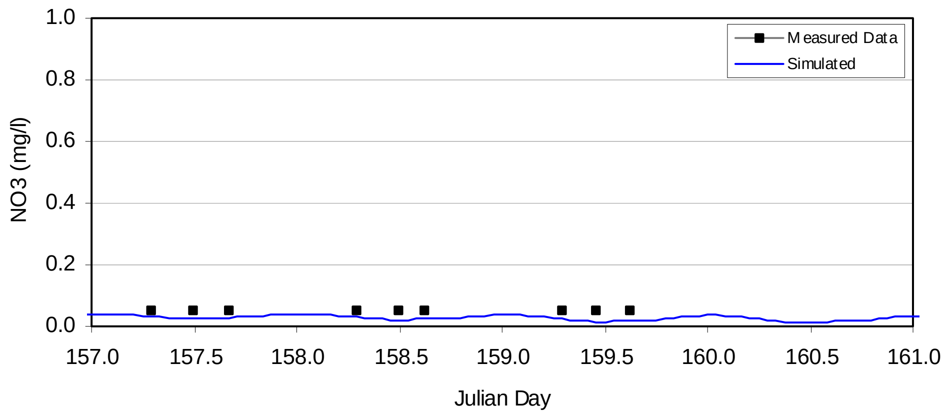


**Figure 225. Klamath River above Scott River simulated versus measured nitrate, June 5-7, 2000**

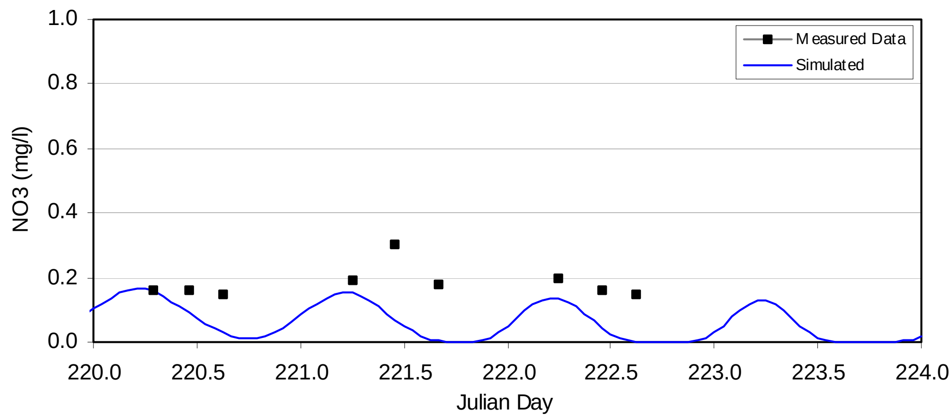



**Figure 226. Klamath River above Scott River simulated versus measured nitrate, August 7-9, 2000**

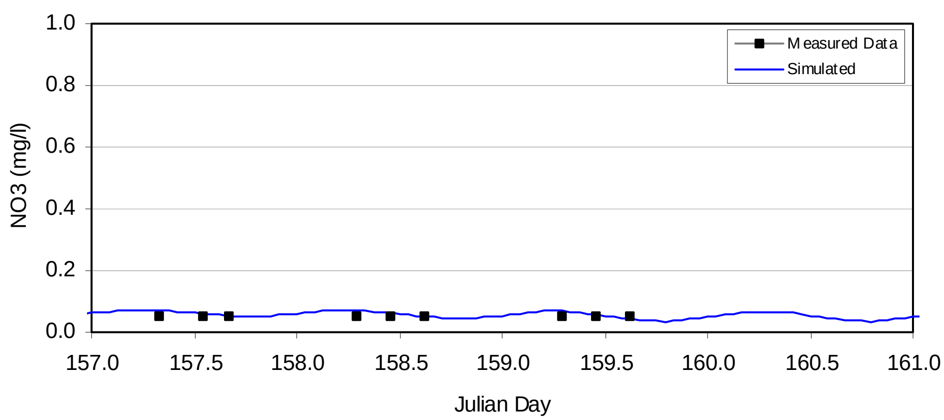



**Figure 227. Klamath River near Seiad Valley simulated versus measured nitrate, June 5-7, 2000**

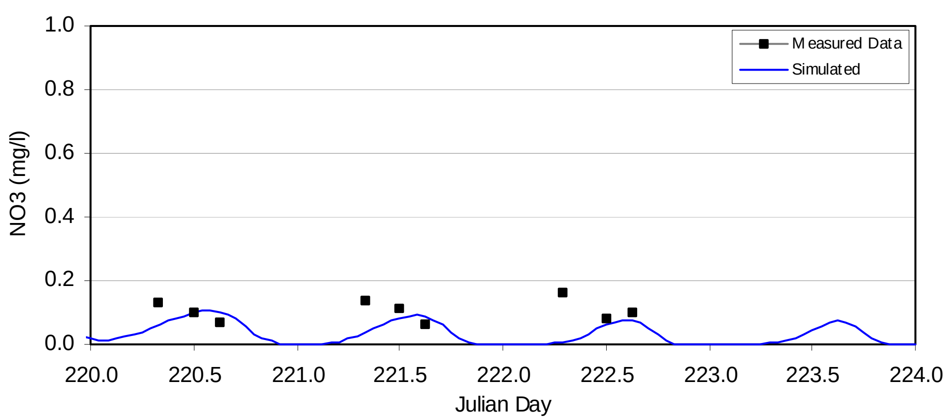


**Figure 228. Klamath River near Seiad Valley simulated versus measured nitrate, August 7-9, 2000**

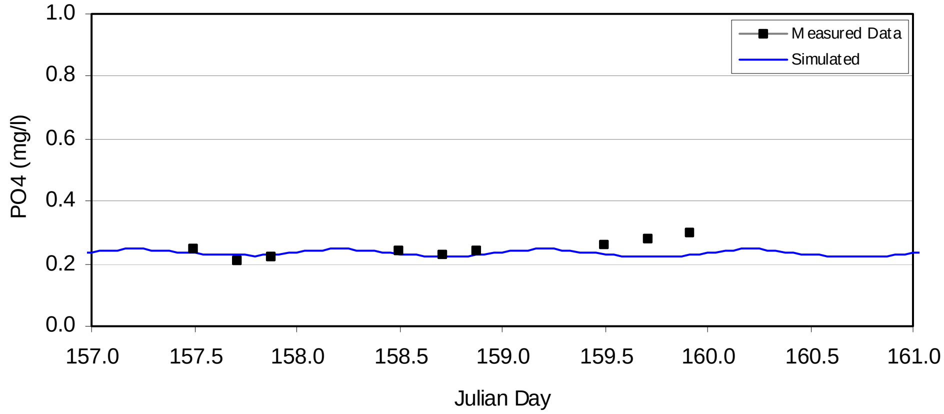



**Figure 229. Klamath River above Shasta River simulated versus measured orthophosphate, June 5-7, 2000**

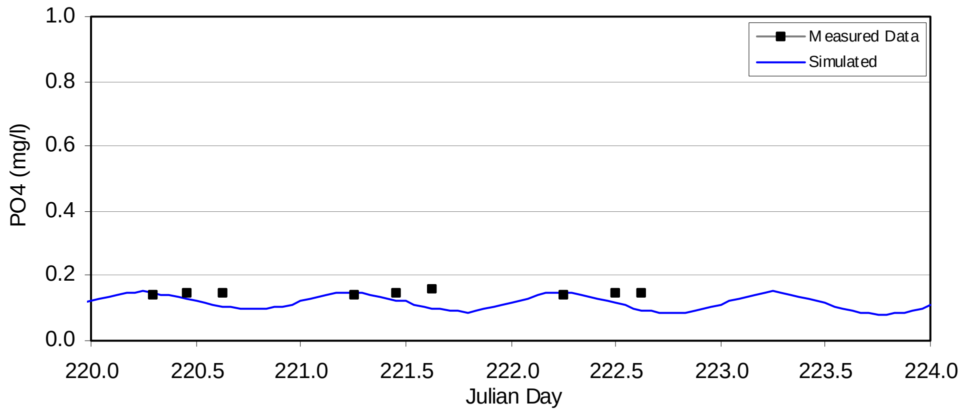



**Figure 230. Klamath River above Shasta River simulated versus measured orthophosphate, August 7-9, 2000**

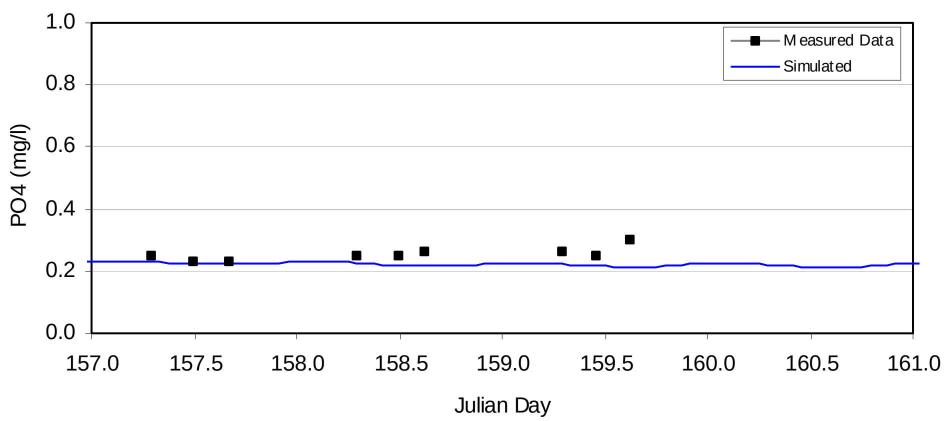


**Figure 231. Klamath River above Scott River simulated versus measured orthophosphate, June 5-7, 2000**

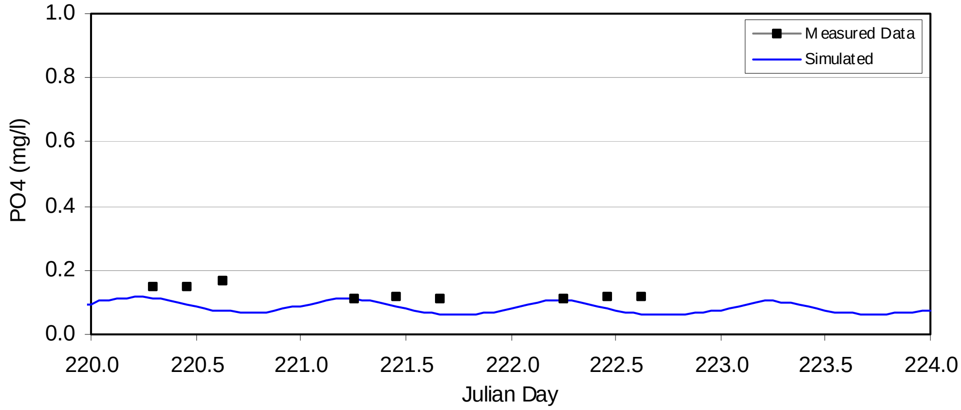



**Figure 232. Klamath River above Scott River simulated versus measured orthophosphate, August 7-9, 2000**

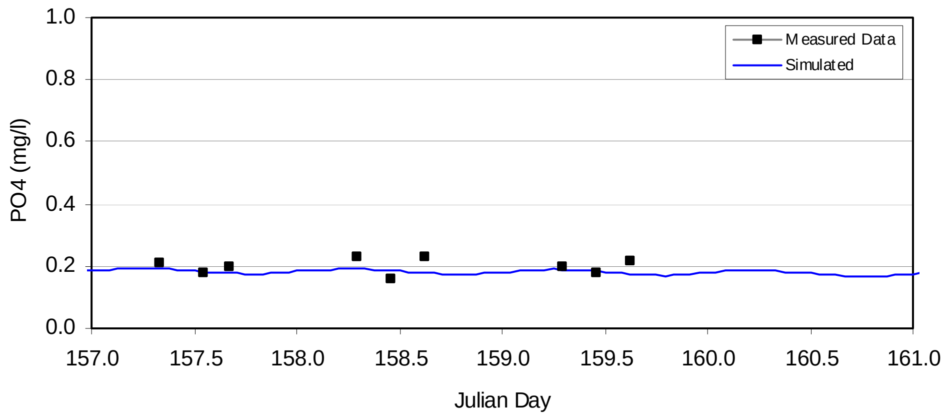



**Figure 233. Klamath River near Seiad Valley simulated versus measured orthophosphate, June 5-7, 2000**

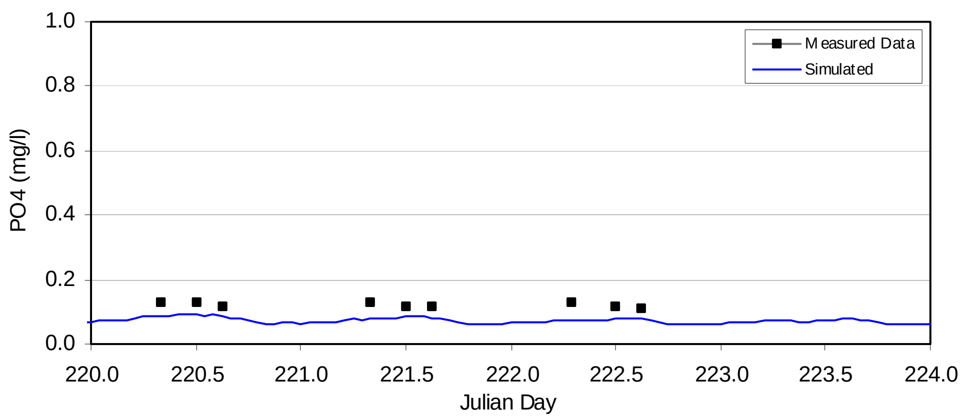


**Figure 234. Klamath River near Seiad Valley simulated versus measured orthophosphate, August 7-9, 2000**

## 3.9.6 Summary of Parameters

**Table 71. RMA-2 and RMA-11 Model rates, coefficients and constants for the Iron Gate Dam to Turwar**

| Variable Name | Description, units | Value |
|---|---|---|
| | Time step, hr | 1.0 |
| | Space step, m | 75 (cal )<br>150 (application) |
| | Manning roughness coefficient | 0.04 |
| | Turbulence factor, Pascal-sec | 100 |
| | Longitudinal diffusion scale factor | 0.10 |
| | Slope Factor | 0.80 |
| ELEV | Elevation of site, m | 520.00 |
| LAT | Latitude of site, degrees | 41.5 |
| LONG | Longitude of site, degrees | 122.45 |
| EVAPA | Evaporative heat flux coefficient a, m $hr^{-1}$ $mb^{-1}$ | 0.000015 |
| EVAPB | Evaporative heat flux coefficient b, m $hr^{-1}$ $mb^{-1}$ $(m/h)^{-1}$ | 0.000010 |
| EXTINC | Light Extinction coefficient, used when algae is not simulated, 1/m | 0.25 |
| ALP0 | Chl *a* to algal biomass conversion factor, phytoplankton, mgChl_a to mg-A | 67 |
| ALP1 | Fraction of algal biomass that is nitrogen, phytoplankton, mg-N/mg A | 0.072 |
| ALP2 | Fraction of algal biomass that is phosphorous, phytoplankton, mg-P/mg A | 0.010 |
| LAMB1 | Linear algal self-shading coefficient, phytoplankton, 1/m | n/a |
| LAMB2 | Non-linear algal self shading coefficient, phytoplankton, 1/m | n/a |
| MUMAX | Maximum specific growth rate, phytoplankton, 1/d | 0.01 |
| RESP | Local respiration rate of algae, phytoplankton, 1/d | 0.05 |
| SIG1 | Settling rate of algae, phytoplankton, 1/d | 0.0 |
| KLIGHT | Half saturation coefficient for light, phytoplankton, KJ $m^{-2}$ $s^{-1}$ | 0.01 |
| KNITR | Michaelis-Menton half saturation constant: nitrogen, phytoplankton, mg/l | 0.01 |
| KPHOS | Michaelis-Menton half saturation constant: phosphorous, phytoplankton, mg/l | 0.001 |
| PREFN | Preference factor for NH3-N, phytoplankton | 0.6 |
| ABLP0 | Chl a to algal biomass conversion factor, bed algae, mgChl_a to mg-A | 50 |
| ABLP1 | Fraction of algal biomass that is nitrogen, bed algae, mg/l | 0.07 |
| ABLP2 | Fraction of algal biomass that is phosphorus, bed algae, mg/l | 0.01 |
| LAMB1 | Linear algal self shading coefficient, bed algae, 1/m | n/a |
| LAMB2 | Non-linear self shading coefficient, bed algae, 1/m | n/a |
| MUMAX | Maximum specific growth rate, bed algae, 1/d | 1.5 |
| RESP | Local respiration rate of algae, bed algae, 1/d | 0.60 |
| MORT | Mortality, bed algae, 1/d | 0.10 |
| KBNITR | Half-saturation coefficient for nitrogen, bed algae, mg/l | 0.01 |
| KBPHOS | Half-saturation coefficient for phosphorus, bed algae, mg/l | 0.002 |
| KBLIGHT | Half-saturation coefficient for light, bed algae, KJ $m^{-2}$ $s^{-1}$ | 0.01 |
| PBREFN | Preference factor for NH3-N, bed algae | 0.75 |
| BET1 | Rate constant: biological oxidation NH3-N, 1/d | 0.3 |
| BET2 | Rate constant: biological oxidation NO2-N, 1/d | 0.5 |
| BET3 | Rate constant: hydrolysis Org N to NH3-N, 1/d | 0.3 |
| BET4 | Rate constant: transformation Org P to P-D, 1/d | 0.3 |
| KNINH | First order nitrification inhibition coefficient, $mg^{-1}$ | n/a |
| ALP3 | Rate $O_2$ production per unit of algal photosynthesis, phytoplankton, mg-O/mg-A | 1.6 |
| ALP4 | Rate $O_2$ uptake per unit of algae respired, phytoplankton, mg-O/mg-A | 1.6 |
| ABLP3 | Rate $O_2$ production per unit of algal photosynthesis, bed algae, mg-O/mg-A | 1.6 |
| ABLP4 | Rate $O_2$ uptake per unit of algae respired, bed algae, mg-O/mg-A | 1.6 |
| ALP5 | Rate $O_2$ uptake per unit NH3-N oxidation, mg-O/mg-N | 3.43 |
| ALP6 | Rate $O_2$ uptake per unit NO2-N oxidation, mg-O/mg-N | 1.14 |
| K1 | Deoxygenation rate constant: BOD, 1/d | 0.3 |
| - | Minimum reaeration rate constant (Churchill formula applied), 1/d | 3.0 |
| SIG6 | BOD settling rate constant, 1/d | 0.0 |

n/a – not applicable

## 3.10 Model Sensitivity

A sensitivity analysis is the test of a model in which the value of a single variable or parameter is changed (while the others remain constant) and the impact of this change on the independent variable is observed. Such analyses can be used to identify the characteristics of importance in a system. Uses of sensitivity analysis include:

- serving as an aid to confirming that the model is consistent with theory
- indicating the effects of errors in each of the variables and parameters, on the dependent variables
- identifying sensitive parameters or variables that must be reliably estimated
- indicating the relationship between control variables and decision variables to help ensure that a change in control variable can have a desirable effect on the decision variables, and
- identifying regions of "design invariance" where desirable levels of the decision variables are insensitive to possible errors of estimation in the model variables and parameters.

Other methods of quantifying uncertainty include first order analysis, Monte Carlo simulations and Kaman filtering, and are based on aggregate error terms and determine the total estimation (or prediction) error in a particular variable (Reckhow and Chapra, 1983). These multivariate methods are beyond the scope of this project.

Selected model parameters in both the RMA and CE-QUAL-W2 models were examined to determine relative sensitivity. There were too many variables to explore, and because many were not altered from default values, only those that were explored during calibration were examined. The input data sets, field observations or estimated values for flow and water quality boundary conditions and meteorological parameters, were not altered.

This qualitative assessment determined the general sensitivity of a particular parameter, (e.g., low, moderate, or high sensitivity, or insensitive), provided insight on model performance (e.g., was model consistent with theory), and to indicate the effects of modifying said parameters on the dependent variables. Many of the changes were carried out over modest ranges in parameter value, i.e., testing the model over extreme ranges for each parameter was not considered. Findings for the RMA models (RMA-2 and RMA-11) and CE-QUAL-W2 are outlined below. Sensitivity identified herein for the Klamath River system may not represent other responses encountered in other systems, i.e., not all of these analysis may be transferable to other river basins.

### 3.10.1 RMA parameters studied for sensitivity

Sensitivity was completed for the RMA-2 and RMA-11 models for selected parameters. In most cases literature values or default values for model constants and coefficients were applied. Through calibration and application of the models it was determined that certain parameters were sensitive. These parameters were explored further to determine the general sensitivity to perturbation.

Conditions are highly variable throughout the system and sensitivity varied by season (cooler periods or periods when there was more or less water in the system) and location. Also, longer river reaches (e.g., Klamath River from Iron Gate Dam to Turwar), where impacts could occur over long distance and long travel times may show more sensitivity than short reaches where water quality changes little from upstream to downstream (e.g. Link River). The parameters discussed herein include:

- n - Manning roughness coefficient
- SF - Slope Factor fraction to reduce bed slope of river to approximate water surface slope in solution of flow equations
- EVAPA, EVAPB – Evaporative heat flux coefficients
- IREAER* – (Minimum reaeration rate)
- MUMAX – nominal bed algae growth
- RESP – bed algae respiration rate
- EXTINC – non-algal light extinction
- EA – atmospheric pressure
- PBREFN –algal preference for ammonia

For a full description of model parameters the reader is referred to the user's manual for RMA-2 and RMA-11.

Table 72 outlines the general findings of the sensitivity testing. Generally temperature was sensitive to bed roughness and slope factor – both parameters that directly impact travel time (akin to residence time) through the river reaches. Likewise, temperature was highly sensitive to the evaporative heat flux parameters.

Dissolved oxygen was sensitive to the minimum reaeration value specified for the river reaches (thus the ultimate value was set relatively low), and highly sensitive to algal growth and respiration parameters.

Nutrients were generally moderately sensitive or experienced low sensitivity to algal growth parameters; however, the ammonia preference factor suggested sensitivity for ammonia and nitrate. The nutrients were moderately sensitive to extinction in certain river reaches – under high extinction rates benthic algal growth was light limited and nutrient uptake suppressed. Algae was very sensitive to growth and respiration rates as well as light extinction.

In addition temperature was examined under different geometric representations of the system. Specifically, temperature output from several reaches was examined while varying river width as well as side slope. The impacts were generally modest, with the exception that marked changes in river width can dramatically impact travel time and thus water temperature. Finally, the river models were run with node-to-node distances of 150 meters and 75 meters, with minimal differences in results. The exception being the hydrodynamic model required the 75 meter grid and fifteen minute time steps to retain stability under the highly variable flow regime of the peaking reach.

**Table 72. RMA-11 water quality constituent sensitivity to different modeling parameters**

| Parameter | Sensitivity to Parameter | | | | | |
|---|---|---|---|---|---|---|
| | Temperature | DO | PO4 | NH4 | NO3 | Algae |
| Manning n | H | - | - | - | - | - |
| SF | H | - | - | - | - | - |
| EVAPA | H | L | - | - | - | - |
| EVAPB | H | L | - | - | - | - |
| IREAER* | N | H | N | L | S | - |
| MUMAX | N | H | N | L | S | H |
| RESP | N | H | N | - | - | H |
| PBREFN | N | - | N | M | M | L |
| EXTINC | N | M | - | L | L | H |
| EA | N | L | - | - | - | - |
| Bathymetry | M | L | - | - | - | - |

N – not sensitive
L – low sensitivity
M – moderate sensitive
H – high sensitivity

If there is no letter in the space, the constituent was not tested for sensitivity to the parameter.

### 3.10.2 CE-QUAL-W2 Parameters studied for sensitivity

Sensitivity was completed for the CE-QUAL-W2 models for selected parameters using the several reservoir applications. In most cases literature values or default values for model constants and coefficients were applied. Through calibration and application of the model to the various reservoirs it was determined that certain parameters were sensitive. These parameters were explored further to determine the general sensitivity to perturbation.

Conditions are highly variable throughout the system reservoirs and sensitivity varied by season (cooler periods or periods when there was more or less water in the system) and location. Response to varying model parameters varied among the shallow Lake Ewauna-Keno Reservoir, the short residence time J.C. Boyle reservoir, and the deep, longer residence time reservoirs of Copco and Iron Gate. The parameters discussed herein include:

- AFW, BFW, and CFW - Evaporative heat flux coefficients
- AG - Algal Growth Rate:
- AR - Algal Respiration Rate: AR
- AM - Algal Mortality Rate:
- ASAT - Algal light saturation intensity at the maximum photosynthetic rate.
- SOD- Sediment Oxygen Demand
- CBHE - Bed heat conduction coefficient

- TSED - Specified bed temperature: TSED
- EXSS Light Extinction due to inorganic suspended solids:
- EXOM - Light extinction due to organic matter
- EXH20 - Light extinction due to water
- EXA - Light extinction due to algae
- BETA - Solar radiation absorption fraction: the BETA parameter is the fraction of incident solar radiation absorbed at the water surface
- LDOMDK - Labile organic matter decay rate
- POMS - Particulate organic matter settling rate
- NH4DK - Ammonia decay rate
- NO3DK - Nitrate decay rate
- O2LIM - Aerobic/anaerobic oxygen Limit: user defined oxygen limit refers to the concentration below which anaerobic processes begin to be simulated.

Table 73 outlines the general findings of the sensitivity testing. Generally temperature was sensitive to the evaporative heat flux parameters. In the deeper reservoirs the impacts were observed over longer periods than in the shallow reservoirs. IN the deeper reservoirs with longer residence time, the bed heat exchange coefficient was modestly sensitive in bottom water temperature.

Dissolved oxygen was sensitive to algal growth, respiration, and mortality parameters, and parameters associated with algal growth such as the various light extinction parameters. The organic matter decay rates also impacted dissolved oxygen concentrations to some degree: the impact was larger in the long residence time reservoirs. Dissolved oxygen sensitivity to ammonia decay rate was low.

Nutrients were generally moderately sensitive or experienced low sensitivity to algal growth parameters (and associated parameters such as extinction); however, nitrate was notably more sensitive to these parameters than ammonia. Algae was very sensitive to growth and respiration rates as well as light extinction.

Two aspects of the reservoir geometric representation were explored: layer thickness and bathymetric representation. The layer thickness in Lake Ewauna-Keno Reservoir was set at 0.61 meters are per Wells (1996). The layer thickness in J.C. Boyle Reservoir was initially set at 0.61 meters; however simulation time exceeded 20 hours (1.2 GHz processor) due to the model frequently dropping and adding segments and layers in this small hydropower peaking reservoir.

The layer resolution was increased to 1.0 meters and the simulation time dropped to approximately 15 minutes, with no significant changes in model output. The 1.0 meter layer thickness was retained. Tests were completed in Iron Gate Reservoir at layer thicknesses of 5 meters, 2.5 meters, and 1 meter. Results between the 5 meter and 2.5 meter layer thickness cases varied considerably; however, the differences between the 2.5 meter and one meter layer thicknesses was insignificant. Iron Gate representation utilized 2.5 meter layer thickness to accommodate run time considerations (approximately 2 hours for a 1.2 GHz processor).

Finally, Lake Ewauna-Keno Reservoir was modeled under multiple bathymetric representations: the original work from Wells (1996), a fictitious bathymetry to determine if model results were sensitive to a different geometry, and utilizing a new bathymetric survey from 2003. The findings suggest that results are sensitive to bathymetry and that using the best available data is important in effective representation – the 2003 data is currently used in the model.

**Table 73. CE-QUAL-W2 water quality constituent sensitivity to different modeling parameters**

| Parameter | Sensitivity to Parameter | | | | | |
|---|---|---|---|---|---|---|
| | Temperature | DO | PO4 | NH4 | NO3 | Algae |
| AFW | M | - | - | - | - | - |
| BFW | M | - | - | - | - | - |
| CFW | L | - | - | - | - | - |
| AG | N | L | L | L | H | H |
| AR | N | M | L | L | M | H |
| AM | N | M | L | L | M | H |
| ASAT | - | - | - | - | - | - |
| SOD | N | M | M | N | N | L |
| CBHE | M | - | - | - | - | - |
| EXSS / EXOM | N | H | L | L | M | H |
| EXH2O | N | H | M | L | M | H |
| BETA | N | H | M | L | M | H |
| EXA | N | H | L | L | H | H |
| LDOMDK | N | M | L | L | L | N |
| POMS | N | L | L | L | L | N |
| NH4DK | N | L | N | L | L | N |
| NO3DK | N | N | N | N | M | N |
| O2LIM | N | N | M | N | L | N |
| Bathymetry | H | H | H | H | H | H |

N – not sensitive
L – low sensitivity
M – moderate sensitive
H – high sensitivity

If there is no letter in the space, the constituent was not tested for sensitivity to the parameter.

The water quality model parameters most sensitive in the prediction of temperature and dissolved oxygen are similar for both RMA-11 and CE-QUAL-W2:

- Evaporative heat flux parameters for temperature
- Algal growth dynamics and light extinction for dissolved oxygen and algae.

It is useful to note that these are common calibration parameters in water quality modeling.

In addition to these studies, many informal sensitivity tests have been completed to assess model performance including

- Varying the vertical resolution of layers in CE-QUAL-W2
- Varying the spatial resolution in the RMA models
- Modifying the locations of accretion/depletions in river and reservoir reaches
- Testing to see if tributary input temperatures affect mainstem or reservoir conditions
- Modified input quantity and quality of major agricultural returns
- Modifying geometry to identify need for more detailed studies
- Modifying meteorological inputs to determine sensitivity,

As well as many other tests during model implementation, calibration, and application. If the findings identified notable changes, the models were updated or modified to more fully represent conditions to recommendations specified to assist in further characterizing the system.

## *3.11 Summary – Model Calibration and Validation*

All system components have been calibrated. There are a few notable reaches where additional information and model testing is recommended; however, the modeling framework is, by and large, complete. Although additional data needs and model testing has been identified, the framework and its individual components have been extremely effective at illustrating flow and water quality processes throughout the system. The exercise of system characterization, model implementation, sensitivity testing, and calibration have resulted in a dramatically improved understanding of Klamath River flow and water quality issues, as well as identifying need for additional data. Available data precluded formal calibration of the models during the winter months. Brief synopses of each reach, plus identified recommendations are outlined below.

### 3.11.1 Link River

This short river reach is fairly insensitive to model conditions, with the exception when Link Dam bypass flows are low and most of the water is passed through the East Side and West Side powerhouses. However, any variability imparted on Link Dam releases by conditions within Link River is quickly overwhelmed in the Lake Ewauna to Keno Dam reach. This reach has been calibrated.

Recommendations: Because Link Dam forms a critical boundary condition for all downstream reaches it is recommended that a formal monitoring program be considered to characterize water quality conditions and more completely characterize the short-term variability at the head of Link River.

### 3.11.2 Lake Ewauna-Keno Dam

The Lake Ewauna-Keno Dam reach is a dynamic and complex reach to model for water quality. This reach is intensively developed for water resources and related activities. There are multiple diversions from the system for industrial and agricultural use, as well as their associated return flows. The Klamath River also is a receiving water for municipal discharge of treated wastewater. Land use practices, predominately agricultural, but also municipal and industrial activities, occur adjacent to the river throughout much of this reach. Finally, review of available literature and discussions with stakeholders suggest historical log rafting and timber industry practices have left considerable organic matter throughout the upper portion of this reach.

Other water resources development of importance include the impoundment of Upper Klamath Lake for diversion to the Reclamation project, as well as impoundment of the reach in question by Keno Dam. The operations of Link Dam, namely actively managing storage in Upper Klamath Lake for summer application within the Reclamation Project, has reduced the frequency, and to some degree the magnitude, of winter flows through the Lake Ewauna to Keno Dam reach. This coupled with impoundment at Keno Dam has created a slow moving waterway that allows primary production (as phytoplankton versus riverine forms of algae) to occur as well as favors deposition. Upstream inputs from hyper-eutrophic Upper Klamath Lake, as well as historical and continued inputs from municipal, industrial, agricultural, and non-point discharges lead to considerable oxygen demands within this reach.

Additional field work in 2003, as well as review of previous data collection efforts suggests that the advective nature of the reservoir – there is a notable current at mid-channel throughout the reach (on the order of 0.2-0.3 feet per second) – coupled with the daily weak stratification and wind dynamics creates a complex conditions within this reach that directly impact water quality. By and large, the Lake Ewauna-Keno Reach is very sensitive to influent conditions from Upper Klamath Lake for dissolved oxygen, nutrients, and algae. All downstream reaches are likewise impacted by outflow water quality conditions at Link Dam. (The exception is water temperature which is only moderately affected in downstream reaches because waters in Upper Klamath Lake are near equilibrium temperature.)

Given the level of complexity encountered within this reach, model application to this dynamic reach was by-and-large successful for temperature. For dissolved oxygen, nutrients, and algae, it was apparent that the resolution (i.e., monitoring frequency) of upstream boundary condition (actually conditions at Link Dam) governed processes within this reach. Sensitivity testing Link Dam as well as other boundary conditions, including sediment oxygen demand supported finding. As such, the model replicates seasonal dissolved oxygen response, but short term conditions are not always well represented. Model performance for nutrients varies dramatically between 2000 and 2001 applications. With the more complete data set of 2001, the model replicates observed conditions appreciably better than in 2000, when composite upstream boundary conditions were applied. The model has undergone a wide range of testing to assess variable conditions and response to modifying model parameters, and, given the level of available data can be considered preliminarily calibrated for dissolved oxygen and nutrients. Recommendations for additional studies are outlined below.

Recommendations: Several of the field studies completed in 2003 were not completed prior to the calibration of the model. These include sediment studies (SOD), and limited field studies. It is recommended that the results of these studies be reviewed and, as necessary, incorporated into the modeling effort. In addition, should a more refined calibration be required, additional field studies should be designed to further characterize conditions throughout the Lake Ewauna-Keno Reach. Field studies should include sampling of appropriate parameters to address nutrient conditions, biochemical oxygen demand, organic matter, algae, and pH, as well as temperature, dissolved oxygen, and other physical parameters. Such field studies should recognize the spatial and temporal scales of critical processes identified herein. If completed, results of these studies should be used to further refine the model application. The recommendation for the Link River reach – improving the information (boundary condition) at the Link Dam is imperative to this effort.

### 3.11.3 Keno Dam to J.C. Boyle

The Keno Dam to J.C. Boyle reach is fairly short with a transit time of a few hours. The models performed well in this steep river reach, replicating temperature and dissolved oxygen well, as well as nutrient concentrations.

Recommendations: Continue monitoring upstream and downstream water quality conditions as necessary.

### 3.11.4 J.C. Boyle Reservoir

J.C. Boyle Reservoir is a small reservoir and experiences residence times of less than a day to more than 3 days. As such it is heavily influenced by inflow water quantity and quality. The system was modeled with CE-QUAL-W2 under several levels of detail and has been tested for a wide range of conditions using calendar year 2000 data. (The system was also modeled with WQRRS prior to applying CE-QUAL-W2.) The model is performs well and is calibrated, but results are sensitive to influent conditions, which are ultimately driven by the boundary condition at Link Dam.

Recommendations: Continue in reservoir monitoring.

### 3.11.5 Bypass / Peaking Reach

The bypass reach experiences a highly dynamic flow regime and variable water quality due to peaking operations and the influence of a large springs complex. Modeling this reach required representing the physical features of this steep reach as well as the short duration hydropower operations. The models performed well for all parameters. This reach is calibrated.

Recommendations: Exploratory field work was carried out in 2003 to assess the benthic algae community. If further model refinement is necessary it is recommended that a more comprehensive survey of benthic algae and the role it may play in dissolved oxygen concentration dynamics as well as nutrient conditions within the reach should be explored.

### 3.11.6 Copco Reservoir

Copco Reservoir receives a peaking flow regime from upstream Klamath River inflows as well as providing peaking flows at Copco Dam for a significant portion of the year. The reservoir was modeled for calendar year 2000 and performance was generally good for both temperature and dissolved oxygen. The model is considered calibrated; however it is sensitive to the upstream boundary condition – inflow from the Klamath River – which is in turn somewhat sensitive to the conditions at Link Dam.

Recommendations: Data from the 2003 field season included more detailed vertical profiles of the reservoir. This data collection and processing was not completed in time to be included herein. If additional model refinement is required, it is recommended that these data be reviewed and, as necessary, used to refine model calibration. Update SOD as information becomes available.

### 3.11.7 Iron Gate Reservoir

Iron Gate Reservoir receives a peaking flow regime from upstream Copco Reservoir and re-regulated the river to provide a steady flow regime below Iron Gate Dam for a significant portion of the year. The reservoir was modeled for calendar year 2000 and performance was generally good for both temperature and dissolved oxygen. The model is considered calibrated; however it is sensitive to the upstream boundary condition – inflow from Copco Reservoir – which is in turn somewhat sensitive to the conditions at Link Dam.

Recommendations: Data from the 2003 field season included more detailed vertical profiles of the reservoir. This data collection and processing was not completed in time to be included herein. If additional model refinement is required, it is recommended that these data be reviewed and, as necessary, used to refine model calibration. Update SOD as information becomes available.

### 3.11.8 Iron Gate Dam to Turwar

The Iron Gate Dam to Turwar reach is the longest single reach in the modeling framework. Multiple tributaries and variable meteorological conditions add complexity to this generally steep reach. Sufficient information was available to calibrate the models throughout the reach for, temperature, dissolved oxygen, and inorganic nutrients.

Recommendations: During 2003 benthic algae surveys were completed providing information on the distribution and approximate biomass at multiple locations within this reach. This information was important in improving the understanding of algal dynamics. Expansion of this information, coupled with the appropriate water quality conditions, could further improve the application of the model.

### 3.11.9 Additional Recommendations

General recommendations, some of which are addressed above, include

- the maintenance of the long term reservoir monitoring programs (profiles),
- maintain the thermistor deployment throughout the project area to characterize water temperatures,
- maintenance of existing meteorological stations at main stem reservoirs,
- ongoing reporting of flow, storage, and operations at project facilities,
- ongoing model updates and maintenance to consider, include
    - improve characterization of organic matter in CE-QUAL-W2 and RMA-11, including sensitivity if model results to organic matter partitioning. If necessary incorporate more detailed organic matter formulation in RMA-11,

  - further sensitivity testing of light extinction conditions in the river reaches on benthic algae,
  - improved distribution of benthic algae in river reaches, including sensitivity to scour (requires field observations),
  - incorporate existing pH model (external processor) into RMA-11,
  - improve sampling frequency and locations of total inorganic carbon (TIC) and alkalinity to support pH modeling,
  - improve representation of A/D as additional flow data and analyses come available,
  - further sensitivity of bed sediment oxygen demand in river reaches. Support with field studies,
  - explore meteorological observations from recently installed meteorological stations in the middle and lower Klamath River regions and re-assess meteorological assumptions,
- improve winter data collections to extend the model application into winter periods, as necessary (identify specific needs first),
- as well as other identified studies.

Long-term studies to improve understanding of the system are encouraged on an as needed basis.

# 4 Model Application

## 4.1 Introduction

Upon completion of model calibration, the models were applied to four system-wide scenarios: existing conditions, steady-flow, and without project (II). These scenarios were intended to bracket the range of potential physical and operational conditions within the project area. Further, these analyses were completed for the years 2000 and 2001.

For each scenario the models were applied for a full calendar year, which allowed the larger reservoirs to attain stratified conditions from an initial isothermal state, as well as exhibit fall turnover. System conditions from Link Dam to the Klamath River at Turwar were simulated – a distance of approximately 250 miles. The existing condition scenario represents the baseline status and is used for comparing conditions without peaking hydropower operations (steady flow scenario) and a river system without hydropower facilities (without project scenario). The without project (II) scenario attempted to smooth river flows at Keno Dam to produce a hydrograph that did not exhibit the fluctuations due to US Bureau of Reclamation project operations.

These analyses are intended to examine large scale system response over periods when critical water quality conditions tend to occur (spring – fall) in the Klamath River basin. More detailed analysis focusing on critical reaches, specific operations, and limited time periods are addressed separately. Basic assumptions for each scenario are discussed below and presented in Table 74.

**Table 74. Basic scenario assumptions**

| Scenario | Geometry / Bathymetry | Meteorology | Hydrology for Boundary Conditions | Water Quality for Boundary Conditions | Operations |
|---|---|---|---|---|---|
| Existing Conditions (EC) | Base | Base | Base | Base | Base |
| Steady Flow (SF) | Base | Base | Base | Base | Modified |
| Without Project (WOP) | Modified | Base | Base | Base | No Operations |
| Without Project II (WOPII) | Modified | Base | Modified[a] | Base | No Operations |

Base – refers to baseline conditions or those applied to the existing condition scenario

Modified – identifies if any basic data information was modified for the identified scenario

Modified[a] – modified from Iron Gate Dam to Keno Dam

The basic output extracted from each scenario was hourly time series data at multiple locations for temperature and dissolved oxygen, although all other parameters are available at the hourly output frequency. The output locations from the models (nodes or segments) and the corresponding physical locations are presented in Table 77. Processed output for all three scenarios included daily mean data, daily maximum data, daily minimum data, monthly mean data, and 7 day maximum average data.

## 4.2 Model Coordination

The models are applied in series, starting with upper most reach – Link River – and passing the output from one reach to the next. The flow conditions are generally not passed from reach to reach. Exceptions include reaches where there is no upstream flow record (i.e., measured flow) above Copco Reservoir, wherein the hydrodynamic model is used to route peaking flows on an hourly basis down to Copco Reservoir – these flows are then used in the CE-QUAL-W2 simulation of Copco Reservoir. For certain scenarios (e.g., without project), flows are passed from one modeled reach to the next because flow conditions cannot be explicitly specified.

Water quality is passed downstream between all simulated river reaches. The river models (RMA) and the reservoir model (CE-QUAL-W2) do not represent all water quality parameters in the same fashion. The river models represent organic matter as organic nitrogen and organic phosphorous, while the reservoir model represents organic matter as refractory and labile dissolved and particulate organic matter. A stoichiometric equivalent is used to convert the fraction of organic matter or nutrients when passing information from one model to the next. Specifically, organic nitrogen from RMA-11 is converted to dissolved labile organic matter for input to CE-QUAL-W2 (the nitrogen fraction of organic matter is assumed to be 0.08 (USACOE-HEC, 1986)). No attempt is made to partition the organic matter among the refractory and labile or the dissolved and particulate compartments due to a lack of sufficient field data. When passing information from CE-QUAL-W2 to RMA-11, the derived constituent for total organic nitrogen and total organic phosphorous are employed; however, the algal component of organic nitrogen and phosphorous are removed from this value so as not to double count the algal fraction (the nitrogen and phosphorous fractions of algae is assumed to be 0.08 and 0.005, respectively (Cole and Wells, 2002)).

## 4.3 Existing Conditions Scenario (EC)

The existing conditions scenario models the actual conditions in the Klamath River during 2000 and 2001. All projects were assumed to be in place and operating under historical 2000 and 2001 conditions. All input information are those recorded in, calculated from records, or estimated for 2000 and 2001 conditions.

The models used in this scenario were RMA2 / RMA11 for the river reaches and CEQUALW2 for the reservoirs.

### 4.3.1 Geometry

The geometry (or bathymetry) for each reach of the existing conditions scenario followed the basic modeling framework outlined in the implementation documentation.

### 4.3.2 Meteorology

The meteorology for each reach of the existing conditions scenario followed the basic modeling framework outlined in the implementation documentation.

### 4.3.3 Hydrology

The hydrology for boundary conditions for each reach of the existing conditions scenario followed the basic modeling framework outlined in the implementation documentation.

### 4.3.4 Water Quality

The water quality data for boundary conditions for each reach of the existing conditions scenario followed the basic modeling framework outlined in the implementation documentation.

### 4.3.5 Operations

The project operations for each reach of the existing conditions scenario followed the basic modeling framework outlined in the implementation documentation.

## *4.4 Steady Flow Scenario (SF)*

The steady flow scenario models alternative flows to those recorded in 2000 and 2001. All projects were assumed to be in place and but were not assumed to be operating under historical 2000 and 2001 conditions.

The models used in this scenario were RMA2 / RMA11 for the river reaches and CEQUALW2 for the reservoirs.

### 4.4.1 Geometry

The geometry (or bathymetry) for each reach of the steady flow scenario followed the basic modeling framework outlined in the implementation documentation.

### 4.4.2 Meteorology

The meteorology for each reach of the steady flow scenario followed the basic modeling framework outlined in the implementation documentation.

### 4.4.3 Hydrology

The hydrology for boundary conditions for each reach of the steady flow scenario followed the basic modeling framework outlined in the implementation documentation.

### 4.4.4 Water Quality

The water quality data for boundary conditions for each reach of the steady flow scenario followed the basic modeling framework outlined in the implementation documentation.

### 4.4.5 Operations

The project operations for each reach of the steady flow scenario were not the same as those described in the basic modeling framework. In the steady flow scenario, the reservoirs were operated with approximately no change in water surface elevation for the entire year. Calculations started by assuming the dam releases from Irongate Reservoir were the same as those used in the existing conditions scenario, calculating overall smoothed existing conditions accretions/depletions for each reach and then moving upstream using a water balance method between each reservoir up to Link Dam. The smoothing method used for the accretion/depletion calculation was to take the average flow of the flow for the day of interest and the following six days. In Table 75 the calculations for the un-smoothed accretion/depletion are presented. In Table 76 the steady flow scenario dam release calculations are presented. Spring flows in the fullflow reach were assumed to be a constant 225 cubic feet per second for these calculations. Fish releases from Irongate and J.C. Boyle reservoirs were assumed to be 50 and 100 cfs respectively. The East side and West Side turbine flows were calculated as a percentage of daily flow from Upper Klamath Lake. The percentage of daily flow was determined per day from existing conditions flows.

As these calculations assumed no daily change in storage in each of the reservoirs, the starting and ending elevations of the reservoirs were those recorded in each reservoir on January 1st, 2000 and 2001.

Below Irongate Reservoir, all flows were assumed to be the same as those used in the existing conditions scenario.

**Table 75. Calculation of un-smoothed accretion/depletions by reach**

| Accretion Depletion | Calculation |
|---|---|
| Copco to Irongate | Irongate Out $_{\text{PacifiCorp}}$ – Copco Out $_{\text{PacifiCorp}}$ + Storage Change in Irongate |
| J.C. Boyle to Copco | Copco Out $_{\text{PacifiCorp}}$ - USGS 11510700 + Storage Change in Copco |
| Copco | ½ J.C. Boyle to Copco A/D |
| Fullflow | ½ J.C. Boyle to Copco A/D |
| J.C. Boyle | Assumed to be zero |
| Keno to J.C. Boyle | J.C. Boyle Out $_{\text{PacifiCorp}}$ - USGS 11509500 + Storage Change in J.C. Boyle |
| Lake Ewauna to Keno | USGS 11509500 – (USGS 11507500 + West Turbine $_{\text{PacifiCorp}}$ + Net Lost River $_{\text{USBR}}$ + Klamath Straits Drain $_{\text{USBR}}$ – North Canal $_{\text{USBR}}$ – ADY Canal $_{\text{USBR}}$) + Storage Change in Keno |

**Table 76. Calculation of steady flow dam releases by reach**

| Release | Calculation |
| --- | --- |
| Irongate Dam | Actual 2000 or 2001 release |
| Copco Dam | Irongate Dam release – “A/D Copco to Irongate” |
| J.C. Boyle Dam | Copco Dam release – “A/D  J.C. Boyle to Copco” – Fullflow  Spring flow |
| Keno Dam | J.C. Boyle Dam release – “A/D J.C. Boyle” – “A/D Keno to J.C. Boyle” |
| Link Dam | Keno Dam releases – “A/D Lake Ewauna to Keno” – East Side – West Side Turbines. |

## *4.5 Without Project Scenario (WOP)*

The without project scenario models the Klamath River as if there are projects in the Klamath River downstream of Link Dam.

The models used in this scenario were RMA2 / RMA11.

### 4.5.1 Geometry

The geometry for the river reaches of the without project scenario followed the basic modeling framework outlined in the implementation documentation. The reservoirs were replaced with river reaches, with the geometry of the reaches estimated from the deepest points in the reservoir bathymetries. River widths within the reservoirs were a linear interpolation between the river width in the element immediately preceding the reservoir and the river width in the element immediately following the reservoir. This process is illustrated in Figure 235, Figure 236, Figure 237 and . All other river widths were the same as those used in the existing conditions scenario. Figure 239 illustrates the method used to create element orientations for the reservoir sections of the without project grid. Other element information, such as element length, was not determined in this way as a uniform grid was used, creating elements of the same length for the entire river. Through this process the existing condition river miles were preserved, except for in Copco Reservoir, where the river was lengthened to capture the sinuosity of the old river bed under the reservoir.

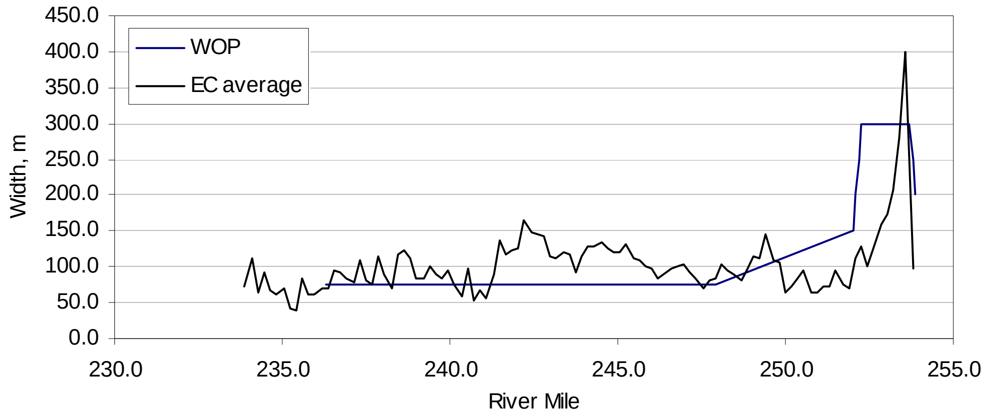



**Figure 235. WOP scenario river widths for the Lake Ewauna to Keno Dam river reach**

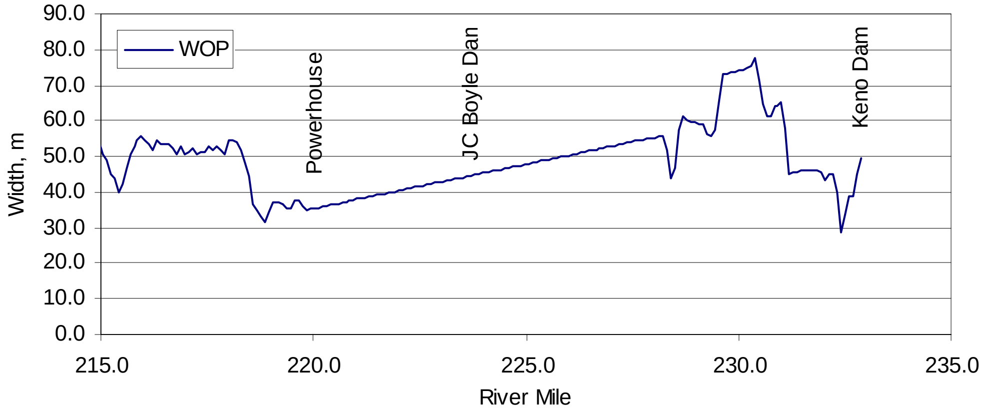



**Figure 236. WOP river widths for J.C. Boyle Reservoir and surrounding river reaches**

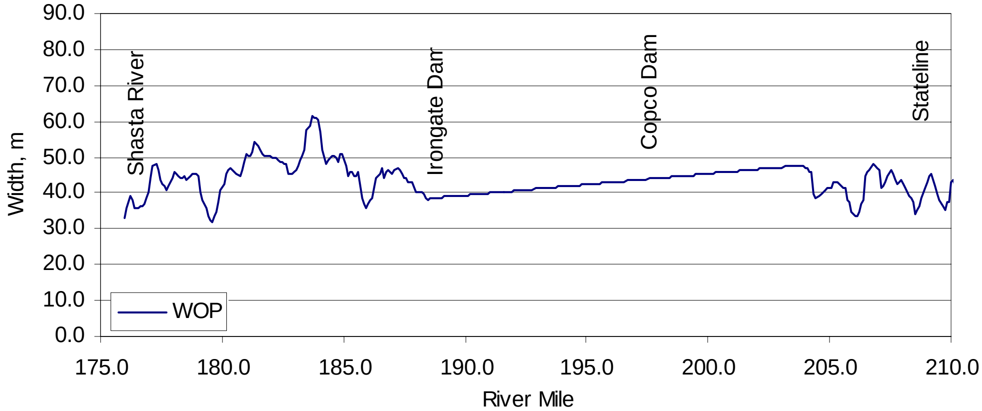



**Figure 237. WOP river widths for Copco Reservoir, Irongate Reservoir and surrounding river reaches**

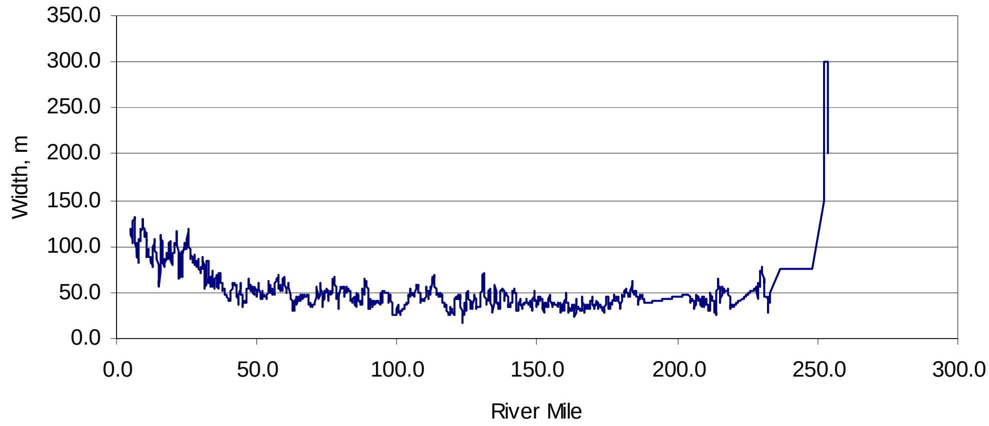



**Figure 238. WOP river widths from Link Dam to Turwar**

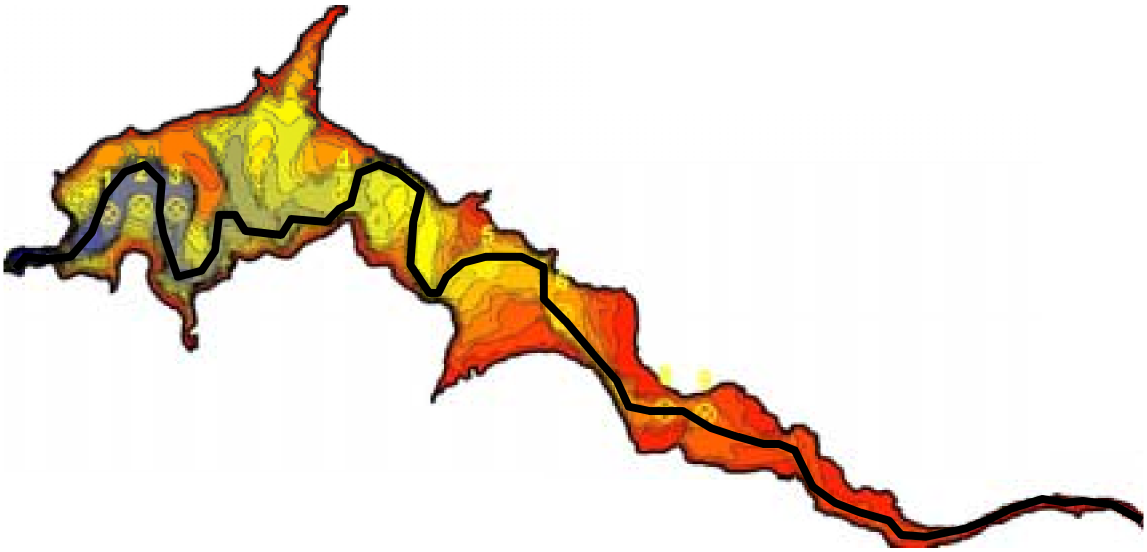


**Figure 239. Example of river element orientation from Copco Reservoir bathymetry. Note the black line running through the reservoir in the deepest parts.**

### 4.5.2 Meteorology

The meteorology for each reach of the without project scenario followed the basic modeling framework outlined in the implementation documentation.

### 4.5.3 Hydrology

The hydrology for boundary conditions for each reach of the without project scenario followed the basic modeling framework outlined in the implementation documentation.

### 4.5.4 Water Quality

The water quality data for boundary conditions for each reach of the without project scenario followed the basic modeling framework outlined in the implementation documentation.

#### 4.5.4.1 Sediment Oxygen Demand

Unlike the sediment oxygen demand exerted in the reservoirs, there is little oxygen demand in the river bed due to scouring. Therefore the SOD which is present in the Existing Conditions scenario is not present in the form of bed BOD in the WOP scenario. Sensitively testing using the modeling framework illustrates that low dissolved oxygen conditions in the Lake Ewauna/Keno reach are most likely due to the oxygen demand imparted on the system from Upper Klamath Lake, and the response is more akin to an oxygen sag in this reach than overwhelming SOD load. SOD plays a role in water quality conditions; however, at this time it is generally presumed to be modest compared to inputs from Upper Klamath Lake.

### 4.5.5 Operations

No project operations were present in the without project scenario as all projects had been removed.

## *4.6 Without Project II Scenario (WOPII)*

All conditions in the without project II scenario are the same as the WOP scenario with exception of the hydrology. The primary purpose of this scenario was to smooth out the flow variability that was being routed down the river during summer periods (Figure 240). These variations, which are most prominent between Julian day 200 and 250, are born out of US Bureau of Reclamation project operations and maintenance of Keno Reservoir at a stable water surface elevation during operations. The fluctuation over the span of a few days can exceed 500 cfs. The original WOP scenario assumed that all US Bureau of reclamation project operations were consistent with historic conditions – in which case the flow variations that occurred were historically “re-regulated” by system reservoirs were routed down the river. Stakeholder input identified this as an unrealistic without project operation and requested that attempts be made to smooth the hydrograph that was routed down the river.

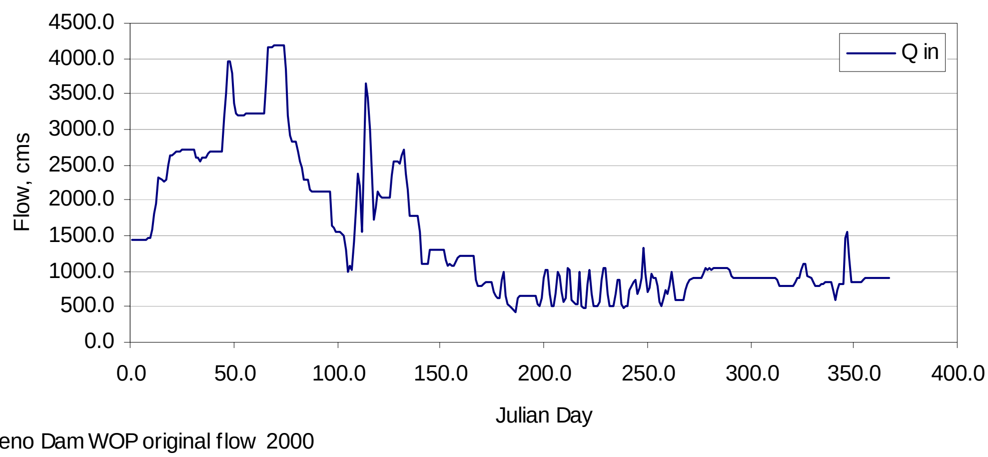



**Figure 240. Keno Dam WOP flow, 2000**

To address this issue, a seven day running average flow was calculated at Keno Dam (Figure 241). Using a water balance on the Link Dam to Keno Dam reach, several attempts were made to identify flow boundary conditions within this reach to achieve a smooth hydrograph at Keno Dam. These attempts failed to attain a hydrograph that was acceptable. Challenges include the variable transit times through the reach from the various inflow points (Link Dam, Lost River Diversion Channel, Klamath Straits Drain, return flow location), a process further confounded by the impacts on transit time due to diversions from various points. Lumping inputs and outputs was initially considered to simplify the transit time issue, but due to the variable timing and water quality of the various waters, this was deemed unacceptable because the results would be difficult to interpret and the results could not be readily compared with the other global scenarios.

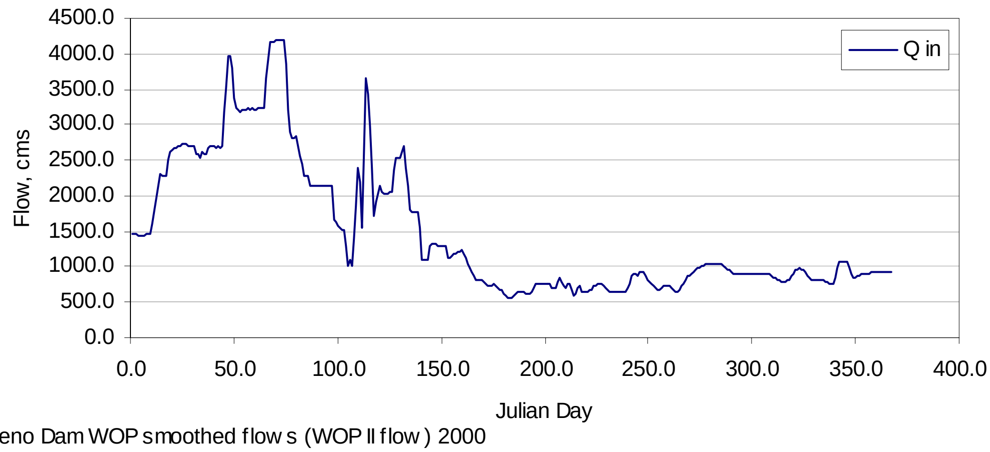



**Figure 241. Keno Dam WOPII flow (smoothed), 2000**

In the interest of time, and with stakeholder input, it was decided to use WOP scenario water quality conditions at Keno Dam and route those results down the river from Keno Dam to Turwar using the smoothed hydrograph presented in Figure Y. This assumption presumes that the results with a smoothed hydrograph are similar to those without smoothing. (The flow and water quality results for all locations above Keno Dam are identical). It is critical that the reader understand this assumption and interpret the results accordingly.

WOP and WOPII flows at Keno Dam for 2001 are presented in Figure 242 and Figure 243. The impacts of smoothing in 2001 were modest because US Bureau of Reclamation operations were offline.

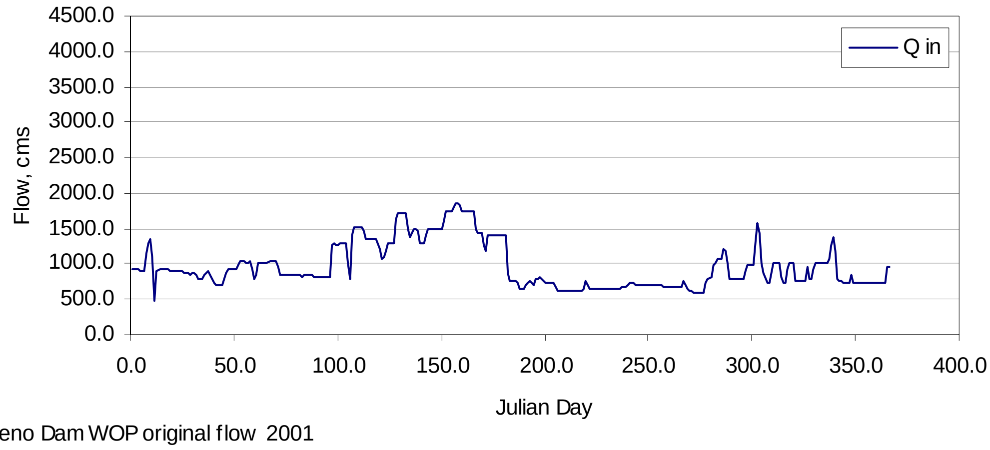



**Figure 242. Keno Dam WOP flow, 2001**

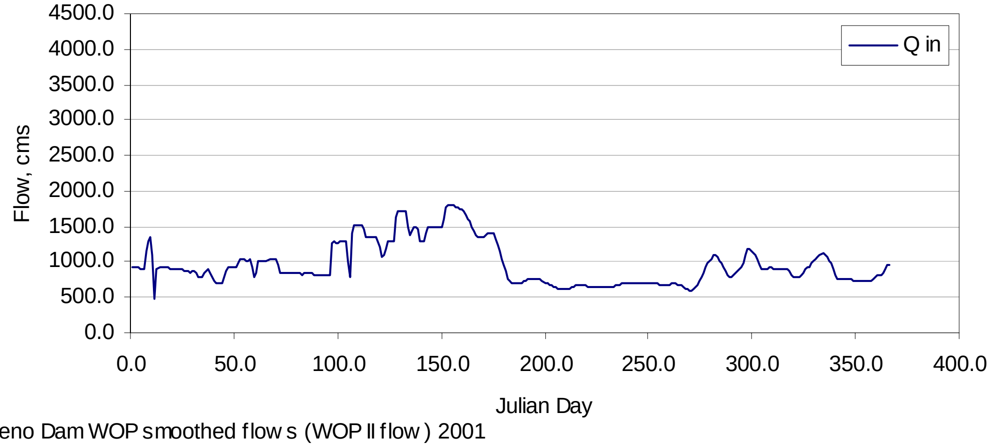



**Figure 243. Keno Dam WOPII flow (smoothed), 2001**

## *4.7 Presentation of Results*

The model framework produces a substantial amount of information. To effectively provide information to the stakeholders, regulators, and various analysts, input was solicited via the monthly PacifiCorp meetings. Specific locations were identified where model output was desired, as well as parameters and summary statistics. Data was produced for 29 locations, primarily for flow, water temperature, and dissolved oxygen. The reporting locations are presented in Table 77. The information is available in tabular form and graphical form. The current graphical output includes:

For Existing Condition, Steady Flow, and Without Project:

- time series (one-hour data) of water temperature and dissolved oxygen
- daily maximum, mean, and minimum of water temperature and dissolved oxygen

- Longitudinal profiles for river reaches (Bypass/Peaking and Iron Gate Dam to Turwar) for the first of each month from April through November) of water temperature and dissolved oxygen
- Daily mean flow and water temperature (double y-axis plot)
- Daily mean flow and dissolved oxygen (double y-axis plot)

Comparisons of:

- Daily mean water temperature (EC vs. other scenarios)
- Daily mean dissolved oxygen (EC vs. other scenarios)
- Longitudinal profiles for the entire river from Link Dam to the Klamath River near Turwar for the first of each month from April through November) of water temperature and dissolved oxygen.

**Table 77. Reporting locations for the Klamath River model simulations**

| Reach | Location | River Mile | Node (Seg) for EC and SF | Node For WOP |
|---|---|---|---|---|
| Link River | Link Dam | 253.9 | 1 | 1 |
| | Link River at Lake Ewauna | 252. 7 | 25 | 10 |
| Lake Ewauna to Keno Dam Reach | Link River at Lake Ewauna | 252.7 | (2) | 77 |
| | RM 248 | 248.0 | (26) | 131 |
| | RM 243 | 243.0 | (53) | 185 |
| | RM238 | 238.0 | (79) | 227 |
| | Keno Dam | 232.9 | (107) | |
| Keno River | Keno Dam | 232.9 | 1 | 1 |
| | Above J.C. Boyle | 227.6 | 110 | 55 |
| J.C. Boyle Reservoir | J.C. Boyle Dam | 224.3 | - | 94 |
| Bypass / Peaking Reach | bel J.C. Boyle Dam | 224.3 | 1 | 94 |
| | Above Powerhouse | 220.0 | 94 | 138 |
| | Below Powerhouse | 221.0 | 103 | 144 |
| | Stateline | 209.2 | 332 | 259 |
| | Above Copco | 203.6 | 448 | 309 |
| | Copco Reservoir headwaters | | 453 | |
| Copco Reservoir | Copco Dam | 198.6 | - | 387 |
| Iron Gate Reservoir | Irongate Dam | 190.5 | - | 473 |
| Irongate to Turwar Reach | Irongate Dam | 190.5 | 1 | 1 |
| | Above Shasta River | 177.5 | 141 | 141 |
| | At Walker Bridge | 156.6 | 369 | 369 |
| | Above Scott River | 143.6 | 510 | 510 |
| | At Seiad Valley | 129.0 | 672 | 672 |
| | Above Clear Creek | 99.0 | 994 | 994 |
| | Above Salmon River | 67.1 | 1354 | 1361 |
| | At Orleans | 57.6 | 1441 | 1441 |
| | Above Bluff Creek | 50.0 | 1545 | 1545 |
| | Above Trinity River | 43.5 | 1609 | 1609 |
| | At Martins Ferry | 39.5 | 1649 | 1649 |
| | At Blue Creek | 16.9 | 1901 | 1901 |
| | At Turwar | 5.6 | 1974 | 1974 |

# 5 References

American Public Health Assc., American Water Works Assc., and Water Environment Federation (APHA). (1995) *Standard Methods for the examination of water and wastewater*, 19th Ed. Editors. A.E. Eaton, L.S. Clesceri, and A.E. Greenberg. Washington D.C.

Bowie, G.L. W.B. Mills, D.B. Porcella, C.L. Campbell, J.R. Pagenkopf, G.L. Rupp, K.M. Johnson, P.W. Chan, and S.A. Gherini. (1985) *Rates, constants and kinetics formulations in surface water quality modeling*, 2nd Ed. EPA/600/3-87/700. U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, GA. May.

Chapra, S.C. (1997) *Surface Water-Quality Modeling*. McGraw-Hill, InC. New York. 843 pp.

Cole, T.M. and S.A. Wells (2002) *CE-QUAL-W2: A Two-Dimensional Laterally Averaged, Hydrodynamic and Water Quality Model, Version 3.1: User Manual*. Instruction Report EL-2002-1. U.S. Army Engineering and Research Development Center, Vicksburg, MS.

Deas, M.L. and G.T. Orlob. (1999) *Klamath River Modeling Project*. Sponsored by the United States Fish and Wildlife Service Klamath Basin Fisheries Task Force. Project No. 96-HP-01. December.

*Handbook of Hydrology* (1993) Ed. David Maidment. McGraw Hill Inc. New York.

Horne, A. J., and Goldman, C. R. (1994) *Limnology*. 2nd ed. McGraw-Hill, New York. 576 pp.

J.C. Headwaters, Joe Eilers

Kalff, J. (2002) *Limnology*. Prentice Hall, New Jersey. 592 pp.

Kann, J. (2001) *Compilation of Klamath Tribes Upper Klamath Lake Water Quality Data, 1990-2001*. Prepared for the Klamath Tribes Natural Resources Department and U.S. Bureau of Reclamation Cooperative Studies. May 3.

Linacre, E. (1992) *Climate Data and Resources: A reference guide*. Routledge. London. 366 pp.

Martin, J.L. and S.M. McCutcheon (1999) *Hydrodynamics and Transport for Water Quality Modeling*. Lewis Publishers, Boca Raton FL. 794 pp.

MaxDepth Aquatics, Inc. Hydroacoustic Analysis of the Klamath River from Lake Ewauna to Keno Reservoir. Prepared for PacifiCorp. January.

Reckhow, K.H., and S.C. Chapra. 1983. Engineering Approaches for Lake Management. Volume 1: Data Analysis and Empirical Modeling. Butterworth Publishers. Boston. 340 pp.

PacifiCorp (2002) *Explanation of Facilities and Operational Issues Associated with PacifiCorp's Klamath Hydroelectric Project*. Portland Oregon. May 1.

PacifiCorp (2000). First Stage Consultation Document and Appendices: Klamath Hydroelectric Project (FERC Project No. 2082). PacifiCorp, Portland Oregon. December 15, 2000.

Thomann, R.V. and J.A. Mueller (1987) *Principles of Surface Water Quality Modeling and Control*. Harper-Collins Publishers, Inc. New York. 644 pp.

Tchobanoglous, G and E.D. Schroeder (1985) *Water Quality*. Addison-Wesley Publishing Co., Inc. Menlo Park, CA.

United States Army Corps of Engineers - Hydrologic Engineering Center (USACOE-HEC). (1986) *WQRRS Water Quality for River-Reservoir Systems: User's Manual*. Document CPD-8. December.

United States Environmental Protection Agency (EPA). 1997. *Technical guidance manual for developing total maximum daily loads*. Book 2: Streams and rivers, Part 1: Biochemical oxygen demand/dissolved oxygen and nutrients/eutrophication. 823-B-97-002. March.

United States Environmental Protection Agency (EPA). (1976) *Quality Criteria for Water (Red Book)*. Washington D.C. July.

United States Geological Survey (USGS). (1997) 1997 *Completion Report: Water Quantity Model Development*. Prepared for the Technical Work Group of the Klamath Basin Fisheries Task Force by M. Flug and J. Scott. Fort Collins, CO. May.

United States Geological Survey (USGS). (1995) "Klamath River Basin Characterization of Hydrology Data from U.S.G.S. Records," in *Compilation of Phase I reports for the Klamath River Basin*. Prepared for the Technical Work Group of the Klamath Basin Fisheries Task Force. Fort Collins, CO. May.

University of California - Cooperative Extension. (____) *Converting humidity expressions with computers and calculators*, Leaflet 21372.

Watercourse Engineering, Inc.(Watercourse) (2003) *Klamath River Water Quality 2000 Monitoring Program: Project Report*. Sponsored by the U.S. Bureau of Reclamation, Klamath Area Office, with support from PacifiCorp. January.

Wetzel, R.G. (2001) Limnology: Lake and River Ecosystems, 3$^{rd}$ Ed. Academic Press, San Diego. 1006 pp.

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# Appendix A: Modeling Framework

# Appendix B: Model Descriptions

# Appendix C: River Geometry

# Appendix D: Flow Data

# Appendix E: Meteorological Data

# Appendix F: Water Quality Data

# Appendix G: Data processing for Calibration / Validation

# Appendix H: 2001 Lake Ewauna/Keno Reach Boundary Conditions – Graphical and Tabular Presentation