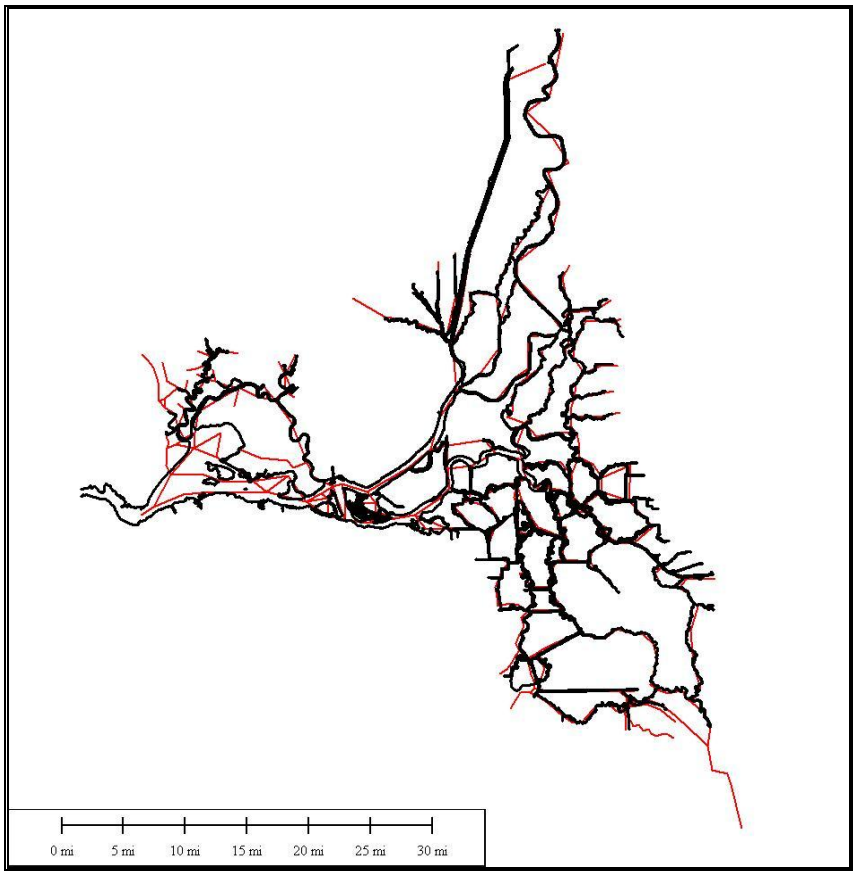
Modeling the Fate and Transport of Nutrients Using DSM2: Calibration/Validation Report

November 2011



Prepared For:
State Water Contractors and
State and Federal Contractors Water Agencies
Sacramento, CA 95814

Contact:
Paul Hutton
Senior Engineer
Metropolitan Water District
916-650-2620

Prepared By:
Resource Management Associates
4171 Suisun Valley Road, Suite J
Fairfield, CA 94534

Contact:
Marianne Guerin
707-864-2950

RMA Resource Management Associates

1 Table of Contents

1 Executive Summary 2

1.1 Summary – Objectives and Proposed Applications (Section 2) 2

1.2 Summary – Background, Model Configuration, and Nutrient Model Conceptualization (Sections 3 through 5) 3

1.3 Summary – Data (Sections 6 -8) 4

1.4 Boundary Conditions (Section 9) 5

1.5 Summary – Calibration and Validation (Sections 10 – 12) 6

1.5.1 Calibration Process 6

1.5.2 Calibration and Validation results for Water Temperature 9

1.5.3 Calibration and Validation Results for Nutrients 10

1.5.4 Range of Nutrient Model Validity Assessed from Calibration and Validation 10

1.6 Summary – Simulation Results (Sections 16 to 18) 11

1.7 Summary – Monitoring Program (Section 21) 12

1.8 Summary – Model Adequacy and Suggested Improvements (Section 19) 12

2 Project Objectives and Proposed Applications 13

3 Background 14

3.1 DSM2 – general 14

3.2 Issues with ammonia and temperature in the Delta 16

3.3 Previous nutrient models using DSM2 16

3.4 Additional analysis – aqueous geochemistry and isotopes 17

4 DSM2 Model Configuration 18

4.1 Model Grid 18

4.2 Numerical Solution Parameters 18
4.3 Model Boundaries 18
4.3.1 Flow and Stage Boundaries 18
4.3.2 Transport Model Boundaries – Nutrients, salinity and temperature 19
4.4 Previous DSM2 calibration 20

5 QUAL's Conceptual Model for Nutrient Dynamics 25
5.1 QUAL Conceptual Background 25
5.2 Nutrient Model formulation 26
5.2.1 Temperature 27
5.2.2 Dissolved Oxygen (DO) 28
5.2.3 Carbonaceous Biochemical Oxygen Demand (CBOD) 28
5.2.4 Algae (Phytoplankton) 29
5.2.5 Organic nitrogen (Org-N) 29
5.2.6 Ammonia (NH_3) 30
5.2.7 Nitrite (NO_2) 30
5.2.8 Nitrate (NO_3) 30
5.2.9 Organic Phosphorus (Org-P) 31
5.2.10 Dissolved Phosphorus (PO_4) 31
5.3 Reaction Rates and Parameters 31

6 Conceptual Model of the Delta Used in QUAL's Nutrient Model 36
6.1 A Very Brief Description of Delta Hydrodynamics 36
6.2 QUAL-Nutrient Parameterization Regions 36

7 Data: Sources and Refinement 46
7.1 Data Sources 46

7.2 Data processing methodology 46
7.3 Data Quality....47
7.4 Missing data....48

8 Data Availability: Time Spans and Locations 59
8.1 USGS Data 59
8.2 U.C. Davis - R. Dahlgren and M. Johnson....60
8.3 WWTP Receiving Water Measurements 60
8.4 WWTP Effluent Data....61
8.5 BDAT....61
8.6 Lehman Data for Liberty Island 62
8.7 Other Sources 62
8.8 Data Availability by Category....63
8.8.1 Meteorological Data....63
8.8.2 Water Temperature Data 63
8.8.3 DO Data....64
8.8.4 DICU Data....64
8.8.5 Chlorophyll a (Chl-a)....64

9 Setting Boundary Conditions 77
9.1 Background....77
9.2 Flow, stage and salinity....77
9.3 Meteorology....78
9.4 Water Temperature 79
9.5 Nutrients – Delta Boundary Conditions....80
9.5.1 Ammonia....81

9.6 Nutrients - DICU 85
9.7 Nutrients – Effluent Boundaries 85

10 Chemical Speciation Modeling and Isotope Analysis 96
10.1 EQ3/6 modeling 96
10.2 Isotope Analysis 97

11 Calibration/Validation Methodology 98
11.1 Methodology for Calibration and Validation 99
11.2 Residual Analysis 100
11.3 Methodology for nutrient residual analysis 102

12 Calibration and Validation for Water Temperature and Nutrients 102
12.1 Background for Water Temperature Calibration 102
12.1.1 Methodology for Water Temperature Calibration and Validation 103
12.1.2 Residual Analysis – Water Temperature 104
12.1.3 Calibration/Validation Results for Water Temperature 104
12.4 Nutrient Calibration and Validation Process 132
12.5 Residual analysis methodology for nutrients 133
12.5.1 Calibration and Validation Time Periods and Data 134
12.5.2 Nutrient Model Results: Calibration/validation for 1990 - 2008 138
12.5.3 Nutrient Model Results: Calibration/validation for 2000 – 2008 (Version 8.0.6) 139
12.6 Discussion of Calibration and Validation 140

13 Volumetric Fingerprinting and Liberty Island Grid 163
13.1 Volumetric Fingerprinting Results 163
13.2 Inclusion of Liberty Island 164

14 Jones Tract Modeling 177

15 Lehman Data inclusion 177

16 Scenarios – Sensitivity to Changes in N-concentrations 182
16.1 Increase/decrease DICU N-constituents 182
16.2 Increase/decrease N-constituents at the Sacramento Boundary 183
16.3 Increase/decrease N-constituents at the San Joaquin Boundary 184
16.4 Increase/decrease N-constituents in Sac Regional Effluent 185
16.5 Increase/decrease Sac Regional Effluent Volume 187
16.6 Increase/decrease N-constituents at Stockton WWTP Boundary 187
16.7 Summary of Sensitivity Scenarios 188

17 Scenario: Modify Sac Regional WWTP Process for Nitrification ... 188

18 Scenarios: Clams (*Corbula* and *Corbicula*) 196

19 Adequacy of QUAL's Current Formulation and Potential Areas for Model Development 221
19.1 Current Formulation- Strengths and Weaknesses 221
19.2 Areas for Model Development 222
19.2.1 Temperature/meteorology 222
19.2.2 Algae, bacteria and plant growth 223
19.2.3 Other Benthic interactions 223
19.2.4 Mass Balance and Organic Matter 224

20 Discussion 224

21 Monitoring program 225
21.1 Current/past data gathering efforts 226
21.1.1 Data Coverage 226
21.1.2 Sufficiency for Ammonia/temperature modeling 226
21.2 Suggested Monitoring Regime for the Current Conceptual Model 226
21.2.1 Temporal coverage 227
21.2.2 Spatial/Regional coverage 227
21.2.3 Supplementary measurements 227
21.3 Priority measurements 228
21.4 Monitoring for an Improved Conceptual Model 228

22 Summary and Conclusions 234

23 Next Steps 235
23.1 Extending Model to Current Day 235
23.2 Better DICU Boundary Conditions 236
23.3 Publication 236
23.4 Extending Modeled Period Back in Time 236
23.5 Uncertainty Analysis 236
23.6 Comparative Nutrient Model/Isotope Analyses 237
23.7 Yolo/Cache Region and Liberty Island Recalibration 237
23.8 Suisun Marsh region 237

24 References 239

25 APPENDIX I 244

25.1 Data Sources – Figures and Tables 244

25.2 CBOD and BOD 266

25.3 Fluorescence Data 267

25.4 Singular Spectrum Analysis 269

25.5 Model Boundary Conditions 273

25.6 Wet Bulb Temperature Calculations 285

25.7 Methodology for Setting Sacramento River NH_3 and NO_3 Boundary Conditions 286

25.8 Calibration Statistics and Residual Analysis Methodology 298

25.9 Solution Chemistry and EQ 3/6 calculations 302

25.9.1 Concentrations of Ammonium Ion and Ammonia 302

25.9.2 Water Chemistry at the Sacramento and San Joaquin boundaries. 302

25.10 Volumetric and Liberty Grid Figures (From Sections 12 and 13) 307

25.11 Scenario Figures 341

25.12 Estimating Mass Loss at the Martinez Boundary in DSM2 383

25.12.1 RMA Model Representation 383

25.12.2 Martinez Boundary Condition - Tracer Simulations 391

APPENDIX I, continued

26 Calibration Figures and Categorical Statistics (Version 8.0.6).....404
26.1 Algae.....404
26.2 Dissolved Oxygen.....425
26.3 NH3.....445
26.4 NO3+NO2.....454
26.5 Organic-N.....467
26.6 PO4.....478
27 Analysis of Revised Categorical Intervals for Nutrient Statistics(Version 8.0.6).....488
27.1 Algae.....489
27.2 Dissolved Oxygen.....501
27.3 NH3.....513
27.4 NO3+NO2.....519
27.5 Organic-N.....527
27.6 PO4.....532
28 Calibration Statistics and Histograms (Version 8.0.6).....537
28.1 Algae.....537
28.2 Dissolved Oxygen.....557
28.3 NH3.....576
28.4 NO3+NO2.....585
28.5 Organic-N.....597
28.6 PO4.....606

FIGURES

Figure 4-1 Channels (red), reservoirs (blue numbers), and nodes (black) in the DSM2 model grid. 21

Figure 4-2 Approximate location of the model inflow boundaries and the stage boundary is at Martinez (blue stars). Export locations are indicated by red stars. 22

Figure 4-3 Approximate locations of effluent boundary conditions for waste water treatment plants considered in this report. 23

Figure 4-4 Changes implemented in the DSM2 Version 8 model grid include the new Liberty Island "reservoir" location (red oval), and changes to the grid and nodes along the upstream portion of the Sacramento River (blue circles). 24

Figure 5-1. The interactions among the main constituents, and external influences (an adaptation from original DWR references). Water temperature (blue region) influences reaction rates, denoted by arrows. 33

Figure 6-1 The Delta is a physically diverse system, as illustrated at several locations within the DSM2 model domain. 39

Figure 6-2 Overview figure of some major influences on Delta hydrodynamics – river inflow, exports, and tidal influences. Large volumes of water are exchanged between Threemile Slough and at the confluence of the Sacramento and San Joaquin Rivers. 40

Figure 6-3 The parameterization region extending from the confluence west to the model boundary at Martinez, including Suisun Marsh. Dashed line indicates the confluence region of the Sacramento and San Joaquin Rivers 41

Figure 6-4 The parameterization region extending north from the confluence to the Sacramento River inflow model boundary, and incorporating the Yolo Basin and Cache Slough. Although Liberty Island is included in this region geographically, it is not included in this parameterization region. 42

Figure 6-5 The parameterization region for the upstream portion of the San Joaquin River. 43

Figure 6-6 The parameterization region for the central and southern portion of the Delta. The reservoirs within the boundary of this region were parameterized separately. These area is affected by exports and low flow during the summer months. Invasive water weeds can severely restrict flow and alter nutrient dynamics. 44

Figure 6-7 The parameterization region encompassing the East Delta – this region is heavily influenced by the Sacramento River when the Delta Cross Channel (DCC) is open, but mainly

from the Cosumnes and Mokelumne Rivers when the DCC is closed. There are also many agricultural influences in this region. 45

Figure 7-1 Suspect data were identified at RSAC123 (blue line) by large jumps in value at low temperatures in comparison with water temperature data at RSAC142 (red line). These locations are on the Sacramento River (See Table 25-1). 50

Figure 7-2 Comparison of EMP (same as BDAT) and USGS measurements at Point Sacramento (upper) Rio Vista (lower) – chlorophyll a measurements were converted to biomass of algae which is shown in the plots above. 51

Figure 7-3 Comparison of EMP and USGS DO measurements at Point Sacramento (upper) Rio Vista (lower). 52

Figure 7-4 Comparison of EMP and USGS Nitrate+Nitrite (NO3+NO2) measurements at Point Sacramento (upper) Rio Vista (lower). 53

Figure 7-5 Comparison of EMP and USGS ortho-phosphate (PO_4) measurements at Point Sacramento. 54

Figure 7-6 Comparison of ortho-phosphate (PO_4) measurements taken by EMP (lower) and USGS (upper) at Point Sacramento and a similar downstream location showing differences between locations and measurement agencies. 54

Figure 7-7 Comparison of EMP and USGS Nitrate+Nitrite measurements near Martinez (upper) and near Chipps and Pittsburg (lower). 55

Figure 7-8 Comparison of EMP and USGS PO_4measurements near Martinez. 56

Figure 7-9 Comparison of EMP and USGS algae (upper) and DO (lower) measurements near Chipps and Pittsburg. 57

Figure 7-10 Water temperature data with gaps at Hood on the Sacramento River (red line) – fill-in data were approximated using Singular Spectrum Analysis (blue line). 58

Figure 8-1 USGS nutrient and other water quality parameters measurements (blue crosses) were utilized from location 8 just downstream of Martinez to location 657 at Rio Vista. 65

Figure 8-2 USGS temperature data at various depths from Martinez to Pittsburg on July 07, 2006. 66

Figure 8-3 USGS temperature data at various depths from Chain Island to Rio Vista on August 15, 2006. 67

Figure 8-4 Approximate location of data (indicated by yellow stars) in Dahlgren's (UC Davis) data set used to help define nutrient boundary conditions. 68

Figure 8-5 Location of the Stockton WWTP receiving water measurement locations (Figure from C. Kendall, personal communication). 69

Figure 8-6 Location of the two Sacramento Regional WWTP receiving water measurements used in this report – Freeport Marina and at River Mile 44. 70

Figure 8-7 Meteorological measurements from NOAA at the Stockton airport (yellow star), and CIMIS measurements, indicated by yellow Google Earth push-pins. 73

Figure 8-8 Locations of temperature data regular time series. Data quality and length of record is variable. 74

Figure 8-9 The coverage and quality of temperature data used in model or the years 1999 – 2008. 75

Figure 8-10 The coverage and quality of temperature data used in model for the years 1990 – 1998. 76

Figure 9-1 A minimum two meteorological regions are needed to calibrate QUAL for water temperature. 86

Figure 9-2 Modeled water temperature at RSAN058 on the San Joaquin River for two wind speeds – Base speed and wind speed*1.5 – in comparison with data (blue line). 87

Figure 9-3 Data (blue line) and modeled water temperature at RSAC081 for two wind speeds – Base (red) and wind speed*1.5 (green). Increasing wind speed produces a better fit to the data. 88

Figure 12-1 Temperature model calibration and validation periods. Data 1999 – 2008 was generally of better quality, but early Critical Water Years ("1" in the chart) were also used. 106

Figure 12-2 Five regions were used in the calibration and validation of water temperature. 107

Figure 12-3 Hourly calibration results for water temperature at RSAN018, Jersey Point. Blue line is hourly data, red line is the modeled hourly result averaged from 15-minute model output. 113

Figure 12-4 Daily calibration results for water temperature at RSAC101, Rio Vista. Blue line is daily data, red line is the modeled daily result averaged from 15-minute model output. 114

Figure 12-5 Hourly calibration results for water temperature at RSAC123, Sac near Georgiana Sl. Blue line is hourly data, red line is the modeled hourly result averaged from 15-minute model output. 115

Figure 12-6 Hourly calibration results for water temperature at locations in the Cache Slough area (CDEC CCS station). Blue line is daily data, red line is the modeled daily result averaged from 15-minute model output. 116

Figure 12-7 Hourly calibration results for water temperature at ROLD024, Old River at Hwy 4. Blue line is hourly data, red line is the modeled hourly result averaged from 15-minute model output. 117

Figure 12-8 Calibration plots in the Critically Dry Water Year 2008 at Emmaton and Jersey Point. 118

Figure 12-9 Calibration plots in the Critically Dry Water Year 2008 at RSAN072 on the San Joaquin and at Collinsville. 119

Figure 12-10 Calibration plots in the Critically Dry Water Year 2008 at RMID023 on Middle R. in the South Delta and at RSAC123 on the upper Sacramento R. 120

Figure 12-11 Calibration plots in the Dry Water Year 2007 at Emmaton and Jersey Point. 121

Figure 12-12 Calibration plots in the Dry Water Year 2007 at RSAN072 on the San Joaquin and at Collinsville. 122

Figure 12-13 Calibration plots in the Dry Water Year 2007 at RMID023 on Middle R. in the South Delta and at RSAC123 on the upper Sacramento R. 123

Figure 12-14 Calibration plots in the Above Normal Water Year 2005 at Emmaton and Jersey Point. 124

Figure 12-15 Calibration plots in the Abv Normal Water Year 2005 at RMID023 on Middle R. in the South Delta and at RSAC123 on the upper Sacramento R. 125

Figure 12-16 Calibration plots in the Abv Normal Water Year 2005 at Cache Sl. and at Goodyear Sl. 126

Figure 12-17 Calibration plots in the Abv Normal Water Year 2005 at RSAN072 on the San Joaquin and at Collinsville. 127

Figure 12-18 Calibration plots in the Wet Water Year 2006 at Jersey Point and Emmaton. 128

Figure 12-19 Calibration plots in the Wet Water Year 2006 at RMID023 on Middle R. in the South Delta and at RSAC123 on the upper Sacramento R 129

Figure 12-20 Calibration plots in the Wet Water Year 2006 at RSAN072 on the San Joaquin and at Collinsville. 130

Figure 12-21 Calibration plots in the Wet Water Year 2006 at Cache Sl. and at Goodyear Sl. .131

Figure 12-22 Nutrient calibration (blue) and validation (red) periods. 142

Figure 12-23 Location of nutrient data time series used in model calibration and validation. Model constituents vary by location. 143

Figure 12-24 Box plot of the 2000 – 2008 data for the Algae/chl-a constituent used in the calibration of QUAL Version 8.0.6. 144

Figure 12-25 Box plot of the 2000 – 2008 data for the DO constituent used in the calibration of QUAL Version 8.0.6. 145

Figure 12-26 Box plot of 2000 – 2008 data for the NO_3+NO_2 constituent(s) used in the calibration of QUAL Version 8.0.6. 146

Figure 12-27 Box plot of 2000 – 2008 data for the NH_3 constituent(s) used in the calibration of QUAL Version 8.0.6. 147

Figure 12-28 Box plot of 2000 – 2008 data for the Organic-N constituent(s) used in the calibration of QUAL Version 8.0.6. 148

Figure 12-29 Box plot of 2000 – 2008 data for the PO_4 constituent(s) used in the calibration of QUAL Version 8.0.6. 149

Figure 12-30 Illustration of the changes in max/min envelope width for NO3+NO2 (left) and Po4 (right) for the 10% and 20% reductions. 162

Figure 13-1 Ag and Sac Regional effluent volumes at Greene's Landing. 166

Figure 13-2 Sac Regional effluent volumes along the Sacramento River. 167

Figure 13-3 Three output locations in the DSM2 grid used to study the effects of a flooded Liberty Island. 168

Figure 13-4 Algal biomass and ammonia concentrations at the Yolo location for Base and Liberty grids. 169

Figure 13-5 Nitrate and nitrite concentrations at the Yolo location for Base and Liberty grids. 170

Figure 13-6 DO and CBOD concentrations at the Yolo location for Base and Liberty grids. 171

Figure 13-7 Organic-N and PO_4 concentrations at the Yolo location for Base and Liberty grids. 172

Figure 13-8Algal biomass at RSAC101 and RSAC092 for Base and Liberty grids. 173

Figure 13-9 Ammonia at RSAC101 for Base and Liberty grids. 174

Figure 13-10 Nitrate and nitrite at RSAC101 for Base and Liberty grids. 175

Figure 13-11 DO and CBOD at RSAC101 for Base and Liberty grids. 176

Figure 15-1 Comparison of data averaged from four locations in Liberty Island (Lehman et al., 2010) with DSM2 Historical nutrient model output for NH_3 and NO_3+NO_2. Model output is represented as the monthly MAX and MIN of the original 15-minute model output. 179

Figure 15-2 Comparison of data averaged from four locations in Liberty Island (Lehman et al., 2010) with DSM2 Historical nutrient model output for Organic-N and PO_4. Model output is represented as the monthly MAX and MIN of the original 15-minute model output. 180

Figure 15-3 Comparison of data averaged from four locations in Liberty Island (Lehman et al., 2010) with DSM2 Historical nutrient model output for Algae (calculated using a conversion 67 g algae (dry weight)/mg chl-a) and DIN:DIP, where DIN=NO_3+NO_2+NH_3, and DIP=PO_4. Model output is represented as the monthly MAX and MIN of the original 15-minute model output. .181

Figure 18-1 Model output locations in the northern Delta for the scenarios.....197

Figure 18-2 Model output locations in the western Delta for the scenarios.....198

Figure 18-3 Model output locations near the confluence of the Sacramento and San Joaquin Rivers for the scenarios. 199

Figure 18-4 Model output locations on the lower San Joaquin River for the scenarios. 200

Figure 18-5 Changes in ammonia in Georgiana Slough for the scenarios changing Sacramento R. N-constituents. 201

Figure 18-6 Changes in nitrate in Georgiana Slough for the scenarios changing Sacramento R. N-constituents. 202

Figure 18-7 Changes in ammonia concentration at Potato Point for the scenarios changing Sacramento R. N-constituents. 203

Figure 18-8 Changes in nitrite concentration at Potato Point for the scenarios changing Sacramento R. N-constituents. 204

Figure 18-9 Changes in nitrate concentration at Potato Point for the scenarios changing Sacramento R. N-constituents. 205

Figure 18-10 Nitrate concentration at downstream locations from the San Joaquin boundary after changing N-concentrations – RSAN018 and RSAN037.....206

Figure 18-11 Changes in ammonia and nitrite at Isleton in the scenario changing Sac Regional N-constituents. 207

Figure 18-12 Changes in organic-N and nitrate at Isleton in the scenario changing Sac Regional N-constituents. 208

Figure 18-13 Changes in DO and chl-a/algae at Isleton in the scenario changing Sac Regional N-constituents. 209

Figure 18-14 Changes in ammonia and chl-a/algae at Rio Vista in the scenario changing Sac Regional N-constituents. 210

Figure 18-15 Changes in nitrite and nitrate at Rio Vista in the scenario changing Sac Regional N-constituents. 211

Figure 18-16 Ammonia and DO concentrations at RSAN037 downstream of the Stockton WWTP after changing wastewater concentrations. 212

Figure 18-17 Nitrate and organic-N concentrations at RSAN037 downstream of the Stockton WWTP after changing wastewater concentrations. 213

Figure 18-18 Chl-a/algae and DO concentrations at Isleton for the Sac Regional Nitrification scenario. 214

Figure 18-19 Nitrate and nitrate concentrations at Isleton for the Sac Regional Nitrification scenario. 215

Figure 18-20 Nitrate and organic-N concentrations at Isleton for the Sac Regional Nitrification scenario 216

Figure 18-21 Chl-a/algae and DO concentrations at Rio Vista for the Sac Regional Nitrification scenario. 217

Figure 18-22 Ammonia and nitrite concentrations at Rio Vista for the Sac Regional Nitrification scenario. 218

Figure 18-23 Nitrate and organic-N concentrations at Rio Vista for the Sac Regional Nitrification scenario. 219

Figure 18-24 Suitable habitat areas for *Corbula* and *Corbicula* do not tend to overlap. 220

Figure 21-1 Suggested and prioritized locations for an enhanced nutrient monitoring scheme in the north Delta. 230

Figure 21-2 Suggested and prioritized locations for an enhanced nutrient monitoring scheme in the eastern Delta. 231

Figure 21-3 Suggested and prioritized locations for an enhanced nutrient monitoring scheme in the western Delta. 232

Figure 21-4 Suggested and prioritized locations for an enhanced nutrient monitoring scheme in the south Delta. 233

Figure 25-1Availability of USGS nutrient data at six USGS sites. Shading (hashes, dots) indicates partial year of data. 246

Figure 25-2 Availability of USGS data at the remaining four sites. Shading (hashes, dots) indicates partial year of data. 247

Figure 25-3 Availability of Stockton WWTP receiving water measures for sites RW-1 to RW-4. Shading (hashes, dots) indicates partial year of data. 248

Figure 25-4 Availability of Stockton WWTP receiving water measures for sites RW-5 to RW-8. Shading (hashes, dots) indicates partial year of data. 249

Figure 25-5 Availability of Sac Regional WWTP receiving water measurements. Shading (hashes, dots) indicates partial year of data. 250

Figure 25-6 Availability of EMP/BDAT NH_3, NO_3+NO_2, and chlorophyll a measurements (Part 1). Hatching means partial-year data. 251

Figure 25-7 Availability of EMP/BDAT NH_3, NO_3+NO_2, and chlorophyll a measurements (Part 2). Hatching means partial-year data. 252

Figure 25-8 Availability of EMP/BDAT NH_3, NO_3+NO_2, and chlorophyll a measurements (Part 3). Hatching means partial-year data. 253

Figure 25-9 Availability of EMP/BDAT DO, Organic-N, and PO_4 measurements (Part 1). Hatching means partial-year data....254

Figure 25-10 Availability of EMP/BDAT DO, Organic-N, and PO_4 measurements (Part 2). Hatching means partial-year data....255

Figure 25-11 Availability of EMP/BDAT DO, Organic-N, and PO_4 measurements (Part 3). Hatching means partial-year data....256

Figure 25-12 Availability of EMP/BDAT BOD measurements. Partial-year data only....256

Figure 25-13 Location of BDAT grab-sample measurements for chl-a in the northern Delta. ..257

Figure 25-14 Location of BDAT-sourced grab-sample measurements for chl-a in the southern Delta. 258

Figure 25-15 Location of BDAT grab-sample measurements for chl-a in the western Delta. ...259

Figure 25-16 Nutrient levels in two large regions of the Delta are totally or partially unconstrained in calibration (i.e., no measurement data for some constituents). 260

Figure 25-17 Linear regression between concentration of chlorophyll a and signal strength of fluorescence at Hood. Red line indicates 5 µg/L of Chlorophyll a. 267

Figure 25-18 Linear regression between concentration of chlorophyll a and signal strength of fluorescence at Mossdale. Red line indicates 5 µg/L of Chlorophyll a. 267

Figure 25-19 Linear regression between concentration of chlorophyll a and signal strength of fluorescence at Martinez. Red line indicates 5 µg/L of Chlorophyll a. 268

Figure 25-20 CAT-MV (red lines) approximations to hourly water temperature data (blue lines) at Martinez. Black vertical lines indicate missing data points. Upper plot used 4 eigenvectors, the lower plot used 24. 270

Figure 25-21 Upper: Residual plot and histogram of a Cat-MV model fit to one-year of hourly water temperature at Martinez, window length was 288, 24 eigenvectors. Lower: Residuals applied to a two-year data set: the fit during summer months poor in comparison to winter. 271

Figure 25-22 Large data gaps (dark bands) used a window length shorter than the largest data gap to get better results. Cat-MV fit (red) to the data series (blue line) and the missing data. ..272

Figure 25-23 Flow data at the Lisbon Toe Drain (LIS, red line) and boundary condition data from DSM2 at the Yolo boundary (blue line). 273

Figure 25-24Wind speeds for the CIMIS stations at Lodi and at Twitchell Island show a factor of two difference in wind speed. 274

Figure 25-25 Wind speeds for the CIMIS station at Lodi and the NOAA station at Stockton show a factor two variation in reported speed. 275

Figure 25-26 Red line is the smoothed boundary (dry bulb upper, wet bulb lower) used to get model convergence during these periods. 276

Figure 25-27 Ammonia concentration data above Freeport from three sources, UC Davis (blue), BDAT (black) and Sac Regional receiving waters monitoring (two data sets, red and dark blue). 277

Figure 25-28 NH_3 concentration from Sac Regional receiving water measurements (blue and red) in comparison with NH_3 boundary condition set at BDAT Greens/Hood ammonia*0.4. 277

Figure 25-29 Sac Regional flow, temperature, ammonia and organic-N effluent concentrations. 278

Figure 25-30 Sac Regional nitrate, nitrite, organic-P, CBOD and PO_4 effluent concentrations. 279

Figure 25-31 Stockton WWTP flow, temperature, ammonia and nitrate effluent concentrations. 280

Figure 25-32 Stockton WWTP organic-N, nitrite, organic-P, CBOD and PO_4 effluent concentrations. 281

Figure 25-33 Sac Regional and Stockton WWTP effluent EC concentrations. 282

Figure 25-34 Sacramento R. NH_3 boundary condition (red) calculated using a mass balance approach in comparison with previous boundary condition (blue). 289

Figure 25-35 Sacramento R. NH_3 boundary (blue) calculated using a revised mass balance approach in comparison with Sac Regional receiving water NH_3 data (red) and previous boundary condition (green). 289

Figure 25-36 Two calculated NH_3 boundary conditions: low flow (red) and high flow (blue) constraint with a minimum value compared with Sac Regional receiving water NH_3 (green) and previous BC (purple). 290

Figure 25-37 The same two calculated boundary conditions as in Figure 25-36, in comparison with UC Davis Freeport measured ammonia (green) 290

Figure 25-38 Modeled (blue) and measured (green symbol) ammonia at Greens Landing (RSAC139). Upper: Model V12 Sac R. BC with high flow constraint; V11 (red) with a GRNSHOOD*0.4 BC. Lower: V12 model output at Greenes Landing vs. Greenes (C3) and Hood (C3A) ammonia data.....291

Figure 25-39 V12 model (calculated ammonia BC w/high flow constraint) at downstream locations, Point Sacramento (upper, PO-649) and at Potato Point (lower, D26). 292

Figure 25-40 Four nitrate concentrations at or near Freeport – UC Davis data (green), BDAT data (red) and two Sac Regional receiving water datasets (blue, solid and dashed). 292

Figure 25-41 Nitrate data at or near Freeport *vs.* Sacramento R. BC: (black) BC set using EMP (Greens/Hood nitrate)*(0.825) vs. UC Davis data (green), Sac Regional receiving water data (blue) and MWQI monitoring data (green). 293

Figure 25-42 Modeled ammonia with constant concentration boundary (blue), “high flow” V12 boundary (red dash) vs. UC Davis ammonia data near Freeport (green symbols). 293

Figure 25-43 Modeled ammonia with the constant concentration boundary (blue) and. the “high flow” V12 boundary (red dash) vs. Sac Regional receiving water ammonia near Freeport (green symbols). 294

Figure 25-44 Modeled ammonia using the constant concentration boundary (blue) and the “high flow” V12 boundary (red dash) vs. EMP ammonia calibration data near Greens Landing (green symbols) 295

Figure 25-45 Mixing model calculation (red) compared with the flow ratio (Total flow)/Sac BC Inflow (blue) 296

Figure 25-46 Modeled ammonia with three ammonia BC: constant concentration (green dash), “high flow” V12 (red dash), and previous calibrated model V10 with (Greens/Hood ammonia)*(0.4) (blue dash) vs. EMP data near Greens Landing (black symbols). 297

Figure 25-47 Calibration/validation locations in the northern Delta 298

Figure 25-48 Calibration/validation locations in the western Delta. 299

Figure 25-49 Calibration/validation locations in the central Delta. 300

Figure 25-50 Calibration/validation locations in the south Delta. 301

Figure 25-51 Volumetric results at Rio vista (upper) and in Three Mile Slough (lower). 307

Figure 25-52Sac Regional effluent volumes along the lower San Joaquin and Sacramento Rivers. 308

Figure 25-53 Volumetric contributions near the Yolo/Cache Slough area. 309

Figure 25-54 Volumetric contributions near the Lisbon Toe Drain and the outflow from the Liberty Island area. 310

Figure 25-55 Sac Regional effluent volumes in the eastern Delta. 311

Figure 25-56 Sac Regional effluent volumes along the lower Sacramento River into Grizzly and Honker Bays. 312

Figure 25-57 Sac Regional effluent volumes in and near Suisun Marsh. 313

Figure 25-58 Volumetric contributions of smaller WWTP’s in the Suisun area. 314

Figure 25-59 Higher volume of San Joaquin River contributions are seasonal. 315

Figure 25-60 Sac Regional effluent volumes remain high at Potato Point, although Ag contributions are higher here. 316

Figure 25-61 Contributions from smaller WWTPs in the lower San Joaquin River. 317

Figure 25-62 Sac Regional effluent contributions are small in the south Delta. 318

Figure 25-63 Algal biomass and ammonia concentrations at the Liberty location for Base and Liberty grids.....319

Figure 25-64 Nitrate and nitrite concentrations at the Liberty location for Base and Liberty grids. 320

Figure 25-65 DO and CBOD concentrations at the Liberty location for Base and Liberty grids. 321

Figure 25-66 PO_4 and organic-N concentrations at the Liberty location for Base and Liberty grids.....322

Figure 25-67 Algal biomass and ammonia concentrations at SLCCH016 for Base and Liberty grids.....323

Figure 25-68 Nitrate and nitrite concentrations at SLCCH016 for Base and Liberty grids.....324

Figure 25-69 DO and CBOD concentrations at SLCCH016 for Base and Liberty grids. 325

Figure 25-70 Organic-N and PO_4 concentrations at SLCCH016 for Base and Liberty grids. 326

Figure 25-71 Organic-N and PO_4 concentration at RSAC101 for Base and Liberty grids.....327

Figure 25-72 Ammonia concentration at RSAC092 for Base and Liberty grids. 328

Figure 25-73 Nitrate and nitrite concentrations at RSAC092 for Base and Liberty grids. 329

Figure 25-74 CBOD and DO concentrations at RSAC092 for Base and Liberty grids.....330

Figure 25-75 Organic-N and PO_4 concentrations at RSAC092 for Base and Liberty grids. 331

Figure 25-76 Algal biomass Point Sacramento for Base and Liberty grids. 332

Figure 25-77 Ammonia concentration at Point Sacramento for Base and Liberty grids. 333

Figure 25-78 Nitrate and nitrite concentrations at Point Sacramento for Base and Liberty grids. 334

Figure 25-79 DO and CBOD concentrations at Point Sacramento for Base and Liberty grids. .335

Figure 25-80 Organic-N and PO4 concentrations at Point Sacramento for Base and Liberty grids. 336

Figure 25-81 Algal biomass and ammonia concentrations at Potato Point for Base and Liberty grids.....337

Figure 25-82 Nitrate and nitrite concentrations at Potato Point for Base and Liberty grids. 338

Figure 25-83 DO and CBOD concentrations at Potato Point for Base and Liberty grids. 339

Figure 25-84 Organic-N and PO_4 concentrations at Potato Point for Base and Liberty grids. ...340

Figure 25-85 Changes in nitrate concentration were very small at Point Sacramento in the DICU changes scenarios. 341

Figure 25-86 Changes in nitrate concentration were hard to distinguish at Isleton in the DICU changes scenarios. 342

Figure 25-87 Changes in nitrate concentration at Antioch in the DICU changes scenarios. 343

Figure 25-88 Changes in ammonia concentration at RSAN037 on the San Joaquin River. 344

Figure 25-89 Changes in nitrate concentration at RSAN037 on the San Joaquin River. 345

Figure 25-90 Changes in ammonia concentration at RSAN052 on the San Joaquin River. 346

Figure 25-91 Changes in nitrate concentration at RSAN052 on the San Joaquin River. 347

Figure 25-92 Changes in algal biomass were very small at Isleton for the scenarios changing Sacramento R. N-constituents. 348

Figure 25-93 Changes in algal biomass were very small at Point Sacramento for the scenarios changing Sacramento R. N-constituents. 349

Figure 25-94 Changes in ammonia at Isleton for the scenarios changing Sacramento R. N-constituents. 350

Figure 25-95 Changes in nitrite at Isleton for the scenarios changing Sacramento R. N-constituents. 351

Figure 25-96 Changes in nitrate at Isleton for the scenarios changing Sacramento R. N-constituents. 352

Figure 25-97 Changes in ammonia concentration at Antioch for the scenarios changing Sacramento R. N-constituents. 353

Figure 25-98 Changes in nitrite concentration at Antioch for the scenarios changing Sacramento R. N-constituents.....354

Figure 25-99 Changes in nitrate concentration at Antioch for the scenarios changing Sacramento R. N-constituents.....355

Figure 25-100 Ammonia and chl-a/algae concentrations at RSAN037 downstream the San Joaquin boundary. 356

Figure 25-101 Nitrite and organic-N concentrations at RSAN037 downstream of the San Joaquin boundary. 357

Figure 25-102 Changes in ammonia and chl-a/algae at the Confluence-1 location in the scenario changing Sac Regional N-constituents. 358

Figure 25-103 Changes in nitrite and nitrate at the Confluence-1 location in the scenario changing Sac Regional N-constituents. 359

Figure 25-104 Changes in ammonia and chl-a/algae at Suisun at Nichols in the scenario changing Sac Regional N-constituents. 360

Figure 25-105 Changes in nitrite and nitrate at Suisun Nichols in the scenario changing Sac Regional N-constituents. 361

Figure 25-106 Changes in ammonia and chl-a/alga at Jersey point (RSAN018) in the scenario changing Sac Regional N-constituents. 362

Figure 25-107 Changes in nitrite and nitrate at Jersey point (RSAN018) in the scenario changing Sac Regional N-constituents. 363

Figure 25-108 Changes in ammonia and chl-a/algae in Georgiana Slough in the scenario changing Sac Regional N-constituents. 364

Figure 25-109 Changes in nitrite and nitrate in Georgiana Slough in the scenario changing Sac Regional N-constituents. 365

Figure 25-110 Changes in ammonia and nitrite at Potato Point in the scenario changing Sac Regional N-constituents. 366

Figure 25-111 Changes in nitrate at Potato Point in the scenario changing Sac Regional N-constituents. 367

Figure 25-112 Nitrite concentration at RSAN037and ammonia at RSAN024 downstream of the Stockton WWTP. 368

Figure 25-113 Nitrate and nitrite concentrations at RSAN024 downstream of the Stockton WWTP. 369

Figure 25-114 Ammonia and nitrate concentrations at Potato Point downstream of the Stockton WWTP. 370

Figure 25-115 Chl-a/algae and ammonia concentrations at Point Sacramento for the Sac Regional Nitrification scenario. 371

Figure 25-116 Nitrite and nitrate concentrations at Point Sacramento for the Sac Regional Nitrification scenario. 372

Figure 25-117 DO and Chl-a/algae concentrations at Confluence-3 for the Sac Regional Nitrification scenario 373

Figure 25-118 Ammonia and nitrite concentrations at Confluence3 for the Sac Regional Nitrification scenario 374

Figure 25-119 Nitrate concentration at Confluence3 for the Sac Regional Nitrification scenario. 375

Figure 25-120 Nitrate concentration at Jersey Point for the Sac Regional Nitrification scenario. 375

Figure 25-121 DO and Chl-a/algae concentrations at Jersey Point for the Sac Regional Nitrification scenario 376

Figure 25-122 Ammonia and nitrite concentrations at Jersey Point for the Sac Regional Nitrification scenario. 377

Figure 25-123 Ammonia and nitrate concentration at Suisun Nichols for the Sac Regional Nitrification scenario. 378

Figure 25-124 Chl-a/algae and DO concentrations at Suisun Nichols for the Sac Regional Nitrification scenario. 379

Figure 25-125 Nitrite concentration at Suisun Nichols for the Sac Regional Nitrification scenario. 380

Figure 25-126 Nitrite concentration at Potato Point for the Sac Regional Nitrification scenario. 380

Figure 25-127 DO and chl-a/algae concentrations at Potato Point for the Sac Regional Nitrification scenario. 381

Figure 25-128 Nitrate and ammonia concentration at Potato Point for the Sac Regional Nitrification scenario. 382

Figure 25-129 Finite element mesh of San Francisco Bay and Delta. 385

Figure 25-130 Finite element mesh in the vicinity of Suisun Bay and the western and central Delta, with the CCCSD effluent outfall location indicated in red. 386

Figure 25-131RMA2/RMA11 Bay-Delta network used to examine effect of Martinez water quality boundary condition location. 387

Figure 25-132 Finite element mesh in the vicinity of the CCCSD outfall. Expanded view shows outfall element in red.....388

Figure 25-133 Model bathymetry contours.....389

Figure 25-134 Model bathymetry contours in the vicinity of the CCCSD outfall. 390

Figure 25-135 Concentration contours for a non-conservative tracer (λ = 1/day) at maximum ebb (top) and maximum flood (bottom), after one week of simulation.....394

Figure 25-136 Concentration contours for a non-conservative tracer (λ = 1/day) at time of maximum ebb (Aug 23, 2002 @ 16:30) for a zero concentration boundary condition at the Golden Gate (top) vs. Martinez. 395

Figure 25-137 Concentration contours for a conservative tracer at time of maximum ebb (Aug 23, 2002 @ 16:30) with a zero concentration boundary condition at the Golden Gate (top) vs. Martinez.....396

Figure 25-138 Tracer mass time series for the non-conservative CCCSD tracer (λ = 1/day). Blue line is tracer mass in the entire Bay-Delta network, red is the "Delta Only" tracer mass (upstream of Martinez), green is the "Mtz BC=0" tracer mass with a zero concentration boundary at Martinez.....397

Figure 25-139 Tracer mass time series for the conservative CCCSD tracer (no decay. Blue is the tracer mass in the entire Bay-Delta network, red is the "Delta Only" tracer mass (upstream of the Martinez), green is the "Mtz BC=0" tracer mass with a zero concentration boundary at Martinez. 398

Figure 25-140 Comparison of Godin-filtered non-conservative tracer mass for three RMA11 simulations, shows that a significant amount of CCSD outfall mass and thus from all locations near the Martinez boundary, is lost under the standard DSM2 boundary condition settings.....399

Figure 25-141. (top) Times series plots of ("Mtz BC=0")/("Delta Only") tracer mass for conservative and non-conservative CCCSD tracers. (bottom) Stage time series at the CCCSD discharge location. 400

Figure 25-142 Tracer mass time series for the non-conservative CCCSD tracer (λ = 1/day). The NDO is 11,000 to 16,000 cfs over the simulation period.....401

Figure 25-143 Tracer mass time series for the conservative CCCSD tracer (no decay). The NDO is 11,000 to 16,000 cfs over the simulation period. 402

Figure 25-144 Times series plots of ("Mtz BC=0")/("Delta Only") tracer mass for the conservative and non-conservative CCCSD tracers. The NDO is 11,000 to 16,000 cfs over the simulation period. 403

Figure 26-1 Modeled algae/chl-a calibration results at Antioch – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 404

Figure 26-2 Modeled algae/chl-a calibration results at SJR Buckley Cove – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 405

Figure 26-3Modeled algae/chl-a calibration results at Chipps– data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 406

Figure 26-4 Modeled algae/chl-a calibration results at Disappointment Sl. – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 407

Figure 26-5 Modeled algae/chl-a calibration results at Emmaton – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 408

Figure 26-6 Modeled algae/chl-a calibration results at Greens-Hood – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 409

Figure 26-7 Modeled algae/chl-a calibration results at Grizzly Bay – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 410

Figure 26-8 Modeled algae/chl-a calibration results at Mallard-RSAC075 – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 411

Figure 26-9 Modeled algae/chl-a calibration results at Martinez – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.....412

Figure 26-10 Modeled algae/chl-a calibration results at Montezuma Sl. Bend 2– data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 413

Figure 26-11 Modeled algae/chl-a calibration results at Old R. at Rancho Del Rio – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 414

Figure 26-12 Modeled algae/chl-a calibration results at Pittsburg-RSAC077 – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 415

Figure 26-13 Modeled algae/chl-a calibration results at Potato Pt. – data points are located at blue symbols; monthly modeled maximum and minimum are denoted by solid red lines. 416

Figure 26-14 Modeled algae/chl-a calibration results at Pt. Sacramento – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 417

Figure 26-15 Modeled algae/chl-a calibration results at Rio Vista – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.....418

Figure 26-16 Modeled algae/chl-a calibration results at Roe Island – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 419

Figure 26-17 Modeled algae/chl-a calibration results at Stockton-RSAN063 – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 420

Figure 26-18 Modeled algae/chl-a calibration results at Suisun-Nichols – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 421

Figure 26-19 Modeled algae/chl-a calibration results at Suisun-Volanti – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 422

Figure 26-20 Modeled algae/chl-a calibration results at Twitchell – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.....423

Figure 26-21 Modeled algae/chl-a calibration results at Russo – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.....424

Figure 26-22 Modeled dissolved oxygen calibration results at Antioch – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 425

Figure 26-23 Modeled dissolved oxygen calibration results at SJR Buckley Cove –data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 426

Figure 26-24 Modeled dissolved oxygen calibration results at Chipps – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 427

Figure 26-25 Modeled dissolved oxygen calibration results at Disappointment Sl. – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 428

Figure 26-26 Modeled dissolved oxygen calibration results at Emmaton – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 429

Figure 26-27 Modeled dissolved oxygen calibration results at Greens-Hood – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 430

Figure 26-28 Modeled dissolved oxygen calibration results at Grizzly Bay – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 431

Figure 26-29 Modeled dissolved oxygen calibration results at Little Potato Sl. at Terminous – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 432

Figure 26-30 Modeled dissolved oxygen calibration results at Martinez – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 433

Figure 26-31 Modeled dissolved oxygen calibration results at Montezuma Sl. Bend 2 – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 434

Figure 26-32 Modeled dissolved oxygen calibration results at Old R. at Rancho Del Rio – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 435

Figure 26-33 Modeled dissolved oxygen calibration results at Potato Pt – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 436

Figure 26-34 Modeled dissolved oxygen calibration results at Pittsburg-RSAC077– data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 437

Figure 26-35 Modeled dissolved oxygen calibration results at Pt. Sacramento – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 438

Figure 26-36 Modeled dissolved oxygen calibration results at Rio Vista – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 439

Figure 26-37 Modeled dissolved oxygen calibration results at Roe Island –data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 440

Figure 26-38 Modeled dissolved oxygen calibration results at Suisun-Nichols – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 441

Figure 26-39 Modeled dissolved oxygen calibration results at Suisun-Volanti – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 442

Figure 26-40 Modeled dissolved oxygen calibration results at Twitchell – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 443

Figure 26-41 Modeled dissolved oxygen calibration results at Russo – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 444

Figure 26-42 NH_3 calibration results at SJR Buckley Cove – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.....445

Figure 26-43 NH_3 calibration results at Disappointment Sl. – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.....446

Figure 26-44 NH_3 calibration results at Greens-Hood – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 447

Figure 26-45 NH_3 calibration results at Grizzly Bay – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 448

Figure 26-46 NH_3 calibration results at Martinez – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 449

Figure 26-47 NH_3 calibration results at Old R. at Rancho Del Rio – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 450

Figure 26-48 NH_3 calibration results at Potato Pt. – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 451

Figure 26-49 NH_3 calibration results at Pt. Sacramento – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 452

Figure 26-50 NH_3 calibration results at Suisun-Nichols – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 453

Figure 26-51 NH_3 calibration results at Russo – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 454

Figure 26-52 $NO_3 + NO_2$ calibration results at SJR Buckley Cove – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 455

Figure 26-53 $NO_3 + NO_2$ calibration results at Disappointment Sl. – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 456

Figure 26-54 NO_3 + NO_2 calibration results at Greens-Hood – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 457

Figure 26-55 NO_3 + NO_2 calibration results at Grizzly Bay – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 458

Figure 26-56 NO_3 + NO_2 calibration results at Martinez – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 459

Figure 26-57 NO_3 + NO_2 calibration results at Old R. at Rancho Del Rio – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 460

Figure 26-58NO_3 + NO_2 calibration results at Old R. at RSAC077-Pittsburg – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines 461

Figure 26-59 NO_3 + NO_2 calibration results at Potato Pt. – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 462

Figure 26-60 NO_3 + NO_2 calibration results at Pt. Sacramento – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 463

Figure 26-61 NO_3 + NO_2 calibration results at Rio Vista – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 464

Figure 26-62 NO_3 + NO_2 calibration results at Roe Island – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 465

Figure 26-63 NO_3 + NO_2 calibration results at Suisun-Nichols – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 466

Figure 26-64NO_3 + NO_2 calibration results at Russo – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 467

Figure 26-65 Organic-N calibration results at SJR Buckley Cove – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 468

Figure 26-66 Organic-N calibration results at Disappointment Sl. – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 469

Figure 26-67 Organic-N calibration results at Greens-Hood – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 470

Figure 26-68 Organic-N calibration results at Grizzly Bay – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 471

Figure 26-69 Organic-N calibration results at Martinez – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 472

Figure 26-70 Organic-N calibration results at Old R. at Rancho Del Rio – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 473

Figure 26-71 Organic-N calibration results at Potato Pt. – data points are located at blue symbols; monthly modeled maximum and minimum are denoted by solid red lines.....474

Figure 26-72 Organic-N calibration results at Pt. Sacramento – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.....475

Figure 26-73 Organic-N calibration results at Suisun-Nichols – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.....476

Figure 26-74Organic-N calibration results at Russo – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines 477

Figure 26-75 Modeled PO_4 calibration results at SJR Buckley Cove – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 478

Figure 26-76 Modeled PO_4 calibration results at Disappointment Sl. – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 479

Figure 26-77 Modeled PO_4 calibration results at Greens-Hood – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.....480

Figure 26-78 Modeled PO_4 calibration results at Grizzly Bay – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.....481

Figure 26-79 Modeled PO_4 calibration results at Martinez – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.....482

Figure 26-80 Modeled PO_4 calibration results at Old R. at Rancho Del Rio – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 483

Figure 26-81 Modeled PO_4 calibration results at Potato Pt. – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.....484

Figure 26-82 Modeled PO_4 calibration results at Pt. Sacramento – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.....485

Figure 26-83 Modeled PO_4 calibration results at Suisun-Nichols – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.....486

Figure 26-84Modeled PO_4 calibration results at Russo – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines. 487

Figure 27-1Comparison of data and the 95%, 90%, 80% and 75% envelope max/min widths for Algae/chl-a at Twitchell. 490

Figure 27-2Comparison of data and the 95%, 90%, 80% and 75% envelope max/min widths for DO at Twitchell.....502

Figure 27-3Comparison of data and the 95%, 90%, 80% and 75% envelope max/min widths for NH3 at Pt. Sacramento. 514

Figure 27-4Comparison of data and the 90% and 80% envelope max/min widths for NO_3+NO_2at Pt. Sacramento. 520

Figure 27-5Comparison of data and the 90% and 80% envelope max/min widths for organic-N at Pt. Sacramento. 528

Figure 27-6Comparison of data and the 90% and 80% envelope max/min widths for PO_4 at Pt. Sacramento. 533

Figure 28-1 Calibration/validation statistics for Algae at Antioch. Upper figure is calibration & validation statistics for dry years; lower figure is calibration &validation statistics for wet years. 537

Figure 28-2 Calibration/validation statistics for Algae at Buckley Cove. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 538

Figure 28-3 Calibration/validation statistics for Algae at Chipps. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 539

Figure 28-4 Calibration/validation statistics for Algae at Disappointment Sl. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 540

Figure 28-5 Calibration/validation statistics for Algae at Emmaton. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 541

Figure 28-6 Calibration/validation statistics for Algae at Greens-Hood. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 542

Figure 28-7 Calibration/validation statistics for Algae at Grizzly Bay. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 543

Figure 28-8 Calibration/validation statistics for Algae at Mallard-RSAC075. Upper figure is calibration & validation statistics for dry years, Validation for Dry Years (2007, 2008) missing due to lack of data; lower figure is calibration & validation statistics for wet years. 544

Figure 28-9 Calibration/validation statistics for Algae at Martinez. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 545

Figure 28-10 Calibration/validation statistics for Algae at Montezuma Sl. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 546

Figure 28-11 Calibration/validation statistics for Algae at Old R. Rancho Del Rio. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 547

Figure 28-12 Calibration/validation statistics for Algae at Pittsburg, RSAC077. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 548

Figure 28-13 Calibration/validation statistics for Algae at Potato Pt. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 549

Figure 28-14 Calibration/validation statistics for Algae at Pt. Sacramento. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 550

Figure 28-15Calibration/validation statistics for Algae at Rio Vista. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 551

Figure 28-16 Calibration/validation statistics for Algae at Roe Island. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 552

Figure 28-17 Calibration/validation statistics for Algae at Stockton-RSAN063. Upper figure is calibration & validation statistics for dry years, Validation for Dry Years (2007, 2008) is missing due to lack of data; lower figure is calibration & validation statistics for wet years. 553

Figure 28-18 Calibration/validation statistics for Suisun-Nichols. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 554

Figure 28-19 Calibration/validation statistics for Algae at Suisun-Volanti. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 555

Figure 28-20 Calibration/validation statistics for Algae at Twitchell. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 556

Figure 28-21 (intentionally left blank) Insufficient data to calculate calibration statistics for Russo. 556

Figure 28-22 Calibration/validation statistics for DO at Antioch. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 557

Figure 28-23 Calibration/validation statistics for DO at Buckley Cove. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 558

Figure 28-24 Calibration/validation statistics for DO at Chipps. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 559

Figure 28-25 Calibration/validation statistics for DO at Disappointment Sl. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 560

Figure 28-26 Calibration/validation statistics for DO at Emmaton. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 561

Figure 28-27 Calibration/validation statistics for DO at Greens-Hood. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 562

Figure 28-28 Calibration/validation statistics for DO at Grizzly Bay. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 563

Figure 28-29 Calibration/validation statistics for DO at Little Potato Sl. at Terminous. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. Validation for Dry Years missing due to lack of data. 564

Figure 28-30 Calibration/validation statistics for DO at Martinez. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 565

Figure 28-31 Calibration/validation statistics for DO at Montezuma Sl. Bend 2. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 566

Figure 28-32 Calibration/validation statistics for DO at Old R. Rancho Del Rio. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 567

Figure 28-33 Calibration/validation statistics for DO at Potato Pt. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 568

Figure 28-34 Calibration/validation statistics for DO at Pittsburg-RSAC077. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 569

Figure 28-35 Calibration/validation statistics for DO at Pt. Sacramento. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 570

Figure 28-36 Calibration/validation statistics for DO at Rio Vista. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 571

Figure 28-37 Calibration/validation statistics for DO at Roe Island. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 572

Figure 28-38 Calibration/validation statistics for DO at Suisun-Nichols. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 573

Figure 28-39 Calibration/validation statistics for DO at Suisun-Volanti. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 574

Figure 28-40 Calibration/validation statistics for DO at Twitchell. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 575

Figure 28-41 (Intentionally left blank) Insufficient data at Russo to calculate calibration statistics. 575

Figure 28-42 Calibration/validation statistics for NH3 at Buckley Cove. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 576

Figure 28-43 Calibration/validation statistics for NH3 at Disappointment Sl. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 577

Figure 28-44 Calibration/validation statistics for NH3 at Greens-Hood. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 578

Figure 28-45 Calibration/validation statistics for NH3 at Grizzly Bay. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 579

Figure 28-46 Calibration/validation statistics for NH3 at Martinez. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 580

Figure 28-47 Calibration/validation statistics for NH3 at Old R. at Rancho Del Rio. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 581

Figure 28-48 Calibration/validation statistics for NH3 at Potato Pt. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 582

Figure 28-49 Calibration/validation statistics for NH3 at Pt. Sacramento. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 583

Figure 28-50 Calibration/validation statistics for NH3 at Suisun-Nichols. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 584

Figure 28-51 (Intentionally left blank) Insufficient data at Russo to calculate calibration statistics. 584

Figure 28-52 Calibration/validation statistics for NO3+NO2 at Buckley Cove. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 585

Figure 28-53 Calibration/validation statistics for NO3+NO2 at Disappointment Sl. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 586

Figure 28-54 Calibration/validation statistics for NO3+NO2 at Greens-Hood. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 587

Figure 28-55 Calibration/validation statistics for NO3+NO2 at Grizzly Bay. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 588

Figure 28-56 Calibration/validation statistics for NO3+NO2 at Martinez. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 589

Figure 28-57 Calibration/validation statistics for NO3+NO2 at Old R. at Rancho Del Rio. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 590

Figure 28-58 Calibration/validation statistics for NO3+NO2 at Pittsburg,-RSAC077. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 591

Figure 28-59 Calibration/validation statistics for NO3+NO2 at Potato Pt. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 592

Figure 28-60 Calibration/validation statistics for NO3+NO2 at Pt. Sacramento. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 593

Figure 28-61 Calibration/validation statistics for NO3+NO2 at Rio Vista. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 594

Figure 28-62 Calibration/validation statistics for NO3+NO2 at Roe Island. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 595

Figure 28-63 Calibration/validation statistics for NO3+NO2 at Suisun-Nichols. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 596

Figure 28-64 (Intentionally left blank) Insufficient data for Russo to calculate calibration statistics. 596

Figure 28-65 Calibration/validation statistics for Organic N at Buckley Cove. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 597

Figure 28-66 Calibration/validation statistics for Organic N at Disappointment Sl. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 598

Figure 28-67 Calibration/validation statistics for Organic N at Greens-Hood. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 599

Figure 28-68 Calibration/validation statistics for Organic N at Grizzly Bay. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 600

Figure 28-69 Calibration/validation statistics for Organic N at Martinez. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 601

Figure 28-70 Calibration/validation statistics for Organic N at Old R. at Rancho Del Rio. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 602

Figure 28-71 Calibration/validation statistics for Organic N at Potato Pt. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 603

Figure 28-72 Calibration/validation statistics for Organic N at Pt. Sacramento. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 604

Figure 28-73 Calibration/validation statistics for Organic N at Suisun-Nichols. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 605

Figure 28-74 (Intentionally left blank) Insufficient data to Russo calculate calibration statistics. 605

Figure 28-75 Calibration/validation statistics for PO4 at Buckley Cove. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 606

Figure 28-76Calibration/validation statistics for PO4 at Disappointment Sl. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 607

Figure 28-77 Calibration/validation statistics for PO4 at Greens-Hood. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 608

Figure 28-78 Calibration/validation statistics for PO4 at Grizzly Bay. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 609

Figure 28-79 Calibration/validation statistics for PO4 at Martinez. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 610

Figure 28-80 Calibration/validation statistics for PO4 at Old R. Rancho Del Rio. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 611

Figure 28-81 Calibration/validation statistics for PO4 at Potato Pt. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 612

Figure 28-82 Calibration/validation statistics for PO4 at Pt. Sacramento. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 613

Figure 28-83 Calibration/validation statistics for PO4 at Suisun-Nichols. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. 614

Figure 28-84 (Intentionally left blank) Insufficient data at Russo to calculate calibration statistics. 614

TABLES

Table 5-1 Definitions for variables appearing in equations 1 – 10. 27

Table 5-2 Parameters used in the model. Some parameters do not appear explicitly in the equations as discussed in this report. 34

Table 5-3 Model parameters, continued. Some parameters do not appear explicitly in the equations as discussed in this report. 35

Table 8-1 Metadata for the EMP-DWR measurements. 71

Table 8-2Meteorological data – the difference between CIMIS and NOAA measurements, such as measurement height above ground, timing (instantaneous vs. average). 72

Table 9-1 Details on effluent water temperature settings. The Time column indicates the frequency of time series, and the Source column indicates the identity of the data source. 89

Table 9-2 Detail on nutrient model boundary conditions for the DSM2 Version 8.0.6 2000 -2008 calibration. The Time column indicates the frequency of time series, and the Other column indicates additional information. 90

Table 9-3 More detail on nutrient model boundary conditions for the DSM2 Version 8.0.6 2000 - 2008 calibration. . The Time column indicates the frequency of time series, and the Other column indicates additional information. 91

Table 9-4 DICU constant concentration boundary conditions for the nutrient model (all units in mg L^{-1}). 92

Table 9-5 Effluent boundary condition detail for Stockton, Sac Regional, Central Contra Costa Sanitary District (CCSD), and Delta Diablo. The Time column indicates the frequency of time series, and the Source/Other column indicates additional information. 93

Table 9-6 More effluent boundary condition detail for Discovery Bay, Fairfield-Suisun, Lodi, and Manteca. The Time column indicates the frequency of time series, and the Source/Other column indicates additional information. 94

Table 9-7 Even more effluent boundary condition detail for Mountain House, Martinez+ Tesoro, Tracy and Valero. The Time column indicates the frequency of time series, and the Source/Other column indicates additional information. 95

Table 12-1 Comparison of Calibration and Validation statistics for Critically Dry Water Years. 108

Table 12-2 Comparison of Calibration and Validation statistics for Dry Water Years. 109

Table 12-3 Comparison of Calibration and validation statistics for Above Normal Water Years. 110

Table 12-4 Comparison of Calibration and validation statistics for Wet Water Years. 111

Table 12-5 Calibration statistics for the Below Normal water Year 2004. 111

Table 12-6 Categories used to rate the quality of the nutrient calibration/validation. 150

Table 12-7 Specification of calibration and validation years by Wet and Dry Water Year types for the 2000 – 2008 calibration. 150

Table 12-8 Calibration/Validation results for NH_3 and NO_3+NO_2: VG=Very Good, G=Good, SAT=Satisfactory and U=Unsatisfactory, in red font 151

Table 12-9 Calibration/Validation results for Org-N and DO: VG=Very Good, G=Good, SAT=Satisfactory and U=Unsatisfactory, in red font. 152

Table 12-10 Calibration/Validation results for Chl-a/Algae andPO_4: VG=Very Good, G=Good, SAT=Satisfactory and U=Unsatisfactory, in red font. 153

Table 12-11 Calibration and validation statistics for DO (100%, QUAL Version 8.0.6). 154

Table 12-12 Calibration and validation statistics for Algae/chl-a (100%, QUAL Version 8.0.6) 155

Table 12-13 Calibration and validation statistics for NH3 (100%, QUAL Version 8.0.6). 156

Table 12-14 Calibration and validation statistics for NO3+NO2 (100%, QUAL Version 8.0.6). 156

Table 12-15 Calibration and validation statistics for organic-N (100%, QUAL Version 8.0.6). 157

Table 12-16 Calibration and validation statistics for PO4, orthophosphate (100%, QUAL Version 8.0.6) 157

Table 12-17Calibration and validation statistics for DO (80% QUAL Version 8.0.6). 158

Table 12-18 Calibration and validation statistics for Algae/chl-a (80% QUAL Version 8.0.6). 159

Table 12-19 Calibration and validation statistics for NH3 (80% QUAL Version 8.0.6). 160

Table 12-20 Calibration and validation statistics for NO3+NO2 (80% QUAL Version 8.0.6). .160

Table 12-21 Calibration and validation statistics for Organic-N (80% QUAL Version 8.0.6)...161

Table 12-22 Calibration and validation statistics for PO4, orthophosphate (80% QUAL Version 8.0.6).....161

Table 13-1 Volumetric fingerprinting source names. 165

Table 16-1Average monthly percent change from Base Historical model (+/- 20% change in DICU N-constituents). Symbols + or – used for increase or decrease, respectively, when numerical changes were too small to record. 183

Table 16-2Average monthly percent change from Base Historical model (+/- 20% change in Sacramento boundary N-constituents) 184

Table 16-3 Average monthly percent change from Base Historical model (+/- 20% change in San Joaquin boundary N-constituents). Symbols + or – used for increase or decrease, respectively, when numerical changes were too small to record. 185

Table 16-4Averagemonthly percent change from Base Historical model (+/- 20 % change in Sac Regional effluent N-constituents) 186

Table 16-5Averagemonthly percent change from Base Historical model (+/- 20% change in Stockton WWTP N-constituents). Symbols + or – used for increase or decrease, respectively, when numerical changes were too small to record. 187

Table 17-1 Results from nitrification scenarios at RSAC101 (chl-a/algae and ammonia). 190

Table 17-2 Results from nitrification scenarios at RSAC101 (nitrate and nitrite). 191

Table 17-3 Results from nitrification scenarios at Pt. Sacramento (chl-a/algae and ammonia). 192

Table 17-4 Results from nitrification scenarios at Pt. Sacramento (nitrate and nitrite).....193

Table 17-5 Results from nitrification scenarios at Jersey Point (chl-a/algae and ammonia). 194

Table 17-6 Results from nitrification scenarios at Jersey Point (nitrate and nitrite). 195

Table 21-1 Basic temporal measurement scheme for the current nutrient model. 229

Table 25-1 Data source naming conventions. 244

Table 25-2 Data sources for effluent data and in-Delta measurements. 245

Table 25-3 Nutrient data obtained from BDAT (#1) 261

Table 25-4 Nutrient data obtained from BDAT (#2) 262

Table 25-5 Nutrient data from BDAT (#3) 263

Table 25-6 Sacramento Regional WWTP receiving water data at the Freeport location from 2004 – 2008. *Italic fon*t indicates the measurement was at the instrument detection limit. 264

Table 25-7 Sacramento Regional WWTP receiving water data at the RM 44 (River Mile 44) location from 2004 – 2008. *Italic fon*t indicates the measurement was at the instrument detection limit. 265

Table 25-8 Availability of measurements for seven WWTPs in the DSM2 model domain 283

Table 25-9 Availability of measurements from the other WWTP's with effluent reaching the Delta. Vacaville, Davis and Woodland were not considered in this model. Benicia outfall is downstream of the model boundary. 284

Table 25-10Average Solution Chemistry Used as Input for in Speciation Modeling 304

Table 25-11 EQ3/6 Speciation Results 305

Table 26-1 Model calibration/validation statistics at Antioch for algae/chl-a for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 404

Table 26-2 Model calibration/validation statistics at SJR Buckley Cove for algae/chl-a for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 405

Table 26-3 Model calibration/validation statistics at Chipps for algae/chl-a for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 406

Table 26-4 Model calibration/validation statistics at Disappointment Sl. for algae/chl-a for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 407

Table 26-5 Model calibration/validation statistics at Emmaton for algae/chl-a for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 408

Table 26-6 Model calibration/validation statistics at Greens-Hood for algae/chl-a for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 409

Table 26-7 Model calibration/validation statistics at Grizzly Bay for algae/chl-a for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 410

Table 26-8 Model calibration/validation statistics at Mallard-RSAC075 for algae/chl-a for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years Wet Years (2005, 2006), Validation for Dry Years (2007, 2008) missing due to lack of data. 411

Table 26-9 Model calibration/validation statistics at Martinez for algae/chl-a for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 412

Table 26-10 Model calibration/validation statistics at Montezuma Sl. for algae/chl-a for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 413

Table 26-11 Model calibration/validation statistics at Old R. at Rancho Del Rio for algae/chl-a for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 414

Table 26-12 Model calibration/validation statistics at Pittsburg-RSAC077 for algae/chl-a for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 415

Table 26-13 Model calibration/validation statistics at Potato Pt. for algae/chl-a for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 416

Table 26-14 Model calibration/validation statistics at Pt. Sacramento for algae/chl-a for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 417

Table 26-15 Model calibration/validation statistics at Rio Vista for algae/chl-a for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 418

Table 26-16 Model calibration/validation statistics at Roe Island for algae/chl-a for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 419

Table 26-17 Model calibration/validation statistics at Stockton-RSAN063 for algae/chl-a for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Wet Years (2005, 2006). Validation for Dry Years (2007, 2008) is missing due to lack of data. 420

Table 26-18 Model calibration/validation statistics at Suisun-Nichols for algae/chl-a for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 421

Table 26-19 Model calibration/validation statistics at Suisun-Volanti for algae/chl-a for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 422

Table 26-20 Model calibration/validation statistics at Twitchell for algae/chl-a for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 423

Table 26-21 (intentionally left blank) Insufficient data to calculate calibration statistics. 424

Table 26-22 Model calibration/validation statistics at Antioch for dissolved oxygen for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 425

Table 26-23 Model calibration/validation statistics at SJR Buckley Cove for dissolved oxygen for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 426

Table 26-24 Model calibration/validation statistics at Chipps for dissolved oxygen for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 427

Table 26-25 Model calibration/validation statistics at Disappointment Sl. for dissolved oxygen for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for DryYears (2007, 2008) and Wet Years (2005, 2006). 428

Table 26-26 Model calibration/validation statistics at Emmaton for dissolved oxygen for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 429

Table 26-27 Model calibration/validation statistics at Greens-Hood for dissolved oxygen for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 430

Table 26-28 Model calibration/validation statistics at Grizzly Bay for dissolved oxygen for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 431

Table 26-29 Model calibration/validation statistics at Little Potato Sl. at Terminous for dissolved oxygen for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation Wet Years (2005, 2006). Validation for Dry Years (2007, 2008) missing due to lack of data. 432

Table 26-30 Model calibration/validation statistics at Martinez for dissolved oxygen for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 433

Table 26-31 Model calibration/validation statistics at Montezuma Sl. Bend 2 for dissolved oxygen for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 434

Table 26-32 Model calibration/validation statistics at Old R. at Rancho Del Rio for dissolved oxygen for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 435

Table 26-33 Model calibration/validation statistics at Potato Pt for dissolved oxygen for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 436

Table 26-34 Model calibration/validation statistics at Pittsburg-RSAC077 for dissolved oxygen for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 437

Table 26-35 Model calibration/validation statistics at Pt. Sacramento for dissolved oxygen for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 438

Table 26-36 Model calibration/validation statistics at Rio Vista for dissolved oxygen for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 439

Table 26-37 Model calibration/validation statistics at Roe Island for dissolved oxygen for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 440

Table 26-38 Model calibration/validation statistics at Suisun-Nichols for dissolved oxygen for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 441

Table 26-39 Model calibration/validation statistics at Suisun-Volanti for dissolved oxygen for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 442

Table 26-40 Model calibration/validation statistics at Twitchell for dissolved oxygen for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 443

Table 26-41 (Intentionally left blank) Insufficient data to calculate calibration statistics. 444

Table 26-42 Model calibration/validation statistics at SJR Buckley Cove for $NH_3$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 445

Table 26-43 Model calibration/validation statistics at Disappointment Sl. for $NH_3$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 446

Table 26-44 Model calibration/validation statistics at Greens-Hood for $NH_3$for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 447

Table 26-45 Model calibration/validation statistics at Grizzly Bay for $NH_3$for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 448

Table 26-46 Model calibration/validation statistics at Martinez for $NH_3$for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 449

Table 26-47 Model calibration/validation statistics at Old R. at Rancho Del Rio for $NH_3$for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 450

Table 26-48 Model calibration/validation statistics at Potato Pt. for $NH_3$for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 451

Table 26-49 Model calibration/validation statistics at Pt. Sacramento for $NH_3$for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 452

Table 26-50 Model calibration/validation statistics at Suisun-Nichols for $NH_3$for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 453

Table 26-51 (Intentionally left blank) Insufficient data to calculate calibration statistics. 454

Table 26-52 Model calibration/validation statistics at SJR Buckley Cove for $NO_3 + NO_2$for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 455

Table 26-53 Model calibration/validation statistics at Disappointment Sl. for $NO_3 + NO_2$for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 456

Table 26-54 Model calibration/validation statistics at Greens-Hood for $NO_3 + NO_2$for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 457

Table 26-55 Model calibration/validation statistics at Grizzly Bay for NO_3 + $NO_2$for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 458

Table 26-56 Model calibration/validation statistics at Martinez for NO_3 + $NO_2$for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 459

Table 26-57 Model calibration/validation statistics at Old R. at Rancho Del Rio for NO_3 + $NO_2$for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 460

Table 26-58Model calibration/validation statistics at RSAC077-Pittsburg for NO_3 + $NO_2$for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 461

Table 26-59 Model calibration/validation statistics at Potato Pt. for NO_3 + $NO_2$for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 462

Table 26-60 Model calibration/validation statistics at Pt. Sacramento for NO_3 + $NO_2$for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 463

Table 26-61 Model calibration/validation statistics at Rio Vista for NO_3 + $NO_2$for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 464

Table 26-62 Model calibration/validation statistics at Roe Island for NO_3 + $NO_2$for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 465

Table 26-63 Model calibration/validation statistics at Suisun-Nichols for NO_3 + NO_2f or the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 466

Table 26-64 (Intentionally left blank) Insufficient data to calculate calibration statistics. 467

Table 26-65 Model calibration/validation statistics at SJR Buckley Cove for Organic-N for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 468

Table 26-66 Model calibration/validation statistics at Disappointment Sl. for Organic-N for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 469

Table 26-67 Model calibration/validation statistics at Greens-Hood for Organic-N for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 470

Table 26-68 Model calibration/validation statistics at Grizzly Bay for Organic-N for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 471

Table 26-69 Model calibration/validation statistics at Martinez for Organic-N for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 472

Table 26-70 Model calibration/validation statistics at Old R. at Rancho Del Rio for Organic-N for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 473

Table 26-71 Model calibration/validation statistics at Potato Pt. for Organic-N for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 474

Table 26-72 Model calibration/validation statistics at Pt. Sacramento for Organic-N for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 475

Table 26-73 Model calibration/validation statistics at Suisun-Nichols for Organic-N for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 476

Table 26-74 (Intentionally left blank) Insufficient data to calculate calibration statistics. 477

Table 26-75 Model calibration/validation statistics at SJR Buckley Cove for $PO_4$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 478

Table 26-76 Model calibration/validation statistics at Disappointment Sl. for $PO_4$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 479

Table 26-77 Model calibration/validation statistics at Greens-Hood for $PO_4$for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 480

Table 26-78 Model calibration/validation statistics at Grizzly Bay for $PO_4$for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 481

Table 26-79 Model calibration/validation statistics at Martinez for $PO_4$for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 482

Table 26-80 Model calibration/validation statistics at Old R. at Rancho Del Rio for $PO_4$for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 483

Table 26-81 Model calibration/validation statistics at Potato Pt. for $PO_4$for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 484

Table 26-82 Model calibration/validation statistics at Pt. Sacramento for $PO_4$for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 485

Table 26-83 Model calibration/validation statistics at Suisun-Nichols for $PO_4$for the entire modeled period (“All”); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006). 486

Table 26-84 (Intentionally left blank) Insufficient data to calculate calibration statistics. 487

Table 27-1Categorical statistics for several envelope ranges at Greens-Hood (left) and Pt. Sacramento (right). Colors indicate change from the 100% envelope range. 491

Table 27-2 Categorical statistics for several envelope ranges at Potato Point (left) and Old River at Rancho del Rio (right). Colors indicate change from the 100% envelope range. 492

Table 27-3 Categorical statistics for several envelope ranges at SJR Buckley Cove (left) and Disappointment Sl. (right). Colors indicate change from the 100% envelope range. 493

Table 27-4 Categorical statistics for several envelope ranges at Montezuma Sl. (left) and Suisun-Volanti (right). Colors indicate change from the 100% envelope range. 494

Table 27-5 Categorical statistics for several envelope ranges at Suisun-Nichols (left) and Grizzly Bay (right). Colors indicate change from the 100% envelope range. 495

Table 27-6 Categorical statistics for several envelope ranges at Twitchell (left) and Rio Vista (right). Colors indicate change from the 100% envelope range. 496

Table 27-7 Categorical statistics for several envelope ranges at Chipps (left) and RSAC077-Pittsburg (right). Colors indicate change from the 100% envelope range. 497

Table 27-8 Categorical statistics for several envelope ranges at Antioch (left) and Emmaton (right). Colors indicate change from the 100% envelope range. 498

Table 27-9 Categorical statistics for several envelope ranges at RSAC075-Mallard (left) and RSAC063-Stockton (right). Colors indicate change from the 100% envelope range. 499

Table 27-10 Categorical statistics for several envelope ranges at RSAC054-Martinez (left) and Roe Island (right). Colors indicate change from the 100% envelope range.....500

Table 27-11 Categorical statistics for several envelope ranges at Greens-Hood (left) and Pt. Sacramento (right). Colors indicate change from the 100% envelope range. 503

Table 27-12 Categorical statistics for several envelope ranges at Potato Pt. (left) and Old River at Rancho del Rio (right). Colors indicate change from the 100% envelope range. 504

Table 27-13 Categorical statistics for several envelope ranges at Twitchell (left) and Rio Vista (right). Colors indicate change from the 100% envelope range. 505

Table 27-14 Categorical statistics for several envelope ranges at Chipps (left) and RSAC077-Pittsburg (right). Colors indicate change from the 100% envelope range. 506

Table 27-15 Categorical statistics for several envelope ranges at RSAC054-Martinez. Colors indicate change from the 100% envelope range. 507

Table 27-16 Categorical statistics for several envelope ranges at SJR Buckley Cove (left) and Disappointment Sl. (right). Colors indicate change from the 100% envelope range.....508

Table 27-17 Categorical statistics for several envelope ranges at Montezuma Sl. (left) and Suisun-Volanti (right). Colors indicate change from the 100% envelope range.....509

Table 27-18 Categorical statistics for several envelope ranges at Suisun-Nichols (left) and Grizzly Bay (right). Colors indicate change from the 100% envelope range.....510

Table 27-19 Categorical statistics for several envelope ranges at Antioch (left) and Emmaton (right). Colors indicate change from the 100% envelope range. 511

Table 27-20 Categorical statistics for several envelope ranges at Roe Island (left) and Little Potato Sl. At Terminous (right). Colors indicate change from the 100% envelope range. 512

Table 27-21 Categorical statistics for several envelope ranges at Roe Island (left) and Little Potato Sl. At Terminous (right). Colors indicate change from the 100% envelope range. 515

Table 27-22 Categorical statistics for several envelope ranges at Potato Pt. (left) and Old River at Rancho del Rio (right). Colors indicate change from the 100% envelope range. 516

Table 27-23 Categorical statistics for several envelope ranges at Suisun-Nichols (left) and Grizzly Bay (right). Colors indicate change from the 100% envelope range.....517

Table 27-24 Categorical statistics for several envelope ranges at RSAC054-Martinez. Colors indicate change from the 100% envelope range. 518

Table 27-25 Categorical statistics for several envelope ranges at Greens-Hood (left) and Pt. Sacramento (right). Colors indicate change from the 100% envelope range. 521

Table 27-26 Categorical statistics for several envelope ranges at Potato Point (left) and Old River at Rancho del Rio (right). Colors indicate change from the 100% envelope range.....522

Table 27-27 Categorical statistics for several envelope ranges at Disappointment Sl. (left) and SJR Buckley Cove (right). Colors indicate change from the 100% envelope range. 523

Table 27-28 Categorical statistics for several envelope ranges at Suisun-Nichols (left) and Grizzly (right). Colors indicate change from the 100% envelope range.....524

Table 27-29 Categorical statistics for several envelope ranges at Rio Vista (left) and RSAC077-Pittsburg (right). Colors indicate change from the 100% envelope range. 525

Table 27-30 Categorical statistics for several envelope ranges at RSAC054-Martinez (left) and Roe Island (right). Colors indicate change from the 100% envelope range.....526

Table 27-31 Categorical statistics for several envelope ranges at Green-Hoods (upper left), Potato Point (lower left), Pt. Sacramento (upper right), and Old River at Rancho del Rio (lower right). Colors indicate change from the 100% envelope range. 529

Table 27-32 Categorical statistics for several envelope ranges at SJR Buckley Cove (upper left), Grizzly (lower left), Disappointment Sl. (upper right), and Suisun-Nichols (lower right). Colors indicate change from the 100% envelope range. 530

Table 27-33 Categorical statistics for several envelope ranges at RSAC054-Martinez. Colors indicate change from the 100% envelope range. 531

Table 27-34 Categorical statistics for several envelope ranges at Green-Hoods (upper left), SJR Buckley Cove (lower left), Pt. Sacramento (upper right), and Disappointment Sl. (lower right). Colors indicate change from the 100% envelope range.....534

Table 27-35 Categorical statistics for several envelope ranges at Old River at Rancho del Rio (upper left), Grizzly Bay (lower left), Potato Pt. (upper right), and Suisun-Nichols (lower right). Colors indicate change from the 100% envelope range. 535

Table 27-36 Categorical statistics for several envelope ranges at RSAC054-Martinez. Colors indicate change from the 100% envelope range. 536

PREFACE

During the course of the revision of this document, the model grid (representing the Delta) for DSM2 was revised substantially, requiring a "mini-recalibration" of the hydrodynamics module, HYDRO, after the initial DRAFT calibration documentation was written. The DSM2-QUAL nutrient model formulation and numerical solution was also revised several times, with the changes incorporated in the current Version 8.0.6 of DSM2. As a consequence of these revisions, the QUAL nutrient model was recalibrated several times after the initial DRAFT documentation was written, creating a quandary in how to organize the final document.

To this end, three separate documents were created: (1) a stand-alone expanded Executive Summary document was created to summarize the available documentation; (2) a Main document, containing the expanded Executive Summary, the entire text written for the project, and a detailed Appendix I that includes calibration information only for the latest revision of the QUAL nutrient model (Version 8.0.6); and, (3) a separate document containing only DSM2 Version 6 nutrient model calibration information comprised of a series of appendices, Appendix II – Appendix V, containing the details of the Version 6 nutrient model calibration which are no longer relevant as Version 6 has been superseded.

This document is the Main set of documentation, which contains the expanded Executive Summary, all of the textual documentation, and Appendix I. Appendix I includes details on the most recent recalibration of the QUAL nutrient model. The Main document contains all of documentation except for the details of the calibration of the old version of DSM2, Version 6.

In addition, the set of documentation includes revisions as suggested from a limited set reviewers including a "Peer review" of the documentation (Mike Deas, Principal at Watercourse Engineering) sponsored by the State and Federal Contractors Water Agency (SFCWA) and several of the individual scientists members of the technical review committee for the original development of the model calibration.

QUAL's conceptual model for nutrient dynamics is a mixed model, with greater detail in some aspects of nutrient dynamics than in others. On the plus side, this results in a relatively simple nutrient model and, except for one constituent, there is generally at least some data available for setting or estimating boundary conditions. On the negative side, there are processes that would have been valuable to include, such as more complete representation of sediment interactions.

However, the ultimate determination of the application of the model to the Delta is data availability – this limits the useful extent of model complexity. In other words, if there is no data with which to either check the models results or to develop parameters for specific reactions, then that reaction will not increase the accuracy of the overall model results.

1 Executive Summary

Resource Management Associates (RMA) was contracted by the State Water Contractors (SWC) and the State and Federal Contractors Water Agency (SFCWA) to model nutrient dynamics in the Sacramento-San Joaquin Delta (Delta) using the Delta Simulation Model-2 (DSM2) water quality module, DSM2-QUAL (QUAL). Because of the length and complexity of the documentation for this project, the Executive Summary section has been expanded to include an extensive summary of information contained in major subsections of the Main document. This is the Main document containing detailed results, as well as the expanded executive Summary Section. The text of this Executive Summary includes information on the sections of the Main document where supporting detail is found.

1.1 Summary – Objectives and Proposed Applications (Section 2)

The main goals of the project were to: calibrate and validate QUAL for temperature and nutrients for the period 1990 – 2008[1]; develop a prioritized monitoring program to fill data gaps and improve the understanding of nutrient dynamics in the Delta; and, critique QUAL's existing nutrient and temperature model formulation and suggest improvements. As the intended applications spurring development of the QUAL nutrient model focus on ammonia dynamics along the Sacramento River, this document also has a focus on ammonia including hypothetical model scenarios and sensitivity analyses focusing on nitrogen-containing constituents (see: Discussion Section 20). However, model calibration and data-gathering efforts did not focus on any particular constituent, and each constituent represented in the conceptual model was calibrated to the extent possible given the constraints in data availability and project budget.

At present, the potential applications of the nutrient model are focused on inter-comparison of hypothetical scenarios developed with monthly boundary conditions. The source of hydrodynamic model input for these scenarios will most likely be from CalSim II. The CalSim model was developed by the California Department of Water Resources (DWR) to simulate California State Water Project (SWP) and Federal Central Valley Project (CVP) operations in planning studies that simulate operation of California's reservoirs and water delivery system. Most projects using CalSim II Planning models use a *comparative analysis* approach[2]. In this approach, the model is run twice, once with conditions representing a baseline and another time with some specific changes to assess the change in modeled outcome due to the given change in model input configuration. The assumption is that, while the model might not produce results reflecting these changes with absolute certainty, it nevertheless produces a reasonably reliable estimate of the relative change in outcome.

[1] The Version 8 implementation runs from 2000 -2008 – the superseded Version 6 implementation runs 1990 -2008.
[2] 2003, http://sacramentoriverportal.org/modeling/CALSIM-Review.pdf

1.2 Summary – Background, Model Configuration, and Nutrient Model Conceptualization (Sections 3 through 5)

The implementation of the DSM2 modules HYDRO and QUAL for hydrodynamics and water quality, respectively, discussed in this report extends the standard configuration of the DSM2 "Historical Model", which simulates historical conditions in the Delta from 1990 – 2008[3], by including effluent flows and constituent concentrations from most of the wastewater treatment plants (WWTPs) with outfalls in DSM2's model domain in the Delta. Although the volume of these effluent inflows is small in comparison with other inflows to the Delta (for example ~3 % by volume on the Sacramento River near Threemile Slough), they are important sources of the nutrients modeled in QUAL. This project builds on the previous calibration and applications of the QUAL nutrient model by the Delta Modeling Section (DMS) of the Department of Water Resources (DWR), which focused on dissolved oxygen (DO) in the San Joaquin River for the period 1996 - 2000 (Rajbhandari, 2001). Using this DWR nutrient model calibration as a basis, this project's effort for DSM2 Version 6 extended the calibration to the entire Delta and the time frame to the period covered by the DSM2 Historical model at the initiation of the project, 1990 - 2008.

The QUAL nutrient model has equations for nine non-conservative constituents – ammonia, nitrate, nitrite, organic-N (organic-Nitrogen), orthophosphate, organic-P (organic-Phosphorus), DO, algae (a conceptual simplification for total phytoplankton biomass), and carbonaceous biochemical oxygen demand (CBOD) – salinity modeled as a conservative constituent (EC, electrical conductivity), and temperature. Calculations from the DSM2 hydrodynamic model of the Delta, DSM2-HYDRO, supply the velocity field used to model the transport of these constituents. Note that the hydrodynamics in HYDRO were calibrated prior to their use in this project, and there is an explicit assumption that HYDRO's calibration is sufficient for project purposes. In addition, the calibration of QUAL's salinity model is also viewed as sufficient. In both cases, the calibration was accomplished under the supervision of DWR's DMS.

During the term of this project, a new version (Version 8) of the DSM2 suite of modules was introduced. Although it did not officially replace the prior Version 6 implementation of DSM2 until late in 2009, the Version 8 implementation was also used in this project. One major change in DSM2 Version 8 was the introduction of a new "Liberty Island" reservoir in the model grid to simulate the permanent flooding of Liberty Island in 1998.

This report includes documentation on the calibration of the two versions of the DSM2 nutrient model used for this project – DSM2 Version 6 calibration spans the years 1990 - 2008 and the DSM2 Version 8.0.6 calibration spans the years 2000 – 2008. In Version 8.0.6, the most recent version as of the date of this document, QUAL includes several modifications that improved or

[3] Historical modeling available for the original contract ended in 2008. The Historical model is updated regularly so there are more recent versions of the flow and salinity simulations available.

corrected the formulation of nutrient dynamics in QUAL - these are discussed at the DWR-DMS website[4]. Calibration statistics and reference plots are included in Appendices II - V for Version 6 of QUAL and at the end of Appendix I for Version 8.0.6.

Because of the focus on ammonia in the applications discussed in this project, terminology needs to be set to avoid confusion - the following terminology will be used: the term "ammonia" will refer to the combined amount of the two chemical species in solution NH_3 (*aq*) and NH_4^+. Where important for clarity, or where there is a need to discuss the distinct species, the terms ammonia or unionized ammonia are used to refer to NH_3 (*aq*) and the terms "ammonium" or "ammonium ion" are used to refer to NH_4^+. The reason for this choice of terminology is discussed in Section 5.1.

1.3 Summary – Data (Sections 6 -8)

This project required the collection and synthesis of the large quantity of data needed to set the nutrient model boundary conditions (river, effluent, and stage) over the 19 year time span, 1990 – 2008, and to calibrate and validate the model calculations for each of the constituents conceptualized in QUAL to drive nutrient dynamics in the Delta. In addition, data was required to set meteorological boundary conditions. Salinity and flow boundary conditions at the river inflow boundaries and water elevation data for the stage boundary at Martinez were developed for the Historical model by DWR's DMS but supplemented where necessary for this project.

The description of the data acquired for the project, the methodology for transforming the data into boundary conditions suitable for model application, and summaries of data usage thus comprise a substantial portion of the documentation, as the quality of the model calibration and the potential types of application are determined in large part by the availability and quality of the data. The adequacy of the conceptual model to simulate nutrients dynamics is a function both of the model itself and of the data available to inform and constrain model boundaries and the parameters in the underlying equations.

Data gathered from source agencies and individuals for setting boundary conditions and for use in calibration and validation were evaluated for quality and accuracy and suspicious data were removed. Constituent concentration data were originally reported in a variety of measurement units depending on data source, so reported concentrations were converted to units of mg L^{-1}, the measurement unit used in QUAL, in terms of the molecular weight the atom characterizing the chemical species (*e.g.*, mg L^{-1} PO_4-P).

In some locations in the Delta, measurements were available from more than one agency. For example, at Rio Vista in the Sacramento River, the USGS and state agencies collected grab sample measurements for chlorophyll-a. Although the samples were not collected on the same date, comparisons in trends and magnitudes of data between agency datasets gave confidence in

[4] http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dsm2/dsm2.cfm

the quality of the data. Gaps in data used for developing time series of boundary conditions were filled where necessary, but gaps were not filled in time series of data used for calibration and validation. Specific methodologies for assessing the quality of the data and filling data gaps are covered in Sections 7.4 and 25.4.

Most effluent data only covered recent years (after 2000), while spatial and temporal coverage for in-Delta nutrient measurements was greatest 1990 – 1995. Flow data and constituent concentrations were not always available for individual WWTPs, and none of the WWTPs had effluent concentration data available for the modeled constituents over the entire modeled time span. Several methods were used to fill in missing effluent data, for example, by setting constituent concentrations at regulatory limits set by the Central Valley Regional Water Quality Control Board.

Most in-Delta nutrient data came from grab samples collected irregularly at monthly or, at most, bi-weekly intervals, while regular time series of water temperature and meteorological data was available hourly to daily. Water temperature and meteorological data had good spatial and temporal coverage over much of the modeled time span, 1990 - 2008. Dissolved oxygen data was also available as regular time series at the hourly to daily time scale at a number of locations.

Measurement data gathered by the Environmental Monitoring Program (EMP) was used preferentially over other data sources at similar locations because: long time series of data were available from EMP at or near most boundaries and at several in-Delta locations; the EMP data was consistent with measurements from other data sources such as the USGS; the data was gathered by a single organization using well-documented methodologies; and, ancillary documentation was readily available.

1.4 Boundary Conditions (Section 9)

The values used to set boundary conditions were dictated by the availability and quality of data. Except for effluent boundaries, boundary conditions for HYDRO and concentrations of salinity (as EC) in QUAL were accepted as presented in DWR's Historical model.

Meteorological data is set at hourly intervals in the model. Meteorological data is applied globally in QUAL, although it was evident that two regions (at a minimum) would be preferable. No single location had a complete set of boundary conditions for the entire modeled period, 1990 – 2008. Therefore, meteorological boundary condition data was compiled from several locations, although the Stockton and Brentwood locations supplied most of the data.

A model sensitivity analysis on meteorological boundary conditions showed that modeled water temperature was most sensitive to the value set for wind speed, so considerable effort was taken to set wind boundary conditions.

Daily or hourly time series of water temperature data were available through the IEP and CDEC data bases for many of the modeled years at or near the boundaries for the Sacramento and San Joaquin Rivers, and at Martinez. Boundary inflow temperatures prepared for the Sacramento boundary were used at the Mokelumne and Cosumnes River boundaries, while the San Joaquin River temperature was used both at Vernalis and at the Calaveras River boundary. The Yolo Bypass boundary was synthesized.

Where possible, the nutrient model boundaries, with the exception of DO, were set using DWR's EMP data which was available at approximately monthly to bi-monthly intervals. Data were processed to yield a regular time series, typically monthly or daily. Although the main model boundaries did not necessarily coincide with data measurement locations, approximations were made using nearby downstream measurements to account for the dynamics that occurred between the nearby points and the model boundary. The approximation was generally made by applying a constant factor (less than 1.0) to the available concentration time series, and possibly also a time shift, to obtain calibration at the downstream measurement location. The main model boundaries generally had enough data to produce time series for the constituents with the highest concentrations. DO measurements were available at or near the main flow boundaries as hourly or daily time series.

Data were gathered from a variety of sources for setting boundary conditions at WWTP effluent locations and processed to yield daily, bi-weekly or monthly values to use as boundary conditions. When data gaps appeared in time series data, either average values or data synthesized by Water Year type were used to fill the gaps.

1.5 Summary – Calibration and Validation (Sections 10 – 12)

1.5.1 Calibration Process

In this document we assume the simple definition that calibration is the process of adjusting a set of model parameters so that model agreement with respect to a set of experimental data is maximized (Trucano et al., 2005). Similarly, validation is the quantification of the predictive ability of the model through comparison with a set of experimental data (Trucano et al., 2005). These definitions assume that a set of criteria for assessing the goodness-of-fit of the model to the data has been selected. For our purposes, the general methodology discussed in Moriasi (2007) was employed for this assessment. A set of statistics were calculated separately for calibration and validation for all available data of sufficient quality - detailed statistics are discussed in the text and documented more thoroughly in the Appendices.

The statistics used to assess model calibration and validation at each Delta location were calculated from model residuals – a residual is the difference between a data value and the corresponding calculated model value (*i.e.*, data - model). Several statistics were calculated, but only three statistical measures were used as measures of the quality of the calibration and validation – Nash-Sutcliffe Efficiency (NSE), RMSE-Standard deviation Ratio (RSR), and

Percent Bias (PBIAS). These three statistics give an overall view of the quality of the calibration (Moriasi *et al.*, 2007).

At each location where calibration data was available, model statistics were calculated and ranked categorically as Very Good, Good, Satisfactory or Unsatisfactory using ranges for model calibration performance ratings for the NSE, RSR and PBIAS statistics (Moriasi *et.al.*, 2007). Water temperature and nutrient calibration were considered separately, and the methodology for calculating calibration statistics was different due to the large difference in the availability of data both for setting boundary conditions and for calibration and validation. In order to ascertain that model calibration and validation were sufficient for both low and high inflow conditions, statistics were calculated by Water Year (WY) Type.

Subsequent to the original calibration for this project (for the modeled period 1990 – 2008), several changes were made to DSM2. As mentioned above, in DSM2 Version 8 a new "Liberty Island" reservoir was added to the model grid to simulate the permanent flooding of Liberty Island in 1998. The Version 8 Historical model used in this document is simulated using the time frame from 2000 to 2008. In QUAL Version 8 (and modifications to Version 8), DWR-DMS: (1) corrected an error in the formulation for the ammonia constituent; (2) the numerical formulation for calculating source terms was changed; and, (3) the formulation for mixing in dead end sloughs and other locations with zero upstream flow was improved. These changes in QUAL were significant enough to require recalibration of nutrient model parameters - water temperature was not recalibrated.

The original calibration process (for Version 6) began by calibrating the temperature model which is independent of the nutrients as it relies only on meteorological data, water temperature boundary conditions and model output from HYDRO in its calculations. Meteorological data is currently applied globally in QUAL, however, the calibration process identified that a minimum of two meteorological regions are suggested in order to improve water temperature calibration and validation statistics. Implementing this capability would require changes in the computer code used in QUAL calculations.

Once the temperature model was considered calibrated and the predictive value of the model was assessed by validation statistics, the nutrient model calibration process began by subdividing the model domain into five regions with broadly similar physical characteristics and/or that are influenced by similar sources of water and nutrients. Open water areas, conceptualized as fully-mixed reservoirs in DSM2, were considered as a group. Calibration proceeded iteratively, by changing parameter values regionally and then comparing model results with calibration data. In the latter stages of iteration, calibration statistics were calculated and some parameters changes were implemented locally within regions and within reservoirs. Once parameter changes became insignificant in terms changes to calibration statistics, validation statistics were calculated.

Due to budgetary limitations, the parameter range for sediment oxygen demand (SOD) originally used by Rajbhandari (2000, 2001) in calibrating the QUAL nutrient model for DO along the San Joaquin River was accepted as given although the parameter range was outside standard literature ranges. Using this approach, only minor parameter changes were needed along the San Joaquin River, which significantly reduced the effort needed to calibrate the entire Delta, *i.e.*, the model domain for this project.

Several regions in the model domain were lacking nutrient data. At river boundaries where there were few or no measurements, boundary conditions were set at reasonable levels to obtain calibration at downstream locations or by synthesizing time series using the available data at these locations. There was no data available within the Delta for calibrating the organic-P constituent and only a few data points along the San Joaquin River for calibrating CBOD. Therefore, neither organic-P nor CBOD are considered calibrated.

Calibration was obtained by varying the minimal numbers of sensitive parameters needed to obtain an acceptable level of accuracy, as assessed by the set of calibration statistics. A sensitive parameter in the context of this report is one where +/- 10% changes in the parameter produced measureable changes in concentration of at least one constituent. Due to time and budgetary constraints, although parameter sensitivity was assessed iteratively at the early stages of model calibration, the results were not formally documented.

Numerical statistics were calculated for the residuals for each constituent at each available location. Categorical ranges for NSE, PBIAS and RSR – Very Good, Good, Satisfactory and Unsatisfactory - were modified from ranges discussed in Moriasi (2007) and used to assess the quality of the calibration and predictive value of the validation. In order to ascertain that model calibration and validation were sufficient for both low and high inflow conditions, calibration and validation were considered separately by Water Year (WY) Type.

Water temperature statistics were assessed hourly on an annual basis using five hydrological Water Year types from critically dry to wet, and splitting the Delta into five regions in which to asses the statistics (statistics were also calculated at each location within each region). Nutrient statistics were also assessed annually. For the original 1990 – 2008 calibration of QUAL Version 6, calibration and validation statistics were assessed using the five Water Year types, while the subsequent Version 8.0.6 statistics were assessed by grouping Water Years into dry and wet year types due to the reduced quantity of data available for calculations.

Both graphical and statistical model evaluation techniques were used in the analysis of calibration and validation results. Different techniques and strategies were used for temperature calibration and validation than for the nutrient model, as the data availability was very different between the two. In either case – nutrients or water temperature – calibration was carried out “by hand”, as funding was not sufficient to employ software to automate the calibration.

The combined effects of nutrient data variability between agencies and sparse measurement intervals, generally monthly, meant that some measure of uncertainty needed to be included in assessing the quality of model calibration and validation. For example, the monthly nutrient boundary conditions and in-Delta measurements were not all collected at time intervals to allow the direct comparison between a model calculation and a data value at a calibration location made during that month. As a consequence, there was a mismatch between the timing of the boundary condition and the timing of the downstream data. The variability between measurement data sets from different agencies indicated that daily fluctuations, tidal influences and extreme events could influence the measurement.

To capture this variability for nutrient model calibration, an "envelope" of model values was used to incorporate these different sources of uncertainty (see Sections 11.3 and 12.5.3). The maximum and minimum monthly values of 15 minute model output were calculated to create the upper and lower bounds of the envelope, respectively. At a given location, if the calibration data fell within that max/min envelope, then the residual was calculated as zero. Values falling outside of the envelope were calculated as residuals using the either the maximum of the envelope (data higher than maximum value) or the minimum value of the envelope (data less than the minimum value) for that month. In a refinement of this methodology, the width of the envelope was reduced in (down to 95%, 90%, 80% and 75% of the original envelope width) for comparison using the Version 8.0.6 calibration for the years 2000 - 2008.

Ranges for model calibration performance ratings for the NSE, RSR and PBIAS statistics under monthly time steps are given in (Moriasi *et al*. 2007). Following those general guide lines, a water temperature calibration is viewed as "Very Good" for the NSE statistic if NSE is greater than 0.75. Similarly, a PBIAS value less than +/-(10 – 25)% (depending on category such as streamflow, sediment or N,P constituent) and a RSR value less than 0.50 are rated "Very Good".

Statistical ranges were modified for the nutrient model calibration and validation. The PBIAS ranges are specific to N- and P-nutrients, but the ranges for RSR and NSE are not constituent-specific in the general performance ratings presented in Moriasi (2007) and thus would be quite strict if applied to constituent calibration/validation statistics. To accommodate this observation somewhat, the NSE range for "Satisfactory" was extended to all positive values. The range for RSR was not altered, so can be considered very strict when applied to nutrient model calibration and validation.

1.5.2 Calibration and Validation results for Water Temperature

Evaluation of the three statistics - NSE, RSR and PBIAS - indicates that the water temperature model calibration is generally ranked Very Good when considered for the Delta as a whole, although the quality differs by region and location within each of the five regions. Modeled water temperature in the south Delta was generally biased low in the summer months, while modeled water temperature along the Sacramento River was consistent with measurement data.

Validation statistics for water temperature are consistent with the use of the model on a daily to hourly time scale.

1.5.3 Calibration and Validation Results for Nutrients

Calibration and validation statistics were calculated for all non-conservative constituents (except organic-P and CBOD) at a monthly time scale. For the original 1990 – 2008 calibration, ranges for the calibration statistics for the N-constituents and dissolved oxygen were generally very good, except at a few locations. Calibration for the other constituents varied from very good to acceptable. Results were poorest where measurements were sparse spatially and/or temporally. Validation statistics mirrored calibration statistics, indicating the appropriate use of the nutrient model for calibrated parameters (i.e., excluding organic-P and CBOD) on a monthly time scale.

The calibration statistics for the newer QUAL Version 8.0.6 improved significantly due to several factors. The changes in nutrient model representation and numerical calculation prompted a detailed update of the parameterization, and an overall simplification in the regional parameter values. An error in the calibration data for orthophosphate along the Sacramento River was corrected, which resulted in a significant improvement in those statistics. Additional information was obtained to improve the representation of boundary conditions for the Liberty Island area, resulting in a modification in the inflow boundary conditions for the Yolo Bypass/Toe Drain location.

Because of the reduction in the number of years and data points available for calibration and validation, the statistics for Version 8.0.6 were calculated with a smaller number of values. For this reason, statistics were calculated for eight years - four calibration years plus four validation years - as well as separately for the two wet and two dry years within each category of Water Year type, Wet or Dry.

Version 8.0.6 nutrient model calibration was assessed using both the 100% and 80% residual envelope calculations (See Section 27, Appendix I). The 80% envelope width was the level at which changes in the category of the NSE, PBIAS or RSR statistic would become evident. In comparing the 100% and 80% envelopes, only for the nitrate+nitrite constituent did the calibration and/or validation statistics deteriorate to any extent. In addition, the deterioration was generally not in a single Water Year type (i.e., not just in Wet or Dry), and validation statistics generally mirrored calibration statistics. This observation demonstrates that using the 100% max/min envelope gives a reasonable assessment of the quality of the calibration and validation residual statistics, and that although the 80% envelope does give a refinement of the statistics; it does not change the overall assessment of the quality of the nutrient model calibration and validation.

1.5.4 Range of Nutrient Model Validity Assessed from Calibration and Validation

As the validation statistics mirrored calibration statistics, the conclusion is that the nutrient model's appropriate use for calibrated constituents (i.e., excluding organic-P and CBOD) is at a

monthly time scale. The calibration and validation statistics for nutrients in QUAL Version 8.0.6 are Very Good for all constituents except for algae, which ranged from Very Good to Satisfactory. For algae, the model generally missed peak values in the Delta during algal blooms, which is not surprising given the monthly time scale of boundary conditions.

The nutrient model in DSM2-QUAL has a simple conceptual formulation that proved sufficient for the task of modeling the entire Delta with output averaged on a monthly basis using data collected for this project. This claim is supported with goodness-of-fit assessed by the calibration statistics, and with the predictive ability of the model affirmed by the validation statistics (Larsen, 1997; Gilroy and McCuen, 2011; Friedel, 2006; Schoups et al., 2008).

1.6 Summary – Simulation Results (Sections 16 to 18)

The inclusion of new flow data available 2004 - 2008 at the Lisbon Toe Drain had a noticeable influence on nutrient dynamics and on volumetric contributions around Rio Vista and at downstream locations. Inclusion of a flooded Liberty Island in the DSM2 grid generally resulted in increased algal biomass at downstream locations and decreased concentrations of N-constituents.

Several scenarios were developed to test model sensitivity to changes (increases or decreases) in the concentration of N-constituents – changes to DICU, changes to Sacramento or San Joaquin boundary, and Sac Regional or Stockton WWTP. These scenarios generally changed the concentration of all of the N-constituents by +/- 20%. In addition, a scenario was defined that changed Sac Regional's wastewater treatment process to nitrification. The sensitivity results test the response of the model to changes in the suite of N-constituents and are presented as percent difference from Base scenario, *i.e.*, the Historical model.

Generally, increases and decreases in N-constituent concentrations were mirrored in percent change in monthly concentrations - i.e., increases and decreases were generally of the same magnitude within 1 – 2 %, the only difference being the difference in sign. As the N-constituents were all varied at once, it is difficult to separate out specific effects. Downstream of the Sacramento and San Joaquin boundaries, nitrification was evident in the change in nitrite concentration as that N-constituent wasn't varied. In general, increasing N-constituents resulted in increased algal biomass, while decreasing N-constituents resulted in a decrease in algal biomass.

The scenario developed to test the downstream consequences for Delta nutrient dynamics of a change to a nitrification wastewater treatment process at Sacramento Regional WWTP presented a complicated picture of the dynamics resulting from the change in the effluent boundary. As expected, there is a large decrease in ammonia – there is also a substantial increase in nitrate concentrations at all downstream locations, although this happens mainly in the winter months. Many of the detailed changes for other constituents can be linked to the decrease in ammonia in

the effluent – for example, algal growth decreased as there was less ammonia available for algal growth.

1.7 Summary – Monitoring Program (Section 21)

Although the currently available data was sufficient to develop a nutrient model focusing on ammonia dynamics, as demonstrated by the calibration and validation statistics, the existing monitoring programs should be improved to improve the spatial and temporal resolution of the calibration and, particularly with respect to organic-P and CBOD, to improve confidence in the calibration. The model constituent organic-P is not measured and carbonaceous biochemical oxygen demand (CBOD) was only measured historically in a few locations along the San Joaquin R. Some regions of the model do not have any coverage, and some areas have marginal coverage. The Yolo/Cache Slough area and portions of the eastern Delta need regular measurement locations as there are currently none. Suisun Marsh and the central Delta need additional measurement locations, as most of the data that is currently available ends in 1995.

The measurement time frame for the monitoring program will dictate the accuracy of the modeled constituents, so measurements need to be taken at a time scale commensurate with the quality of the desired results. Ancillary measurements should be taken along with the main constituents at infrequent intervals. For example, measurements to distinguish between dominant algal species and bacteria would help clarify the nutrient dynamics, and would inform the setting of model parameters QUAL. Finally, sediments should be sampled to help analyze possible contributions to nutrient dynamics from resident algae or macrophytes and the potential for sediment to release and/or sequester orthophosphate, ammonia, nitrite and nitrate.

1.8 Summary – Model Adequacy and Suggested Improvements (Section 19)

Several improvements are suggested for the conceptual model in QUAL. To improve calibration of water temperature, meteorological inputs need to be set on a regional basis to allow for variations across the model domain – this option is not currently available as meteorology is set globally. One improvement in the model that would help clarify nutrient dynamics for ammonia is the inclusion of a refined level of state variables at the base of the food web – for example, additional algal species and more than one species of bacteria – would increase the ability to capture the consumption and production of N-constituents at the expense of additional data gathering requirements. However, an improved formulation and additional data acquisition would address the central questions of this study on the role of ammonia in nutrient dynamics, and if high concentrations are suppressing algal growth.

The model formulation proved inadequate to capture the effect of clams (*Corbula* and *Corbicula*). There are several possible approaches for improving the conceptual model to capture their effects on the food web, although these changes would require substantial revision to the computer code. The most difficult area to improve in the model is the treatment of organic materials, where any change would require a major overhaul of the conceptual model and the

computer code. Refining the model sufficiently to attain a set of state variables that each observe a mass balance criterion and that can describe both the water column, pelagic and benthic interactions is an ideal goal, but would require a rewrite of the entire model.

One of the great strengths of the water temperature and nutrient formulations in QUAL is their simplicity. Because there are invariably constituent concentrations missing at boundaries and within the model domain in nutrient models, as was the case in the Delta over this long time frame, it was still possible to produce a satisfactorily calibrated model. In addition, the lack of regular time series of measurements was not insurmountable – model calibration was generally good at a monthly time scale despite having some locations and times without sufficient data.

Increasing the complexity of the model might increase its ability to model a specific situation, but the increase in the number of required parameters will necessarily result in greater uncertainty in the model results unless accompanied by a supporting data framework. The ability to forecast Delta conditions could decline due to the greater level of uncertainty. The strategy adopted for the QUAL nutrient model calibration - minimizing the reaction rates that are varied by selecting the most sensitive parameters - generally will result in a model with better predictive power as it avoids over-fitting which reduces predictive ability of the calibrated model (Larsen, 1997; Gilroy and McCuen, 2011; Friedel, 2006; Schoups et al., 2008; Fischer et al., 2009; Leangruxa et al., 2004).

2 Project Objectives and Proposed Applications

The recent decline in the health of the San Francisco-San Joaquin Delta (Delta) ecosystem has increased the importance of understanding ecosystem function, and the linkages between ecosystem health and system drivers such as water temperature and nutrient levels. The complexity of these linkages presents a challenge that data analysis alone has not clarified, so conceptual and numerical models have been developed and used to increase our understanding of ecosystem functions.

The Delta Simulation Model-2, or DSM2, was used in this project to model the hydrodynamic and water quality interactions, including nutrient dynamics, in the Delta. DSM2 is a suite of models developed by California's Department of Water Resources (DWR). The hydrodynamic and water quality modules, HYDRO and QUAL, respectively, have been developed by DWR to model the historical conditions in the Delta from 1990 to 2008 – this implementation is called the "Historical Model". The calibration of the Historical Model has previously focused on simulating hydrodynamics and the transport of salinity, modeled as electrical conductivity (EC), and dissolved organic carbon (DOC). In this project, additional constituents in the conceptual model for QUAL were used to model the transport of nutrients and water temperature, as an

extension of the base Historical Model implementation. Hypothetical scenarios and other simulations focused on applications simulating the fate and transport of ammonia.

The main objectives of the work covered in this document are to: (1) calibrate and validate DSM2-QUAL to simulate temperature and nutrient interactions, with a focus on ammonia and nitrogen dynamics, in the model domain from 1990 - 2008, and (2) develop a prioritized water quality monitoring program with the intent of (3) improving the understanding of ammonia and temperature dynamics in the Delta and improving the quality of the model calibration. In addition, (4) the current conceptual model used in QUAL to simulate nutrient dynamics in the Delta is critiqued and potential modifications are suggested.

At present, the potential applications of the nutrient model are focused on inter-comparison of hypothetical scenarios developed with monthly boundary conditions. The source of hydrodynamic model input will most likely be from CalSim II, the latest version of the CalSim model that was developed by the California Department of Water Resources to simulate California State Water Project (SWP) and Central Valley Project (CVP) operations in planning studies that simulate operation of California's reservoirs and water delivery system for current and future facilities, flood control operating criteria, water delivery policies, instream flow and Delta outflow requirements, and hydroelectric power generation operations. CalSim II generates monthly flows, showing the effect of land use, potential climate change, and water operations on flows throughout the Central Valley.

It is customary in most projects using CalSim II Planning models to use a *comparative analysis* approach[5]. In an *absolute analysis*, the model is run once to predict an outcome. In a *comparative analysis*, the model is run twice, once with conditions representing a baseline and another time with some specific changes in order to assess change in modeled outcome due to the given change in model input configuration. The assumption is that, while the model might not produce results reflecting these changes with absolute certainty, it nevertheless produces a reasonably reliable estimate of the relative change in outcome.

3 Background

3.1 DSM2 – general

DSM2 is a one-dimensional (1-D) hydrodynamic and water quality simulation model used to represent conditions in the Sacramento-San Joaquin Delta. The model is frequently used to model impacts associated with projects in the Delta, such as changes in exports, diversions, or channel geometries associated with dredging in Delta channels. It is considered the official Delta water quality model, and as such it has been used extensively to model hydrodynamics and

[5]2003, http://sacramentoriverportal.org/modeling/CALSIM-Review.pdf

salinity as well as Dissolved Organic Carbon (DOC). Salinity is modeled as electrical conductivity (EC), which is assumed to behave as a conservative constituent. DOC is also modeled as a conservative constituent (independent of the nutrient model).

The simplification of the Delta to a one-dimensional (1-D) model domain means that DSM2 can simulate the entire Delta region rapidly in comparison with many higher dimensional models. Although many channels in the Delta are modeled well in 1-D, the loss of spatial detail in areas that are clearly multi-dimensional limit DSM2's accuracy in those areas.

DSM2 contains three separate modules, a hydrodynamic module (HYDRO), a water quality module (QUAL), and a particle tracking module (PTM). HYDRO was developed from the USGS FOURPT model (USGS, 2008). DWR adapted the model to the Delta, accounting for such features as operable gates, open water areas, and export pumps. The water quality module, QUAL, is based on the Branched Lagrangian Transport Model (Jobson, 1997), also developed by the USGS. QUAL uses the hydrodynamics simulated in HYDRO as the basis for its transport calculations. The capability to simulate nutrient dynamics and primary production in QUAL was developed by Rajbhandari (1995a, 1995b). The third module in the DSM2 suite is PTM, which simulates the fate and transport of neutrally buoyant particles. PTM also uses hydrodynamic results from HYDRO to track the fate of particles released at user-defined points in space and in time.

During the term of this project, a new version of the DSM2 suite of modules was introduced. Although it did not officially replace Version 6 of DSM2 until late in 2009, the new Version 8 implementation was also used in this project. One major change in DSM2 Version 8 is the introduction of a new "Liberty Island" reservoir in the model grid to simulate the permanent flooding of Liberty Island in 1998. This change prompted a "Mini-recalibration" effort for HYDRO undertaken by C. Chilmakuri (employee at CH2MHill)[6]. Additional changes to the Version 6 implementation that affect nutrient model simulations were implemented in Version 8.0.6 - these changes are discussed at the DWR-DMS website[7].

Detailed descriptions of the mathematical formulation implemented in the hydrodynamic module, DSM2-HYDRO and for salinity in the water quality module, DSM2-QUAL, the data required for simulation, calibration of HYDRO and QUAL, and past applications of the DSM2 Historical model are documented in a series of reports available at:

http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/annualreports.cfm.

Documentation on the calibration and validation of the modules used in the current implementation of the Historical model is available at that website. The calibrations of HYDRO

[6] See: http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/DSM2UsersGroup/DSM2_Recalibration_102709.pdf
[7] http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dsm2/dsm2.cfm

for hydrodynamics and of QUAL for salinity are assumed to be sufficient for our purposes, and areas where the model implementation is less accurate are discussed where relevant in the text.

3.2 Issues with ammonia and temperature in the Delta

In recent years, the community of pelagic fish and other pelagic organisms has experienced a severe decline in the Delta, a phenomenon now known as the "Pelagic Organism Decline". High concentrations of ammonium ion (NH_4^+) have been hypothesized by some researchers as potentially contributing to fish declines and poor phytoplankton growth in the Delta. Unionized ammonia ($NH_3(aq)$) is known to be toxic to fresh water organisms (Randall and Tsui, 2002)), although the toxicity is dependent on pH and temperature. High ammonium levels may interfere with algal growth, as some algae have been observed to utilize ammonium instead of nitrate when the concentration of ammonium is above 1 – 2.5 µmoles L^{-1} (Dugdale et al., 2007). Nitrate is used more efficiently by some algae and algal growth rates are higher when nitrate is utilized instead of ammonium, all other things being equal.

Waste water treatment plants and agricultural drainage are known to contribute nitrogen-containing compounds in the Delta, along with other nutrients. Although nutrient loads from known sources are closely monitored to maintain beneficial levels for the identified uses of Delta waters, such as recreation and ecosystem health, there is uncertainty associated with the current levels and they are subject to re-evaluation if new data suggests these levels are incorrect.

Water temperature is also a critical parameter regulating the functioning of the Delta ecosystem. For example, water temperatures in some areas can reach lethal levels during the summer months for susceptible species inhabiting the Delta, such as delta smelt. As reaction rates for nutrient-related processes are generally temperature dependent, a combination of an over-abundant nutrient supply and optimal temperature for algal growth may result in algal blooms - the associated depleted dissolved oxygen levels can be lethal to some aqueous inhabitants. Alternatively, if nutrient levels are poor or unbalanced, as may occur if ammonium levels are too high, algal growth may be inhibited even at optimal temperatures, or algal species composition may shift to less desirable species. As algae form a basis for the food supply for higher level organisms, if algal growth is inhibited the supply of food for higher level organisms from zooplankton to fish is also limited. If this occurs at locations and times when fish populations are dependent on a source of food or when nutritional requirements are high, such as the areas in and around Suisun Bay or when juvenile fish are present, the result may be inhibitory to growth in the fish population.

3.3 Previous nutrient models using DSM2

Previous uses of QUAL to simulate nutrient dynamics in the Delta focused on dissolved oxygen (DO). Rajbhandari (2000, 2001, 2003, 2004, and 2005) used QUAL to model DO dynamics on the San Joaquin River, addressing concerns about low DO in the vicinity of Stockton. Subsequently, the application and area of calibration were extended to the San Joaquin Deep

Water Ship Channel. Another application focusing on DO extended model development to a wider region of the Delta to support technical studies for the In-Delta Storage Project Feasibility Study - this model study assessed the potential impact of the project on temperature and DO levels using CALSIM II (Rajbhandari, 2004) output for the hydrological conditions in the 16-year scenarios (1975 – 1991). The latter type of study is an example of a Planning Study in which DSM2 is used to quantify the effects that a modification in the Delta water regime, such as construction of a new gate, may have on hydrodynamics and water quality. DSM2 Planning models currently cover the period from 1922 to 2003 using CALSIM II simulated hydrology, while older Planning models covered the period 1975 - 1991.

3.4 Additional analysis – aqueous geochemistry and isotopes

Additional modeling analysis using the aqueous geochemical model EQ3/6 (Wolery, 1992) was performed to establish a baseline for chemical speciation in the waters at the two main model boundaries on the Sacramento and San Joaquin Rivers. As discussed in Section 4.3.2, QUAL's nutrient model does not include chemical speciation, knowledge of which can give important insight into the detailed chemical interactions among the constituents in the water. The EQ3/6 analysis is discussed in Section 10.1.

A collaborative effort between this project and C. Kendall (USGS) has been started to use isotopic data to inform and constrain the DSM2 nutrient model. Isotope data can be used to identify sources of nutrients and dominating processes involved in their transformation, and the collaboration is hoping to combine DSM2 QUAL results with results from isotopic analyses and water quality measurements. The distinctive isotope "fingerprints" are more diagnostic than standard chemical measurements to sources and sinks of various materials which can often be identified, traced, and semi-quantified using stable isotopes. For example, nitrate derived from animal waste is isotopically distinguishable from nitrate derived from inorganic fertilizer, and organic matter derived from algae is isotopically distinguishable from organic matter derived from terrestrial plants. Different kinds of sinks (i.e., biogeochemical removal mechanisms) sometimes cause distinctive shifts in isotopic compositions. For example, nitrification and assimilation cause predictable and distinctive changes in isotopic composition.

4 DSM2 Model Configuration

The implementation of the DSM2 modules HYDRO and QUAL discussed in this report extends the standard configuration of the "Historical Model", which simulates historical conditions in the Delta from 1990 – 2008, by including effluent flows from most of the wastewater treatment plants (WWTPs) with outfalls within DSM2's model domain in the Delta. Although the volume of these effluent inflows is small (and variable) in comparison with other inflows to the Delta (~ 3 % by volume on the Sacramento River near Threemile Slough), they are important sources of the nutrients modeled in QUAL.

4.1 Model Grid

The DSM2 model grid is shown in Figure 4-1. The grid consists of one-dimensional channels, indicated by red lines, linked by nodes, indicated by black symbols, and open water areas whose approximate locations are indicated by blue numbers. Open water areas are modeled as well-mixed reservoirs.

4.2 Numerical Solution Parameters

The user can specify the computational time step of the solution algorithms used in HYDRO and QUAL. The standard time step for HYDRO and QUAL simulations is 15 minutes – this was the computational step used in the Historical Model simulations used in the nutrient modeling discussed in this report.

4.3 Model Boundaries

4.3.1 Flow and Stage Boundaries

Boundaries that define the movement of water into and out of the Delta consist of inflow boundaries, outflow boundaries and a stage boundary set at Martinez (Figure 4-2). Exports and diversions remove water from the model – water also flows out of the model at its downstream stage boundary at Martinez. In addition, there are structures in the model, such as gates and weirs, that are operated to control flow, stage or the transport of salinity that simulate the operation of these physical structures in the Delta.

In Figure 4-2, the main inflow boundaries are denoted by blue stars. These boundaries are found at the each of the major rivers (Sacramento, San Joaquin, Calaveras, Mokelumne and Cosumnes), and at the Yolo Bypass and the Lisbon Toe Drain (in the Yolo region). The Yolo Bypass only has inflow during periods of high Sacramento River inflow which can occur in the late fall through early spring. Flows at the Lisbon Toe Drain near Liberty Island on the north western edge of the Delta, normally not included in HYDRO, were added when available as some effluent sources eventually enter the model domain at that point. Flow data for the Lisbon Toe Drain was available starting in 2004. Figure 4-2 also shows Delta export locations, denoted

by red stars. The greatest (combined) volume of export occurs at the State Water Project (SWP) and the federal Central Valley Project (CVP). Contra Costa Water District (CCWD) maintains two export/diversion locations, at Rock Slough and in Old River (Note – CCWD also has an export location in Victoria Canal but that was not completed over the modeled time span).

Figure 4-3 shows the location of effluent inflow boundaries discussed in this report. The volume of effluent water is small in comparison with other inflow contributions (for example ~3 % by volume on the Sacramento River near Threemile Slough).

The effects of evaporation, precipitation, and channel depletions and additions ascribed to agricultural influences are modeled using the Delta Island Consumptive Use (DICU) model[8]. This model is used to set boundary conditions at 258 locations throughout the Delta – these locations are subdivided into 142 regions. DICU boundary conditions vary monthly and are set by Water Year Type. The uncertainty in the estimates of DICU inflow, outflow and constituent concentrations is high. During periods of low inflow, volumes ascribed to DICU boundaries may dominate model results at some locations.

4.3.2 Transport Model Boundaries – Nutrients, salinity and temperature

Each flow boundary type, including river, stage, DICU and effluent boundaries, is also a boundary for transported constituents. There are eleven equations in the transport model, nine of which are referred to as "nutrient model constituents" in this report, plus one equation for salinity and one equation for temperature. Water temperature plays an important role in nutrient dynamics but (clearly) has no mass, while each of the other ten equations in the model represents a constituent with mass. Salinity is important in modeling dissolved oxygen saturation, as an increase in salinity can decrease DO saturation. Salinity generally only plays an important role near the Martinez boundary but otherwise does not significantly influence nutrient dynamics in the model.

The formulation used for the heat transport equation requires data for barometric pressure, air temperature, wet bulb temperature, wind speed and cloud cover. Meteorological conditions are used in modeling the exchange of heat at the air-water interface. Modeled water temperature plays a role in the rate of each constituent reaction (except salinity). Atmospheric pressure is used in modeling the saturation of dissolved oxygen in water, along with other conditions such as water temperature, salinity and reaeration. QUAL can be run to simulate water temperature alone, as water temperature is independent of the other constituents in the nutrient model.

The current model formulation only allows for a single meteorological region for the entire model domain. As discussed in Section 9.5 and in Section 12, this has proved to be a disadvantage in the simulation of modeled water temperature in DSM2.

---

[8] http://www.iep.ca.gov/dsm2pwt/reports/DSM2FinalReport_v07-19-02.pdf, http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dicu/DICU_Dec2000.pdf

4.4 Previous DSM2 calibration

The DSM2 module HYDRO was recalibrated for flow and stage by DWR and the Interagency Ecological Program's Project Work Team in 2003[9]. QUAL was most recently recalibrated for salinity in 2000. Salinity is modeled using EC in QUAL, under the assumption that EC can be approximated as a conservative substance. Hydrodynamic calibration was conducted for 4 separate periods, three spring events (May 1998, April 1997, April 1998) and one fall event (September and October 1988). The hydrodynamic calibration effort made use of tidal flow meter data and measured stages. Roughness coefficients were adjusted to improve the ability of the model to reproduce measured stage and flow.

With the inclusion of the flooded Liberty Island in Version 8 of DSM2, HYDRO underwent a "Mini-recalibration"[10]. C. Chilmakuri (employee at CH2MHill) extended the grid on the inflow section of the Sacramento River and included a new open water area (see Figure 4-4), conceptualized as a reservoir in DSM2, to model the effect of the newly flooded area due a levee break on Liberty Island. The HYDRO calibration was reviewed by the body of DSM2 users (the DSM2 User's Group).

The DSM2 Version 6 water quality model QUAL was calibrated for salinity by DWR with the use of extensive EC measurements throughout the Delta. A three year period (October 1991 to September 1994) was used for the calibration. Unlike the hydrodynamic calibration, a single time period was required because the system is strongly influenced by recent salinity conditions. Reproduction of measured EC values was accomplished by adjusting dispersion coefficients throughout the system.

The nutrient model in QUAL was calibrated for DO on the San Joaquin River, approximately between Vernalis and Prisoner's Point for the period 1996 – 2000 (Rajbhandari, 2001). The main application of this modeling effort was simulating problems with DO concentration in the region near the Stockton Deep Water Ship Channel (SDWSC). This effort is documented in several DWR reports, including (Rajbhandari, 2001) and (Rajbhandari, 2003). An additional DO model application of the nutrient model for planning purposes is documented in (Rajbhandari, 2004).

[9] http://www.iep.ca.gov/dsm2pwt/ This is Version 6 of DSM2.
[10] http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/DSM2UsersGroup/DSM2_Recalibration_102709.pdf

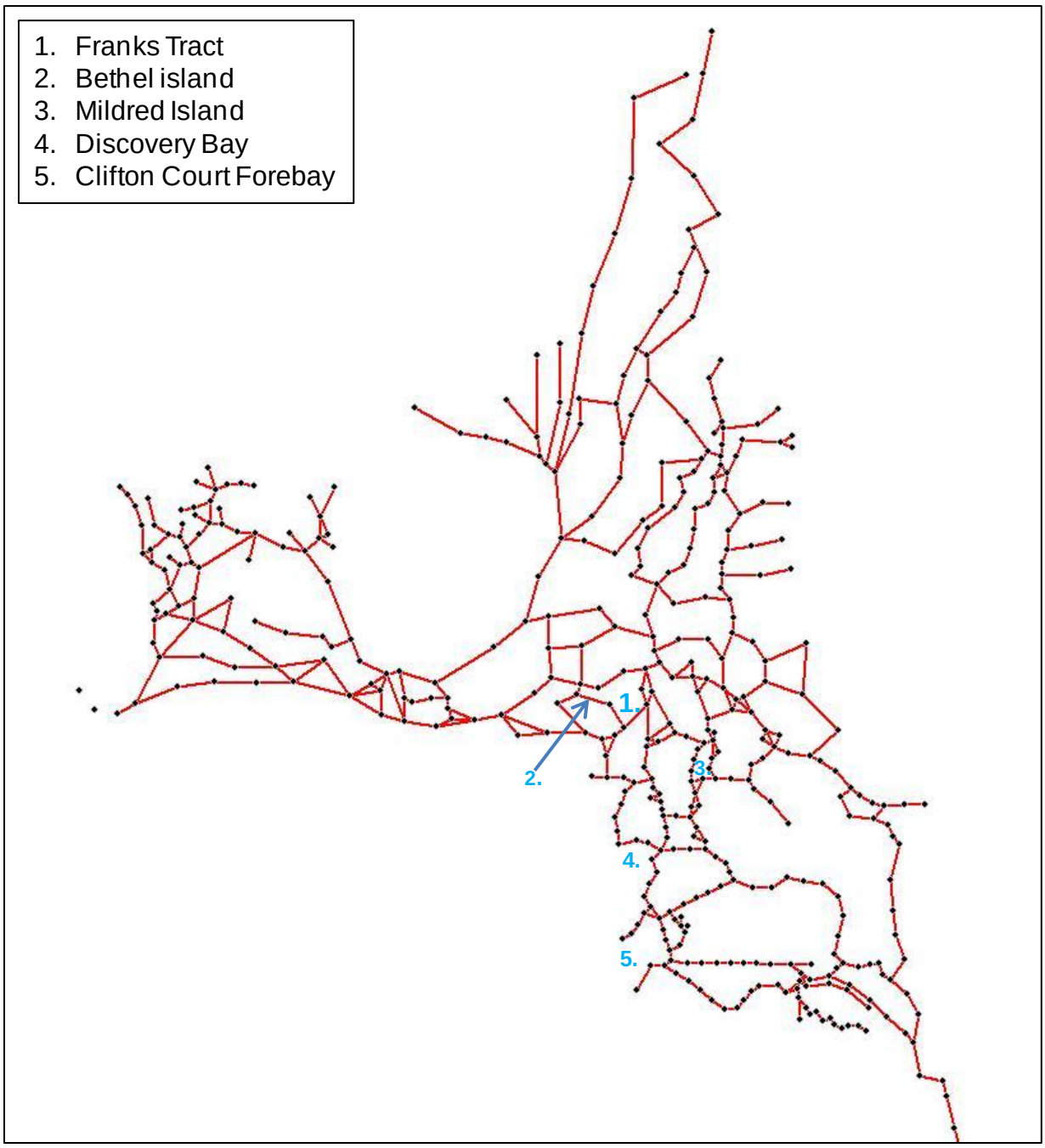


Figure 4-1 Channels (red), reservoirs (blue numbers), and nodes (black) in the DSM2 model grid.

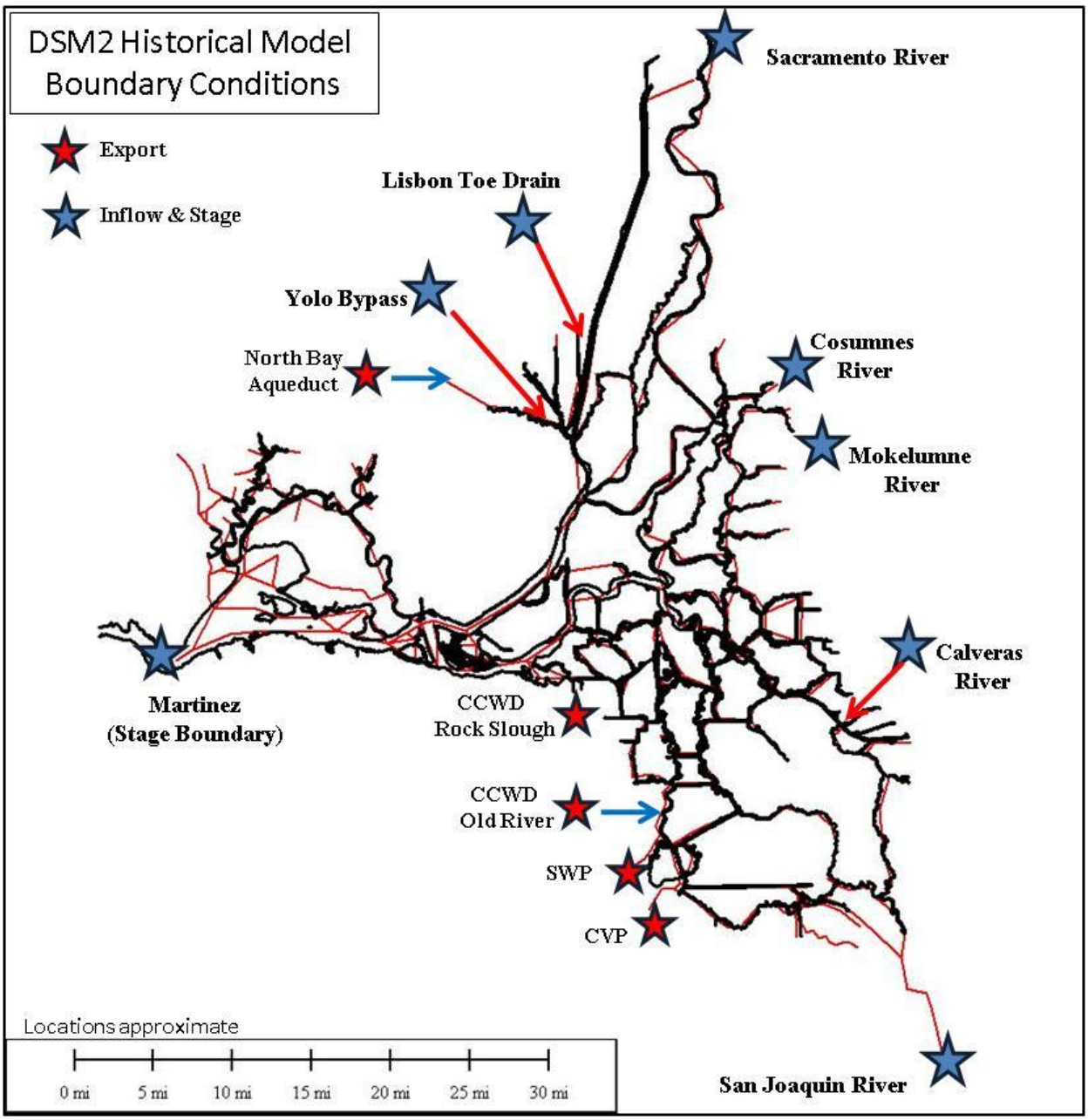


Figure 4-2 Approximate location of the model inflow boundaries and the stage boundary is at Martinez (blue stars). Export locations are indicated by red stars.

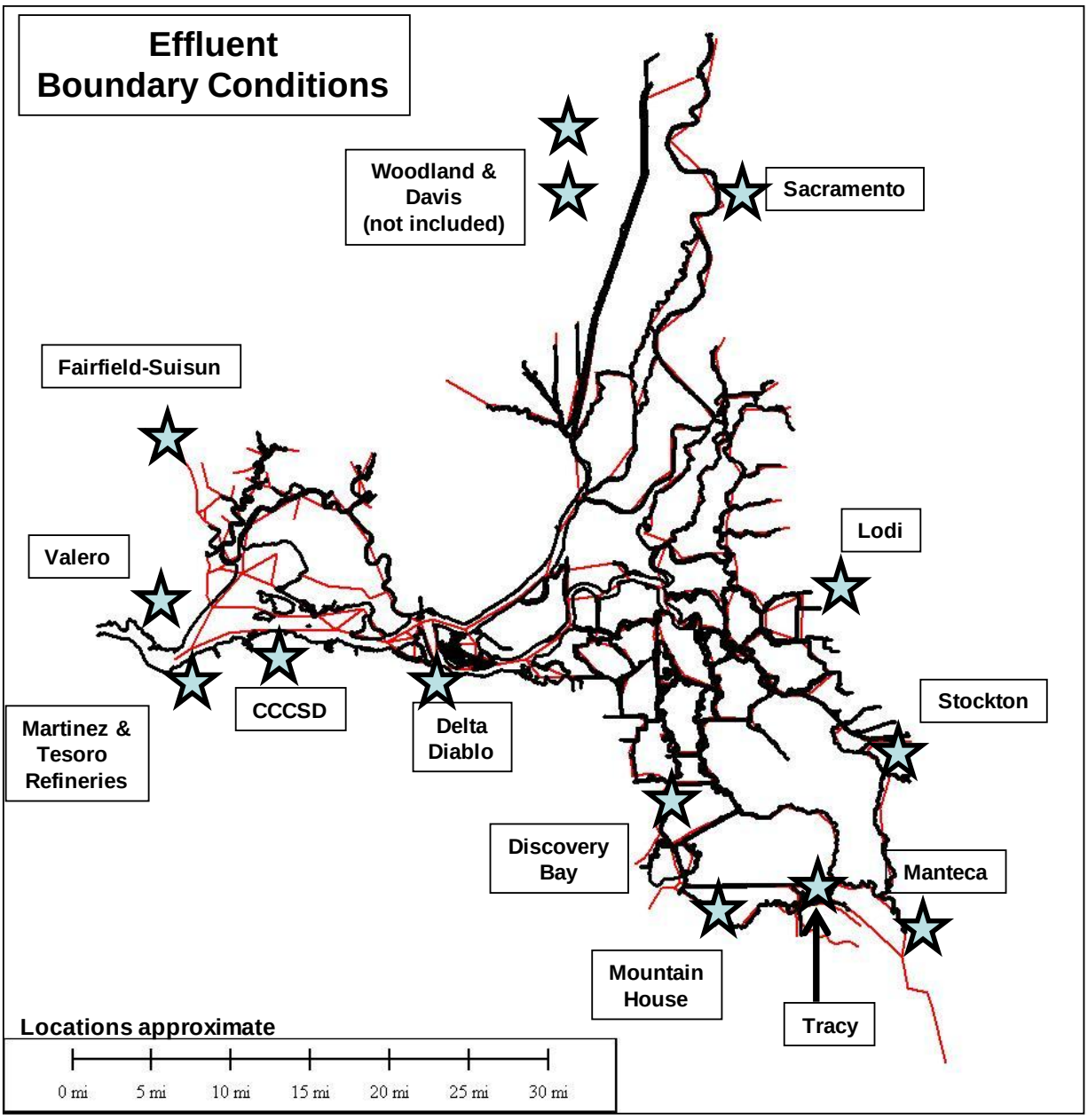


Figure 4-3 Approximate locations of effluent boundary conditions for waste water treatment plants considered in this report.

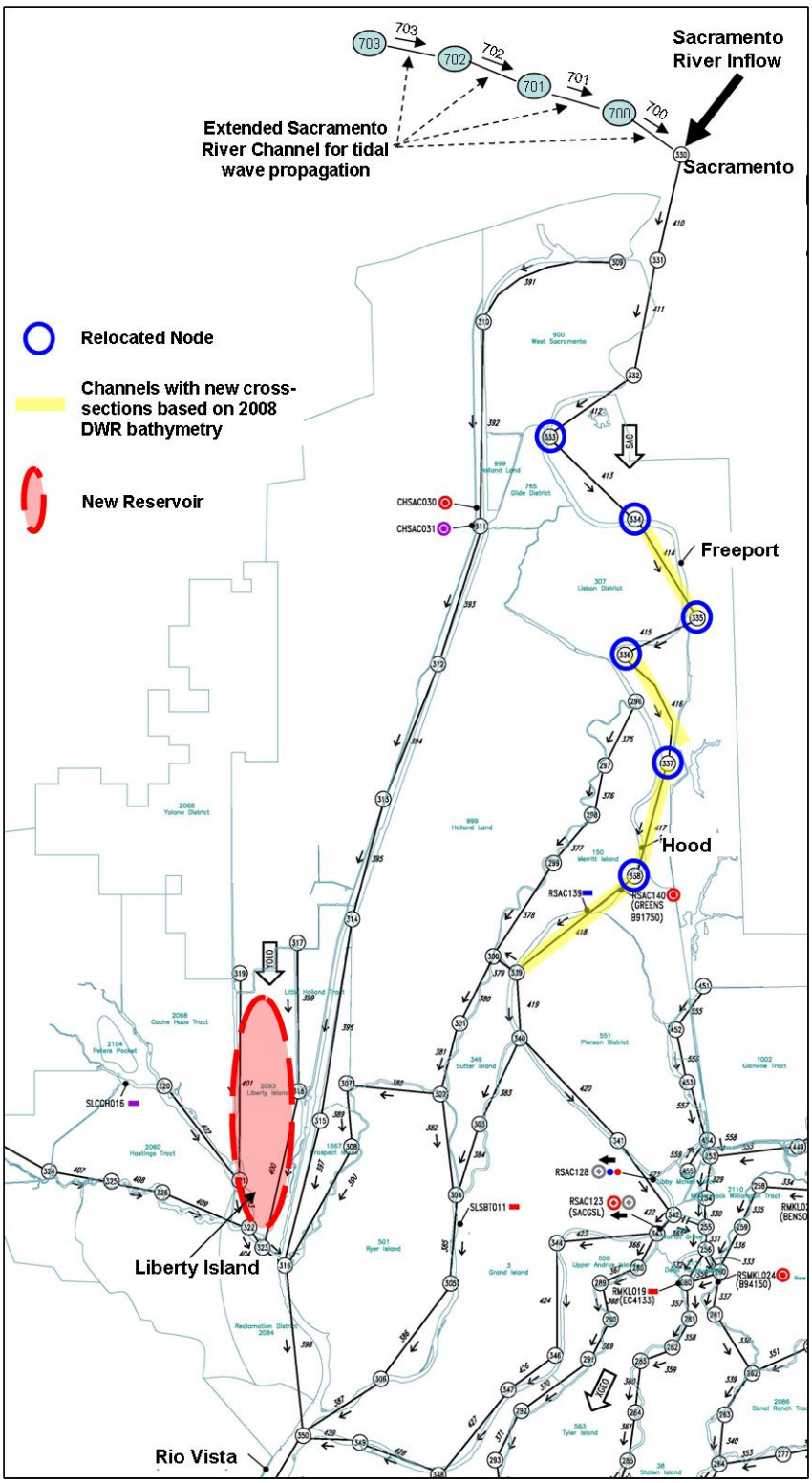


Figure 4-4 Changes implemented in the DSM2 Version 8 model grid include the new Liberty Island "reservoir" location (red oval), and changes to the grid and nodes along the upstream portion of the Sacramento River (blue circles).

5 QUAL's Conceptual Model for Nutrient Dynamics

5.1 QUAL Conceptual Background

Figure 5-1 is a conceptualization of the interactions between the main constituents used to model nutrient dynamics in the QUAL mass transport model - this figure is an adaptation of figures shown in (Rajbhandari, 2003). Each box (or oval) in the blue region (water) symbolizes one of the nine equations for non-conservative constituents in the transport model. There are equations for simulating the transport and reaction of dissolved oxygen (DO), nitrate (NO_3), nitrite (NO_2), ammonia (NH_3), organic-N, carbonaceous biochemical oxygen demand (CBOD), orthophosphate (PO_4, dissolved-P in the Figure), organic-P, and algae. Chlorophyll a (chl-a) measurements are used to calculate the biomass of algae in the model. Salinity is modeled as a conservative constituent - it is not included in Figure 5-1.

Arrows in Figure 5-1 indicate a relationship, modeled as a temperature-dependent reaction rate, between two variables for adding or removing mass into or out of the model calculation for a given constituent, respectively. Water temperature influences the dynamics of the constituent interactions as a factor in the rate of reactions - an increase in water temperature results in a change, generally an increase, in reaction rates. Conversely, modeled DO saturation decreases with increased temperature. The reactions themselves do not influence the temperature of the water in QUAL.

Although each of the constituents occurs in an ionized form in aqueous solutions, charges on the constituents are not used in the model or in this report except where specifically indicated. In reality, each constituent occurs as a suite of chemical sub-species in solution with variable charge and potentially associated with many other aqueous species. As this level of interaction is not explicitly accounted for QUAL, no single charge can be legitimately assigned.

An important distinction needs to be made between term "ammonia" and the concentrations of each of the chemical species NH_3 and NH_4^+. NH_3 occurs naturally as a gas that is dissolved in the aqueous phase, but the gas is also ionized to NH_4^+, *i.e.* ammonium, in a pH-dependent reaction in solution. At neutral pH (pH = 7.0), the majority of the "ammonia" in solution occurs in its ionized form as NH_4^+. For example, at a water temperature of 25°C the equilibrium reaction constant, $\log_K$, for the aqueous association reaction yields that approximately 50% of the "ammonia" occurs as NH_4^+ at pH 9.5. The amount of NH_4^+ increases with decreasing pH, so that at pH 8.5 only about 9% of the ammonia is present in its unionized (NH_3) form. In most of the Delta, data sources indicate that the pH is typically less than pH 8.5 except for episodic, localized increases. Further detail on these calculations is found in Appendix I, Section 25.9.

Because QUAL does not explicitly model pH and cannot distinguish between the unionized and ionized forms, the term "ammonia" is used in this report to indicate the total concentration[11] of $[NH_3] + [NH_4^+]$. A simplifying assumption in interpreting model results is that the majority of the "ammonia" concentration reported in calculations is occurring in the ionized "ammonium" form. Measured data collected for setting boundary conditions and as calibration/validation data is generally reported by the collecting agency as "ammonia", and is actually reporting the total $[NH_3] + [NH_4^+]$.

The conceptual model for each constituent is discussed in greater detail in the following sections.

5.2 Nutrient Model formulation

The ten equations that comprise the nine non-conservative constituents in the nutrient model plus temperature are discussed individually below. The equation for salinity, the conservative constituent, is not discussed. Each mass balance equation represents the mass per unit volume of water. The transport of the constituent due to advection is not shown due to the assumption of a Lagrangian reference frame that moves through the domain at the mean velocity of the water - additional information can be found in (Rajbhandari, 1995a and 1995b).

Table 5-2 and Table 5-3 detail the adjustable parameters that are used in the equations. Some of the symbols documented in the Tables do not appear explicitly in the equations discussed in this Section (5.2) (for example, some of the parameters used in modeling water temperature). Parameters that appear in the equations that are not listed in the Tables are defined at their initial appearance in the text.

There are sixteen temperature coefficients for reaction rates shown in Table 5-3. Temperature coefficients are defined by the relationships $k(T) = k(20)\Theta^{(T-20)}$, where k(T) is the reaction rate day^{-1} at temperature T in °C and Θ is the user-defined temperature coefficient for the reaction shown in the Table. The values used for these coefficients were set at standard literature values.

[11] Unlike the convention in aqueous chemistry, square brackets are used to symbolize the concentration of an aqueous species (not the activity) in solution. The units of concentration are understood to be the units in the model unless specifically stated otherwise.

Table 5-1 Definitions for variables appearing in equations 1 – 10.

Variable Symbol	Modeled Constituent	Measurement Unit
O	DO	mg/L
L	CBOD	mg/L
NH_3	Total ammonia as N	mg/L
NO_2	Nitrite as N	mg/L
NO_3	Nitrate as N	mg/L
A	Phytoplankton biomass	mg/L[1]
N-org	Organic nitrogen as N	mg/L
P-org	Organic phosphorus as P	mg/L
PO_4	Orthophosphate as P	mg/L
T	Water Temperature	° C

1. This is the dry weight as estimated from chl-a concentrations.

5.2.1 Temperature

The formulation for the transport of temperature in the model, equation (1) was adapted from the QUAL2E model (Brown and Barnwell, 1987), with several changes documented in (Rajbhandari, 1995b). Water temperature influences the interactions between the modeled constituents as discussed in Section 5.1, but is independent of the these constituents.

The net transfer of energy, Q_n, across the air-water interface is formulated as a function of net short wave radiation flux, net long wave atmospheric radiation flux, water surface back radiation flux, evaporative heat flux and sensible heat flux. The expressions accounting for this energy transfer are functions of the meteorological inputs (not shown). In equation (1), p is the density of water, c is the specific heat of water and d is the hydraulic depth of the water. E_x is the longitudinal dispersion coefficient.

$$\frac{\partial[T]}{\partial t} = \frac{\partial}{\partial \xi}\left[E_x \frac{\partial T}{\partial \xi}\right] + Q_n \Big/ pcd \qquad (1)$$

Diffusion **Energy**

5.2.2 Dissolved Oxygen (DO)

DO concentration is a critical indicator of the general health of an aquatic ecosystem (Rajbhandari, 1995a; Cole and Wells, 2008). Equation (2) specifies the rate of change in DO concentration due to dispersion, sources (reaeration and photosynthesis), and sinks (CBOD, oxidation of NH_3 and NO_2, algal respiration and benthic demand). The expressions used to model DO saturation and reaeration are discussed in detail in (Rajbhandari, 1995a).

Benthic oxygen demand represents a generic expression encompassing several processes in the sediment that remove oxygen from the water column, including the decay of organic matter and utilization of dissolved oxygen by benthic species (such as clams) and macrophytes.

$$\frac{\partial[O]}{\partial t} = \frac{\partial}{\partial \xi}\left[E_x \frac{\partial[O]}{\partial \xi}\right] - (k_1 + k_3) L + k_2 (O_s - [O]) - \alpha_5 k_n [NH_3] - \alpha_6 k_{ni} [NO_2] + \alpha_3 \mu [A] - \alpha_4 \rho [A] - {K_4}/{d} \quad (2)$$

Diffusion CBOD Reaeration Ammonia ox. Nitrite ox. Photosyn. Respir. Benthic

5.2.3 Carbonaceous Biochemical Oxygen Demand (CBOD)

Carbonaceous biochemical oxygen demand (CBOD) refers to the potential for microorganisms to consume oxygen as they utilize organic-carbon substrates. A related measurement is nitrogenous BOD (NBOD) – this refers to the oxygen consumed by nitrifying bacteria as they consume organic and inorganic materials that contain a reduced form of nitrogen. Collectively, CBOD+NBOD is called BOD, and tests that measure any of the three forms occur over a number of days, typically five or twenty days. For the purposes of this project, we utilized $CBOD_5$, a five-day test for CBOD. Further detail is found in the Appendix I, Section 25.2.

Equation (3) accounts for the sinks and sources of CBOD due to oxidation and settling, and the contribution to CBOD from the death of algae, respectively.

$$\frac{\partial[L]}{\partial t} = \frac{\partial}{\partial \xi}\left[E_x \frac{\partial[L]}{\partial \xi}\right] - (k_1 + k_3) L + \sigma_7 [A] \quad (3)$$

Diffusion Oxidize/Settle Algal death

5.2.4 Algae (Phytoplankton)

Equation (4) accounts for the biomass of algae in the model. Algae utilize chlorophyll pigments to convert solar radiation to energy, and chl-a (a particular form of pigment) measurements are typically used as an indicator of algal biomass. A conversion factor is used to convert chl-a concentrations to algal biomass. For this project, we used a conversion factor of 67 g algae/mg chl-a (dry weight of algae) (Clesceri et al., 1999). Although there are many different algal species (Cole and Wells, 2008) with variable characteristics including growth rates, preferred nutrient sources, and levels of chlorophyll per unit of mass, in QUAL a single equation is used to estimate a generic algal species.

$$\frac{\partial[A]}{\partial t} = \frac{\partial}{\partial \xi}\left[E_x \frac{\partial[A]}{\partial \xi}\right] + (\mu - \rho)[A] - \sigma_1 [A]/d - \sigma_6 [A] \quad \textbf{(4)}$$

Diffusion Algae Grow Settle Die

Algal growth is a function of the difference between the respiration rate, ρ, and the growth rate, μ, of this generic algal population. The growth in algal biomass is assumed to be limited by availability of light, F_L, inorganic nitrogen, N, as the sum of the concentrations of NH_3 and NO_3, and inorganic phosphorus, P, as expressed in the following equation (4a):

$$\mu = \mu_{MAX}\ F_L\ Min\left(\frac{N}{K_N + N}, \frac{P}{K_P + P}\right) \quad \textbf{(4a)}$$

where K_N and K_P are the half-saturation constants of nitrogen and phosphorus, respectively. F_L is further expressed as a Monod equation as a function of light intensity at a given depth (Rajbhandari, 1995a). When algae die, their decomposition contributes to CBOD. Algae settle out from the water column and are lost from the system.

The generic algal biomass is assumed to be composed of a ratio of N:P concentrations. Although this ratio is known to vary between different algal species, only a single generic algal species is modeled and the parameters defining this ratio are set globally in the model domain.

5.2.5 Organic nitrogen (Org-N)

Organic nitrogen dynamics (as N) are represented by equation (5):

$$\frac{\partial[N-org]}{\partial t} = \frac{\partial}{\partial \xi}\left[E_x \frac{\partial[N-org]}{\partial \xi}\right] + \alpha_1 \rho [A] - k_{N-org}[N-org] - \sigma_4 [N-org] \quad \textbf{(5)}$$

Diffusion Algae Decay to NH3 Settle

The only source of nitrogen due to nutrient dynamics occurs as a result of algal respiration as a fraction of the algal biomass assumed to be nitrogen. Org-N is lost from the system as it decays and settles.

When organic-N measurements are unavailable, Total Kjeldahl Nitrogen (TKN) can be used to calculate organic-N if ammonia measurements are also available, as TKN = organic-N + ammonia.

5.2.6 Ammonia (NH_3)

Ammonia (as N) dynamics are represented by equation (6):

$$\frac{\partial[NH_3]}{\partial t} = \frac{\partial}{\partial \xi}\left[E_x \frac{\partial[NH_3]}{\partial \xi}\right] - f\,\alpha_1 \mu[A] + k_{N-org}[N-org] - k_n[NH_3] + {}^{\sigma_3}\!/_{d} \quad (6)$$

Diffusion **Algae** **Org – N Decay** **NH3 Decay** **Sediment Source**

Although ammonia concentration is represented in this equation by the formula NH_3, in fact the concentration of ammonia is assumed implicitly to be the total of aqueous NH_3 (g) and NH_4^+,as discussed previously (see: Section 3.2). NH_3 is a nutrient source for algae as is NO_3, and the preferential consumption of these two sources of nitrogen is given by a preference factor, $0.0 \leq p \leq 1.0$, in the following expression:

$$f = \frac{p[NH_3]}{p[NH_3] + (1-p)[NO_3]} \quad (6a)$$

where the square brackets indicate modeled concentration. For example, a preference factor set at p=0.5 indicates no algal preference for either nutrient, so at equal concentrations equal amounts of NH_3 and NO_3 would be consumed for algal growth.

5.2.7 Nitrite (NO_2)

Sources and sinks of NO_2 (as N) are shown in equation (7). In equation (6), NH_3 is seen to decay at a set rate – in equation 7 we see that that the NH_3 has decayed into NO_2, and that NO_2 decays to NO_3:

$$\frac{\partial[NO_2]}{\partial t} = \frac{\partial}{\partial \xi}\left[E_x \frac{\partial[NO_2]}{\partial \xi}\right] - k_{ni}[NO_2] + k_n[NH_3] \quad (7)$$

Diffusion **Decay to NO3** **NH3 Decay**

5.2.8 Nitrate (NO_3)

Nitrate dynamics are given by equation (8). Here we see that NO_2 has decayed into NO_3 (as N):

$$\frac{\partial[NO_3]}{\partial t} = \frac{\partial}{\partial \xi}\left[E_x \frac{\partial[NO_3]}{\partial \xi}\right] - (1-f)\alpha_1 \mu[A] + k_{ni}[NO_2]$$

Difusion Algae NO2 Decay (8)

Nitrate is consumed by algae, where the rate is assumed to be governed by the preference of algae for NH_3 or NO_3 (see equation (6a)).

5.2.9 Organic Phosphorus (Org-P)

Equation (9) shows the sources (algal biomass) and sinks (decay and settling) for org-P (as P) in the nutrient dynamics:

$$\frac{\partial[P-org]}{\partial t} = \frac{\partial}{\partial \xi}\left[E_x \frac{\partial[P-org]}{\partial \xi}\right] + \alpha_2 \rho[A] - k_{P-org}[P-org] - \sigma_5[P-org]$$

Diffuson Algae Decay Settling (9)

5.2.10 Dissolved Phosphorus (PO_4)

The final equation. (10), represents the sources (decay of organic-P, benthic source) and sinks (algal growth) of inorganic phosphorus, which is assumed to the concentration of ortho-phosphate (as P), PO_4:

$$\frac{\partial[PO_4]}{\partial t} = \frac{\partial}{\partial \xi}\left[E_x \frac{\partial[PO_4]}{\partial \xi}\right] - \alpha_2 \mu[A] + k_{P-org}[PO_4] + \sigma_2 / d$$

Diffusion Algae grow Org – P Decay Benthic (10)

5.3 Reaction Rates and Parameters

There are 15 Regional Reaction Rate parameters (Table 5-2 and Table 5-3) that can that can be varied by channel in the grid as well as in each open water body (DSM2 reservoir). There are 31 Global Reaction Parameters that are set for the entire model domain, sixteen of which are temperature coefficients for reaction rates (Table 5-3). The values listed in the "Calibrated Values" column give the ranges set in the model. The values for regionally-set rate parameters may differ somewhat within a region or in a reservoir within a region. The parameter values are consistent with the ranges used by the Department of Water Resources in the applications of DSM2-QUAL for modeling DO in the Delta (Rajbhandari, 2001; Rajbhandari, 2003; Rajbhandari, 2004). As mentioned in the Executive Summary, the parameter specifying SOD lies outside standard literature parameter ranges. This parameter was utilized as a fitting parameter to calibrate DO in the original DO simulations (Rajbhandari, 2001) – due to the limited budget and time for the current project, the parameterization for nutrients along the San Joaquin River was largely accepted as received.

Details on the specification of values used in calibrating the model are found in Section 12.4. Many of the parameter ranges shown in these Tables were obtained from Cole and Wells (2008),

the CE-QUAL-W2 manual. CE-QUAL-W2 is routinely applied by the U.S. Army Corps of Engineers (USACE), and was developed under the auspices of the USACE (Cole, 1994).

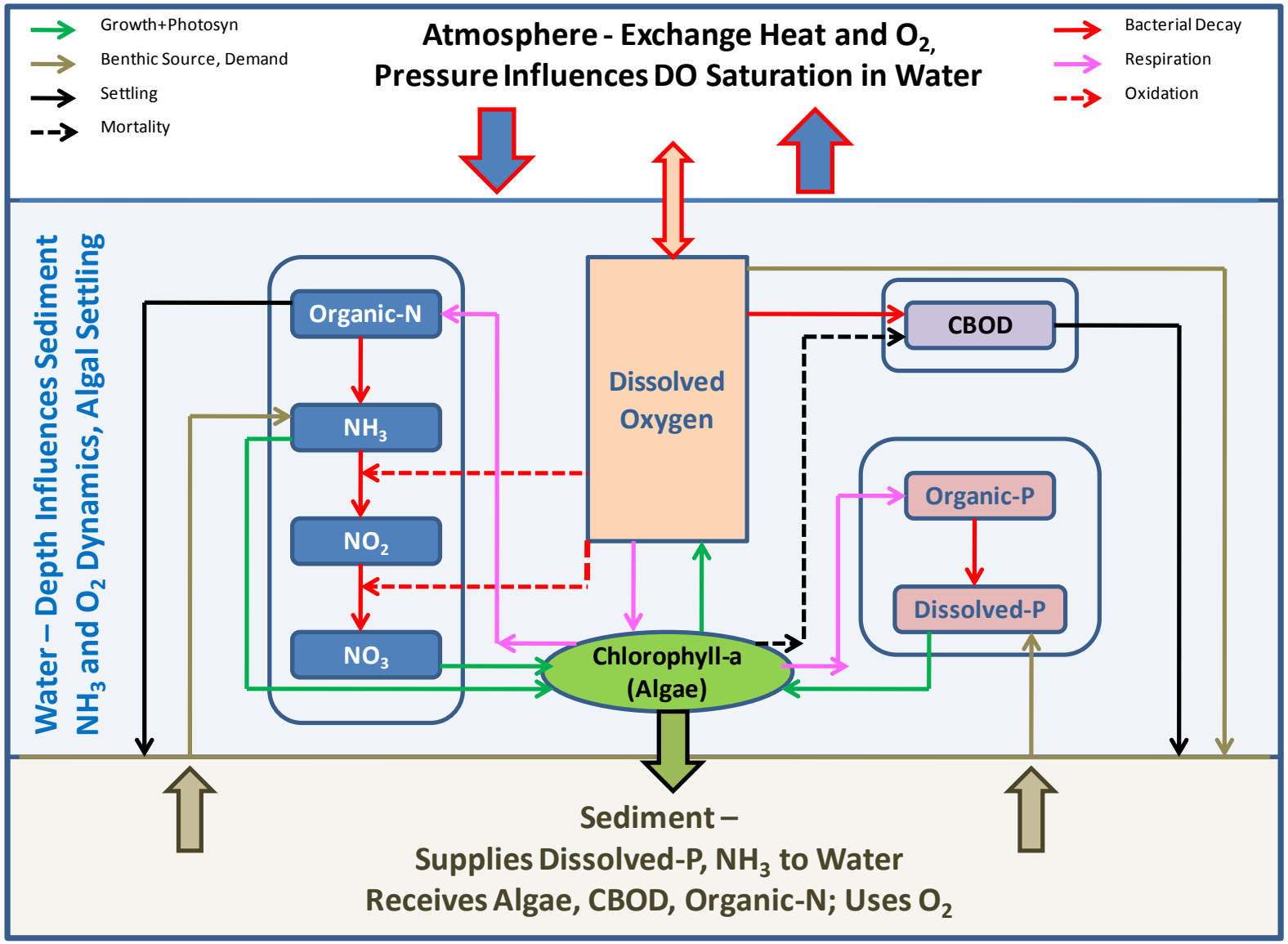


Figure 5-1. The interactions among the main constituents, and external influences (an adaptation from original DWR references). Water temperature (blue region) influences reaction rates, denoted by arrows.

Table 5-2 Parameters used in the model. Some parameters do not appear explicitly in the equations as discussed in this report.

Symbols	Description	Lit. Range Min/Max	Calibrated Value	Units	Source
Global Reaction Parameters					
α_5	Amount of oxygen consumed in conversion of ammonia to nitrite	3.0-4.0	3.0	-	Rajbhandari (1995)
α_6	Amount of oxygen consumed in conversion of nitrite to nitrate	1.0-1.14	1.14	-	Rajbhandari (1995)
p	Preference factor for ammonia nitrogen	0-1.0	0.5	-	Rajbhandari (1995)
α_7	Conversion factor Chlorophyll-a *vs.* algal biomass	10-100	14.9	µg-Chl-a mg^{-1}	Rajbhandari (1995)
α_1	Fraction of algal biomass, which is nitrogen	0.07-0.09 0.02-0.11	0.09	-	Rajbhandari (1995) Chapra (2008)
α_2	Fraction of algal biomass, which is phosphorus	0.01-0.02 0.001-0.03	0.03	-	Rajbhandari (1995) Chapra (2008)
α_3	Amount of oxygen produced per unit of algal photosynthesis	1.4-4.8	1.60	-	Rajbhandari (1995)
α_4	Amount of oxygen consumed per unit of algal respired	1.6-2.3	2.0	-	Rajbhandari (1995)
-	Dust attenuation coefficient (not shown)	0.04	0.04	-	Rajbhandari (1995)
k_2	Reaeration rate at the ambient temperature	0.02-3.4 0.01 – 0.06	0.12	day^{-1}	Rajbhandari (1995) Chapra (2008)
κ_L	Half saturation constant for light	0.02-0.1	0.085	Kcal m^{-2} s^{-1}	Rajbhandari (1995)
κ_N	Half saturation constant for nitrogen	0.01-0.3 0.01–4.3	0.05	mg L^{-1}	Rajbhandari (1995) Chapra (2008)
κ_P	Half saturation constant for phosphorus	0.001-0.05 0.001-1.5	0.02	mg L^{-1}	Rajbhandari (1995) Chapra (2008)
λ_0	Non-algal portion of the light extinction coefficient (not shown)	0.116	0.26	ft^{-1}	Rajbhandari (1995)
λ_1	Linear algal self shading coefficient (not shown)	0.002-0.02	0.003	ft^{-1} (µg-Chla L^{-1}) $^{-1}$	Rajbhandari (1995)
λ_2	Nonlinear algal self shading coefficient (not shown)	0.0165	0.0165	ft^{-1} (µg-Chla L^{-1}) $^{-2/3}$	Rajbhandari (1995)
σ_7	Algal mortality contribution to CBOD	1.0	1.0	mg (m^2 day)$^{-1}$	Rajbhandari (2002)
Regional Reaction Parameters					
k_1	CBOD decay rate at the ambient temperature	0.02-3.4 0.01 – 0.06	0.12	day^{-1}	Rajbhandari (1995) Chapra (2008)
k_3	Rate of loss of CBOD due to settling at the ambient temperature	-0.36-0.36	0.1	day^{-1}	Rajbhandari (1995)
μ_{max}	Maximum algal growth rate at the ambient temperature	1.0-3.0	1.2 - 3.0	day^{-1}	Rajbhandari (1995)
ρ	Phytoplankton respiration rate at the ambient temperature	0.05-0.5 0.01-0.04	0.15	day^{-1}	Rajbhandari (1995) Chapra (2008)
σ_1	Phytoplankton settling rate at the ambient temperature	0.5-6.0 0.06-33.0	0.1 – 1.5	ft day^{-1}	Rajbhandari (1995) Chapra (2008)
σ_6	Phytoplankton death rate at the ambient temperature	0.2 0.03-0.3	0.11 – 1.0	ft day^{-1}	Rajbhandari (2002) Chapra (2008)

Table 5-3 Model parameters, continued. Some parameters do not appear explicitly in the equations as discussed in this report.

Symbols	Description	Lit. Range Min/Max	Calibrated Values	Symbols	Source
k_n	Ammonia decay rate at the ambient temperature Ammonium decay rate	0.1-1.0 0.001 – 0.95	0.05 - 0.3	day^{-1}	Rajbhandari (1995) Chapra (2008)
k_{ni}	Nitrite decay rate at the ambient temperature	0.2-2.0	2.0 – 2.5	day^{-1}	Rajbhandari (1995)
$k_{N\text{-}org}$	Rate constant for hydrolysis of organic nitrogen to ammonia nitrogen at the ambient temperature	0.02-0.4	0.02 - 0.1	day^{-1}	Rajbhandari (1995)
σ_4	Organic nitrogen settling rate at the ambient temperature	0.001-0.1	0 - 0.005	day^{-1}	Rajbhandari (1995)
$k_{P\text{-}org}$	Organic phosphorus decay rate at the ambient temperature	0.01-0.7	0.005	day^{-1}	Rajbhandari (1995)
σ_5	Organic phosphorus settling rate at the ambient temperature	0.001-0.1	0.01 – 0.1	day^{-1}	Rajbhandari (1995)
σ_2	Benthic release rate for orthophosphate at the ambient temperature (mass transfer rate of $PO4$ in the sediment)	1.0 0.0816 0.057–21.0	0.001 - 0.3	$mg\ m^{-2}\ day^{-1}$ $m\ day^{-1}$ $mg\ m^{-2}\ day^{-1}$	Rajbhandari (1995) Sanford and Crawford(2000) Chapra (2008)
σ_3	Benthic release rate for ammonia-N at the ambient temperature (mass transfer rate of $NH3$ in the sediment)	4.0 0.06-0.1464	0.0 – 0.15	$mg\ m^{-2}\ day^{-1}$ $m\ day^{-1}$	Rajbhandari (1995) Sanford and Crawford (2000)
k_4	Benthic oxygen demand	30 – 300 0.3 – 5.8	30 - 250	$g\ m^{-2}\ day^{-1}$	Rajbhandari (1995) Chapra (2008)
Global Temperature Coefficients for Reaction Rates (not explicitly shown)					
θ(1)	BOD decay	1.047 1.02	1.047		Wilson et al. (1998) Chapra (2008)
θ(2)	BOD settling	1.024	1.024		Wilson et al. (1998)
θ(3)	DO Reaeration	1.024	1.024		Wilson et al. (1998); Chapra (2008)
θ(4)	DO SOD	1.060 1.04-1.13	1.06		Wilson et al. (1998) Chapra (2008)
θ(5)	Organic-N decay	1.047	1.047		Wilson et al. (1998)
θ(6)	Organic-N settling	1.024	1.024		Wilson et al. (1998)
θ(7)	Ammonia-N decay	1.083	1.083		Wilson et al. (1998)
θ(8)	Ammonia-N benthic source	1.074	1.074		Wilson et al. (1998)
θ(9)	Nitrite-N decay	1.047	1.047		Wilson et al. (1998)
θ(10)	Organic-P decay	1.047	1.047		Wilson et al. (1998)
θ(11)	Organic-P settling	1.024	1.024		Wilson et al. (1998)
θ(12)	Dissolved-P benthic source	1.074	1.074		Wilson et al. (1998)
θ(13)	Algae growth	1.047	1.047		Wilson et al. (1998)
θ(14)	Algae respiration	1.047	1.047		Wilson et al. (1998)
θ(15)	Algae settling	1.024	1.024		Wilson et al. (1998)
θ(16)	Algae death	1.047	1.047		Wilson et al. (1998)

6 Conceptual Model of the Delta Used in QUAL's Nutrient Model

QUAL's conceptual model of nutrient dynamics (Section 5) is general enough for application in many surface water bodies. However, in its implementation within DSM2-QUAL, this conceptual model is applied specifically in the Delta, a geographically large and physically diverse estuary. Figure 6-1 shows several aspects of the Delta from a flooded island in Franks Tract, to a remnant of functioning tidal marsh in Suisun Marsh, to the channels of water in the central and southern Delta which have been altered by the introduction of a system of levees that channelize flow. Thus, the parameterization of the nutrient model (i.e., the way model parameter values, identified in Table 5-2 and Table 5-3, are set in each channel in the model grid) needs to be varied to account for differences in nutrient dynamics that can be influenced by differences in hydrology, bathymetry and water quality characteristics. Parameter values were set in the nutrient model within five parameterization regions that in large part reflect regional differences in Delta hydrology, and other characteristics that have been observed in specific regions. This section discusses the assumptions behind the regionalization applied in this implementation of the QUAL nutrient model.

6.1 A Very Brief Description of Delta Hydrodynamics

Figure 4-2 shows the general location of the DSM2 river inflow boundaries and the major export locations in the south and central Delta. Inflow, outflow, exports and diversions in the Delta vary seasonally and regionally. Similarly, net outflow volumes moderate the tidal influence represented in DSM2 *via* the stage boundary at Martinez. Figure 6-2 is a cartoon illustrating the major hydrologic influences in the Delta. In DSM2, tidal influences introduced at Martinez produce variations in stage (water level) that can be felt throughout much of the model domain (double-ended arrows in Figure 6-2), although the extent of tidal influence within the Delta depends on the volume of outflow and the timing of the spring-neap cycle. Inflow volume to the Delta (single-ended arrows) varies by source locations and the season. The largest volume of inflow comes from the Sacramento River in the winter wet season – during exceptionally high flow years, flooding in the Yolo Bypass distributes some of this flow further downstream. Large volumes of water are exchanged between the Sacramento and San Joaquin Rivers through Threemile Slough and at the confluence of these two rivers (see: curved, partially transparent arrows in Figure 6-2). Exports and diversions (including agricultural diversions) can strongly influence Delta flow patterns, with the majority of exports removed in the south of the Delta.

6.2 QUAL-Nutrient Parameterization Regions

Figure 6-3 through Figure 6-7 illustrate the areas defining the five general "parameterization regions", as defined below, applied in the current application of the QUAL nutrient model. Note that the open water areas in DSM2, called "reservoirs" in DSM2 terminology, were

parameterized separately as their nutrient dynamics is considered to be different from dynamics in Delta channels. DSM2 "reservoirs" are also dealt with numerically as fully mixed volumes in DSM2, which is different to the numerical treatment for DSM2 channels.

A *parameterization region* in the QUAL nutrient model consists of those channels in DSM2 in which each Regional Reaction Parameter in Table 5-2 and Table 5-3 was set at the same value at the start of the calibration process. As the iterative calibration process proceeded, parameters were varied by region, but not within the regions. In the final few calibration iterations, occasionally the value for given parameter might be varied within a region. For example, in the region denoted "Confluence to Martinez" (see Figure 6-3), the channels defining Grizzly Bay and Honker Bay were found to have quite different characteristics in terms of DO concentrations, so these parameters were varied within the Confluence to Martinez region for each of these bays. Note that this region includes the (stage) boundary at Martinez. Although they are both close, given their differing proximity to Martinez the two bays are affected differently by the Martinez boundary condition.

The five parameterization regions specified for this project in large part reflect regional differences in hydrology. However, there are large variations in hydrology even within these regions as their characteristics will change not only with Delta inflow but also with tidal cycle and with season. For example, in January 1994 the combined inflow from the Sacramento River and the Yolo Bypass was 14,218 cfs (cubic feet per second), inflow from the San Joaquin River was 1773 cfs and combined SWP+CVP exports was 5735 cfs on a monthly average basis, but these flows were 210,006 cfs, 33,122 cfs and 2757 cfs in January 1997, respectively. These values reflect more than an order of magnitude difference in inflow and only a factor of two difference in export levels. As a consequence, in these two examples tidal influences within the parameterization regions will vary significantly.

Figure 6-3 illustrates the "Confluence to Martinez" region. This region is dominated during lower flow periods by high salinity (ocean salinity). Previous work (for the Franks Tract project[12]) has shown that salinity intrusion further upstream on the Sacramento River out of this region occurs primarily under extremely low flow conditions. Water flowing through Montezuma Slough, the main channel in Suisun Marsh, reverses direction tidally and is influenced not only by water flowing through the lower Sacramento River but also by mixing of waters from the smaller side channels and sloughs. The area roughly bounded by the dashed triangle in the lower left corner of Figure 6-3, could almost be considered a sub-region on its own, as it is strongly influenced by both the Sacramento and San Joaquin Rivers and by ocean influences. However, for simplicity, this area was instead incorporated in the Confluence to Martinez region.

[12] http://www.water.ca.gov/frankstract/

Figure 6-4 illustrates the Sacramento River Region. This region includes the main stem of the Sacramento River from the confluence with the San Joaquin River to the model boundary for the Sacramento River, as well as the area which includes the tributaries in the Yolo Basin and Cache Slough. It does not include Liberty Island which is geographically within this portion of the model domain – as discussed above, open water areas like Liberty Island are dealt with separately. This region is dominated by Sacramento River water.

Figure 6-5, the Stockton Region, is mainly influenced by the San Joaquin River. This section of the San Joaquin River, particularly near the Stockton Ship Channel, has experienced problems with low DO during low flow periods. The San Joaquin River has higher nutrient concentrations than the Sacramento River.

Figure 6-6, the Central Delta parameterization region, encompasses the central and southern portion of the Delta including the downstream section of the San Joaquin River. This region is tidally influenced. The parameterization of the reservoirs within the boundary of this region – Franks Tract, Mildred Island, Clifton Court Forebay and Discovery Bay – is considered separately. The flow in these channels is strongly affected by export volumes, and the channels can experience low flow during the summer months. Invasive water weeds can clog and overwhelm some of these channels, severely restricting flow and altering nutrient dynamics particularly in the summer months.

Figure 6-7, the East Delta parameterization region, encompasses the eastern portions of the Delta. This region is heavily influenced by the Sacramento River when the Delta Cross Channel (DCC) is open, but mainly by the Cosumnes and Mokelumne Rivers when the DCC is closed. There are also many agricultural influences in this region, and the flow volume in some of the outer channels is low particularly in the warmer months.

Reservoirs (Liberty Island, Franks Tract, Mildred Island, Clifton Court Forebay and Discovery Bay) were initially given identical parameter values. However, additional nutrient data was identified (Lehman *et al*., 2010) for Liberty Island that allowed this open water area to be parameterized differently from the other reservoirs, and to more effectively represent Liberty Island nutrient dynamics.

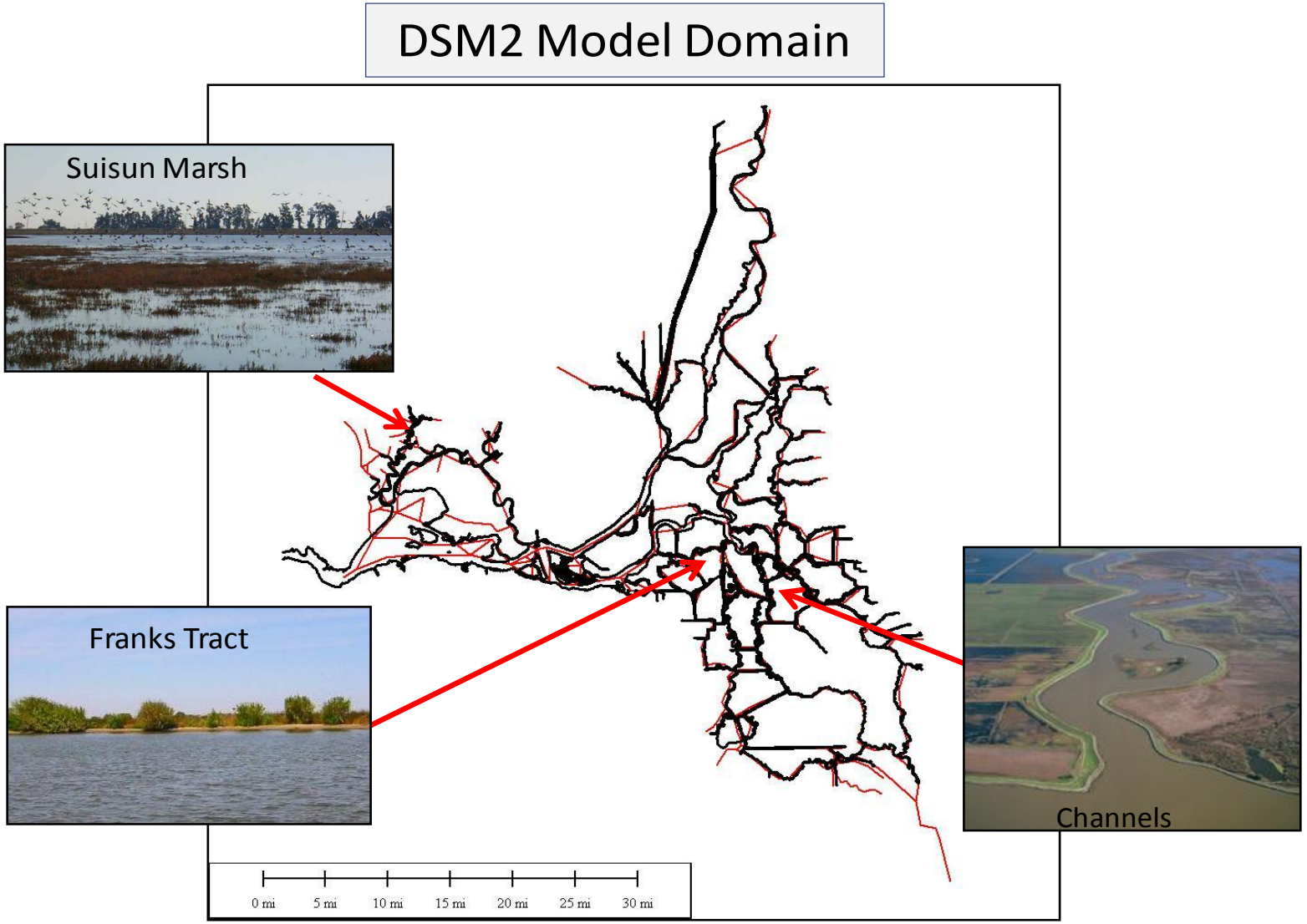


Figure 6-1 The Delta is a physically diverse system, as illustrated at several locations within the DSM2 model domain.

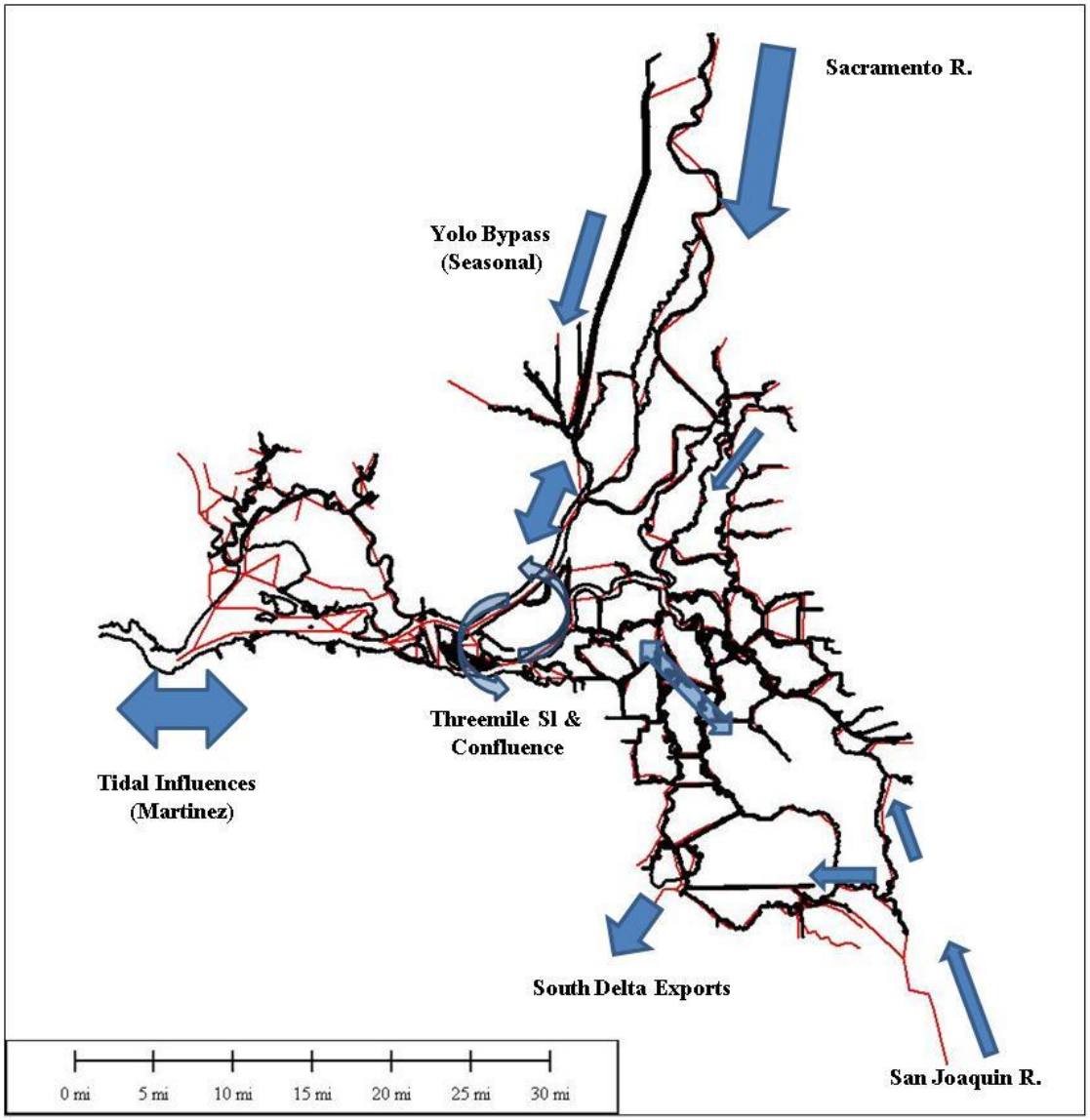


Figure 6-2 Overview figure of some major influences on Delta hydrodynamics – river inflow, exports, and tidal influences. Large volumes of water are exchanged between Threemile Slough and at the confluence of the Sacramento and San Joaquin Rivers.

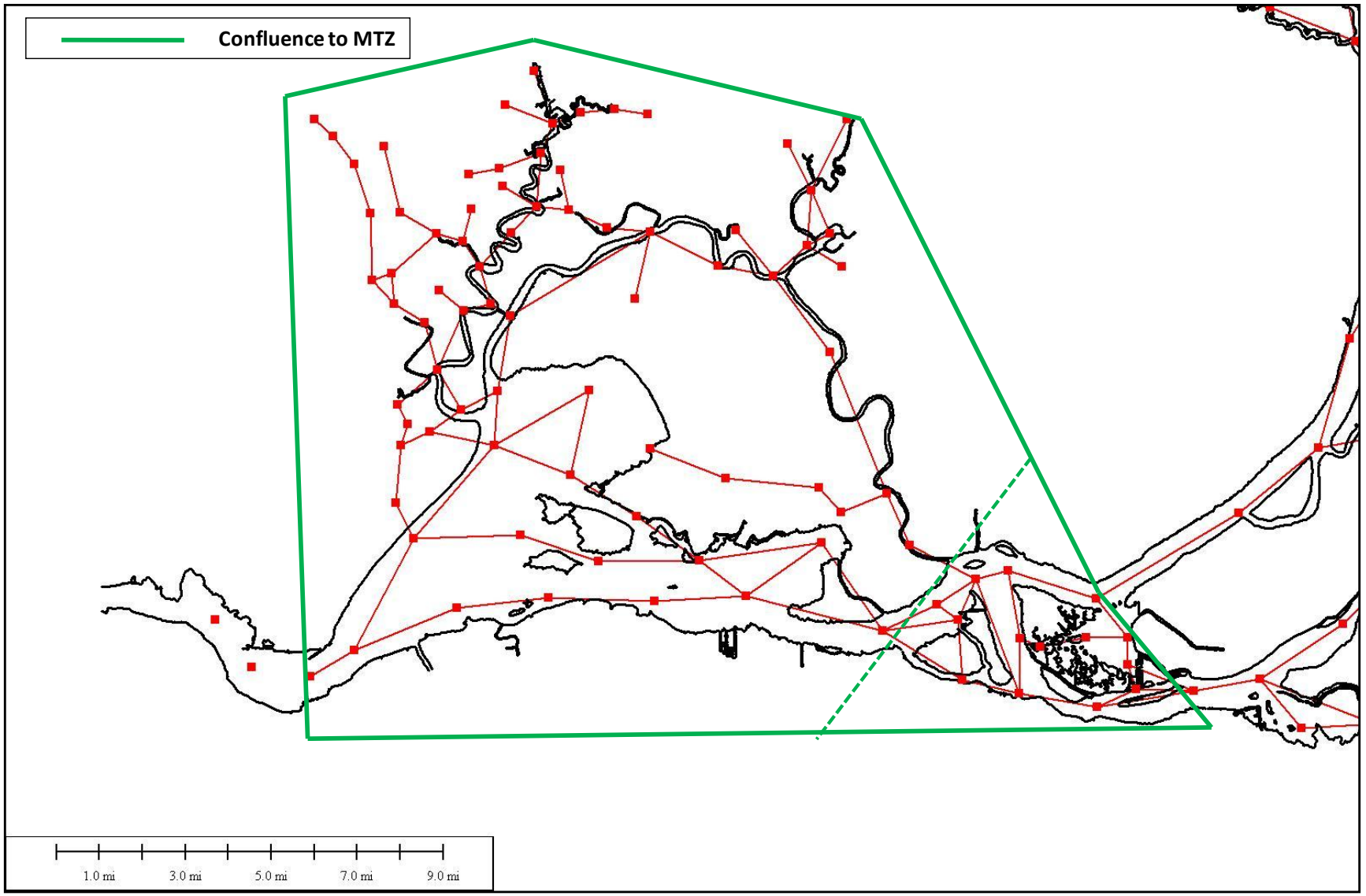


Figure 6-3 The parameterization region extending from the confluence west to the model boundary at Martinez, including Suisun Marsh. Dashed line indicates the confluence region of the Sacramento and San Joaquin Rivers

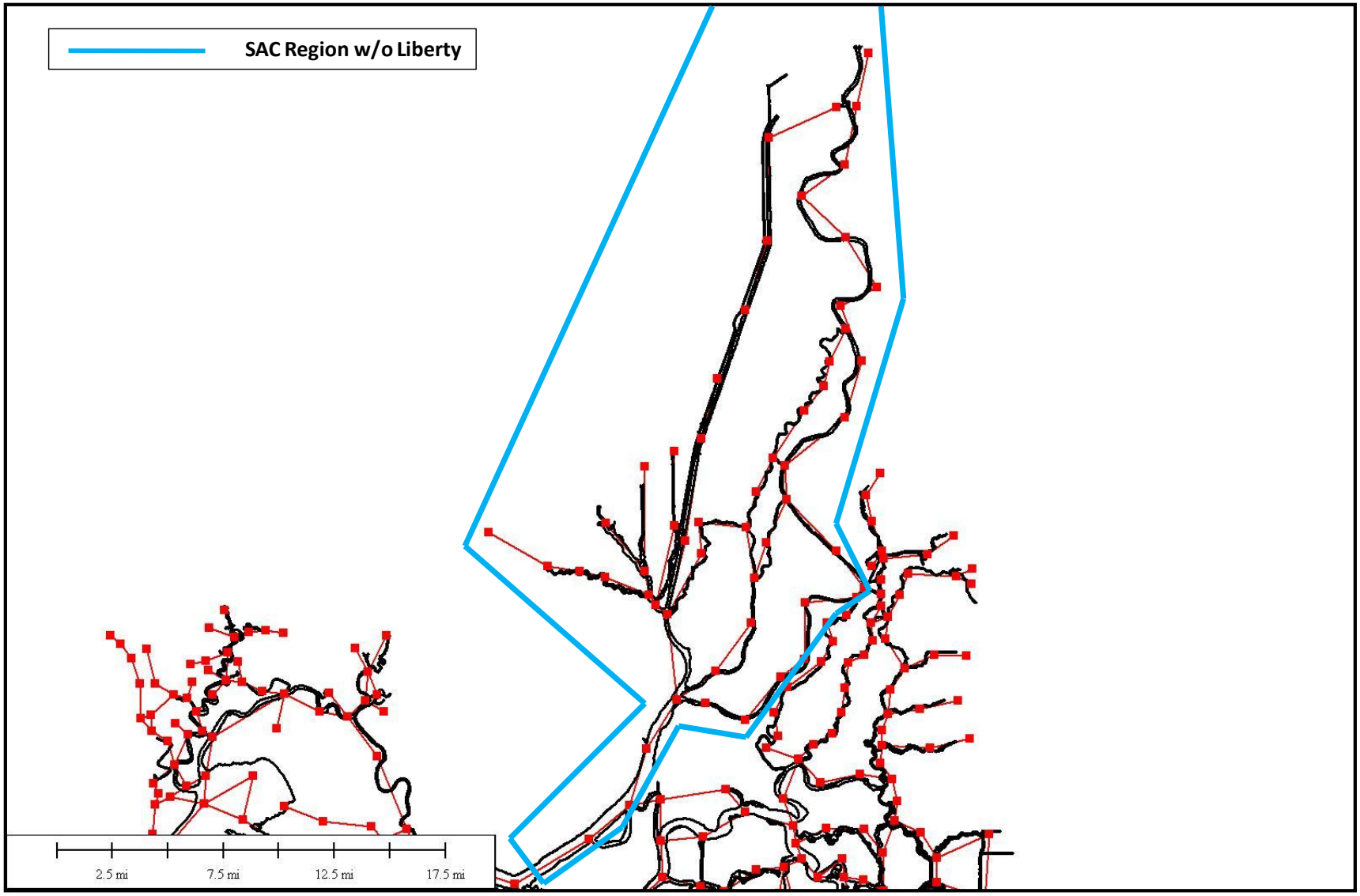


Figure 6-4 The parameterization region extending north from the confluence to the Sacramento River inflow model boundary, and incorporating the Yolo Basin and Cache Slough. Although Liberty Island is included in this region geographically, it is not included in this parameterization region.

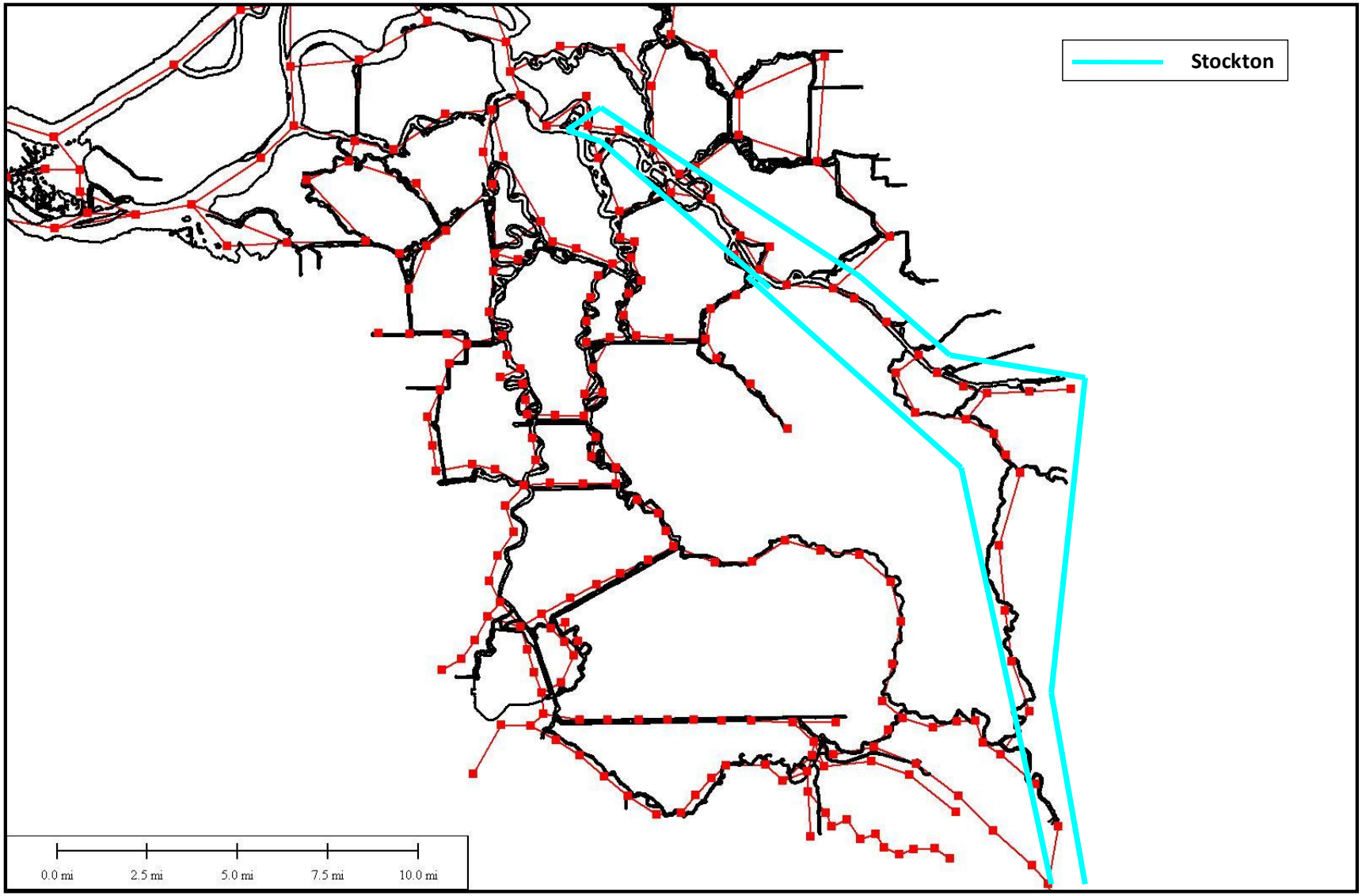


Figure 6-5 The parameterization region for the upstream portion of the San Joaquin River.

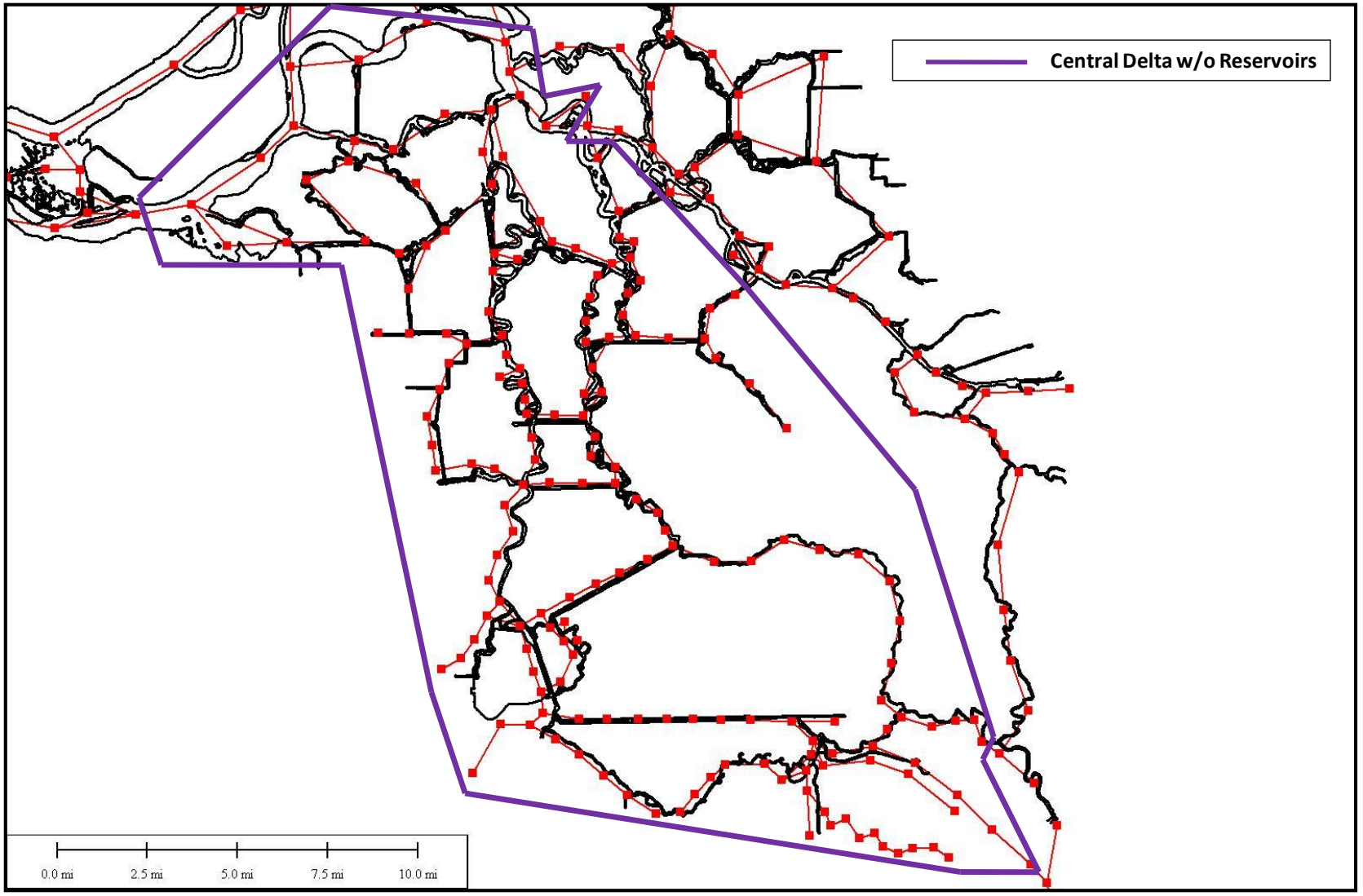


Figure 6-6 The parameterization region for the central and southern portion of the Delta. The reservoirs within the boundary of this region were parameterized separately. These area is affected by exports and low flow during the summer months. Invasive water weeds can severely restrict flow and alter nutrient dynamics.

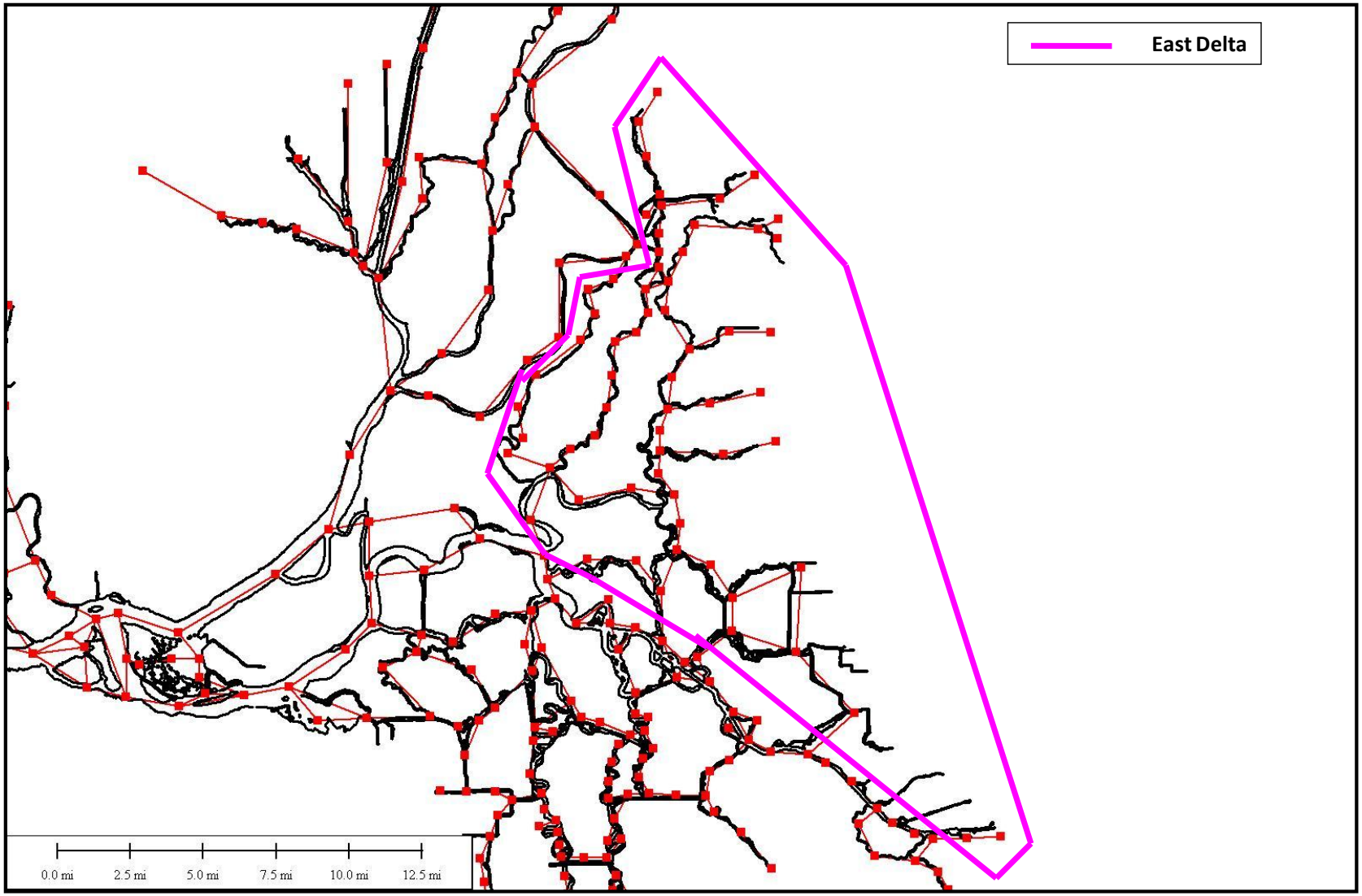


Figure 6-7 The parameterization region encompassing the East Delta – this region is heavily influenced by the Sacramento River when the Delta Cross Channel (DCC) is open, but mainly from the Cosumnes and Mokelumne Rivers when the DCC is closed. There are also many agricultural influences in this region.

7 Data: Sources and Refinement

Several data sources were identified for data needed in the development of boundary conditions and for the model calibration and validation effort. Data quality was assessed and several approaches were used to improve the representation of the data. Details on the data sources and the data gathered for the entire modeling effort are covered in Appendix I, Section 25.1. All of the data collected (whether or not it was used in the modeling) was documented and delivered to SWC. The data was also made available to DWR's DMS.

Constituent concentration data was originally reported in a variety of measurement units depending on data source. Reported concentrations were converted to units of mg L^{-1}, the measurement unit used in QUAL, in terms of the molecular weight the atom characterizing the chemical species. For example, the concentration of orthophosphate, PO_4, is calculated as milligrams of PO_4-P, not in terms of the molecular weight of the entire chemical species *(i.e.*, without accounting for the weight of the oxygen atoms in the chemical species).

Names for locations used in the preparation of this document are listed in Appendix I, Section 25.1. Table 25-1 lists the correspondence between common names for locations in-Delta.

7.1 Data Sources

Raw data were downloaded from the BDAT[13], DWR's Water Data library[14], IEP[15], CDEC[16] and USGS[17] websites. Meteorological data were downloaded from the CIMIS[18] website, and access to NOAA meteorological data was purchased and downloaded from a NOAA website (NNDC Online Store, NOAA Data Center). Some data were obtained directly from individual researchers or from individuals identified as representing an organization. Effluent data were obtained from the Central Valley and San Francisco Regional Water Quality Control Boards, directly from contacts at the individual WWTPs, or from previous compilations of effluent data. Measurements upstream and downstream of effluent outfalls, called receiving water measurements, were collected when available. All data sources obtained from individuals in any of these ways (i.e., not downloaded directly from a publically available database) are documented in Section 25.1 in Appendix I.

7.2 Data processing methodology

Measurement units and data measurement methodology were checked in each data set for consistency with DSM2 model assumptions. Latitude-longitude (lat-long) co-ordinates were

[13]http://bdat.ca.gov/
[14]http://www.water.ca.gov/waterdatalibrary/
[15]http://www.iep.ca.gov/data.html
[16]http://cdec.water.ca.gov/
[17]http://sfbay.wr.usgs.gov/access/wqdata/
[18]http://wwwcimis.water.ca.gov/cimis/welcome.jsp

obtained to verify the position of the data acquisition location and to ensure appropriate placement in the model. Data downloaded from the BDAT website, lat-long co-ordinates of the measurement location, and the name used in model calculations are documented in Figure 25-6 through Figure 25-12 in Appendix I. Raw data were downloaded from BDAT either in EXCEL format, CSV format, tabular text format, or in some cases, was downloaded in DSS format directly to the program HEC-DSSVue[19].

Data obtained in anything other than DSS format required further processing for use in setting model boundaries, as DSM2 uses the DSS data format (employed in HEC-DSSVue) for importing the data into model simulations. MATLAB codes and other data processing tools were developed to automate much of the transfer to DSS format. Irregular time series data were further processed into regular time series data for use in setting boundary conditions, typically as daily or monthly time series with linear interpolation between the irregularly-spaced data points. Processing irregular data into regular time series was not necessary for plotting or for residual calculations in the calibration/validation process.

7.3 Data Quality

Data quality was mixed, depending on the constituent. All data were assessed visually (by plotting) to check for unreasonable values (*e.g.*, negative numbers) and in comparison with data at nearby locations. When problems with data quality clearly occurred (*e.g.*, all nearby stations had significantly different magnitudes), suspect data were deleted from the time series.

Continuous time series (15-minute or hourly) of temperature and DO data were available at or near the main model boundaries on the Sacramento River, the San Joaquin River and at Martinez at well as at several other locations within the model domain. There were frequently large gaps in the data during the modeled period for each of these data types. For example, temperature data at some locations would decrease in magnitude and suddenly jump in value, as illustrated in Figure 7-1.

Chl-a data obtained from continuous measurement equipment as fluorescence was deemed to be of insufficient quality to use in setting model boundary conditions or as calibration data. Jassby (2005) converted fluorescence values into chl-a concentrations using linear regressions between grab sample chl-a data paired with the nearest recorded fluorescence data as a method for conversion to chl-a mass units. Muller-Solger (2002) observed that fluorescence and corresponding chl-a concentrations measured in grab samples were often low (Chl. a < 5 ug/L) and only weakly correlated with each other. We also analyzed fluorescence data for this project and developed regression relationships between fluorescence and chl-a data at Hood, Mossdale and Martinez obtained from BDAT. The model fits, shown in Appendix I Section 25.3, Figure 25-17 through Figure 25-19 respectively, were viewed as too poor in quality to be useful.

[19]http://www.hec.usace.army.mil/software/hec-dss/hecdssvue-dssvue.htm

The quality of grab sample data from BDAT and USGS sources for the nutrients was good, as assessed by comparison with data at nearby locations and from different agencies, although it was generally only available at approximately monthly or bi-monthly intervals and the time span was variable. Nutrient data measurements available through BDAT ceased at many in-Delta locations in 1995.

Figure 7-2 shows a comparison of Environmental Monitoring Program (EMP) and USGS measurements at Rio Vista and Point Sacramento. The original measurement of chl-a was converted to algal biomass as described in Section 5.2.4. Both agencies performed these measurements at irregular intervals, approximately monthly. The measurements from the two agencies are within the same range of magnitude in most months. Although measurements could vary by factors of 2 – 5 particularly when a peak occurred, the general patterns are similar.

Figure 7-3 shows a similar comparison for DO data at the same locations. The measurements generally track very closely, both in magnitude and pattern. Figure 7-4 shows NO_3+NO_2 measurements – again they track fairly closely in magnitude when taken at similar times.

The situation for PO_4 is quite different. Figure 7-5 shows the inter-agency comparison at Point Sacramento is not very good for this constituent. In addition to differences in magnitude of about a factor of two between the agencies, there is no apparent similarity in pattern. On the other hand, measurements by the same agency at nearby locations were more consistent. Figure 7-6 shows the similarity in EMP measurements at Point Sacramento and Chipps both in pattern and magnitude (lower plot), while the USGS measurements at Point Sacramento and a similar downstream location at RSAC077 (upper plot) are very different in pattern and magnitude, although the concentration range of the measurements is similar at the two USGS locations.

Figure 7-7 through Figure 7-9 show interagency comparisons of several constituents at similar locations on the lower Sacramento River below the confluence – comparing Martinez and Suisun at Bulls Head or comparing Chipps and Pittsburg. As with the direct location comparisons, algae (Figure 7-9, upper plot), DO (Figure 7-9, lower plot), and NO_3+NO_2 (Figure 7-7) track closely in magnitude and pattern, while PO_4 (Figure 7-8) measurements again vary in magnitude and pattern between the two agencies. Thus, the constituent comparisons are good between the USGS and EMP measurements except for PO_4.

7.4 Missing data

Although boundary conditions require that data gaps be filled in some manner prior to application to supply a regular time series of data to HYDRO and QUAL, data for calibration and validation required no further modification after removal of suspect data.

Several methods were used to fill gaps in time series of data used for boundary conditions. Missing data for effluent boundaries and flow boundaries presented slightly different problems and different approaches were used for each. The methodology for setting effluent boundary

conditions and the time periods when effluent data were available for each constituent is covered in Section 8.4 The methodology for filling large data gaps in boundary condition data focused on setting values using Water Year Type as the primary criterion. For example, when an entire year or a large portion of a year of data were missing for DO or temperature, a (filled) year of the same Water Year Type was used to replace the missing data. The reasoning behind this is discussed in Section 11.1.

For continuous temperature and DO time series used to set river inflow boundary conditions at Sacramento, Vernalis and Martinez, the software package CatMV 1.1[20] was purchased to automate gap filling. The statistical methodology used in this package, Singular Spectrum Analysis (SSA), is described in Appendix I, Section 25.4. This method was generally used to fill short (~ 2 week) gaps for an entire year or two, and occasionally to fill longer gaps (up to 1 – 2 months). Figure 7-10 illustrates the results when gaps in water temperature for the Sacramento boundary condition were filled using the CAT-MV software.

Some data gaps were filled "by hand" using data from a nearby time period (for example, when temperatures were nearly constant), by selecting data from a time period in a different year with a similar trend and magnitude, or by using data from a near-by location. In cases where the gap was very small (part of a day), linear interpolation was used to fill data gaps, although this method was rarely used with continuous measurement data. Linear interpolation was used on irregular time series when converted to regular interval data – this is the default methodology used in HEC-DSSVue for conversion to regular time series.

When data values were missing because they were below instrument detection limits, the value was set at the half the stated value of the detection limit, for both boundary condition data and for comparison in calibration data. In calibration, comparisons of model with measurements at the detection limit are a source of bias in the statistical measures. Although, such measurements are typically within the uncertainty of the model calculations, an attempt was made to document bias due to detection limit issues when possible. Further discussion is found in Section 12.5.1.3.

For meteorological data, the gaps in NOAA cloud cover data were estimated using solar radiation data (from CIMIS). For example, the gaps of cloud cover were filled using similar patterns of solar radiation. If solar radiation data were not available, the gaps of cloud cover were just estimated comparing the cloud cover just before or after the gaps. Wind speed data gaps were filled using time data from periods with similar wind magnitudes in the same season.

[20] http://www.gistatgroup.com/cat/detail.html#mv

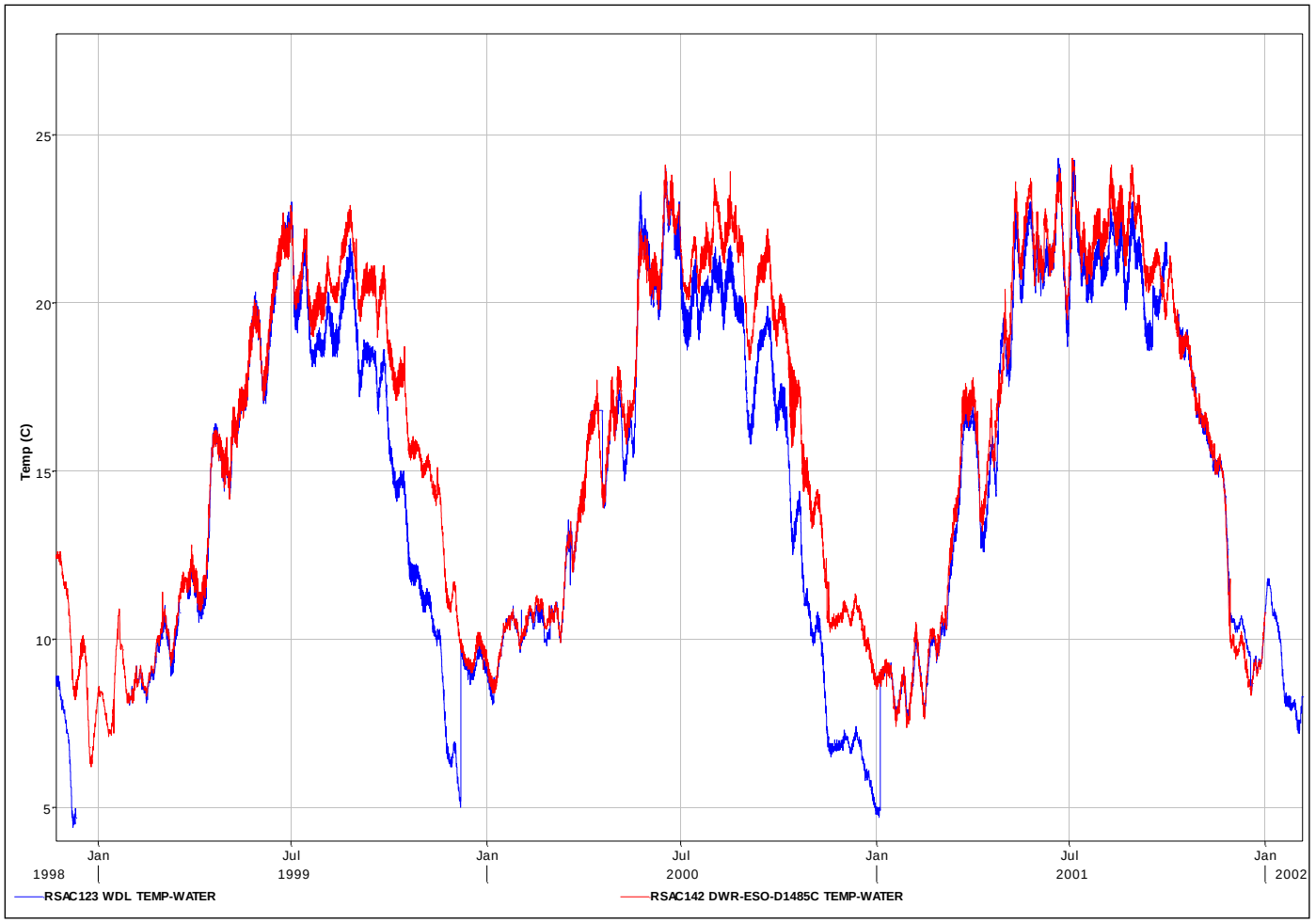


Figure 7-1 Suspect data were identified at RSAC123 (blue line) by large jumps in value at low temperatures in comparison with water temperature data at RSAC142 (red line). These locations are on the Sacramento River (See Table 25-1).

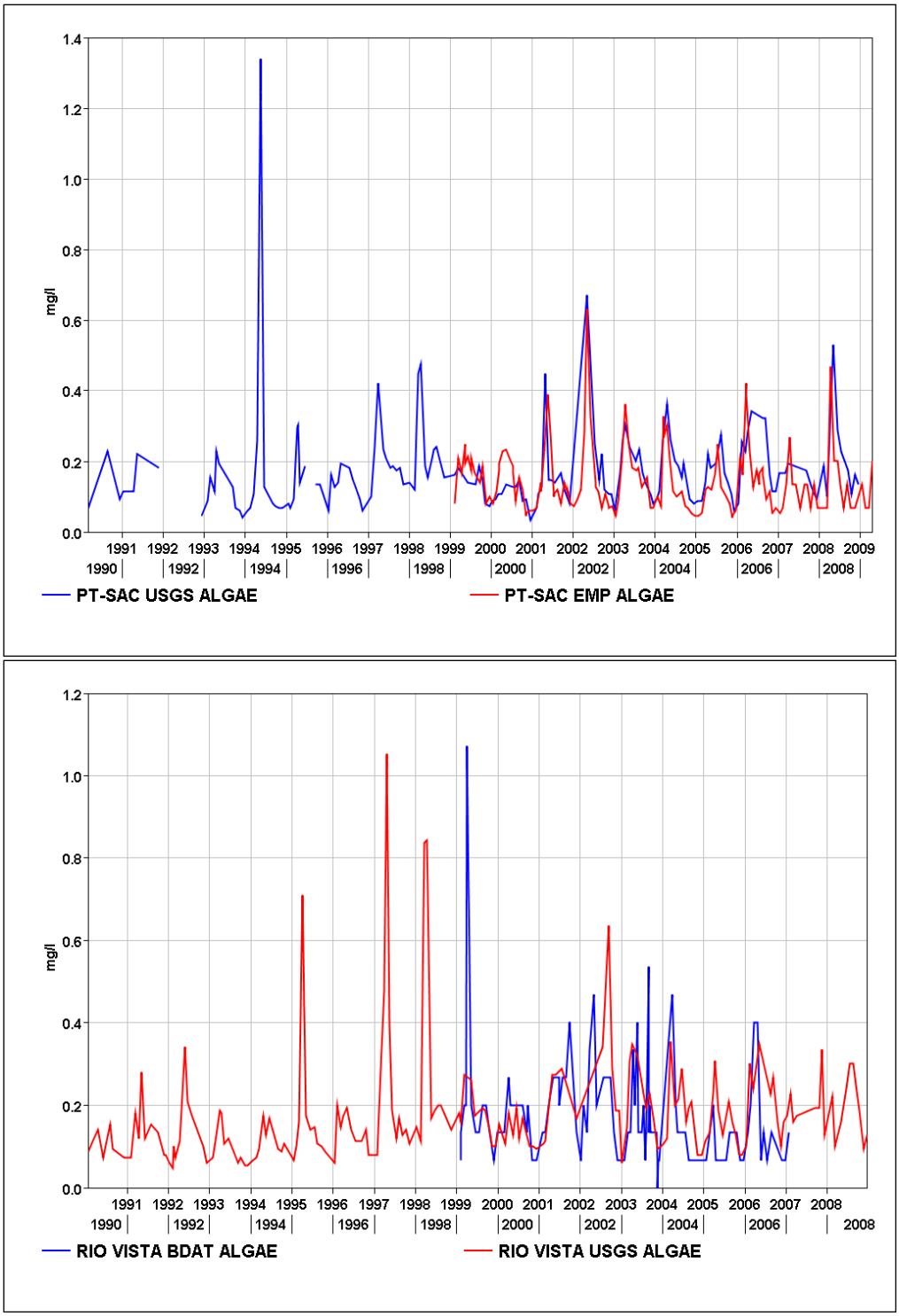


Figure 7-2 Comparison of EMP (same as BDAT) and USGS measurements at Point Sacramento (upper) Rio Vista (lower) – chlorophyll a measurements were converted to biomass of algae which is shown in the plots above.

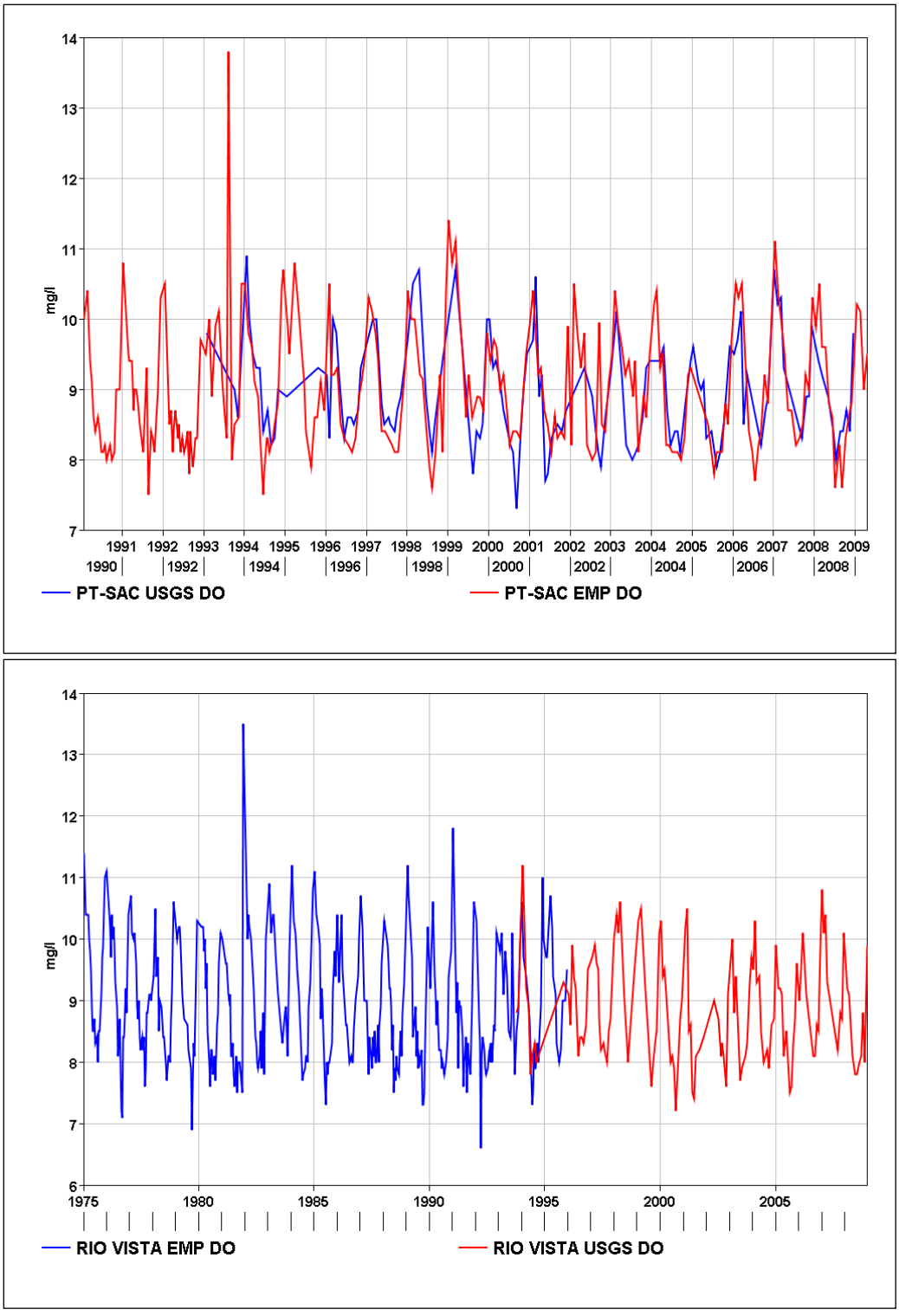


Figure 7-3 Comparison of EMP and USGS DO measurements at Point Sacramento (upper) Rio Vista (lower).

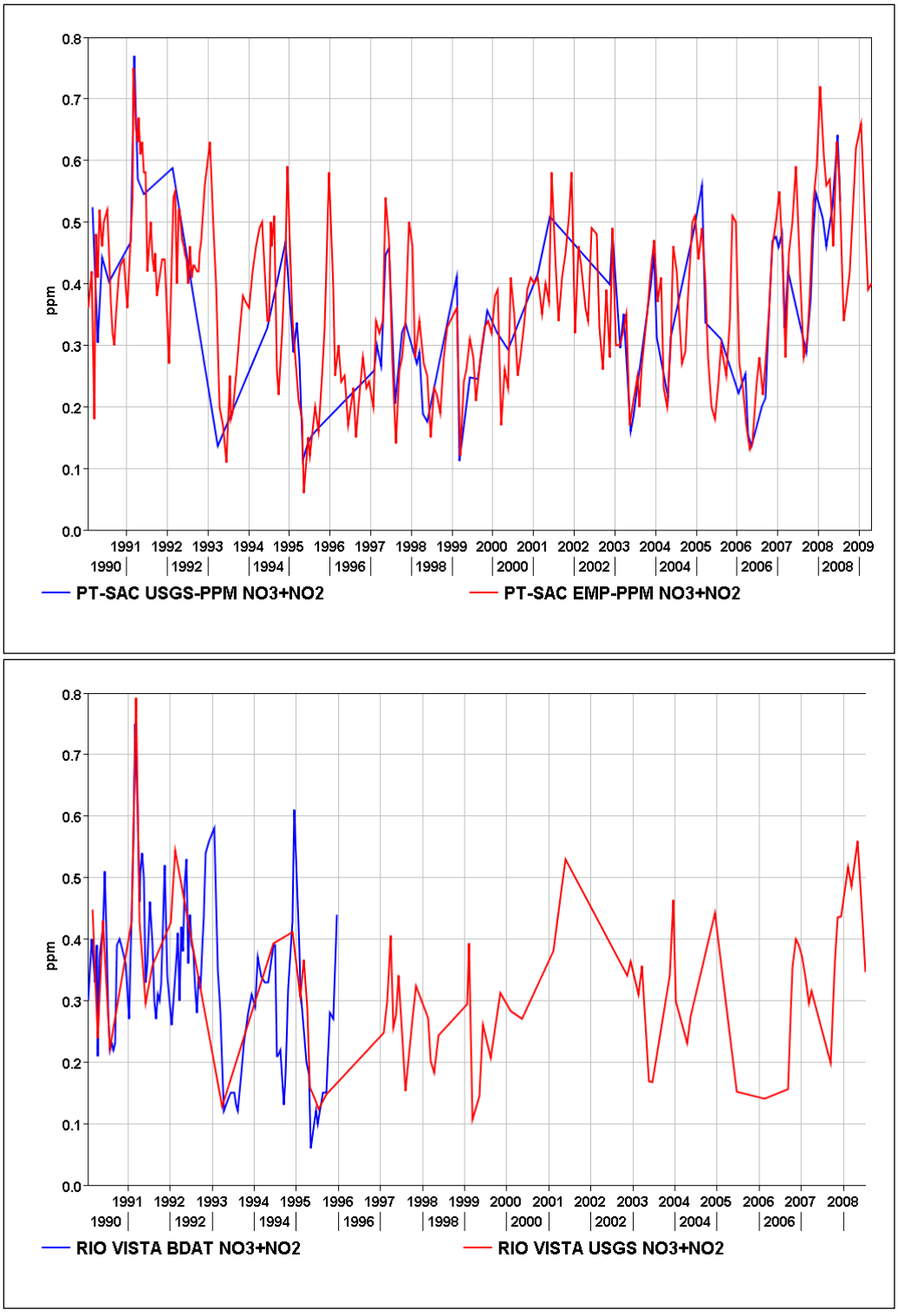


Figure 7-4 Comparison of EMP and USGS Nitrate+Nitrite (NO3+NO2) measurements at Point Sacramento (upper) Rio Vista (lower).

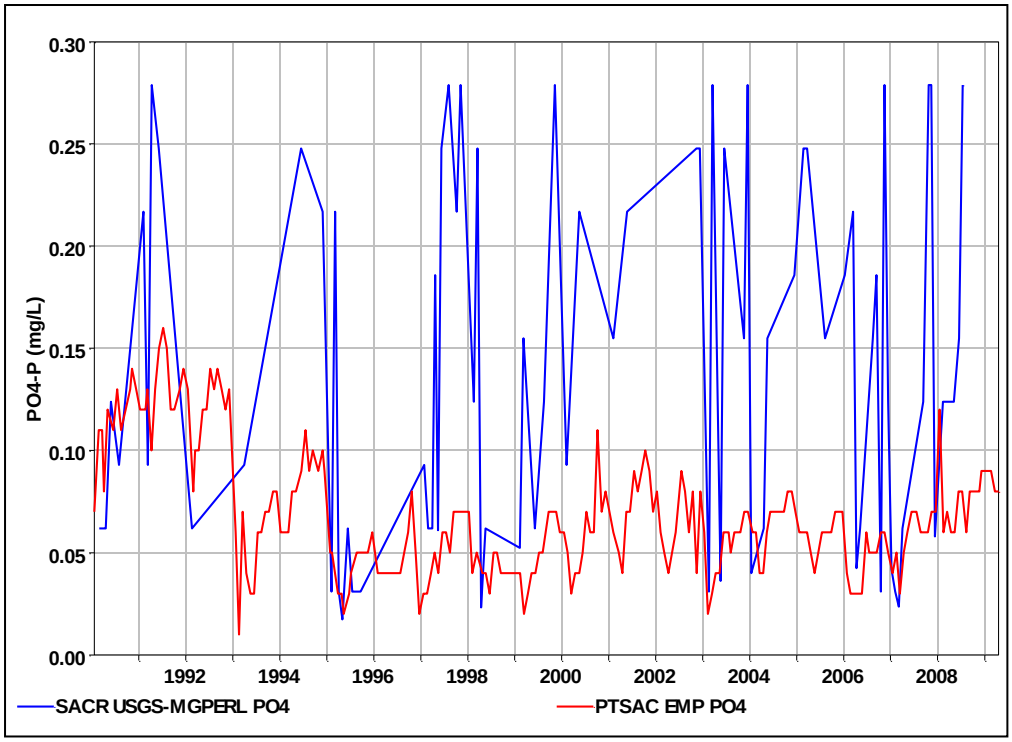


Figure 7-5 Comparison of EMP and USGS ortho-phosphate (PO_4) measurements at Point Sacramento.

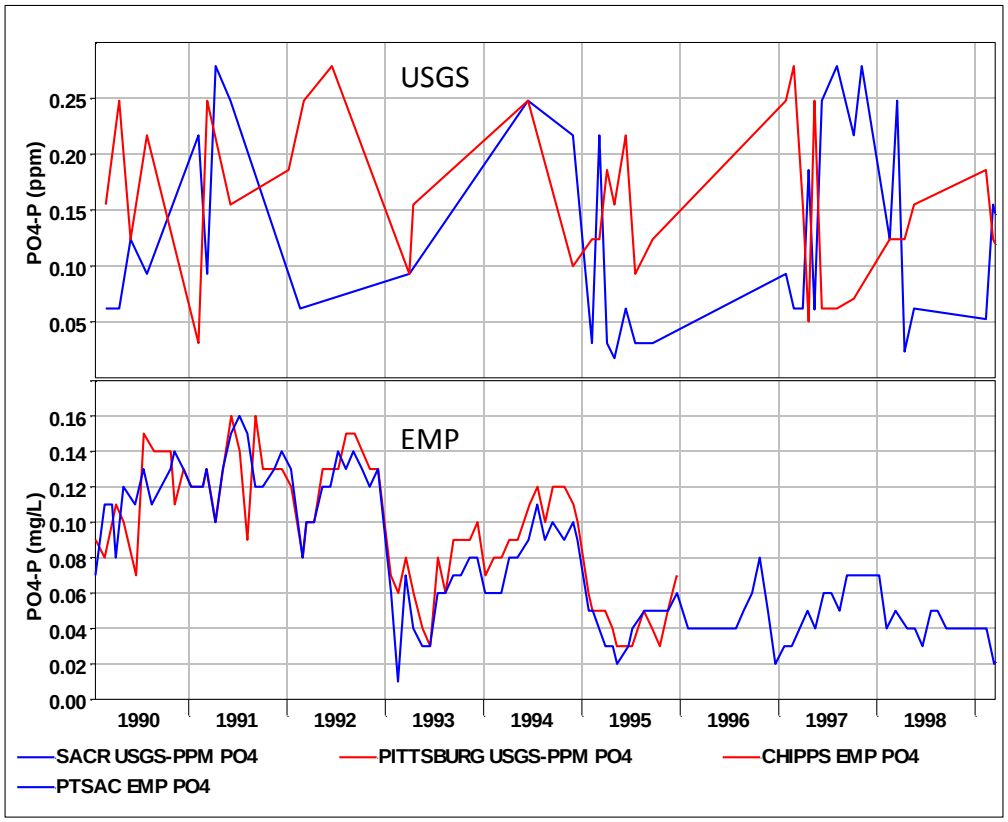


Figure 7-6 Comparison of ortho-phosphate (PO_4) measurements taken by EMP (lower) and USGS (upper) at Point Sacramento and a similar downstream location showing differences between locations and measurement agencies.



Figure 7-7 Comparison of EMP and USGS Nitrate+Nitrite measurements near Martinez (upper) and near Chipps and Pittsburg (lower).

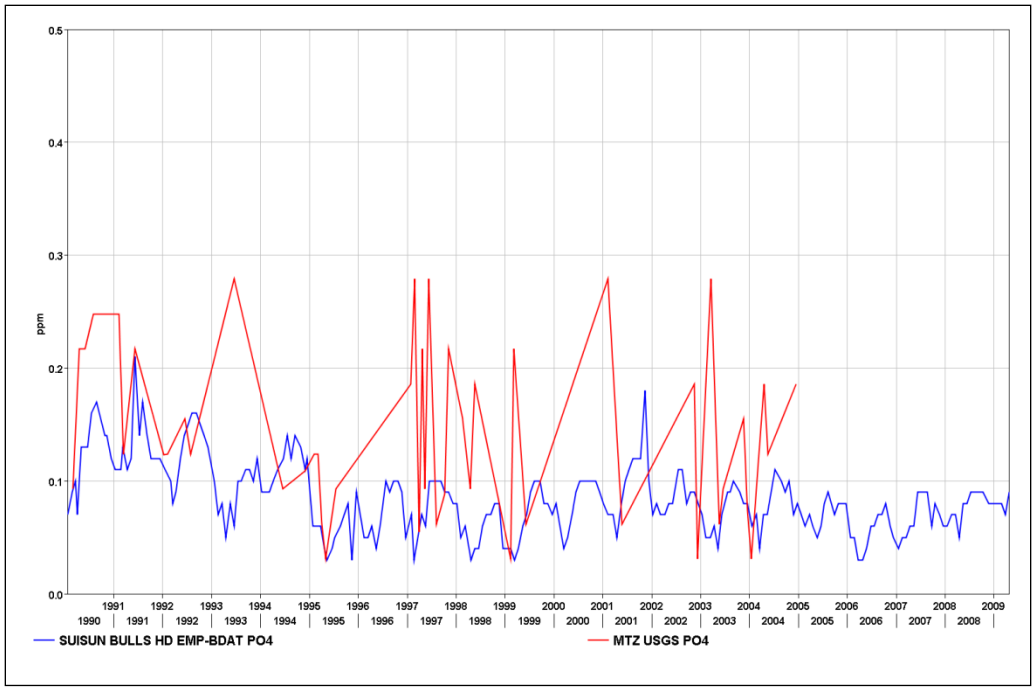


Figure 7-8 Comparison of EMP and USGS PO_4measurements near Martinez.

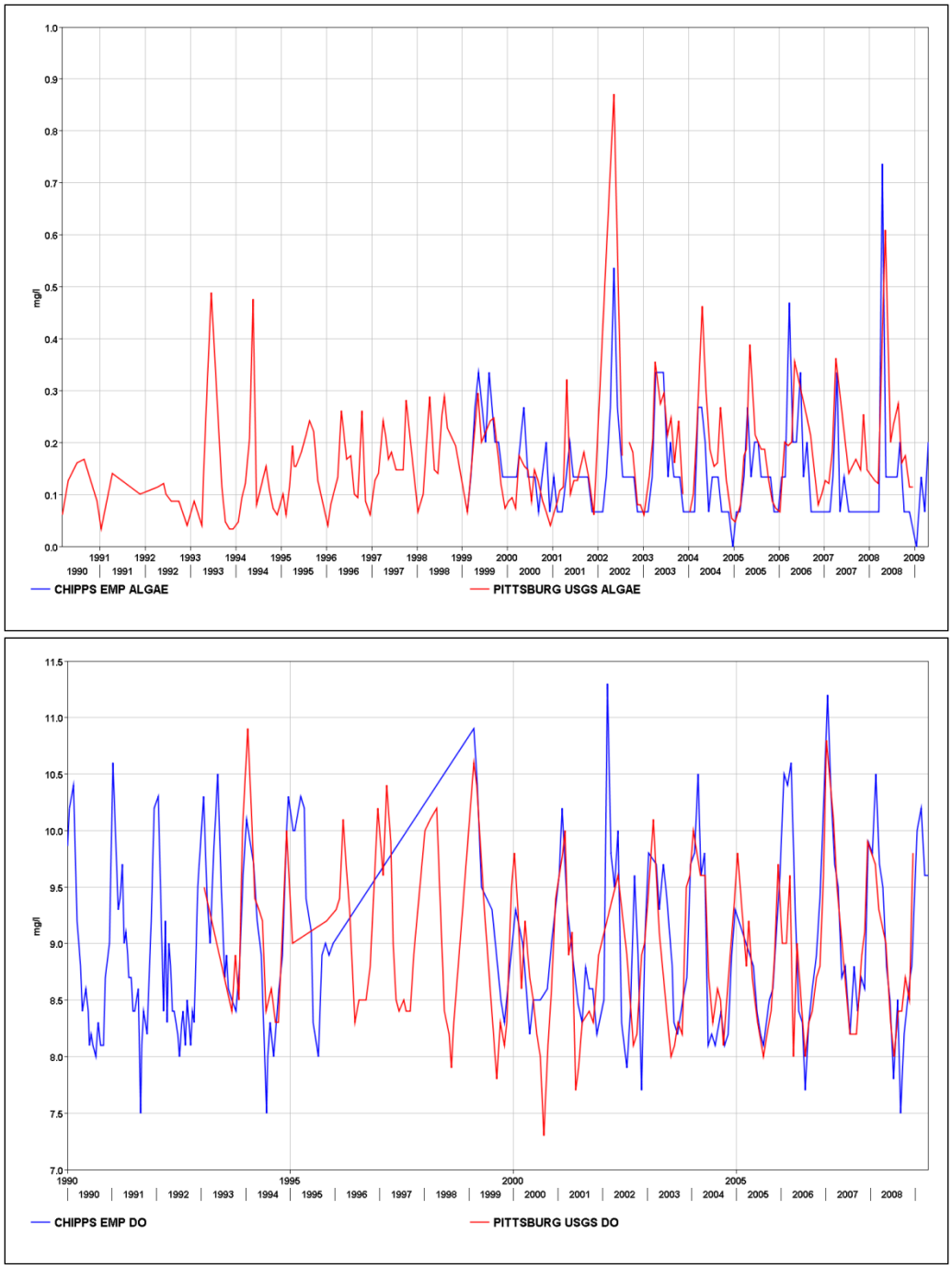


Figure 7-9 Comparison of EMP and USGS algae (upper) and DO (lower) measurements near Chipps and Pittsburg.

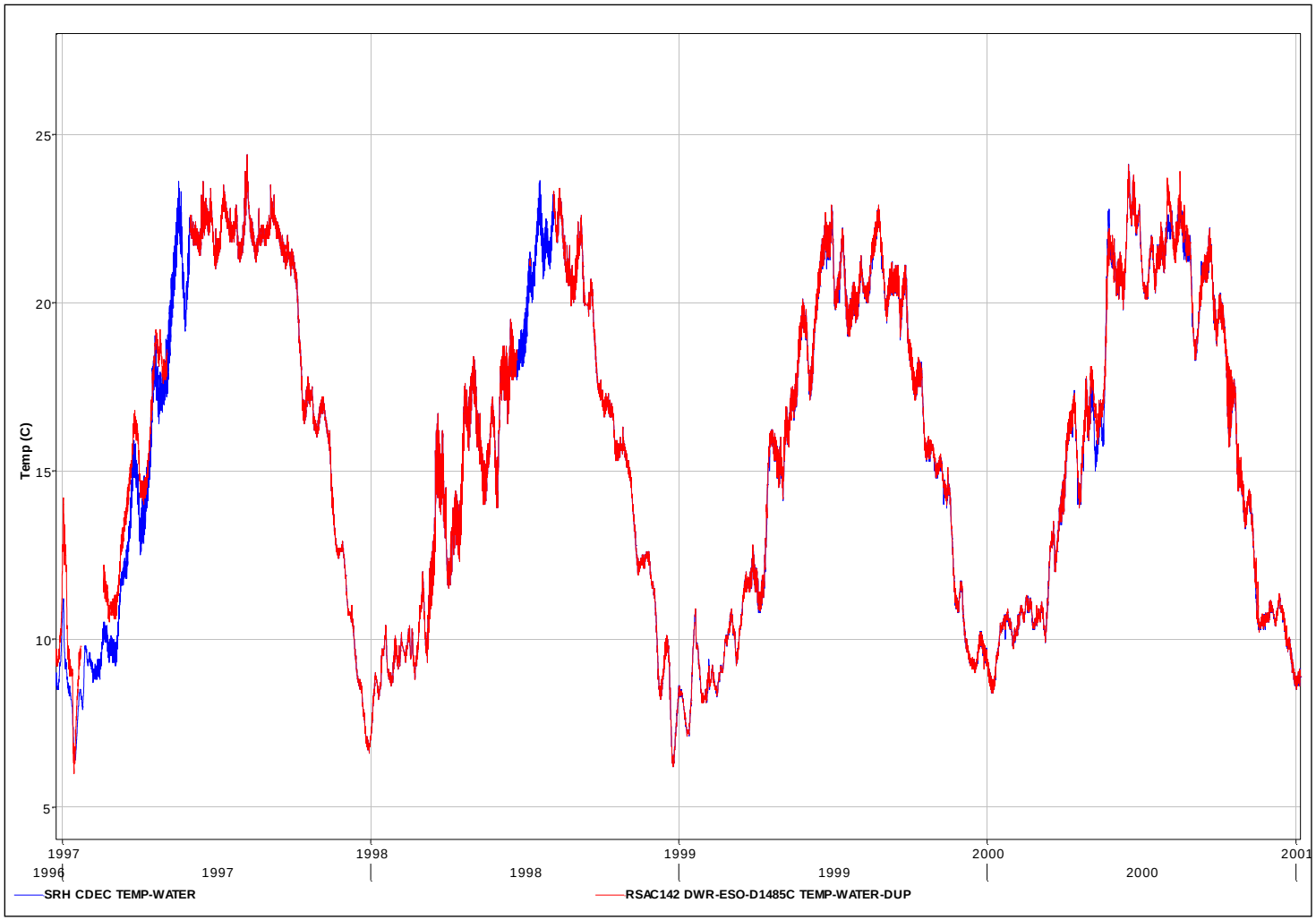


Figure 7-10 Water temperature data with gaps at Hood on the Sacramento River (red line) – fill-in data were approximated using Singular Spectrum Analysis (blue line).

8 Data Availability: Time Spans and Locations

Data were needed to set concentrations for each of the eleven constituents at each river boundary illustrated in Figure 4-2 at each effluent boundary shown Figure 4-3, and at the 258 DICU boundaries for the modeled time period, 1990 – 2008. In addition, data were needed for calibration and validation of the model. Recall (Section 4.3.1), flow and salinity data was available from DWR Historical model at all the standard inflow boundaries (rivers, stage and DICU), but not for effluent boundaries.

Initially (*i.e.*, for the 1990 – 2008 calibration), no data were available to constrain modeled nutrient concentrations or to set boundary conditions in the Yolo/Cache region. Only a few measurements were available in Suisun Marsh, and as a consequence the Suisun Marsh area is not considered to be satisfactorily calibrated in Version 6. Subsequent to the original calibration, nutrient grab sample data was acquired from P. Lehman (pers. comm.) for four locations in Liberty Island at monthly intervals 2004 – 2005.

Data locations are typically known by several names (see Table 25-1). One common method of identifying the location of a measurement is by its "RKI", or River Kilometer Index. The nomenclature RSACnnn, where nnn corresponds to three integers between zero and nine, indicates the distance of the measurement location from the Golden Gate. For example, RSAC054, known commonly as Martinez, is located 54 KM from the Golden Gate on the **SAC**ramento **R**iver. For locations on the San Joaquin River, RSANnnn corresponds to locations nnn KM from the confluence from the San Joaquin and Sacramento Rivers. For example, RSAN018, known commonly as Jersey Point, is on the San Joaquin River 18 KM from the confluence. Table 25-1 lists the various names that locations are known by, in particular those measurement and model output locations that are referred to in this report.

8.1 USGS Data

Figure 8-1 shows the sampling locations for USGS water quality data, including nutrient measurements, downloaded from the USGS website. Data were available at irregular intervals and, depending on the constituent, were sparse at some locations indicated in this figureFigure 25-1and Figure 25-2 illustrate the availability of nutrient data at USGS locations from 1990 – 2008 (USGS temperature data was not used directly in the modeling).

Measurements downloaded from the USGS website, which were generally made at depth increments of one meter, include water temperature, DO, nitrite, combined nitrate+nitrite, orthophosphate, chl-a, and pH (pH was only used in an ancillary manner). Except for temperature, measurements tended to be concentrated at the 1-meter or 2-meter depth at each location. Temperature data were consistently recorded at each available depth, while nutrient data were sparse at many locations.

Nutrient data from a single depth, usually the 1-meter or 2-meter depth, was used although occasionally a couple of data points from one depth below or above were used to fill in missing data. For example, chl-a data from the 2-meter depth had the greatest frequency of measurement, but occasionally a gap occurred and data at 1-meter was available and used to fill the gap. This strategy was utilized when an analysis of the measurements indicated only minor variation with depth. Note that the USGS data was mainly use for comparison with EMP measurement data.

Examination of water temperature at several locations, seasons and years showed there was little variation with depth along the main stem of the Sacramento River indicating that the one-dimensional representation used in DSM2 is sufficient for modeling temperature along the Sacramento River. Two example plots illustrate that the variation in temperature with depth is very small on August 15, 2006 along the Sacramento River - Figure 8-2 and Figure 8-3 are plots of temperature with depth along the transect defined by the USGS station locations.

8.2 U.C. Davis - R. Dahlgren and M. Johnson

R. Dahlgren from U.C Davis supplied several years of data (mid-1999 to early 2005, depending on location) comprising a complete suite of measured water quality parameters at several model boundary locations (see Figure 8-4). Measured parameters were used (see Appendix I, Section 25.9) to develop chemical speciation models at the Sacramento and San Joaquin River model boundaries using the modeling package EQ3/6[21] and data base. These models were used to establish a general sense of the aqueous species in solution at these important boundaries. The EQ3/6 modeling results are discussed further in Section 10.1.

Mike Johnson, also from U.C. Davis, supplied an Access database of water quality measurements in the Delta. The data were utilized to confirm the completeness of data gathered from publically available websites for this project, *i.e.*, data availability in terms of constituent location and time span, but they were not used directly in the modeling.

8.3 WWTP Receiving Water Measurements

An important set of long-term measurements on the San Joaquin River that was supplied by the Stockton WWTP are the WWTP measurements for receiving waters (*i.e.*, waters the effluent flows into). The locations of the measurements are shown in Figure 8-5. Grab sample measurements were taken for chl-a, nitrite, nitrate, ammonia, DO (bottom and mid-depth), organic-N and BOD-10 or BOD-5 (the frequency of the last two data types is very limited). Figure 25-3 and Figure 25-4 illustrate the availability of nutrient data measurements from Stockton's WWTP receiving waters from 1990 – 2009 (except for water temperature which wasn't used in the modeling).

[21] EQ 3/6 is an equilibrium chemical speciation model developed by T. J. Wolery at Lawrence Livermore Laboratory ; http://www.osti.gov/bridge/servlets/purl/6451946-jmax2i/6451946.PDF

Two locations of Sacramento Regional (Sac Regional) WWTP measurements for receiving waters on the Sacramento River were used, one above the effluent outfall location at Freeport Marina and another downstream of the outfall at River Mile 44 (RM-44) as shown on Figure 8-6. Some measurements were also available on their website[22] at infrequent intervals from 2004 – 2008. These data were utilized to help constrain the Freeport boundary condition values. Table 25-6, Table 25-7 and Figure 25-5 show the values and availability of Sac Regional receiving water nutrient measurements for the Freeport Marina and the RM-44 locations, respectively in the tables.

The Fairfield-Suisun WWTP also supplied a few receiving water measurements at several locations downstream of the effluent outfall locations. These were not used as the data available for calibration in the Suisun Marsh area was too limited to consider calibrating the region given budget limitations.

8.4 WWTP Effluent Data

Data were obtained for the effluent flow and nutrient composition from 17 WWTPs. The approximate location of these outfalls is shown in Figure 4-3. The time periods and availability of constituents is shown in Table 25-8 and in Table 25-9 in Appendix I. Data for Vacaville, Davis and Woodland was gathered but not yet been implemented. Because they are located outside of the model domain, estimation of flow containing their effluent into the Yolo/Cache area needs the support of additional data and funding. (Note: Benicia effluent data, although gathered, does not need to be considered as the outfall is downstream of the model boundary at Martinez.)

The source of the data for each WWTP is listed in Table 25-2 in Appendix I.

8.5 BDAT

The data obtained from the BDAT database was the source for most of the nutrient data for the modeled constituents, both for boundary conditions and for calibration and validation. The data were mainly grab sample measurements in the form of irregular time series at intervals of approximately one month, sometimes bi-monthly, and with occasional gaps in measurement.

The most complete set of related data measurements downloaded from BDAT, or obtained directly from DWR staff, was gathered by the Environmental Monitoring Program (EMP). DWR's EMP has gathered data from several sites within the Delta on a long-term basis. Figure 25-6 through Figure 25-12 illustrate the data availability of EMP and BDAT measurements from various sources (except for temperature). The EMP data was well documented, and the measurement protocol was available for all constituents of interest that were measured. Table 8-1

[22] http://www.srcsd.com/

lists the measurement protocols. Organic-P data were not available in the BDAT database and CBOD data was not available at sufficient frequency or in enough locations to be useful.

When dissolved-P measurements are available concurrently with orthophosphate, organic-P can be estimated as the difference between the two measurements. However, the total-P measurements available through EMP cannot be used for this purpose (total-P samples are not filtered through sufficiently fine filters, and therefore the measurement includes P obtained from particulate materials such as fine sediment).

Nutrient data were available from BDAT at the Martinez boundary for all of the constituents except organic-P and CBOD. A combination of data from BDAT and data from the USGS database was used for setting constituents at Martinez. At the San Joaquin River boundary at Vernalis, nutrient data (including DO) were available either at Vernalis or 25 km downstream of Vernalis at Mossdale. For each constituent except organic-P and CBOD, data were obtained from BDAT at Hood, Greens Landing, and occasionally from points further south to develop concentrations at the Freeport boundary on the Sacramento River.

Table 25-3 through Table 25-5 in Appendix I gives the entire list of data locations found in BDAT. At some of these locations, data consisted of a few data points, so these data were not used in calculating boundary conditions or in the calibration process. Some locations were close geographically, so data could be considered to be from the same measurement location (e.g., Greens Landing and Hood).

Figure 25-13 through Figure 25-15show the location of chl-a measurements. Measurements for nitrate+nitrite, ammonia, DO, orthophosphate and organic-N were generally also found at these locations.

8.6 Lehman Data for Liberty Island

P. Lehman supplied data collected in Liberty Island from a study on Liberty Island nutrient dynamics - the background for this data is discussed in (Lehman *et al.*, 2010). In brief, measurements were collected monthly from February 2004 to July 2005 from 4 locations within Liberty Island (See Figure 1 in the Lehman paper). Data from water samples that were analyzed included several modeled constituents, NH_3, NO_3, chlorophyll-a and PO_4 (called soluble-P in the Lehman data set). On each sample date, data for these constituents from the four locations (labeled north, south, east and west in Figure 1 in Lehman's paper) were averaged for comparison with model output.

8.7 Other Sources

Regular time series of DO and water temperature data were downloaded from an Interagency program (IEP) database that is no longer available. Much of this data is available through the CDEC website.

An Access database of water quality measurements was developed for the Central Valley Drinking Water study to characterize drinking water quality within the jurisdiction of the Central Valley Regional Water Quality Control Board. The data set ended in 2004, but included NPDES measurements at locations within and just outside the Delta. Storm water data were included but not used.

A small amount of data from upstream locations on the Sacramento River was obtained from the data base maintained by the Municipal Water Quality Investigations (MWQI) branch of DWR. NH_3, NO_3, NO_3+NO_2 and PO_4data were obtained at Freeport. This data is discussed further in Section 9.9.5 in a discussion of setting boundary conditions at the Sacramento River boundary.

8.8 Data Availability by Category

8.8.1 Meteorological Data

The original nutrient model developed to investigate DO problems on the San Joaquin River near Stockton used meteorological data measured at the Stockton airport by NOAA. Two issues were identified with the use of this original data set for the current modeling effort. The first issue is that data for each of the required inputs was not available from NOAA at this location prior to 1996. In addition, in the process of calibrating the temperature model, it was found that there was sufficient variability in meteorological conditions across the Delta to render the single Stockton dataset ineffective in modeling water temperature across the entire Delta. CIMIS data were collected to supplement the original NOAA data set. Table 8-1 shows a comparison in measurement methodology for the NOAA and CIMIS data measurements.

Figure 8-7shows the locations of the Stockton and CIMIS meteorological measurement data reviewed for this report. NOAA Stockton meteorological measurements were used for the entire period except for wind and wet bulb measurements which were only available from 1996 to 2008. CIMIS Brentwood wind speed measurements were used for the early period 1990 - 1995 as measurements were available for the entire time period. Wet bulb was not available before 1996, and was instead calculated (see Appendix I Section 25.6).

8.8.2 Water Temperature Data

Water temperature data were generally available as regular time series at hourly intervals, or occasionally at 15-minute intervals. Much of the temperature data was obtained from the DWR Water Data library, or from the IEP and CDEC databases. The data were of mixed quality, with data quality and availability generally improving after 2000. Figure 8-8 shows the locations where water temperature data were available in the Delta. Figure 8-9 and Figure 8-10 indicate the time periods and quality of data available. Discussion of the years selected for calibration and validation is covered in detail in Section 12.

8.8.3 DO Data

DO is the only nutrient model constituent (other than water temperature) for which continuous time series were available, and they were downloaded from the IEP and CDEC data bases. Continuous DO data were generally sparse and noisy with large data gaps. DO measurements in the interior of the Delta were available as regular time series at five locations (Rio Vista~RSAC101, RSAC075~Chipps, RSAN007~Antioch, RSAN058~Rough-N-Ready Island and RSAN061~ (not named) and as irregular time series from the USGS and BDAT databases and from the Stockton WWTP receiving water data.

Some USGS measurements were used to help constrain boundary conditions, but they were mainly used in verifying model calibration and validation.

8.8.4 DICU Data

DICU nutrient data were set as constant values in the previous DO-models (Rajbhandari 1995a, 2000, 2001, 2003). Additional data were obtained from MWQI staff for this project. The measurements were not taken at outfalls into the Delta, they were generally sparse and gathered during the early years of the modeled time span, and so deemed of marginal value given the large effort it would take to collate the data.

8.8.5 Chlorophyll a (Chl-a)

As mentioned in Section 7.3, chl-a measurements derived from continuous measurement equipment as fluorescence was deemed to be of insufficient quality to use in setting model boundary conditions or as calibration data. Grab sample measurements from EMP and the USGS were used exclusively for chl-a.

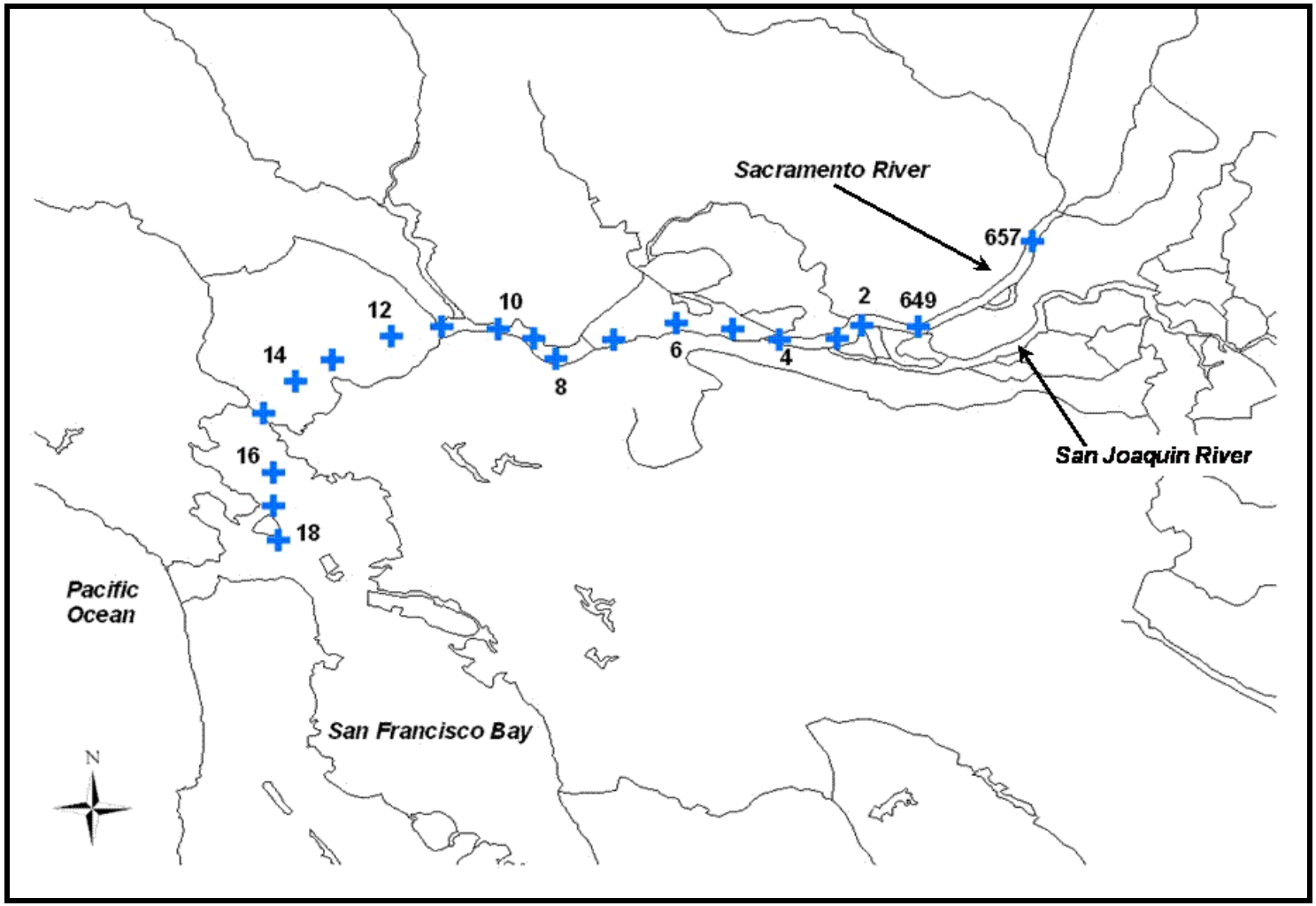


Figure 8-1 USGS nutrient and other water quality parameters measurements (blue crosses) were utilized from location 8 just downstream of Martinez to location 657 at Rio Vista.

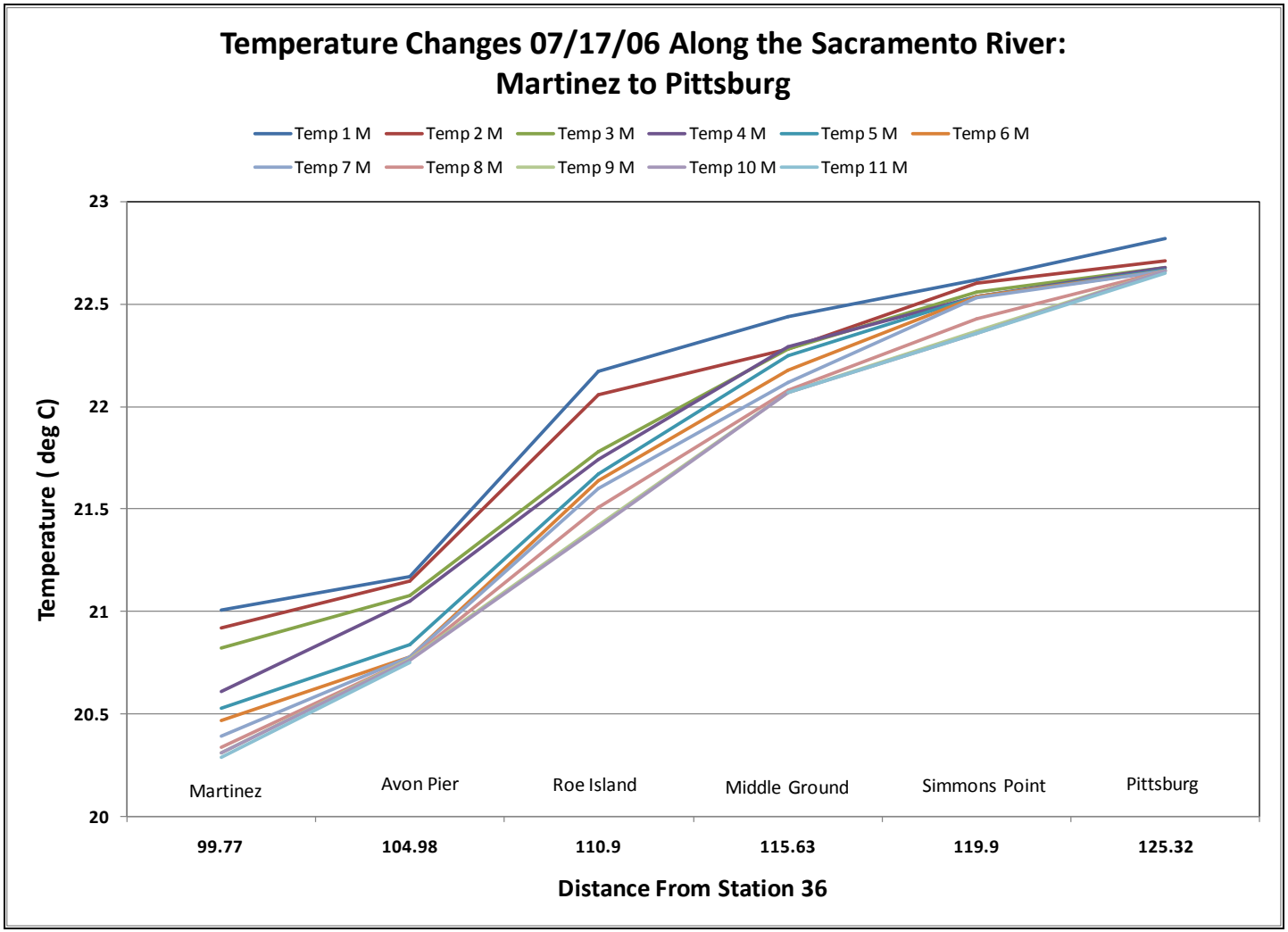


Figure 8-2 USGS temperature data at various depths from Martinez to Pittsburg on July 07, 2006.

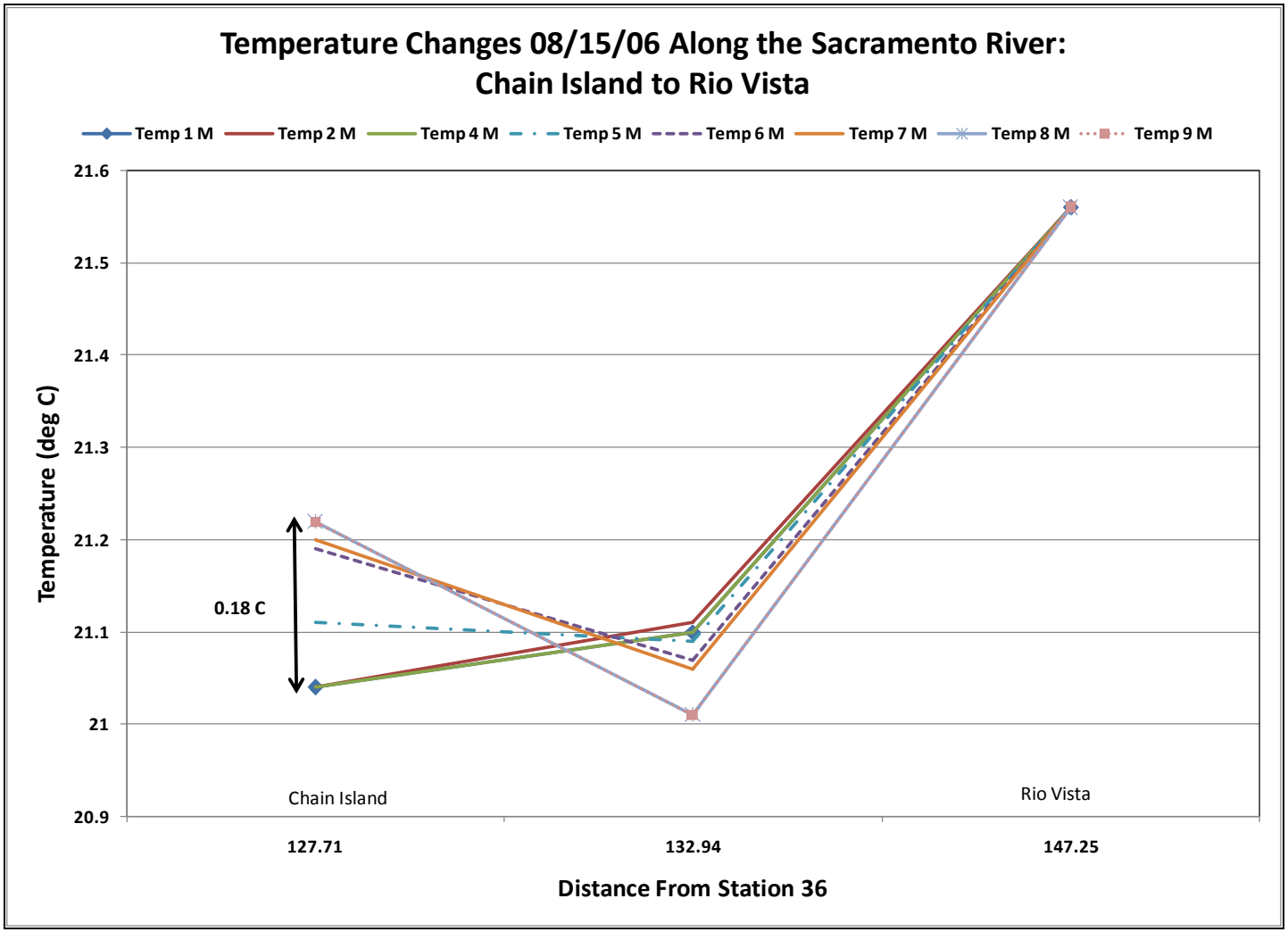


Figure 8-3 USGS temperature data at various depths from Chain Island to Rio Vista on August 15, 2006.

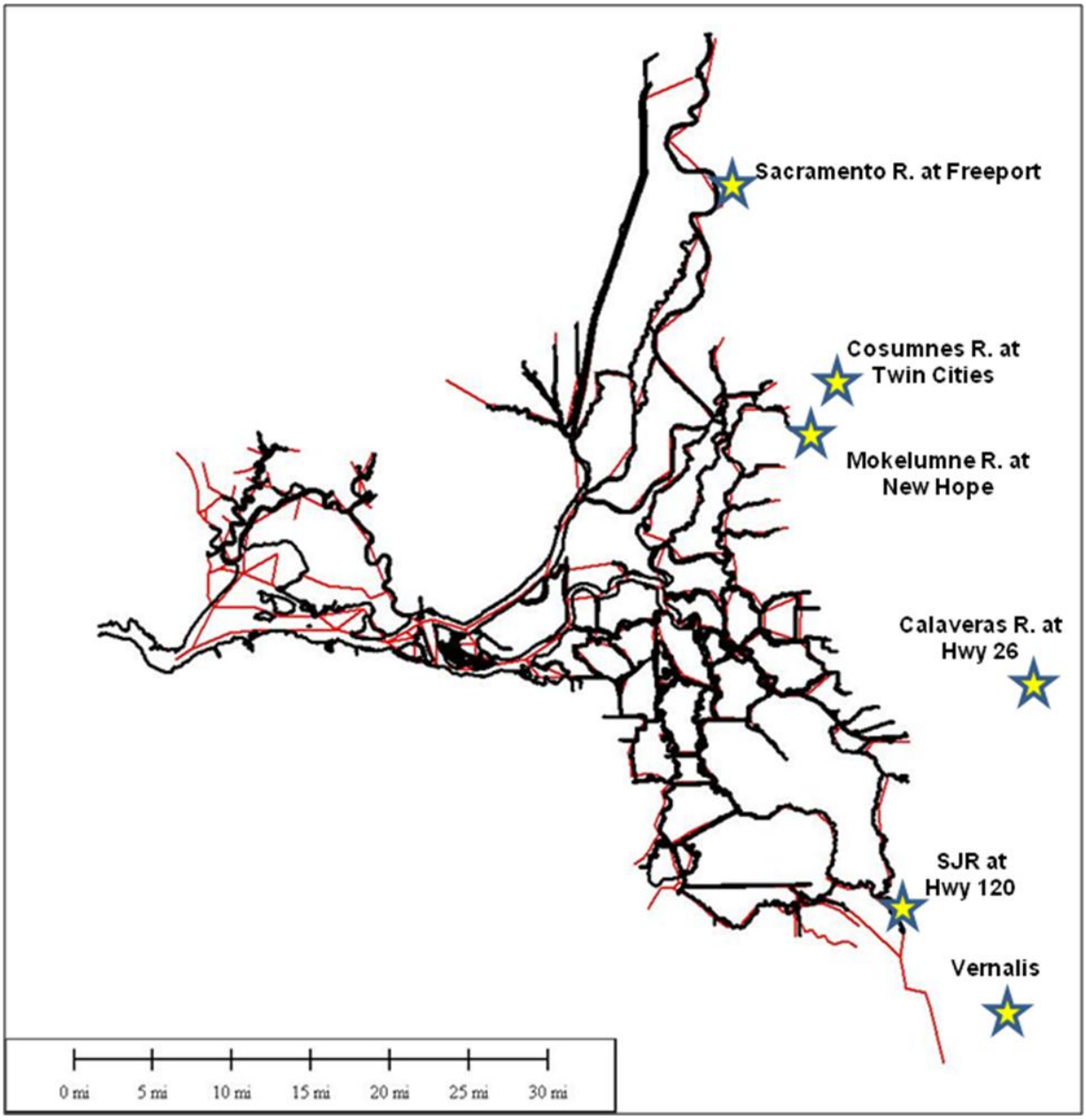


Figure 8-4 Approximate location of data (indicated by yellow stars) in Dahlgren's (UC Davis) data set used to help define nutrient boundary conditions.

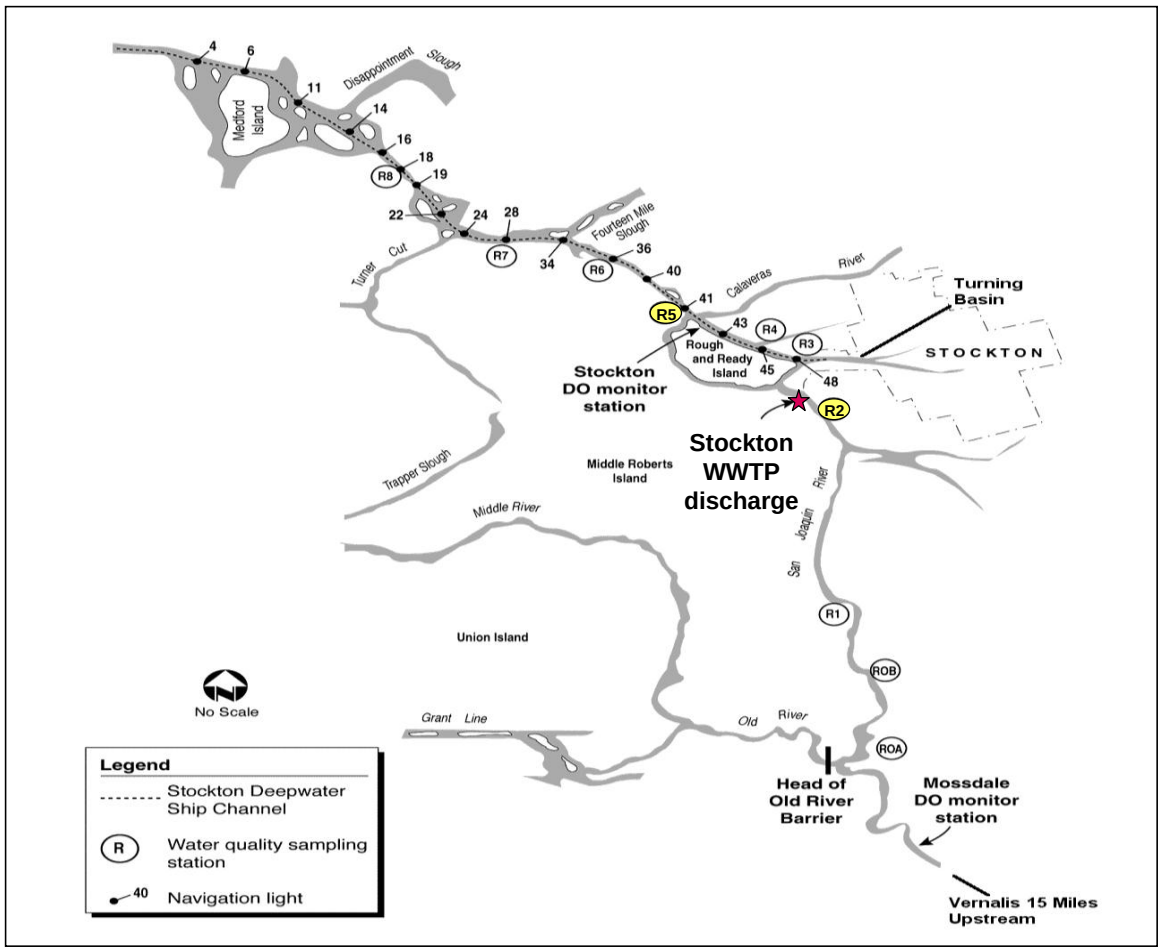


Figure 8-5 Location of the Stockton WWTP receiving water measurement locations (Figure from C. Kendall, personal communication).

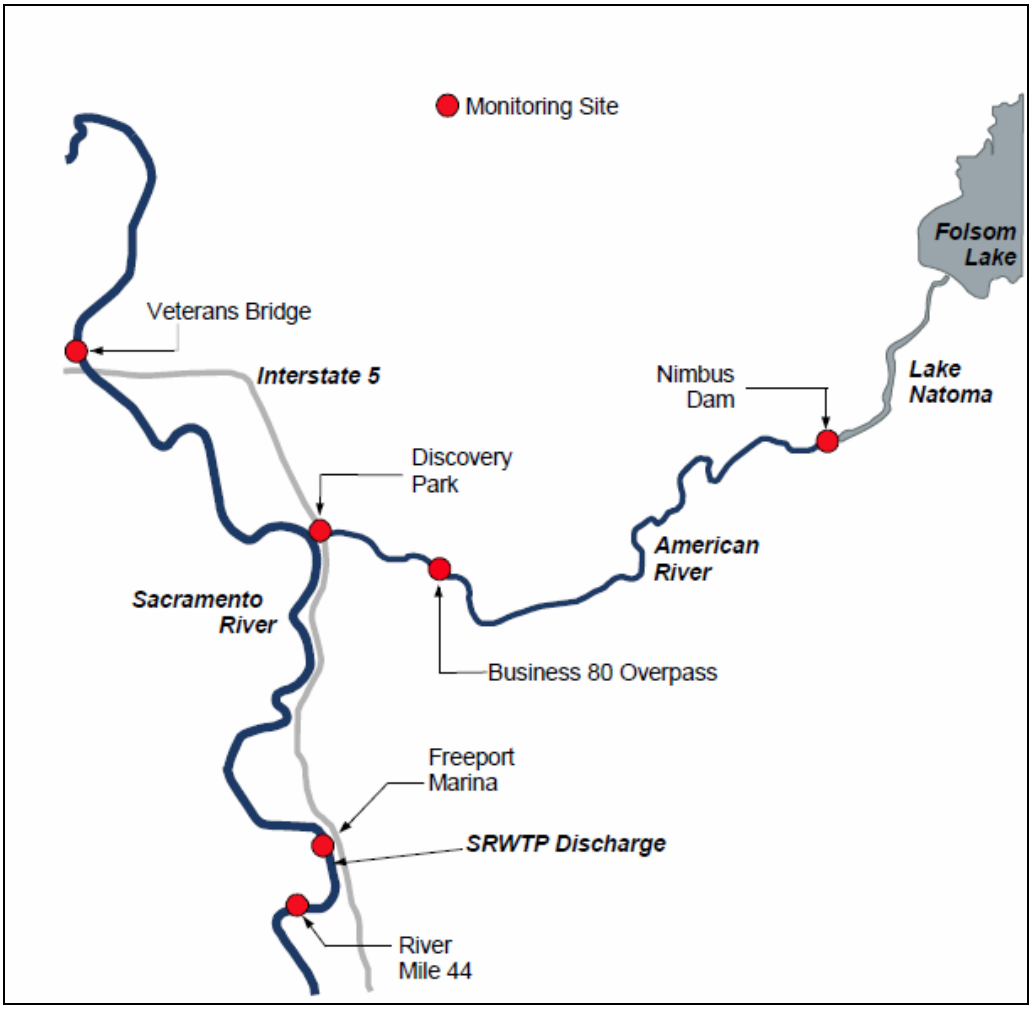


Figure 8-6 Location of the two Sacramento Regional WWTP receiving water measurements used in this report – Freeport Marina and at River Mile 44.

Table 8-1 Metadata for the EMP-DWR measurements.

Metadata for EMP-DWR Measurements - List of Lab Constituents								
Group	**Matrix**	**Fraction**	**Analyte**	**Units**	**Method**	**Data from**	**Data to**	**Comments**
Nutrients	Water	Dissolved	Ammonia	mg/L as N	EPA 350.1	1/16/1979	Ongoing	1979-ongoing
Nutrients	Water	Total	Kjeldahl Nitrogen	mg/L as N	EPA 351.2	5/1/1978	Ongoing	1978-ongoing
Nutrients	Water	Dissolved	Nitrite + Nitrate	mg/L as N	Std Method 4500-NO3-F Modified	7/19/1996	Ongoing	1996-ongoing
Nutrients	Water	Dissolved	Organic Nitrogen	mg/L as N	EPA 351.2 (Dissolved)	5/2/1978	Ongoing	1978-ongoing
Nutrients	Water	Dissolved	Ortho-phosphate	mg/L as P	EPA 365.1 (DWR Modified)	1/16/1979	Ongoing	1979-ongoing
Nutrients	*Water*	*Total*	*Phosphorus - Not Used*	*mg/L*	*EPA 365.4*	*5/2/1978*	*Ongoing*	*1978-ongoing*
Biological	Water			µg/L	Std Method 10200 H	2/2/1998	Ongoing	1998-ongoing

Table 8-2Meteorological data – the difference between CIMIS and NOAA measurements, such as measurement height above ground, timing (instantaneous vs. average).

	CIMIS	NOAA
Measure height	2 m	10 m
Frequency	Hourly/Daily averaged	Hourly
Constituents	Solar Radiation Air Temperature Soil Temperature Dew Point Relative Humidity Wind Speed Wind Direction Wind Gust Vapor Pressure Precipitation Evapotranspiration	Sky Condition Visibility Weather Type Dry Bulb Wet Bulb Dew Point Relative Humidity Wind Speed Wind Direction Value For Wind Character Station Pressure Pressure Tendency Pressure Change Sea Level Pressure Hourly Precipitation Altimeter
Stations in Delta	Brentwood (Jan98 - Dec05) Concord (Apr01 - present) Hasting Tract (Jan98 - present) Lodi (Jan98 - Dec00) Lodi West (Sep00 - present) Manteca (Jan98 - present) Tracy (Sep01 - present) Twitchell Island (Jan98 - present)	Stockton (88-present)

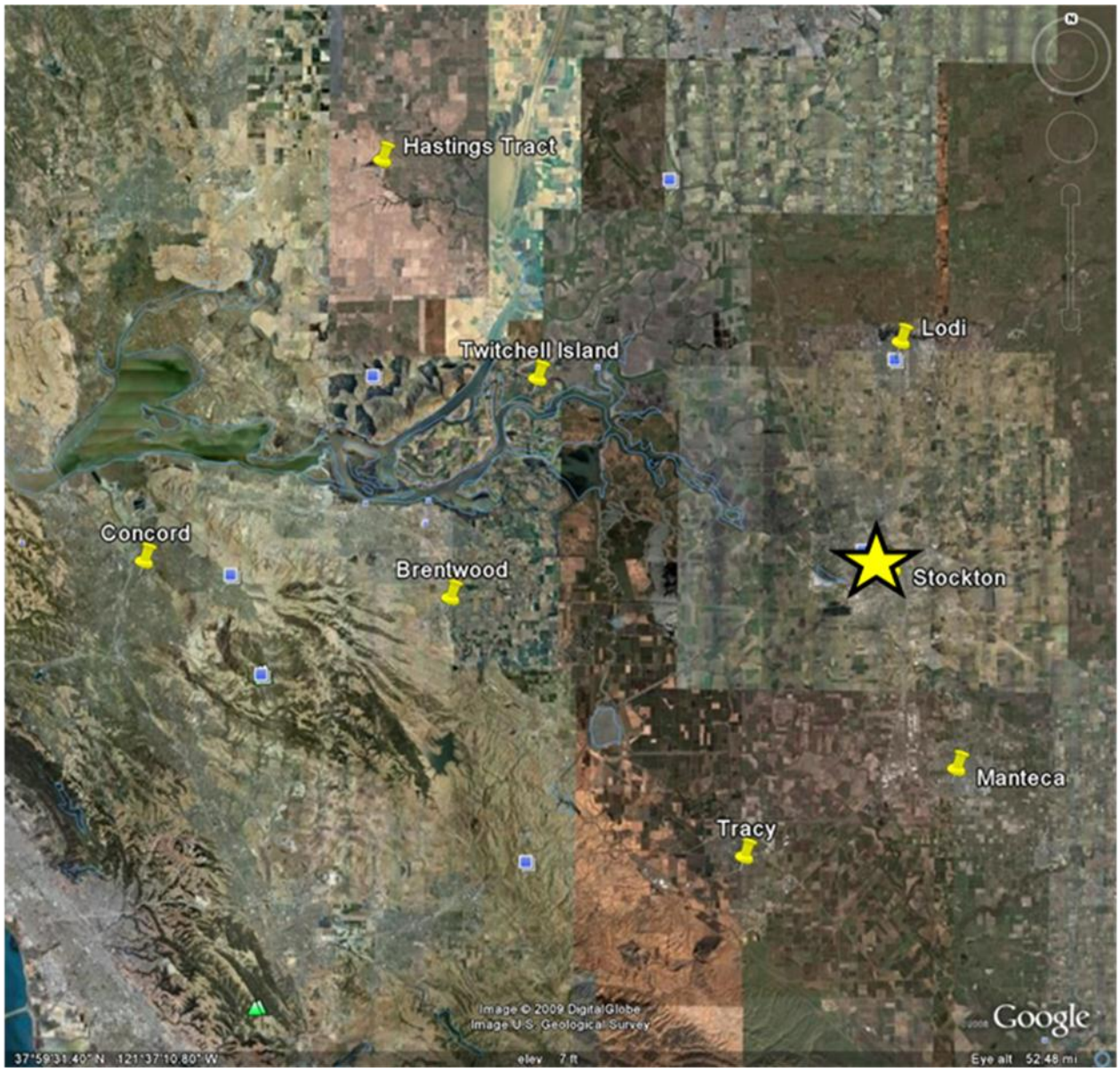


Figure 8-7 Meteorological measurements from NOAA at the Stockton airport (yellow star), and CIMIS measurements, indicated by yellow Google Earth push-pins.

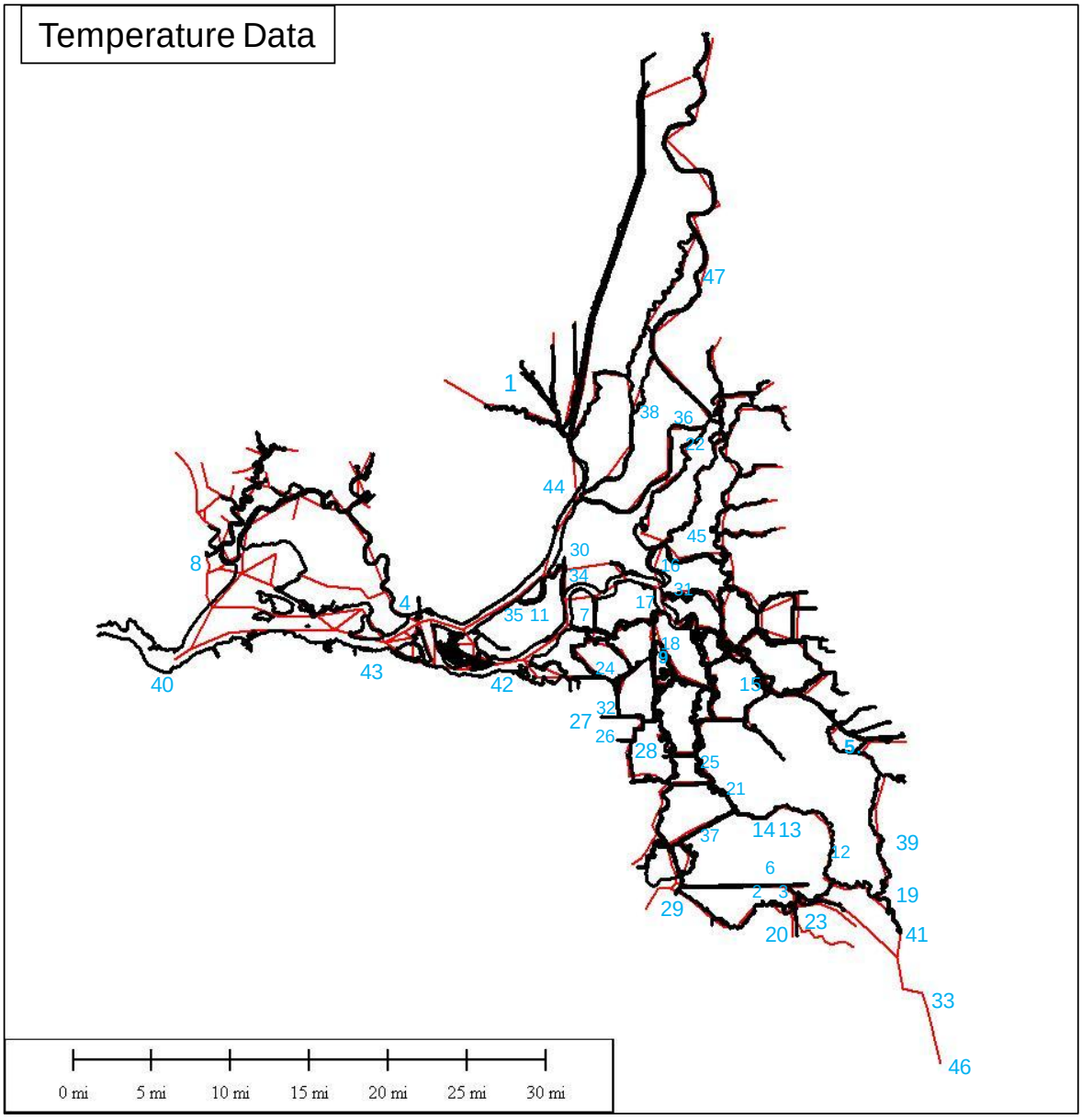


Figure 8-8 Locations of temperature data regular time series. Data quality and length of record is variable.

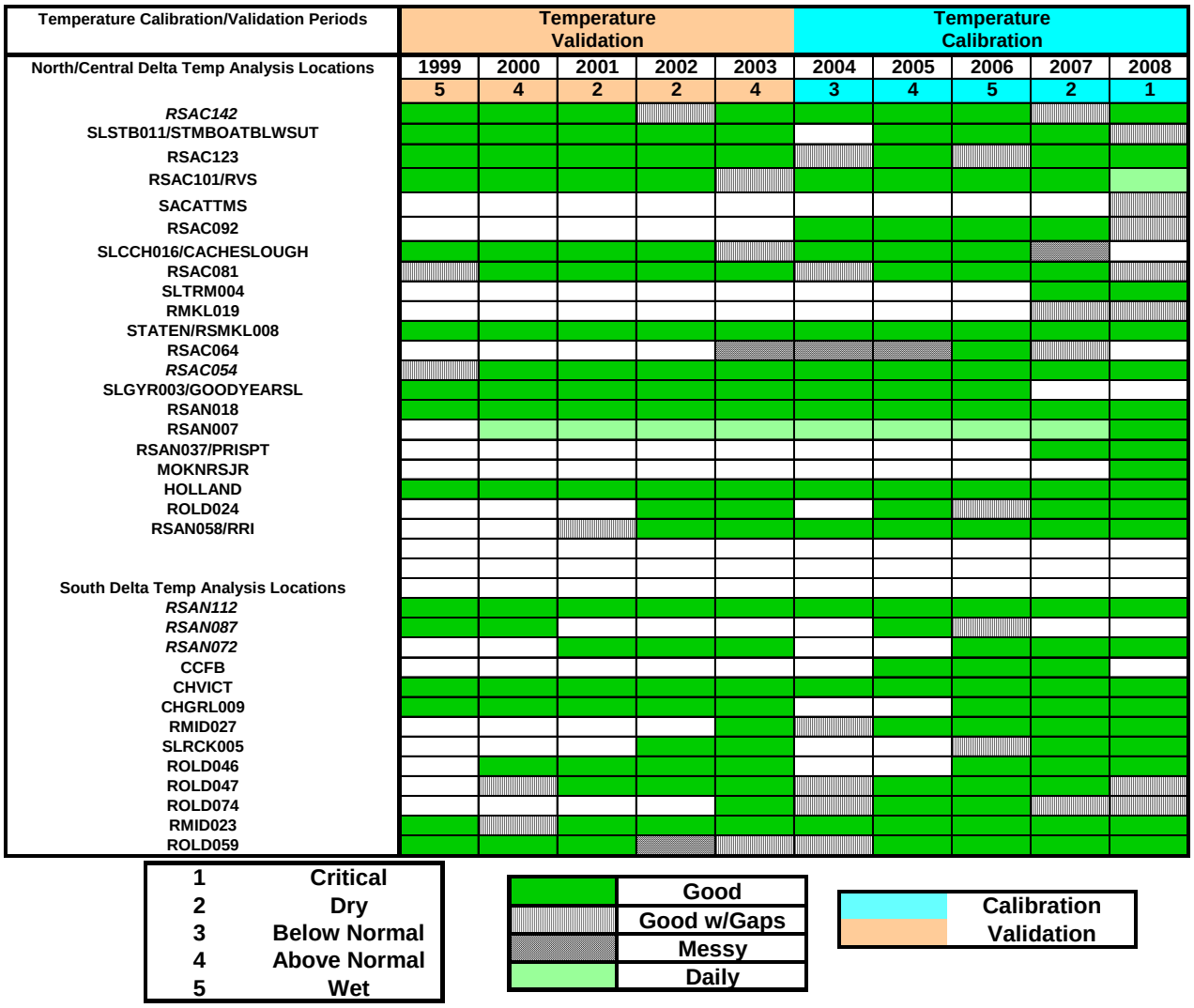


Figure 8-9 The coverage and quality of temperature data used in model or the years 1999 – 2008.

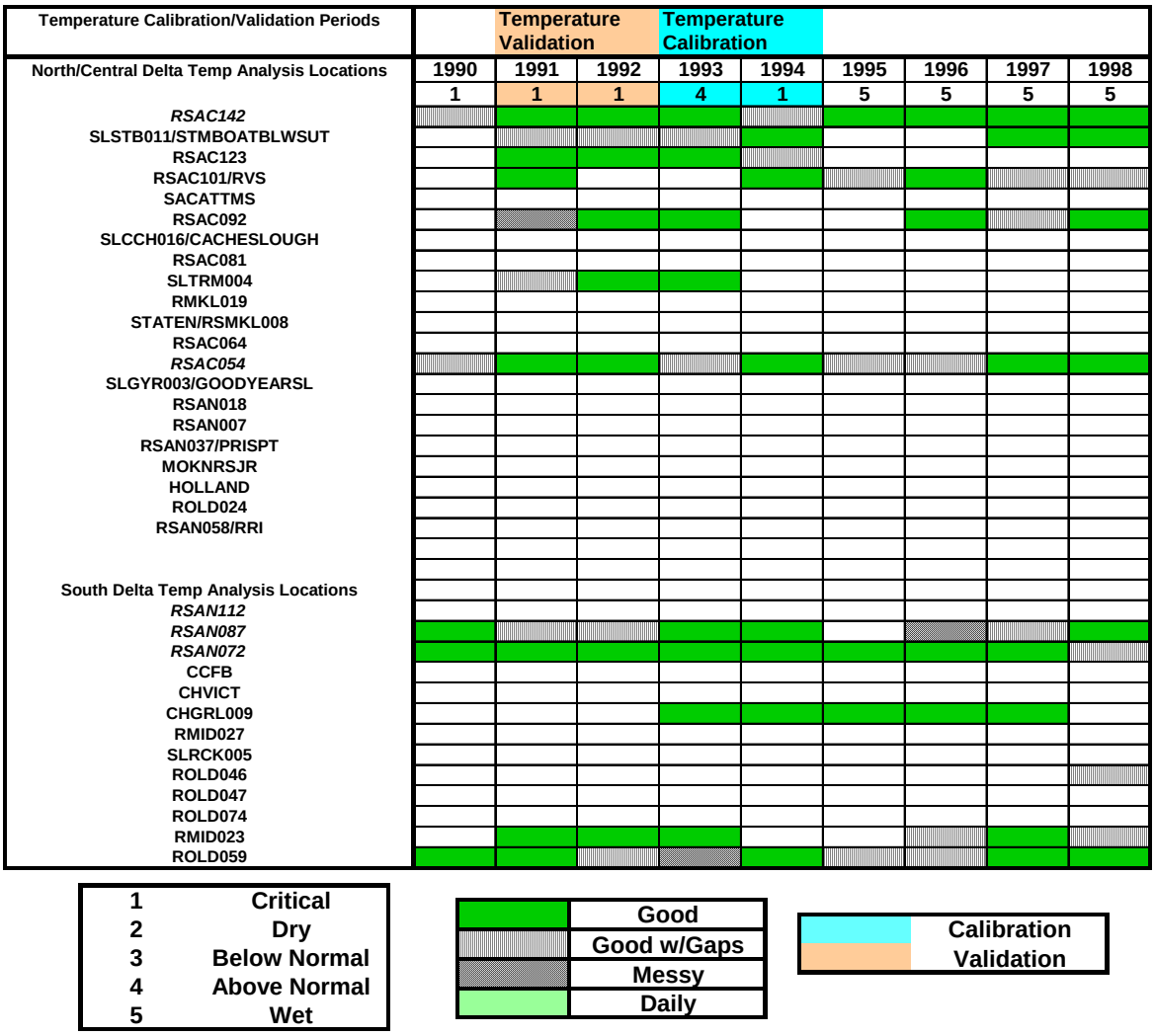


Figure 8-10 The coverage and quality of temperature data used in model for the years 1990 – 1998.

9 Setting Boundary Conditions

9.1 Background

Figure 4-2 shows the locations of the DSM2 Historical model boundaries and Figure 4-3 shows the locations of the effluent boundaries. The values used to set boundary conditions were dictated by the availability and quality of data, and also on a practical limitation in QUAL Version 6. This version of QUAL had a limit on the number of time-varying variables (15MIN, 1HOUR, 1DAY) that can be used in any simulation, so some boundaries were set at monthly intervals (i.e., as constant over each month) or as a constant even if some time-varying data were available more frequently during part of the application period. Depending on the sensitivity of the model calculations to changes in the concentration of a constituent, a constant concentration boundary was used when deemed reasonable even when other data were available (*e.g.*, when measured concentrations showed little variation). In some cases, when the data needed for constituent input values at inflow boundaries were not available directly at the boundary location but available at a downstream location, the downstream data was used. In this case, sometimes small alterations were made to the timing of the data or its magnitude. For example, on the San Joaquin River, water temperature data was available at Mossdale but not at Vernalis. In this case, the Mossdale data was used at Vernalis but shifted in back time to obtain a match in the timing of concentrations at Mossdale.

A number of low volume effluent sources of interest for ammonia and the other nutrients lie within the Suisun Bay and the Carquinez Strait. In QUAL, outgoing tides transport water quality constituents from these sources down past the Martinez boundary and out of the model domain. In the physical system, these constituents would flow back into areas upstream of Martinez on incoming tides, but in QUAL the computation results in a loss of mass at the Martinez boundary which has the potential to significantly alter modeled nutrient concentrations and thus nutrient dynamics upstream of this boundary. Because this area is of significant importance to the Delta ecosystem, an estimate was calculated of the magnitude of this loss. Using a methodology like this, the potential exists to update the Martinez boundary conditions in subsequent model runs to reintroduce this mass on incoming tides – this would be an iterative process. The consequences of this observation are discussed in detail in Appendix I, Section 25.12.

9.2 Flow, stage and salinity

Except for effluent boundaries and the three exceptions noted below, boundary conditions for HYDRO and concentrations of salinity (as EC) in QUAL were accepted as presented in DWR's Historical model. Small problems identified in the Martinez stage boundary in 2007 and 2008 were corrected, and updated data on diversions and exports to Contra Costa Water District was implemented for 2008.

Inflow data for the "Lisbon Toe Drain" in the Yolo Bypass region (CDEC symbol "LIS") was implemented for several years in the modeled 1990 – 2008 time frame (approximately 2004 – 2008). During periods where the DSM2 flow boundary condition for the Yolo was above 2,000 cfs and the Lisbon Toe Drain flows were also above 2,000 cfs, the value of the Lisbon Toe Drain flows was subtracted from the Yolo boundary. As shown in Figure 25-23, the Yolo flows used in DSM2 are only positive at the same time as Lisbon Toe Drain flows (Lis in the Figure) when Lisbon Toe Drain flow exceeds 2,000 cfs. At this value, it is reasonable to assume that they were already included in Yolo Bypass flow estimates in DSM2. Note that the USGS only reports Yolo flows (at their Woodland station) above 1000 cfs.

For the 2000 – 2008 calibration (Version 8.0.6 DSM2 model), only the Yolo inflow location was used for the Yolo and Lisbon Toe Drain flow data. The two flow sources were combined into a single time series and applied at the Yolo inflow location, as this was deemed appropriate given the change in grid geometry with the introduction of Liberty Island.

9.3 Meteorology

Meteorological data is set at hourly intervals in the model. As mentioned previously, several problems were identified in the application of meteorological data, the most important being the inability to apply regional variation in meteorological boundary conditions (*i.e.*, all meteorology is applied globally). In addition, no single location (shown in Figure 8-7) had a complete set of boundary conditions for the entire modeled period, 1990 – 2008. Therefore, meteorological boundary condition data was compiled from several locations.

A model sensitivity analysis on meteorological boundary conditions showed that modeled water temperature was most sensitive to the value set for wind speed, so considerable effort was taken to set wind boundary conditions. Figure 25-24 and Figure 25-25 show that there can be a factor of two variation in wind speed, either at different locations from the same measurement agency (CIMIS) or from different measuring agencies, NOAA vs. CIMIS, respectively, even though the measurement locations are in close proximity (note that the measurement methodology varies among the agencies).

Initial model calculations for water temperature were used to identify preliminary meteorological regions, *i.e.*, regions in which a single set of meteorological conditions would apply. Two main regions were identified, as shown in Figure 9-1. The South Delta region was reasonably well-calibrated using the existing Stockton data set (see Figure 9-2), but in the North Delta region modeled summer water temperature was high except in very wet Water Years (see Figure 9-3). In these figures, calculations from a model run with the existing wind speed at Stockton and one with a higher wind speed (factor of 1.5) are compared with data (blue line). At RSAN058 in the South Delta region, water temperature is modeled very well using the existing wind data, while water temperature at RSAC081, Collinsville, is approximated better using the higher wind speed.

Final wind speeds were set using NOAA data for the Stockton location 1996 - 2008 and the CIMIS data at Brentwood as they were available for this location 1990 - 1995. Brentwood values were initially too high, so they were decreased by a factor of 0.85 to more closely match average Stockton values. During summer, the values for wind speed were increased by a factor of two from April through October, with a three-day linear ramp-up and ramp-down (see Section 12.1.1 for more detail). This modification in wind better approximated water temperature along the Sacramento River. Cloud cover, atmospheric pressure, and air temperature (dry bulb) were also set using NOAA data at Stockton. Prior to 1996, wet bulb measurements were also sourced from NOAA data.

Because wet bulb measurements were not available at any station prior to 1996, they were calculated using measurements of relative humidity, air temperature and dew point available at Brentwood, Lodi and Manteca (see Appendix I Section 25.6 for a description of the method).

Calculations during the water temperature calibration process uncovered convergence problems when both inflow and inflow water temperature were low. In two time periods (portions of 1990 and 1991), the model could not converge to a solution. Analysis of the problem revealed that when the diurnal variations in wet bulb and dry bulb temperatures were too extreme, the model would not converge. The problem was alleviated by smoothing wet bulb and dry bulb temperatures during those time periods. The resulting boundary conditions are illustrated in Figure 25-26.

9.4 Water Temperature

Boundary conditions for water temperature needed to be set at each boundary shown in Figure 4-2 and Figure 4-3. Daily or hourly time series data were available through the IEP and CDEC data bases for many of the modeled years at or near the boundaries for the Sacramento and San Joaquin Rivers, and at Martinez. Missing data were filled as described in Section 7.4. When entire years were missing they were filled using data from the same Water Year Type at that location (or nearby location, depending on availability).

Boundary inflow temperatures prepared for the Sacramento boundary were used at the Mokelumne and Cosumnes River boundaries. Water temperature at the Sacramento boundary was set in large part using data at downstream locations from the actual model boundary – at Sacramento River RKI location 123 (RSAC123) and at a measurement location in Steamboat Slough. Initial temperature model simulations showed that the resulting temperature at Freeport was high by approximate 2°C when these data sets were used. To correct this, the Sacramento River boundary water temperature at Sacramento was decreased by 2°C from 2004 – 2008, the period where downstream measurements were used to fill the data gap.

The San Joaquin River temperature boundary (RSAN112) was used both at Vernalis and at the Calaveras River boundary. Water temperature was mainly available at Mossdale (RSAN087). Examination of initial model results showed there was a small shift in time for measured versus

modeled water temperature at Mossdale due to travel time between Vernalis and Mossdale. The Mossdale time series was shifted back two hours to account for this difference at the Vernalis boundary. The timing mismatch was not uniformly two hours, but that shift gave a good approximation overall.

For the 1990 – 2008 Version 6 DSM2 model, the Yolo water temperature boundary was set at a constant temperature of 9°C as the Yolo flows mainly occur during winter and early spring when water temperatures are generally low. Water temperature for the Lisbon Toe Drain was synthesized, and set at 18.5°C from May to October, and at 11.25°C the rest of the year. The Lisbon Toe Drain may have outflow during a longer portion of the year than the Yolo. For the 2000 - 2008 Version 8.0.6 DSM2 model, the synthetic time series was extended to cover the modeled time span and applied to the combined Yolo/Lisbon water temperature boundary condition.

Martinez water temperature boundary condition was only used at that boundary.

DICU flow temperature was set at a constant 22°C , which is the same value used for previous nutrient models in the San Joaquin River area (Rajbhandari, 2003). Effluent water temperatures were set as in Table 9-1.

9.5 Nutrients – Delta Boundary Conditions

Where possible the nutrient model boundaries were set using EMP data. EMP nutrient data were available at approximately monthly to bi-monthly intervals. The reasoning behind this decision is:

- EMP data is well-documented (methods, locations and meta-data)
- the data is internally consistent (collected by the same agency over many years)
- the data covers the modeled time span.

EMP data downloaded from the BDAT website was processed to yield a regular time series, typically monthly, from the irregular time series data as follows. Replicate values on any day were averaged, and then loaded into HEC DSS-Vue software which was used to convert the irregular time series into regular daily or monthly time series. The irregular time series generally had at least monthly data values, and many times measurements were bi-monthly.

Model boundaries do not necessarily coincide with data measurement locations. This occurs at each of the main boundaries (the Sacramento and San Joaquin Rivers, and at Martinez). The methodology adopted for these boundaries was to transform nearby measurement data to upstream or downstream model boundary conditions. For example, if measurements were not available at the Sacramento or San Joaquin River inflow boundaries, modification to the substitute data were needed either to account for travel time from the inflow location to the measurement point or for changes in concentration between the model boundary and the first

available measurement location. For example, since nutrient data was available at Greene's Landing (RSAC139) and at Hood (RSAC142) for setting boundary conditions, changes in the boundary value of concentration or temperature needed to be made to account for the dynamics that occurred between these two points and the model boundary. To account for this approximation, a constant factor (less than 1.0) was applied to the concentration time series to obtain calibration at the downstream measurement location.

There was little data available directly at the northern boundary of the DSM2 model on the Sacramento River boundary north of Freeport. There was data at the Freeport node in the model, south of northern-most node in the model domain, and at the downstream locations at Greens Landing and Hood. Freeport is also known by its "RKI", or River Kilometer Index, as RSAC155 (located 155 km from the Golden Gate). Several strategies were used to set boundary conditions here, as discussed in subsequent sections.

At the San Joaquin River boundary at Vernalis, nutrient data were available either at Vernalis or 25 km downstream of Vernalis at Mossdale. When Mossdale data were used, a minor modification was occasionally necessary to account for travel time or small changes in concentration as it was for the Sacramento River boundary. DWR's Environmental Monitoring Program (EMP) data were used to set boundary conditions at Vernalis for chl-a, NO_3, NH_3 (total ammonia), organic-N, and PO_4. At the Martinez boundary, setting nutrient boundary values was relatively straightforward as sufficient data were available through BDAT. For some constituents, USGS data were available at nearby locations for comparison.

Table 9-2 and Table 9-3 detail nutrient boundary condition information on river inflow locations and at Martinez, while Table 9-5 and Table 9-6 detail effluent concentrations used in the 2000 - 2008 calibration of the Version 8.0.6 nutrient model. Information on the 1990 - 2008 conditions is described in the text below.

9.5.1 Ammonia

9.5.1.1 *Sacramento River NH3 Boundary Condition*

There was a moderate amount of NH_3 data available at Freeport, above the Sacramento Regional effluent outfall. Variability is high in these measurements as shown in Figure 25-27, and they were sparse. The nearest downstream locations, at Hood and Greens Landing, had much higher NH_3 concentrations as they are downstream of the Sac Regional effluent outfall.

Model sensitivity runs on the Sacramento River NH_3 (andNO_3) boundary conditions showed that Greens Landing and Hood measurements (from BDAT) could be used to set the concentration at this boundary if reduced by a suitable factor. Figure 25-28 illustrates the difference between data values and the Sacramento boundary set at 0.4 times the (merged) data from Greenes Landing and Hood. This boundary condition produced suitable model results at all locations within the

model domain, but the average value for NH_3at the boundary is higher than other data measurement values for a substantial portion of the modeled period.

Because of these factors, mixing calculations using a combination of flow data and NH_3 data for the Sacramento River, Sac Regional and at Greens Landing and Hood data were used to set ammonia at the model boundary (well upstream of Freeport). A detailed discussion of this important boundary condition is found in Appendix I in Section 25.7.

9.5.1.2 *Other NH_3 Boundary conditions*

There was no NH_3 data available for the Yolo or Lisbon Toe Drain boundaries – for the 1990 - 2008 calibration, values were set at 0.03 and 0.04 mg L^{-1}, respectively. Time series for the Mokelumne, Calaveras and Cosumnes River boundaries were synthesized by Water Year Type using the available years in the Dahlgren dataset.

Time series of data were available through BDAT for Martinez and the Sacramento and San Joaquin Rivers.

9.5.1.3 *Nitrate (NO_3)*

There was no NO_3 data available for the Yolo or Lisbon Toe Drain boundaries – for the 1990 - 2008 calibration, values were set at 0.09 mg L^{-1}. Time series for the Mokelumne, Calaveras and Cosumnes River boundaries were synthesized by Water Year Type using the available years in the Dahlgren dataset.

Time series of data were available through BDAT for Martinez and the Sacramento and San Joaquin Rivers. For the Sacramento boundary at Freeport, data from Greenes Landing and Hood were merged, but the values were decreased by a factor 0.825 to obtain calibration at these downstream locations. Further discussion on setting the Sacramento boundary condition for NO_3 is found in Appendix I in Section 25.7.

9.5.1.4 *Organic-N*

There was no organic-N data available for the Yolo or Lisbon Toe Drain boundaries – for the 1990 -2008 calibration, values were set at 0.2 mg L^{-1}. Time series for the Mokelumne, Calaveras and Cosumnes River boundaries were synthesized by Water Year Type using the available years in the Dahlgren dataset.

Time series of data were available through BDAT for Martinez and the Sacramento and San Joaquin Rivers. For the Sacramento boundary at Freeport, data from Greenes Landing and Hood were merged.

9.5.1.5 *Chlorophyll a/Algae*

There was no chl-a data available for the Yolo or Lisbon Toe Drain boundaries – for the 1990 - 2008 calibration, values were set at 0.2 mg L^{-1}. Chl-a time series for the Mokelumne, Calaveras and Cosumnes River boundaries were synthesized by Water Year Type using the available years

in the Dahlgren dataset, and corrected for use in the model as biomass of algae as described in Section 5.5.2.

Time series of data were available through BDAT for Martinez and the Sacramento and San Joaquin Rivers. For the Sacramento boundary at Freeport, data from Greenes Landing and Hood were merged.

9.5.1.6 *Nitrite (NO_2) and Organic-P*

There was no organic-P data available through BDAT and only a limited amount of NO_2 data. Values for organic-P and NO_2 were set using a combination of data sources, including previously used values in DSM2, BDAT and Dahlgren's dataset.

At Freeport, examination of the SRWWTP receiving water measurements for NO_2 (Table 25-6) and Dahlgren's measurements yielded that a reasonable value was 0.004 mg $L^{-1}$for the 1990 - 2008 calibration. For the 1990 - 2008 calibration, the Vernalis boundary was set at 0.15 mg L^{-1}, the Martinez boundary was set to 0.008 mg L^{-1}, the Yolo and Lisbon Toe Drain were set at 0.004 mg L^{-1}, the Mokelumne R. was set at 0.004 mg L^{-1} and the other two river boundaries set at 0.005 mg L^{-1}.

For the 1990 - 2008 calibration, organic-P measurements were set at 0.01 mg L^{-1} at Martinez, Yolo and Lisbon Toe Drain. Some values were available in Dahlgren's dataset which were used to synthesize monthly values data by Water Year type for the Sacramento, San Joaquin, Mokelumne, Calaveras and Cosumnes River boundaries.

9.5.1.7 *DO*

DO boundary conditions were set using continuous time series of measurements, the only nutrient for which regular time series of data were available, although not for the entire modeled time span. Sacramento River boundary DO time series were used at the Sacramento boundary and also at the Yolo/Lisbon Toe Drain boundary. Because measurements were not available for every modeled year, hourly time series were synthesized using Water Year Type as a guide. Missing data were filled as described in Section 7.4.

Martinez and the San Joaquin River each had time series of data available for DO boundary conditions – the San Joaquin used measurements mainly available downstream at Mossdale. For the 1990 - 2008 calibration, the Mokelumne and Cosumnes and River boundaries were set at a constant 9.0 mg L^{-1}, and the Calaveras R. boundary at 7.0 mg L^{-1}.

9.5.1.8 *Ortho-phosphate (PO_4)*

Values for PO_4 were set using a combination of data sources including USGS, BDAT and Dahlgren data sets. Time series of values were synthesized by Water Year Type using data available in Dahlgren's data set for the Cosumnes, Calaveras and Mokelumne Rivers. Yolo and Lisbon Toe Drain boundary PO_4 values were set at 0.1 mg L^{-1}.

Time series of data were available from BDAT for setting the San Joaquin River boundary values. BDAT time series data for the Martinez boundary was supplemented with USGS data as a check on values. For the Sacramento River, time series of data were available at Greenes Landing and Hood. The values were merged then reduced by a factor of 0.7 for use as a boundary condition in order to obtain calibration for this constituent at the downstream measurement location.

9.5.1.9 *CBOD*

There were a few measurements available on BDAT for Biochemical Oxygen Demand, or BOD, at the Sacramento River near Freeport and on the San Joaquin River downstream of Vernalis, mostly prior to 1990. The available values were averaged and transformed into CBOD using regression relationships derived from Stockton WWTP measurements, where both BOD and CBOD data measurements were made. The relationship between CBOD and BOD is discussed in Appendix I, Section 25.2. CBOD values were then set to these averages as constants at each boundary. The Sacramento boundary was set at 1.2 mg L^{-1}, the San Joaquin and Martinez boundaries were set at 2.8 mg L^{-1}, the Mokelumne R. was set at 1.1 mg L^{-1}, and the other Delta inflow boundaries were set at 1.5 mg L^{-1}.

9.6 Nutrients - DICU

Concentrations for the DICU locations were set at values selected for the prior nutrient model efforts (Rajbhandari, 2003) with no modification. DICU nutrient values were applied as constant concentration boundary conditions, with values as indicated in Table 9-4 – these values were used in previous nutrient models (Rajbhandari, 2001; Rajbhandari, 2003; Rajbhandari, 2004).

9.7 Nutrients – Effluent Boundaries

Data were gathered from a variety of sources for setting boundary conditions at WWTP effluent locations. Data were processed to yield daily, bi-weekly or monthly values to use as boundary conditions. When data gaps appeared in time series data, either average values or data synthesized by Water Year type were used to fill the gaps. Bi-weekly data were either extended into daily data or compressed into monthly data. Missing years were either filled with constant values, or with a time series using effluent data from the same Water Year Type.

Because of QUAL's limit on the number of boundary conditions it can process as instantaneous (15 minute), hourly or daily time steps, effluent data from sources with small inflow volume was occasionally treated as a monthly value or a constant even when more frequent data were available over part of the modeled time span. In some cases, data were extended into 15-minute time series if averaging was not desirable.

Salinity (EC) measurements were not recorded for the effluent at some WWTP's. In this case, model output was sometimes used to synthesize an EC boundary condition for the effluent. QUAL EC output time series at the effluent source location was reintroduced at the effluent

node. This approach meant that effluent EC did not change QUAL modeled (historical) EC at those locations.

Figure 25-29 through Figure 25-33 are plots of effluent concentrations for all of the constituents for Sac Regional and Stockton WWTPs. Table 25-8 and Table 25-9 list the availability of constituent measurements for the period 1990 – 2008 for each of the WWTPs.

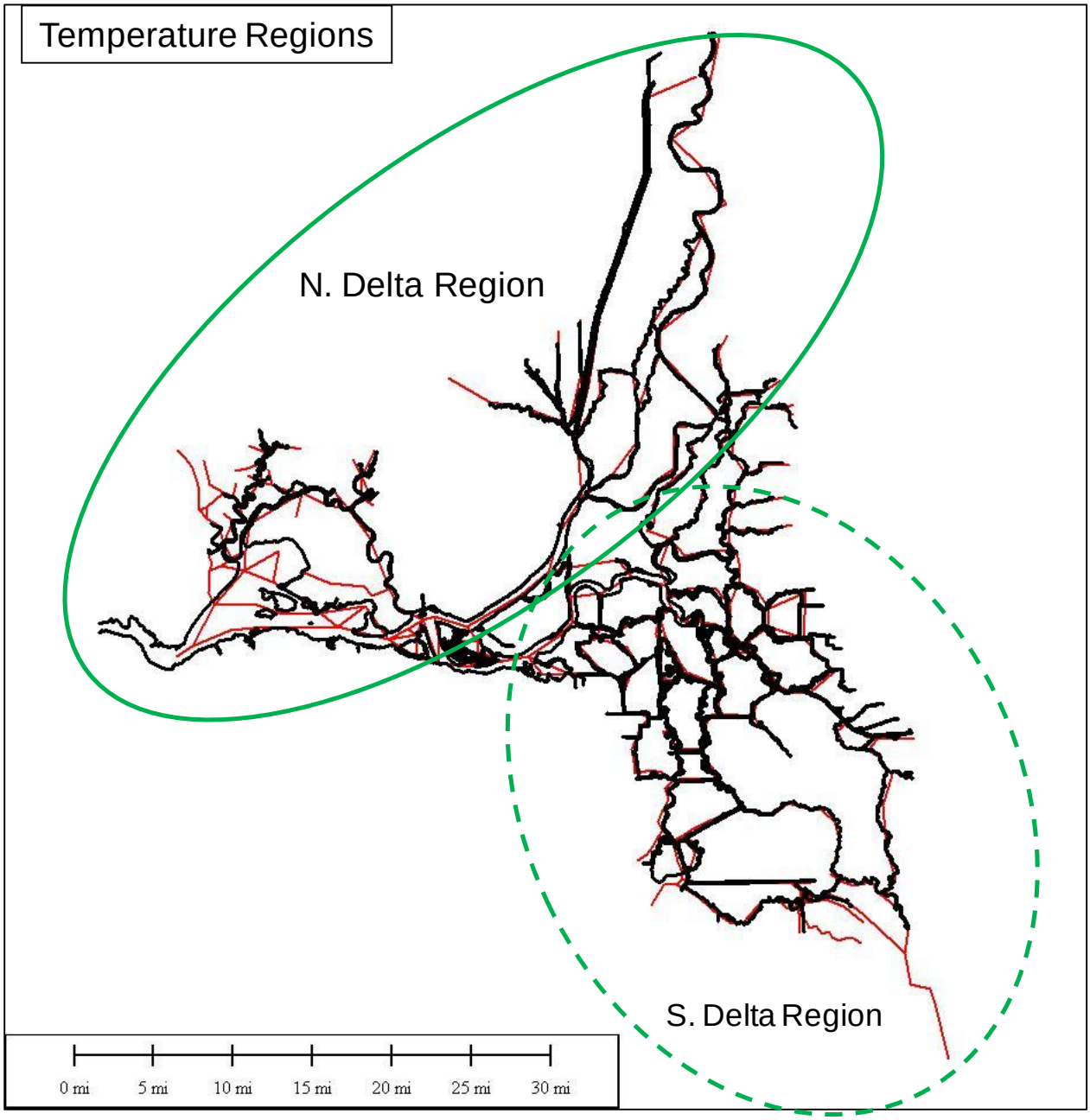


Figure 9-1 A minimum two meteorological regions are needed to calibrate QUAL for water temperature.

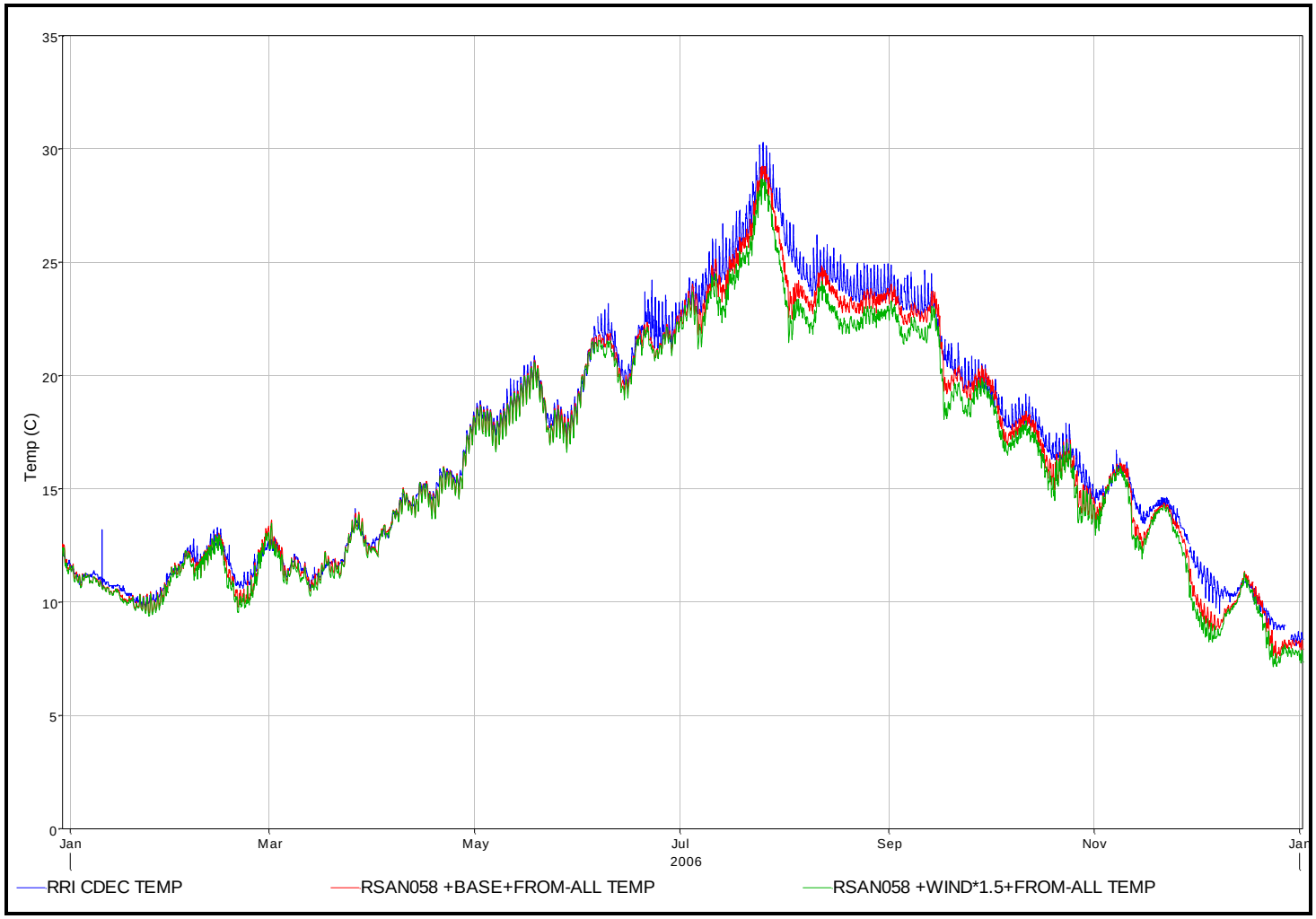


Figure 9-2 Modeled water temperature at RSAN058 on the San Joaquin River for two wind speeds – Base speed and wind speed*1.5 – in comparison with data (blue line).

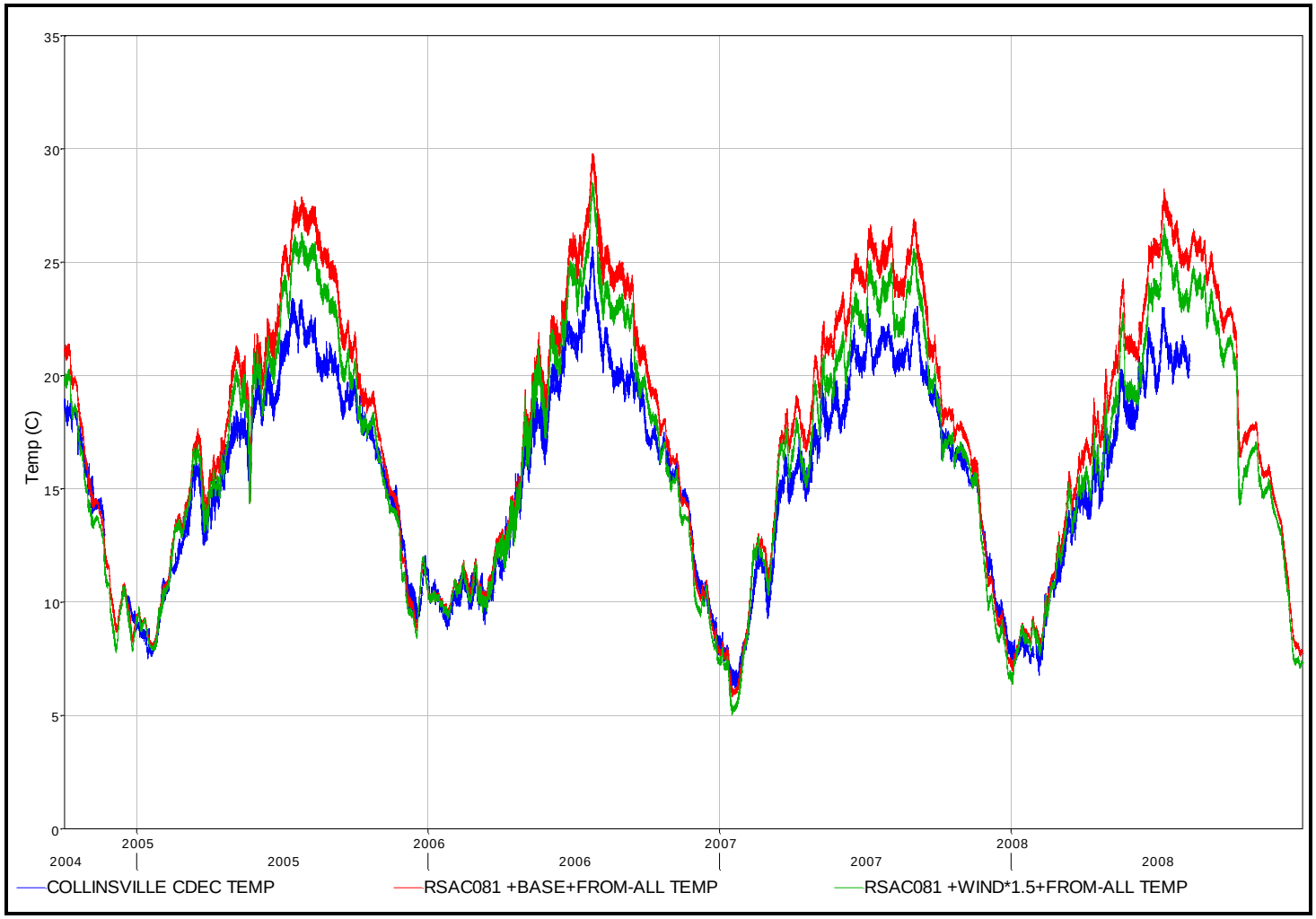


Figure 9-3 Data (blue line) and modeled water temperature at RSAC081 for two wind speeds – Base (red) and wind speed*1.5 (green). Increasing wind speed produces a better fit to the data.

Table 9-1 Details on effluent water temperature settings. The Time column indicates the frequency of time series, and the Source column indicates the identity of the data source.

Location	Time	Source
SRWWTP	Day	CVRWQCB
STOCKTON	Day	WWTP
Manteca	Day	Limits
Delta Diablo	Month	Max limit
Tracy	Day	WWTP
Lodi	Day	WWTP
Fairfield-Suisun	Day	WWTP
CCSD	Day	WWTP
Discovery Bay	Day	WWTP
Valero	Month	Modeled RSAC056
Mtz-Tesoro	Month	Modeled RSAC057
Mtn House	Month	Modeled ROLD034

Table 9-2 Detail on nutrient model boundary conditions for the DSM2 Version 8.0.6 2000 -2008 calibration. The Time column indicates the frequency of time series, and the Other column indicates additional information.

Location	Constituent	Time	Constant (mg/L)	Other
Calaveras	po4	Month		Synthesis-UCD
Calaveras	organic_p	Month		Synthesis-UCD
Calaveras	no3	Month		Synthesis-UCD
Calaveras	nh3	Month		Synthesis-UCD
Calaveras	organic_n	Month		Synthesis-UCD
Calaveras	algae	Month		Synthesis-UCD
Calaveras	no2	constant	0.005	
Calaveras	do	constant	7	
Calaveras	bod	constant	1.5	
Calaveras	ec	constant	125	
Cosumnes	po4	Month		Synthesis-UCD
Cosumnes	organic_p	Month		Synthesis-UCD
Cosumnes	no3	Month		Synthesis-UCD
Cosumnes	algae	Month		Synthesis-UCD
Cosumnes	nh3	Month		Synthesis-UCD
Cosumnes	organic_n	Month		Synthesis-UCD
Cosumnes	no2	constant	0.005	
Cosumnes	bod	constant	1.5	
Cosumnes	do	constant	9	
Cosumnes	ec	constant	125	
Mokelumne	algae	Month		Synthesis-UCD
Mokelumne	po4	Month		Synthesis-UCD
Mokelumne	organic_p	Month		Synthesis-UCD
Mokelumne	no3	Month		Synthesis-UCD
Mokelumne	nh3	Month		Synthesis-UCD
Mokelumne	organic_n	Month		Synthesis-UCD
Mokelumne	do	constant	9	
Mokelumne	bod	constant	1.1	
Mokelumne	no2	constant	0.004	
Mokelumne	ec	constant	12	

Table 9-3 More detail on nutrient model boundary conditions for the DSM2 Version 8.0.6 2000 -2008 calibration. . The Time column indicates the frequency of time series, and the Other column indicates additional information.

Location	Constituent	Time	Constant (mg/L)	Other
Martinez	organic_n	Month		EMP
Martinez	nh3	Day		EMP
Martinez	do	Hour		
Martinez	algae	Day		EMP
Martinez	no3	Day		EMP
Martinez	po4	Day		EMP
Martinez	ec	Hour		DWR-DMS
Martinez	organic_p	constant	0.01	
Martinez	bod	constant	2.8	
Martinez	no2	constant	0.008	
Freeport	organic_n	Day		Greens-Hood EMP
Freeport	do	Hour		
Freeport	nh3	Day		Calculated (See Appendix)
Freeport	no3	Hour		Greens-Hood*0.75 EMP
Freeport	organic_p	Month		Synthesis-UCD
Freeport	po4	Day		Greens-Hood*0.8 EMP
Freeport	algae	Day		Greens-Hood EMP
Freeport	ec	15 Min		DWR-DMS
Freeport	no2	constant	0.004	
Freeport	bod	constant	1.2	
Vernalis	nh3	Day		EMP
Vernalis	organic_n	Month		EMP
Vernalis	algae	Day		EMP
Vernalis	no3	Day		EMP
Vernalis	do	Hour		CDEC-Mossdale
Vernalis	po4	Hour		EMP
Vernalis	organic_p	Month		Synthesis-UCD
Vernalis	ec	15 Min		DWR=DMS
Vernalis	bod	constant	2.8	
Vernalis	no2	constant	0.15	
Yolo/Toe Drain	do	15 Min		Freeport DO
Yolo/Toe Drain	ec	15 Min		DWR-DMS RSAC139
Yolo/Toe Drain	bod	constant	1.5	
Yolo/Toe Drain	organic_n	constant	0.2	
Yolo/Toe Drain	nh3	constant	0.03	
Yolo/Toe Drain	organic_p	constant	0.01	
Yolo/Toe Drain	no2	constant	0.004	
Yolo/Toe Drain	po4	constant	0.1	
Yolo/Toe Drain	algae	constant	0.2	
Yolo/Toe Drain	no3	constant	0.09	

Table 9-4 DICU constant concentration boundary conditions for the nutrient model (all units in mg L^{-1}).

Constituent	DICU Constant Value
po4	0.2
organic_p	0.09
algae	1
nh3	0.31
no2	0.02
no3	1.3
bod	3.9
temperature	22

Table 9-5 Effluent boundary condition detail for Stockton, Sac Regional, Central Contra Costa Sanitary District (CCSD), and Delta Diablo. The Time column indicates the frequency of time series, and the Source/Other column indicates additional information.

Location	Constituent	Time	Constant (mg/L)	Source/Other
STOCKTON	DO	15 Min		WWTP
STOCKTON	BOD	15 Min		WWTP
STOCKTON	NH3	15 Min		WWTP
STOCKTON	NO2	15 Min		WWTP
STOCKTON	NO3	15 Min		WWTP
STOCKTON	organic_n	15 Min		WWTP
STOCKTON	EC	15 Min		WWTP
STOCKTON	PO4	Month		WWTP
STOCKTON	ALGAE		0.04	Guess
STOCKTON	organic_p	Day	0.35	Guess
SRWWTP	BOD	Day		CVRWQCB/Transform
SRWWTP	NO2	Day		CVRWQCB
SRWWTP	NH3	Day		CVRWQCB
SRWWTP	NO3	Day		CVRWQCB
SRWWTP	organic_n	Month		CVRWQCB
SRWWTP	EC	Month		CVRWQCB
SRWWTP	DO		8	Guess
SRWWTP	ALGAE		0.01	Guess
SRWWTP	PO4		0.75	Guess
SRWWTP	organic_p		0.35	Guess
CCSD	DO	Day		WWTP
CCSD	BOD	Day		WWTP
CCSD	NH3	Day		WWTP
CCSD	NO2	Day		WWTP
CCSD	NO3	Day		WWTP
CCSD	organic_n	Day		WWTP
CCSD	PO4	Day		WWTP
CCSD	EC	Month		Modeled RSAC064
CCSD	organic_p		0.35	Guess
CCSD	ALGAE		0.01	Guess
Delta Diablo	BOD	Month		BOD-5 MAX Limit
Delta Diablo	EC	Month		Modeled RSAN007
Delta Diablo	organic_n		3	Guess
Delta Diablo	NH3		10	Guess
Delta Diablo	NO3		0.2	Guess
Delta Diablo	NO2		0.1	Guess
Delta Diablo	DO		7	Limit
Delta Diablo	ALGAE		0.01	Guess
Delta Diablo	PO4		1	Guess
Delta Diablo	organic_p		0.35	Guess

Table 9-6 More effluent boundary condition detail for Discovery Bay, Fairfield-Suisun, Lodi, and Manteca. The Time column indicates the frequency of time series, and the Source/Other column indicates additional information.

Location	Constituent	Time	Constant (mg/L)	Source/Other
Discovery Bay	DO	Day		Limit
Discovery Bay	BOD	Month		Limit
Discovery Bay	NH3	Month		Limit
Discovery Bay	NO3	Month		Limit
Discovery Bay	EC	Month		Limit
Discovery Bay	ALGAE		0.01	Guess
Discovery Bay	NO2		1	Guess
Discovery Bay	organic_n		2	Guess
Discovery Bay	organic_p		0.35	Guess
Discovery Bay	PO4		1	Guess
Fairfield-Suisun	BOD			WWTP/Transform
Fairfield-Suisun	NH3	Day		WWTP
Fairfield-Suisun	NO3	Day		WWTP
Fairfield-Suisun	organic_n	Day		WWTP
Fairfield-Suisun	PO4	Month		WWTP
Fairfield-Suisun	EC	Day		Modeled SLCBN002
Fairfield-Suisun	ALGAE	Month	0.01	Guess
Fairfield-Suisun	DO		8	Average
Fairfield-Suisun	NO2		0.4	Guess
Fairfield-Suisun	organic_p		0.35	Guess
Lodi	DO	Day		WWTP
Lodi	BOD	Day		WWTP
Lodi	NH3	Day		WWTP
Lodi	EC	Day		WWTP
Lodi	ALGAE		0.01	Guess
Lodi	NO3		0.2	Guess
Lodi	NO2		0.1	Guess
Lodi	organic_n		0.5	Guess
Lodi	organic_p		0.35	Guess
Lodi	PO4		1	Guess
Manteca	BOD	Day		WWTP
Manteca	NH3	Hour		WWTP
Manteca	NO2	15 Min		WWTP
Manteca	NO3	15 Min		WWTP
Manteca	organic_n	Hour		WWTP
Manteca	EC	Month		WWTP
Manteca	ALGAE		0.01	Guess
Manteca	DO		8	Guess
Manteca	organic_p		0.35	Guess
Manteca	PO4		0.5	Guess

Table 9-7 Even more effluent boundary condition detail for Mountain House, Martinez+ Tesoro, Tracy and Valero. The Time column indicates the frequency of time series, and the Source/Other column indicates additional information.

Location	Constituent	Time	Constant (mg/L)	Source/Other
Mtn House	EC	Month		Modeled ROLD034
Mtn House	NH3		1	Limit
Mtn House	NO2		1	Limit
Mtn House	NO3		10	Limit
Mtn House	organic_n		1	Guess
Mtn House	PO4		1	Guess
Mtn House	DO		5	Limit
Mtn House	BOD		5.616	Limit
Mtn House	ALGAE		0.005	Guess
Mtn House	organic_p		0.35	Guess
Mtz-Tesoro	NH3	Month		Avg Both WWTP
Mtz-Tesoro	EC	Month		Guess
Mtz-Tesoro	ALGAE		0.005	Guess
Mtz-Tesoro	BOD		5.616	Guess
Mtz-Tesoro	DO		5	Guess
Mtz-Tesoro	NO3		1	Guess
Mtz-Tesoro	NO2		0.25	Guess
Mtz-Tesoro	organic_n		1	Guess
Mtz-Tesoro	organic_p		0.35	Guess
Mtz-Tesoro	PO4		1	Guess
Tracy	BOD	Day		WWTP/Transform
Tracy	NH3	Day		WWTP
Tracy	NO2	Month		WWTP
Tracy	NO3	Day		WWTP
Tracy	EC	Hour		WWTP
Tracy	PO4	Month		WWTP
Tracy	ALGAE		0.01	Guess
Tracy	DO		8	Guess
Tracy	organic_n		3	Guess
Tracy	organic_p		0.35	Guess
Valero	NH3	Month		WWTP
Valero	EC	Month		Modeled RSAC064
Valero	DO		5	Guess
Valero	BOD		5.616	Guess
Valero	NO2		0.25	Guess
Valero	NO3		1	Guess
Valero	organic_n		1	Guess
Valero	PO4		1	Guess
Valero	ALGAE		0.005	Guess
Valero	organic_p		0.35	Guess

10 Chemical Speciation Modeling and Isotope Analysis

10.1 EQ3/6 modeling

Measurement data supplied by R. Dahlgren (U.C. Davis) was used to develop chemical speciation models using the EQ3/6 program. A complete suite of water quality constituents were measured in the data at each location shown in Figure 8-4. Using Dahlgren's measurements, EQ3/6 models (Wolery, 1992) were developed to investigate general trends in the water chemistry, and the speciation of constituents in solution at Vernalis and Freeport. The details of model formulation and the speciation results are covered in Appendix I, Section 25.9.

Initial calculations using equilibrium constants for the ammonia dissociation reaction, assuming water temperature at 25°C, were made to assess the range of NH_3 (*aq*) and NH_4^+ concentrations that are likely to be found in the Delta. At the pH levels normally found in the Delta, pH = 7.0 – 8.0, calculations yield that less than 1.0% and less than 6.0%, respectively, of the total ammonia in solution would be found as NH_3(*aq*). As a simplification given the long time frame modeled, apart from extreme events, it is reasonable to assume that the ammonia modeled in QUAL is predominantly NH_4^+. If a short time frame event were to be modeled or examined, that assumption would not necessarily be justified, depending on the conditions. In the Dahlgren measurements, pH at Vernalis varied between 7.4 and 7.6, and at Freeport, pH varied between 7.3 and 8.3.

The speciation calculations were used as a heuristic to understanding the chemistry of waters entering the Delta at its major inflow boundaries. Clearly, due to biological activity constituent concentrations these waters are not at equilibrium as the model calculations assume. However, several interesting features of the calculations were noted. First, the average pH of the incoming waters was near pH = 8.0, so most of the ammonia in solution was NH_4^+, as discussed in Appendix I, Section 25.9. Nitrate concentration was at the same order of magnitude as NH_4^+ concentration, while nitrite was two orders of magnitude less. On average, the NH_4^+ concentration in the incoming water is approximately in the range considered as critical for algal uptake of NO_3*vs*. NH_4^+ (Dugdale et al., 2007; Wilkerson et al., 2006).

Interaction between the CO_2 in the atmosphere and surface waters can sometimes be an important factor in determining the pH of surface water, as the gas dissolves into the water and dissociates. In the EQ3/6 speciation calculations, it was found that on average the water was supersaturated with respect to CO_2(g) in comparison with the concentration expected if the solutions were at equilibrium with the atmosphere. This higher concentration of CO_2(g) in solution is (most likely) due to biological activity from algal respiration. As a consequence, we can expect that the waters would be out-gassing CO_2, not gaining it from atmospheric interactions. This biological activity would tend to continue as waters travel through the Delta, as the contribution of new nutrient sources within the Delta would tend to promote continued

biological activity. Thus, the mass transfer of atmospheric CO_2 into the water is not likely to be a primary factor regulating the pH of Delta waters.

The implication of this observation is that changing the conceptual model formulation in QUAL to include the mass transfer of atmospheric CO_2 into the water would not be considered a high priority at the Delta-wide spatial scale, and at the long time frame considered in the initial calibrated model, 1990 - 2008. At shorter time frames and at smaller spatial scales, i.e. if considering a "local" model, this simplification may not be justified.

10.2 Isotope Analysis

In Kendall's CALFED-funded PIN700 project "Determination of Sources of Organic Matter and Nutrients in the San Joaquin River" (Kendall et al., 2008), samples collected from 33 sites in the San Joaquin and Sacramento Rivers from 8/06 to 5/08 were analyzed for NO_3, POM (particulate organic matter, which is mostly comprised of algae and bacteria), DOC, and other isotopes to determine the seasonal and spatial changes in the sources of NO_3 and POM, and in the link between NO_3 and POM. Analysis of the NO_3 and POM for $\delta^{15}N$ showed that the $\delta^{15}N$ of algae is sensitive to the nutrient sources, extent of nitrification of NH_4 to NO_3, and instream biogeochemical processes.

The intent has been to incorporate results from isotopic analyses into the analysis of DSM2 Historical model output, but the additional funding needed to accomplish this goal has not been obtained to date.

11 Calibration/Validation Methodology

Although there are many different ways to define model calibration, in this document we assume the simple definition that calibration is the process of adjusting a set of model parameters so that model agreement with respect to a set of experimental data is maximized (Trucano et al., 2005). Similarly, validation is the quantification of the predictive ability of the model through comparison with a set of experimental data (Trucano et al., 2005). For both calibration and validation, these definitions assume that a set of criteria for assessing the goodness-of-fit of the model to the data have been selected. For our purposes, the general methodology discussed in Moriasi (2007) was employed for this assessment. A set of statistics were calculated separately for calibration and validation for all available data of sufficient quality - detailed statistics are documented in the text, and some cases more thoroughly in the Appendices along with categorical interpretations.

As mentioned in the Executive Summary (Section 1), the original nutrient model calibration has been updated several times since the original calibration in 2009. After the first DRAFT of this document was released, substantial changes were implemented in DSM2. The main change to DSM2 came with the introduction of Liberty Island into the model domain – Liberty Island flooded in 1998, prior to that time it had protected from flooding by levees. As with other open water areas in the Delta, Liberty Island is represented as a single well-mixed water body in DSM2. At the same time, the grid at the northern boundary of the DSM2 model on the Sacramento River was extended and the bathymetry was updated using additional data. Because of the timing of the flooding of Liberty Island, the original calibration period, 1990 – 2008, was shortened – the current calibration period is substantially shorter, 2000 – 2008, which corresponds to the time frame after the physical changes in Delta bathymetry in the area of Liberty Island.

Subsequent to the original calibration (for 1990 – 2008): DWR-DMS corrected an error in the formulation for the ammonia constituent; the numerical formulation for calculating source terms was changed; and, the formulation for mixing in dead end sloughs and other locations with zero upstream flow was improved. These changes in QUAL were significant enough to require recalibration of nutrient model parameters - water temperature was not recalibrated.

In this chapter, the result of each of these calibration exercises is discussed. However, it should be recognized the latest calibration is currently the one that is being utilized in application as it incorporates corrections to the nutrient model formulation and calculation, and a major improvement in Delta bathymetry. Additional detail and information on each of the calibration and verification results of the nutrient model is found in Appendices II – V for the 1990 - 2008

calibration, and in Appendix I for the 2000 - 2008 calibration. The general methodology for calibrating nutrients, a statistical residual analysis, is consistent across the different calibrations. In all cases, although numerical statistics are calculated at all available in-Delta locations, the quality of the final calibration and validation is assessed categorically.

11.1 Methodology for Calibration and Validation

The statistics used to assess model calibration and validation at each Delta location were calculated from model residuals – a residual is the difference between a data value and the corresponding calculated model value (*i.e.,* data - model). Residuals were calculated for each calendar year at each location, and then grouped by Water Year Type. Three widely used statistics were used to assess the goodness-of-fit of the model to the data – the Nash-Sutcliff efficiency (NSE), Percent Bias (PBIAS) and root mean square error standard deviation ratio (RSR). Each of the three numerical statistics was then grouped into categories – Very Good, Good, Satisfactory and Unsatisfactory - which were used to assess the quality of the calibration and predictive value of the validation.

In order to ascertain that model calibration and validation were sufficient for both low and high inflow conditions, calibration and validation were considered separately by Water Year (WY) Type. Both graphical and statistical model evaluation techniques were used in the analysis of calibration and validation results. As described in subsequent sections, water temperature and nutrient calibration were considered separately, and the methodology for calculating calibration statistics was different due to the large difference in the availability of data both for setting boundary conditions are for calibration and validation.

In either case – nutrients or water temperature – calibration was carried out "by hand", as funding was not sufficient to employ software to automate the calibration.

The calibration process began by calibrating the water temperature model. Water temperature in QUAL is independent of nutrient dynamics as it relies only on meteorological data and the settings of a few meteorological parameters, water temperature boundary conditions and model output from HYDRO in its transport calculations. On the other hand, nutrient dynamics are temperature-dependent so water temperature needed to be calibrated prior to the nutrient model calibration.

Several factors guided calibration methodology and the selection of time periods for calibration and validation. The most important factor was the availability and quality of calibration data, and the second was the need to include a variety of inflow conditions, as represented by Water Year Type, to identify variations in model calculations due to factors such as outflow volume and reservoir releases, as well as Delta operations such as meeting X2 salinity targets or the use of the Delta Cross Channel gates.

Another factor in the calibration methodology, particularly in setting concentrations for unconstrained boundary conditions, was the need to develop a methodology consistent with possible future uses of the calibrated model, where measurement data may not exist to inform the boundary conditions. In two likely routes for future model development, modeling a Historical time frame before 1990 or simulating Planning model scenarios which currently cover the period from 1922 – 2003, there are few or no nutrient and/or effluent measurements available. Models such as these could be used to quantify the effect on hydrodynamics and water quality of a shift in Delta dynamics, such as the introduction of invasive species, or a new project resulting in a modification in the Delta water regime such as construction of a new structure such as a gate, respectively. In either case, synthetic boundary conditions would need to be developed.

The most consistent measurement that is available over extended time spans is inflow from rivers into the Delta and Delta outflow, so a practical criterion for setting synthetic boundary conditions is that they should largely rely on relationships with flow or be set in accord with Water Year type. Thus in order to synthesize data for any time period, having a methodology for representing boundary conditions by Water Year Type when data is not available becomes a sensible strategy – this strategy was adopted here.

11.2 Residual Analysis

Residuals are defined as the difference (data – model) between the measured data and the modeled result. The following definitions (Moriasi et al., 2007) were used for calculating residual statistics:

Mean Residual– The mean of the residual values gives an indication of the magnitude of model under-prediction (positive residuals) or over-prediction in a region. The optimal value is zero, which occurs in the unlikely situation that the model is a perfect fit for the data.

Standard Deviation of Residual– The standard deviation of the residual values gives an indication of the variability in model under-prediction and over-prediction in a region.

Residual Histogram – The histogram documents the shape of the residual distribution. Along with the mean and standard deviation, this gives a first-order view of the goodness of model fit. The ideal histogram would have an approximately normal shape centered at zero with a small spread. Histograms were prepared using annual calculations at each location.

MSE – The Mean Squared Error is a standard statistic that measures the quality of the prediction. The optimal value is zero:

$$MSE = \left[\frac{\sum_{i=1}^{n} \left(Y_i^{Obs} - Y_i^{Sim} \right)^2}{n} \right] \quad \text{(A3)}$$

RMSE – The Root Mean Squared Error is a standard statistic used to indicate the accuracy of the simulation. It is the square root of the MSE. The optimal value is zero.

NSE – The Nash-Sutcliffe Efficiency is a normalized statistic that measures the relative magnitude of the residual variance compared to the data variance. NSE indicates how well the measured vs. modeled data fit the 1:1 line (Moriasi et al., 2007). A value of 1 of optimal, values between 0 and 1 are acceptable, and negative values indicate that the data mean is a better predictor of the data than the model:

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n} \left(Y_i^{Obs} - Y_i^{Sim} \right)^2}{\sum_{i=1}^{n} \left(Y_i^{Obs} - Y_i^{Mean} \right)^2} \right] \quad \text{(A4)}$$

PBIAS– Percent bias measures the average tendency of the simulated data to be larger or smaller than the measured data. A value of 0 of optimal – a positive value indicates underestimation bias and a negative value indicate overestimation bias:

$$PBIAS = \left[\frac{\sum_{i=1}^{n} \left(Y_i^{Obs} - Y_i^{Sim} \right) * 100}{\sum_{i=1}^{n} \left(Y_i^{Obs} \right)} \right] \quad \text{(A5)}$$

RSR– The RMSE-observation standard deviation ratio is a statistic that normalizes the RMSE using the standard deviation of the observations. Because it is normalized, it can be used to compare errors among various constituents (Moriasi et al., 2007). A value of 0 is optimal:

$$RSR = \frac{\left[\sqrt{\sum_{i=1}^{n} \left(Y_i^{Obs} - Y_i^{Sim} \right)^2} \right]}{\left[\sqrt{\sum_{i=1}^{n} \left(Y_i^{Obs} - Y_i^{Mean} \right)^2} \right]} \quad \text{(A6)}$$

11.3 Methodology for nutrient residual analysis

The combined effects of data variability between agencies and sparse measurement intervals, generally monthly, meant that some measure of uncertainty needed to be included in assessing the quality of model calibration and validation. For example, the monthly nutrient boundary conditions and in-Delta measurements were not all collected at time intervals to allow the direct comparison between a model calculation and a data value at a calibration location made during that month. As a consequence, there was invariably a mismatch between the timing of the boundary condition and the timing of the downstream data. The EMP and USGS had data along the Sacramento River at the same or similar measurement locations, as discussed in Section 7.3, and the variability between the measurement data sets indicated that daily fluctuations, tidal influences and extreme events would influence the monthly values.

To capture this variability, an "envelope" of model values was used to incorporate these different sources of uncertainty. The maximum and minimum monthly values of 15 minute model output were calculated to create the upper and lower bounds of the envelope, respectively. At a given location, if the calibration data fell within that max/min envelope, then the residual was calculated as zero. Values falling outside of the envelope were calculated as residuals using the either the maximum of the envelope (data higher than maximum value) or the minimum value of the envelope (data less than the minimum value) for that month. Note that this methodology could be refined, as the partition of data and model values along strict monthly time intervals in somewhat artificial. However, for simplicity, the monthly approach was deemed reasonable. A similar approach was documented in Kim *et al.* (2009).

For the 2000 – 2008 calibration, this methodology was expanded to reduce the maximum monthly value and increase the minimum monthly value by a percentage of the difference between these values in each month – 95%, 90%, 80% and 75%. These results are discussed briefly below (Section12.5.3), and more thoroughly in Appendix I, Section 27.

12 Calibration and Validation for Water Temperature and Nutrients

12.1 Background for Water Temperature Calibration

The time periods selected for water temperature calibration are shown in Figure 12-1, the locations used to collect meteorological data are shown in Figure 8-7 and the availability and quality of water temperature data is illustrated in Figure 8-8 through Figure ??. Temperature data coverage was adequate spatially to assess calibration, apart from the Yolo/Cache and Suisun Marsh areas, and data were available at either hourly or daily time intervals. Data quality was variable over the modeled time span, and both availability and quality were greater after 2000.

Data from different sources sometimes overlapped spatially, and the comparisons were helpful is establishing an expected temporal variability and a range in measurement magnitude (as an indicator of data quality).

Water temperature residuals were first calculated on an annual basis by Water Year Type at each location, and then the averages were calculated regionally for all locations in each of the three major regions. The Suisun and Yolo/Cache regions had only one data location, so averages were just calculated over the years present in a particular Water Year Type. Maximum and minimum values were determined by individual year and location within a region and Water Year type.

12.1.1 Methodology for Water Temperature Calibration and Validation

The meteorological data from the previous calibration (Rajbhandari 2003) modeled water temperature the South Delta region adequately in the period 1996 – 2000 (i.e., residuals is this region showed the calibration was at least satisfactory). Unfortunately given the current project focus, water temperatures in the North Delta region were not modeled as well as in the south Delta using this meteorological data and parameterization. In addition, during the 1990 - 2008 calibration time frame, there was no single meteorological station with a data set that covered the entire time span, so it was necessary to combine meteorological data from several different stations – this is discussed in detail in Section 9.3. These factors prompted the need for an improved calibration of water temperature with new data in an expanded time frame.

As discussed in Section 9.3, wind speeds prior to 1996 were taken from the CIMIS Brentwood location which generally had a much higher average wind speeds than the Stockton NOAA data which was available over most of the modeled time frame. Wind speeds from 1990 - 1995 sourced from the Brentwood station were decreased in value by a factor of 0.85 so the average wind speed matched the average from 1996 – 2008 (sourced from Stockton NOAA data). This set of wind speeds was used in the calibration and validation. Once a complete set of meteorological and water temperature boundary conditions was assembled, a model parameter and boundary condition sensitivity analysis showed that water temperature was most sensitive to variation in wind speed, so wind speeds were varied in the calibration process.

Using this data set, wind speed was increased by factor of two each year from April – October, with a linear ramp up/ramp down period of three days in order to obtain sufficient quality in the calibration statistics. This increase in wind speed was implemented as a type of fitting parameter, as it was apparent during the calibration process that it was either possible to obtain an acceptable calibration within this period or outside of this period, but not in both periods, with the current model formulation for meteorological effects on water temperature. This same effect was subsequently noted in two different numerical models of Delta water temperature – in the RMA two-dimensional model and in a three-dimensional model developed by the USACE (US Army Corps of Engineers). It is interesting to note that this April – October period generally

overlaps with the period of high afternoon westerly wind speeds that develop due to temperature and pressure differences between the interior valleys in California and the ocean.

Five sub-regions were selected in the Delta for calibration/validation comparison – along the San Joaquin River corridor, along the Sacramento River corridor, the South Delta, the Yolo region and Suisun Marsh (Figure 12-2). Only one measurement location was available in each of the Yolo and Suisun regions, so they are characterized by those points.

12.1.2 Residual Analysis – Water Temperature

Residuals were calculated as (Data – Model) for each calendar year at each location, and are grouped by Water Year Type. Although Water Years begin in October of the previous year, the final Water Year Type is finalized several months later after a portion of the wet season reveals the likely depth of the snow pack. Although grouped by Water Year, statistics were calculated on an annual time frame, under the assumption that decisions on water operations October - December may be based on factors from the previous Water Year (the same calendar year) such as reservoir levels, particularly in drier years.

Although the results were regionalized for analysis, residual results were calculated at each location in each region – for the Suisun and Yolo regions, only a single location was available. For each statistic, an average result was calculated, and the maximum and minimum results identified. The following statistics were used for comparison of calibration and validation results: Residual mean and standard deviation, mean square error (MSE), root mean square error (RMSE), Nash-Sutcliff efficiency (NSE), percent bias (PBIAS), and RMSE-standard deviation ratio (RSR). The reasoning behind this methodology is discussed in Section 11.2.

12.1.3 Calibration/Validation Results for Water Temperature

Table 12-1through Table 12-4 document the water temperature calibration and validation results by region and by the four Water Year Types. Because only one Below Normal Water Year occurred during the modeled time span, calibration and validation periods could not be selected for comparison.

Ranges for model calibration performance ratings for the NSE, RSR and PBIAS statistics under monthly time steps are given in (Moriasi et.al. 2007). Following those general guide lines, a calibration is viewed as “Very Good” for the NSE statistic if NSE is greater than 0.75. Similarly, a PBIAS value less than +/-(10 – 25)% (depending on category such as streamflow, sediment or N,P constituent) and a RSR value less than 0.50 are “Very Good”. Under each of these three criteria, both the calibration and the validation of water temperature is “Very Good” in all five regions over all Water Year types.

Results for the validation period are very similar to the calibration period, with the most noticeable change in the model bias in wet Water Years (note: only a single year was available

for wet calibration and validation). For the Sacramento region, the validation results very good, as well as for the other regions for the other regions. Generally speaking, summer water temperatures were low (underestimated) in the San Joaquin and South Delta regions.

Figure 12-8 through Figure 12-21 illustrate results of the calibration and validation of QUAL for water temperature at several locations for each Water Year type except Below Normal, where only one year of data was available. Figures show a comparison of model (red line) and data (blue line) in the upper plot, the residual (center plot), and the histogram of the residual (lower plot). In the upper plot, vertical blue lines are missing data points (not included in any calculation).

In the central and south Delta the residual histograms tend to be skewed positively indicating model under-prediction, while along the lower Sacramento R. the histograms tend to be skewed to negative values, indicating the model values were too high (Figure 12-9, Figure 12-12, Figure 12-17, Figure 12-20). On either side of Three Mile Slough, the model calculations are not skewed and the model predictions are very good (Figure 12-8, Figure 12-11, Figure 12-14, Figure 12-18)

If the application of meteorological data is "regionalized" in future versions of DSM2, a calibrated two-region water temperature model should be available using the meteorological data from the current calibration for the North Delta and from the previous calibration for the South Delta (Rajbhandari 2003).

Temperature Validation					Temperature Calibration				
1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
5	4	2	2	4	3	4	5	2	1

	Temperature Validation		Temperature Calibration					
1990	1991	1992	1993	1994	1995	1996	1997	1998
1	1	1	4	1	5	5	5	5

1	Critical
2	Dry
3	Below Normal
4	Above Normal
5	Wet

Calibration
Validation

Figure 12-1 Temperature model calibration and validation periods. Data 1999 – 2008 was generally of better quality, but early Critical Water Years ("1" in the chart) were also used.

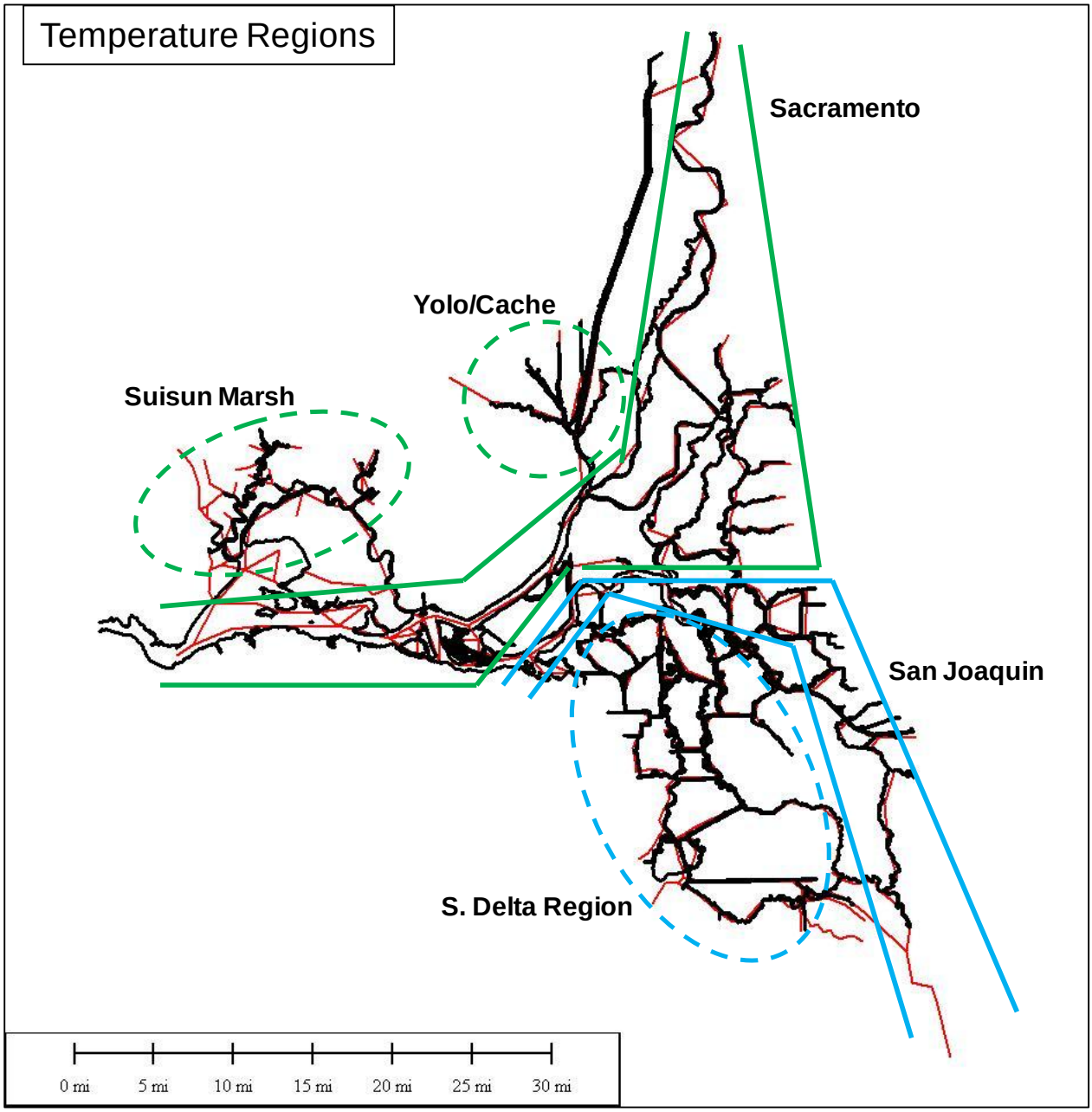


Figure 12-2 Five regions were used in the calibration and validation of water temperature.

Table 12-1 Comparison of Calibration and Validation statistics for Critically Dry Water Years.

Calibration Critical	Mean_Residual	StDev_Residual	NSE_stat	MSE_stat	RMSE_stat	PBIAS_stat	RSR_stat	Mean_data	StDev_data
SJR									
Average	0.64	1.16	0.95	2.54	1.46	3.90	0.28	16.41	5.09
Max	0.93	1.21	0.98	2.03	1.42	5.28	0.28	17.70	5.70
Min	-0.18	0.94	0.94	0.89	0.02	-1.04	0.00	16.21	4.75
SAC									
Average	0.18	1.02	0.96	1.31	1.13	0.98	0.22	16.23	5.14
Max	0.93	1.21	0.98	2.03	1.42	5.28	0.28	17.70	5.70
Min	-0.64	0.78	0.94	0.76	0.87	-4.17	0.16	15.41	4.77
S Delta									
Average	1.51	1.38	0.94	4.47	2.08	8.57	0.36	17.62	5.73
Max	2.11	2.11	2.11	3.90	2.11	7.18	2.11	17.72	6.12
Min	0.81	1.20	0.94	2.49	0.14	0.00	0.00	17.38	5.62
Cache Sl									
Value	-0.78	1.54	0.91	2.96	1.72	-4.79	0.33	16.28	5.16
Suisun Marsh									
Value	-0.02	1.43	0.91	2.04	1.43	-0.11	0.29	17.06	4.88
Validation									
Critical	Mean_Residual	StDev_Residual	NSE_stat	MSE_stat	RMSE_stat	PBIAS_stat	RSR_stat	Mean_data	StDev_data
SJR									
Average	0.51	1.24	0.95	2.63	1.46	2.80	0.25	16.01	5.62
Max	1.60	1.94	0.98	6.29	2.51	9.12	0.37	18.45	6.70
Min	-0.27	0.63	0.92	0.41	0.64	-1.69	0.16	11.22	3.56
SAC									
Average	0.10	0.74	0.98	0.65	0.77	0.49	0.16	15.89	5.01
Max	0.46	1.10	0.99	1.22	1.10	2.48	0.22	18.56	5.88
Min	-0.19	0.44	0.95	0.22	0.47	-1.46	0.10	11.99	3.76
S Delta									
Average	0.92	1.24	0.93	3.37	1.79	3.31	0.37	15.62	5.41
Max	1.97	1.58	0.97	6.37	2.52	11.09	0.67	17.91	6.38
Min	-1.10	0.80	0.84	1.82	1.35	-17.68	0.25	6.21	2.01
Cache Sl									
Value									
Suisun Marsh									
Value									

Table 12-2 Comparison of Calibration and Validation statistics for Dry Water Years.

Calibration Dry	Mean_Residual	StDev_Residual	NSE_stat	MSE_stat	RMSE_stat	PBIAS_stat	RSR_stat	Mean_data	StDev_data
SJR									
Average	0.32	1.04	0.96	1.58	1.17	1.84	0.22	16.67	5.17
Max	1.43	1.45	0.97	4.13	2.03	8.10	0.34	17.64	5.97
Min	-0.24	0.80	0.94	0.64	0.80	-1.45	0.16	16.33	4.62
SAC									
Average	-0.01	0.83	0.97	0.78	0.87	-0.07	0.17	16.18	5.02
Max	0.42	1.07	0.98	1.17	1.08	2.58	0.22	16.37	5.41
Min	-0.41	0.66	0.96	0.54	0.74	-2.61	0.14	15.84	4.63
S Delta									
Average	1.07	1.31	0.95	2.89	1.69	6.14	0.29	17.48	5.82
Max	1.28	1.34	0.95	3.42	1.85	7.27	0.32	17.56	5.83
Min	0.87	1.27	0.95	2.37	1.54	5.00	0.26	17.39	5.81
Cache Sl									
Value	-0.55	1.22	0.95	1.80	1.34	-3.46	0.25	15.98	5.42
Suisun Marsh									
Value	0.15	1.04	0.92	1.10	1.05	1.14	0.28	13.26	3.78

Validation Dry	Mean_Residual	StDev_Residual	NSE_stat	MSE_stat	RMSE_stat	PBIAS_stat	RSR_stat	Mean_data	StDev_data
SJR									
Average	0.53	1.13	0.95	1.91	1.34	2.97	0.26	17.22	5.11
Max	1.25	1.59	0.98	3.30	1.82	6.90	0.31	18.11	5.94
Min	-0.24	0.79	0.92	0.63	0.79	-1.45	0.15	16.45	4.28
SAC									
Average	-0.11	0.85	0.89	1.23	1.03	-0.60	0.31	15.80	4.55
Max	1.19	1.30	0.99	3.84	1.96	9.45	1.59	17.68	5.54
Min	-1.77	0.46	-0.05	0.24	0.49	-12.79	0.09	9.29	0.71
S Delta									
Average	0.61	1.19	0.95	2.02	1.40	3.42	0.26	17.61	5.48
Max	1.12	1.27	0.96	2.82	1.68	6.32	0.30	18.01	5.85
Min	-0.06	1.09	0.94	1.35	1.16	-0.33	0.21	16.74	5.27
Cache Sl									
Value	-0.59	1.38	0.91	2.33	1.52	-3.58	0.31	16.54	4.87
Suisun Marsh Value	-0.14	1.28	0.92	1.70	1.29	-0.86	0.28	16.37	4.59

Table 12-3 Comparison of Calibration and validation statistics for Above Normal Water Years.

Calibration AN	Mean_Residual	StDev_Residual	NSE_stat	MSE_stat	RMSE_stat	PBIAS_stat	RSR_stat	Mean_data	StDev_data
SJR									
Average	0.39	0.96	0.96	1.30	1.10	2.23	0.22	17.12	4.95
Max	1.03	1.43	0.98	2.32	1.52	5.90	0.29	18.84	5.58
Min	-0.17	0.77	0.96	0.64	0.01	-1.03	0.00	16.52	4.43
SAC									
Average	0.04	0.72	0.98	0.65	0.64	0.10	0.14	16.20	4.40
Max	0.48	0.97	1.00	1.13	1.06	2.91	0.25	16.36	4.75
Min	-0.43	0.38	0.95	0.15	0.06	-2.68	0.00	16.02	4.17
S Delta									
Average	0.56	1.19	0.95	1.84	1.34	3.25	0.26	17.20	5.20
Max	1.03	1.43	0.96	2.32	1.52	5.90	0.29	17.60	5.58
Min	0.34	0.97	0.94	1.15	0.08	0.00	0.00	17.00	4.91
Cache Sl									
Value	-0.33	1.51	0.89	2.38	1.54	-1.95	0.33	17.00	4.63
Suisun Marsh									
Value	-0.14	1.18	0.93	1.40	1.18	-0.85	0.26	16.72	4.51

Validation AN	Mean_Residual	StDev_Residual	NSE_stat	MSE_stat	RMSE_stat	PBIAS_stat	RSR_stat	Mean_data	StDev_data
SJR									
Average	0.11	1.04	0.94	1.44	1.15	0.52	0.26	16.81	4.62
Max	1.12	1.72	0.97	3.27	1.81	6.19	0.49	18.15	5.68
Min	-0.57	0.78	0.78	0.64	0.80	-3.61	0.17	15.82	3.68
SAC									
Average	-0.38	0.83	0.96	1.72	1.09	-2.53	0.24	16.18	4.58
Max	0.62	1.50	0.99	9.23	3.04	3.61	0.74	17.47	5.17
Min	-2.91	0.35	0.90	0.12	0.35	-18.92	0.07	14.56	4.08
S Delta									
Average	0.65	1.02	0.96	1.65	1.26	3.56	0.24	17.96	5.32
Max	1.30	1.13	0.97	2.70	1.64	6.98	0.30	18.59	5.44
Min	0.11	0.92	0.95	0.85	0.92	0.67	0.17	17.19	5.12
Cache Sl									
Value	-0.54	1.28	0.94	1.94	1.39	-3.26	0.28	16.60	5.03
Suisun Marsh Value	-0.28	1.16	0.93	1.44	1.20	-1.73	0.26	16.49	4.53

Table 12-4 Comparison of Calibration and validation statistics for Wet Water Years.

Calibration Wet	Mean_Residual	StDev_Residual	NSE_stat	MSE_stat	RMSE_stat	PBIAS_stat	RSR_stat	Mean_data	StDev_data
SJR									
Average	0.15	0.63	0.98	0.46	0.68	0.89	0.14	16.32	4.89
Max	0.35	0.73	0.99	0.56	0.75	2.17	0.16	16.48	4.97
Min	-0.08	0.49	0.98	0.36	0.60	-0.50	0.12	16.21	4.75
SAC									
Average	0.12	0.71	0.84	0.53	0.77	0.43	2.67	14.01	4.72
Max	0.62	1.00	1.00	0.89	1.03	3.94	15.24	16.01	4.90
Min	-0.30	0.34	0.13	0.11	0.34	-1.93	0.07	4.86	4.59
S Delta									
Average	0.40	0.90	0.97	1.03	0.99	2.39	0.18	16.68	5.46
Max	0.41	1.16	0.99	1.48	1.22	2.50	0.22	16.90	5.65
Min	0.39	0.64	0.96	0.57	0.76	2.29	0.14	16.46	5.26
Cache Sl									
Value	-0.25	1.17	0.95	1.43	1.20	-1.52	0.24	16.48	5.07
Suisun Marsh									
Value	-0.27	1.06	0.95	1.20	1.10	-1.68	0.23	16.36	4.80

Validation Wet	Mean_Residual	StDev_Residual	NSE_stat	MSE_stat	RMSE_stat	PBIAS_stat	RSR_stat	Mean_data	StDev_data
SJR									
Average	0.61	0.46	0.96	1.55	1.07	5.38	0.77	12.51	2.26
Max	1.94	0.83	0.99	3.77	1.94	17.35	1.84	17.16	4.19
Min	-0.10	0.13	0.92	0.19	0.43	-1.09	0.20	9.20	1.05
SAC									
Average	-0.32	0.98	0.82	1.38	0.95	-2.48	2.46	14.36	4.26
Max	0.37	1.69	0.99	4.94	2.22	0.44	15.62	17.92	4.89
Min	-1.45	0.51	0.14	0.26	-0.04	-10.18	0.10	4.97	3.45
S Delta									
Average	0.92	1.19	0.96	2.41	1.51	5.32	0.26	17.16	5.69
Max	1.27	1.38	0.97	3.51	1.87	7.13	0.32	17.80	5.89
Min	0.58	0.99	0.95	1.32	1.15	3.51	0.21	16.51	5.49
Cache Sl									
Value	-0.27	1.34	0.91	1.86	1.36	-1.62	0.31	16.99	4.37
Suisun Marsh	-0.20	1.28	0.93	1.67	1.29	-1.27	0.27	15.64	4.70
Value									

Table 12-5 Calibration statistics for the Below Normal water Year 2004.

Calibration BN	Mean_Residual	StDev_Residual	NSE_stat	MSE_stat	RMSE_stat	PBIAS_stat	RSR_stat	Mean_data	StDev_data
SJR									
Average	0.73	1.02	0.96	1.80	1.28	4.03	0.25	17.53	5.02
Max	1.25	1.35	0.97	3.37	1.84	6.56	0.33	19.06	5.56
Min	0.21	0.85	0.94	0.76	0.87	1.28	0.18	16.60	4.64
SAC									
Average	0.22	0.78	0.97	0.78	0.88	1.30	0.18	16.39	4.88
Max	0.61	0.97	0.99	1.01	1.00	3.66	0.22	16.89	5.49
Min	-0.33	0.57	0.95	0.47	0.68	-2.07	0.13	15.88	4.49
S Delta									
Average	1.50	1.30	0.95	3.93	1.98	8.36	0.34	17.97	5.79
Max	1.50	1.30	0.95	3.93	1.98	8.36	0.34	17.97	5.79
Min	1.50	1.30	0.95	3.93	1.98	8.36	0.34	17.97	5.79
Cache Sl									
Value	-0.29	1.36	0.92	1.93	1.39	-1.78	0.29	16.48	4.78
Suisun Marsh									
Value	0.37	1.15	0.94	1.45	1.21	2.23	0.25	16.75	4.74

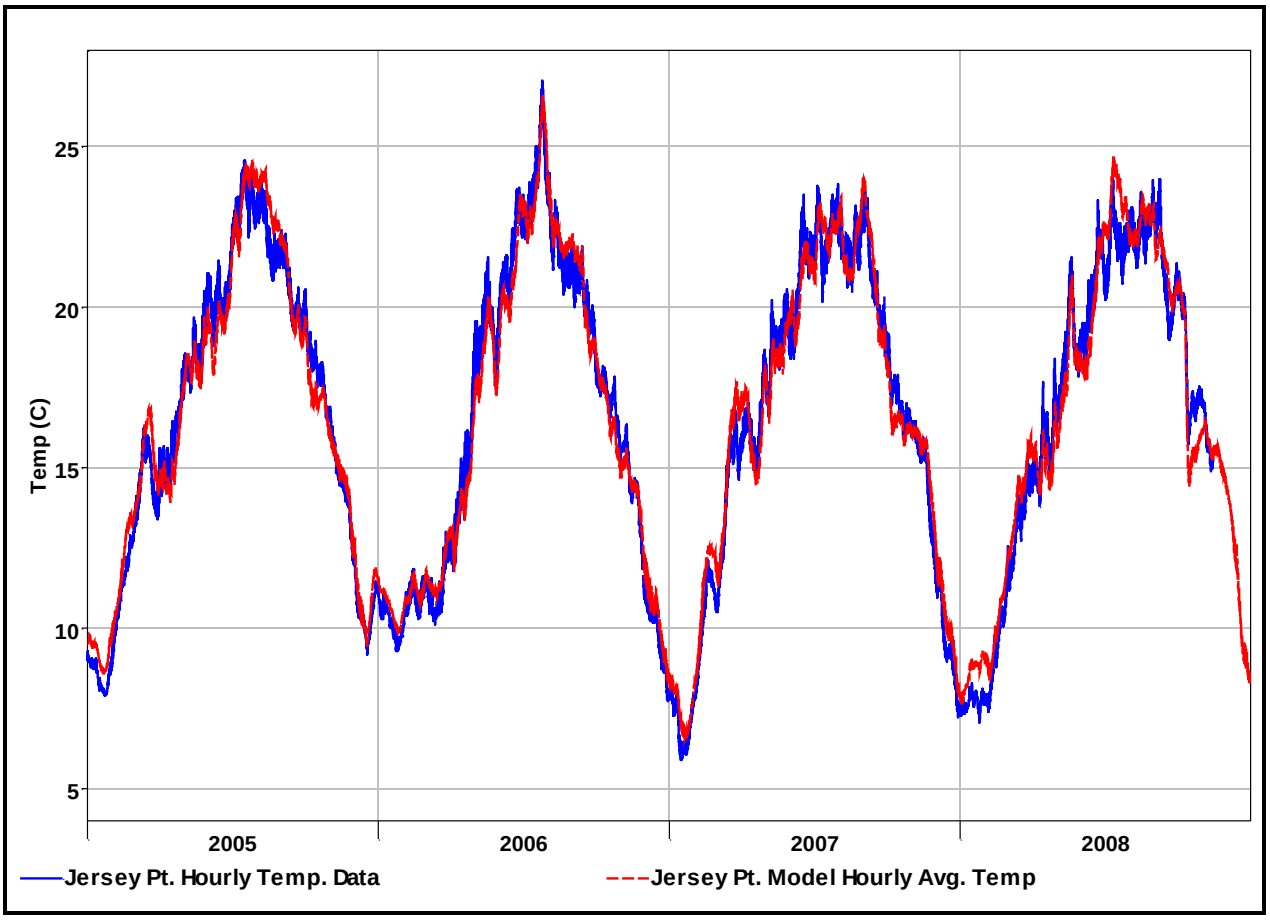


Figure 12-3 Hourly calibration results for water temperature at RSAN018, Jersey Point. Blue line is hourly data, red line is the modeled hourly result averaged from 15-minute model output.

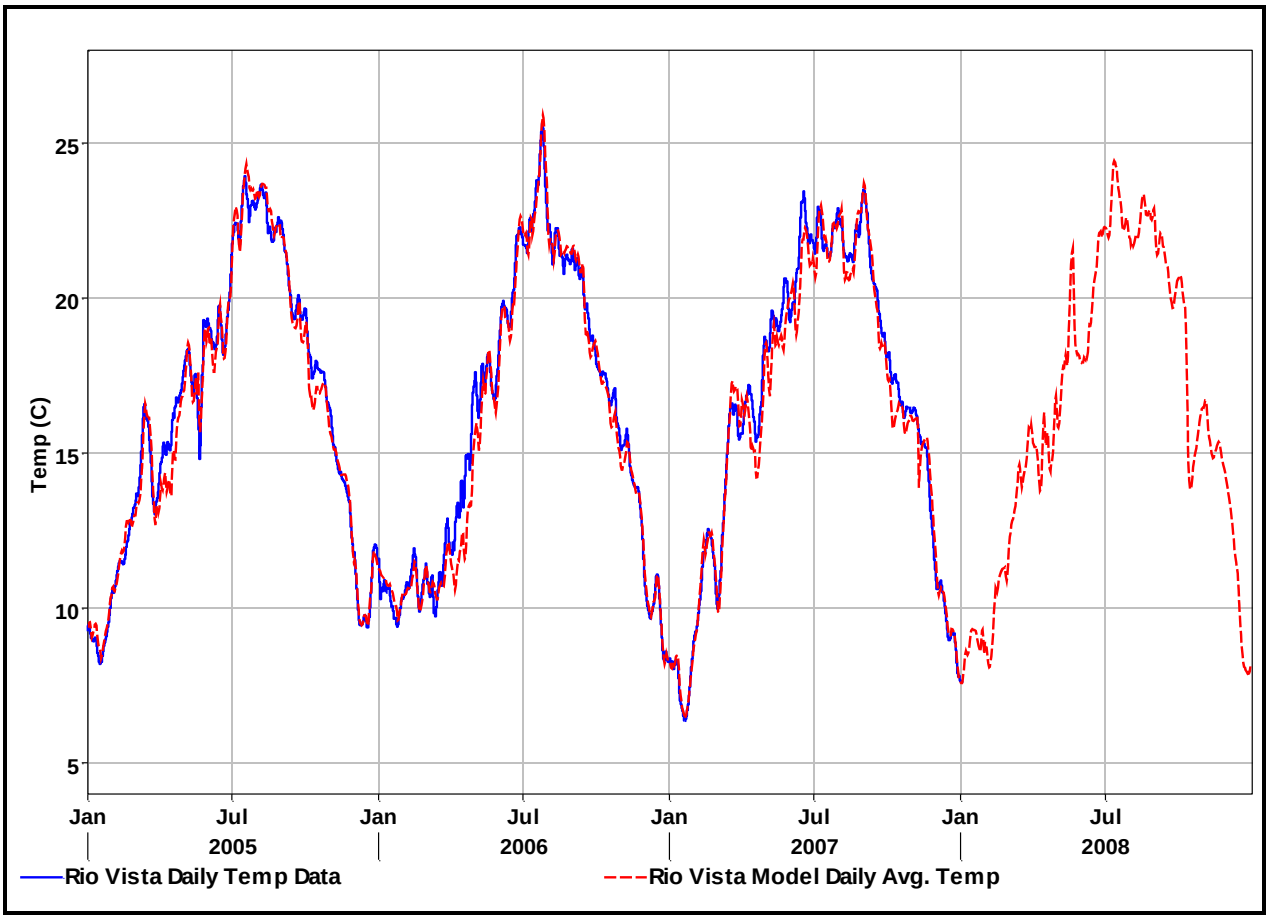


Figure 12-4 Daily calibration results for water temperature at RSAC101, Rio Vista. Blue line is daily data, red line is the modeled daily result averaged from 15-minute model output.

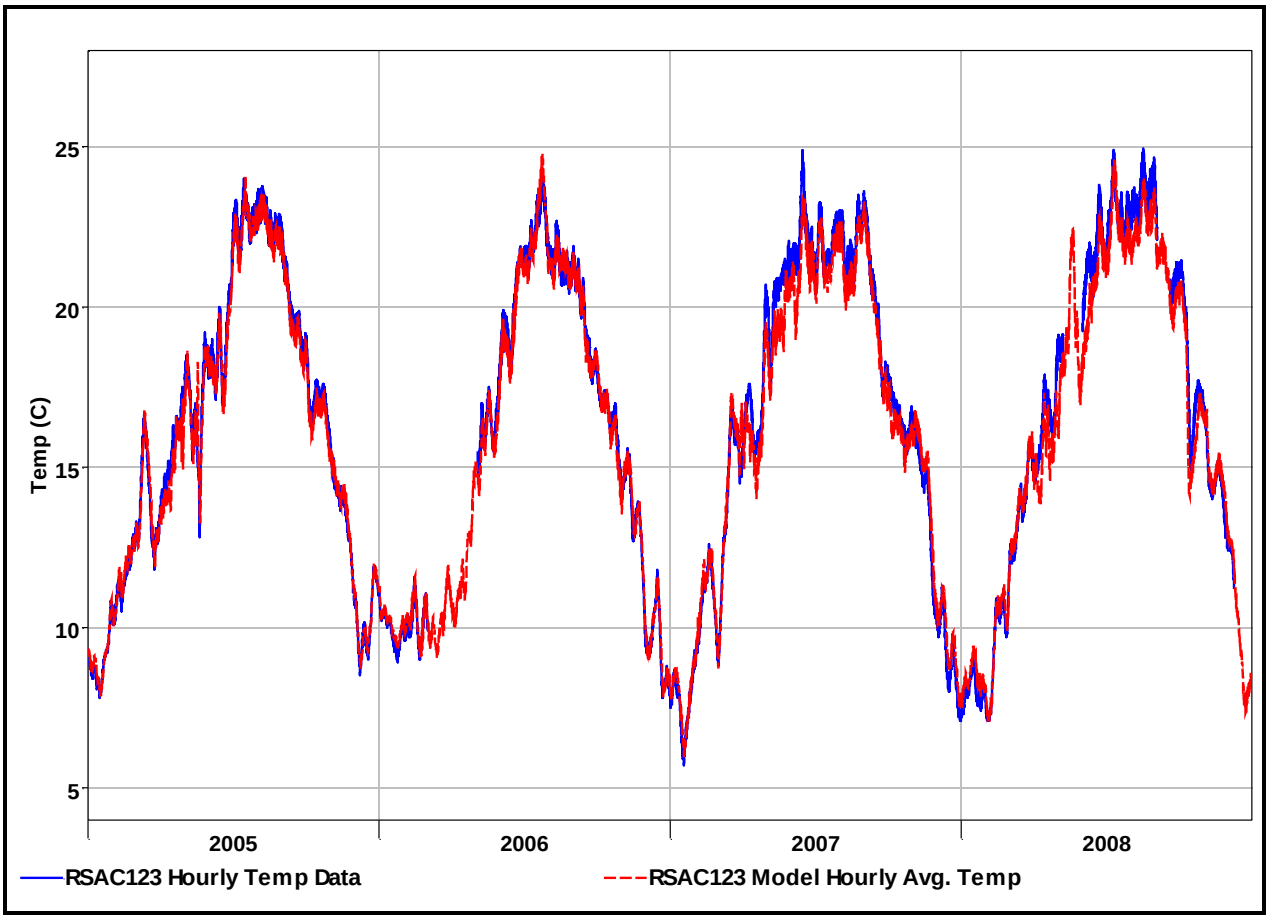


Figure 12-5 Hourly calibration results for water temperature at RSAC123, Sac near Georgiana Sl. Blue line is hourly data, red line is the modeled hourly result averaged from 15-minute model output.

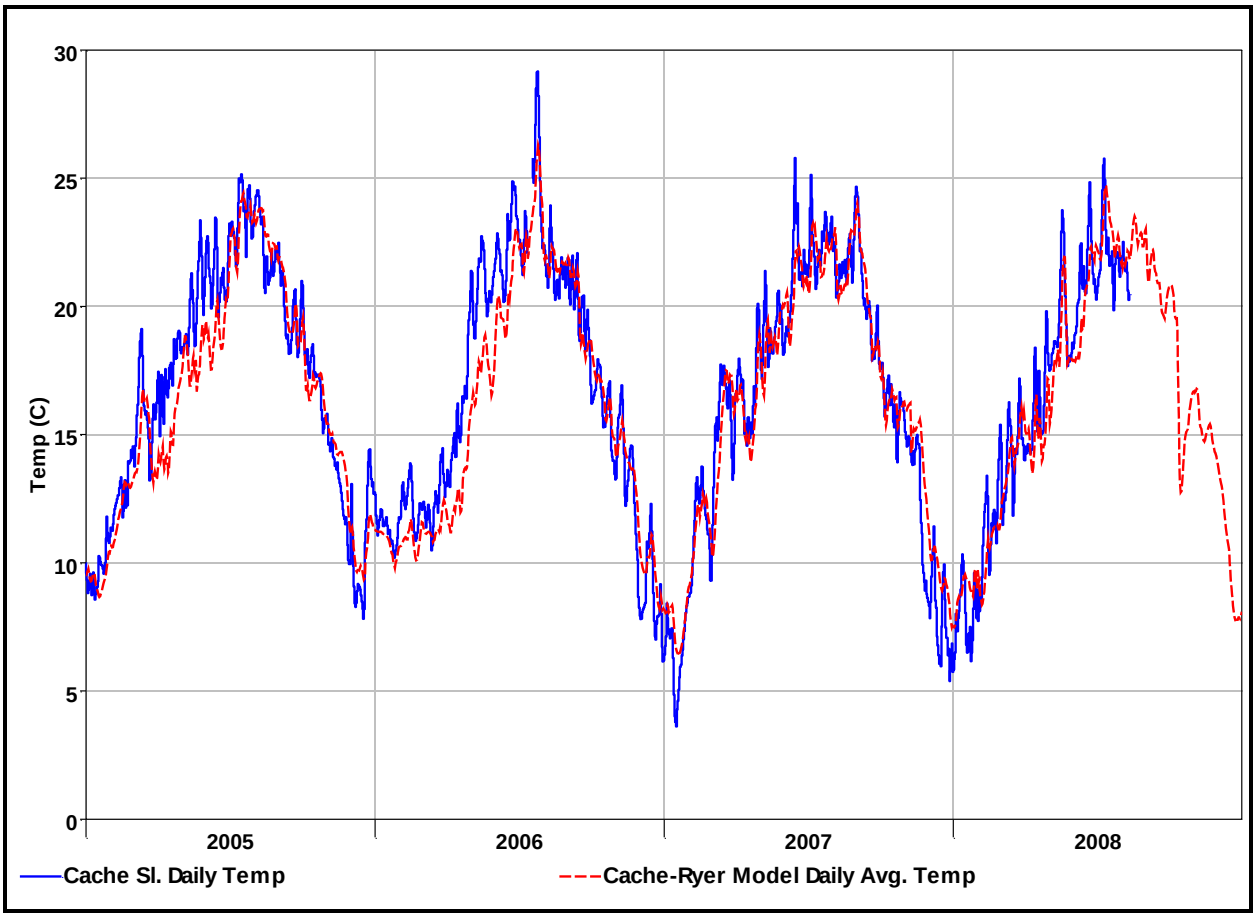


Figure 12-6 Hourly calibration results for water temperature at locations in the Cache Slough area (CDEC CCS station). Blue line is daily data, red line is the modeled daily result averaged from 15-minute model output.

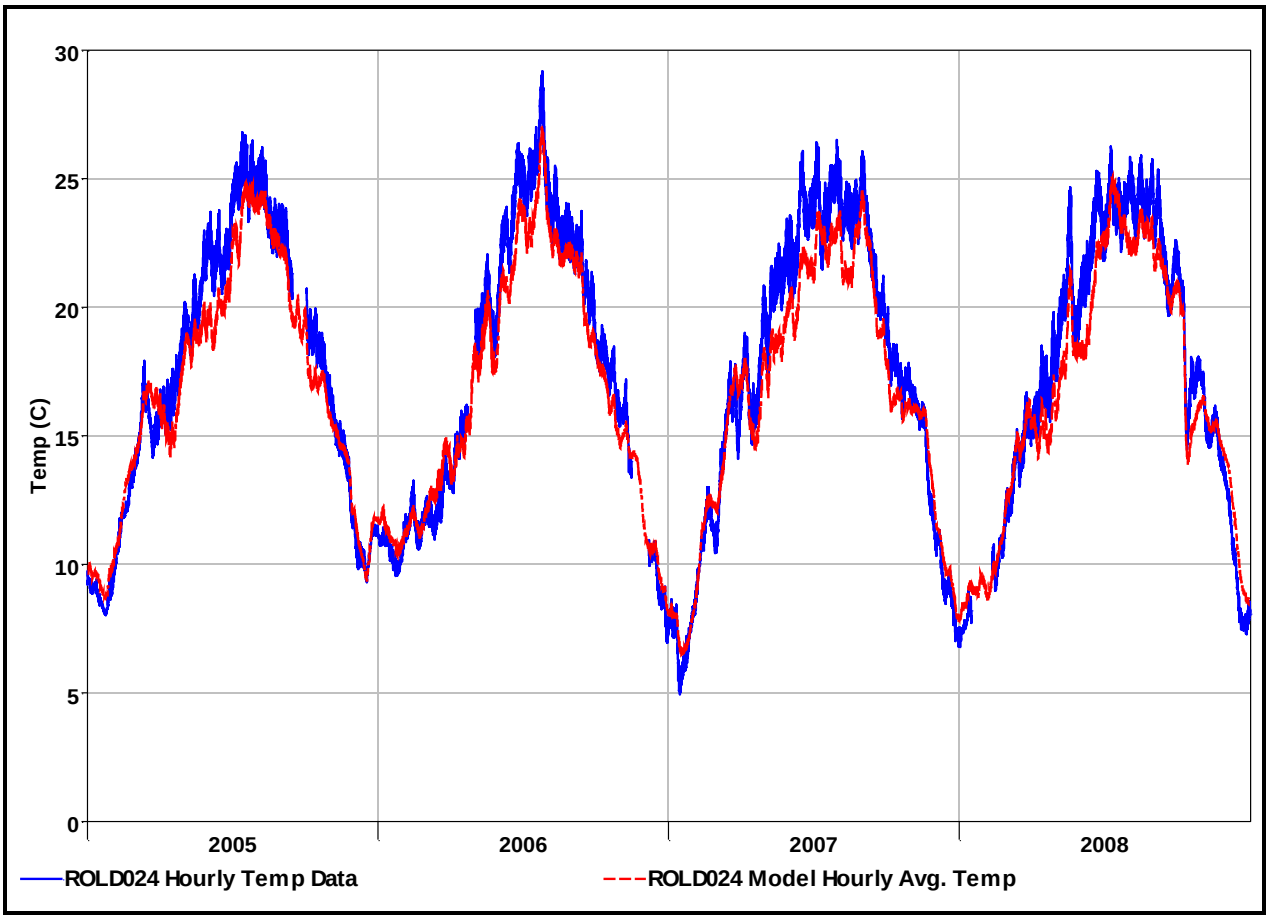


Figure 12-7 Hourly calibration results for water temperature at ROLD024, Old River at Hwy 4. Blue line is hourly data, red line is the modeled hourly result averaged from 15-minute model output.

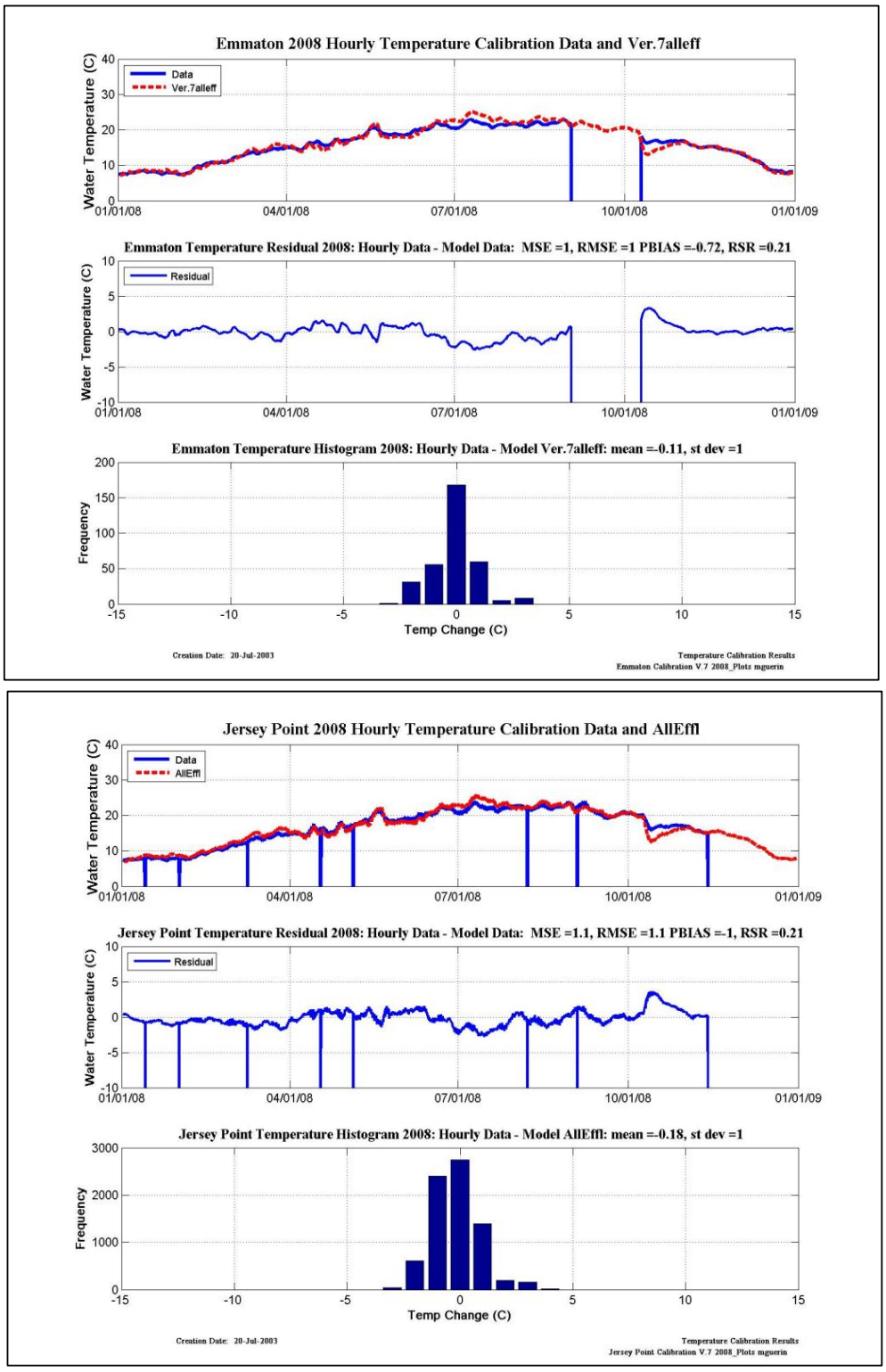


Figure 12-8 Calibration plots in the Critically Dry Water Year 2008 at Emmaton and Jersey Point.

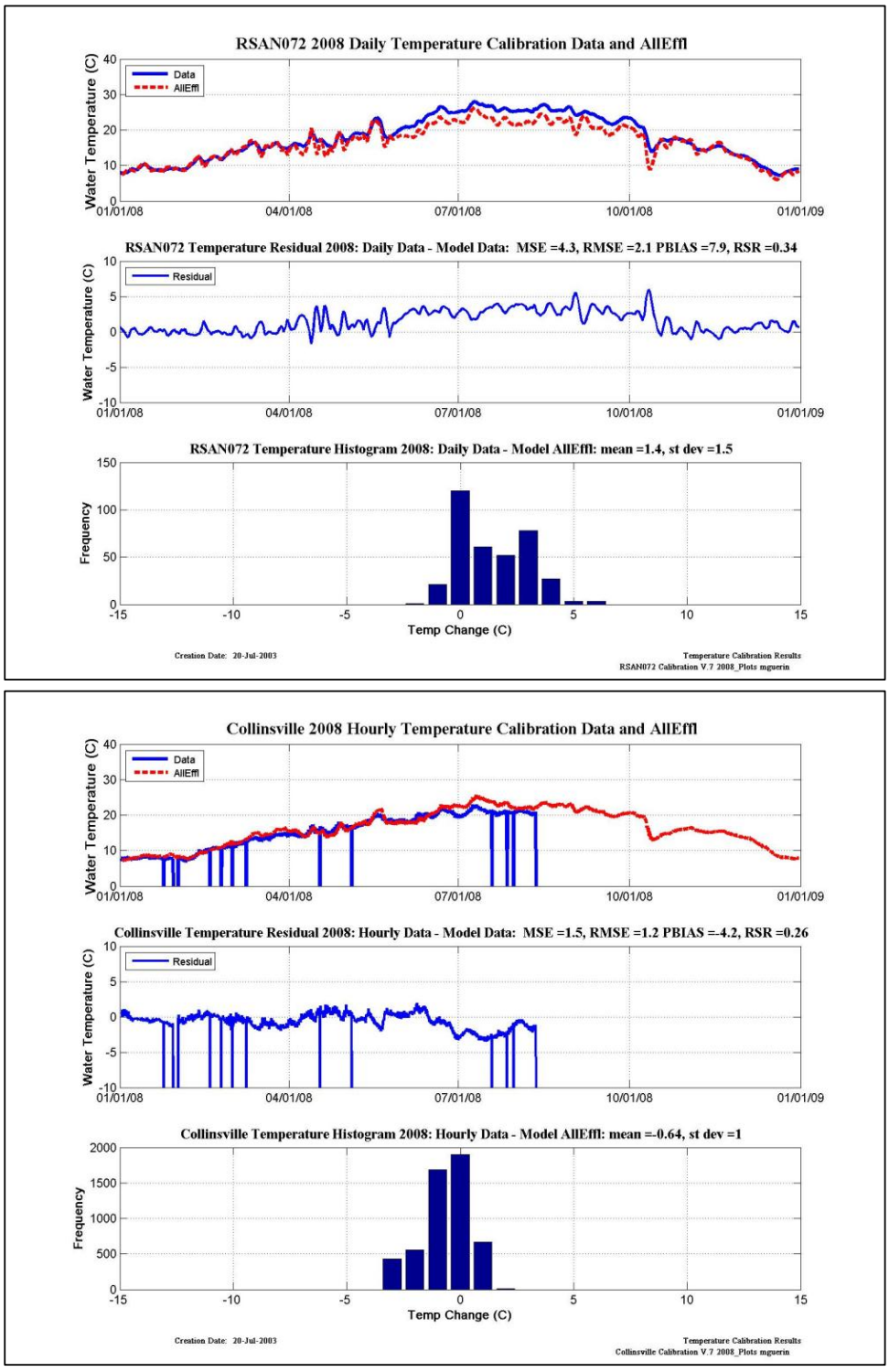


Figure 12-9 Calibration plots in the Critically Dry Water Year 2008 at RSAN072 on the San Joaquin and at Collinsville.

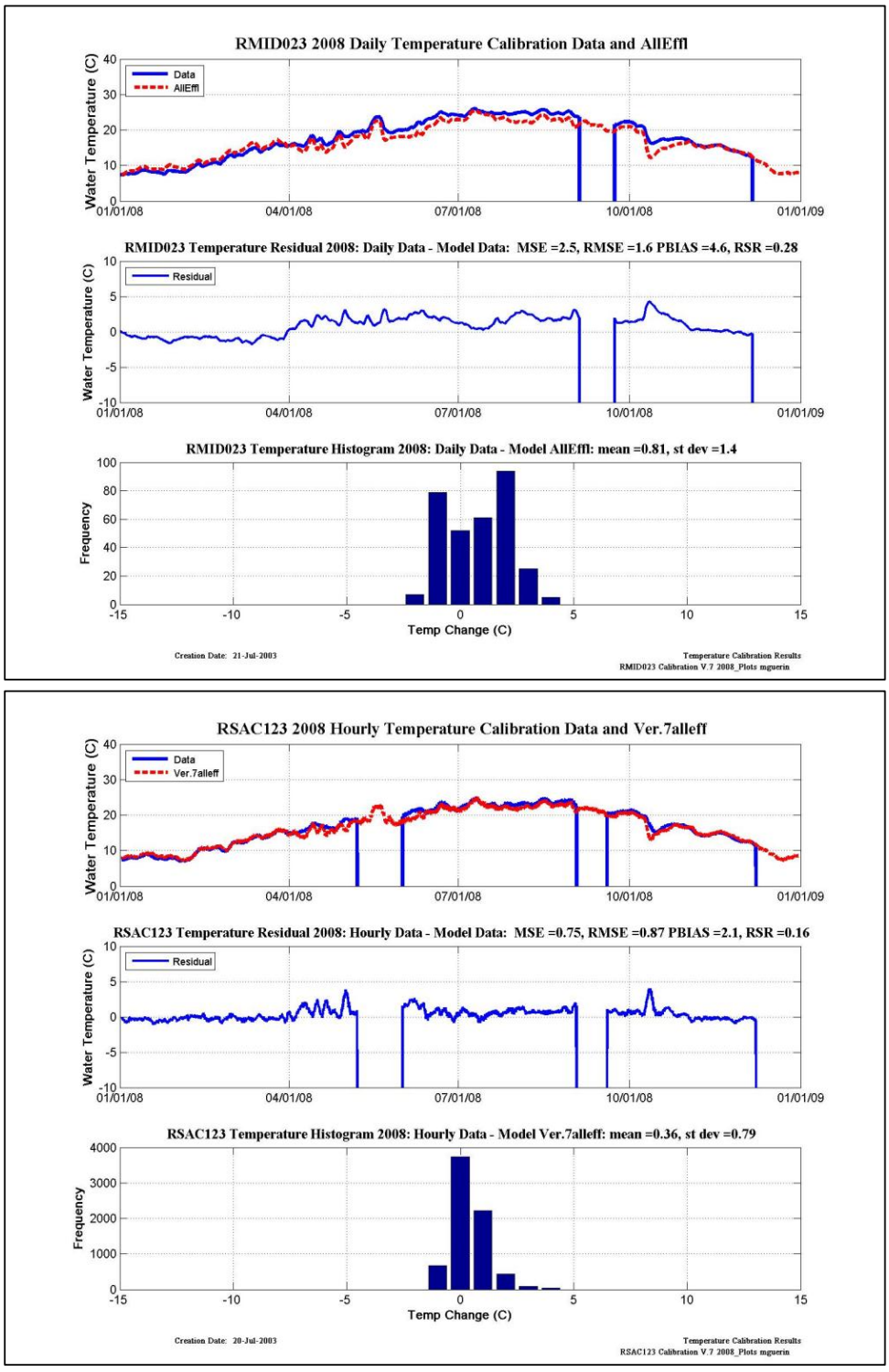


Figure 12-10 Calibration plots in the Critically Dry Water Year 2008 at RMID023 on Middle R. in the South Delta and at RSAC123 on the upper Sacramento R.

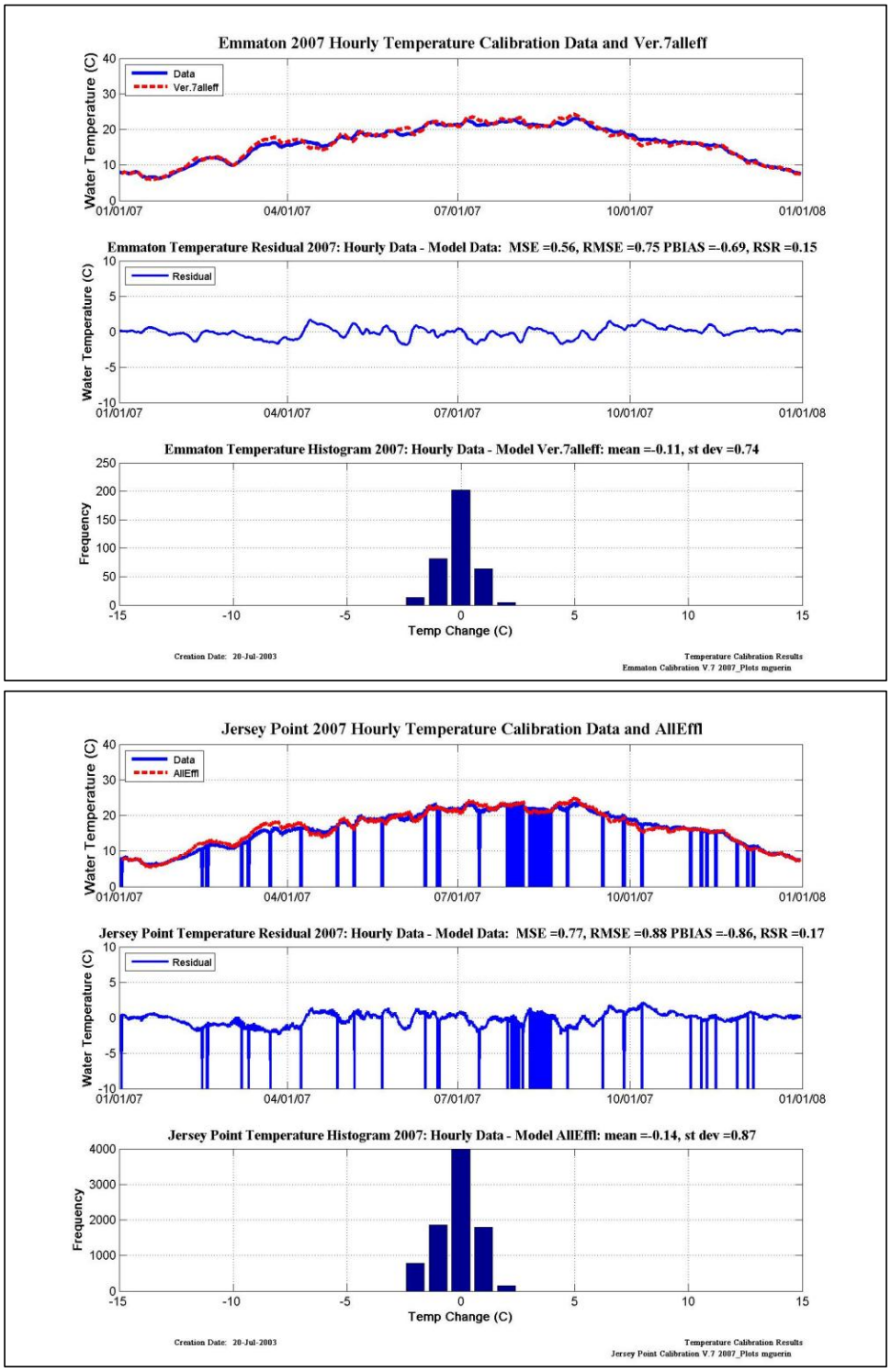


Figure 12-11 Calibration plots in the Dry Water Year 2007 at Emmaton and Jersey Point.

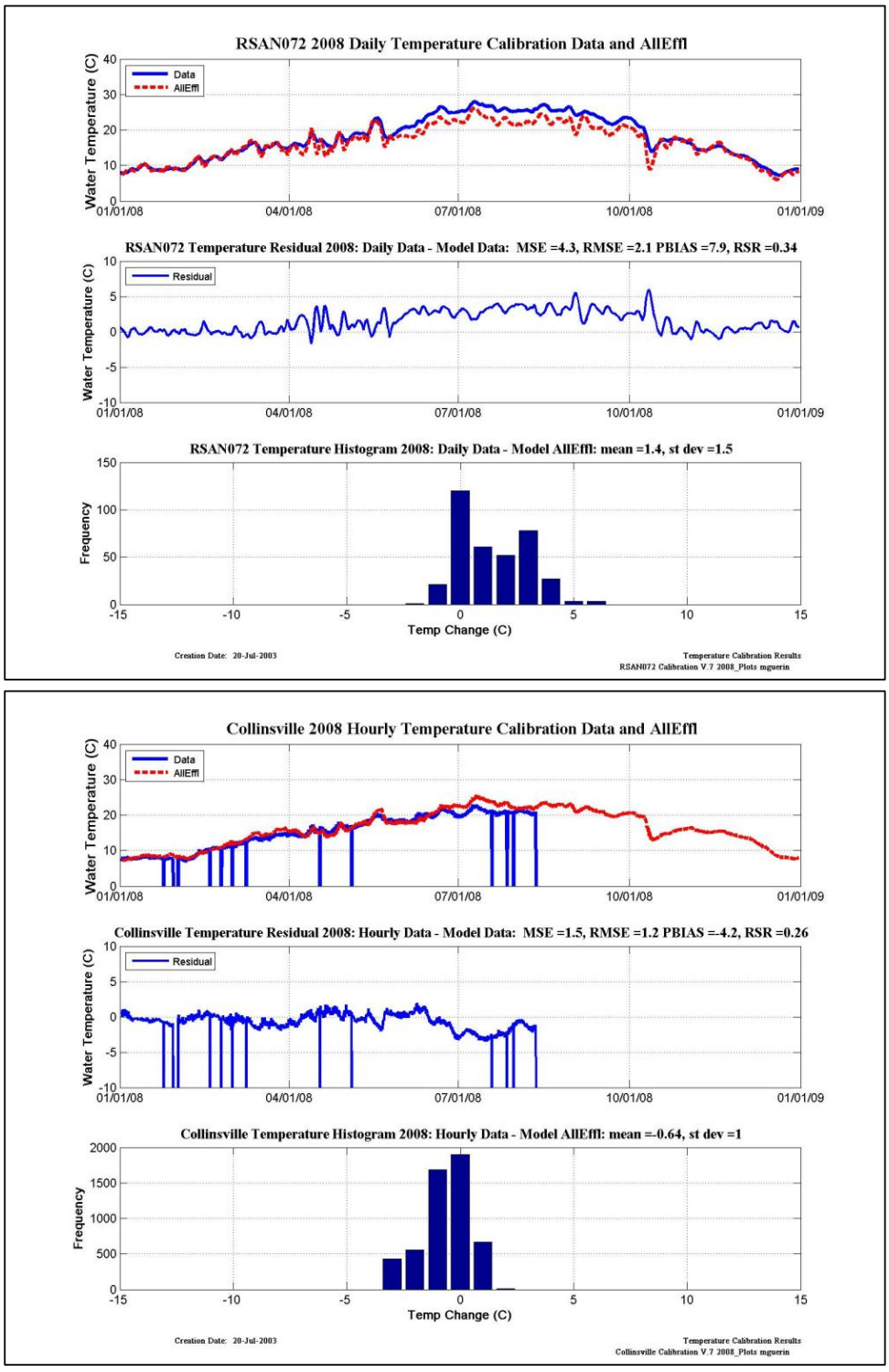


Figure 12-12 Calibration plots in the Dry Water Year 2007 at RSAN072 on the San Joaquin and at Collinsville.

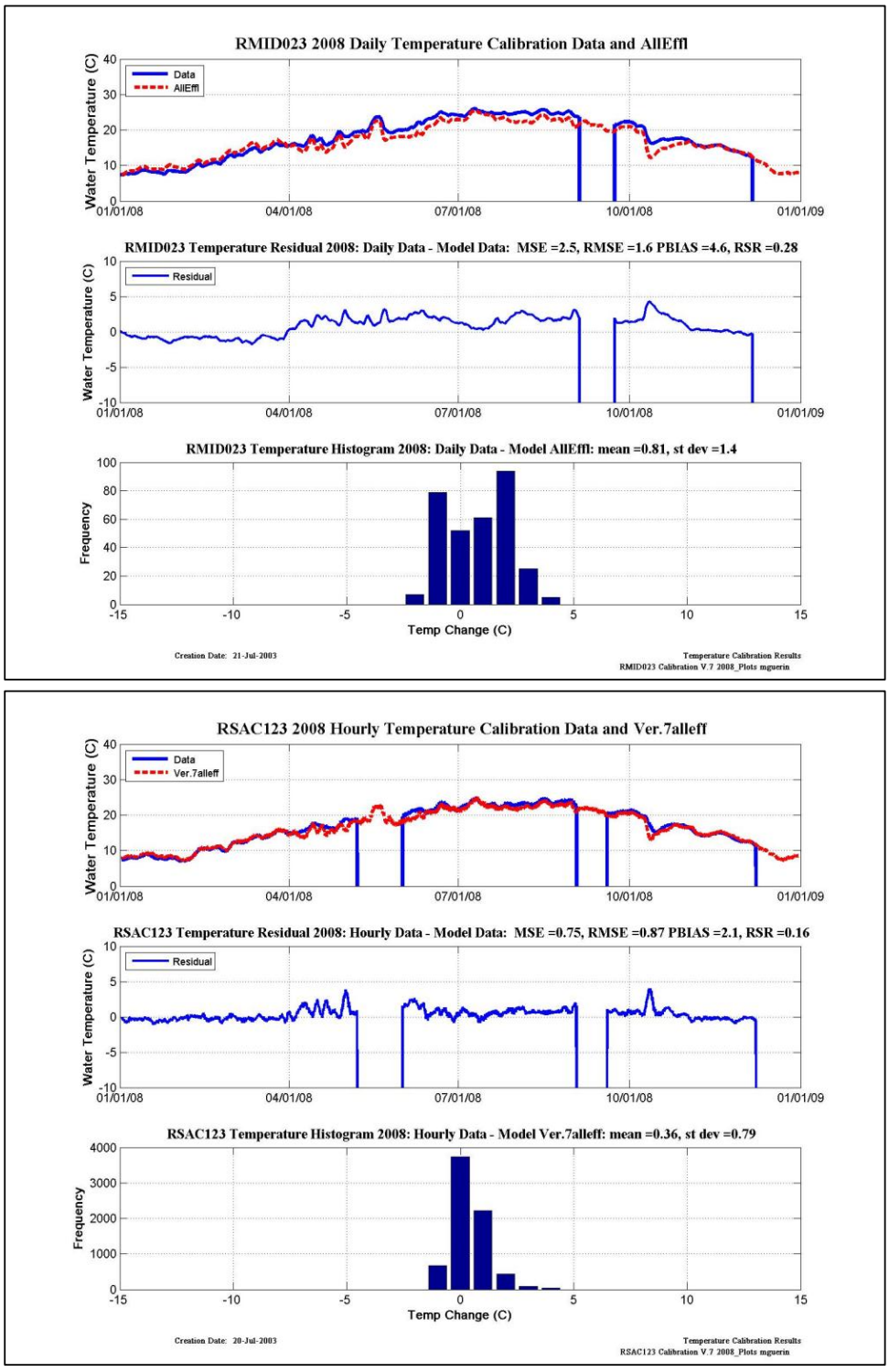
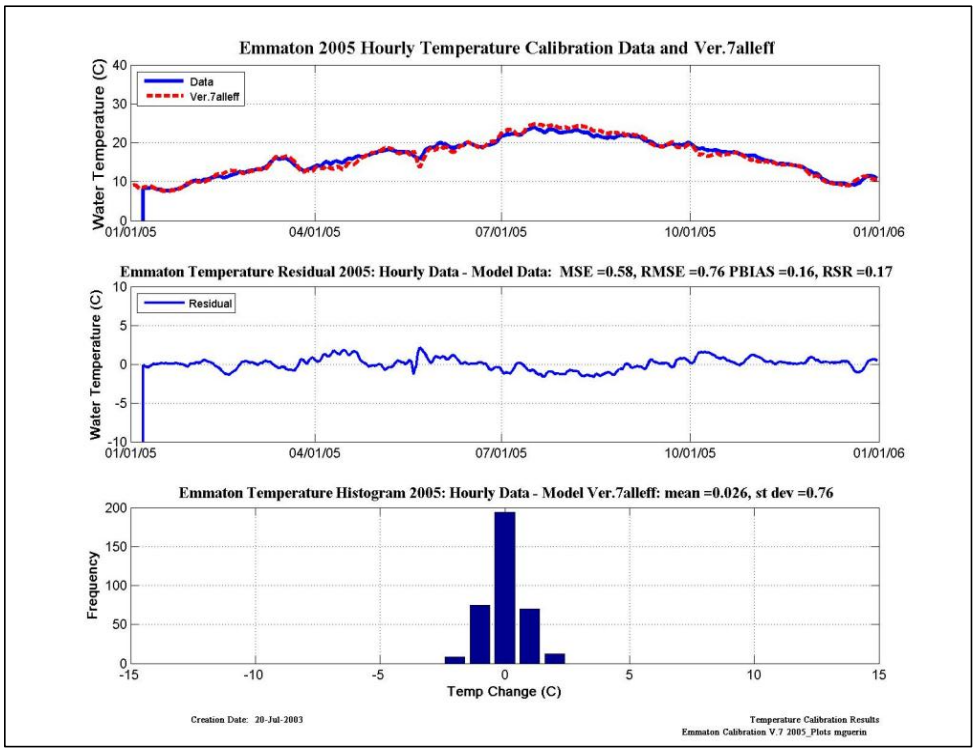


Figure 12-13 Calibration plots in the Dry Water Year 2007 at RMID023 on Middle R. in the South Delta and at RSAC123 on the upper Sacramento R.



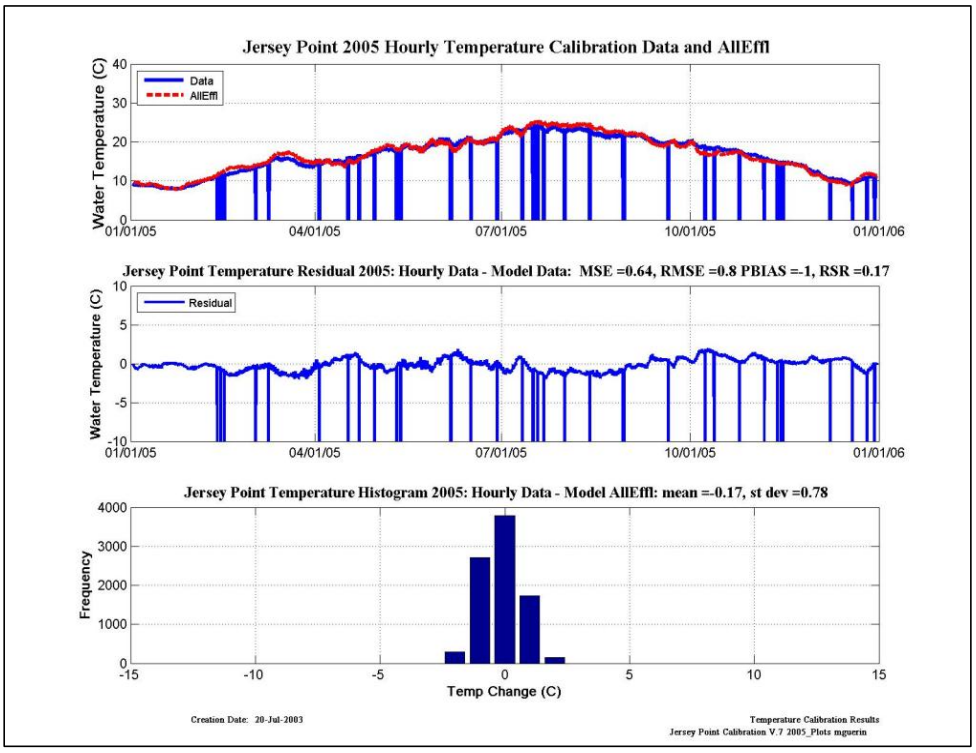
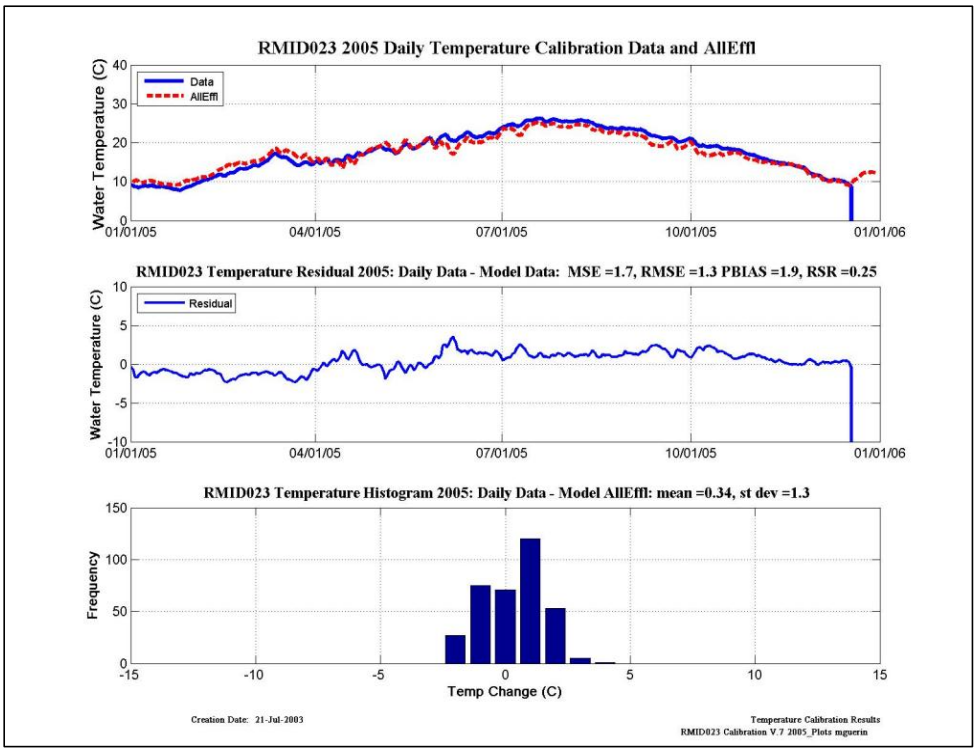


Figure 12-14 Calibration plots in the Above Normal Water Year 2005 at Emmaton and Jersey Point.



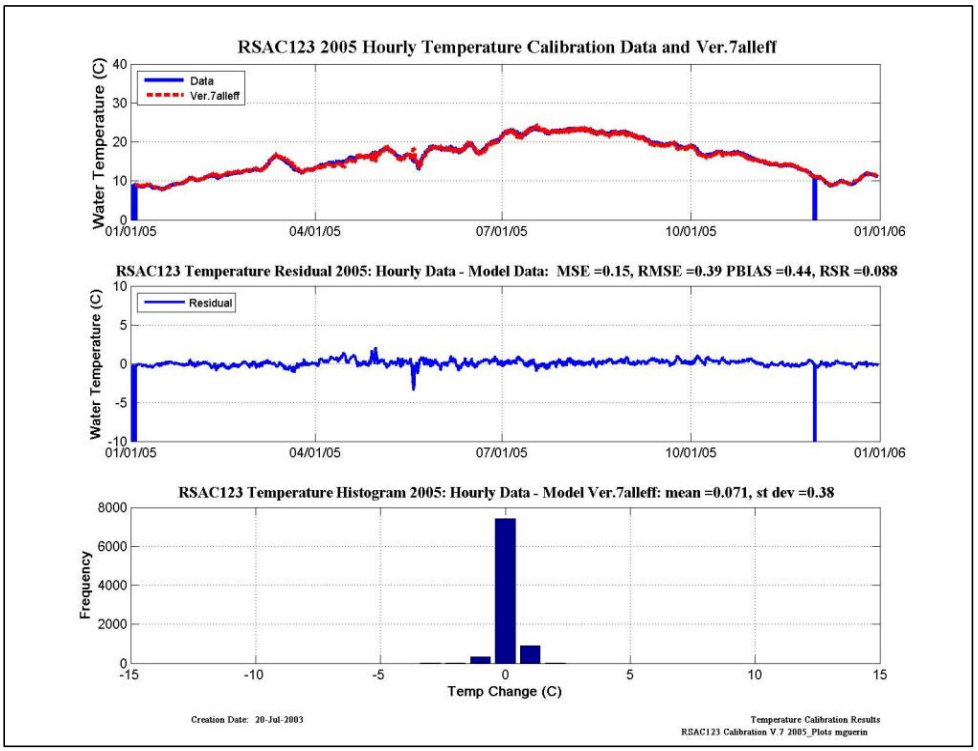
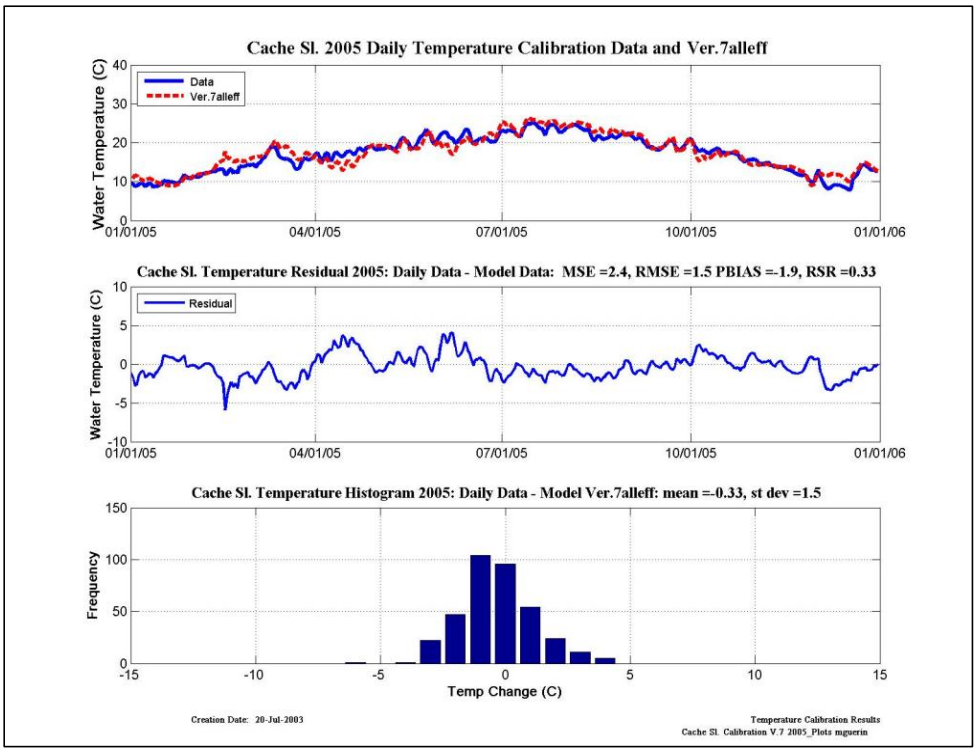


Figure 12-15 Calibration plots in the Abv Normal Water Year 2005 at RMID023 on Middle R. in the South Delta and at RSAC123 on the upper Sacramento R.



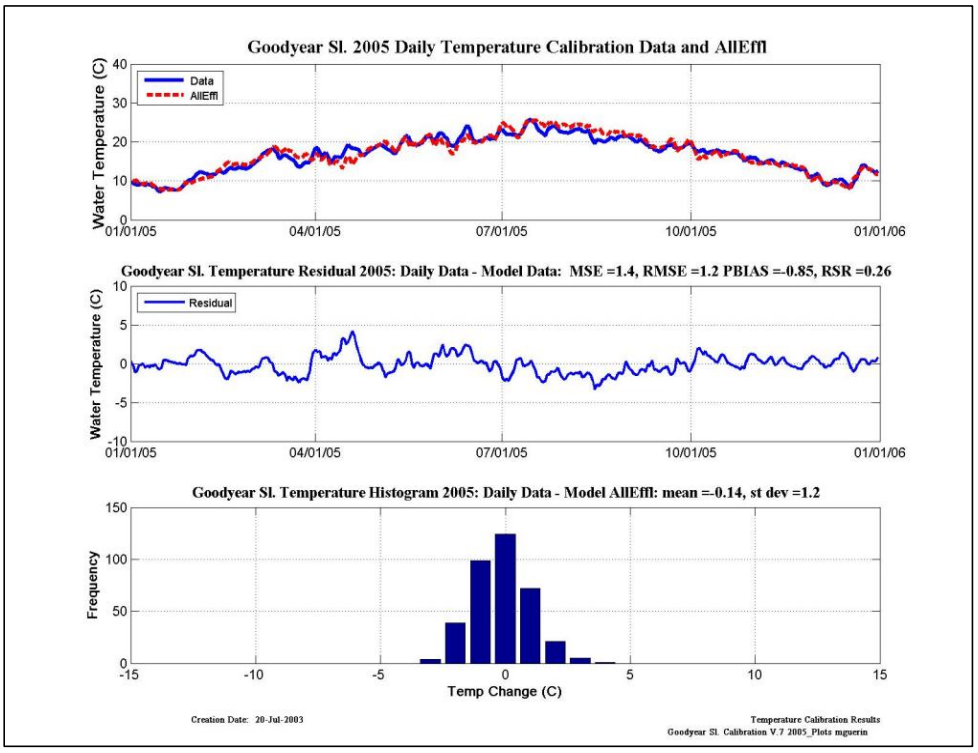


Figure 12-16 Calibration plots in the Abv Normal Water Year 2005 at Cache Sl. and at Goodyear Sl.

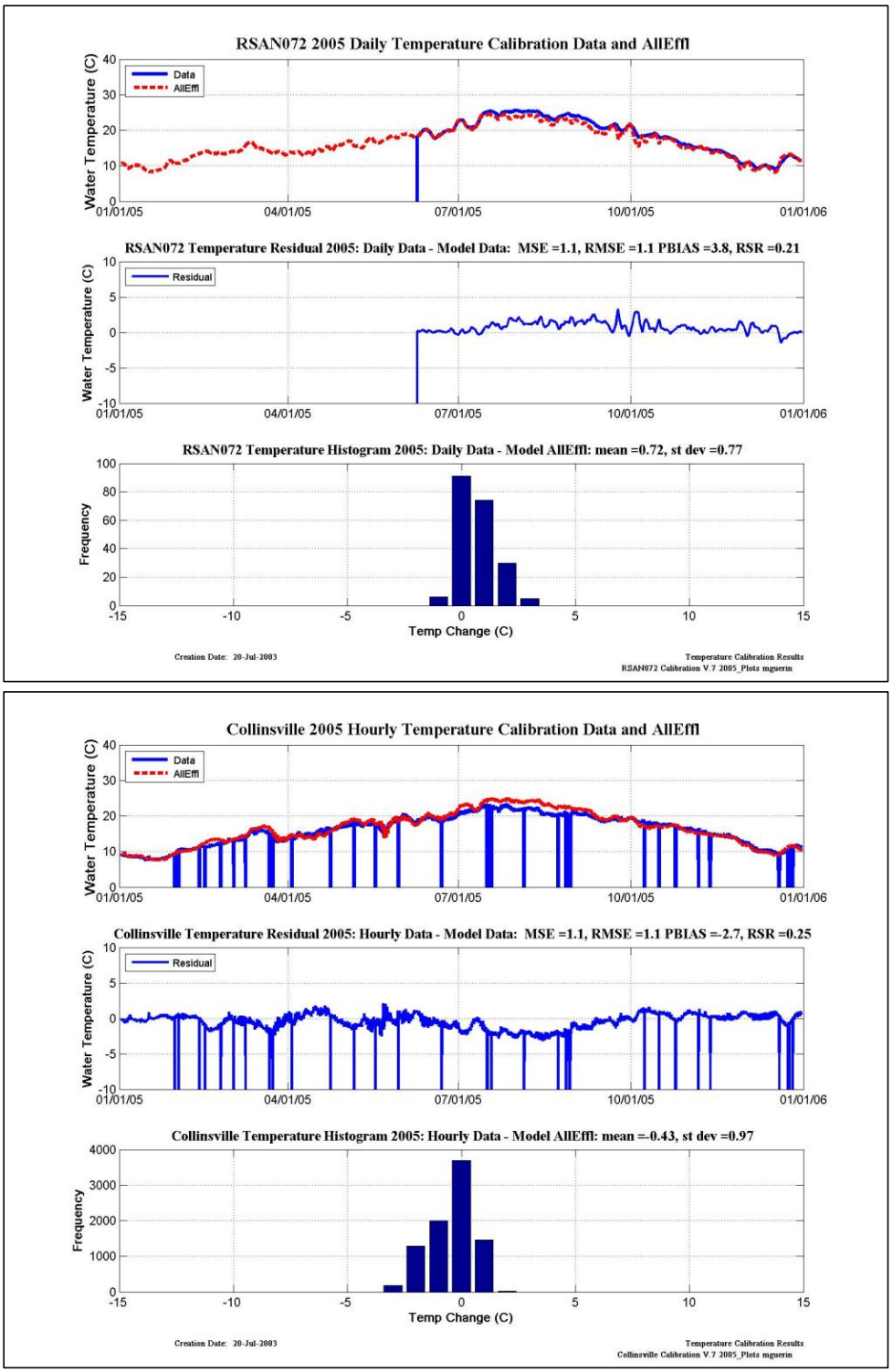
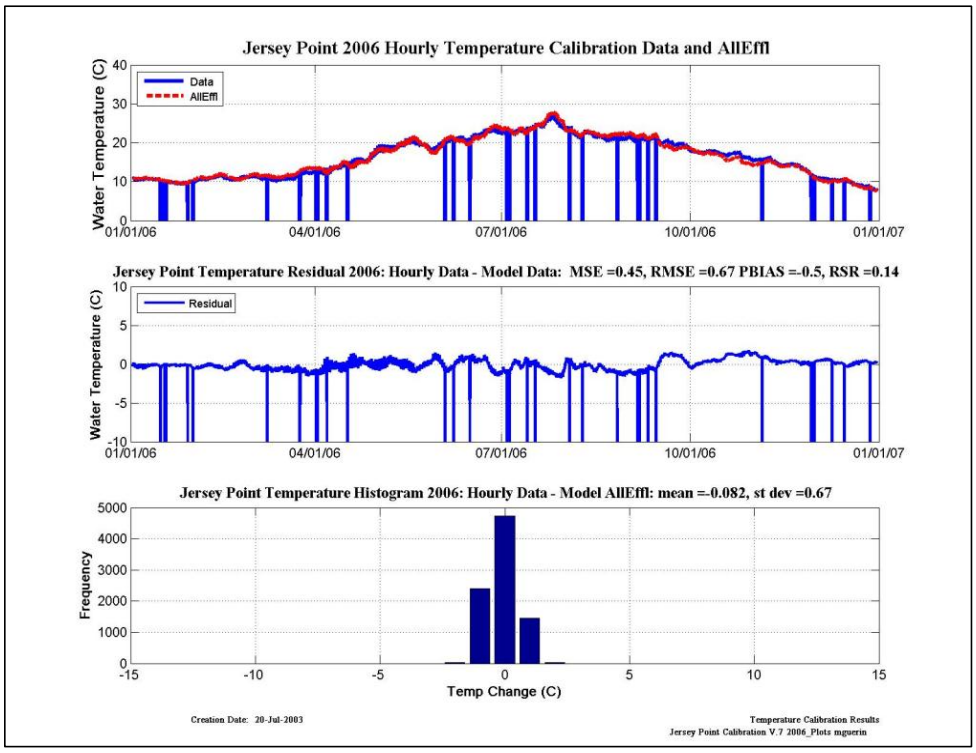


Figure 12-17 Calibration plots in the Abv Normal Water Year 2005 at RSAN072 on the San Joaquin and at Collinsville.



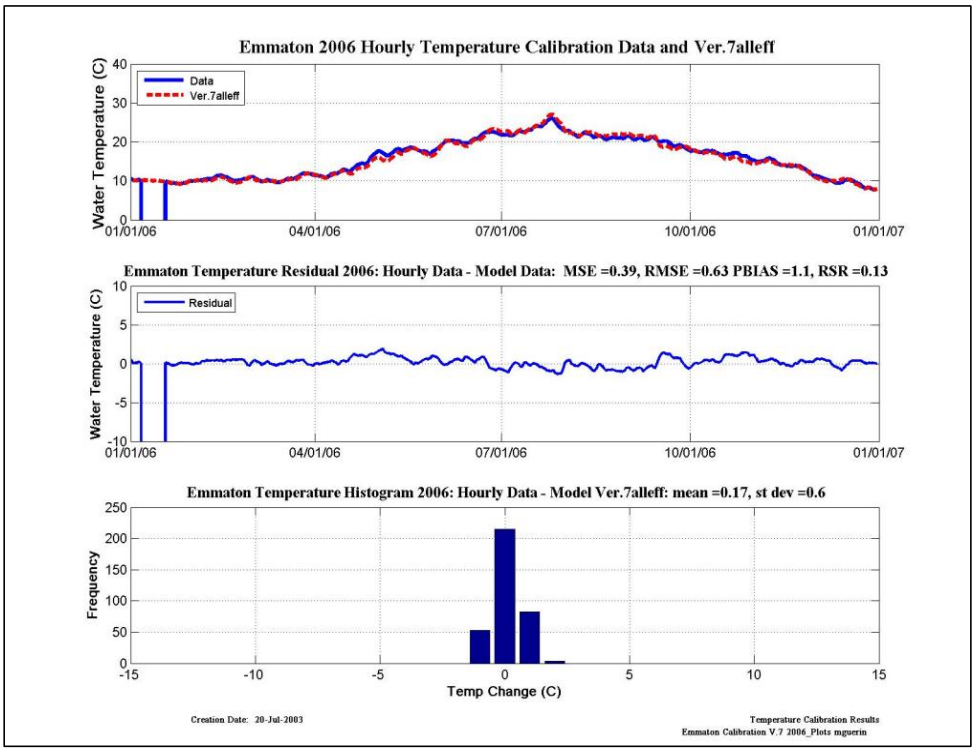
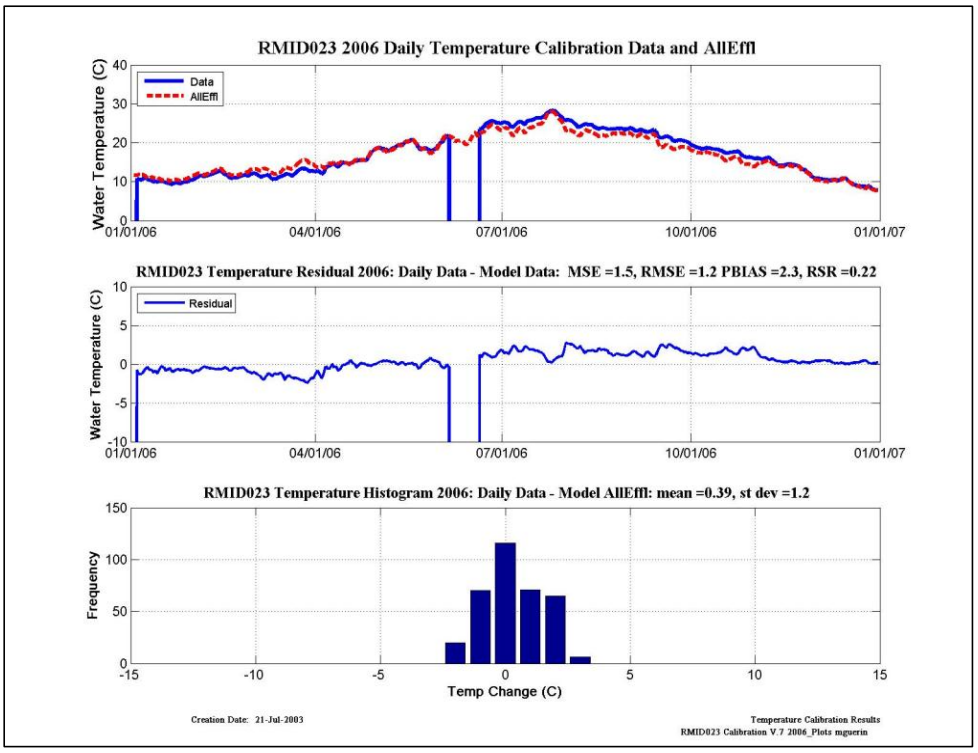


Figure 12-18 Calibration plots in the Wet Water Year 2006 at Jersey Point and Emmaton.



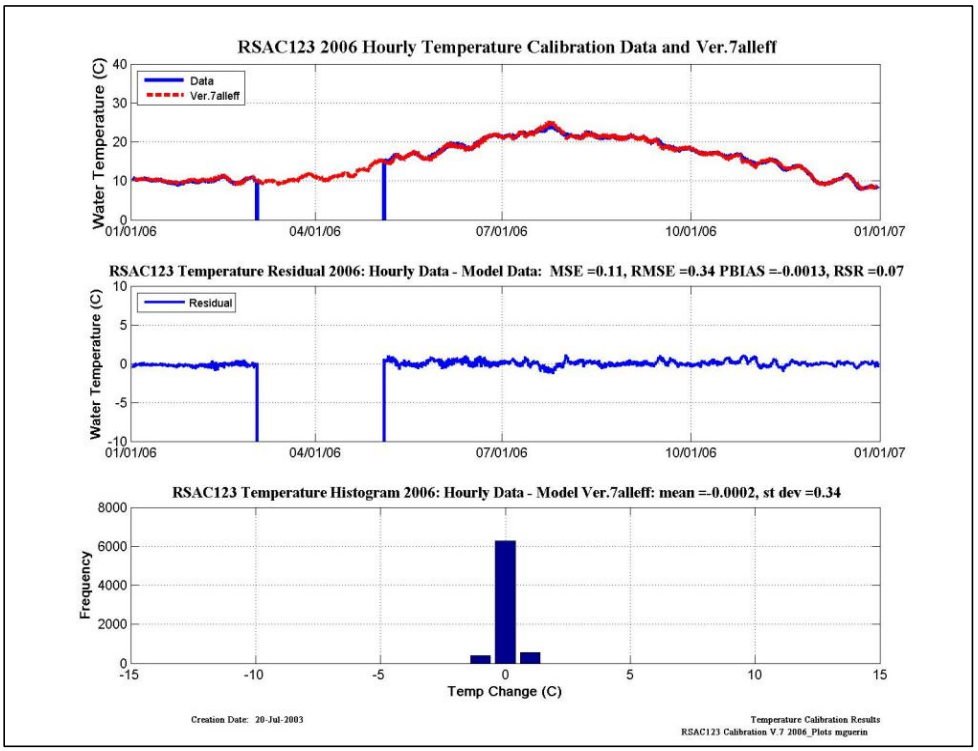
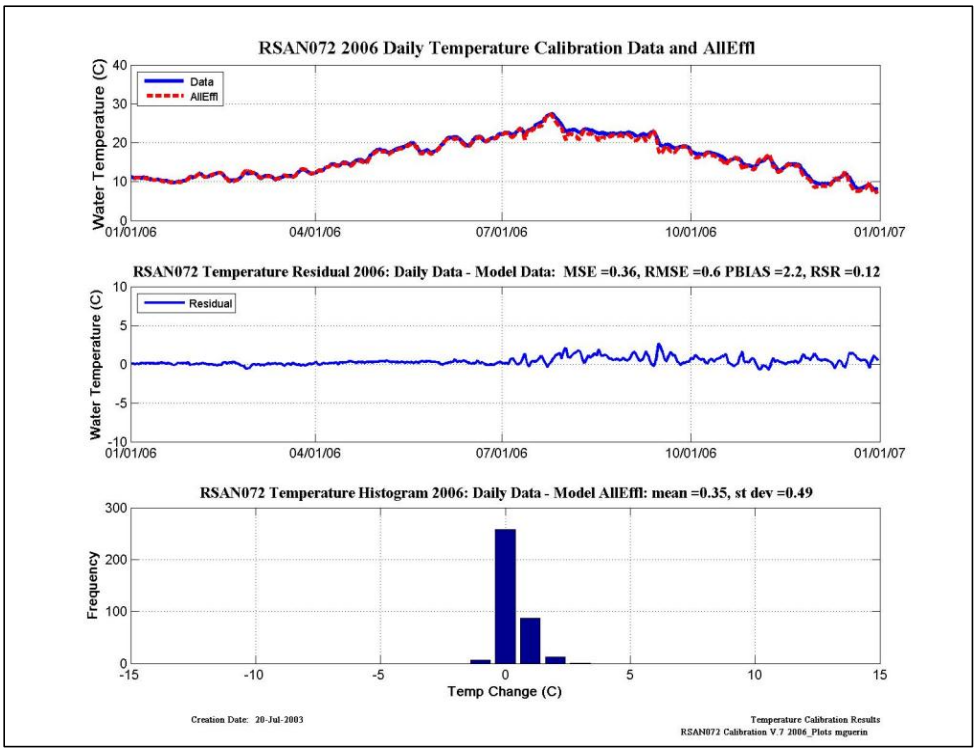


Figure 12-19 Calibration plots in the Wet Water Year 2006 at RMID023 on Middle R. in the South Delta and at RSAC123 on the upper Sacramento R



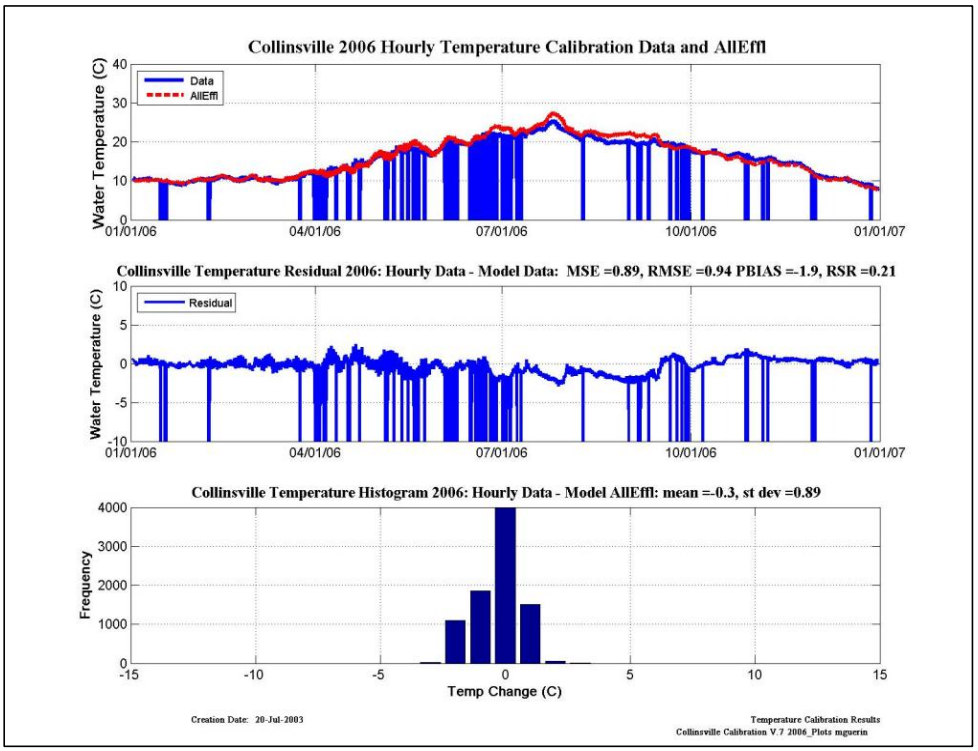


Figure 12-20 Calibration plots in the Wet Water Year 2006 at RSAN072 on the San Joaquin and at Collinsville.

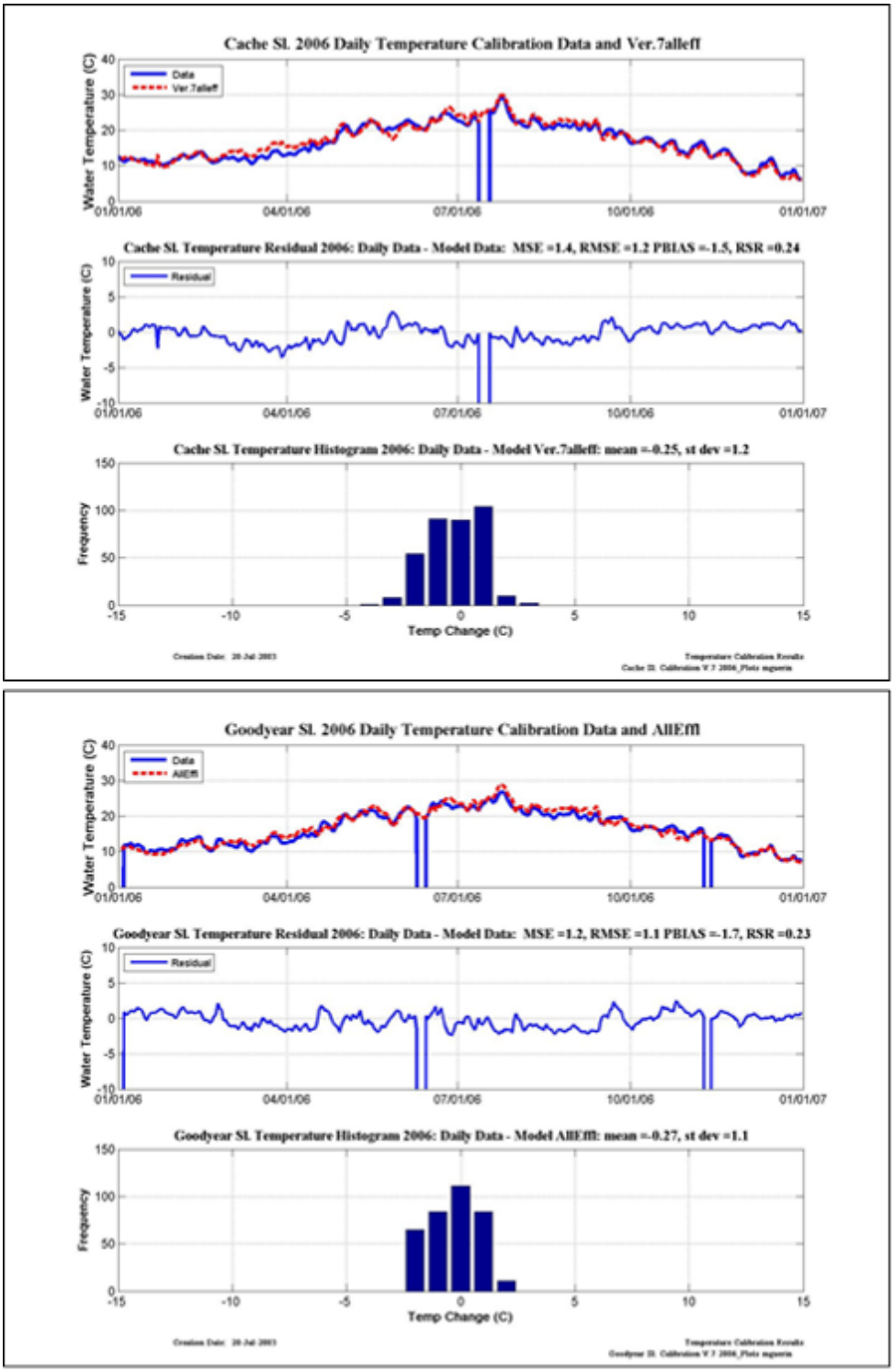


Figure 12-21 Calibration plots in the Wet Water Year 2006 at Cache Sl. and at Goodyear Sl.

12.4 Nutrient Calibration and Validation Process

The calibration process (for Version 6) for the 1990 -2008 period began by calibrating the temperature model which is independent of nutrient dynamics as it relies only on meteorological data, water temperature boundary conditions and model output from HYDRO in its calculations.

Once the temperature model was considered calibrated and the predictive value of the water temperature model was affirmed by validation statistics, the nutrient model calibration process began by subdividing the model domain into five regions (see Section 6.2, Figure 6-3 to Figure 6-7) with broadly similar physical characteristics and/or that are influenced by similar sources of water and nutrients. Open water areas, conceptualized as fully-mixed reservoirs in DSM2, were initially considered as a group. Calibration proceeded iteratively, by changing parameter values regionally and then comparing model results with calibration data. In the latter stages of iteration, calibration statistics were calculated and some parameters changes were implemented locally within regions and within reservoirs. Once parameter changes became insignificant in terms changes to calibration statistics, validation statistics were calculated.

Due to budgetary limitations, the parameter range for sediment oxygen demand (SOD) originally used by Rajbhandari (2000, 2001) in calibrating the QUAL nutrient model for DO along the San Joaquin River was accepted as given although the parameter range was outside standard literature ranges. Using this approach, only minor parameter changes were needed along the San Joaquin River, which significantly reduced the effort needed to calibrate the entire Delta, *i.e.*, the model domain.

At river boundaries where there were few or no measurements, boundary conditions were set at reasonable levels to obtain calibration at downstream locations using several methods - by synthesizing time series using the available data at these locations, by setting boundaries at reasonable constant values, or by utilizing downstream measurements typically scaled by some factor(s) to obtain downstream agreement. There was no data available within the Delta for calibrating the organic-P constituent and only a few data points along the San Joaquin River for calibrating CBOD. Therefore, neither organic-P nor CBOD are considered calibrated.

Calibration was obtained by varying the minimal numbers of sensitive parameters needed to obtain an acceptable level of accuracy, as assessed by the set of calibration statistics. A sensitive parameter in the context of this report is one where +/- 10% changes in the parameter produced measureable changes in concentration of at least one constituent. Due to time and budgetary constraints, although parameter sensitivity was assessed iteratively at the early stages of model calibration, the results were not formally documented.

12.5 Residual analysis methodology for nutrients

Numerical statistics were calculated and are presented in the results for each constituent at each available location, and the stated ranges for NSE, RSR, and PBIAS (see Table 12-6) were used to assess the quality of the calibration. The PBIAS ranges are specific to N- and P-nutrients, but the ranges for RSR and NSE are not constituent-specific in the general performance ratings presented in Moriasi (2007). Since they are applied to nutrient statistics, PBIAS ranges in Table 12-6 are more lenient than those listed for streamflow or sediment transport in Moriasi (2007). Conversely, the ratings for RSR and NSE in Moriasi (2007) would be quite strict if applied to constituent calibration/validation statistics. To accommodate this observation somewhat, the NSE range for "Satisfactory" was extended to all positive values in Table 12-6. The range for RSR was not altered, so can be considered very strict when applied to nutrient model calibration and validation.

Residual statistics for the nutrients were assessed on an annual basis using five hydrological year types from critically dry to wet for the original 1990 – 2008 calibration of QUAL Version 6, while the subsequent Version 8.0.6 was assessed by grouping Water Years into dry and wet year types due to the reduced quantity of data available for calculations. Calibration and validation statistics were calculated for all non-conservative constituents (except organic-P and CBOD) at a monthly time scale. Both graphical and statistical model evaluation techniques were used in the analysis of calibration and validation results.

The combined effects of data variability between agencies and sparse measurement intervals, generally monthly, meant that some measure of uncertainty needed to be included in assessing the quality of model calibration and validation. For example, the monthly nutrient boundary conditions and in-Delta measurements were not all collected at time intervals to allow the direct comparison between a model calculation and a data value at a calibration location made during that month. As a consequence, there was invariably a mismatch between the timing of the boundary condition and the timing of the downstream data. The EMP and USGS had data along the Sacramento River at the same or similar measurement locations, as discussed in Section 7.3, and the variability between the measurement data sets indicated that daily fluctuations, tidal influences and extreme events would influence the monthly values.

To capture this variability, an "envelope" of model values was used to incorporate these different sources of uncertainty. The maximum and minimum monthly values of 15 minute model output were calculated to create the upper and lower bounds of the envelope, respectively. At a given location, if the calibration data fell within that max/min envelope, then the residual was calculated as zero. Values falling outside of the envelope were calculated as residuals using the either the maximum of the envelope (data higher than maximum value) or the minimum value of the envelope (data less than the minimum value) for that month. Note that this methodology

could be refined, as the partition of data and model values along strict monthly time intervals in somewhat artificial. However, for simplicity, the monthly approach was deemed reasonable.

For the 2000 – 2008 calibration, this methodology was expanded to reduce the maximum monthly value and increase the minimum monthly value by a percentage of the difference between these values in each month – 95%, 90%, 80% and 75%.These results are discussed briefly below (Section12.5.3), and more thoroughly in Appendix VI.

For the six constituents used in the calibration – NH_3, NO_3+NO_2, organic-N, DO, chl-a/algae, and PO_4 – calibration statistics were calculated at each available location. Histograms of the residuals were prepared, and the available data was plotted along with the modeled max/min calibration envelopes. The statistical categories specified in Table 12-6 for NSE, PBIAS and RSR are documented along with these figures in the Appendices, and as Tables in this section.

12.5.1 Calibration and Validation Time Periods and Data

The time periods selected for the 1990 – 2008 nutrient calibration are shown in Figure 12-22, and in Table 12-7 for the 2000 – 2008 calibration for Version 8.0.6. The availability and quality of nutrient data are illustrated in Appendix I, Section 25.1. Figure 12-23 illustrates the final set of data locations that were used for nutrient model calibration and validation.

The nutrient data used for the 2000 - 2008 calibration (Version 8.0.6) were plotted to illustrate the characteristics of the individual data locations and constituents. The box plots[23] of the data, Figure 12-24 through Figure 12-29, show a range of statistics – the upper and lower blue lines of the box show the 75th and 25th percentiles, respectively, the central red line is the median (50th percentile), the whiskers extend to the most extreme data points not considered outliers, while the outliers are plotted individually (as red crosses).

The Algae "data" *(i.e.*, chl-a data converted to the modeled constituent, Algae) in Figure 12-24 show a large number of outliers at the higher concentrations at most of the calibration/validation locations – outlier values would be difficult to capture in the modeling unless they represent an event captured in the model boundary conditions. Along the San Joaquin River, the "concentration" of algae is much higher – in other words, there is significantly more algal growth (note the concentration scale is double that of the other locations). DO data, Figure 12-25, show a much smaller range of variation with only a few outliers, and the median value (just under 9.0 mg L^{-1}) is consistent along the Sacramento River, both above and below the confluence.

Figure 12-26 shows the data for the measurement of NO_3+NO_2 – there are quite a few outliers at the higher concentrations, and a broader range of data medians along the Sacramento River than for DO, particularly for the data at Hood and along the San Joaquin River and at Potato Point.

[23] Calculated and plotted in MATLAB

Note the concentration scale along the San Joaquin River is double that of the other locations. In Figure 12-27, the box plots for NH_3 have fewer measurement locations. There are still quite a few outliers at the higher concentrations; Hood shows a much higher concentration than other Sacramento River locations. The San Joaquin River location at Buckley Cove has the highest concentrations, plotted at a scale double that of the other locations – the inset shows the locations at Disappointment Slough and Potato Point plotted at the lesser scale.

The organic-N measurement box plots, Figure 12-28, show the biasing effect of measurements recorded below the instrument detection limit at several of the locations. Recall (Section 7.4), measurements recorded as below the instrument detection limit were set at half the stated detection limit. For example, at Point Sacramento, the median value (red line) shows that a large number of the measurements were recorded as below detection limit. Outliers occur only at the higher concentrations. Figure 12-29 illustrates the measurement statistics for PO_4 – the outliers are again all at the higher concentrations and, with the exception of Buckley Cove, the median value of the measurements is fairly consistent throughout the Delta.

12.5.1.1 *Calibration Version 6, 1990 -2008*

Although data were available at many locations over portions of each of the calibration and validation periods, only data that spanned the years 1992 – 2008 was used for calibration and validation. The majority of these data were from EMP locations, although a few constituents were available from other agencies. Under these criteria, there was no BOD/CBOD data available for calibration and validation over the selected time span. BOD measurements were lacking except in a short reach along the San Joaquin River, and these were limited in the temporal frame. There were no measurements for organic-P and the measurements for nitrite and nitrate individually were sparse.

The great disparity in the availability of boundary condition data for the various WWTPs complicated the selection of calibration and validation periods for nutrients in the original 1990 - 2008. For all but two of the WWTPs, boundary condition data were only available in recent years. In the Delta, nutrient data coverage had similar spatial coverage to temperature data. Unlike temperature data, nearly all nutrient model measurements were taken as grab samples, and temporal coverage was typically monthly (sometimes less and sometimes bi-monthly). Data quality was generally good over the entire modeled time span (1990 – 2008), although for many sites there was more data 1990 – 1995 than in later periods. Data quality is discussed in Section 7.3.

12.5.1.2 *Calibration Version 8.0.6, 2000 - 2008*

Nutrient calibration results were grouped for the calculation of calibration statistics for the entire calibration/validation period (all years, i.e., 2000 – 2003 plus 2005 – 2008). These years were also subdivided into calibration and validation ranges, shown in Table 12-7.

Because nutrient data was mainly available on a monthly basis and the number of values available was limited, only two types of hydrologic conditions[24] were considered is assessing the quality of the calibration (see Table 12-7). The Wet type is composed of Wet and Above Average Water Year types, while the Dry type is composed of Critically Dry and Dry Water Year types.

Regional parameterization for the Version 8.0.6 2000 - 2008 calibration was changed from the Version 6 nutrient model calibration for 1990 – 2008 primarily by changing organic-N and organic-P settling and decay rates. For Version 8.0.6 calibration, organic-N and organic-P settling and decay rates were each set (in each channel) at a constant value Delta-wide. Reservoir parameterization was changed from the original DSM2/QUAL nutrient model calibration, again by changing organic-N and organic-P settling and decay rates. These rates were set to the same values for all reservoirs at the same values set Delta-wide for the channels.

12.5.1.3 *General Calibration Data and Parameter Information*

Figure 12-23 illustrates the final set of locations that were used for nutrient model calibration and validation, although not all of the constituents had data available at each location. Nitrate and nitrite were combined in model output, as the EMP measurement of NO_3+NO_2 was common and available over the entire model period. Figure 25-1 through Figure 25-15 (Appendix I) show the full set of data locations, not all of these data were used for various reasons (NOTE – some of these measurement locations are shown in the RMA model 2-D grid).

Calibration of the nutrient model entailed setting the parameters discussed in Section 5.3 and listed in Table 5-2 and Table 5-3, as well as setting constituent values at boundaries where no data or only limited data were available. The Tables list the range of values used in calibration. Although there was some iteration between setting the global parameters and the regional parameters, the global parameters were fixed after an initial acceptable value was chosen. Values for nutrient boundary conditions at unconstrained boundaries were also set well before the fine-tuning of parameters was complete. Boundary conditions were varied early in the nutrient calibration process to observe model sensitivity to boundary conditions. Due to limitations on budget and time, this process was not documented. However, it was found that the model was most sensitive to settings on the Sacramento and San Joaquin Rivers (not surprisingly.

As a strategy, the number of reaction rates that were varied was kept to a minimum by selecting the most sensitive parameters, as this generally will result in a model with better predictive power – i.e., it avoids over-fitting which reduces predictive ability of the calibrated model (Larsen, 1997; Gilroy and McCuen, 2011;Friedel, 2006; Schoups et al.,2008). Five regions were selected as a basis for setting regionally-based parameters - the regions are shown in Figure 6-3

[24] See: http://cdec.water.ca.gov/cgi-progs/iodir/wsihist for a discussion of Water Year type.

to Figure 6-7. There was a limited amount of variation of parameter values within these regions. For example, channels adjacent to the location Suisun-Volanti were fine-tuned to optimize the calibration statistics there. In some locations, algal mortality was used in an attempt to capture some of the influence of clams, which was evident during the summer and fall of drier Water Years. During these periods, algal growth peaks looked like craters – with the summer and early fall concentrations lower than spring and late fall.

The underlined, **bold** parameters were the primary parameters varied during the 1990 – 2008 calibration. In the 2000 - 2008 calibration, parameter settings were simplified within the five regions from the earlier calibration settings:

- Algal rates:
  - **Growth (max), Mortality**, Settling, Respiration
- Decay rates:
  - **Ammonia, Nitrite**, CBOD, **Organic-P, Organic-N**
  - Hydrolysis: Organic-N to NH_3
- Settling rates:
  - CBOD, **Organic-N, Organic-P**
- Benthic:
  - **Oxygen Demand (SOD)**
  - **Release of PO_4, NH_3**
- Oxygen reaeration

Parameter values were chosen within ranges documented in the literature – SOD is the only exception. Recall, (Section 12.4), the range for allowed SOD rates in the nutrient model was expanded from the literature range to include the ranges during the DO calibration on the San Joaquin River (Rajbhandari 2000, 2001). This strategy was chosen to minimize the time needed to calibrate the entire Delta for the current project, as the previous parameterization of the San Joaquin River had produced satisfactory results, particularly for DO.

The ranges for maximum growth rate (day^{-1}) for algal species vary widely: for diatoms from 0.3 to 3.4; for green algae from 0.6 to 9.0; for golden-brown algae from 0.4 to 2.9; for Dinoflagellates from 0.3 to 2.1; for cyanobacteria from 0.07 to 11.0. The values are either gross or net production rates and were measured at a range of temperatures (see references in Cole and Wells, 2008).

In P-limited environments, Grover (in: Cole and Wells, 2008) measured maximum algal growth rates that were between 0.5 and 1.0 day^{-1}, and P-half-saturation constants from 6.0 E-0.6 to 0.0015 mg L^{-1}. In Cole and Wells (2008), the reported range of literature values for P-half-saturation constants varied from 0.001 to 1.5 mg L^{-1}, and for N-half-saturation constants from

0.01 to 4.3 mg L^{-1}, with the highest values reported for experiments using NO_3 and the highest reported rate for NH_3 experiments was 0.14 mg L^{-1}.

Under varying light intensities (factor of two), Litchman (in: Cole and Wells, 2008) measured maximum algal growth rates from 1.2 to 1.4 day^{-1} and respiration rates from 0.001 to 0.6 day^{-1}. CE-QUAL-W2 uses a default value of 0.04 day^{-1} for algal respiration rate, and suggests a maximum mortality rate of 10% of the maximum algal growth rate. The default value for algal mortality was 0.1 day^{-1}, with a range of 0.03 to 0.3 used in previous studies.

12.5.2 Nutrient Model Results: Calibration/validation for 1990 - 2008

The complete set of figures and histograms for the 1990 – 2008 calibration are numerous, and so supplied in separate documents as Appendices II - V. Figures were produced at all locations where there was sufficient data to plot more than a couple years. Where data were available for (nearly) the full model term, plots were produced for the full time span and the spans 1990 – 1999 and 2000 – 2008. Model plots sometimes begin in May or June 1990, as at some locations the initial condition values were somewhat too high or too low and the model required a spin-up at those locations for the first few months. The figures are organized by constituent.

Appendix II contains figures and tables with categorical statistics for ammonia and nitrate+nitrite model results *vs.* measurements, Appendix III, contains DO and algae, and Appendix IV contains PO_4 and organic-N. Appendix V contains calibration histograms of the residuals along with detailed statistics.

For the original 1990 – 2008 calibration, ranges for the calibration statistics for the N-constituents and dissolved oxygen was generally very good, except at a few locations. Calibration for the other constituents varied from very good to acceptable. Results were poorest where measurements were sparse spatially and/or temporally. Validation statistics mirrored calibration statistics, and in some cases improved on the calibration, indicating the appropriate use of the nutrient model for calibrated parameters (i.e., excluding organic-P and CBOD) on a monthly time scale.

Table 12-8 through Table 12-10[25] list the results of the 1990 – 2008 calibration/validation – in these tables, the quality of the calibration was assessed at each location using the methodology detailed in Section 12.5. Using these criteria, the quality of a calibration can be rated from Very Good (VG) to Unsatisfactory (U) for individual constituents (Moriasi et al., 2007).

Unsatisfactory results tended to be grouped at a few locations over all nutrients, with Grizzly Bay and Disappointment Slough having the worst results, followed by Potato Point and Old River at RDR. Organic-N and PO_4 had the worst results. Note that it was later found that PO_4 measurements along the Sacramento River were found to be in error, so this result is not surprising. Organic-P and organic-N are each consumed during algal growth, so the lack of the compensating organic-P measurement necessarily affected the ability to calibrate organic-N. Also, many organic-N measurements were below the detection limit. The RSR statistic was the most frequent unsatisfactory rating –this is not unexpected as the ranges for this statistic were not modified from the ranges in Moriasi (2007, and are thus strict as applied to nutrients.

Overall, the model calibration is rated Very Good to Satisfactory for all constituents at all locations, as there is no location with Unsatisfactory results across all three criteria for all constituents. The worst results occurred in areas where there were the fewest measurements near-by to constrain upstream or local parameterizations. Validation and calibration results are very similar, although validation statistics were somewhat better, probably because more very recent years were included and the recent years tended to have better quality of measurements.

12.5.3 Nutrient Model Results: Calibration/validation for 2000 – 2008 (Version 8.0.6)

Appendix VI contains the complete set of figures and histograms for the 2000 – 2008 calibration.

The calibration statistics for the newer QUAL Version 8.0.6 improved significantly over the Version 6.0 calibration due to several factors. The changes in nutrient model representation and numerical calculation prompted a detailed update of the parameterization, and an overall simplification in the regional parameter values. An error in the calibration data for orthophosphate along the Sacramento River was corrected, which resulted in a significant improvement in the calibration and validation statistics. Additional information was obtained to improve the representation of boundary conditions for the Liberty Island area, resulting in an improvement in the inflow boundary conditions for the Yolo Bypass/Toe Drain location.

Because of the reduction in the number of years and data points available for calibration and validation, the statistics were calculated with a smaller number of values. For this reason, calibration statistics were calculated for all eight years – combining the four calibration years and

[25] Each category of measurement – dry or wet and calibration or validation – had at least 36 measurements, i.e., $N \geq 36$. Many categories had significantly larger values of N.

for all four validation years - as well as separately for the two wet and two dry years within each category.

For the 2000 – 2008 calibration, the calibration and validation results for DO, NH_3, and NO_3+NO_2 (Table 12-11, Table 12-13 and Table 12-14 respectively) are Very Good at most locations for both Dry and Wet year types for the three criteria with only a few exceptions – the RSR has the majority of the Unsatisfactory ratings, as expected due to the strictness of the ranges as applied to nutrients. The results for algae (Table 12-12) ranged from Very Good to Satisfactory, although there are more Unsatisfactory results for the RSR statistics particularly in the calibration Wet year type. For algae, the model generally missed peak values during algal blooms, which is not surprising given the monthly time scale of boundary conditions.

The results for organic-N (Table 12-15) and PO_4 (Table 12-16) are significantly improved over the 1990 -2008 calibration, particularly for PO_4. For both of these constituents, only the Old River at Rancho del Rio location had any Unsatisfactory ratings outside of the RSR statistic.

Calibration statistics for the "All Years" category were generally better than the categories broken out by Water Year. However, calibration and validation statistics were similar for both Wet and Dry year types.

Recall, calibration and validation statistics were also calculated with the max/min envelope width reduced by various percentages (see Section 11.3). Table 12-17 through Table 12-22 illustrate the calibration results for statistics calculated with the envelope width reduced to 80% of the max/min envelope (20% reduction). Out of all the constituents, only the NO_3+NO_2 statistics deteriorated noticeably with reduction of the envelope width (Table 12-20). Figure 12-30 illustrates the change in envelope width for NO_3+$NO_2$and PO_4 for 10% and 20% reductions in envelope width. Appendix VI, Section 27 covers this aspect of the statistics (*i.e.*, envelope width) in greater detail.

12.6 Discussion of Calibration and Validation

The nutrient model in DSM2-QUAL has a simple conceptual formulation that proved sufficient for the task of modeling the entire Delta with output averaged on a monthly basis using data collected for this project. This claim is supported with goodness-of-fit assessed by the calibration statistics, and with the predictive ability of the model affirmed by the validation statistics. As validation statistics mirrored calibration statistics, the conclusion is that the nutrient model's appropriate use for calibrated parameters (*i.e.*, excluding organic-P and CBOD) is at a monthly time scale.

There is no unique way to calibrate a model with this many parameters (48), and numerous unconstrained or poorly constrained boundaries, such as the Yolo/Cache Slough/Liberty Island region (Larsen, 1997; Gilroy and McCuen, 2011; Friedel, 2006; Schoups et al., 2008). However,

the final parameterization of the model is arguably sensible, as parameter values are within literature ranges, with the exception of one parameter, and unconstrained boundaries were set at reasonable values. In addition, the calibration results are very good for those constituents that had the best constraining data, and generally satisfactory for the other constituents. In fact, the calibration for algae is remarkably good given the sparse data and the important factors in their dynamics not included in the model, such as loss to clams. The criteria applied for nutrient calibration and validation assessment are likely too strict, in particular for RSR which was developed for parameters with lower measurement uncertainty than nutrients.

Calibration and validation statistics indicate that the application of this model to investigate nutrient dynamics in the Delta at a monthly time step is justified, as calibration statistics are generally Very Good to Satisfactory, except at a few locations, and validation statistics mirror calibration, indicating the predictive value of the model is also Very Good to Satisfactory. In addition, this statement can be applied to application over different Water Year types, as the calibration and validation were carried out with the additional constraint of residual analysis by Water Year type.

If the application of meteorological data is "regionalized" in future versions of DSM2, a calibrated two-region water temperature model will be available using the current calibration for the North Delta and the previous calibration for the South Delta (Rajbhandari, 2003). Even with the current single region model, the calibration statistics are very good (although regionally biased) despite the large amount of synthesized data.

Suisun Marsh has few nutrient measurements to constrain the setting of boundary conditions or parameters. This presented difficulties in calibrating the model in that region. Although some effort went into identifying the cause of extreme events in the data, such as a large spike in algal mass, the length of the time period (19 years) and limitations on budget precluded detailed analysis.

Nutrient Calibration/Validation Periods

Nutrient Calibration				Nutrient Validation		Nutrient Calibration		Nutrient Validation	
1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
5	4	2	2	4	3	4	5	2	1

		Nutrient Calibration		Nutrient Validation				
1990	1991	1992	1993	1994	1995	1996	1997	1998
1	1	1	4	1	5	5	5	5

1	Critical
2	Dry
3	Below Normal
4	Above Normal
5	Wet

	Calibration
	Validation

Figure 12-22 Nutrient calibration (blue) and validation (red) periods.

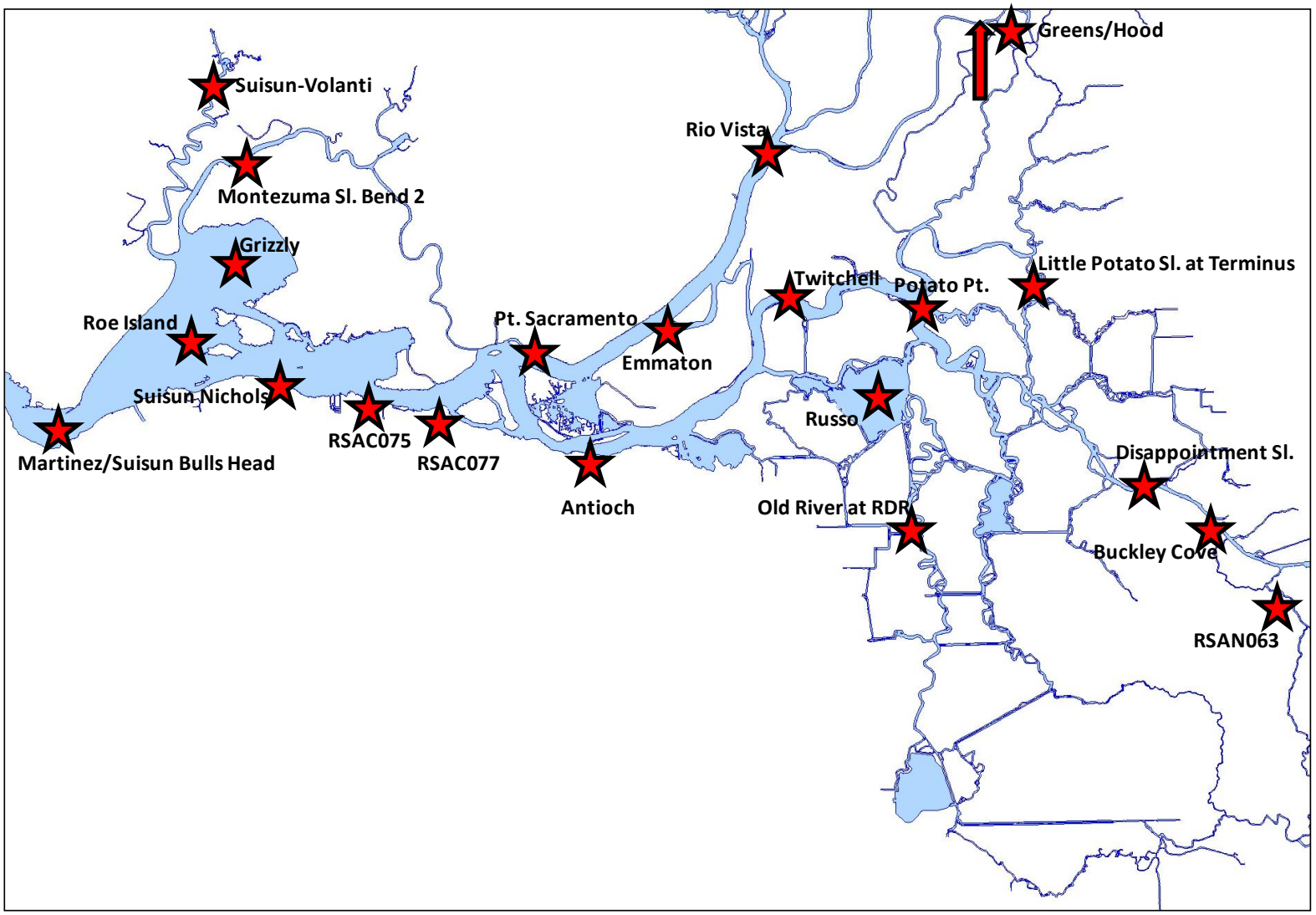


Figure 12-23 Location of nutrient data time series used in model calibration and validation. Model constituents vary by location.

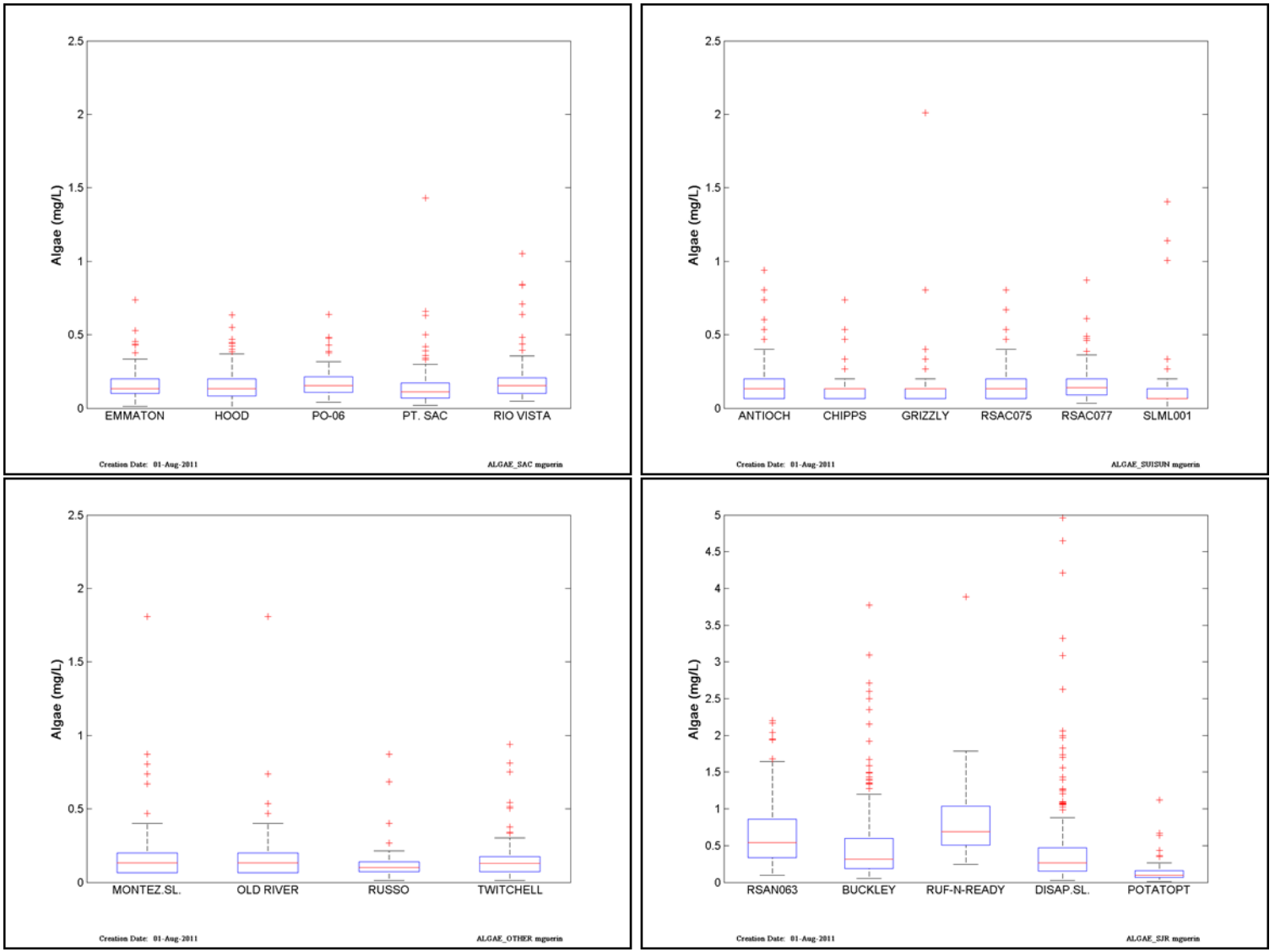


Figure 12-24 Box plot of the 2000 – 2008 data for the Algae/chl-a constituent used in the calibration of QUAL Version 8.0.6.

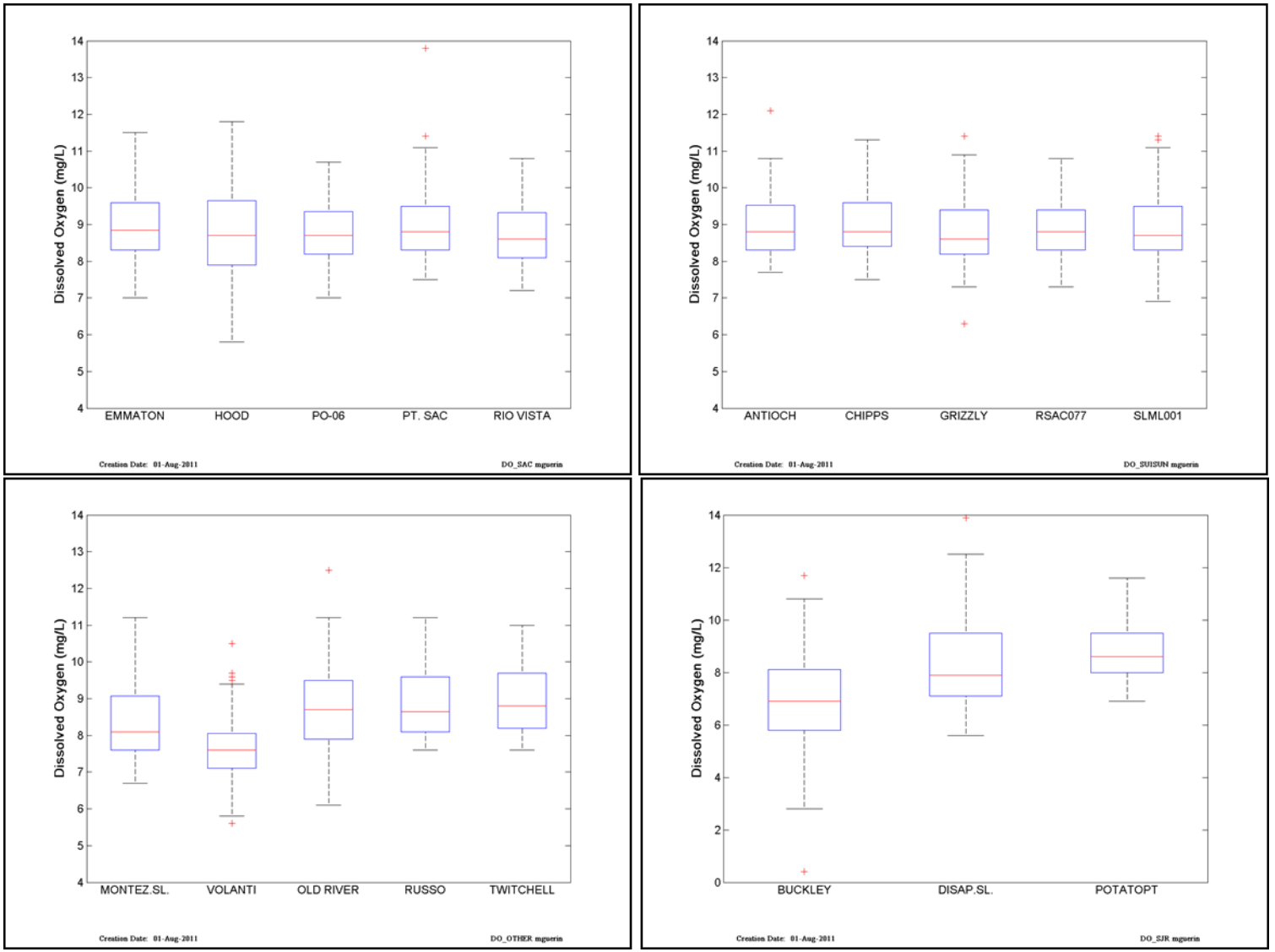


Figure 12-25 Box plot of the 2000 – 2008 data for the DO constituent used in the calibration of QUAL Version 8.0.6.

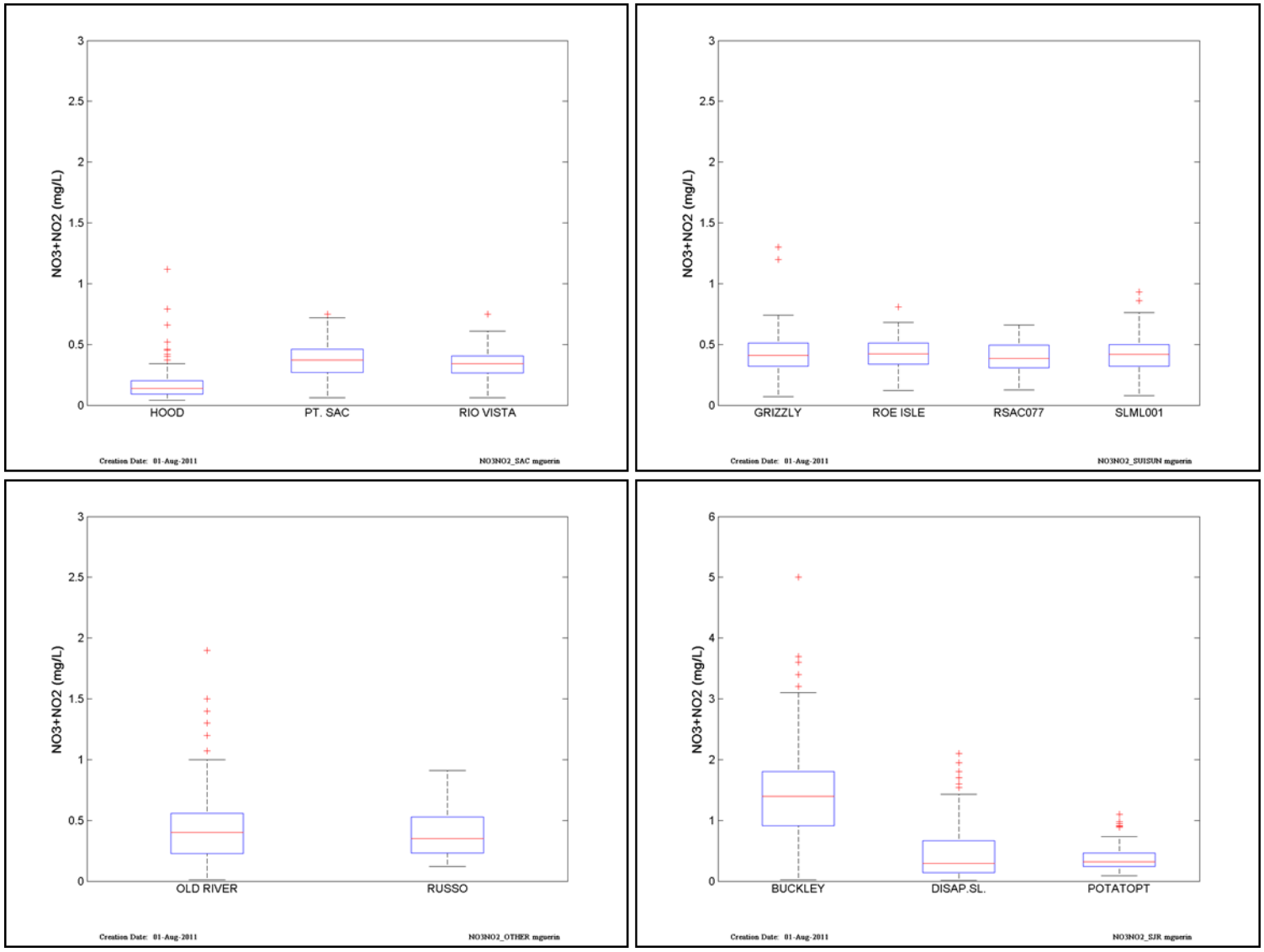


Figure 12-26 Box plot of 2000 – 2008 data for the NO_3+NO_2 constituent(s) used in the calibration of QUAL Version 8.0.6.

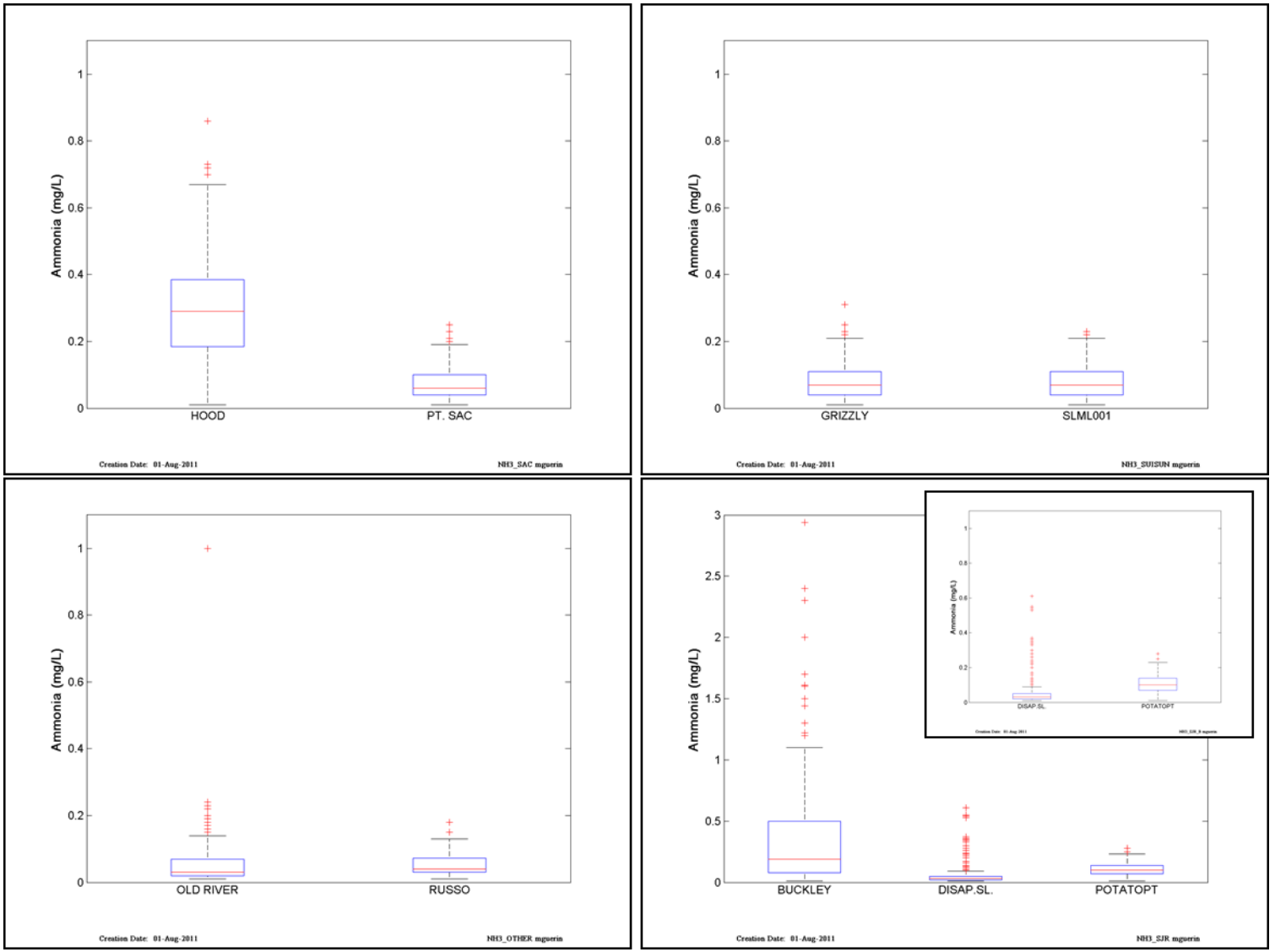


Figure 12-27 Box plot of 2000 – 2008 data for the NH_3 constituent(s) used in the calibration of QUAL Version 8.0.6.

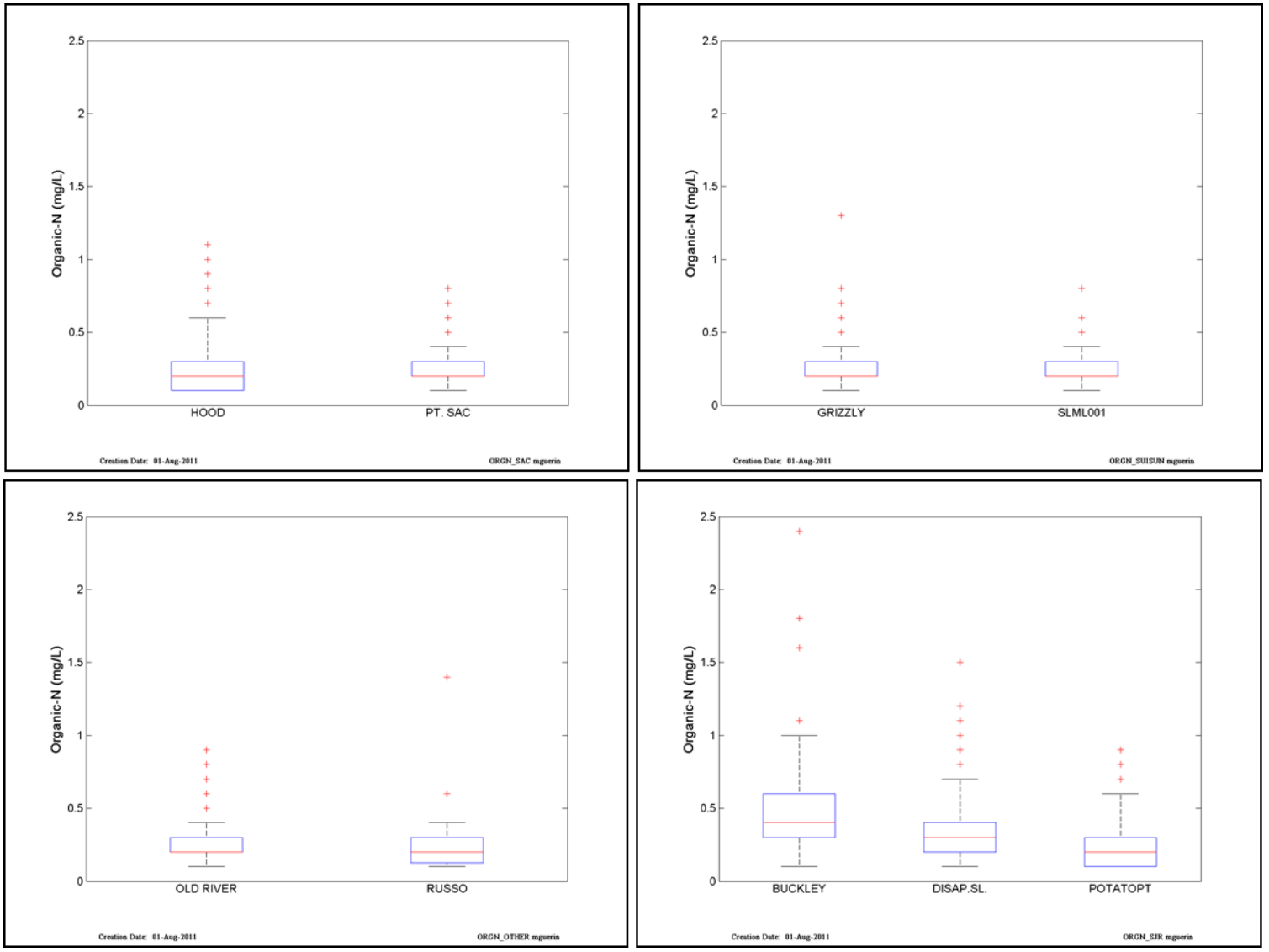


Figure 12-28 Box plot of 2000 – 2008 data for the Organic-N constituent(s) used in the calibration of QUAL Version 8.0.6.

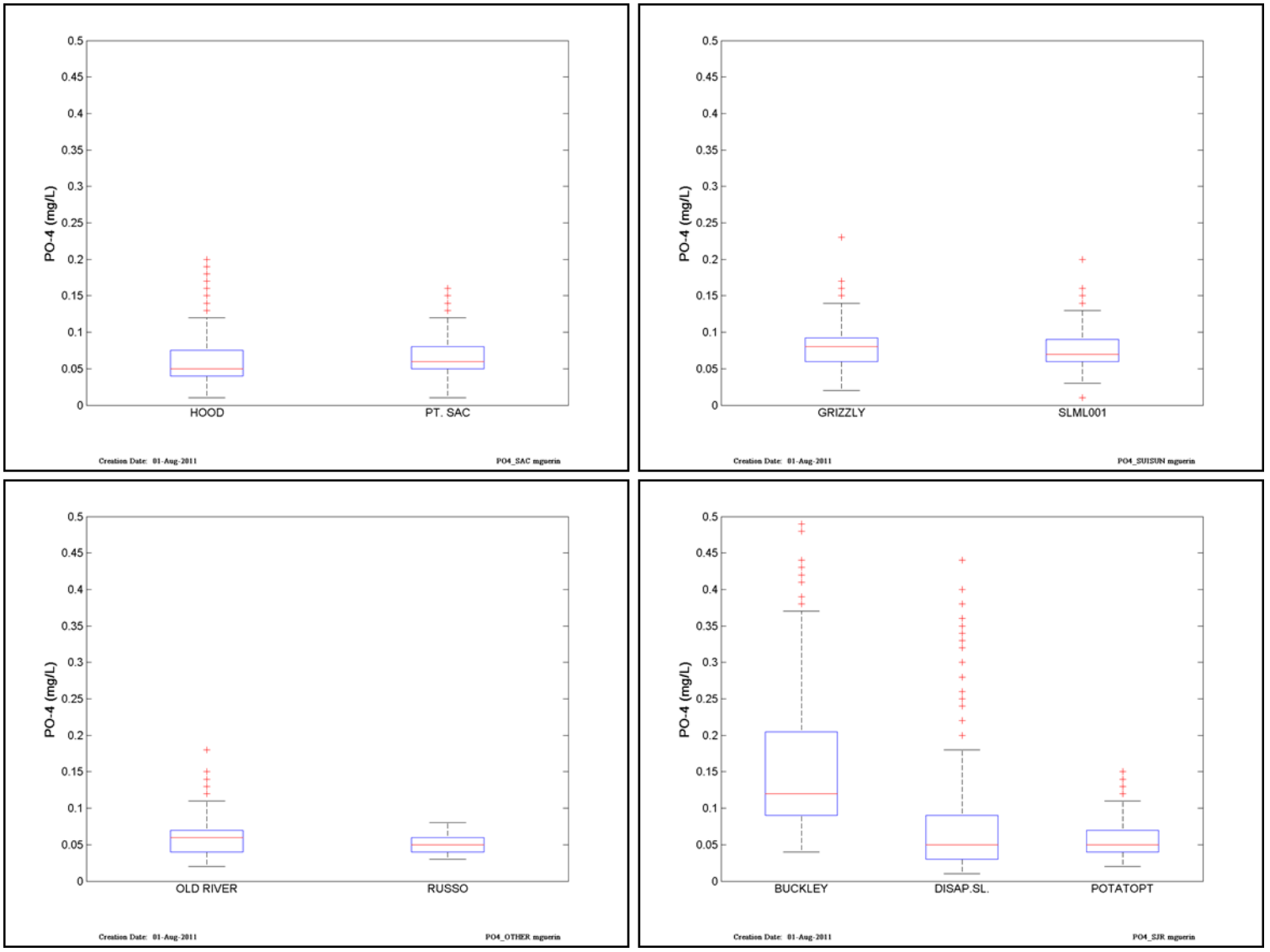


Figure 12-29 Box plot of 2000 – 2008 data for the PO_4 constituent(s) used in the calibration of QUAL Version 8.0.6.

Table 12-6 Categories used to rate the quality of the nutrient calibration/validation.

Performance Rating	RSR	NSE	PBIAS (%)
Very Good	$0.00 \leq$ RSR ≤ 0.50	$0.75 <$ NSE ≤ 1.00	PBIAS < +/- 25
Good	$0.50 <$ RSR ≤ 0.60	$0.65 <$ NSE ≤ 0.75	+/- 25 $\leq$ PBIAS < +/- 40
Satisfactory	$0.60 <$ RSR ≤ 0.70	$0.00 \leq$ NSE ≤ 0.65	+/- 40 $\leq$ PBIAS < +/- 70
Unsatisfactory	RSR > 0.7	NSE < 0.0	PBIAS $\geq$ +/- 70

Table 12-7 Specification of calibration and validation years by Wet and Dry Water Year types for the 2000 – 2008 calibration.

	Calibration Years	Validation Years
DRY	2001, 2002	2007, 2008
WET	2000, 2003	2005, 2006

Table 12-8 Calibration/Validation results for NH_3 and NO_3+NO_2: VG=Very Good, G=Good, SAT=Satisfactory and U=Unsatisfactory, in red font

Ammonia

Calibration - Dry	NSE	PBIAS	RSR	Validation - Dry	NSE	PBIAS	RSR
Susiun near Nichols	VG	VG	VG	Susiun near Nichols	VG	VG	VG
Grizzly	U	VG	U	Grizzly	U	VG	U
Potato Point	SAT	VG	SAT	Potato Point	VG	VG	SAT
Old River at RDR	SAT	VG	U	Old River at RDR	VG	VG	G
Point Sacramento	VG	VG	VG	Point Sacramento	VG	VG	VG
Buckley Cove	VG	VG	VG	Buckley Cove	VG	VG	VG
Greens/Hood	VG	VG	VG	Greens/Hood	VG	VG	VG
Disappointment Sl.	U	VG	U	Disappointment Sl.	SAT	VG	U
Calibration - Wet				Validation - Wet			
Susiun near Nichols	VG	VG	VG	Susiun near Nichols	VG	VG	VG
Grizzly	U	VG	U	Grizzly	U	VG	U
Potato Point	VG	VG	VG	Potato Point	VG	VG	VG
Old River at RDR	SAT	VG	U	Old River at RDR	U	VG	U
Point Sacramento	VG	VG	VG	Point Sacramento	VG	VG	VG
Buckley Cove	VG	VG	VG	Buckley Cove	VG	VG	VG
Greens/Hood	VG	VG	VG	Greens/Hood	VG	VG	VG
Disappointment Sl.	SAT	VG	U	Disappointment Sl.	U	VG	U

NO3+NO2

Calibration - Dry	NSE	PBIAS	RSR	Validation - Dry	NSE	PBIAS	RSR
Susiun near Nichols	SAT	VG	U	Susiun near Nichols	SAT	VG	U
Rio Vista	VG	VG	VG	Rio Vista	VG	VG	VG
Grizzly	U	VG	U	Grizzly	SAT	VG	SAT
Potato Point	SAT	VG	SAT	Potato Point	G	VG	G
Old River at RDR	SAT	VG	U	Old River at RDR	G	VG	G
Point Sacramento	SAT	VG	U	Point Sacramento	SAT	VG	U
Buckley Cove	VG	VG	G	Buckley Cove	VG	VG	VG
Greens/Hood	VG	VG	VG	Greens/Hood	VG	VG	VG
Disappointment Sl.	SAT	VG	U	Disappointment Sl.	SAT	VG	SAT
Calibration - Wet				Validation - Wet			
Susiun near Nichols	SAT	VG	SAT	Susiun near Nichols	SAT	VG	U
Rio Vista	VG	VG	VG	Rio Vista	VG	VG	VG
Grizzly	G	VG	G	Grizzly	G	VG	G
Potato Point	VG	VG	VG	Potato Point	VG	VG	VG
Old River at RDR	G	VG	G	Old River at RDR	VG	VG	G
Point Sacramento	VG	VG	VG	Point Sacramento	G	VG	G
Buckley Cove	VG	VG	VG	Buckley Cove	VG	VG	VG
Greens/Hood	VG	VG	VG	Greens/Hood	VG	VG	VG
Disappointment Sl.	VG	VG	VG	Disappointment Sl.	VG	VG	VG

Table 12-9 Calibration/Validation results for Org-N and DO: VG=Very Good, G=Good, SAT=Satisfactory and U=Unsatisfactory, in red font.

Organic-N

Calibration - Dry	NSE	PBIAS	RSR	Validation - Dry	NSE	PBIAS	RSR
Susiun near Nichols	U	VG	U	Susiun near Nichols	U	VG	U
Grizzly	U	VG	U	Grizzly	U	VG	U
Potato Point	U	VG	U	Potato Point	U	VG	U
Old River at RDR	U	VG	U	Old River at RDR	SAT	VG	U
Point Sacramento	U	VG	U	Point Sacramento	U	VG	U
Buckley Cove	SAT	VG	SAT	Buckley Cove	U	VG	U
Greens/Hood	VG	VG	VG	Greens/Hood	VG	VG	VG
Disappointment Sl.	U	Sat	U	Disappointment Sl.	U	G	U
Calibration - Wet				Validation - Wet			
Susiun near Nichols	SAT	VG	U	Susiun near Nichols	G	VG	G
Grizzly	U	VG	U	Grizzly	SAT	VG	U
Potato Point	SAT	VG	U	Potato Point	SAT	VG	U
Old River at RDR	SAT	VG	U	Old River at RDR	SAT	VG	U
Point Sacramento	SAT	VG	U	Point Sacramento	VG	VG	G
Buckley Cove	VG	VG	VG	Buckley Cove	SAT	VG	U
Greens/Hood	VG	VG	VG	Greens/Hood	VG	VG	VG
Disappointment Sl.	U	Sat	U	Disappointment Sl.	U	G	U

DO

Calibration - Dry	NSE	PBIAS	RSR	Validation - Dry	NSE	PBIAS	RSR
Susiun near Nichols	VG	VG	VG	Susiun near Nichols	VG	VG	VG
Grizzly	VG	VG	VG	Grizzly	VG	VG	VG
Little Potato Sl at Terminous	U	VG	U	Little Potato Sl at Terminous	SAT	VG	U
Potato Point	VG	VG	VG	Potato Point	VG	VG	VG
Old River at RDR	VG	VG	VG	Old River at RDR	G	VG	G
Twitchell	VG	VG	VG	Twitchell	VG	VG	VG
Point Sacramento	VG	VG	VG	Point Sacramento	VG	VG	VG
Buckley Cove	U	Sat	U	Buckley Cove	VG	VG	VG
Greens/Hood	VG	VG	VG	Greens/Hood	VG	VG	VG
Calibration - Wet				Validation - Wet			
Susiun near Nichols	SAT	VG	U	Susiun near Nichols	VG	VG	VG
Grizzly	VG	VG	VG	Grizzly	VG	VG	VG
Little Potato Sl at Terminous	SAT	VG	U	Little Potato Sl at Terminous	U	VG	U
Potato Point	VG	VG	VG	Potato Point	VG	VG	VG
Old River at RDR	G	VG	SAT	Old River at RDR	G	VG	G
Twitchell	VG	VG	VG	Twitchell	SAT	VG	SAT
Point Sacramento	U	VG	U	Point Sacramento	G	VG	G
Buckley Cove	SAT	VG	U	Buckley Cove	U	Sat	U
Greens/Hood	VG	VG	VG	Greens/Hood	VG	VG	VG

Table 12-10 Calibration/Validation results for Chl-a/Algae andPO_4: VG=Very Good, G=Good, SAT=Satisfactory and U=Unsatisfactory, in red font.

Chl-a/Algae

Calibration - Dry	NSE	PBIAS	RSR	Validation - Dry	NSE	PBIAS	RSR
Point Sacramento	VG	VG	VG	Point Sacramento	VG	VG	VG
Susiun near Nichols	VG	VG	VG	Susiun near Nichols	VG	VG	VG
Rio Vista	G	VG	G	Rio Vista	VG	VG	VG
SJR at Pittsburg	SAT	VG	SAT	SJR at Pittsburg	VG	G	G
Buckley Cove	U	Sat	U	Buckley Cove	VG	VG	VG
Greens/Hood	VG	VG	VG	Greens/Hood	VG	VG	VG
Disappointment Sl.	SAT	VG	U	Disappointment Sl.	SAT	VG	U
Calibration - Wet				Validation - Wet			
Point Sacramento	U	VG	U	Point Sacramento	G	VG	G
Susiun near Nichols	U	VG	U	Susiun near Nichols	G	VG	SAT
Rio Vista	U	VG	U	Rio Vista	SAT	VG	U
SJR at Pittsburg	SAT	VG	U	SJR at Pittsburg	SAT	VG	U
Buckley Cove	SAT	VG	U	Buckley Cove	U	Sat	U
Greens/Hood	VG	VG	VG	Greens/Hood	VG	VG	VG
Disappointment Sl.	G	VG	G	Disappointment Sl.	VG	VG	VG

PO4

Calibration - Dry	NSE	PBIAS	RSR	Validation - Dry	NSE	PBIAS	RSR
Susiun near Nichols	SAT	Sat	U	Susiun near Nichols	SAT	Sat	U
Grizzly	U	VG	U	Grizzly	U	VG	U
Potato Point	U	VG	U	Potato Point	U	VG	U
Old River at RDR	SAT	Sat	U	Old River at RDR	SAT	Sat	U
Point Sacramento	U	VG	U	Point Sacramento	U	G	U
Buckley Cove	VG	VG	VG	Buckley Cove	VG	VG	G
Greens/Hood	VG	VG	VG	Greens/Hood	VG	VG	SAT
Disappointment Sl.	U	Sat	U	Disappointment Sl.	U	Sat	U
Calibration - Wet				Validation - Wet			
Susiun near Nichols	SAT	Sat	U	Susiun near Nichols	SAT	Sat	U
Grizzly	U	VG	U	Grizzly	U	VG	U
Potato Point	U	Sat	U	Potato Point	U	Sat	U
Old River at RDR	U	Sat	U	Old River at RDR	U	Sat	U
Point Sacramento	U	VG	U	Point Sacramento	SAT	VG	U
Buckley Cove	VG	VG	VG	Buckley Cove	VG	VG	VG
Greens/Hood	VG	VG	VG	Greens/Hood	VG	VG	VG
Disappointment Sl.	U	Sat	U	Disappointment Sl.	U	G	U

Table 12-11 Calibration and validation statistics for DO (100%, QUAL Version 8.0.6).

	All Years			Calibration Dry			Validation Dry			Calibration Wet			Validation Wet		
Location	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***
Antioch	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
SJR Buckley Cove	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Chipps	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Disappointment Sl.	S	VG	S	VG	VG	VG	S	VG	U	G	VG	G	G	VG	G
Emmaton	VG	VG	VG	VG	VG	VG	VG	VG	VG	G	VG	G	VG	VG	VG
Greens-Hood	VG	VG	VG	VG	VG	VG	S	VG	S	VG	VG	VG	VG	VG	VG
Grizzly Bay	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Little Potato Sl. at Terminous	VG	VG	VG	G	VG	G	-	-	-	G	VG	VG	S	VG	VG
Martinez	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Montezuma Sl.	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	S	VG	U
Old R. at Rancho Del Rio	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Potato Pt	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Pittsburg-RSAC077	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	S	VG	U
Pt. Sacramento	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Rio Vista	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Roe Island	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	G	VG	G
Suisun-Nichols	VG	VG	VG	G	VG	G	VG	VG	VG	G	VG	G	VG	VG	VG
Suisun-Volanti	VG	VG	G	S	VG	S	VG	VG	VG	G	VG	G	S	VG	U
Twitchell	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	G	VG	VG	VG

Table 12-12 Calibration and validation statistics for Algae/chl-a (100%, QUAL Version 8.0.6)

	All Years			Calibration Dry			Validation Dry			Calibration Wet			Validation Wet		
Location	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***
Antioch	S	VG	U	S	G	U	S	VG	U	S	VG	U	G	VG	S
SJR Buckley Cove	VG	VG	VG	VG	VG	G	S	VG	U	S	G	U	VG	VG	G
Chipps	S	VG	U	S	VG	U	S	VG	U	G	VG	S	S	VG	U
Disappointment Sl.	S	G	U	S	S	U	S	S	U	G	VG	G	G	VG	G
Emmaton	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	S	VG	G
Greens-Hood	VG	VG	VG	S	VG	S	VG	VG	VG	VG	VG	VG	VG	VG	VG
Grizzly Bay	S	VG	U	S	VG	U	G	VG	G	S	VG	U	G	VG	G
Mallard-RSAC075	S	G	U	S	G	U	-	-	-	S	G	U	S	VG	U
Martinez	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Montezuma Sl.	S	VG	U	S	G	U	S	VG	U	VG	VG	VG	G	VG	G
Old R. at Rancho Del Rio	S	VG	U	G	VG	G	S	VG	S	S	S	U	VG	VG	VG
Pittsburg-RSAC077	G	G	G	S	G	U	S	G	U	G	VG	S	G	VG	S
Potato Pt	S	VG	U	G	VG	G	S	VG	U	S	G	U	G	VG	G
Pt. Sacramento	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Rio Vista	VG	VG	VG	VG	VG	VG	S	VG	U	S	G	U	VG	VG	VG
Roe Island	S	VG	U	S	VG	U	S	VG	U	S	VG	S	S	G	U
Stockton-RSAN063	S	G	U	S	VG	U	-	-	-	U	G	U	S	VG	U
Suisun-Nichols	G	VG	G	G	VG	G	VG	VG	VG	S	G	U	VG	VG	G
Suisun-Volanti	S	G	U	U	S	U	S	VG	U	S	VG	U	S	VG	U
Twitchell	S	VG	U	S	VG	U	S	VG	U	S	VG	S	VG	VG	VG

Table 12-13 Calibration and validation statistics for NH3 (100%, QUAL Version 8.0.6).

	All Years			Calibration Dry			Validation Dry			Calibration Wet			Validation Wet		
Location	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***
SJR Buckley Cove	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Disappointment Sl.	VG	S	G	VG	S	U	S	S	U	VG	S	G	VG	S	VG
Greens-Hood	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Grizzly Bay	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Martinez	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Old R. at Rancho Del Rio	VG	G	G	VG	VG	G	G	G	S	S	VG	U	S	S	U
Potato Pt	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Pt. Sacramento	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Suisun-Nichols	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG

Table 12-14 Calibration and validation statistics for NO3+NO2 (100%, QUAL Version 8.0.6).

	All Years			Calibration Dry			Validation Dry			Calibration Wet			Validation Wet		
Location	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***
SJR Buckley Cove	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Disappointment Sl.	G	S	G	G	S	U	G	S	U	S	S	U	VG	G	VG
Greens-Hood	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Grizzly Bay	VG	VG	VG	VG	VG	VG	S	VG	U	VG	VG	VG	VG	VG	VG
Martinez	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Old R. at Rancho Del Rio	VG	VG	VG	S	VG	S	S	G	U	S	VG	U	VG	VG	G
Pittsburg-RSAC077	VG	VG	VG	G	VG	S	VG	VG	VG	VG	VG	VG	VG	VG	VG
Potato Pt.	VG	VG	VG	G	VG	U	S	VG	U	G	VG	U	VG	VG	VG
Pt. Sacramento	VG	VG	VG	VG	VG	VG	G	VG	S	VG	VG	VG	VG	VG	VG
Rio Vista	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Roe Island	VG	VG	VG	VG	VG	G	S	VG	U	VG	VG	G	VG	VG	VG
Suisun-Nichols	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG

Table 12-15 Calibration and validation statistics for organic-N (100%, QUAL Version 8.0.6).

	All Years			Calibration Dry			Validation Dry			Calibration Wet			Validation Wet		
Location	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***
SJR Buckley Cove	VG	VG	VG	VG	VG	G	G	VG	G	G	VG	G	VG	VG	VG
Disappointment Sl.	VG	VG	VG	G	VG	G	S	VG	S	G	VG	S	VG	VG	VG
Greens-Hood	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Grizzly Bay	VG	VG	VG	S	VG	U	S	VG	S	S	G	U	S	VG	U
Martinez	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Old R. at Rancho Del Rio	VG	VG	VG	S	VG	S	S	VG	U	U	VG	U	S	VG	U
Potato Pt	VG	VG	VG	S	VG	U	S	VG	U	S	VG	U	S	VG	U
Pt. Sacramento	VG	VG	VG	S	VG	S	S	G	U	S	VG	S	S	G	U
Suisun-Nichols	VG	VG	VG	G	VG	G	S	VG	S	S	VG	S	S	VG	S

Table 12-16 Calibration and validation statistics for PO4, orthophosphate (100%, QUAL Version 8.0.6).

	All Years			Calibration Dry			Validation Dry			Calibration Wet			Validation Wet		
Location	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***
SJR Buckley Cove	VG	VG	VG	S	VG	U	VG	VG	VG	VG	VG	VG	VG	VG	VG
Disappointment Sl.	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Greens-Hood	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Grizzly Bay	VG	VG	VG	S	VG	U	S	VG	S	VG	VG	G	VG	VG	VG
Martinez	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Old R. at Rancho Del Rio	VG	VG	VG	U	VG	U	U	VG	U	U	VG	U	S	VG	U
Potato Pt	VG	VG	VG	S	VG	U	S	VG	S	S	VG	U	VG	VG	VG
Pt. Sacramento	VG	VG	VG	S	VG	U	S	VG	U	S	VG	S	G	VG	G
Suisun-Nichols	VG	VG	VG	VG	VG	VG	VG	VG	VG	S	VG	U	VG	VG	VG

Table 12-17Calibration and validation statistics for DO (80% QUAL Version 8.0.6).

	All Years			Calibration Dry			Validation Dry			Calibration Wet			Validation Wet		
Location	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***
Antioch	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
SJR Buckley Cove	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Chipps	VG	VG	VG	G	VG	G	VG	VG	VG	G	VG	G	VG	VG	VG
Disappointment Sl.	S	VG	S	G	VG	VG	S	VG	U	G	VG	G	G	VG	G
Emmaton	VG	VG	VG	VG	VG	VG	VG	VG	VG	G	VG	G	VG	VG	VG
Greens-Hood	VG	VG	VG	VG	VG	VG	S	VG	S	VG	VG	VG	VG	VG	VG
Grizzly Bay	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Little Potato Sl. at Terminous	VG	VG	VG	G	VG	G	-	-	-	G	VG	VG	S	VG	VG
Martinez	VG	VG	VG	G	VG	G	VG	VG	VG	VG	VG	VG	VG	VG	VG
Montezuma Sl.	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	S	VG	U
Old R. at Rancho Del Rio	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	G	VG	VG	VG
Potato Pt	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Pittsburg-RSAC077	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	S	VG	U
Pt. Sacramento	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Rio Vista	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Roe Island	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	G	VG	G
Suisun-Nichols	VG	VG	VG	G	VG	G	VG	VG	VG	G	VG	G	VG	VG	VG
Suisun-Volanti	VG	VG	G	S	VG	S	VG	VG	VG	G	VG	G	S	VG	U
Twitchell	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	G	VG	VG	VG

Table 12-18 Calibration and validation statistics for Algae/chl-a (80% QUAL Version 8.0.6).

	All Years			Calibration Dry			Validation Dry			Calibration Wet			Validation Wet		
Location	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***
Antioch	S	VG	U	S	G	U	S	VG	U	S	VG	U	S	VG	S
SJR Buckley Cove	VG	VG	VG	VG	VG	G	S	VG	U	S	G	U	VG	VG	G
Chipps	S	VG	U	S	VG	U	S	VG	U	G	VG	S	S	VG	U
Disappointment Sl.	S	G	U	S	S	U	S	S	U	G	VG	G	G	VG	G
Emmaton	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	S	VG	G
Greens-Hood	VG	VG	VG	S	VG	S	VG	VG	VG	VG	VG	VG	VG	VG	VG
Grizzly Bay	S	VG	U	S	VG	U	G	VG	G	S	VG	U	G	VG	G
Mallard-RSAC075	S	G	U	S	G	U	-	-	-	S	G	U	S	VG	U
Martinez	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Montezuma Sl.	S	VG	U	S	G	U	S	VG	U	VG	VG	VG	S	VG	G
Old R. at Rancho Del Rio	S	VG	U	G	VG	G	S	VG	S	S	S	U	VG	VG	VG
Pittsburg-RSAC077	G	G	G	S	G	U	S	G	U	G	VG	S	VG	VG	S
Potato Pt	S	VG	U	G	VG	G	S	VG	U	S	G	U	G	VG	G
Pt. Sacramento	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Rio Vista	VG	VG	VG	VG	VG	VG	U	VG	U	S	G	U	G	VG	G
Roe Island	S	VG	U	S	VG	U	S	VG	U	S	VG	S	S	G	U
Stockton-RSAN063	S	G	U	S	VG	U	-	-	-	U	G	U	S	VG	U
Suisun-Nichols	G	VG	G	G	VG	G	VG	VG	VG	S	G	U	VG	VG	G
Suisun-Volanti	S	G	U	U	S	U	S	VG	U	S	VG	U	S	VG	U
Twitchell	S	VG	U	S	VG	U	S	VG	U	S	VG	S	VG	VG	VG

Table 12-19 Calibration and validation statistics for NH3 (80% QUAL Version 8.0.6).

	All Years			Calibration Dry			Validation Dry			Calibration Wet			Validation Wet		
Location	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***
SJR Buckley Cove	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Disappointment Sl.	VG	S	G	S	S	U	S	S	U	VG	S	G	VG	S	VG
Greens-Hood	VG	VG	VG	VG	VG	VG	S	VG	U	VG	VG	VG	VG	VG	VG
Grizzly Bay	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Martinez	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Old R. at Rancho Del Rio	VG	G	G	VG	VG	G	G	G	S	S	VG	U	S	S	U
Potato Pt	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Pt. Sacramento	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Suisun-Nichols	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG

Table 12-20 Calibration and validation statistics for NO3+NO2 (80% QUAL Version 8.0.6).

	All Years			Calibration Dry			Validation Dry			Calibration Wet			Validation Wet		
Location	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***
SJR Buckley Cove	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Disappointment Sl.	G	S	G	G	S	U	G	S	U	S	S	U	VG	G	VG
Greens-Hood	VG	VG	VG	S	G	U	VG	VG	VG	S	G	U	S	VG	U
Grizzly Bay	VG	VG	VG	VG	VG	G	S	VG	U	S	VG	U	VG	VG	S
Martinez	VG	VG	G	VG	VG	VG	S	VG	U	S	VG	U	VG	VG	U
Old R. at Rancho Del Rio	VG	VG	G	S	VG	U	S	G	U	S	VG	U	VG	VG	G
Pittsburg-RSAC077	G	VG	S	U	VG	U	G	VG	S	U	VG	U	S	VG	U
Potato Pt.	VG	VG	VG	S	G	U	S	VG	U	U	VG	U	G	VG	G
Pt. Sacramento	VG	VG	VG	S	VG	U	S	VG	U	S	VG	U	VG	VG	G
Rio Vista	VG	VG	VG	U	VG	U	S	VG	U	VG	VG	VG	VG	VG	VG
Roe Island	G	VG	S	S	G	U	U	VG	U	G	G	U	VG	VG	S
Suisun-Nichols	VG	VG	VG	S	VG	U	G	VG	S	S	VG	U	VG	VG	G

Table 12-21 Calibration and validation statistics for Organic-N (80% QUAL Version 8.0.6).

	All Years			Calibration Dry			Validation Dry			Calibration Wet			Validation Wet		
Location	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***
SJR Buckley Cove	VG	VG	VG	G	VG	G	G	VG	G	G	VG	G	VG	VG	VG
Disappointment Sl.	VG	VG	VG	G	VG	G	S	VG	S	VG	VG	S	VG	VG	VG
Greens-Hood	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Grizzly Bay	VG	VG	VG	S	VG	U	S	VG	S	S	G	U	S	VG	U
Martinez	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Old R. at Rancho Del Rio	VG	VG	VG	S	VG	S	S	VG	U	U	VG	U	S	VG	U
Potato Pt	VG	VG	VG	S	VG	U	S	VG	U	S	VG	U	S	VG	U
Pt. Sacramento	VG	VG	VG	S	VG	S	S	G	U	S	VG	S	S	G	U
Suisun-Nichols	VG	VG	VG	G	VG	G	S	VG	S	S	VG	S	S	VG	S

Table 12-22 Calibration and validation statistics for PO4, orthophosphate (80% QUAL Version 8.0.6).

	All Years			Calibration Dry			Validation Dry			Calibration Wet			Validation Wet		
Location	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***	***NSE***	***PBIAS***	***RSR***
SJR Buckley Cove	VG	VG	VG	S	VG	U	VG	VG	VG	VG	VG	VG	VG	VG	VG
Disappointment Sl.	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Greens-Hood	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Grizzly Bay	VG	VG	VG	S	VG	U	S	VG	S	VG	VG	G	VG	VG	VG
Martinez	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG	VG
Old R. at Rancho Del Rio	VG	VG	VG	U	VG	U	U	VG	U	U	VG	U	S	VG	U
Potato Pt	VG	VG	VG	S	VG	U	S	VG	S	S	VG	U	VG	VG	VG
Pt. Sacramento	VG	VG	VG	S	VG	U	S	VG	U	S	VG	S	G	VG	G
Suisun-Nichols	VG	VG	VG	VG	VG	VG	VG	VG	VG	S	VG	U	VG	VG	VG

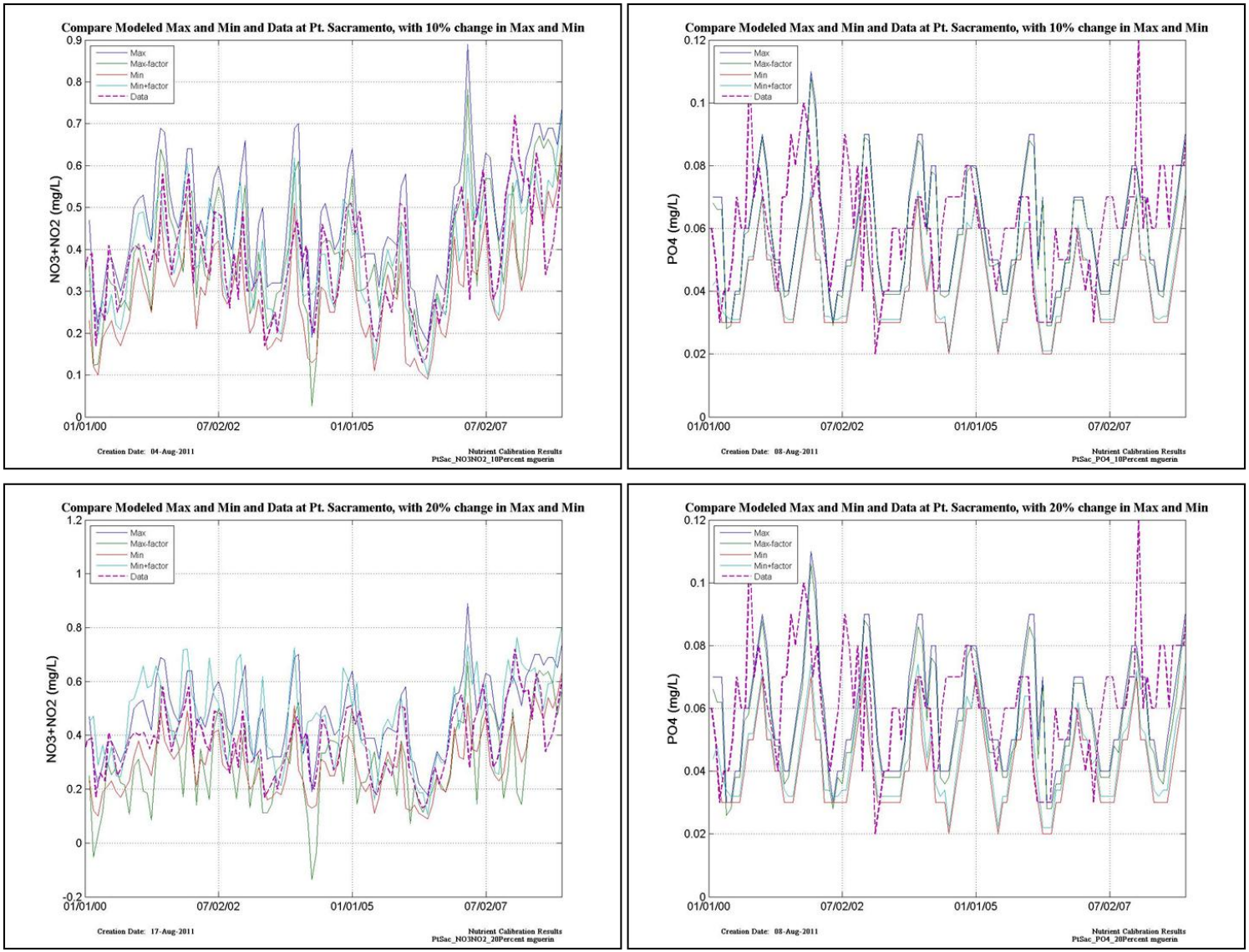


Figure 12-30 Illustration of the changes in max/min envelope width for NO3+NO2 (left) and Po4 (right) for the 10% and 20% reductions.

13 Volumetric Fingerprinting and Liberty Island Grid

13.1 Volumetric Fingerprinting Results

QUAL can be used to calculate a type of output called a volumetric fingerprint (Anderson, 2002). This calculation technique produces the relative contribution of various sources of water at any location in the model domain. At the Sacramento River boundary, for instance, all the water (100%) comes from that location, but at Rio Vista there will be additional volumetric contributions from the Sac Regional WWTP and from the Yolo Bypass boundary (and perhaps very small contributions from the Eastside Rivers). Volumetric contributions are calculated for each source of water input as a flow boundary condition (including DICU). At any model location, the sum of the various sources of water will be 100%. Volumetric fingerprinting was performed using the calibrated Version 6 model. Some model boundaries were combined for simplicity. The naming convention for the combined sources is found in Table 13-1. Figures illustrating volumetric fingerprinting are found at the end this section, and also in Appendix I Section 25.10.

Figure 13-1 shows that at Greens Landing, in additional to main volumetric contribution from the Sacramento R. boundary there are two lesser contributions, one from Sac Regional, ranging from near zero to about 4.0%, and the other from DICU sources, ranging from near zero to about 1.5%. Results are shown at a variety of locations in Figure 13-1, Figure 13-2 and (in the Appendix) Figure 25-51 through Figure 25-62, with a focus on volumetric contributions from effluent flows.

In general, the effluent volumes of most WWTPs are small (less than 1.0%) at most locations examined. Stockton and Sac Regional have the largest contributions – Stockton WWTP volumes are only noticeable along the San Joaquin River. For both WWTPs, the volume contribution falls off with distance. Ag (DICU) inflows are also high in nutrients, and at some locations the Ag contributions are higher than WWTP volumes.

Along the lower San Joaquin and Sacramento Rivers, the volume of Sac Regional effluent is very similar at several locations (Figure 25-52). When Lisbon Toe Drain flows begin around 2004, the pattern of Sac Regional effluent volume changes in the Yolo region. In upstream areas of Cache Slough, AG volumes dominate until the Toe Drain flows begin (Figure 25-54). Sac Regional volumes remain higher year-round in the northern areas on the Mokelumne River.

On the lower Sacramento and San Joaquin Rivers, the volumetric contributions from other WWTP's is very small – this is illustrated in Figure 25-58. These volumes are lower than Sac Regional volumes (Figure 25-61).

13.2 Inclusion of Liberty Island

Recently, DSM2 was recalibrated in the area influenced by Liberty Island, which was flooded in 2000. The nutrient model was rerun under this new configuration to determine the influence this region would have on nutrient dynamics. The extended DSM2 grid[26], called the Liberty grid herein, is shown in Figure 4-4. The previous grid is referred to as the Base grid. Recall, the flows for the Lisbon Toe Drain were included from 2004 – 2008, as they were not available before that time.

Three output locations were included in model output for the constituents downstream of the Yolo inflow location, downstream of the outflow location for Liberty Island, and also at the end of Cache Slough (SLCCH016) at the location of a the temperature calibration time series. These three locations are shown in the DSM2 grid in Figure 13-3. Figures illustrating results are found at the end of this section, and also in Appendix I Section 25.10.

Large changes in comparison with the Base grid results were seen in all constituent concentration at the three locations in the Yolo/Liberty/Cache area (organic-P was not examined). Algal biomass, CBOD and organic-N increased at two of the locations, DO increased slightly, and the concentrations of each of the other constituents decreased in comparison with the Base grid. Yolo output is shown in Figure 13-4 through Figure 13-7, Liberty output is shown in Figure 25-63 through Figure 25-66, and SLCCH016 output is shown in Figure 25-67 through Figure 25-70. The results for the SLCCH016 location are quite different – it is located at the end of the grid (dead-end channel), and the constituent concentrations there are dominated by DICU flows.

Three locations are illustrated moving down the Sacramento River – RSAC101, RSAC092 and Point Sacramento (Figure 13-8 through Figure 13-11 and Figure 25-76 through Figure 25-80). Algal biomass increased in comparison with Base at all three locations, and all of the N-constituents decreased in concentration, although differences with the Base decreased with distance from the Yolo/Liberty area. At RSAC101 and RSAC092, CBOD and PO_4 were higher than Base concentrations. At Point Sacramento, CBOD was higher and PO_4 were lower than Base. At each of the three locations, there were clear shifts in the timing of concentration or in the width of peaks in comparison with the Base for algal biomass, nitrate and CBOD.

At Potato Point (Figure 25-81 through Figure 25-84), the comparisons with respect to the Base case were very similar to the trends at Point Sacramento.

In general, constituent concentration differences were substantial immediately downstream of the confluence of the Sacramento River and Cache Slough and decreased with distance. Within the Yolo/Liberty/Cache Slough area, the changes in comparison with Base were even larger, so it is

[26] Many thanks are extended to CH2MHill and DWR-DMS for releasing an early version of this grid and model input.

appears that the influence of the flooded Liberty Island could be substantial if modeled nutrient are considered in selecting areas for their potential restoration area.

Table 13-1 Volumetric fingerprinting source names.

Volume Source	Volumetric Output Name
Martinez Boundary	VOL-MTZ
Sacramento River	VOL-SAC
Yolo Bypass	VOL-YOLO
Toe Drain (2004 – 2008 only)	VOL- TOE
San Joaquin River	VOL-SJR
Calaveras River	VOL-CAL
Mokelumne River	VOL-EAST
Cosumnes River	
Sac Regional WWTP	VOL-SACRWW
Stockton WWTP	VOL-STCKWW
Lodi WWTP	VOL-LODIWW
Manteca WWTP	VOL-MNTCAWW
Central Contra Costa WWTP	VOL-CCCSDWW
Delta Diablo WWTP	VOL-DDWW
Tracy WWTP	VOL-SDELWW
Discovery Bay WWTP	
Mountain House WWTP	
Fairfield-Suisun WWTP	VOL-MTZWW
Martinez Refinery+Tesoro	
Valero Refinery	

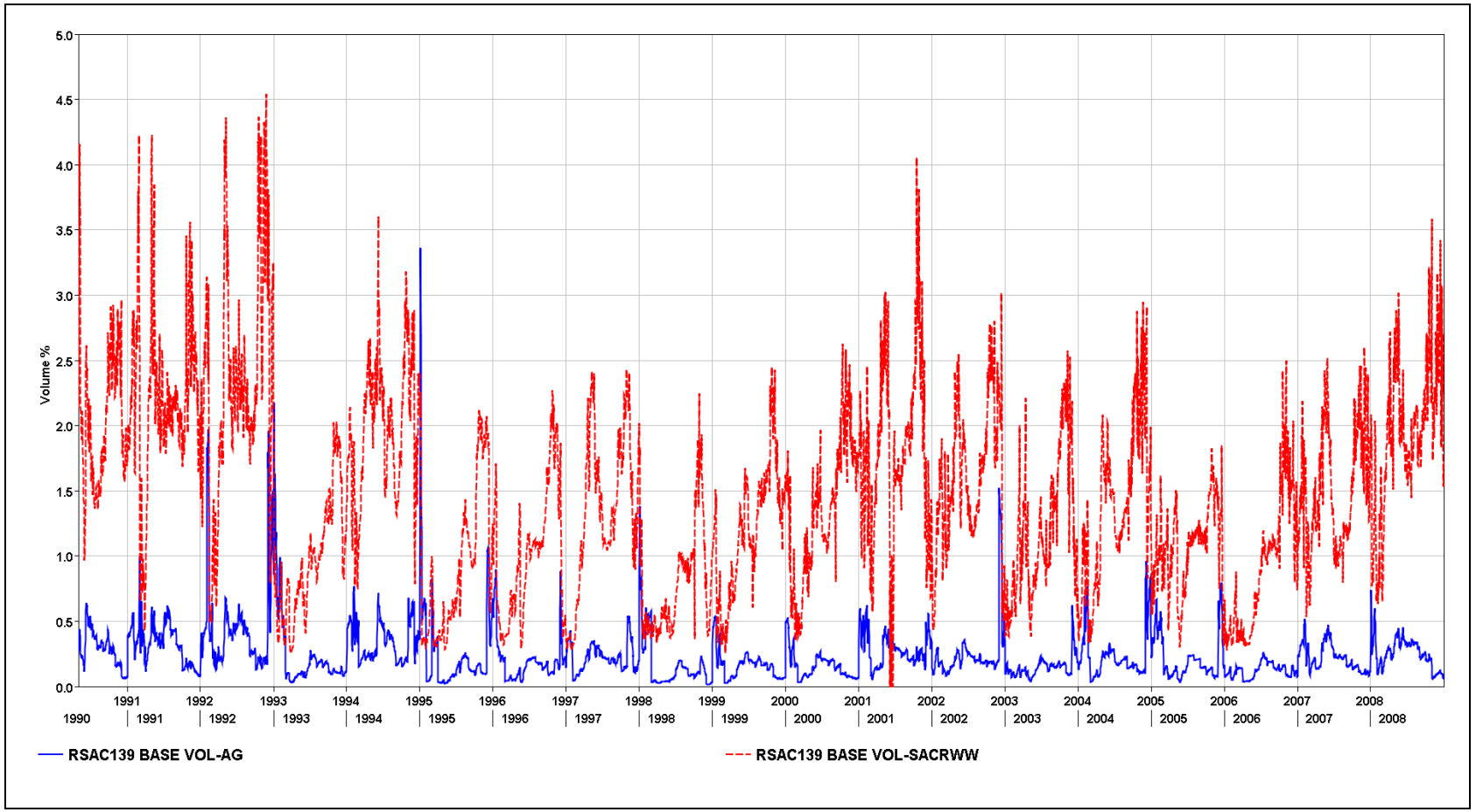


Figure 13-1 Ag and Sac Regional effluent volumes at Greene's Landing.

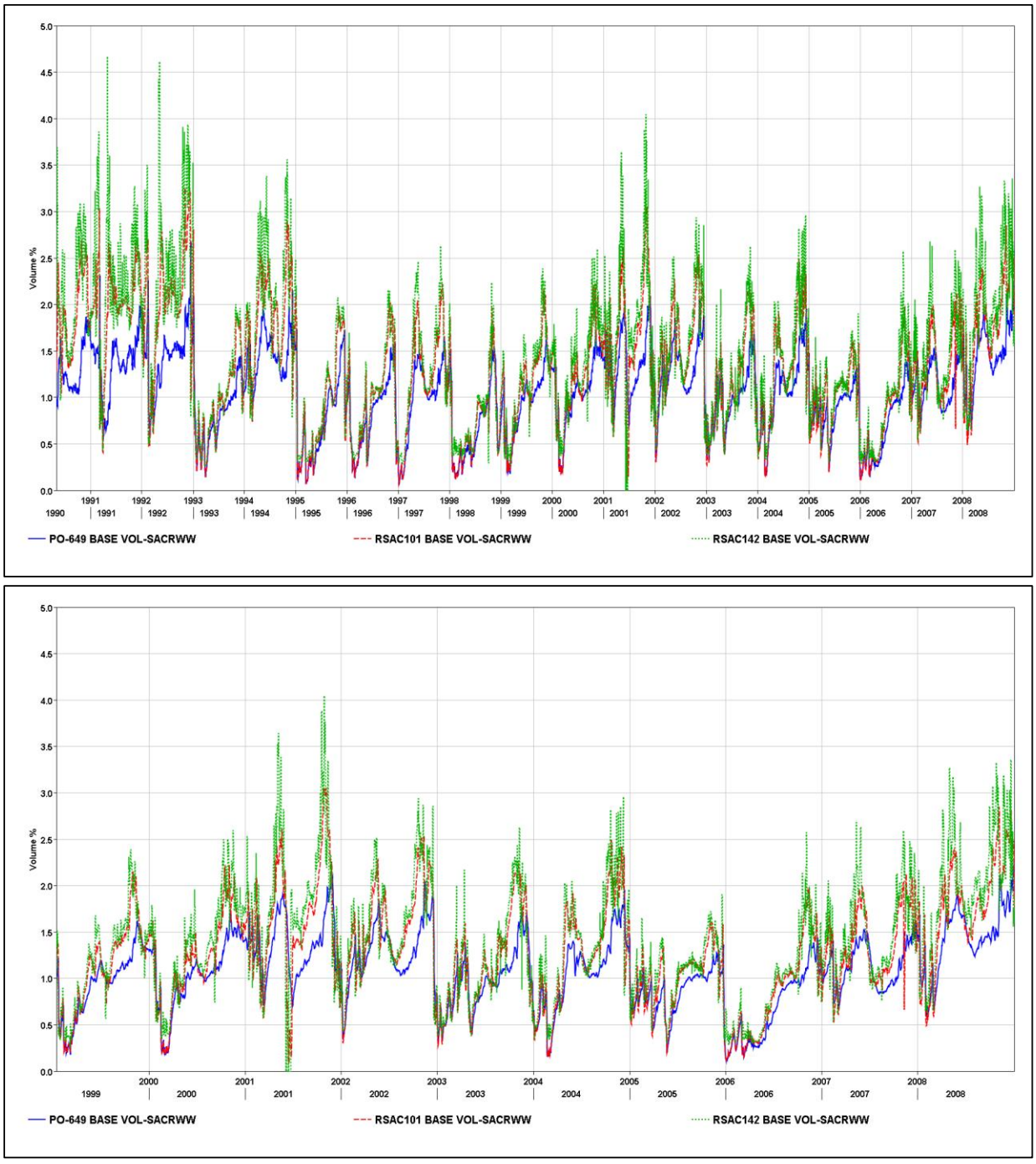


Figure 13-2 Sac Regional effluent volumes along the Sacramento River.

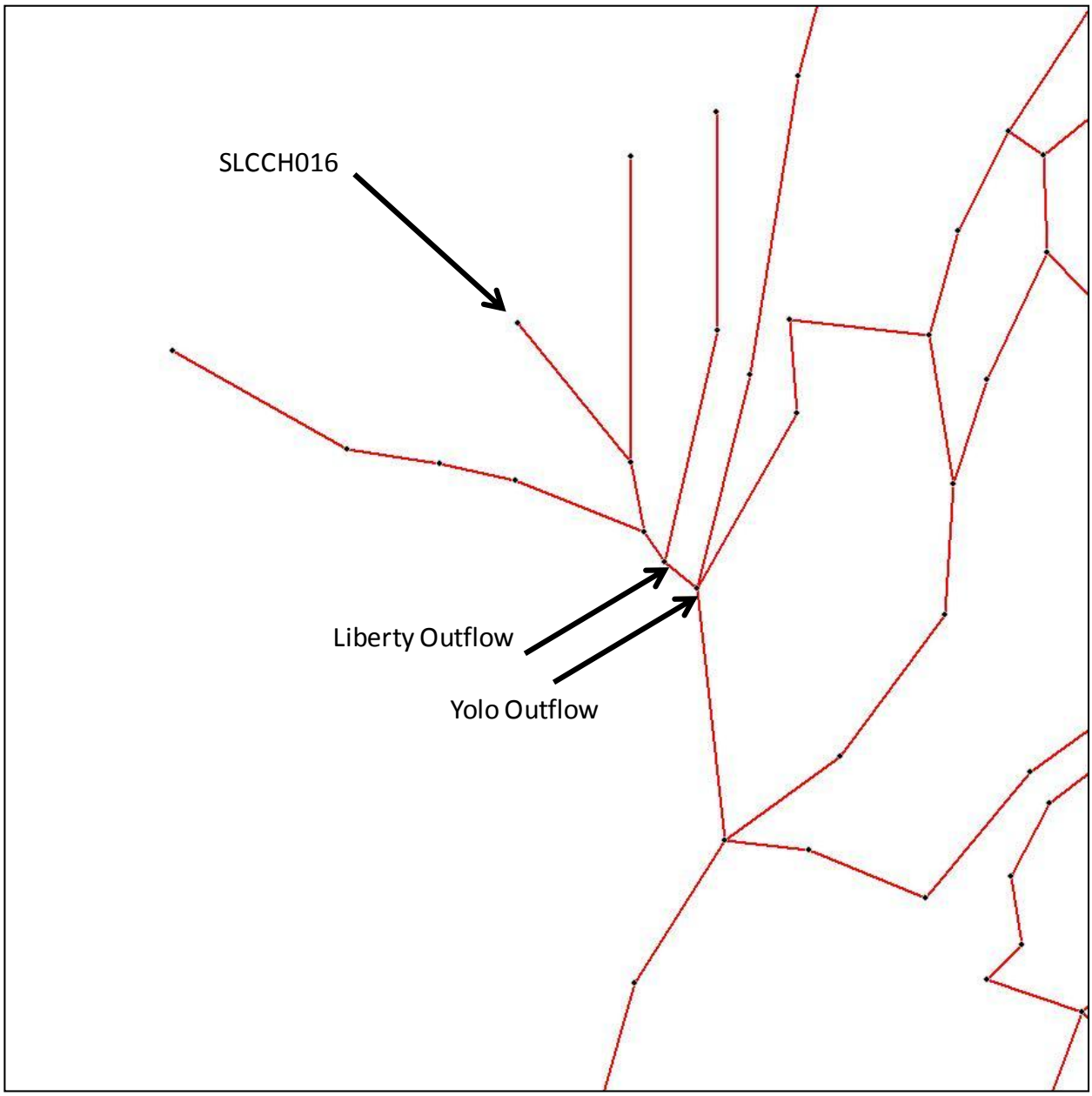


Figure 13-3 Three output locations in the DSM2 grid used to study the effects of a flooded Liberty Island.

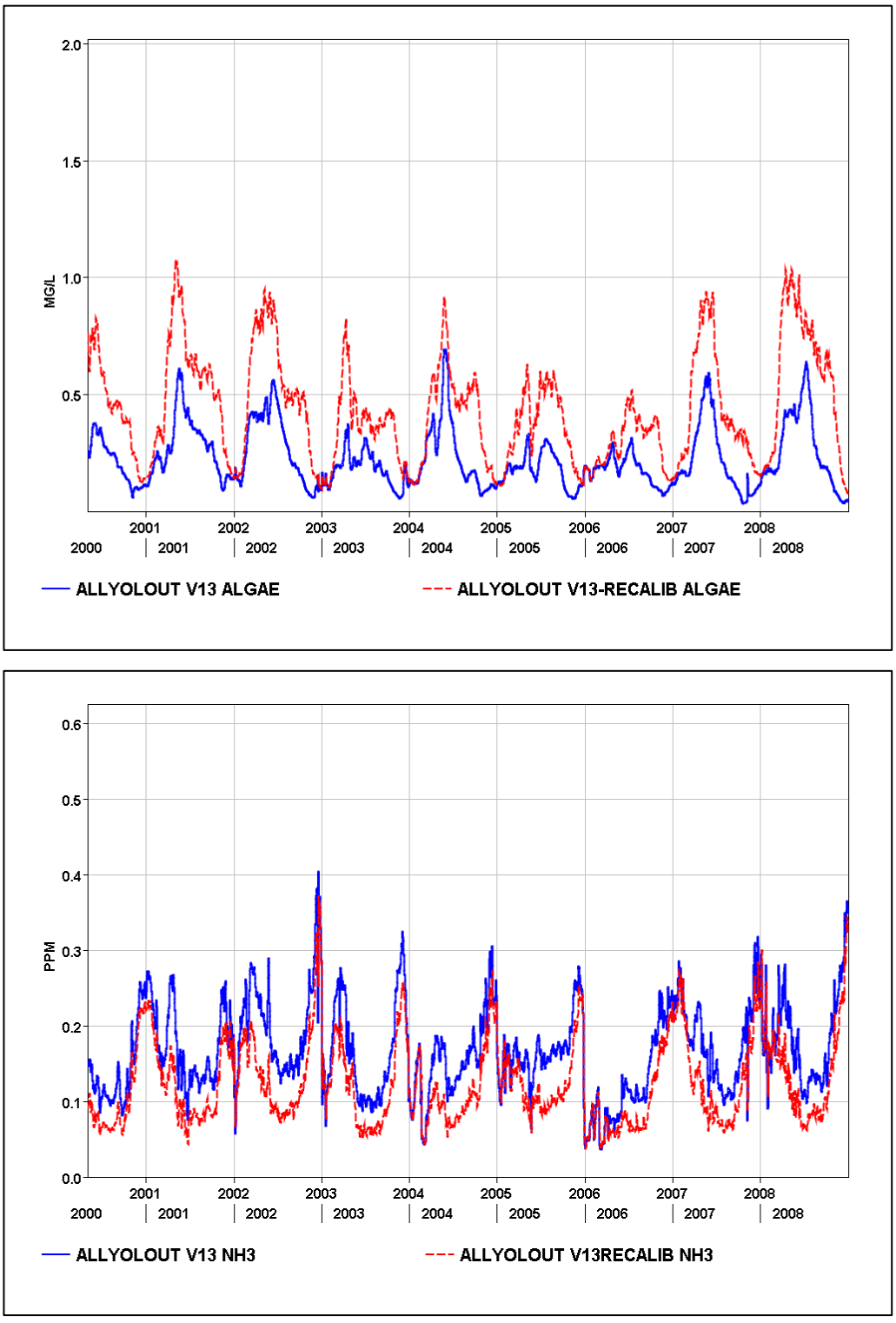


Figure 13-4 Algal biomass and ammonia concentrations at the Yolo location for Base and Liberty grids.

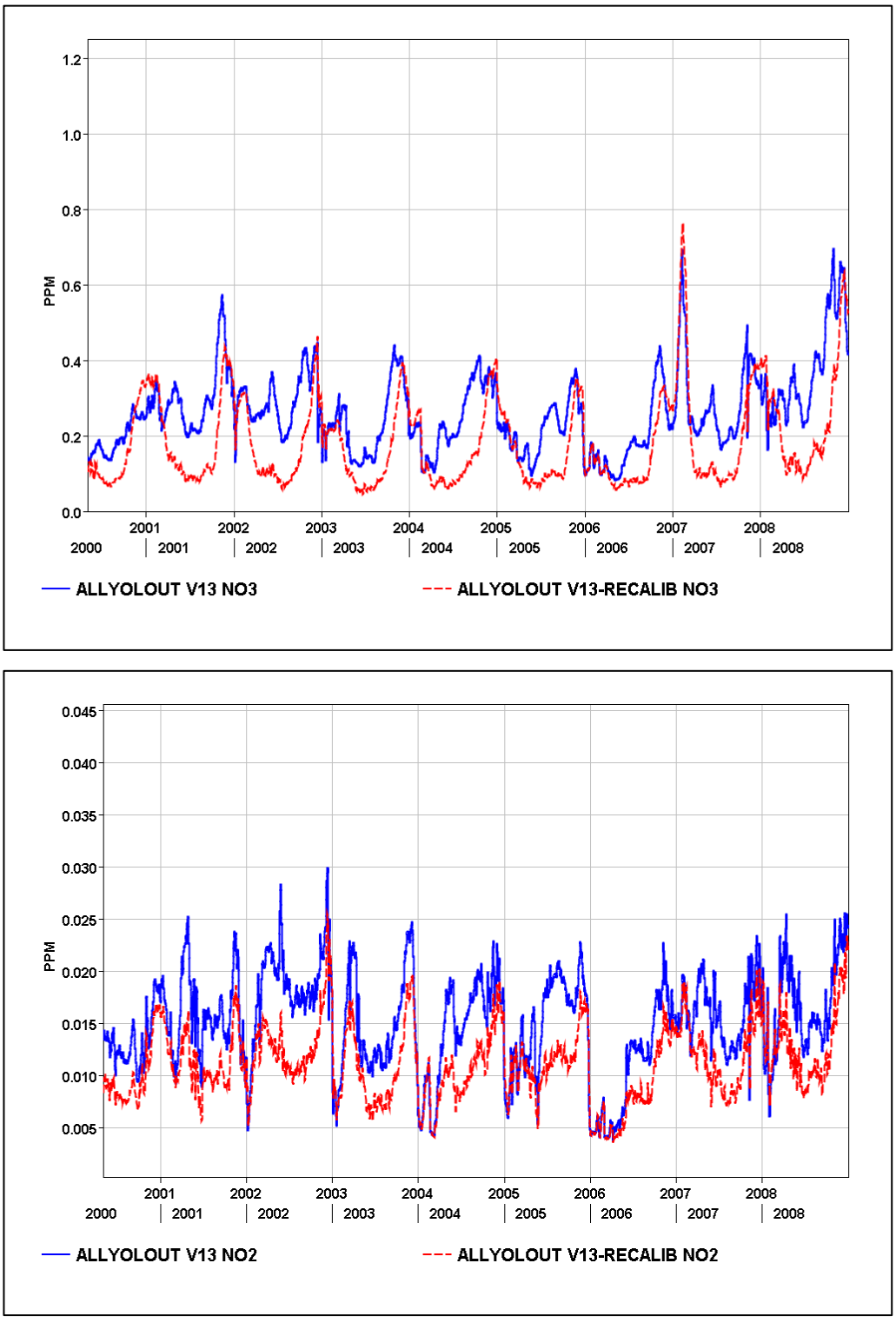


Figure 13-5 Nitrate and nitrite concentrations at the Yolo location for Base and Liberty grids.

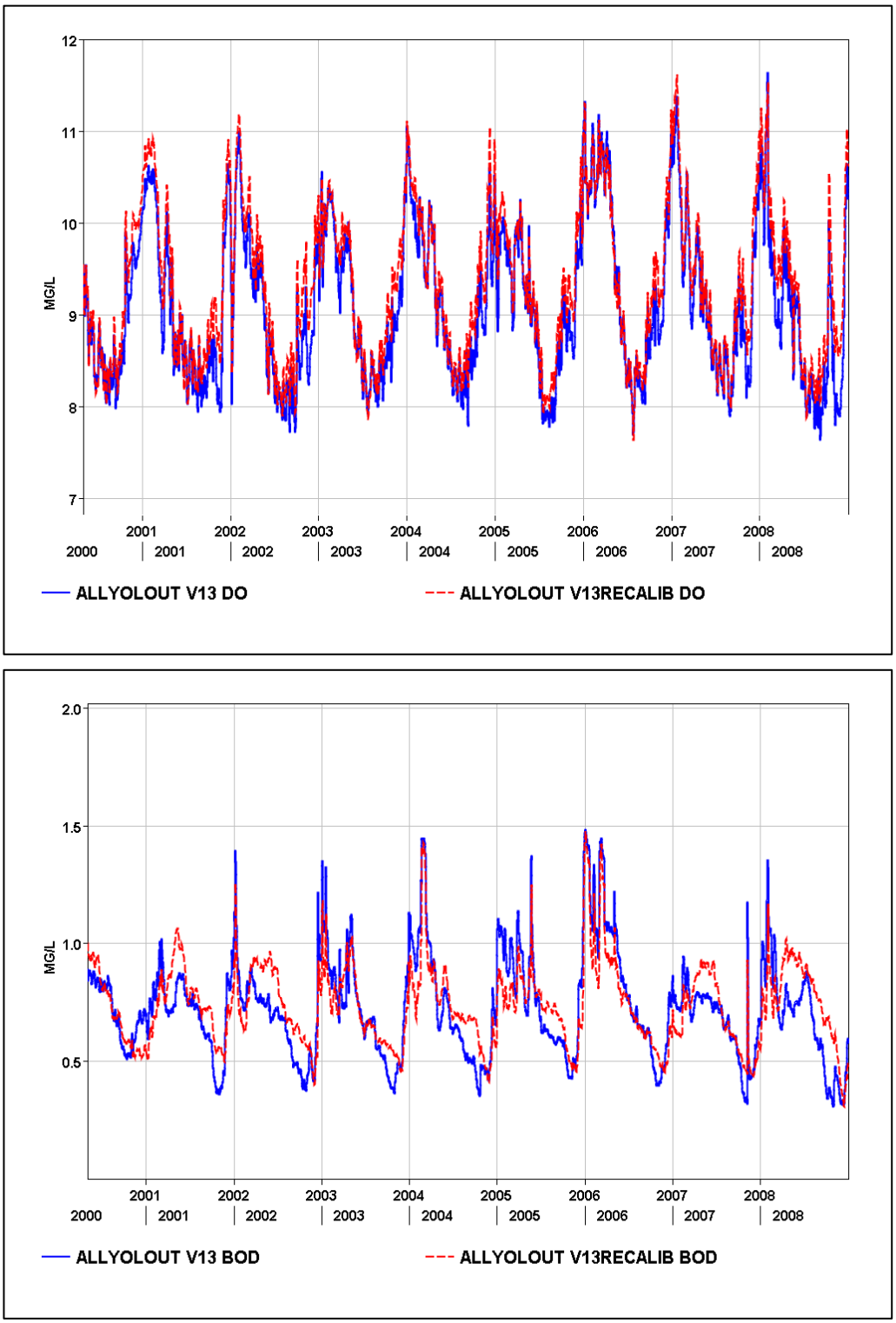


Figure 13-6 DO and CBOD concentrations at the Yolo location for Base and Liberty grids.

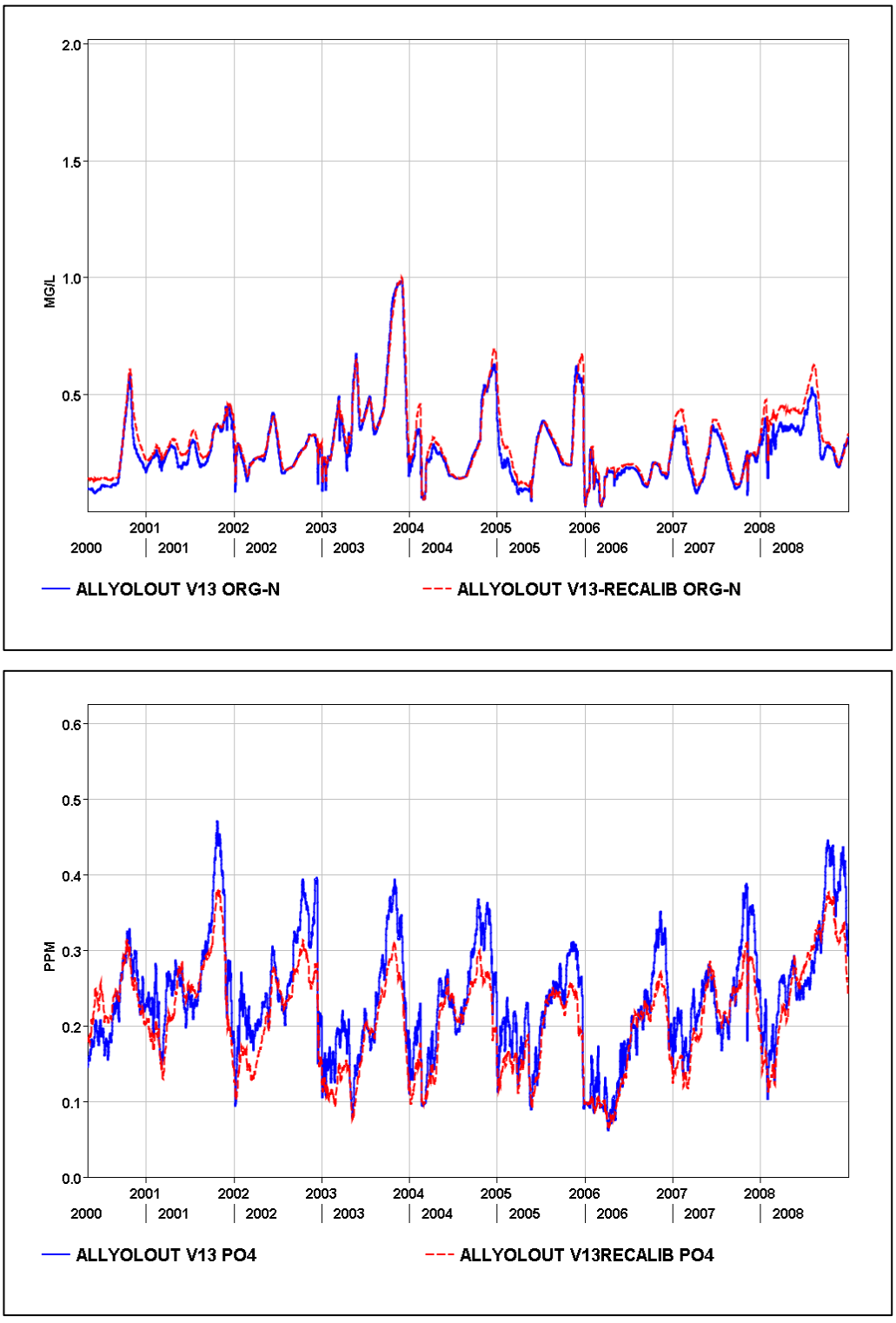


Figure 13-7 Organic-N and PO_4 concentrations at the Yolo location for Base and Liberty grids.

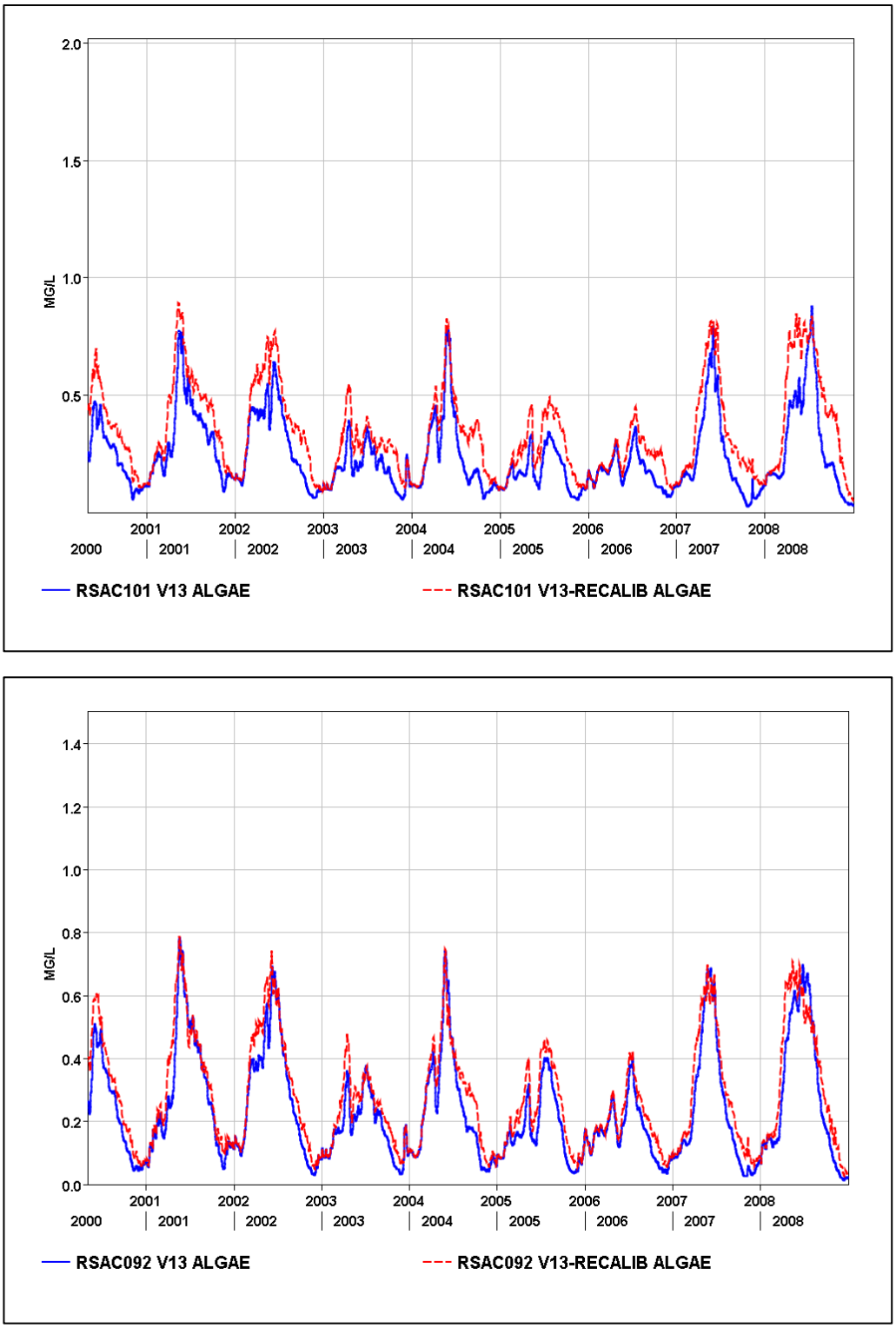


Figure 13-8Algal biomass at RSAC101 and RSAC092 for Base and Liberty grids.

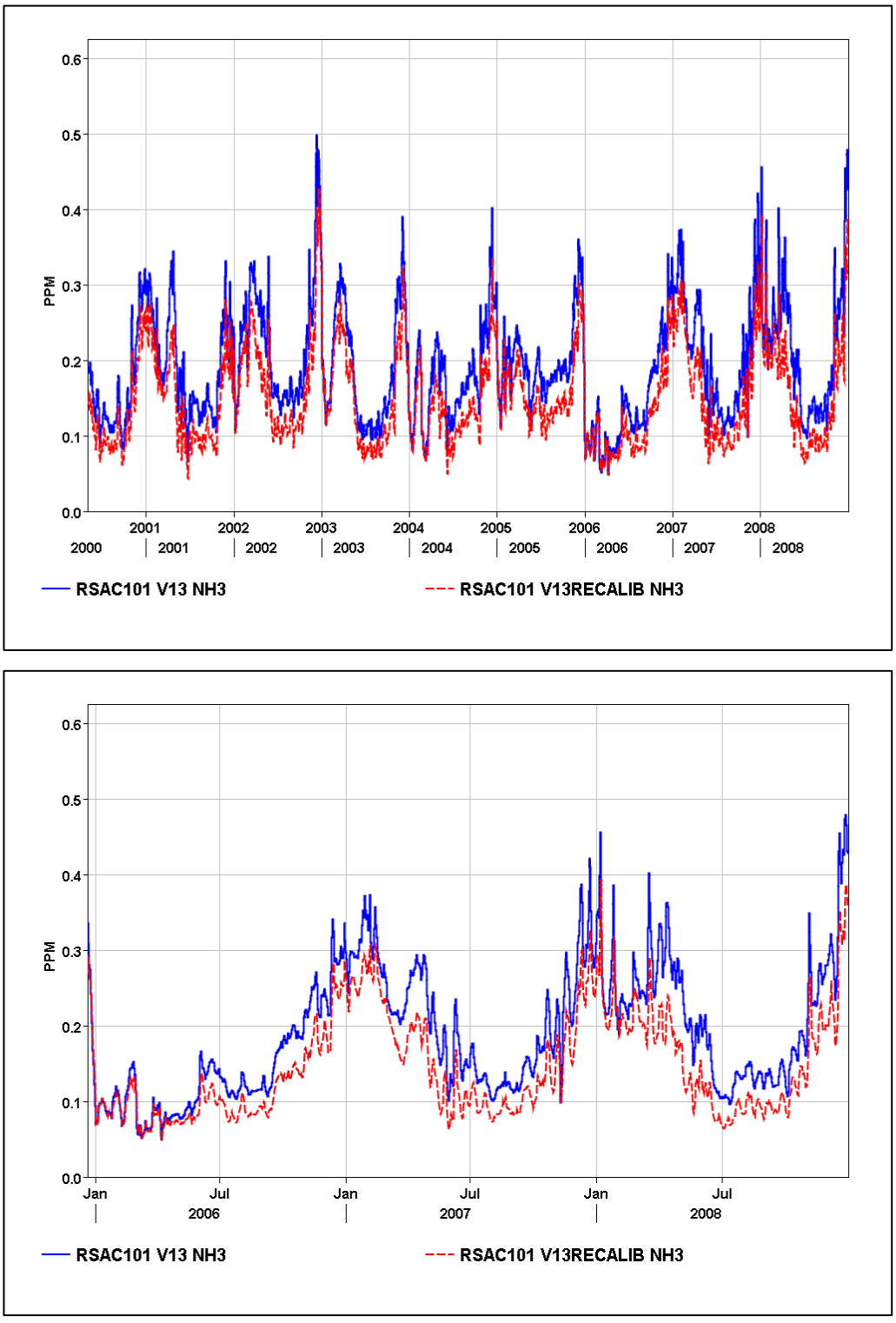


Figure 13-9 Ammonia at RSAC101 for Base and Liberty grids.

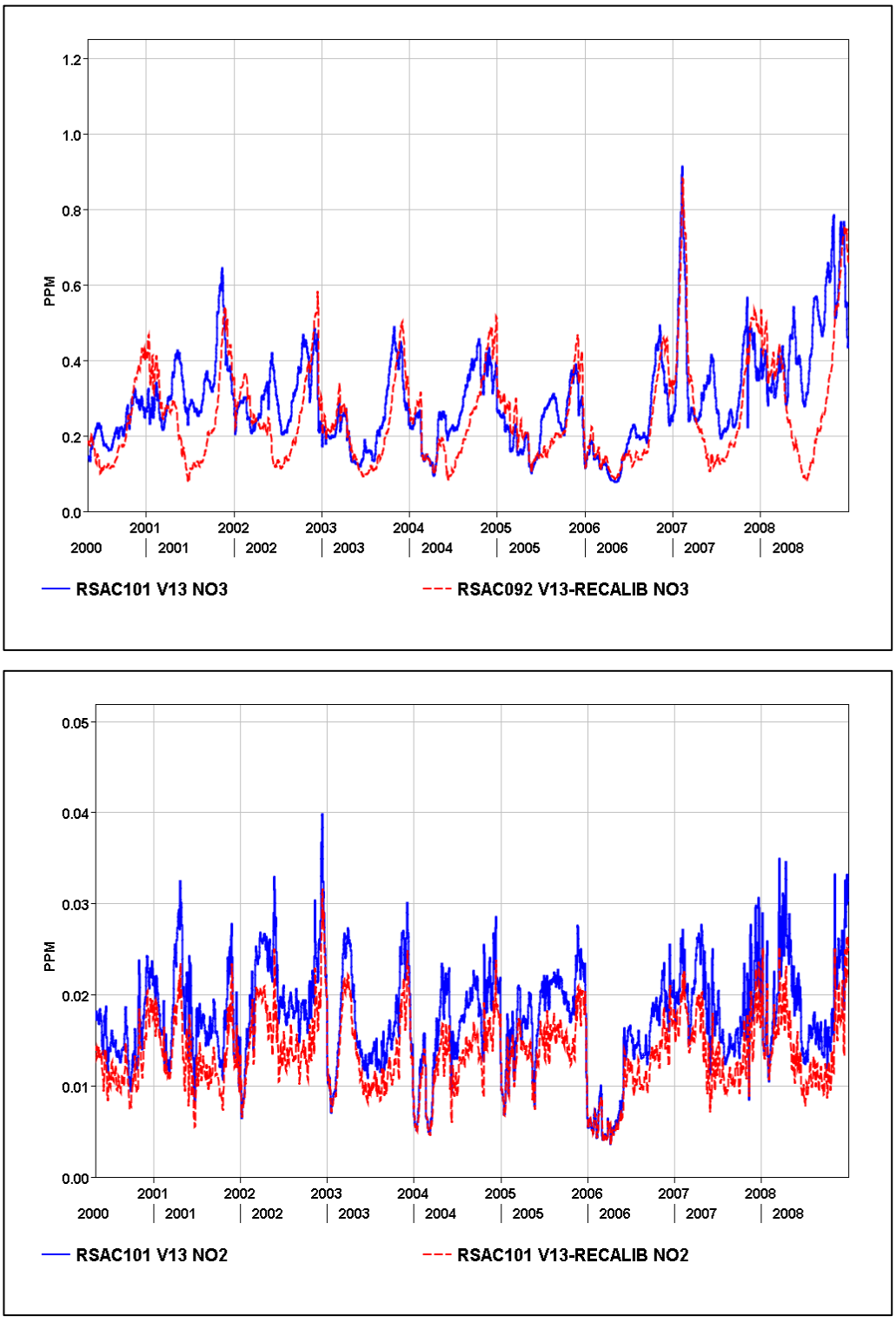


Figure 13-10 Nitrate and nitrite at RSAC101 for Base and Liberty grids.

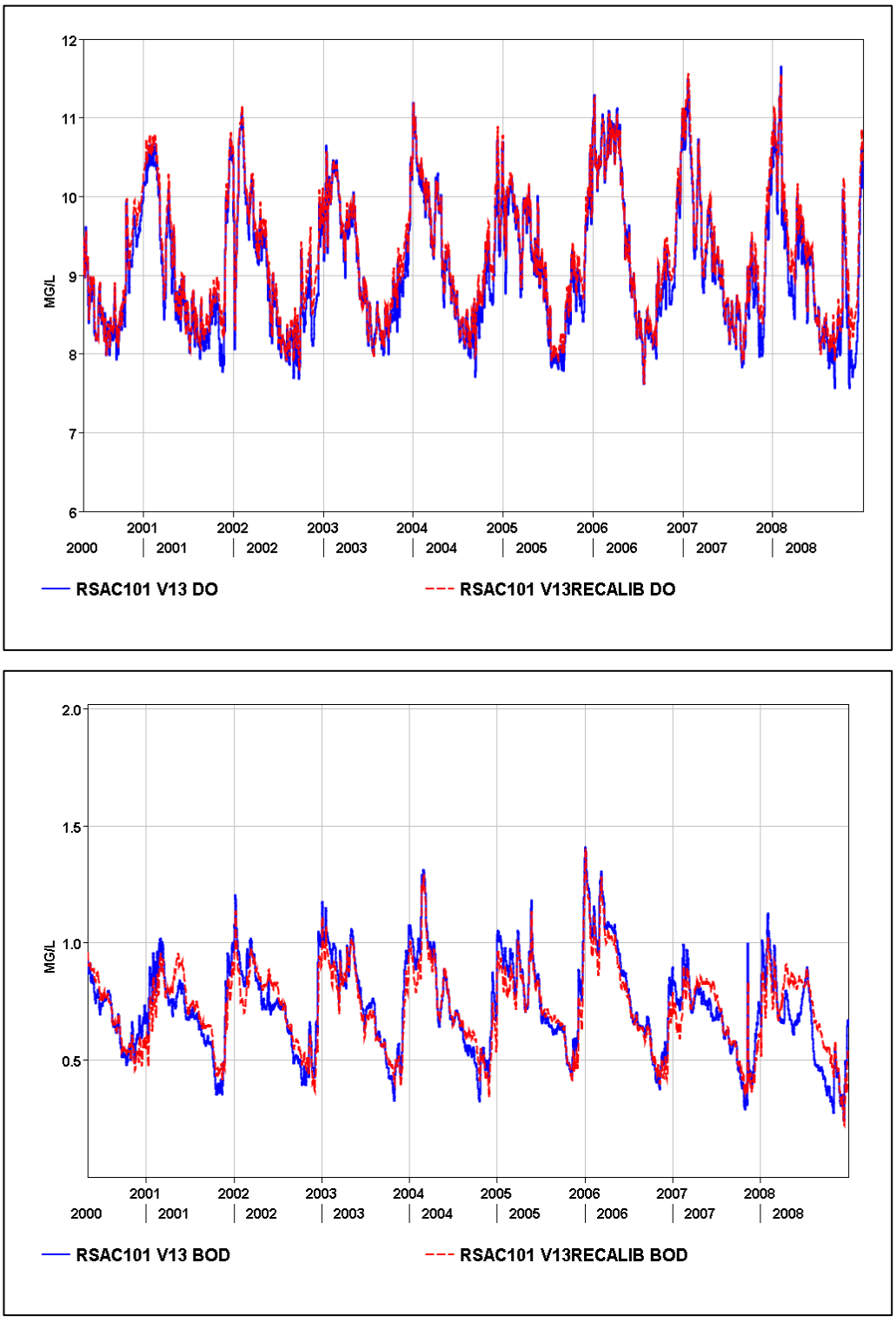


Figure 13-11 DO and CBOD at RSAC101 for Base and Liberty grids.

14 Jones Tract Modeling

A levee on the southwest side Upper Jones Track failed on June 3rd, 2004 allowing water to flood both Upper Jones Tract and Lower Jones Tract to the north. After flooding, the exchange of water and nutrients between the submerged island and Middle River continued until the breach was filled. Subsequently the water was pumped out of both Upper and Lower Jones Tract into Middle River, delivering an interesting mixture of water quality constituents into Middle River. In the process of updating the QUAL nutrient model calibration for Version 8.0.6, nutrient concentrations for the flows involved in the 2004 Jones Tract levee break were developed.

Data was obtained (Ted Swift, MWQI, personal communication) as documented in Chapters 3.1 and 3.4 of a report entitled "Jones Tract Flood Water Quality Investigations" (Swift *et al.*, 2009). This data supplied most of the information needed for a set of boundary conditions.

The levee break is split into two main periods in DSM2 – the time from the levee break (June 3rd, 2004) until the break was closed (June 30th), and the pump-out period (June 12th through December 18th). Data availability for nutrients and temperature was mixed. Automated water quality sondes collected continuous data for part of this period at a couple of locations – these supplied a partial time series of 15-minute temperature and DO data. Before and after the sondes were operational, grab sample data was used to create the BC for all constituents. When data wasn't available, too sparse to create a decent time series, or questionable once water levels became very low in the island, constants were used as boundary conditions.

15 Lehman Data inclusion

In the original nutrient model calibration (1990 - 2008), the DSM2 grid did not include Liberty Island which flooded in 1998. In 2010, Liberty Island was included in the DSM2 grid (Chilmakuri, 2010). In DSM2, areas such as Liberty Island are set as open water "reservoirs", even though they are actually tidally influenced with changes in flooded area as the tidal cycle progresses. These reservoirs are thus conceptualized as fully mixed tank reactors. This simplification will be less valid as the area of the "reservoir" increases and the actual reactions due to tidal wetting and drying, tidal mixing and local changes in residence time depart from the simple tank calculation.

At the time that Liberty Island was initially included in the DSM2 grid, there was no data available to check the parameterization of the new area or to set inflow boundary concentrations influencing the region such as the Yolo Bypass inflow. Boundary conditions and model parameterization in the area in and around Liberty Island were based on calibration targets at Rio Vista and downstream.

Data was supplied by P. Lehman (personal communication) from DWR to use in checking the Historical nutrient model in Liberty Island. The comparison of that data with model results

calculated with Version 8.0.6 is covered in this section. The data was collected for a project that is discussed in (Lehman *et al.*, 2010). The reader is referred to that document for details about data collection and analysis methods (in the Methods section of the Lehman paper).

In brief, data was collected monthly from February 2004 to July 2005 from 4 locations within Liberty Island (see Figure 1 in the Lehman paper). Analysis data from water samples included several modeled constituents, NH_3, NO_3, chl-a and PO_4 (called Soluble-P in the Lehman data). On each sample date, data for these constituents from the four locations (labeled north, south, east and west in Figure 1 in Lehman's paper) were averaged for comparison with model output. These comparisons are shown in Figure 15-1 through Figure 15-3.

The comparisons show that the modeled constituents NH_3 and Organic-N in Liberty Island compare well with Lehman's data, Figure 15-1 and Figure 15-2 respectively, while modeled NO_3 and PO_4 (Soluble-P in Lehman's terminology) are too low by approximately a factor of two in comparison with data. The largest difference occurs in the magnitude of Algae where the DSM2 concentration of Algae is nearly an order of magnitude greater than Lehman's data. Lehman's chl-a data was converted to the modeled "Algae" constituent using the conversion factor between chl-a and Algae assumed in the DSM2 nutrient modeling (conversion factor is 67 g algae (dry weight)/mg chl-a).

After calibration, the Algal growth rate set in the Liberty Island parameterization was somewhat higher than the rates used for the other reservoirs and the same as rates used in many of the model channels. For example in other reservoirs, growths rates varied from 7 – 30% in comparison with the Liberty Island rate. The Liberty Island growth rate was about 30% higher than the growth rate used in Franks Tract, but only 7% higher than rates used in Mildred and Bethel Islands.

A more extensive analysis should also be undertaken to help define potential pitfalls with the conceptualization of Liberty Island as a fully mixed reservoir in DSM2. This analysis could include implementation of a nutrient model in a 2-D setting, such as the RMA11 nutrient model and also a brief literature review. Since Liberty Island is essentially at the model boundary (e.g., in comparison with Franks Tract) once the Yolo Bypass stops flowing, it could be that this simplification is causing problems with the parameterization of the "bed" of the reservoir. In particular, DSM2 parameters conceptualizing benthic releases of NH3, PO4 and benthic demand on DO may be overestimating Liberty Island interactions once the Yolo flows become very low. In DSM2 reservoirs such as Franks Tract and Mildred Island, benthic releases/interactions are mixed with Delta waters flowing through the Islands at each time step. In Liberty Island on the other hand, these mixing processes are muted due to its location near the model boundary. Finally, DICU contributes a source of nutrients that might be incorrectly estimated – resolving this question would require gathering additional information on agricultural sources of nutrient loads to this area in the DSM2 model domain.

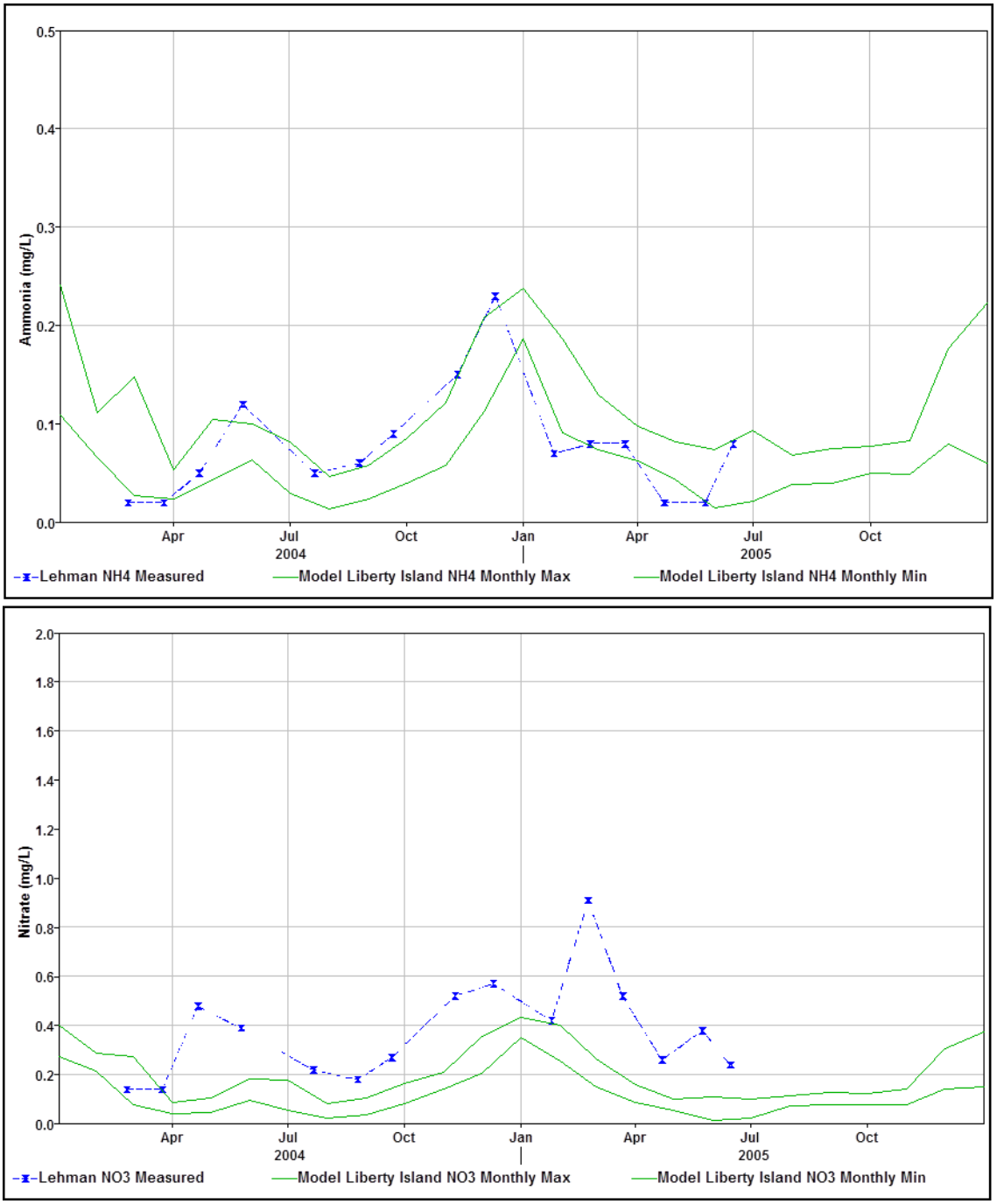


Figure 15-1 Comparison of data averaged from four locations in Liberty Island (Lehman et al., 2010) with DSM2 Historical nutrient model output for NH_3 and NO_3+NO_2. Model output is represented as the monthly MAX and MIN of the original 15-minute model output.

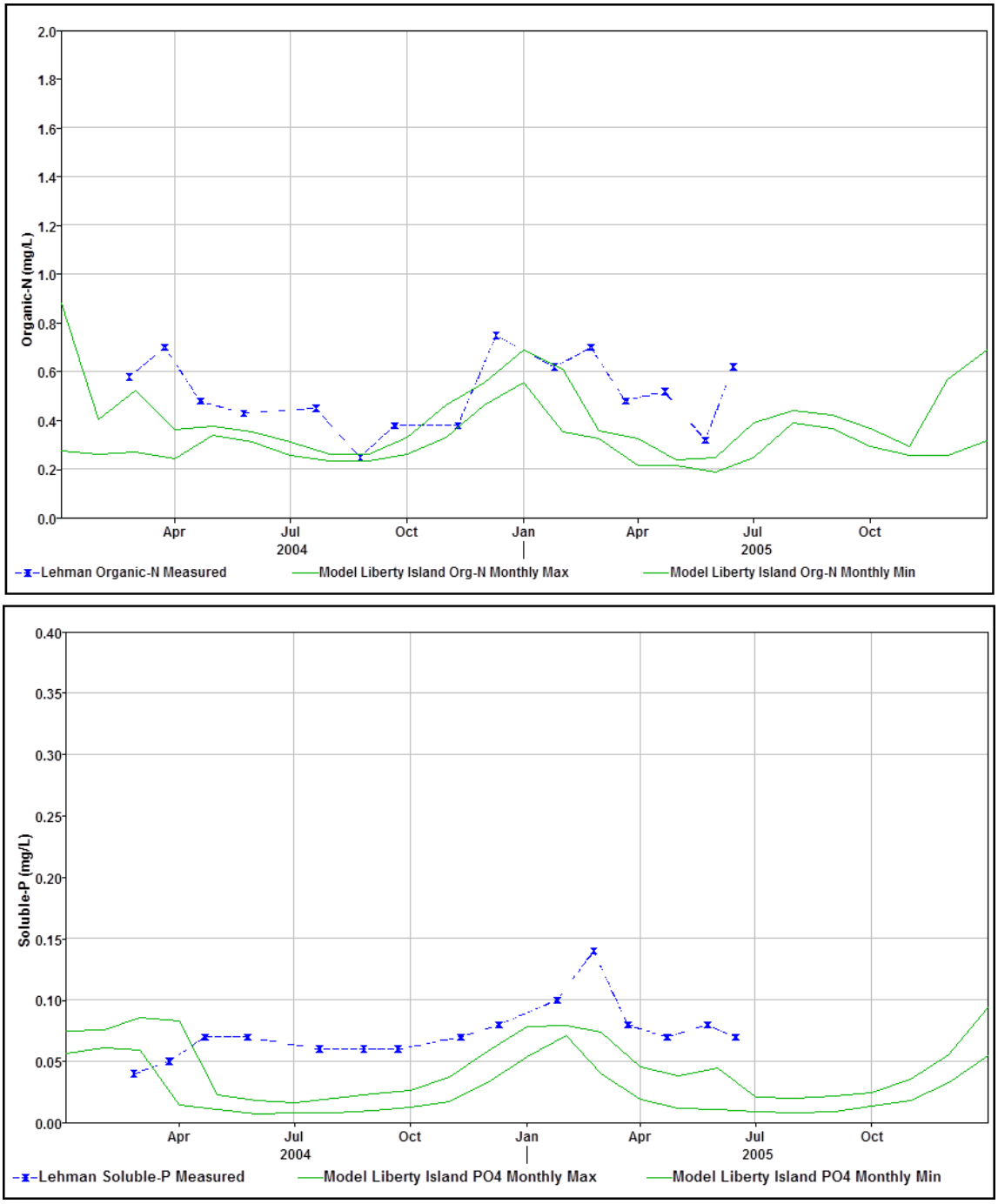


Figure 15-2 Comparison of data averaged from four locations in Liberty Island (Lehman et al., 2010) with DSM2 Historical nutrient model output for Organic-N and PO_4. Model output is represented as the monthly MAX and MIN of the original 15-minute model output.

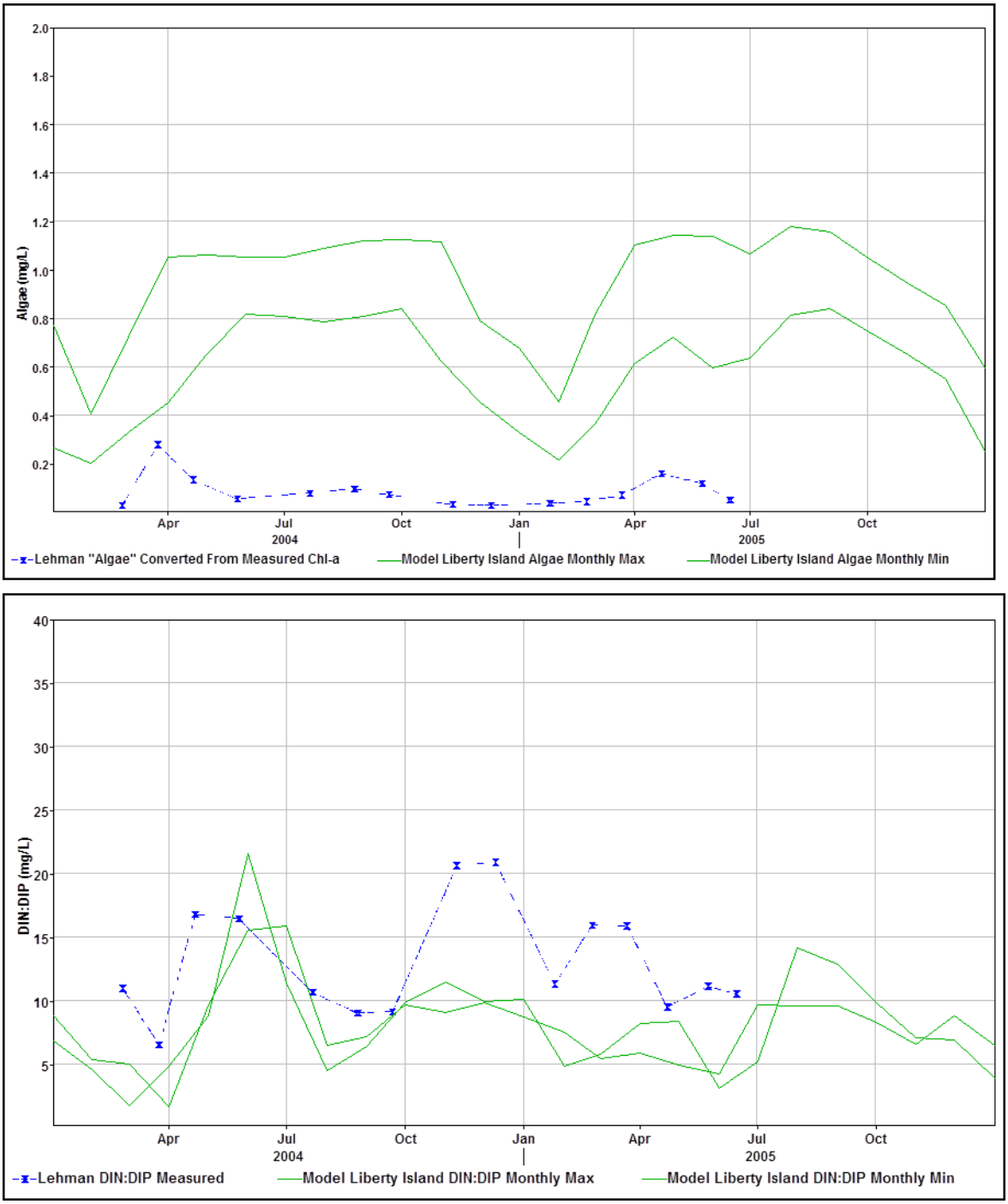


Figure 15-3 Comparison of data averaged from four locations in Liberty Island (Lehman et al., 2010) with DSM2 Historical nutrient model output for Algae (calculated using a conversion 67 g algae (dry weight)/mg chl-a) and DIN:DIP, where DIN=NO_3+NO_2+NH_3, and DIP=PO_4. Model output is represented as the monthly MAX and MIN of the original 15-minute model output.

16 Scenarios – Sensitivity to Changes in N-concentrations

Several scenarios were developed to test model sensitivity to changes (increases or decreases) in the concentration of N-constituents – changes to DICU, changes to Sacramento or San Joaquin boundary, Sac Regional or Stockton WWTP, and a change on Sac Regional process to nitrification. Model output locations described in the scenarios are documented in Figure 18-1 through Figure 18-4. Not all locations have corresponding figures in the text below. Results are summarized as monthly percent change from Base in each section. Figures illustrating results are found at the end of this section, and also in Appendix I Section 25.10. These analyses generally changed the concentration of all of the N-constituents by +/- 20%, except where noted.

Boundary conditions for all constituents, including N-constituents, were set as hourly, daily, monthly or constant inputs during model development. The choice was dictated for each constituent by data availability, magnitude of constituent concentration and the sensitivity of the model calculations to changes in timing and magnitude. The sensitivity results below test the response of the model to changes in the suite of N-constituents.

16.1 Increase/decrease DICU N-constituents

To test the sensitivity of model results to changes in N-constituent concentrations at the DICU boundaries, two scenarios were run in which the constant NO_3, NO_2, NH_3 and organic-N boundary concentrations were increased or decreased by 20%.

Changes in nutrient concentrations due to changes in DICU boundary condition concentrations were extremely small along the Sacramento River corridor and in the north Delta, and nearly undetectable in general on a monthly-averaged basis. This is illustrated in Figure 25-85 and Figure 25-86. Nitrate changes were the largest – there were small changes (increases and decreases) in PO_4 and DO in response to nutrient dynamics due to changes in N-constituents. Results are summarized as average monthly percent change from Base, although the symbols + or – were used for increase or decrease, respectively, when numerical changes were too small to record.

During dry periods, the effects were small but noticeable along the San Joaquin River, mainly upstream of Antioch (Figure 25-87). Changes in ammonia and nitrate increased somewhat at upstream locations (Figure 25-88 through Figure 25-91). Changes are most noticeable where DICU flow contributions are greatest, mainly in periods of low boundary inflow during Dry and Critically Dry Water Years.

Table 16-1Average monthly percent change from Base Historical model (+/- 20% change in DICU N-constituents). Symbols + or – used for increase or decrease, respectively, when numerical changes were too small to record.

	Algae	NH3	NO3	NO2	Org-N	PO_4/DO
Increase DICU-N						
RSAC101	+ 1 – 4 %	+ 1 – 4 %	+ 3 – 7 %	+ 1 – 4 %	0 %	+/+and-
RSAN037	+ 0 – 3 %	+ 2 – 6 %	+ 2 – 6 %	+ 2 – 6 %	+ 0 %	+and-/+and -
RSAN018	+ 2 – 7 %	+ 3 – 8 %	+ 3 – 6 %	+ 3 – 8 %	0 %	+/+and-
Decrease DICU-N						
RSAC101	-(0 – 3) %	- (0 – 1) %	-(0 – 1) %	-(0 – 1) %	0 %	+/+
RSAN037	-(0 – 3) %	- (2 – 6) %	-(2 – 5) %	-(2 – 6) %	-0 %	+and -/+and -
RSAN018	-(0 – 3) %	- (1 – 4) %	-(1 – 3) %	-(1 – 4) %	0 %	+/+and-

16.2 Increase/decrease N-constituents at the Sacramento Boundary

To test the sensitivity of model results to changes in N-constituent concentrations at the Sacramento R. boundary, scenarios were run in which NO_3, NH_3 and organic-N concentrations were increased or decreased by 20%. NO_2 concentration was not changed as it was very low and constant. Results are summarized as percent change from Base below for three downstream locations.

At Isleton on the upstream end of the Sacramento R., no changes were seen in algae dynamics (Figure 25-92) – these also held true for downstream locations (Figure 25-93). For N-constituents, changes were moderate and largest for nitrate (Figure 25-94 through Figure 25-96). Similar results were seen at Georgiana Slough (Figure 18-5 and Figure 18-6). Nitrite concentration changes were largest in drier years, while nitrate concentrations were largest in wetter years indicating that decay into nitrite and algal consumption of nitrate were noticeably concentration and temperature-dependent. Changes in organic-N persisted downstream, as the boundary contributes most of the organic-N along the Sacramento corridor.

Changes at Potato Point were still quite noticeable (Figure 18-7 through Figure 18-9). They decreased for ammonia and nitrite at Antioch, but still remained quite noticeable for nitrate (Figure 25-97 through Figure 25-99). Nitrite changes are due to decay of ammonia. There were essentially no changes in PO_4 and DO. Differences between drier and wetter year types were greatest for nitrate.

Table 16-2Average monthly percent change from Base Historical model (+/- 20% change in Sacramento boundary N-constituents)

	Algae	NH3	NO3	NO2	Org-N
Increase Sac River-N					
RSAC101	+ 0 – 2 %	+ 3 –6 %	+ 9 – 15 %	+ 3 –6 %	+ 16 – 18 %
PO649	+ 0 – 6 %	+ 3 – 6 %	+ 7 – 12 %	+ 3 – 6 %	+ 14 – 17 %
RSAN018	+ 0 – 7 %	+ 3 – 5 %	+ 6 – 9 %	+ 3 – 5 %	+ 11 – 16 %
Decrease Sac River-N					
RSAC101	-(0 – 2) %	- (4 –6) %	-(9 – 14) %	-(3 –6) %	-(16 – 18) %
PO649	-(0 – 6) %	- (3 – 6) %	-(7 – 12) %	-(3 – 6) %	-(14 – 17) %
RSAN018	-(0 – 7) %	- (3 – 5) %	-(6 – 9) %	-(3 – 5) %	-(11 – 16) %

16.3 Increase/decrease N-constituents at the San Joaquin Boundary

To test the sensitivity of model results to changes in N-constituent concentration at the San Joaquin R. boundary, two scenarios were run in which NO_3, NH_3 and organic-N were increased or decreased by 20%. NO_2 concentration was not changed to maintain similarity with Sacramento R. boundary changes.

Concentration changes were relatively minor except for changes in NO_3. Nitrate concentrations are variable on the SJR past Jersey Point (RSAN018) during higher SJR flow conditions. This is illustrated in Figure 18-10, Figure 25-100 and Figure 25-101. Results are summarized below as percent change from Base for two downstream locations.

Table 16-3 Average monthly percent change from Base Historical model (+/- 20% change in San Joaquin boundary N-constituents). Symbols + or – used for increase or decrease, respectively, when numerical changes were too small to record.

	Algae	NH3	NO3	NO2	Org-N	PO_4/DO
Increase SJR-N						
RSAN037	+ 0 - 1 %	+ 0 – 4 %	+ 0 – 16 %	+ 0 – 4 %	+ 0 – 12 %	+and-/+and-
RSAN018	+ 0 – 3 %	+ 0 – 2 %	+ 0 – 9 %	+ 0 – 1 %	+ 0 - 5 %	+and-/+and-
Decrease SJR-N						
RSAN037	- (0 – 2) %	- (0 - 4) %	-(1 - 16) %	-(0 - 4)%	-(0 - 12) %	+and-/+
RSAN018	-(0 - 3) %	- (0 - 2) %	-(0 - 9) %	-(0 - 2) %	-(0 - 5) %	+/+and-

16.4 Increase/decrease N-constituents in Sac Regional Effluent

To test the sensitivity of model results to changes in N-constituent concentration at the Sac Regional WWTP effluent boundary, two scenarios were run in which NO_3, NO_2, NH_3, and organic-N were increased or decreased by 20%. Results are summarized as percent change from Base below for three downstream locations.

The changes in N-constituent concentration downstream of the Sac Regional WWTP were large and sustained along the Sacramento R. corridor to Suisun Bay. Ammonia and nitrite concentrations showed the largest shifts – nitrite is produced as ammonia decays. Changes in the dynamics of the other constituents, organic-N, chl-a/algae and DO, were minor and sporadic, but also extended down to Suisun Bay in periods where there were detectable changes in concentration. There was essentially no change in the concentration of PO_4.

The changes in constituent concentrations along the Sacramento R. from Isleton to Suisun Nichols are documented in Figure 18-11 through Figure 18-15 and Figure 25-102 through Figure 25-111. Small increases in algal growth with increased effluent N-concentrations appear with increasing distance from the Sac Regional outfall along the Sacramento R. main stem. Decreases in effluent-N resulted in small decreases of algal growth. Changes in constituent concentrations are seen at other locations receiving Sac Regional wastewater- Jersey Point (Figure 25-106 and Figure 25-107), Georgiana Slough (Figure 25-108 and Figure 25-109), and at Potato Point

(Figure 25-110 and Figure 25-111). Results are summarized below for three downstream locations.

Organic-N changes are small, as contributions are dilute in comparison with the Sacramento boundary inputs. Changes were most extreme during drier years for algae, ammonia and nitrate.

Table 16-4Averagemonthly percent change from Base Historical model (+/- 20 % change in Sac Regional effluent N-constituents)

	Algae	NH3	NO3	NO2	Org-N
Increase SRWWTP-N					
RSAC101	+ 0 – 2 %	+ 13 – 16 %	+ 2 – 11 %	+ 12 – 16 %	+ 1 – 4%
PO649	+ 0 – 7 %	+ 9 – 13 %	+ 4 – 12 %	+ 9 – 13 %	+ 1 – 4%
RSAN018	+ 0 – 9 %	+ 9 – 13 %	+ 4 – 11 %	+ 9 – 13 %	+ 1 – 4%
Decrease SRWWTP-N					
RSAC101	-(0 – 3) %	- (14 – 16) %	-(3 – 11) %	-(12 – 16) %	-(1 – 4) %
PO649	-(0 – 8) %	- (9 – 13) %	-(4 – 11) %	-(9 – 13) %	-(2 – 4) %
RSAN018	-(0 – 10) %	- (8 – 13) %	-(4 – 11) %	-(9 – 14) %	-(1 – 4) %

16.5 Increase/decrease Sac Regional Effluent Volume

To test the sensitivity of model results to changes in N-constituent concentration at the Sac Regional WWTP effluent boundary, the volume of effluent was increased or decreased by 20%. The results for N-constituent concentration were for all practical purposes indistinguishable from the +/- 20% change in N-constituent concentration (Section 16.4), so results are not included here.

16.6 Increase/decrease N-constituents at Stockton WWTP Boundary

To test the sensitivity of model results to changes in N-constituent concentration at the Stockton WWTP effluent boundary, two scenarios were run in which NO_3, NO_2, NH_3, and organic-N were increased or decreased by 20%.

The results show that the changes to N-constituent concentration, DO and algae are minor along the San Joaquin River downstream of the WWTP, and do not extend past Twitchell (RSAN024) in any appreciable degree (Figure 18-16, Figure 18-17, and Figure 25-112 through Figure 25-114). Results are summarized below for two downstream locations.

Table 16-5Averagemonthly percent change from Base Historical model (+/- 20% change in Stockton WWTP N-constituents). Symbols + or – used for increase or decrease, respectively, when numerical changes were too small to record.

	Algae	NH3	NO3	NO2	Org-N	PO_4/DO
Increase Stockton-N						
RSAN037	+ 0 %	+ 0 – 4 %	+ 0 – 3 %	+ 0 – 4 %	+ 0 – 2 %	+/-
RSAN018	+ 0 – 1 %	+ 0 – 1 %	+ 0 – 2 %	+ 0 – 1 %	+ 0 - 1 %	+and-/+and-
Decrease Stockton-N						
RSAN037	- 0 %	- (0 - 4) %	-(0 - 3) %	-(0 - 4)%	-(0 - 2) %	+/+
RSAN018	-(0 - 3) %	- (0 - 2) %	-(0 - 9) %	-(0 - 2) %	-(0 - 5) %	+/+and-

16.7 Summary of Sensitivity Scenarios

Generally, increases and decreases in N-constituent concentrations were mirrored in percent change in monthly concentrations - i.e., increases and decreases were generally of the same magnitude within 1 – 2 %, the only difference being the difference in sign. The two exceptions to this are the DICU and Stockton WWTP scenarios – in these cases, during periods of low flow the nutrient dynamics were no longer symmetric (positive and negative differed between the scenarios).

As the N-constituents were all varied at once, it is difficult to separate out specific effects. Downstream of the Sacramento and San Joaquin boundaries, nitrification was evident in the change in nitrite concentration as that N-constituent wasn't varied. In general, increasing N-constituents resulted in increased algal biomass, while decreasing N-constituents resulted in a decrease in algal biomass.

17 Scenario: Modify Sac Regional WWTP Process for Nitrification

A scenario was developed to test the downstream consequences for Delta nutrient dynamics of a change to a nitrification wastewater treatment process at SAC Regional WWTP. Stockton and Tracy WWTPs had each switched their treatment processes to nitrification, so the changes in their effluent concentrations were used as a guide to develop a reasonable set of effluent conditions. In both plants, the changes to CBOD, NO3, NH3, and organic-N concentrations were quite substantial.

For the scenario, the original Sac Regional effluent flows were maintained and only constituent concentrations were changed. The NH_3 concentrations were decreased by multiplying by a factor of 0.04, the NO_3, concentrations were increased by multiplying by a factor of 15, the organic-N concentrations were cut in half, and the CBOD concentration was multiplied by a factor of 0.23.

The results for this scenario present a complicated picture of the dynamics resulting from the change in the effluent boundary. As expected, there is a large decrease in ammonia – there is also a substantial increase in nitrate concentrations at all downstream locations, although this happens mainly in the winter months. There is a relatively small increase in DO and a decrease in algal biomass, with a few exceptions where biomass may increase for a year or two (Figure 25-121 and Figure 25-124). Nitrite shows large decreases at all locations which are apparently linked to the ammonia decrease as decay is no longer a factor in nitrite production. The decrease in organic-N is minor.

In some cases, there is a shift in the timing of high points and low points in concentration (e.g., Figure 25-116 and Figure 25-128) particularly for nitrate. Algal biomass is nearly unchanged at some locations during Wet Water Years (Figure 25-121).

Results are summarized below (Table 17-1 through Table 17-6) for three downstream locations (RSAC101~Rio Vista, Pt. Sacramento, and RSAN018~Jersey Point) as percent change from Base (Base being the Historical model) as a monthly average for each month, and separated by Water Year type.

Change from Base for Algal growth resulted in substantial decreases in the concentration of Algal biomass which were the largest in magnitude during the summer months (Table 17-1, Table17-3, and Table17-5, top section in each). Ammonia concentration decreased somewhat during this same period in comparison with Base (lower section of (Table 17-1, Table17-3, and Table17-5). Nitrite concentration changed substantially at all locations, while nitrate concentration showed quite noticeable change at Rio Vista, increasing in concentration in the winter months in all Water Year types and decreasing in concentration in the drier years in the summer. Many of these changes can be linked to the decrease in ammonia in the effluent – algal growth decreased as there was less ammonia available for algal growth. In the summer months, the nitrate concentrations decreased in comparison with Base as there was less conversion of ammonia to (nitrite to) nitrate.

Table 17-1 Results from nitrification scenarios at RSAC101 (chl-a/algae and ammonia).

Percent Change from Base Due to Sac Regional Switch to Nitrification

RSAC101 Algae	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Average	-0.75	-0.45	-0.33	-0.57	-2.25	-6.85	**-11.08**	-8.29	-3.84	-3.61	-4.14	-2.61
Average Dry+Critical	-1.22	-1.11	-0.74	-1.13	-4.05	**-11.23**	**-17.42**	**-13.22**	-3.04	-7.08	-6.12	-3.95
Average Wet+AbvNormal	-0.32	-0.03	-0.08	-0.18	-0.72	-2.87	-4.13	-4.24	-4.38	-2.14	-3.38	-1.92
RSAC101 NH_3	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Average	-72.47	-66.55	-64.98	-63.57	-72.16	-71.78	-67.50	-63.37	-66.71	-67.70	-72.20	-76.81
Average Dry+Critical	-77.85	-72.12	-70.50	-67.51	-75.80	-74.25	-62.82	-60.08	-62.51	-69.27	-72.93	-78.38
Average Wet+AbvNormal	-67.33	-61.63	-61.54	-59.63	-68.39	-69.56	-69.48	-64.57	-69.93	-64.76	-70.60	-75.47

Table 17-2 Results from nitrification scenarios at RSAC101 (nitrate and nitrite).

Percent Change from Base Due to Sac Regional Switch to Nitrification

RSAC101 NO_2	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Average	-71.00	-60.87	-56.82	-57.20	-68.75	-70.68	-67.49	-64.08	-67.59	-68.21	-72.50	-76.98
Average Dry+Critical	-77.81	-71.04	-69.62	-67.39	-75.98	-75.31	-64.30	-61.55	-64.02	-70.05	-73.33	-78.73
Average Wet+AbvNormal	-64.61	-52.92	-48.04	-48.91	-61.86	-66.58	-68.18	-64.71	-70.39	-64.95	-70.75	-75.48
RSAC101 NO_3	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Average	**26.98**	**39.81**	**32.79**	19.27	11.28	3.84	-3.16	3.30	13.99	11.47	6.35	11.98
Average Dry+Critical	**24.16**	**20.12**	**20.88**	9.64	-5.54	**-22.04**	**-35.02**	**-21.55**	8.42	-0.68	7.59	15.71
Average Wet+AbvNormal	33.70	**53.35**	**41.21**	26.17	26.74	28.82	27.74	25.32	20.84	15.18	1.88	5.98

Table 17-3 Results from nitrification scenarios at Pt. Sacramento (chl-a/algae and ammonia).

Percent Change from Base Due to Sac Regional Switch to Nitrification

Pt. SAC Algae	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Average	-1.97	-0.70	-0.71	-0.97	-6.08	-13.46	**-20.29**	**-20.31**	-13.15	-10.30	-11.33	-7.80
Average Dry+Critical	-3.54	-1.71	-1.60	-1.83	-11.41	**-24.09**	**-33.28**	**-29.68**	-16.69	-16.24	-13.96	-8.14
Average Wet+AbvNormal	-1.13	-0.07	-0.18	-0.31	-1.88	-6.05	**-10.45**	**-13.85**	**-11.61**	-7.03	-9.80	-7.25
Pt. SAC NH_3	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Average	-62.15	-57.92	-57.49	-55.88	-58.93	-48.56	-40.37	-34.78	-33.27	-37.12	-37.37	-54.36
Average Dry+Critical	-62.67	-59.89	-58.98	-56.54	-55.22	-38.04	-28.25	-25.36	-23.42	-35.85	-36.77	-53.09
Average Wet+AbvNormal	-60.97	-55.21	-56.50	-54.21	-60.49	-56.49	-50.33	-40.64	-39.79	-39.27	-39.54	-55.86

Table 17-4 Results from nitrification scenarios at Pt. Sacramento (nitrate and nitrite).

Percent Change from Base Due to Sac Regional Switch to Nitrification

Pt. SAC NO_2	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Average	-62.46	-56.36	-54.73	-54.18	-58.96	-49.41	-41.57	-36.52	-35.10	-38.75	-38.49	-55.41
Average Dry+Critical	-63.50	-60.42	-59.54	-57.44	-56.61	-39.44	-29.09	-26.31	-24.53	-37.39	-37.86	-54.20
Average Wet+AbvNormal	-60.84	-52.12	-51.27	-50.61	-59.36	-56.77	-51.73	-42.94	-42.20	-40.87	-40.65	-56.84

Pt. SAC NO_3	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Average	-0.37	**14.88**	**17.28**	4.39	-9.26	-13.89	-13.66	-10.54	-8.98	-8.32	-11.68	-10.73
Average Dry+Critical	0.84	-4.21	-0.13	-8.10	**-26.08**	**-29.85**	**-31.87**	**-19.36**	-12.01	-17.08	-14.83	-7.27
Average Wet+AbvNormal	2.11	26.84	29.24	13.12	6.84	2.08	3.76	-1.00	-4.82	-5.52	-12.23	-15.10

Table 17-5 Results from nitrification scenarios at Jersey Point (chl-a/algae and ammonia).

Percent Change from Base Due to Sac Regional Switch to Nitrification

RSAN018 Algae	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Average	-2.38	-0.68	-0.62	-1.26	-7.93	-12.22	-20.34	-21.00	-13.96	-11.09	-12.54	-9.13
Average Dry+Critical	-3.52	-1.65	-1.51	-2.30	**-14.63**	**-23.89**	**-34.49**	**-31.29**	**-16.82**	-6.84	-8.96	-8.00
Average Wet+AbvNormal	-1.83	-0.08	-0.07	-0.41	-2.16	-4.04	-9.55	**-13.16**	**-12.80**	**-18.19**	**-21.91**	**-14.81**
RSAN018 NH_3	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Average	-62.46	-51.75	-47.55	-44.57	-49.60	-41.77	-35.53	-30.94	-32.47	-40.04	-46.64	-62.00
Average Dry+Critical	-67.77	-61.15	-59.90	-54.17	-55.50	-42.16	-30.77	-26.42	-25.85	-39.74	-46.23	-62.28
Average Wet+AbvNormal	-57.52	-44.10	-38.50	-37.32	-43.27	-40.87	-38.96	-33.06	-36.62	-41.14	-47.29	-62.12

Table 17-6 Results from nitrification scenarios at Jersey Point (nitrate and nitrite).

Percent Change from Base Due to Sac Regional Switch to Nitrification

RSAN018 NO_2	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Average	-63.16	-52.24	-47.87	-45.41	-50.82	-43.57	-37.50	-32.96	-34.48	-41.84	-47.86	-62.99
Average Dry+Critical	-68.66	-61.85	-60.60	-55.24	-57.06	-44.09	-32.18	-27.74	-27.36	-41.48	-47.44	-63.32
Average Wet+AbvNormal	-58.07	-44.41	-38.52	-37.86	-44.19	-42.47	-41.33	-35.60	-39.04	-42.86	-48.43	-63.03

RSAN018 NO_3	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Average	-4.49	6.25	4.18	-3.90	-13.07	-15.32	-16.95	-12.61	-8.20	-7.67	-11.08	-10.89
Average Dry+Critical	-1.26	-8.60	-6.27	-11.69	-26.04	-28.44	-33.24	-21.80	-10.07	-16.66	-14.21	-7.39
Average Wet+AbvNormal	-3.66	15.71	11.05	1.50	-0.28	-2.98	-1.08	-3.27	-5.06	-4.98	-11.81	-15.25

18 Scenarios: Clams (*Corbula* and *Corbicula*)

Attempts to modify model parameters to mimic the change in nutrient dynamics due to clams, generally through increased nutrient consumption (including consumption of algae) were unsuccessful. The main parameters that could be varied were algal growth and death rates. Increases or decreases in constituent concentrations associated with the dynamics of their life cycle, for example the potential for an increase in the production of benthic NH_3 to mimic excretion, were difficult to quantify in the literature examined.

The change in consumption of nutrients due to consumption by clams needed to be variable in time and tied to other parameters, such as salinity – this was not possible in the current conceptual model available in QUAL. *Corbula* and *Corbicula* do not necessarily consume nutrients year-round, and their growth and maturation cycles depend on having the correct conditions for salinity and water temperature, for example. *Corbula* (J. Thompson, PowerPoint available on web[27]) recruits prefer more saline conditions, settling downstream of X2[28], so generally do not appear in significant numbers upstream Collinsville. Historically, *Corbula* has invaded the greatest proportion of the Delta during low outflow conditions leading to their expansion into upstream locations. *Corbicula* favors fresher water environments, and juveniles generally settle upstream of X2.

Implementing changes in algal growth and death rates tended to change both the increasing and decreasing arms of the annual growth curves. The result would be peaks that might have the correct integrated area for a season, but that would miss the timing and pattern of increasing and declining growth. Figure 18-24 shows potential habitat for the two clams – this figure is just meant to give a general indication of potential locations.

[27] http://science.calwater.ca.gov/pdf/workshops/workshop_dcm2_presentation_Thompson.pdf
[28] X2 is the distance in km from the Golden Gate Bridge to the 2 psu bottom salinity location

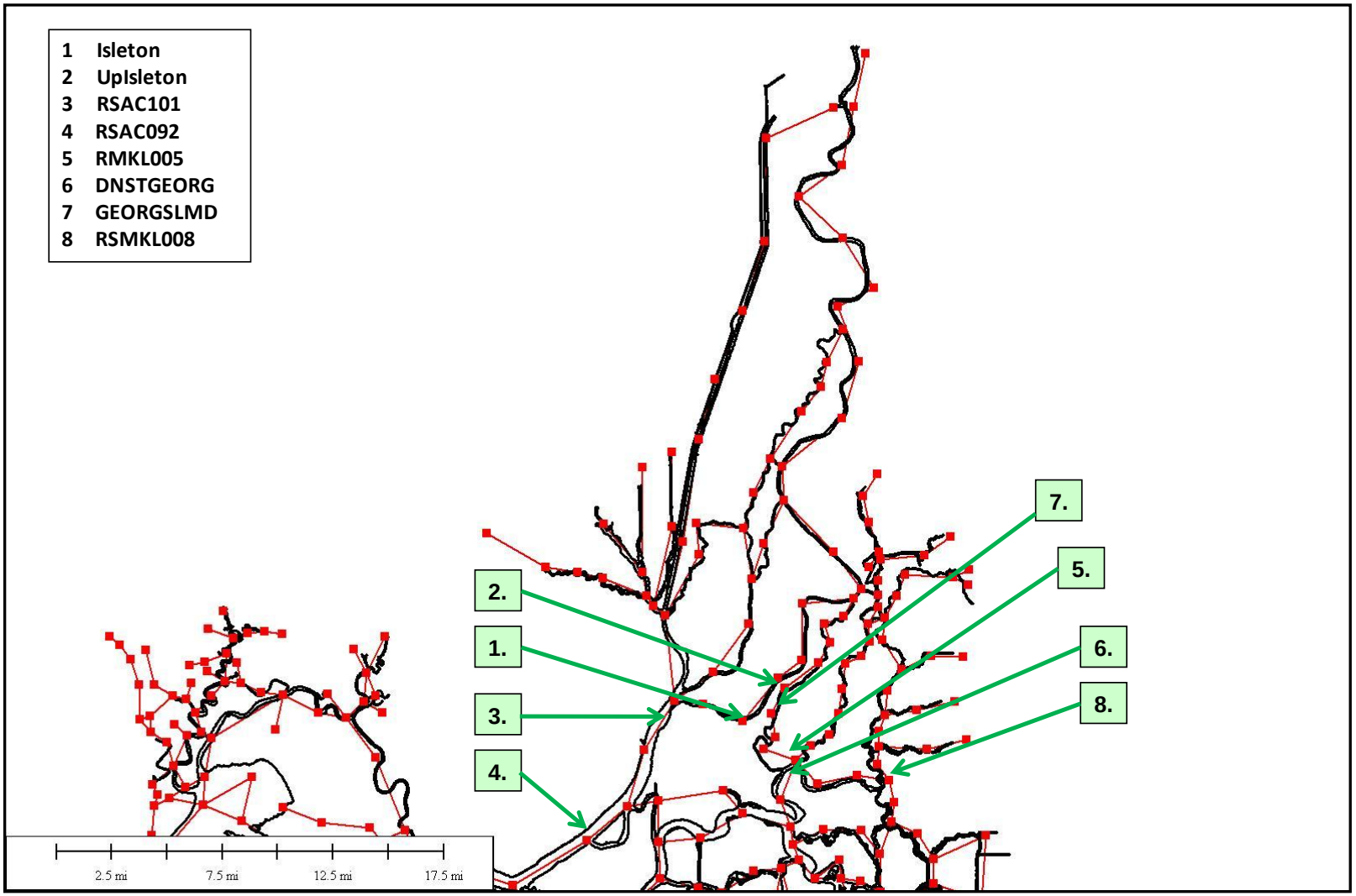


Figure 18-1 Model output locations in the northern Delta for the scenarios.

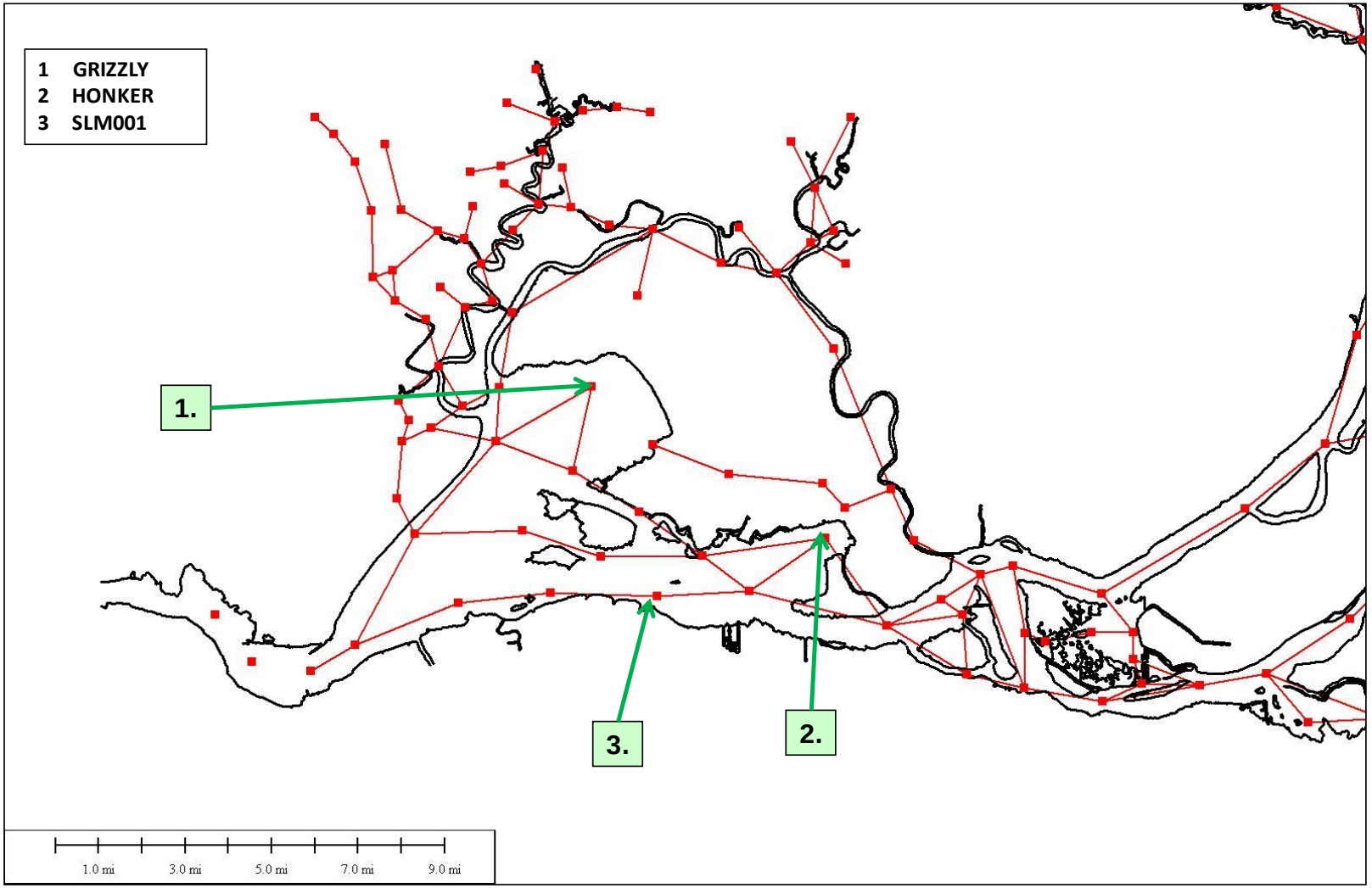


Figure 18-2 Model output locations in the western Delta for the scenarios.

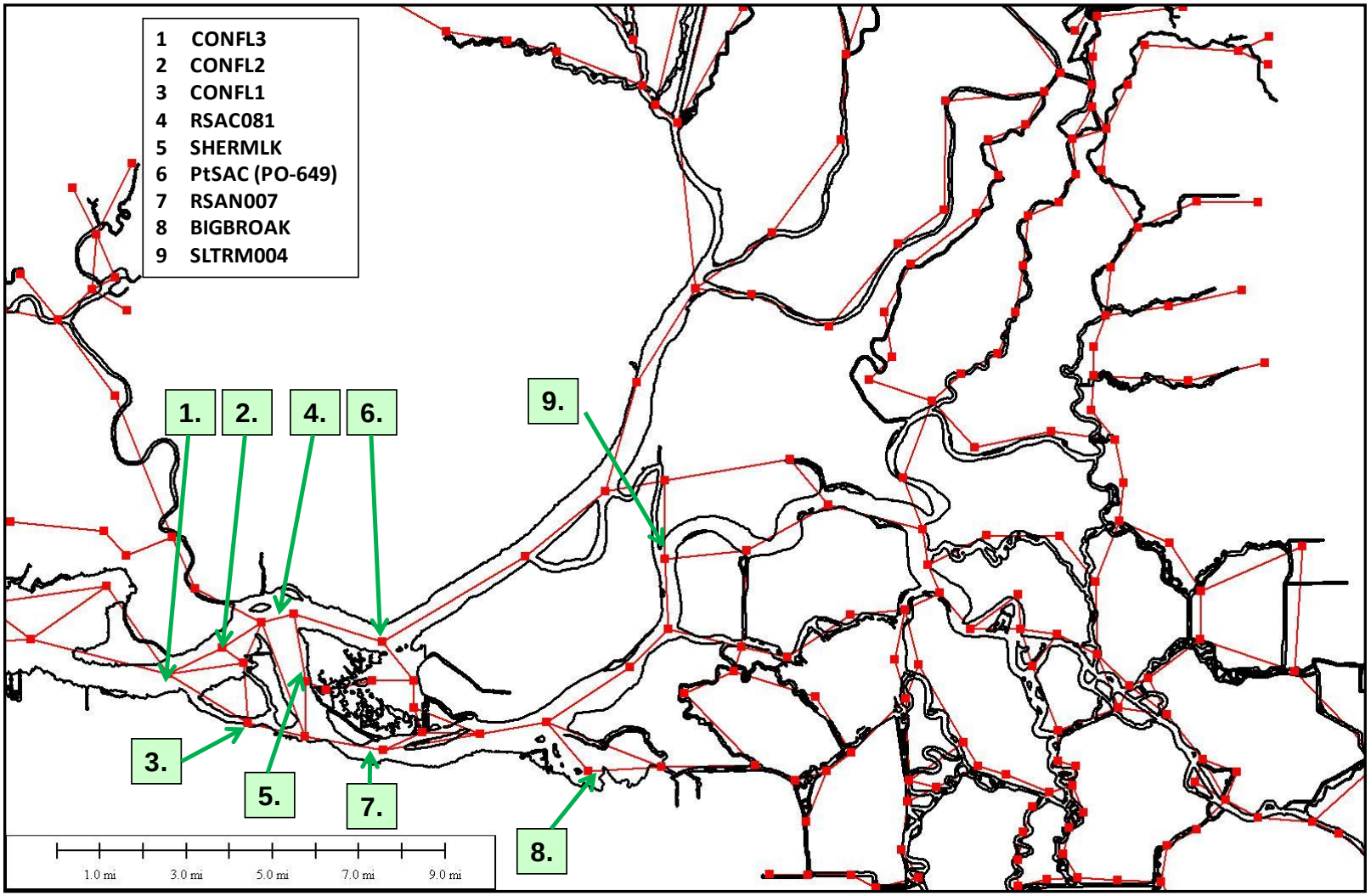


Figure 18-3 Model output locations near the confluence of the Sacramento and San Joaquin Rivers for the scenarios.

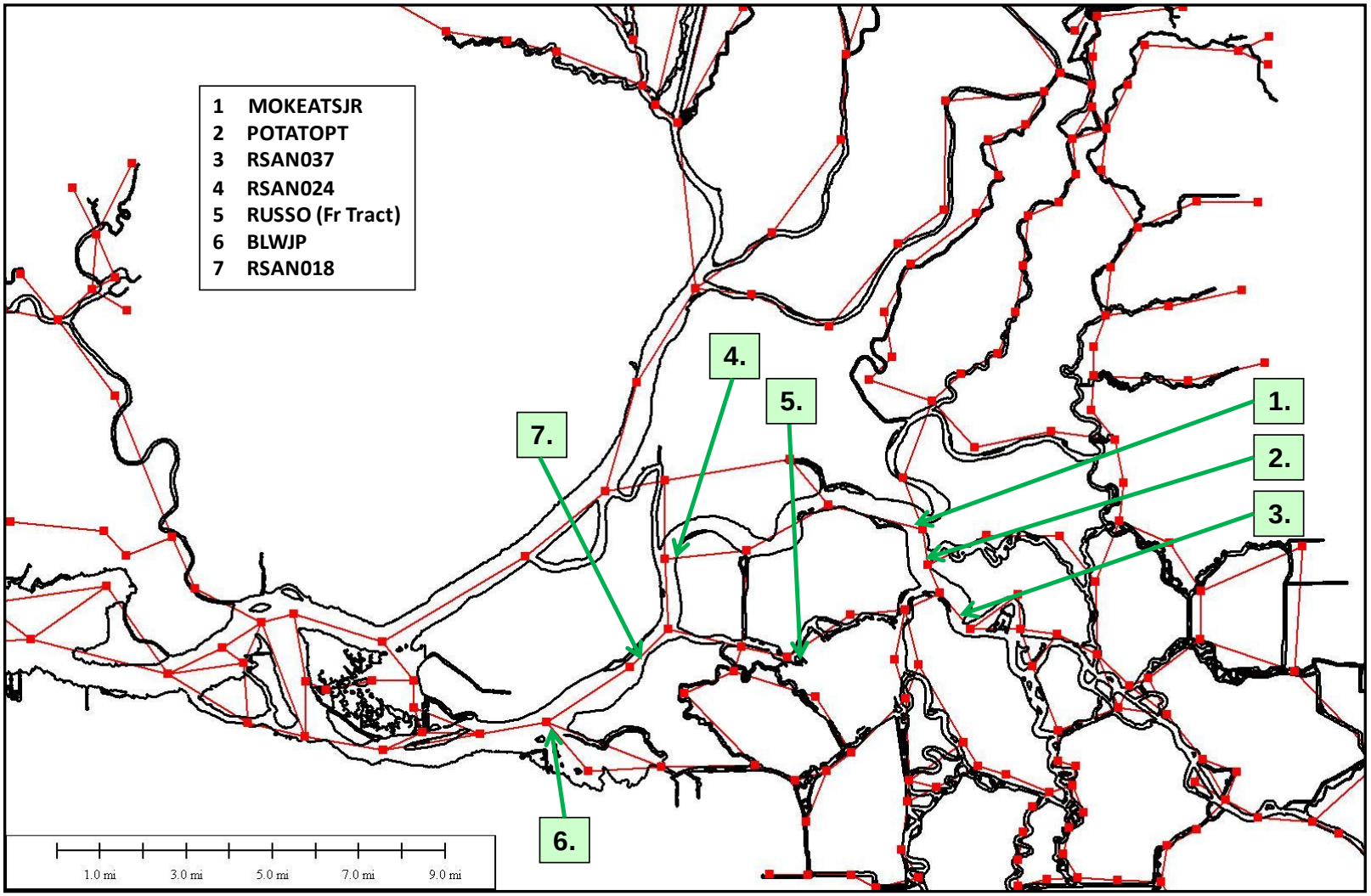


Figure 18-4 Model output locations on the lower San Joaquin River for the scenarios.

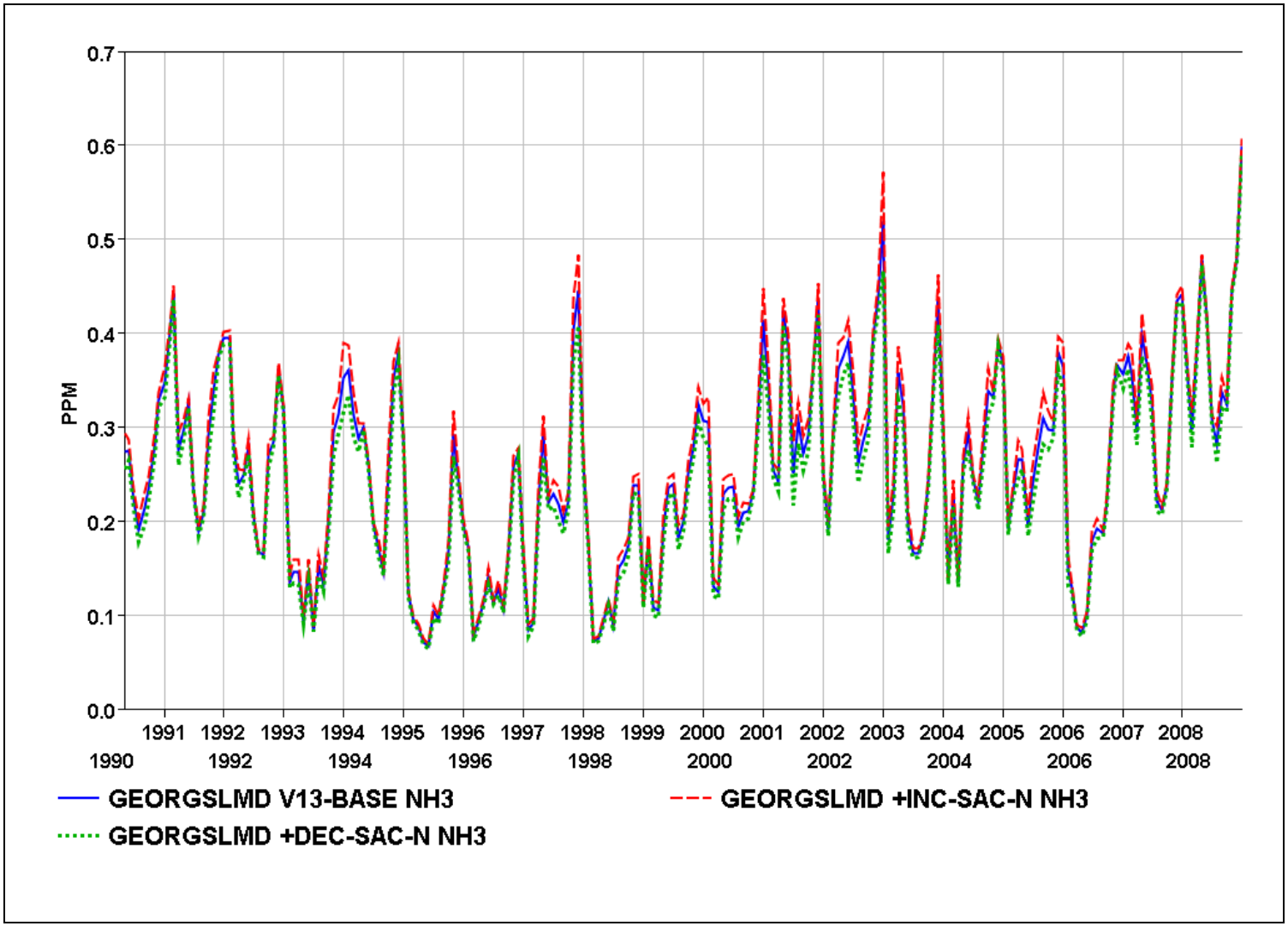


Figure 18-5 Changes in ammonia in Georgiana Slough for the scenarios changing Sacramento R. N-constituents.

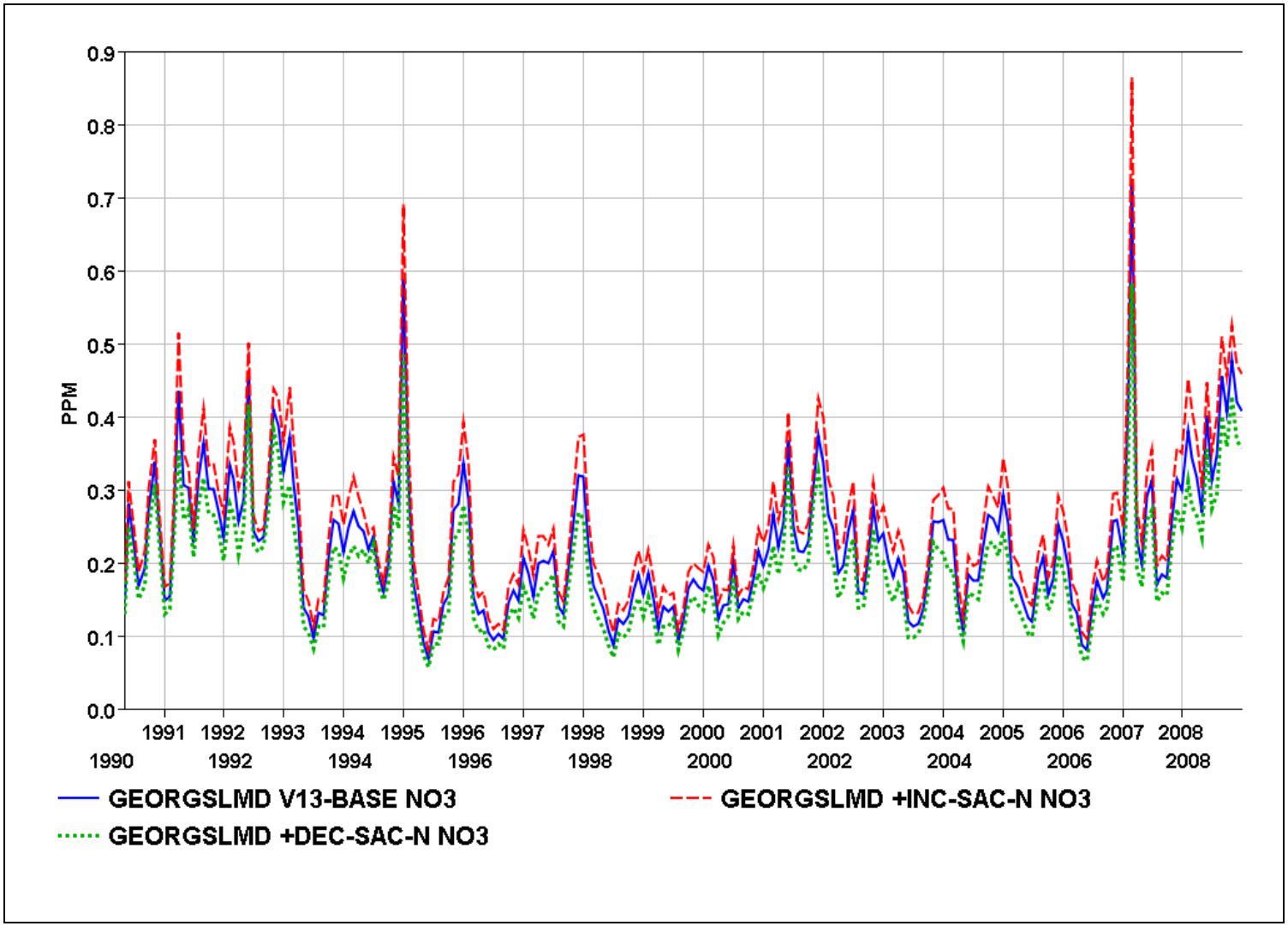


Figure 18-6 Changes in nitrate in Georgiana Slough for the scenarios changing Sacramento R. N-constituents.

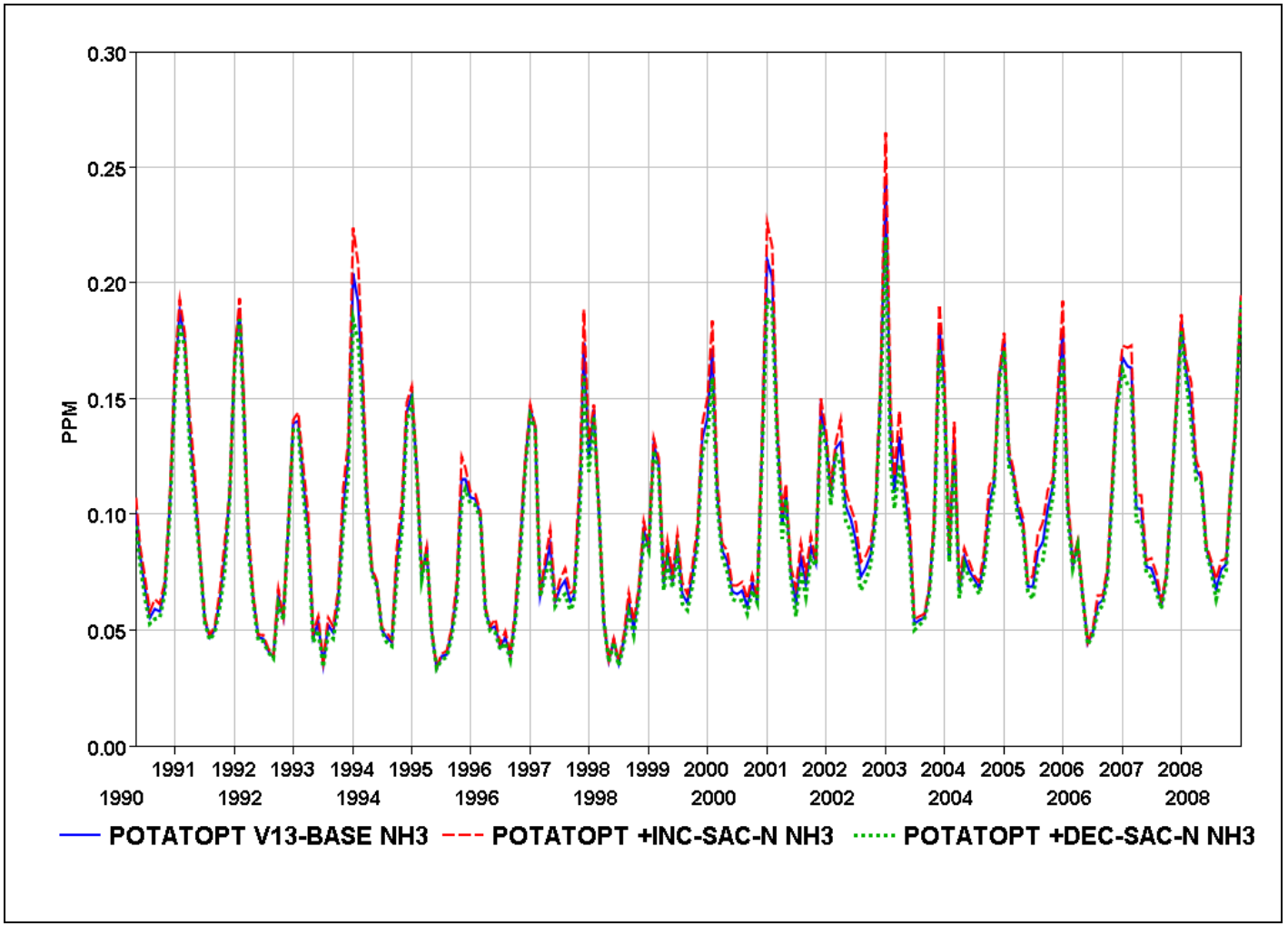


Figure 18-7 Changes in ammonia concentration at Potato Point for the scenarios changing Sacramento R. N-constituents.

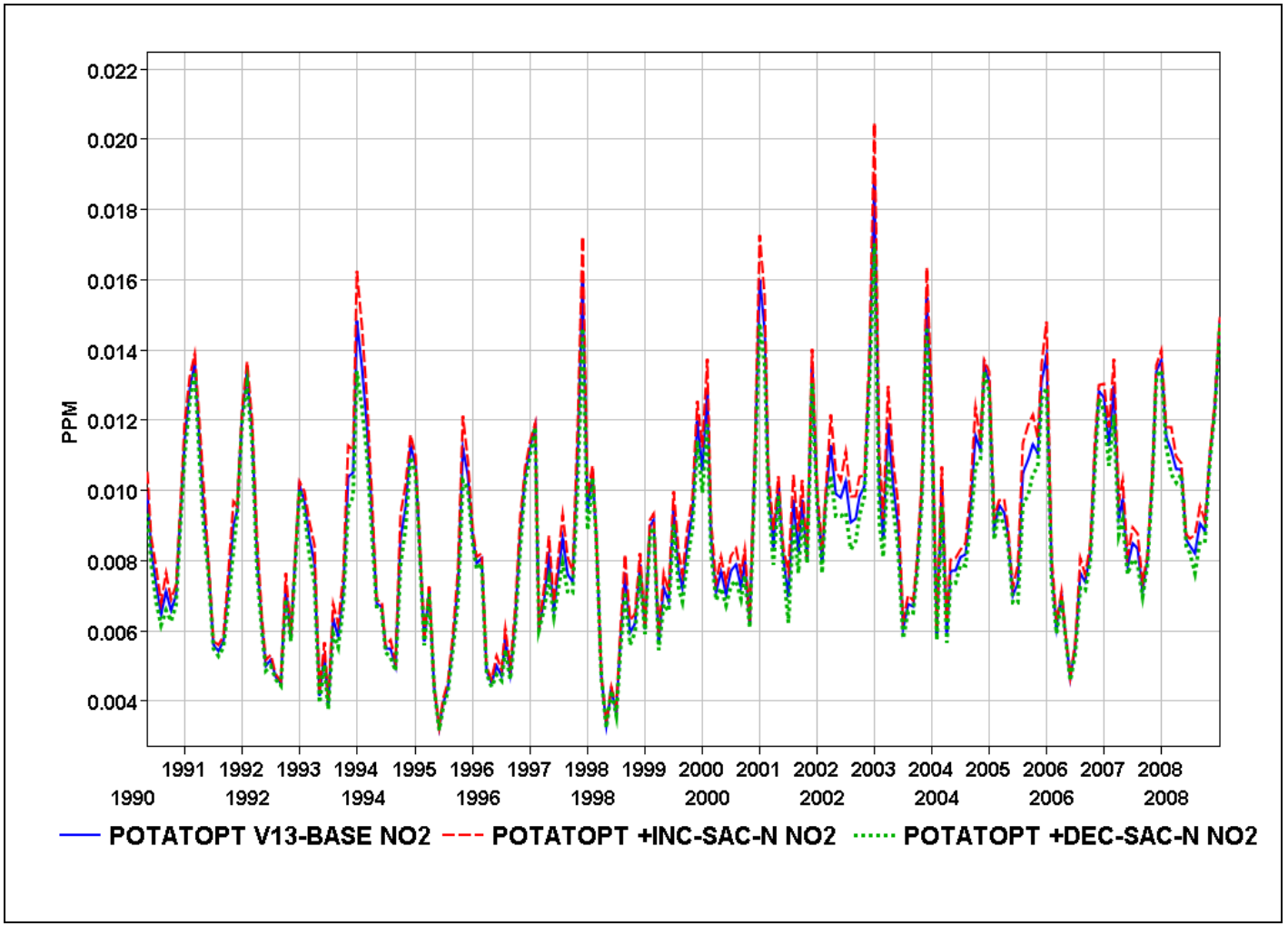


Figure 18-8 Changes in nitrite concentration at Potato Point for the scenarios changing Sacramento R. N-constituents.

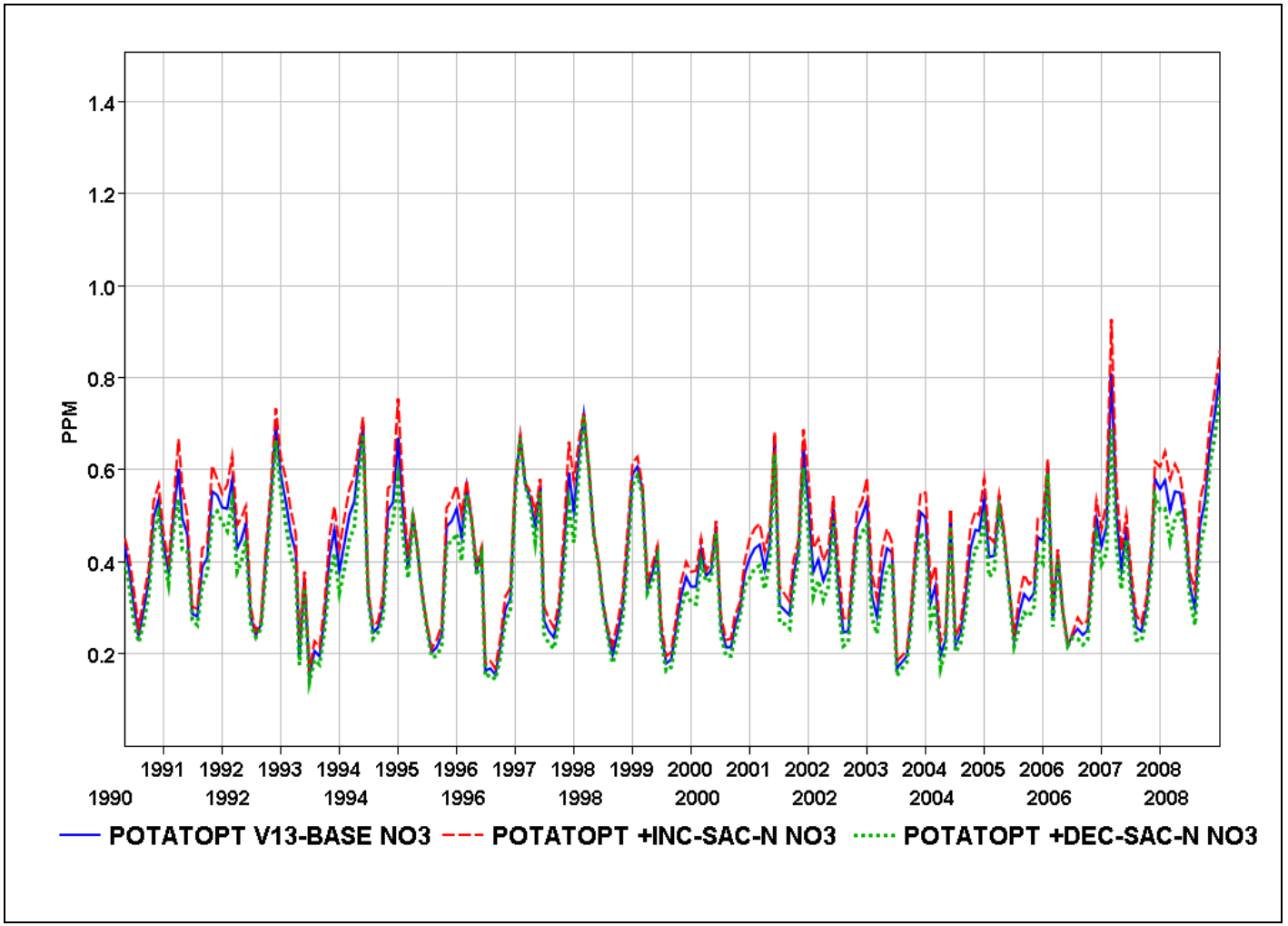


Figure 18-9 Changes in nitrate concentration at Potato Point for the scenarios changing Sacramento R. N-constituents.

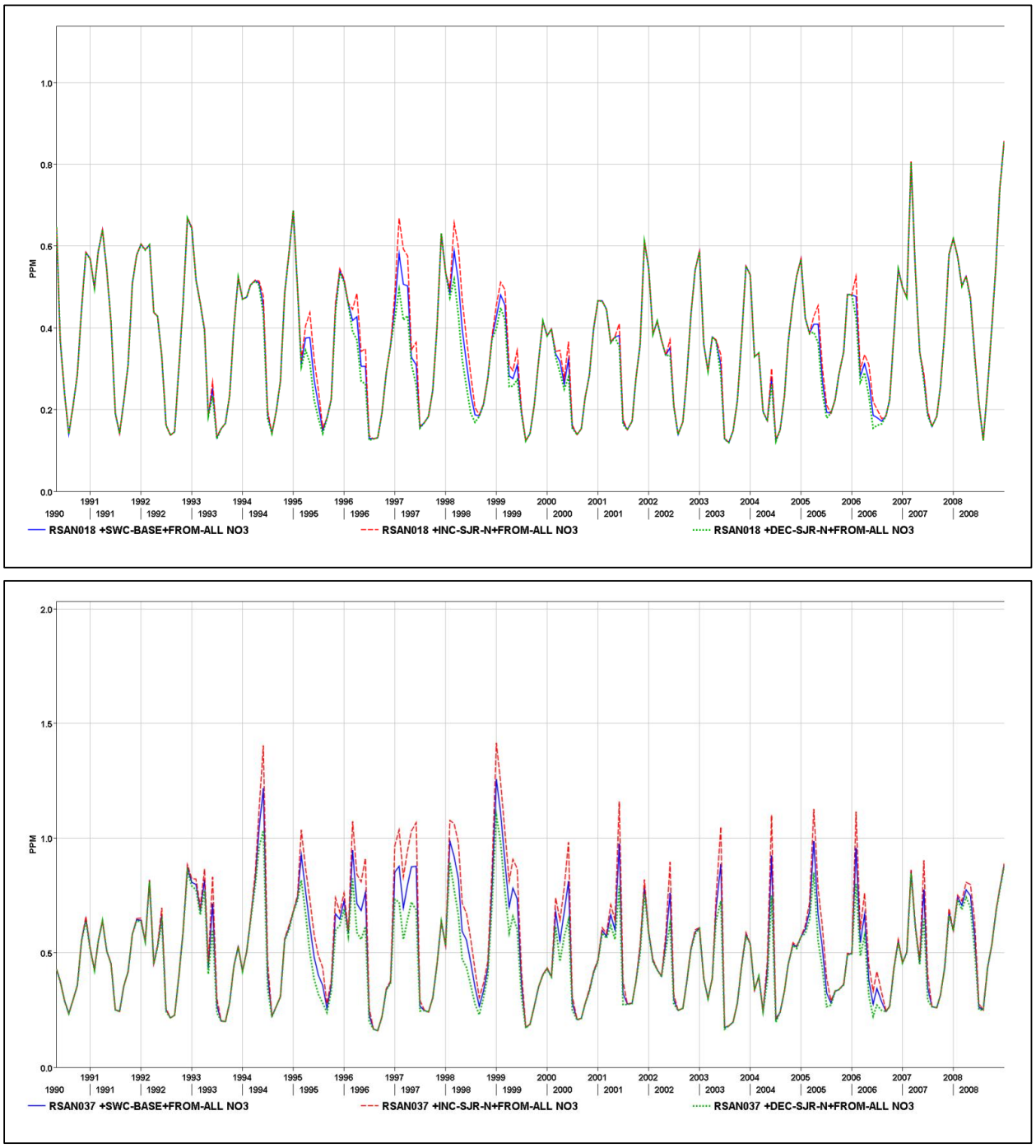


Figure 18-10 Nitrate concentration at downstream locations from the San Joaquin boundary after changing N-concentrations – RSAN018 and RSAN037.

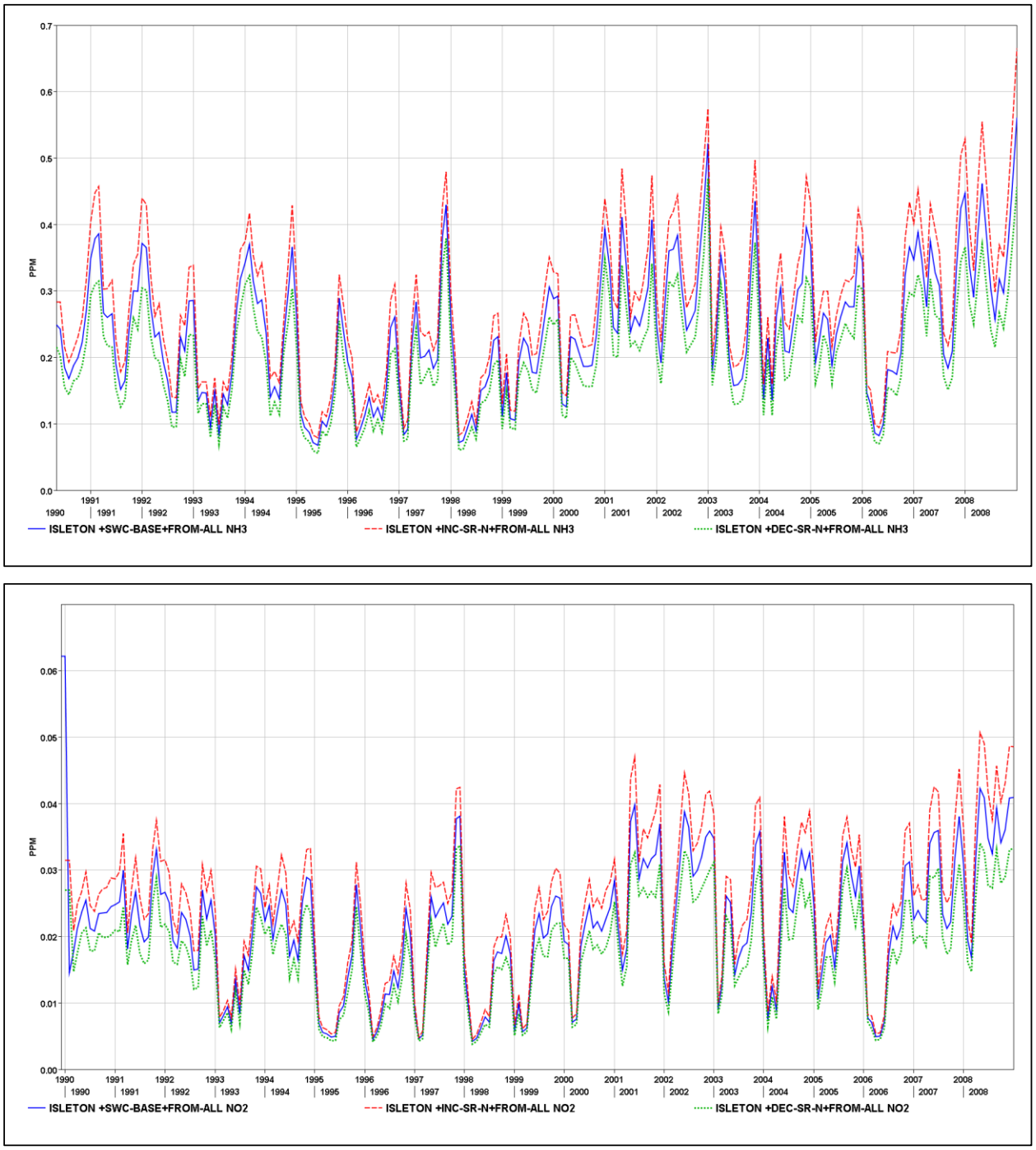


Figure 18-11 Changes in ammonia and nitrite at Isleton in the scenario changing Sac Regional N-constituents.

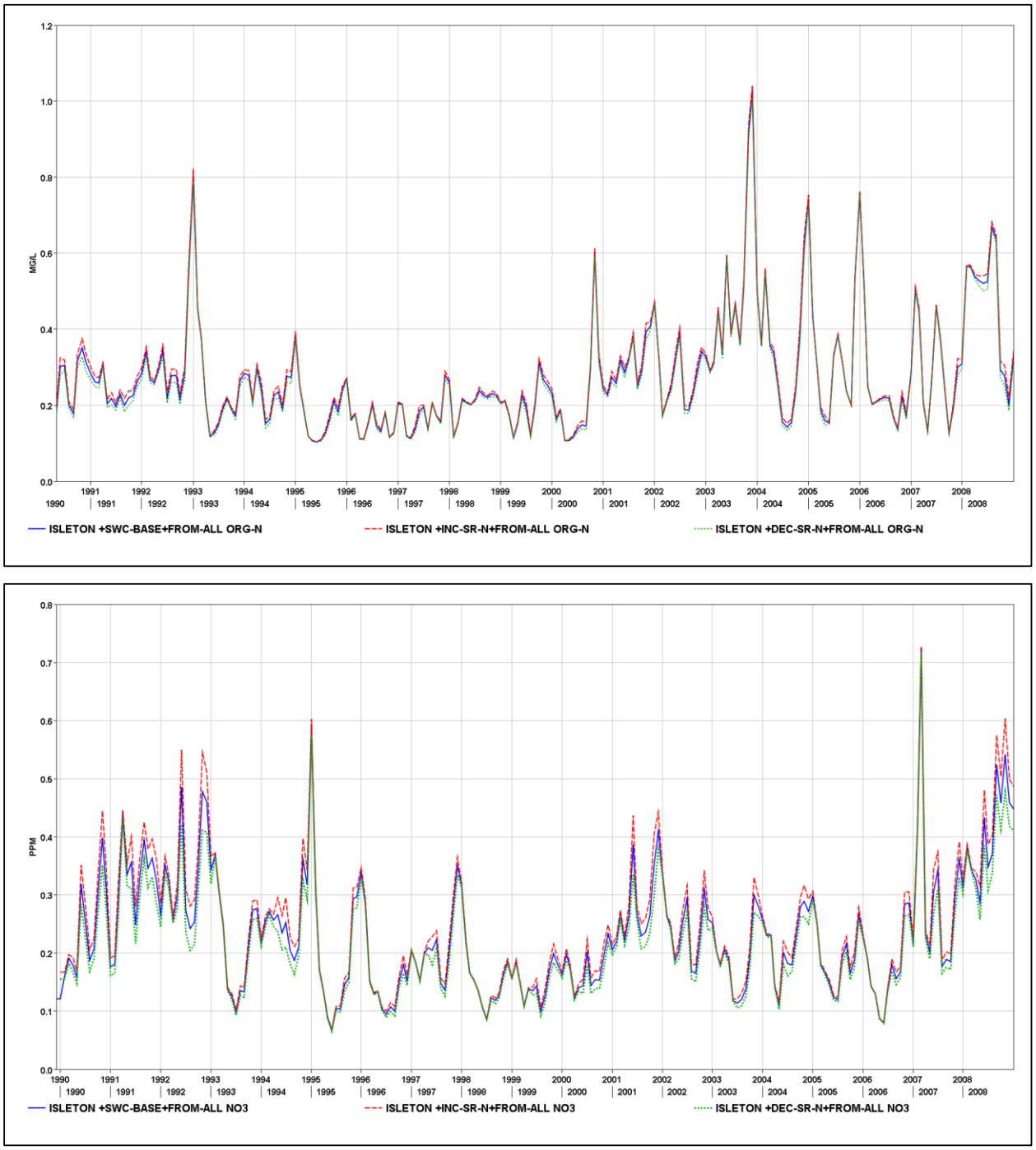


Figure 18-12 Changes in organic-N and nitrate at Isleton in the scenario changing Sac Regional N-constituents.

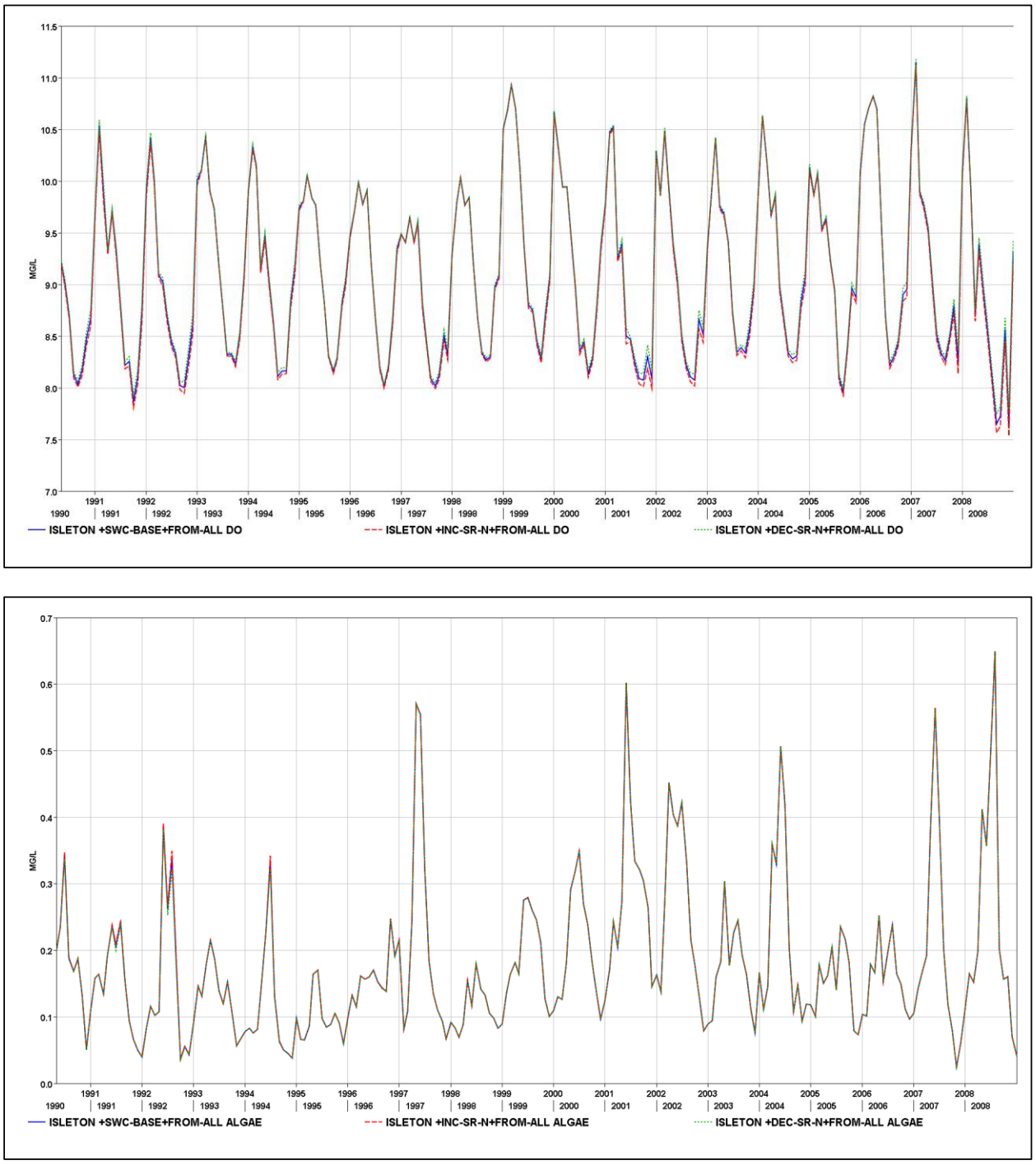


Figure 18-13 Changes in DO and chl-a/algae at Isleton in the scenario changing Sac Regional N-constituents.

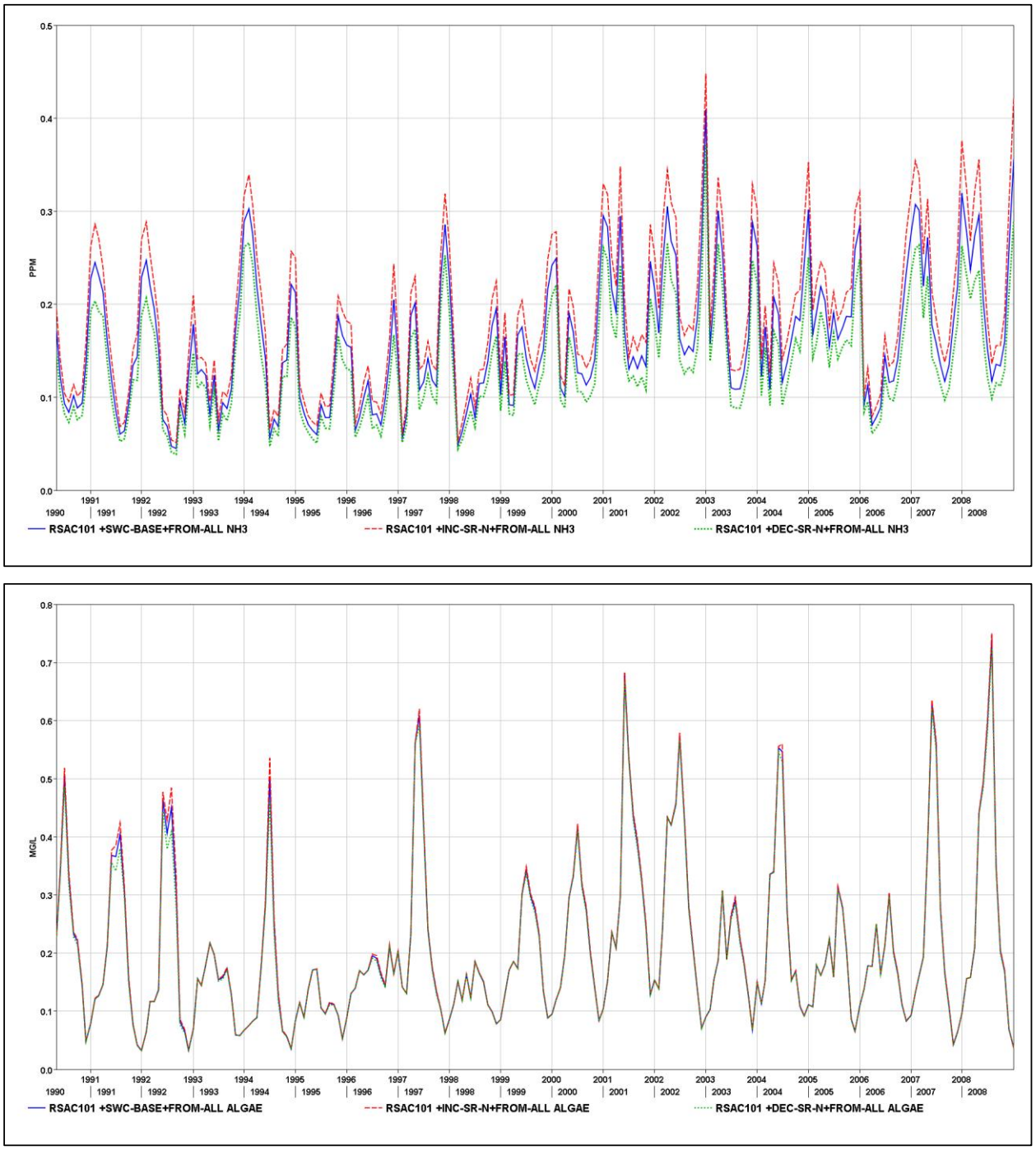


Figure 18-14 Changes in ammonia and chl-a/algae at Rio Vista in the scenario changing Sac Regional N-constituents.

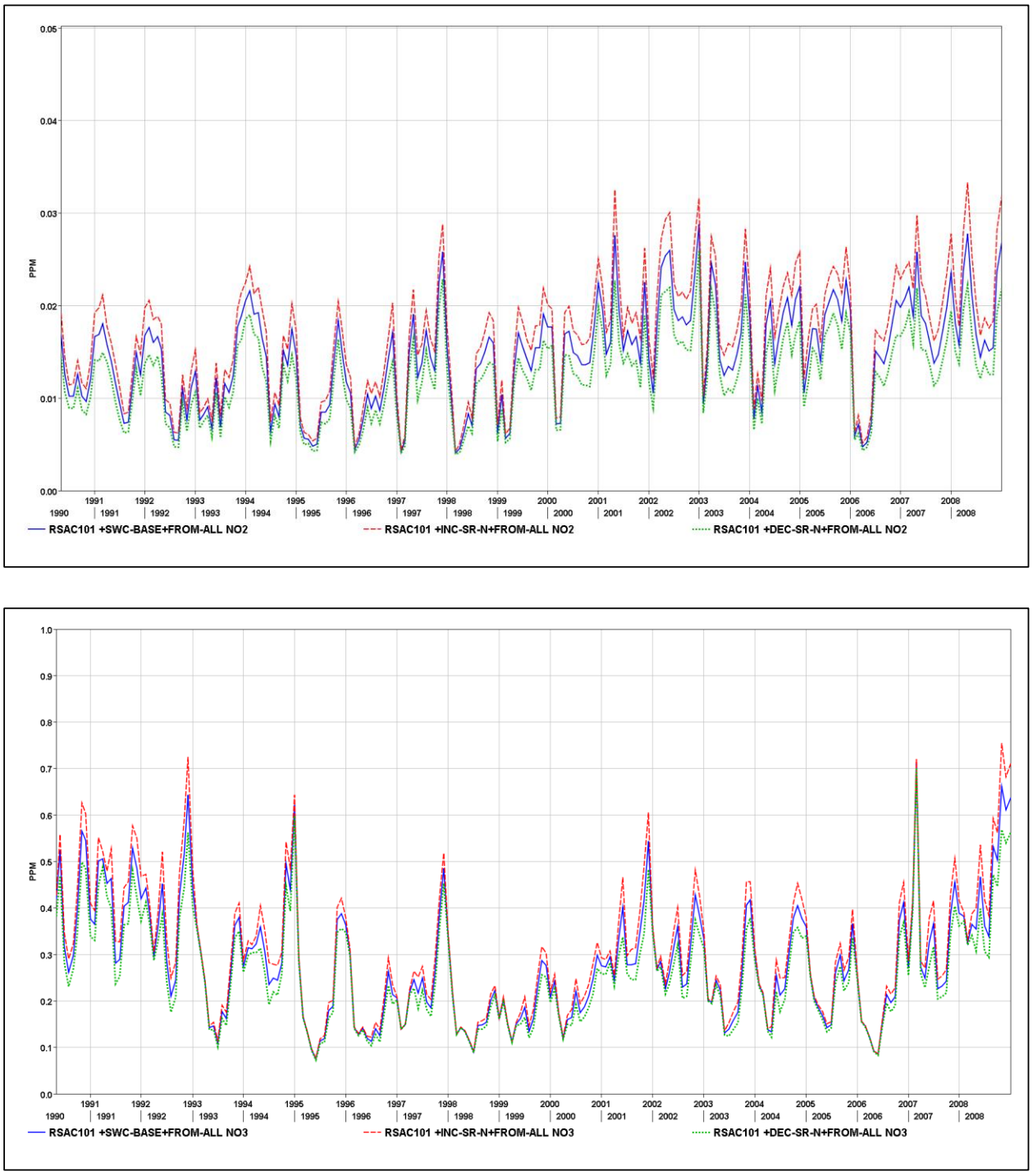


Figure 18-15 Changes in nitrite and nitrate at Rio Vista in the scenario changing Sac Regional N-constituents.

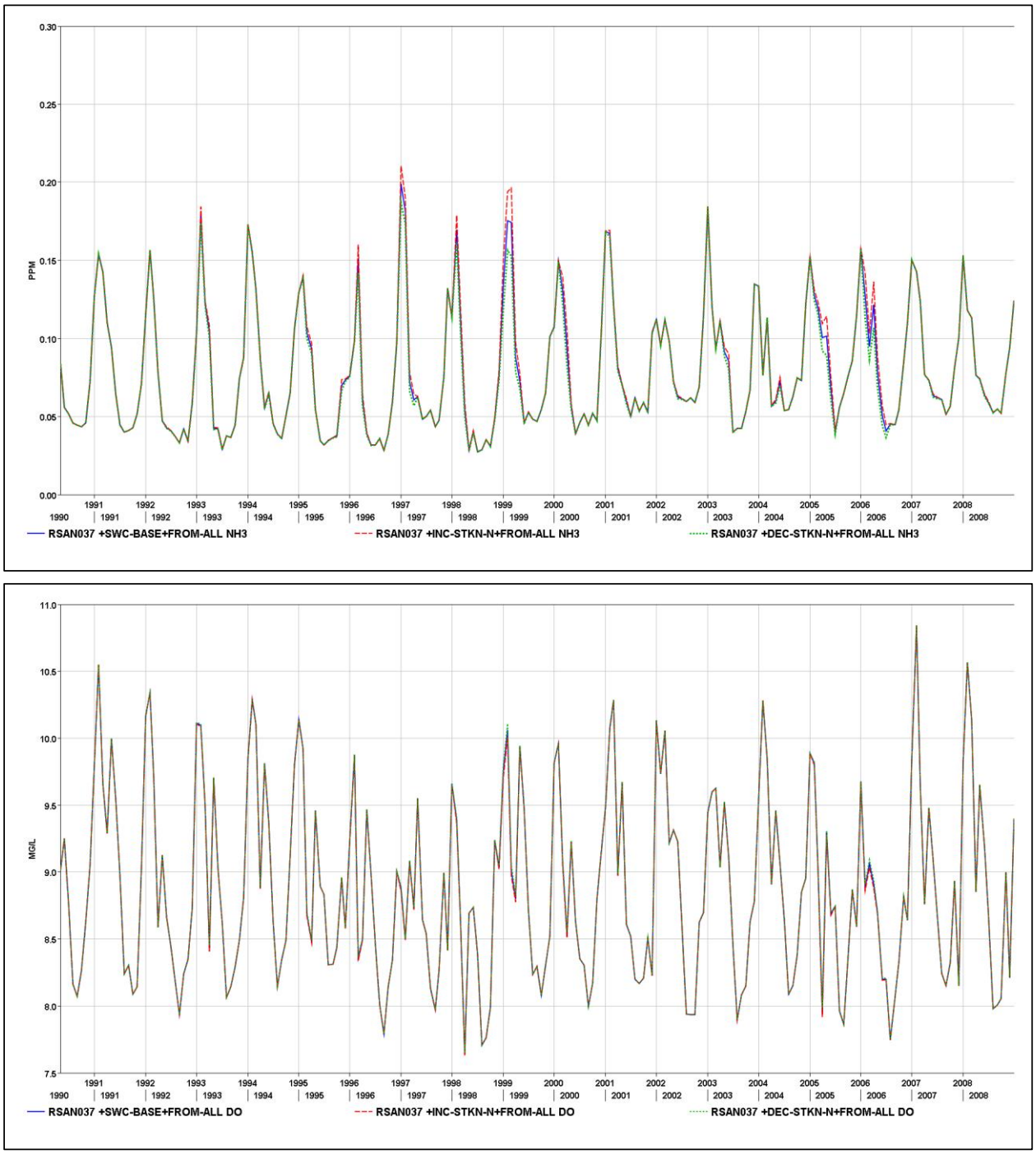


Figure 18-16 Ammonia and DO concentrations at RSAN037 downstream of the Stockton WWTP after changing wastewater concentrations.

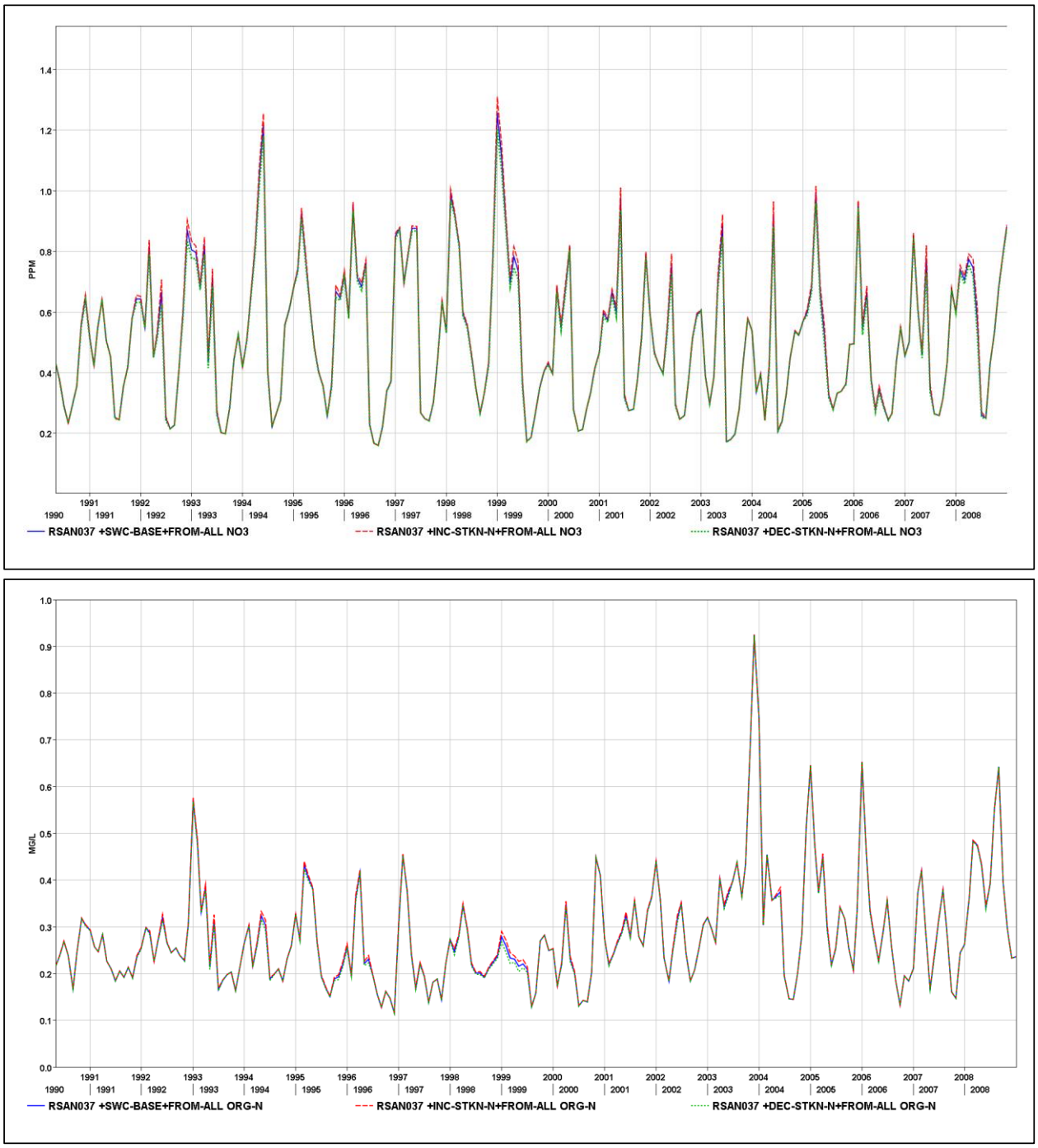


Figure 18-17 Nitrate and organic-N concentrations at RSAN037 downstream of the Stockton WWTP after changing wastewater concentrations.

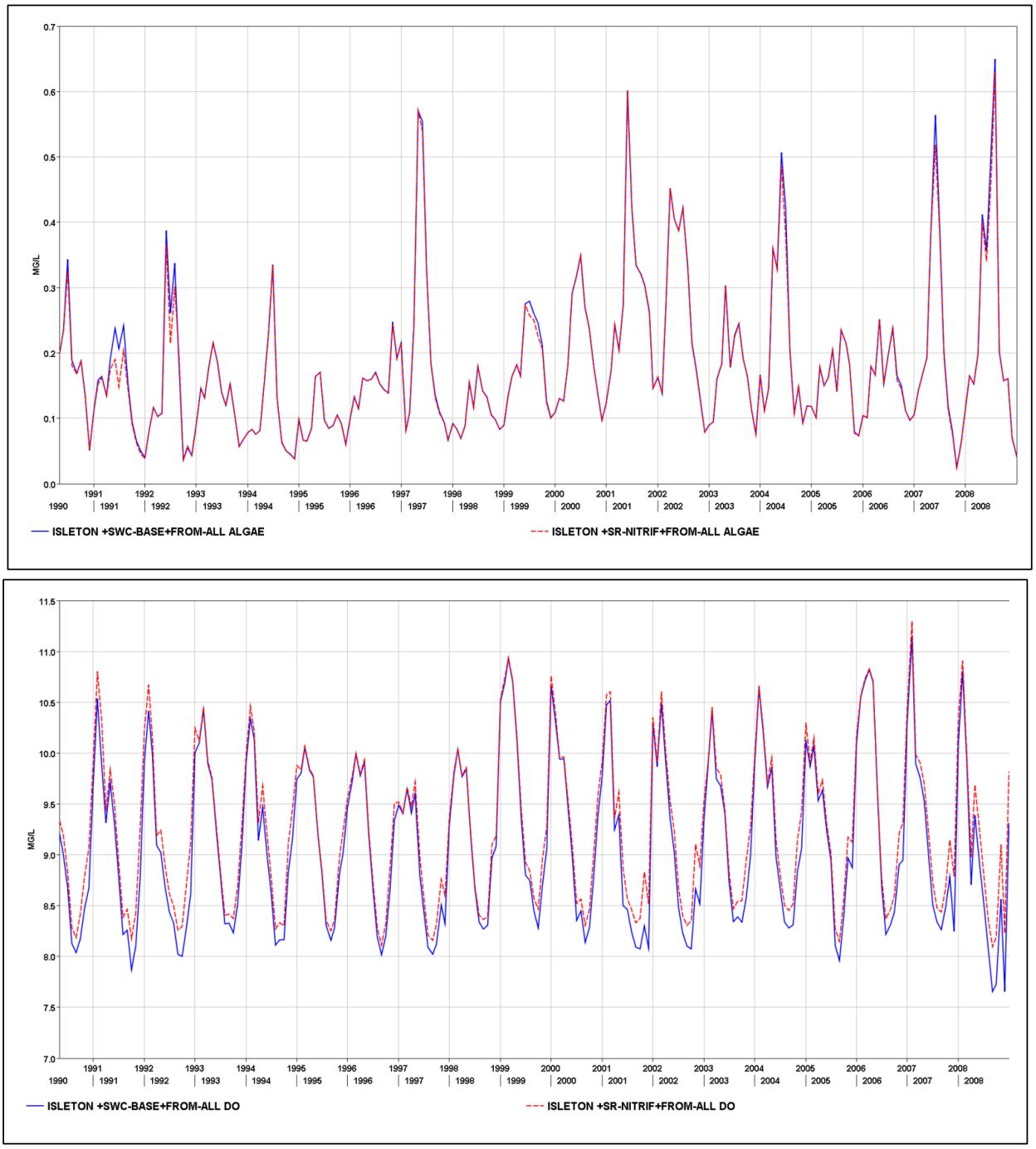


Figure 18-18 Chl-a/algae and DO concentrations at Isleton for the Sac Regional Nitrification scenario.

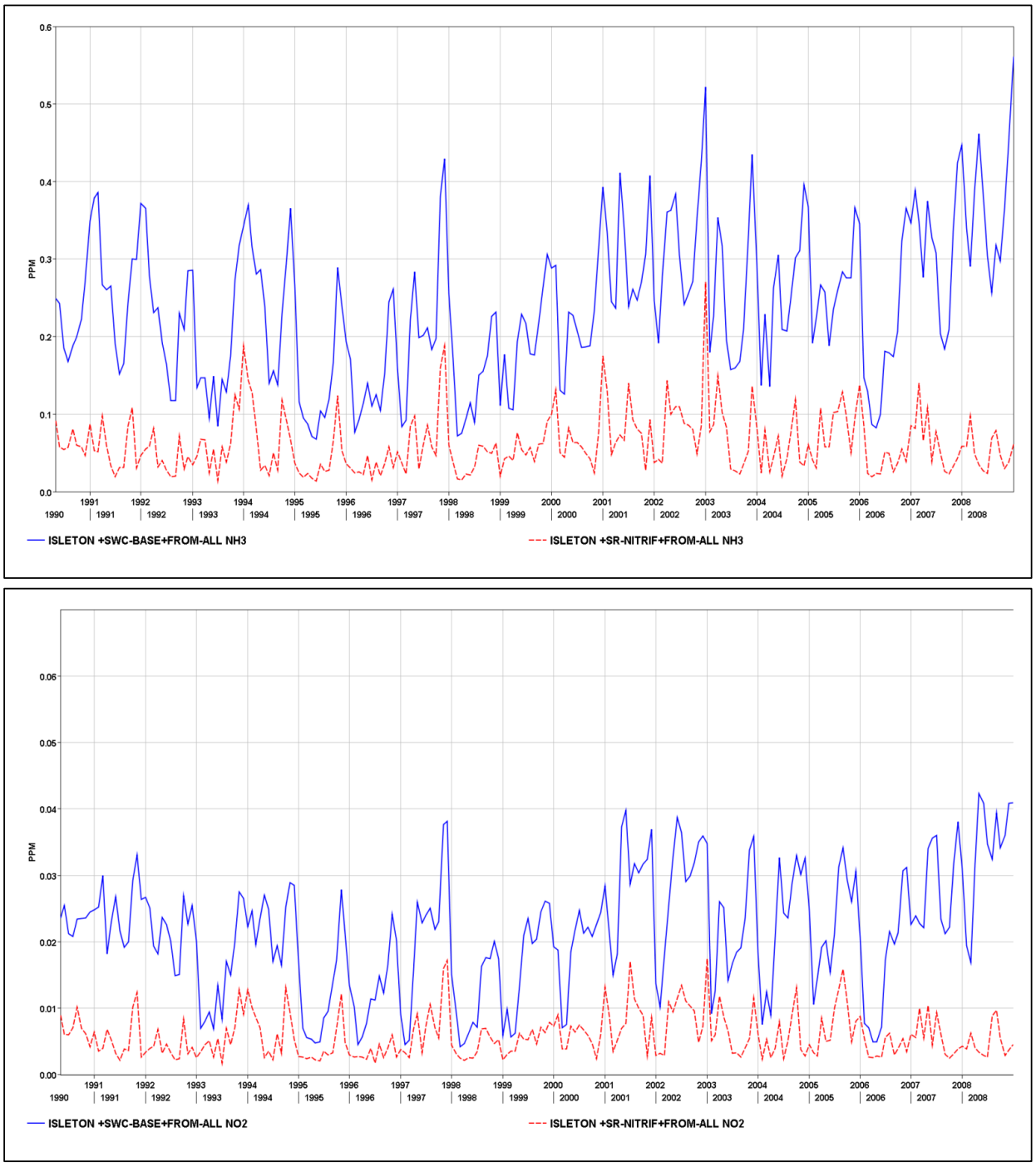


Figure 18-19 Nitrate and nitrate concentrations at Isleton for the Sac Regional Nitrification scenario.

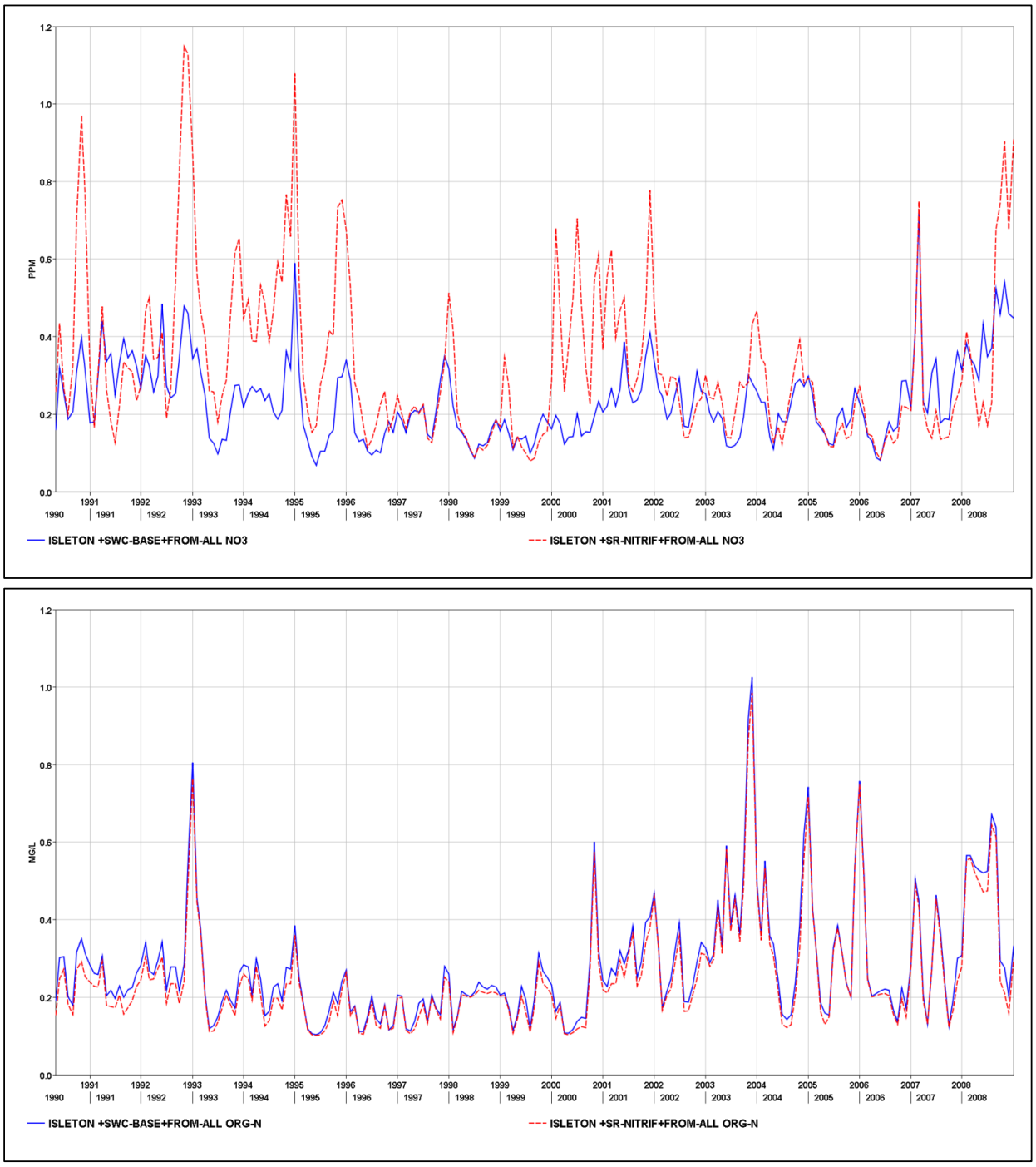


Figure 18-20 Nitrate and organic-N concentrations at Isleton for the Sac Regional Nitrification scenario

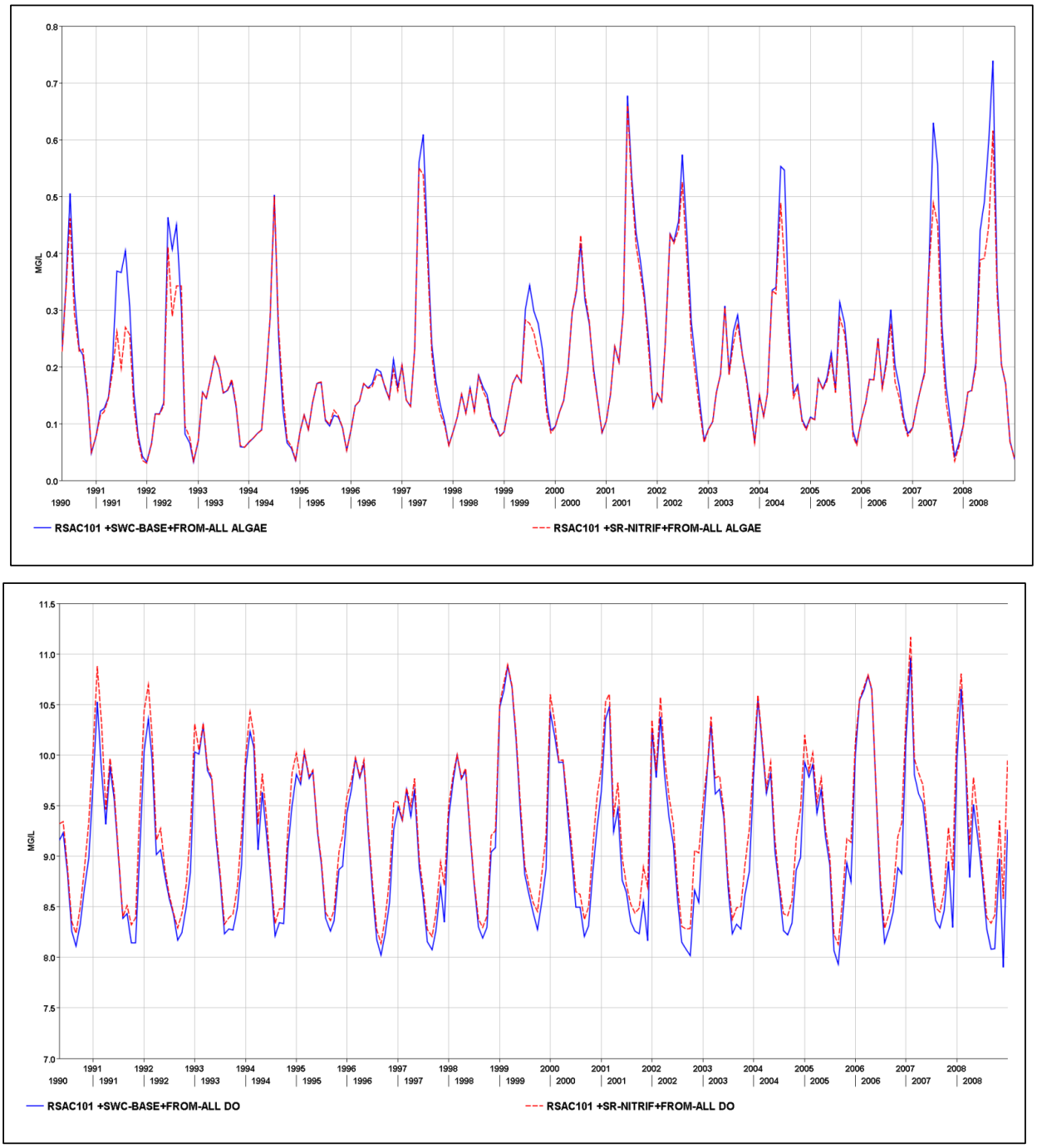


Figure 18-21 Chl-a/algae and DO concentrations at Rio Vista for the Sac Regional Nitrification scenario.

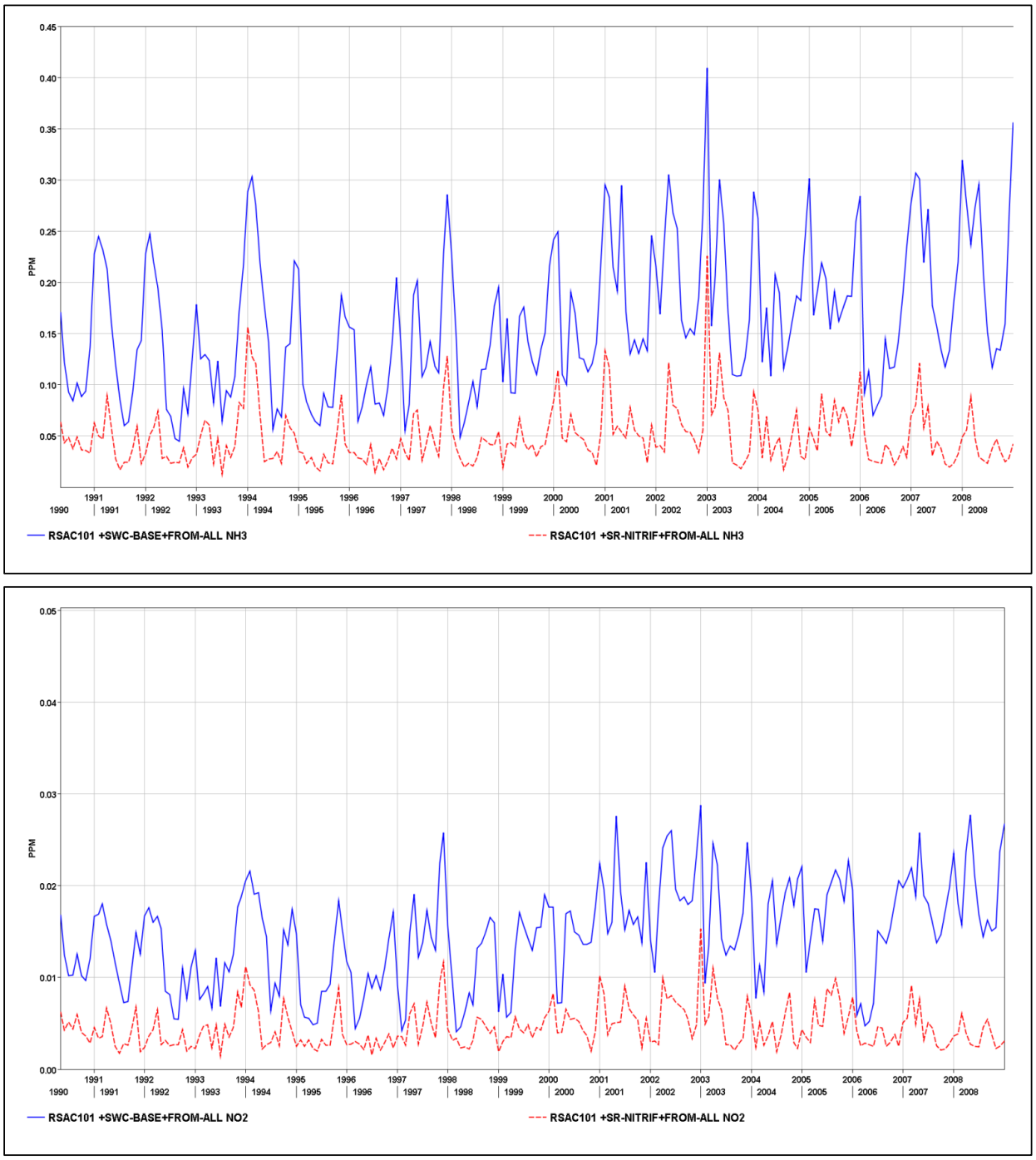


Figure 18-22 Ammonia and nitrite concentrations at Rio Vista for the Sac Regional Nitrification scenario.

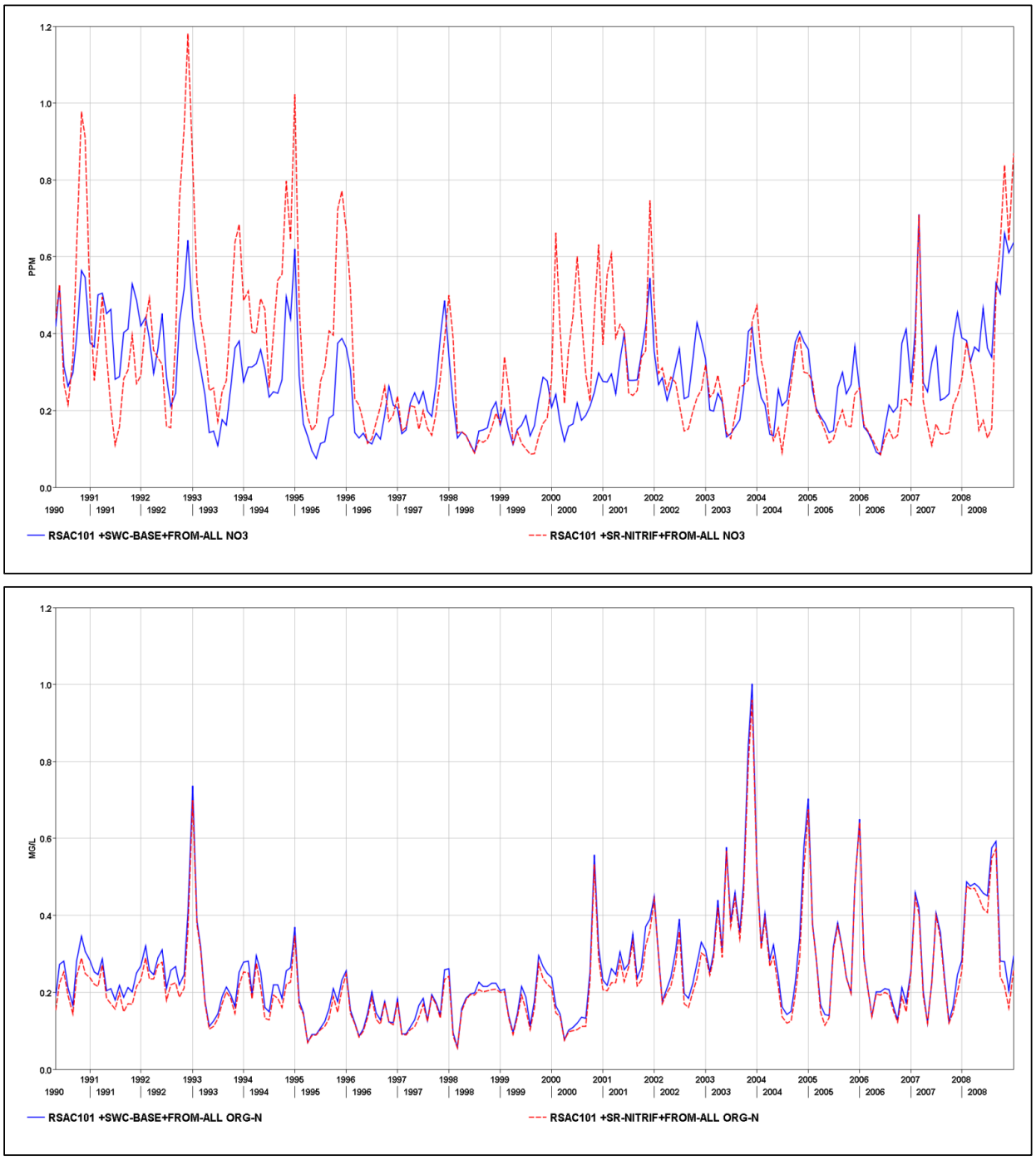


Figure 18-23 Nitrate and organic-N concentrations at Rio Vista for the Sac Regional Nitrification scenario.

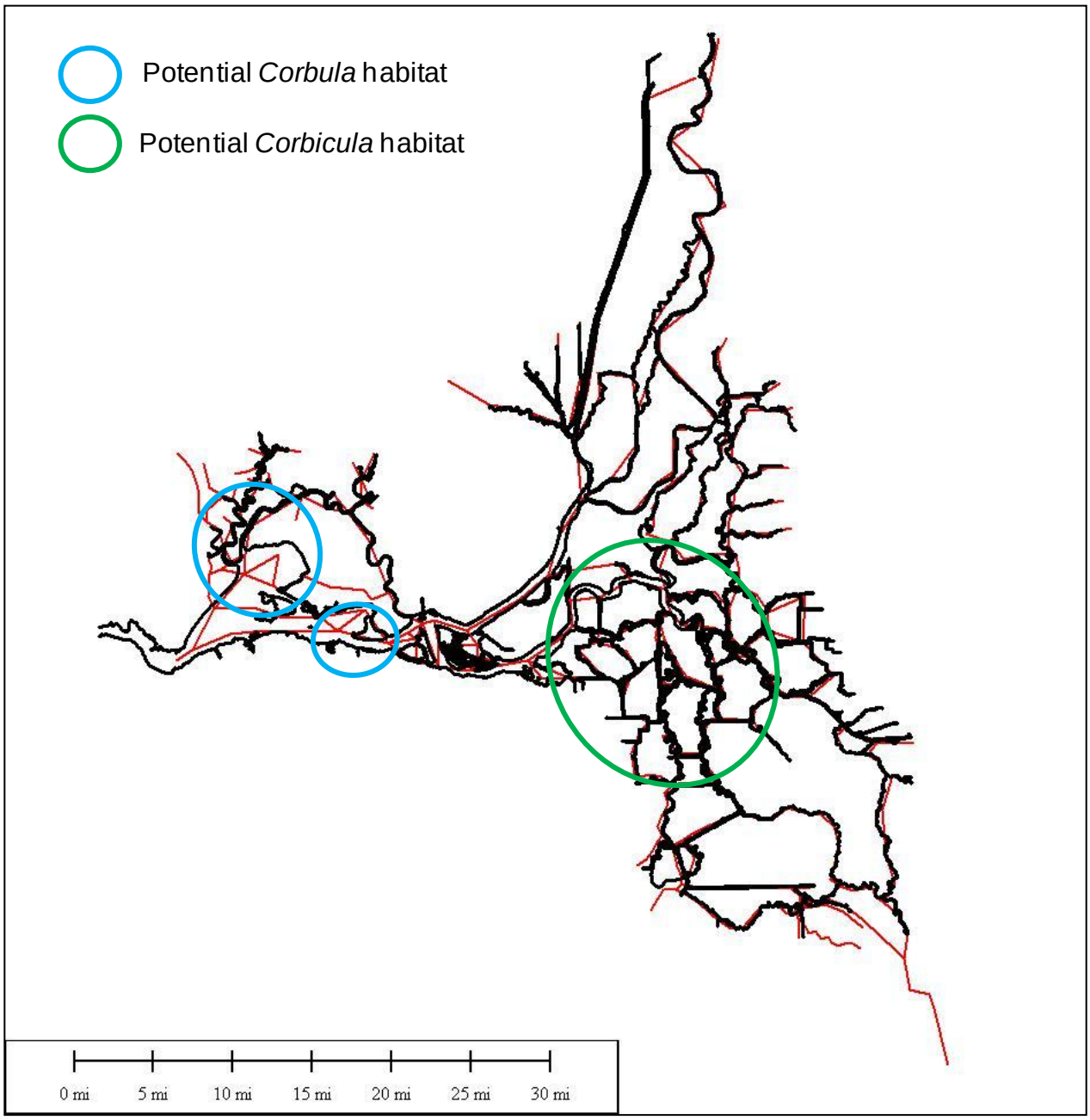


Figure 18-24 Suitable habitat areas for *Corbula* and *Corbicula* do not tend to overlap.

19 Adequacy of QUAL's Current Formulation and Potential Areas for Model Development

19.1 Current Formulation- Strengths and Weaknesses

One of the great strengths of the water temperature and nutrient formulations in QUAL is their simplicity. Because there are invariably constituent concentrations missing at boundaries and within the model domain in nutrient models, as was the case in the Delta over this long time frame, it was still possible to produce a satisfactorily calibrated model. In addition, the lack of regular time series of measurements was not insurmountable – model calibration was generally good at a monthly time scale despite having some locations and times without sufficient data.

Increasing the complexity of the model might increase its ability to model a specific situation, but the increase in the number of required parameters will necessarily result in greater uncertainty in the model results unless accompanied by a supporting data framework. The ability to forecast Delta conditions could decline due to the greater level of uncertainty. The strategy adopted for the QUAL nutrient model calibration - minimizing the reaction rates that are varied by selecting the most sensitive parameters - generally will result in a model with better predictive power as it avoids over-fitting which reduces predictive ability of the calibrated model (Larsen, 1997; Gilroy and McCuen, 2011; Friedel, 2006; Schoups et al., 2008; Fischer et al., 2009; Leangruxa et al., 2004).

The weaknesses in QUAL's nutrient formulation are shared somewhat with many of the models in use at present (Edelfeldt and Fritzen, 2008; Kazezyilmaz-Alhan et al., 2007). One clear weakness discussed in several sections of this report is the constraint of setting all meteorological parameters globally. Wind speed in particular can influence water quality conditions for other constituents, not just temperature, although the greatest improvement with regionalized meteorology would be in improving seasonal water temperature results.

Another weakness is the limitation to a single algal group and the lack of other categories at the lower rungs of the food web, such as zooplankton. Discussions with biologists highlighted the need to incorporate additional equations to simulate more complex interactions at this level. As different species of algae will utilize nutrients differently, for example, temperature-dependent growth rates will vary across species and there are differences in preferred habitat (e.g., water column vs. substrate, still water vs. flowing water). In addition, bacteria have a large influence on nutrient dynamics, but there is no clear mechanism to capture their overall effects in the model as they do not appear as biomass in any equation. Setting decay rates for some of the constituents partially compensates for this lack. There is data available on zooplankton, so adding additional relationships at this level can be justified.

The question of whether the current conceptual model is adequate to characterize the inhibitory effect of too much ammonia is open. Some biologists (e.g., Pat Gilbert) suggested that it is not

the absolute concentration that dictates utilization of ammonia over nitrate by some algae (e.g., Dugdale's inhibitory level), but instead the relative availability of the nutrients. The current model formulation allows for a preference factor between ammonia and nitrate expressed as a ratio, which she suggested should be sufficient once the algal species that are present have been determined.

Although the current conceptual formulation that models the dynamics of organic matter is somewhat standard, the lack of measurements of two components – CBOD/BOD and organic-P – meant the ability to model a large portion of the nutrient dynamics was missing. This is a combined problem of lack of measurement and lack of a suitable concept to model the measurements that exist.

Finally, as discussed below in Section 19.2.4, the model does not track mass efficiently. It is theoretically possible to account for all sources and sinks of mass in a nutrient model, but it is not possible in QUAL as the movement of nutrients is not tracked. Carbon is not accounted for at all in QUAL, although it is clearly presented in CBOD, organic-N and organic-P. As a consequence, it is not possible to utilize QUAL's fingerprinting capabilities for nutrients.

19.2 Areas for Model Development

As mentioned above, the simplicity of QUAL's nutrient formulation was generally a strength in its ability to model the entire Delta over the long time frames considered here given the limitations on data availability. While inclusion of more complex dynamics may improve the ability to conceptualize a greater range of systems, it requires a commensurate level of increase in data collection to support the increased complexity.

To adequately address the question of model development needed for specific applications, such as testing the inhibitory effect of ammonium ion concentration on primary productivity, a clear problem statement and a modeling objective would need to be formulated.

19.2.1 Temperature/meteorology

As discussed several times, meteorological input needs to be regionalized – set locally rather than globally – to capture the range of conditions found across the Delta, particularly wind speed.

Water temperature proved to be very sensitive to heat loss due to evaporation. In QUAL, surface heat conduction, Q_e, is a function of wind speed, $f(W)$, e_s and e_a (saturation vapor pressure and water vapor pressure, respectively) and a constant C (specific weight of water times the latent heat of vaporization):

$$Q_e = C*f(W)* (e_s – e_a)$$

Note that e_s and e_a are functions of surface water temperature, air temperature and wet bulb temperature. The formulation for the wind speed function, $f(W)$, is given by:

$$f(W) = a + bW$$

where *W* is wind speed, assumed measured at 2.0 m height and *a* and *b* are empirical coefficients that are used to calibrate the effects of evaporation.

There are other formulations available for the effects of wind on water temperature (Cole and Wells, 2008). During the calibration process, it was found that the available parameters were not quite sufficient for capturing heat loss during summer periods. Instead, the effects of wind were increased during warm periods - in the Delta summer winds generally increase in the afternoon. This indicates that the following formulation (Cole and Wells, 2008) may be more appropriate:

$$f(W) = a + bW^C$$

where *c* is another empirical coefficient, assumed in (Cole and Wells, 2008) to be two (2). If set to a value greater than 1, evaporative cooling would increase with wind speed which might be sufficient to capture decreased water temperature (increased evaporative loss) in the summer.

19.2.2 Algae, bacteria and plant growth

An important extension to the model would be the ability to simulate the dynamics of multiple algae species, or more generically, multiple low-level consumers and producers. In a practical sense, incorporating more than one equation for algae is no more difficult than incorporating multiple equations to model algal species, or for other producers and consumers low in the food web. This statement incorporates the discussion on mass balance, where as mentioned in Sections 19.2.and 19.2.4 below, bacteria are active in the dynamics of the system but their mass is not accounted for in the model formulation.

There are also primary producers in or at sediment level that participate in nutrient dynamics that are not accounted for, such as aquatic plants. Sediment dynamics are represented in a rudimentary manner and inclusion of macrophytes and benthic algae as individual entities would help capture the actual dynamics in some regions of the model. Some researchers have included macrophytes in a rudimentary manner consistent with the current formulation in QUAL (Park and Uchrin, 1997).

19.2.3 Other Benthic interactions

The current model formulation does not adequately allow for the effects of clams – *Corbula* and *Corbicula* in particular – that are currently believed to be causing problems at the base of the food web. Although it is would be difficult to include the biomass of clams (i.e., it would be difficult to include clam biomass as a state variable), it is possible to include their effect nutrient dynamics as rate coefficients. Salinity and temperature would need to be incorporated in the rates, as discussed in Section 18.

19.2.4 Mass Balance and Organic Matter

A basic problem with the nutrient formulation in QUAL, as in many nutrient models, is the lack of closure in mass balance. There are several contributions to this problem – CBOD, ignoring mass of other primary producers and lack of mass balance in the sediment. CBOD is ill-defined as it does not account for all biodegradable organic matter (Shanahan et al., 1998). The value for CBOD changes with the source of the material – so rates of CBOD consumption and biomass consumed can vary widely (Shanahan et al., 1998).

In addition, calculating a mass balance for the state variables requires that mass losses and gains to sediment must be properly accounted for. Because the SOD losses are not tied to CBOD mass loss or gain, mass balance overall cannot be accounted for.

Although bacteria mediate the loss rates for constituents through decay rates, their biomass is also ignored. Bacteria would need to be treated as a state variable, similar to algae, with an equation describing the movement of mass into and out of the water column as a function of the rate coefficients.

There are disaggregated formulations in nutrient models (Cole and Wells, 2008) for the representation of organic matter and CBOD – representing, for example, "fast" and "slow" reacting CBOD (Shen et al., 2002) and/or dissolved and particulate labile and refractory organic matter for both N- and P-fractions. Using the labile and refractory split for organic matter requires eight equations (Cole and Wells, 2008), plus measurements and rate parameters to support the dynamics of these refined nutrient interactions.

20 Discussion

Of the areas for development discussed above, only a few are important to improve the representation of nitrogen dynamics given the available data. Clearly, improving the representation of meteorology through regionalization is a straightforward fix that is necessary if the model is to be used in a predictive manner if greater detail on Delta-wide water temperature is important in a given study.

Including a refined level of state variables at the base of the food web – for example, additional algal species and more than one species of bacteria – would increase the ability to capture the consumption and production of N-constituents at the expense of additional data gathering requirements. However, an improved formulation and additional data acquisition would address the central questions of this study on the role of ammonia in nutrient dynamics, and if high concentrations are suppressing algal growth.

Refining the model sufficiently to attain a set of state variables that each observe a mass balance criterion and that can describe both the water column, pelagic and benthic interactions is an ideal goal, but would require a rewrite of the entire model.

Including additional reaction rates for nutrient sinks and sources for teasing out the effects of *Corbula* and *Corbicula* would allow a better representation of the nutrient sinks in the Delta (Jassby 2008). This could be approached by tying reaction rates to salinity (and potentially other state variables) without requiring a strict mass balance, similar to the approach currently used for bacteria. Or, the biomass of clams could be included in a more rigorous fashion through a set of equations conceptualizing generic benthic inhabitants in which a mass balance for the system is better approximated than at present.

Some models have simplified the representation of P-constituents (Shen et al., 2002), which might work well in this system, given the lack of organic-P measurements available in the Delta.

Although the effect of pH may be important in specialized situations, the current study did not find an overwhelming need to include pH-dependence in the reactions, as equilibrium calculations indicated that under typical conditions in the Delta, ammonia will be generally found in its ionized form as NH_4^+. In addition, the system will be outgassing CO_2 as biotic activity overwhelms atmospheric contributions of CO_2 so pH buffering by the atmosphere is generally not a driving force in the dynamics. However, a specialized study on a smaller scale (than the entire Delta) with adequate spatial and temporal data acquisition could justify the expense of this addition, as it is not conceptually difficult to include CO_2 chemistry tied to pH in surface waters.

Macrophytes and Submerged Aquatic vegetation (SAV) will be important in Delta nutrient dynamics, but their effect was not evident in the current study, perhaps because the focus was on the Sacramento River corridor, and not on the central and south Delta.

21 Monitoring program

Two considerations dominate the definition of a monitoring program – frequency of measurement and spatial density of measurement locations. In the current modeling effort, it was mainly the time scale of the data (monthly-irregular) that dictated the accuracy of the results, although there were two regions of the model where data coverage was clearly insufficient. Despite these constraints, the data available for developing the model was generally sufficient for the task of modeling nutrient dynamics with a focus on ammonia on the Sacramento River on a monthly time scale.

The third consideration is cost – that constraint is not explicitly considered here, other than in the evaluation of priorities. EC monitoring is not included in this section, as the Delta salinity monitoring program is quite extensive and not in need of overhaul in order to improve the modeling of nutrient dynamics.

21.1 Current/past data gathering efforts

Generally, the quality of data considered in this report (generally from publically funded sources) was better in recent years (2000 –present), while geographical coverage was better historically (1990 – 1995). Sections 6 - 8 cover the current data set, from data sources, availability to use in setting boundary conditions. Section 25.1 in Appendix 1 details all of the data sources and the frequency of measurement for each of the modeled constituents.

21.1.1 Data Coverage

There are three regions in the model domain where the spatial density of data was most problematic – in the Yolo/Cache area in the northeastern Delta, and in Suisun Marsh (Figure 25-16). There were measurements available in the south and central Delta, but the spatial coverage was low and the time span was not consistent. There was insufficient data available at the northernmost boundary of the model (see Section 9.5.1.1) particularly for N-constituents, although this difficulty was not critical as there were downstream measurements available to help develop the Sacramento R. boundary condition.

The situation was somewhat better for temperature modeling, although the same areas (Suisun Marsh and the Yolo/Cache Slough area) were clearly deficient in spatial data density. The density of in-Delta measurements and the number of measurements available for calibration and validation were sufficient to produce a Delta-wide temperature model. However, there is the proviso that meteorological boundary conditions need to be regionalized in the numerical model, so the calibration in the north Delta is superior to the results in the south Delta.

As discussed in previous sections of this report, there were two constituents, organic-P and CBOD, that did not have sufficient data available to calibrate the model parameters with any confidence.

21.1.2 Sufficiency for Ammonia/temperature modeling

The availability of N-constituents, including ammonia, was better than for other constituents, so the data were sufficient for developing a model with accuracy up to a monthly time scale. The EMP has a long-term dataset that includes several measurement locations in the Delta and at or near the model boundaries, and the main sources of N-constituents from waste water, near Stockton and Sacramento, each had data sets with most of the modeled constituents that covered most of the 19-year modeled period. The smaller waste water treatment facilities had mixed coverage. Sections 8.8.2 and 21.1.1 discuss the availability of temperature data, which was sufficient for validation and calibration. Sections 8 and 9 have detailed descriptions of the data available for defining the model boundaries and for calibration.

21.2 Suggested Monitoring Regime for the Current Conceptual Model

This section covers suggestions for a monitoring program under the assumption that the scheme will be used in the current model formulation, and that measurements should be taken for each of the modeled constituents.

21.2.1 Temporal coverage

The desired temporal coverage depends somewhat on the demands of the modeling effort –a model aiming at temporal scale on the order of months requires fewer data points than a model hoping to capture diurnal or tidal variations. Table 21-1 gives a listing of the suggested timing for the measurement of the primary model constituents, other than EC, with a coarse breakdown by desired temporal accuracy under the assumption of a daily accuracy requirement (approximately).

For water temperature modeling, because instrumentation is relatively simple to maintain and it can be placed in-situ, the suggested measurement frequency is hourly and at a minimum daily. Meteorological measurements are generally taken at least hourly.

If a special study were to be developed, then tidal timing and measurement frequency would need to considered together, under the assumption that the more difficult or costly measurements would be taken sporadically at a higher frequency, and most likely at a finer spatial scale. Occasional high frequency measurements (several times a day) are important for teasing out tidal effects and day/night fluctuations in dynamics.

21.2.2 Spatial/Regional coverage

Figure 21-1 through Figure 21-4 illustrate suggested sampling locations for an enhanced monitoring scheme, with lesser priority locations indicated by yellow stars. Ideally, for most of the nutrients, all locations would be sampled. The new monitoring locations cover areas that appear to important dynamically in the model (Cache Slough, Jersey Point) or because they are near model boundaries (Figure 21-1) or in major channels or sloughs (for example, in Suisun Marsh, Figure 21-3).

21.2.3 Supplementary measurements

Full sets of water analyses at monthly or weekly intervals are valuable in providing a detailed view of the water chemistry, For example, in this report R. Dahlgren's dataset was used to develop EQ3/6 geochemical models that helped define aspects of the system's water chemistry such as level of biological activity.

Pat Gilbert and others recognized the need to distinguish between algal species and bacteria utilizing and transforming the nutrients. Although the current model formulation only allows for one algal species, one suggested improvement to the conceptual and numerical models is the inclusion of multiple algal and bacterial species. This would require additional measurements as a high priority.

Currently, measurements of biological activity in the sediment are not available. Although the model concept for sediment interactions is currently rudimentary, the lack of information to inform parameters utilized in the sediment dynamics was a drawback.

21.3 Priority measurements

Each of the modeled constituents needs to be measured, including CBOD and organic-P which are not currently measured. The frequency should be at least at the desired temporal accuracy in Table 21-1, under the assumption that a model with daily temporal accuracy should be developed. Of the locations identified as higher priority in Figure 21-1 through Figure 21-4, the Yolo/Cache region and the north Delta (Sacramento River model boundary through Georgiana Slough) are the most important areas to obtain supplementary measurements for ammonia dynamics in the current study.

21.4 Monitoring for an Improved Conceptual Model

Organic matter can be more or less bioavailable, and the current model does not allow the disaggregation of organic materials. A major improvement to the conceptual model would be an improved methodology for the dynamics of organic matter consumption and production. This would require an extensive collection regime for organic data measurements.

Table 21-1 Basic temporal measurement scheme for the current nutrient model.

Location	Constituent	Desired Temporal Accuracy	Measurement Frequency	Max/Min	Special Study
Inflow/outflow Boundary	Water temperature	hourly	hourly		several times/day
	All meteorlogy	hourly	hourly		
	Flow	hourly to daily	hourly to daily		
	Ammonia	Daily	Daily to several times/wk		several times/day
	Nitrate	Daily	Daily to several times/wk		several times/day
	Nitrite	Daily	Daily to several times/wk		several times/day
	CBOD	weekly	weekly		daily
	DO	hourly	hourly		hourly
	PO_4	Daily	Daily to several times/wk		several times/day
	Chl-a/POM	Daily to several times/wk	Daily to several times/wk		several times/day
	TKN or Organic-N	Daily to several times/wk	Daily to several times/wk		several times/day
	Organic-P	several times/wk	several times/wk		daily
In-Delta/Receiving Water	Water temperature	12 hour	hourly	daily	
	All meteorlogy	hourly	hourly	daily	
	Flow	6 hour	Hourly to daily		
	Ammonia	Daily	Daily to several times/wk		several times/day
	Nitrate	Daily	Daily to several times/wk		several times/day
	Nitrite	Daily	Daily to several times/wk		several times/day
	CBOD	weekly	weekly		daily
	DO	hourly	hourly		hourly
	PO_4	Daily	Daily to several times/wk		several times/day
	Chl-a/POM	Daily to several times/wk	Daily to several times/wk		several times/day
	TKN or Organic-N	Daily to several times/wk	Daily to several times/wk		several times/day
	Organic-P	several times/wk	several times/wk		daily
Effluent	Water temperature	12 hour	hourly	daily	
	Flow	6 hour	hourly to daily	daily	
	Ammonia	12 hour	12 hour		
	Nitrate	daily	daily		
	Nitrite	weekly	weekly		
	CBOD	weekly	weekly		
	DO	daily	daily		
	PO_4	daily	daily		
	Chl-a/POM	monthly	monthly		
	TKN or Organic-N	several times/wk	several times/wk		
	Organic-P	weekly	weekly		

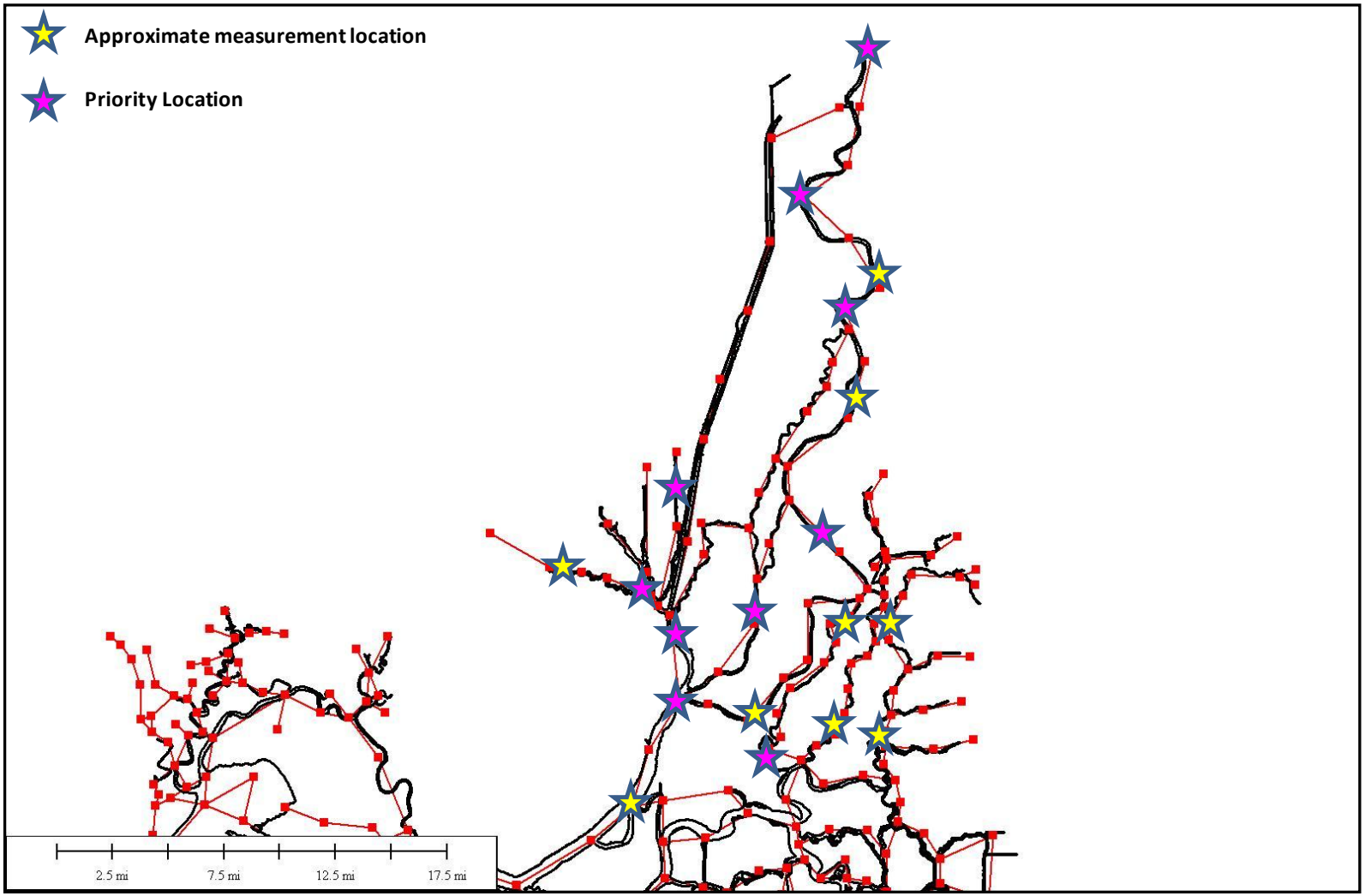


Figure 21-1 Suggested and prioritized locations for an enhanced nutrient monitoring scheme in the north Delta.

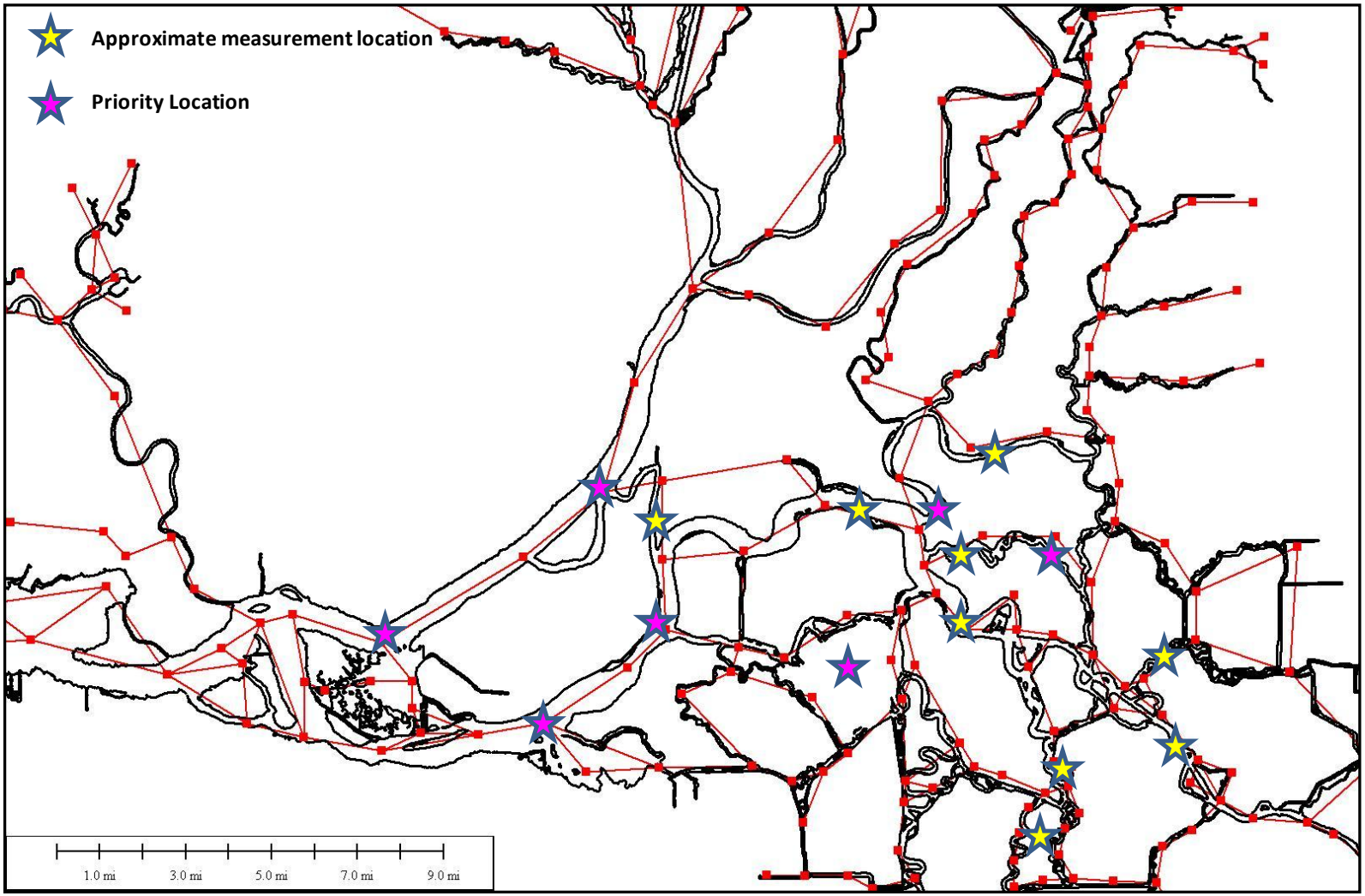


Figure 21-2 Suggested and prioritized locations for an enhanced nutrient monitoring scheme in the eastern Delta.

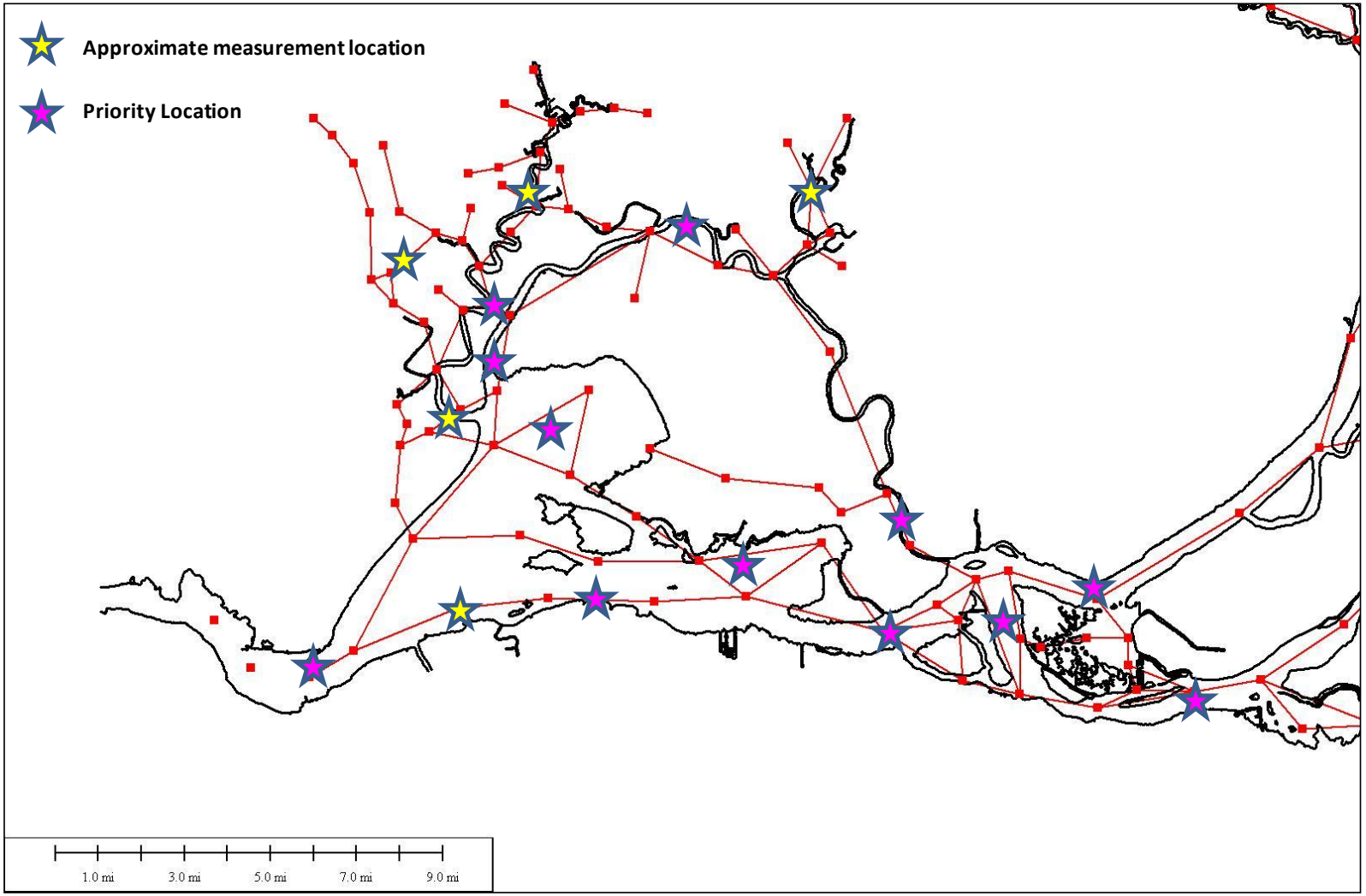


Figure 21-3 Suggested and prioritized locations for an enhanced nutrient monitoring scheme in the western Delta.

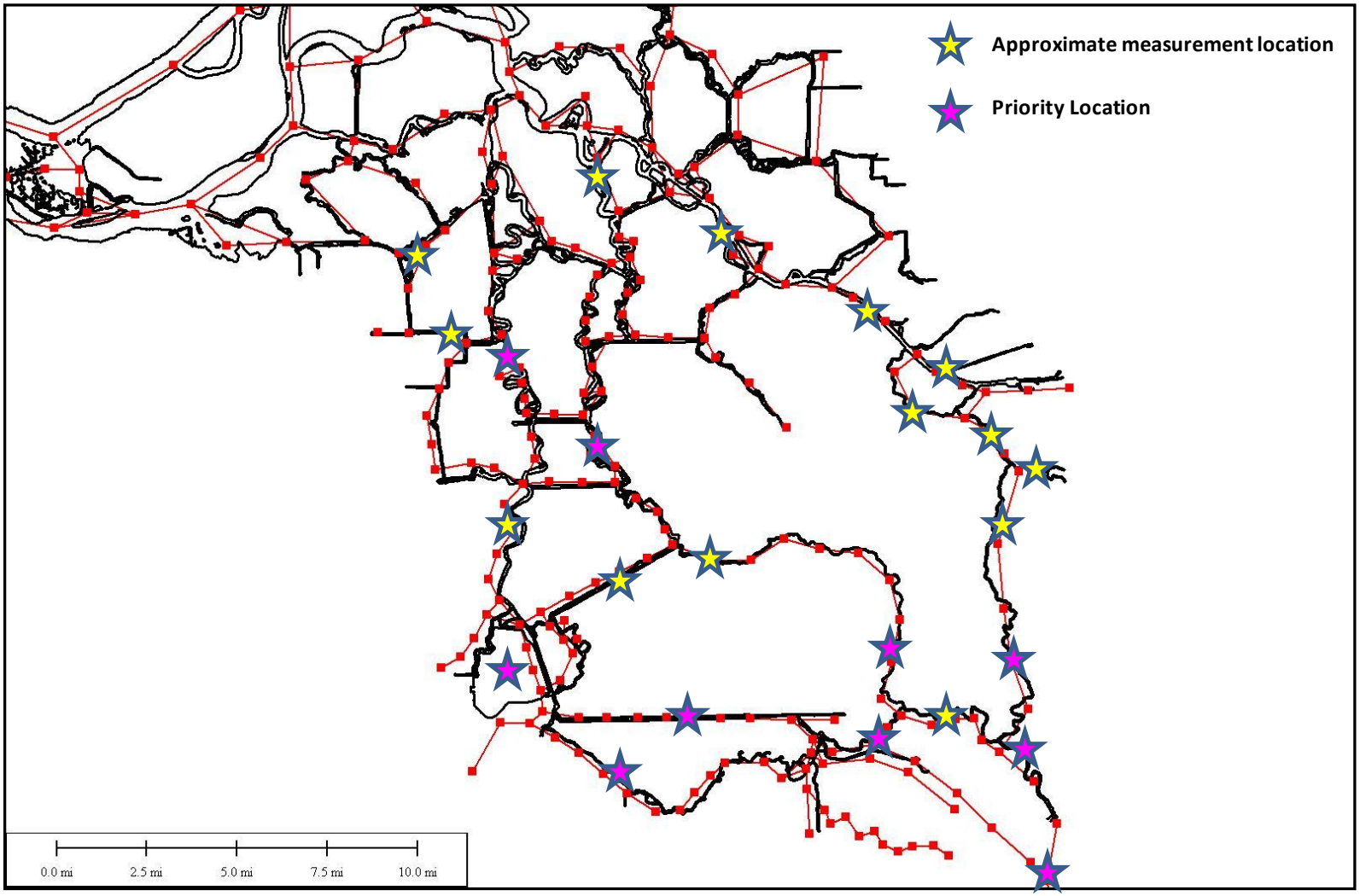


Figure 21-4 Suggested and prioritized locations for an enhanced nutrient monitoring scheme in the south Delta.

22 Summary and Conclusions

DSM2-QUAL was calibrated for water temperature and nutrients, with a focus on ammonia dynamics. Calibration and validation statistics indicate that the model calibration is very good for temperature along the Sacramento River corridor and the lower San Joaquin River, and good but biased to cooler-than desire temperatures in the south Delta and at upstream locations on the San Joaquin River.

The nutrient model in DSM2, QUAL, has a simple conceptual formulation that proved sufficient for the task of modeling a long time frame, 1990 – 2008, over the entire Delta. The frequency of boundary conditions for the nutrients, essentially monthly, dictated the level of accuracy in model results. Calibration for the N-constituents was generally very good, except at a few locations. Calibration for the P-constituents was not as good, as organic-P measurements are not available to help constrain those constituents. In areas where there were few or no measurements, boundary conditions were set at reasonable levels to maintain calibration at downstream locations.

The Yolo/Cache area appears to be important locally near Rio Vista and downstream to the confluence. The inclusion of new flow data at the Lisbon Toe Drain had a noticeable influence on nutrient dynamics and on volumetric contributions around Rio Vista and at downstream locations. Inclusion of a flooded Liberty Island in the DSM2 grid generally increased algal biomass at downstream locations and decreased concentrations of N-constituents.

One improvement in the model that would help clarify nutrient dynamics for ammonia is the inclusion of a refined level of state variables at the base of the food web – for example, additional algal species and more than one species of bacteria – would increase the ability to capture the consumption and production of N-constituents at the expense of additional data gathering requirements. However, an improved formulation and additional data acquisition would address the central questions of this study on the role of ammonia in nutrient dynamics, and if high concentrations are suppressing algal growth.

The model formulation proved inadequate to capture the effect of clams (*Corbula* and *Corbicula*). There are several possible approaches for improving the conceptual model to capture their effects on the food web. The most difficult area to improve in the model is the treatment of organic materials. Most changes would require a major overhaul of the conceptual model.

Although the data were sufficient to develop a nutrient model focusing on ammonia dynamics, there are several ways in which the monitoring programs should be improved. First, some model constituents are not measured (organic-P and CBOD), which becomes a problem in P-constituent dynamics. Next, some regions of the model do not have any coverage, and some areas have marginal coverage. The Yolo/Cache area and portions of the eastern Delta need measurement locations as there are currently none. Next, Suisun Marsh and the central Delta could use

measurement locations, as most of the data that currently available ends in 1995. Ancillary measurements should be taken along with the main constituents at infrequent intervals. Full sets of chemical analyses sufficient to develop geochemical (thermodynamically-based) models help clarify the driving processes. Also, measurements to distinguish between dominant algal species and bacteria would help clarify the dynamics, and could inform an improved conceptual model in QUAL. Finally, sediments should be sampled to analyzed possible contributions to nutrient dynamics from resident algae or macrophytes.

A sensitivity study of the model to increases and decreases in N-constituent concentrations for DICU, at the Sacramento and Joaquin Rivers, and for the Sacramento and Stockton WWTP's was completed. Changing the Stockton WWTP concentrations had only minor effect, mainly in nitrate concentration. The effects ceased at Twitchell Island. Similar results were seen in changing the concentrations at the San Joaquin boundary, although the effects persisted past Jersey Point.

Changing concentrations at the Sacramento River boundary produced changes in nitrite concentration which were largest in drier years, while nitrate concentration changes were largest in wetter years. Changes persisted past Potato Point into the lower San Joaquin and to a small degree into the Suisun Bay area. Changing N-constituent concentrations at the Sac Regional WWTP had a larger effect. The changes in N-constituent concentration downstream of the Sac Regional WWTP were large and sustained along the Sacramento R. corridor to Suisun Bay. Ammonia and nitrite concentrations showed the largest shifts. Algal biomass increased or decreased to small degree as effluent-N increased and decreased.

A scenario was developed in which Sac Regional WWTP operations were switched to nitrification. As expected, concentrations of ammonia decrease and nitrate increase. Nitrite shows large decreases at all locations which are apparently linked to the ammonia decrease. The dynamics are complicated, and in some cases, there is a shift in the timing of high points and low points in concentration particularly for nitrate. Algal growth is inhibited somewhat, with a few exceptions in wetter years.

23 Next Steps

The following suggestions highlight possible areas for extending the results of the current study.

23.1 Extending Model to Current Day

The Historical nutrient model ends Dec. 31, 2008, but there are new sets of high quality nutrient measurements available to extend the nutrient model results through July. Boundary conditions for HYDRO and QUAL-EC are also available.

As discussed at the "Ammonia Summit", several groups and agencies have recently undertaken extensive nutrient measurements in the investigation of ammonia issues. These measurements are available for use to further our understanding of nutrient dynamics, and as an additional

means of assessing and improving model definition. These data remove some of the major problems with the historic data – the spatial density of measurements is much higher, measurements have been taken in the critically important Yolo/Cache area, and measurements have been taken at a higher temporal frequency to allow for assessment on a fine time scale (less than daily). Because overlapping measurements have been taken by several parties, the uncertainty in the data and model can be minimized.

23.2 Better DICU Boundary Conditions

Due to time and budgetary constraints, the DICU boundary conditions utilized in the nutrient modeling of DO problems in the San Joaquin River (Rajbhandari, 2001) were accepted without modification in the nutrient modeling discussed in this report – these estimates are applied as constant concentrations. Estimation of DICU return flow concentrations (including water temperature) are available on a monthly basis (DWR 1995, 1995b), and these values could be easily be applied in the current nutrient model.

23.3 Publication

With some additional work, the effort undertaken for this report can form the backbone and a major portion of the work required for producing a publication in a peer-reviewed journal. A refinement of some aspects of the model calibration should be completed. For example, it is possible to develop return values for mass currently lost at the Martinez boundary due to tidal activity. A refinement of the Yolo, and Sacramento and San Joaquin River boundary conditions could improve the downstream results of some constituents. Although much work has been completed (summarized in this report), the analysis of the results can be deepened, and more pointedly address the issue of the sources and sinks of ammonia in the Delta. A synthesis of model results and data would greatly strengthen publication potential.

23.4 Extending Modeled Period Back in Time

The current Historical model time span begins in 1990, but the DMS in DWR has been working to extend the Historical model back to the time before *Corbula* invaded the estuary. The model calibration to date was limited by the inability to model algal dynamics without the interference of *Corbula*. Calibrating the model to a *Corbula*-free period could allow a better attempt at quantitatively assessing the effect clams have had on the base of the food web in the Delta.

The EMP has been collecting measurements at many locations in the Delta since the 1970's, so there is a dataset of measurements available to use in setting inflow boundary conditions and in calibrating the model.

23.5 Uncertainty Analysis

All models are plagued by various sources of uncertainty, and there are methodologies available to capture the uncertainty in model calculations (Abrishamchi et al., 2005; Himesh et al., 2000). For example, it is possible to run a Monte Carlo analysis using DSM2/QUAL over reasonable

time frames, such as several years. These model runs are sufficiently short and computing power is easily available to accommodate such analyses.

A Monte Carlo analysis could set bounds on the uncertainty of model predictions that are important to understand both in a scientific sense and in a regulatory sense.

23.6 Comparative Nutrient Model/Isotope Analyses

Although some collaboration has taken place with USGS researchers (Kendall *et al.*), there was not funding in the original scope of work to pursue a full comparative analysis of the isotope findings in the nutrient model results. DSM2 model results are useful in understanding isotope analyses, and there is great potential for constraining and analyzing modeled nutrient results.

23.7 Yolo/Cache Region and Liberty Island Recalibration

The new DSM2 Liberty grid results have shown that the Yolo/Liberty/Cache Sl. area can have important effect of nutrient levels downstream of the confluence with the Sacramento R. RMA has worked extensively on the representation of this regions, so an improved set of flow boundary conditions is available for use. Additional research into nutrient data acquired by special studies would be helpful - collecting this data were an effort that went beyond the needs for this calibration report.

The Yolo/Cache region has proved particularly important in nutrient dynamics downstream of the Sac Regional effluent outfall, as recent measurements indicate the dynamics near Rio Vista are apparently heavily influenced by the tidal dynamics with the Yolo/Cache area. Improving the model representation of this region could help resolve some of the questions the measurement analyses have been posing.

Several WWTPs have effluent flowing into this region – their contributions were not included as the Liberty grid had not been finalized when the model was developed. Given the relatively large effect the region has on downstream nutrient dynamics and the large effect the inclusion of a flooded Liberty Island has on ammonia and algal dynamics, the refinement of the nutrient dynamics and inclusion of additional effluent sources should be a priority. These areas are becoming increasingly important as restoration areas, and the first step in understanding restoration potential is improving the understanding what is currently happening in nutrient dynamics there.

23.8 Suisun Marsh region

RMA has worked extensively on improving the representation of the Suisun Marsh, so an improved set of flow and salinity boundary conditions and calibration data are available for use. DWR Suisun Marsh Branch has developed an improved grid in the marsh area (Kate Le, personal communication). Additional effort in obtaining nutrient data acquired by special studies would be needed, an effort that went beyond the effort required for this calibration report.

As discussed in Sections 8 and 15, data documented in Lehman (2010) and compared to model output resulted in a modification of Yolo/Cache boundary conditions and parameterization in Liberty Island. Although this has improved the model in this region, the Yolo/Cache region is complex hydrodynamically and therefore requires more detailed data and analysis.

24 References

Abrishamchi, A., M. Tajrishi, and P. Shafieian. 2005. Uncertainty analysis in QUAL2E model of Zayandeh-Rood River. Water Environment Research, 77(2).

Anderson, J. 2002. California Department of Water Resources: 2002 Annual Progress Report. Chap 14: DSM2 Fingerprinting Methodology.

Brake, B. E. Biochemical Oxygen Demand and Carbonaceous BOD in Water and Wastewater. 1998. Washington State Department of Ecology.

Brown, L. C., and T. O. Barnwell, Jr. 1987.The Enhanced Stream Water Quality Models QUAL2E and QUAL2E-UNCAS: Documentation and User Manual.EPA-600/3-87/007. U.S. Environmental Protection Agency.

Chapra, S., G. Pelletier and H. Tao. 2008. QUAL2K Model Documentation: A modeling framework for simulating river and stream water quality.

Chilmakuri,C. 2010. Overview of Recent DSM2 Recalibration for BDCP. http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/DSM2UsersGroup/DSM2_Recalibration_102709.pdf

Chow, A.T., R.A. Dahlgren, and J. Harrison. 2007. Watershed sources of disinfection byproduct precursors in the Sacramento and San Joaquin Rivers, California. Environ. Sci. and Technology. Vol. 41.

Clesceri, L.S., A.E. Greenberg and A.D. Eaton (eds). 1999. Standard Methods for Examination of Water and Wastewater 20th edition. American Public Health. Association. Washington DC

Cole, T.M. and S. A. Wells. 2008. CE-Qual-W2: User's Manual. U.S. Army Corps of Engineers.

Cole, T.M. 1994. CE-QUAL-W2. Version 2.0," Vol. E-94-1. U.S. Army Corps of Engineers.

DWR, 1995a. "Estimation of Delta Island Diversions and Return Flows". California Department of Water Resources, Division of Planning.

DWR, 1995b. "Representative Delta Island Return Flow Quality for Use in DSM2". California Department of Water Resources, Division of Planning. February.

DWR, 2007. "LiDAR Survey of the Sacramento-San Joaquin Delta". California Department of Water Resources, Delta-Suisun Marsh Office. May.

Dugdale, R.C., F.P Wilkerson, V.E. Hoague, A. Marchi. 2007. The role of ammonium and nitrate in spring bloom development in San Francisco Bay. Est. Coastal and Shelf Sci. Vol. 73.

Edelfeldt, S. and P. Fritzson. 2007. Evaluation and comparison of models and modeling tools simulating nitrogen processes in treatment wetlands. Simulation Modelling. Vol. 16.

Fischer, C. S. Kralisch, P. Krause, M. Fink, W.-A. Flugel. 2009. Calibration of hydrologic model parameters with the JAMS framework. (Conference Proceedings) MODSIM Congress. Cairns, Australia.

Firiedel, M.J. 2008. Predictive streamflow uncertainty in relation to calibration-constraint information, and model bias. International J. of River Basin Management. Volume 4:2, 109 – 123.

Gilory, K.L. R.H. McCuren. 2011 The effect of hydrologic model development and calibration complexity on prediction accuracy. Int. J. Hydrology Science and Technology. Vol.1, No.'s 1/2.

Himesh, S. C. Rao and A. Mahajan. 2000. Calibration and Validation of Water Quality Model (CAE 1 River). Technical Report CM 002. CSIRO Centre for Mathematical Modelling and Computer Simulation.

Jassby, A. D. 2008. Phytoplankton in the upper San Francisco estuary: Recent biomass trends, their causes and their trophic significance. SF Estuary and Watershed Sci. 6(1).

Jassby, A. D., A. B. Muller-Solger, and M. Vayssieres. 2005. Short-term variability of chlorophyll and implications for sampling frequency in the San Joaquin River, IEP Newsletter 18(1).

Jobson, H.E. 1997. Enhancements to the Branched Lagrangian Transport Modeling System. USGS Water resources Investigation Report 97-4050.

Kazezyilmaz-Alhan, C. M., M. A. Medina Jr., and C. J. Richardson.2007. A wetland and water quality model incorporating surface and water quality interactions. Water Resources Res. Vol. 43.

Kendall, C., Young, M.B., and Silva, S.R. (2008) Determination of Sources of Organic Matter and Nutrients in the San Joaquin River, Final Interpretive Report for the PIN700 project, September 2008, 470p (unpublished).

Kim, S.M., C.H. Seong, S.W. Park. 2009. Assessment of water quality calibration criteria for field-scale water quality model. 7th World Congress on Computers in Agriculture Conference Proceedings. Reno, NV, USA.

Larsen, T. 1997. Some remarks on the calibration and validation of numerical water quality models. (Conference Proceedings) First International Conference on Measuring and Modeling Environmental Pollution. Madrid, Spain.

Leangruxa,P., K-J. Hesse, R. Mayerle. 2004. Calibration of a water quality model for the nutrient distribution in the Meldorf Bight, Germany. (Conference Proceedings) Coastal Engineering 2004.

Lehman, P. W. S. Mayr, L. Mecum. C. Enright. (2010) The freshwater tidal wetland Liberty Island, CA was both a source and a sink of inorganic and organic material to the San Francisco estuary. Aquatic Ecology. 0(0) pp. 1-14.

Moriasi, D.N., J.G. Arnold, M.W. Van Liew, R.L. Bingner, R.D. Harmel, and T.L. Vieth. 2007 Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the ASABE. Vol. 50(3).

Muller-Solger, A. 2002. EMP Multiparameter-Shore Station Fluorescence to Chlorophyll a conversions (Source: personal communication).

Park, S.S. and C.G. Uchrin. 1997. A stoichiometric model for water quality interactions in macrophyte dominated water bodies. Ecological Modelling. Vol. 96.

Rajbhandari, H. 2005. California Department of Water Resources: 2005 Annual Progress Report, Chap 4: Sensitivity of DSM2 Temperature Simulations to Time Step Size.

Rajbhandari, H. DWR 2004. Annual Progress Report, Chap 4: Modeling Dissolved Oxygen and Temperature in DSM2 Planning Studies. 2004.

Rajbhandari, H. 2003. California Department of Water Resources: 2003 Annual Progress Report, Chap 3: Extending DSM2-QUAL Calibration of Dissolved Oxygen.

Rajbhandari, H. 2001. California Department of Water Resources: 2001 Annual Progress Report, Chap 6: Dissolved Oxygen and Temperature Modeling Using DSM2.

Rajbhandari, H. 2000. California Department of Water Resources: 2000 Annual Progress Report, Chap 9: Dissolved Oxygen Modeling Using DSM2-QUAL.

Rajbhandari, H. 1995a. Dynamic simulation of water quality in surface water systems utilizing a Lagrangian reference frame. Ph.D. Dissertation. University of California, Davis.

Rajbhandari, H. 1995b. California Department of Water Resources: 1995 Annual Progress Report, Chap 3: Water Quality.

Randall, D.J. and T.K.N. Tsui. 2002. Ammonia toxicity in fish. Marine Pollution Bul. Vol. 45.

RMA (Resource Management Associates) 2000. Flooded Islands Pre-Feasibility Study: RMA Delta Island Calibration Report.

Schoellhamer, D.H. 2001. Singular spectrum analysis for time series missing data. Geophys. Research Letters. 28(16).

Schoups, G., N.C. van der Giesen, H.H.G. Savneijie.2008. Model complexity control for hydrologic prediction. Water Res. Res. Vol. 44

Shanahan, P. M. Henze, L. Koncsos, W. Rauch, P. Reichert, L. Somlyody and P. Vanrolleghem. 1998. River water quality modeling: II. Problems of the Art. Presented at: IAWQ Biennial International Conference. Vancouver, B.C.

Shen, Y., Y. Zheng, T. Komatso and N. Kohashi. 2002. A three-dimensional numerical model of hydrodynamics and water quality in Hakata Bay. Ocean Engr. Vol. 29.

Swift, T., R. DuVall, S. Balachandra. 2009. Jones Tract Flood Water Quality Investigations. Division of Environmental Services, California Department of Water Resources.

Thompson, J. PowerPoint presentation available on web: http://science.calwater.ca.gov/pdf/workshops/workshop_dcm2_presentation_Thompson.pdf

Trucano, T.G., L.P. Swiler, T. Igusa, W.L. Oberkampf, M. Pilch. 2005. Calibration, validation and sensitivity analysis: What's what. Reliability Engr.& Sys. Safety. Vol. 91: 1331-1357.

USGS, 2008. The Computer Program FourPt (Version 95.01). Water Resources Investigation Report 97-4016.

Wilkerson, F.P, R.C. Dugdale, V.E. Hogue and A. Marchi. 2006. Phytoplankton blooms and nitrogen productivity in San Francisco Bay. Estuaries and Coasts. 29(3).

Wolery, T.J. 1992. A computer program for geochemical aqueous speciation solubility calculations: theoretical manual user's guide, and related documentation (Version 7.0).Lawrence Livermore Nat. Lab. Report, UCRL-MA-110662 PT III.

25 APPENDIX I

25.1 Data Sources – Figures and Tables

Table 25-1 Data source naming conventions.

Common Name	RKI Label	USGS Label	EMP name	Other
Martinez	RSAC054	PO-08	Suisun Bulls-Head	MTZ
Chipps	RSAC075			
Pittsburg	RSAC077			
Collinsville	RSAC081			
Emmaton	RSAC092			
Rio Vista	RSAC101	PO-657		
Sac Nr Georgiana Sl.	RSAC123			
Greens Landing	RSAC139			
Hood	RSAC142			
Freeport	RSAC155			
Antioch	RSAN007			
Jersey Point	RSAN018			
	SLSUS012		Suisun Volanti	
			Montezuma Sl. Bend 2	
		PO-649	Pt. Sacramento	
Stockton	RSAN063			
Roe Island		PO-06		
Vernalis	RSAN112			
Mossdale	RSAN087			
Rough N'Ready	RSAN058			
			SJR Buckley Cove	
			Disappointment Sl.	
			Grizzly Bay	
			Little Potato Sl. at Terminous	
Old River at Hwy 4	ROLD024		Old R. at Rancho Del Rio	
Potato Pt.				
Mallard Sl.			Suisun-Nichols	SLML001
Twitchell				
Steamboat Sl.				SLSBT011
Cache Sl at Ryer Island				

Table 25-2 Data sources for effluent data and in-Delta measurements.

Effluent Data Locations	Name	Organizatiion
Sacramento Regional County Sanitation District	Robert Seyfried,Vyomini Pandya	Sac Regional
Woodland	Mark Hierholzer, Erich Delmas	Woodland
Vcacaville	Tony Pirondini	(contact only)
City of Stockton - M.U.D.	Larry Huber	City of Stockton - M.U.D.
City of Tracy	(Steven Bayley)	(contact only)
Lodi	Charles Swimley	Lodi
Manteca	Heather Grove	Manteca
Delta Diablo	Amanda Wong Roa	Delta Diablo
Fairfield-Suisun	Meg Herston	Fairfield-Suisun
CCCSD	Bhupinda Dhalewal, May Lou Esparza	CCCSD
Effluent Data - Regional Board		
Various Central Valley sources		Regional Board - Chris Foe
Various San Francisco Bay sources		Regional Board
In-Delta measurements		
Access data base for Central Valley Drinking Water Study	Elaine Archibald	CUWA
Various effluent and in-Delta measurements	Lynda Smyth - MWD	MWD
Boundary condition measurements	Randy Dahlgren	U.C. Davis
Access data base of nutrients	Mike Johnson	U. C. Davis
DICU data	Ted Swift , Bruce Agee	MWQI
2007 - 2009 nutrient data	Anke Mueller-Solger, Scott Waller	EMP

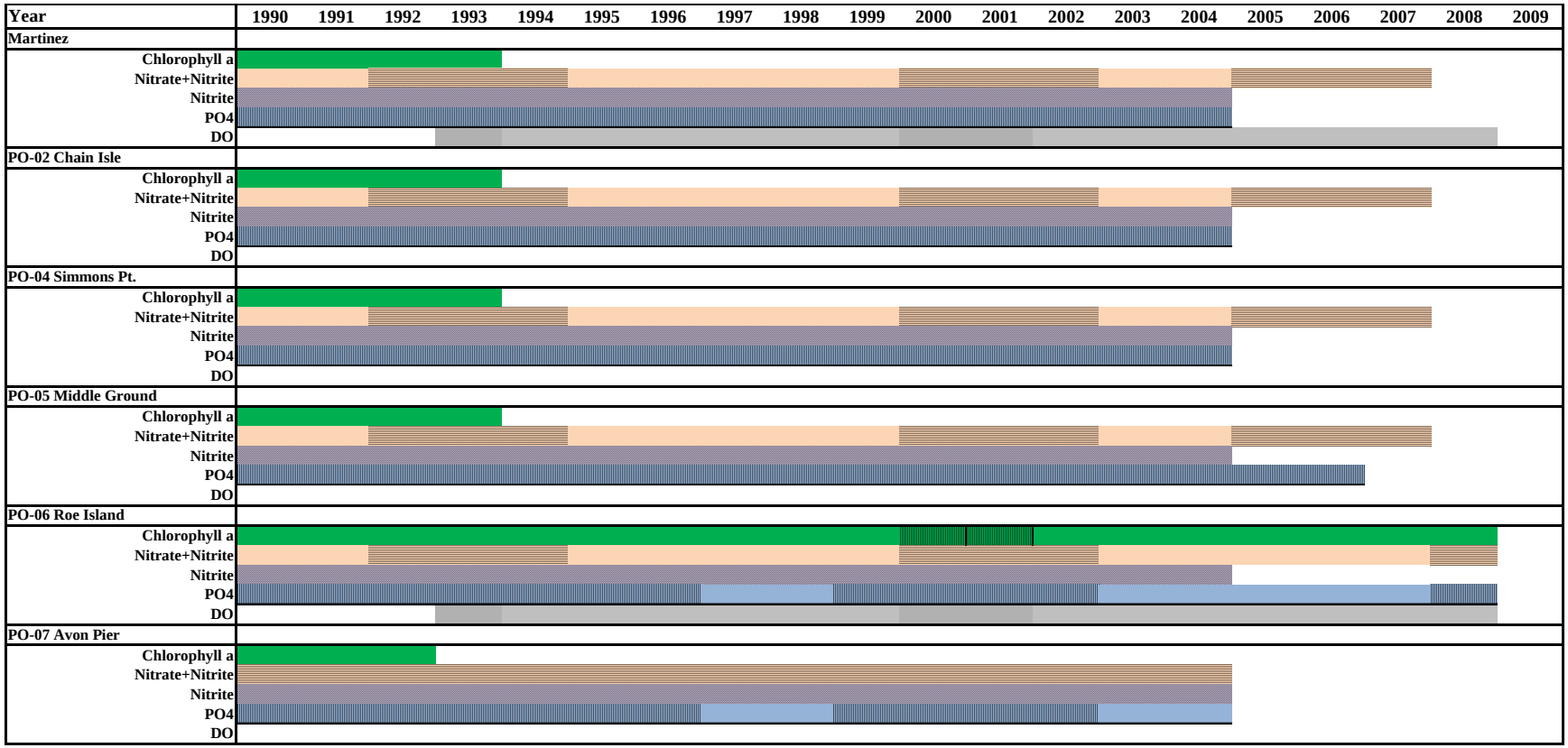


Figure 25-1Availability of USGS nutrient data at six USGS sites. Shading (hashes, dots) indicates partial year of data.

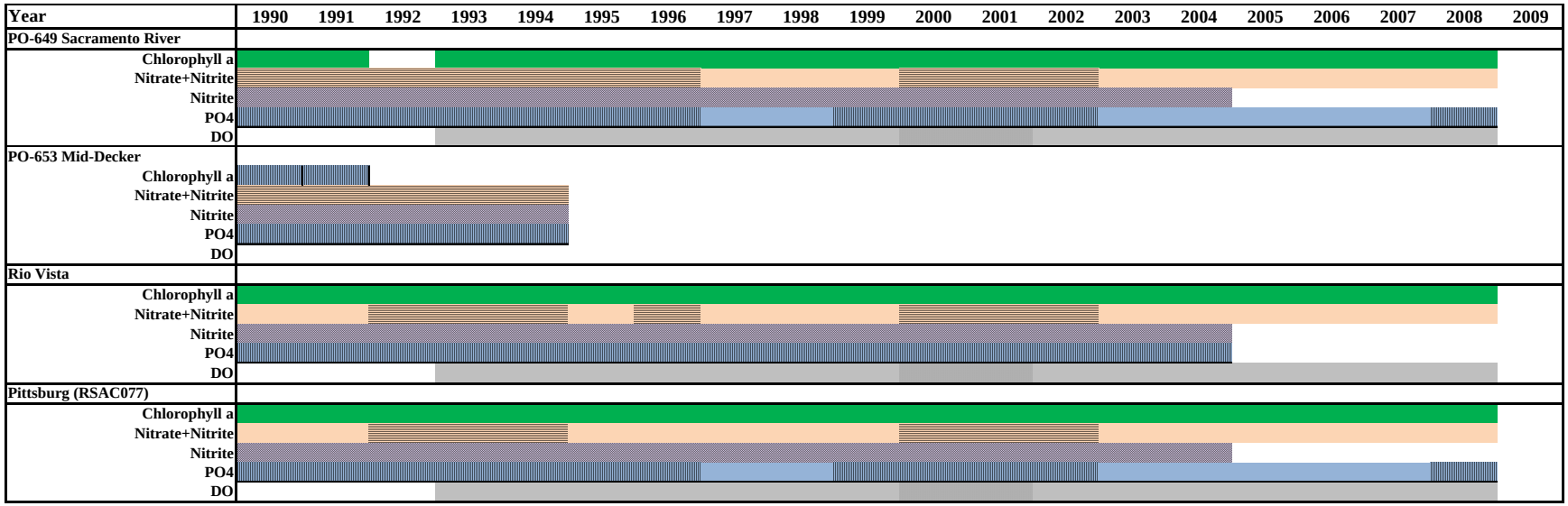


Figure 25-2 Availability of USGS data at the remaining four sites. Shading (hashes, dots) indicates partial year of data.

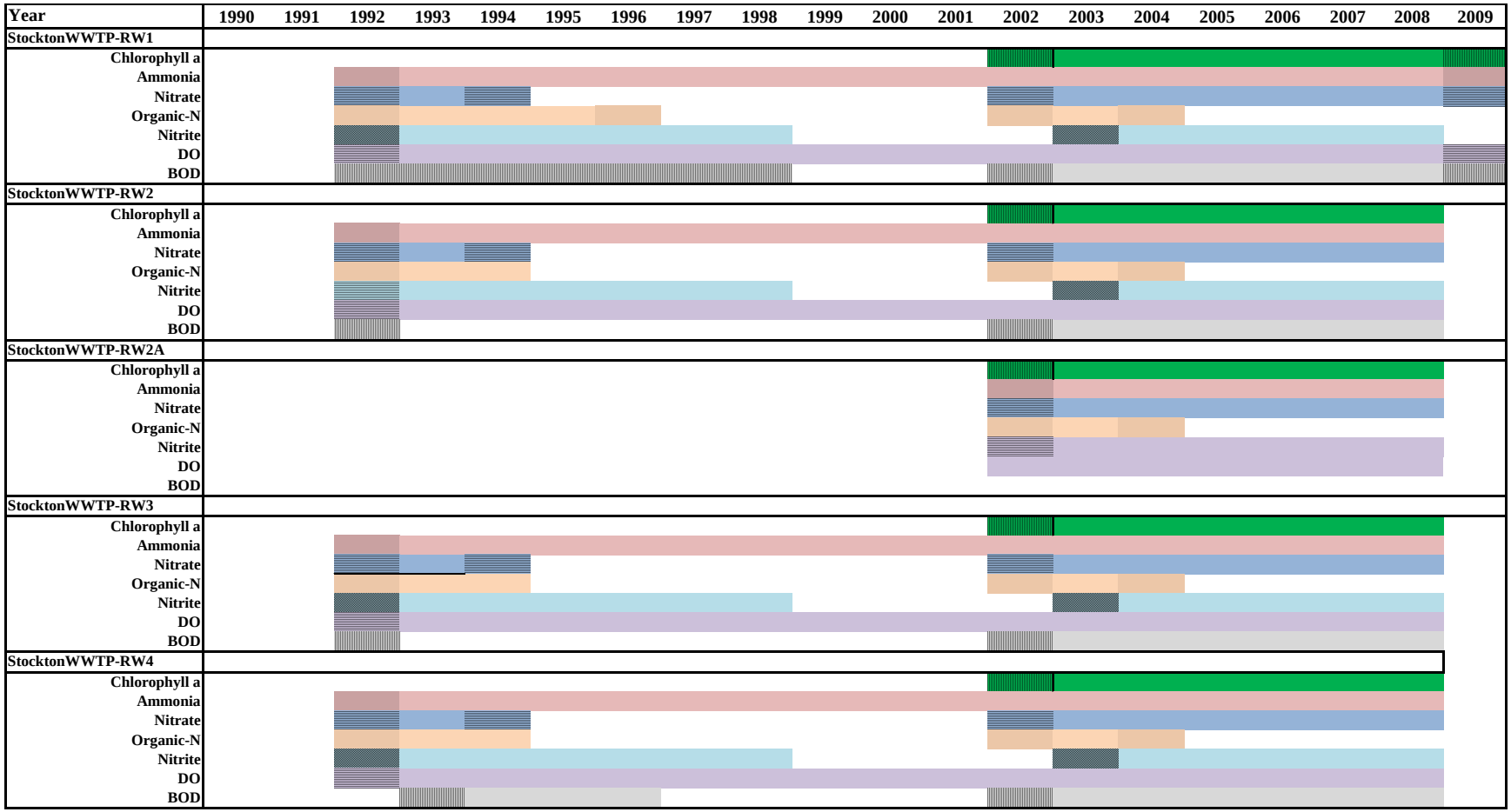


Figure 25-3 Availability of Stockton WWTP receiving water measures for sites RW-1 to RW-4. Shading (hashes, dots) indicates partial year of data.

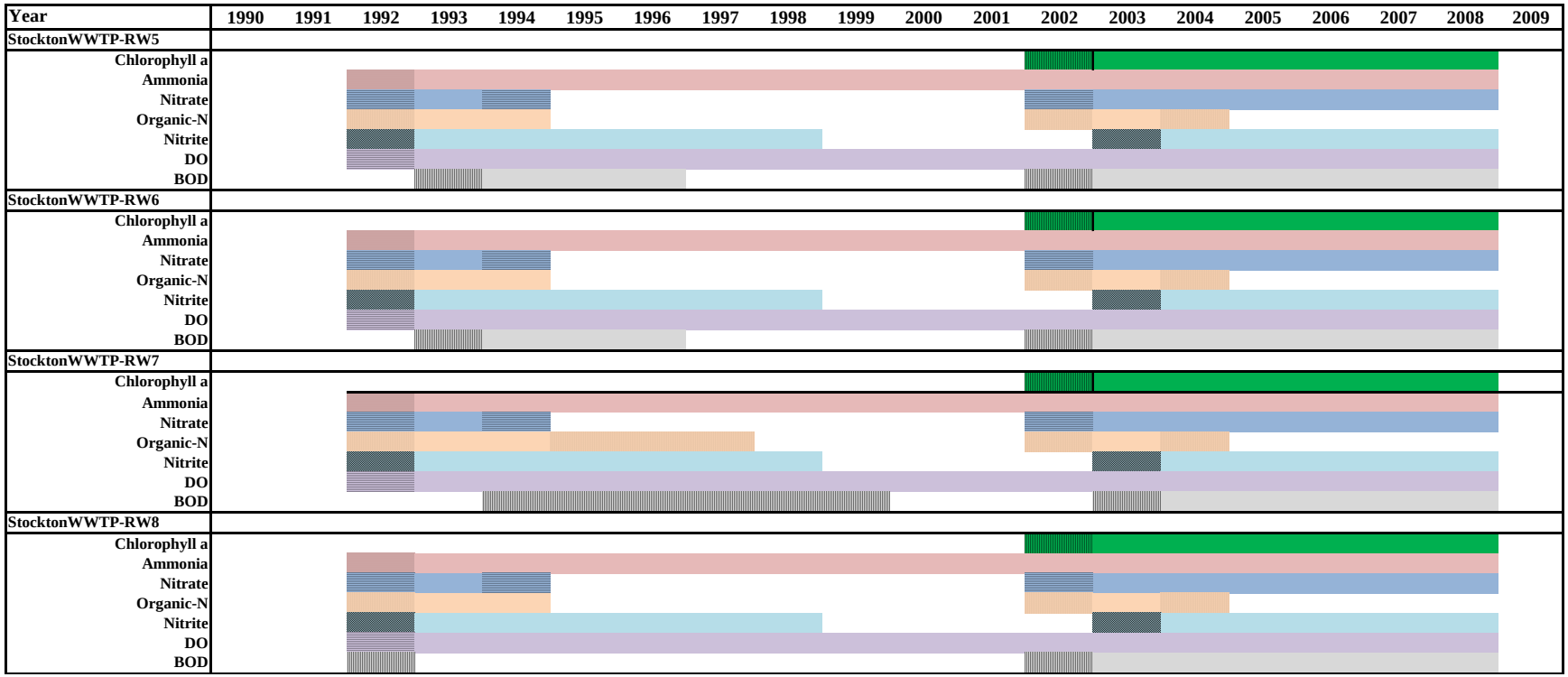


Figure 25-4 Availability of Stockton WWTP receiving water measures for sites RW-5 to RW-8. Shading (hashes, dots) indicates partial year of data.

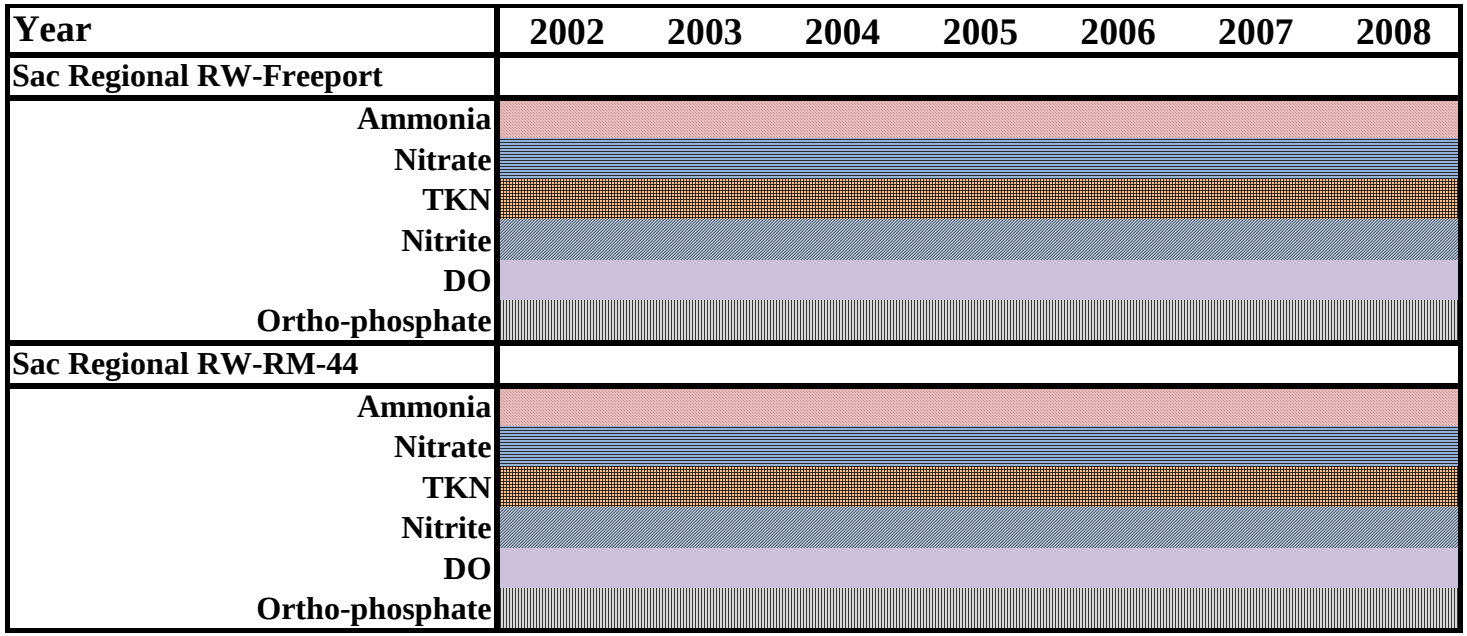


Figure 25-5 Availability of Sac Regional WWTP receiving water measurements. Shading (hashes, dots) indicates partial year of data.

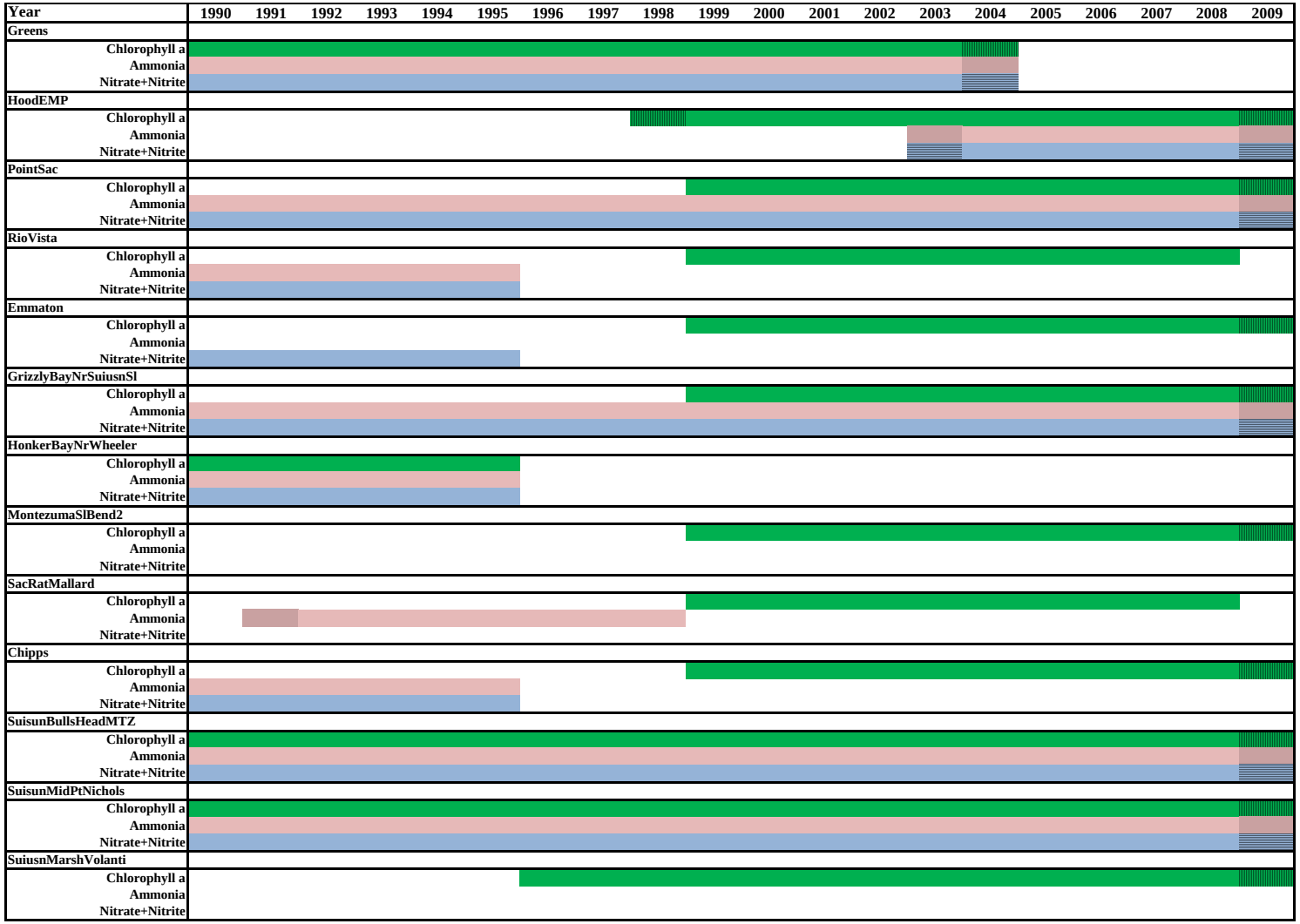


Figure 25-6 Availability of EMP/BDAT NH_3, NO_3+NO_2, and chlorophyll a measurements (Part 1). Hatching means partial-year data.

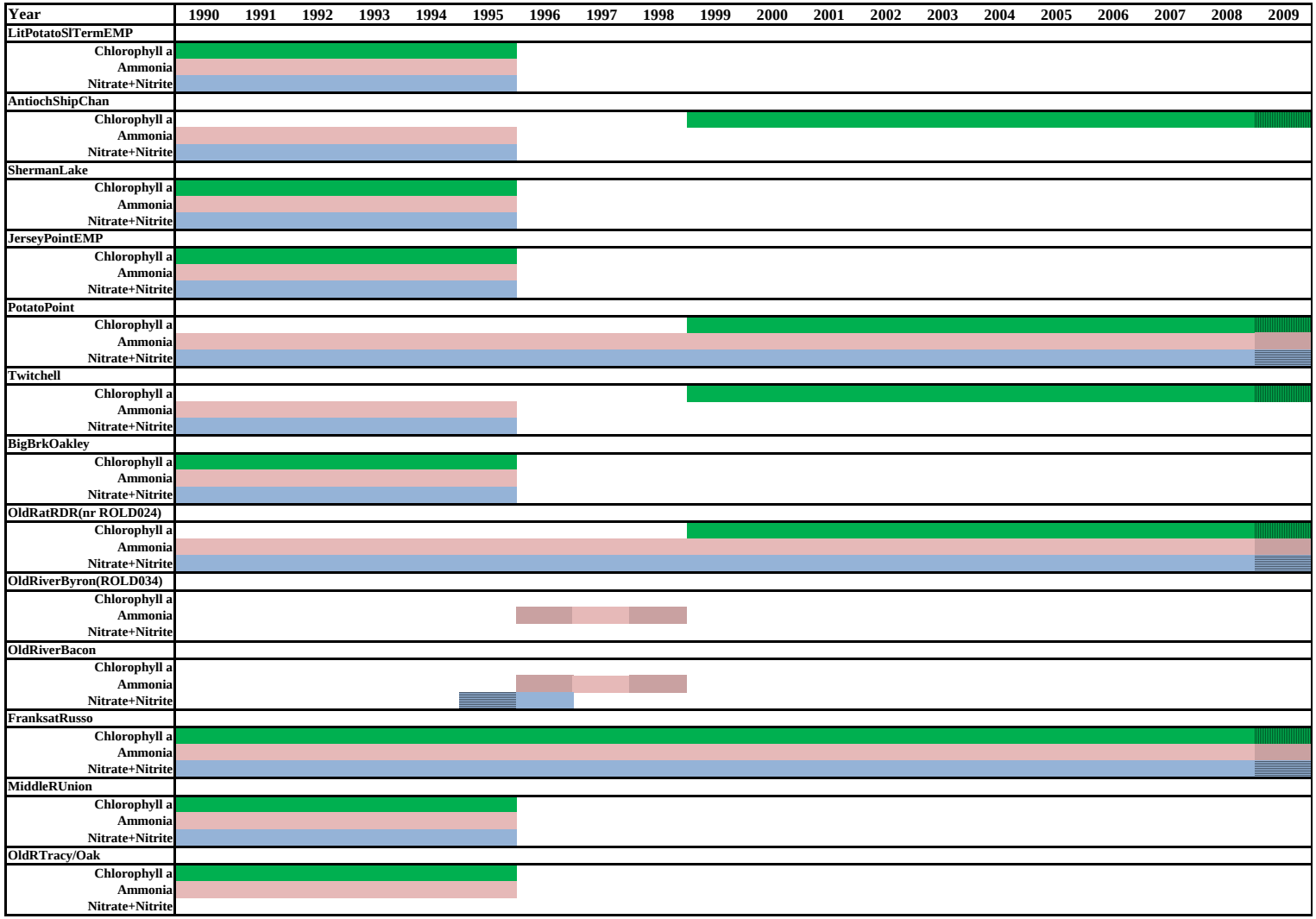


Figure 25-7 Availability of EMP/BDAT NH_3, NO_3+NO_2, and chlorophyll a measurements (Part 2). Hatching means partial-year data.

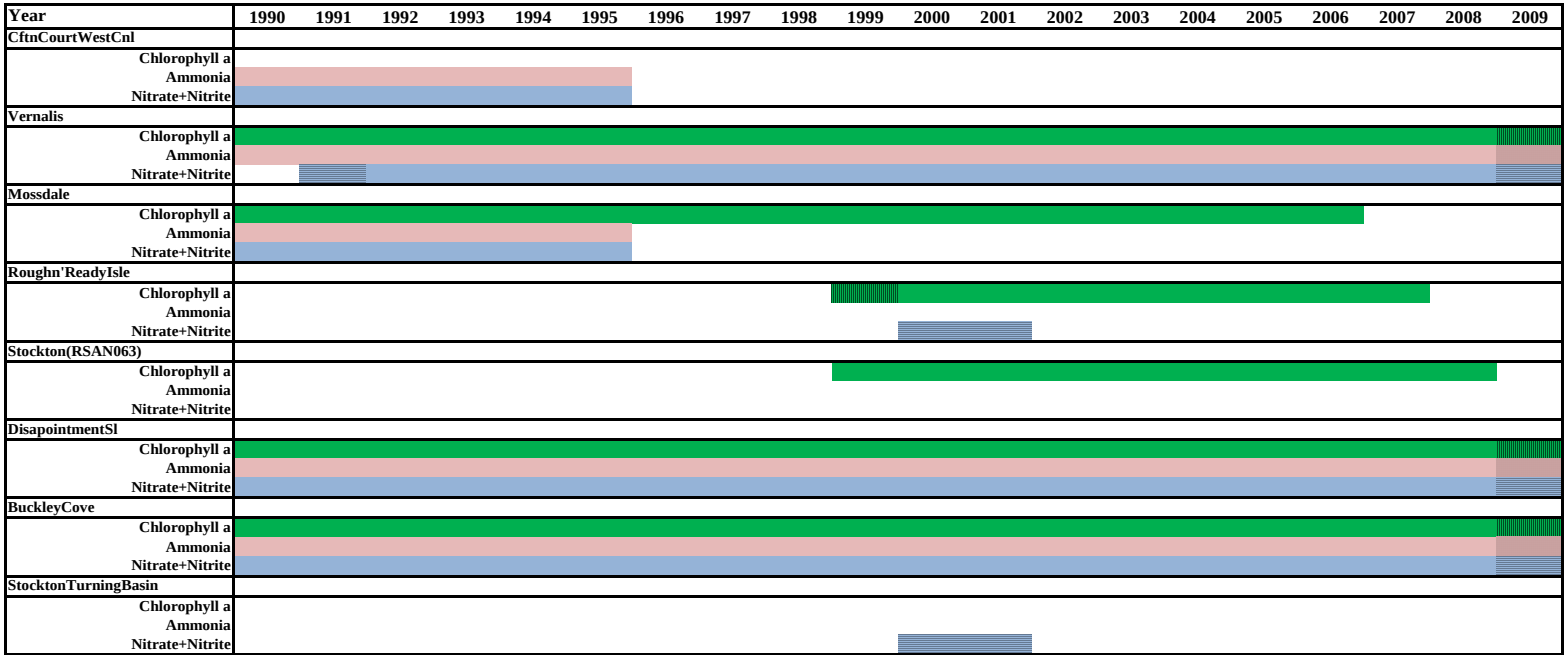


Figure 25-8 Availability of EMP/BDAT NH_3, NO_3+NO_2, and chlorophyll a measurements (Part 3). Hatching means partial-year data.

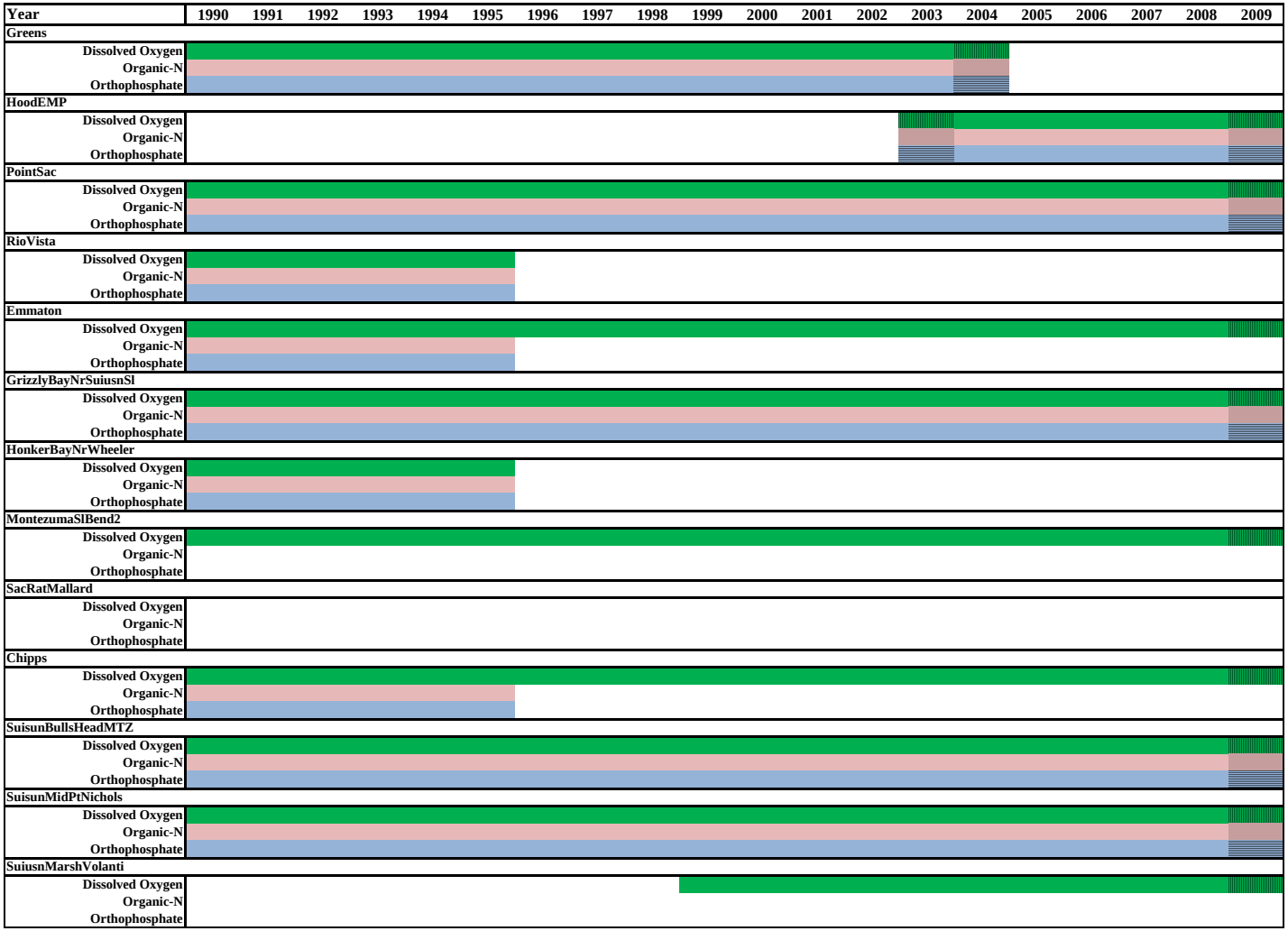


Figure 25-9 Availability of EMP/BDAT DO, Organic-N, and PO_4 measurements (Part 1). Hatching means partial-year data.

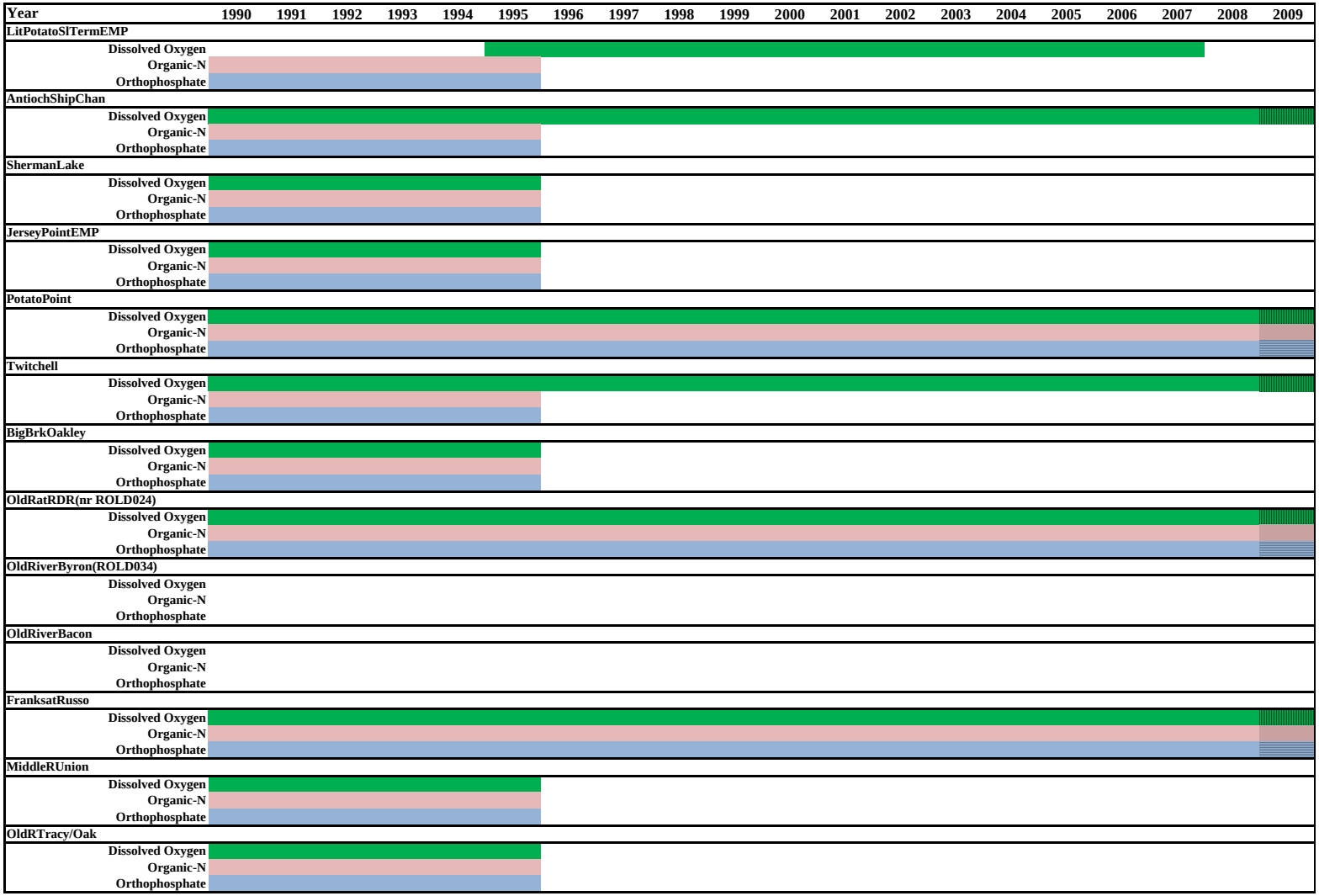


Figure 25-10 Availability of EMP/BDAT DO, Organic-N, and PO_4 measurements (Part 2). Hatching means partial-year data.



Figure 25-11 Availability of EMP/BDAT DO, Organic-N, and PO_4 measurements (Part 3). Hatching means partial-year data.

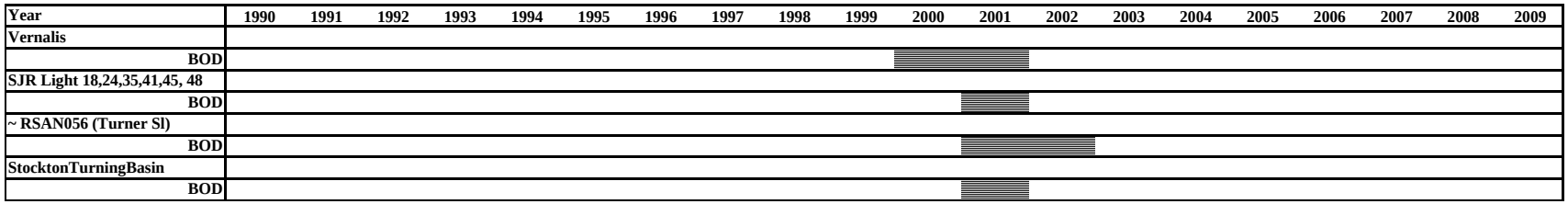


Figure 25-12 Availability of EMP/BDAT BOD measurements. Partial-year data only

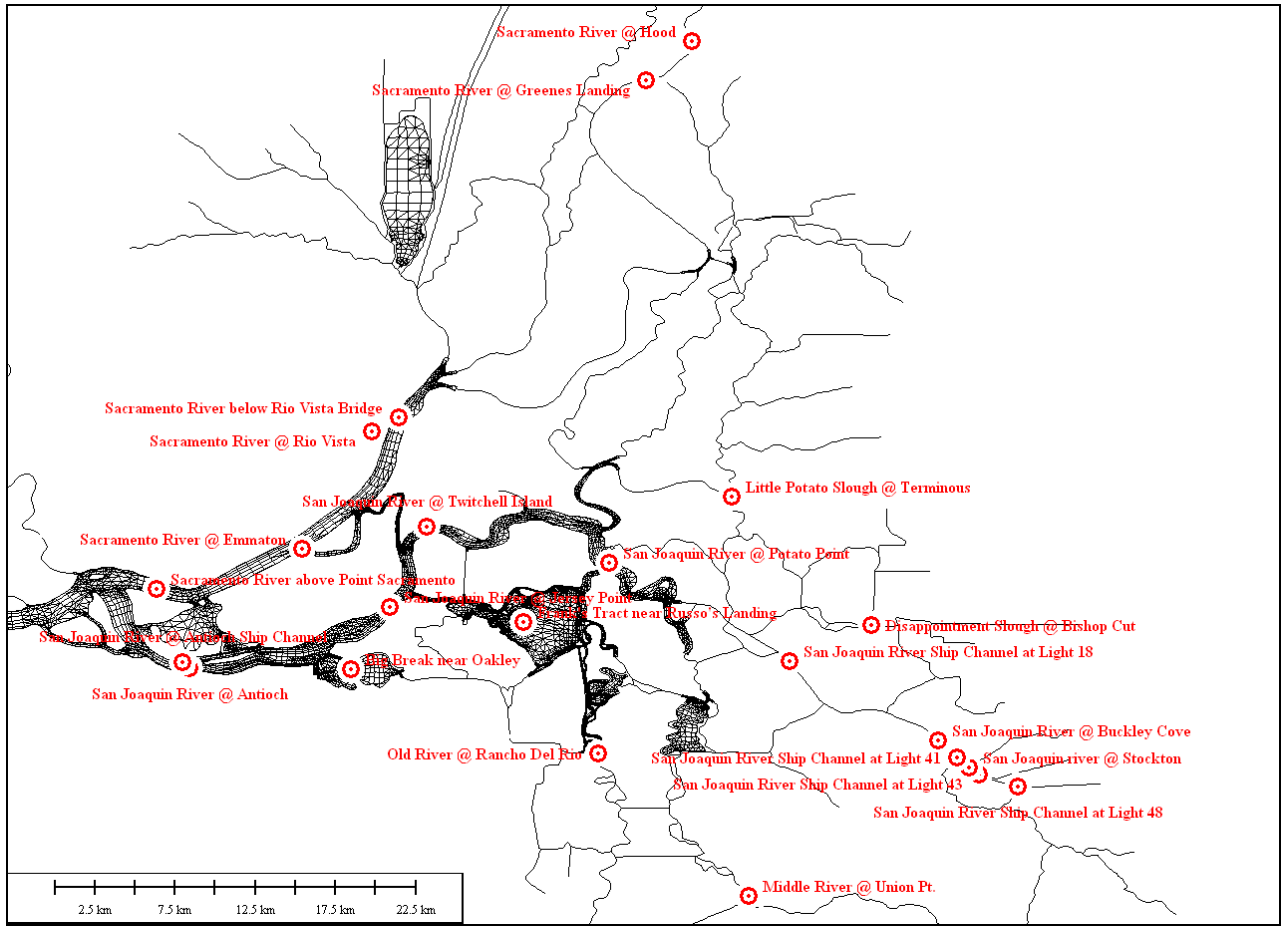


Figure 25-13 Location of BDAT grab-sample measurements for chl-a in the northern Delta.

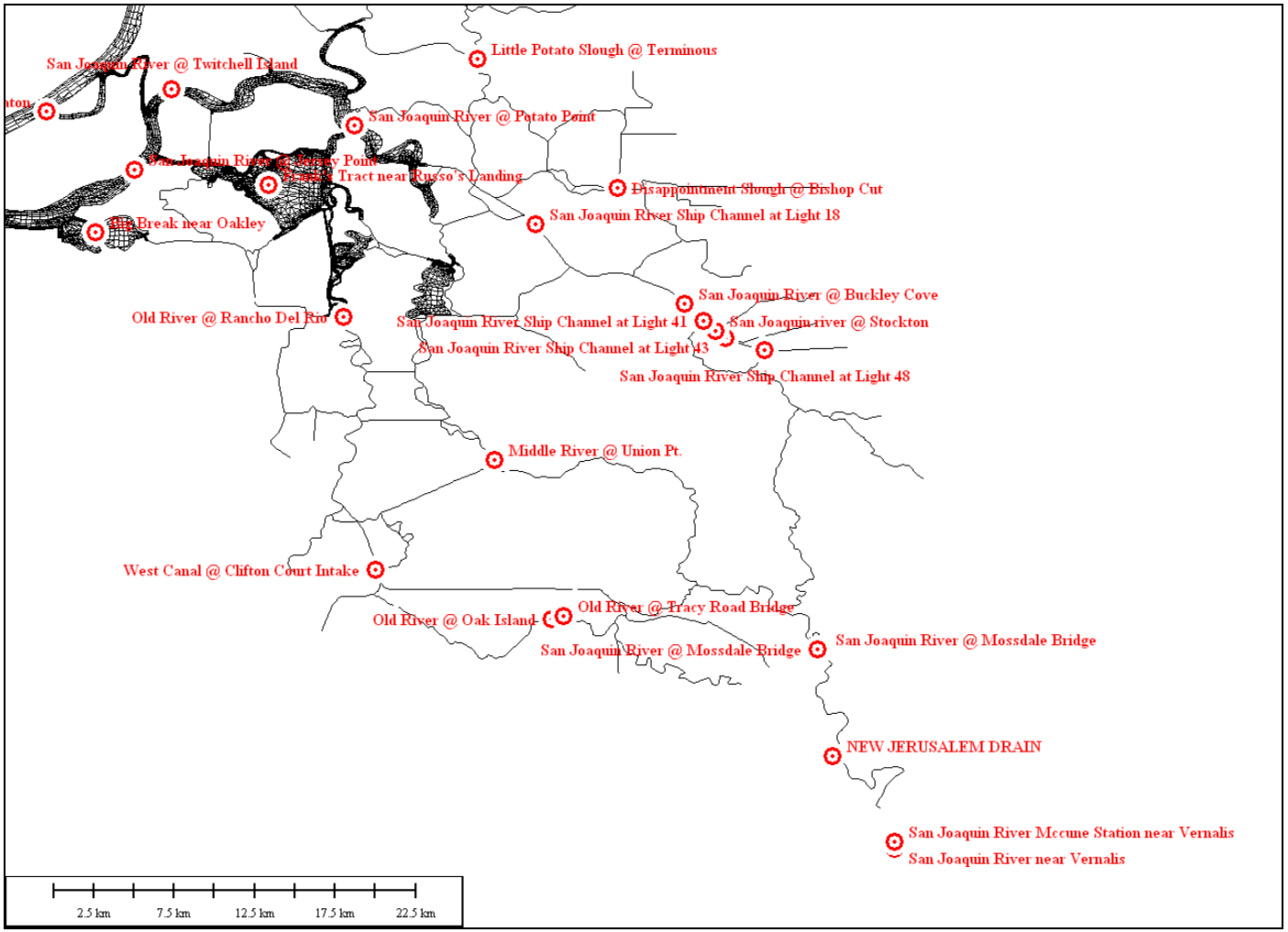


Figure 25-14 Location of BDAT-sourced grab-sample measurements for chl-a in the southern Delta.

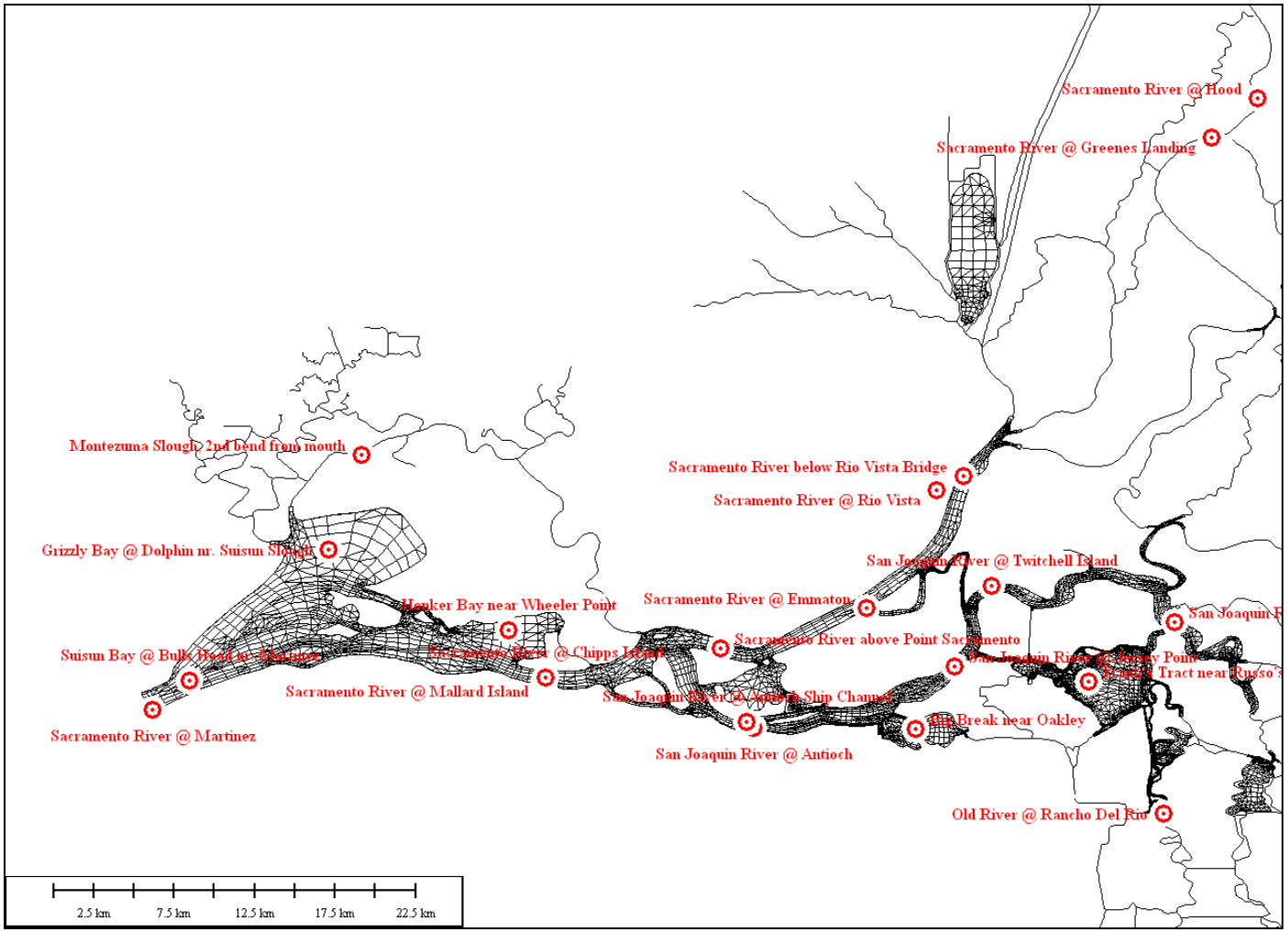


Figure 25-15 Location of BDAT grab-sample measurements for chl-a in the western Delta.

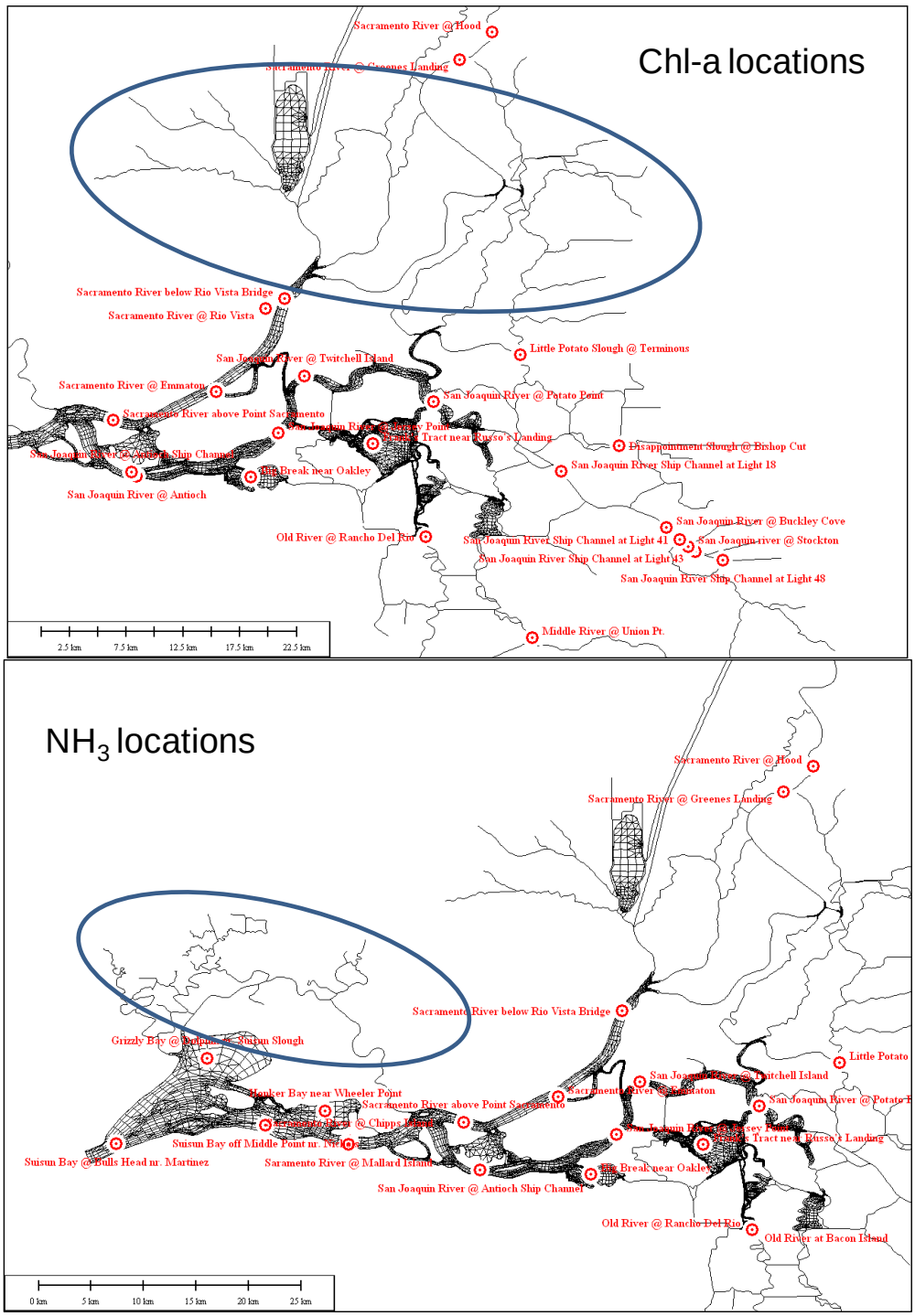


Figure 25-16 Nutrient levels in two large regions of the Delta are totally or partially unconstrained in calibration (i.e., no measurement data for some constituents).

Table 25-3 Nutrient data obtained from BDAT (#1)

Station Name	Name in Model	Station ID	Other Name	Latitude	Longitude	Sources
Antioch	Antioch	RSAN007		38.01777778	-121.801667	IEP
Between Navy and RR bridgesmg/L as N	TurnerCut	Turner Cut	CFTRN000, DSM2 Ch 172, L=727			BDAT
Big Break near Oakley	BigBrkOakley	D14A		38.01776	-121.7114	EMP
Carquinez Strait near Glencove Harbor	GlencoveHarbor	NZ002		38.06529	-122.2152	EMP
Carquinez Strait near Ozol Pier	OzolPier	NZ004		38.03576	-122.1616	EMP
City Of Stockton Treatment Plant	StocktonWWTP	FE(RWCF)	DSM2 Node 15			BDAT?
Clifton Court Intake	ClftCrtIntake	KA000000	DSM2 Res CLFCT	37.829781	-121.557353	WDL
Disappointment Slough @ Bishop Cut	DisapointmentSl	MD10	DSM2 Ch 317 L=7700	38.04381	-121.4188	EMP
Disappointment Slough @ Bishop Cut	DisapointmentSlA	MD10A	DSM2 Ch 317 L=7701	38.04226	-121.4199	EMP
Frank's Tract near Russo's Landing	FranksatRusso	D19	DSM2 Node 225	38.04376	-121.6148	EMP
From end of dock at Mossdale county park	MossdalePark	Mossdale				BDAT?
Georgiana Slough above Mokelumne River	GeorgianaSlatMoke	MD2	DSM2 RMKL005			EMP
Georgiana Slough at Walnut Grove Bridge	GeorgianaSlatWalnutGr	B9D81441309		38.2375	-121.516389	WDL
Grant Line/Fabian/Bell Canals nr Old R.	GrantLineNrOldR	B9D74931328		37.819444	-121.547222	WDL
Grant Ln Can @ Tracy Rd Bdg	GrantLineatTracy	B9D74921269		37.82	-121.448889	WDL
Grizzly Bay @ Dolphin nr. Suisun Slough	GrizzlyBayNrSuisunSl	D7	DSM2 Node 228	38.11714	-122.0397	EMP
Honker Bay near Wheeler Point	HonkerBayNrWheeler	D9	DSM2 Node 328	38.07244	-121.9392	EMP
Honker Cut at Atherton Road Bridge	HonkerCutatAtherton	B9D80361275		38.059444	-121.458333	WDL
Hood	HoodIEP	RSAC142		38.36805556	-121.519444	IEP
L. Potato Slough @ Terminous	LitPotatoSlTermWDL	B9D80691298		38.114722	-121.496389	WDL
Light 12	SJRLight12	Station ID from Kendall	SC-12	38.04267	-121.49883	SJRDO Study
Light 14	SJRLight14		SC-14	38.034	-121.48367	SJRDO Study
Light 28	SJRLight28		SC-28	37.99383	-121.4325	SJRDO Study
Light 34	SJRLight34		SC-34	37.994	-121.41367	SJRDO Study
Light 4	SJRLight4		SC-04	38.0555	-121.5295	SJRDO Study
Light 40	SJRLight40		SC-40	37.97817	-121.3825	SJRDO Study
Light 6	SJRLight6		SC-06	38.05383	-121.51517	SJRDO Study
Little Potato Slough @ Terminous	LitPotatoSlTermEMP	MD7A		38.11382	-121.498	EMP
Mallard Isl	MallardIsle	RSAC075		38.04361111	-121.918611	IEP
Mallard Slough	MallardSl	DO-62	? DSM2 SLML001	37.19187	-120.82379	SJRDO Study
Martinez	Martinez	RSAC054		38.02805556	-121.138056	IEP
Middle R. @ Borden Hwy.	MiddleRBordenHwy	B9D75351293	DSM2 RMID023	37.891111	-121.488889	WDL
Middle River @ Union Pt.	MiddleRUnion	P10A	DSM2 ec5500	37.89126	-121.4883	EMP
Middle River @ Victoria canal	MiddleRVictCanal	P10		37.8912	-121.4894	EMP
Middle River at Bacon Island Bridge	MiddleRBacon	B9D75741317		37.955833	-121.527778	WDL
Middle River North of Bacon Island Bridge	MiddleRBaconN	MD5				EMP
Mokelumne R. below Georgiana Sl	MokeBlwGeorgianna	B9D80771345		38.126944	-121.578333	WDL
Mokelumne River @ Franklin road bridge	MokeFranklin	P2		38.25542	-121.4403	EMP
Montezuma Slough, 2nd bend from mouth	MontezumaBend2	NZ032		38.16991	-122.0211	EMP
Mossdale	MossdaleIEP	RSAN087		37.78638889	-121.306111	IEP
NEW JERUSALEM DRAIN	NewJerusDrain	CDEC-NJD		37.7267	-121.2996	CDEC
Old R. nr. Byron (St 9) (NEAR HWY 4 BRIDGE)	OldRByron	B9D75351342	DSM2 ROLD034	37.891111	-121.569167	WDL
Old River @ Oak Island	OldROakIsle	P12A	DSM2 ROLD059	37.80284	-121.4569	EMP
Old River @ Rancho Del Rio	OldRatRDR	D28A	DSM2 ROLD024	37.97048	-121.573	EMP

Table 25-4 Nutrient data obtained from BDAT (#2)

Station Name	Name in Model	Station ID	Other Name	Latitude	Longitude	Sources
Old River @ Tracy Road Bridge	OldRTracyEMP	P12	DSM2 Ch 71, length	37.80472	-121.45	EMP
Old River at Bacon Island	OldRBacon	B9D75811344	DSM2 ROLD024	37.969444	-121.571111	WDL
Old River nr Tracy	OldRTracyWDL	B9D74731285	DSM2 ROLD059	37.788889	-121.475	WDL
Old River PP on Hwy 4	OldRHwy4	B9D75331345	DSM2 ROLD034	37.888333	-121.575278	WDL
Prisoner's Point/ Light 57	PrisonerPt	Prisoner Pt	SC-57	38.05967	-121.556	SJRDO Study
Rio Vista	RioVistaIEP	RSAC101		38.145	-121.691667	IEP
Rock Slough at Contra Costa Canal Intake	RockSlatCCC	D27	DSM2 CHCCC006			EMP
Rough and Ready Island	RRIsland	Rough and Ready	DSM2 Ch 20, length			SJRDO Study
SACRAMENTO R A HOOD	HoodWDL	B9D82211312	RSAC142	38.368611	-121.520556	WDL
Sacramento River @ Chipps Island	Chipps	D10	DSM2 eiether Ch 437, 442 Length	38.04631	-121.9183	EMP
Sacramento River @ Emmaton	Emmaton	D22	Rsac092	38.08453	-121.7391	EMP
Sacramento River @ Greenes Landing	Greens	C3	PSAC139	38.34575	-121.5461	EMP
Sacramento River @ Hood	HoodEMP	C3A	RSAC142	38.36771	-121.5205	EMP
Sacramento River @ Mallard Island	MallardIsleEMP	D10A		38.044	-121.919	EMP
Sacramento River @ Martinez	MartinezEMP	D6A	RSAC054	38.028	-122.138	EMP
Sacramento River @ Rio Vista	RioVistaEMP	D24A	RSAC101	38.15	-121.7	EMP
Sacramento River @ Rio Vista Bridge	RioVistaWDL	B9D80961411		38.159722	-121.685	WDL
Sacramento River above Point Sacramento	PointSac	D4	DSM2 PO-649	38.06248	-121.8205	EMP
Sacramento River below Rio Vista Bridge	RioVistaBridge	D24		38.15778	-121.6847	EMP
Sacramento River below Walnut Grove	SacRWalnutGrove	MD1				EMP
San Joaquin R nr Vernalis	VernalisUSGS	11303500	RSAN112	37.67611111	-121.265278	USGS
San Joaquin R. @ Hwy 4	SJRatHwy4	B9D75571196	RSAN087	37.928333	-121.327222	WDL
San Joaquin R. @ Mossdale Bridge	MossdaleBrWDL	B9D74711184		37.786111	-121.305833	WDL
San Joaquin R. nr. Vernalis	VernalisWDL	B0702000	RSAN112	37.676111	-121.264167	WDL
San Joaquin River @ Antioch	Antioch	D12A	RSAN007	38.018	-121.802	EMP
San Joaquin River @ Antioch Ship Channel	AntiochShipChan	D12		38.02161	-121.8063	EMP
San Joaquin River @ Buckley Cove	BuckleyCove	P8	DSM2 P8-SJRBuck	37.97817	-121.3823	EMP
San Joaquin River @ Jersey Point	JerseyPointEMP	D15	RSAN018	38.05217	-121.6896	EMP
San Joaquin River @ Mossdale Bridge	MossdaleBrEMP	C7		37.78607	-121.3077	EMP
San Joaquin River @ Mossdale Bridge	MossdaleBrEMPA	C7A		37.786	-121.306	EMP
San Joaquin River @ Potato Point	PotatoPoint	D26	DSM2 Ch 44, 0	38.07664	-121.5669	EMP
San Joaquin river @ Stockton	Stockton	P8A	RSAN063	37.963	-121.365	EMP
San Joaquin River @ Twitchell Island	Twitchell	D16		38.0969	-121.6691	EMP
San Joaquin River at Bowman Road	SJRBowmanRd	R1				SJRDO Study
San Joaquin River at Brandt Bridge	SJRBrandtBr	C6	RSAN072	37.864926	-121.322723	EMP
San Joaquin River at Highway 4 Bridge	SJRHwy4Br	R2				SJRDO Study
San Joaquin River at Mossdale	MossdaleSJRDO	MY	RSAN087			SJRDO Study
San Joaquin River at Vernalis	VernalisSJRDO	VS	RSAN112			SJRDO Study
San Joaquin River Mccune Station near Vernalis	SJRMcCune	C10A		37.67929	-121.26511	EMP
San Joaquin River near Mokelumne River	SJRatMoke	MD11	DSM2 Ch 45, 0			EMP
SAN JOAQUIN RIVER NEAR VERNALIS	VernalisCDEC	CDEC-VNS	RSAN112	37.667	-121.267	CDEC
San Joaquin River near Vernalis	VernalisEMP	C10	RSAN112	37.67575	-121.265	EMP

Table 25-5 Nutrient data from BDAT (#3)

Station Name	Name in Model	Station ID	Other Name	Latitude	Longitude	Sources
San Joaquin River Ship Channel at Light 18	SJRLight18	R8	SC-18	38.02183	-121.46567	SJRDO Study
San Joaquin River Ship Channel at Light 19	SJRLight19	Lt 19	SC-19	38.01067	-121.45667	SJRDO Study
San Joaquin River Ship Channel at Light 24	SJRLight24	R7				SJRDO Study
San Joaquin River Ship Channel at Light 36	SJRLight36	R6				SJRDO Study
San Joaquin River Ship Channel at Light 38	SJRLight38	SJR Ship Channel @ Lt 38				SJRDO Study
San Joaquin River Ship Channel at Light 41	SJRLight41	R1	SC-41	37.96867	-121.3715	SJRDO Study
San Joaquin River Ship Channel at Light 43	SJRLight43	SJR Ship Channel @ Lt 43	SC-43	37.95867	-121.35933	SJRDO Study
San Joaquin River Ship Channel at Light 45	SJRLight45	R4				SJRDO Study
San Joaquin River Ship Channel at Light 48	SJRLight48	SJR Ship Channel @ Lt 48	SC-48	37.95217	-121.33783	SJRDO Study
Saramento River @ Mallard Island	SacRatMallard	E0B80261551	RSAC075	38.043611	-121.918611	WDL
Sherman Lake near Antioch	ShermanLake	D11		38.04229	-121.7995	EMP
SJR at Mossdale	MossdaleSJRDO2	DO-04	RSAN087	37.7871	-121.30757	SJRDO Study
South Fork Mokelumne below Sycamore Slough	SForkMokeblwSycmrSl	MD7		38.12513	-121.497	EMP
Stockton	StocktonIEP	RSAN063		37.96277778	-121.365	IEP
Stockton Turning Basin	StocktonTurnBasin	TB	SC-STB, STKN-TB	37.95233	-121.31733	SJRDO Study
Suisun Bay @ Bulls Head nr. Martinez	SuisunBullsHeadMTZ	D6	near DSM2 RSAC054	38.04436	-122.1177	EMP
Suisun Bay near Preston Point	SuisunPrestonPt	D2		38.06544	-122.0545	EMP
Suisun Bay off Middle Point nr. Nichols	SuisunMidPtNichols	D8	DSM2 SLML001	38.05992	-121.99	EMP
Suisun Slough @ Volanti Slough	SuisunatVolanti	NZS42	DSM2 SLSUS012	38.18045	-122.0476	EMP
Suisun Slough 300' south of Volanti Slough	SuisunSofVolanti	S42		38.18047	-122.0469	EMP
Sycamore Slough near Mouth	SycamoreSlMouth	MD6		38.1415	-121.4687	EMP
Turning Basin Deep Water Ship Channel at Port of Stockton	PortofStockton	Turning Basin	SC-STB, STKN-TB	OK - MG can locate		SJRDO Study
West Canal @ Clifton Court Intake	ClftnCourtWestCnl	C9	DSM2 Node 72	37.83028	-121.5549	EMP
White Slough above Honker Cut	WhiteSlHonkerCut	MD9				EMP

Table 25-6 Sacramento Regional WWTP receiving water data at the Freeport location from 2004 – 2008. *Italic font* indicates the measurement was at the instrument detection limit.

Freeport	DOC mg/L	DO mg/L	EC umhos/ cm	pH	Temp (° C)	TOC mg/L	Turbidity NTU	Ammonia mg/L	Nitrate mg/L	Nitrite mg/L	Orthophosphate-dissolved mg/L	Phosphorus as P mg/L	TKNmg/ L
08/10 - 11/04	1.8	10	150	7.7	21.6	1.9	9.4	*0.10*	0.10	0.100	0.130	0.20	0.51
10/5/2004	1.8	10	150	7.7	21.6	1.9	9.4	*0.10*	0.10	0.100	0.130	0.20	0.51
10/19-20/04	1.6	10	130	7.4	16.1	1.7	6.4	*0.10*	0.14	0.100	0.150	0.10	0.19
12/07-08/04	2.5	14	210	7.9	9.10	2.6	9.1	*0.10*	0.17	0.100	*0.100*	0.13	0.40
1/28-29/05	2.3	11	250	7.9	10.2	2.4	24	*0.10*	0.32	0.100	*0.100*	0.13	0.36
02/15-16/05	2	14	200	7.8	11.3	2	11	*0.10*	0.27	0.100	0.110	0.085	0.29
04/12-13/05	1.9	12	150	7.7	14.8	1.8	19	*0.10*	0.15	0.100	*0.100*	0.050	0.50
06/07-08/05	1.3	8.5	110	7.7	17.4	1.3	11	*0.10*	0.10	0.100	0.050	0.050	0.25
8/2/2005	1.7	12	150	8.1	22.1	1.7	13	*0.1*	0.11	*0.100*	*0.050*	0.17	0.062
10/4/2005	1.4	13	130	7.8	16	1.4	6.2	*0.1*	0.1	*0.100*	*0.050*	0.29	*0.05*
12/1/2005		11	190	7.7	10.5		12	0.1	0.16	*0.100*	0.060	0.37	0.078
2/7/2006	2.2	12	100	7.2	9.7	3.3	55	*0.1*	0.12	*0.100*	0.050	0.16	0.059
2/27/2006	3.3	15	130	7.7	10.4		19	*0.1*	0.27	*0.100*	0.055	0.1	*0.05*
3/7/2006		16	95	7.4	9.6		39						
4/4/2006	3	14	95	7.6	10.2	2.4	38	*0.1*	*0.1*	*0.100*	0.050	0.31	0.075
6/13/2006	2.8	10	180	7.7	18	1.2	18	*0.1*	*0.1*	*0.100*	0.050	0.25	*0.05*
8/3/2006	11	11	140	7.8	21	*2.1*	16	*0.1*	*0.1*	*0.100*	*0.050*	*0.2*	*0.05*
10/11/2006	1.3	9.1	140	7.8	16.9	3.6	6.2	*0.1*	*0.15*	*0.100*	*0.050*	*0.27*	*0.05*
11/3/2006	1.5	11	140	7.7	14.6	*2.1*	5.9	*0.1*	0.17	0.100	*0.050*	*0.36*	*0.05*
12/9/2006	1.1	12	170	7.6	10	*1.8*	10	*0.1*	*0.14*	*0.100*	*0.050*	*0.32*	*0.054*
2/8/2007	2.8	13	190	7.6	10.5	5.2	14	0.14	0.13	*0.100*	*0.050*	0.5	0.054
4/3/2007	4.5	11	130	7.9	15.9	3.9	6.8	*0.1*	*0.1*	*0.100*	*0.050*	0.2	*0.05*
6/5/2007	5.6	9.2	210	7.1	21.5	6.8	6.2	*0.1*	*0.1*	*0.100*	*0.050*	0.27	*0.05*
08/07/2007 - 8/8/2007	2.0	9.1	180	7.8	19.8	2.0	7.4	0.028	0.039	*0.0029*	0.0140	0.05	0.18
10/09/2007 - 10/10/2007	1.2	10	170	7.9	16.5	1.4	3.2	0.026	0.082	0.0020	0.0240	0.034	0.57
12/04/2007 - 12/5/2007		10	190	7.8	10.4		11	0.042	0.14	0.0042	0.0680	0.042	0.48
01/04/2008 - 01/05/2008	2.7	14	200	7.8	7.67	2.7	20	0.12	0.25	0.0056	0.0480	0.065	0.89
02/05/2008 - 02/06/2008	5.2	13	150	7.6	7.2	3.6	250	0.017	0.31	0.0063	0.0390	0.24	0.89
04/01/2008 - 04/03/2008	1.9	10	200	8	14.4	2.1	7.2	*0.1*	0.13	0.0034	0.0330	*0.05*	0.81
06/11/2008 - 06/11/2008	3.6	8.9	130	7.7	19.8	4.9	12	*0.062*	0.023	*0.0031*	0.0260	0.044	0.51
Average	2.7	11.5	158.7	7.7	14.5	2.6	22.5	0.1	0.1	0.0039	0.1	0.2	0.3
Max	11.0	16.0	210.0	8.1	22.1	6.8	250.0	0.1	0.3	0.0063	0.1	0.5	0.9
Min	1.1	8.5	95.0	7.1	7.2	1.2	3.2	0.0	0.0	0.0020	0.0	0.0	0.1

Table 25-7 Sacramento Regional WWTP receiving water data at the RM 44 (River Mile 44) location from 2004 – 2008. *Italic font* indicates the measurement was at the instrument detection limit.

RM 44	DOC mg/L	DO mg/L	EC umhos/ cm	pH	Temp (° C)	TOC mg/L	Turbidity NTU	Ammonia mg/L	Nitrate mg/L	Nitrite mg/L	Orthophosphate-dissolved mg/L	Phosphorus as P mg/L	TKN mg/L
8/10-11/04	1.9	11	160	7.7	21.8	1.7	9.7	0.14	0.10	0.10	0.10	0.078	0.40
10/5-6/04	1.4	9.6	150	7.8	19.4	1.6	6.5	0.24	0.11	0.10	0.10	0.11	0.70
12/7-8/04	2.6	14	210	7.6	9.10	3	7.3	0.32	0.17	0.10	0.10	0.16	0.76
2/15-16/05	2.2	14	220	7.5	11.4	2.3	12	0.38	0.25	0.10	0.10	0.11	0.73
4/12-13/05		12	160	7.7	14.7		20	0.12	0.16	0.10	0.10	0.058	0.79
6/7-8/05	1.4	9.9	120	7.6	17.5	1.3	14	0.14	0.10	0.10	0.050	0.10	0.47
8/2/2005	1.5	9.8	160	8	22.3	1.6	9.2	0.21	*0.1*	*0.1*	0.074	0.48	0.11
10/4/2005	1.6	13	140	7.6	16.3	1.8	7	0.32	*0.1*	*0.1*	0.06	0.67	0.079
12/1/2005		10	190	7.4	10.6		11	0.42	0.15	*0.1*	0.069	0.85	0.088
2/7/2006	2.2	12	97	6.5	9.8	3.1	58	*0.1*	0.15	*0.1*	*0.05*	0.28	0.072
4/4/2006	3	14	98	7.5	10.2	2.2	43	0.12	0.11	*0.1*	*0.05*	0.35	0.083
6/13/2006	2.3	11	190	7.4	18	0.91	13	0.12	0.14	*0.1*	0.051	0.5	0.064
8/3/2006	*1*	11	150	7.5	20.9	*2.5*	12	*0.1*	*0.15*	*0.1*	*0.05*	*0.45*	*0.085*
10/11/2006	1.9	9.1	140	7.8	17.1	*1.8*	7.1	*0.31*	*0.47*	*0.1*	*0.077*	0.76	*0.11*
12/9/2006	2.4	12	180	7.7	10.2	*1.5*	11	*0.39*	*0.14*	*0.1*	*0.052*	0.71	*0.082*
2/8/2007	2.5	13	200	7.6	10.7	5.5	16	0.41	0.13	*0.1*	0.064	0.76	0.07
4/3/2007	4.3	11	140	7.7	16	4.3	8.7	0.34	*0.1*	*0.1*	0.05	0.81	0.054
6/5/2007	6.3	8.3	220	7	21.6	6.6	6.4	*0.1*	*0.1*	*0.1*	0.058	0.7	*0.05*
08/07/2007 - 8/8/2007	2.0	9	190	7.7	20	1.5	6.8	0.11	0.026	*0.0082*	0.027	0.036	0.45
10/09/2007 - 10/10/2007	1.7	10	180	7.6	16.7	1.9	4.8	0.37	0.082	0.0027	0.074	0.096	0.84
12/04/2007 - 12/5/2007		10	200	7.5	10.3		6.3	0.29	0.15	0.0044	0.1	2.5	0.73
02/05/2008 - 02/06/2008	5.5	12	150	6.8	7.1	3.6	260	0.088	0.29	0.0061	0.046	0.21	0.99
04/01/2008 - 04/03/2008	2	10	190	7.9	14.3	2	5.7	0.077	0.12	0.0035	0.04	0.046	0.88
06/11/2008 - 06/11/2008	3.1	8.6	150	7.3	19.5	2.8	12	0.34	0.036	*0.0039*	0.058	0.085	0.83
Average	2.5	11.0	166.0	7.5	15.2	2.5	23.6	0.23	0.14	0.0048	0.07	0.45	0.40
Max	6.3	14.0	220.0	8.0	22.3	6.6	260.0	0.42	0.47	0.0042	0.10	2.50	0.99
Min	1.0	8.3	97.0	6.5	7.1	0.9	4.8	0.08	0.03	0.0045	0.03	0.04	0.05

25.2 CBOD and BOD

Biochemical Oxygen Demand, or BOD, is a test used to measure the mass of oxygen consumed for unit volume of water, and is considered a measure of the concentration of biodegradable organic material present in solution (Brake 1998). It is a widely used test important in nutrient studies as dissolved oxygen is consumed when organic matter is oxidized by microbes. The measurement is further distinguished by the number of days the test is allowed to run, so the BOD5 test runs for 5 days. BOD5 is typically assumed to represent about 60 – 80% of the ultimate BOD, or BODu, which is the measurement taken after 20 days. Waste water treatment plants frequently measure BOD in the effluent as receiving waters can only assimilate limited quantities of organic matter before adverse effects occur.

The BOD measurement can be split into two stages – Carbonaceous BOD, or CBOD, and Nitrogenous BOD, or NBOD. CBOD measures the oxygen consumption due oxidation of carbon and NBOD measures the oxygen consumed due to the oxidation of nitrogenous compounds. Because nitrifying bacteria can take 8 – 10 days before sufficient numbers are available to oxidize the N-compounds, BOD_5 is an approximate measure of CBOD after applying a correction factor for the length of the test. Unless nitrification is inhibited in the BOD test, longer BOD tests such as BOD_{20} will include the NBOD.

In reality, all organic matter is not equal in terms of a BOD, CBOD or NBOD measurements. Some organic material is labile, or easily utilized by microbes, and some is refractory or recalcitrant, i.e., practically unavailable as an energy source over the short term. For example, sewage effluent organic matter is considered labile, while paper mill effluent is refractory or recalcitrant in nature (Chapra, 2008).

Some WWTPs measure both BOD_5 and CBOD, such as City of Stockton WWTP and Lodi WWTP. Regression relationships between BOD_5 and CBOD for these measurements sets give similar regression relationships. Stockton WWTP had a fairly extensive set of measurements to compare which gave the following regression relationship which was used to convert all BOD_5 to CBOD:

$$CBOD = (0.48)*BOD_5 + 0.8.$$

25.3 Fluorescence Data

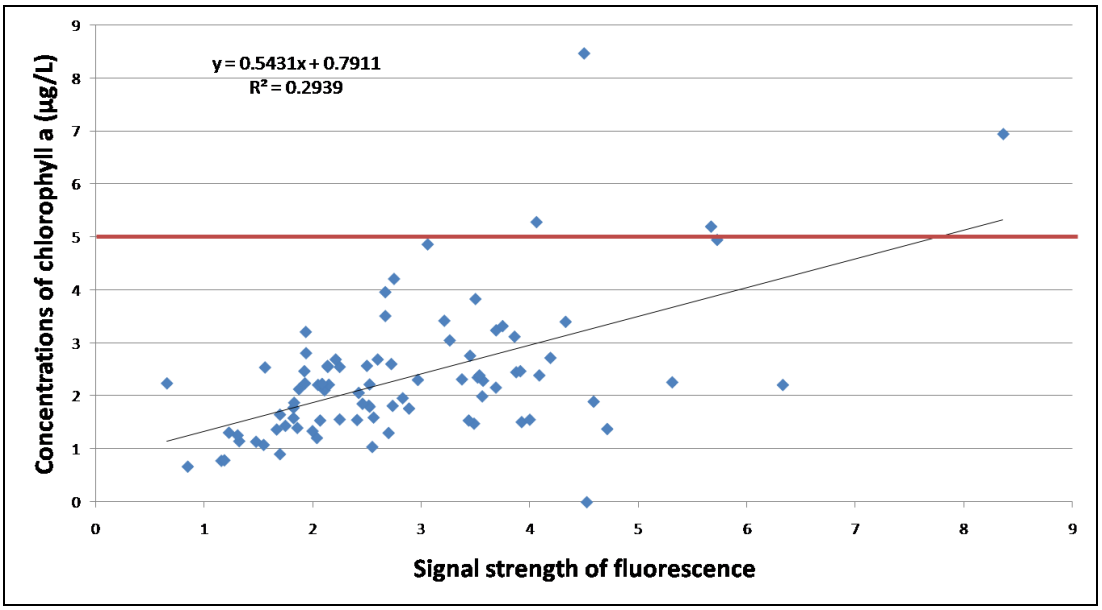


Figure 25-17 Linear regression between concentration of chlorophyll a and signal strength of fluorescence at Hood. Red line indicates 5 µg/L of Chlorophyll a.

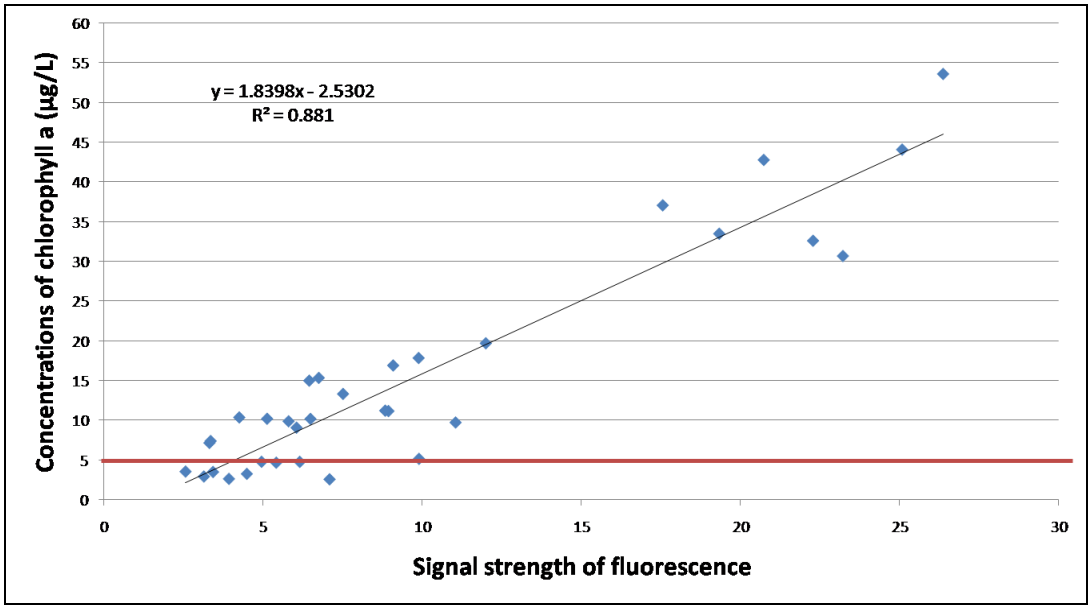


Figure 25-18 Linear regression between concentration of chlorophyll a and signal strength of fluorescence at Mossdale. Red line indicates 5 µg/L of Chlorophyll a.

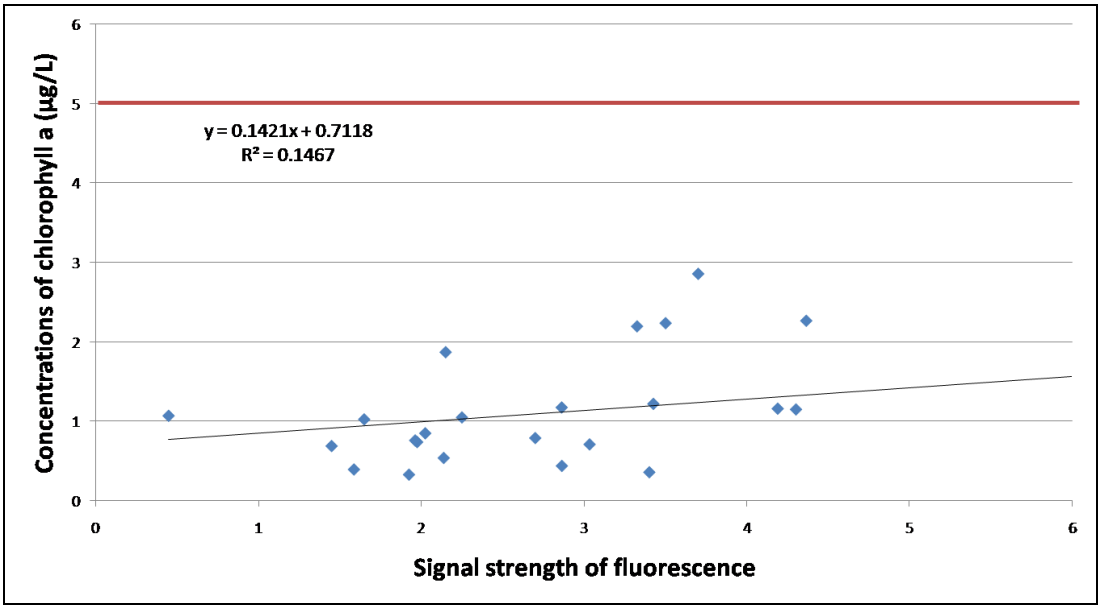


Figure 25-19 Linear regression between concentration of chlorophyll a and signal strength of fluorescence at Martinez. Red line indicates 5 µg/L of Chlorophyll a.

25.4 Singular Spectrum Analysis

Singular Spectrum Analysis (SSA) is essentially a variation on Principle Components Analysis. This is a relatively new analytical method used in various fields to analyze time series data (*e.g.*, stream flow, global temperature). Schoelhammer (2001) developed and used SSA methodology to fill data gaps in suspended sediment concentration data – up to 50% of the data in the time series was missing or invalid, and SSA was used to fill these data gaps. When used for filling data gaps, the SSA methodology is akin to forecasting methodology for time series.

For this project, a software package CAT-MV (for the "Caterpillar-SSA" method) was purchased to use in filling data gaps for continuous (15-minute or hourly interval) data. CAT-MV uses the SSA method to approximate time series data and fill in missing data with approximations. As illustrated in Figure 25-20 to Figure 25-22, below, the following methodology was used on data that had been pre-screened to remove invalid data:

- A time series of data of a given length (such as a year or several months) was selected and imported into the CAT-MV software
- A window length, related to the length of the largest data gap was selected and the SSA methodology was used in the software to approximate the time series
- The software develops a lagged set of sub-vectors (the lag is related to the "window length") to form a trajectory matrix $\boldsymbol{X}$
- An orthogonal basis of eigenvectors for the matrix$\boldsymbol{X}*\boldsymbol{X}^t$ is calculated to approximate the time series as a set of additive components to estimate trend and periodicity
- A subset of the entire solution set is selected by the user to approximate the data, the fit is examined, and the resulting approximated dataset is exported
- Gaps in the original dataset are then filled using the SSA approximations, but the original data is retained.

Figure 25-20 shows that for a time series of hourly water temperature data at Martinez with short gaps (black lines), using a larger set of approximating eigenvectors (24 instead of 4) significantly improved the fit. The CAT-MV (red lines) approximations to hourly water temperature data (blue lines) at Martinez both used a window length of 288 hours. Black vertical lines indicate missing data points. The upper plot used only 4 out of the available eigenvectors, while the lower plot used 24 eigenvectors. Figure 25-21 shows the residuals from one year (upper) and two-year approximations to this data. Residuals are larger in summer months, but are generally within +/- 1 °C. Longer data gaps (Figure 25-22) were generally approximated better using a window length shorter than the data gap.

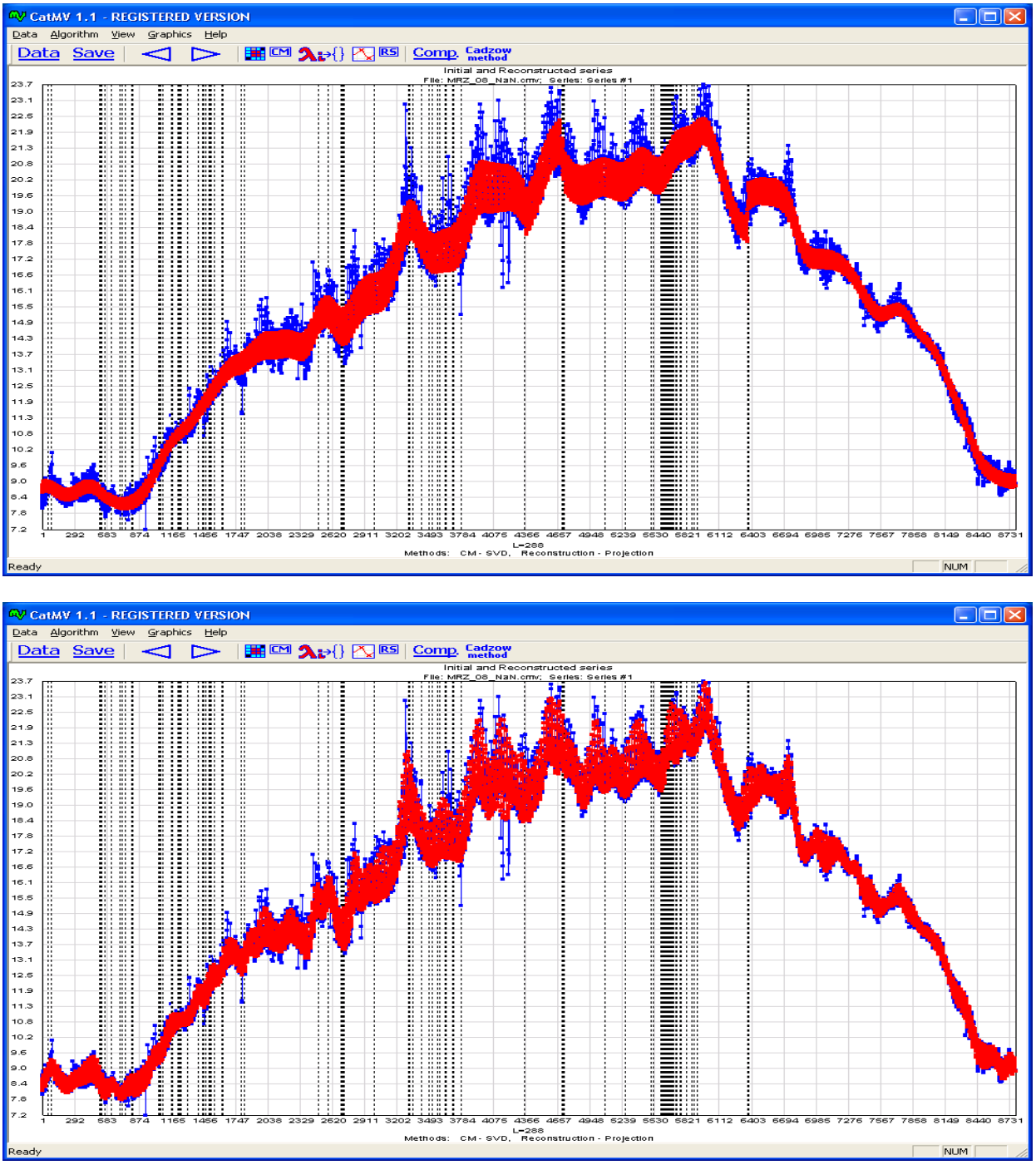


Figure 25-20 CAT-MV (red lines) approximations to hourly water temperature data (blue lines) at Martinez. Black vertical lines indicate missing data points. Upper plot used 4 eigenvectors, the lower plot used 24.

Residuals and Histogram WL=288, EV = 24, One Year MTZ

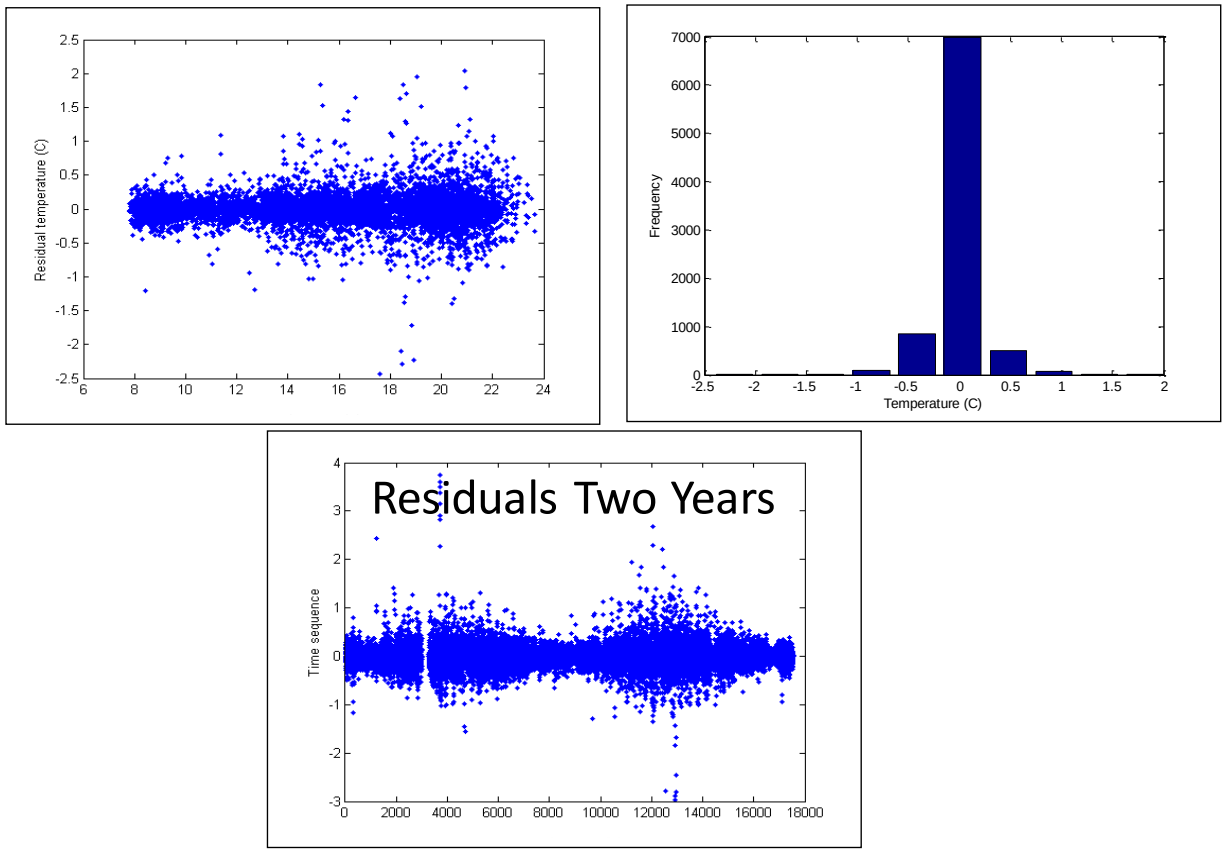


Figure 25-21 Upper: Residual plot and histogram of a Cat-MV model fit to one-year of hourly water temperature at Martinez, window length was 288, 24 eigenvectors. Lower: Residuals applied to a two-year data set: the fit during summer months poor in comparison to winter.

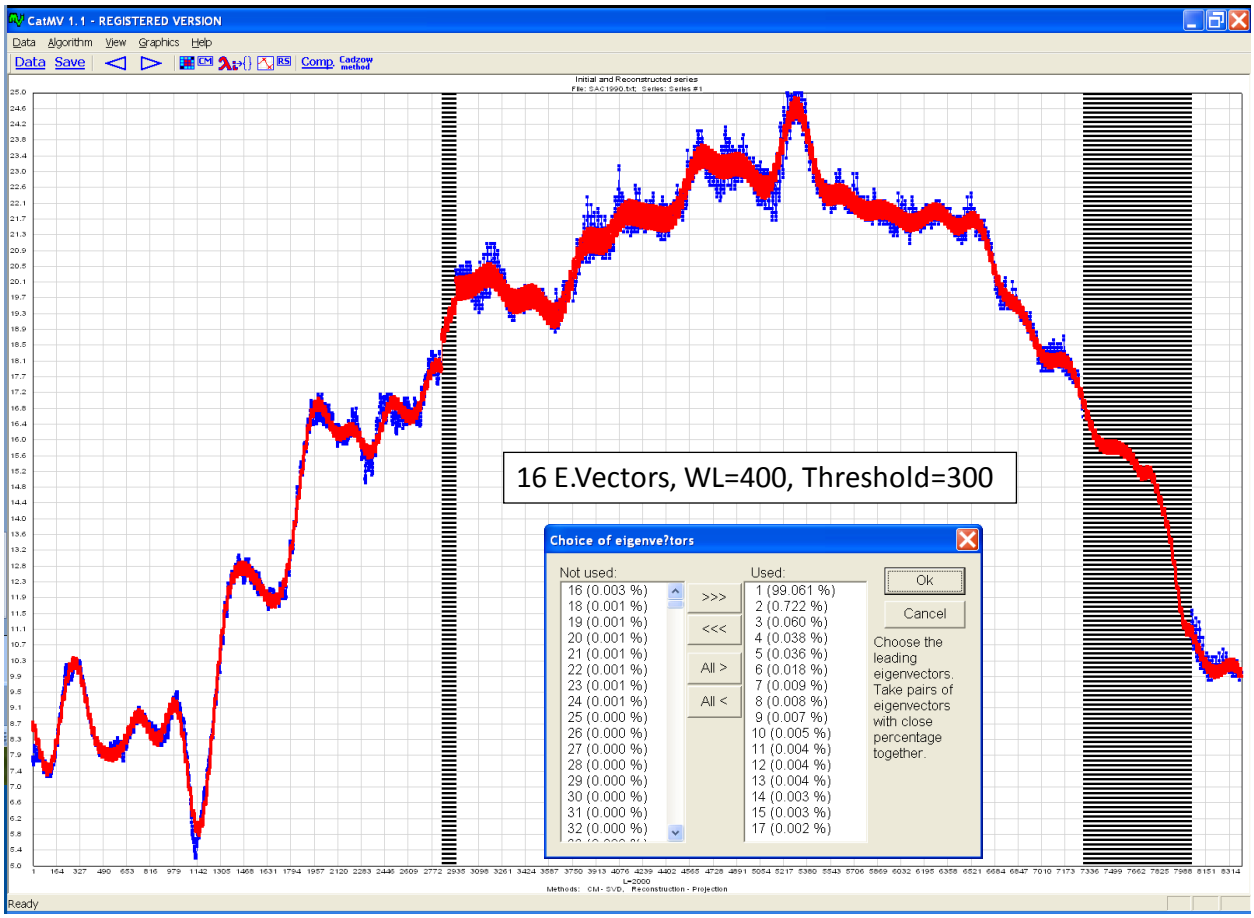


Figure 25-22 Large data gaps (dark bands) used a window length shorter than the largest data gap to get better results. Cat-MV fit (red) to the data series (blue line) and the missing data.

25.5 Model Boundary Conditions

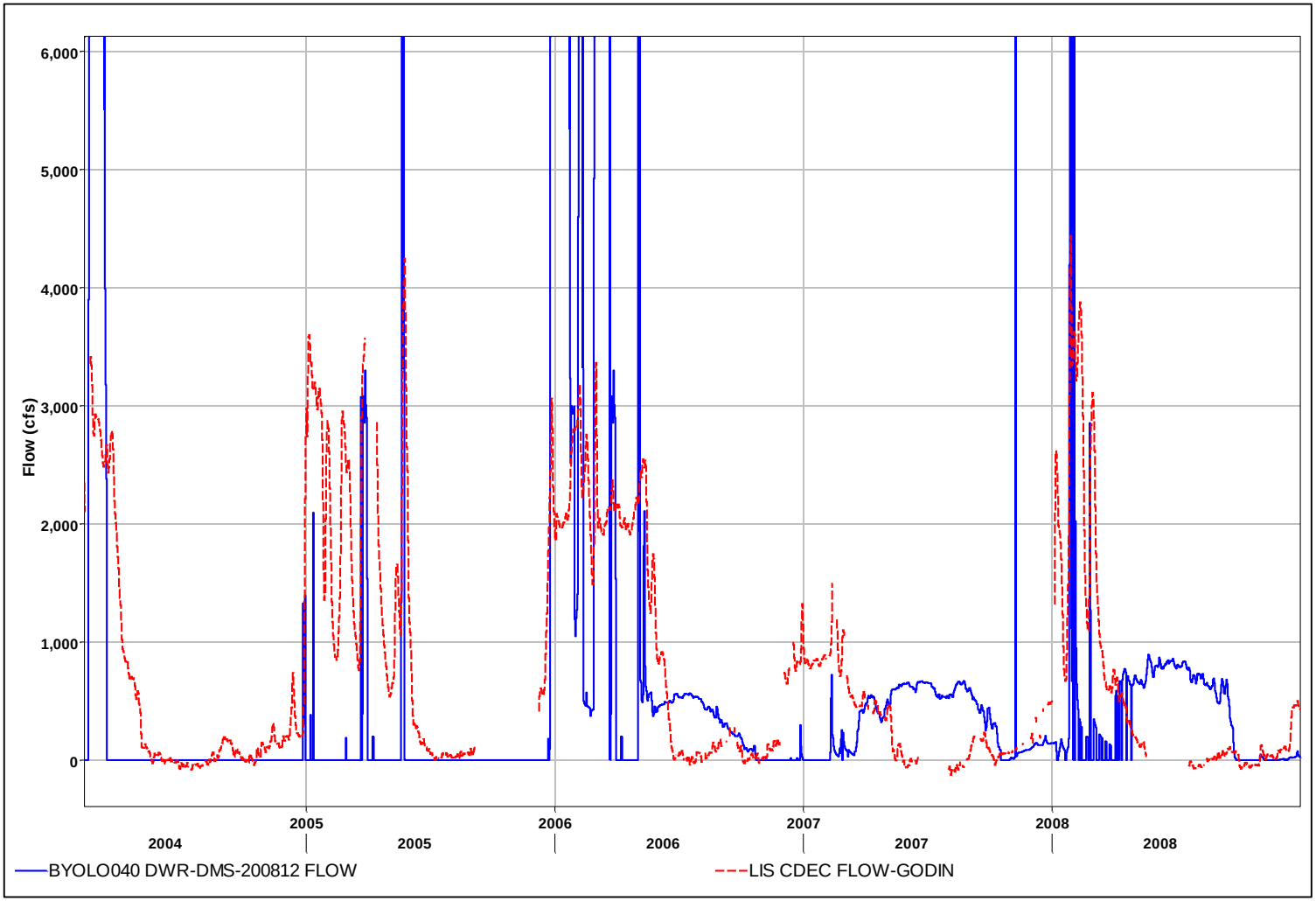


Figure 25-23 Flow data at the Lisbon Toe Drain (LIS, red line) and boundary condition data from DSM2 at the Yolo boundary (blue line).

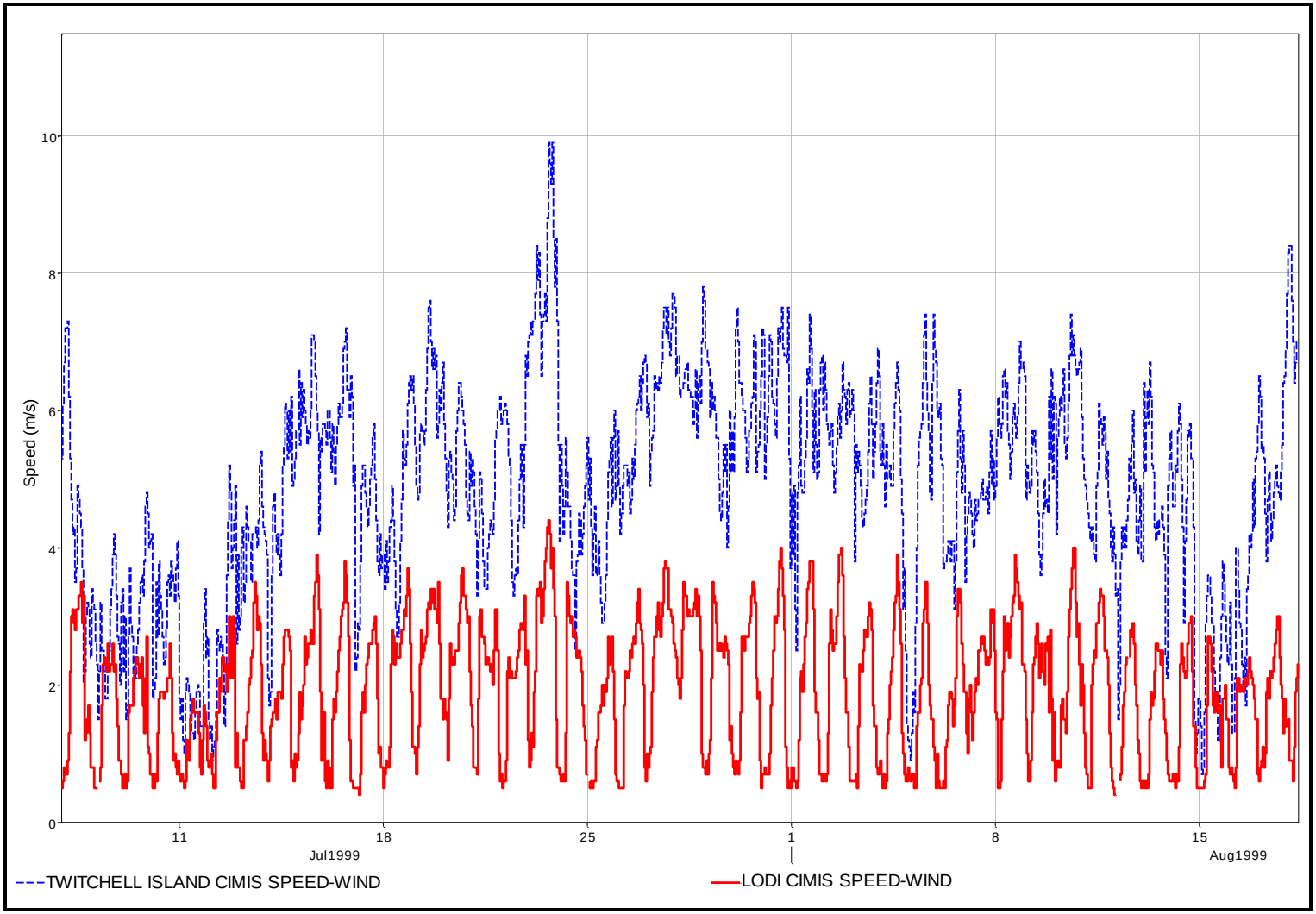


Figure 25-24Wind speeds for the CIMIS stations at Lodi and at Twitchell Island show a factor of two difference in wind speed.

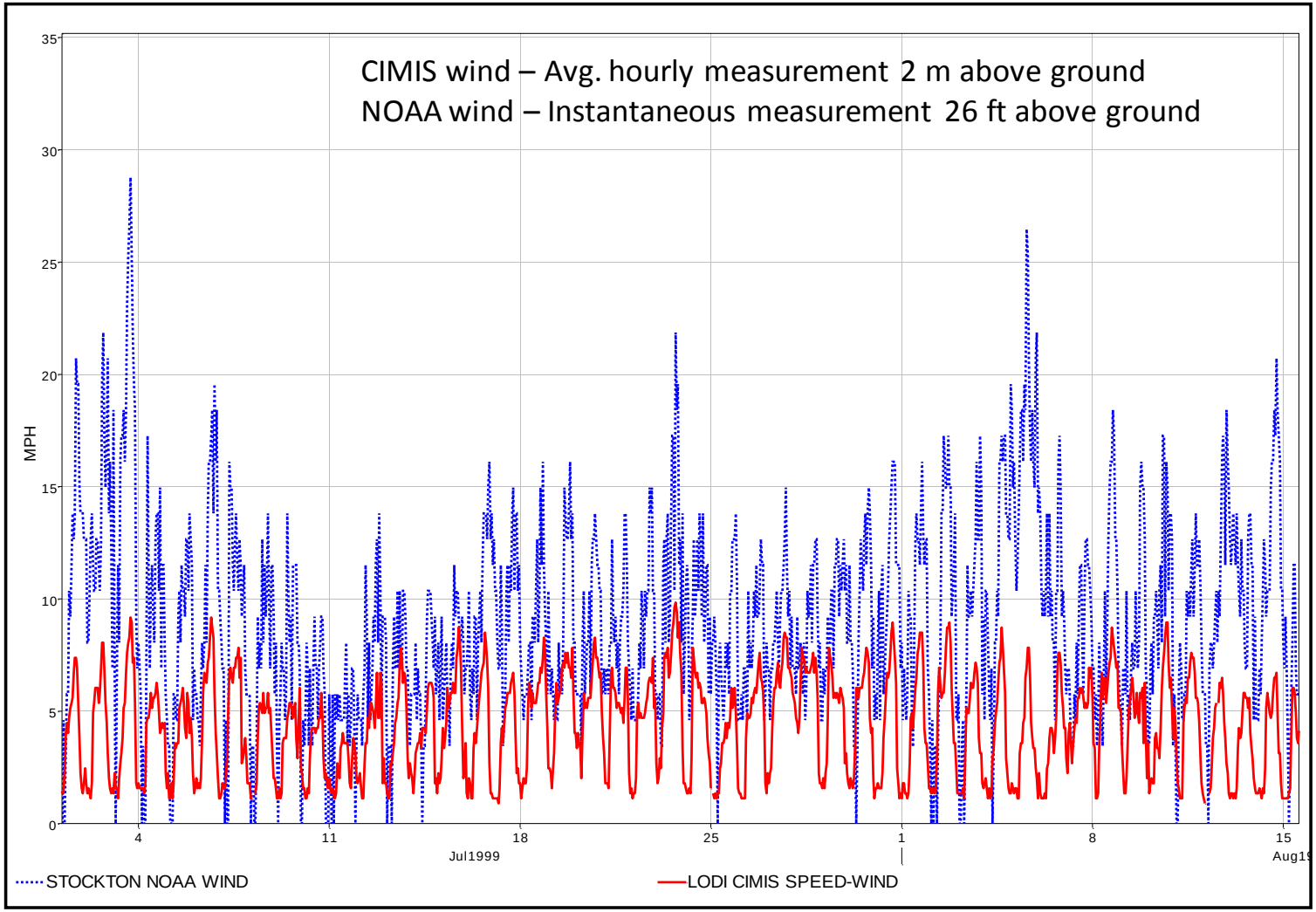


Figure 25-25 Wind speeds for the CIMIS station at Lodi and the NOAA station at Stockton show a factor two variation in reported speed.

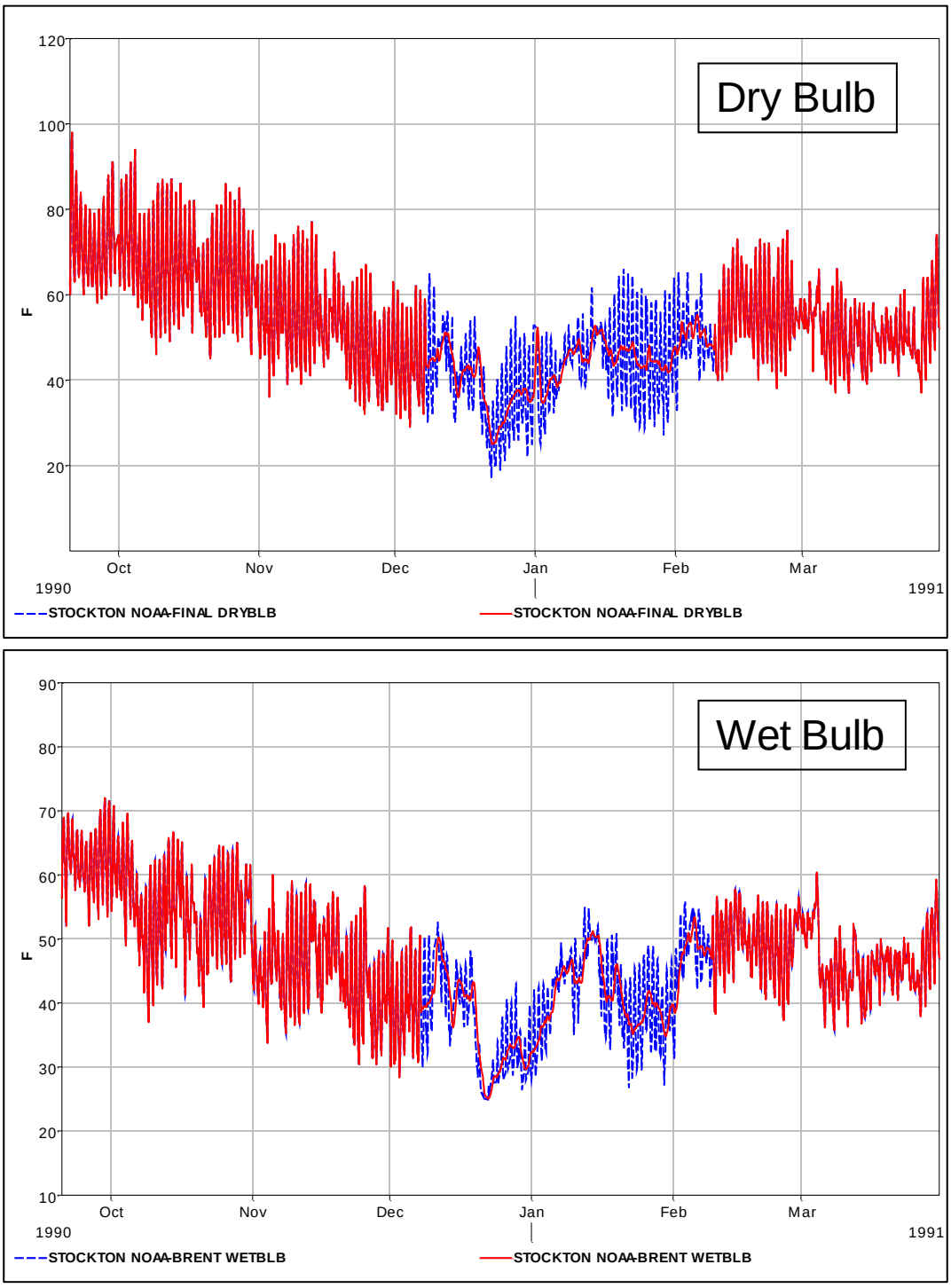


Figure 25-26 Red line is the smoothed boundary (dry bulb upper, wet bulb lower) used to get model convergence during these periods.

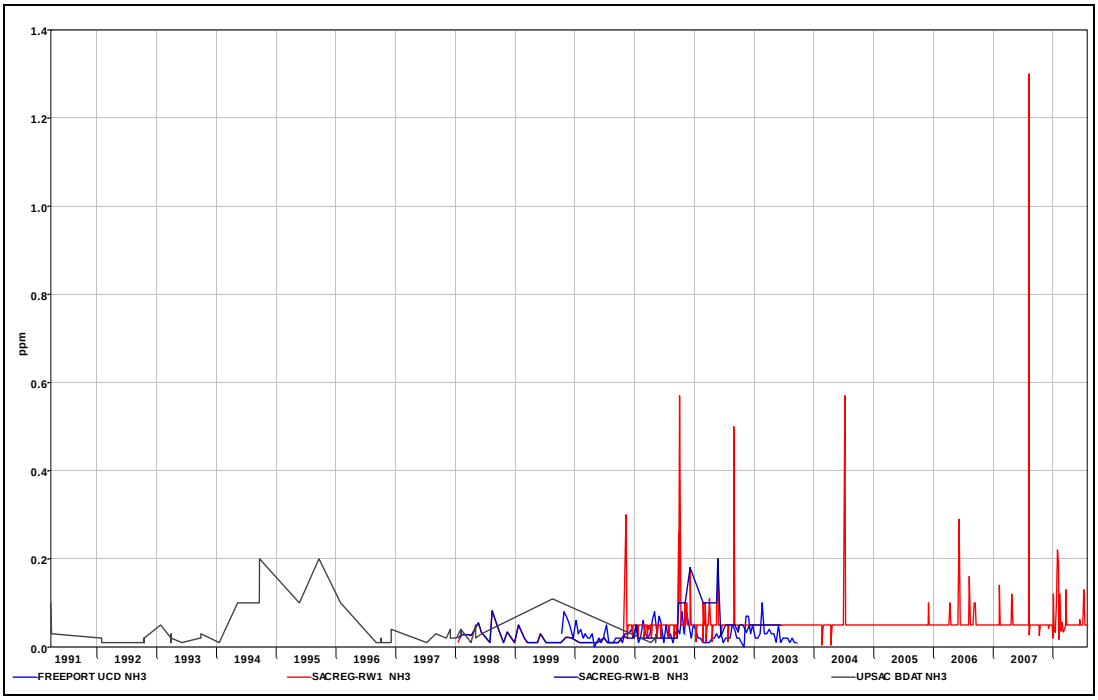


Figure 25-27 Ammonia concentration data above Freeport from three sources, UC Davis (blue), BDAT (black) and Sac Regional receiving waters monitoring (two data sets, red and dark blue).

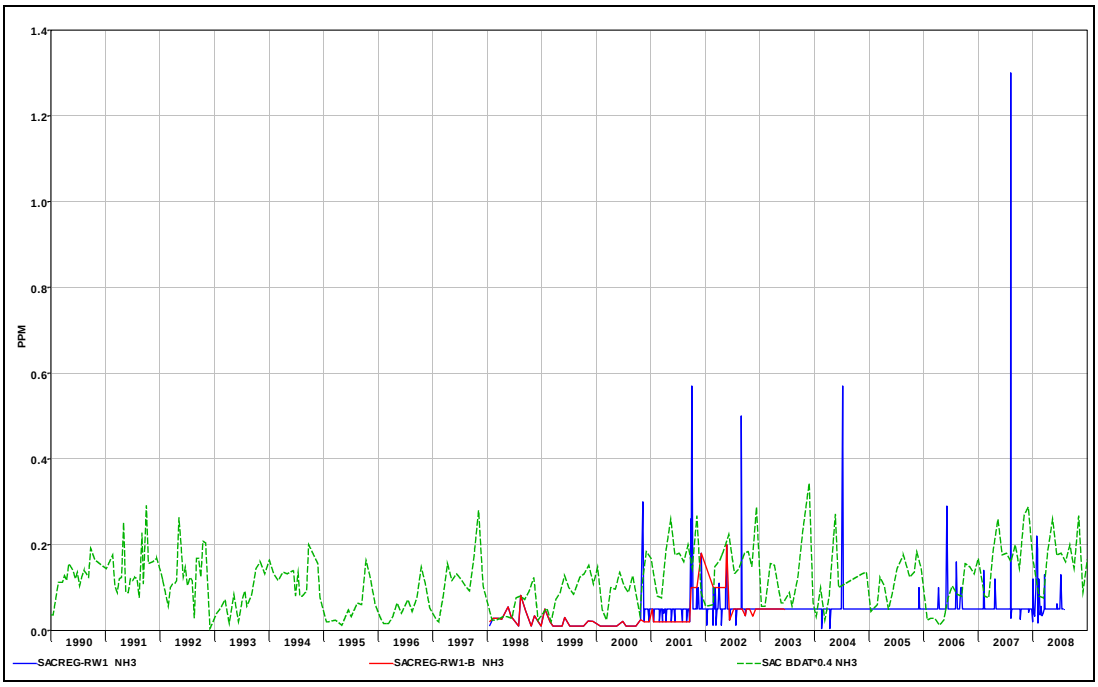


Figure 25-28 NH_3 concentration from Sac Regional receiving water measurements (blue and red) in comparison with NH_3 boundary condition set at BDAT Greens/Hood ammonia*0.4.

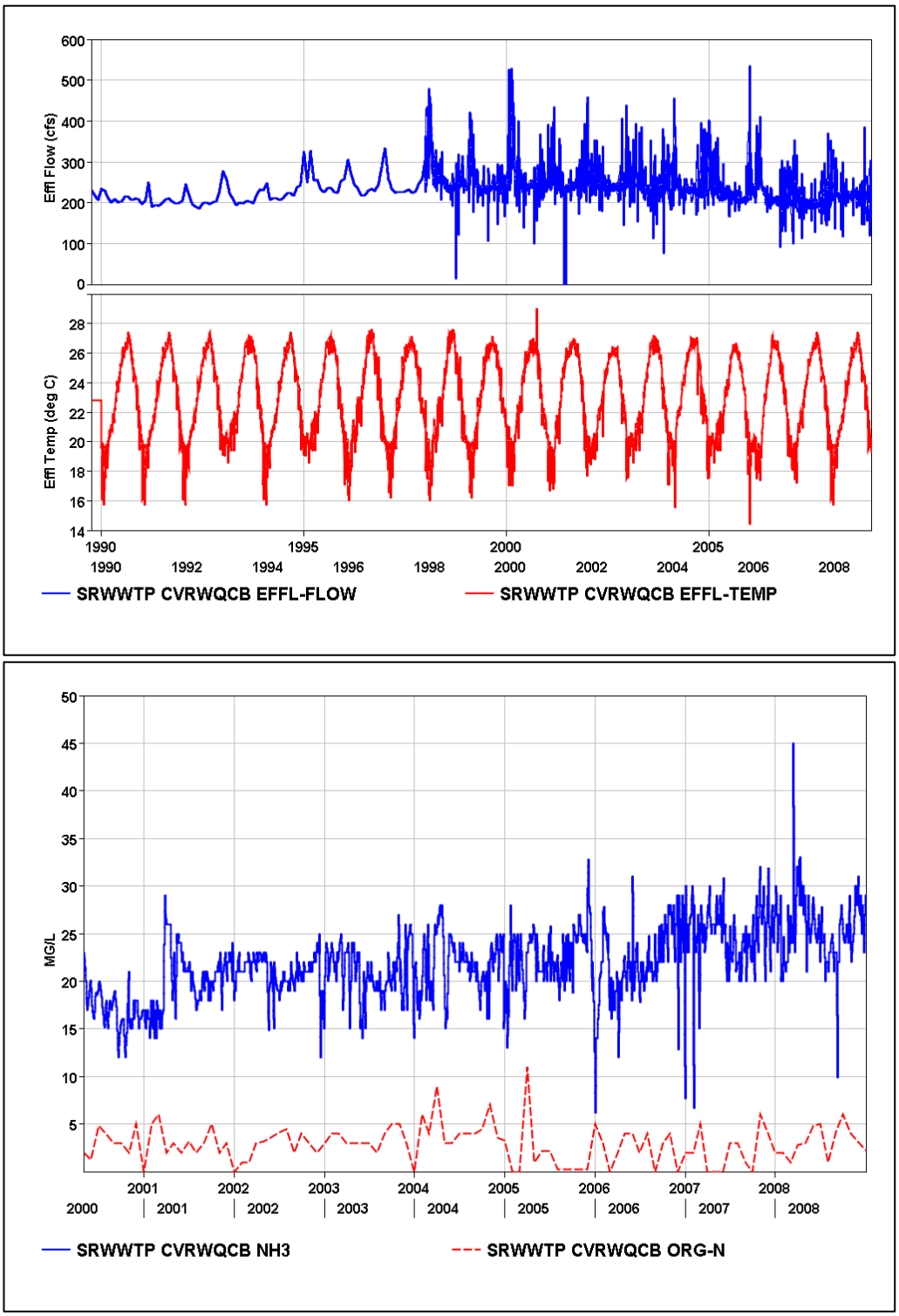


Figure 25-29 Sac Regional flow, temperature, ammonia and organic-N effluent concentrations.

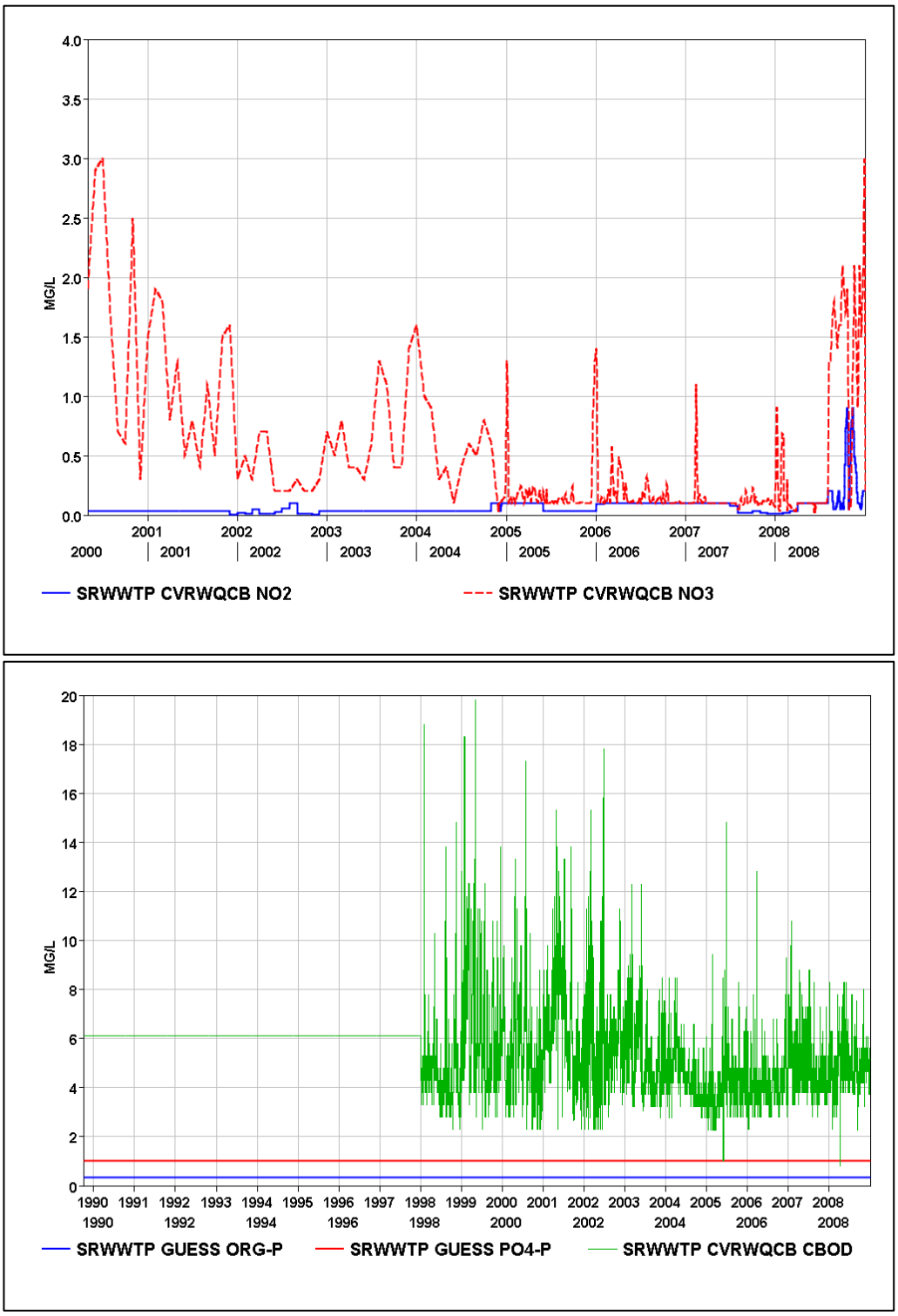


Figure 25-30 Sac Regional nitrate, nitrite, organic-P, CBOD and PO_4 effluent concentrations.

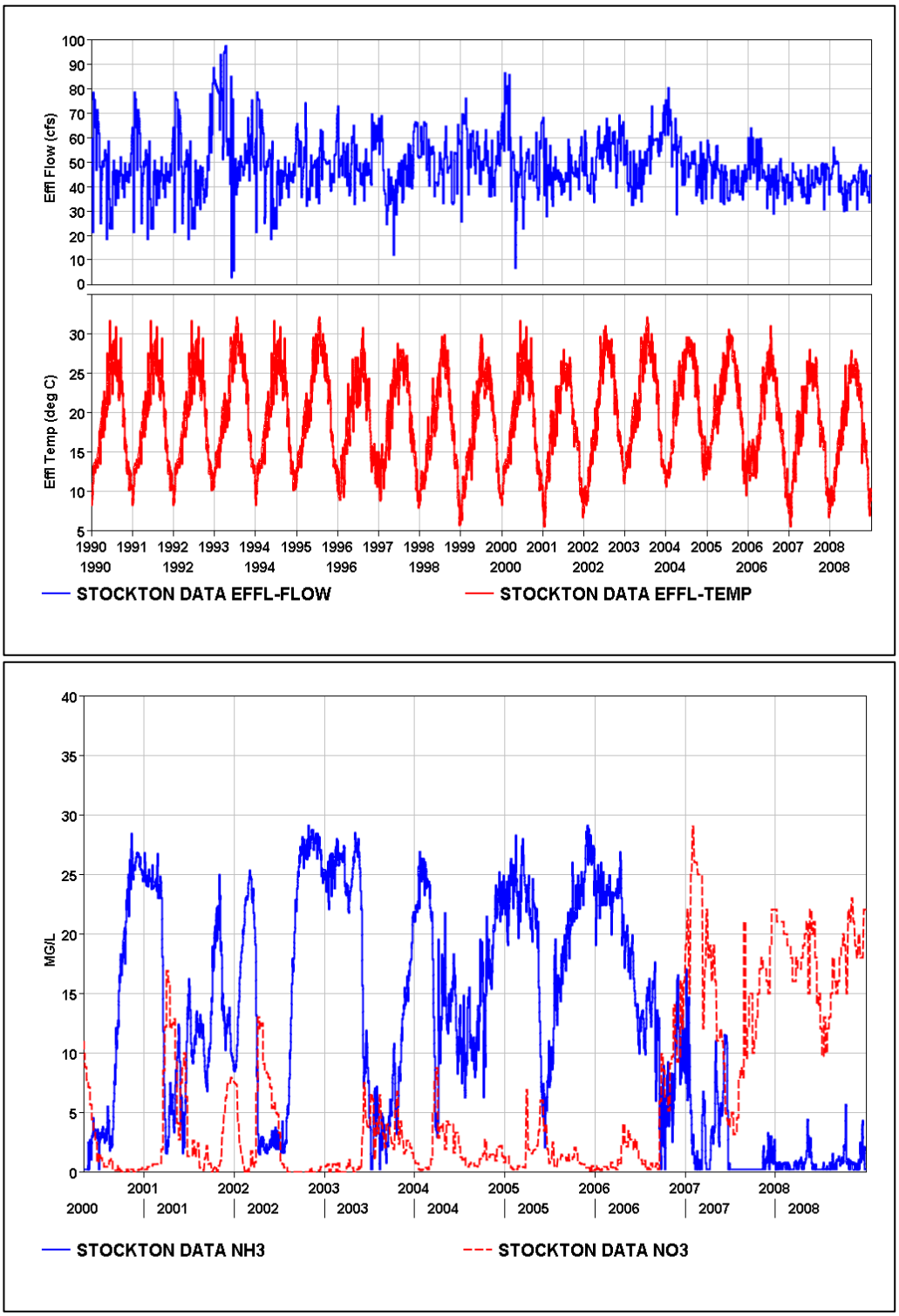


Figure 25-31 Stockton WWTP flow, temperature, ammonia and nitrate effluent concentrations.

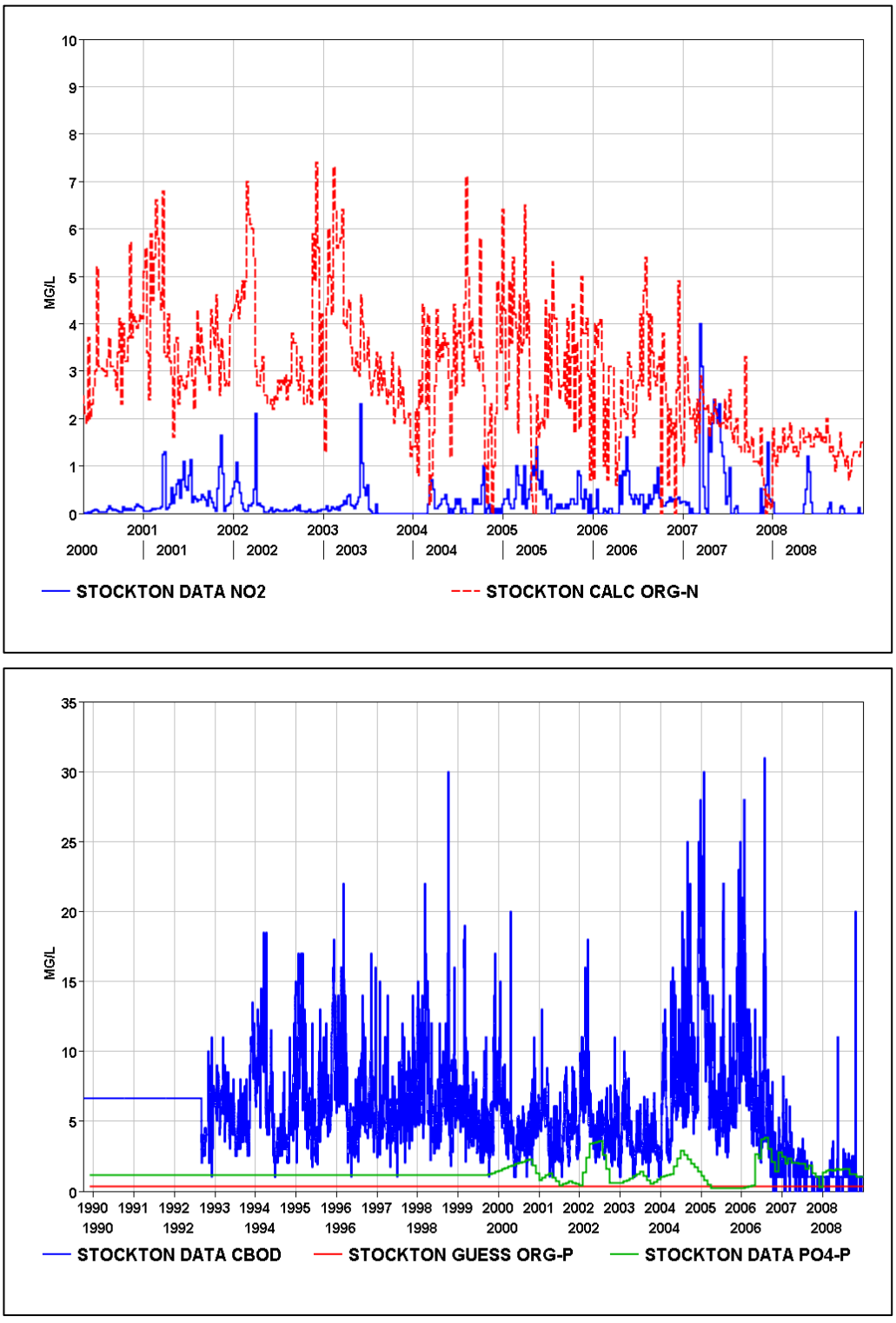


Figure 25-32 Stockton WWTP organic-N, nitrite, organic-P, CBOD and PO_4 effluent concentrations.

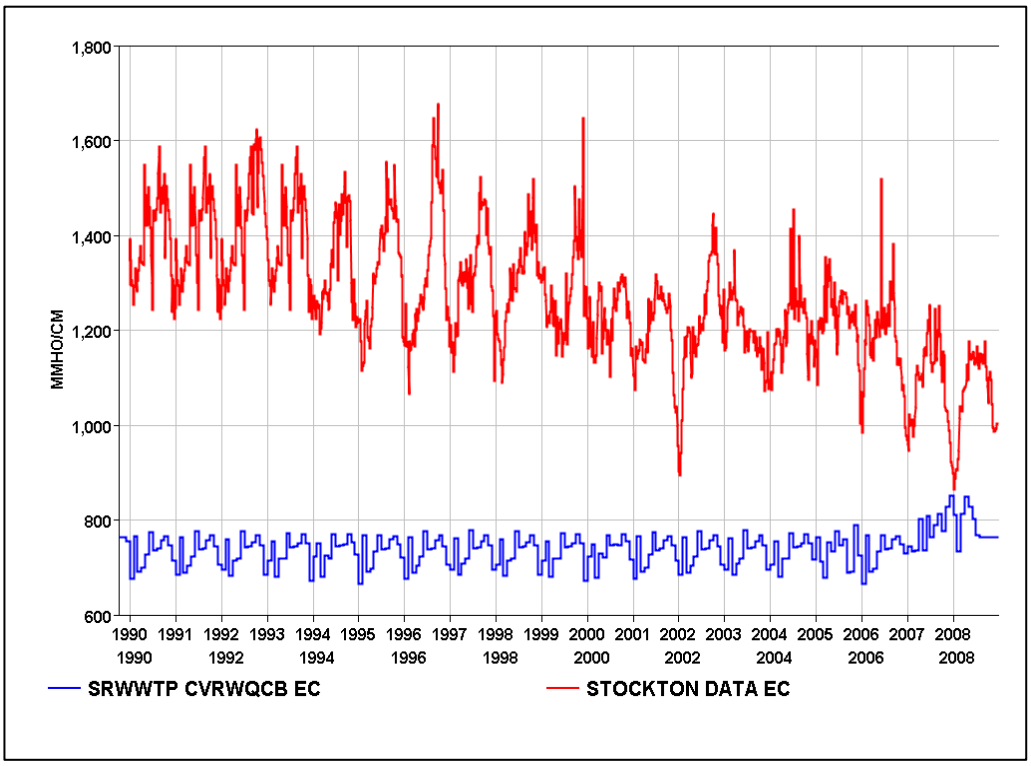


Figure 25-33 Sac Regional and Stockton WWTP effluent EC concentrations.

Table 25-8 Availability of measurements for seven WWTPs in the DSM2 model domain

Location	Stockton Tertiary since September 20'06	Sac Regional Secondary	CCCSD Secondary	Delta Diablo Secondary	Tracy Tertiary since July 2007	Manteca Tertiary since 06-08/03	Lodi Tertiary	Fairfield-Suisun Advanced secondary
Flow	mid-1992 - 2008	1990 - 2008	2000 - 2008	2004 - 2008	07/98 to 2008	04/04 to 08/08	05/00 - 07/06	2004 - 2008
Temp	1996 -2008, missing 2001, 2002	1998 - 2008	2000 - 2008	no data	07/98 to 2008	04/04 to 08/08	02/05 - 07/06	2004 - 2008
NH3	mid-1992 - 2008	1990 - 2008	2000 - 2008	03/04 to 2008	07/98 to 2008	05/04 to 08/08	05/00 - 07/06	03/04 to 2008
NO3	mid-1992 - 2008	1990 - 2008, missing short periods	2000 - 2008	no data	07/2007 to 2008	07/06 to 08/08	no data	10/07 to 2008
NO2	mid-1992 - 2008	2002 - 2008, missing segments	2000 - 2008	no data	07/2007 to 2008	07/06 to 08/08	no data	no data
Org-N	mid-1992 - 2008	1990 -2008, missing segments	2000 - 2008	no data	07/2007 to 2008	no data	no data	10/07 to 2008
BOD5	mid-1992 - 2008	1998 - 2008		no data	07/98 to 2008	04/04 to 08/08	05/00 - 07/06	2004 - 2008
CBOD	mid-1992 - 2008		2000 - 2008	no data				
PO4	mid-1992 - 2008	1998 - mid-08, missing segments	2000 - 2008	no data	no data	no data	no data	10/2007 to 2008
Org-P	no data	no data	no data	no data	no data	no data	no data	no data
DO	mid-1999 - 2008	no data	2000 - 2008	no data	no data	no data	02/05 - 05/06	no data
Chl-a	no data	no data	no data	no data	no data	no data	no data	no data
EC	mid-1992 - 2008	2004 - 2008	no data	no data	07/98 to 2008	09/05 to 08/08	05/00 - 07/06	no data
pH	mid-1993 - 2008	2000 - 2008	no data	no data	07/98 to 2008	04/04 to 08/08	02/05 - 07/06	2004 to 05/07

Table 25-9 Availability of measurements from the other WWTP's with effluent reaching the Delta. Vacaville, Davis and Woodland were not considered in this model. Benicia outfall is downstream of the model boundary.

Location	MTZ Refinery (Biological treatment)	Tesoro Refinery (Various treatments)	Valero (Ben) Refinery (Various treatments)	Benicia	Davis Secondary	Woodland Secondary	Vacaville	Disc. Bay Secondary	Mtn House Secondary (?) Mo Avg 05/04 - 06
Flow	2006 - 2008	2006 - 2008	2006 - 2008	2006 - 2008	2001 to 10-05	1996 - 2008	01/05 to 2008	2004 - 2007	Yes
Temp	no data	no data	no data	no data	2001 to 10-05	1996 - 2008	no data	2004 - 2007	Yes
NH3	2006 - 2008	2006 - 2008	2006 - 2008	few points	2001 to 10-05	1996 - 2008	no data	2004 - 2007	Yes
NO3	no data	no data	no data	no data		1996 - 2008	12/04 - 11/07	2004 - 2007	Yes
NO2	no data	no data	no data	no data	no data	no data	12/04 - 11/07	no data	Yes
Org-N	no data	no data	no data	no data	no data	no data	no data	no data	No
BOD5	no data	no data	no data	no data	2001 to 10-05	1996 - 2008	no data	2004 - 2007	No
CBOD	no data	no data	no data	no data			no data		No
PO4	no data	no data	no data	no data	no data	1996 - 2008	(TOT-P)	no data	Tot-P
Org-P	no data	no data	no data	no data	no data	no data	no data	no data	No
DO	no data	no data	no data	no data	no data	no data	no data	2004 - 2007	No
Chl-a	no data	no data	no data	no data	no data	no data	no data	no data	No
EC	no data	no data	no data	no data	2001 to 10-05	1996 - 2008	12/04 - 11/07	2004 - 2007	Yes
pH	no data	no data	no data	no data	2001 to 10-05	1996 - 2008	12/04 - 11/07	2004 - 2007	Yes

25.6 Wet Bulb Temperature Calculations

Because wet bulb temperature is used in the model and data were not available prior to 1996, an algorithm was used to calculate wet bulb temperature derived from relationships between saturated vapor pressure, relative humidity or dew point and air temperature.

Relative humidity is defined as the ratio of the ambient vapor pressure to the saturated vapor pressure (100 % humidity). The dew point is the temperature that corresponds to the ambient vapor pressure. The wet bulb temperature is the temperature measured by an apparatus that relies on evaporated cooling that is a function of humidity, high wind speed and atmospheric pressure. The wet bulb temperature always falls between the ambient temperature and the dew point.

Saturated vapor pressure can be computed using the following fit of physical data:

$$VP_s = 2.1718\ e^{8} * e^{(-4157/Ta)} \qquad (A1)$$

Where VP_s is the saturated vapor pressure in millibars and T_a is the air temperature in degrees Kelvin (°C+239.09).

If air temperature is available, then vapor pressure can be computed if relative humidity, dew point or wet bulb temperature is available. Assuming that the dew point is available, the ambient humidity can be computed which yields the relative humidity. Assuming relative humidity is available; the ambient vapor pressure may be computed as relative humidity (fractional) times "VP_s" and then the dew point can be computed.

A simple approach was used to compute dew point. Air temperature "T_a" was incremented (in steps of 0.025 °C in this application) using equation (A1) until the difference between the ambient and computed vapor pressure was minimized.

Given the dew point temperature (observed or computed), the following expression, derived from a fit of physical data, defines the vapor pressure at the wet bulb temperature as:

$$VP_s = 2.1718\ e^{8} * e^{(-4157/Ta)} - P*(T_c-T_w)*(6.6\ e^{-4} + (7.59\ e^{-7})* T_w) \qquad (A2)$$

where T_c is the air temperature in degrees Celsius, P is the atmospheric pressure in millibars and

T_w is the air temperature in degrees Celsius.

A simple approach was also used to compute the wet bulb temperature by incrementing "T_w" (in increments of 0.025 °C) of the above equation until the difference between the ambient and computed vapor pressure was minimized.

25.7 Methodology for Setting Sacramento River NH_3 and NO_3 Boundary Conditions

Data to set the NH_3 boundary condition (BC) on the Sacramento River was obtained from a variety of sources, including Sac Regional receiving water measurements, MWQI and a dataset from R. Dahlgren at UC Davis. The ammonia data, as seen from are sparse, generally range from 0.01 mg/L to a maximum of about 1.3 mg/L, and are quite variable between measurement agencies as shown in Figure 25-27.

Figure 25-28 shows a comparison of Sac Regional receiving water measurements near Freeport and the boundary condition for ammonia set using merged BDAT data from Greenes Landing and Hood, but reduced by a factor 0.4. Although the ranges of the data values shown in Figure 25-27 are comparable for the different agencies, particularly at maximum values, these data suggest that the ammonia boundary condition shown in Figure 25-28 at the Sacramento River boundary is frequently high. Note that the detection level of ammonia for the Sac Regional receiving water dataset varies, although it was frequently quoted as 0.1 mg/L. For the purposes of comparisons in plotting, the plotted value was set at (detection limit)/2 on dates where a measurement was taken but below the specified limit.

Several strategies were used to develop a revised Sacramento R. ammonia BC. Several of these strategies are illustrated in figures, below. A straight-forward mass balance approach[29] is shown in Figure 25-34 in comparison with the boundary condition (blue) set at (Greens/Hood ammonia)*(0.4). The boundary concentration values calculated using this simple mass balance approach are frequently negative – negative values have been suppressed in the figure. A variation on this approach was used for the calculation shown in Figure 25-35 to avoid negative values – the Sac Regional receiving water data is shown for comparison (red line). In this case, scaling factors were applied in the calculation to lower the effluent ammonia concentration and the overall concentration at the Sac R. boundary.

The effect of the Sacramento flow magnitude was also investigated - some results are shown in Figure 25-36 and in Figure 25-37 in comparison with Sac Regional receiving water data (Figure 25-36, green) and with the UC Davis data (Figure 25-37, green). In the "low flow" case, the boundary value was set at 0.015 mg/L below 10,000 cfs Sacramento R. flow, and otherwise at 0.015 mg/L plus an additional factor of 15% of the scaled mass-balance ammonia calculation. In the "high flow" case, above 60,000 cfs Sacramento R. flow, the value was calculated at 0.015 mg/L plus 15% of the mass balance ammonia and at 0.015 mg/L otherwise. In both of these cases, the components in the mass balance calculation were altered by constant scaling factors to improve the fit.

---

[29] (Final Concentration*Final Volume) = (Concentration at BC)*(Volume BC) + (Concentration Effl * Volume Effl) Solve for Concentration at BC.

None of the calculations give a clear-cut best fit for the measured ammonia near Freeport, so the high flow case was selected to test as a boundary condition in the nutrient model as it captured some of the variability in the UC Davis dataset. Figure 25-38 and Figure 25-39 illustrate results for modeled ammonia concentration at three locations downstream of the Sacramento R. boundary. Figure 25-38 (upper plot) is a comparison of two models with results at RSAC139 (Greens Landing) – the models were run with different Sacramento R. ammonia BC's. The blue lines are the modeled monthly MAX and MIN envelope (of hourly results, see Section 11.3) for the calculated "high flow" case, denoted the V12 model run. The red lines are the MAX and MIN envelope of the V11 model run with the Sac R. BC set at (Greens/Hood ammonia)*(0.4). Figure 25-38 (lower) shows the V12 results at RSAC139 (Greens Landing) for both the Greens and Hood EMP data over a longer time span. Figure 25-39 shows the V12 ("high flow") Max and Min envelope model results for ammonia at Point Sacramento (upper) and at Potato Point (lower) in comparison with data (green symbols).

Although Figure 25-36 shows that the difference in values between these two boundary conditions ranged between no difference and a factor of four increase (with the Greens/Hood*0.4 values generally higher than the calculated high flow case), there is much less difference in the modeled envelopes between the two models (Figure 25-38, upper). The two model runs would be deemed nearly equivalent in terms of the calibration. This result is generally consistent with the Sac R. ammonia BC sensitivity runs (+/- 20% in BC value) for an earlier set of boundary conditions, where the differences were also not large.

The situation for the Sacramento River nitrate boundary condition was simple in comparison with the ammonia BC. Figure 25-40 and Figure 25-41 show comparisons between different nitrate datasets near Freeport and with the nitrate BC set using the EMP data at Greens/Hood reduced by a factor of 0.825, respectively. The variability in the datasets is small (Figure 25-40), and the nitrate BC was set at a value that is consistent with the data (Figure 25-41).

The conclusions from this analysis are mixed. Because the data for ammonia near the model boundary are quite variable, and only partially consistent between data-gathering agencies, this leads to a high level of uncertainty in the setting of the ammonia boundary condition for the Sacramento R. The final four plots illustrate the implications of this observation.

An additional simulation was run with a constant Sacramento R. ammonia BC – the concentration was set at 0.05 mg/L which is the (higher) Sac Regional detection limit for ammonia*0.5. Note that Freeport (RSAC155) is below the model boundary for Sacramento inflow. Figure 25-42 shows a comparison between the V12 model run ("high flow"), the constant concentration boundary condition and the UC Davis measured ammonia concentration near Freeport. The modeled ammonia for the constant concentration run has changed from the constant boundary value due to algal growth and decay of ammonia from the parameterization for this region. The V12 model boundary condition was selected because it had some

resemblance to the UC Davis data at Freeport, and this resemblance is maintained at Freeport, while the constant concentration boundary has too little variability in comparison with the UC Davis data.

Figure 25-43 shows a comparison of the same two models, constant concentration boundary and V12 ("high flow"), plotted with the Sac Regional receiving water data near Freeport. In this case, neither model appears to yield a suitable representation of the data, as the variability in the data is much greater than the models produced, although the V12 "high flow" model does catch some of the dips in the receiving water measurements.

Figure 25-44 shows that at Greens Landing, RSAC139, the choice of the constant concentration boundary or the calculated "high flow" mass balance approach is immaterial – they are nearly identical. The final comparison, Figure 25-46, is comparison of EMP ammonia data measured at Greens landing with three model runs - constant concentration (green dash), V12 "high flow" (red), and V10 with the Sacramento boundary set at (Greens/Hood ammonia)*(0.4) (blue dash) – showing that each of the three Sacramento R. ammonia BC settings gives a good representation of this sparse calibration dataset, although all but the V10 model run tend to be low in comparison with the Greens Landing data.

The final observation from the data analysis was that negative values produced during of the mixing model calculations for BC NH_3 were apparently related to the ratio:

Flow ratio= (Total Sac flow)/ Sacramento R. inflow)

as shown in Figure 25-45, where the value

Total Sac flow = Sacramento R. BC inflow + Sac Regional effluent flow.

Following this observation, the final mixing model formula for the Sacramento NH_3 BC was set as:

(Total Sac flow)*(NH_3 Grns/Hood) – (Sac Reg Effl flow)*(Effl NH_3)*0.8/ (Total Sac flow)*(Flow ratio)

Any remaining negative values in this time series were then set to 0.025 mg/L, and the factor of 0.8 was used to account for reactions between the outfall and the measurement point at Greenes/Hood.

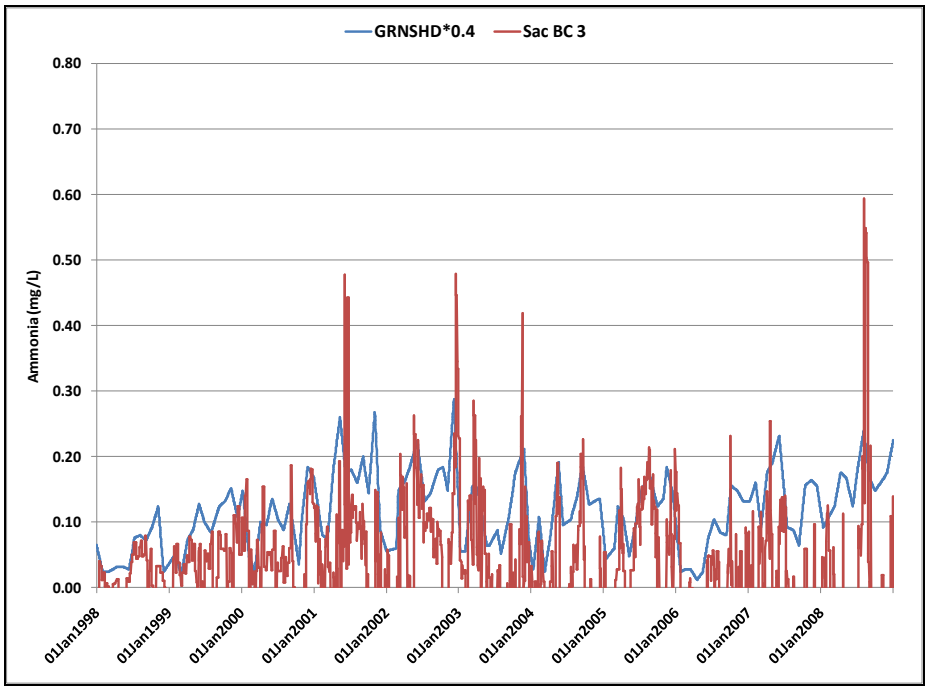


Figure 25-34 Sacramento R. NH_3 boundary condition (red) calculated using a mass balance approach in comparison with previous boundary condition (blue).

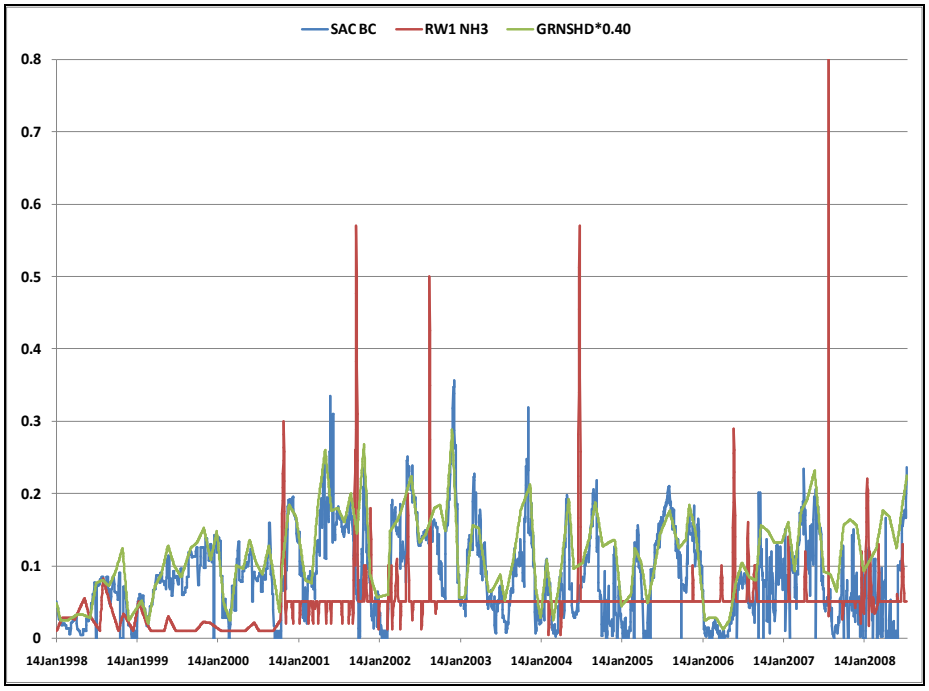


Figure 25-35 Sacramento R. NH_3 boundary (blue) calculated using a revised mass balance approach in comparison with Sac Regional receiving water NH_3 data (red) and previous boundary condition (green).

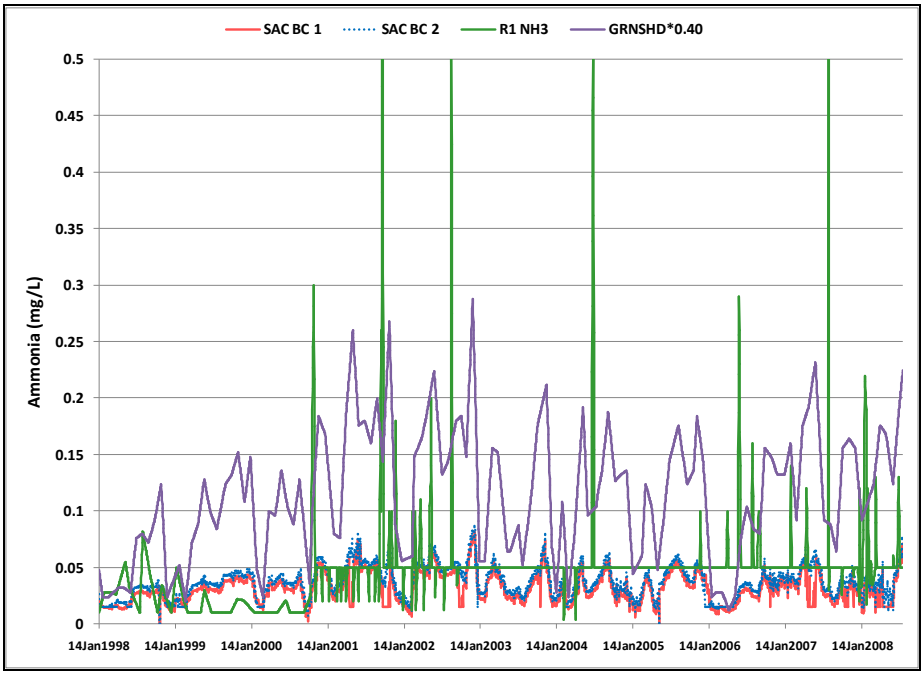


Figure 25-36 Two calculated NH_3 boundary conditions: low flow (red) and high flow (blue) constraint with a minimum value compared with Sac Regional receiving water NH_3 (green) and previous BC (purple).

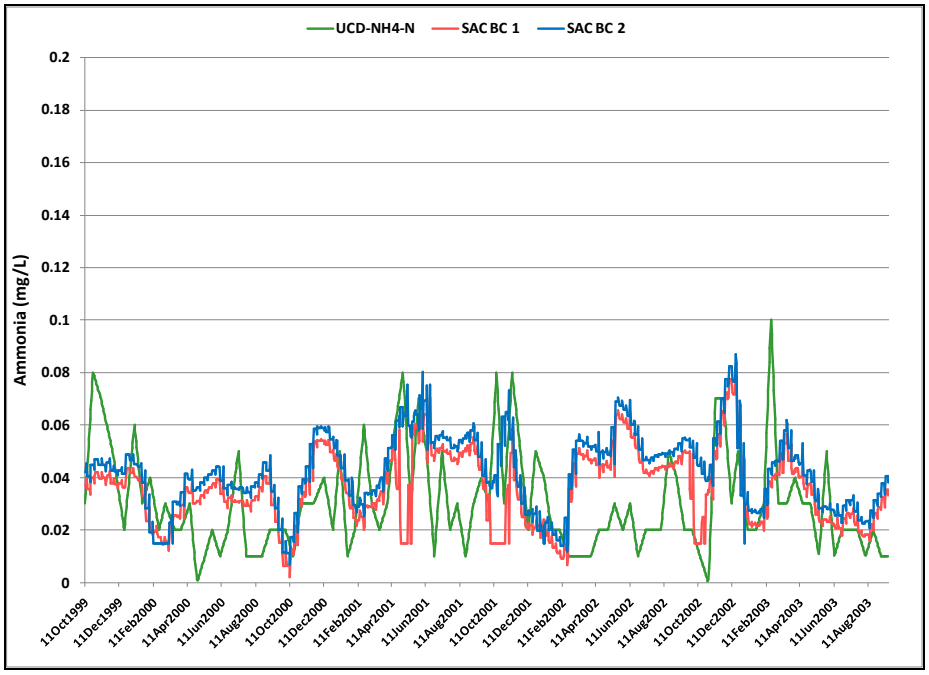


Figure 25-37 The same two calculated boundary conditions as in Figure 25-36, in comparison with UC Davis Freeport measured ammonia (green)

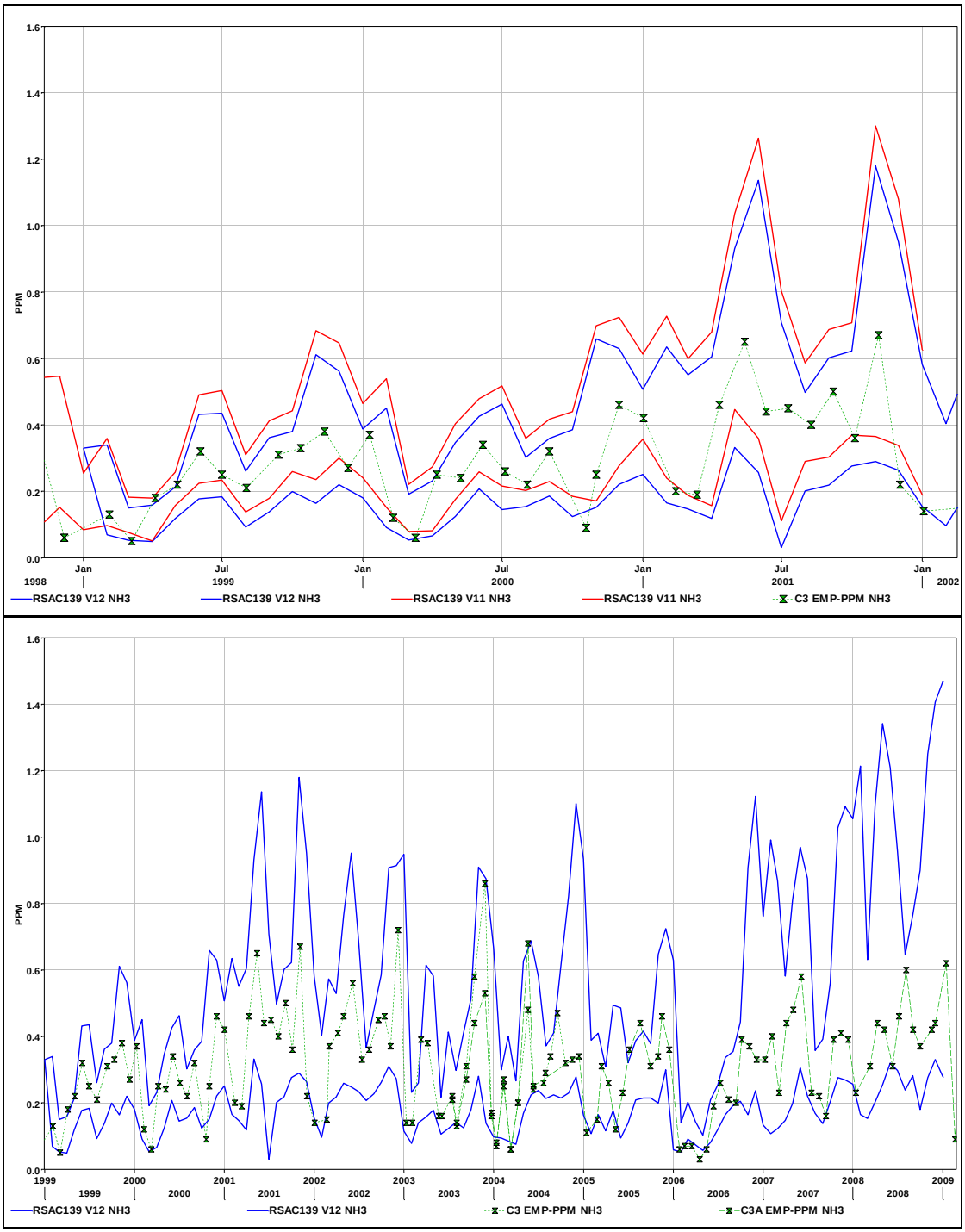
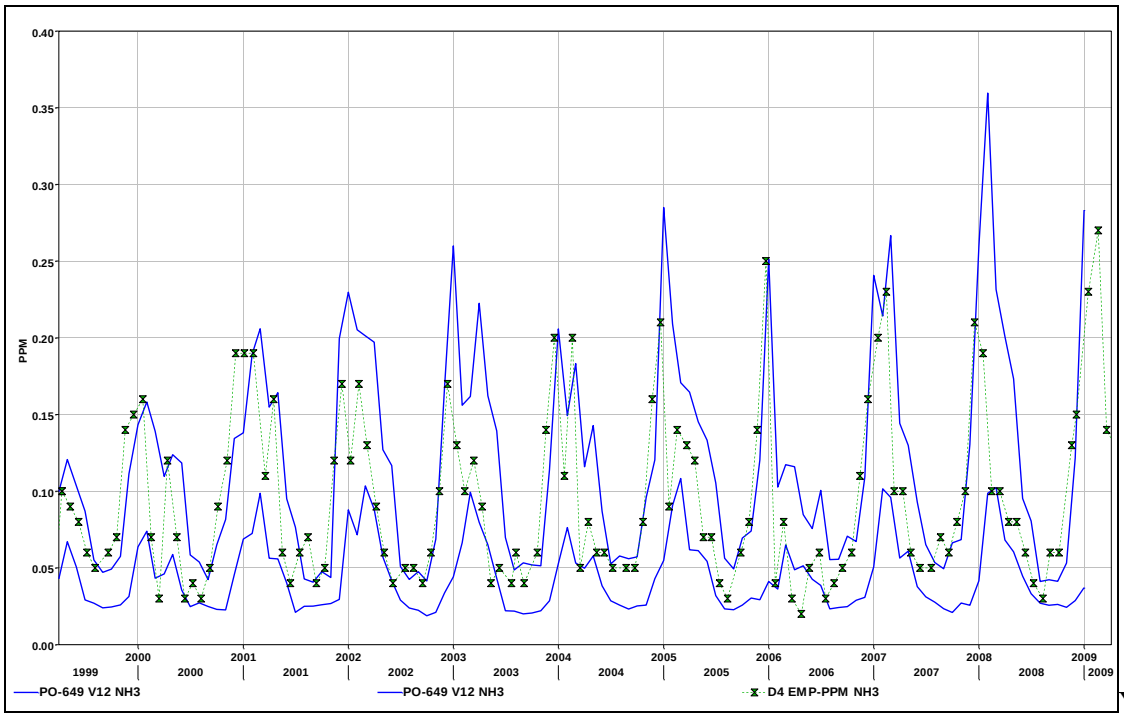


Figure 25-38 Modeled (blue) and measured (green symbol) ammonia at Greens Landing (RSAC139). Upper: Model V12 Sac R. BC with high flow constraint; V11 (red) with a GRNSHOOD*0.4 BC. Lower: V12 model output at Greenes Landing vs. Greenes (C3) and Hood (C3A) ammonia data.



Y

Figure 25-39 V12 model (calculated ammonia BC w/high flow constraint) at downstream locations, Point Sacramento (upper, PO-649) and at Potato Point (lower, D26).

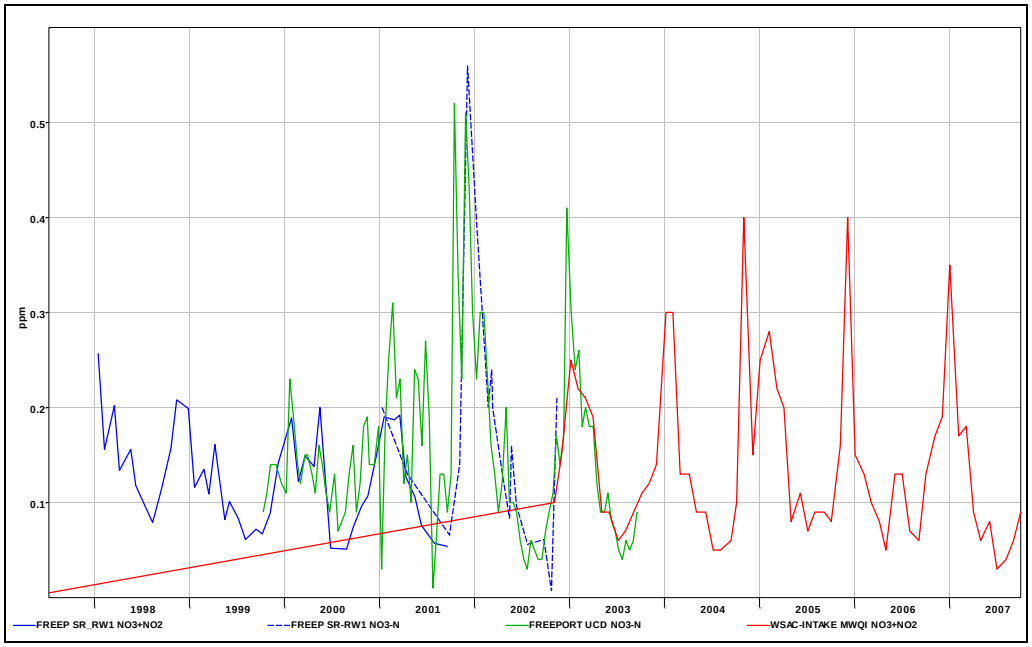


Figure 25-40 Four nitrate concentrations at or near Freeport – UC Davis data (green), BDAT data (red) and two Sac Regional receiving water datasets (blue, solid and dashed).

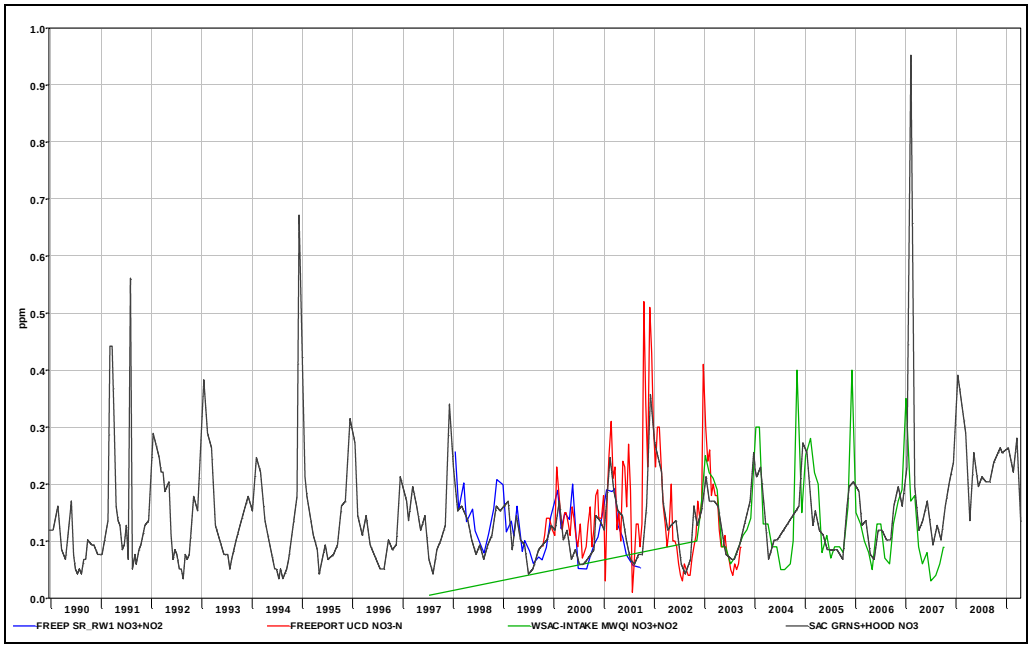


Figure 25-41 Nitrate data at or near Freeport *vs.* Sacramento R. BC: (black) BC set using EMP (Greens/Hood nitrate)*(0.825) vs. UC Davis data (green), Sac Regional receiving water data (blue) and MWQI monitoring data (green).

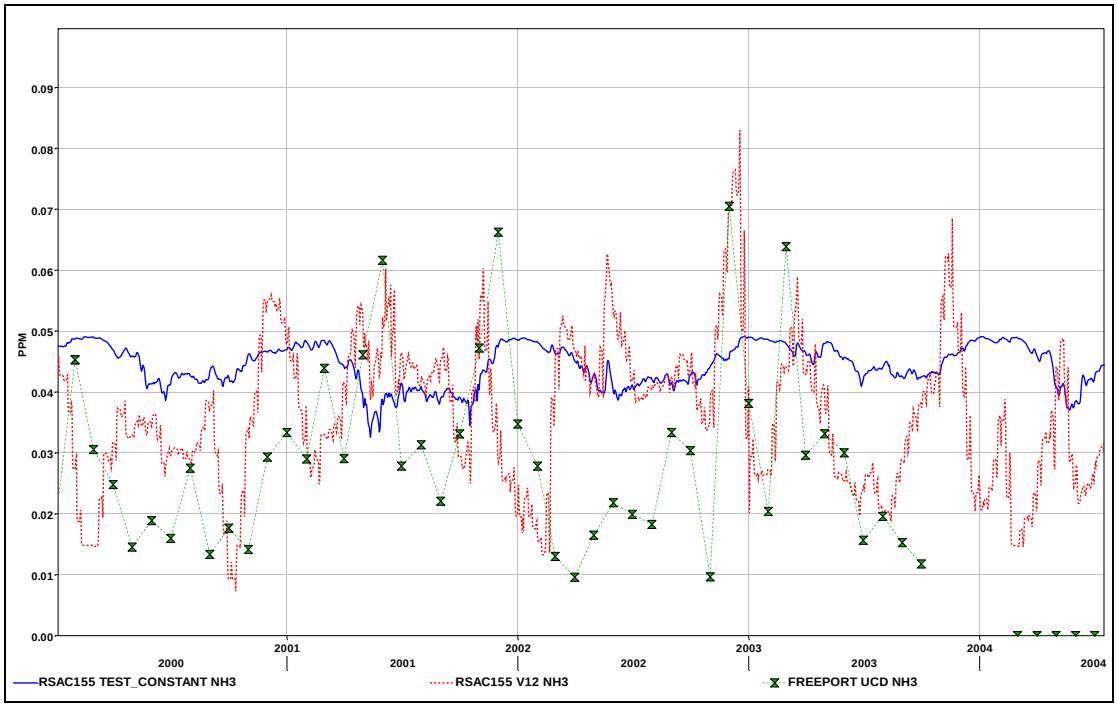


Figure 25-42 Modeled ammonia with constant concentration boundary (blue), "high flow" V12 boundary (red dash) vs. UC Davis ammonia data near Freeport (green symbols).

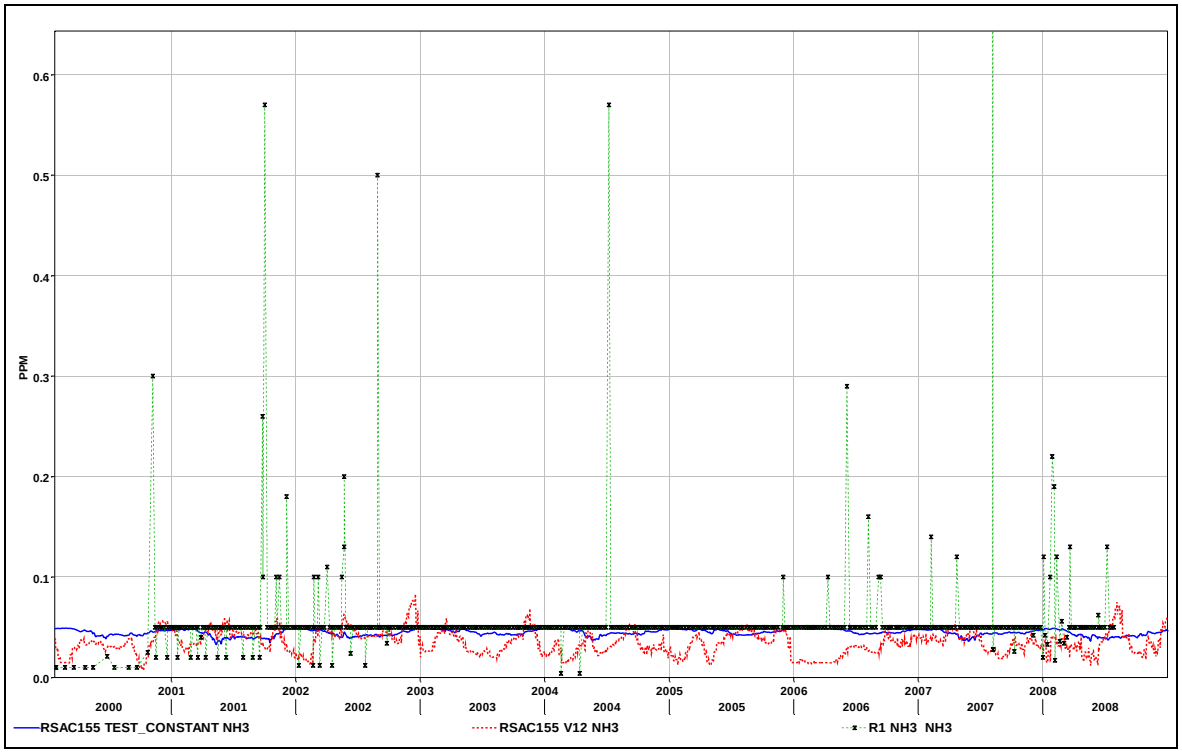


Figure 25-43 Modeled ammonia with the constant concentration boundary (blue) and. the "high flow" V12 boundary (red dash) vs. Sac Regional receiving water ammonia near Freeport (green symbols).

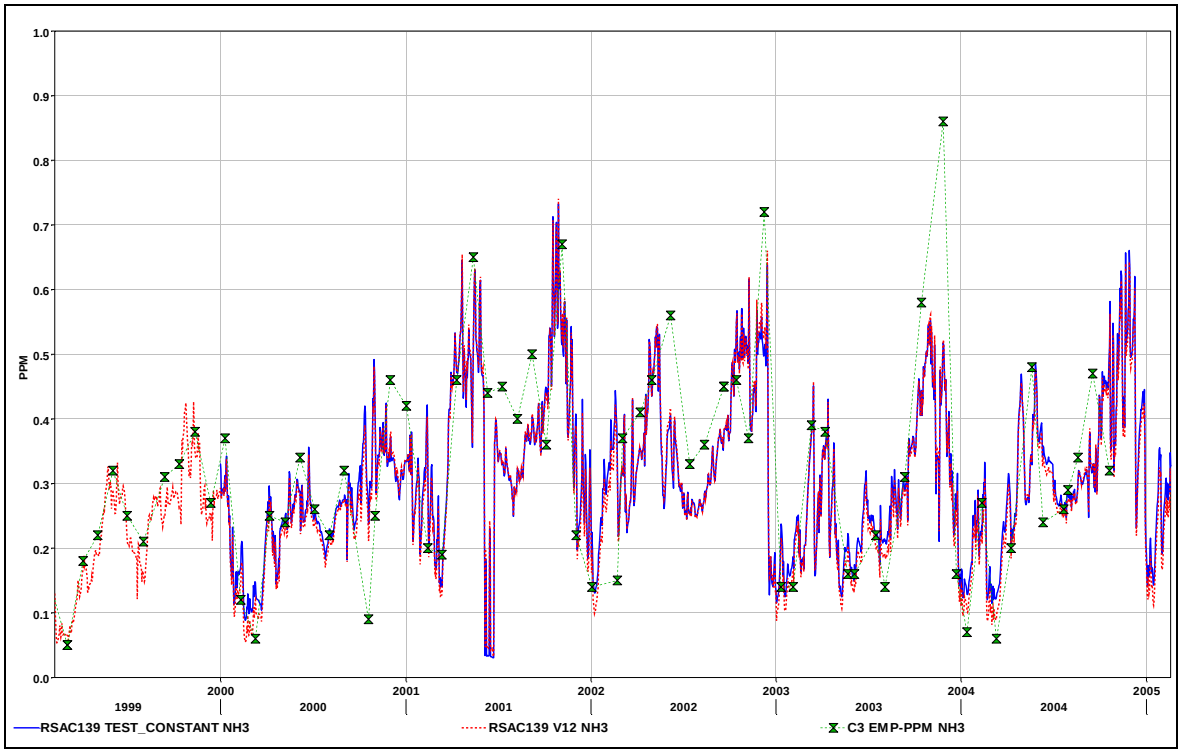


Figure 25-44 Modeled ammonia using the constant concentration boundary (blue) and the "high flow" V12 boundary (red dash) vs. EMP ammonia calibration data near Greens Landing (green symbols)

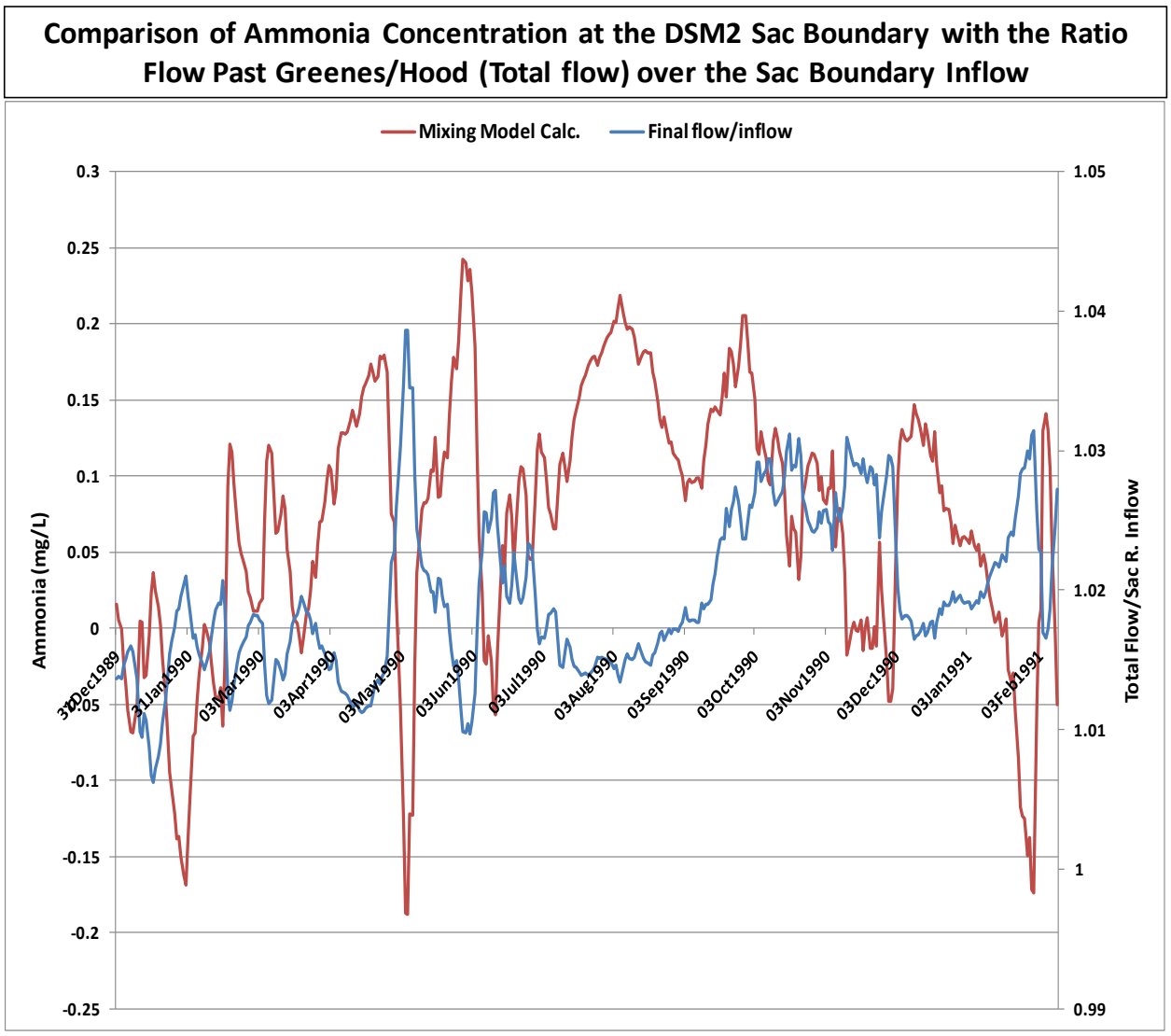


Figure 25-45 Mixing model calculation (red) compared with the flow ratio (Total flow)/Sac BC Inflow (blue)

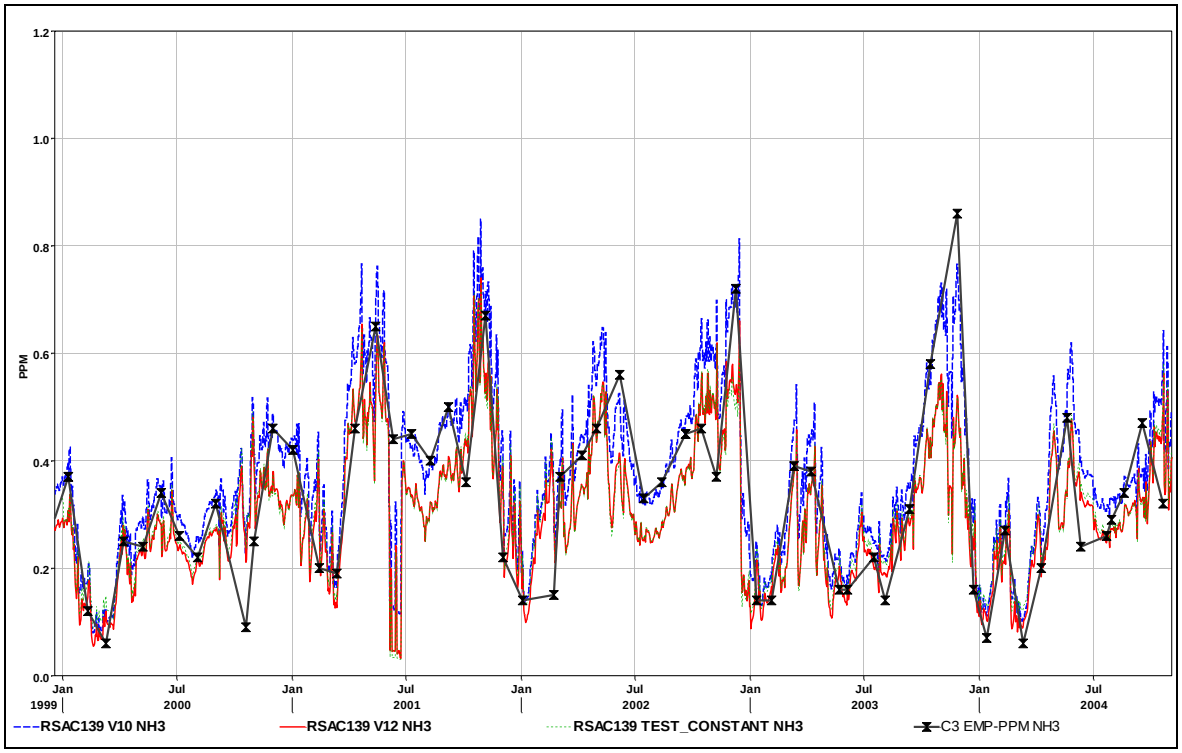


Figure 25-46 Modeled ammonia with three ammonia BC: constant concentration (green dash), "high flow" V12 (red dash), and previous calibrated model V10 with (Greens/Hood ammonia)*(0.4) (blue dash) vs. EMP data near Greens Landing (black symbols).

25.8 Calibration Statistics and Residual Analysis Methodology

Figure 25-47 through Figure 25-50 illustrate the data locations used for calculating calibration and validation statistics for the nutrient model

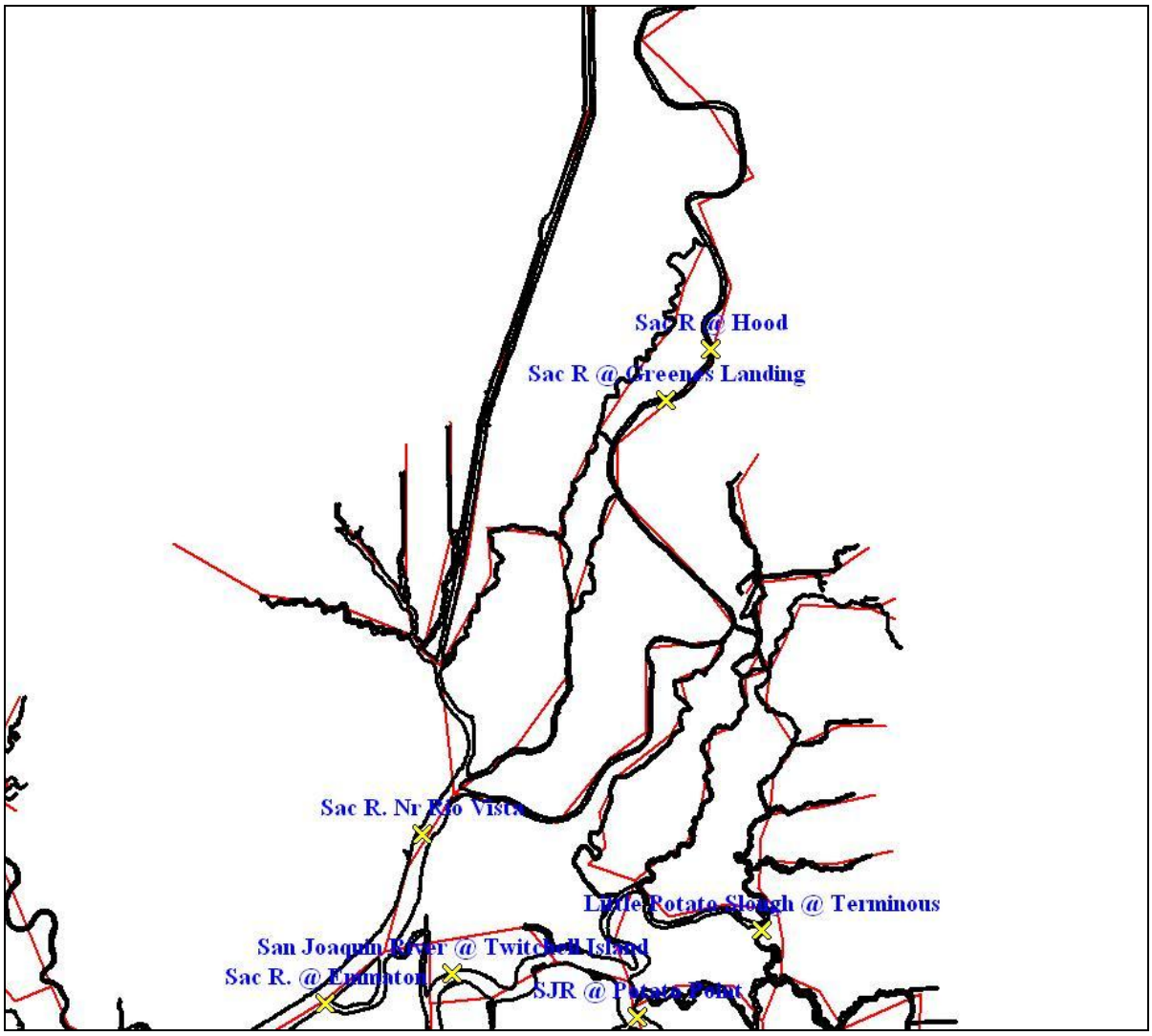


Figure 25-47 Calibration/validation locations in the northern Delta

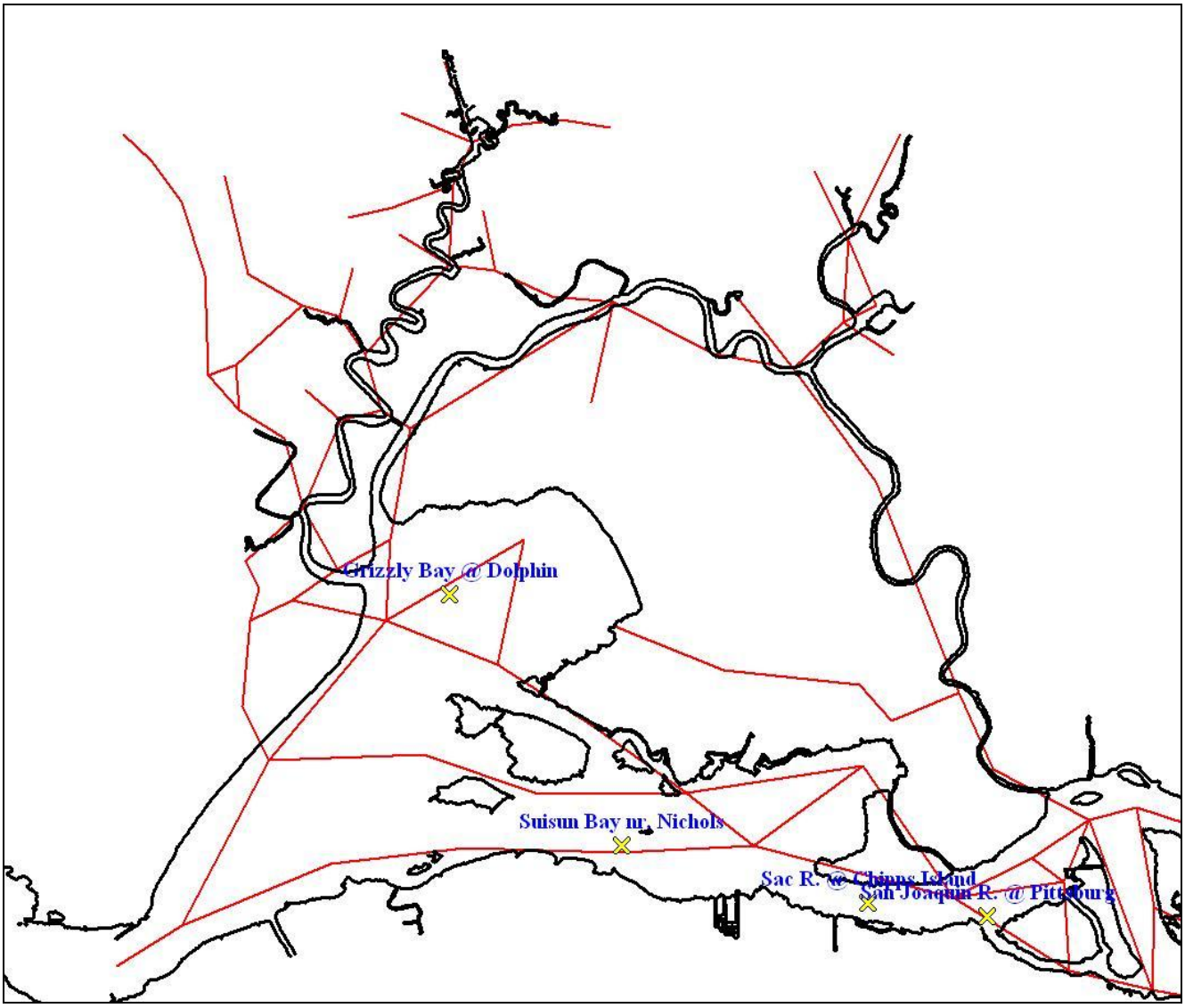


Figure 25-48 Calibration/validation locations in the western Delta.

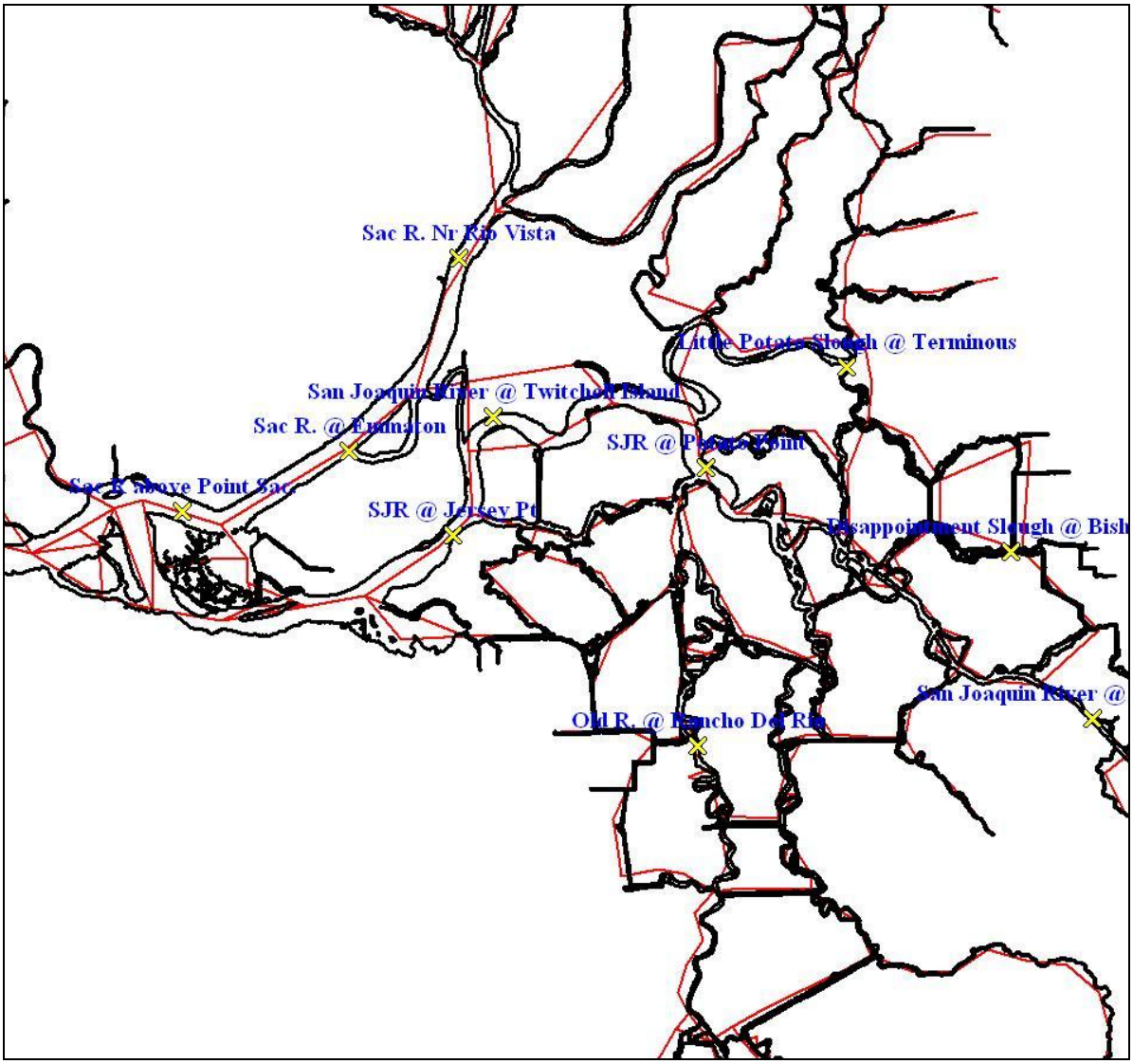


Figure 25-49 Calibration/validation locations in the central Delta.

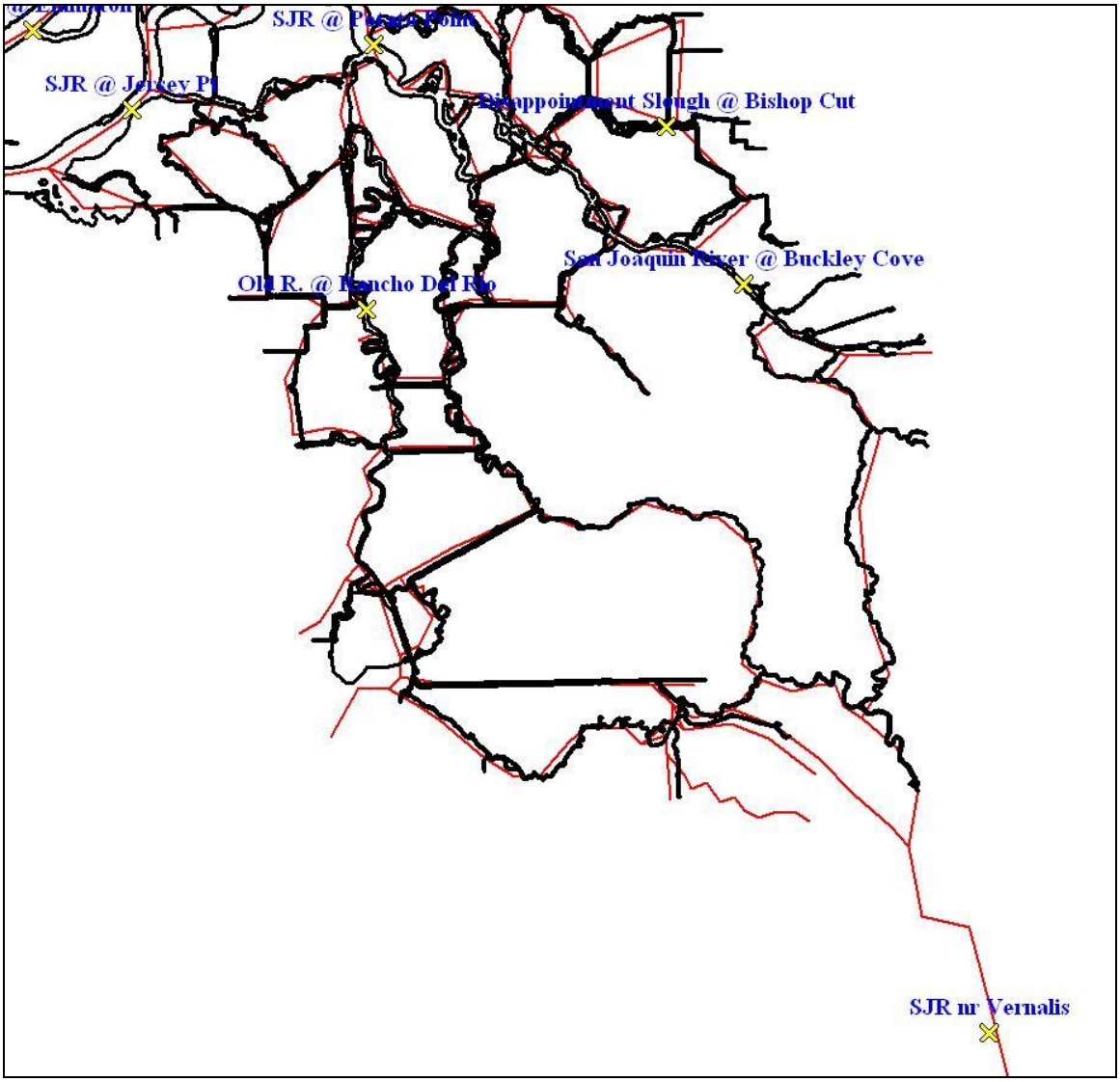


Figure 25-50 Calibration/validation locations in the south Delta.

25.9 Solution Chemistry and EQ 3/6 calculations

25.9.1 Concentrations of Ammonium Ion and Ammonia

The database in EQ3/6 (Wolery, 1997) was used to calculate the equilibrium concentrations of $NH_3\,(aq)$ and NH_4^+ at 25°C. The equilibrium reaction constant for the association reaction:

$$NH_4^+ \leftrightarrow NH_3(aq) + H^+ \quad \text{(A7)}$$

is given by:

$$K_{NH_4^+} = \frac{[H^+][NH_3]}{[NH_4^+]} \quad \text{(A8)}$$

where the activity coefficients have not been explicitly included for clarity and simplicity, and the terms in the brackets are expressed in mole kg^{-1} of solution (molality). At 25°C and one atmosphere of pressure, the logarithm of this reaction, log(K), is -9.24. Assuming the concentrations of NH_3 and NH_4^+ are equal, these terms cancel in equation (A8), we see that the pH of this solution would be -9.24 (approximately). Setting log ($[H^+]$) = -8.0, i.e. pH = 8.0, we see the ratio of $[NH_3]$ to $[NH_4^+]$ is $10^{-1.24}$ = 0.0575 (approximately). In other words, about 5.8 % of the total is present as NH_3. Similarly, at pH = 7.0, only 0.58% of the total is present as NH_3.

25.9.2 Water Chemistry at the Sacramento and San Joaquin boundaries.

R. Dahlgren supplied a database of comprehensive water chemistry measurements at several locations near the boundary of the Delta and in the tributaries (see Figure 8-4), The measurements were collected approximately every two weeks, and they varied in total time span in the years from 2000 to 2005, depending on location (Chow et al, 2007).

In order to get a general understanding of the average chemistry of the waters at the Freeport and Vernalis boundaries, EQ3/6 simulations were prepared using these measurements. For the modeling, each measurement type (e.g., NH_4^+-N) was averaged over the entire measurement time span. Nitrite (NO_2^-) was not measured – its concentration was set at1.0% of the measured nitrate ($NO_3^{-\ -}$) concentration. The equilibrium geochemical model was developed using the average measurements as input, shown in Table VII a, below. The solutions were initially charge balanced at 25°C using the ions of an inert element (Cl^- or Na^+). The temperature was then adjusted to the average, ambient temperature (16.2 or 17.0, as shown in the Table), and a final charge balance was performed using pH. At Vernalis, the initial average pH was -8.0000 and the final pH after charge balancing at the ambient temperature was -8.0966. At Freeport, the initial pH was -7.8500 and the pH after the final adjustment was -7.9259.

The resulting speciation chemistry for each location is shown in Table A. VII b indicating the major species in each solution. As expected, at Freeport the ionic strength of the solution was low, ~I=0.0024, where I is the ionic strength in mol L^{-1}. At Vernalis, the ionic strength of the

solution was an order of magnitude higher, ~I=0.0109. As shown in Table A.VII b., in each location on average NH_4^+ comprised about 97% of the total ammonia in solution.

Another interesting feature of the solutions revealed by the speciation modeling is that both solutions are supersaturated with respect to atmospheric CO_2 (g). This is certainly due to biological activity in solution, with algae releasing CO_2 in respiring. In equilibrium with the atmosphere and in the absence of biological activity, the partial pressure of CO_2 (g) would yield a concentration of about $\log(CO_2) = -3.5$. At Vernalis, calculations indicate that on average the water is supersaturated with respect to CO_2 (g) with $\log(CO_2) = -3.005$. At Freeport, $\log(CO_2)$ -3.0507, and so biological activity is lower in these waters as expected. In either case, CO_2 (g) would be out-gassing from solution (the mass transfer would be from water to atmosphere). We can conclude that the pH of the waters would generally not be controlled by transfer of CO_2 (g) from the atmosphere to the waters[30], but instead by other factors (such as the production of CO_2 (g) from the biological activity).

[30] CO_2 (g) dissociates in aqueous solutions to form HCO_3^- and H^+.

Table 25-10Average Solution Chemistry Used as Input for in Speciation Modeling

	Units	Freeport Chemistry	Units	Vernalis Chemistry
Temp	**°C**	16.2	**°C**	17.0
pH		7.85		8.00
HCO3-	**Moles/kg**	1.43E-03	**Moles/L**	2.33E-03
Na+	**Moles/L**	3.88E-04	**Moles/L**	3.67E-03
K+	**Moles/L**	2.88E-05	**Moles/L**	5.60E-05
Mg++	**Moles/L**	3.01E-04	**Moles/L**	8.88E-04
Ca++	**Moles/L**	3.32E-04	**Moles/L**	1.10E-03
Cl-	**Moles/L**	1.43E-04	**mg/L**	1.06E+02
NH3(aq)	**mg/L**	3.65E-02	**mg/L**	7.30E-02
NO3-	**mg/L**	3.98E-01	**mg/L**	9.47E+00
NO2-	**mg/L**	3.98E-03	**mg/L**	9.47E-02
HPO4--	**mg/L**	8.25E-02	**mg/L**	3.60E-01
SO4--	**Moles/L**	6.79E-05	**Moles/L**	1.05E-03
SiO2(aq)	**Moles/L**	2.91E-04	**Moles/L**	2.33E-04

Table 25-11 EQ3/6 Speciation Results

	Vernalis				Freeport		
Basis Species	**Species Accounting For Basis**	**Molality**	**%**		**Species Accounting For Basis**	**Molality**	**%**
Ca++							
	Ca++	1.02E-03	92.26		Ca++	3.25E-04	97.65
	CaSO4(aq)	5.25E-05	4.75		CaHCO3+	4.05E-06	1.22
	CaHCO3+	1.80E-05	1.63		CaCO3(aq)	1.97E-06	5.92E-01
	CaCO3(aq)	1.28E-05	1.16		CaSO4(aq)	1.69E-06	5.07E-01
Cl-							
	Cl-	2.99E-03	99.88		Cl-	1.43E-04	99.96
HCO3-							
	HCO3-	2.34E-03	95.12		HCO3-	1.37E-03	96.08
	CO2(aq)	4.26E-05	1.73		CO2(aq)	3.94E-05	2.76
	CaHCO3+	1.80E-05	7.33E-01		CO3--	5.18E-06	3.64E-01
HPO4--							
	HPO4--	2.16E-06	57.51		HPO4--	5.83E-07	67.74
	MgHPO4(aq)	6.51E-07	17.33		H2PO4-	1.01E-07	11.78
	CaHPO4(aq)	5.42E-07	14.41		MgHPO4(aq)	9.25E-08	10.74
	H2PO4-	2.17E-07	5.77		CaHPO4(aq)	6.86E-08	7.96
	CaPO4-	1.87E-07	4.97		CaPO4-	1.52E-08	1.77
K+							
	K+	5.58E-05	99.54		K+	2.89E-05	99.96
Mg++							
	Mg++	8.12E-04	91.34		Mg++	2.94E-04	97.8
	MgSO4(aq)	5.58E-05	6.27		MgHCO3+	3.58E-06	1.19
	MgHCO3+	1.42E-05	1.6		MgSO4(aq)	2.01E-06	6.68E-01
NH3(aq)							
	NH4+	4.14E-06	96.52		NH4+	2.10E-06	97.64
	NH3(aq)	1.49E-07	3.48		NH3(aq)	5.07E-08	2.36
Na+							
	Na+	3.65E-03	99.3		Na+	3.88E-04	99.72
SO4--							
	SO4--	9.34E-04	88.66		SO4--	6.42E-05	94.41
	MgSO4(aq)	5.58E-05	5.3		MgSO4(aq)	2.01E-06	2.95
	CaSO4(aq)	5.25E-05	4.98		CaSO4(aq)	1.69E-06	2.48
	NaSO4-	1.09E-05	1.03		NaSO4-	9.70E-08	1.43E-01
SiO2(aq)							
	SiO2(aq)	2.24E-04	95.66		SiO2(aq)	2.83E-04	97.21
	HSiO3-	6.71E-06	2.87		HSiO3-	5.37E-06	1.84
	NaHSiO3(aq)	1.73E-06	7.4E-01		Si2O4(aq)	1.27E-06	8.72E-01

	Vernalis				Freeport		
Basis Species	**Species Accounting For Basis**	**Molality**	**%**		**Species Accounting For Basis**	Molality	%
NO2-	NO2-	2.06E-06	100		NO2-	8.67E-08	100
NO3-	NO3-	1.52E-04	99.66		NO3-	6.43E-06	99.87

25.10 Volumetric and Liberty Grid Figures (From Sections 12 and 13)

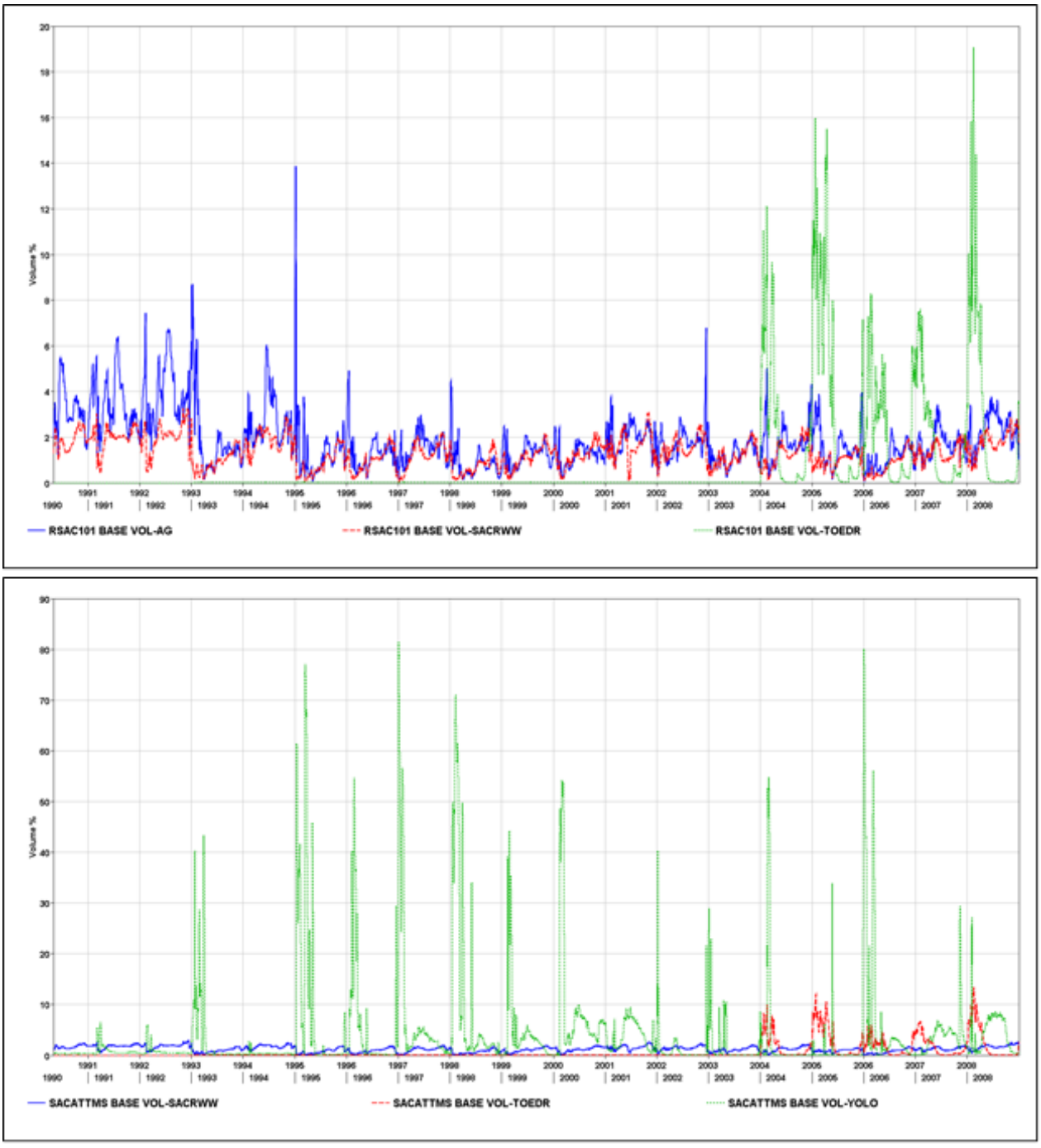


Figure 25-51 Volumetric results at Rio vista (upper) and in Three Mile Slough (lower).

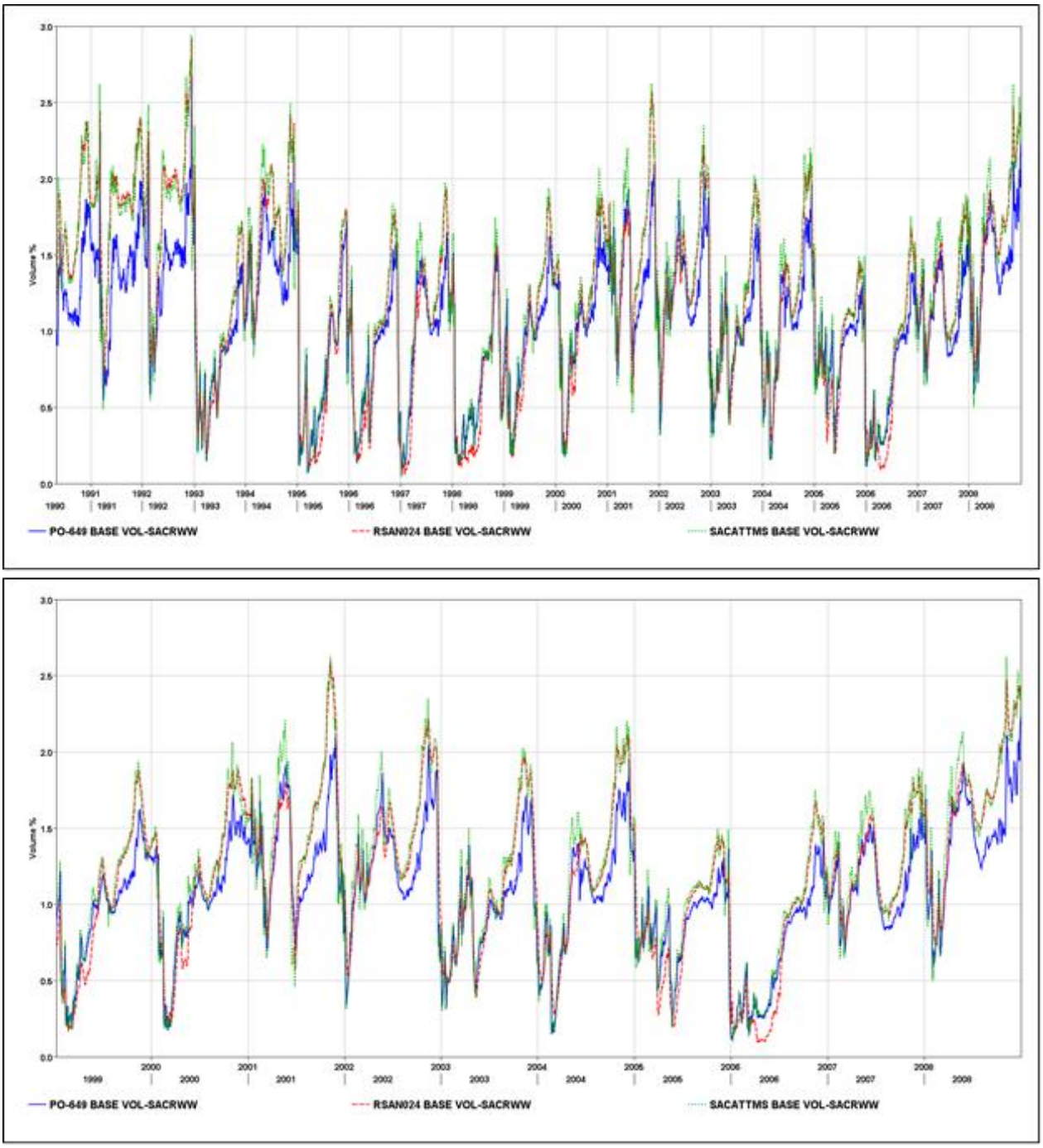


Figure 25-52Sac Regional effluent volumes along the lower San Joaquin and Sacramento Rivers.

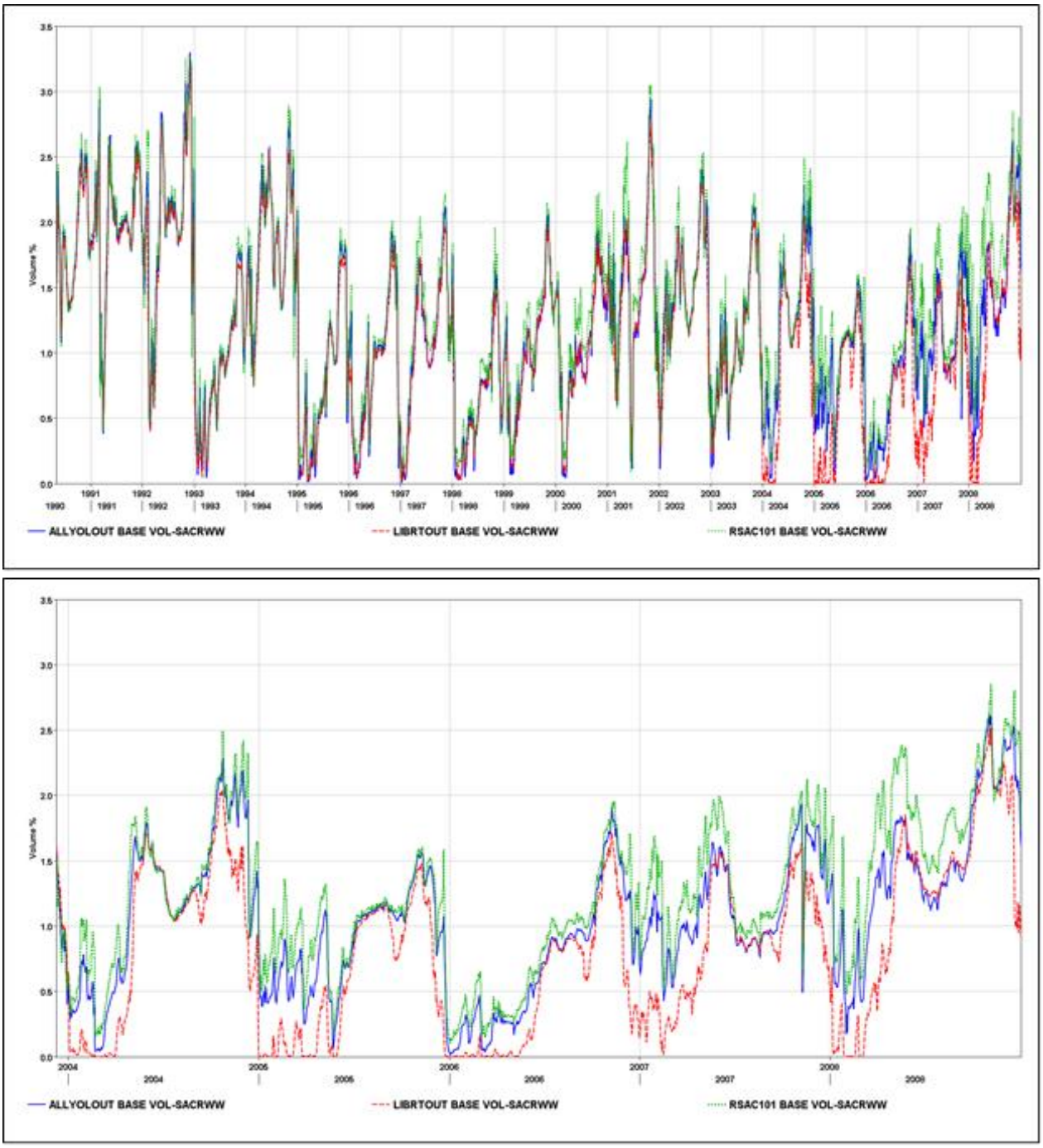


Figure 25-53 Volumetric contributions near the Yolo/Cache Slough area.

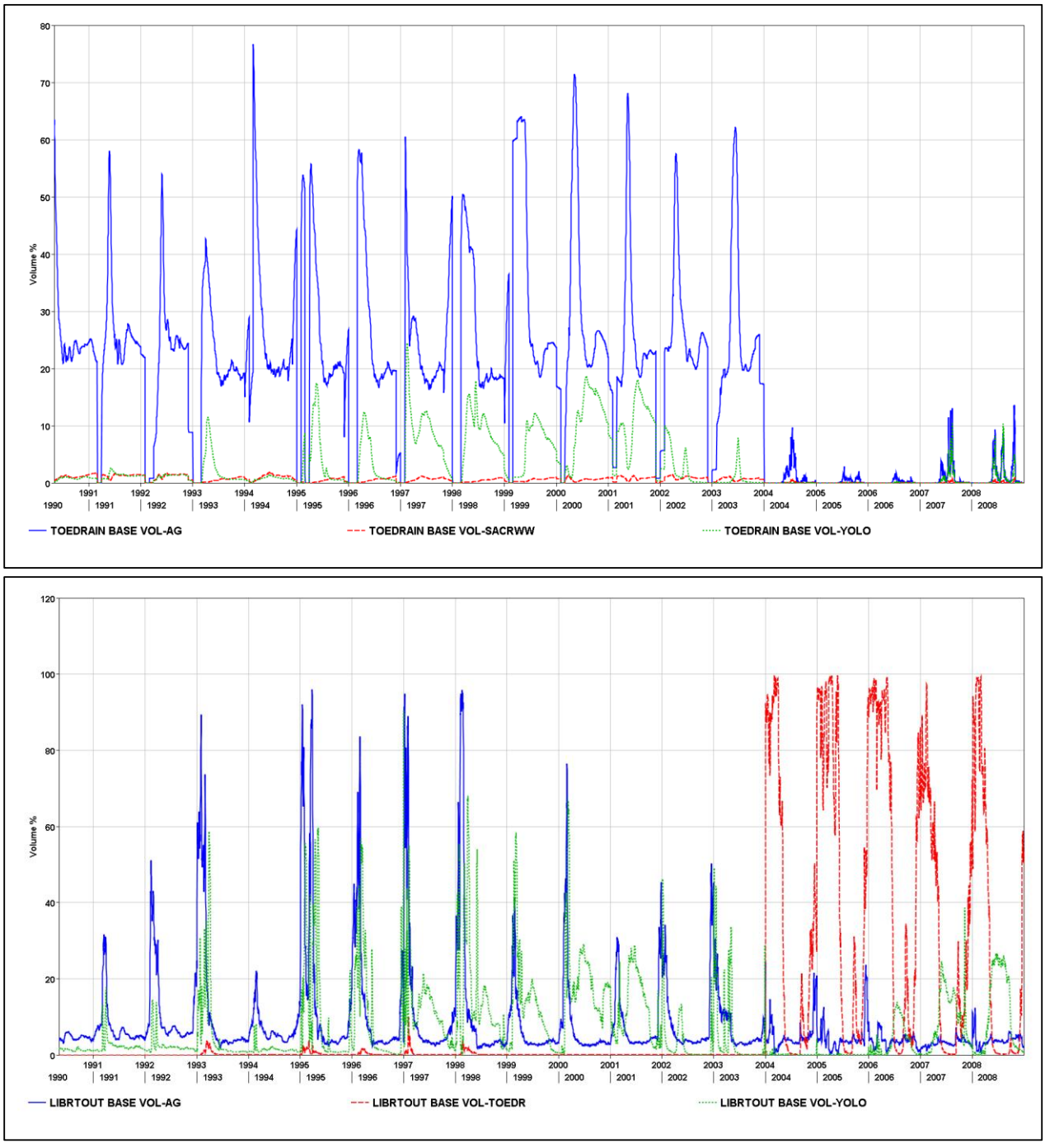


Figure 25-54 Volumetric contributions near the Lisbon Toe Drain and the outflow from the Liberty Island area.

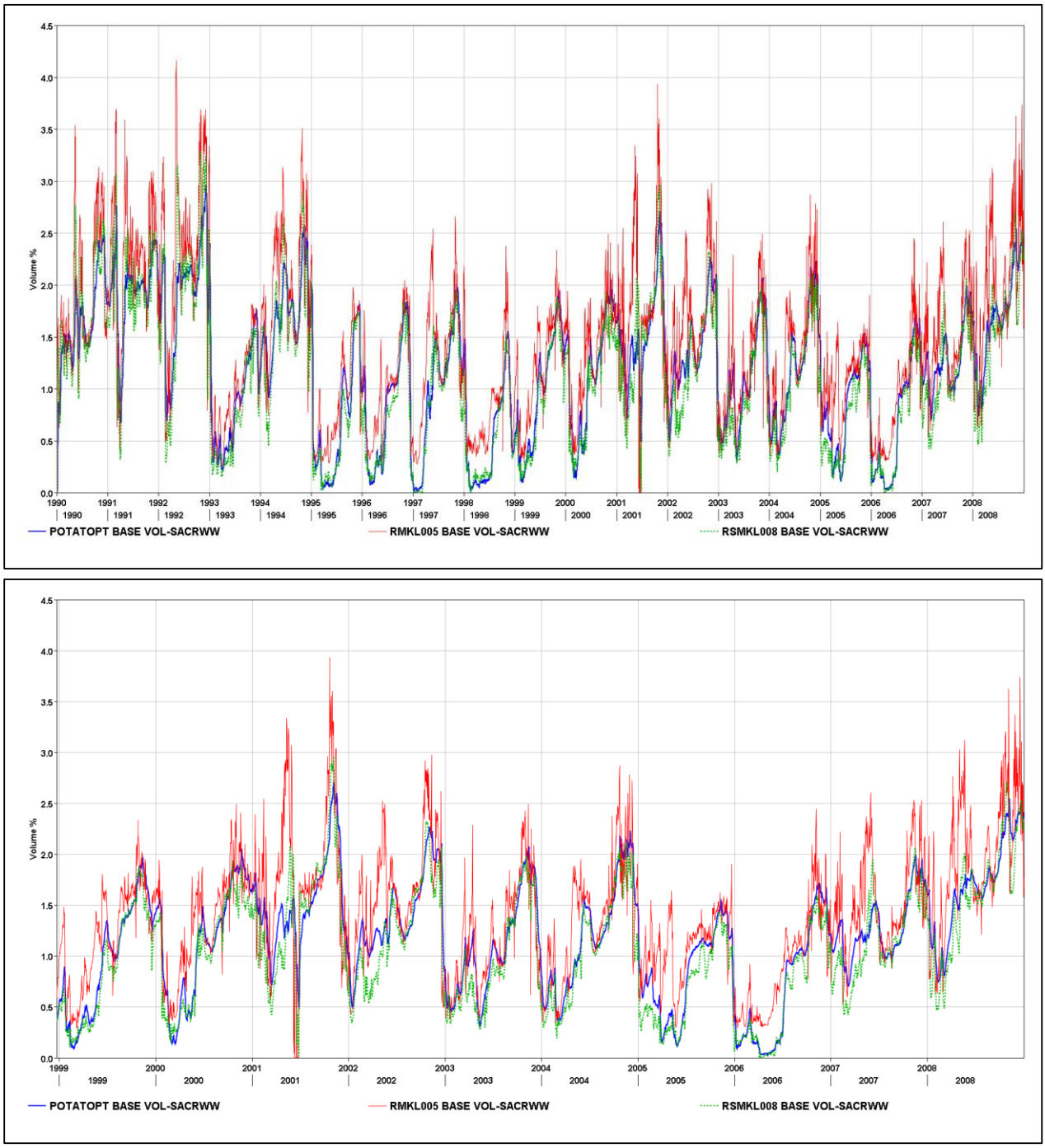


Figure 25-55 Sac Regional effluent volumes in the eastern Delta.

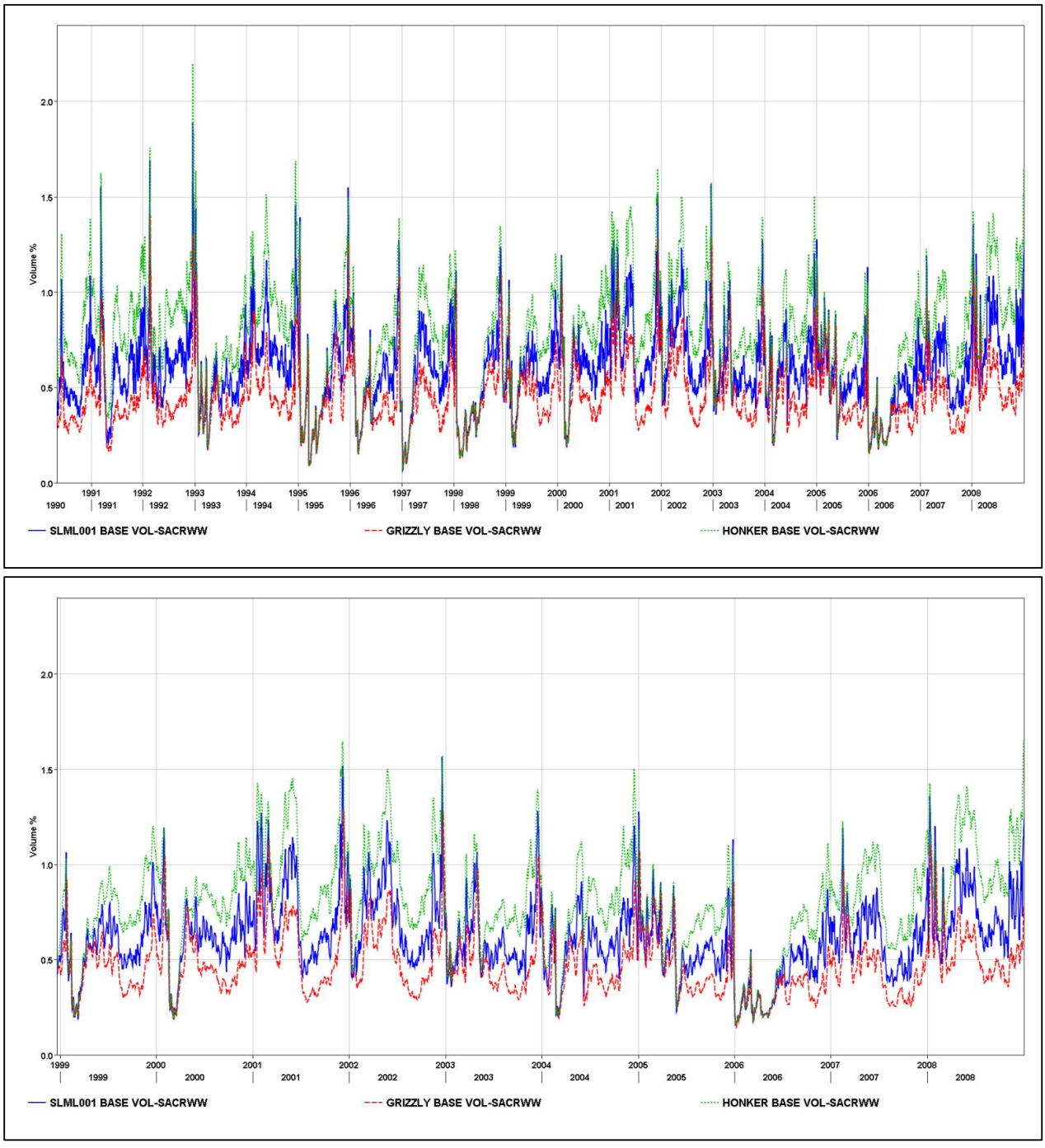


Figure 25-56 Sac Regional effluent volumes along the lower Sacramento River into Grizzly and Honker Bays.

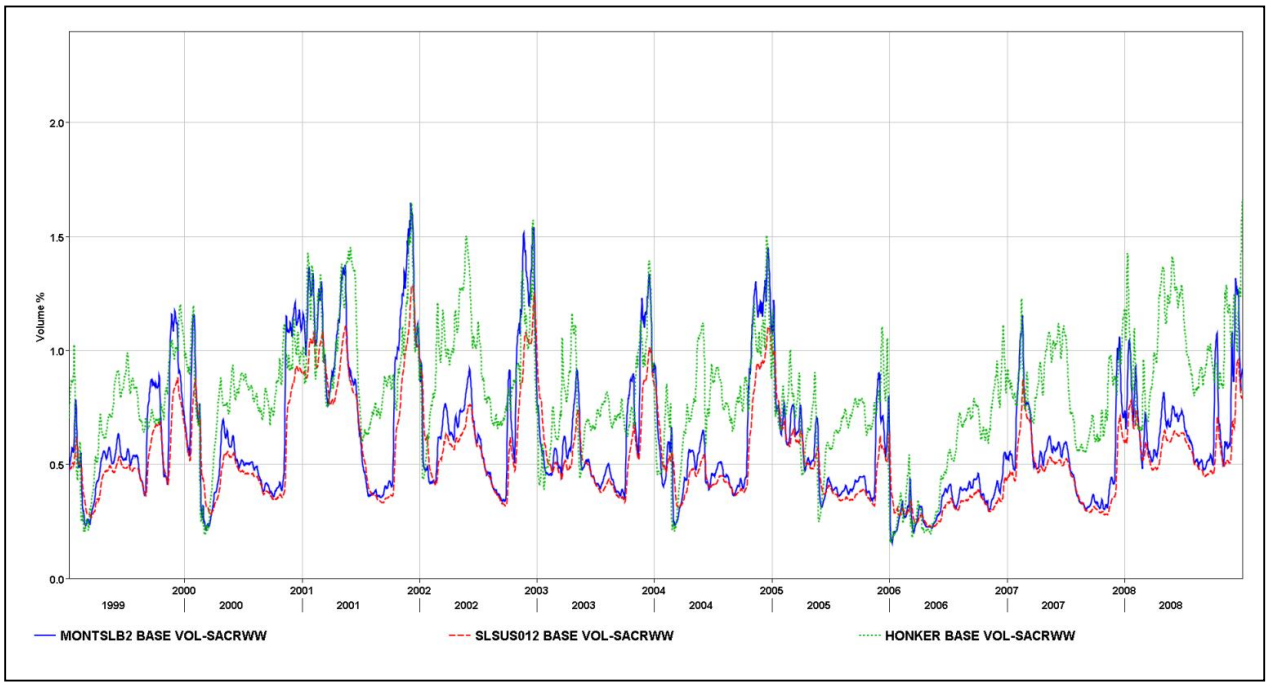


Figure 25-57 Sac Regional effluent volumes in and near Suisun Marsh.

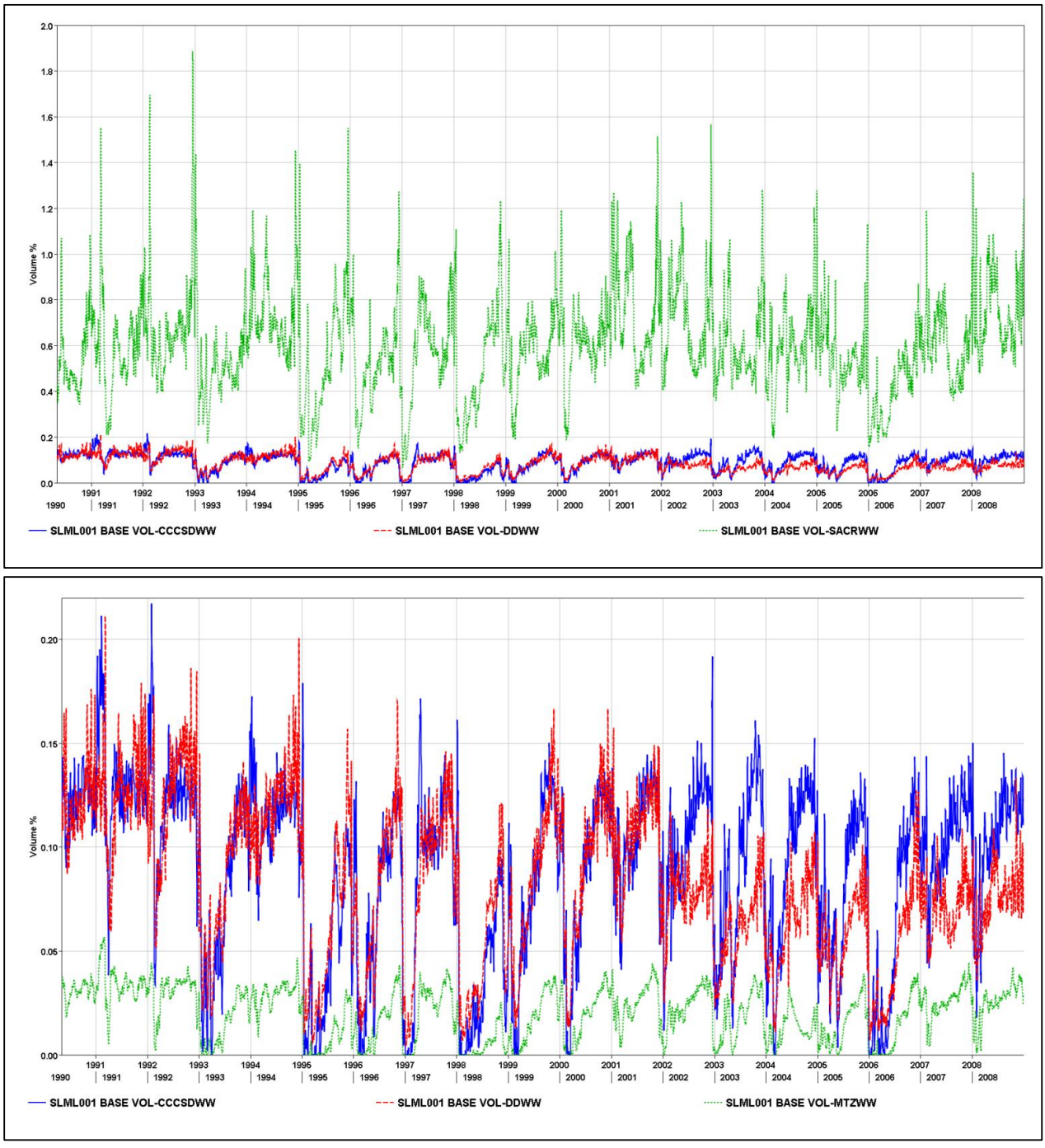


Figure 25-58 Volumetric contributions of smaller WWTP's in the Suisun area.

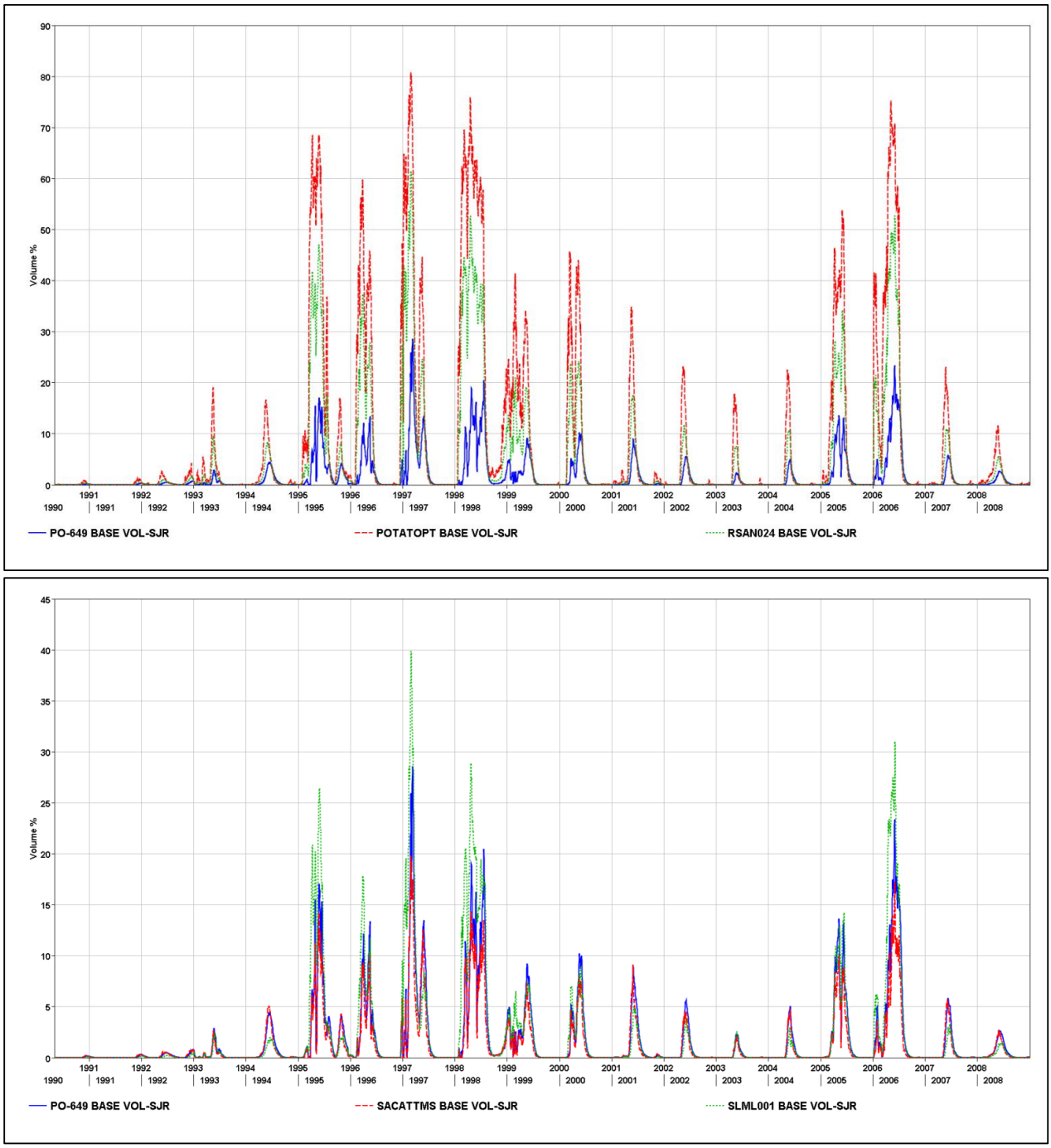


Figure 25-59 Higher volume of San Joaquin River contributions are seasonal.

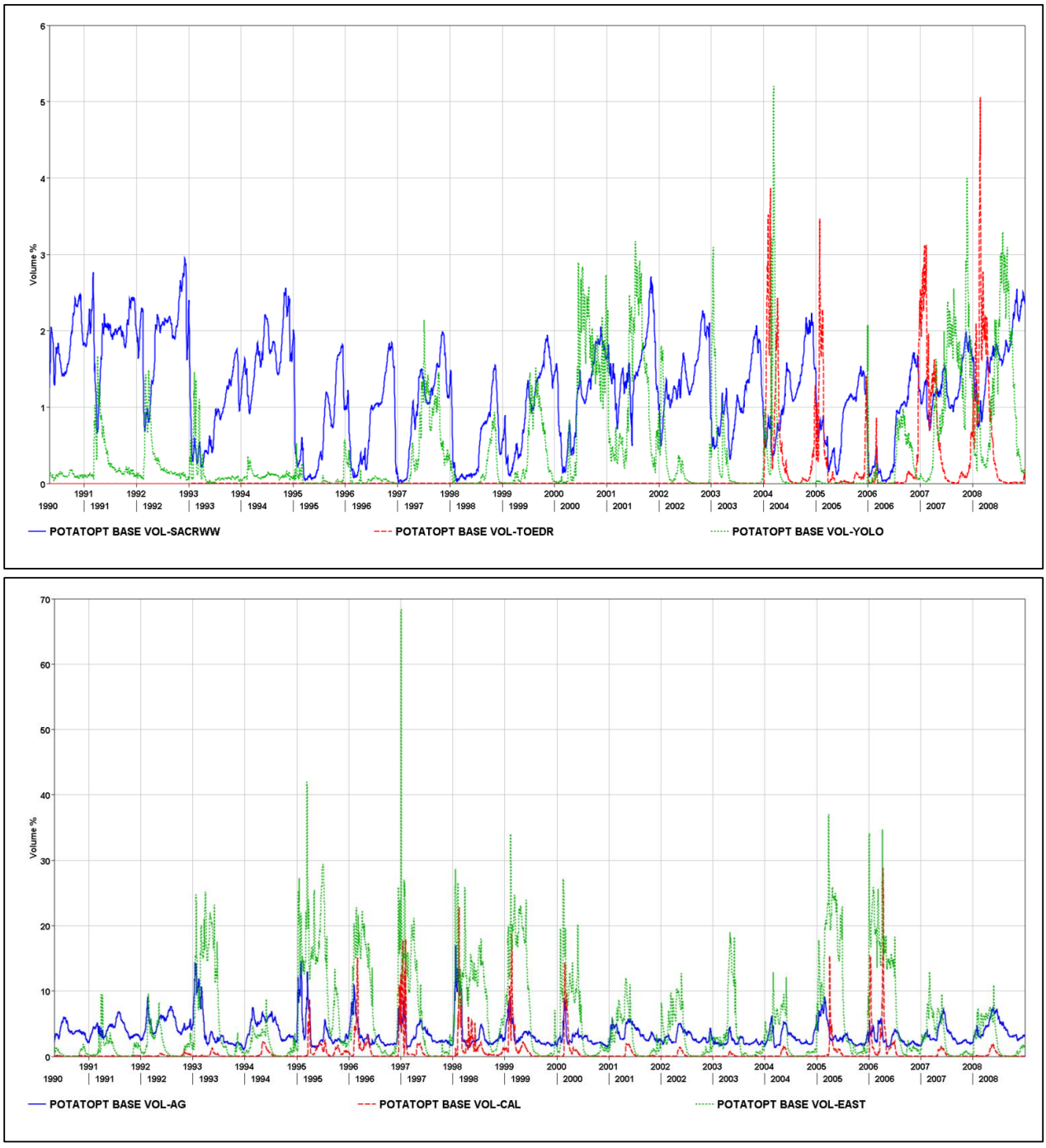


Figure 25-60 Sac Regional effluent volumes remain high at Potato Point, although Ag contributions are higher here.

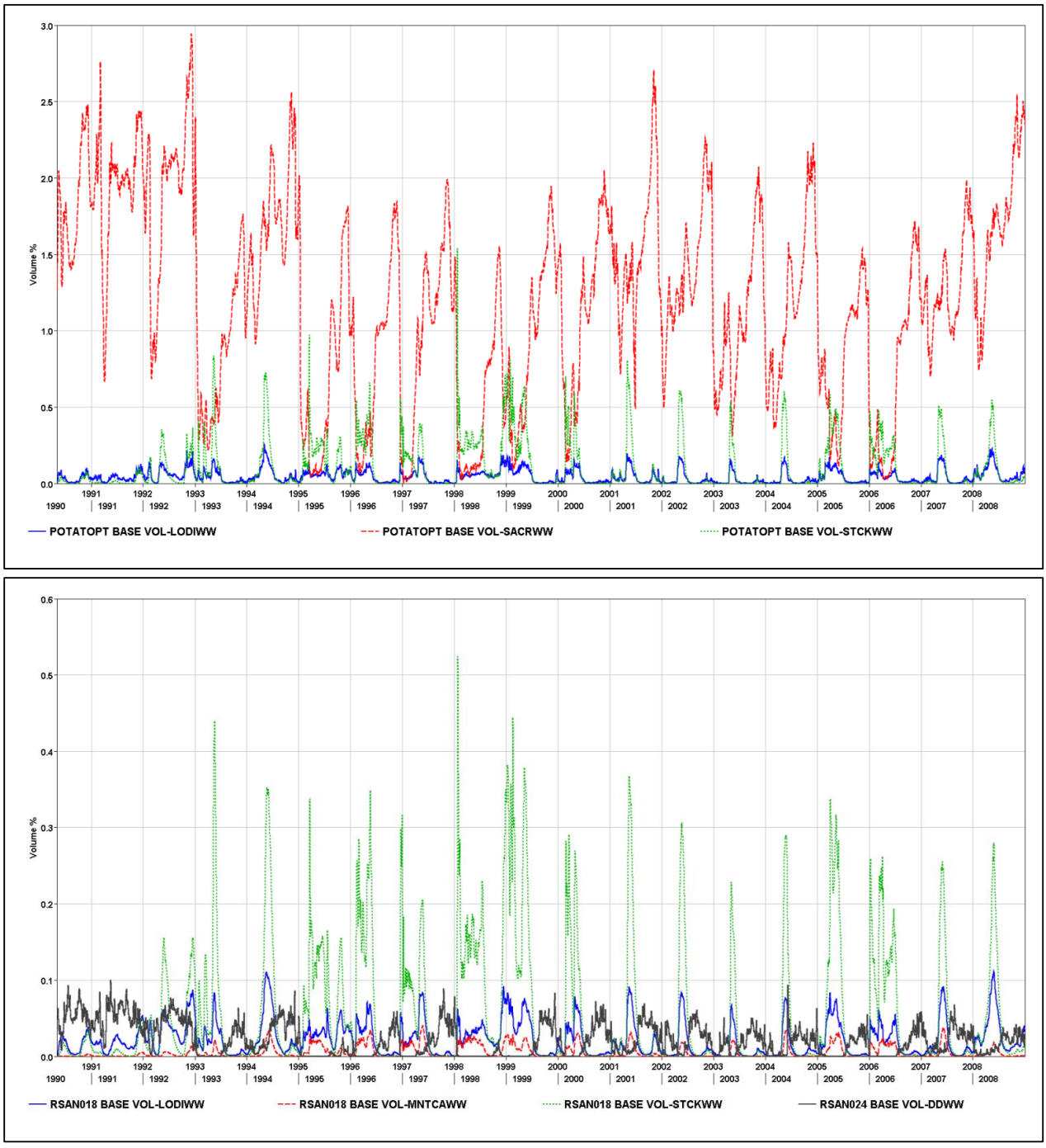


Figure 25-61 Contributions from smaller WWTPs in the lower San Joaquin River.

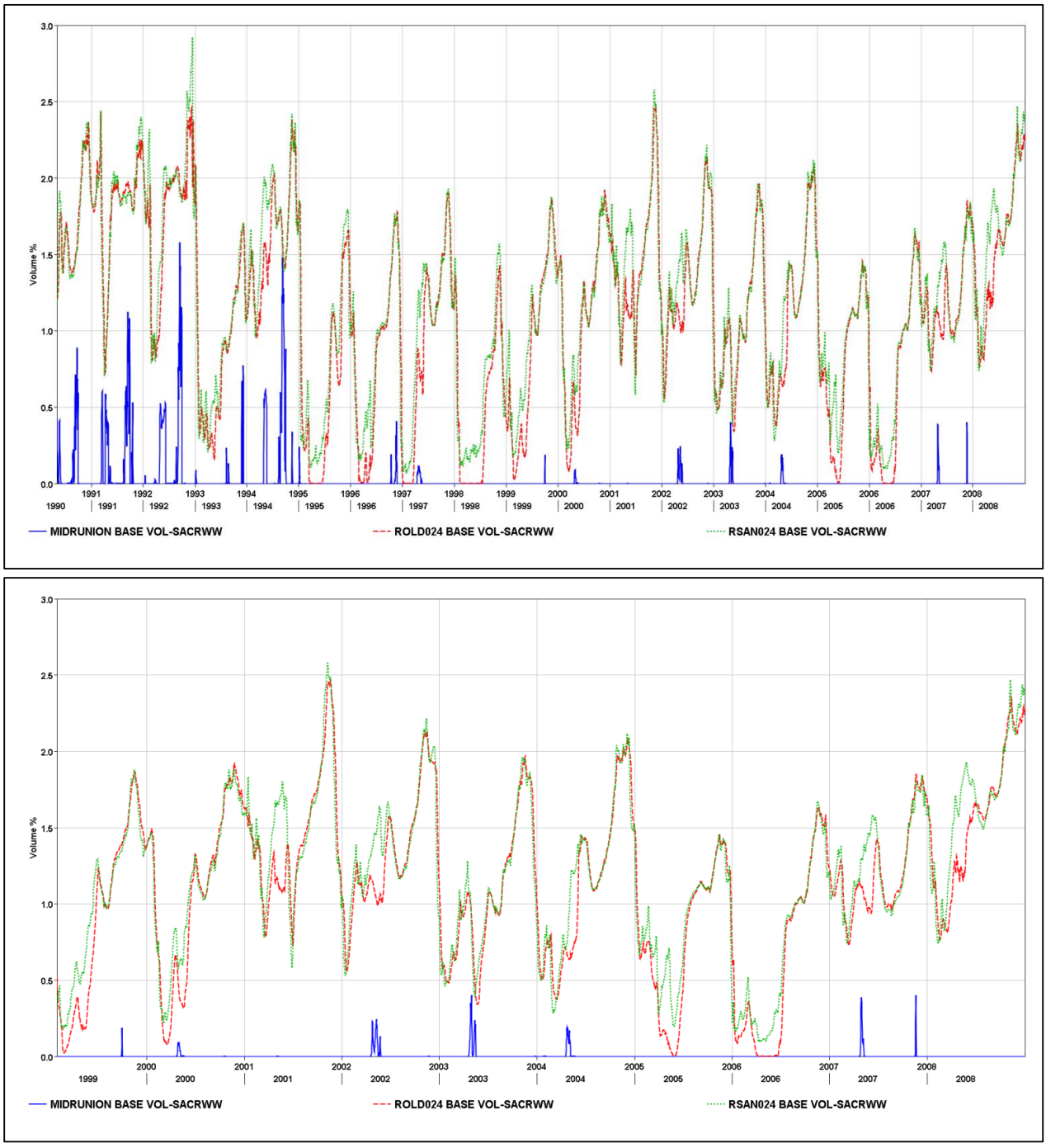


Figure 25-62 Sac Regional effluent contributions are small in the south Delta.

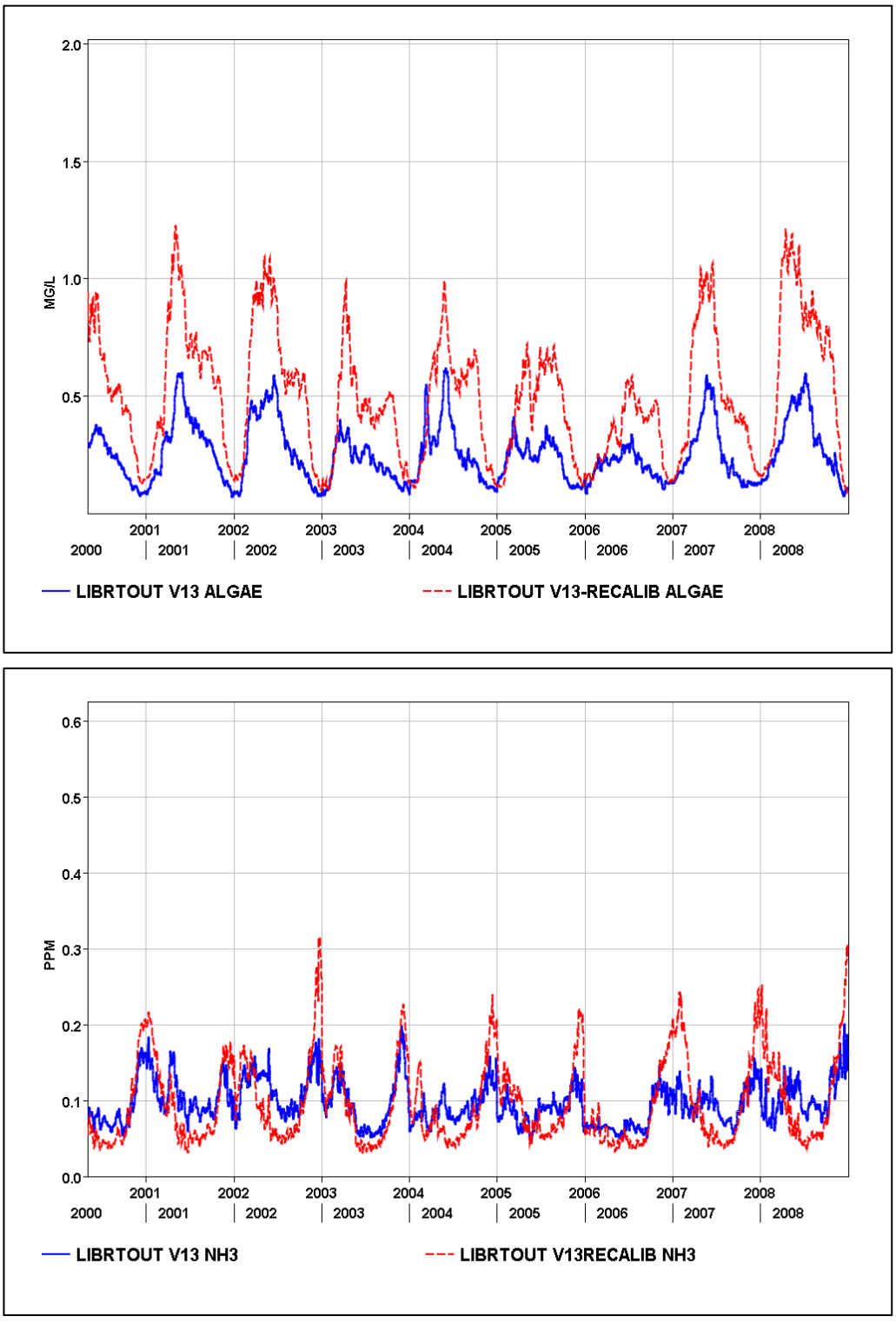


Figure 25-63 Algal biomass and ammonia concentrations at the Liberty location for Base and Liberty grids.

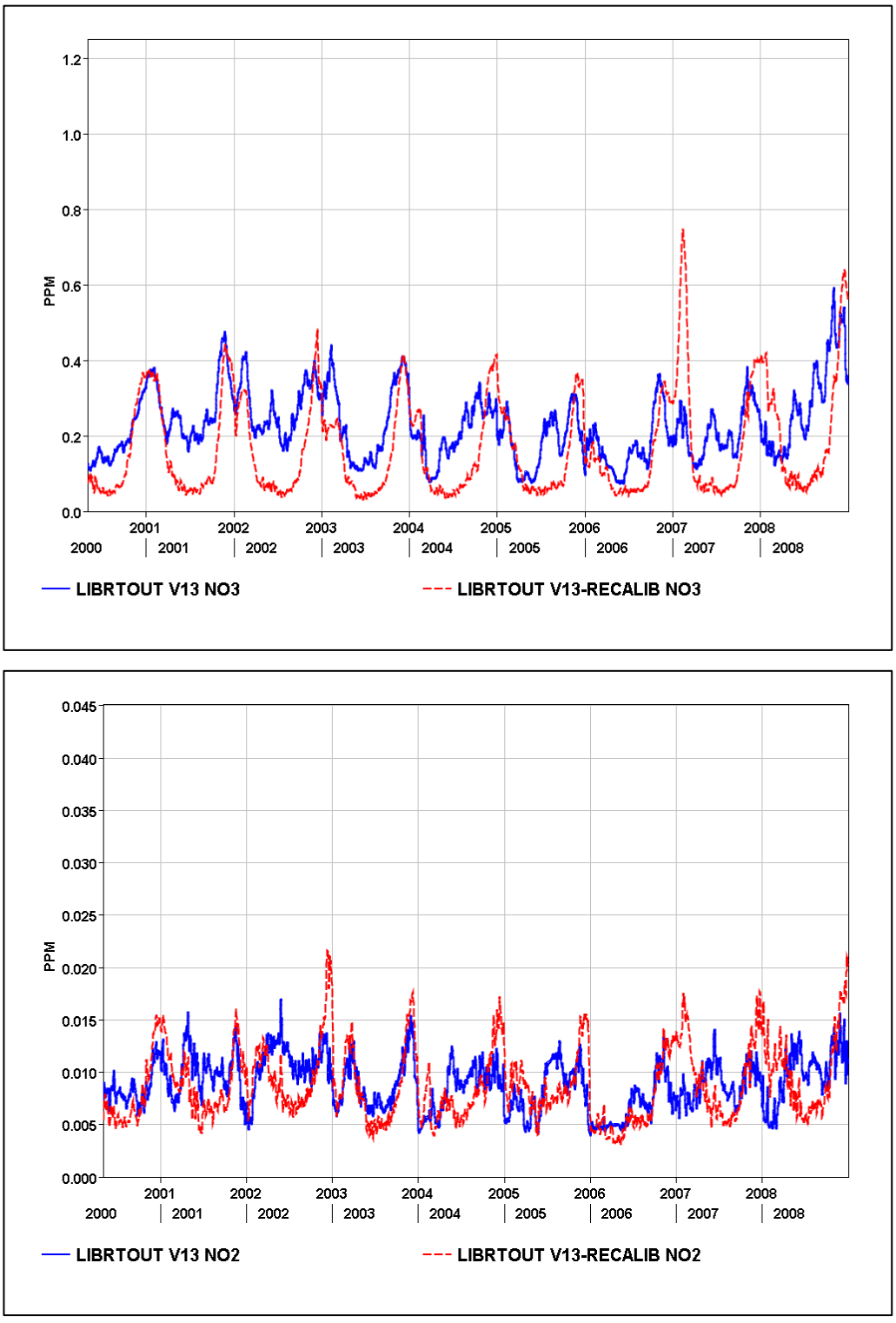


Figure 25-64 Nitrate and nitrite concentrations at the Liberty location for Base and Liberty grids.

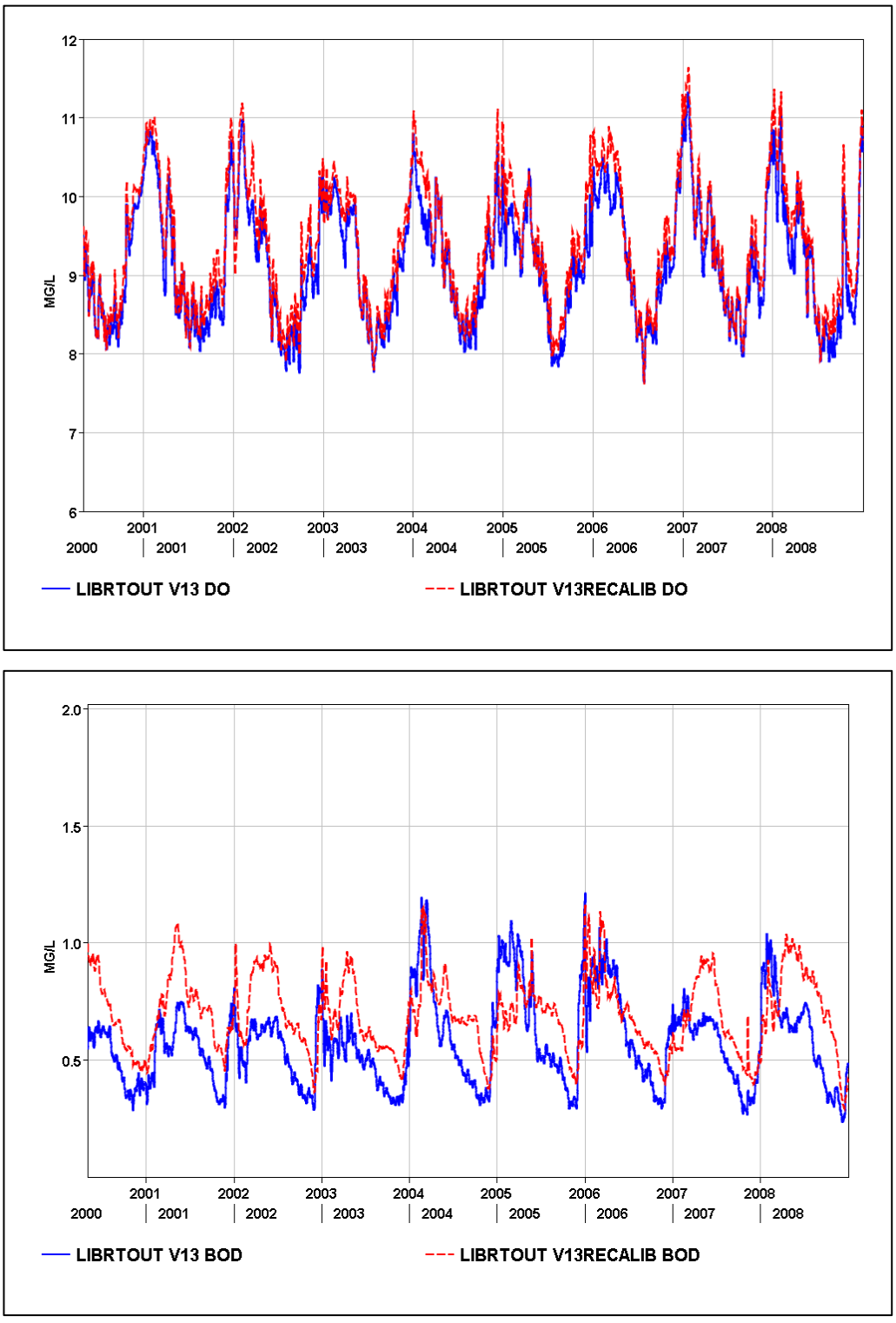


Figure 25-65 DO and CBOD concentrations at the Liberty location for Base and Liberty grids.

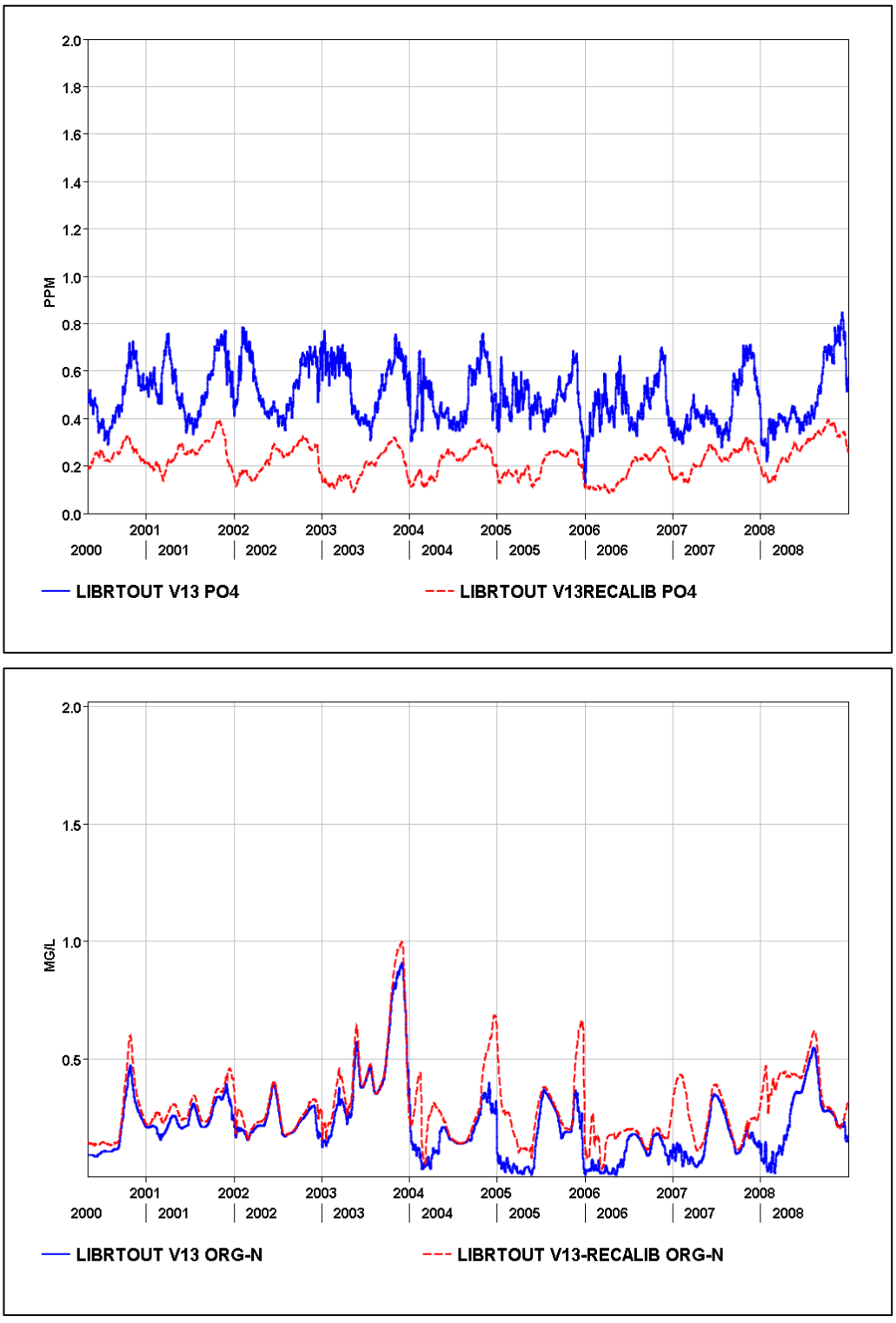


Figure 25-66 PO_4 and organic-N concentrations at the Liberty location for Base and Liberty grids.

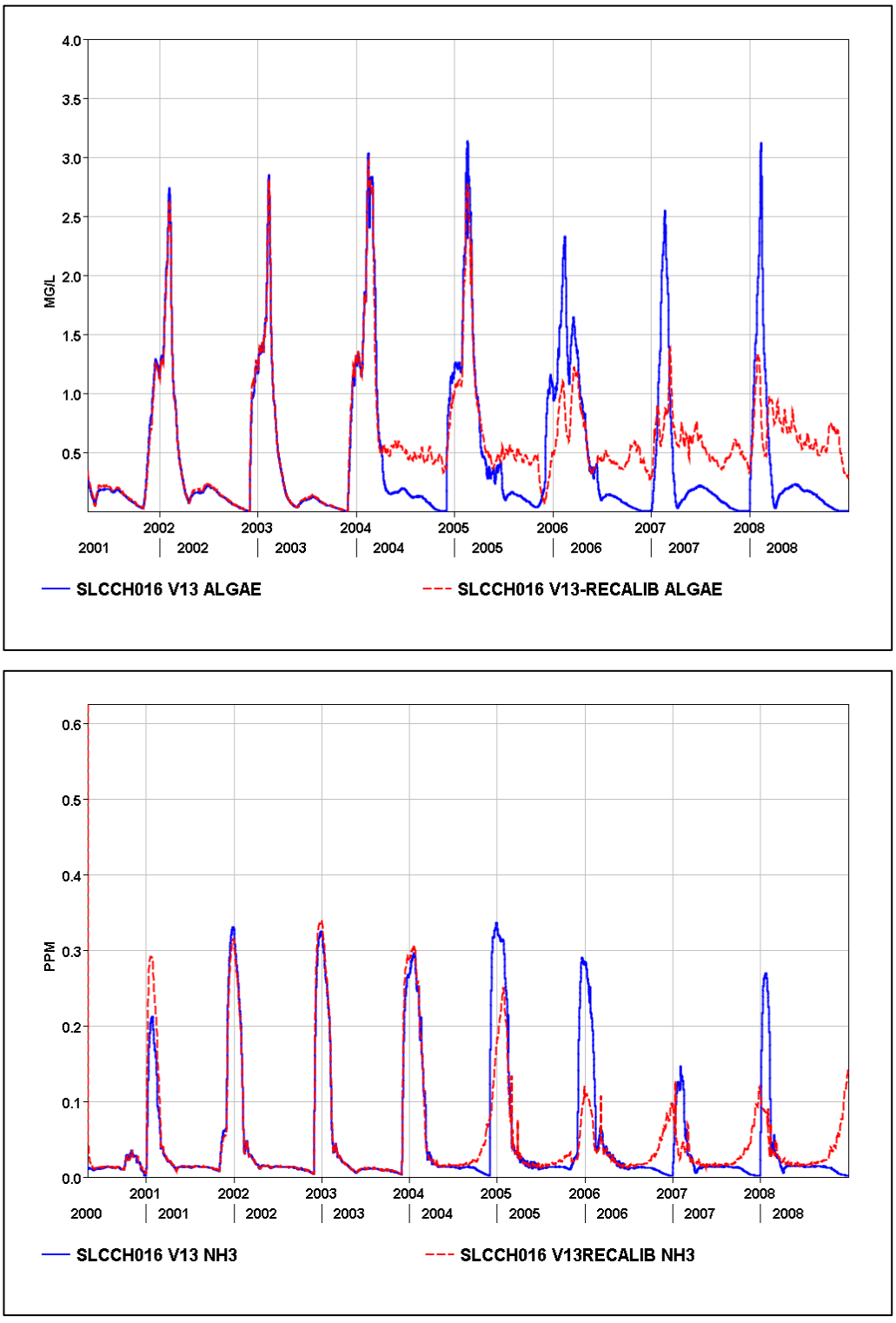


Figure 25-67 Algal biomass and ammonia concentrations at SLCCH016 for Base and Liberty grids.

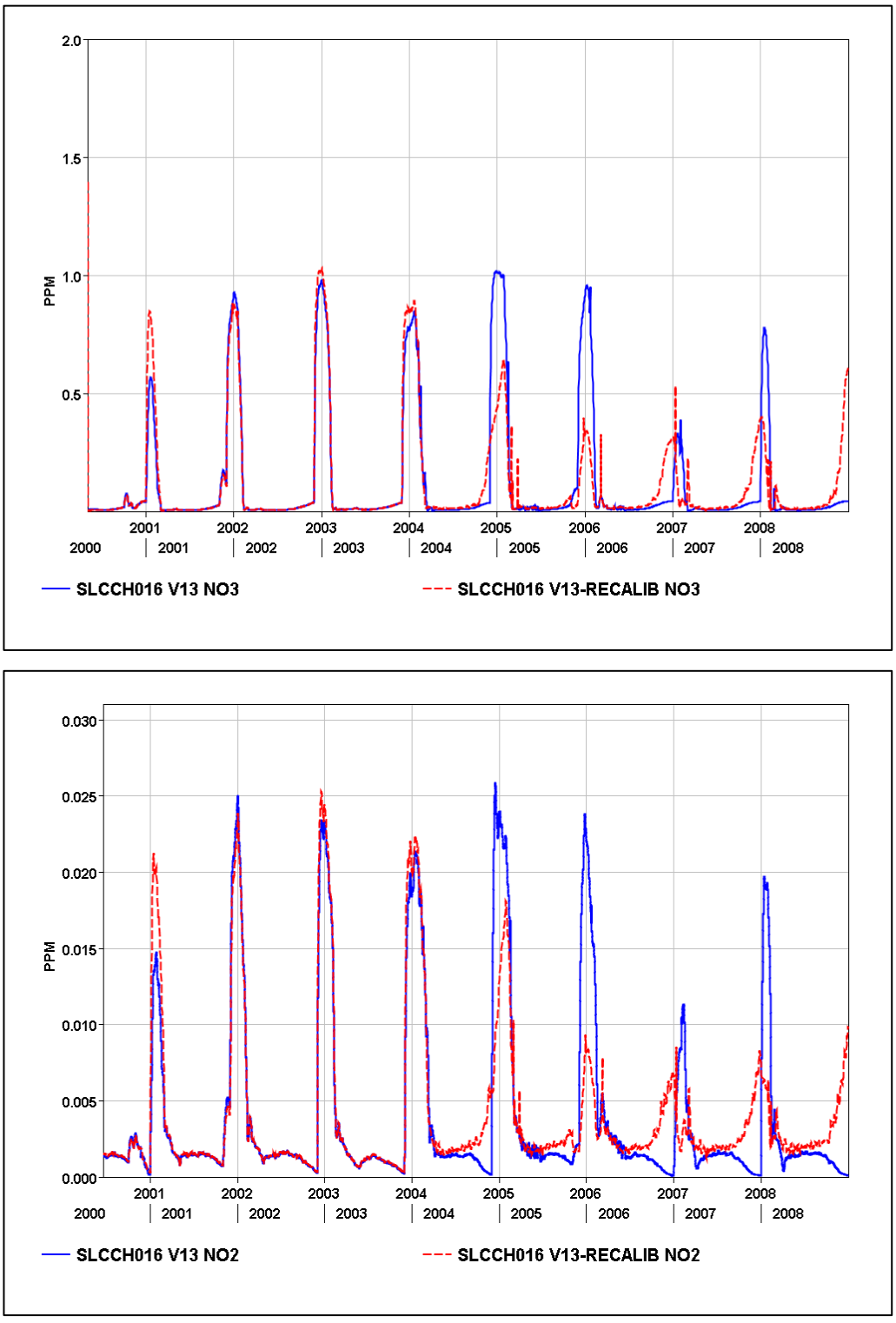


Figure 25-68 Nitrate and nitrite concentrations at SLCCH016 for Base and Liberty grids.

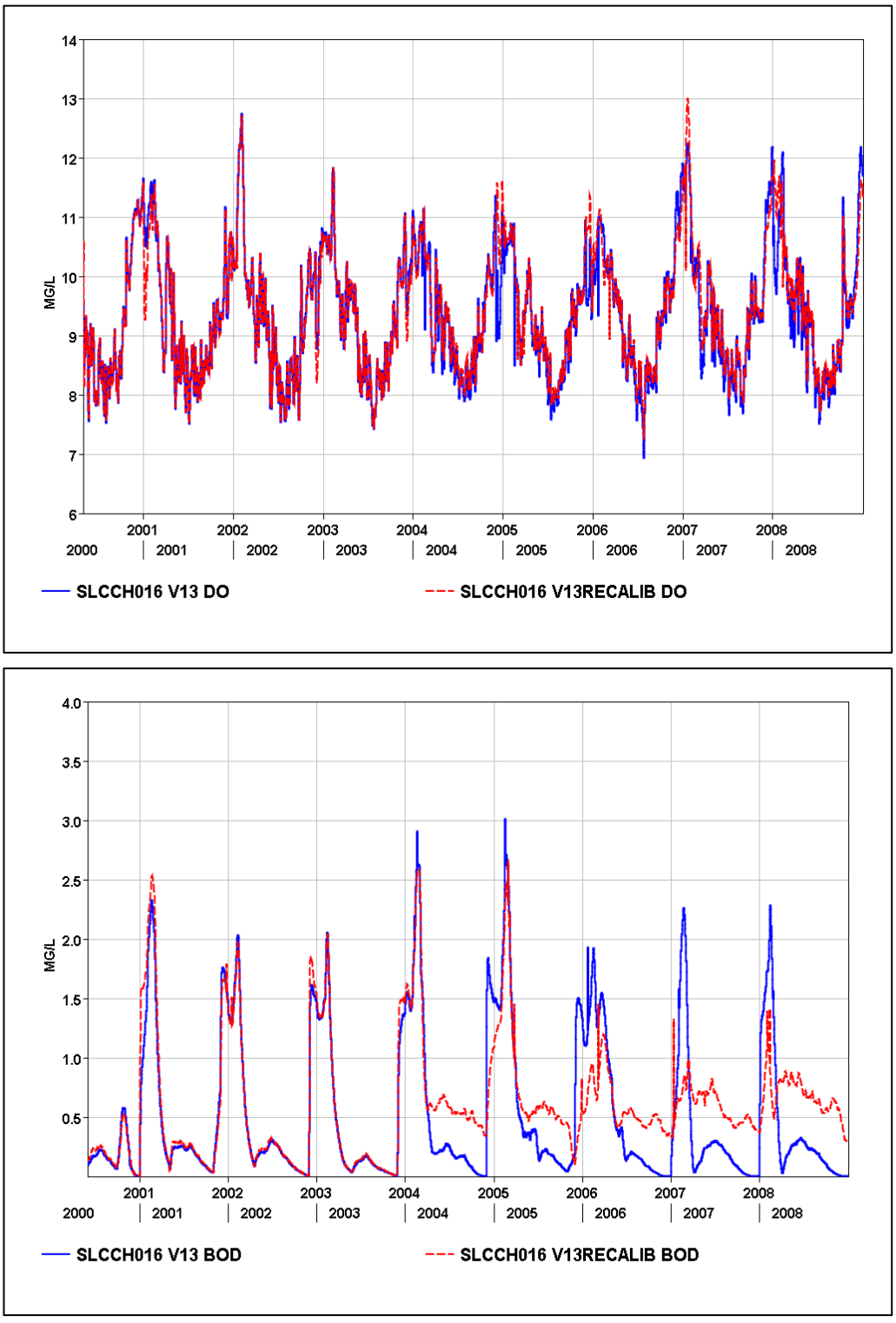


Figure 25-69 DO and CBOD concentrations at SLCCH016 for Base and Liberty grids.

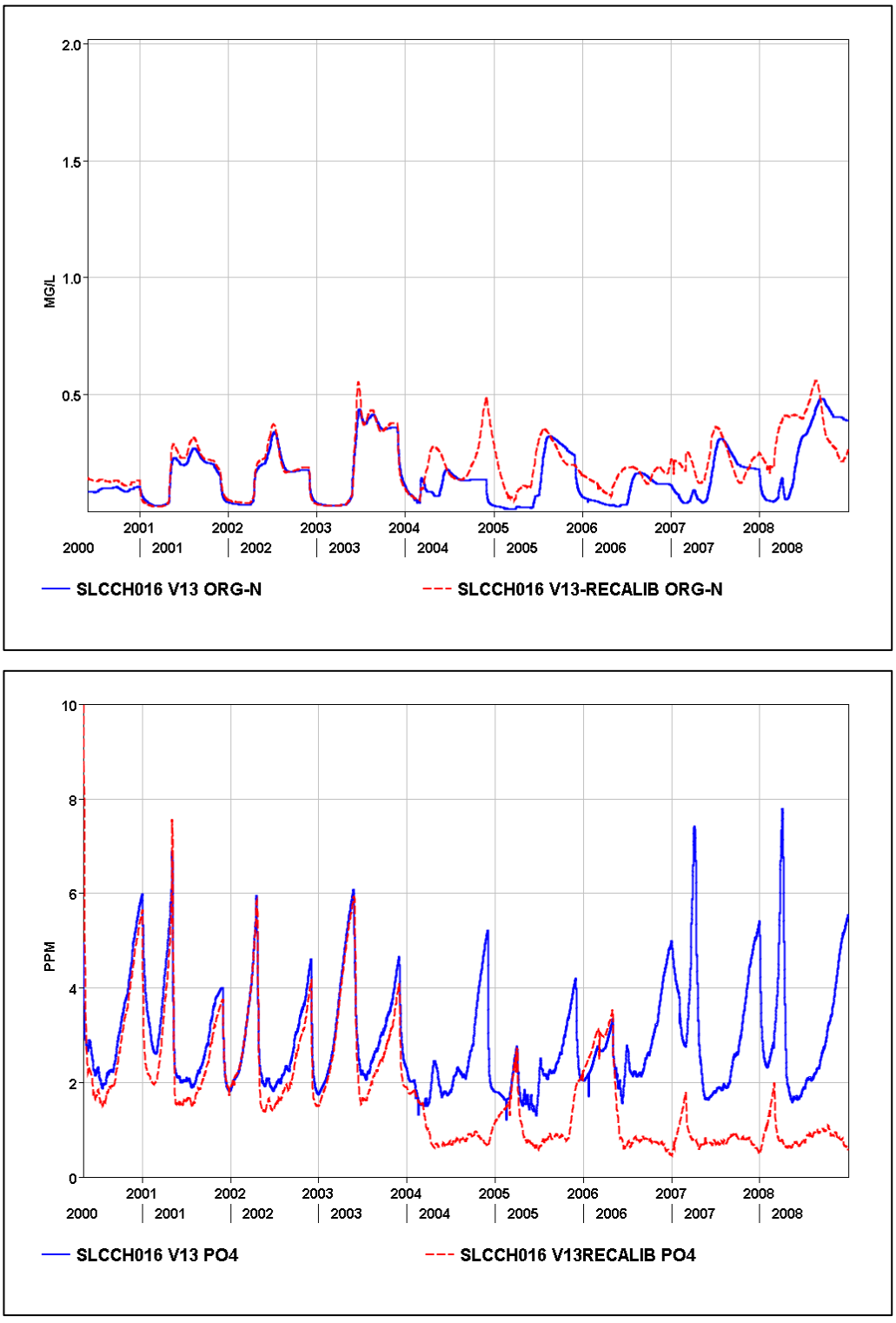


Figure 25-70 Organic-N and PO_4 concentrations at SLCCH016 for Base and Liberty grids.

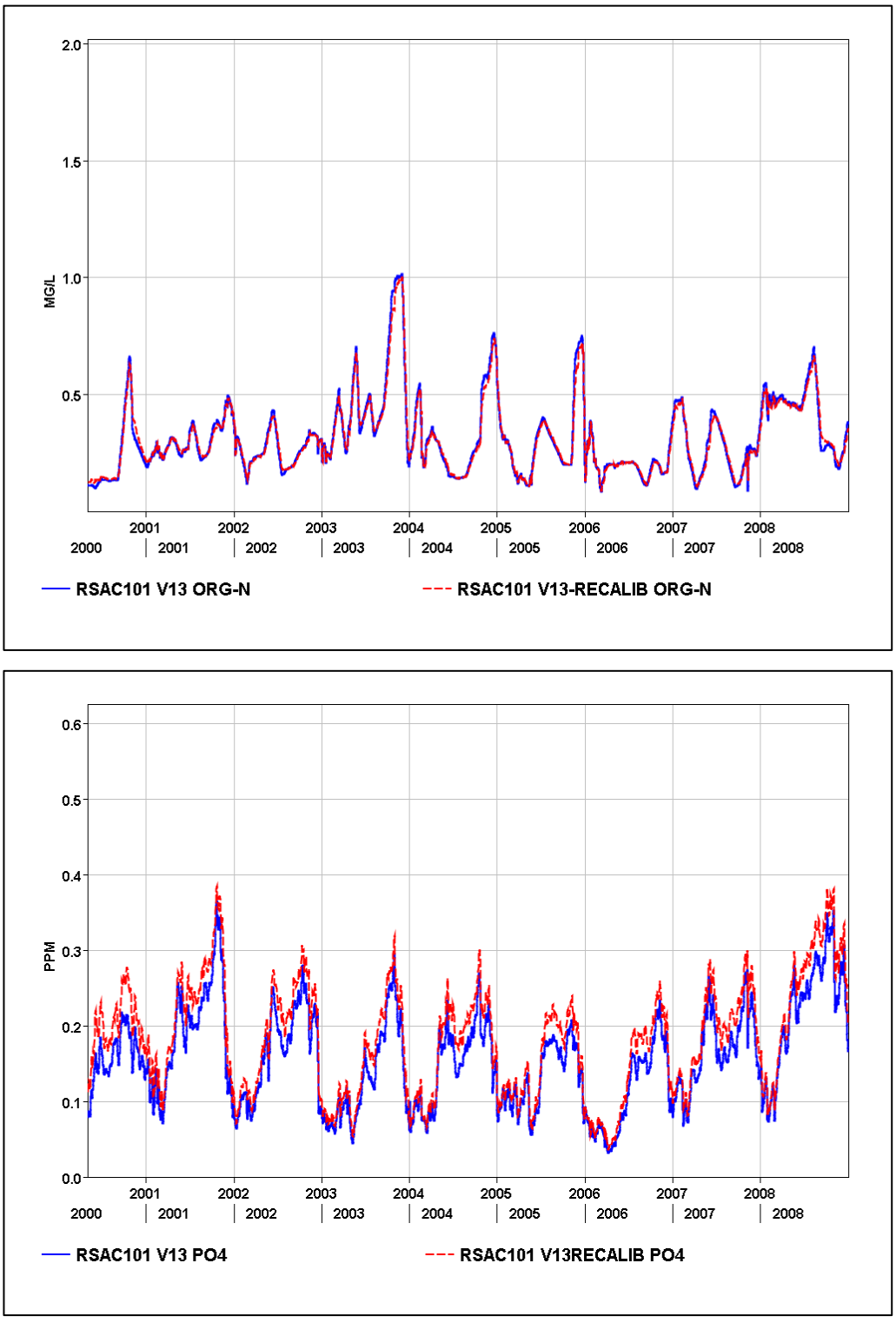


Figure 25-71 Organic-N and PO_4 concentration at RSAC101 for Base and Liberty grids.

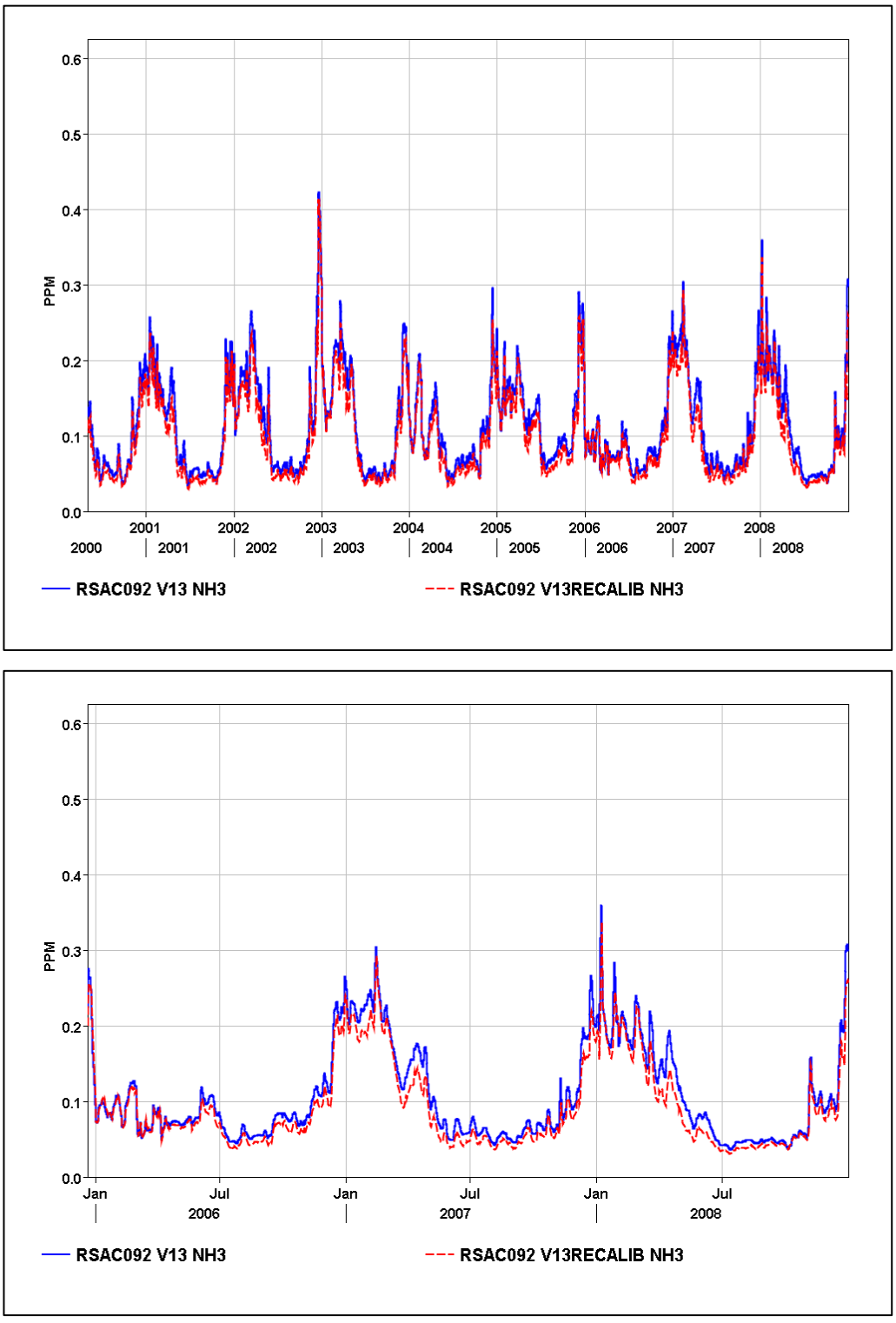


Figure 25-72 Ammonia concentration at RSAC092 for Base and Liberty grids.

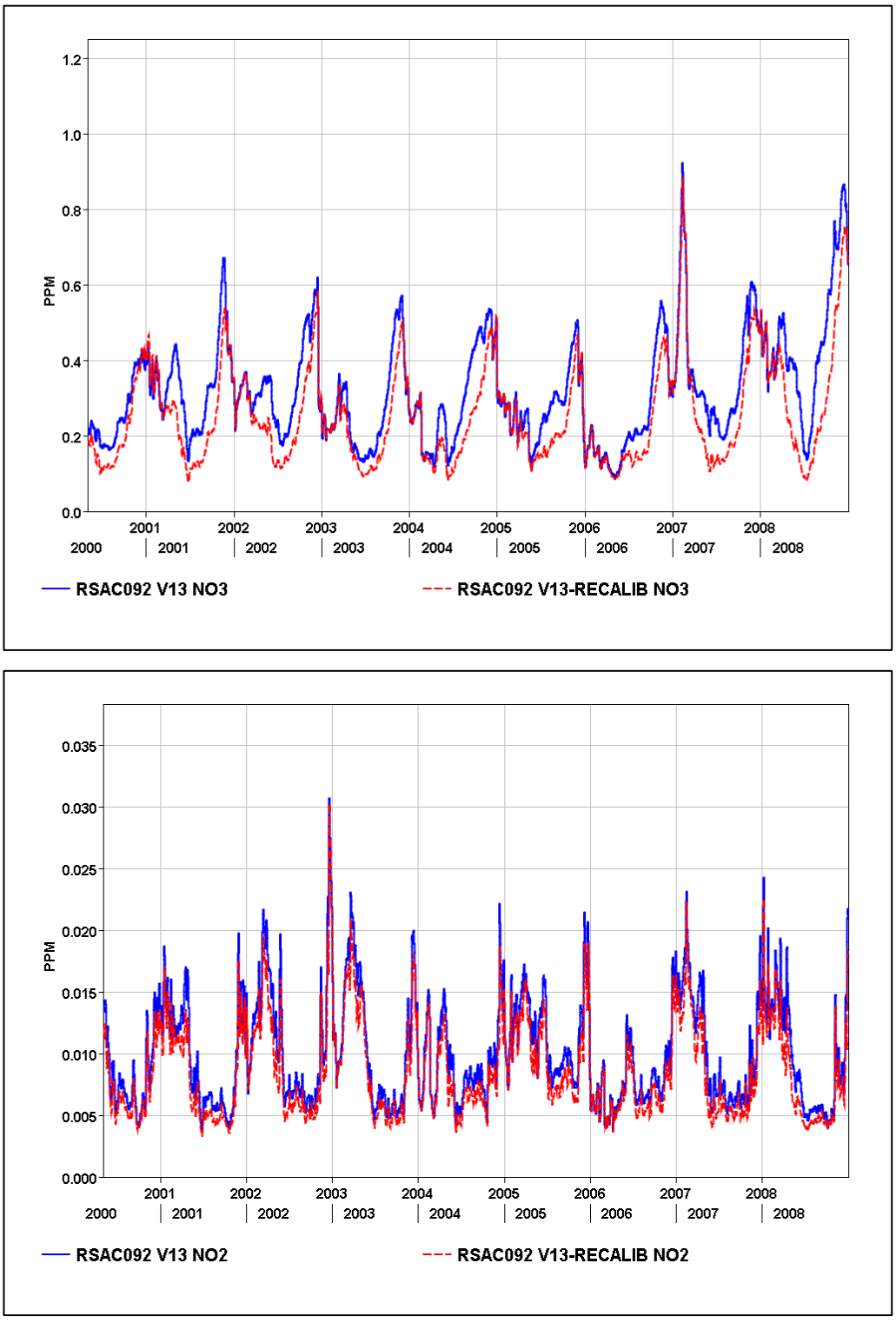


Figure 25-73 Nitrate and nitrite concentrations at RSAC092 for Base and Liberty grids.

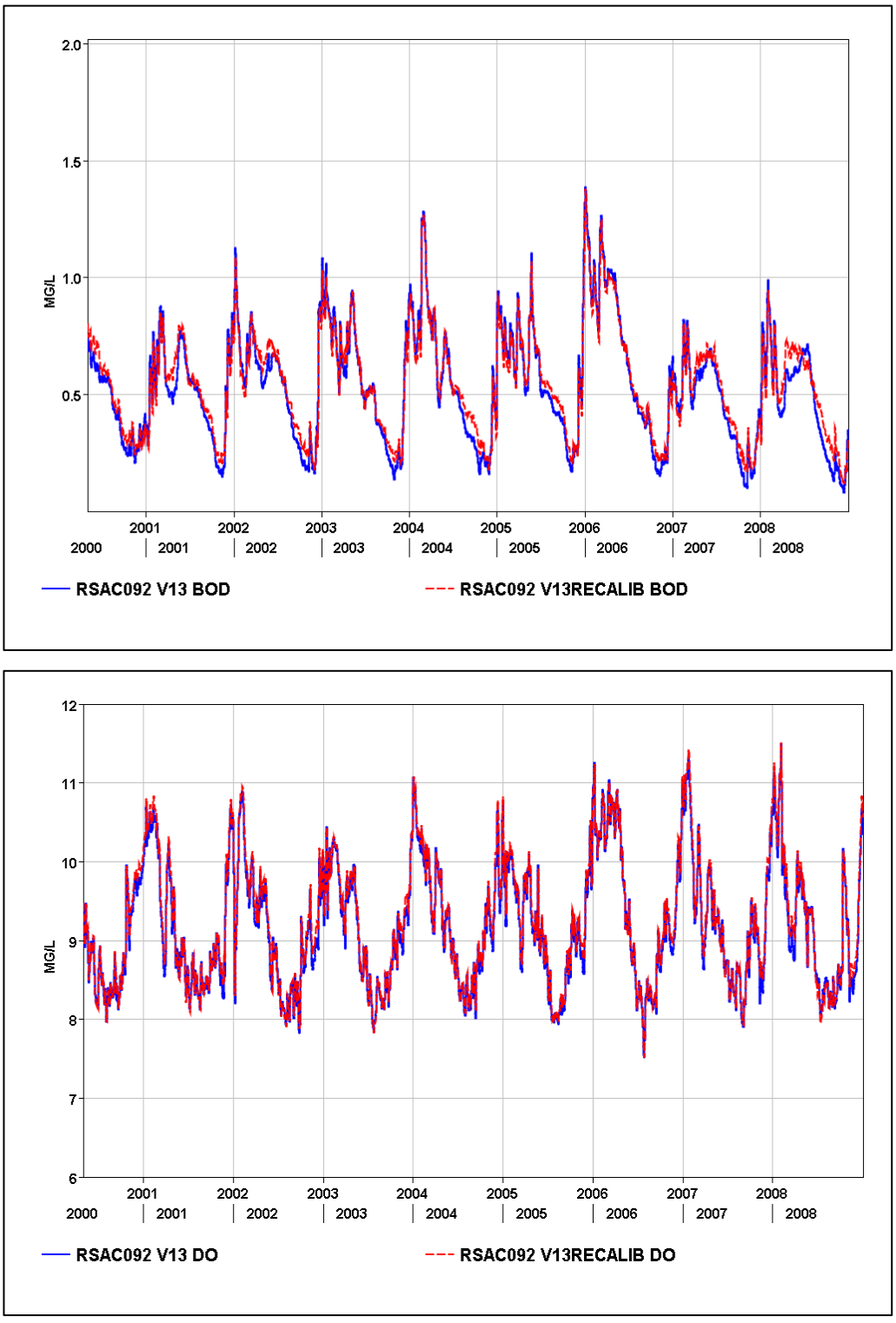


Figure 25-74 CBOD and DO concentrations at RSAC092 for Base and Liberty grids.

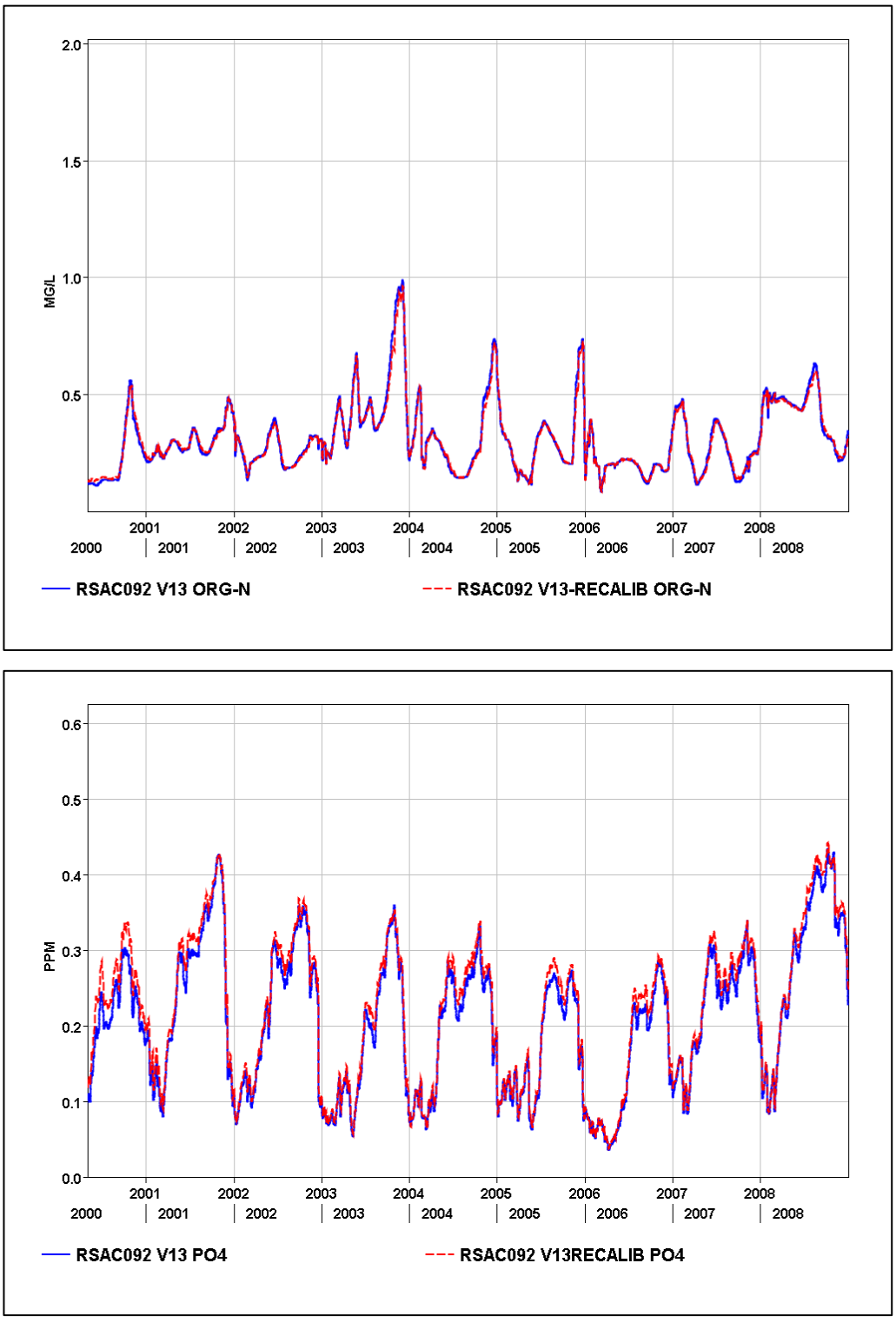


Figure 25-75 Organic-N and PO_4 concentrations at RSAC092 for Base and Liberty grids.

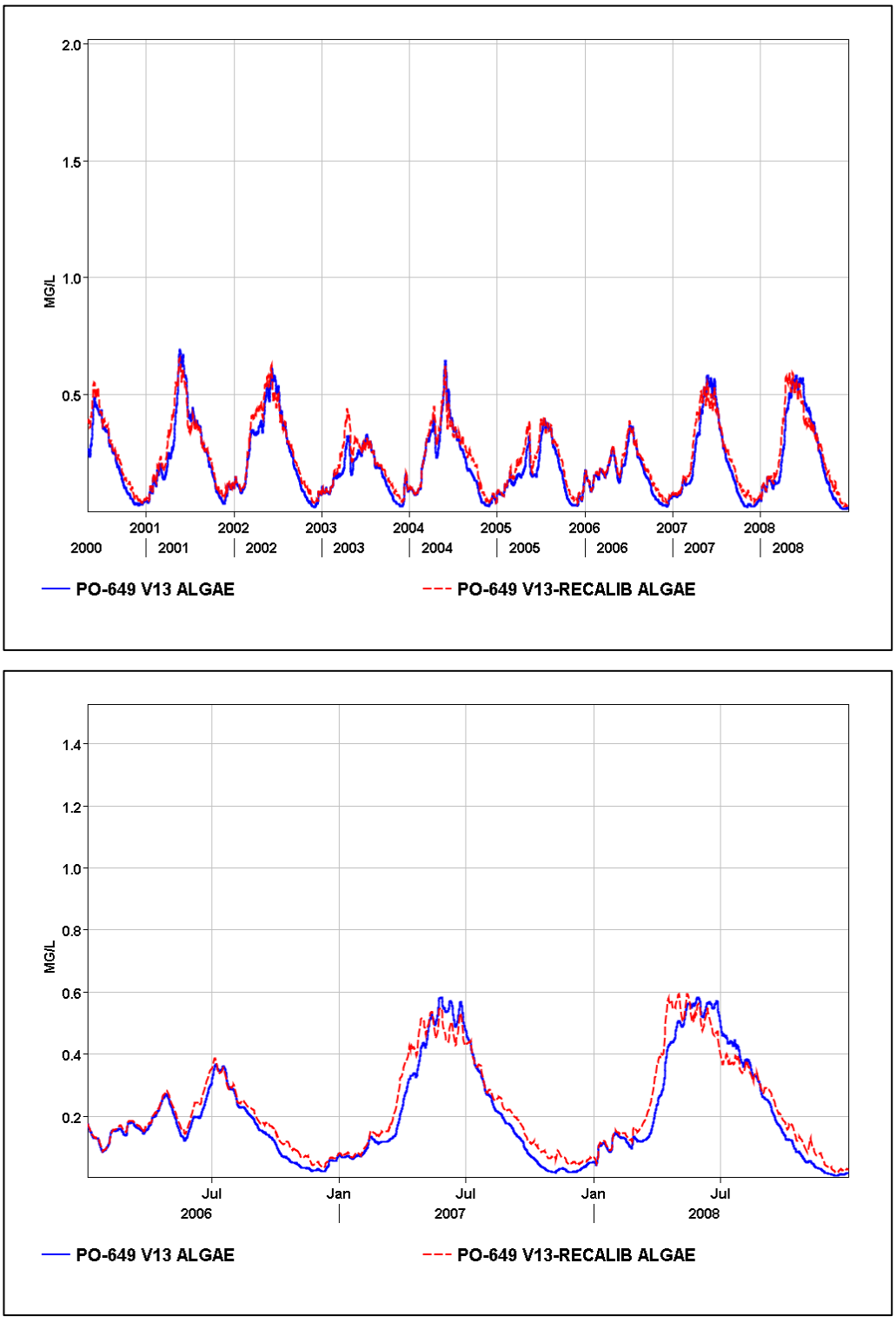


Figure 25-76 Algal biomass Point Sacramento for Base and Liberty grids.

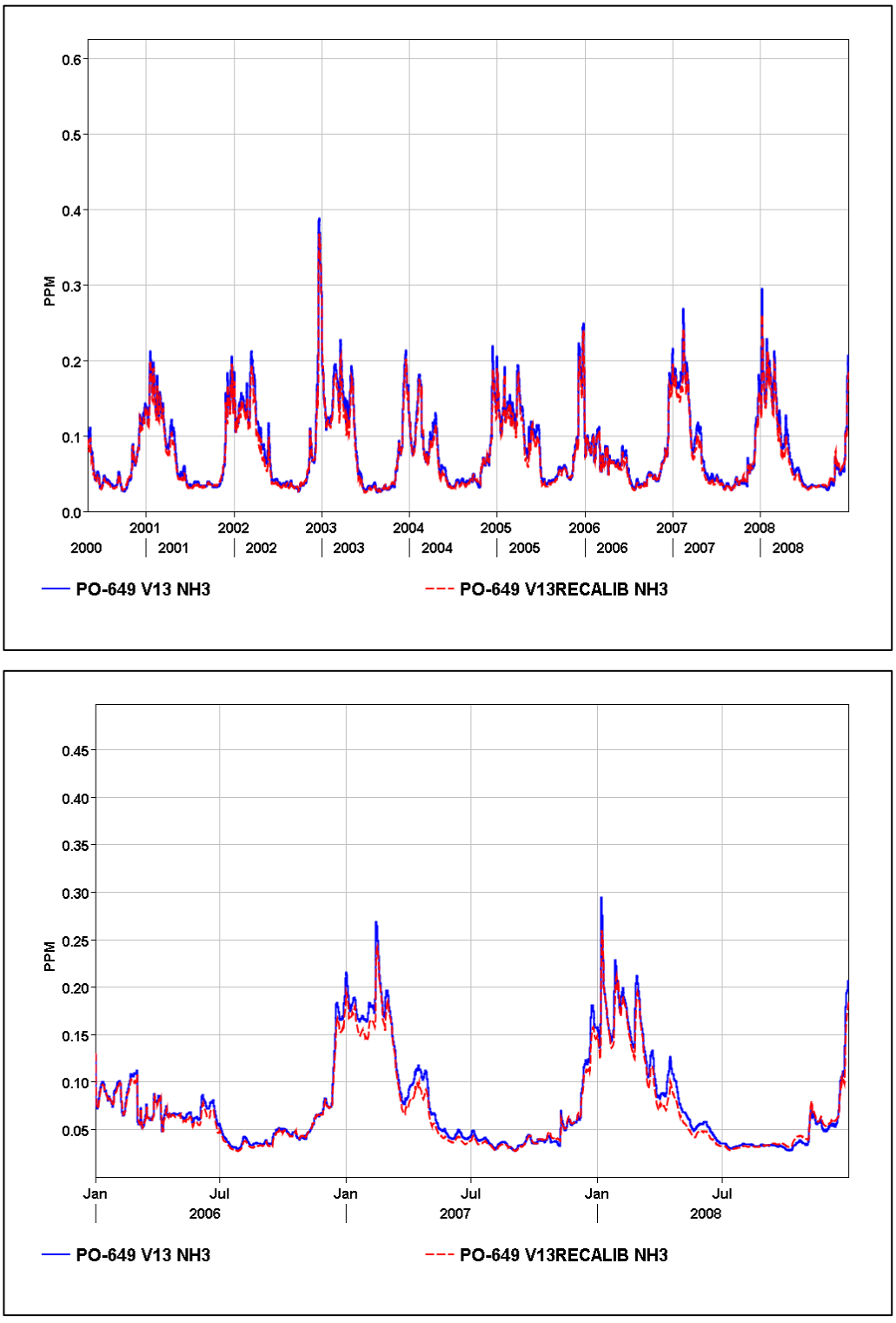


Figure 25-77 Ammonia concentration at Point Sacramento for Base and Liberty grids.

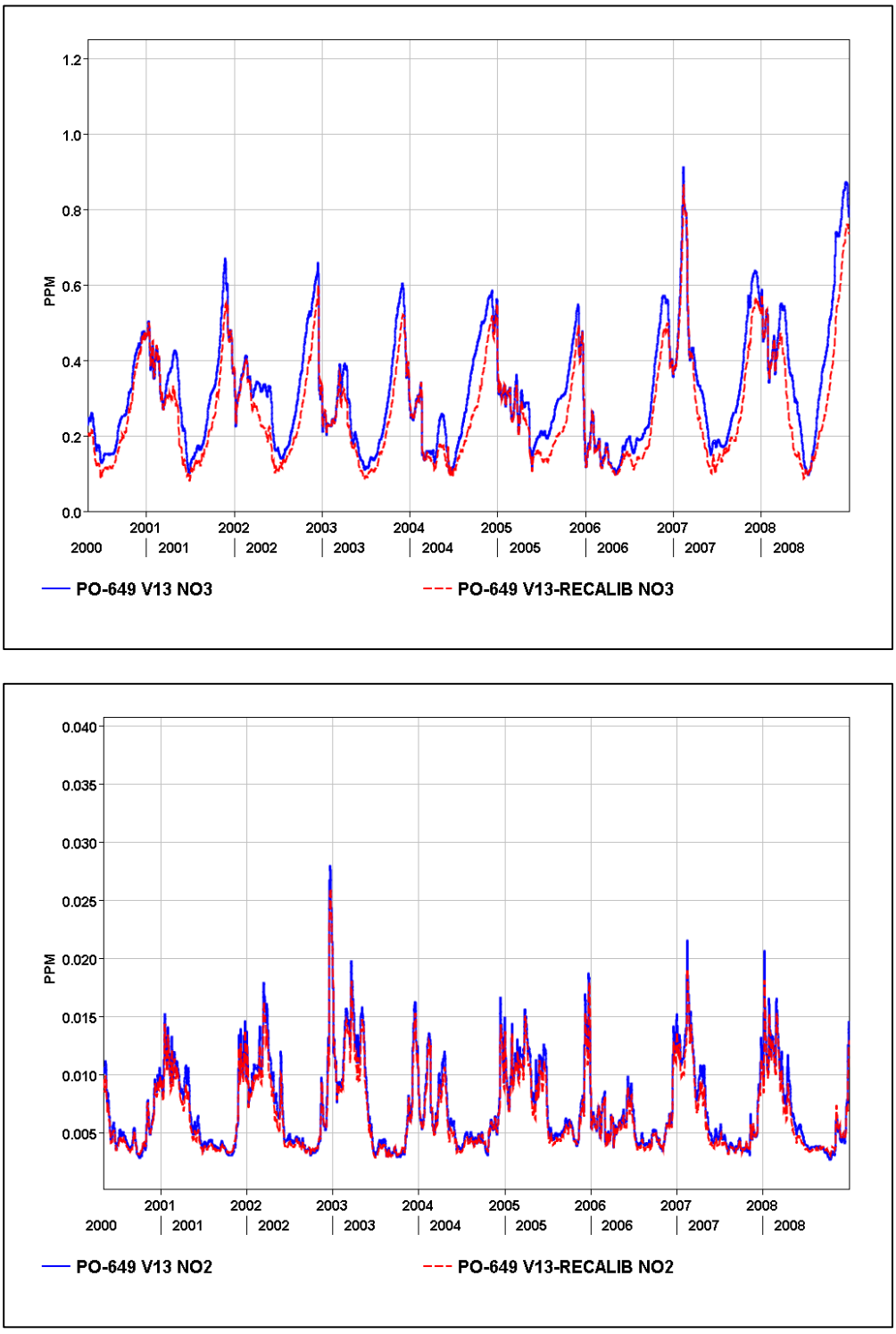


Figure 25-78 Nitrate and nitrite concentrations at Point Sacramento for Base and Liberty grids.

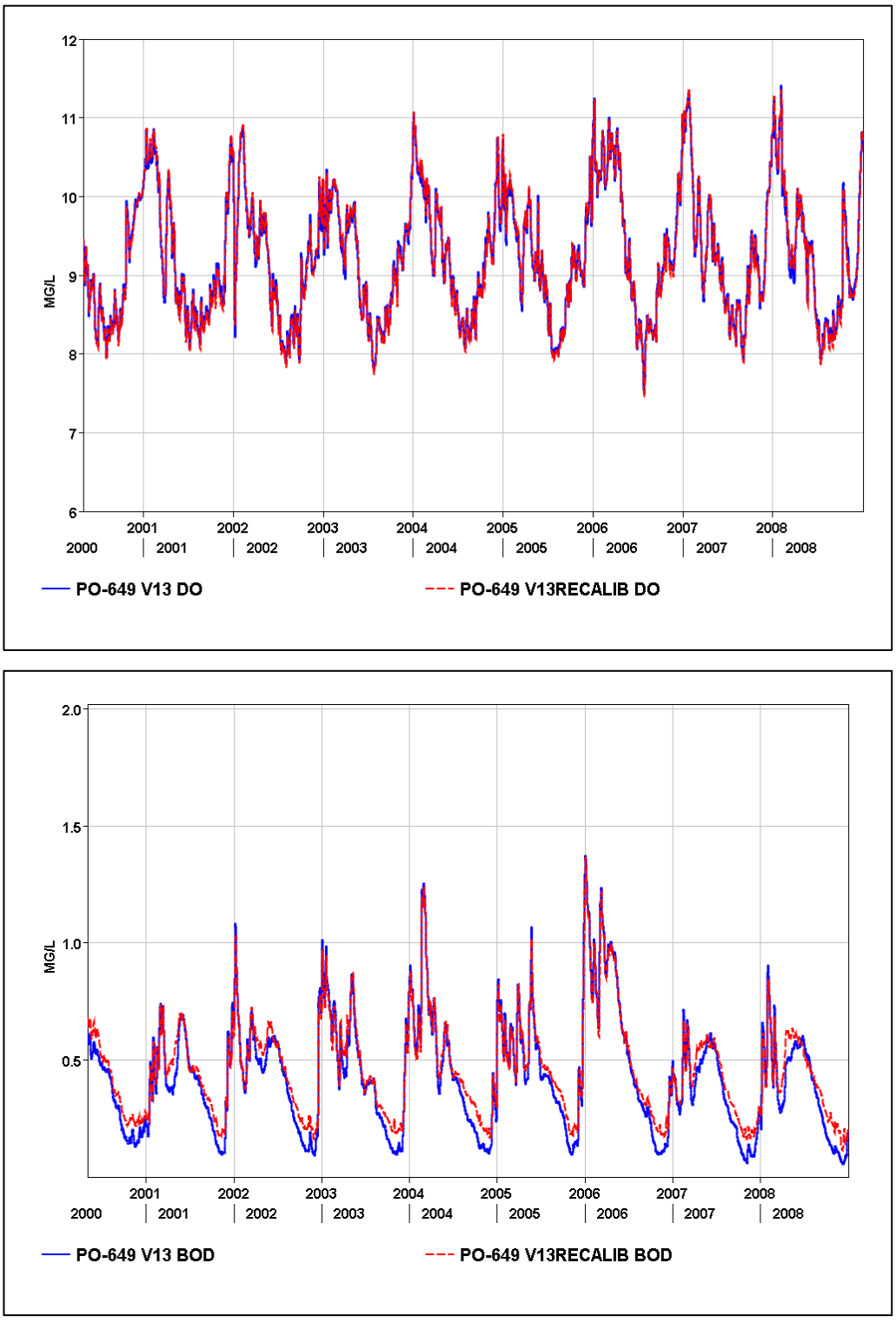
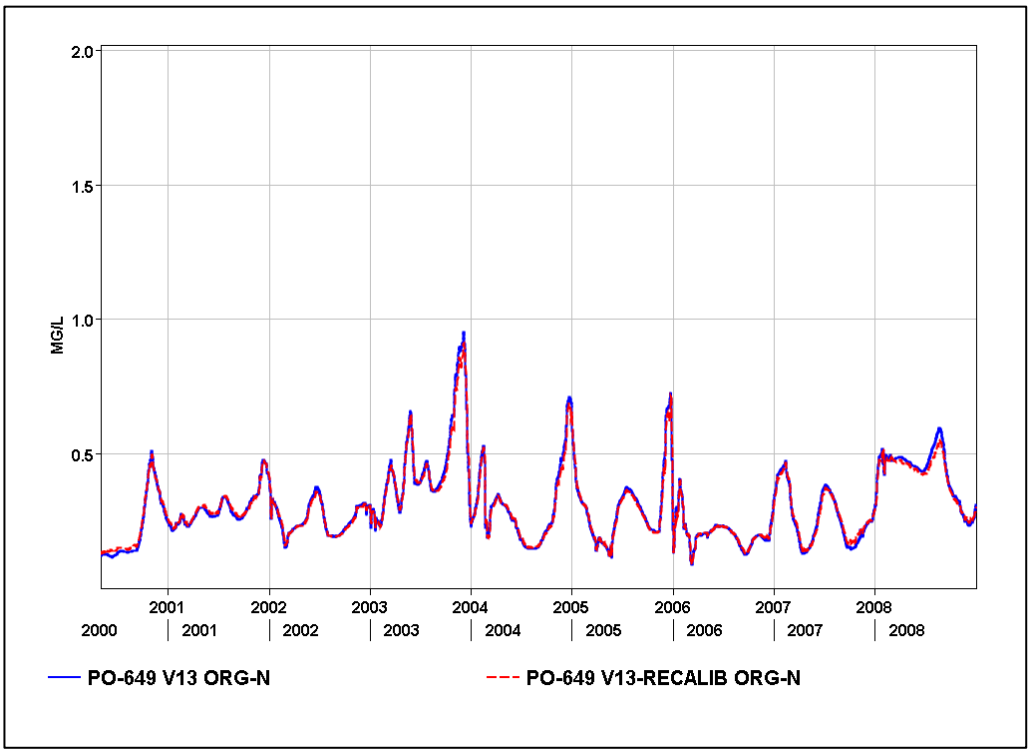


Figure 25-79 DO and CBOD concentrations at Point Sacramento for Base and Liberty grids.



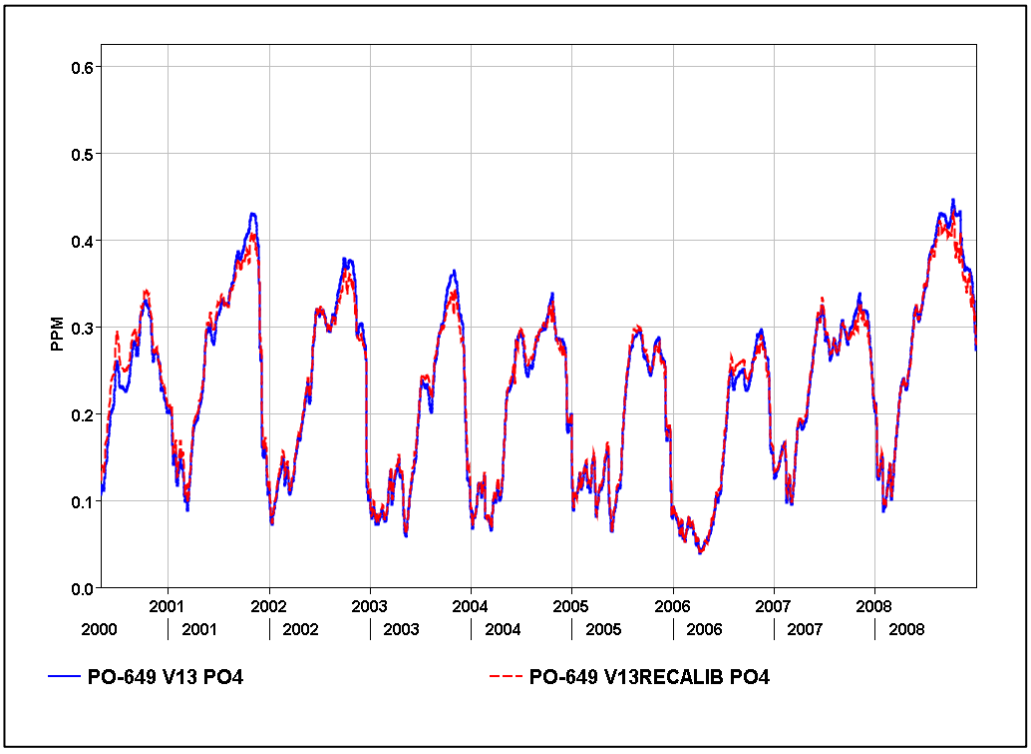


Figure 25-80 Organic-N and PO4 concentrations at Point Sacramento for Base and Liberty grids.

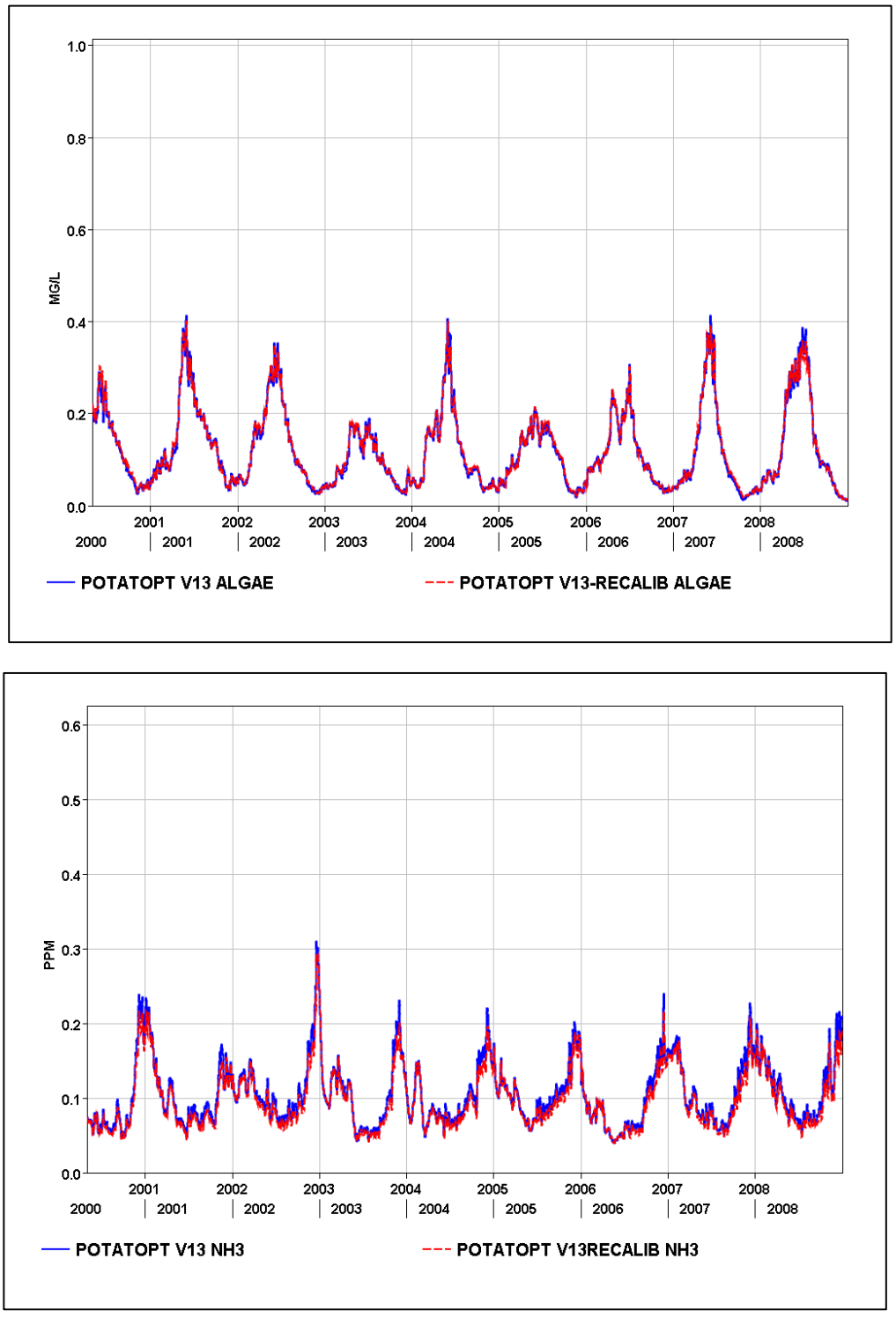


Figure 25-81 Algal biomass and ammonia concentrations at Potato Point for Base and Liberty grids.

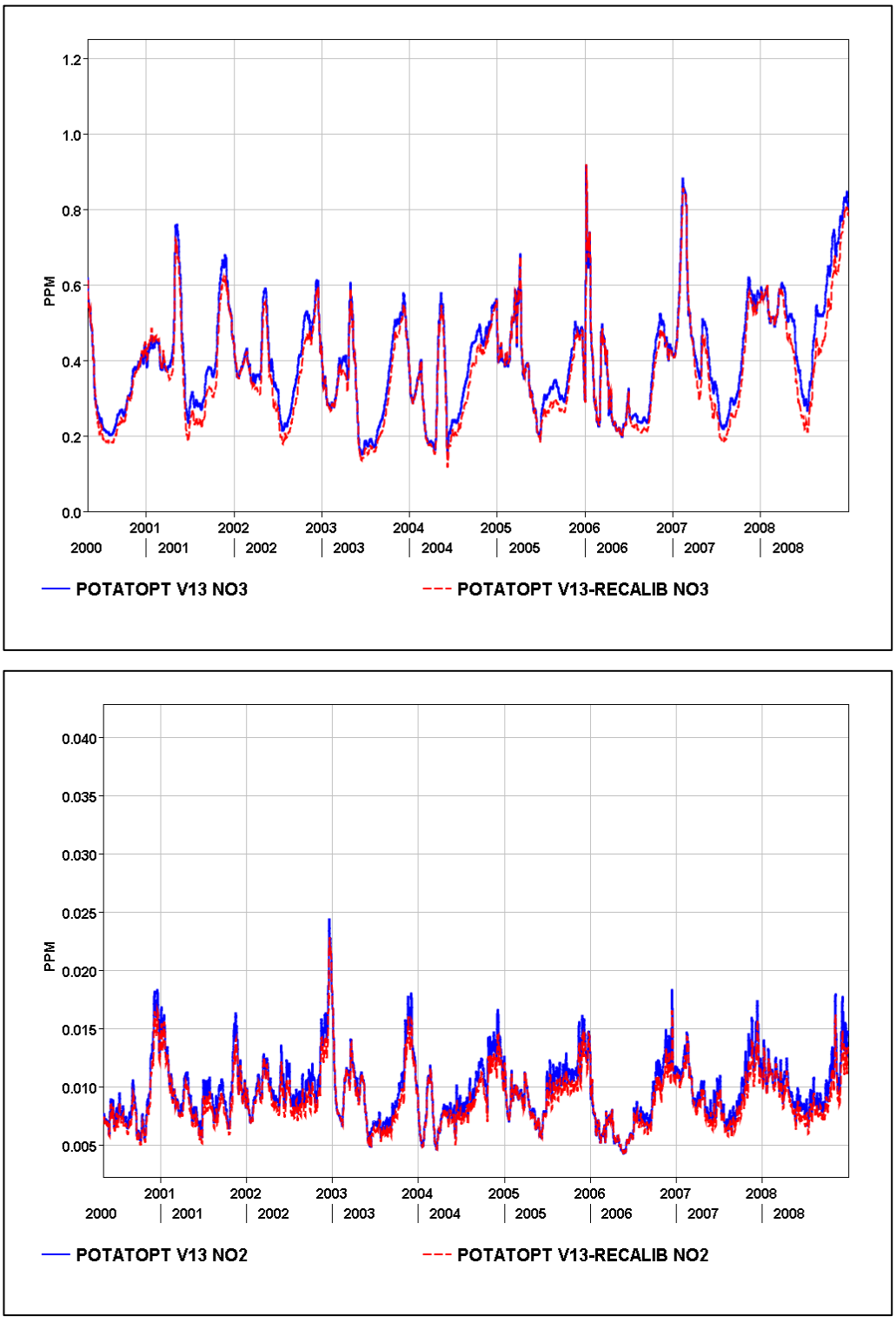


Figure 25-82 Nitrate and nitrite concentrations at Potato Point for Base and Liberty grids.

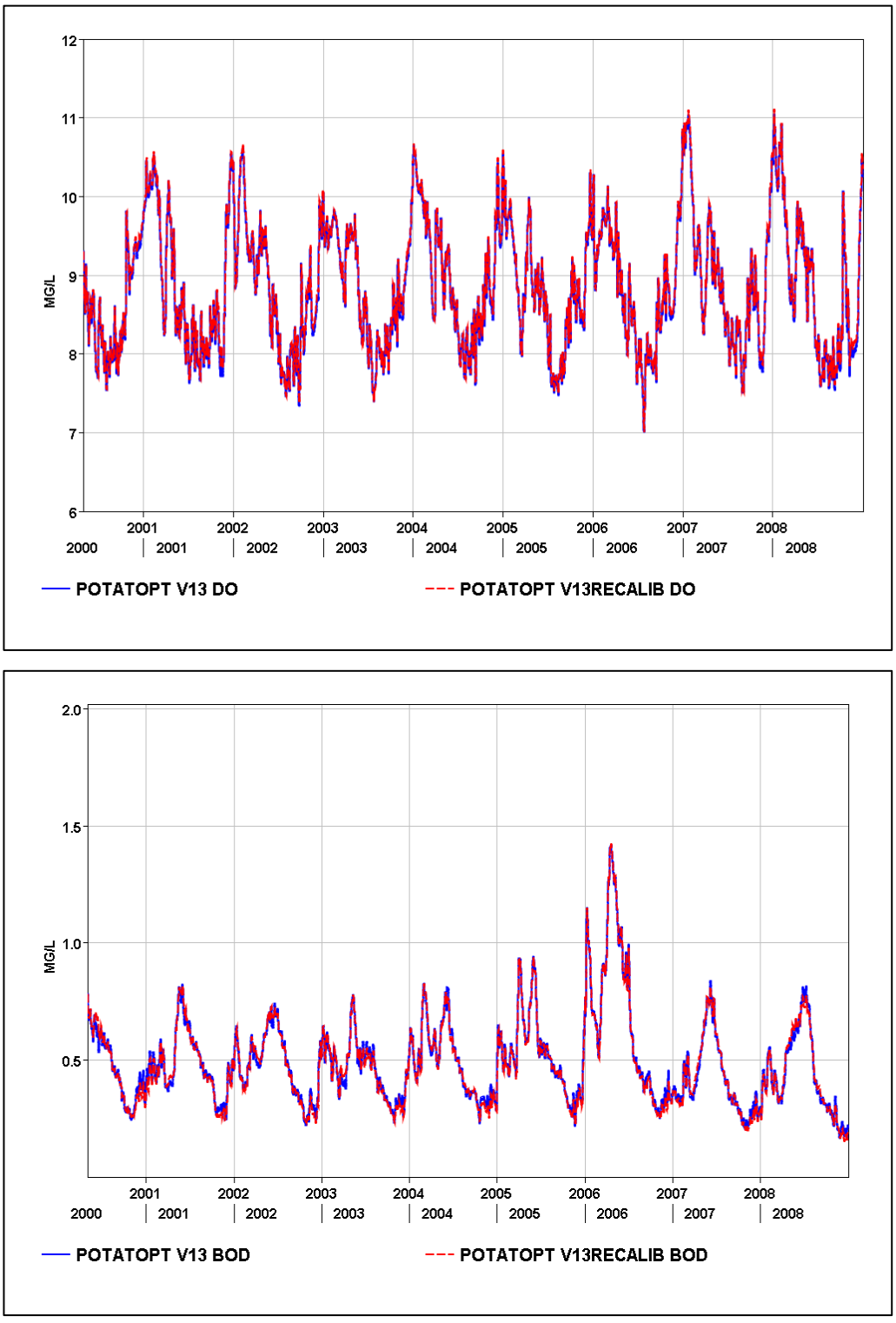


Figure 25-83 DO and CBOD concentrations at Potato Point for Base and Liberty grids.

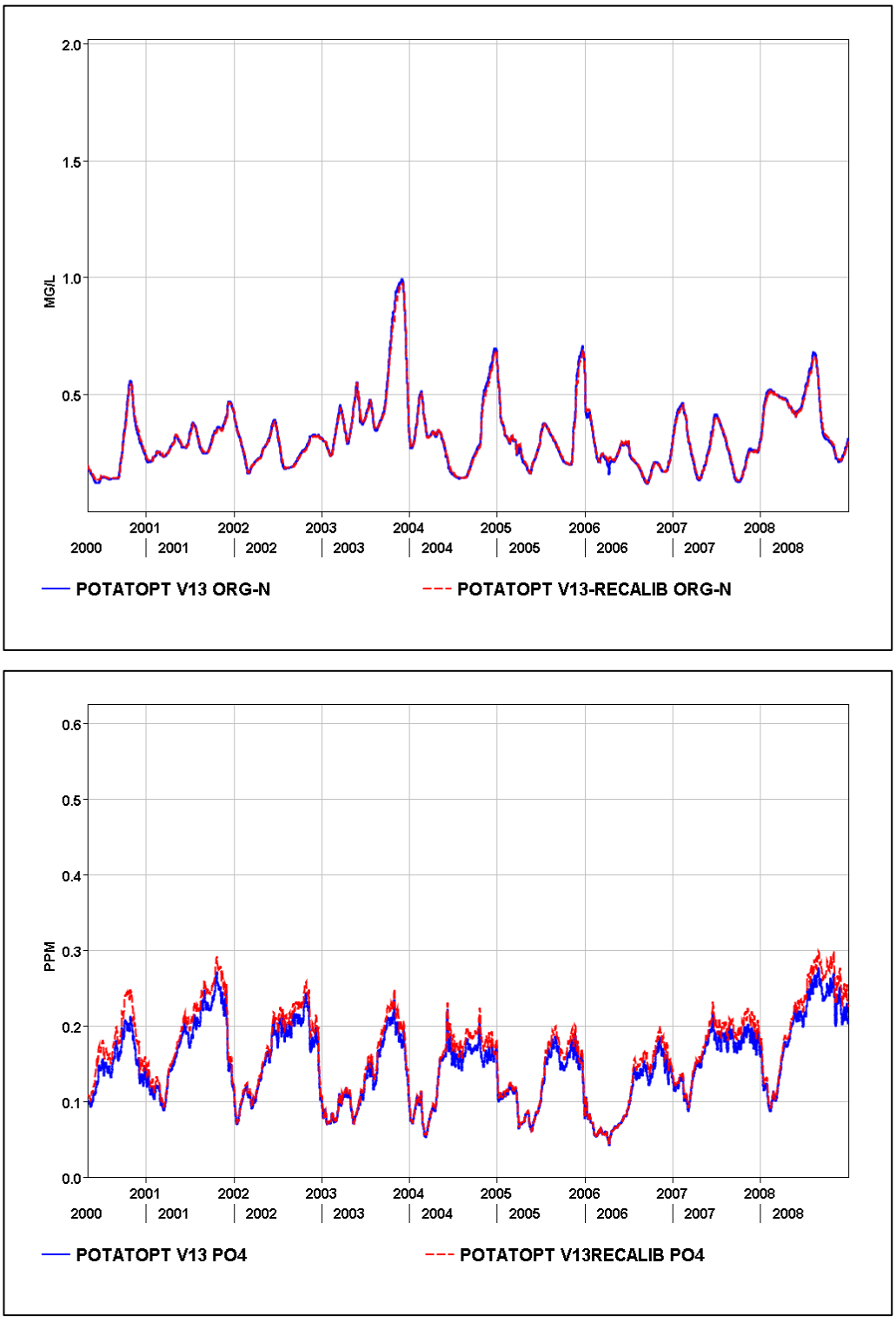


Figure 25-84 Organic-N and PO_4 concentrations at Potato Point for Base and Liberty grids.

25.11 Scenario Figures

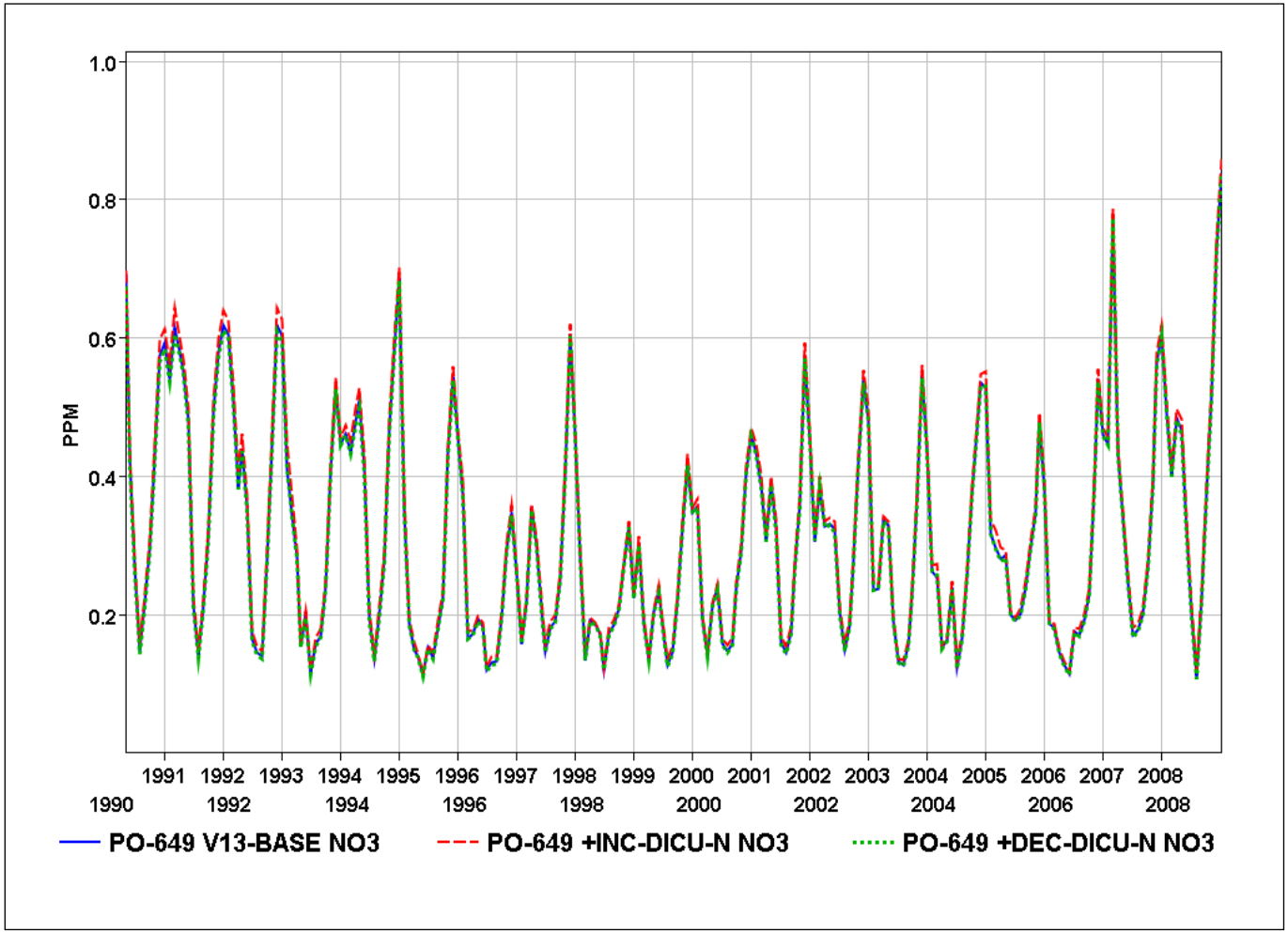


Figure 25-85 Changes in nitrate concentration were very small at Point Sacramento in the DICU changes scenarios.

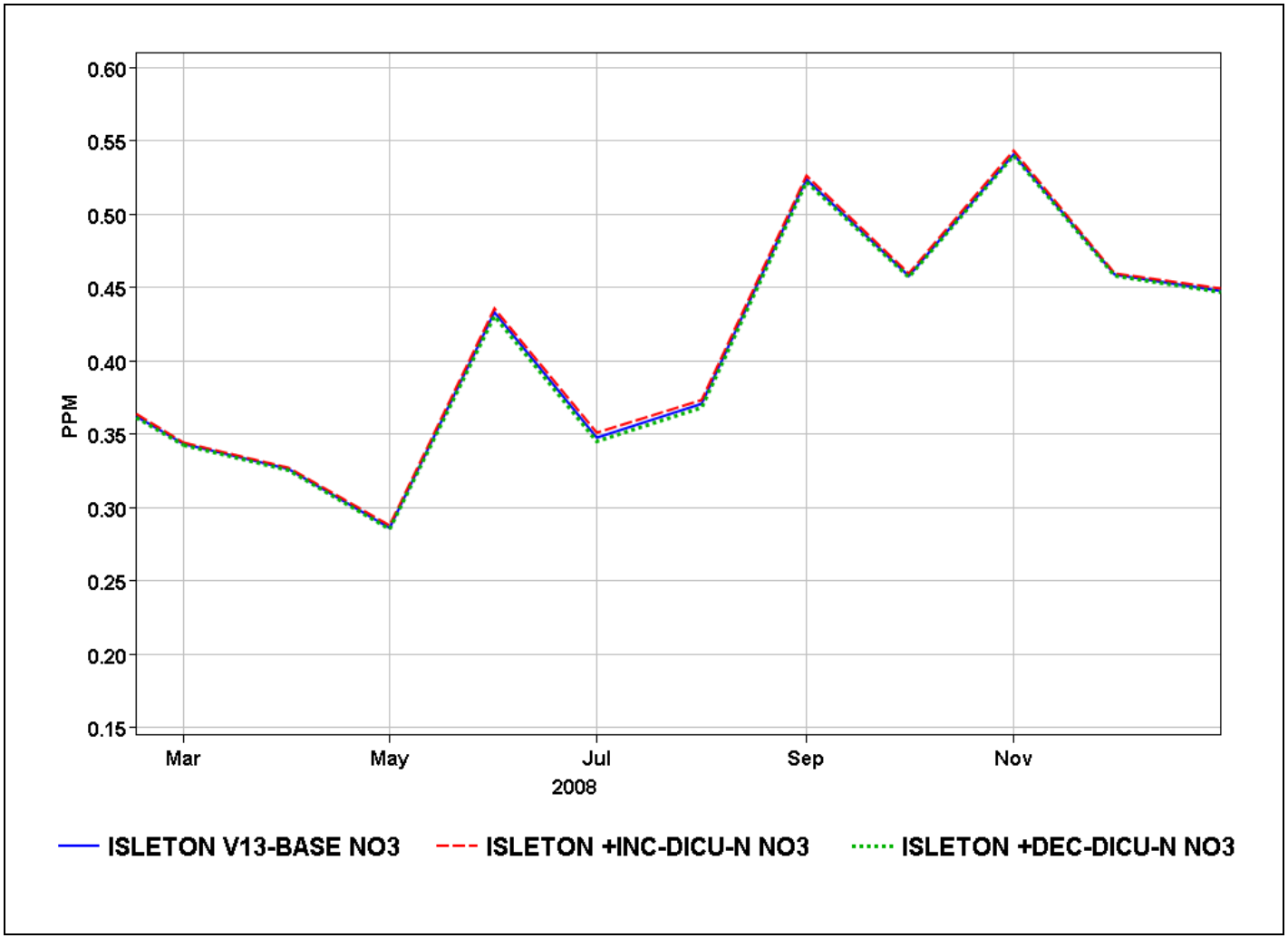


Figure 25-86 Changes in nitrate concentration were hard to distinguish at Isleton in the DICU changes scenarios.

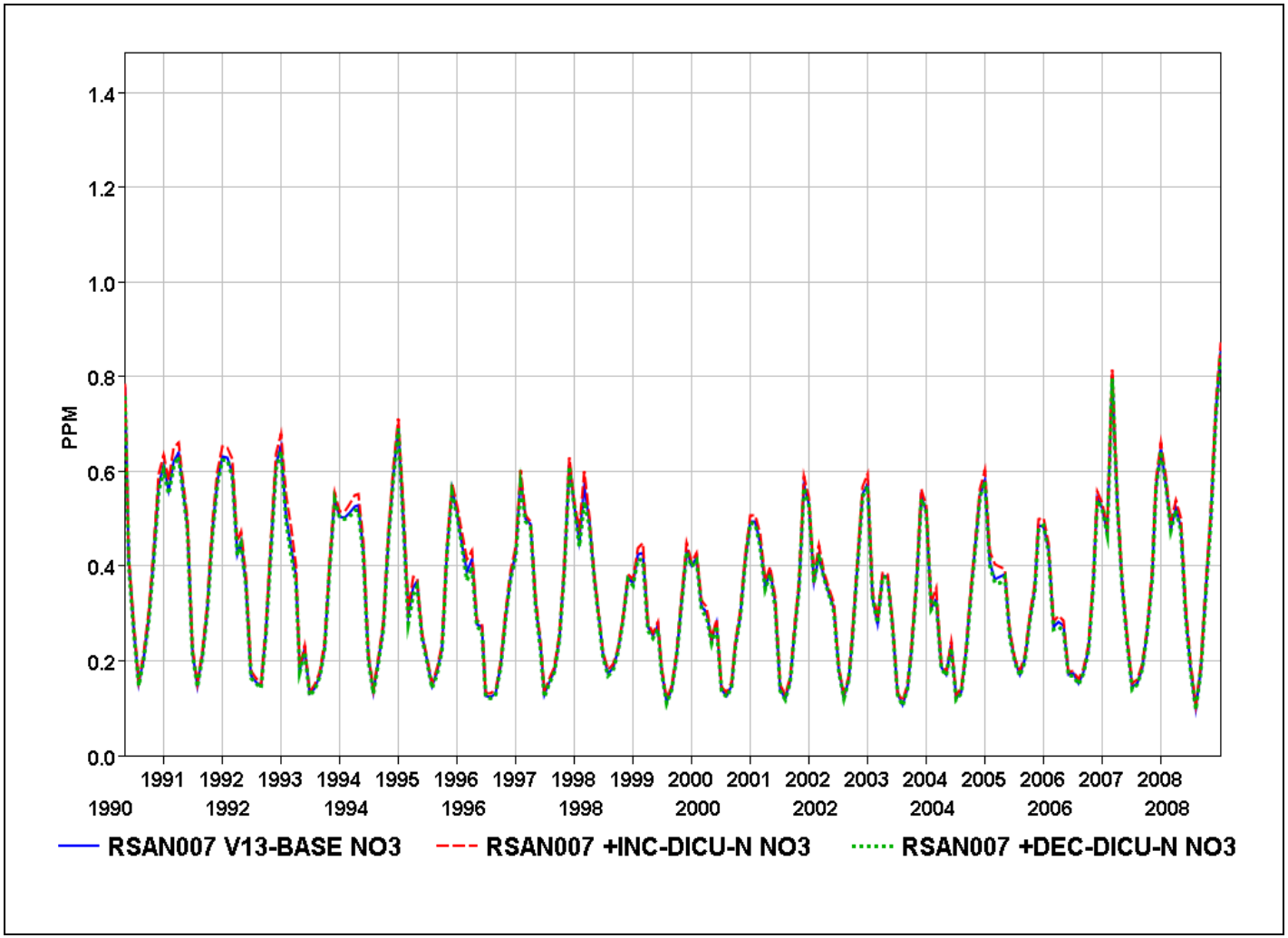


Figure 25-87 Changes in nitrate concentration at Antioch in the DICU changes scenarios.

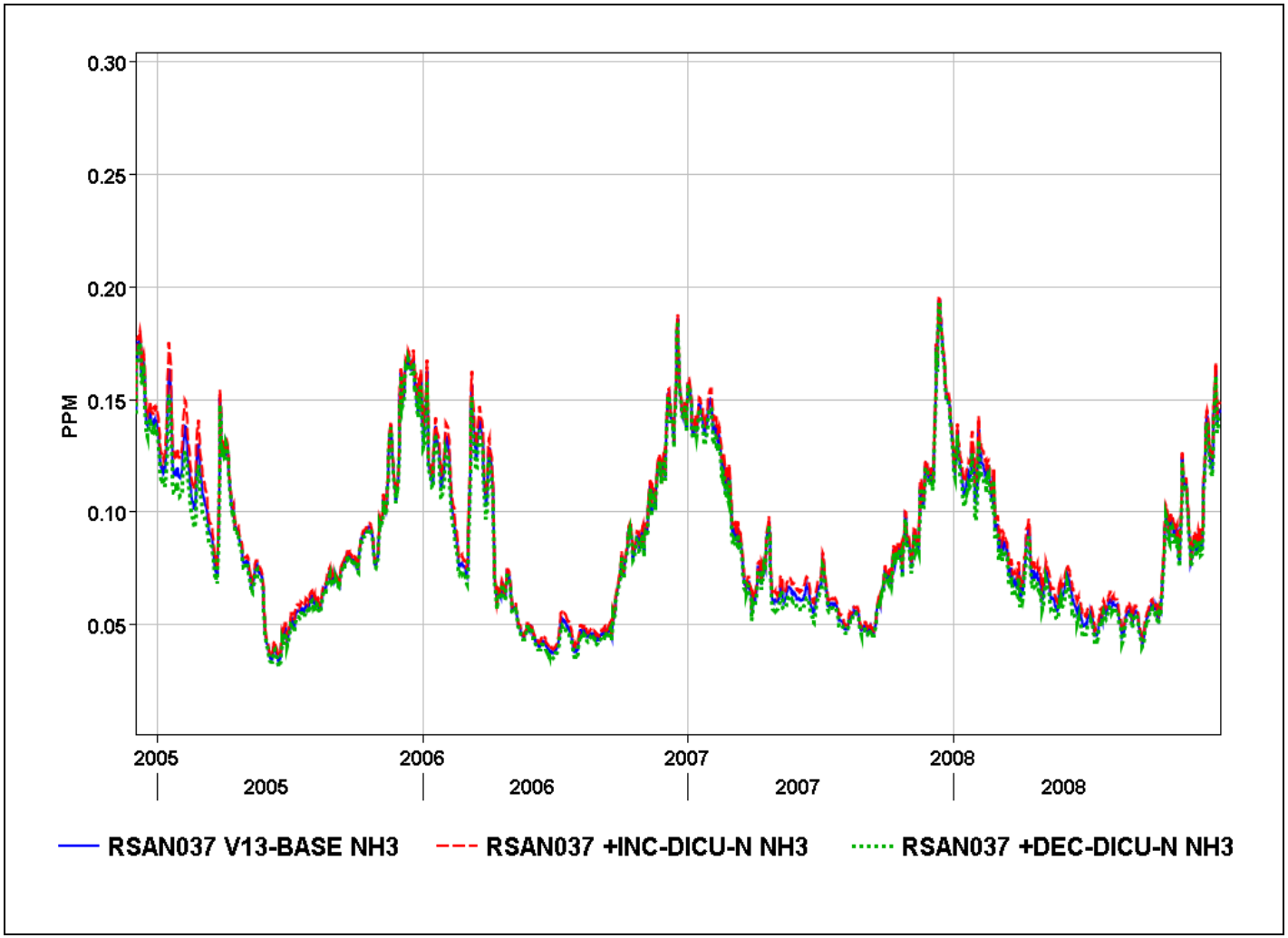


Figure 25-88 Changes in ammonia concentration at RSAN037 on the San Joaquin River.

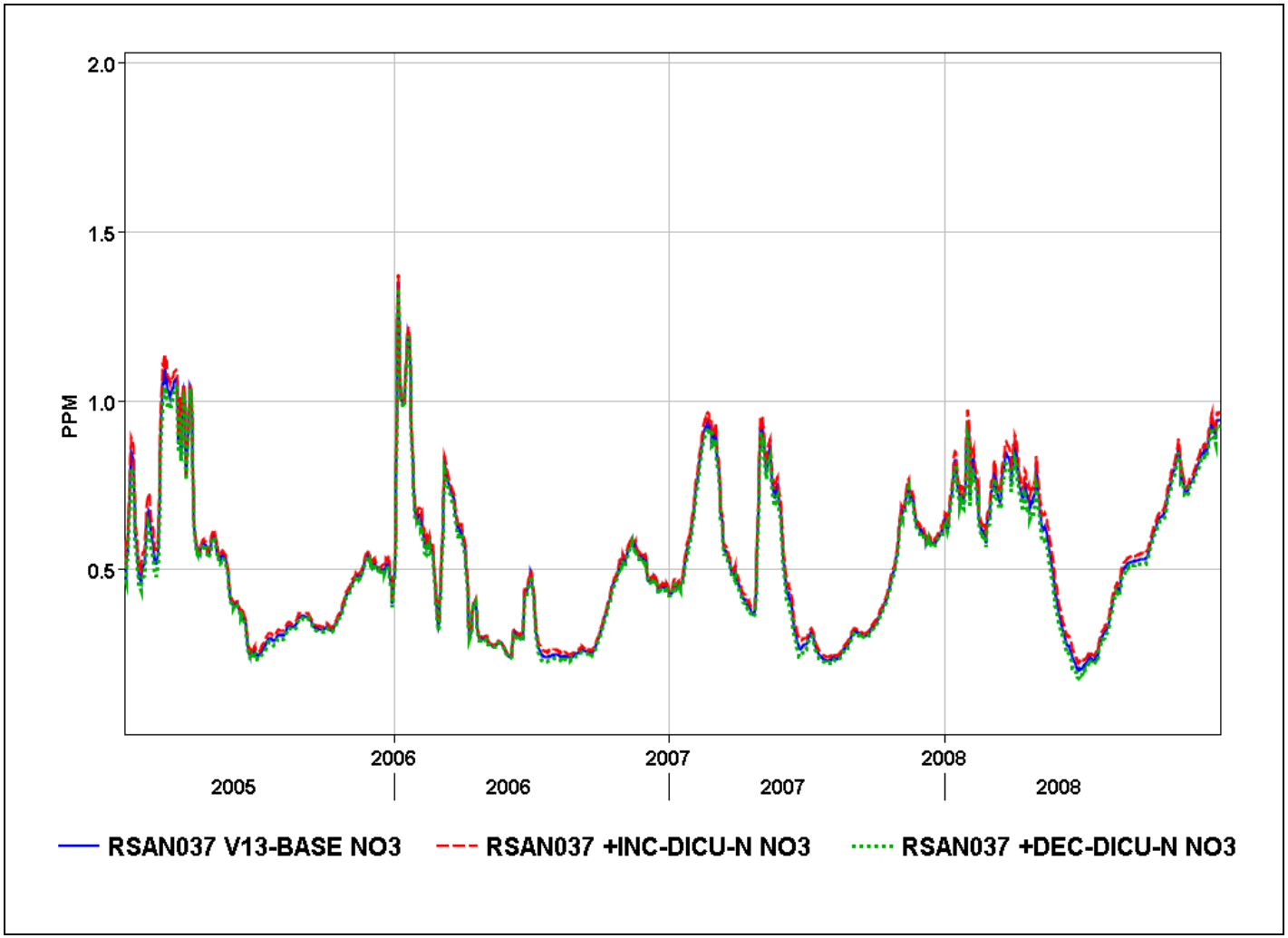


Figure 25-89 Changes in nitrate concentration at RSAN037 on the San Joaquin River.

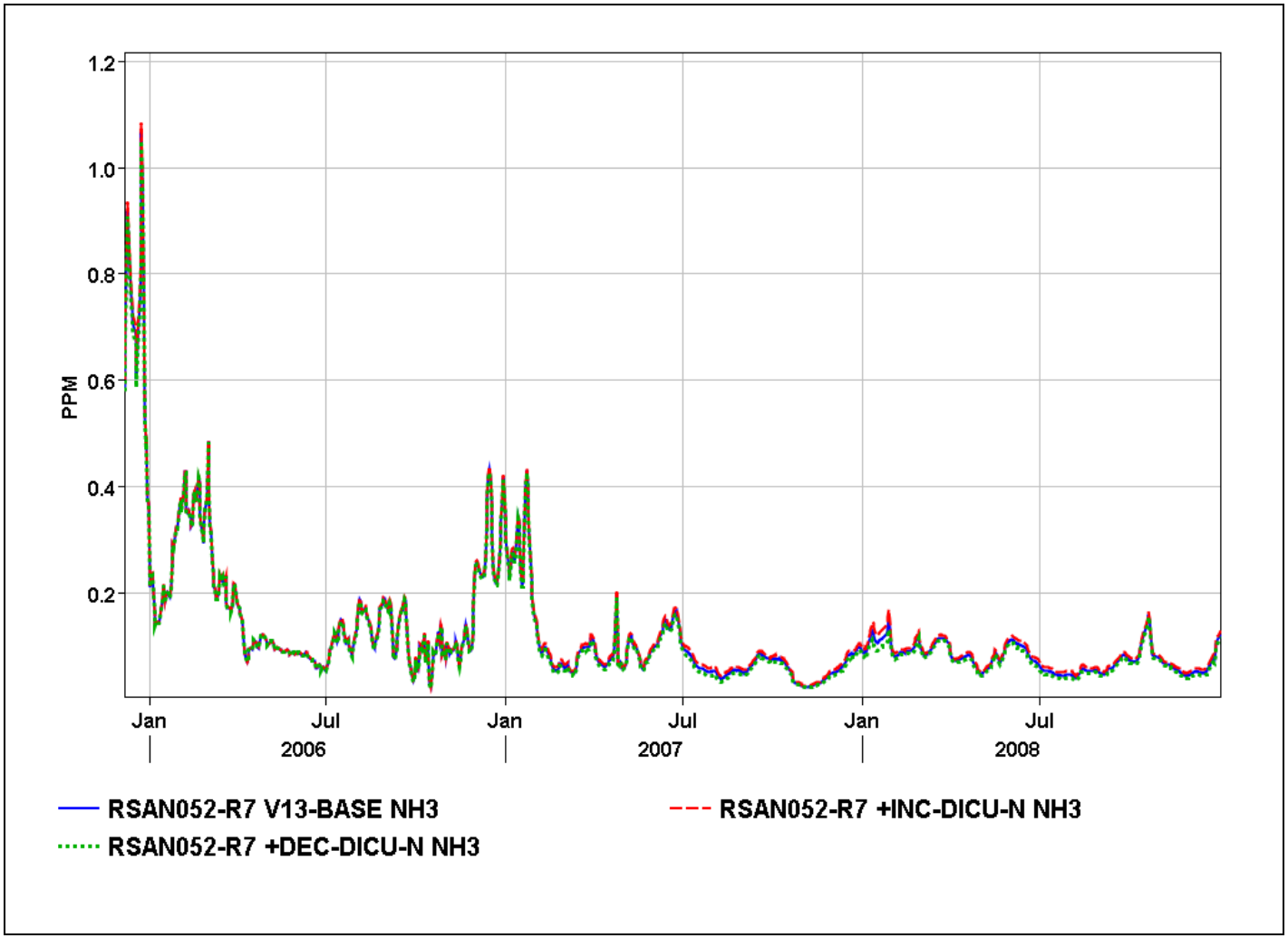


Figure 25-90 Changes in ammonia concentration at RSAN052 on the San Joaquin River.

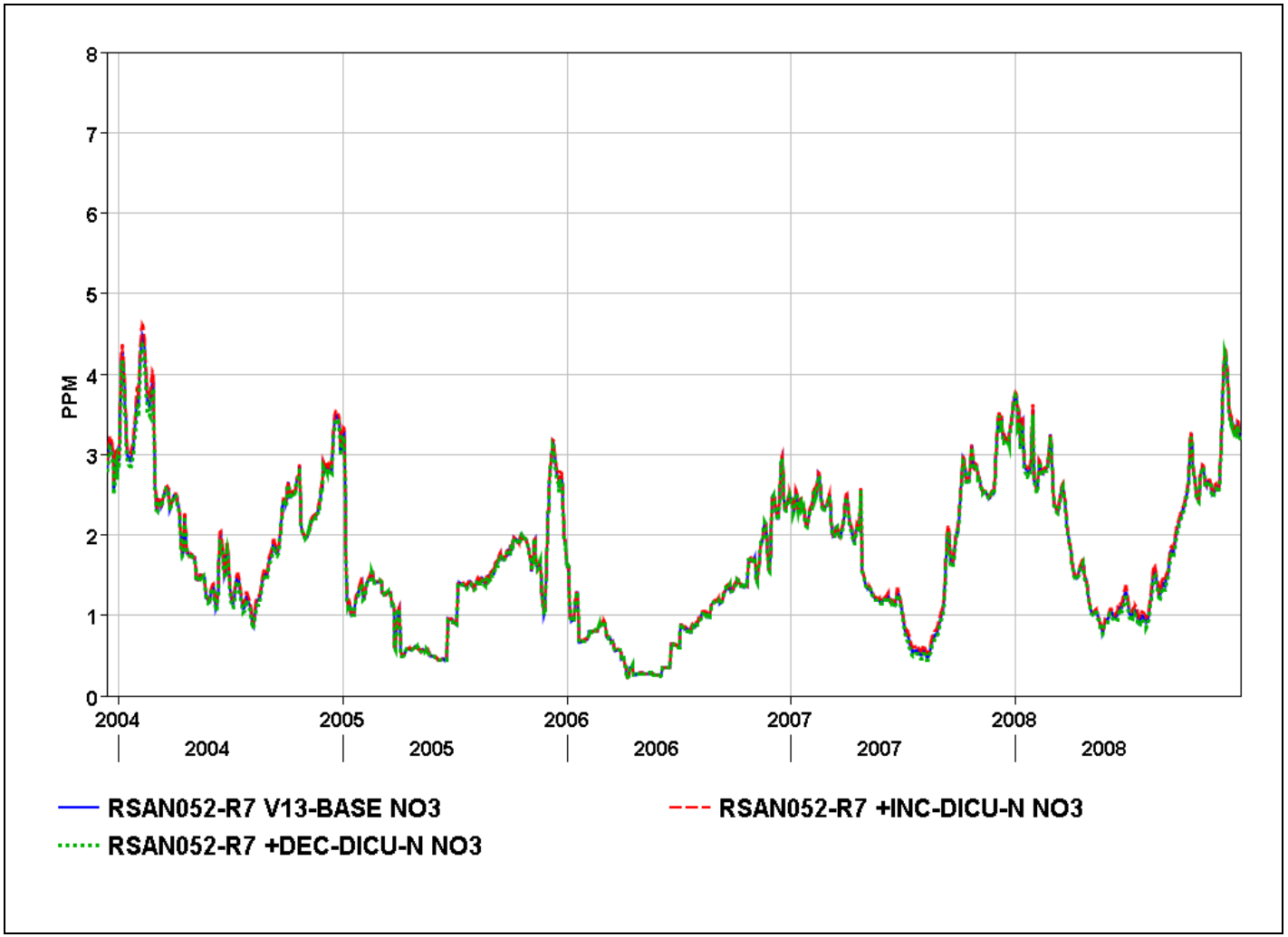


Figure 25-91 Changes in nitrate concentration at RSAN052 on the San Joaquin River.

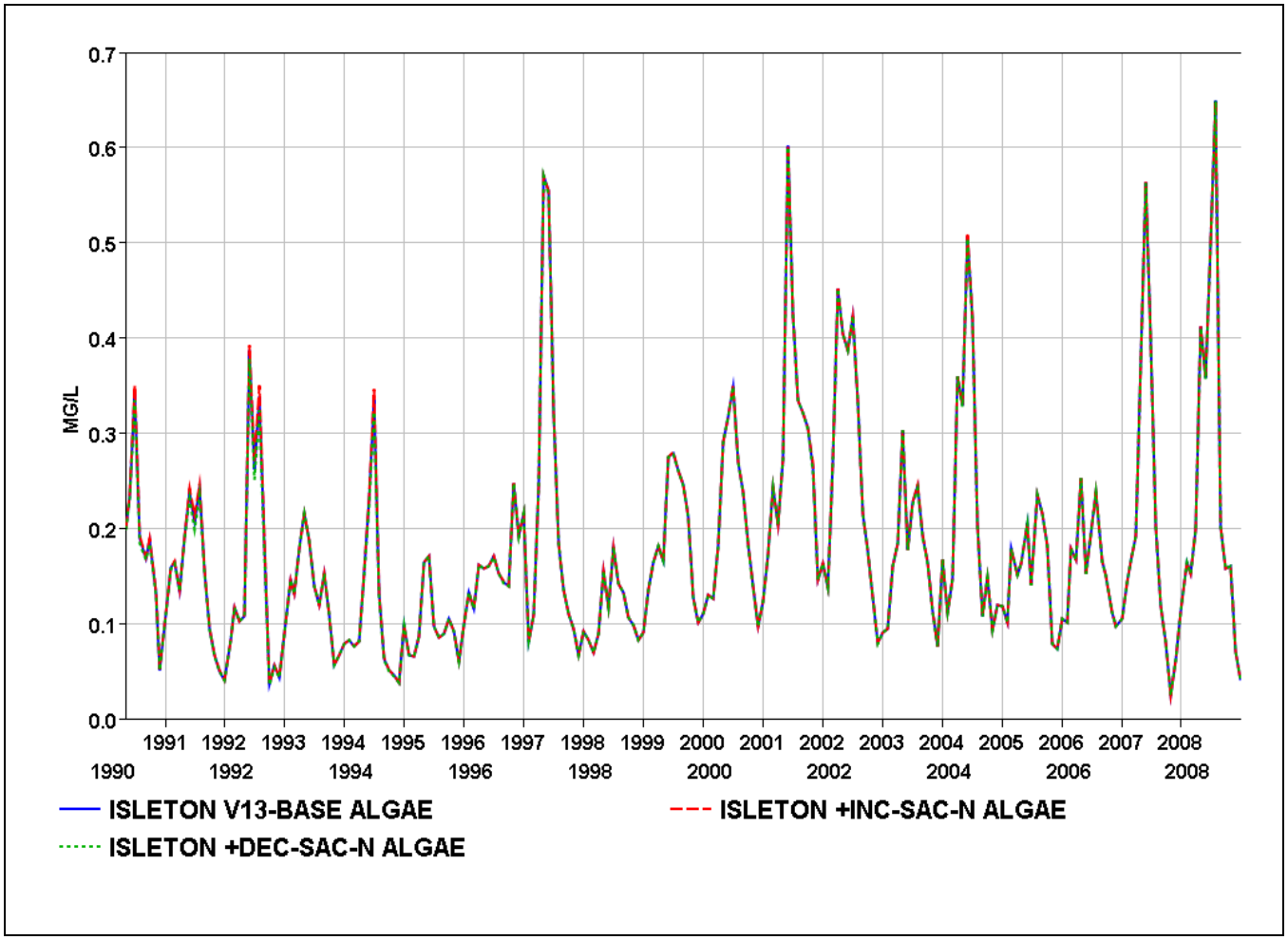


Figure 25-92 Changes in algal biomass were very small at Isleton for the scenarios changing Sacramento R. N-constituents.

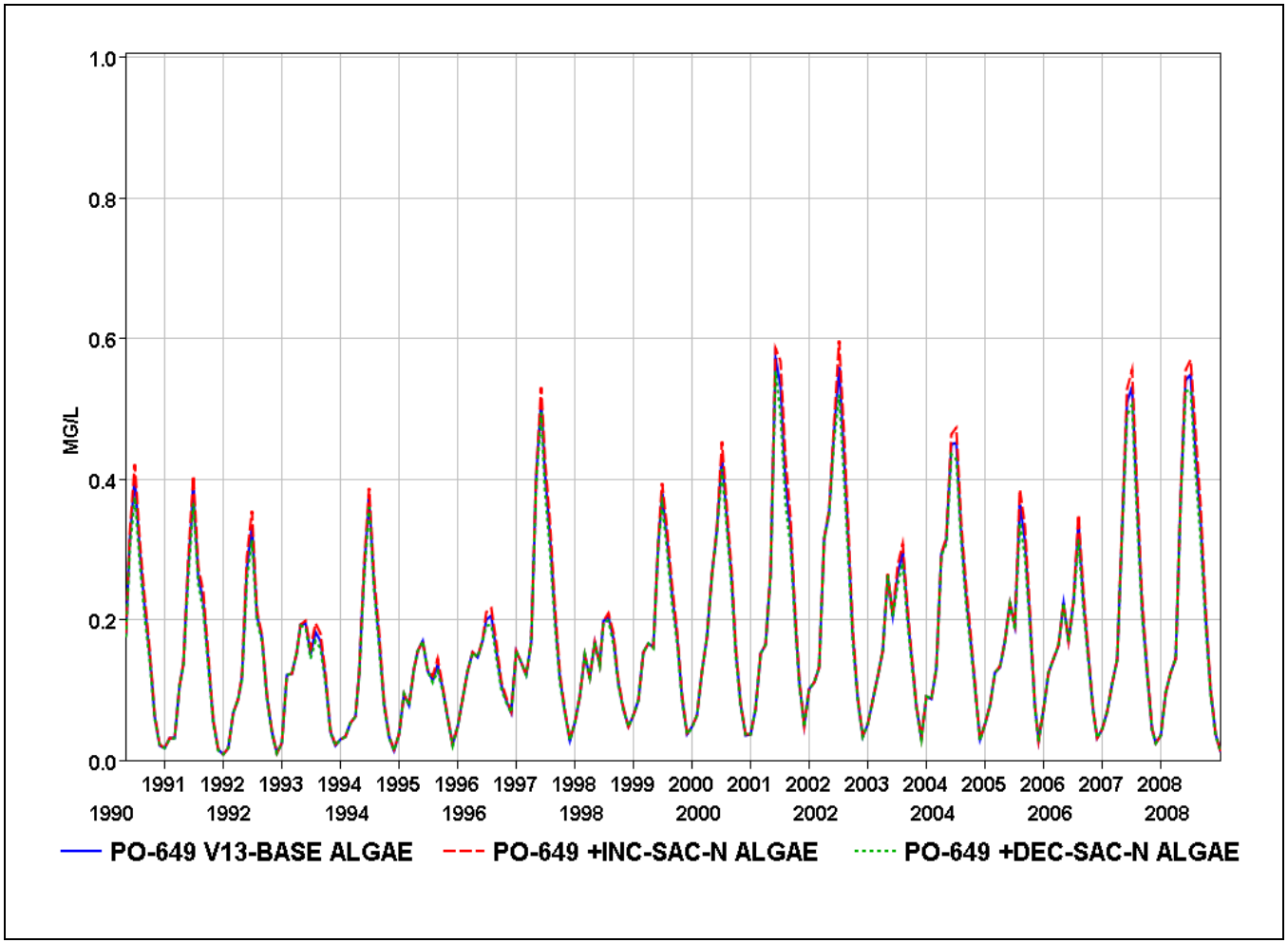


Figure 25-93 Changes in algal biomass were very small at Point Sacramento for the scenarios changing Sacramento R. N-constituents.

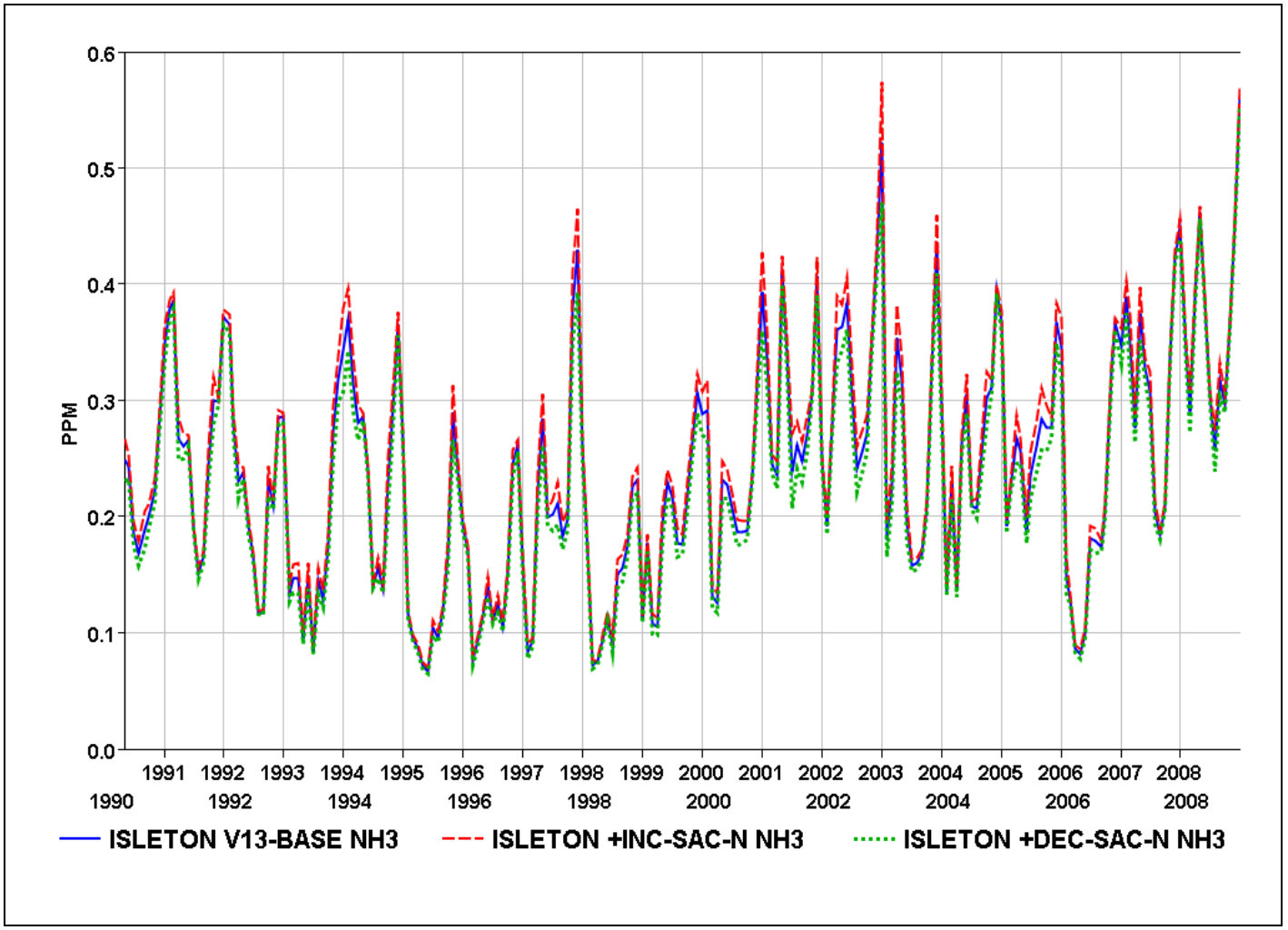


Figure 25-94 Changes in ammonia at Isleton for the scenarios changing Sacramento R. N-constituents.

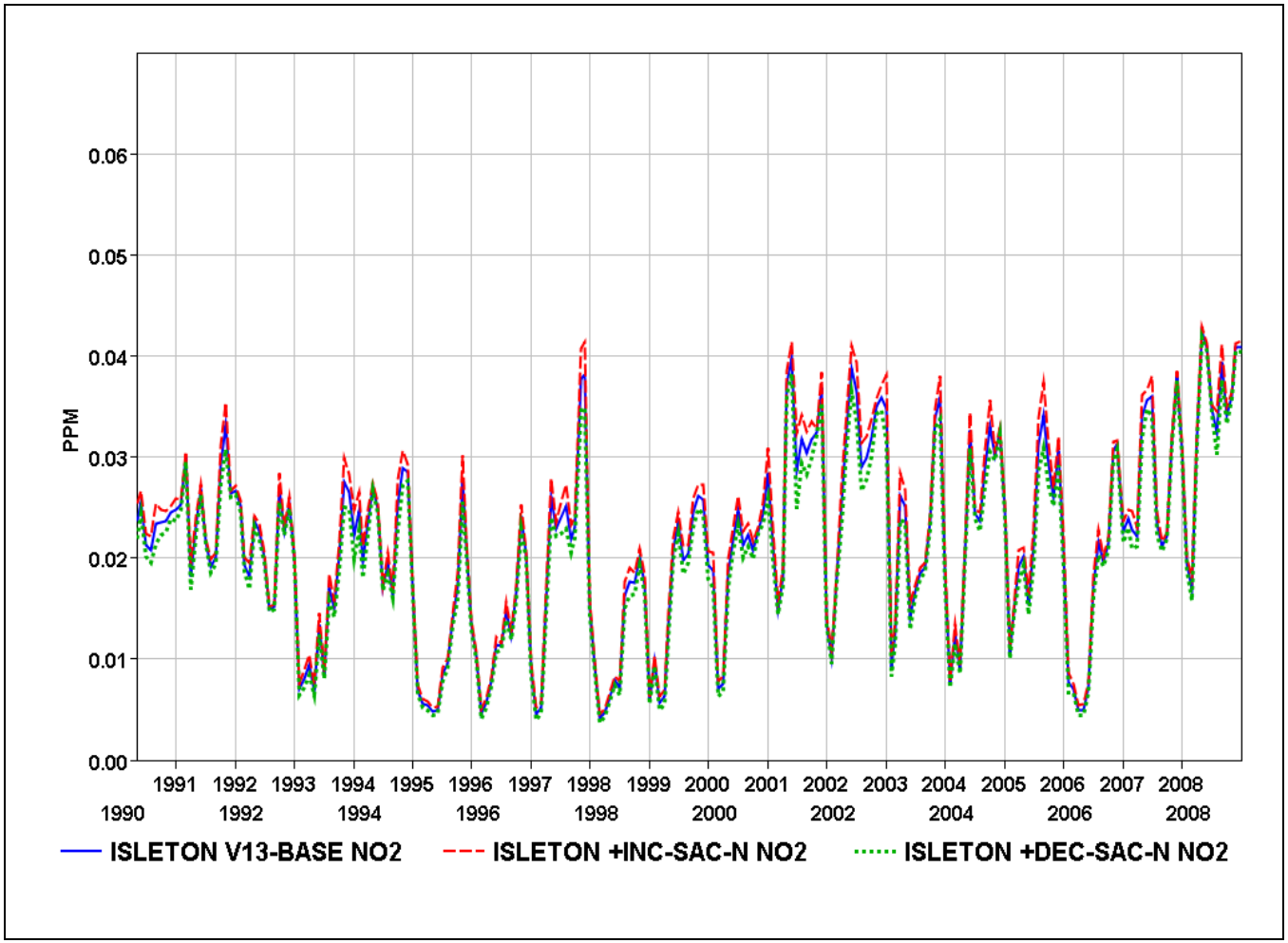


Figure 25-95 Changes in nitrite at Isleton for the scenarios changing Sacramento R. N-constituents.

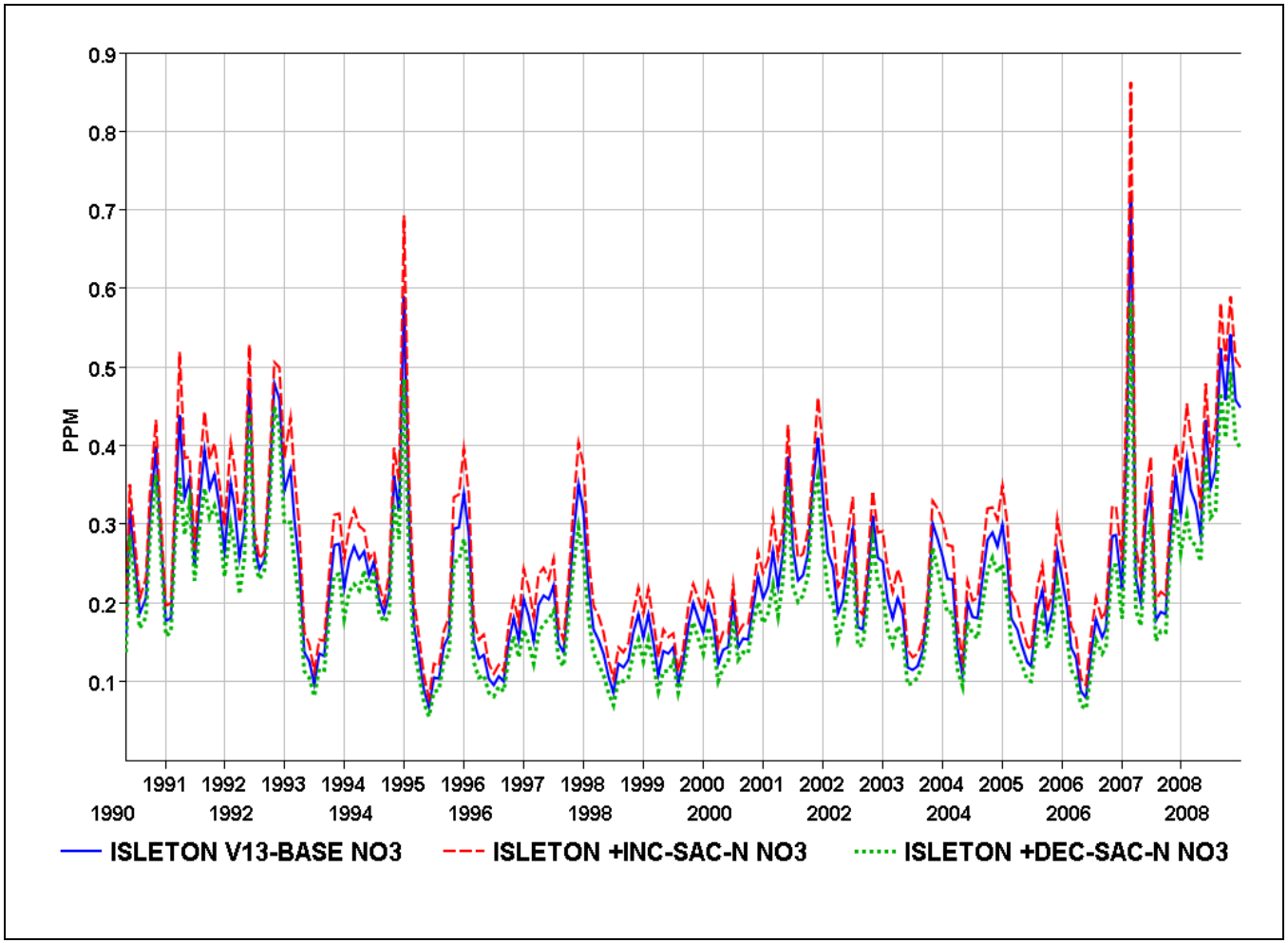


Figure 25-96 Changes in nitrate at Isleton for the scenarios changing Sacramento R. N-constituents.

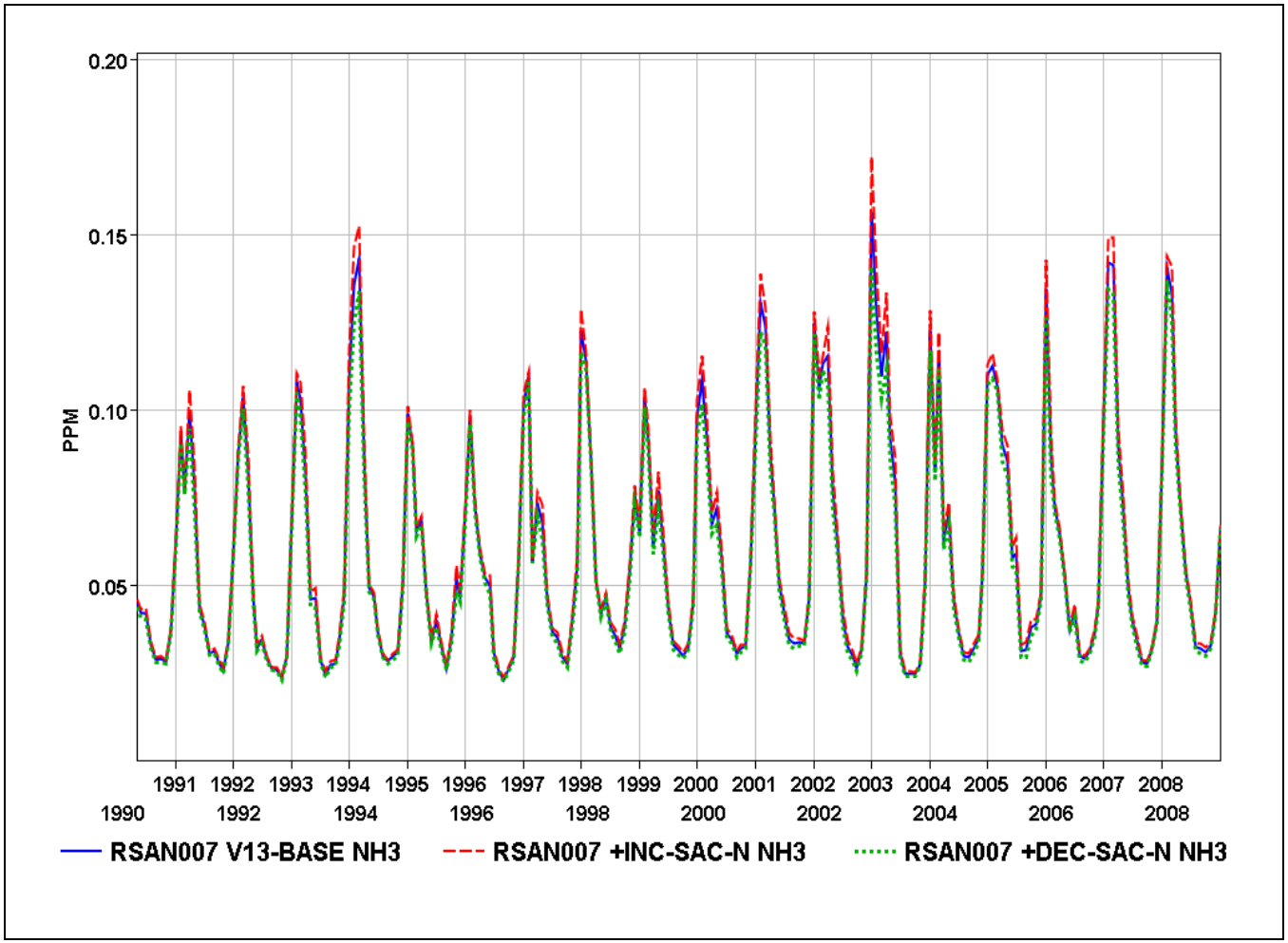


Figure 25-97 Changes in ammonia concentration at Antioch for the scenarios changing Sacramento R. N-constituents.

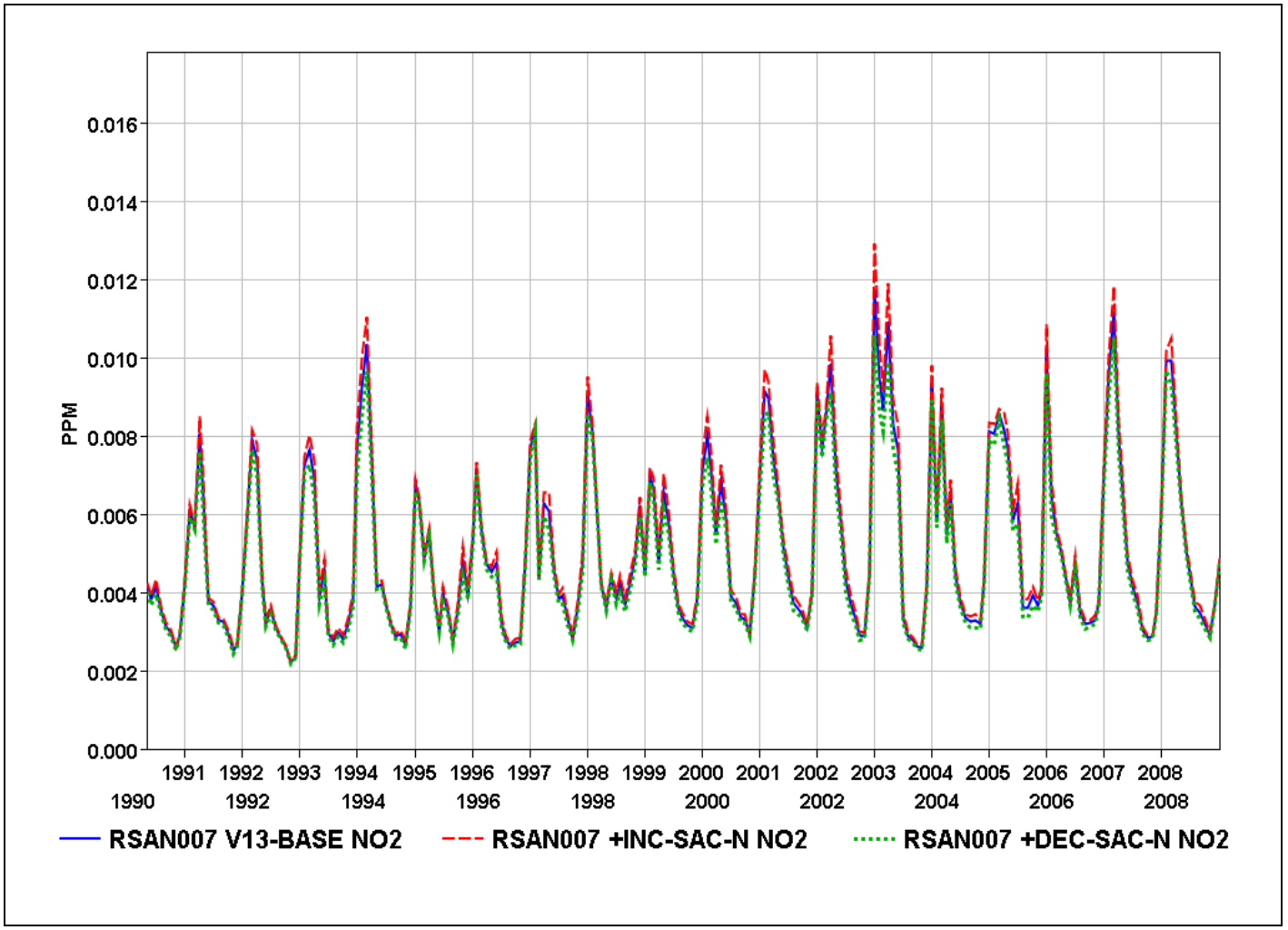


Figure 25-98 Changes in nitrite concentration at Antioch for the scenarios changing Sacramento R. N-constituents.

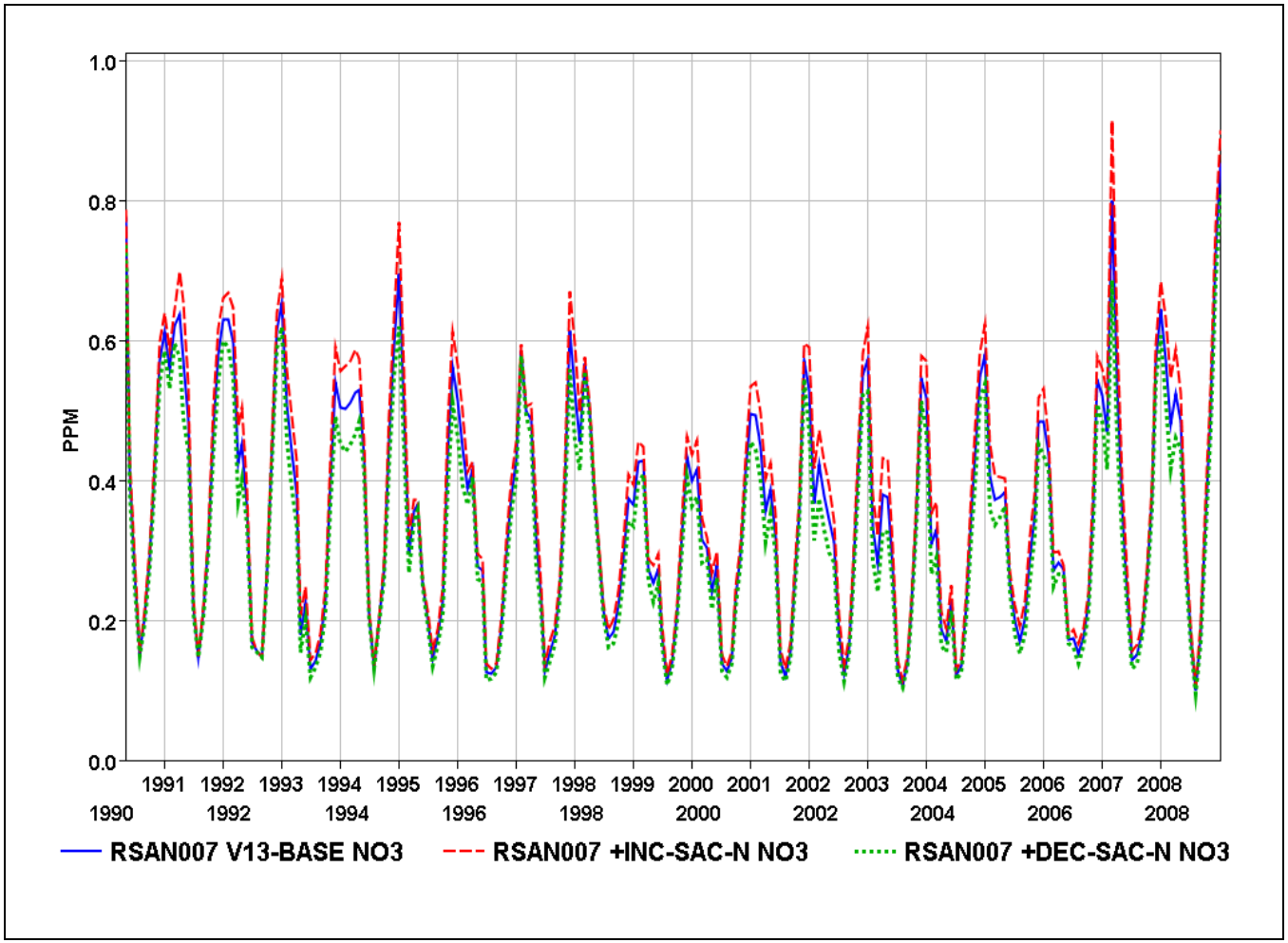


Figure 25-99 Changes in nitrate concentration at Antioch for the scenarios changing Sacramento R. N-constituents

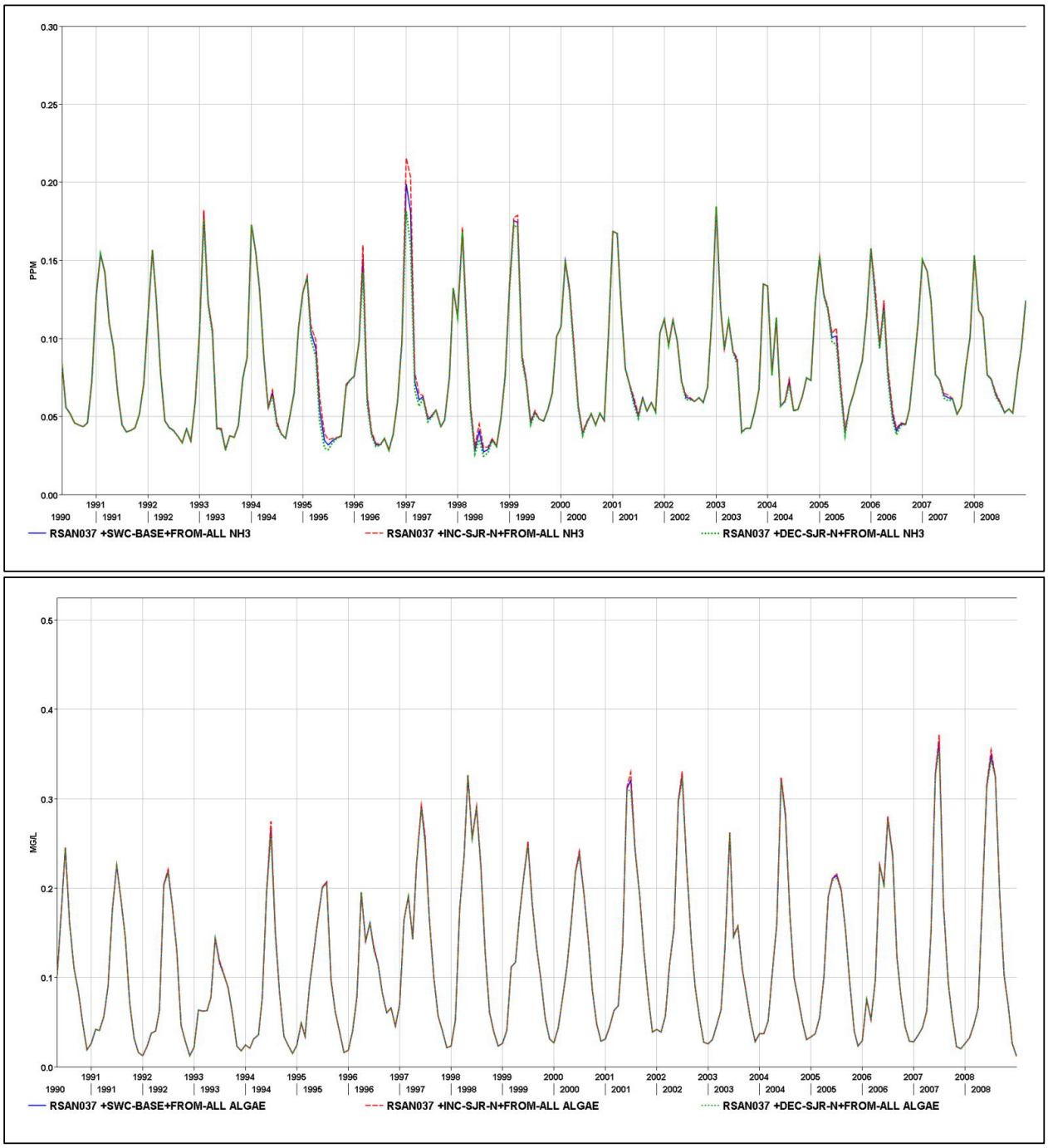


Figure 25-100 Ammonia and chl-a/algae concentrations at RSAN037 downstream the San Joaquin boundary.

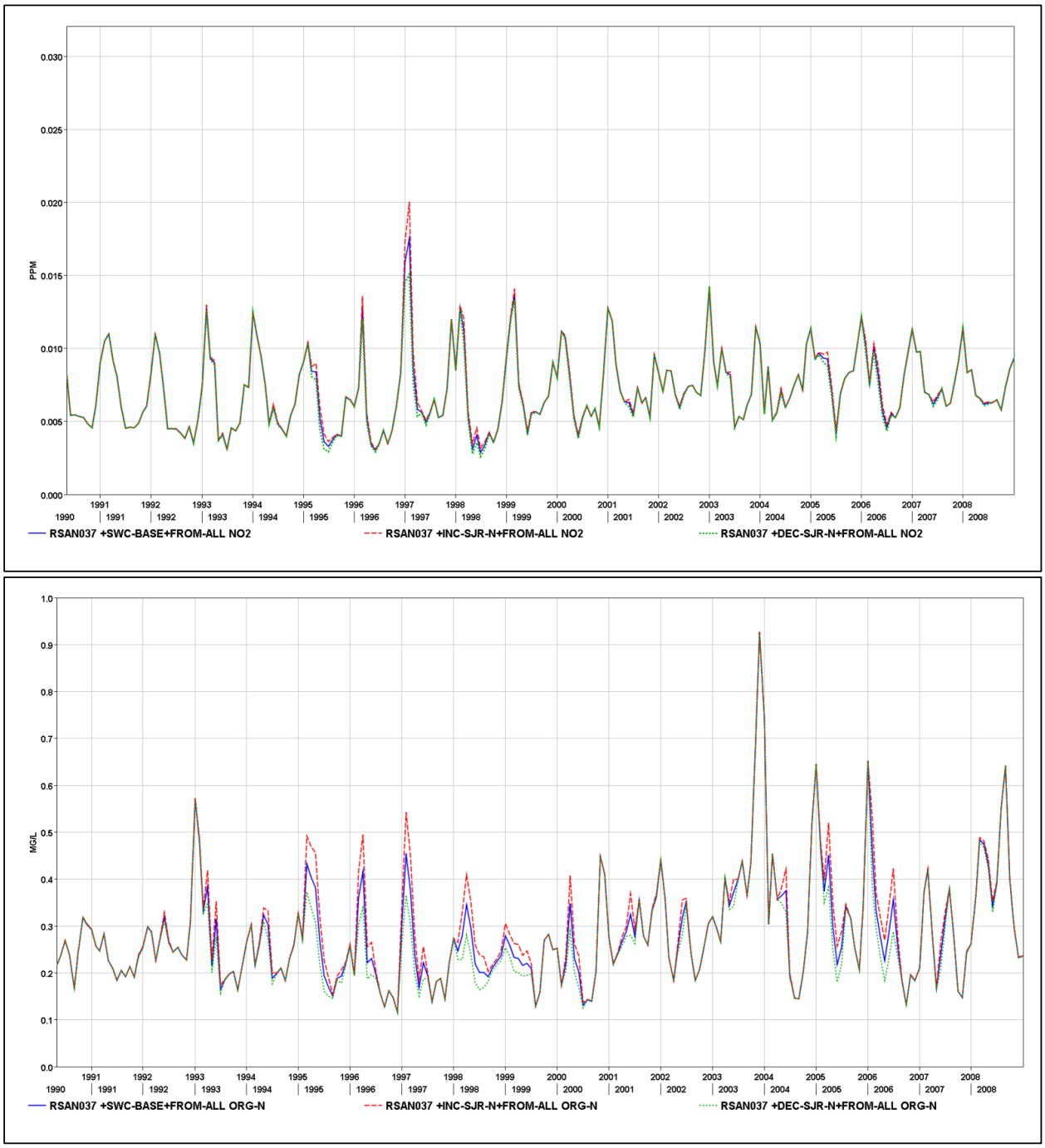


Figure 25-101 Nitrite and organic-N concentrations at RSAN037 downstream of the San Joaquin boundary.

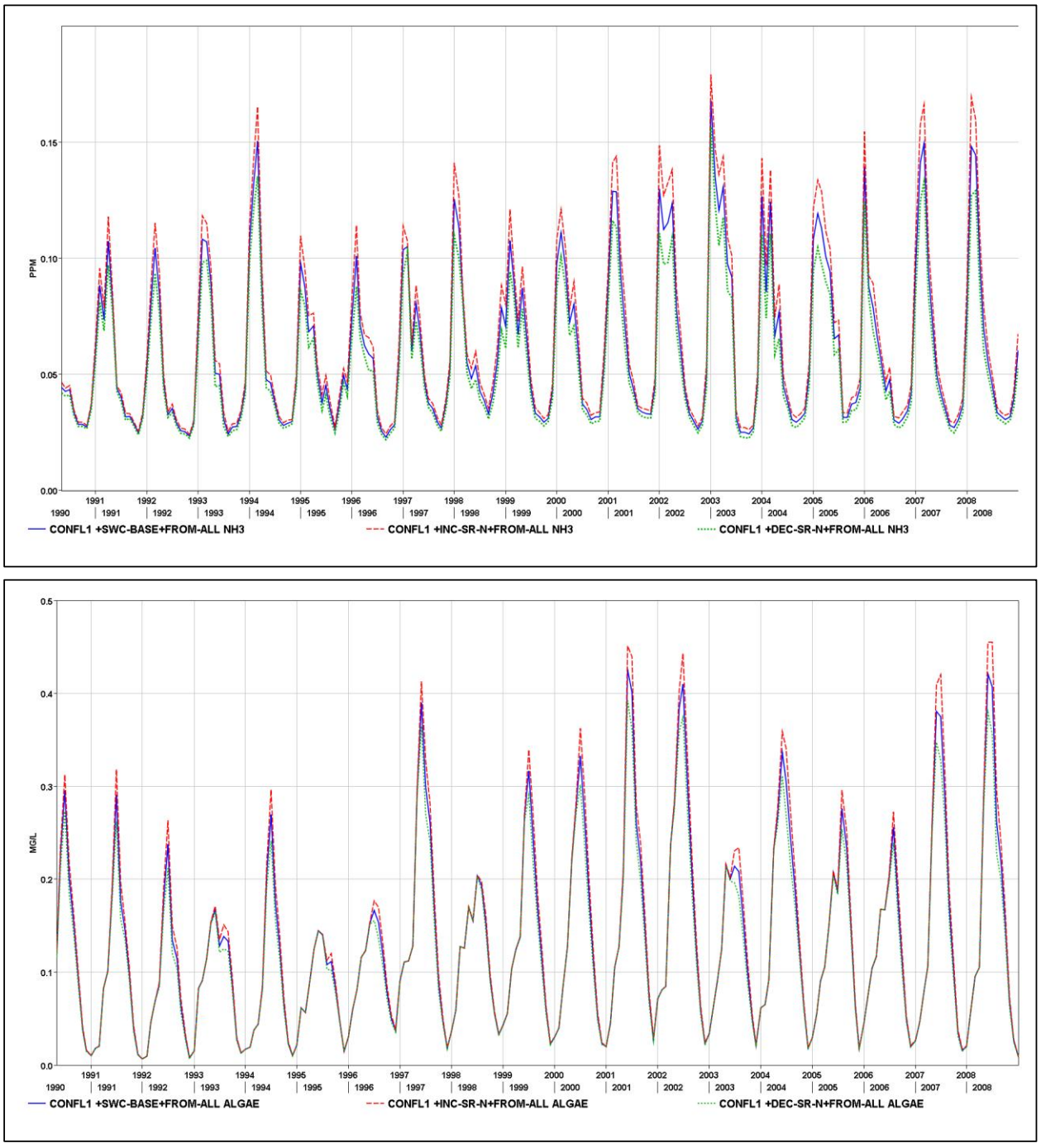


Figure 25-102 Changes in ammonia and chl-a/algae at the Confluence-1 location in the scenario changing Sac Regional N-constituents.

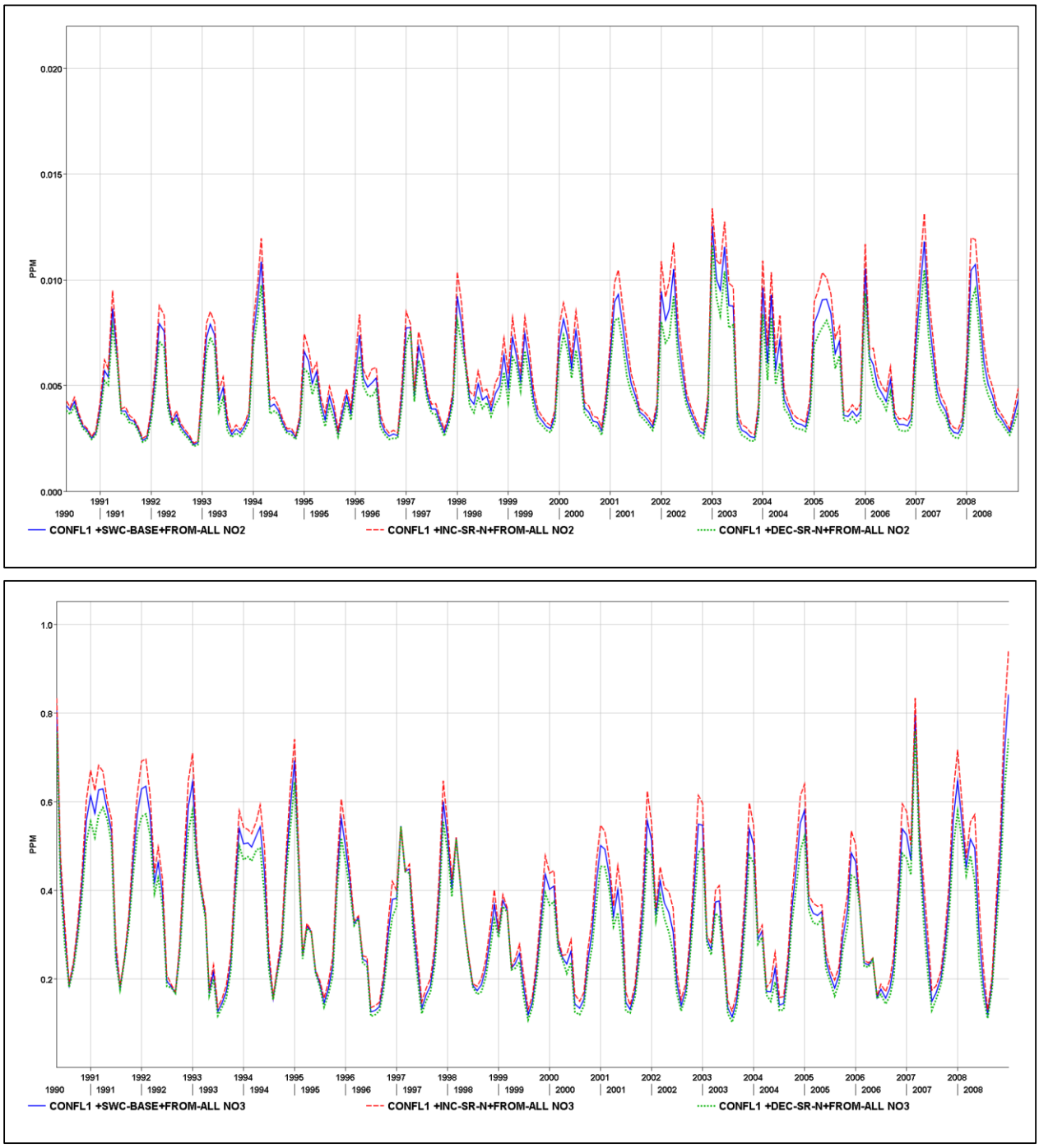


Figure 25-103 Changes in nitrite and nitrate at the Confluence-1 location in the scenario changing Sac Regional N-constituents.

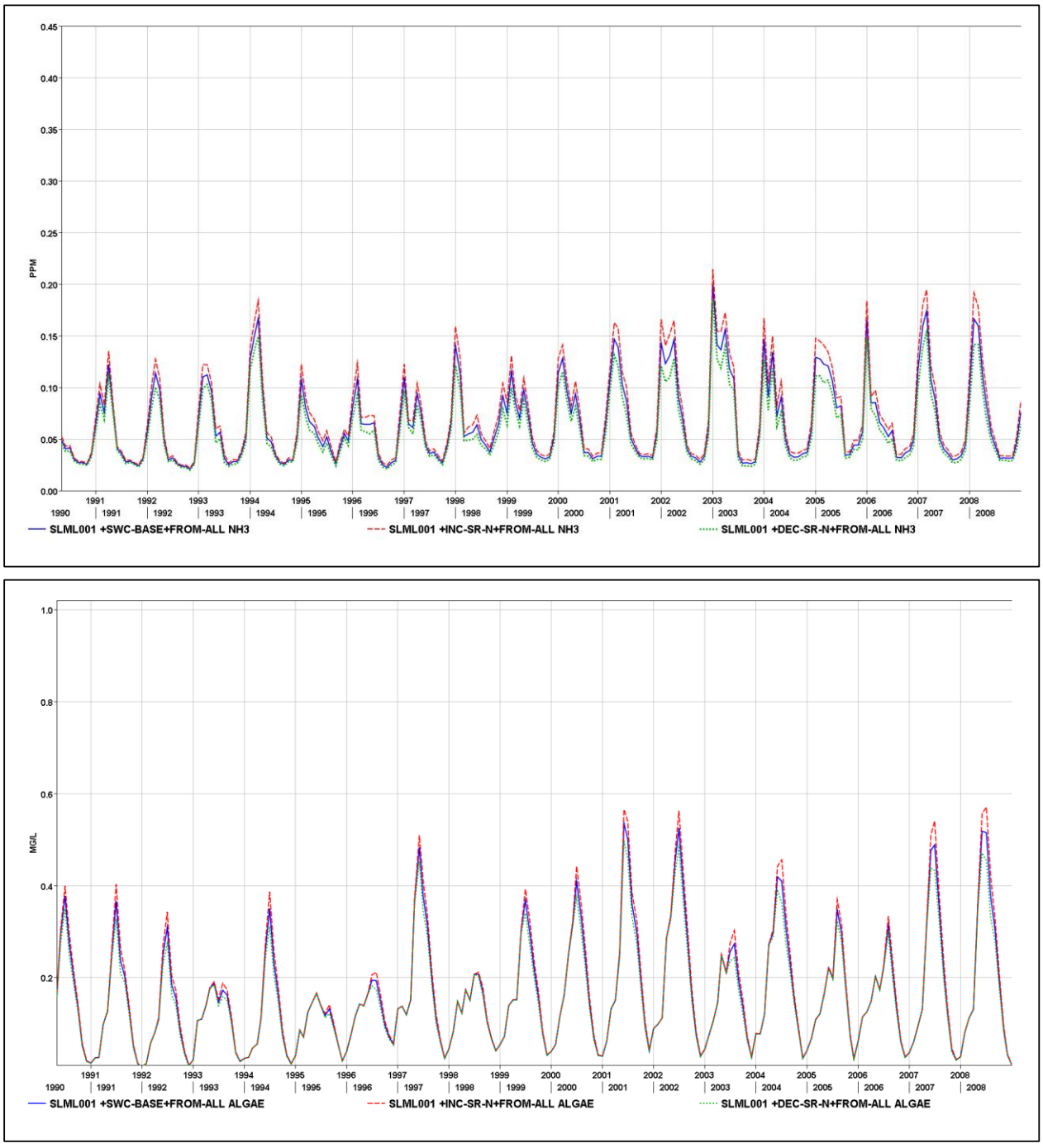


Figure 25-104 Changes in ammonia and chl-a/algae at Suisun at Nichols in the scenario changing Sac Regional N-constituents.

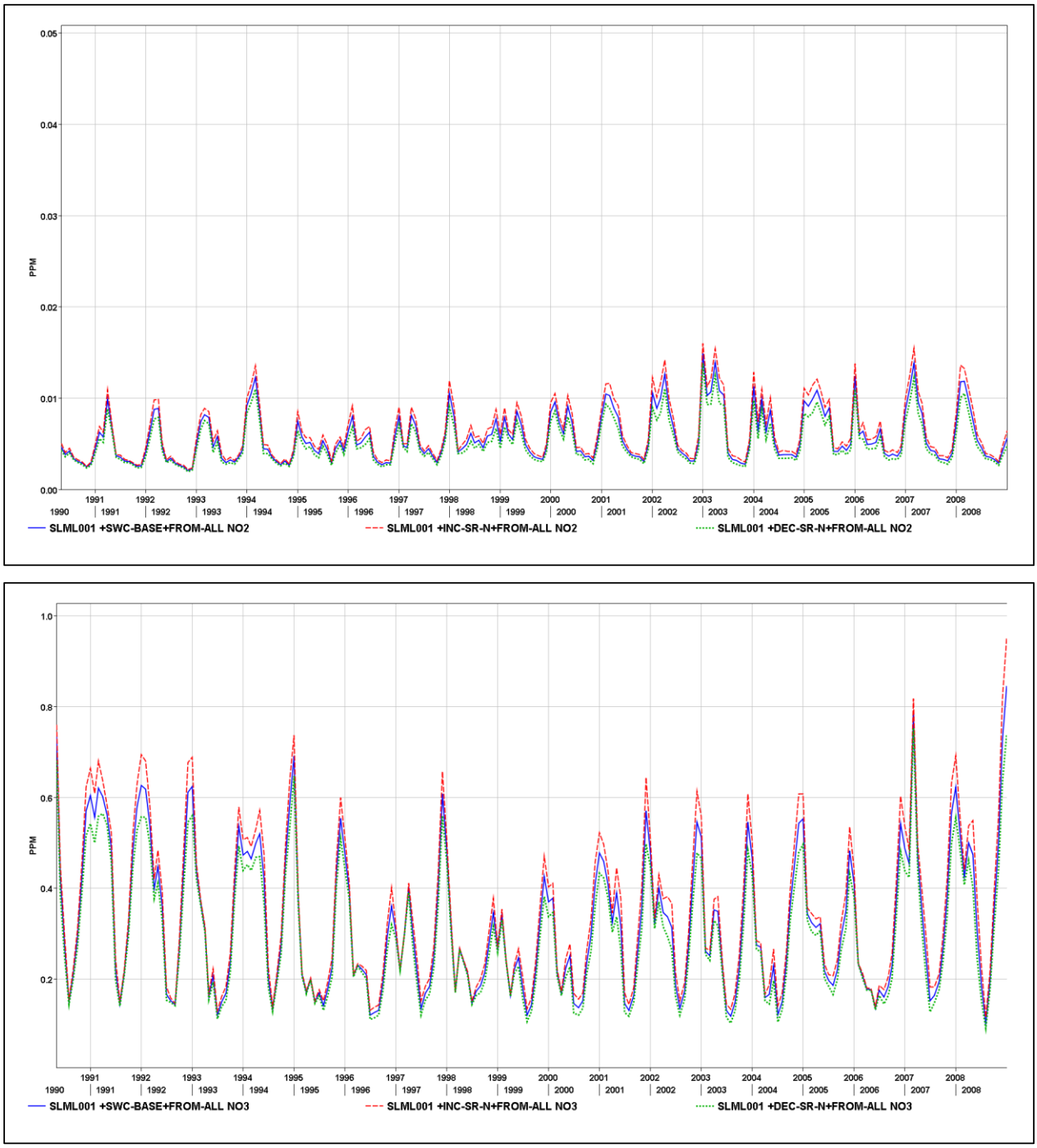
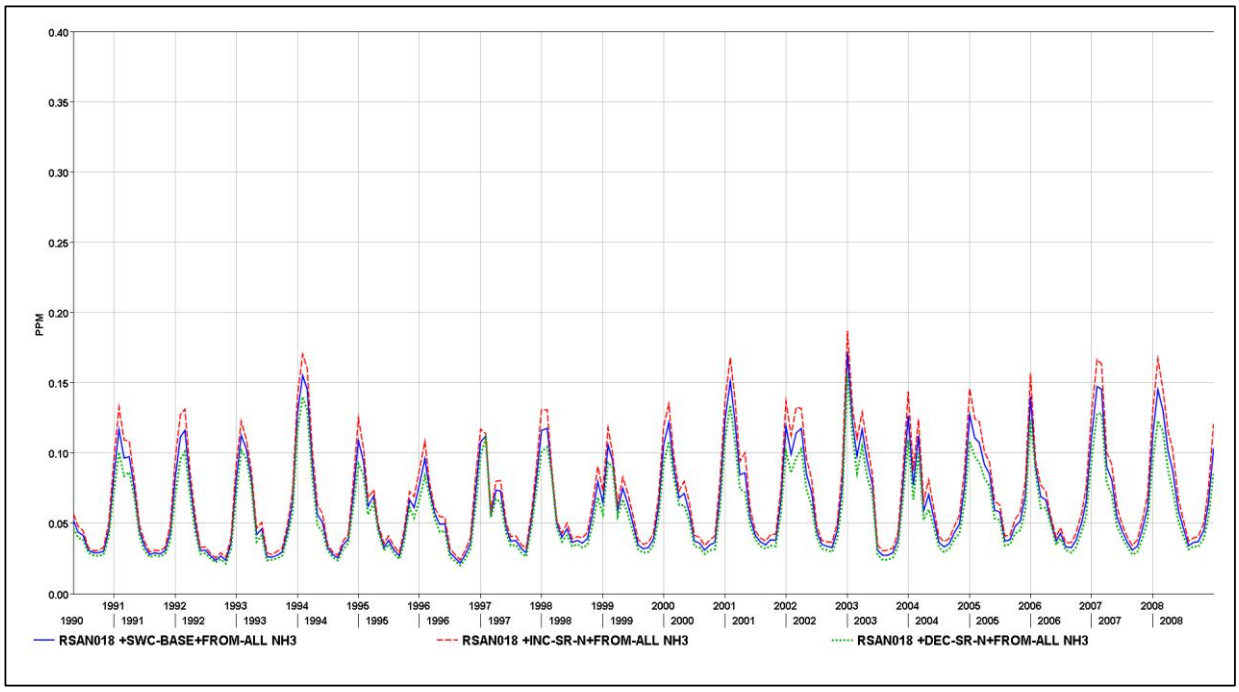


Figure 25-105 Changes in nitrite and nitrate at Suisun Nichols in the scenario changing Sac Regional N-constituents.



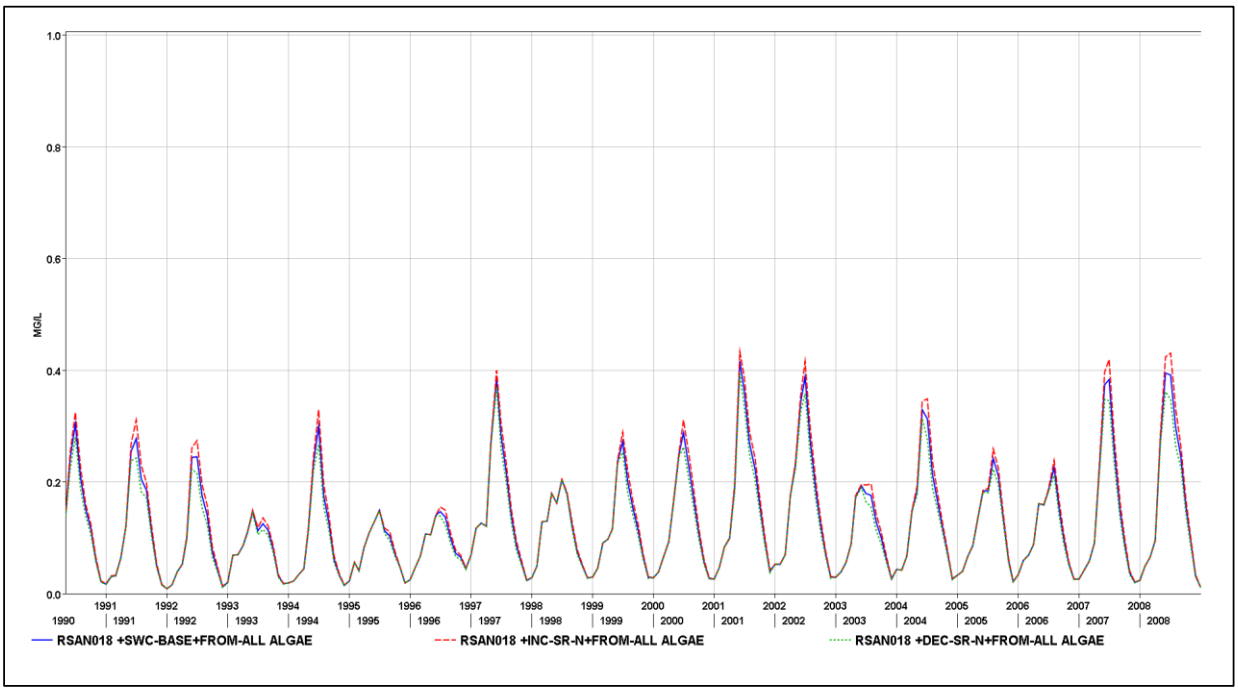


Figure 25-106 Changes in ammonia and chl-a/alga at Jersey point (RSAN018) in the scenario changing Sac Regional N-constituents.

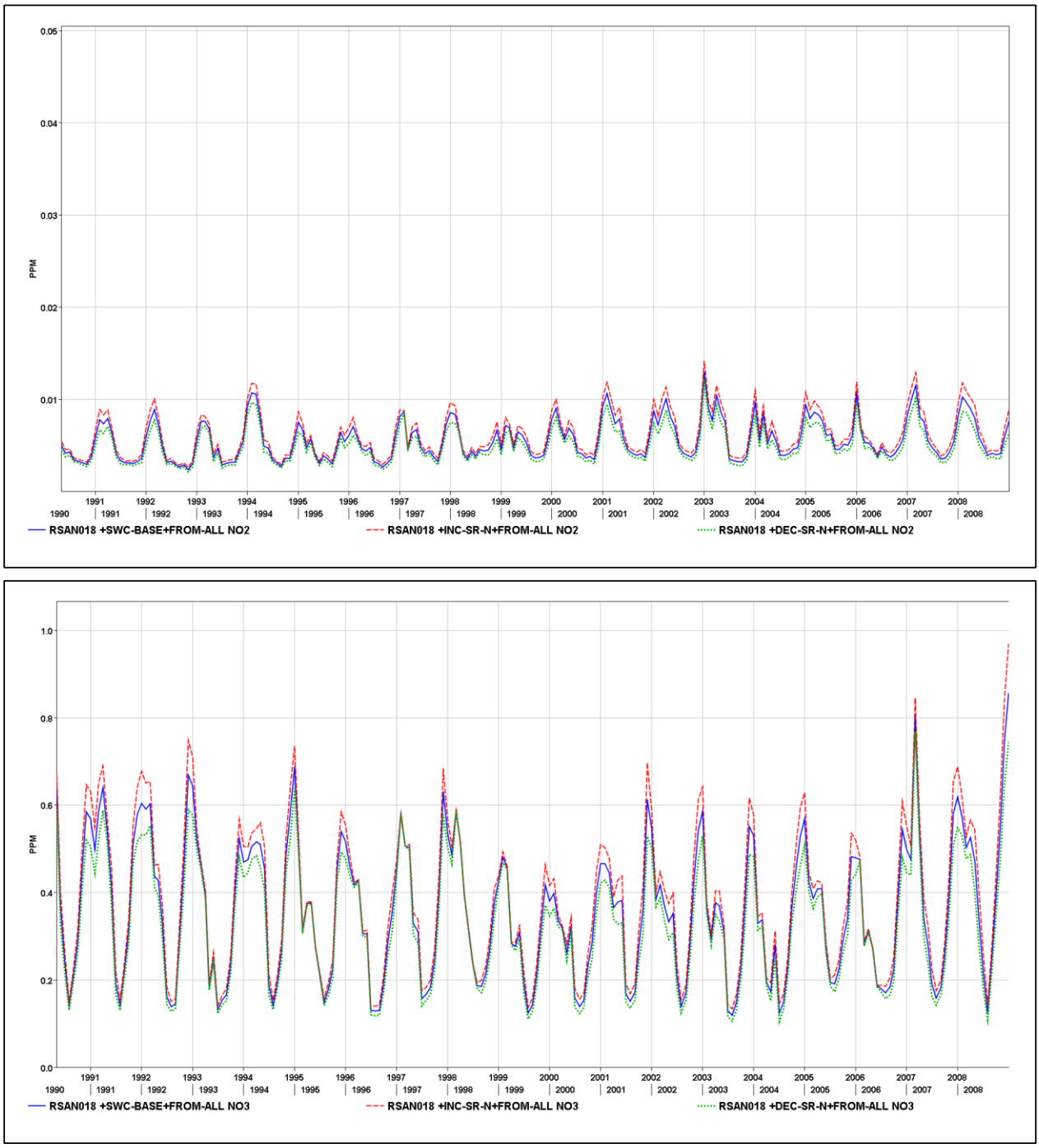


Figure 25-107 Changes in nitrite and nitrate at Jersey point (RSAN018) in the scenario changing Sac Regional N-constituents.

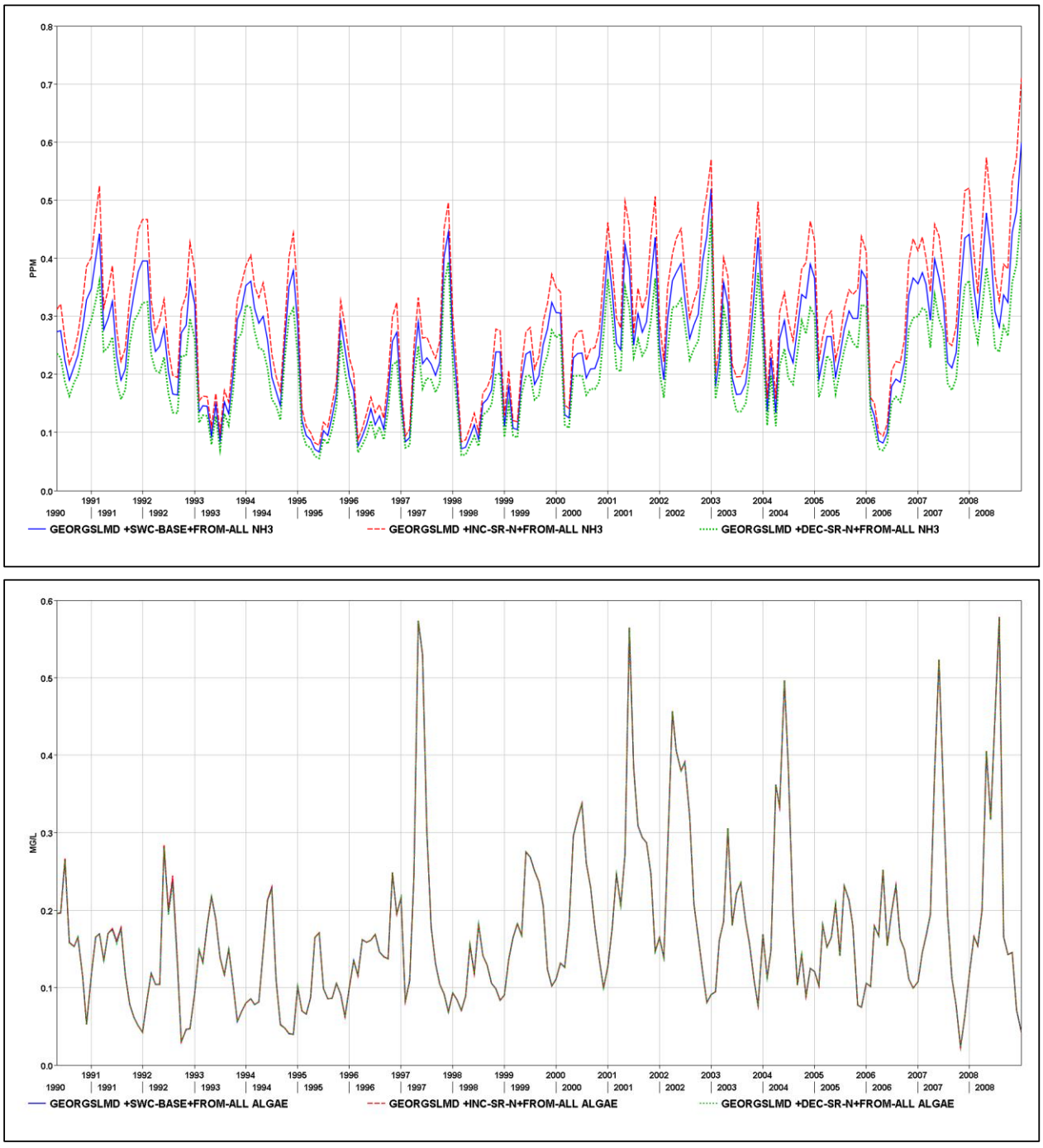


Figure 25-108 Changes in ammonia and chl-a/algae in Georgiana Slough in the scenario changing Sac Regional N-constituents.

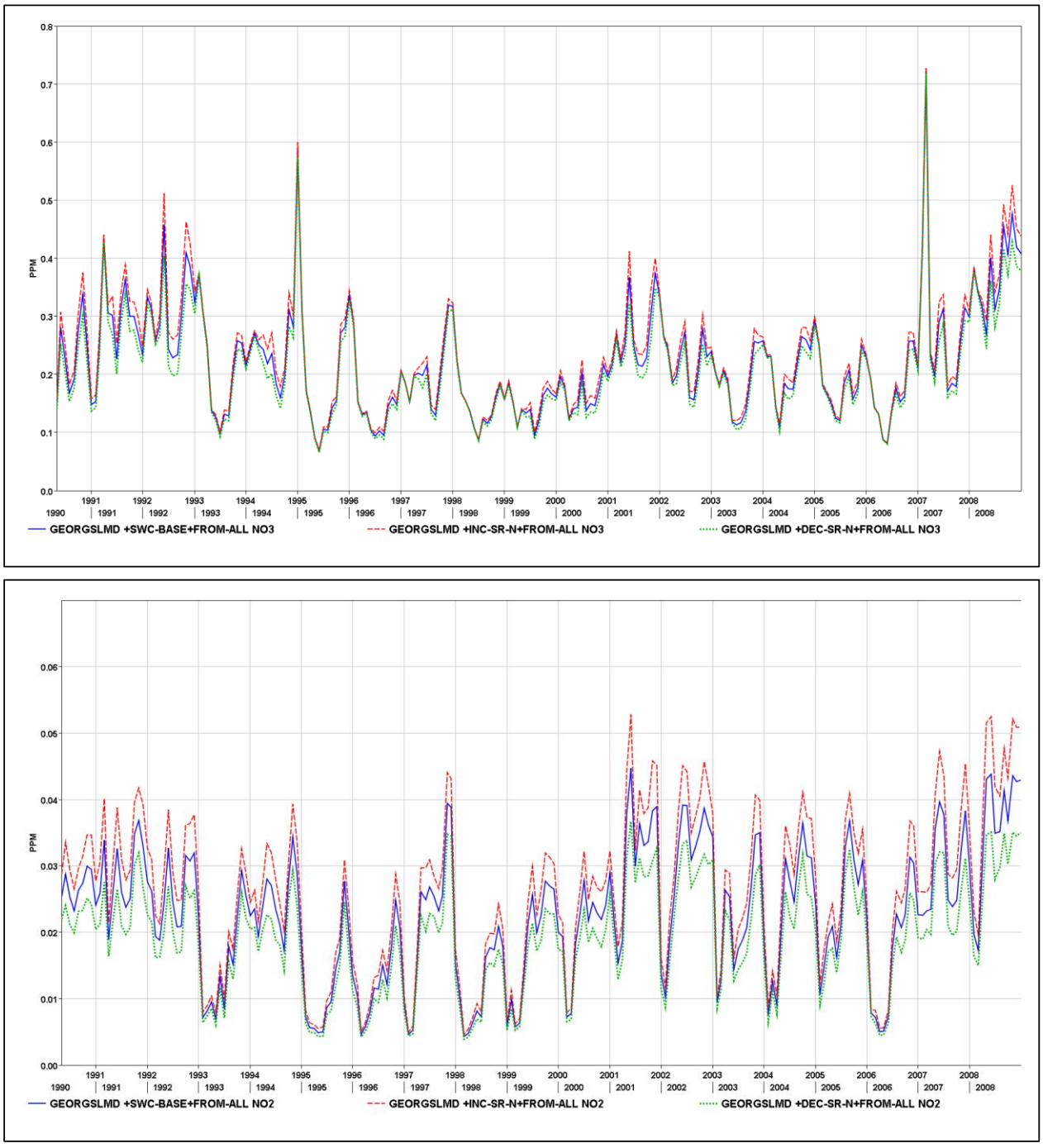


Figure 25-109 Changes in nitrite and nitrate in Georgiana Slough in the scenario changing Sac Regional N-constituents.

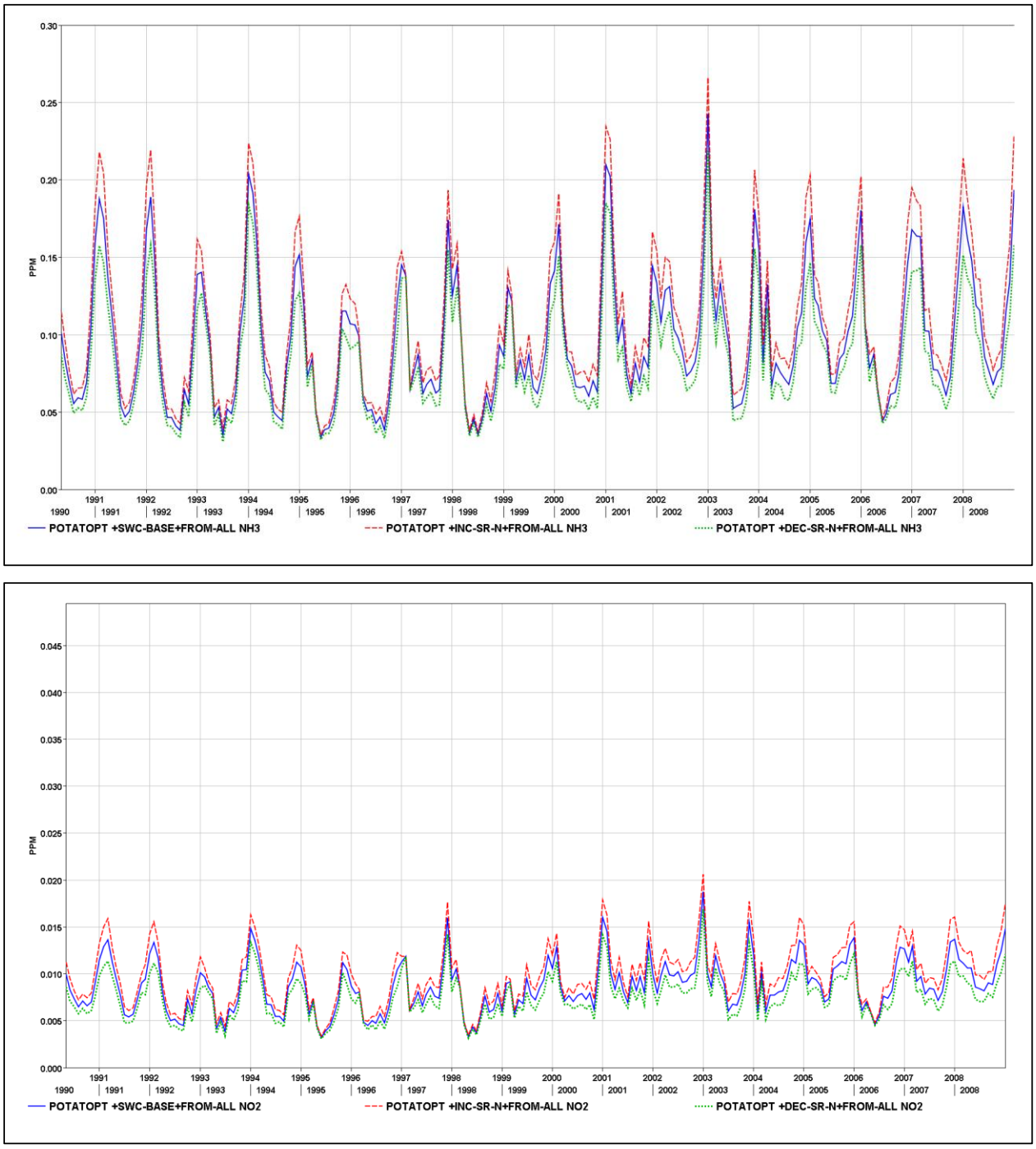


Figure 25-110 Changes in ammonia and nitrite at Potato Point in the scenario changing Sac Regional N-constituents.

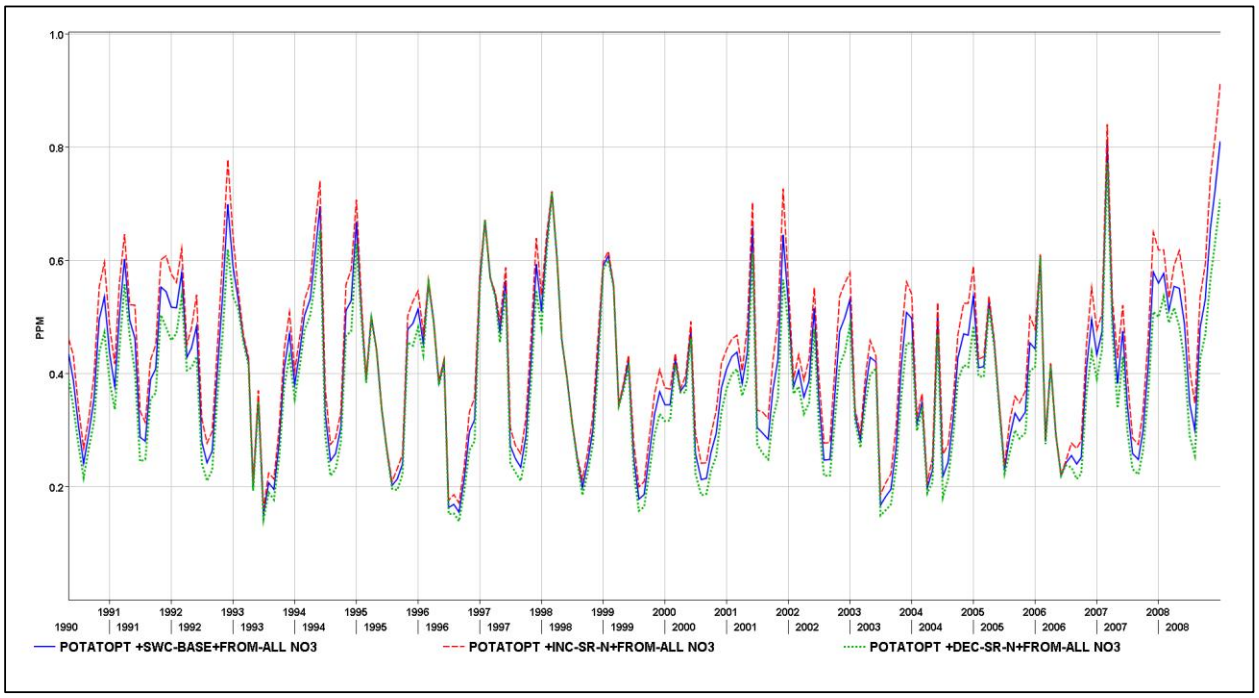


Figure 25-111 Changes in nitrate at Potato Point in the scenario changing Sac Regional N-constituents.

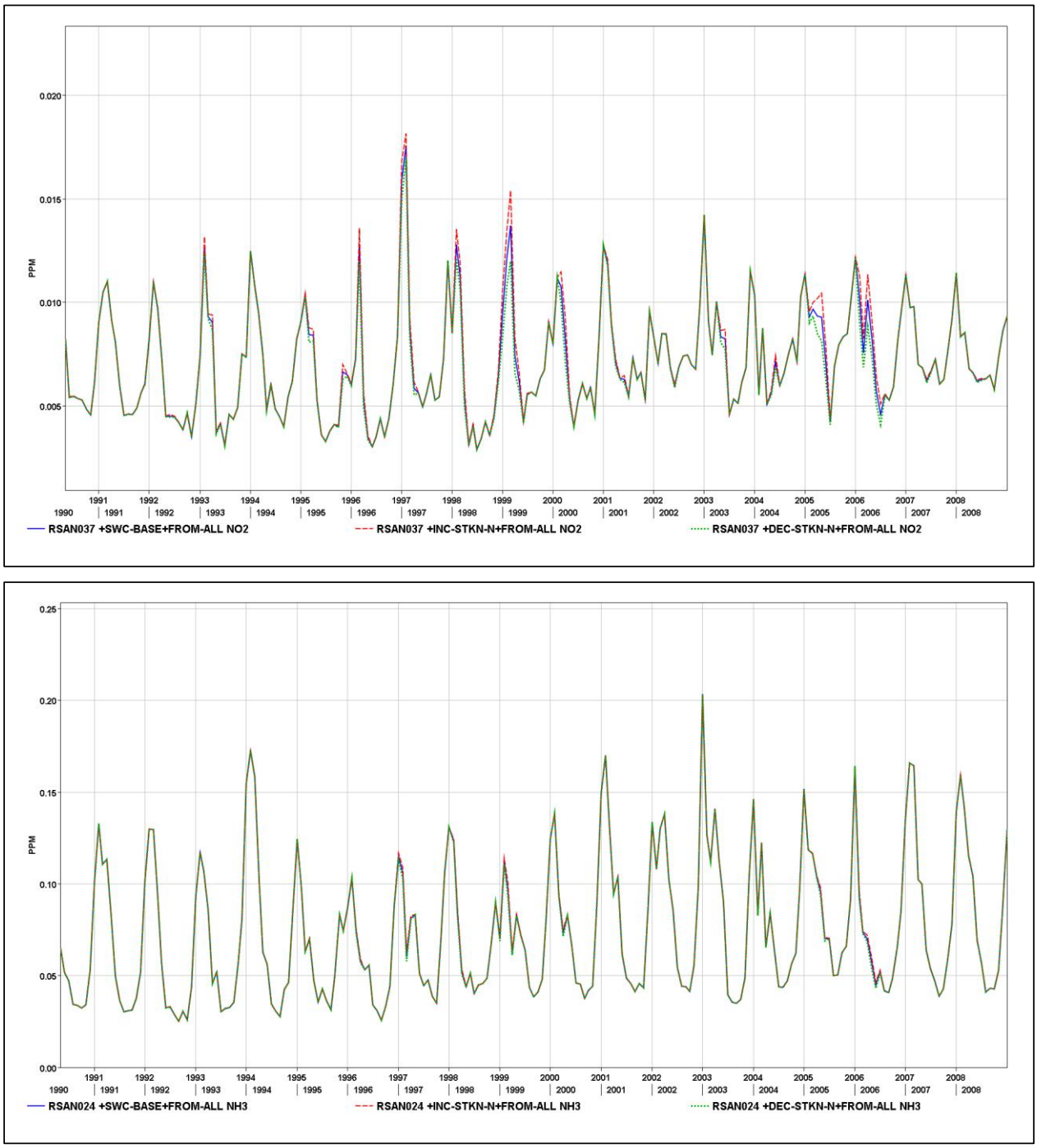


Figure 25-112 Nitrite concentration at RSAN037and ammonia at RSAN024 downstream of the Stockton WWTP.

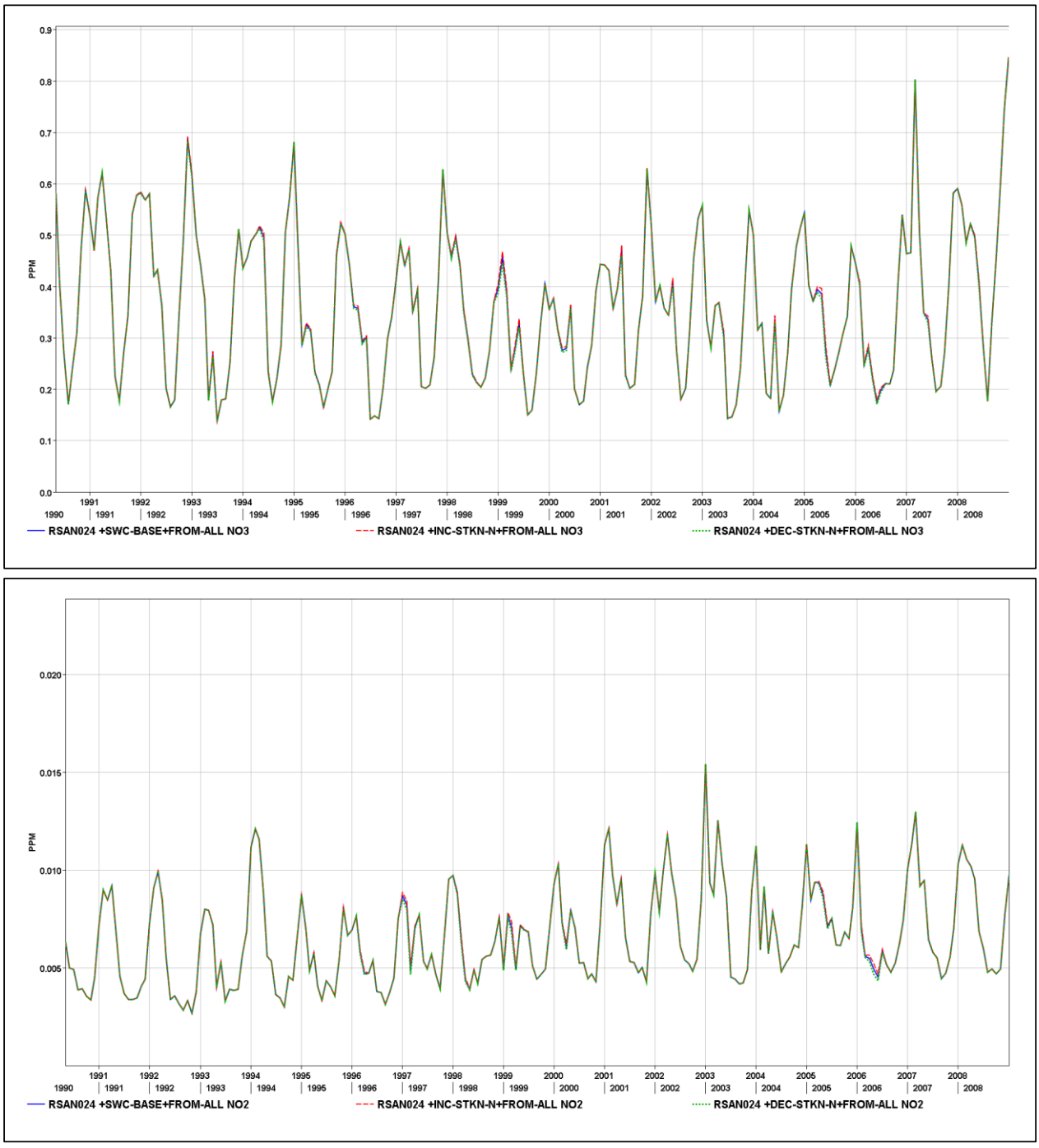


Figure 25-113 Nitrate and nitrite concentrations at RSAN024 downstream of the Stockton WWTP.

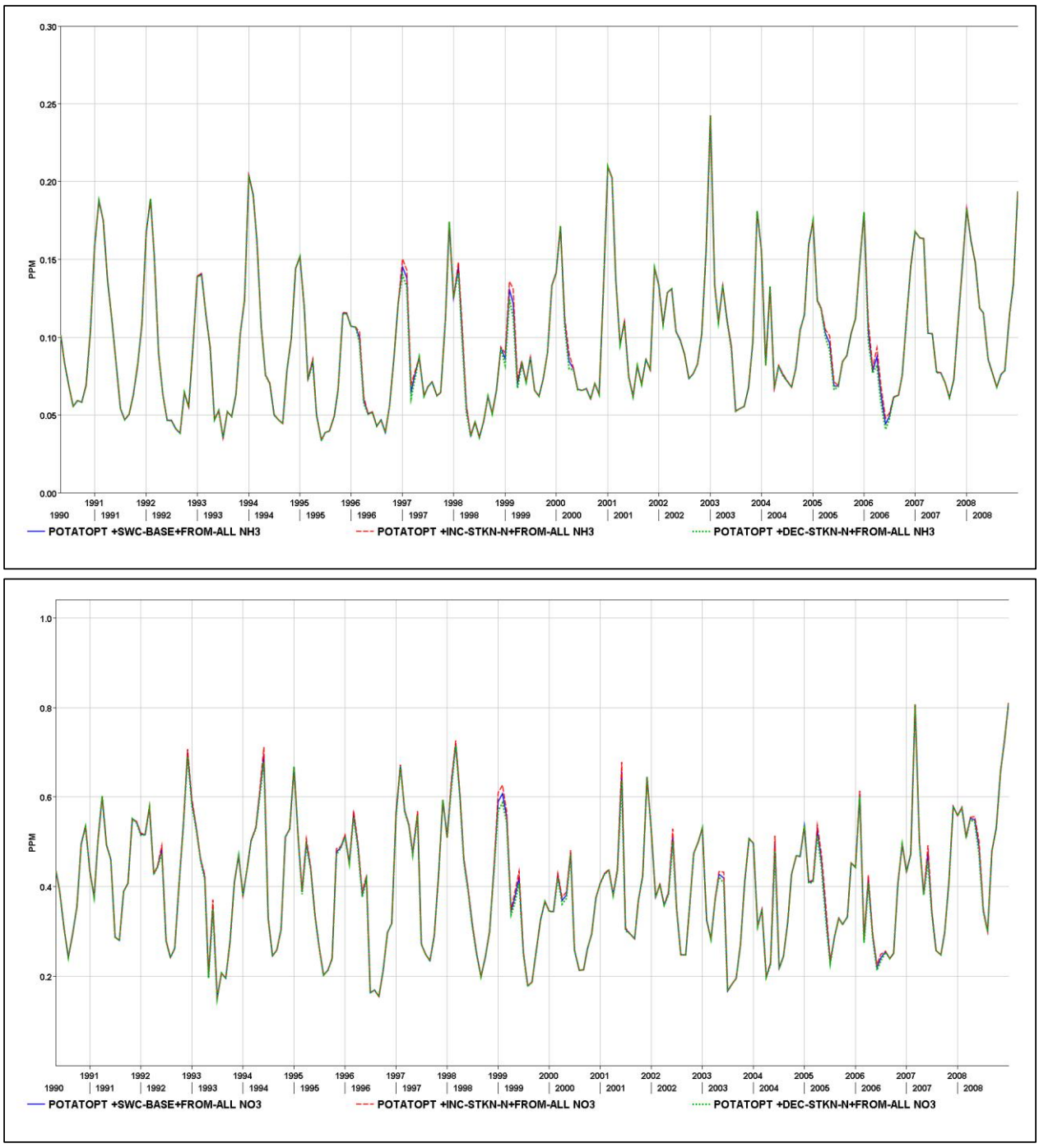


Figure 25-114 Ammonia and nitrate concentrations at Potato Point downstream of the Stockton WWTP.

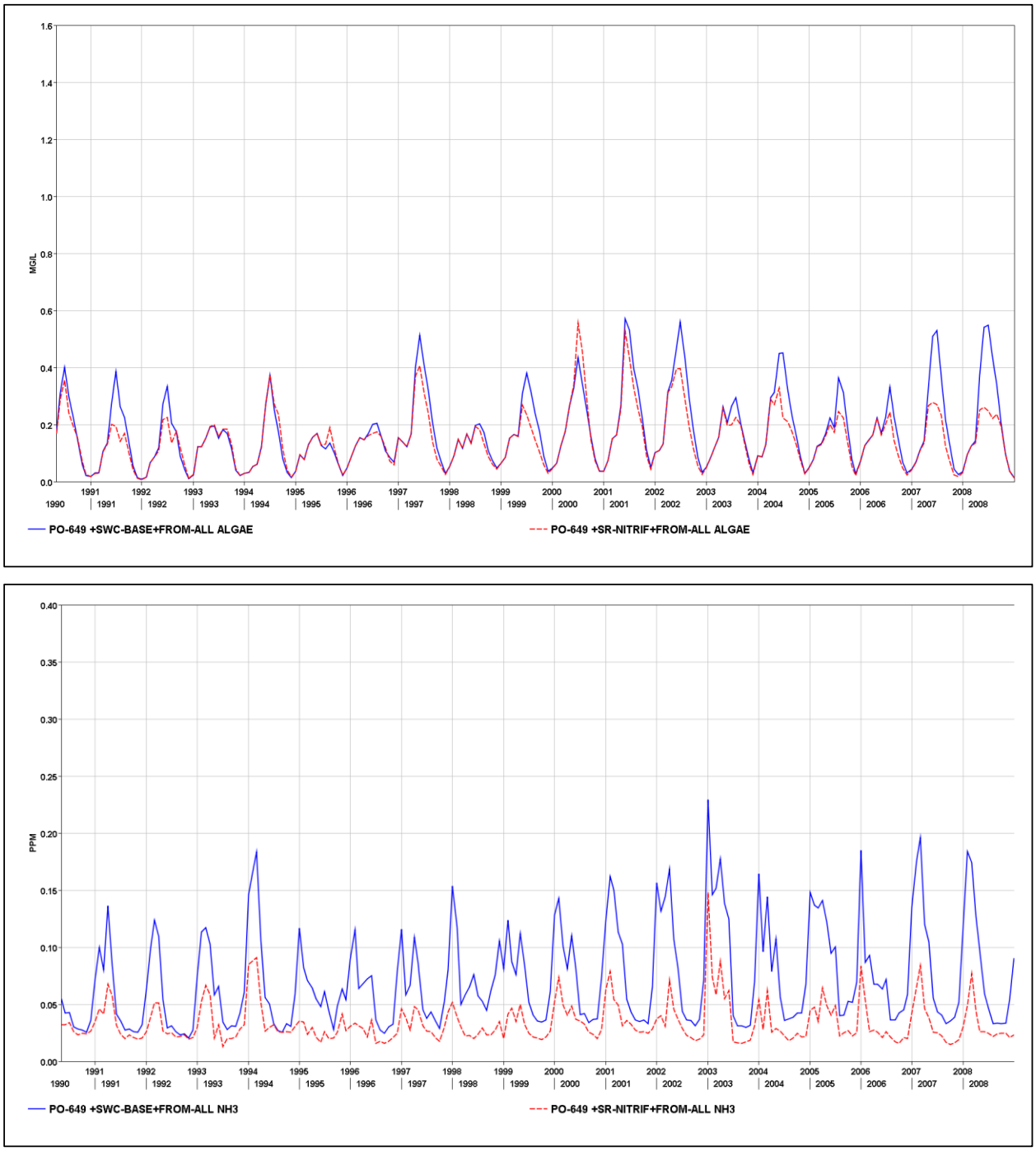


Figure 25-115 Chl-a/algae and ammonia concentrations at Point Sacramento for the Sac Regional Nitrification scenario.

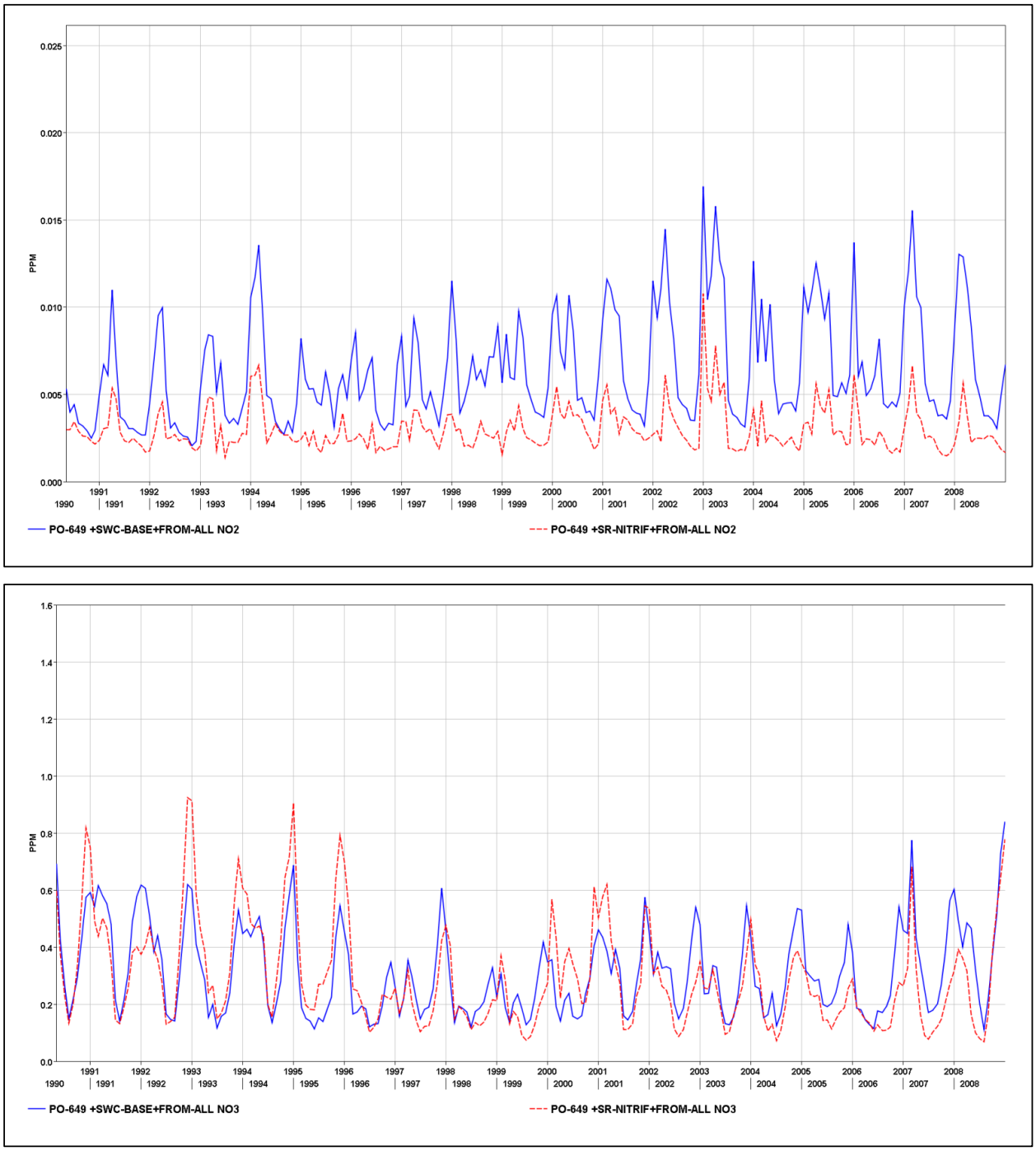


Figure 25-116 Nitrite and nitrate concentrations at Point Sacramento for the Sac Regional Nitrification scenario.

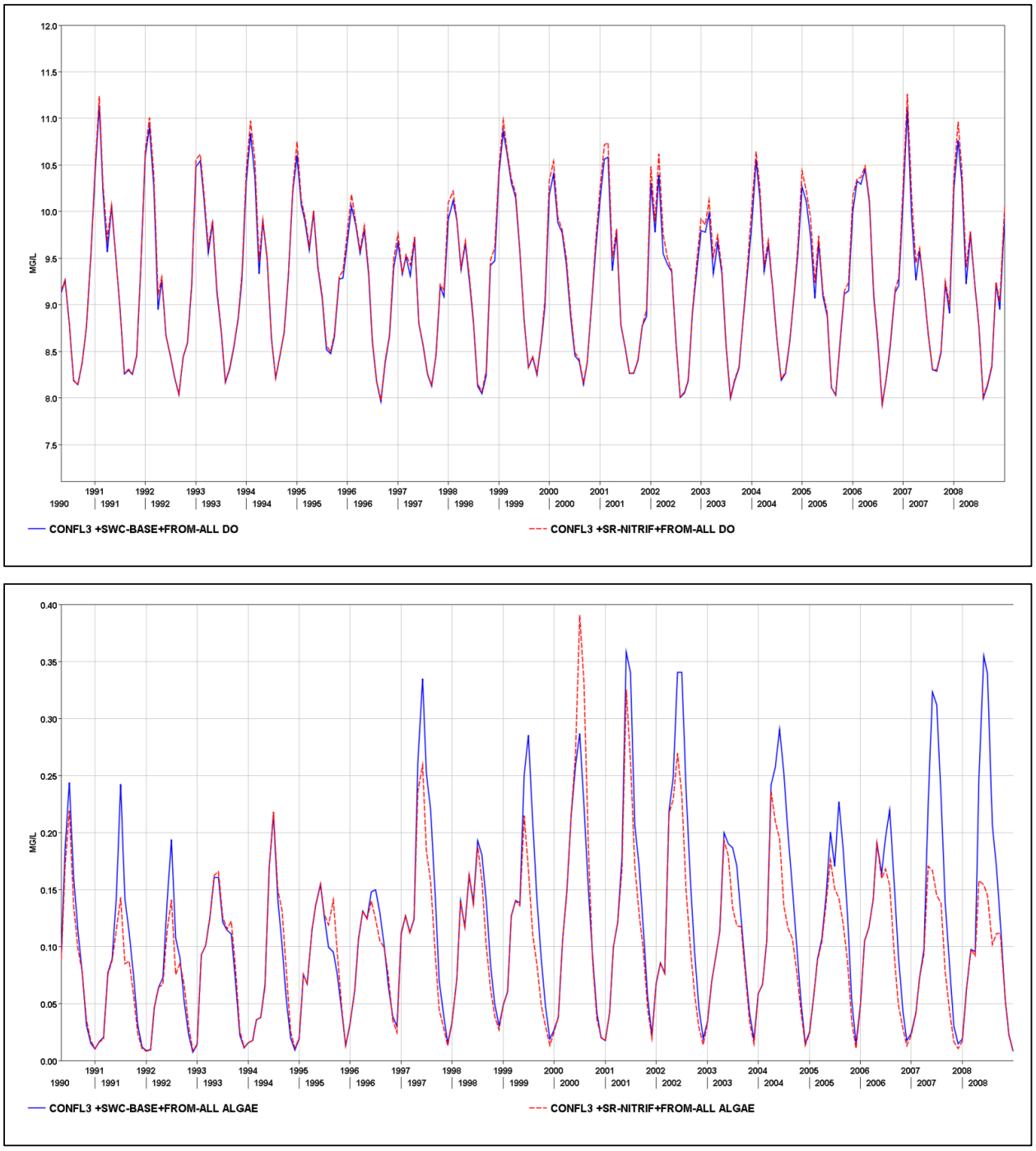


Figure 25-117 DO and Chl-a/algae concentrations at Confluence-3 for the Sac Regional Nitrification scenario

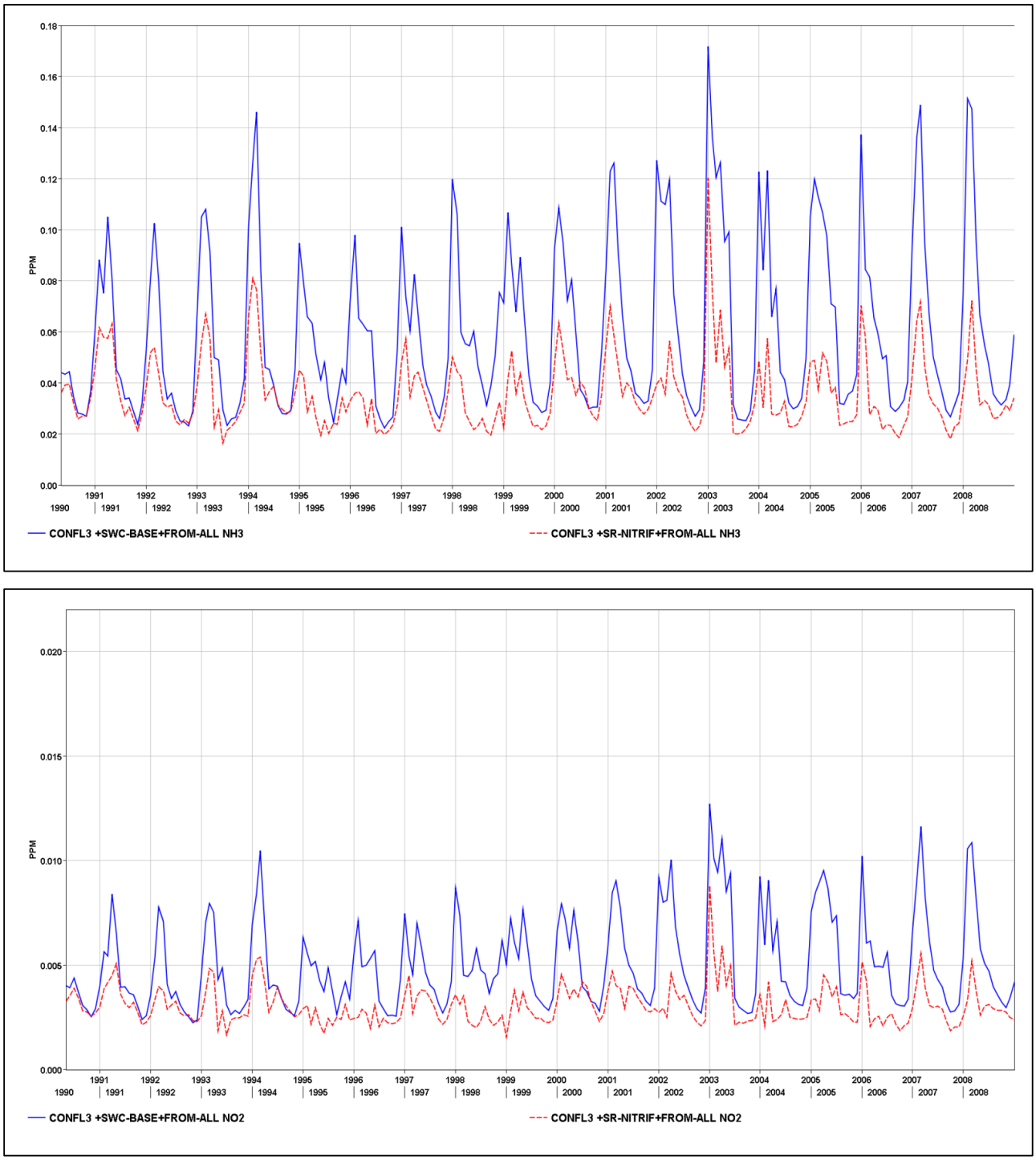


Figure 25-118 Ammonia and nitrite concentrations at Confluence3 for the Sac Regional Nitrification scenario

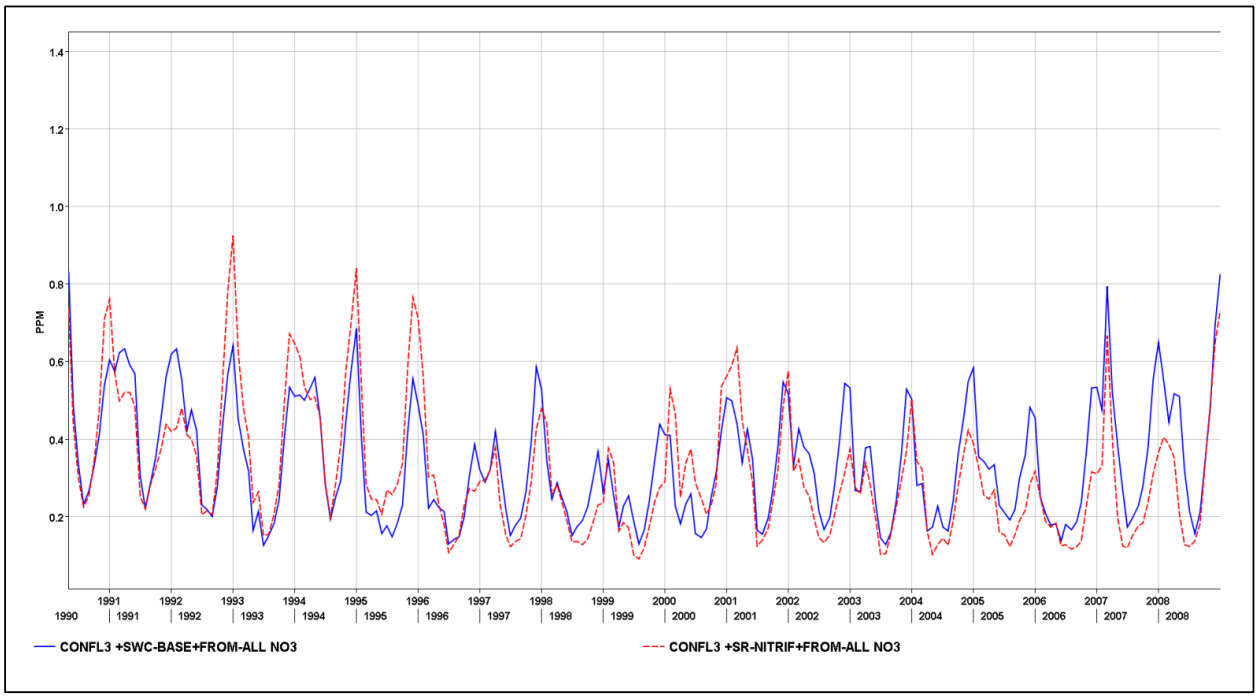


Figure 25-119 Nitrate concentration at Confluence3 for the Sac Regional Nitrification scenario.

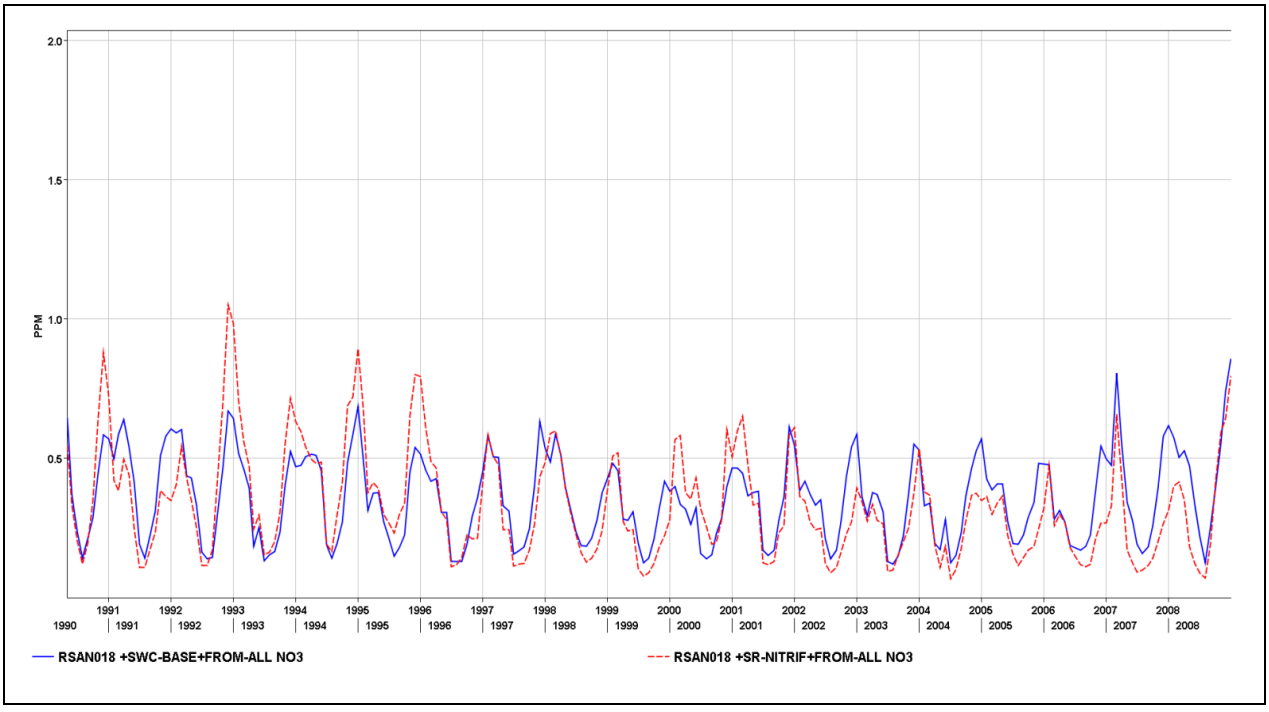


Figure 25-120 Nitrate concentration at Jersey Point for the Sac Regional Nitrification scenario.

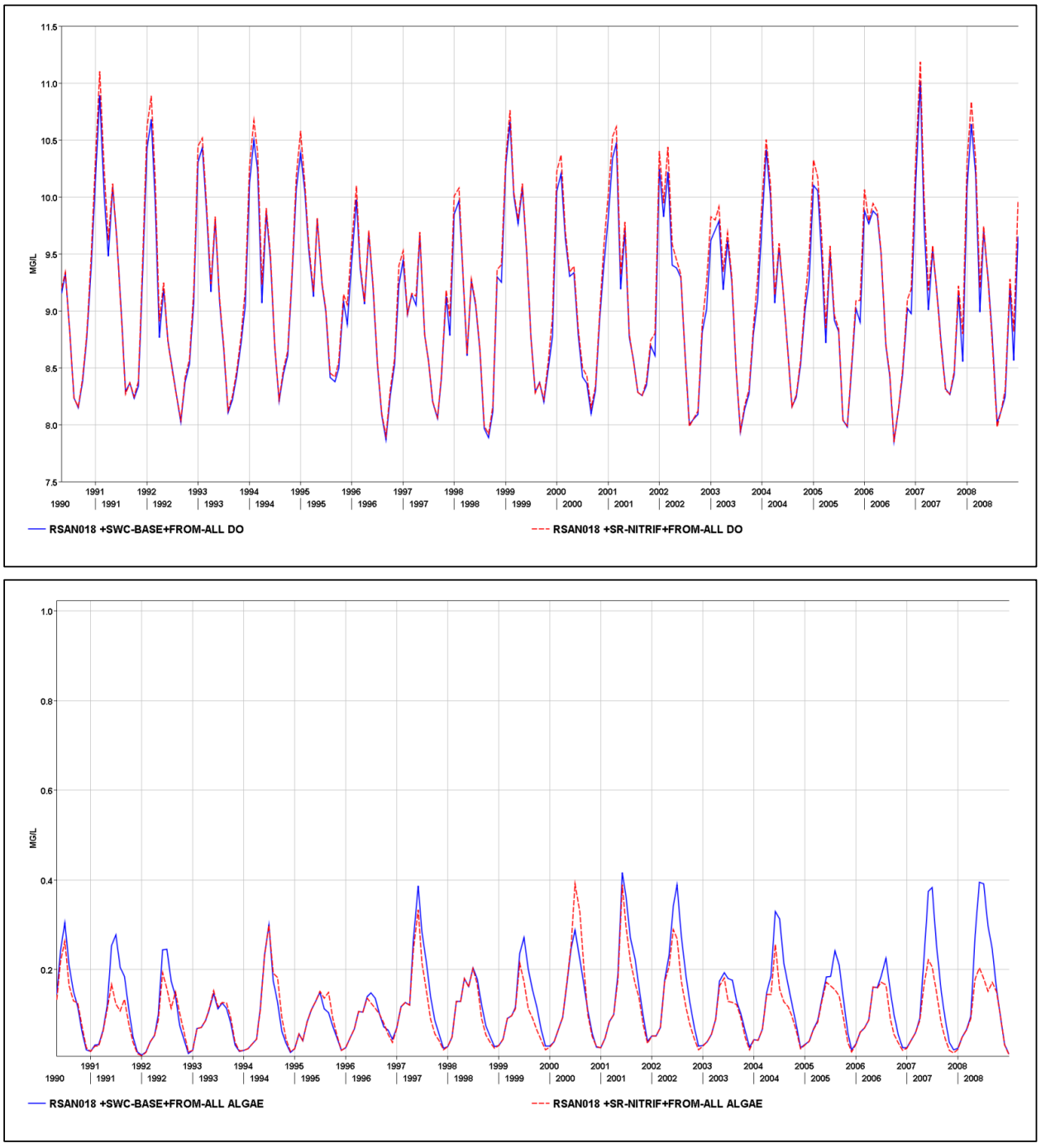


Figure 25-121 DO and Chl-a/algae concentrations at Jersey Point for the Sac Regional Nitrification scenario

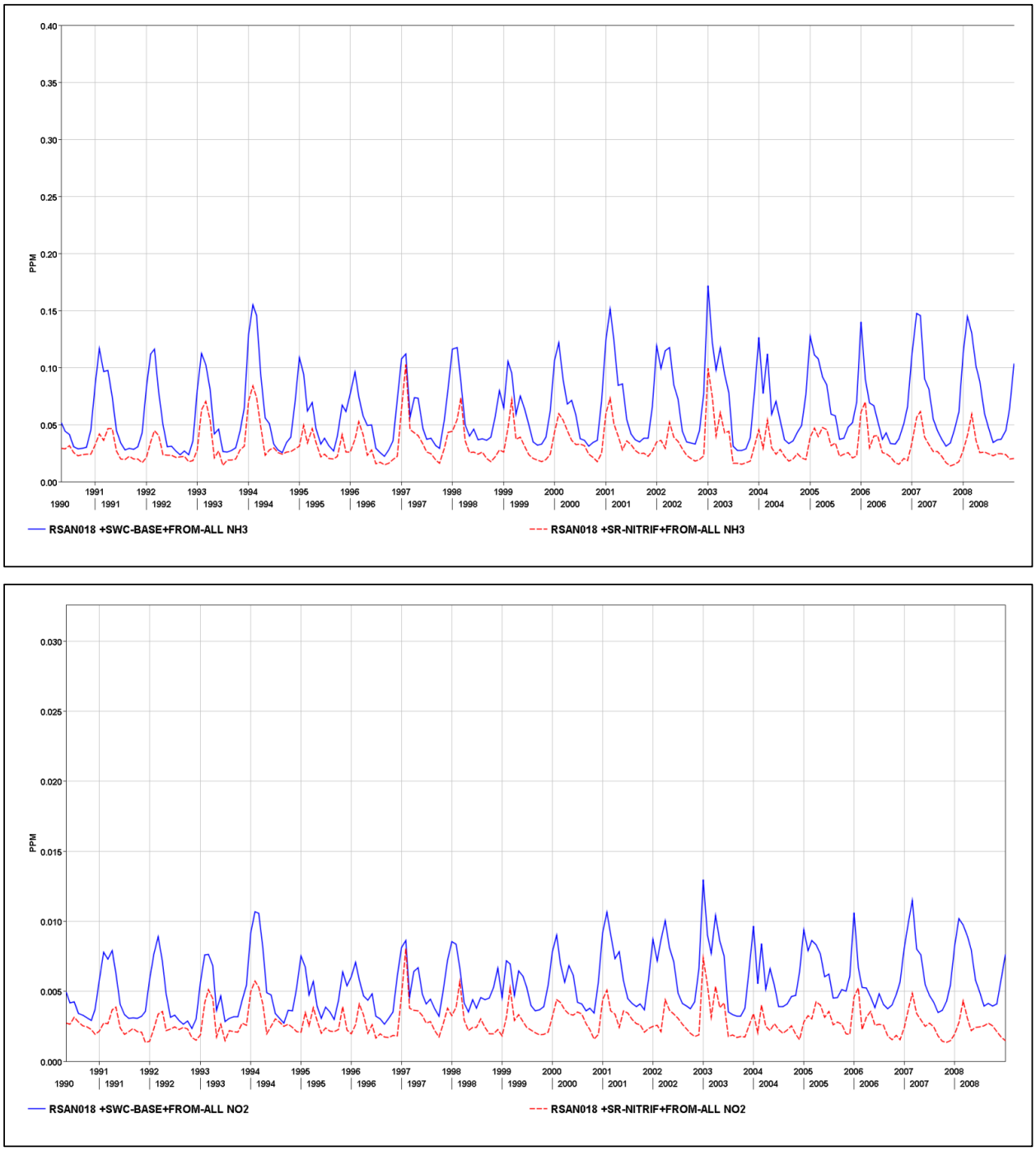


Figure 25-122 Ammonia and nitrite concentrations at Jersey Point for the Sac Regional Nitrification scenario.

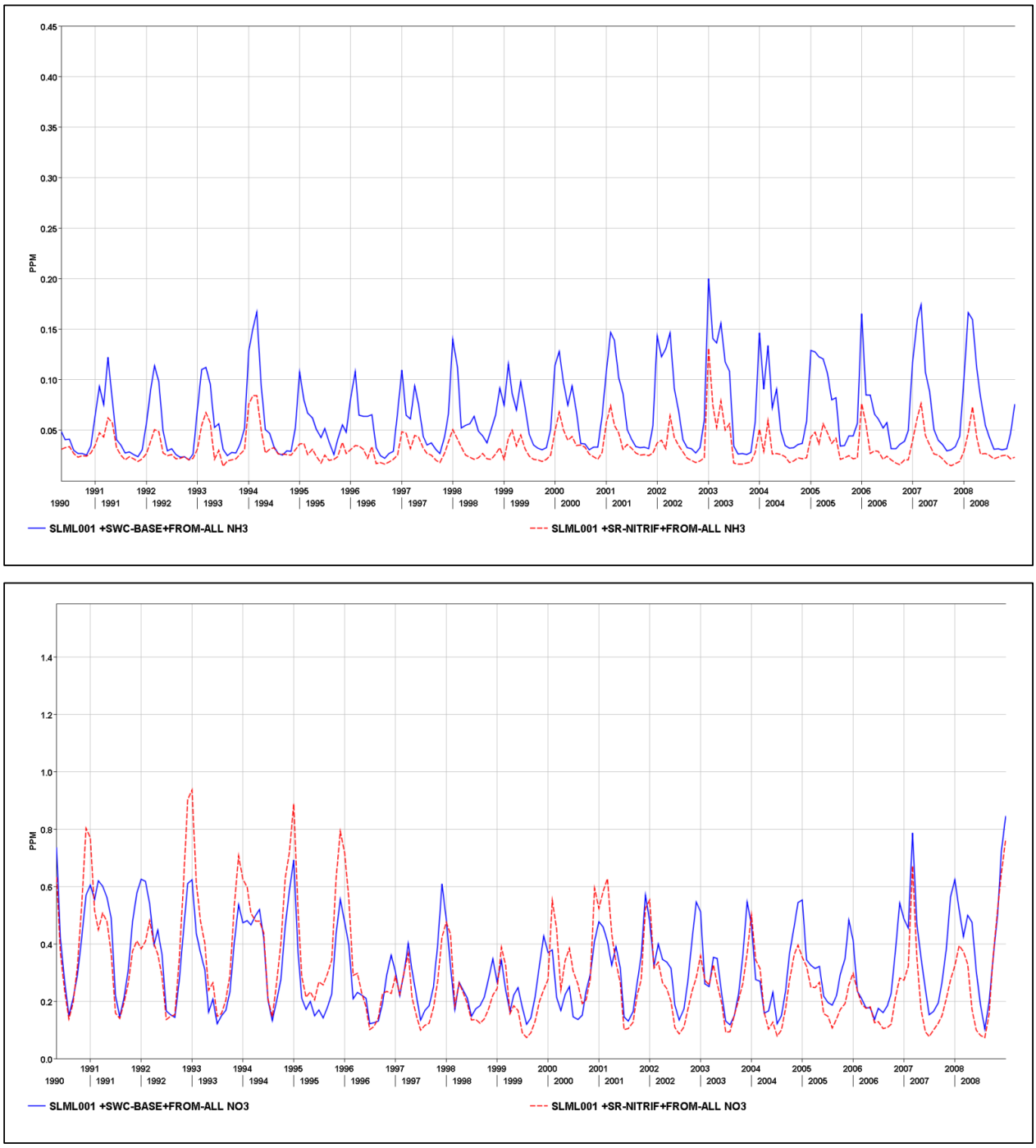


Figure 25-123 Ammonia and nitrate concentration at Suisun Nichols for the Sac Regional Nitrification scenario.

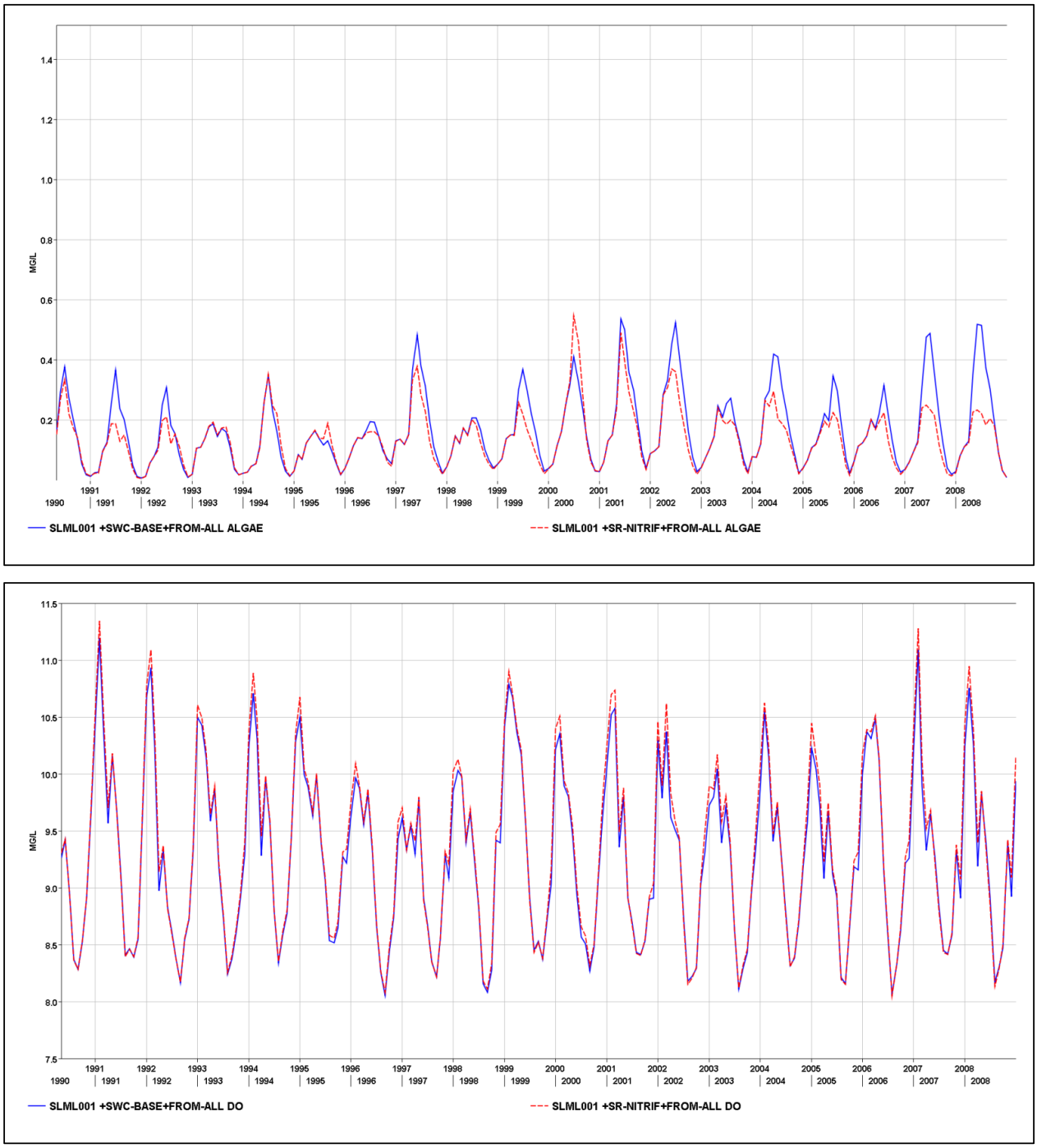


Figure 25-124 Chl-a/algae and DO concentrations at Suisun Nichols for the Sac Regional Nitrification scenario.

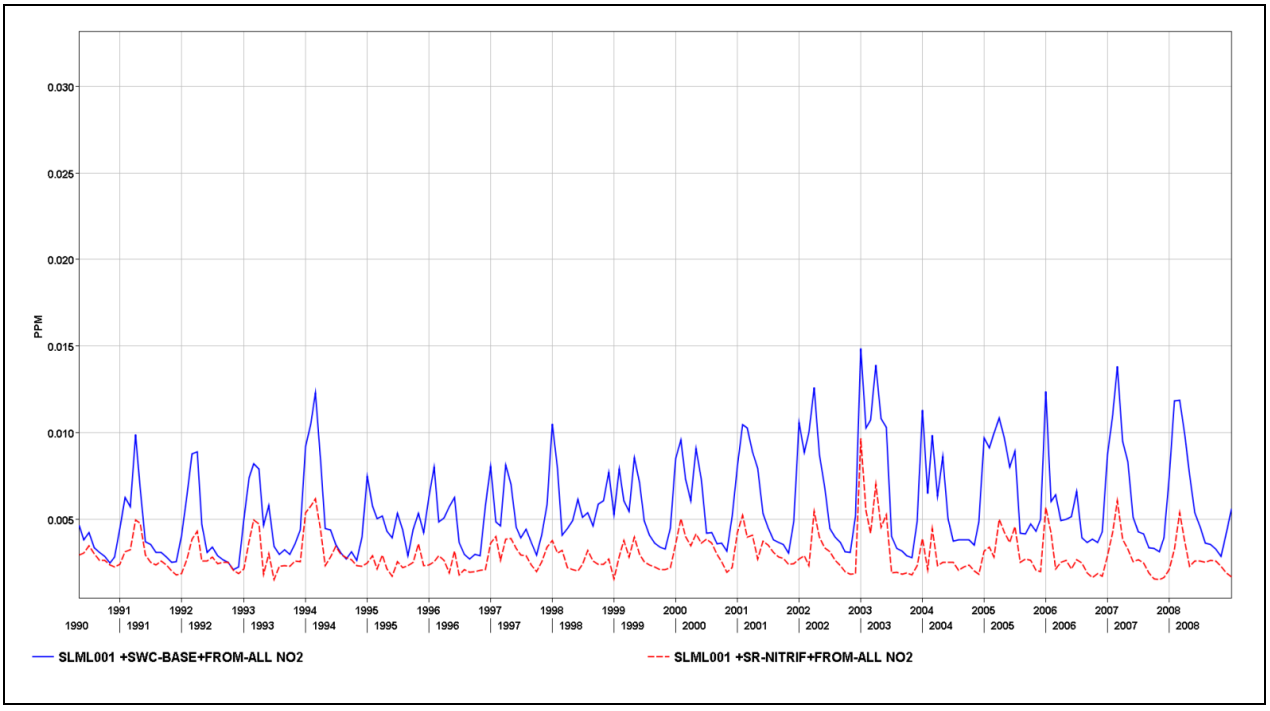


Figure 25-125 Nitrite concentration at Suisun Nichols for the Sac Regional Nitrification scenario.

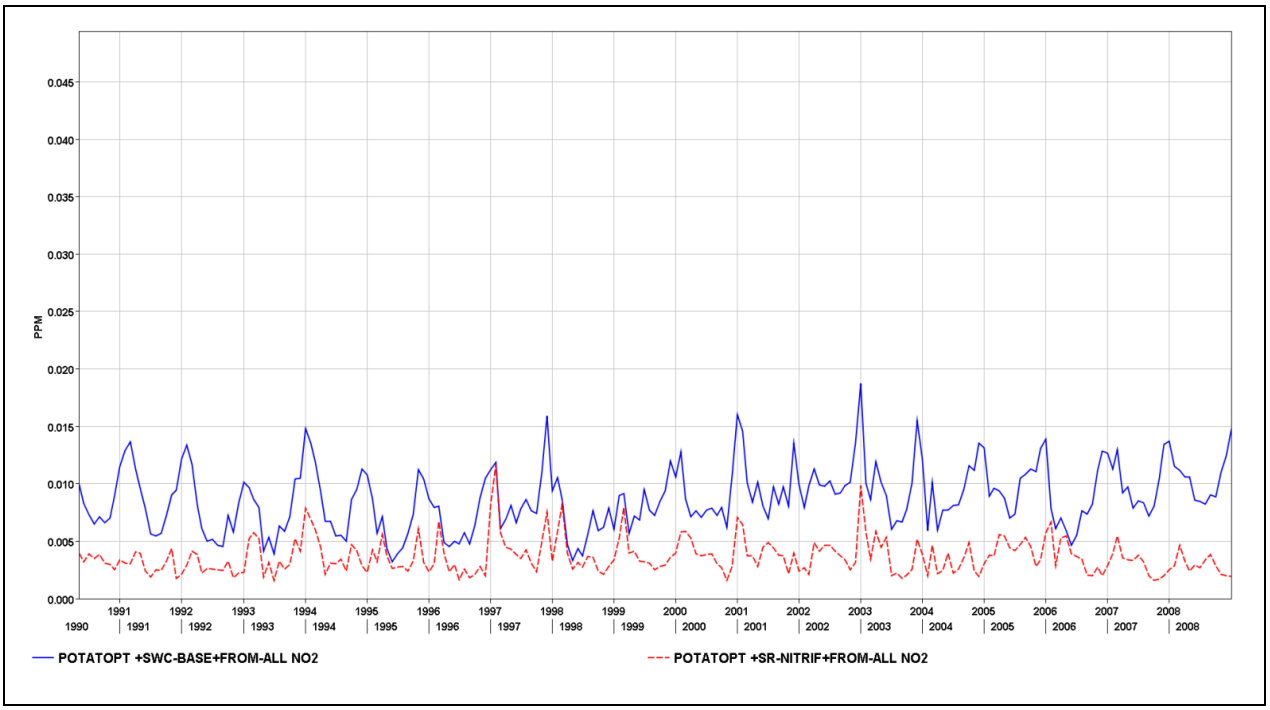


Figure 25-126 Nitrite concentration at Potato Point for the Sac Regional Nitrification scenario.

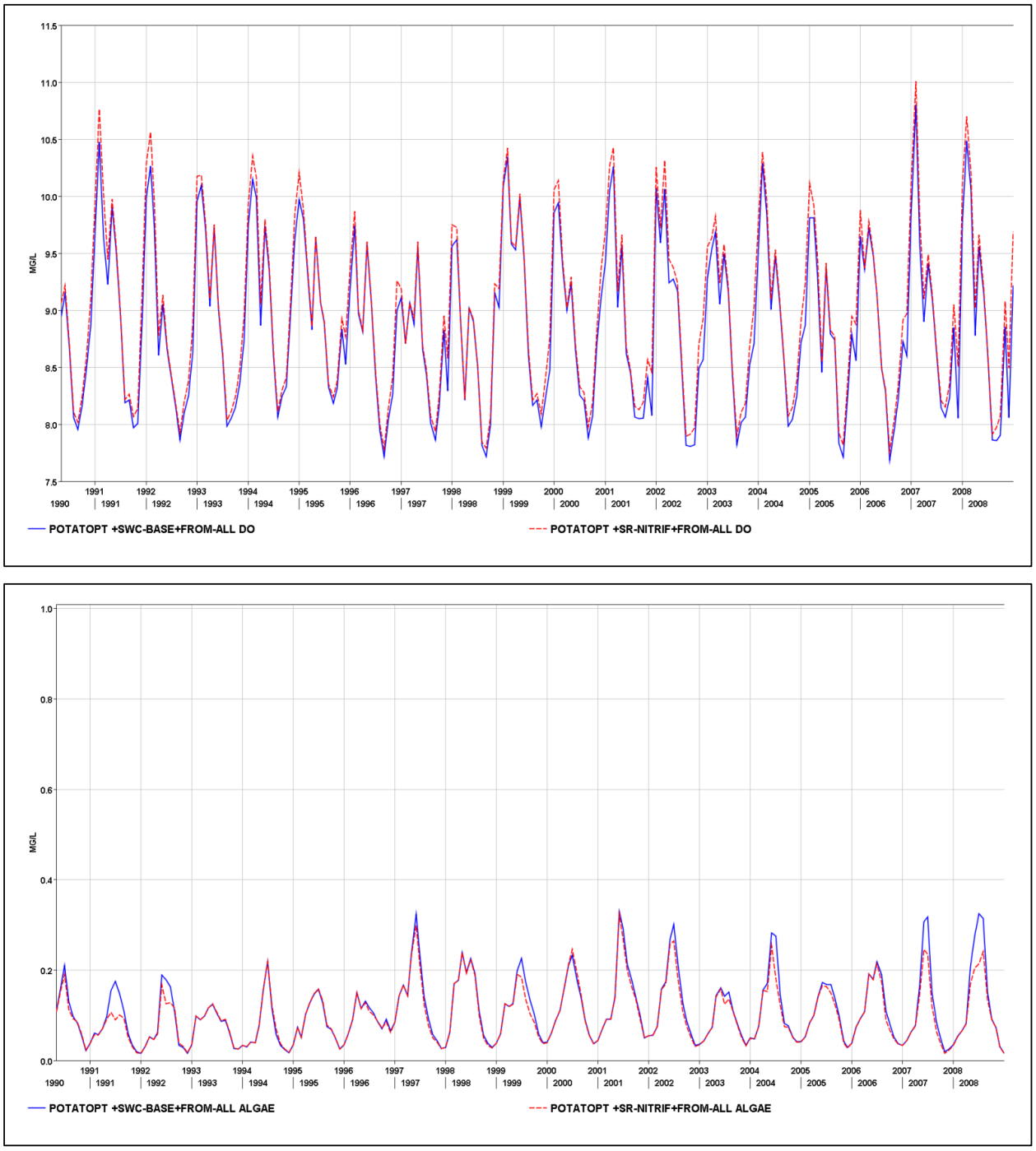


Figure 25-127 DO and chl-a/algae concentrations at Potato Point for the Sac Regional Nitrification scenario.

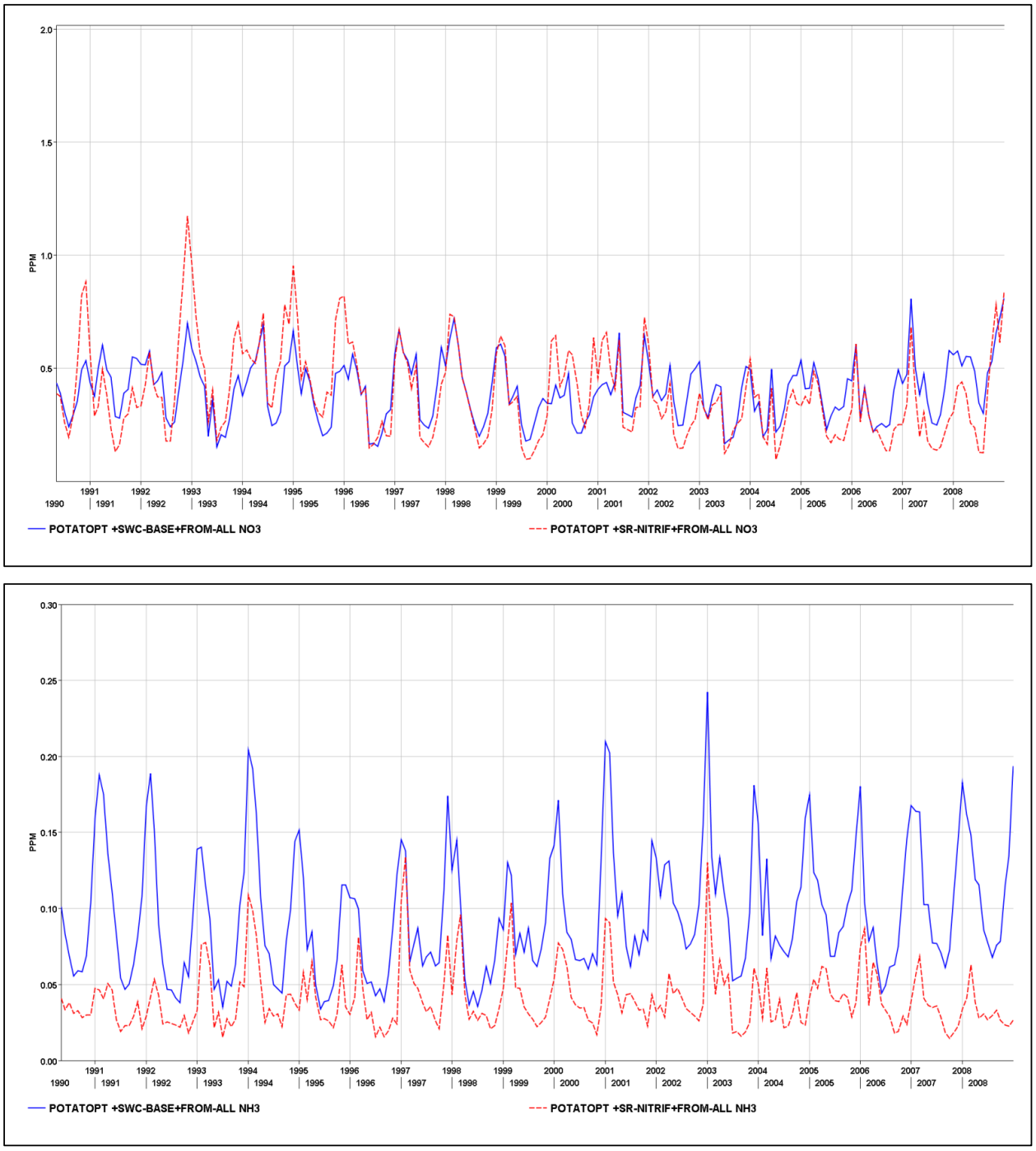


Figure 25-128 Nitrate and ammonia concentration at Potato Point for the Sac Regional Nitrification scenario.

25.12 Estimating Mass Loss at the Martinez Boundary in DSM2

The DSM2 water quality module has a concentration boundary condition at the Martinez tidal boundary. A number of the effluent sources of interest, contributing ammonia and the other nutrients to the Delta, lie within Suisun Bay and the Carquinez Strait. Outgoing tides transport water quality constituents from these sources down past the Martinez boundary and out of the model domain. In the physical system, these constituents would flow back into areas upstream of Martinez on incoming tides, but as the model boundary is typically formulated in DSM2 QUAL, this mass does not return. The result is a loss of mass at the Martinez boundary which has the potential to significantly alter modeled nutrient concentrations and thus the nutrient dynamics upstream of this boundary. Because this area is of significant importance to the Delta ecosystem, an estimate is needed of the magnitude of this loss. In addition, the potential exists to alter the Martinez boundary conditions in a subsequent model run to reintroduce this mass on incoming tides.

The RMA2/RMA11 hydrodynamic and water quality models, described in detail in the next section, were run for a full Bay-Delta geometry (Figure 1) to provide an estimate of the expected constituent mass which should be returning on the incoming tide at the Martinez DSM2 boundary. The simulations were performed for low (3,000-4,000 cfs) and moderate (11,000-16,000 cfs) Net Delta Outflow (NDO) conditions. The simulations specifically examined a discharge from the CCCSD outfall located near Martinez (Figure 25-134) as CCCSD has the largest effluent flow in this region. The model, computations were used to estimate the constituent loss at this boundary condition location and to estimate the need to modify the DSM2 Martinez constituent boundary conditions in order to reintroduce the constituent mass on incoming tides.

25.12.1 RMA Model Representation

The RMA model of the Bay-Delta, shown in Figure 25-129 extends from the Golden Gate to the confluence of the American and Sacramento Rivers, and to Vernalis on the San Joaquin River. San Francisco Bay and Suisun Bay regions, and the Sacramento – San Joaquin confluence area are represented using a two-dimensional (2-D) depth-averaged approximation. The Delta channels and tributary streams are represented using a one-dimensional (1-D) cross-sectionally averaged approximation. The Sacramento-San Joaquin confluence area was refined with the addition of 2-D elements representing marsh areas in Sherman Lake, between Middle Slough and New York Slough and other marsh areas in the vicinity. A closer view of Suisun Bay and the western and central Delta is shown in Figure 25-130.

Detail representing the CCCSD outfall includes mesh refinement around the CCCSD outfall and along the southern shoreline in the vicinity of the outfall. These refinements allow more accurate computation of concentration gradients near the outfall, and better representation of the effluent plume along the southern shoreline. The mesh around the outfall, as shown in Figure 25-131 and

in Figure 25-132, has been used in previous studies (RMA, 2000) with some minor modifications. The element representing the CCCSD effluent outfall (shown in red in Figure 25-132) is approximately 144 ft (44_m) long by 65 ft (20_m) wide. CCCSD's submerged outfall line is 132 ft (40 m) in length.

The size and shape of elements are dictated by changes in bottom elevation and other hydraulic considerations. Wetting and drying of the tidal mudflats has been represented in sufficient detail to provide a good definition of change in the tidal prism that occurs with change in tidal stage. Aside from the latest grid modifications, bottom elevations and the extent of mudflats are based on NOAA navigation charts, NOAA hydrographic survey data, and aerial photo surveys processed by USGS and Stanford University. The latest addition of marsh areas is based on DWR LiDAR data (DWR, 2007) and aerial photographs. Model bathymetry is shown in Figure 25-133, with a close-up view in the vicinity of the CCCSD outfall shown in Figure 25-134.

Hydrodynamic model operation requires specification of the tidal stage at the Golden Gate and inflow and withdrawal rates at other external boundaries. Flow boundary conditions include the Sacramento River, San Joaquin River, and other rim flows, channel depletions, and exports.

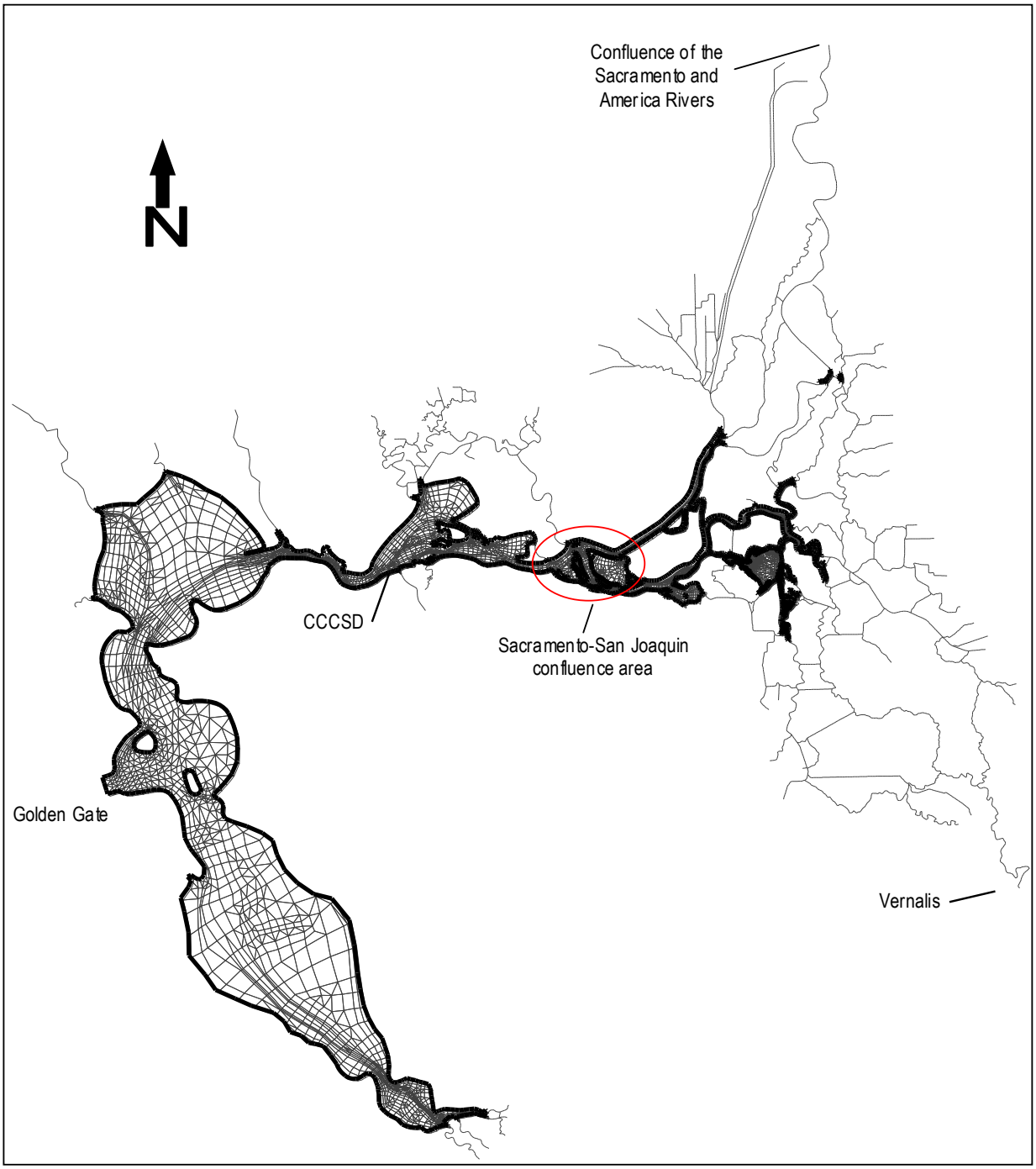


Figure 25-129 Finite element mesh of San Francisco Bay and Delta.

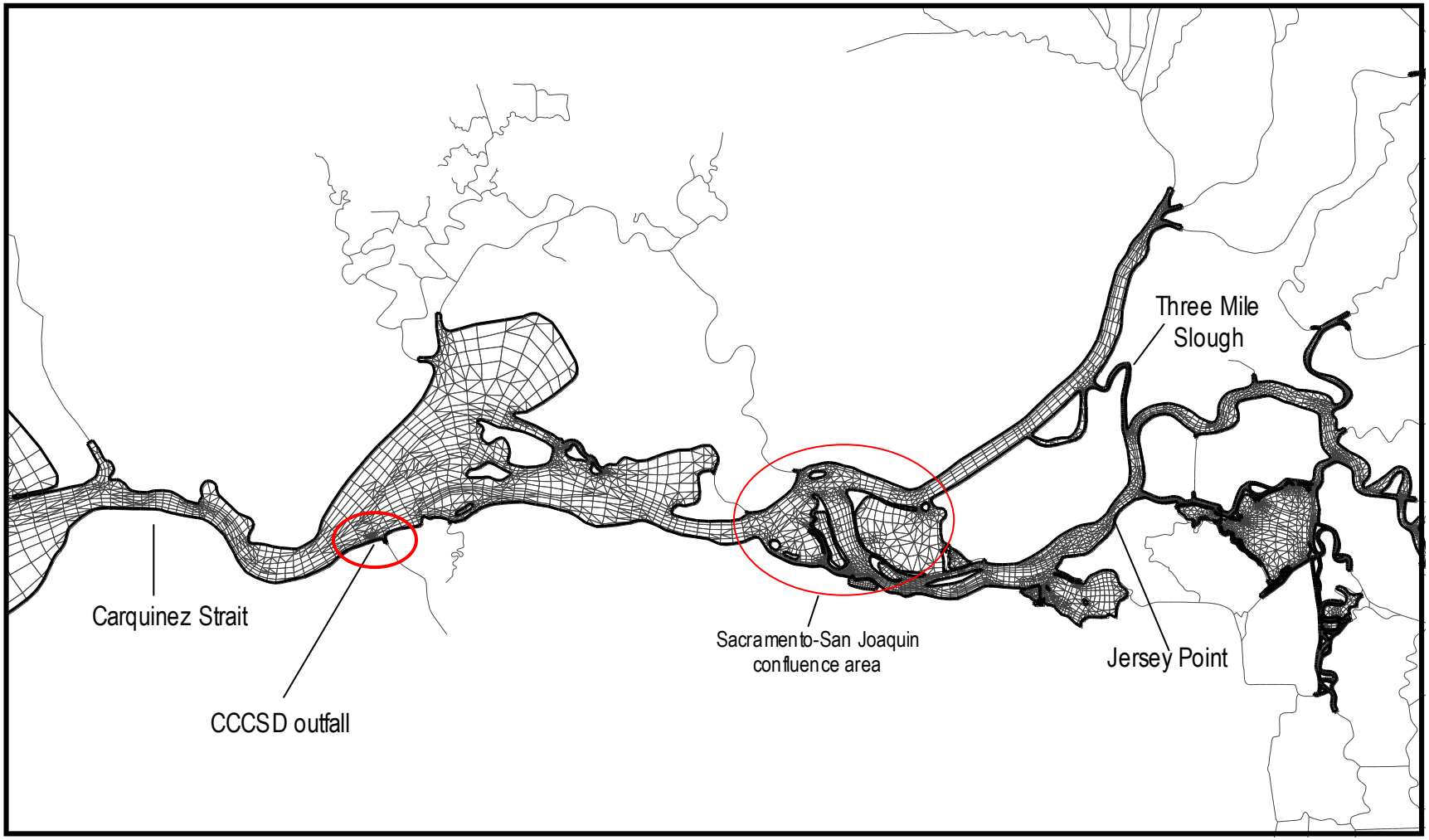


Figure 25-130 Finite element mesh in the vicinity of Suisun Bay and the western and central Delta, with the CCCSD effluent outfall location indicated in red.

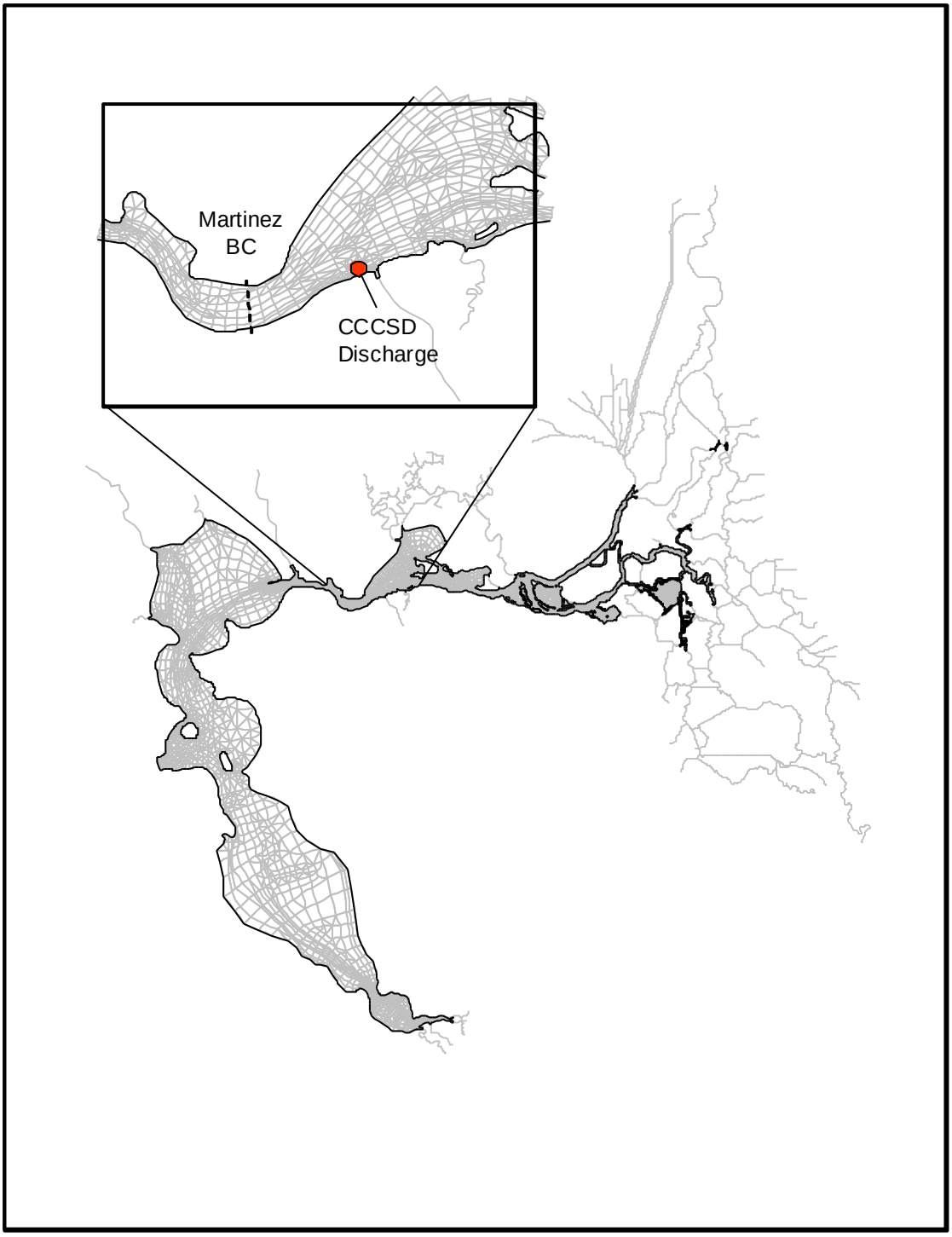


Figure 25-131RMA2/RMA11 Bay-Delta network used to examine effect of Martinez water quality boundary condition location.

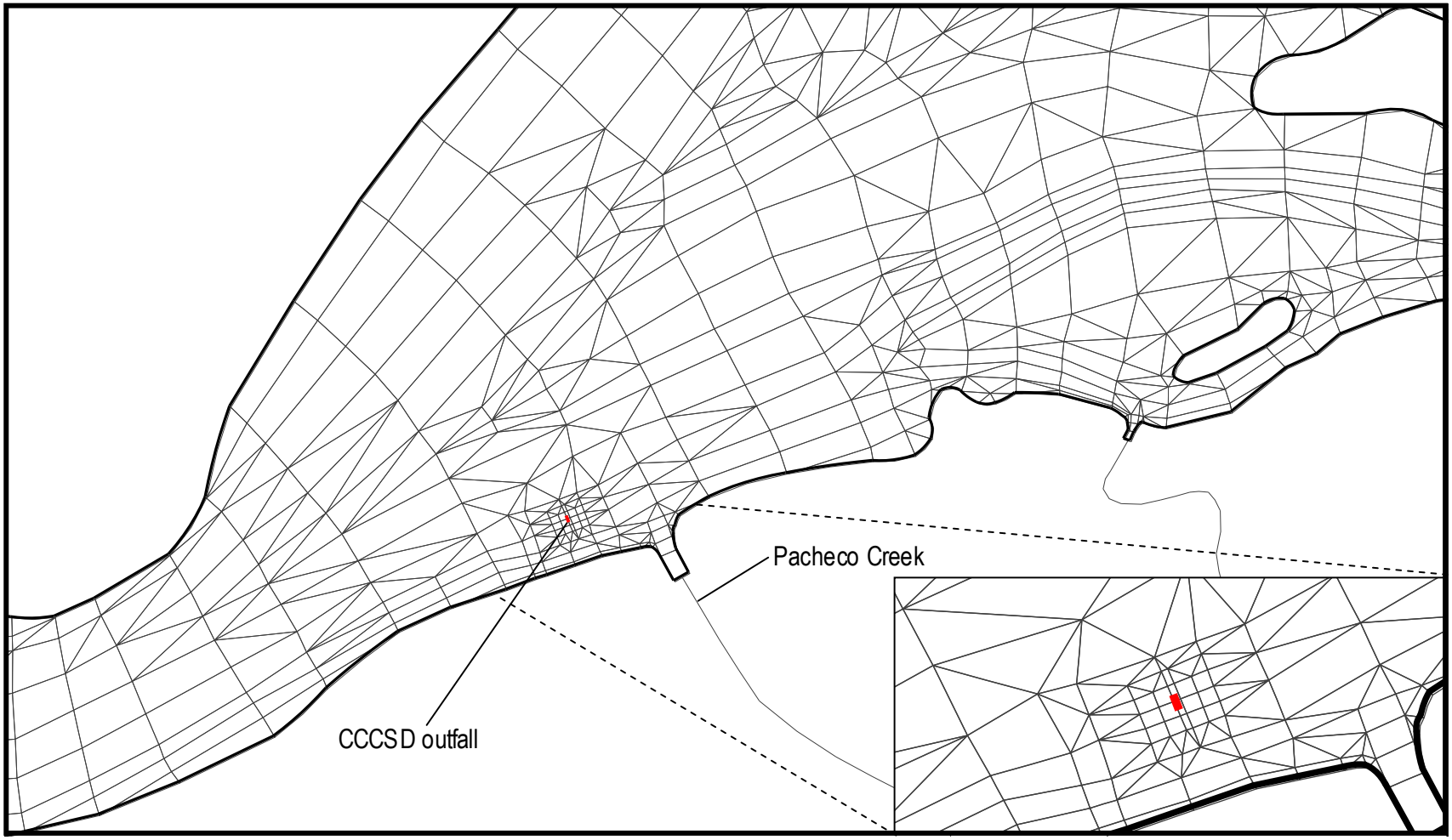


Figure 25-132 Finite element mesh in the vicinity of the CCCSD outfall. Expanded view shows outfall element in red.

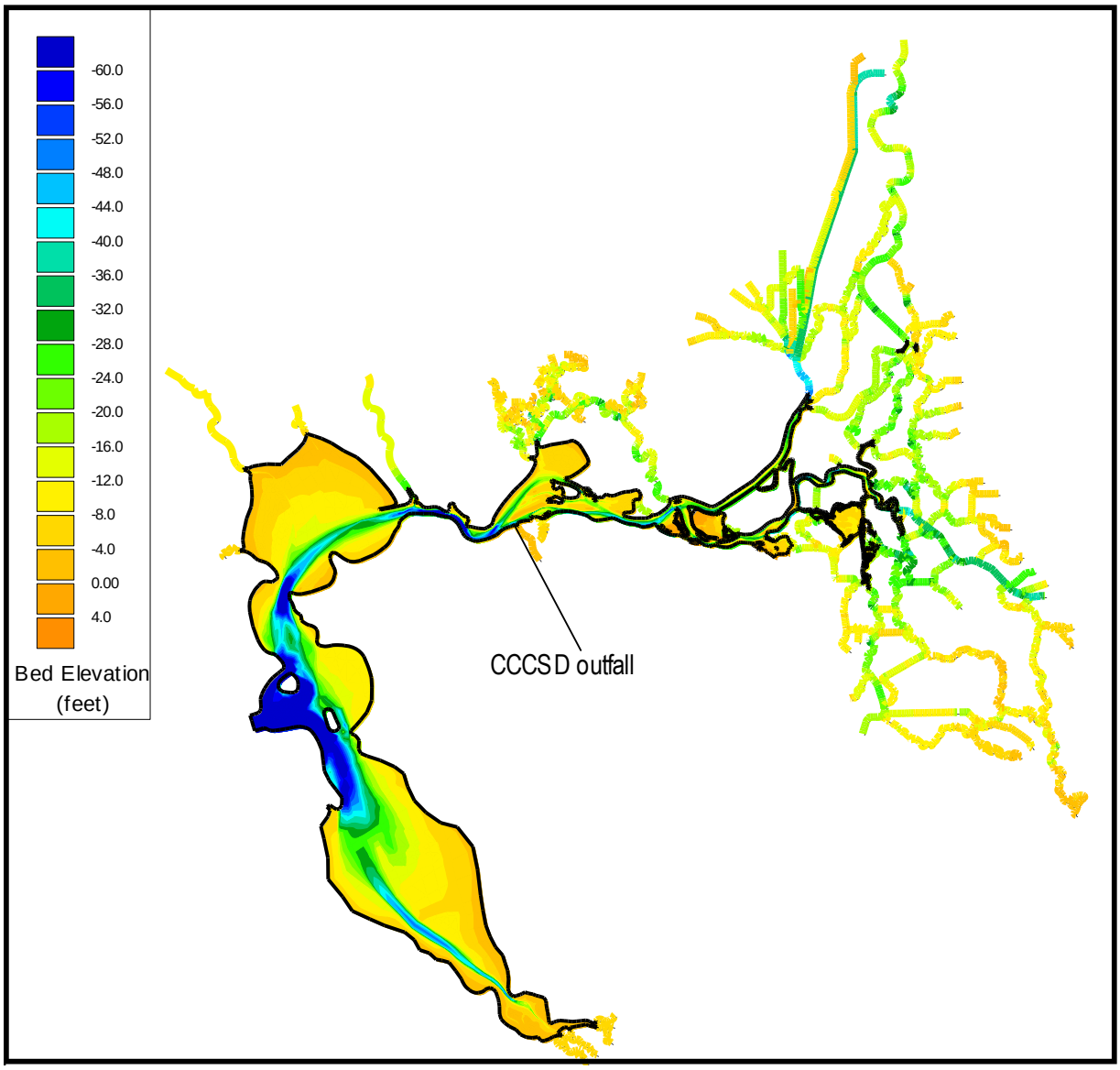


Figure 25-133 Model bathymetry contours.

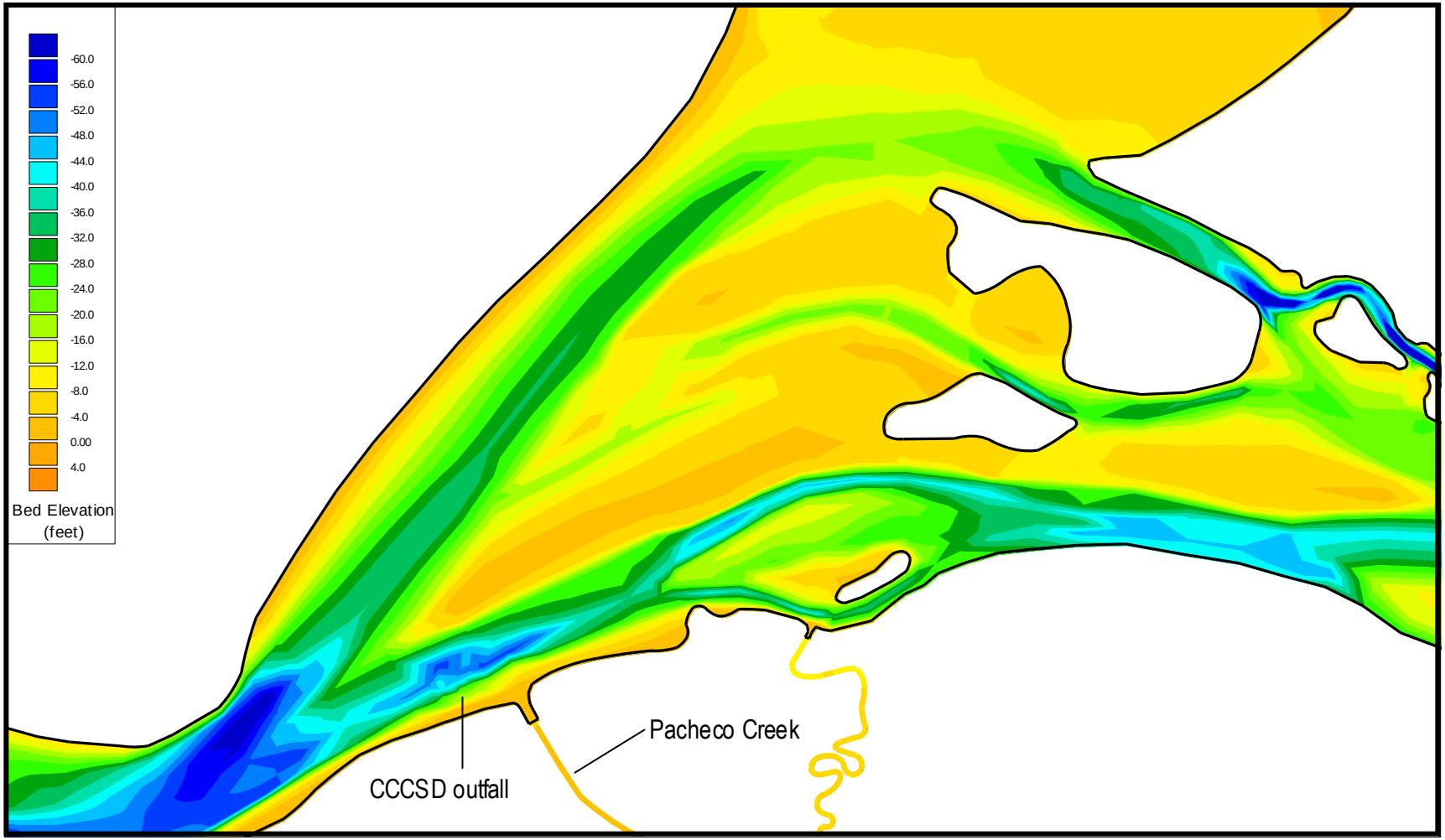


Figure 25-134 Model bathymetry contours in the vicinity of the CCCSD outfall.

25.12.2 Martinez Boundary Condition - Tracer Simulations

The RMA2/RMA11 hydrodynamic and water quality models were run for a full Bay-Delta geometry (Figure 25-129) to provide an estimate of the expected constituent mass which should be returning on the incoming tide at the Martinez DSM2 boundary. The simulations specifically examined a discharge from the CCCSD outfall located near Martinez (Figure 25-131). Both conservative and non-conservative (decay constant = 1 /day) tracer types were modeled. The discharge volume simulated for the CCCSD outfall was 42.2 mgd, or 1.849 m3/sec. Tracer concentration for the discharge was set to 100 g/m3 so results can be interpreted as percent effluent and used to determine the percent of CCCSD effluent that returns to the system on an incoming tide for a model boundary set at Martinez.

Two periods were simulated, one at low net Delta outflow (3,000-4,000 cfs) and one at moderate net Delta outflow (11,000-16,000 cfs). The 29-day period of August 16 through September 13, 2002 represents 10% net Delta outflow exceedance ranking and the April-May 2002 period represents the 50% exceedance ranking. To compute these flow rankings, a 29-day running average of year 2000 – 2006 net Delta outflows, calculated from Dayflow[31] net Delta outflow data, was computed. The averaged outflows were then sorted and ranked based on the percent of time a flow exceeds all other net Delta outflows during that period.

NOAA tide data at San Francisco was used to set the tidal boundary at the Golden Gate. The tide data were smoothed using a five-point moving average, and shifted to NGVD 29 vertical datum. Flow data from the Interagency Ecological Program (IEP) database [32] and Dayflow were used to set flow boundaries for the Sacramento River, San Joaquin River, Yolo Bypass, Mokelumne and Cosumnes Rivers, miscellaneous eastside flows (including Calaveras River, French Camp Slough and other minor tributaries), and exports. USGS flow data[33] were used to set Napa River flows. DWR's computed monthly average channel depletions/precipitation data[34] were used to represent agricultural influences.

Initial tracer simulation results were extracted at several locations from Martinez to the CCCSD outfall. Further tracer runs were performed with and without a zero concentration boundary condition at Martinez implemented in the RMA models.

The period August 16 to September 14, 2002 was simulated to examine the tracer loss for low NDO conditions. Figure 25-135 through Figure 25-137 present concentration contour plots of the CCCSD tracer for August 23, 2009, after 1 week of simulation. Figure 25-135 shows the CCCSD tracer concentration for the non-conservative tracer at times of maximum ebb tide and maximum flood tide.

---

[31] http://iep.water.ca.gov/dayflow/index.html
[32] http://www.iep.water.ca.gov/dss/all/
[33] http://waterdata.usgs.gov/nwis/dv/?site_no=11458000
[34] http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dicu/dicu.cfm

Figure 25-136 illustrates the effect of the zero Martinez concentration boundary condition for the non-conservative tracer. Tracer concentrations for both runs are similar along the south shoreline of the Suisun Bay. These figures indicate that after several tidal cycles, the tracer is mixed across the width of the Carquinez Strait on ebb and travels up both the north and south channels of Suisun Bay on the following flood tide. Distribution for the conservative tracer case is shown in Figure, Figure 25-138 and Figure 25-139 present time series plots of the tracer mass in the model network for the August-September 2002 simulations. In the RMA model, a simulation duplicating the effect of the DSM2 boundary condition, the "Mtz BC=0" simulation, was implemented by setting an artificial zero-concentration boundary at the location of the DSM2 boundary. Figure shows the tracer mass for the non-conservative tracer, for the entire "Bay-Delta", the "Delta Only", and for the Martinez zero concentration boundary condition. The "Delta Only" line represents the tracer mass in the Bay-Delta network that is upstream of the "Martinez BC" location. The difference between the "Delta Only" and the "Mtz BC=0" lines represents the mass missing due to a zero concentration boundary condition at Martinez. At maximum ebb, the "Delta Only" mass approximately equals the "Martinez BC=0" mass. At maximum flood, "Martinez BC=0" mass is about half the "Delta Only" mass. For a non-conservative tracer with a relatively short decay time, total tracer mass in the system comes to equilibrium at M/λ, where "M" is the mass loading from the CCCSD discharge in g/day and "λ" is decay constant in terms of 1/day.

Figure 25-140 illustrates clearly, using a set of Godin-filtered time series for the non-conservative tracer, that a significant amount of mass from the CCSD outfall is lost under the typical DSM2 boundary settings. Under these low outflow conditions, approximately 30% of the tracer mass is lost from the model. Although these simulations were run with a CCSD-only tracer, mass from locations downstream of CCSD would be lost at least these percentages.

The same time series plot for a conservative CCCSD tracer is presented in Figure 25-139. The total "Bay-Delta" mass grows linearly with time until about Aug 21, when mass begins to exit the model boundary at the Golden Gate. Figure 25-141 plots the ratio of the (Mtz BC=0) / (Delta Only) Godin filtered tracer concentrations for both the conservative and non-conservative cases. Figure 25-138 through Figure 25-141 illustrate that there is a greater relative loss of mass with a zero Martinez concentration boundary for the conservative tracer. Figure 25-141 also plots the stage time series at the CCCSD outfall location. Comparatively less tracer mass is lost with the "Mtz BC=0" condition during the neap tide period. The smaller tidal excursion during the neap tide period pushes less tracer past the Martinez boundary.

A set of tracer simulations were run for the April-May 2002 period when the NDO was higher (11,000 to 16,000 cfs). Figure 25-142 and Figure 25-143 show the time series tracer mass plots for the April-May 2002 simulation. Overall there is somewhat less tracer mass upstream of the Martinez boundary location for the non-conservative tracer for the higher NDO period (Figure 25-138 and Figure 25-142). There is visibly less tracer mass upstream of the Martinez boundary location for the conservative tracer under the higher NDO (Figure 25-139 and Figure 25-143).

Figure 25-144 shows the (Mtz BC=0) / (Delta Only) ratio plot for the April-May 2002 simulation period. The April-May 2002 ratios are similar to those for the low NDO period.

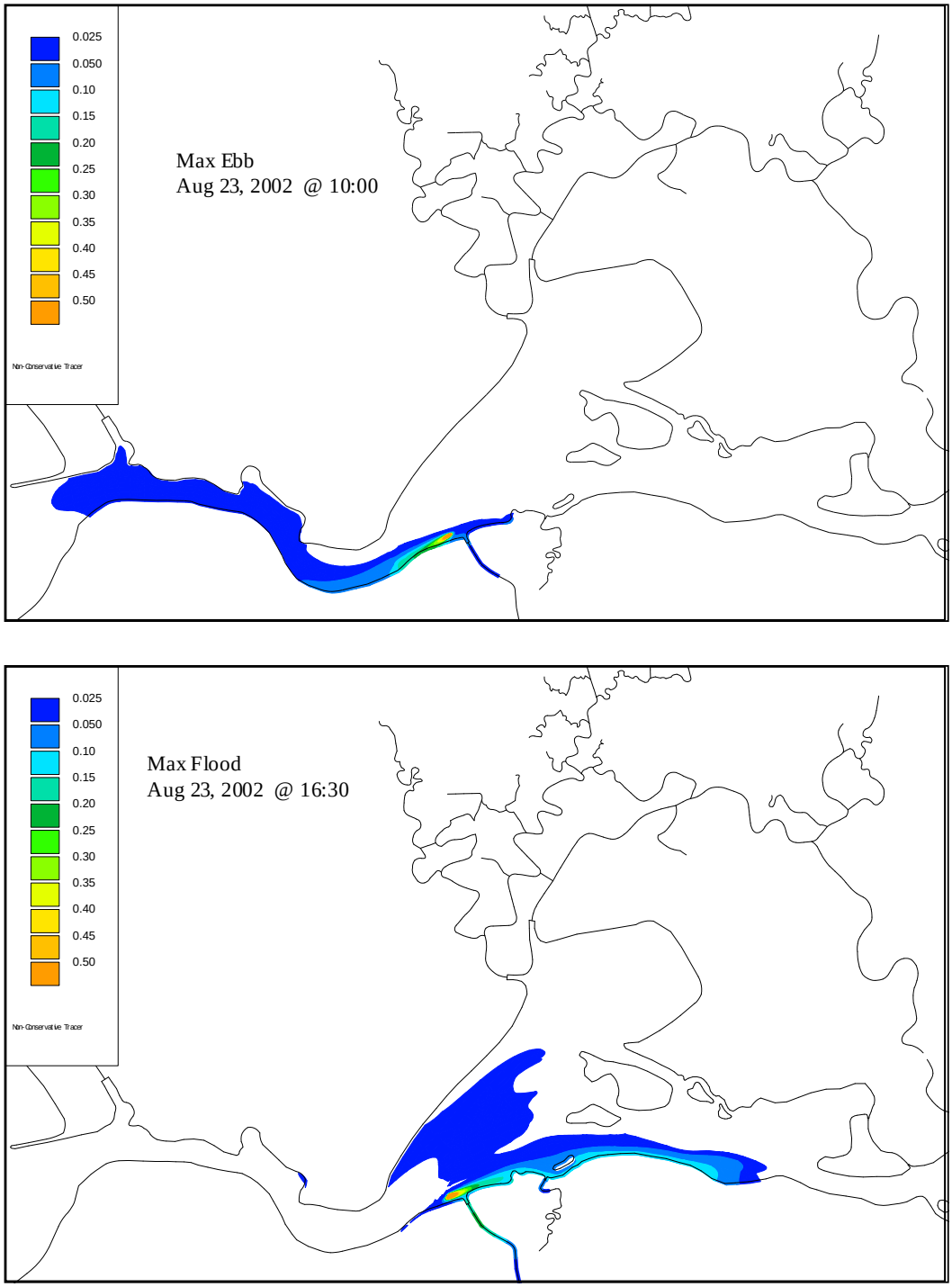


Figure 25-135 Concentration contours for a non-conservative tracer (λ = 1/day) at maximum ebb (top) and maximum flood (bottom), after one week of simulation.

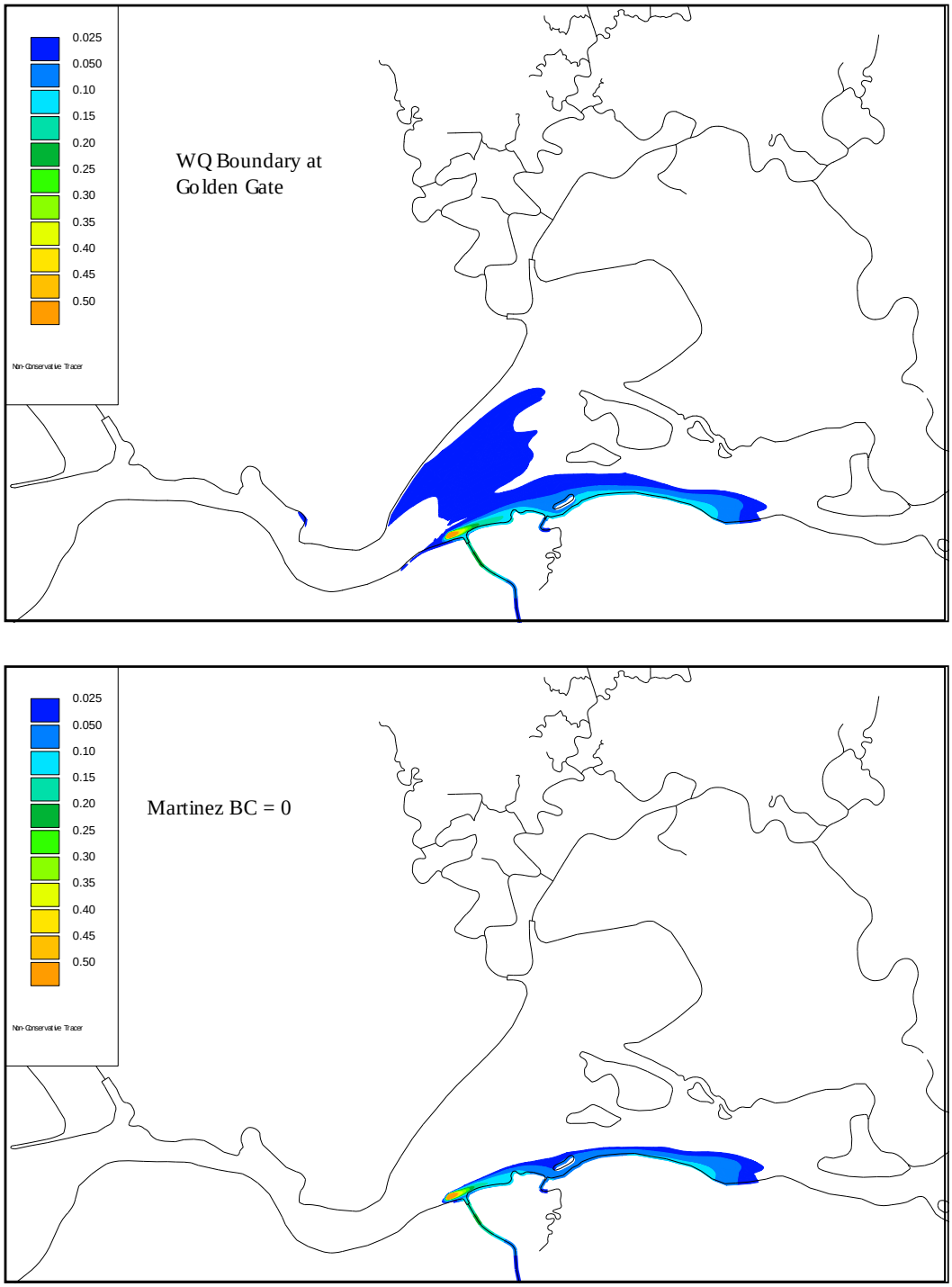


Figure 25-136 Concentration contours for a non-conservative tracer (λ = 1/day) at time of maximum ebb (Aug 23, 2002 @ 16:30) for a zero concentration boundary condition at the Golden Gate (top) vs. Martinez.

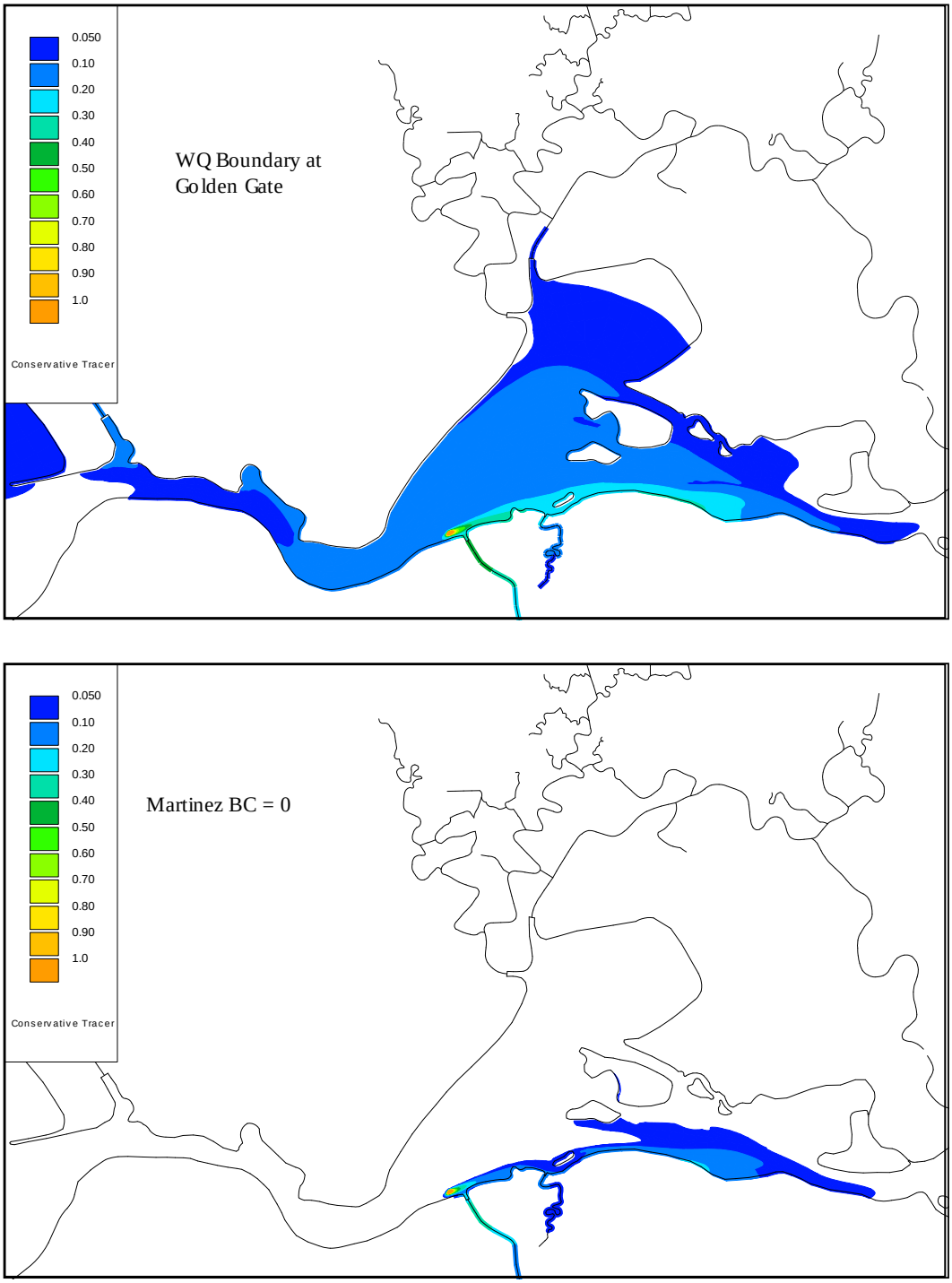


Figure 25-137 Concentration contours for a conservative tracer at time of maximum ebb (Aug 23, 2002 @ 16:30) with a zero concentration boundary condition at the Golden Gate (top) vs. Martinez.

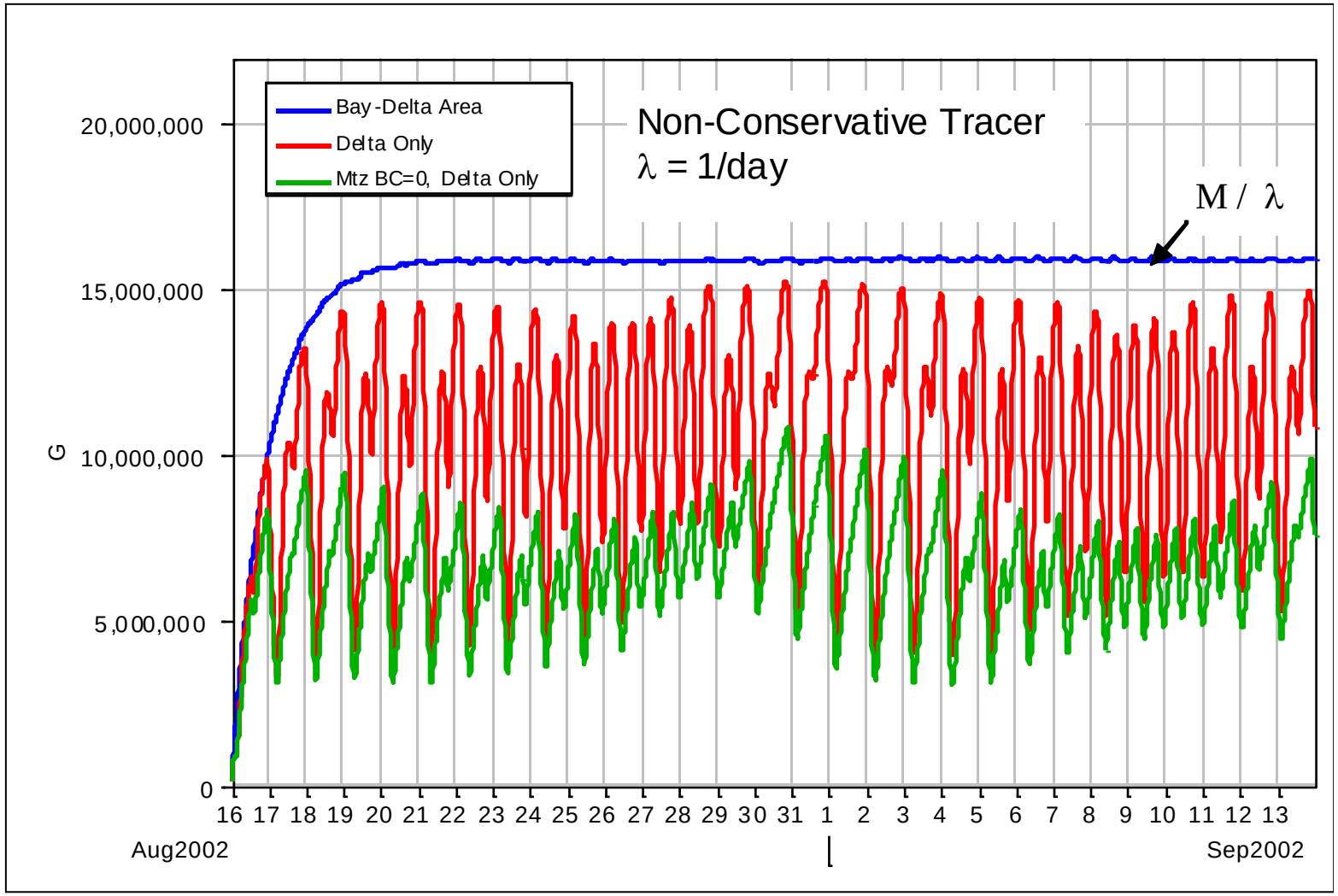


Figure 25-138 Tracer mass time series for the non-conservative CCCSD tracer (λ = 1/day). Blue line is tracer mass in the entire Bay-Delta network, red is the "Delta Only" tracer mass (upstream of Martinez), green is the "Mtz BC=0" tracer mass with a zero concentration boundary at Martinez

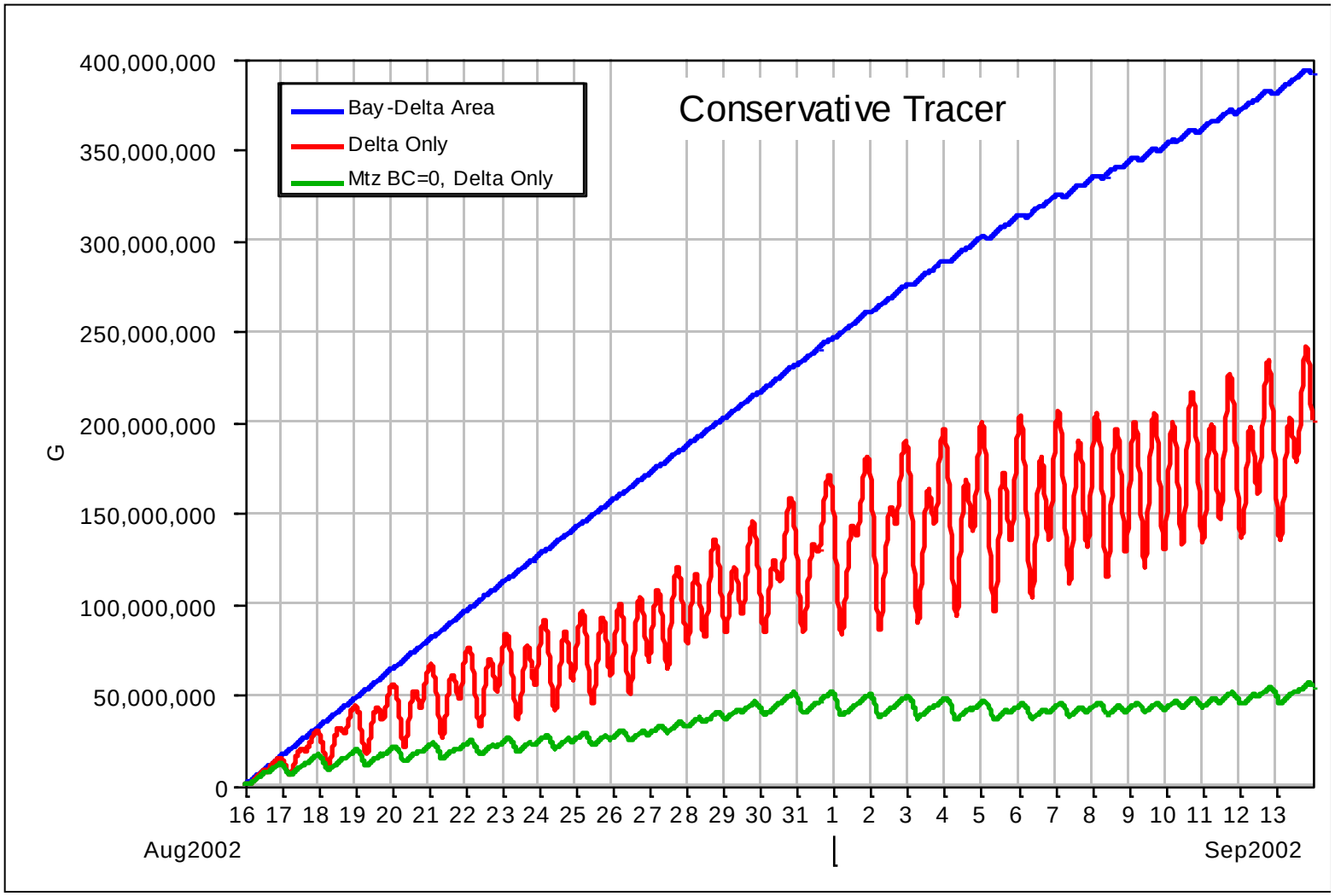


Figure 25-139 Tracer mass time series for the conservative CCCSD tracer (no decay. Blue is the tracer mass in the entire Bay-Delta network, red is the "Delta Only" tracer mass (upstream of the Martinez), green is the "Mtz BC=0" tracer mass with a zero concentration boundary at Martinez.

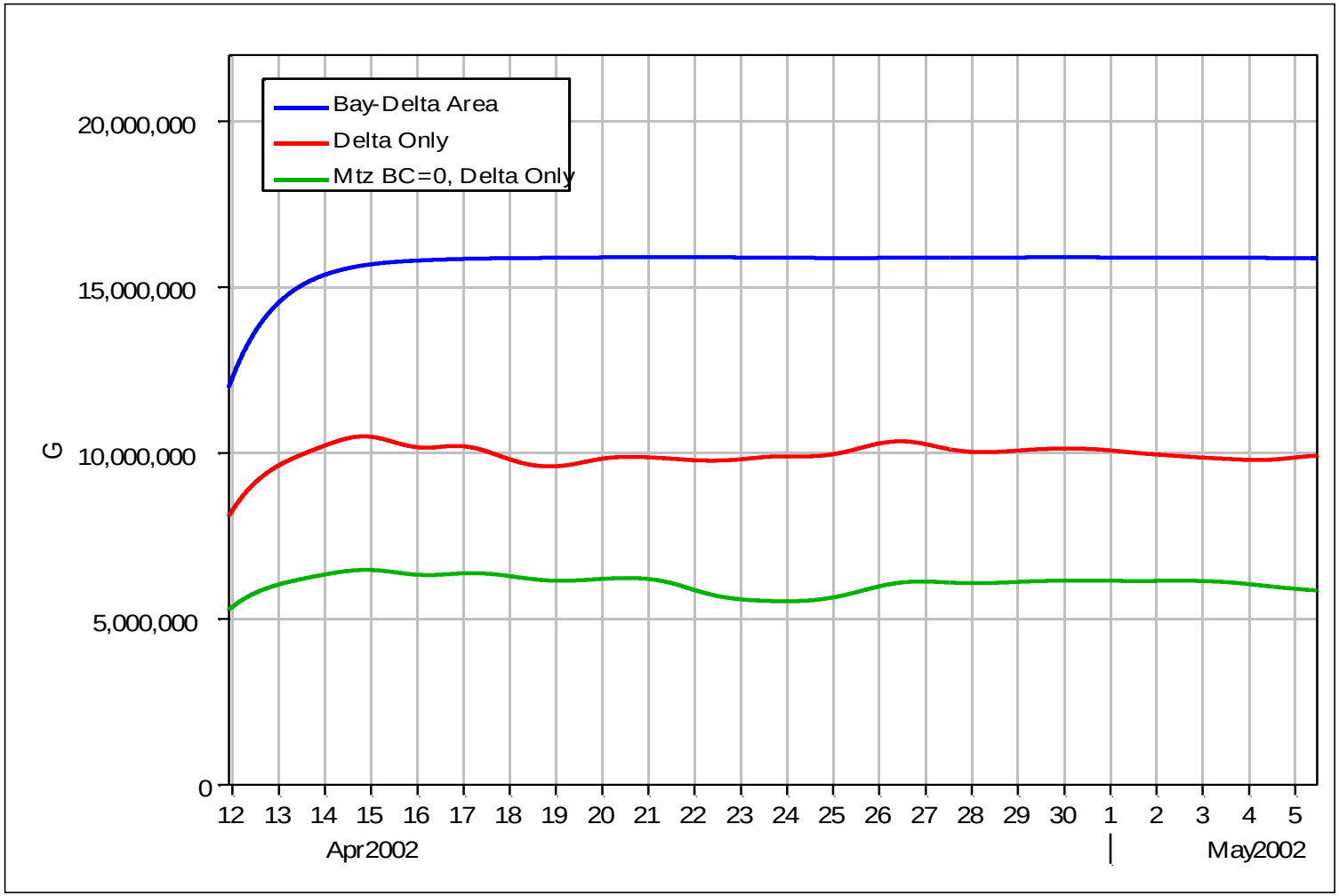


Figure 25-140 Comparison of Godin-filtered non-conservative tracer mass for three RMA11 simulations, shows that a significant amount of CCSD outfall mass and thus from all locations near the Martinez boundary, is lost under the standard DSM2 boundary condition settings.

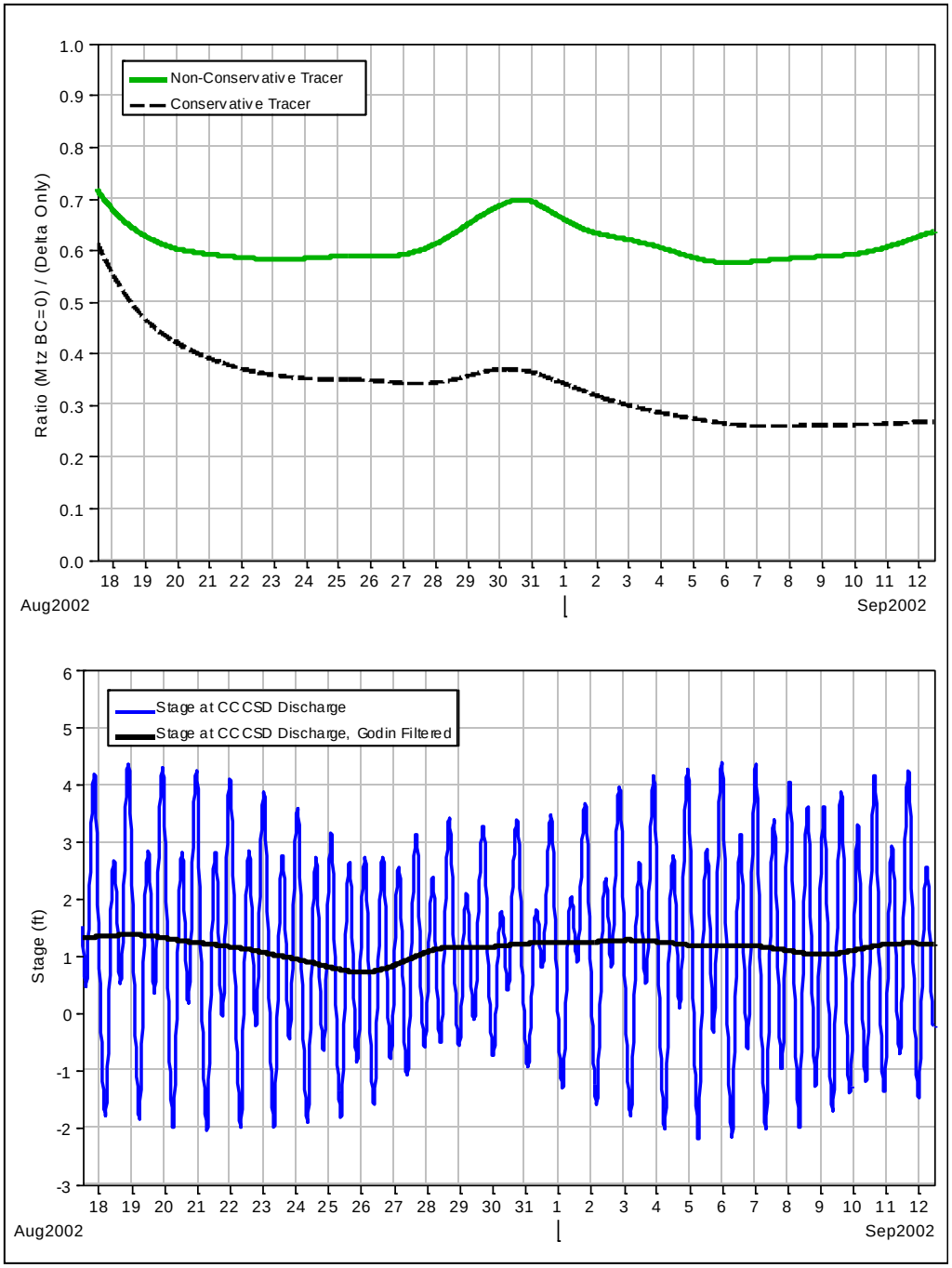


Figure 25-141. (top) Times series plots of ("Mtz BC=0")/("Delta Only") tracer mass for conservative and non-conservative CCCSD tracers. (bottom) Stage time series at the CCCSD discharge location.

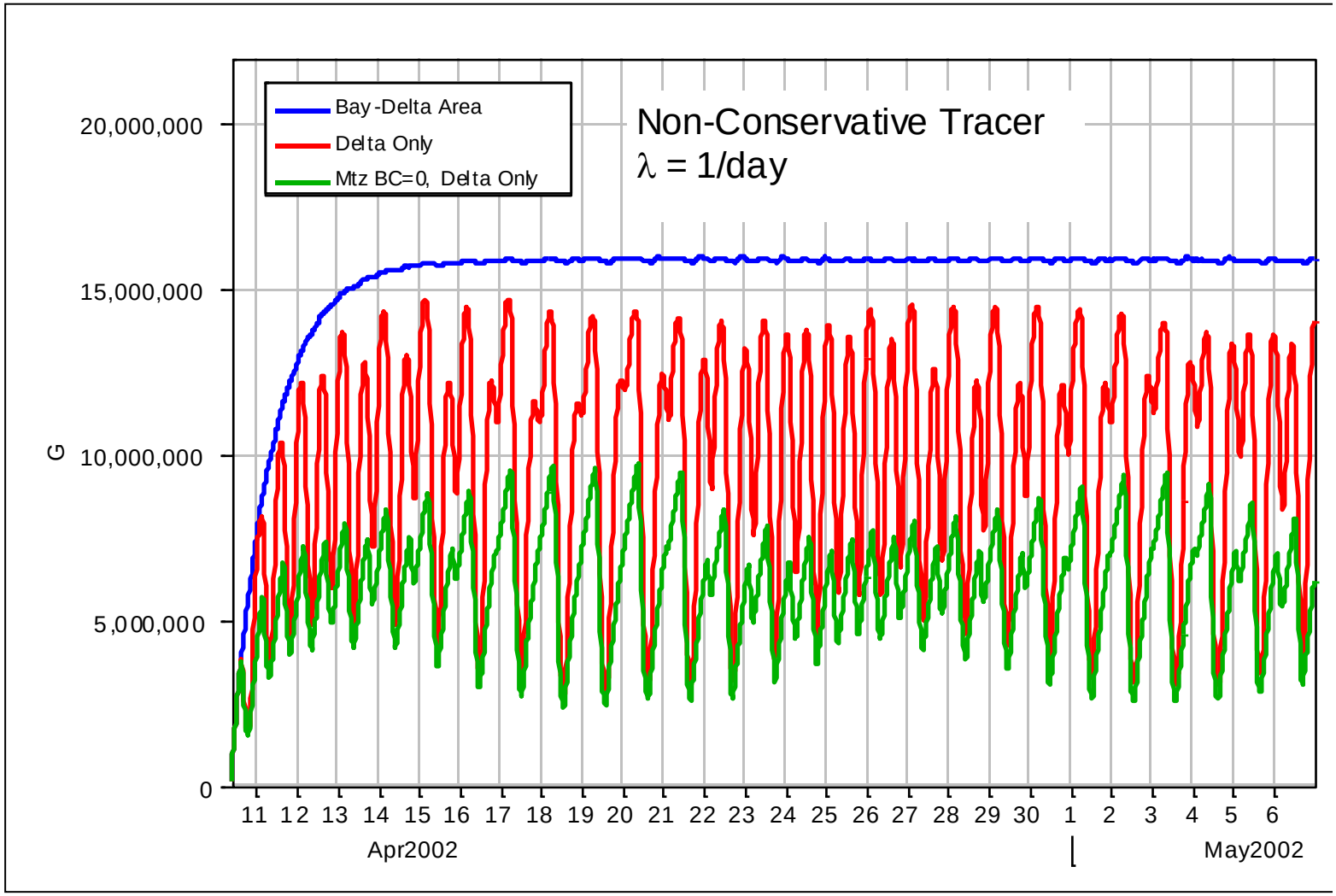


Figure 25-142 Tracer mass time series for the non-conservative CCCSD tracer (λ = 1/day). The NDO is 11,000 to 16,000 cfs over the simulation period.

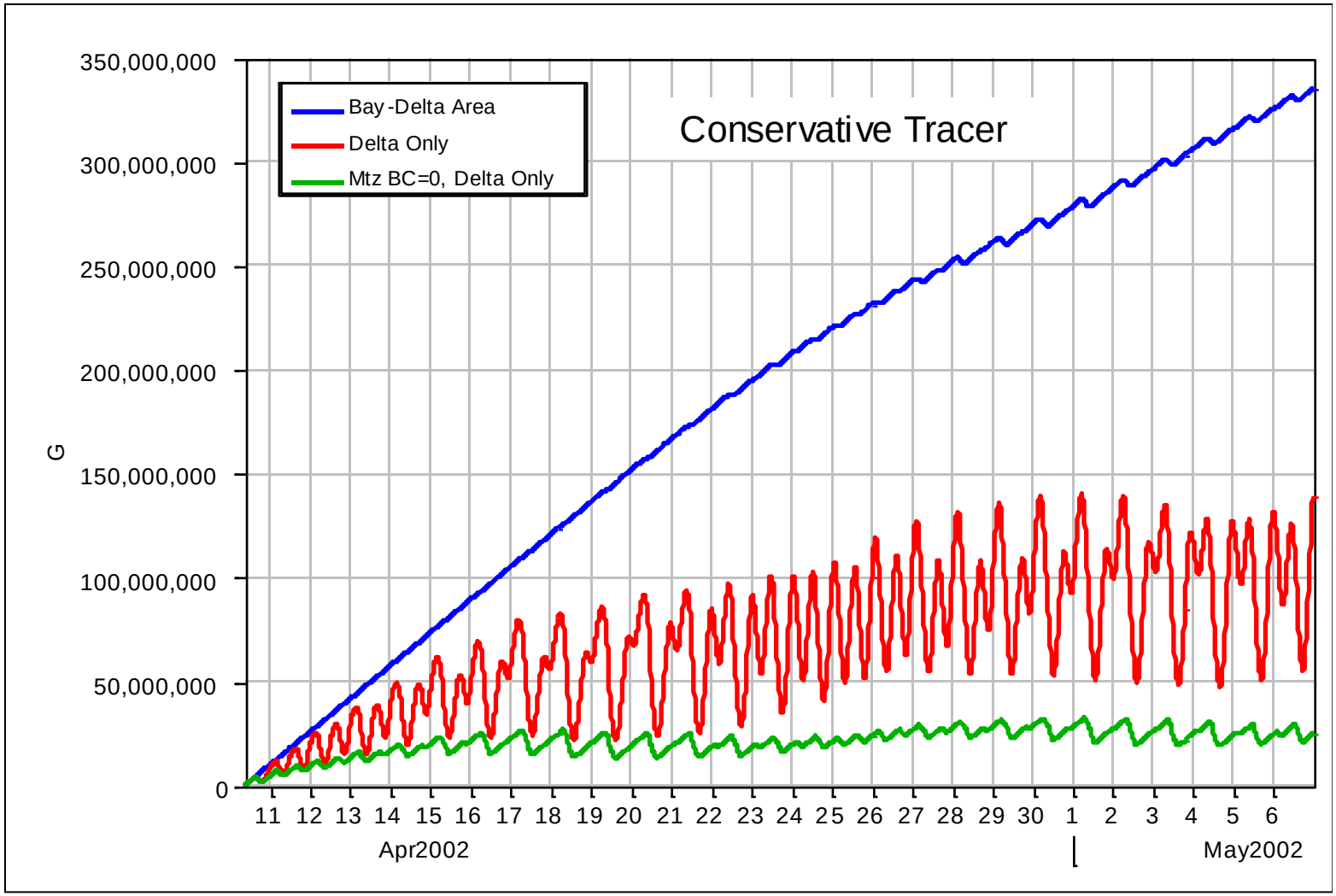


Figure 25-143 Tracer mass time series for the conservative CCCSD tracer (no decay). The NDO is 11,000 to 16,000 cfs over the simulation period.

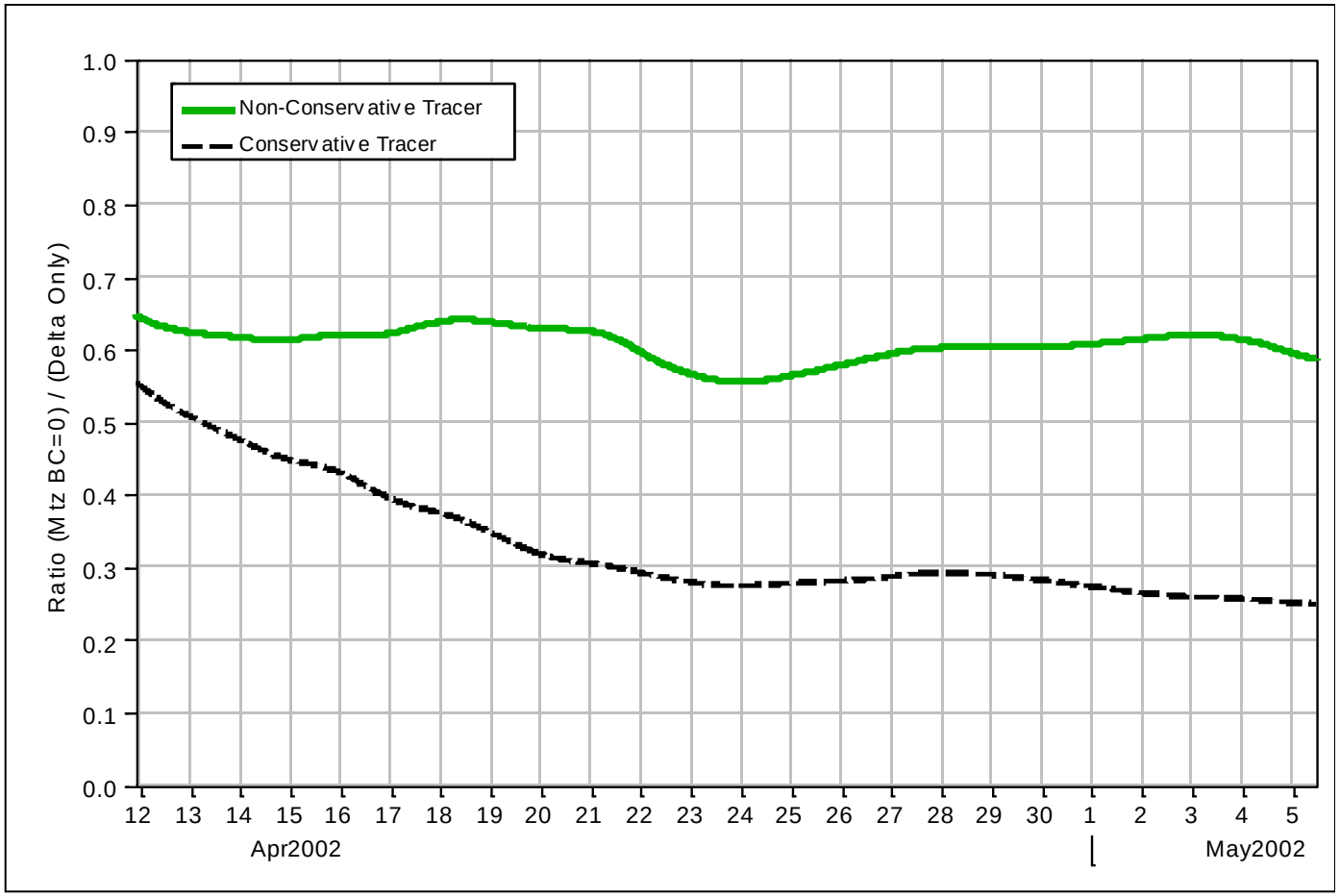


Figure 25-144 Times series plots of ("Mtz BC=0")/("Delta Only") tracer mass for the conservative and non-conservative CCCSD tracers. The NDO is 11,000 to 16,000 cfs over the simulation period.

26 Calibration Figures and Categorical Statistics (Version 8.0.6)

26.1 Algae

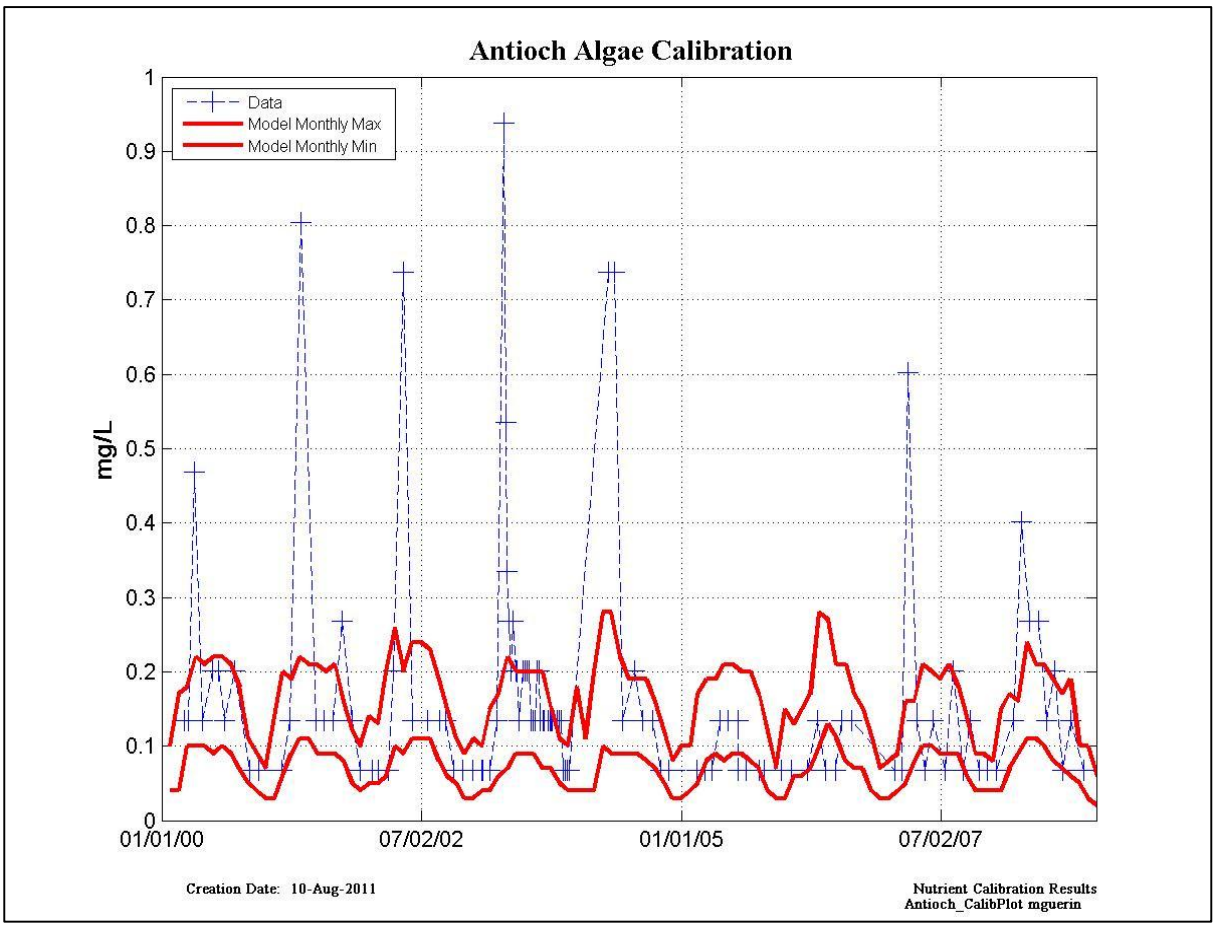


Figure 26-1 Modeled algae/chl-a calibration results at Antioch – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-1 Model calibration/validation statistics at Antioch for algae/chl-a for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	S	VG	Underestimate	U
Dry WY Calibration	S	G	Underestimate	U
Wet WY Calibration	S	VG	Underestimate	U
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	G	VG	Overestimate	S

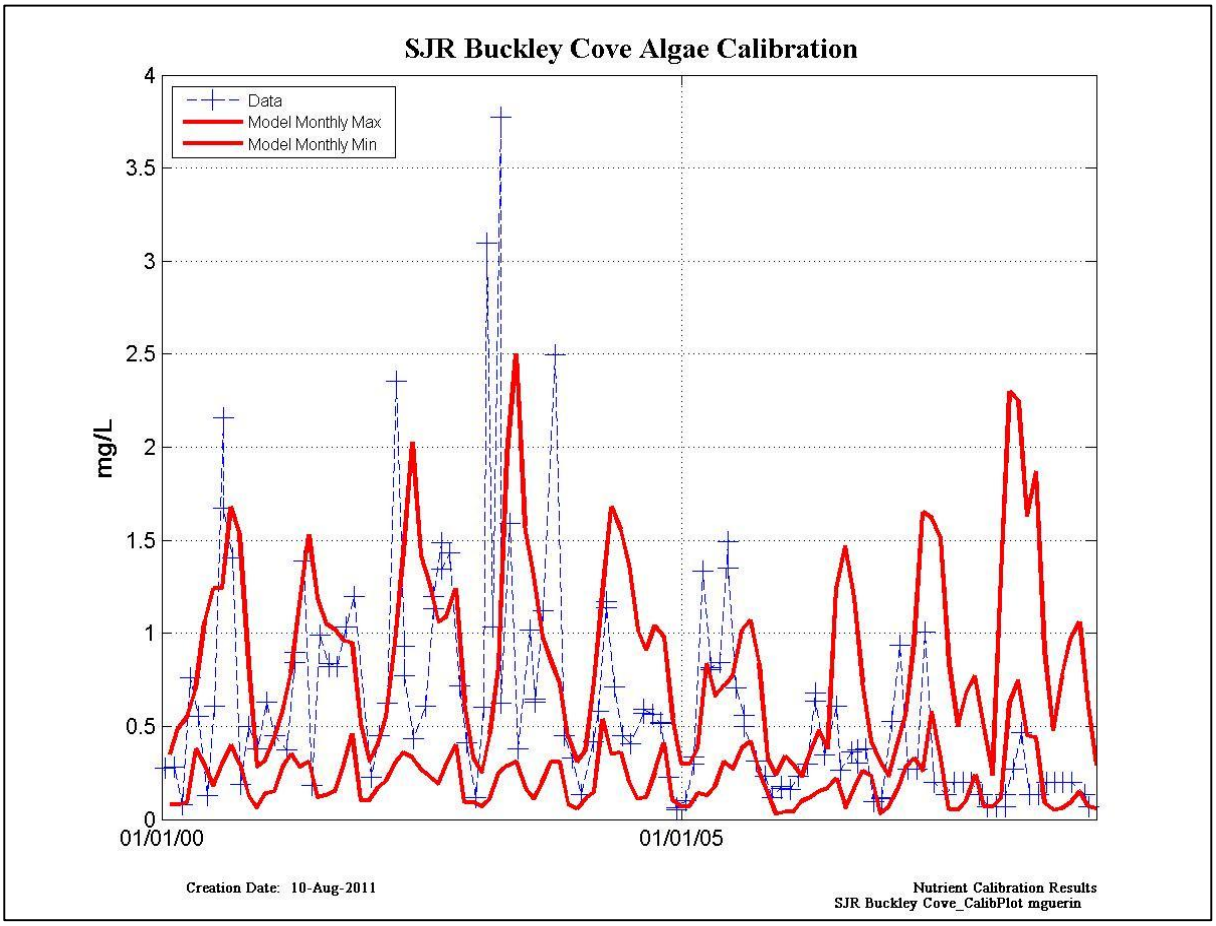


Figure 26-2 Modeled algae/chl-a calibration results at SJR Buckley Cove – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-2 Model calibration/validation statistics at SJR Buckley Cove for algae/chl-a for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	G
Wet WY Calibration	S	G	Underestimate	U
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	VG	VG	Underestimate	G

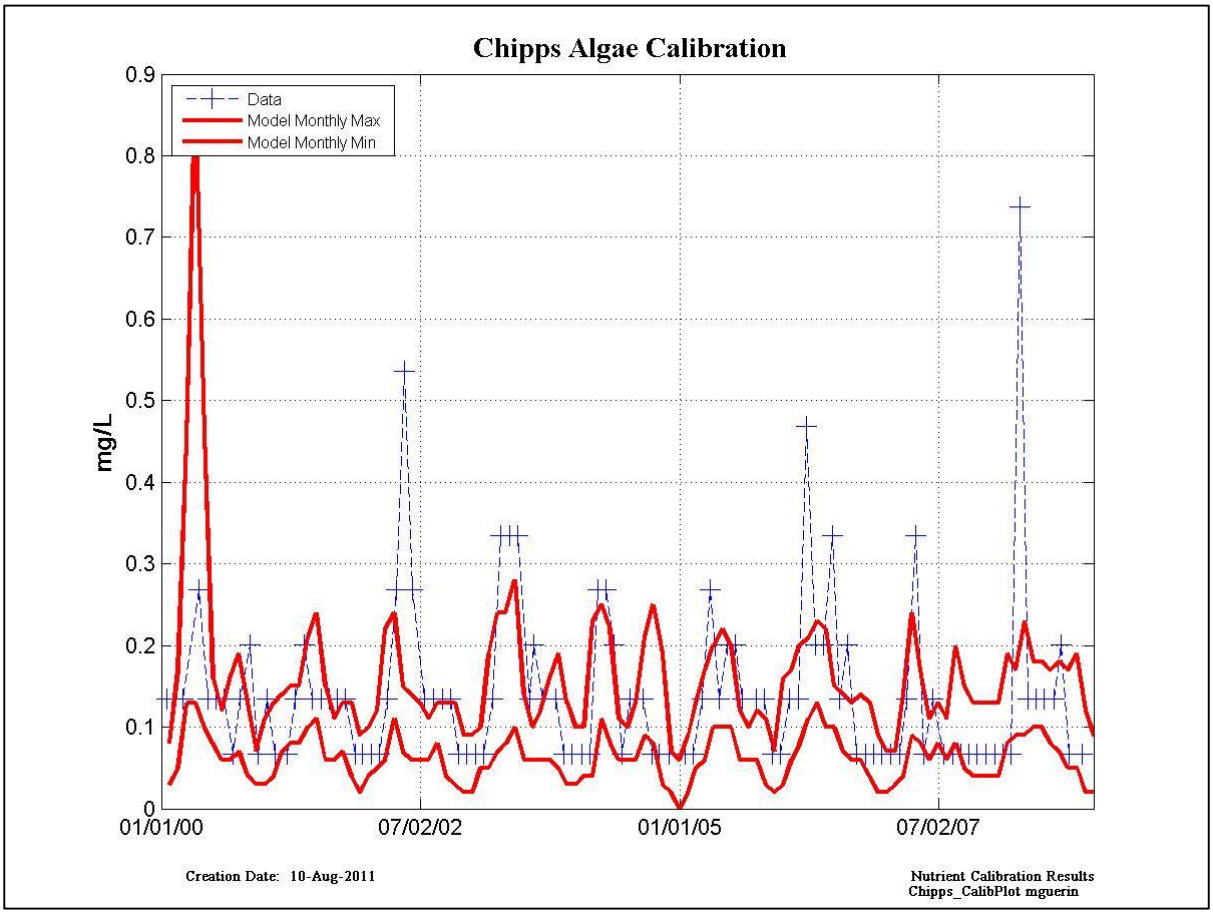


Figure 26-3Modeled algae/chl-a calibration results at Chipps– data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-3 Model calibration/validation statistics at Chipps for algae/chl-a for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	S	VG	Underestimate	U
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	G	VG	Underestimate	S
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	S	VG	Underestimate	U

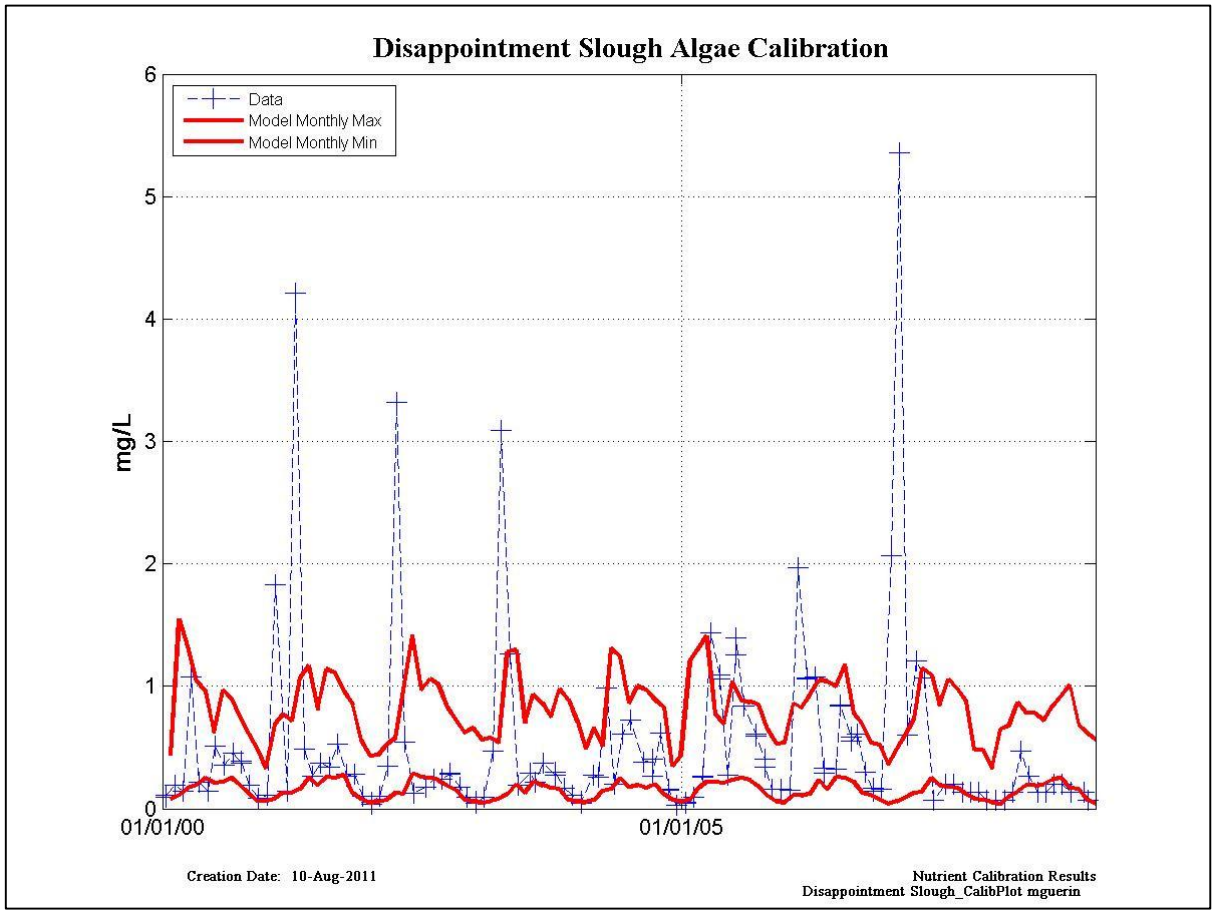


Figure 26-4 Modeled algae/chl-a calibration results at Disappointment Sl. – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-4 Model calibration/validation statistics at Disappointment Sl. for algae/chl-a for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	S	G	Underestimate	U
Dry WY Calibration	S	S	Underestimate	U
Wet WY Calibration	G	VG	Underestimate	G
Dry WY Validation	S	S	Underestimate	U
Wet WY Validation	G	VG	Underestimate	G

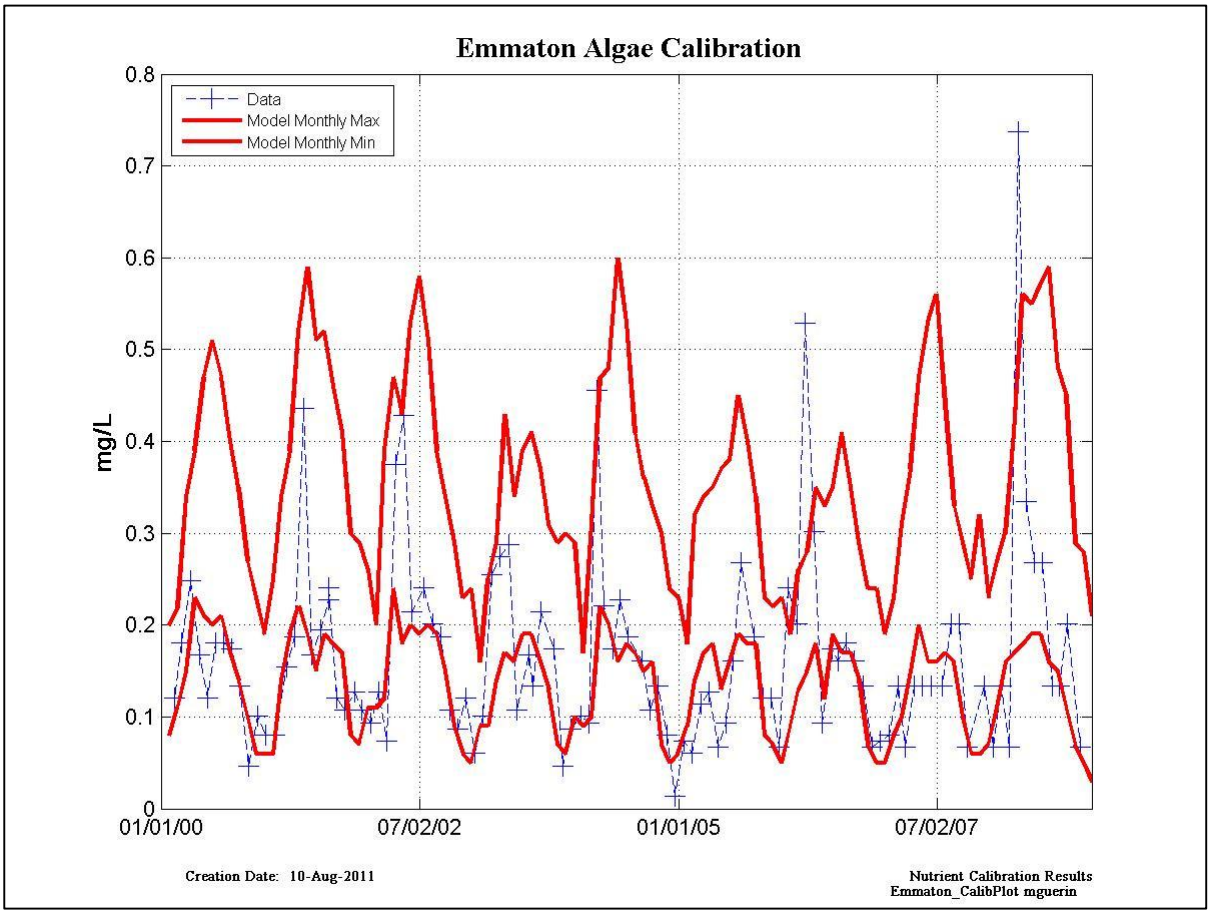


Figure 26-5 Modeled algae/chl-a calibration results at Emmaton – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-5 Model calibration/validation statistics at Emmaton for algae/chl-a for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	S	VG	Overestimate	G

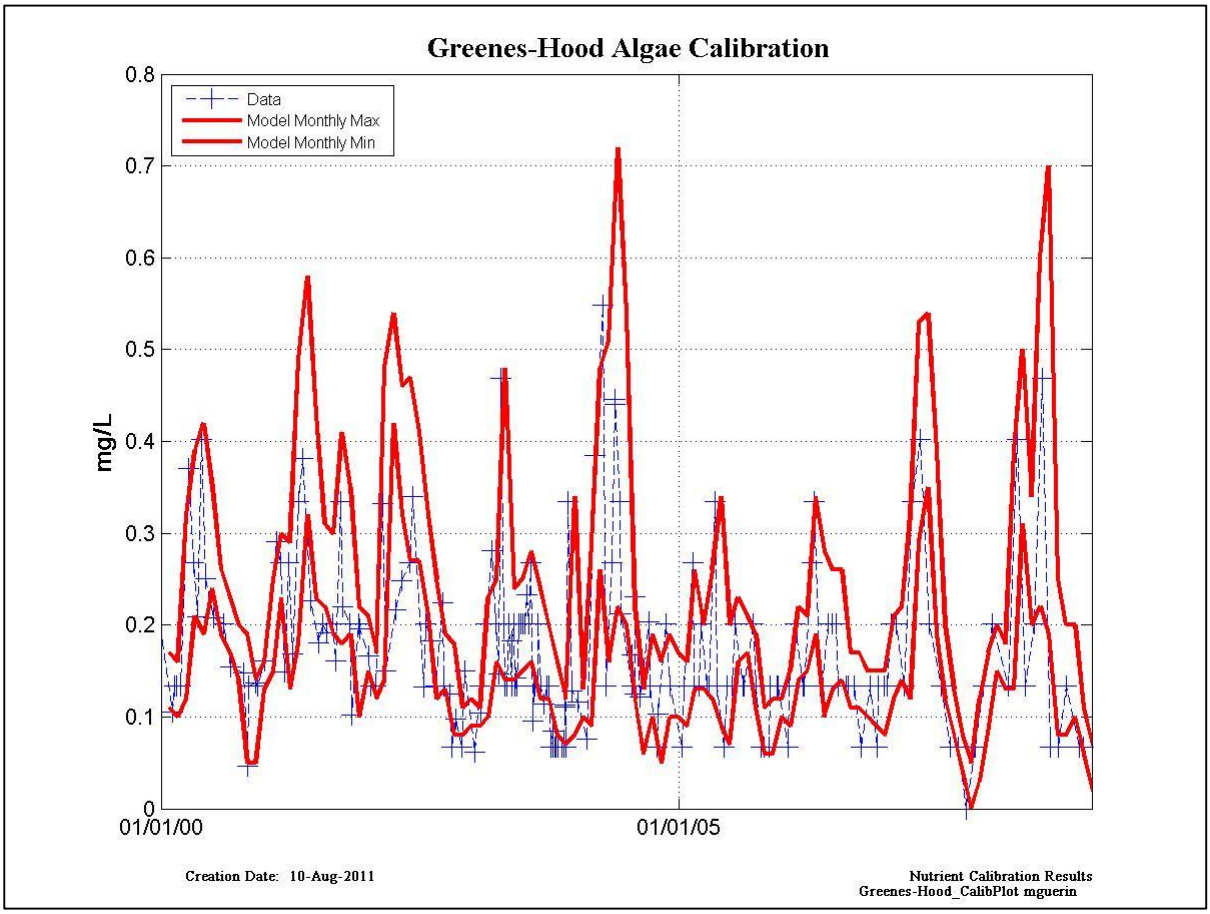


Figure 26-6 Modeled algae/chl-a calibration results at Greens-Hood – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-6 Model calibration/validation statistics at Greens-Hood for algae/chl-a for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	S	VG	Overestimate	S
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

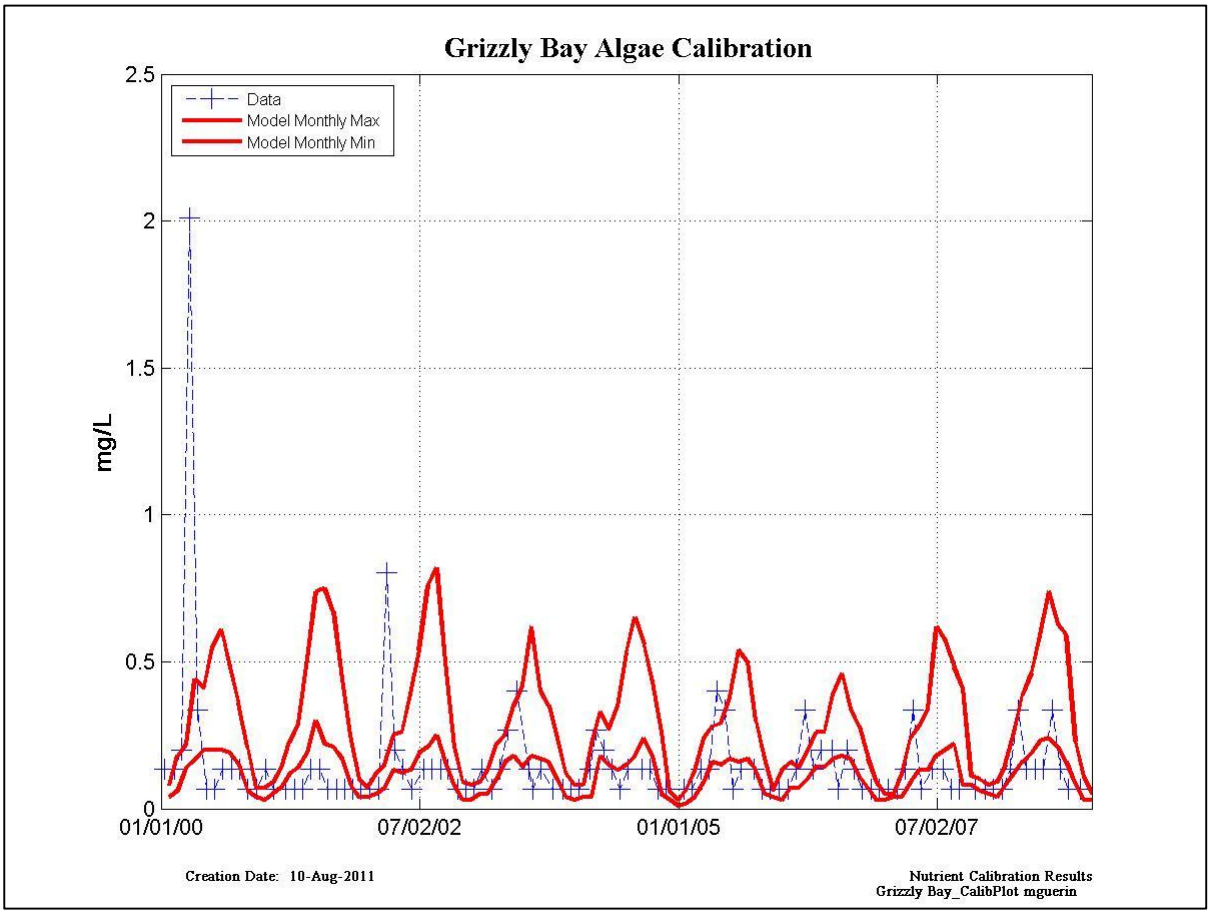


Figure 26-7 Modeled algae/chl-a calibration results at Grizzly Bay – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-7 Model calibration/validation statistics at Grizzly Bay for algae/chl-a for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	S	VG	Overestimate	U
Dry WY Calibration	S	VG	Overestimate	U
Wet WY Calibration	S	VG	Underestimate	U
Dry WY Validation	G	VG	Overestimate	G
Wet WY Validation	G	VG	Underestimate	G

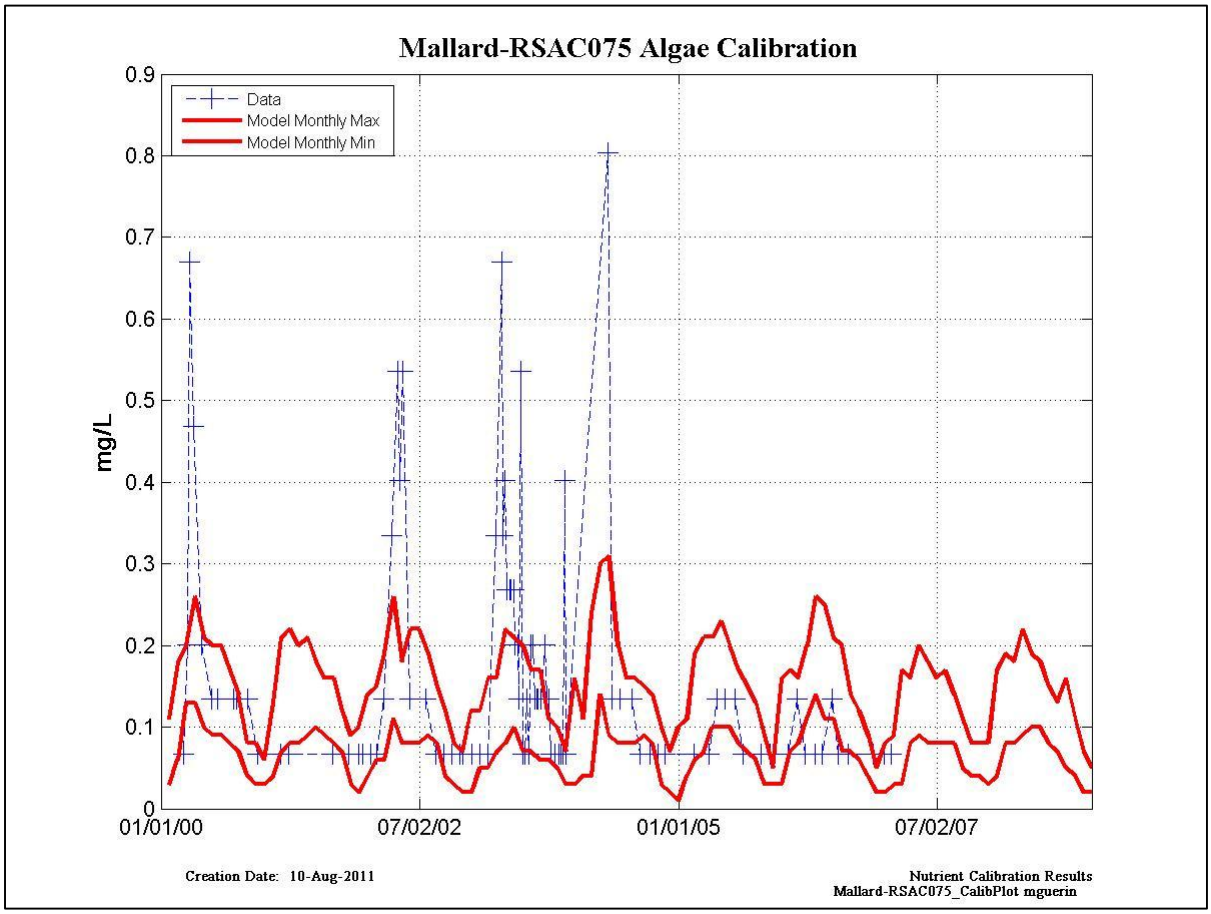


Figure 26-8 Modeled algae/chl-a calibration results at Mallard-RSAC075 – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-8 Model calibration/validation statistics at Mallard-RSAC075 for algae/chl-a for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years Wet Years (2005, 2006), Validation for Dry Years (2007, 2008) missing due to lack of data.

	NSE	PBIAS	Bias	RSR
ALL	S	G	Underestimate	U
Dry WY Calibration	S	G	Underestimate	U
Wet WY Calibration	S	G	Underestimate	U
Dry WY Validation	-	-	-	-
Wet WY Validation	S	VG	Overestimate	U

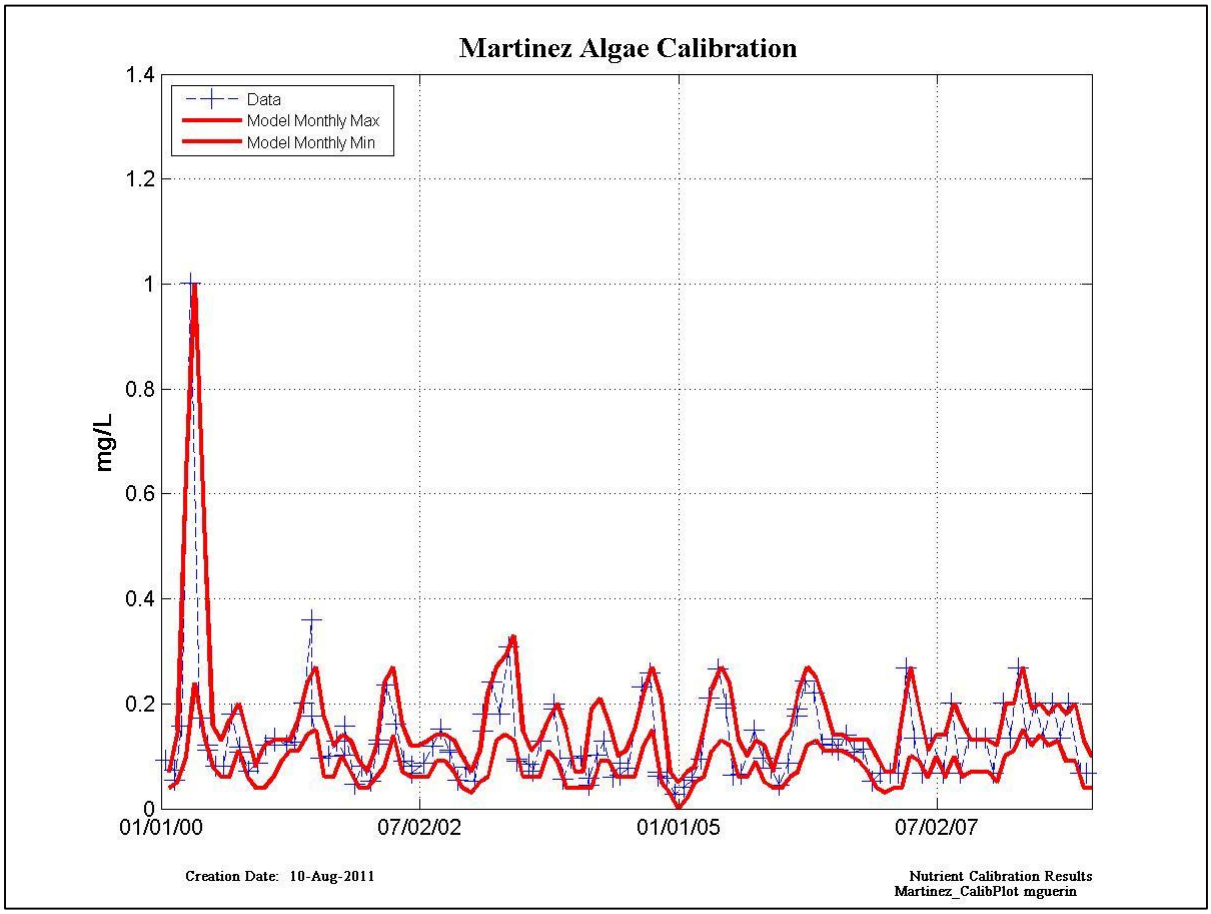


Figure 26-9 Modeled algae/chl-a calibration results at Martinez – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines

Table 26-9 Model calibration/validation statistics at Martinez for algae/chl-a for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG

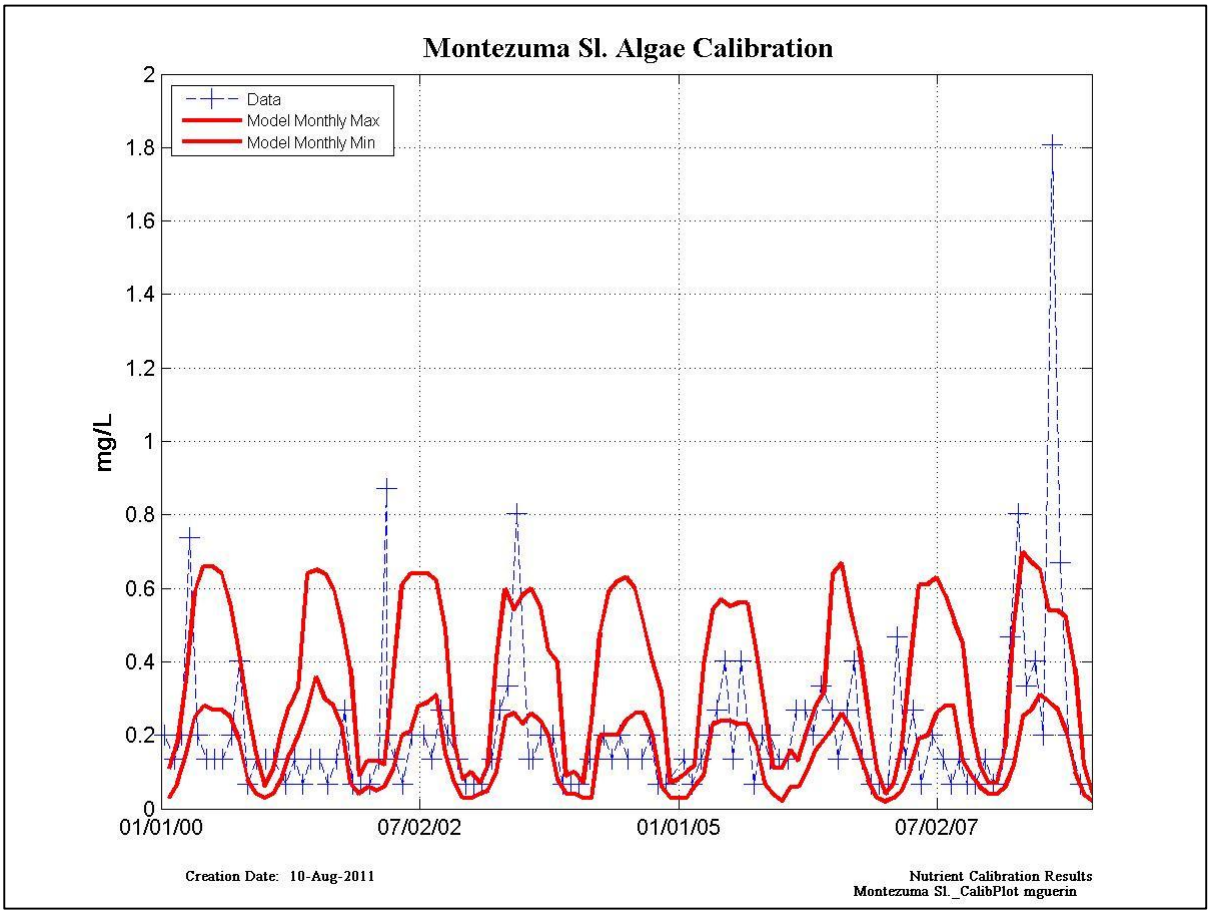


Figure 26-10 Modeled algae/chl-a calibration results at Montezuma Sl. Bend 2– data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-10 Model calibration/validation statistics at Montezuma Sl. for algae/chl-a for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	S	VG	Overestimate	U
Dry WY Calibration	S	G	Overestimate	U
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	G	VG	Overestimate	G

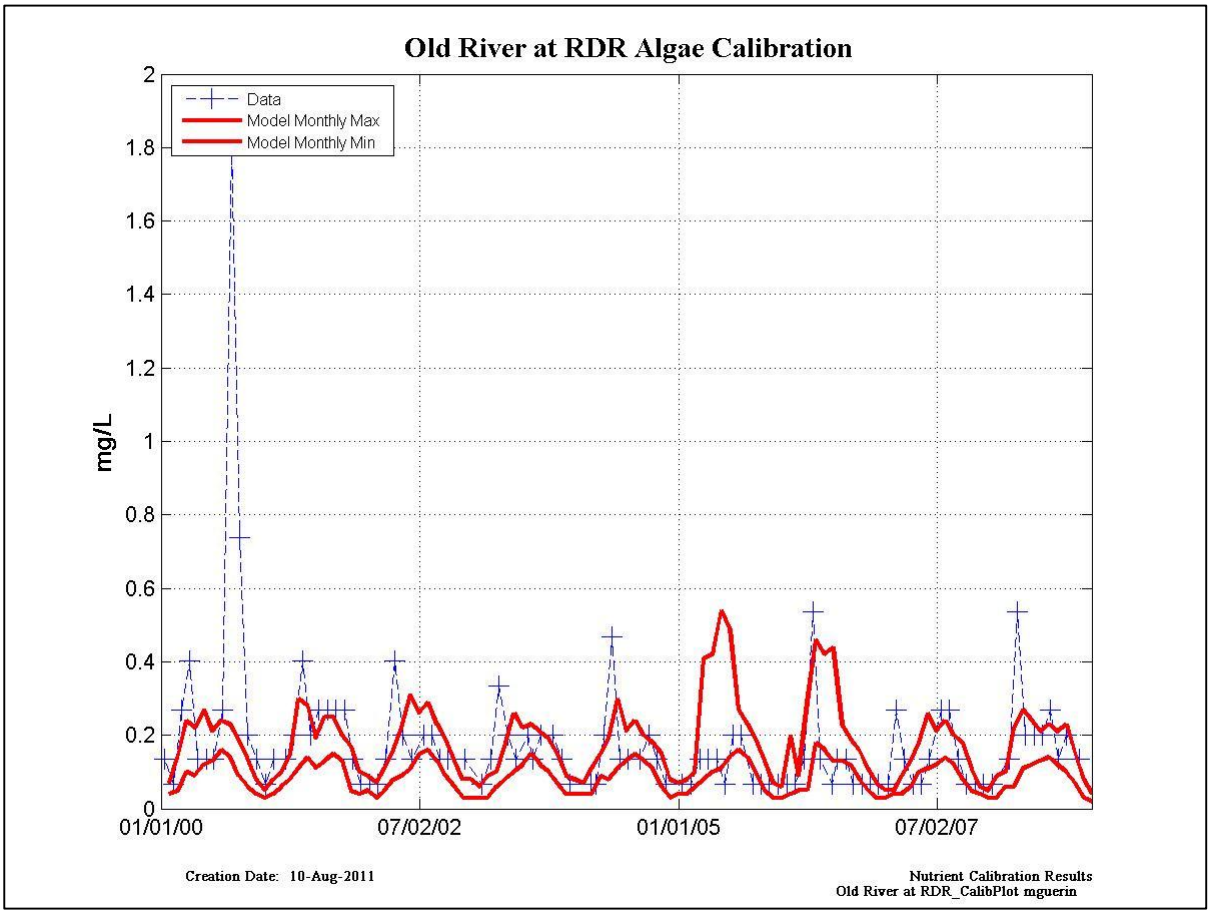


Figure 26-11 Modeled algae/chl-a calibration results at Old R. at Rancho Del Rio – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-11 Model calibration/validation statistics at Old R. at Rancho Del Rio for algae/chl-a for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	S	VG	Underestimate	U
Dry WY Calibration	G	VG	Underestimate	G
Wet WY Calibration	S	S	Underestimate	U
Dry WY Validation	S	VG	Underestimate	S
Wet WY Validation	VG	VG	Overestimate	VG

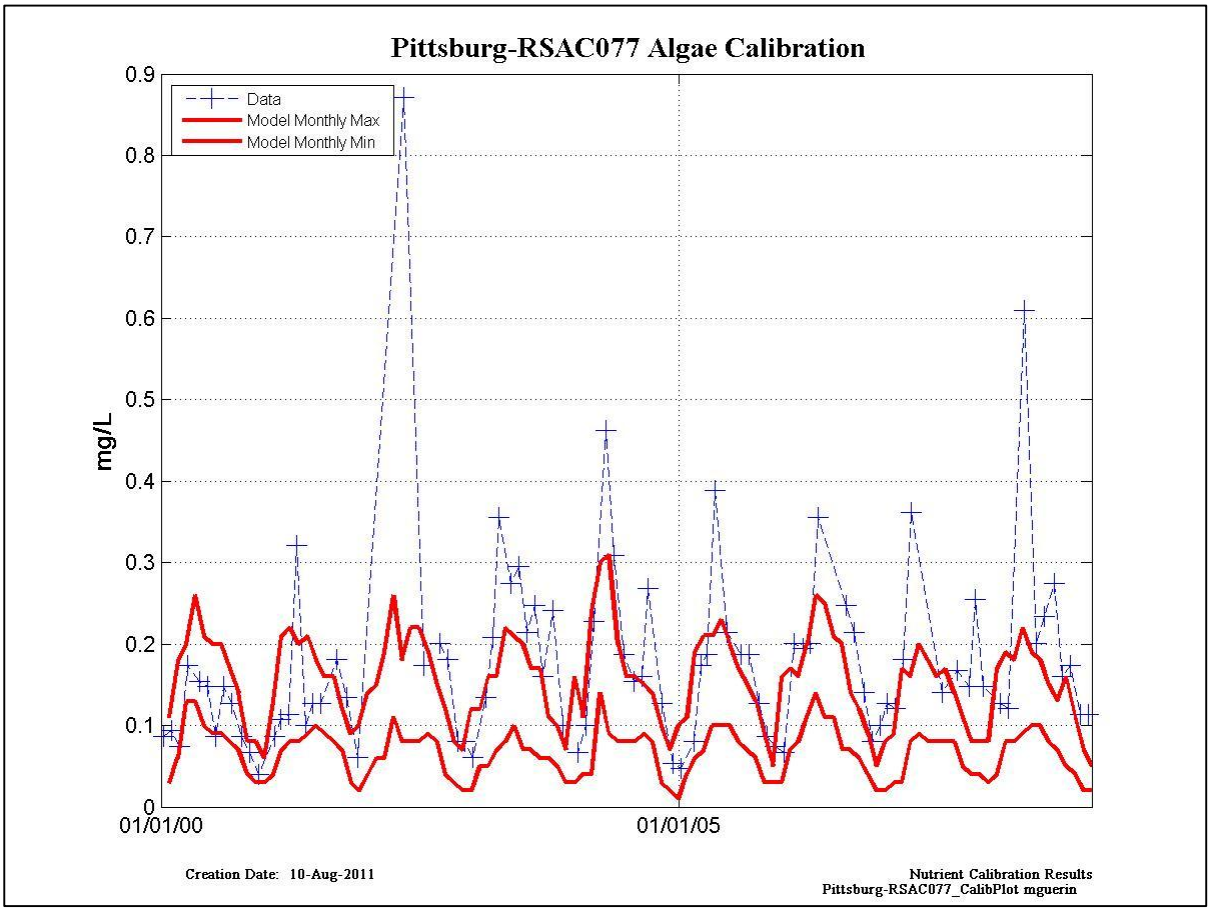


Figure 26-12 Modeled algae/chl-a calibration results at Pittsburg-RSAC077 – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-12 Model calibration/validation statistics at Pittsburg-RSAC077 for algae/chl-a for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	G	G	Underestimate	G
Dry WY Calibration	S	G	Underestimate	U
Wet WY Calibration	G	VG	Underestimate	S
Dry WY Validation	S	G	Underestimate	U
Wet WY Validation	G	VG	Underestimate	S

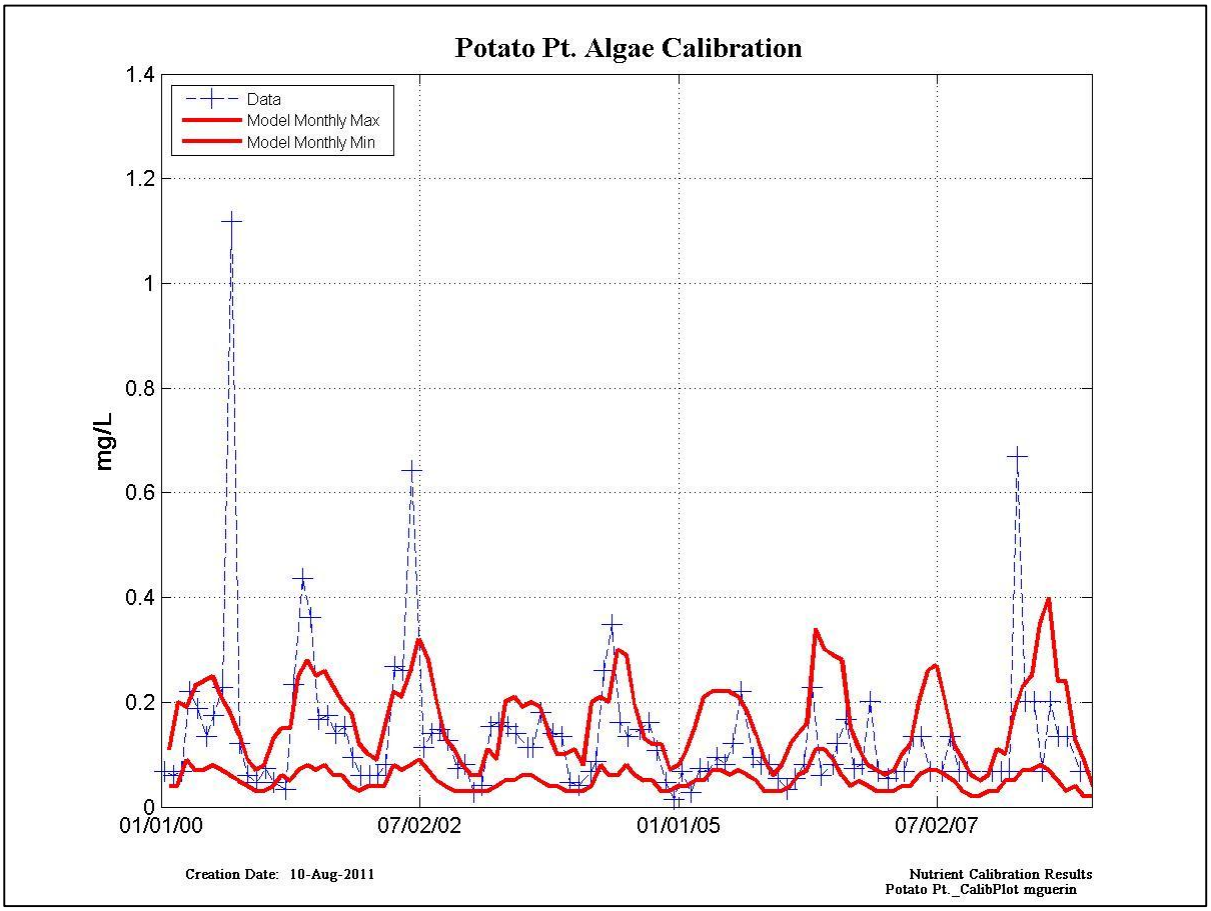


Figure 26-13 Modeled algae/chl-a calibration results at Potato Pt. – data points are located at blue symbols; monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-13 Model calibration/validation statistics at Potato Pt. for algae/chl-a for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	S	VG	Underestimate	U
Dry WY Calibration	G	VG	Underestimate	G
Wet WY Calibration	S	G	Underestimate	U
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	G	VG	Underestimate	G

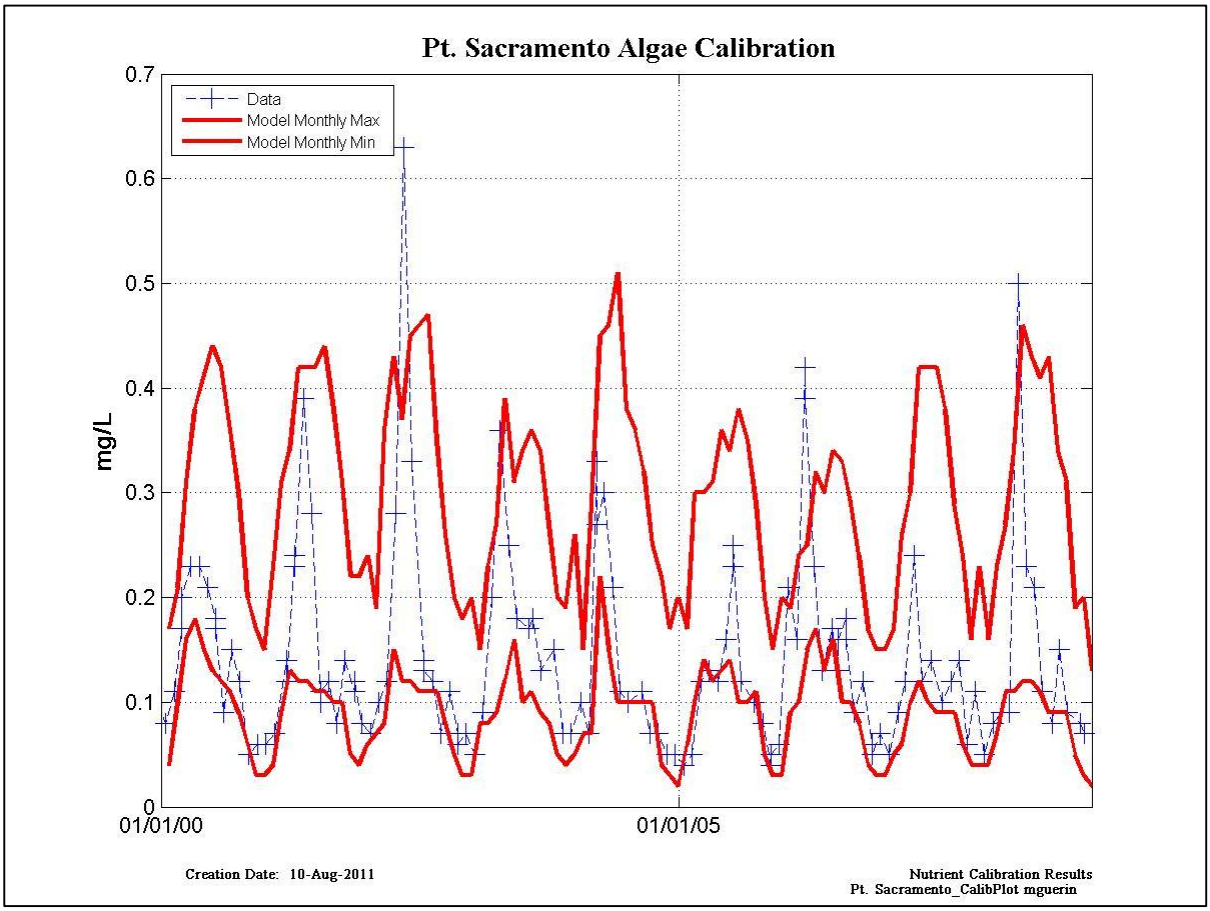


Figure 26-14 Modeled algae/chl-a calibration results at Pt. Sacramento – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-14 Model calibration/validation statistics at Pt. Sacramento for algae/chl-a for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG

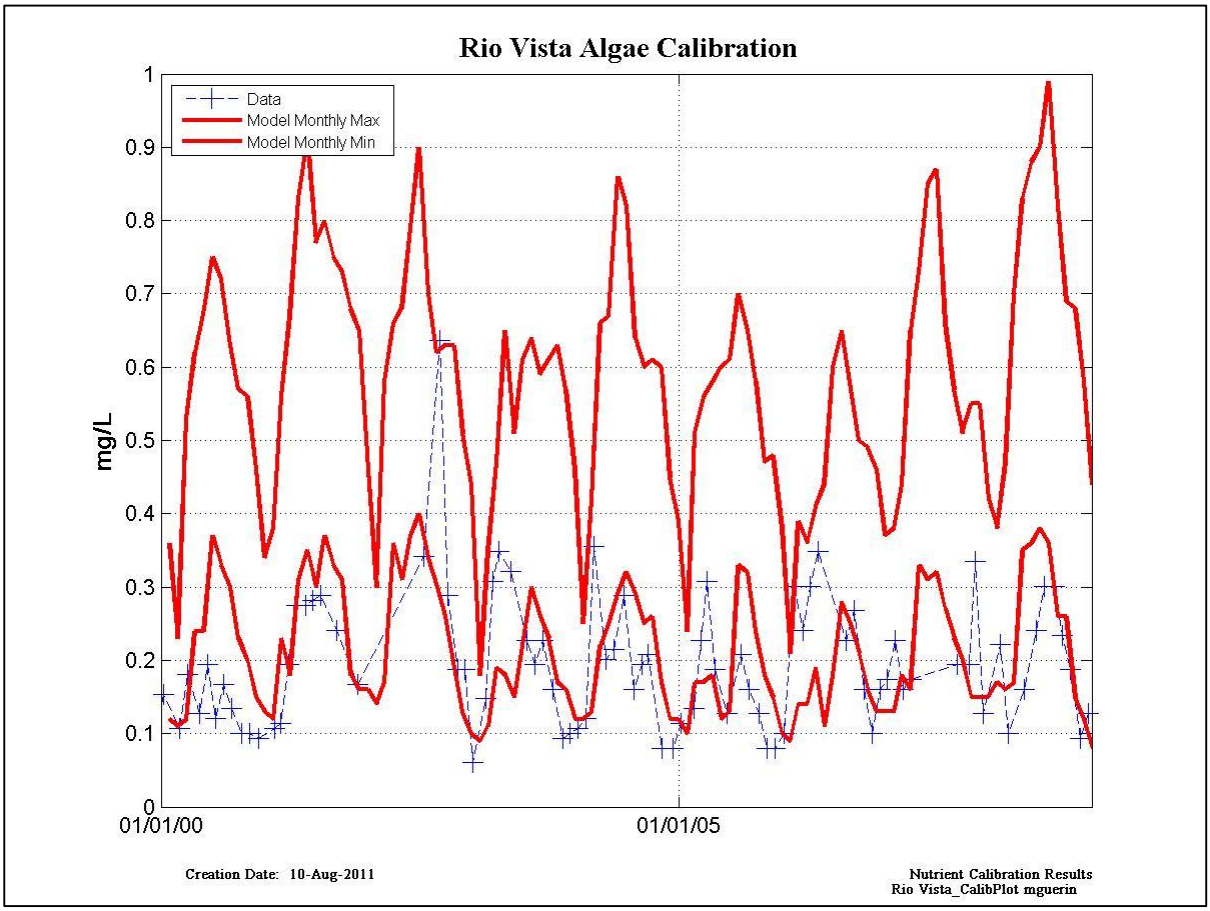


Figure 26-15 Modeled algae/chl-a calibration results at Rio Vista – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-15 Model calibration/validation statistics at Rio Vista for algae/chl-a for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	S	G	Overestimate	U
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	VG	VG	Overestimate	VG

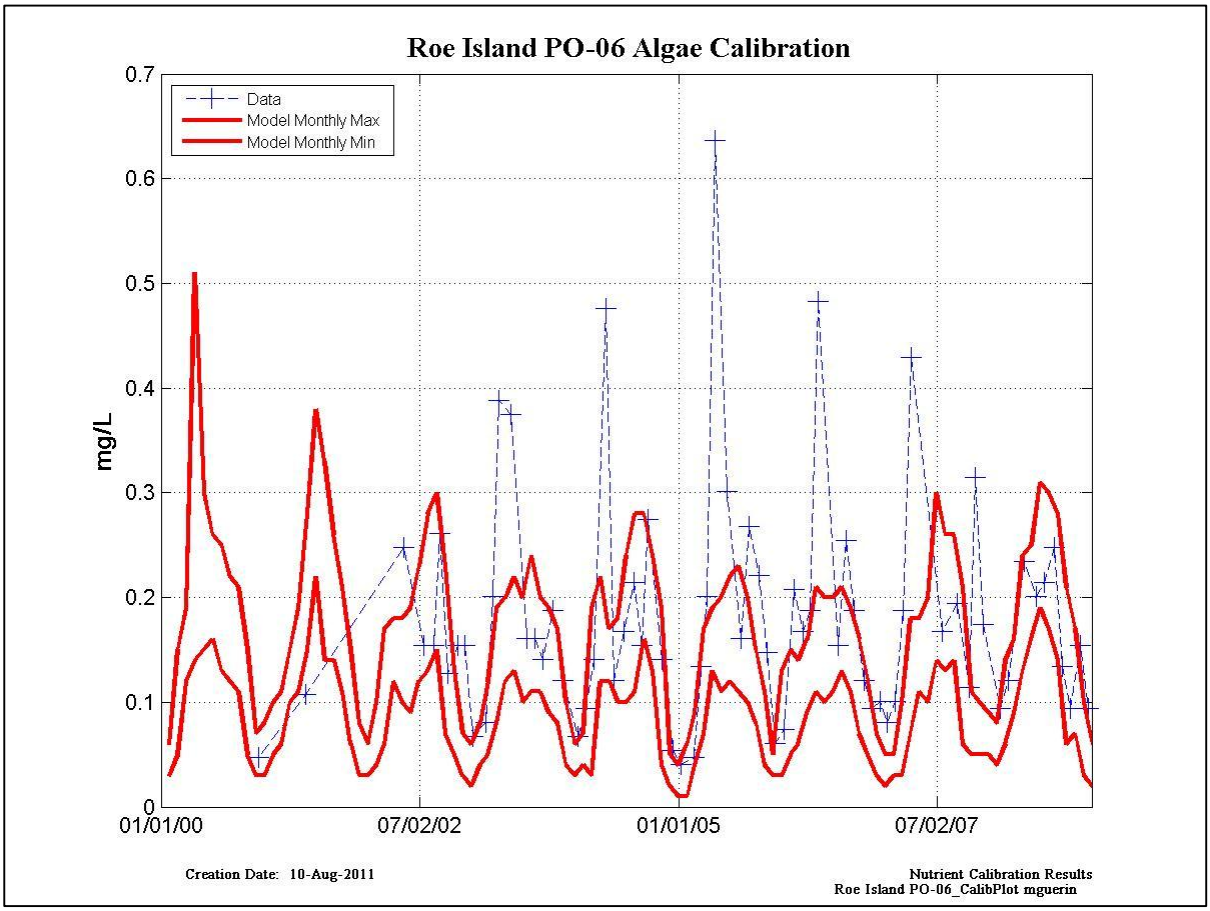


Figure 26-16 Modeled algae/chl-a calibration results at Roe Island – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-16 Model calibration/validation statistics at Roe Island for algae/chl-a for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	S	VG	Underestimate	U
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	S	VG	Underestimate	S
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	S	G	Underestimate	U

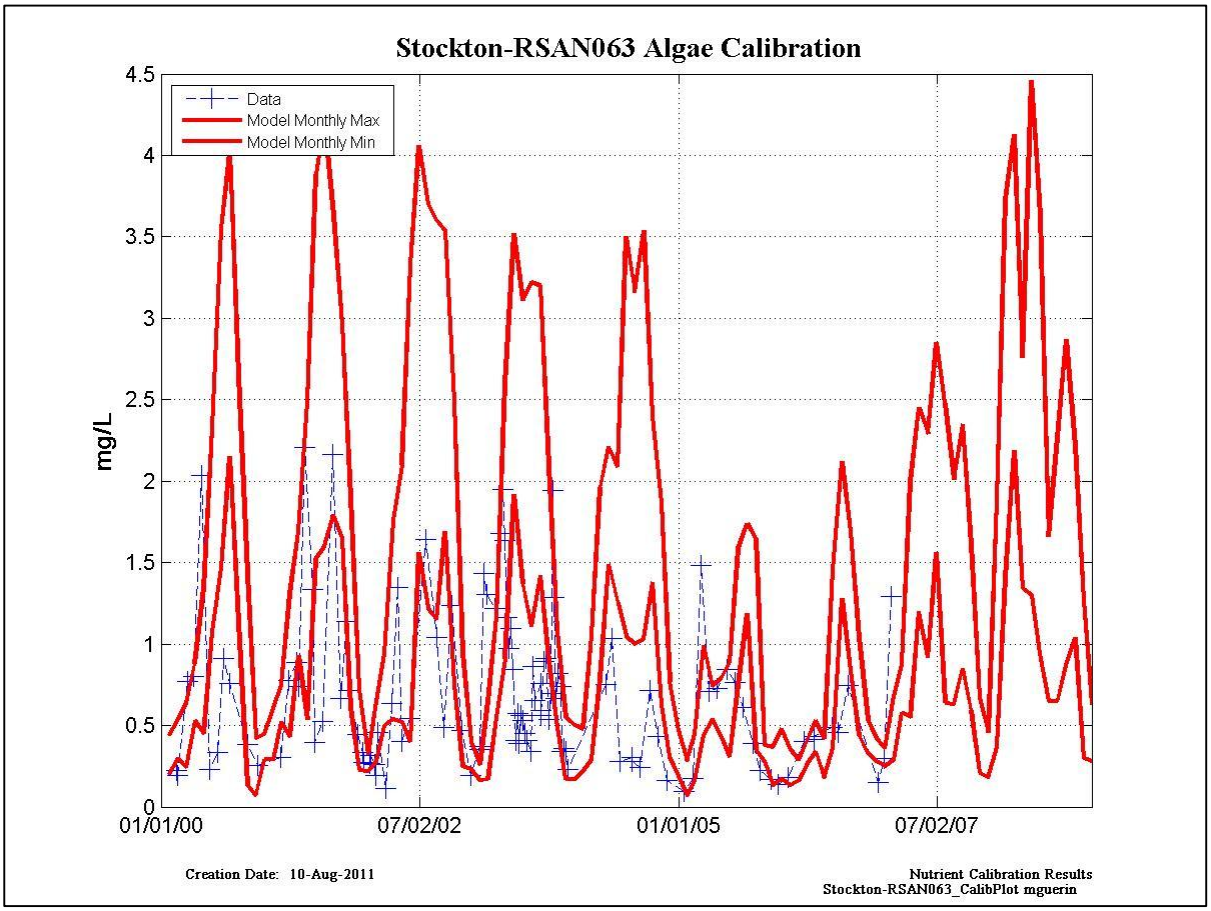


Figure 26-17 Modeled algae/chl-a calibration results at Stockton-RSAN063 – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-17 Model calibration/validation statistics at Stockton-RSAN063 for algae/chl-a for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Wet Years (2005, 2006). Validation for Dry Years (2007, 2008) is missing due to lack of data.

	NSE	PBIAS	Bias	RSR
ALL	S	G	Overestimate	U
Dry WY Calibration	S	VG	Overestimate	U
Wet WY Calibration	U	G	Overestimate	U
Dry WY Validation				
Wet WY Validation	S	VG	Overestimate	U

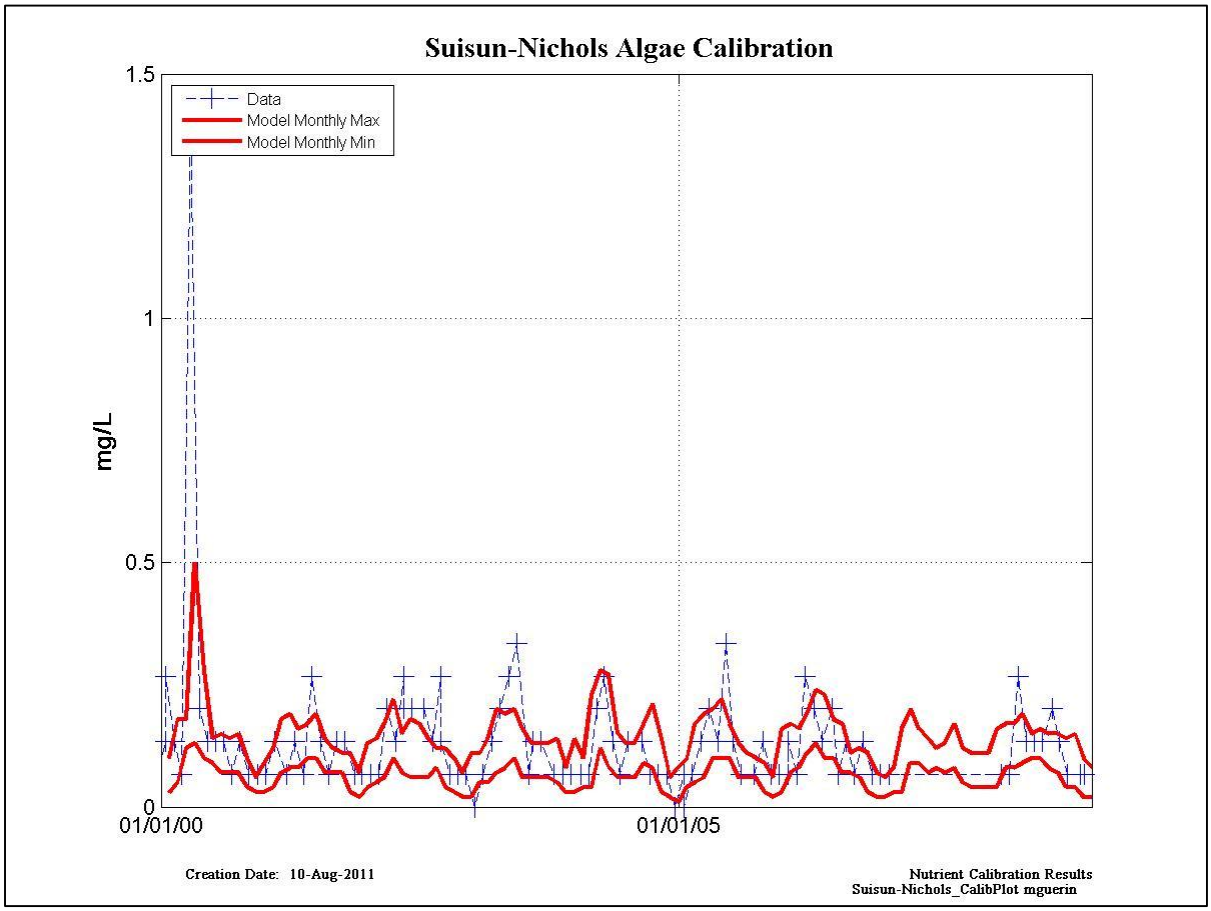


Figure 26-18 Modeled algae/chl-a calibration results at Suisun-Nichols – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-18 Model calibration/validation statistics at Suisun-Nichols for algae/chl-a for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	G	VG	Underestimate	G
Dry WY Calibration	G	VG	Underestimate	G
Wet WY Calibration	S	G	Underestimate	U
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	G

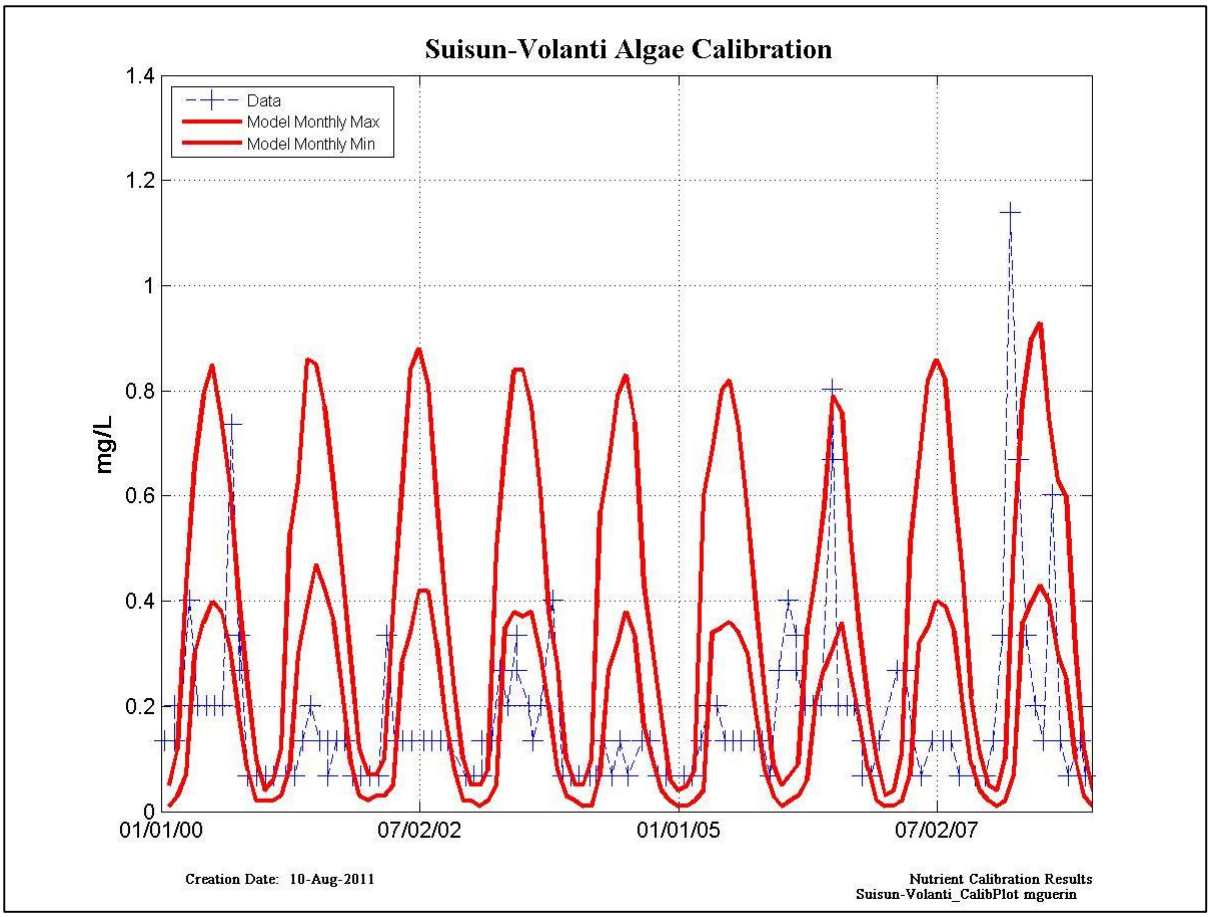


Figure 26-19 Modeled algae/chl-a calibration results at Suisun-Volanti – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-19 Model calibration/validation statistics at Suisun-Volanti for algae/chl-a for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	S	G	Overestimate	U
Dry WY Calibration	U	S	Overestimate	U
Wet WY Calibration	S	VG	Overestimate	U
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	S	VG	Overestimate	U

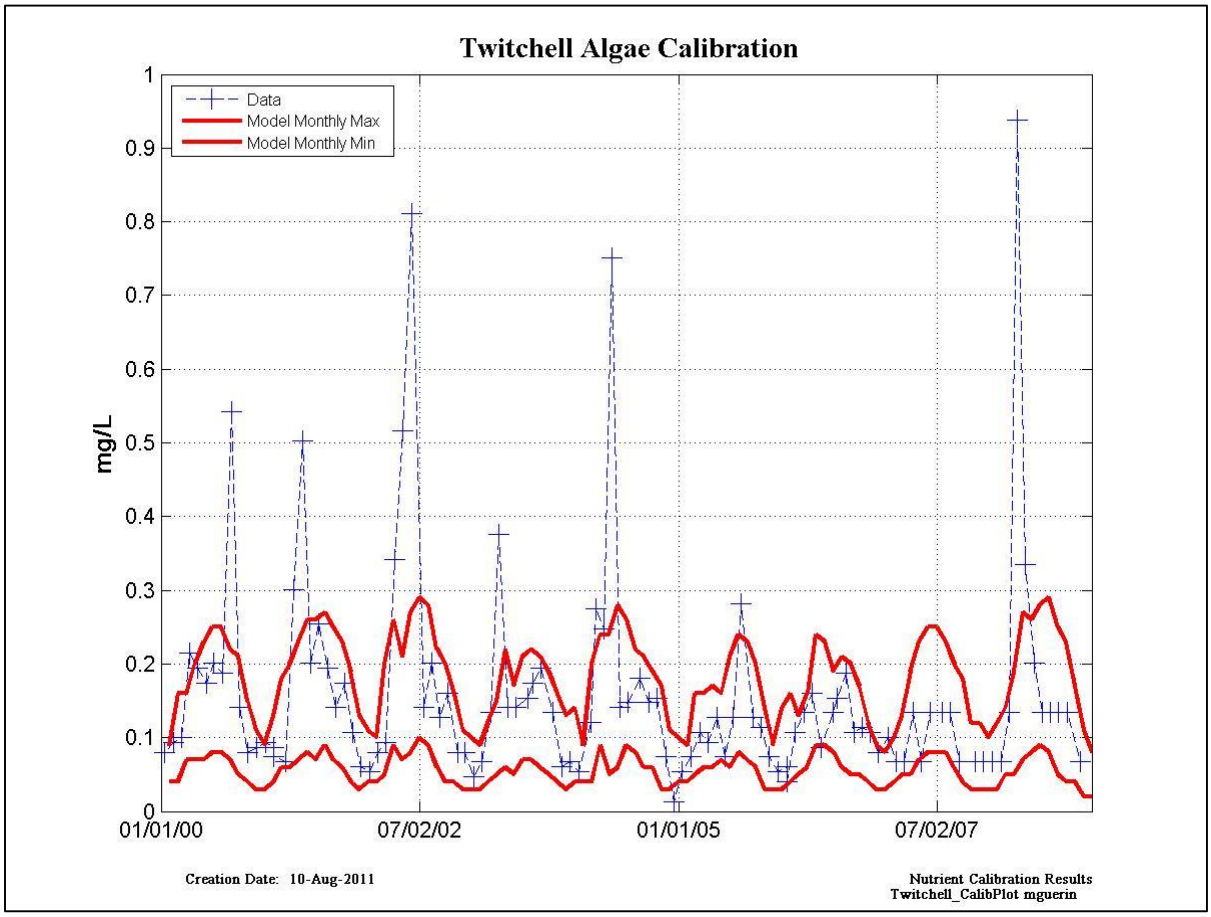


Figure 26-20 Modeled algae/chl-a calibration results at Twitchell – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-20 Model calibration/validation statistics at Twitchell for algae/chl-a for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	S	VG	Underestimate	U
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	S	VG	Underestimate	S
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	VG	VG	Underestimate	VG

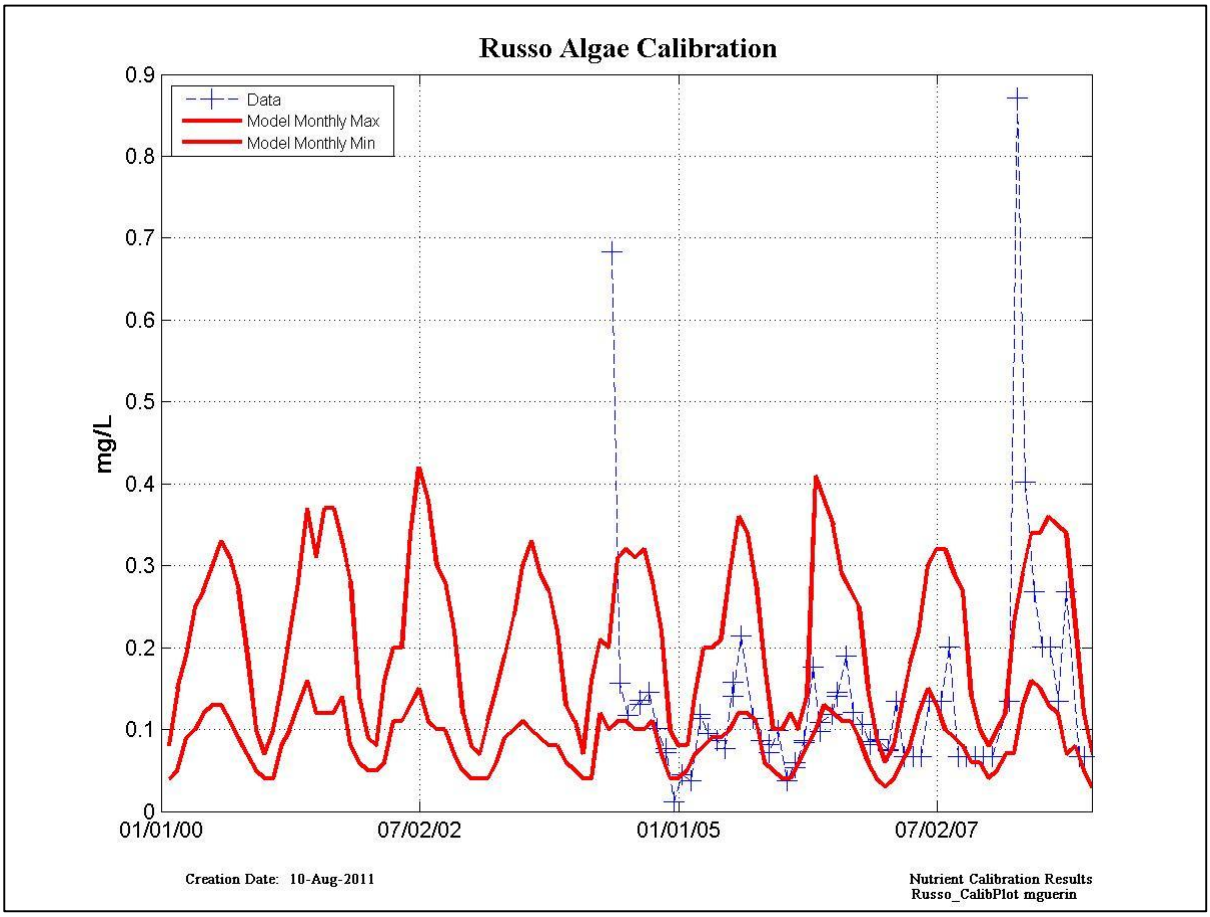


Figure 26-21 Modeled algae/chl-a calibration results at Russo – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-21 (intentionally left blank) Insufficient data to calculate calibration statistics.

26.2 Dissolved Oxygen

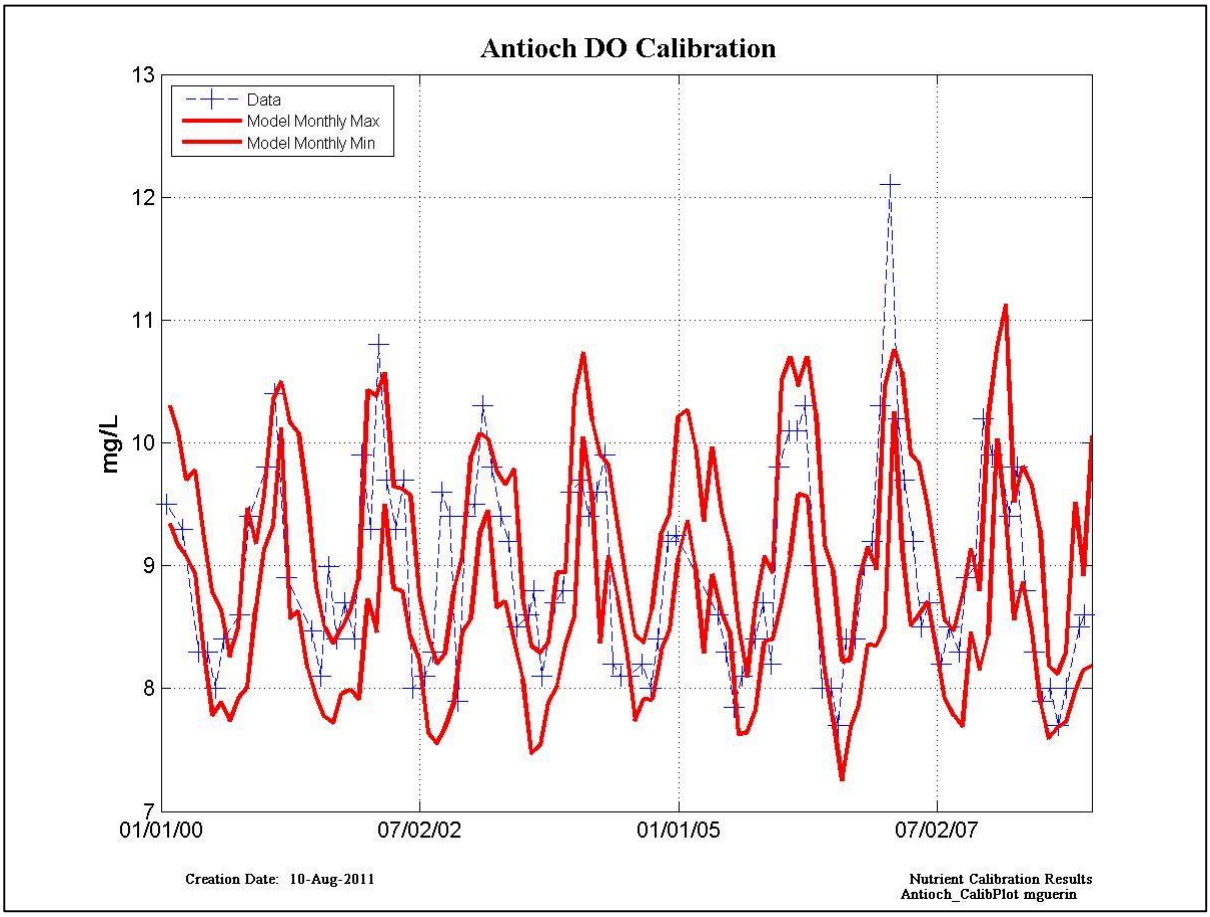


Figure 26-22 Modeled dissolved oxygen calibration results at Antioch – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-22 Model calibration/validation statistics at Antioch for dissolved oxygen for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

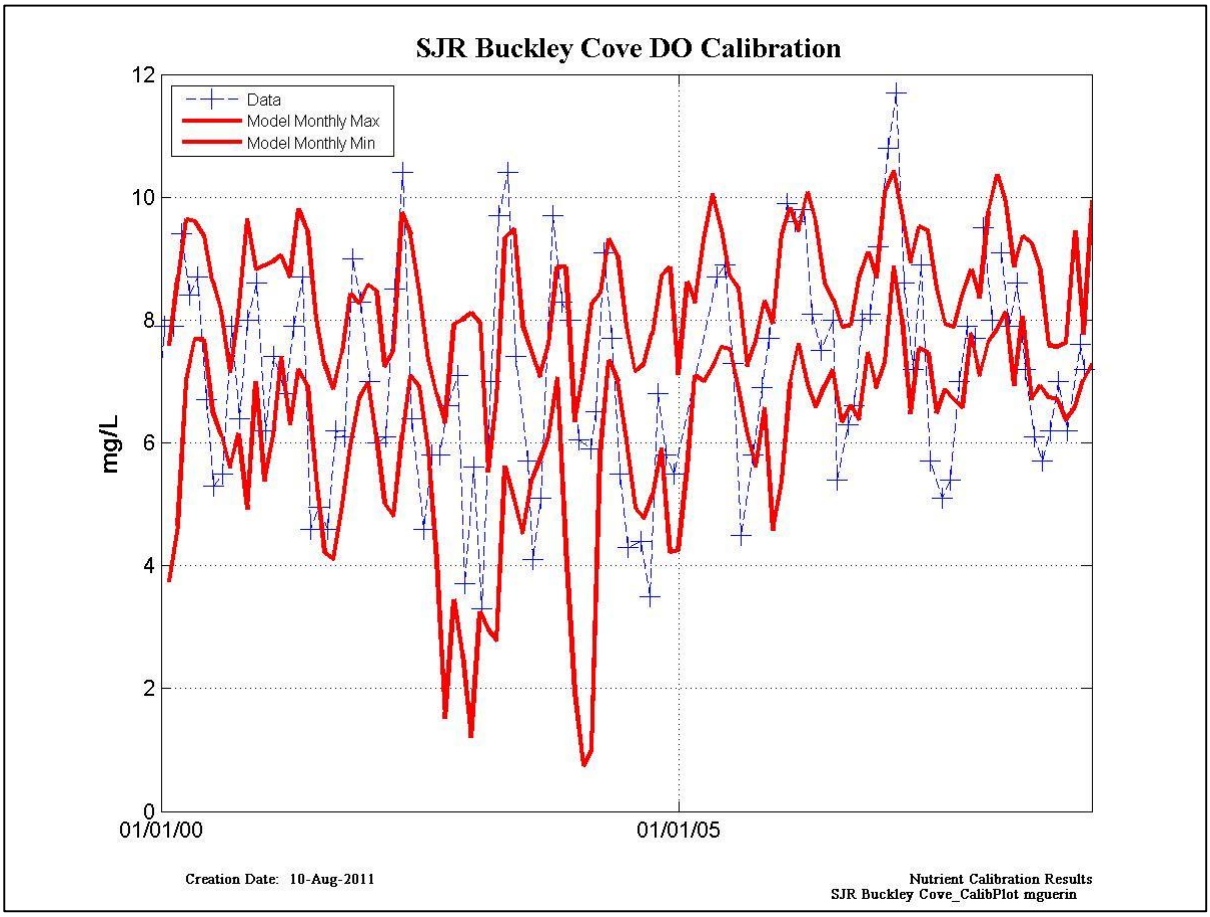


Figure 26-23 Modeled dissolved oxygen calibration results at SJR Buckley Cove –data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-23 Model calibration/validation statistics at SJR Buckley Cove for dissolved oxygen for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

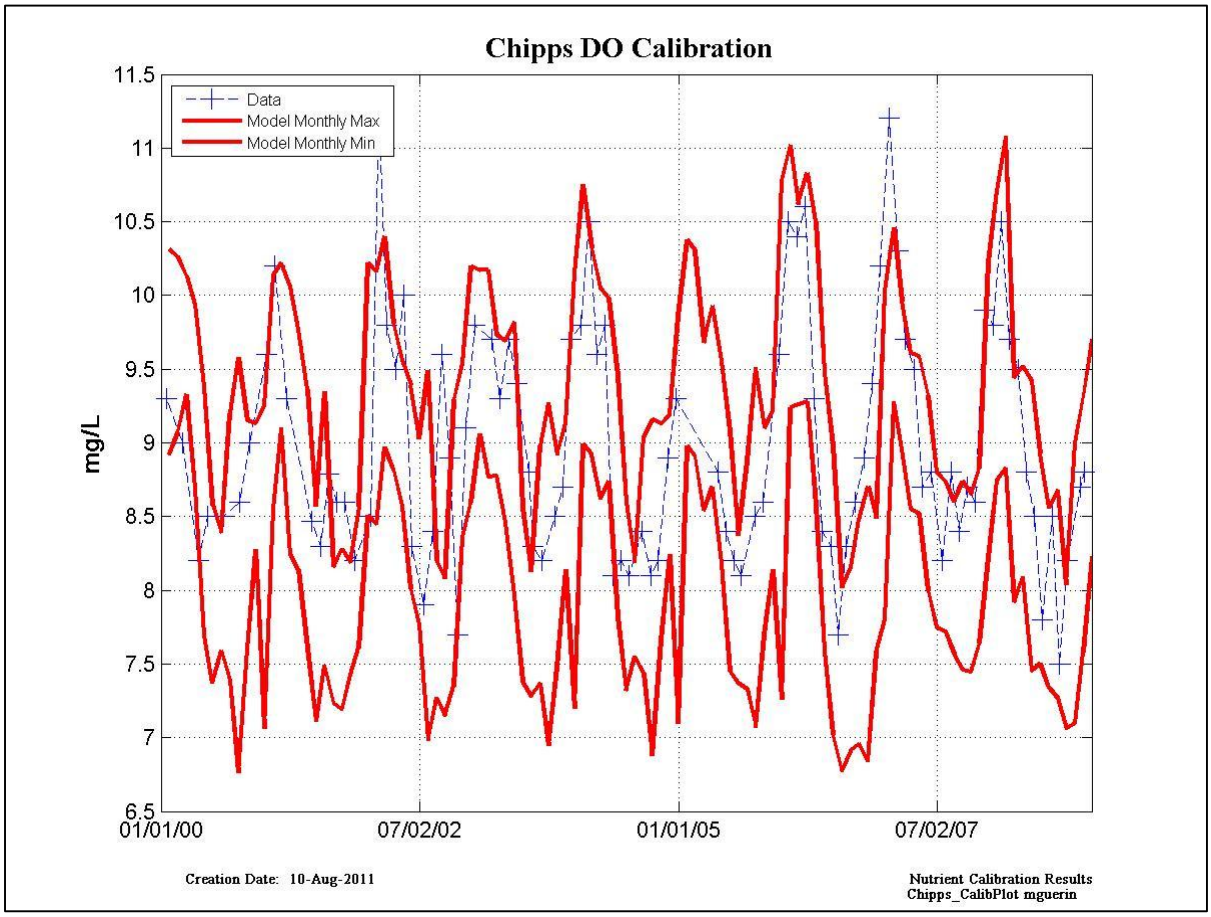


Figure 26-24 Modeled dissolved oxygen calibration results at Chipps – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-24 Model calibration/validation statistics at Chipps for dissolved oxygen for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

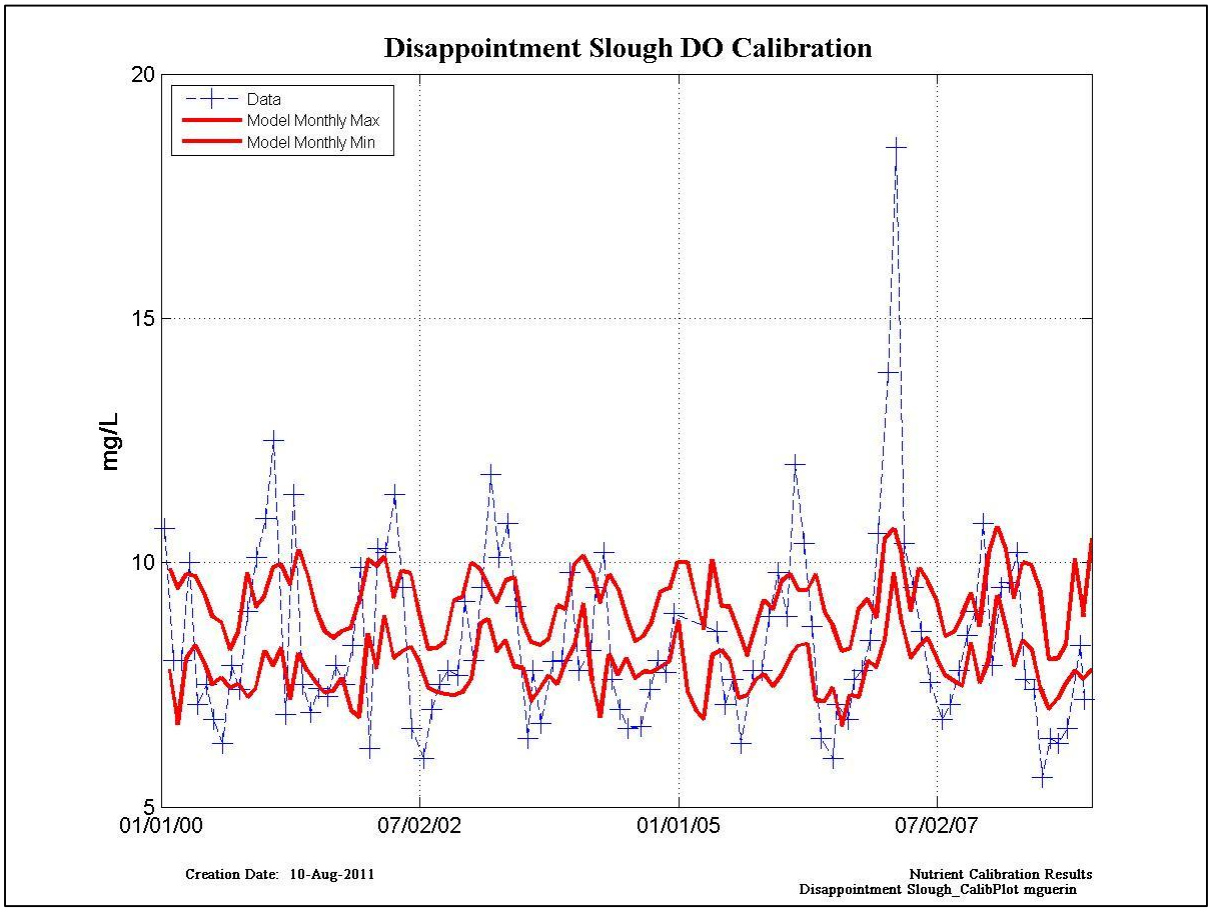


Figure 26-25 Modeled dissolved oxygen calibration results at Disappointment Sl. – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-25 Model calibration/validation statistics at Disappointment Sl. for dissolved oxygen for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for DryYears (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	S	VG	Underestimate	S
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	G	VG	Underestimate	G
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	G	VG	Overestimate	G

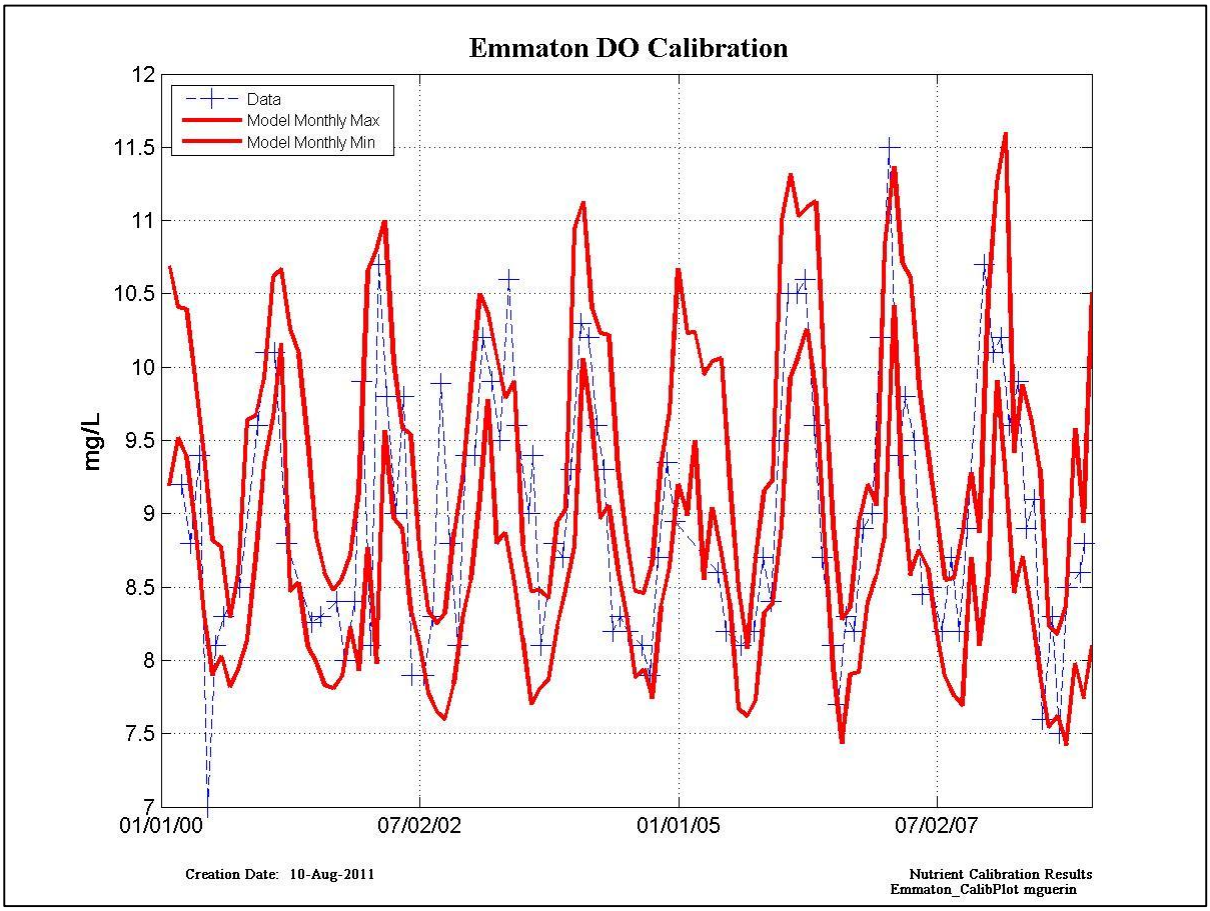


Figure 26-26 Modeled dissolved oxygen calibration results at Emmaton – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-26 Model calibration/validation statistics at Emmaton for dissolved oxygen for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	G	VG	Underestimate	G
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

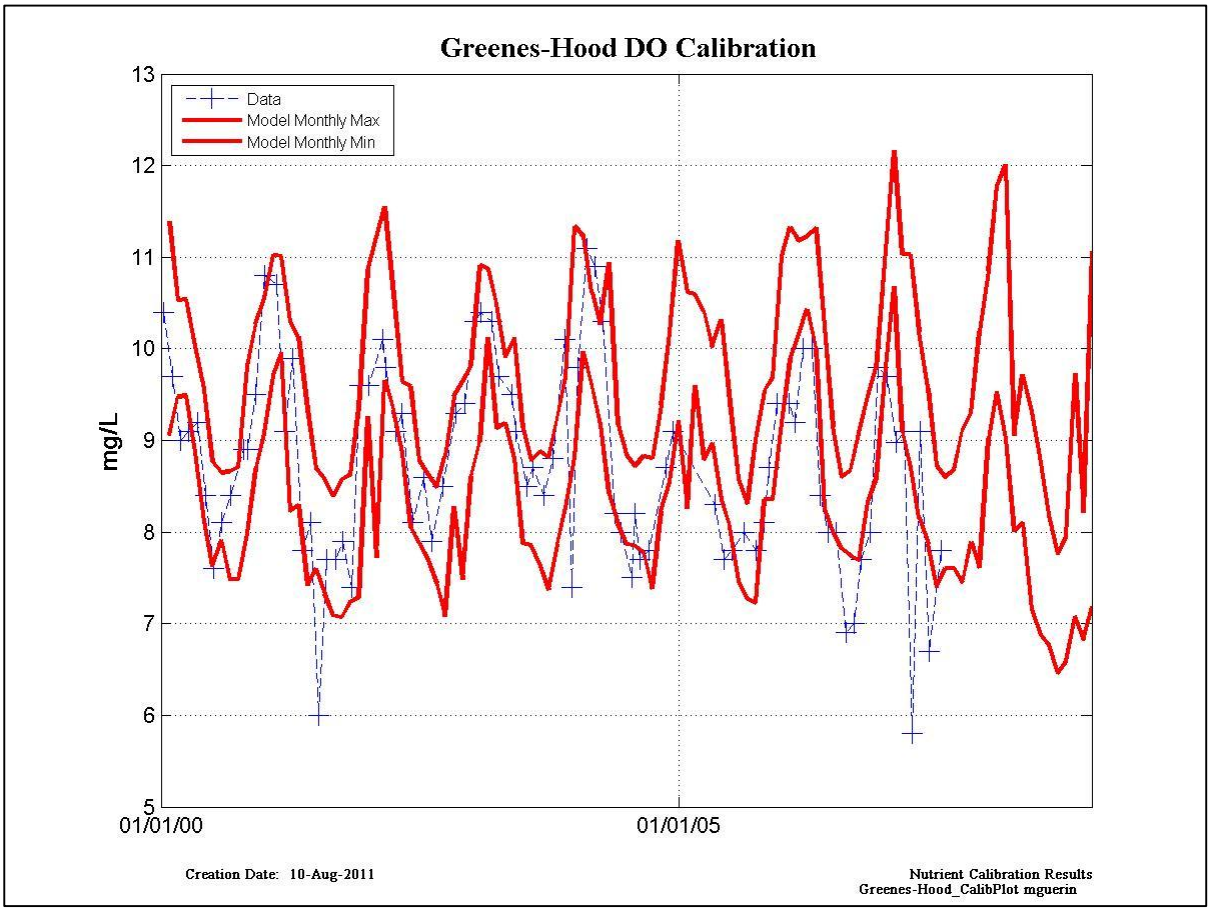


Figure 26-27 Modeled dissolved oxygen calibration results at Greens-Hood – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-27 Model calibration/validation statistics at Greens-Hood for dissolved oxygen for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	S	VG	Overestimate	S
Wet WY Validation	VG	VG	Overestimate	VG

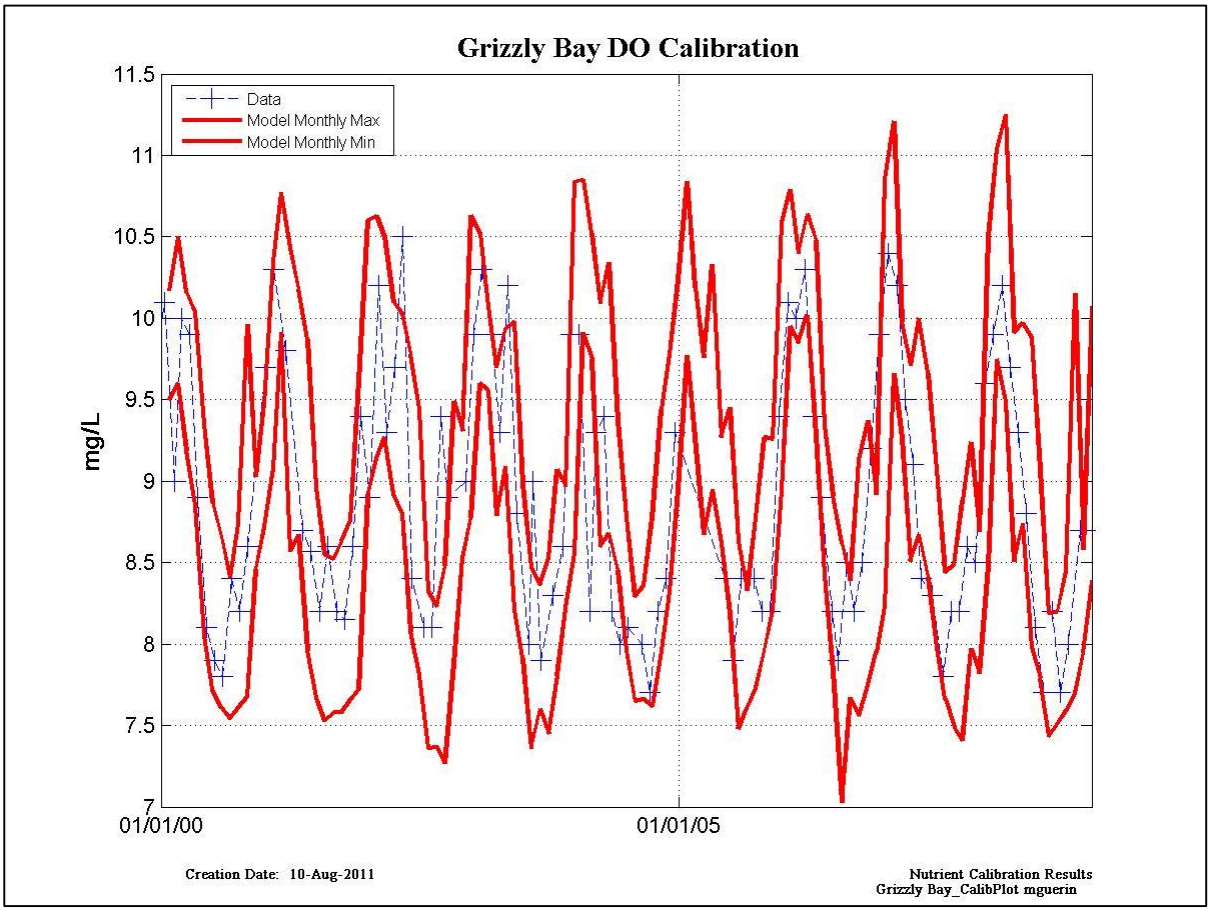


Figure 26-28 Modeled dissolved oxygen calibration results at Grizzly Bay – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-28 Model calibration/validation statistics at Grizzly Bay for dissolved oxygen for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG

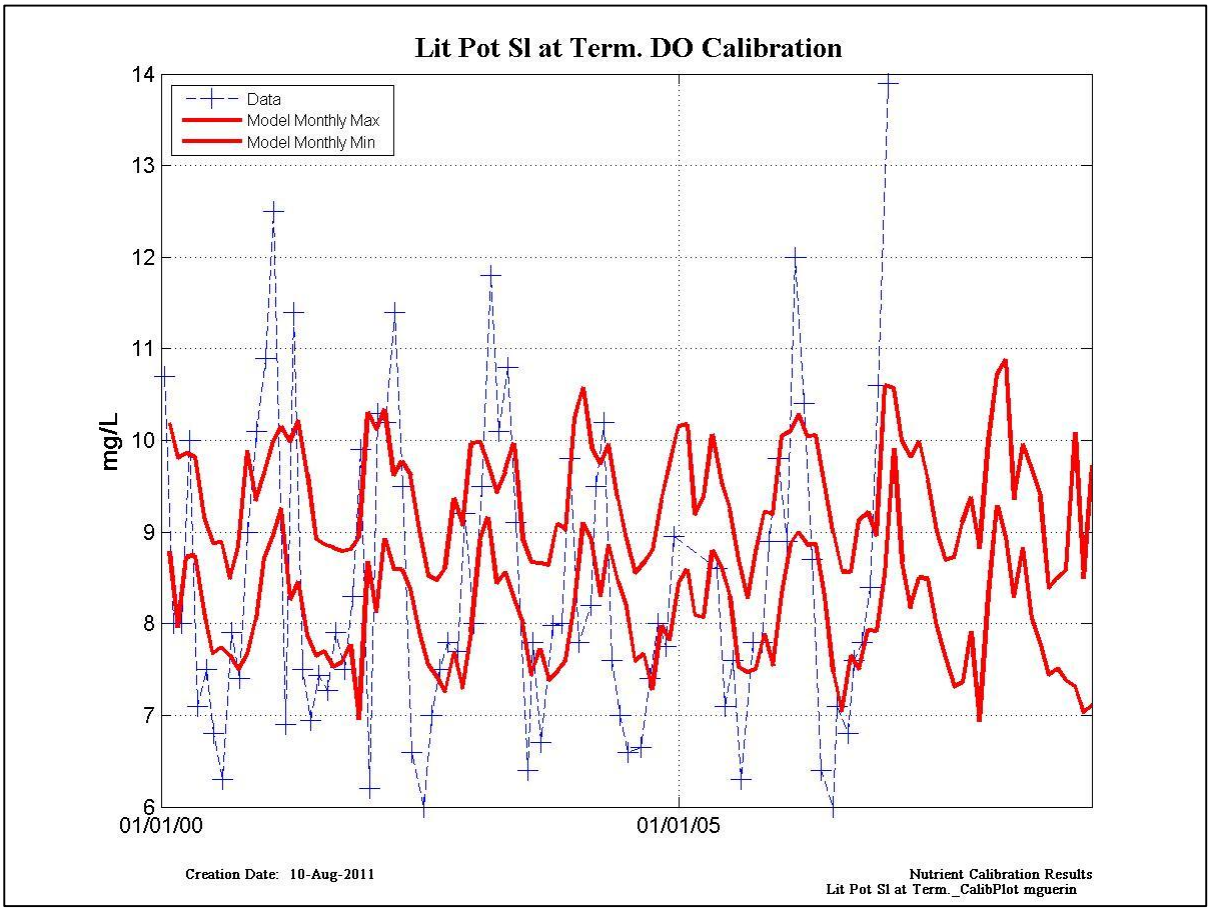


Figure 26-29 Modeled dissolved oxygen calibration results at Little Potato Sl. at Terminous – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-29 Model calibration/validation statistics at Little Potato Sl. at Terminous for dissolved oxygen for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation Wet Years (2005, 2006). Validation for Dry Years (2007, 2008) missing due to lack of data.

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	G	VG	Overestimate	G
Wet WY Calibration	G	VG	Overestimate	VG
Dry WY Validation				
Wet WY Validation	S	VG	No Bias	VG

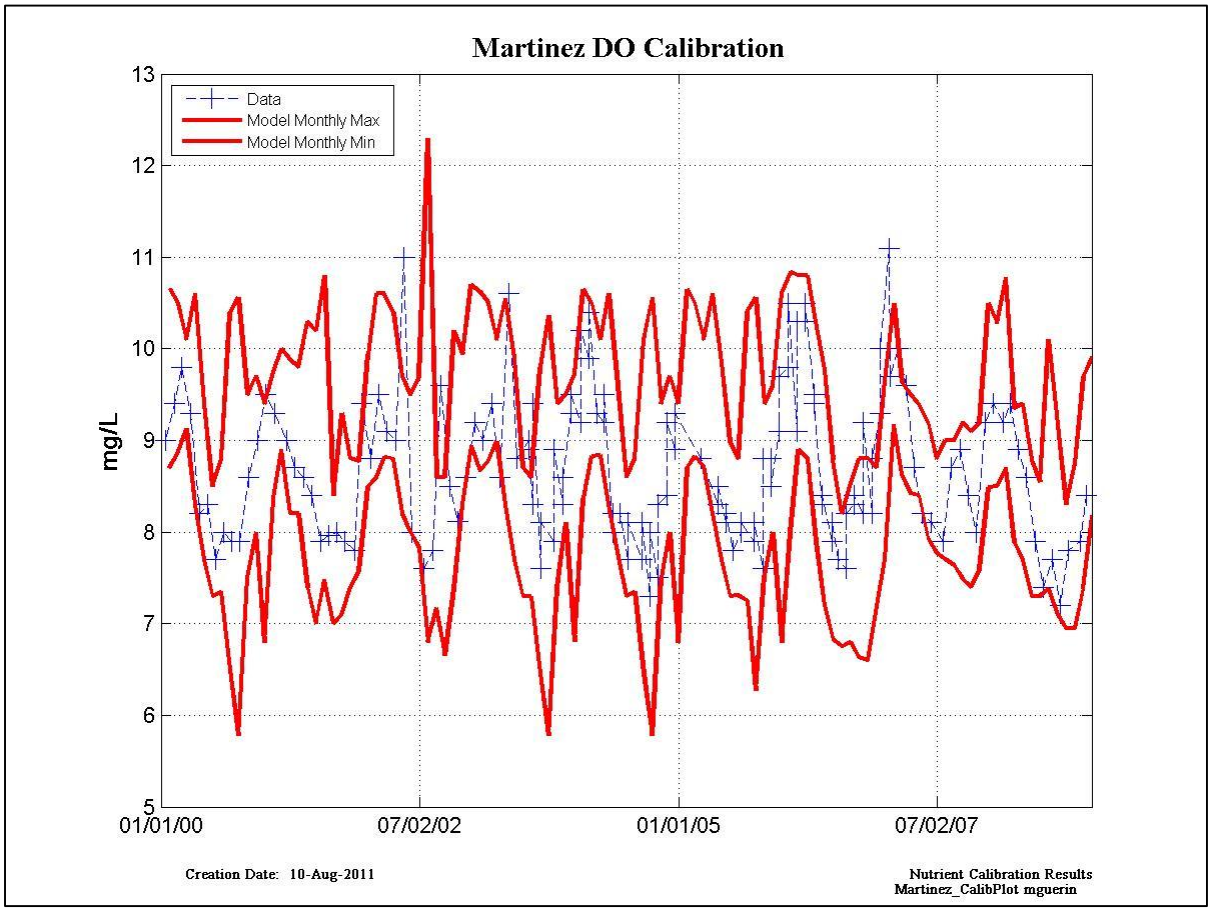


Figure 26-30 Modeled dissolved oxygen calibration results at Martinez – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-30 Model calibration/validation statistics at Martinez for dissolved oxygen for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG

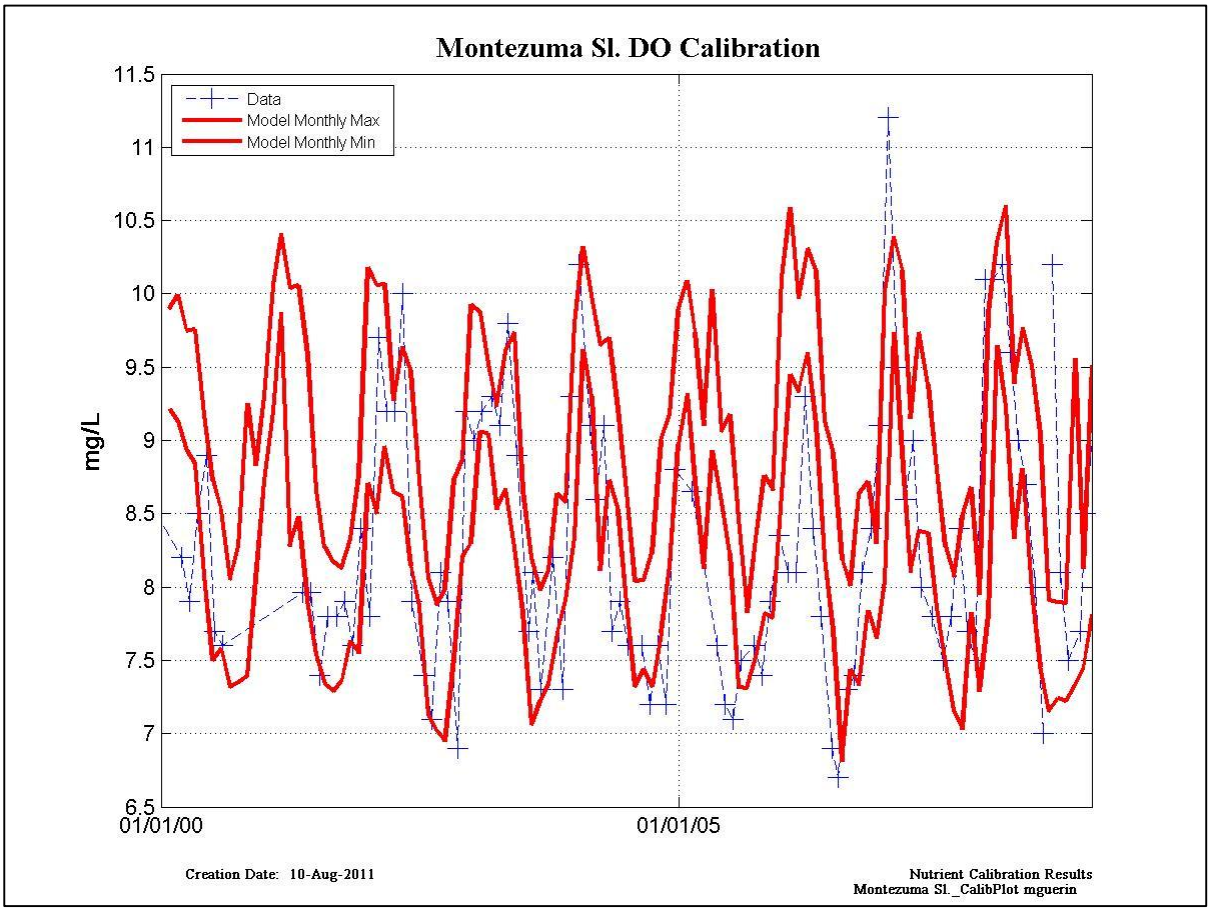


Figure 26-31 Modeled dissolved oxygen calibration results at Montezuma Sl. Bend 2 – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-31 Model calibration/validation statistics at Montezuma Sl. Bend 2 for dissolved oxygen for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	S	VG	Overestimate	U

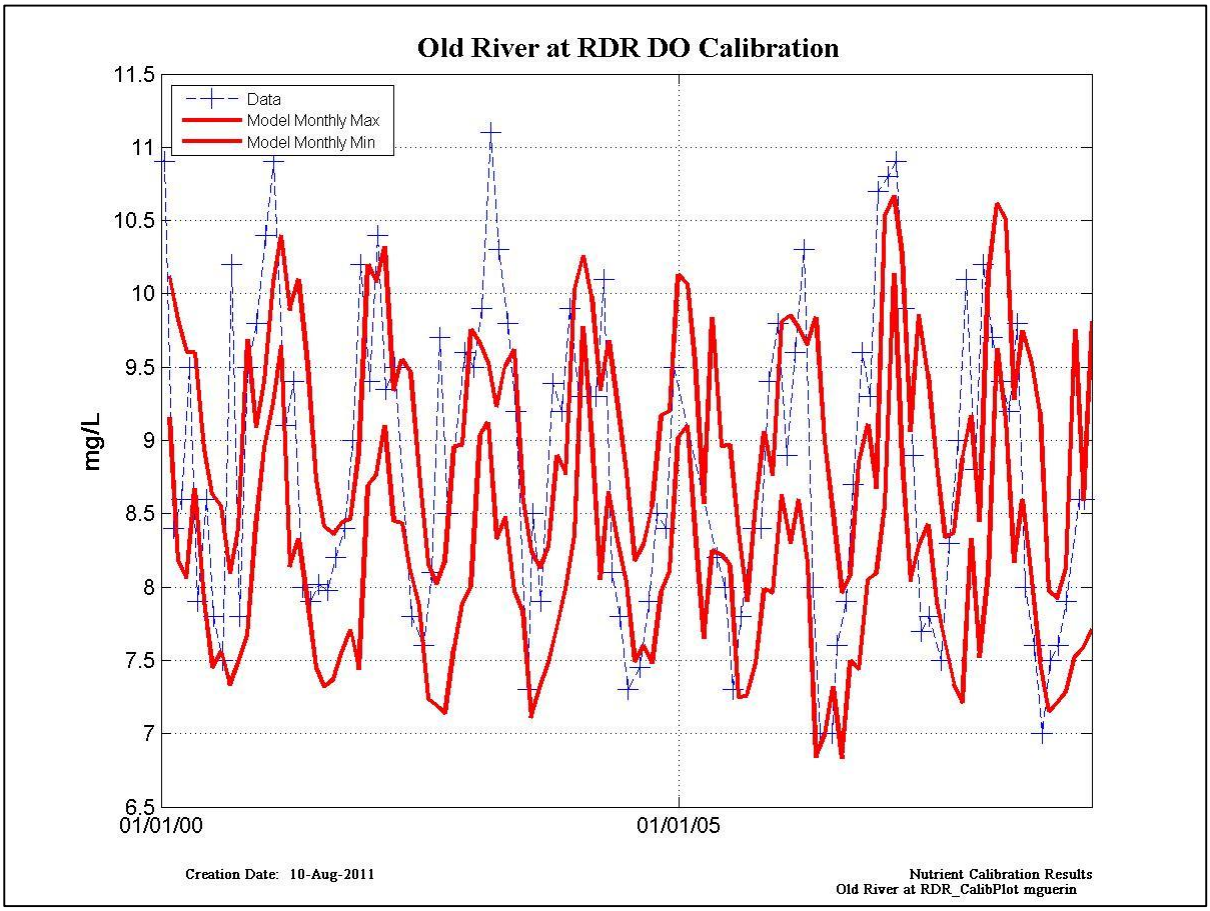


Figure 26-32 Modeled dissolved oxygen calibration results at Old R. at Rancho Del Rio – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-32 Model calibration/validation statistics at Old R. at Rancho Del Rio for dissolved oxygen for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG

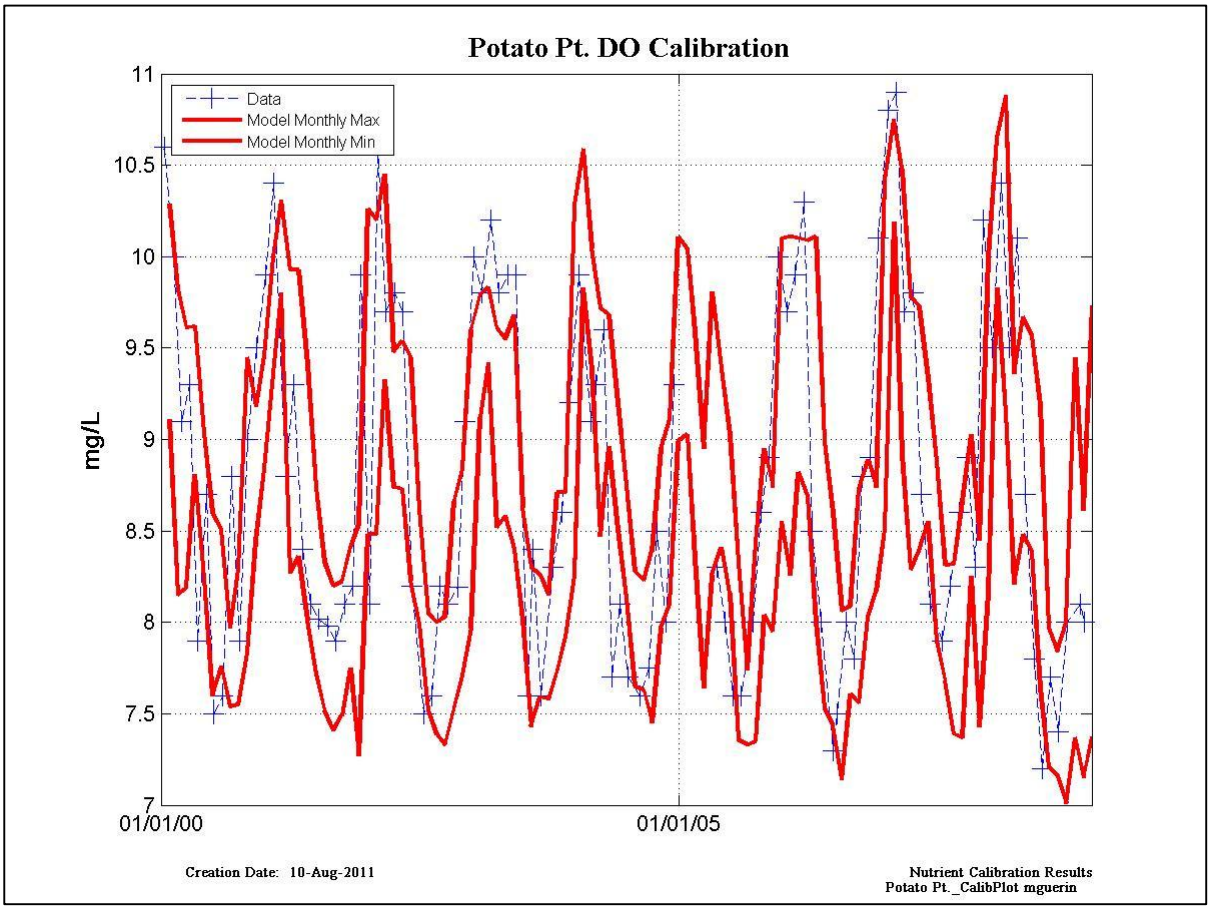


Figure 26-33 Modeled dissolved oxygen calibration results at Potato Pt – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-33 Model calibration/validation statistics at Potato Pt for dissolved oxygen for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG

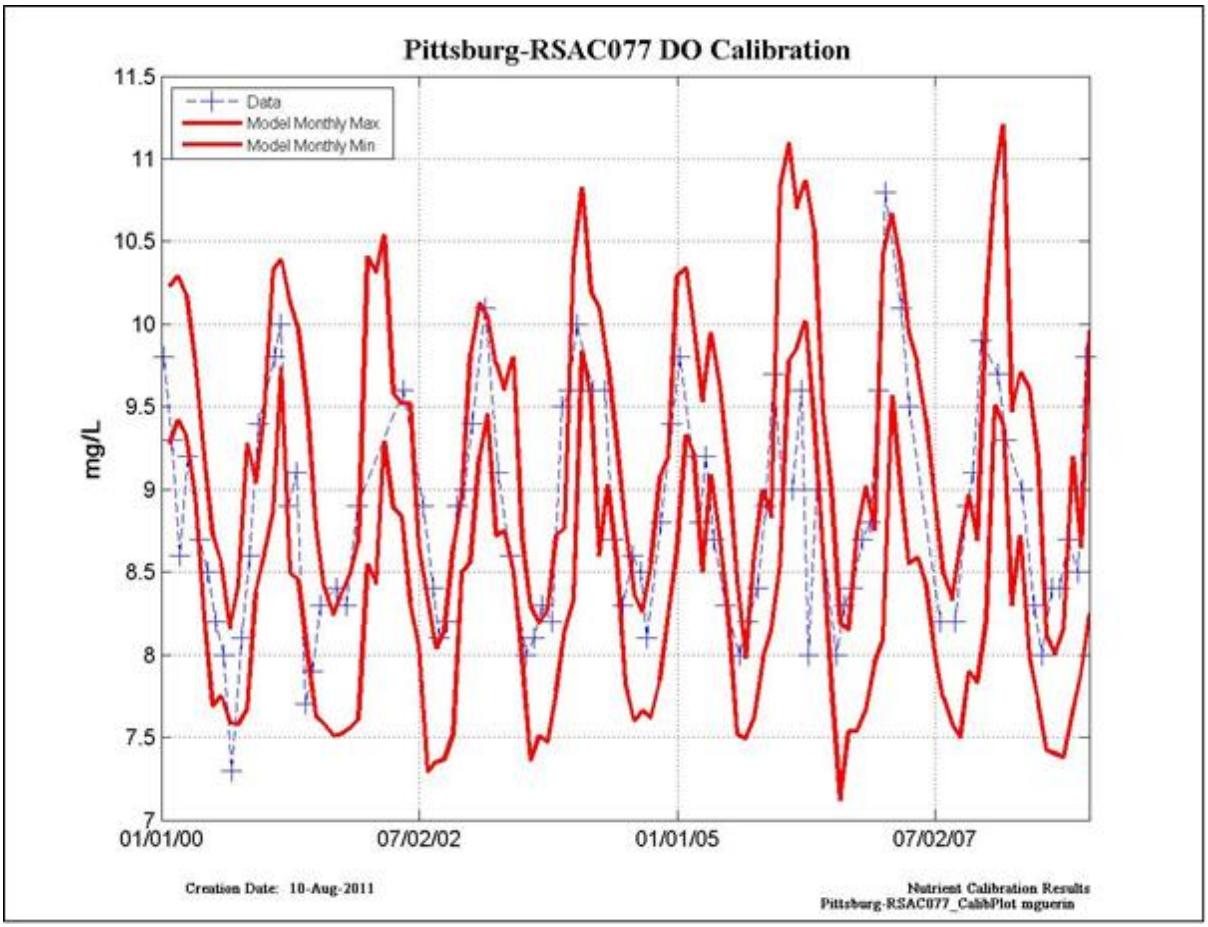


Figure 26-34 Modeled dissolved oxygen calibration results at Pittsburg-RSAC077– data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-34 Model calibration/validation statistics at Pittsburg-RSAC077 for dissolved oxygen for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	S	VG	Overestimate	U

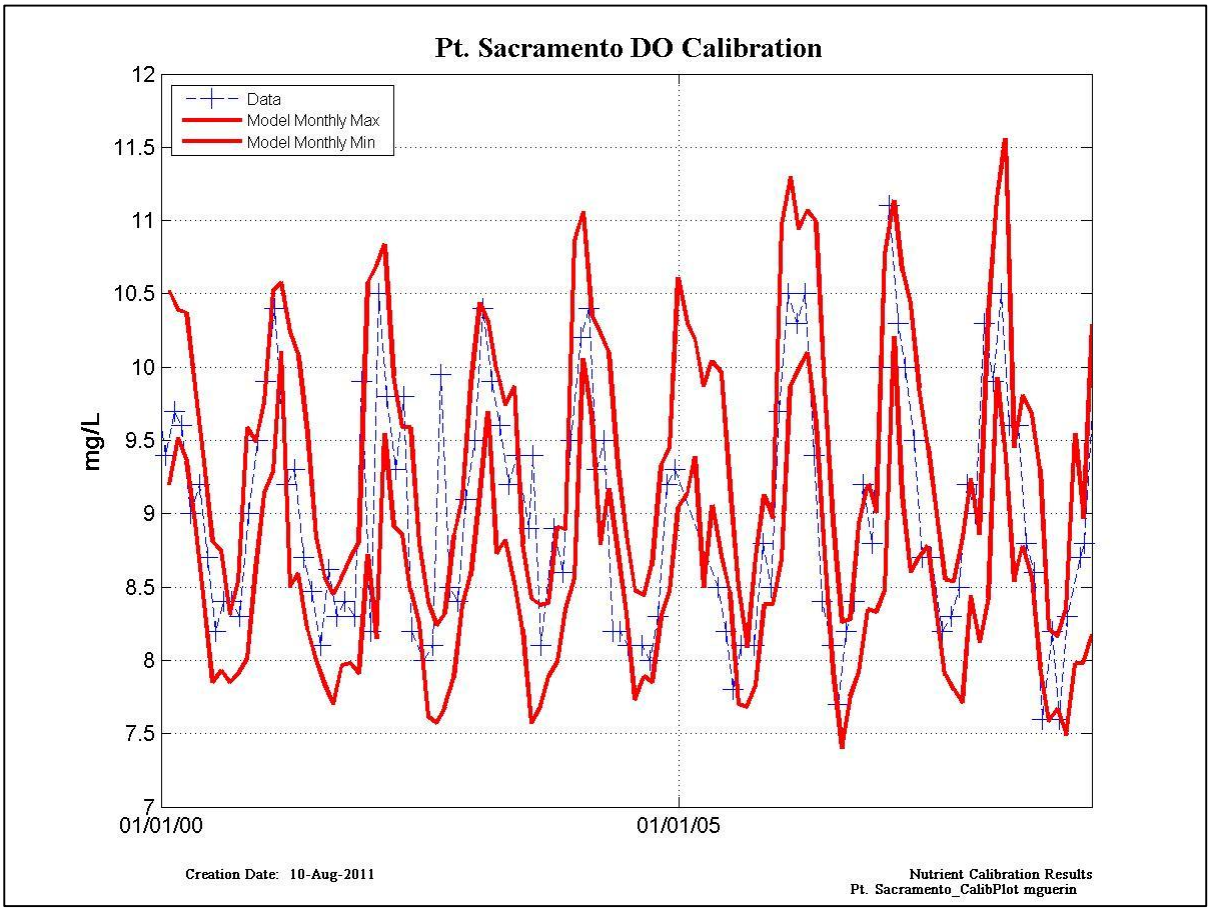


Figure 26-35 Modeled dissolved oxygen calibration results at Pt. Sacramento – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-35 Model calibration/validation statistics at Pt. Sacramento for dissolved oxygen for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

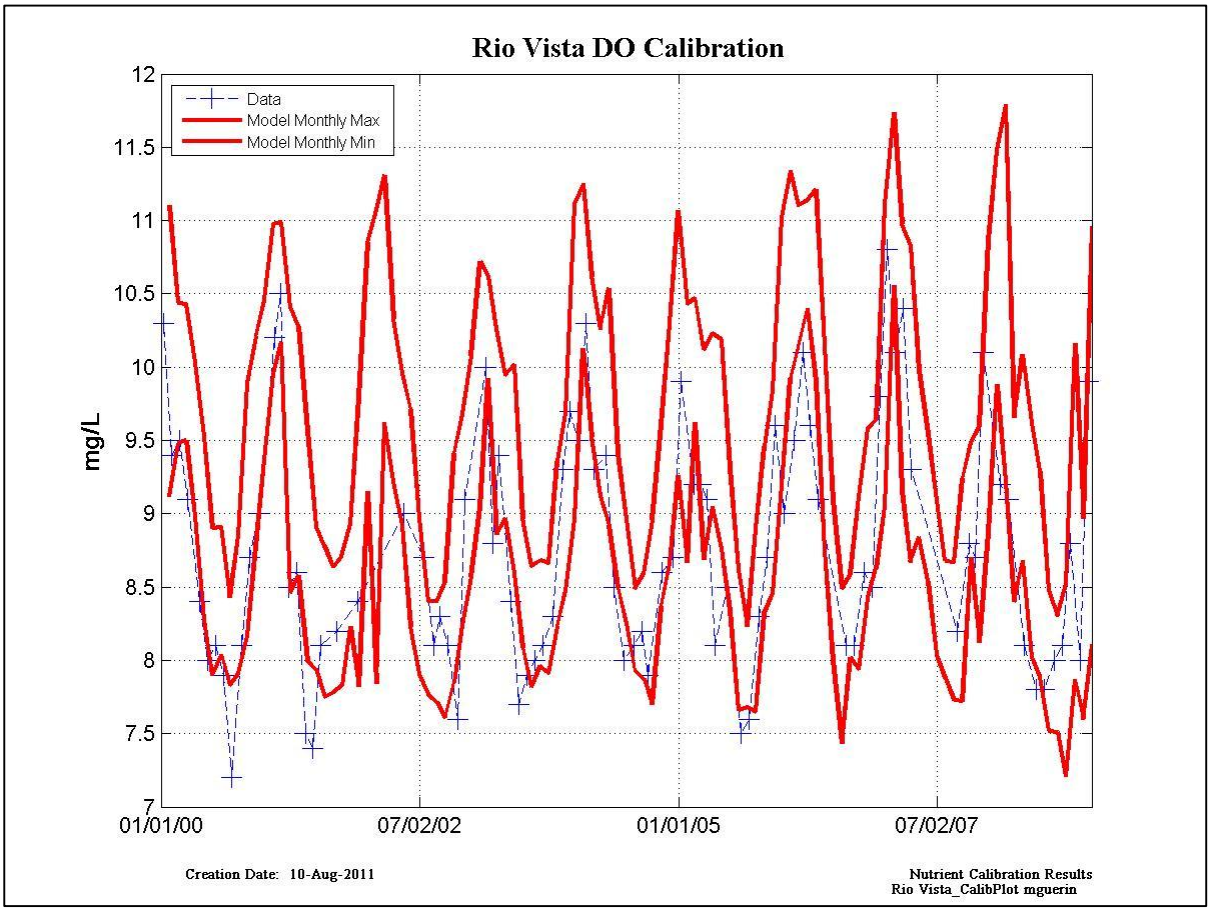


Figure 26-36 Modeled dissolved oxygen calibration results at Rio Vista – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-36 Model calibration/validation statistics at Rio Vista for dissolved oxygen for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

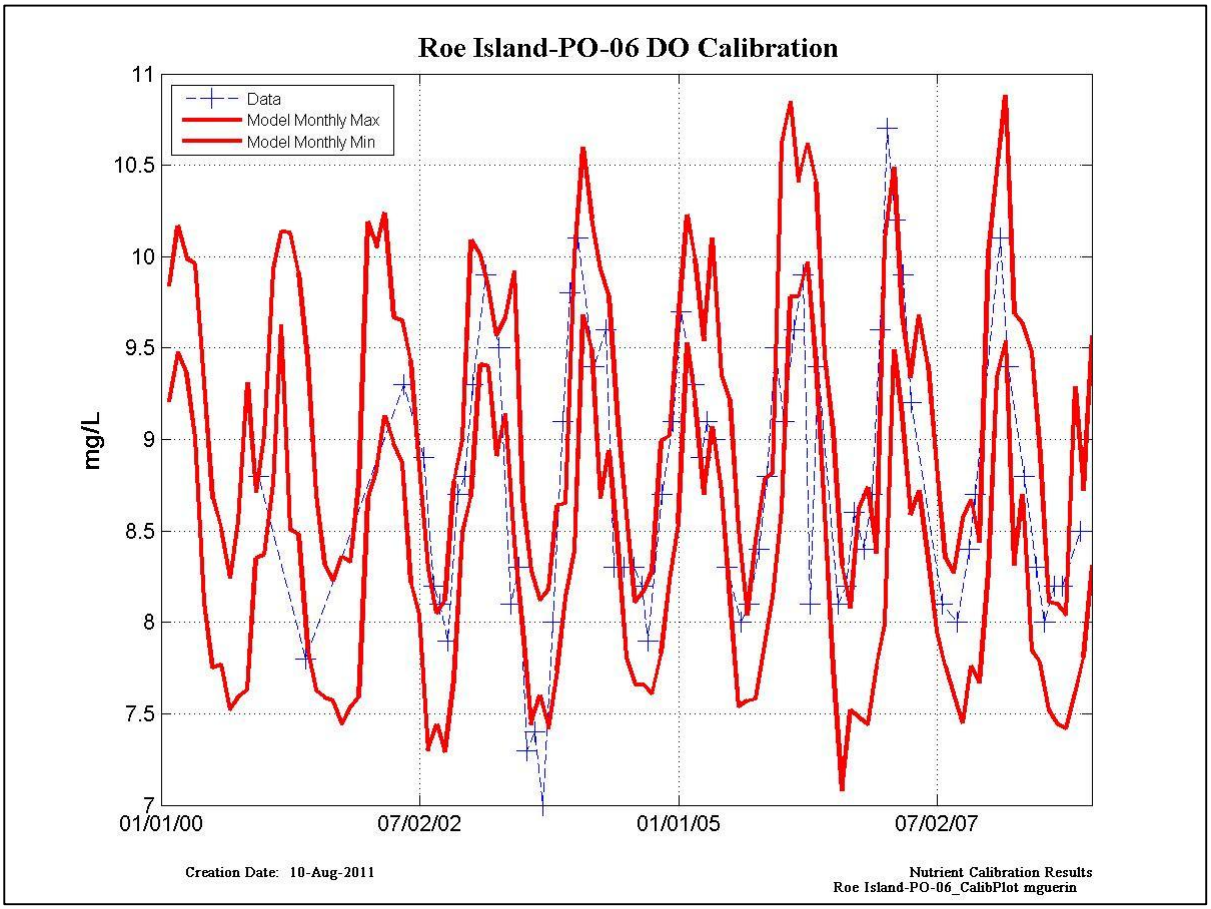


Figure 26-37 Modeled dissolved oxygen calibration results at Roe Island –data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-37 Model calibration/validation statistics at Roe Island for dissolved oxygen for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	G	VG	Overestimate	G

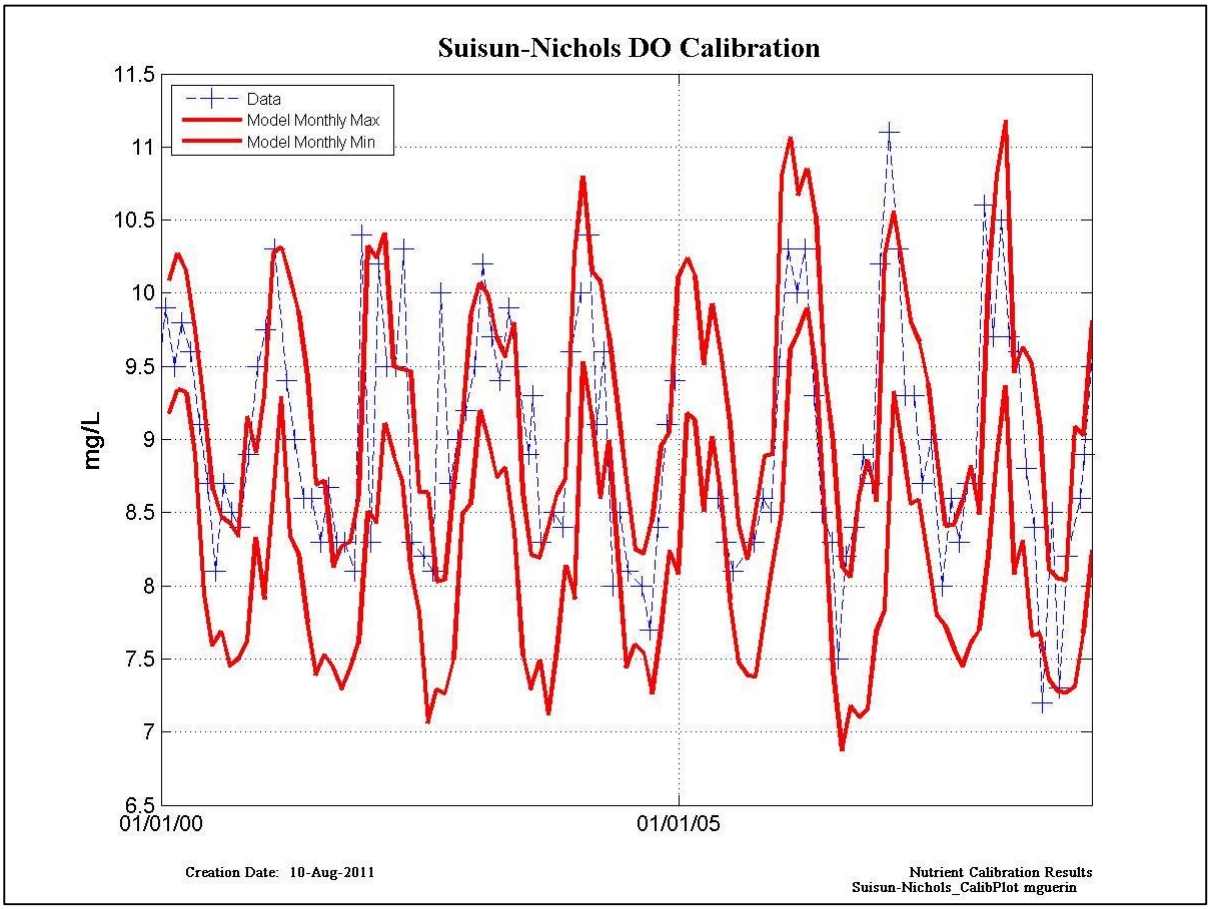


Figure 26-38 Modeled dissolved oxygen calibration results at Suisun-Nichols – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-38 Model calibration/validation statistics at Suisun-Nichols for dissolved oxygen for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	G	VG	Underestimate	G
Wet WY Calibration	G	VG	Underestimate	G
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG

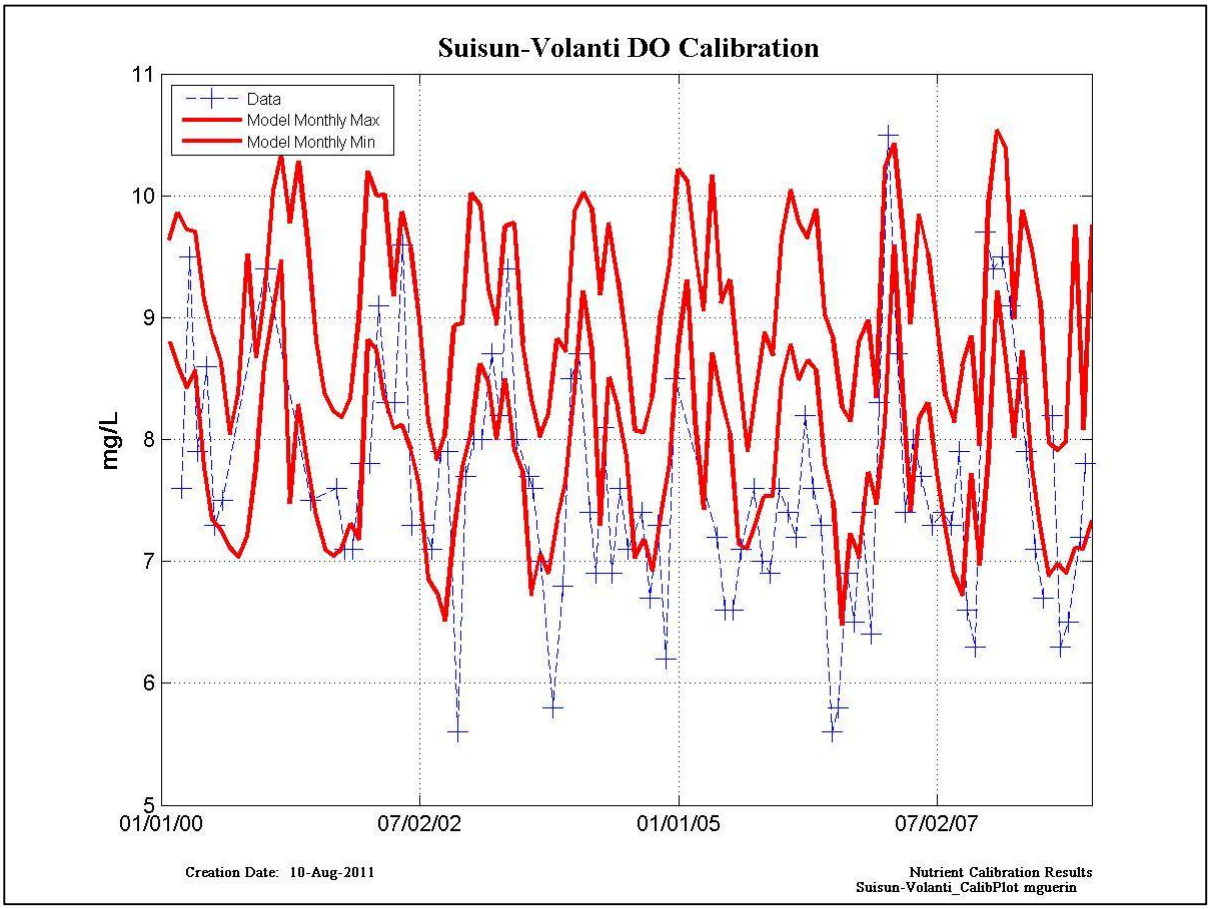


Figure 26-39 Modeled dissolved oxygen calibration results at Suisun-Volanti – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-39 Model calibration/validation statistics at Suisun-Volanti for dissolved oxygen for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	G
Dry WY Calibration	S	VG	Overestimate	S
Wet WY Calibration	G	VG	Overestimate	G
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	S	VG	Overestimate	U

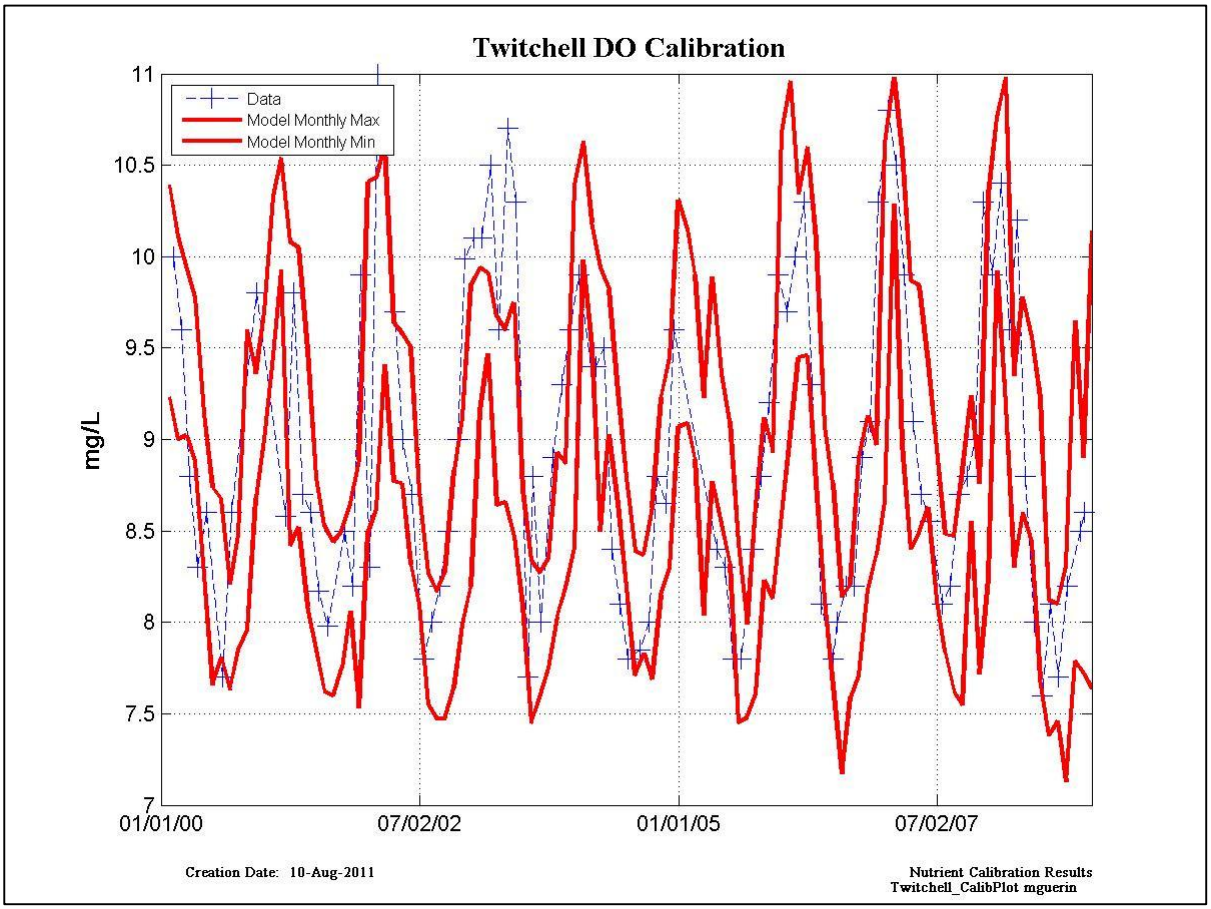


Figure 26-40 Modeled dissolved oxygen calibration results at Twitchell – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-40 Model calibration/validation statistics at Twitchell for dissolved oxygen for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	G
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG

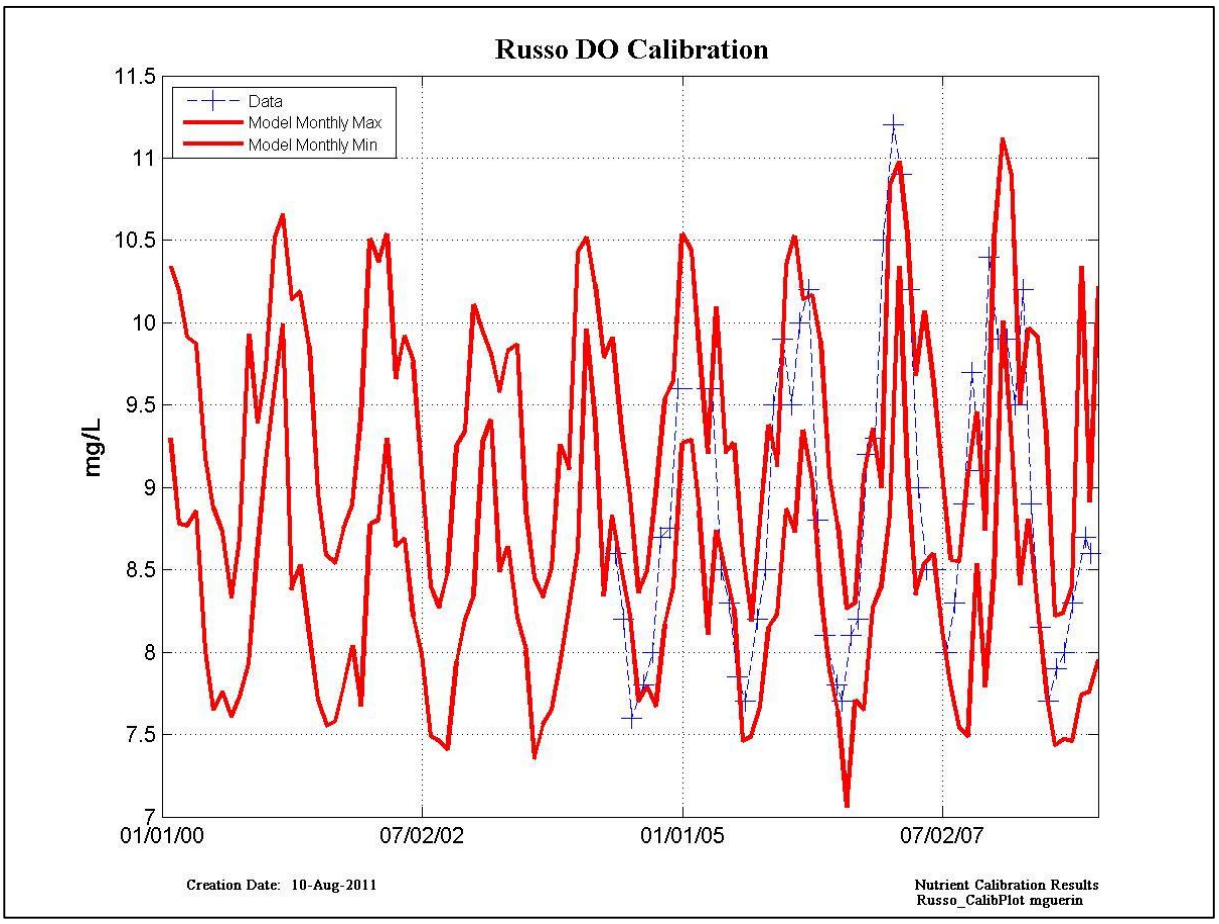


Figure 26-41 Modeled dissolved oxygen calibration results at Russo – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-41 (Intentionally left blank) Insufficient data to calculate calibration statistics.

26.3 NH3

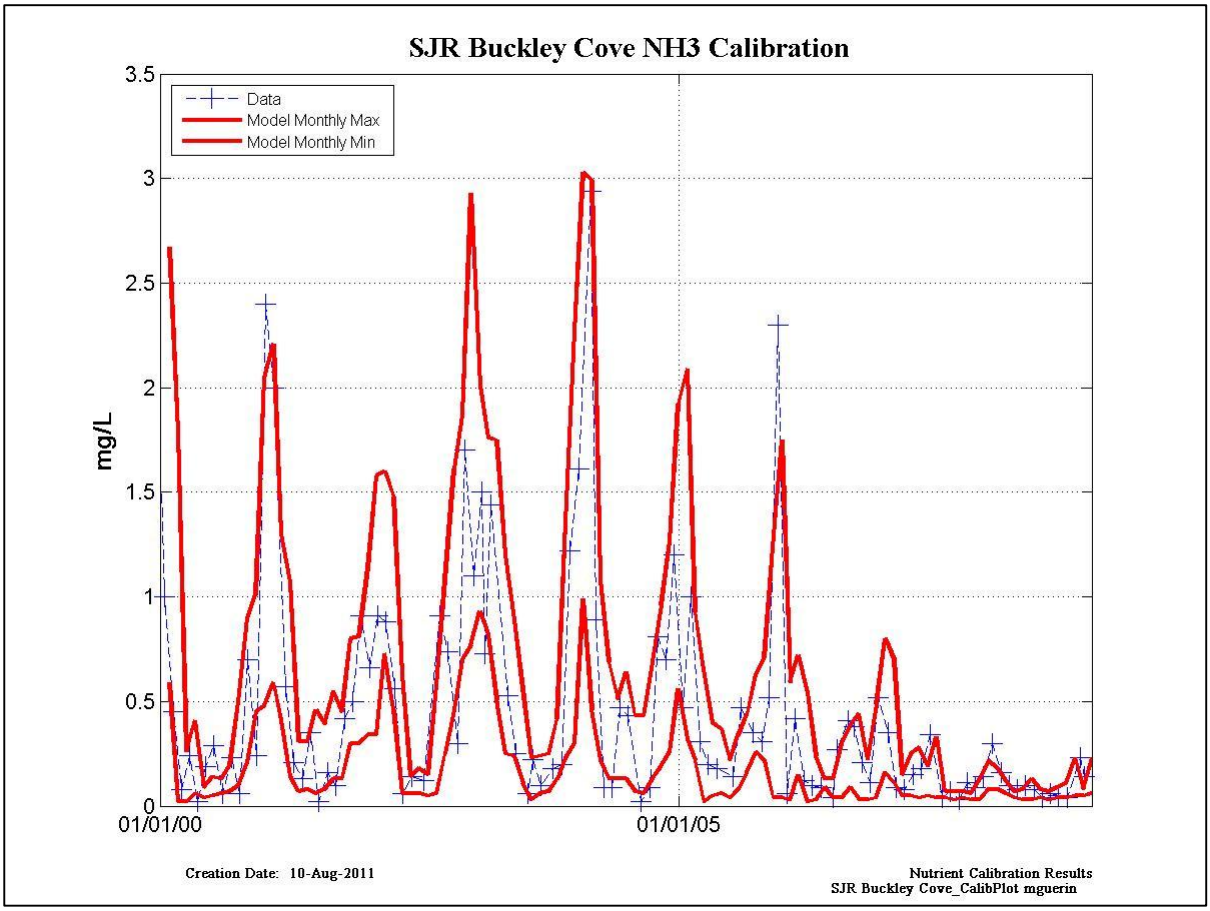


Figure 26-42 NH_3 calibration results at SJR Buckley Cove – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-42 Model calibration/validation statistics at SJR Buckley Cove for $NH_3$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG

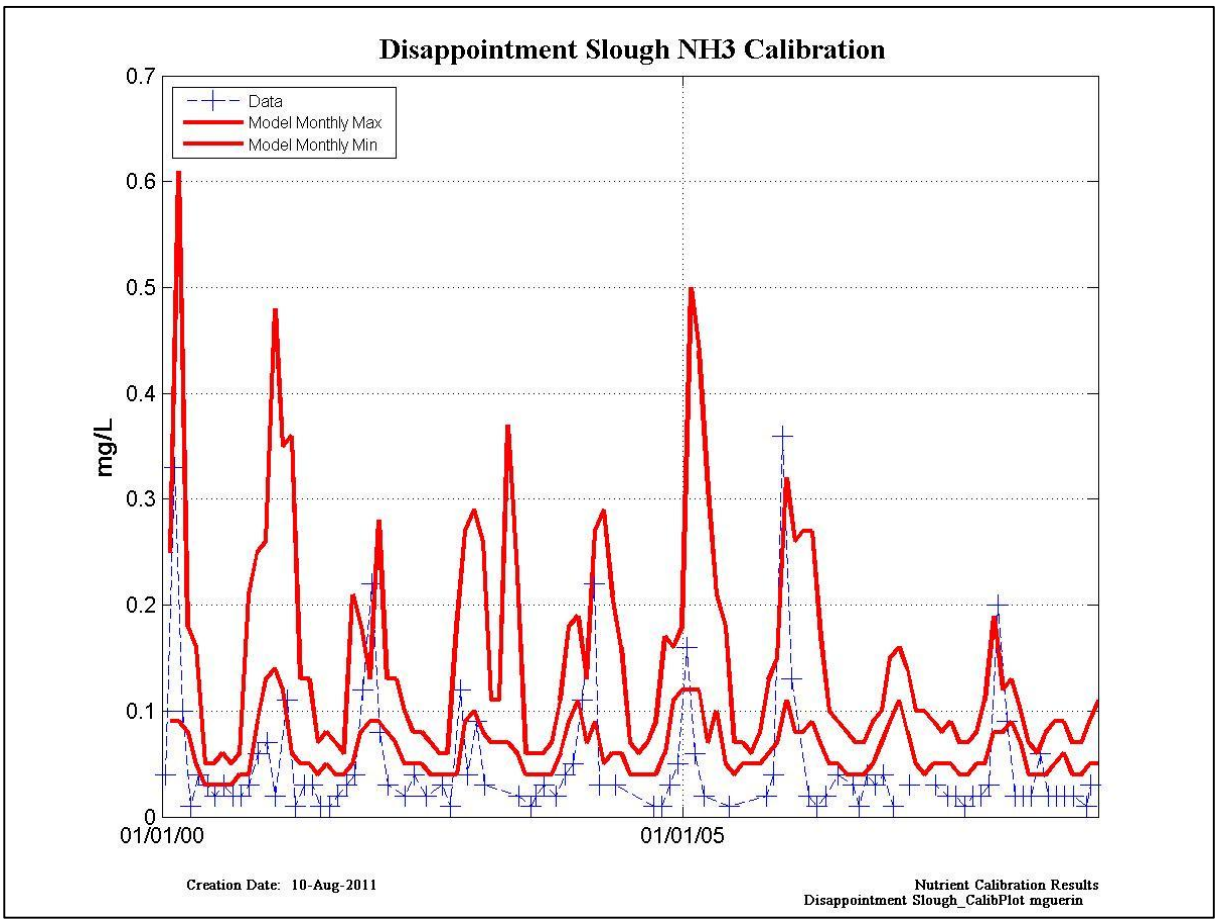


Figure 26-43 NH_3 calibration results at Disappointment Sl. – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-43 Model calibration/validation statistics at Disappointment Sl. for $NH_3$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	S	Overestimate	G
Dry WY Calibration	VG	S	Overestimate	U
Wet WY Calibration	VG	S	Overestimate	G
Dry WY Validation	S	S	Overestimate	U
Wet WY Validation	VG	S	Overestimate	VG

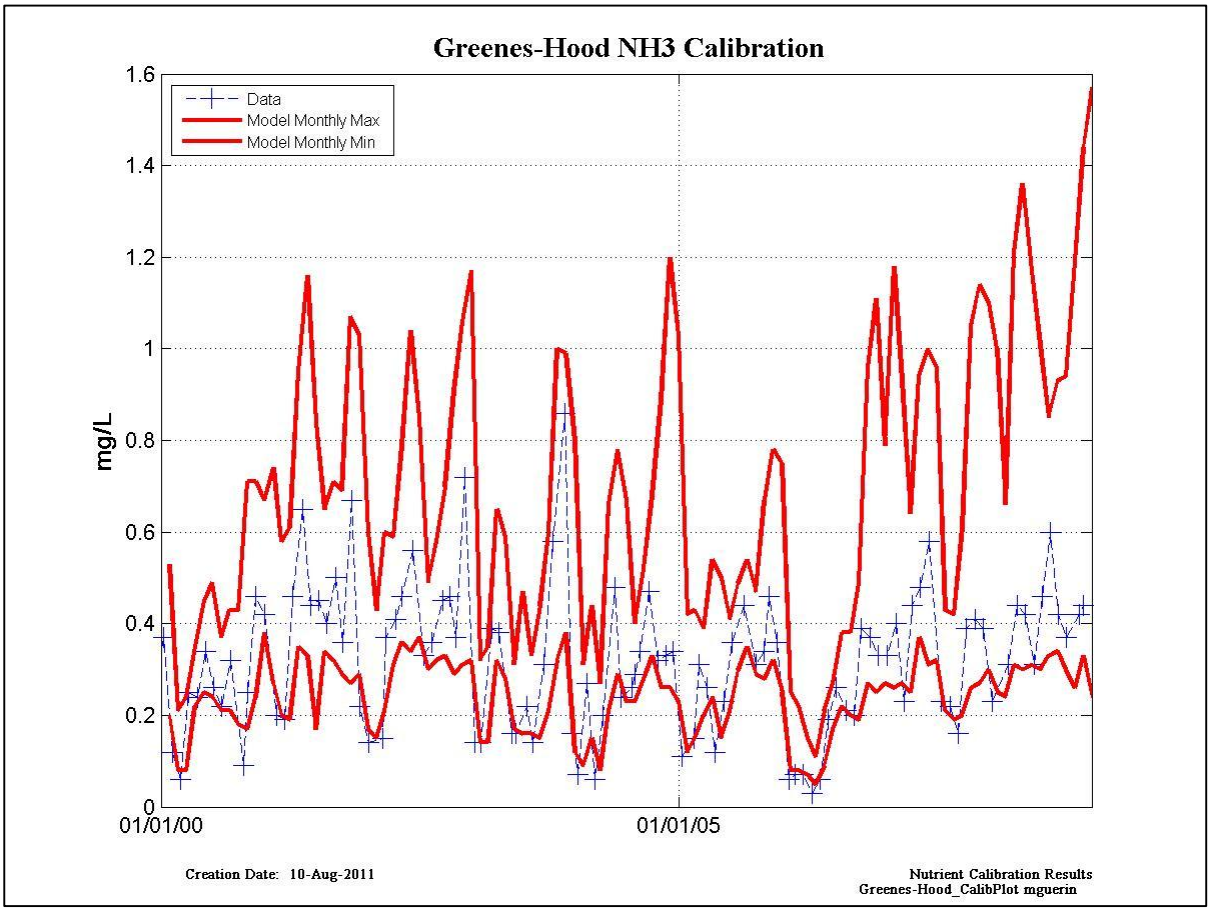


Figure 26-44 NH_3 calibration results at Greens-Hood – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-44 Model calibration/validation statistics at Greens-Hood for $NH_3$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

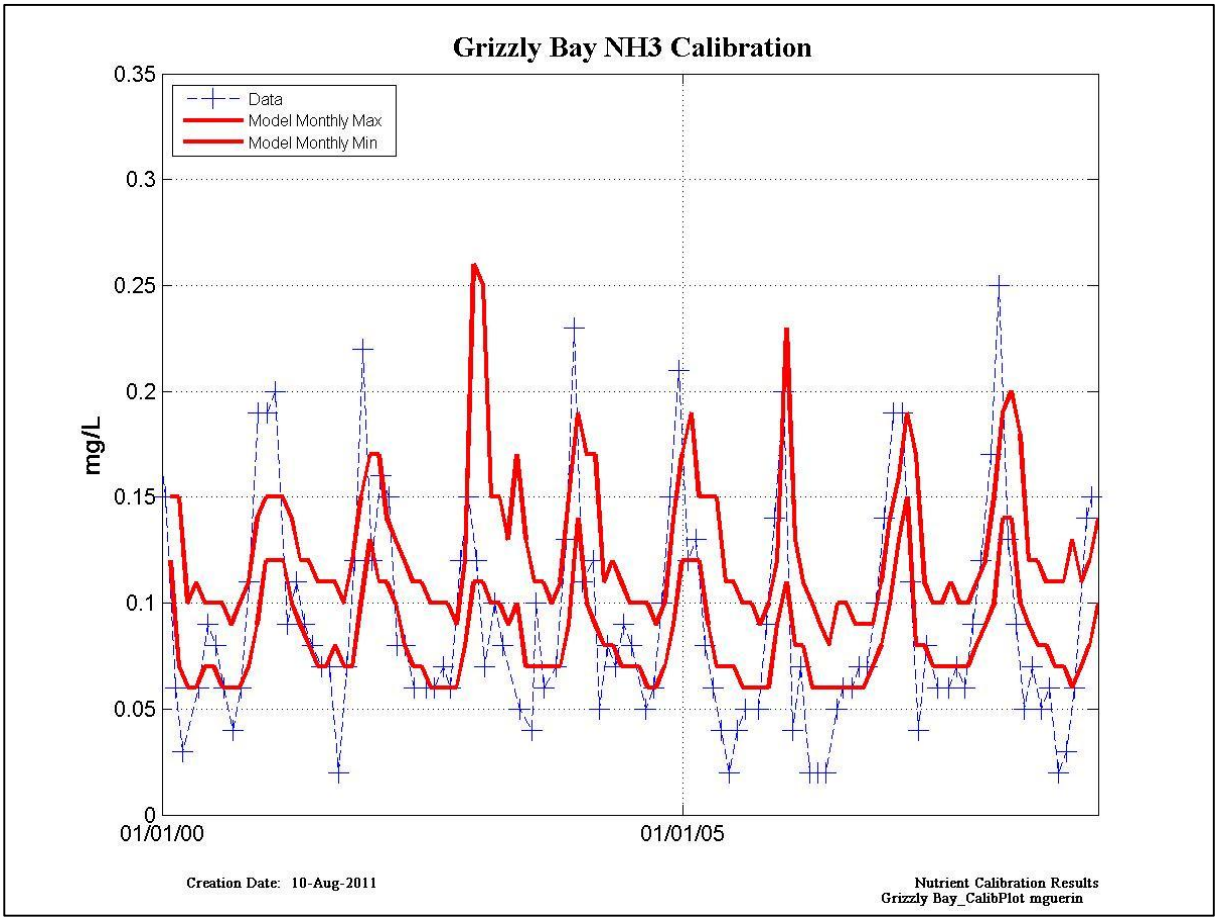


Figure 26-45 NH_3 calibration results at Grizzly Bay – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-45 Model calibration/validation statistics at Grizzly Bay for $NH_3$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

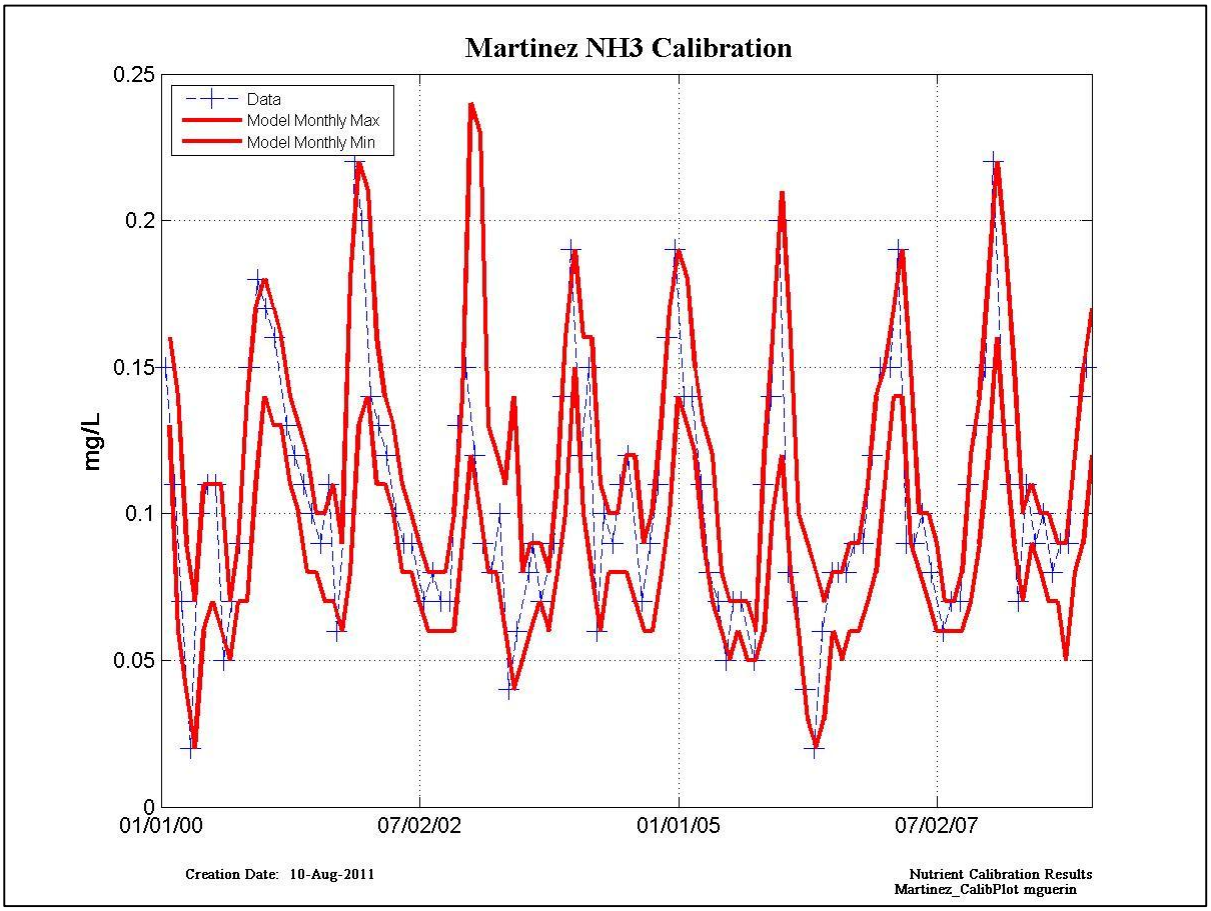


Figure 26-46 NH_3 calibration results at Martinez – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-46 Model calibration/validation statistics at Martinez for $NH_3$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG

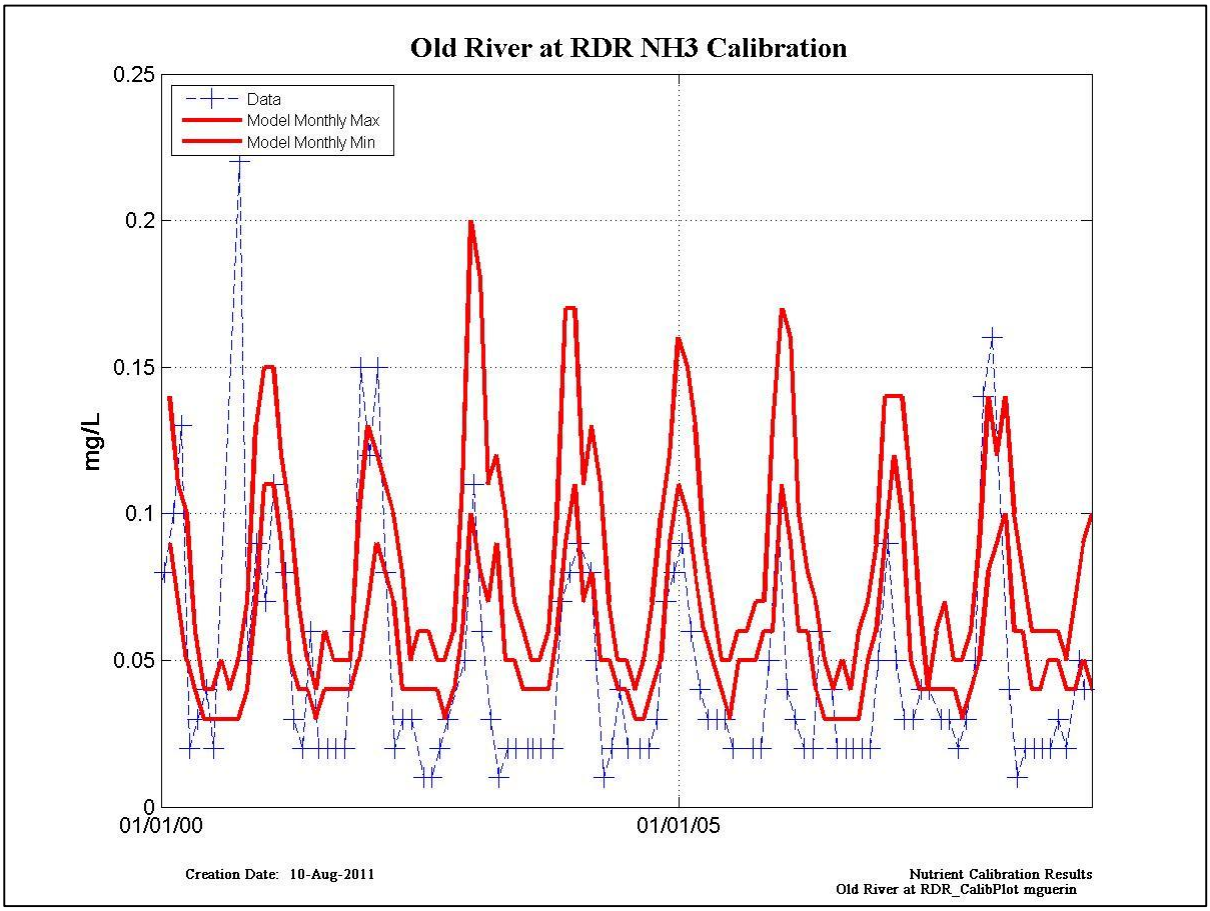


Figure 26-47 NH_3 calibration results at Old R. at Rancho Del Rio – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-47 Model calibration/validation statistics at Old R. at Rancho Del Rio for $NH_3$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	G	Overestimate	G
Dry WY Calibration	VG	VG	Overestimate	G
Wet WY Calibration	S	VG	Overestimate	U
Dry WY Validation	G	G	Overestimate	S
Wet WY Validation	S	S	Overestimate	U

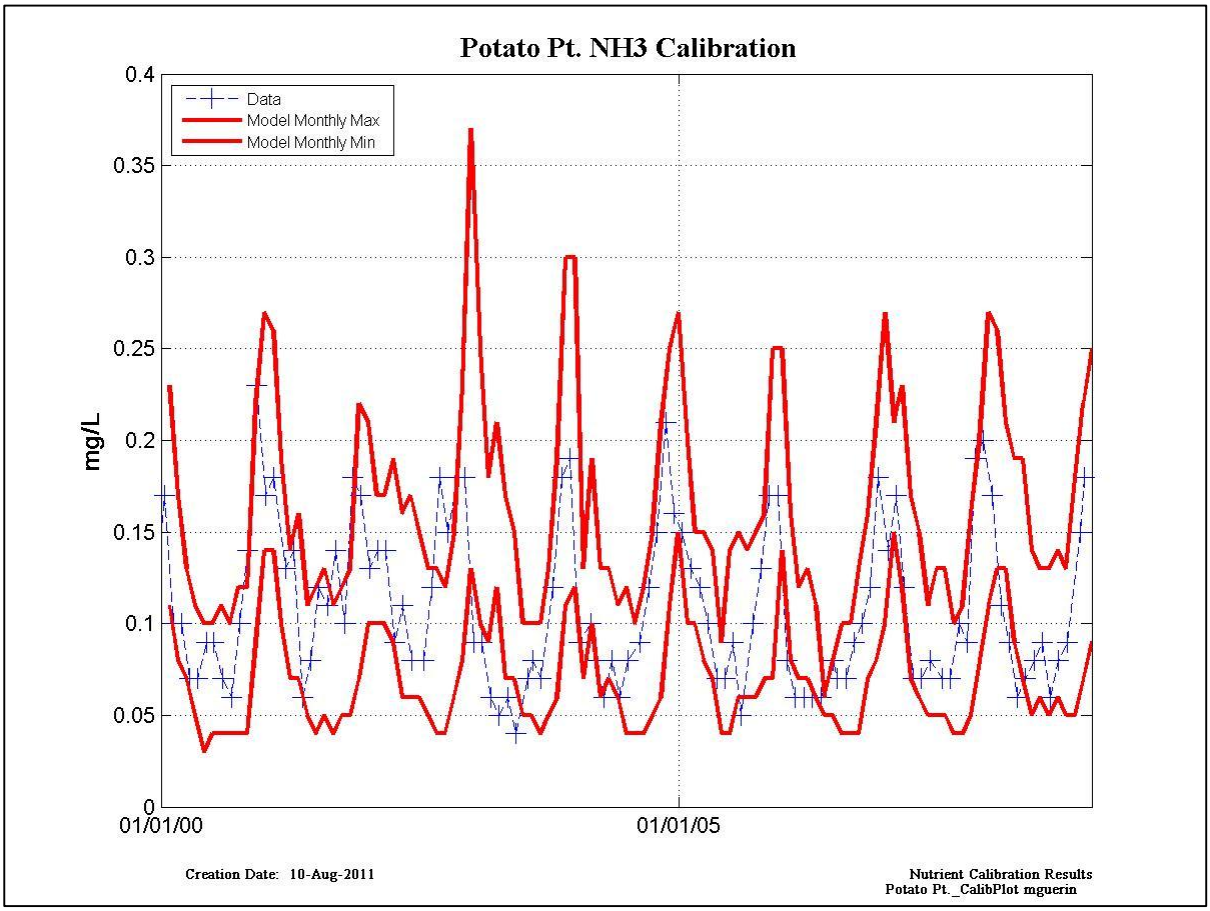


Figure 26-48 NH_3 calibration results at Potato Pt. – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-48 Model calibration/validation statistics at Potato Pt. for $NH_3$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

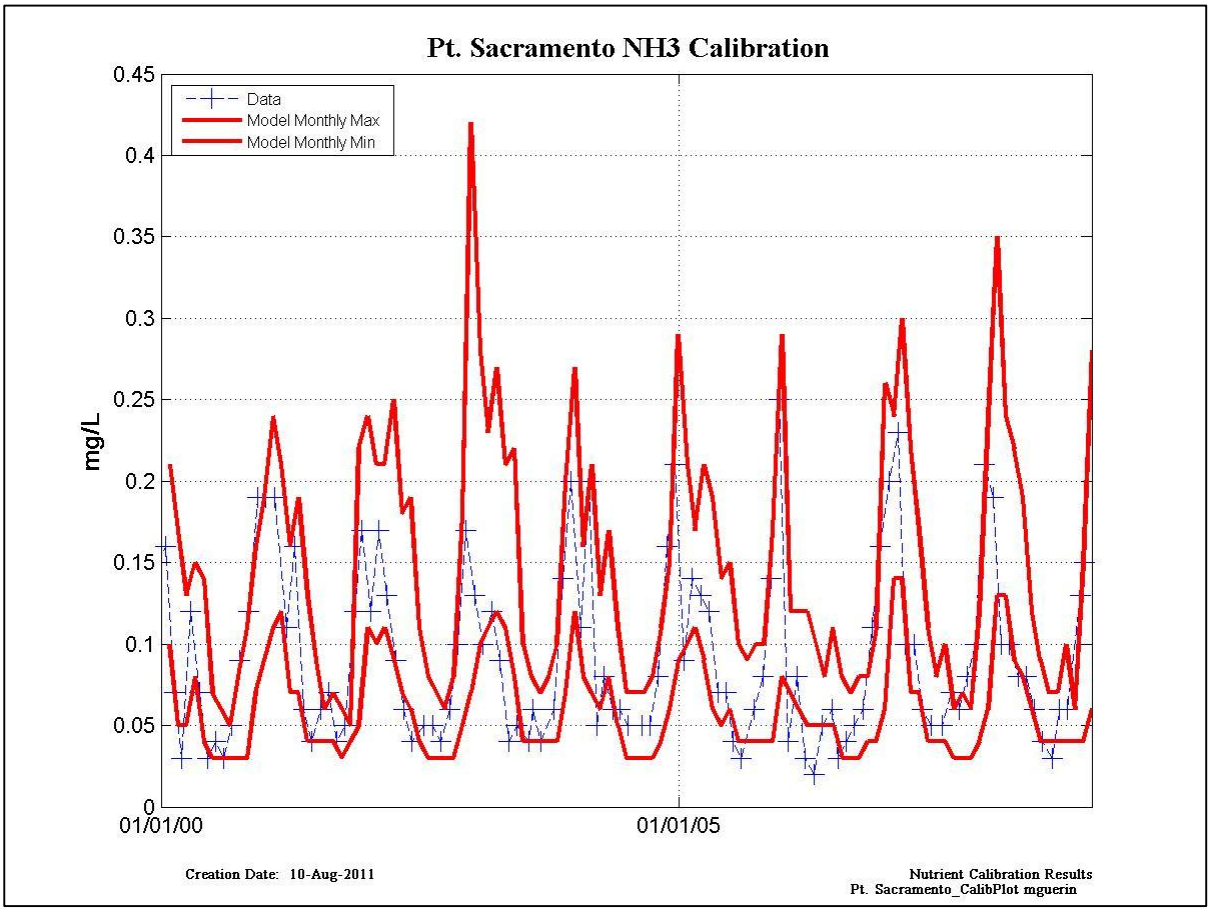


Figure 26-49 NH_3 calibration results at Pt. Sacramento – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-49 Model calibration/validation statistics at Pt. Sacramento for $NH_3$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

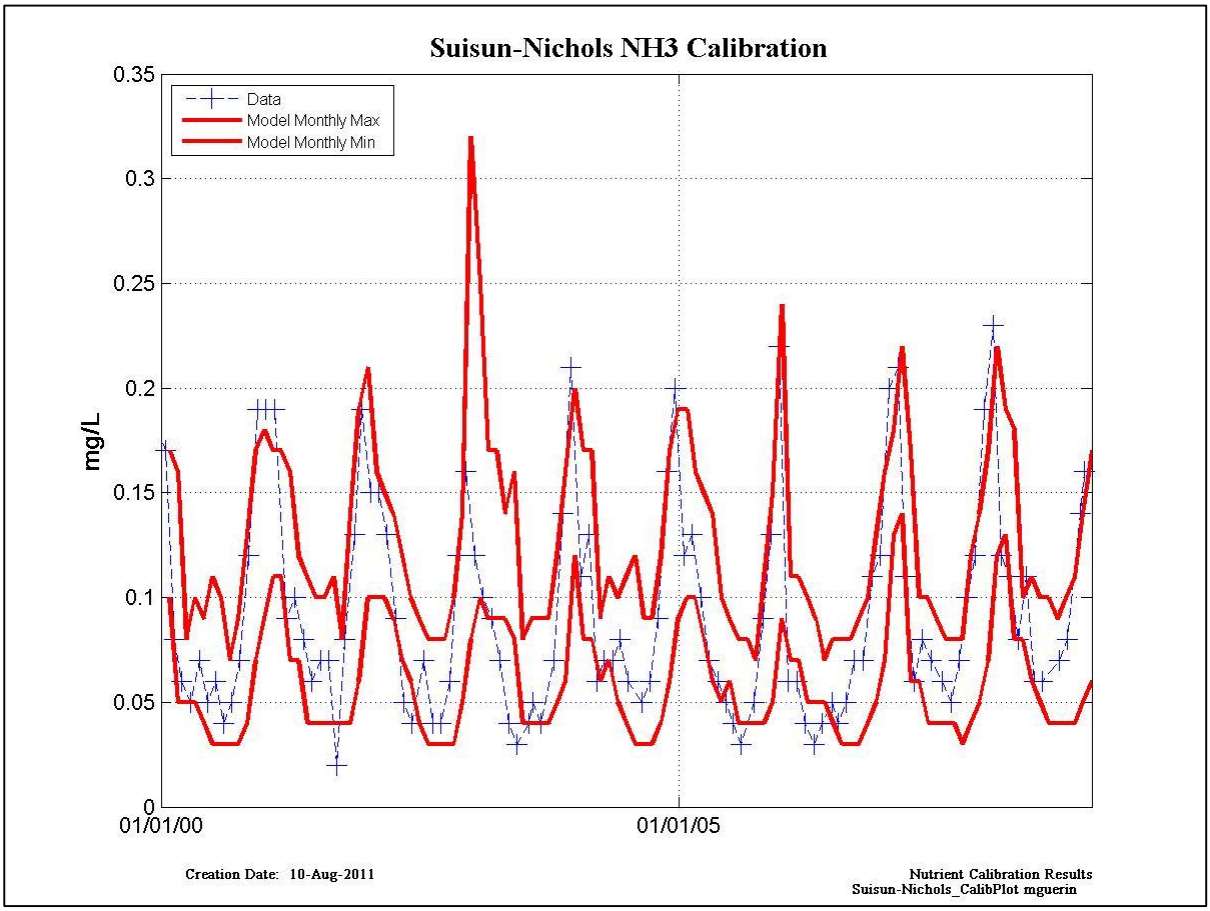


Figure 26-50 NH_3 calibration results at Suisun-Nichols – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-50 Model calibration/validation statistics at Suisun-Nichols for $NH_3$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

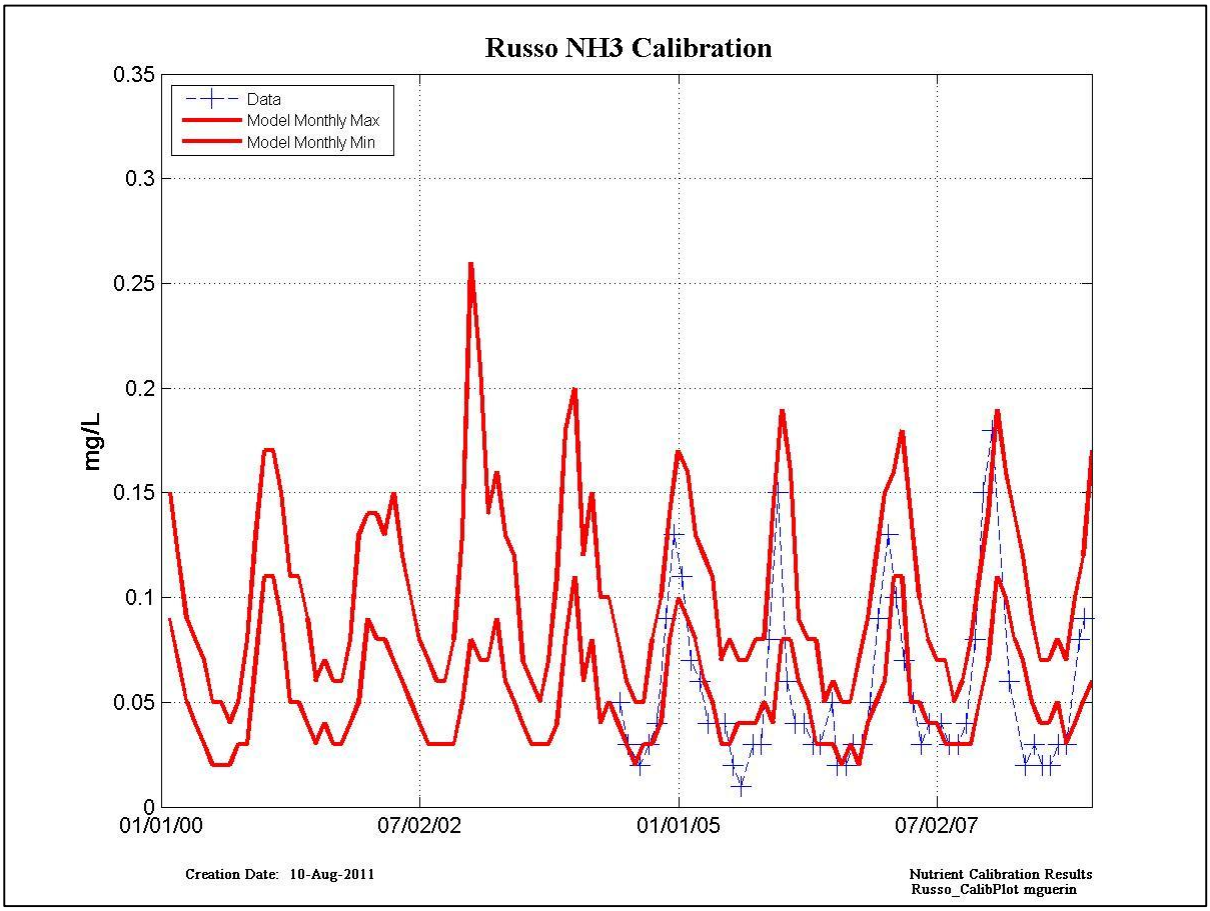


Figure 26-51 NH_3 calibration results at Russo – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-51 (Intentionally left blank) Insufficient data to calculate calibration statistics.

26.4 NO3+NO2

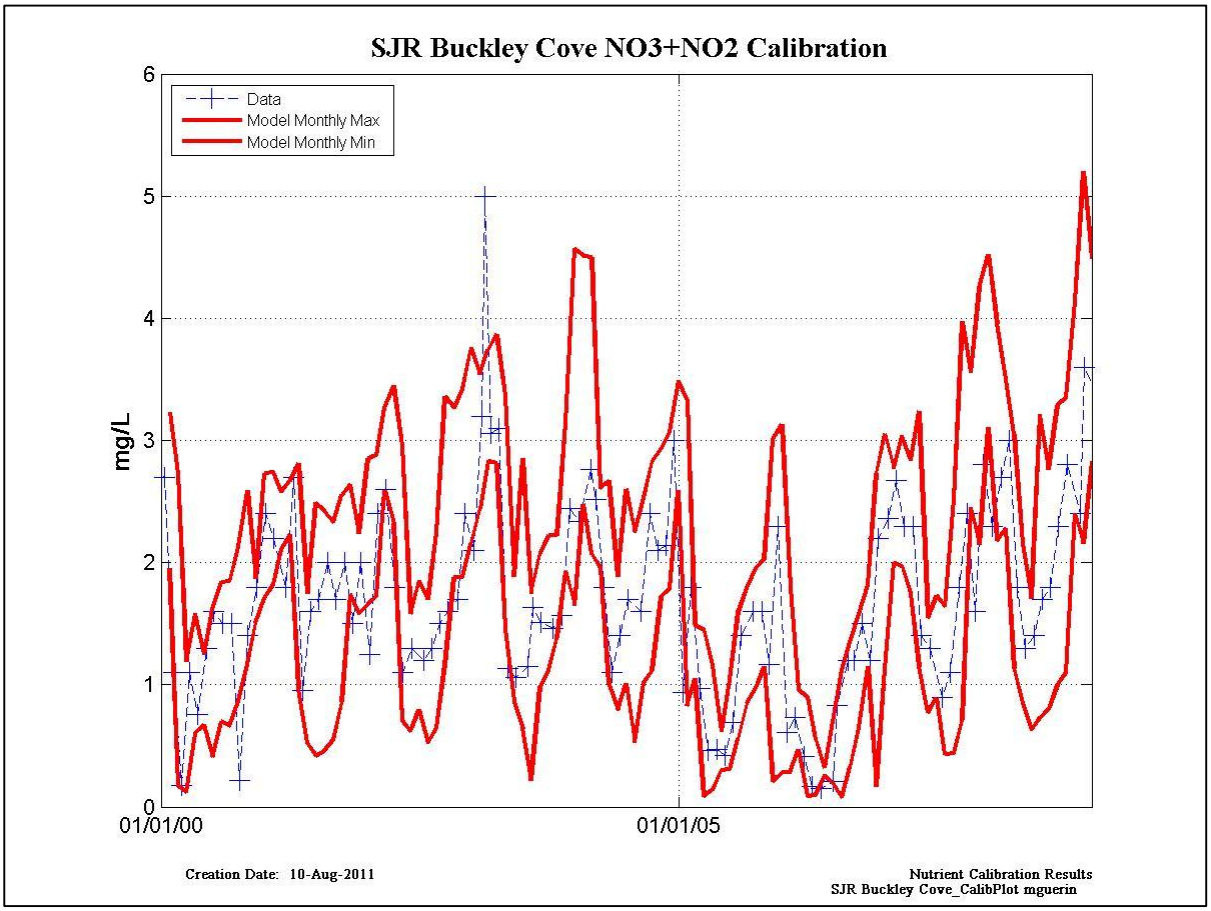


Figure 26-52 NO_3 + NO_2 calibration results at SJR Buckley Cove – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-52 Model calibration/validation statistics at SJR Buckley Cove for NO_3 + $NO_2$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG

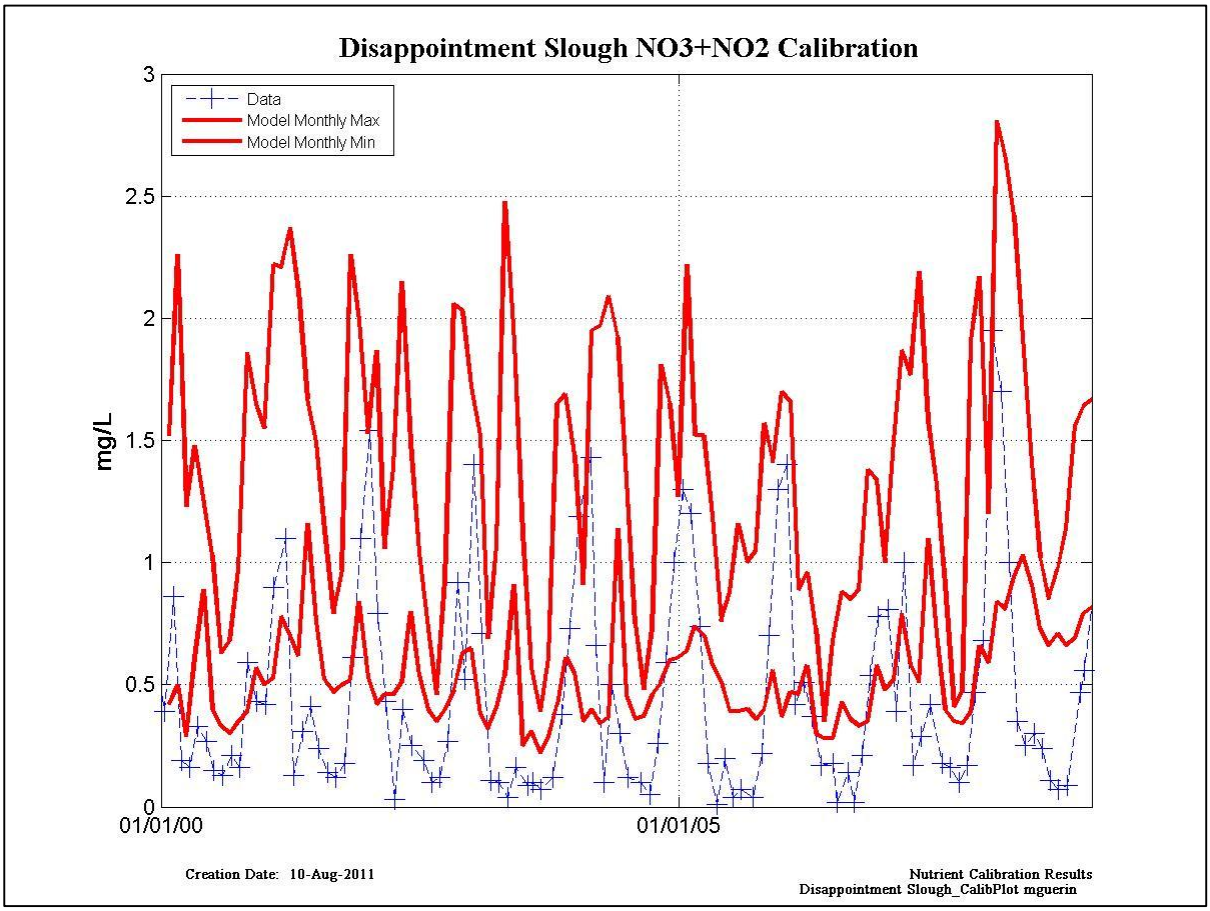


Figure 26-53 NO_3 + NO_2 calibration results at Disappointment Sl. – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-53 Model calibration/validation statistics at Disappointment Sl. for NO_3 + $NO_2$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	G	S	Overestimate	G
Dry WY Calibration	G	S	Overestimate	U
Wet WY Calibration	S	S	Overestimate	U
Dry WY Validation	G	S	Overestimate	U
Wet WY Validation	VG	G	Overestimate	VG

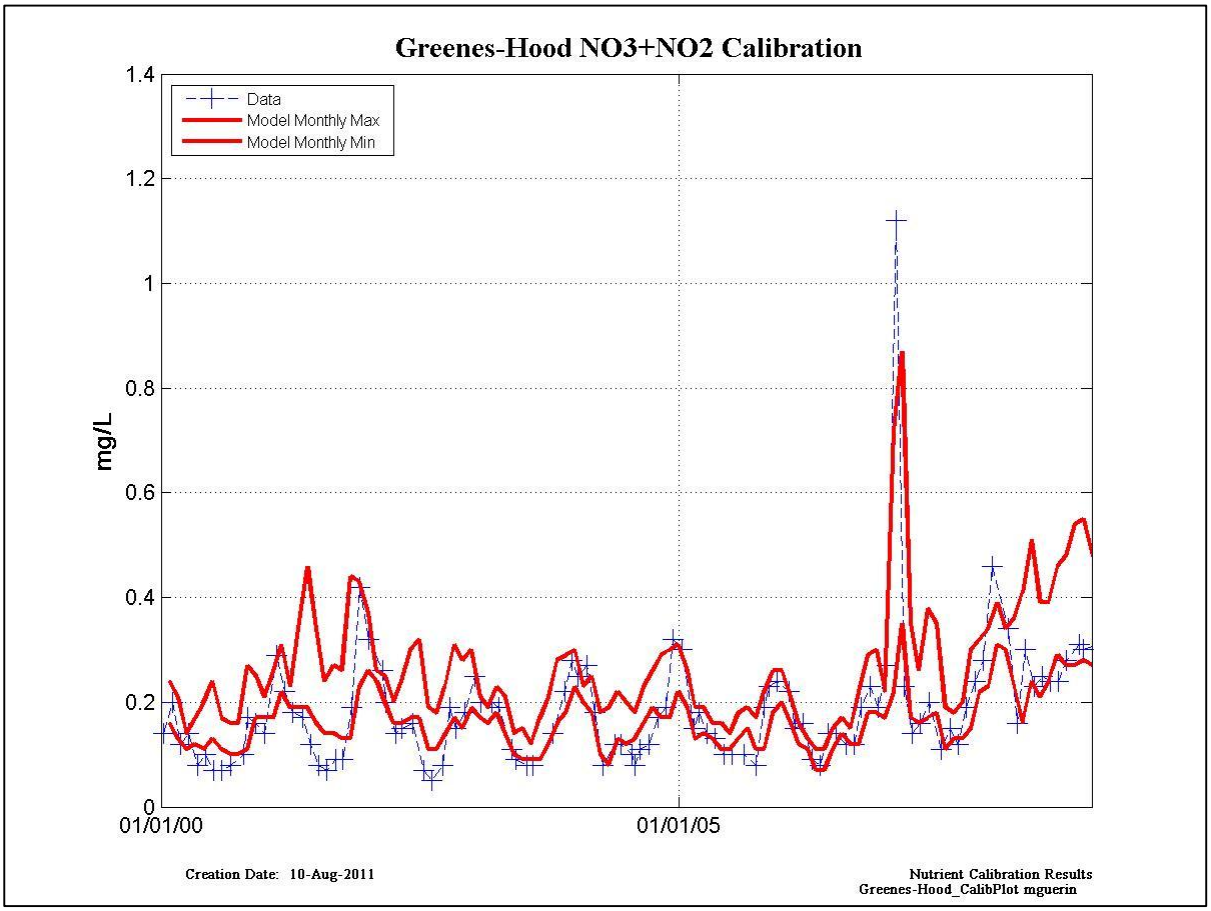


Figure 26-54 NO_3 + NO_2 calibration results at Greens-Hood – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-54 Model calibration/validation statistics at Greens-Hood for NO_3 + $NO_2$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

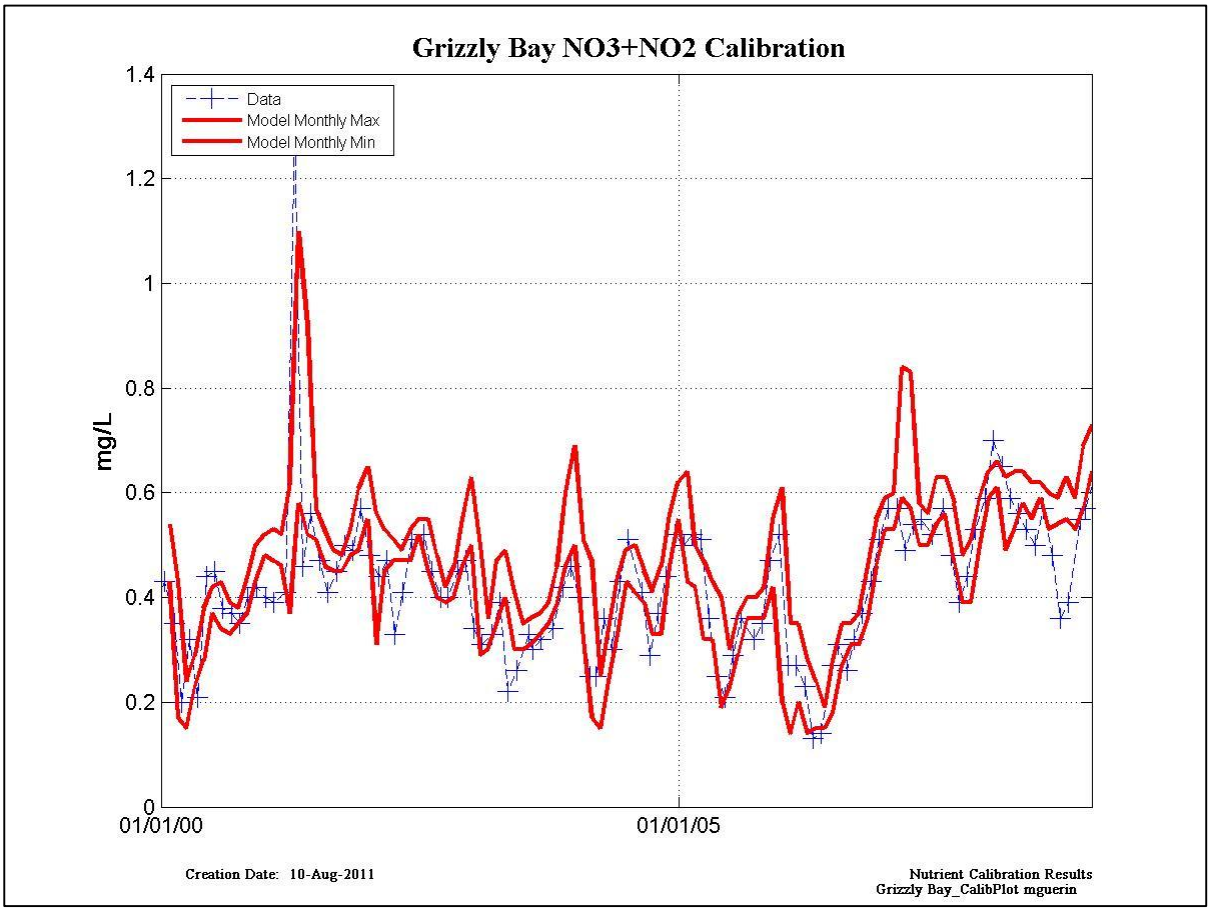


Figure 26-55 NO_3 + NO_2 calibration results at Grizzly Bay – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-55 Model calibration/validation statistics at Grizzly Bay for NO_3 + $NO_2$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	VG	VG	Overestimate	VG

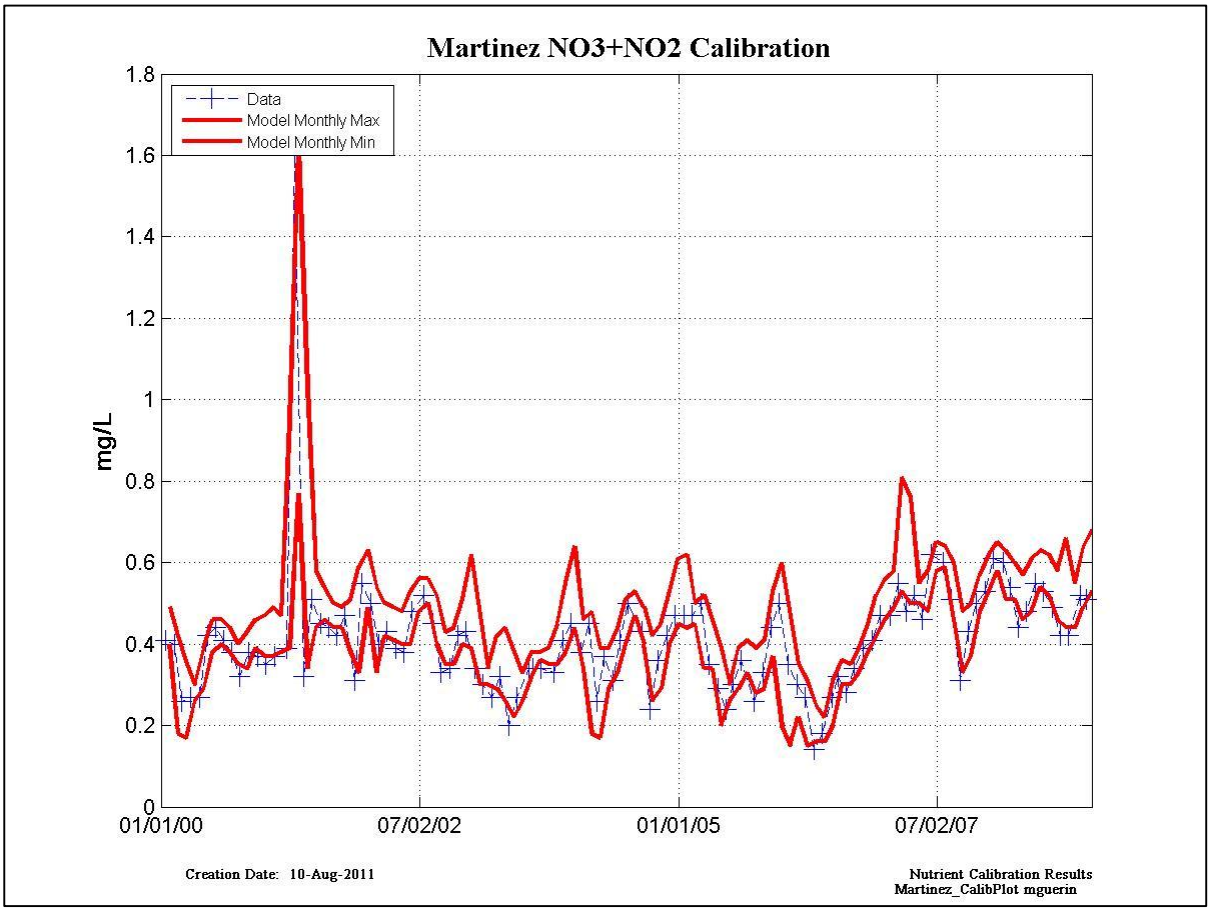


Figure 26-56 NO_3 + NO_2 calibration results at Martinez – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-56 Model calibration/validation statistics at Martinez for NO_3 + $NO_2$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

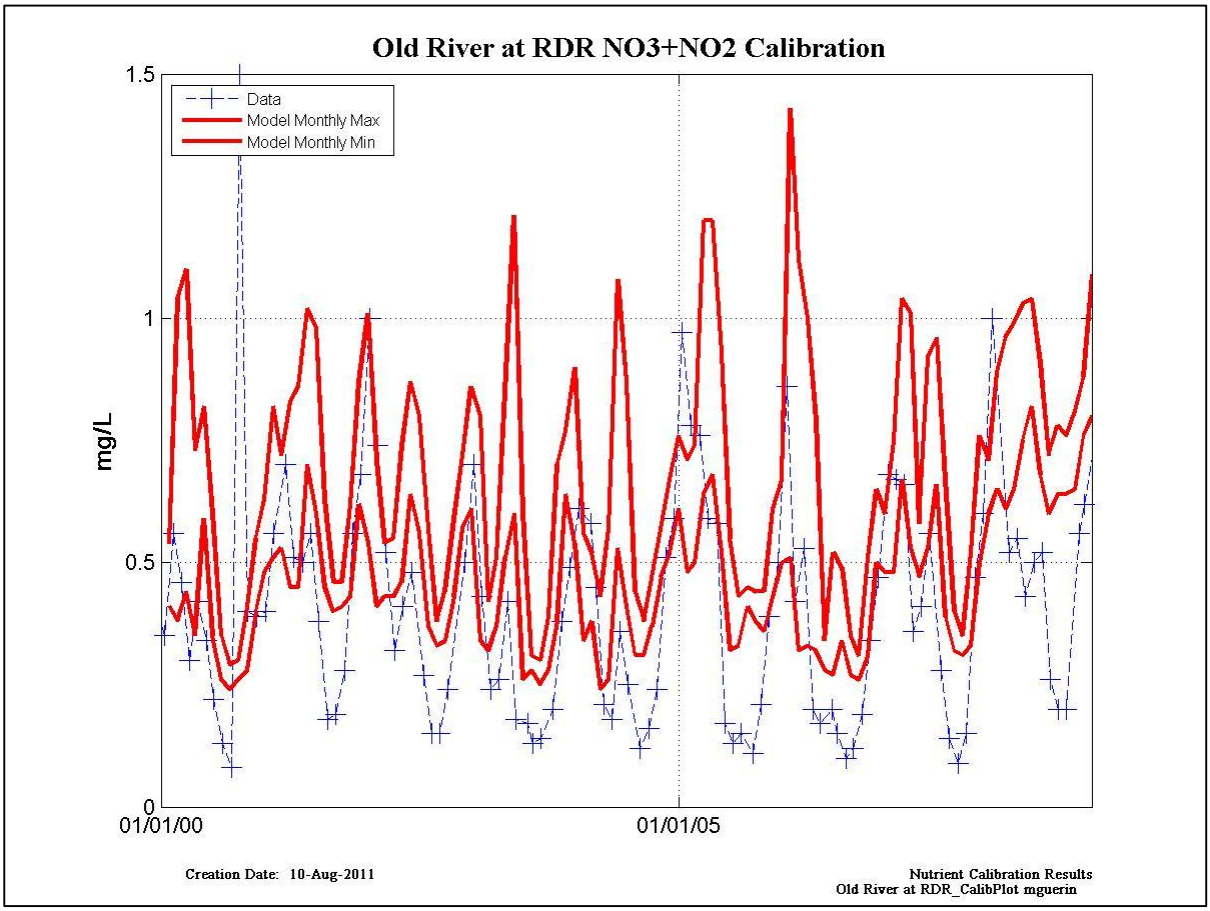


Figure 26-57 NO_3 + NO_2 calibration results at Old R. at Rancho Del Rio – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-57 Model calibration/validation statistics at Old R. at Rancho Del Rio for NO_3 + $NO_2$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	S	VG	Overestimate	S
Wet WY Calibration	S	VG	Overestimate	U
Dry WY Validation	S	G	Overestimate	U
Wet WY Validation	VG	VG	Overestimate	G

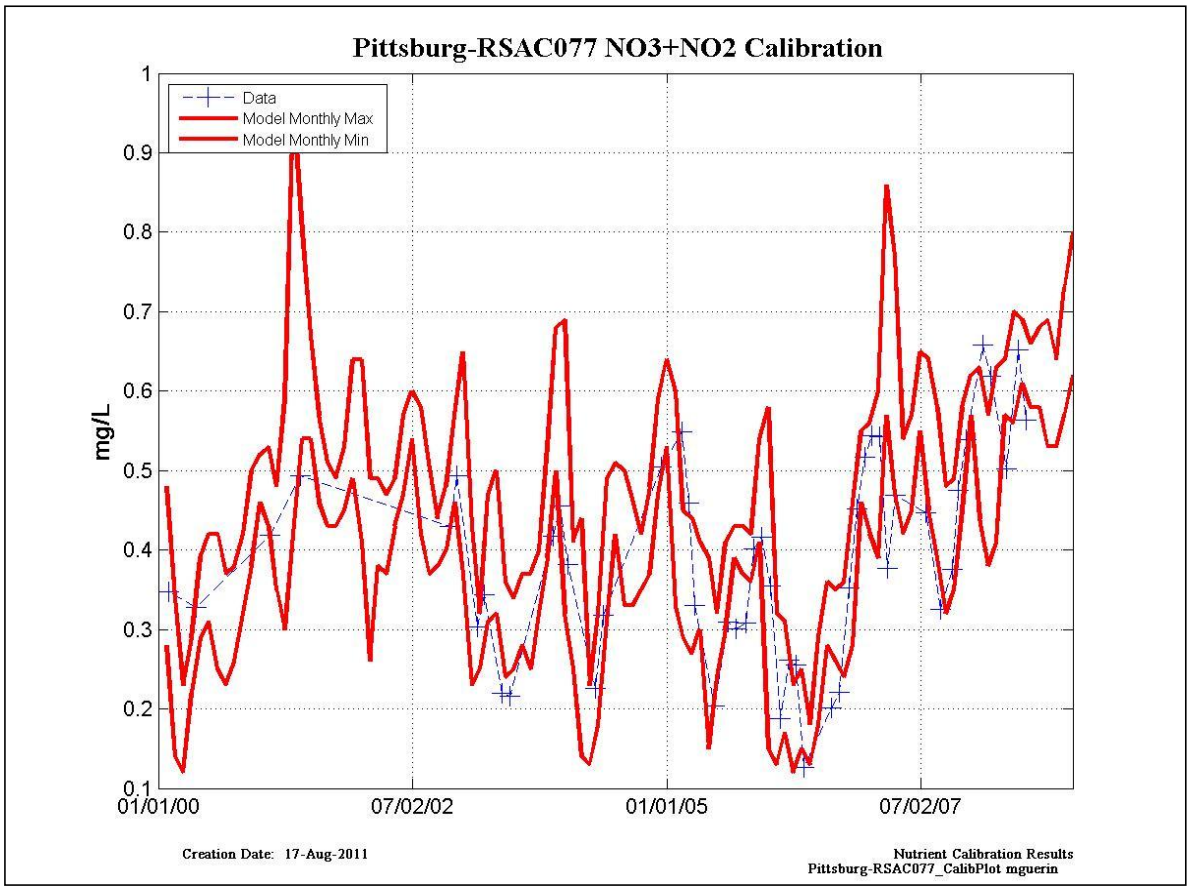


Figure 26-58NO_3 + NO_2 calibration results at Old R. at RSAC077-Pittsburg – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines

Table 26-58Model calibration/validation statistics at RSAC077-Pittsburg for NO_3 + $NO_2$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	G	VG	Overestimate	S
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

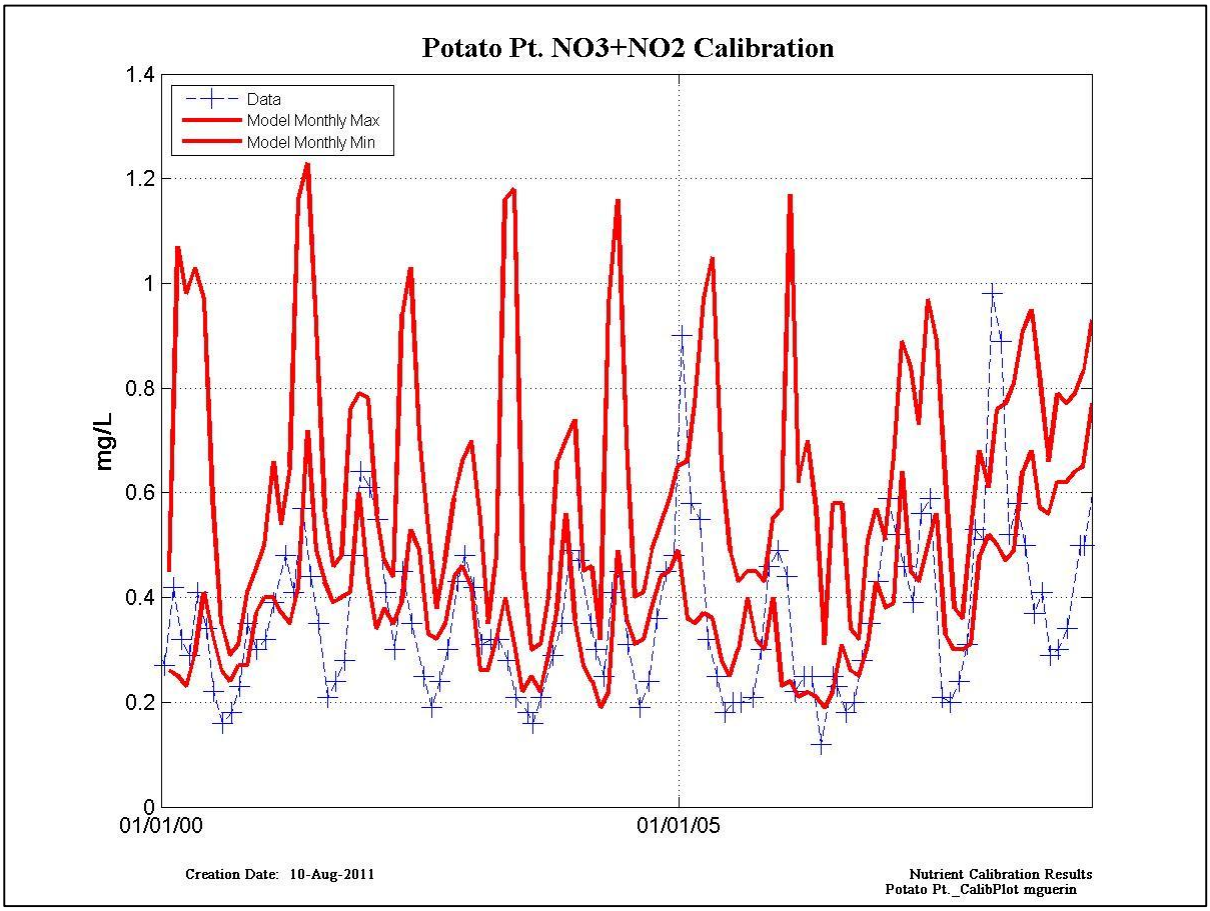


Figure 26-59 NO_3 + NO_2 calibration results at Potato Pt. – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-59 Model calibration/validation statistics at Potato Pt. for NO_3 + $NO_2$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	G	VG	Overestimate	U
Wet WY Calibration	G	VG	Overestimate	U
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	VG	VG	Overestimate	VG

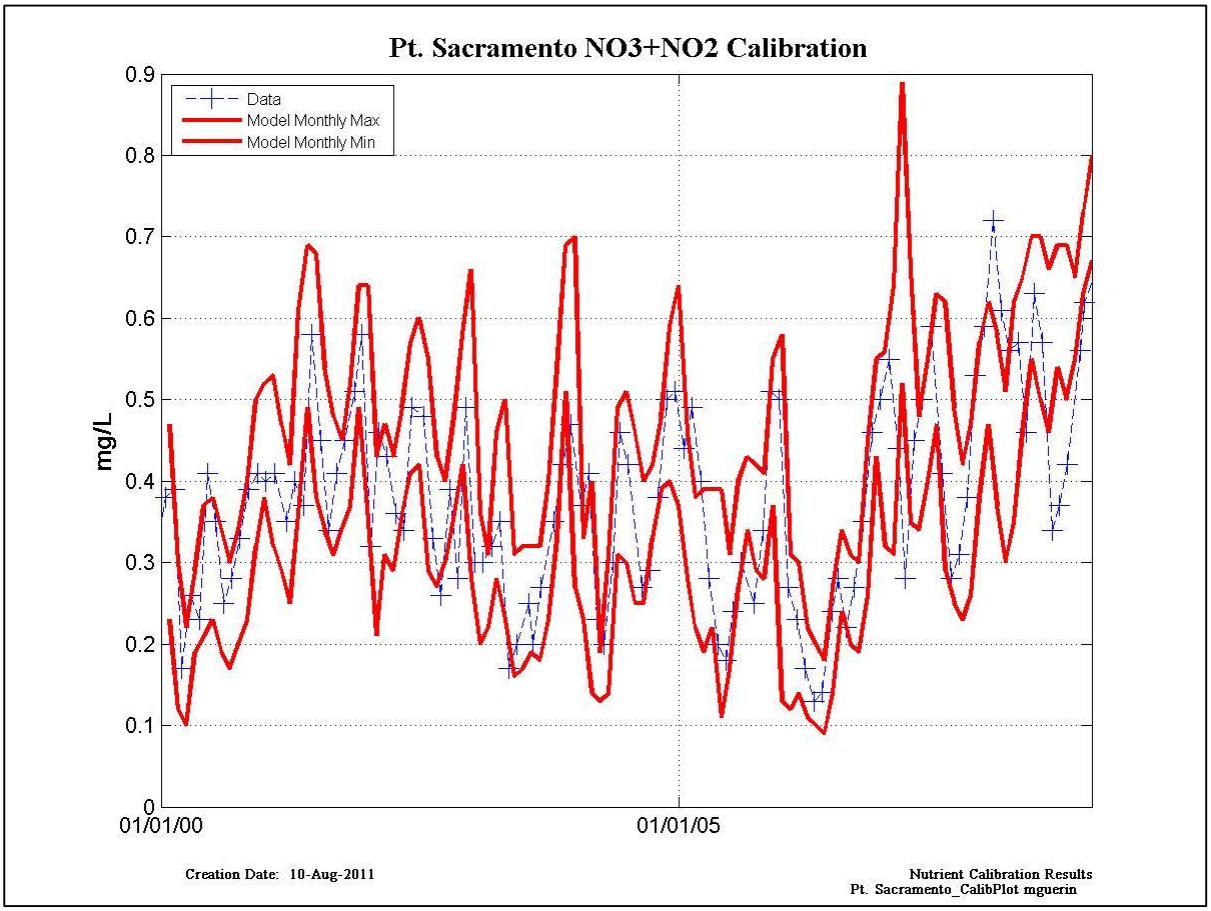


Figure 26-60 NO_3 + NO_2 calibration results at Pt. Sacramento – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-60 Model calibration/validation statistics at Pt. Sacramento for NO_3 + $NO_2$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	G	VG	Overestimate	S
Wet WY Validation	VG	VG	Underestimate	VG

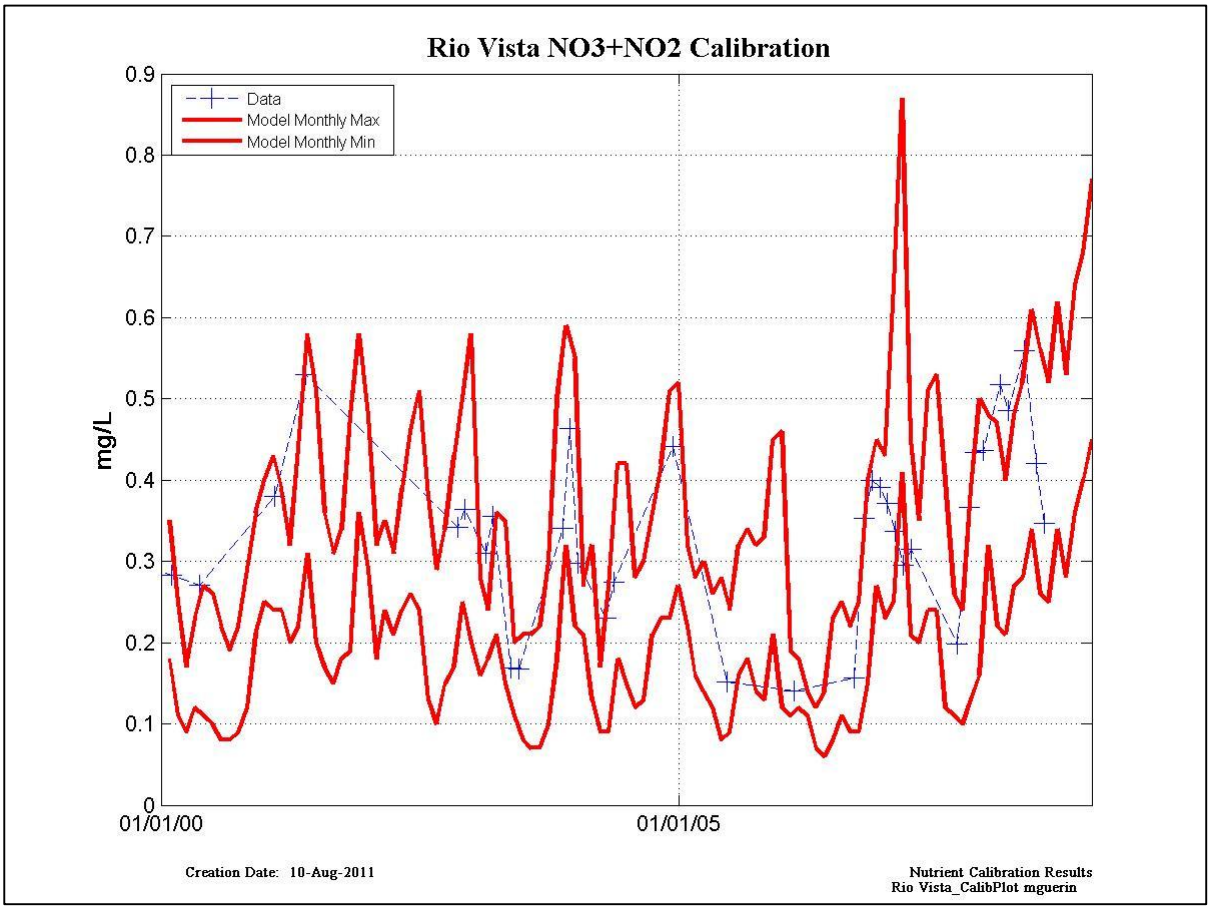


Figure 26-61 NO_3 + NO_2 calibration results at Rio Vista – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-61 Model calibration/validation statistics at Rio Vista for NO_3 + $NO_2$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	No Bias	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	No Bias	VG

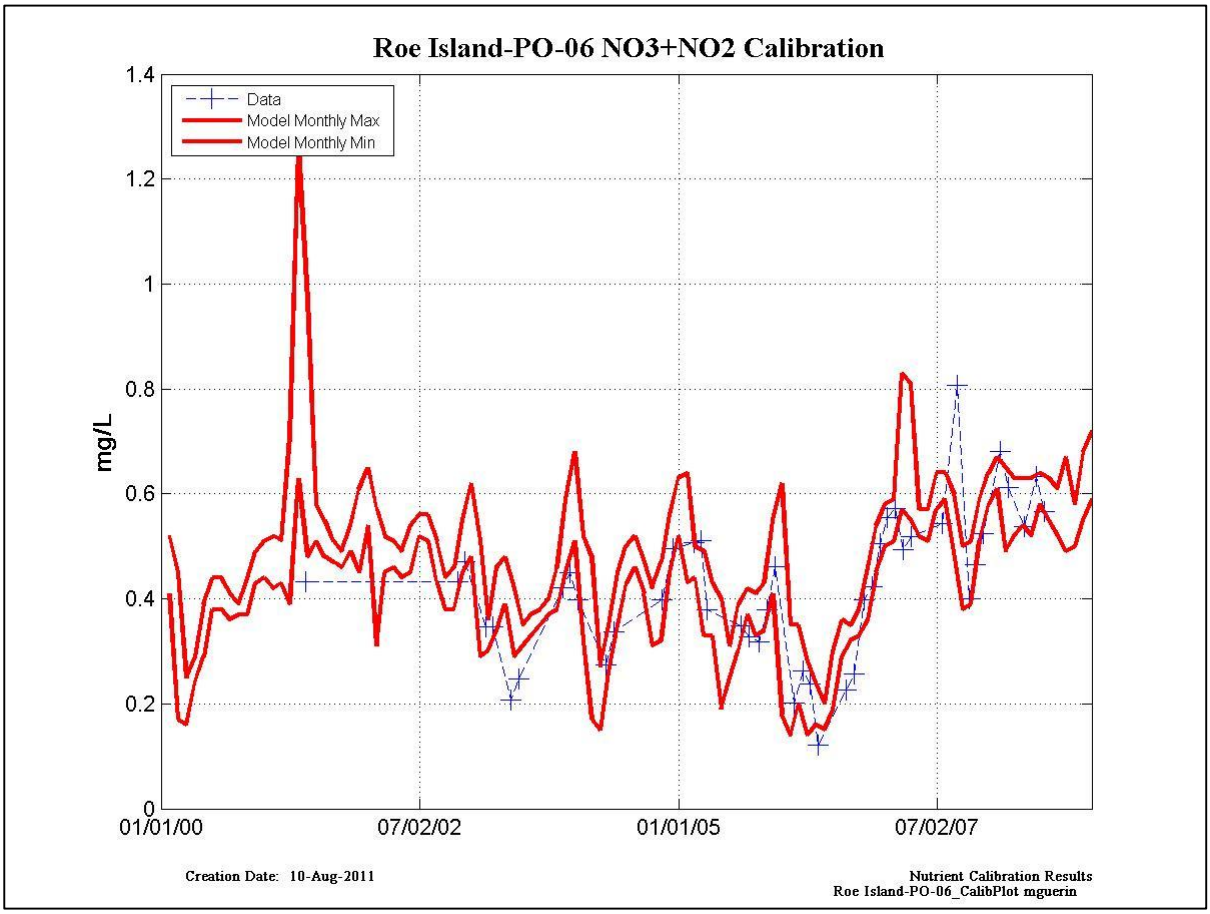


Figure 26-62 NO_3 + NO_2 calibration results at Roe Island – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-62 Model calibration/validation statistics at Roe Island for NO_3 + $NO_2$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	G
Wet WY Calibration	VG	VG	Overestimate	G
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	VG	VG	Overestimate	VG

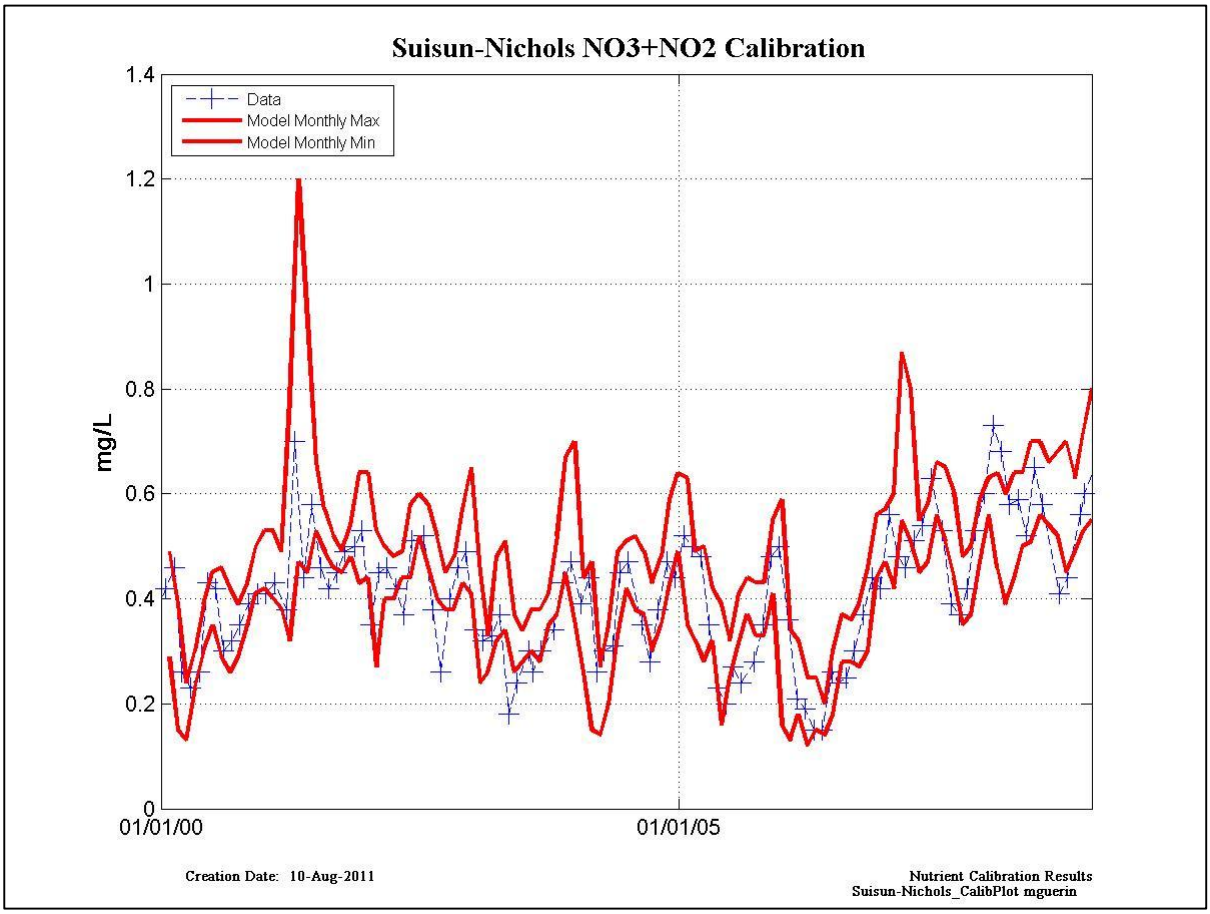


Figure 26-63 NO_3 + NO_2 calibration results at Suisun-Nichols – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-63 Model calibration/validation statistics at Suisun-Nichols for NO_3 + NO_2f or the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

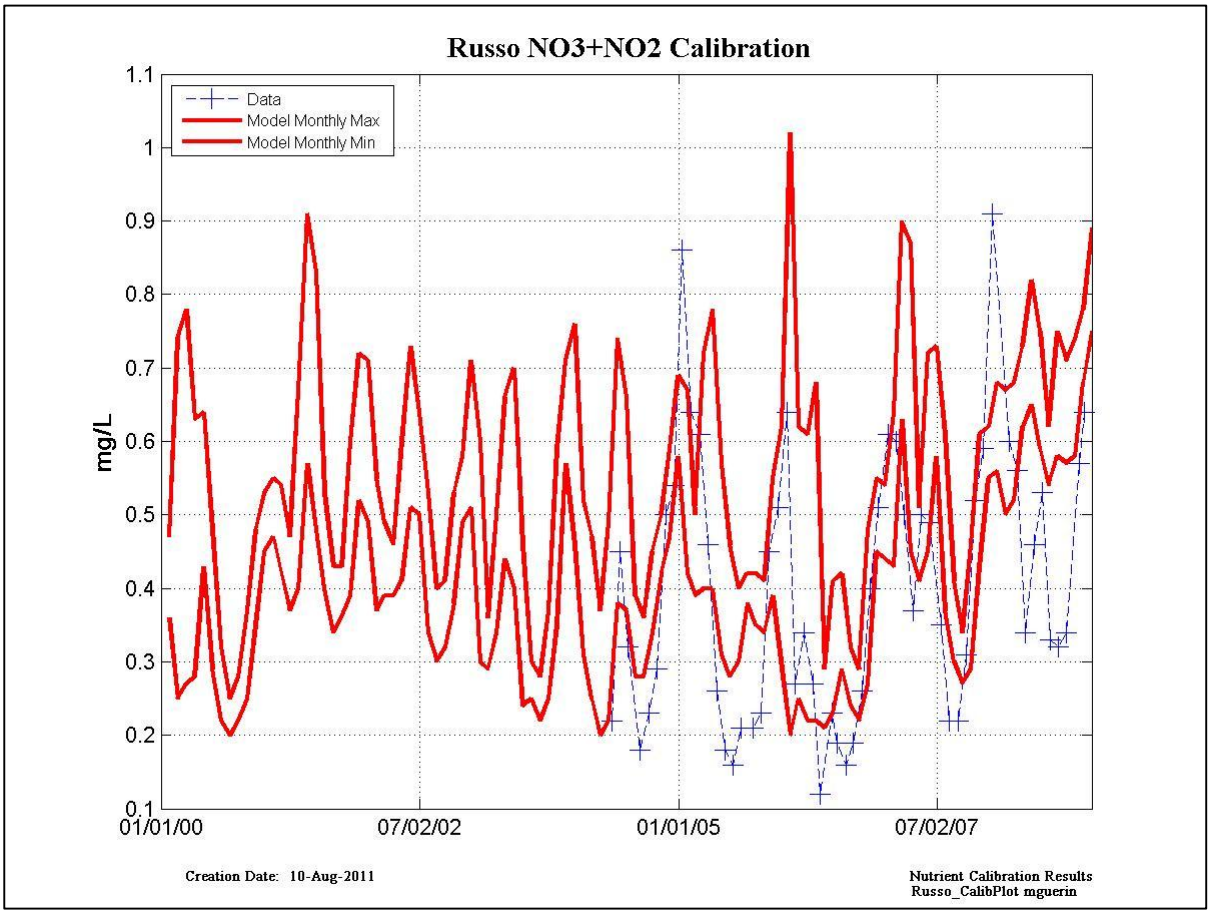


Figure 26-64NO_3 + NO_2 calibration results at Russo – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-64 (Intentionally left blank) Insufficient data to calculate calibration statistics.

26.5 Organic-N

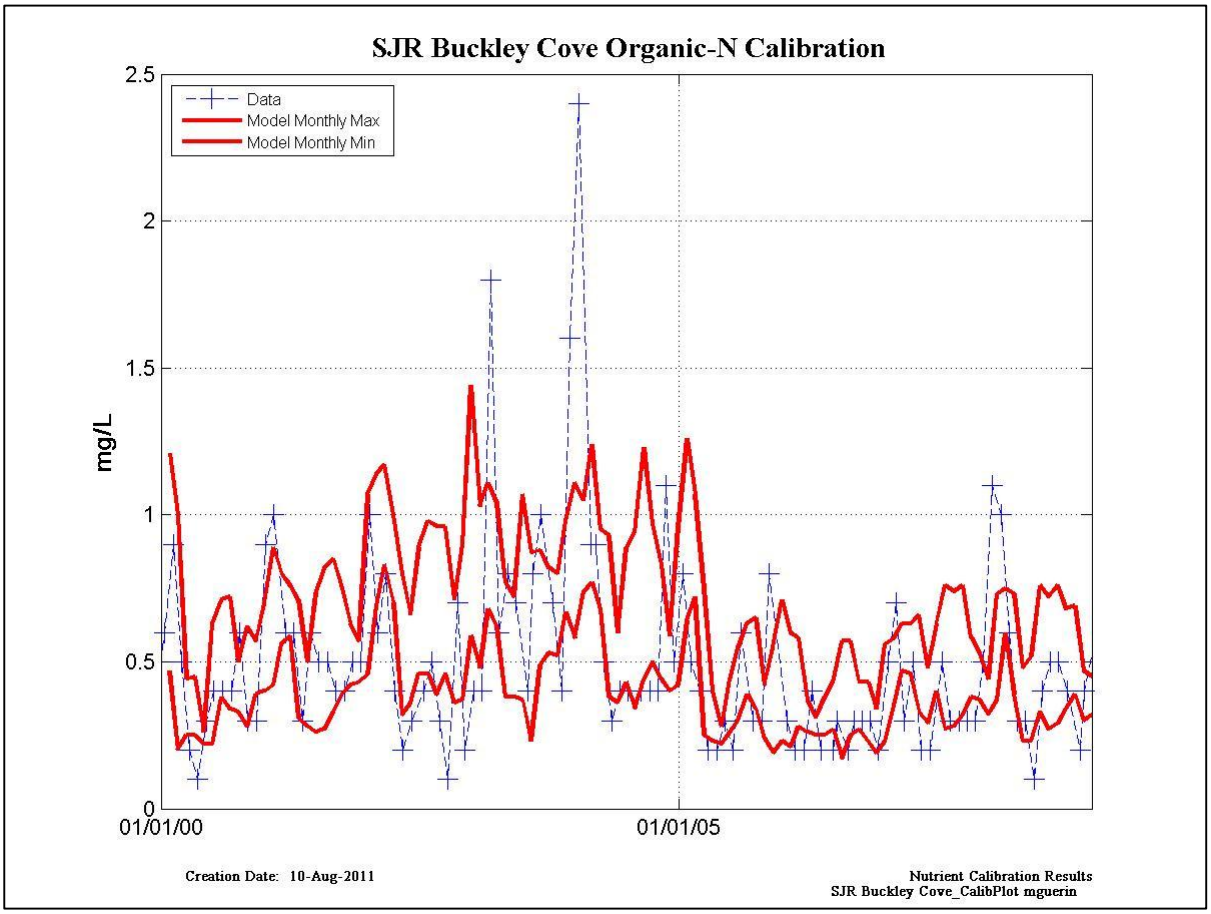


Figure 26-65 Organic-N calibration results at SJR Buckley Cove – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-65 Model calibration/validation statistics at SJR Buckley Cove for Organic-N for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Overestimate	G
Wet WY Calibration	G	VG	Underestimate	G
Dry WY Validation	G	VG	Overestimate	G
Wet WY Validation	VG	VG	Overestimate	VG

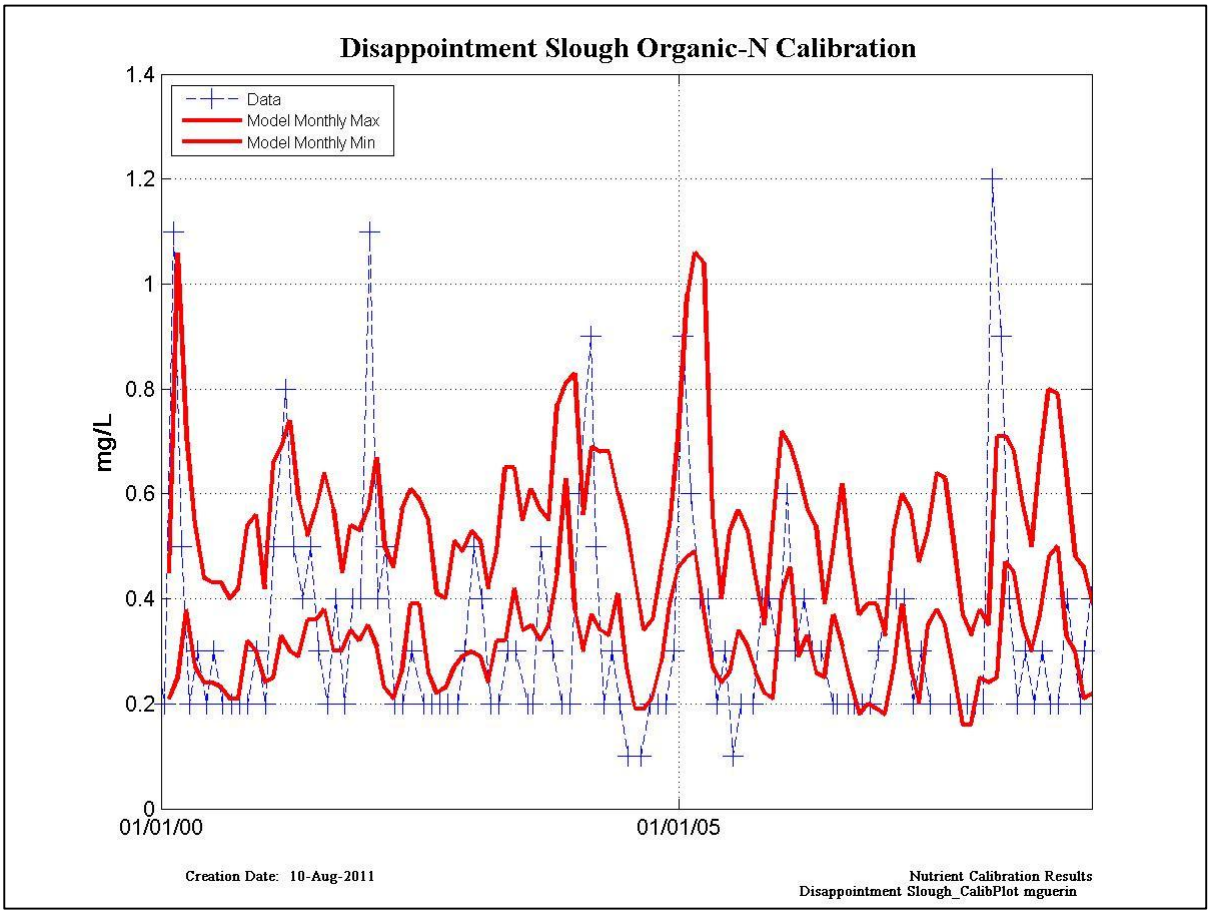


Figure 26-66 Organic-N calibration results at Disappointment Sl. – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-66 Model calibration/validation statistics at Disappointment Sl. for Organic-N for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	G	VG	Overestimate	G
Wet WY Calibration	G	VG	Overestimate	S
Dry WY Validation	S	VG	Overestimate	S
Wet WY Validation	VG	VG	Overestimate	VG

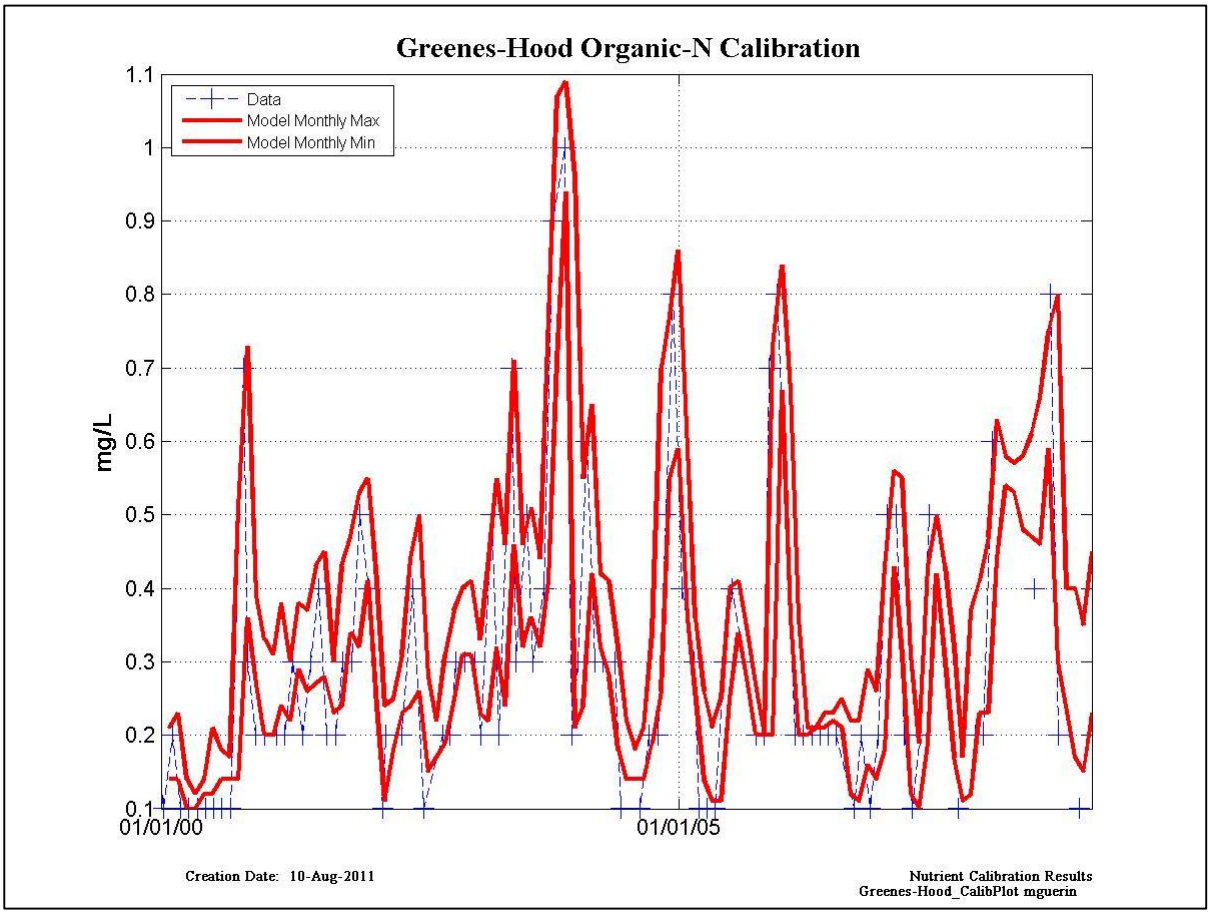


Figure 26-67 Organic-N calibration results at Greens-Hood – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-67 Model calibration/validation statistics at Greens-Hood for Organic-N for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

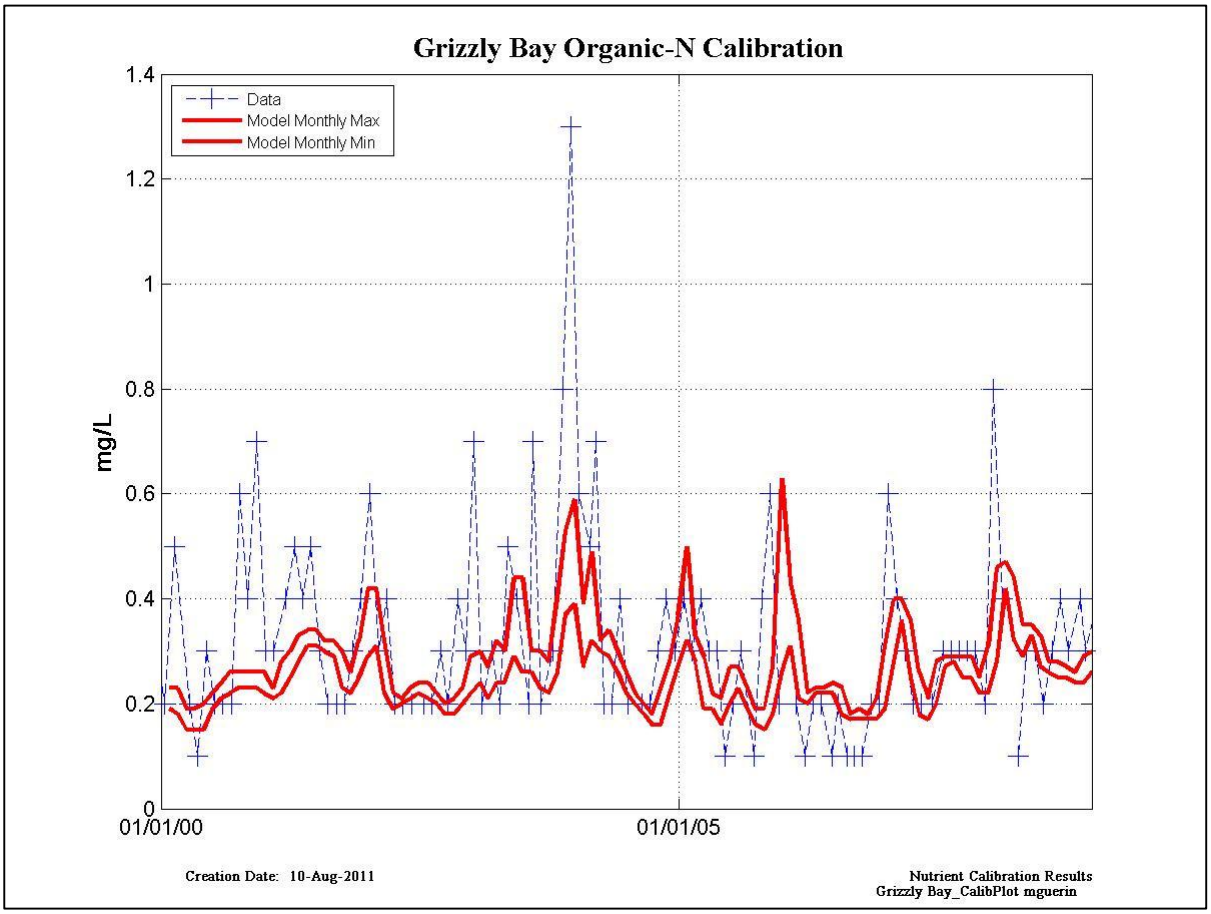


Figure 26-68 Organic-N calibration results at Grizzly Bay – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-68 Model calibration/validation statistics at Grizzly Bay for Organic-N for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	S	G	Underestimate	U
Dry WY Validation	S	VG	Underestimate	S
Wet WY Validation	S	VG	Underestimate	U

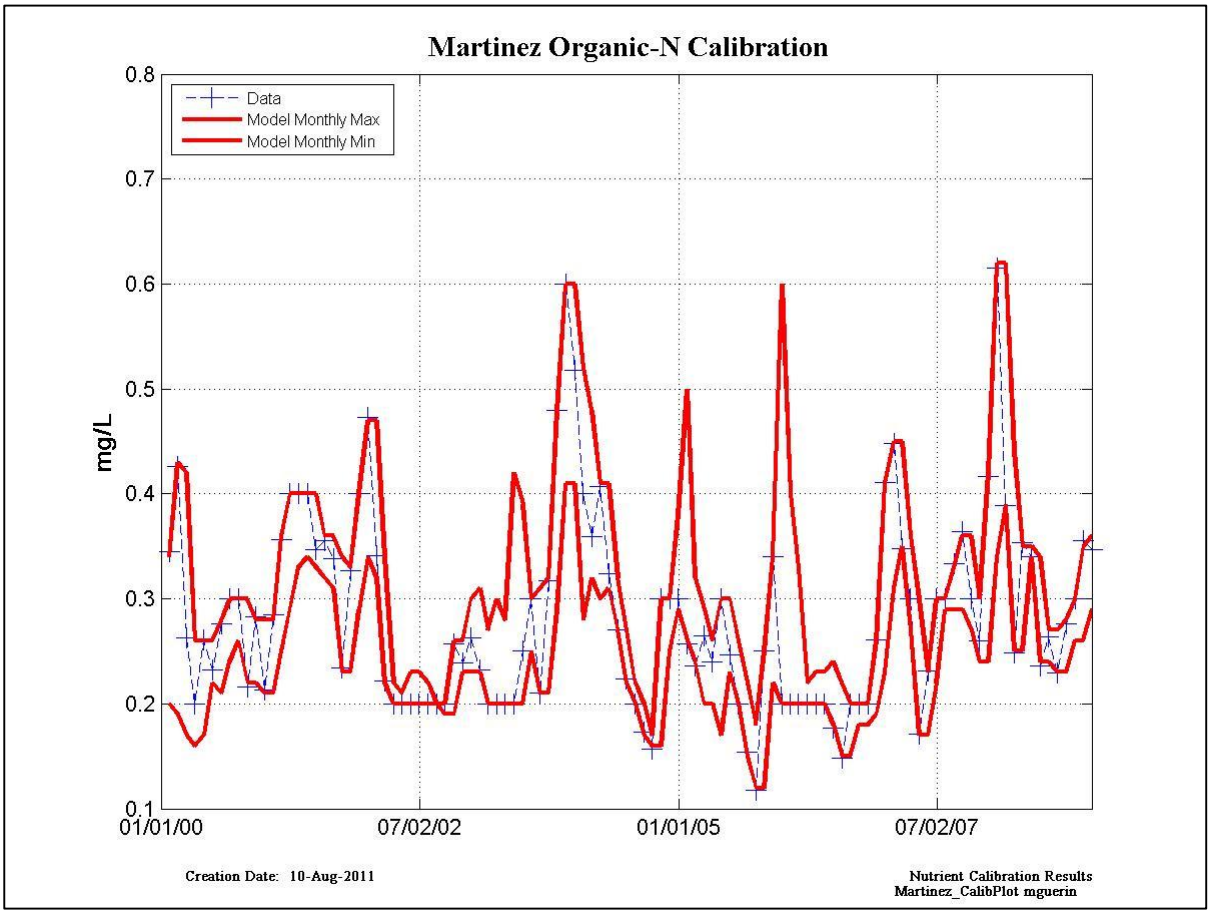


Figure 26-69 Organic-N calibration results at Martinez – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-69 Model calibration/validation statistics at Martinez for Organic-N for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

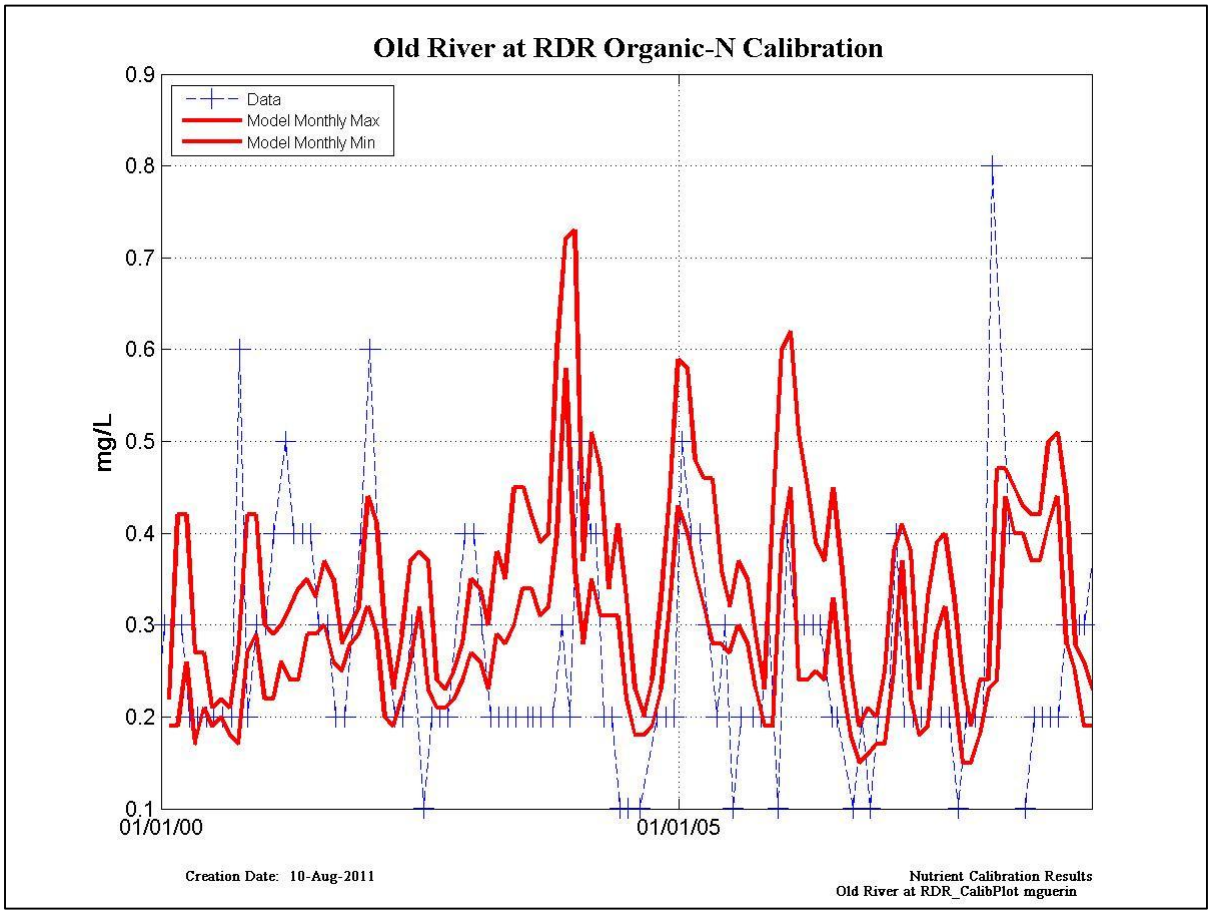


Figure 26-70 Organic-N calibration results at Old R. at Rancho Del Rio – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-70 Model calibration/validation statistics at Old R. at Rancho Del Rio for Organic-N for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	S	VG	Underestimate	S
Wet WY Calibration	U	VG	Overestimate	U
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	S	VG	Overestimate	U

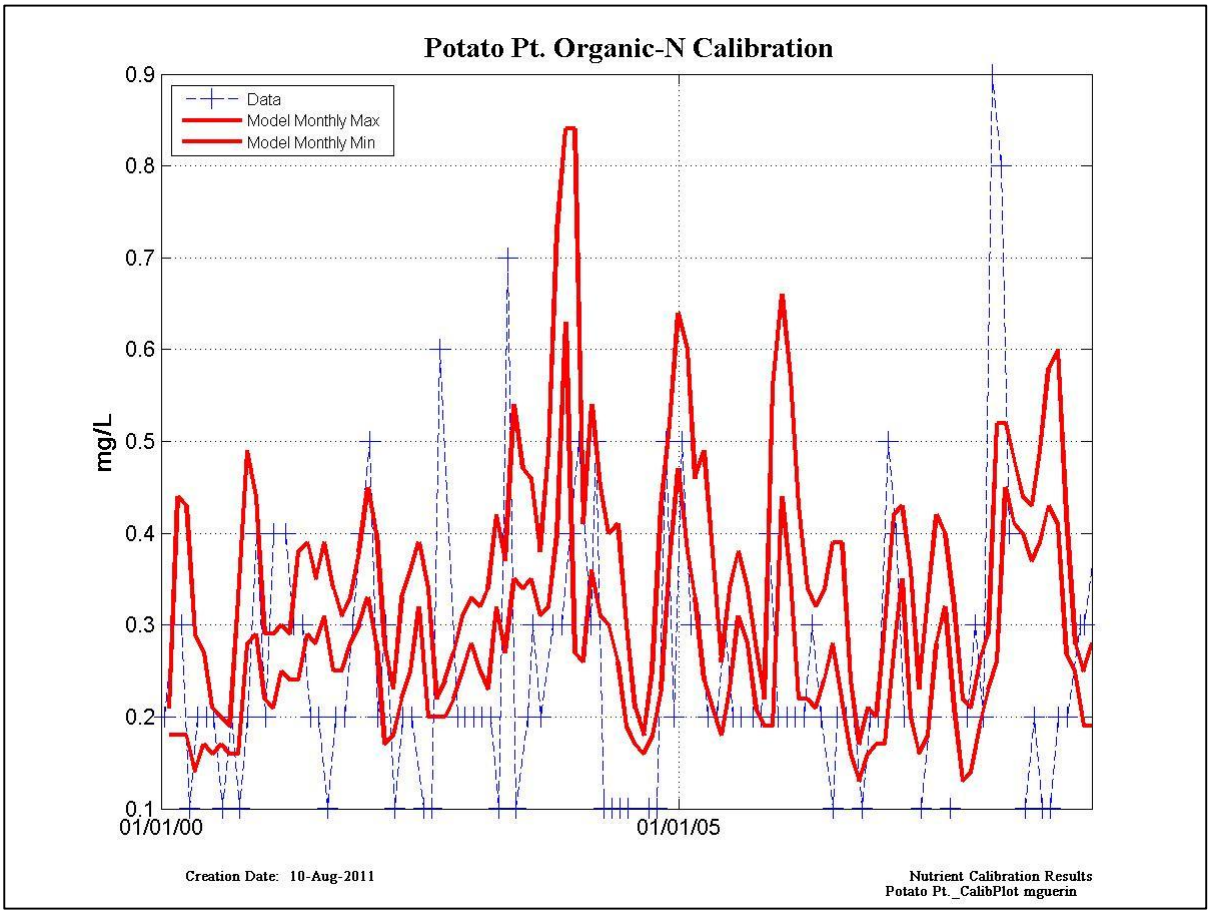


Figure 26-71 Organic-N calibration results at Potato Pt. – data points are located at blue symbols; monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-71 Model calibration/validation statistics at Potato Pt. for Organic-N for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	S	VG	Overestimate	U
Wet WY Calibration	S	VG	Overestimate	U
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	S	VG	Overestimate	U

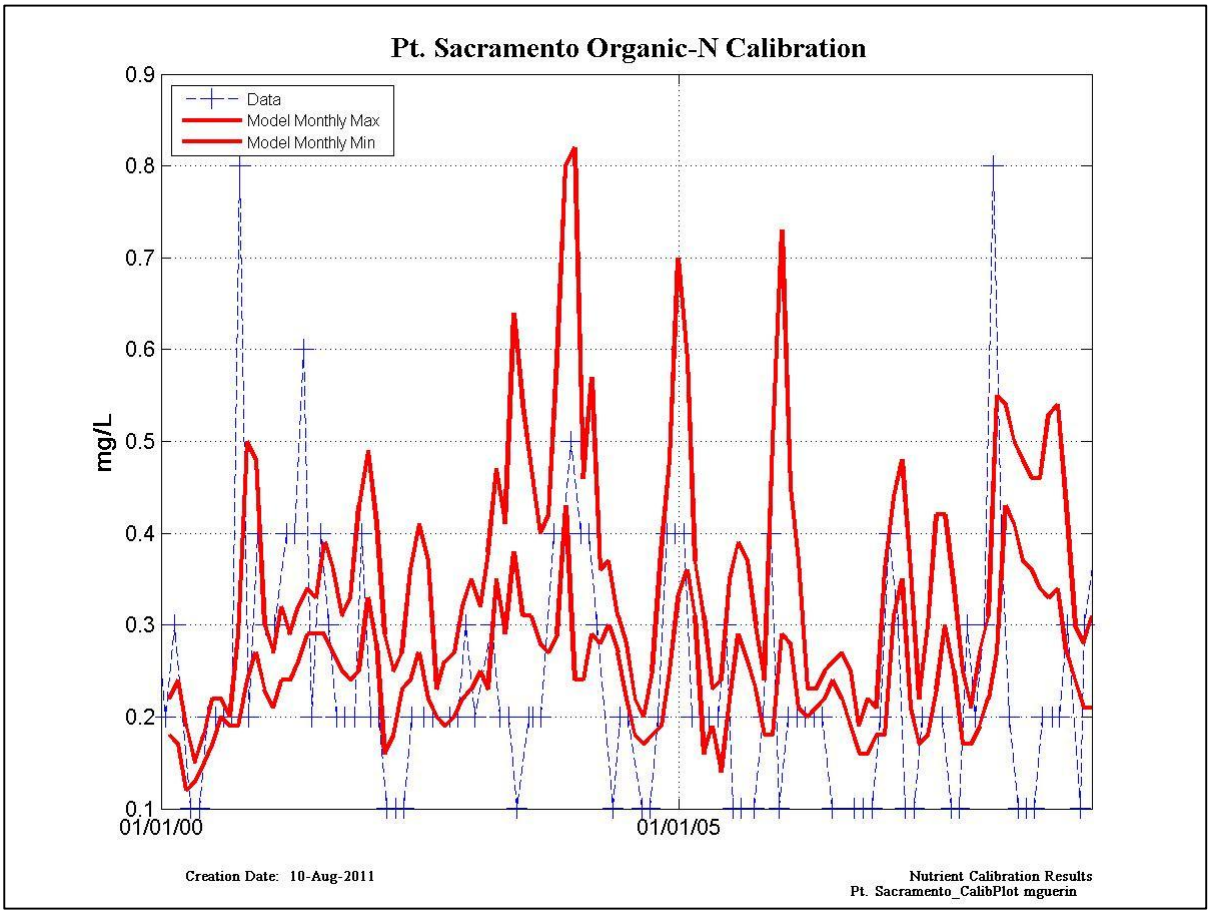


Figure 26-72 Organic-N calibration results at Pt. Sacramento – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-72 Model calibration/validation statistics at Pt. Sacramento for Organic-N for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	S	VG	Overestimate	S
Wet WY Calibration	S	VG	Overestimate	S
Dry WY Validation	S	G	Overestimate	U
Wet WY Validation	S	G	Overestimate	U

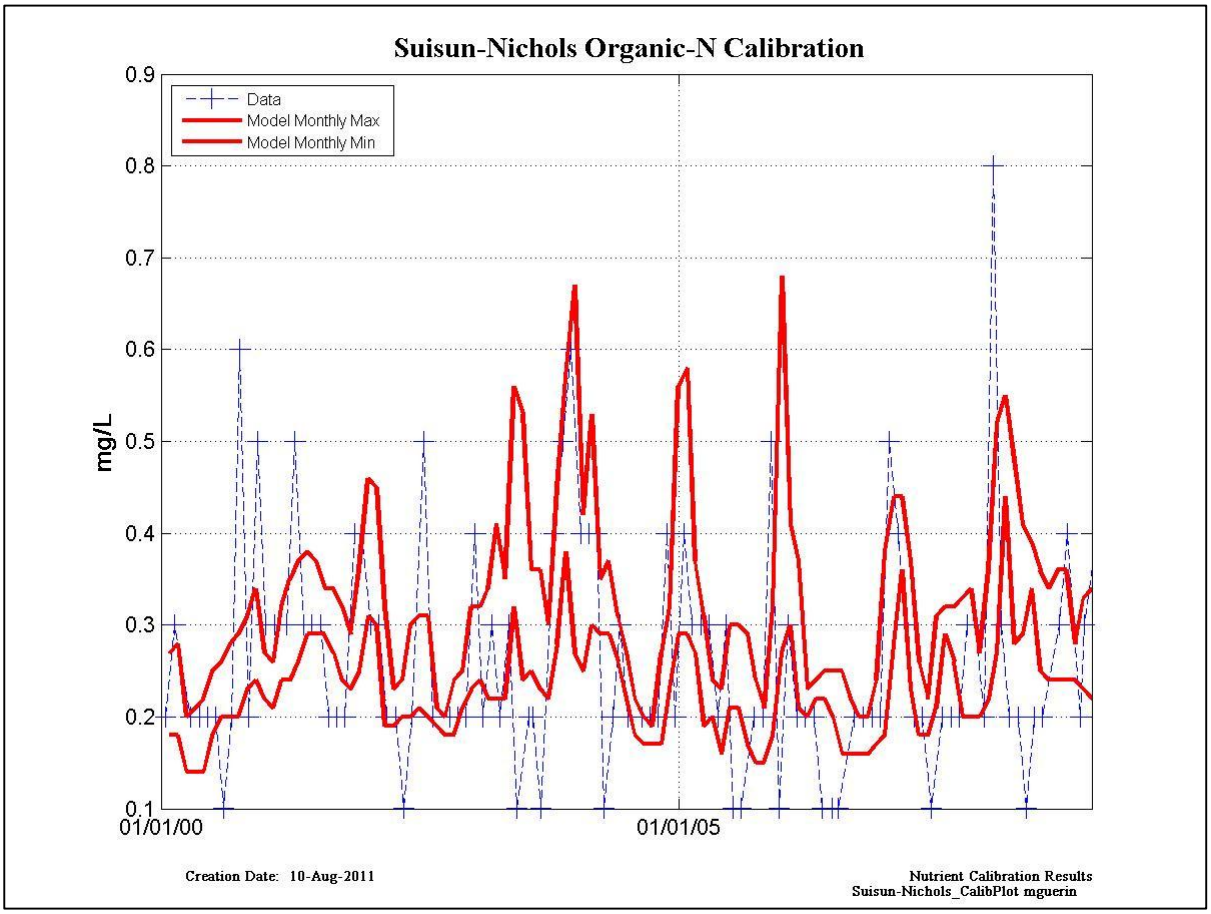


Figure 26-73 Organic-N calibration results at Suisun-Nichols – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-73 Model calibration/validation statistics at Suisun-Nichols for Organic-N for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	G	VG	Underestimate	G
Wet WY Calibration	S	VG	Underestimate	S
Dry WY Validation	S	VG	Overestimate	S
Wet WY Validation	S	VG	Overestimate	S

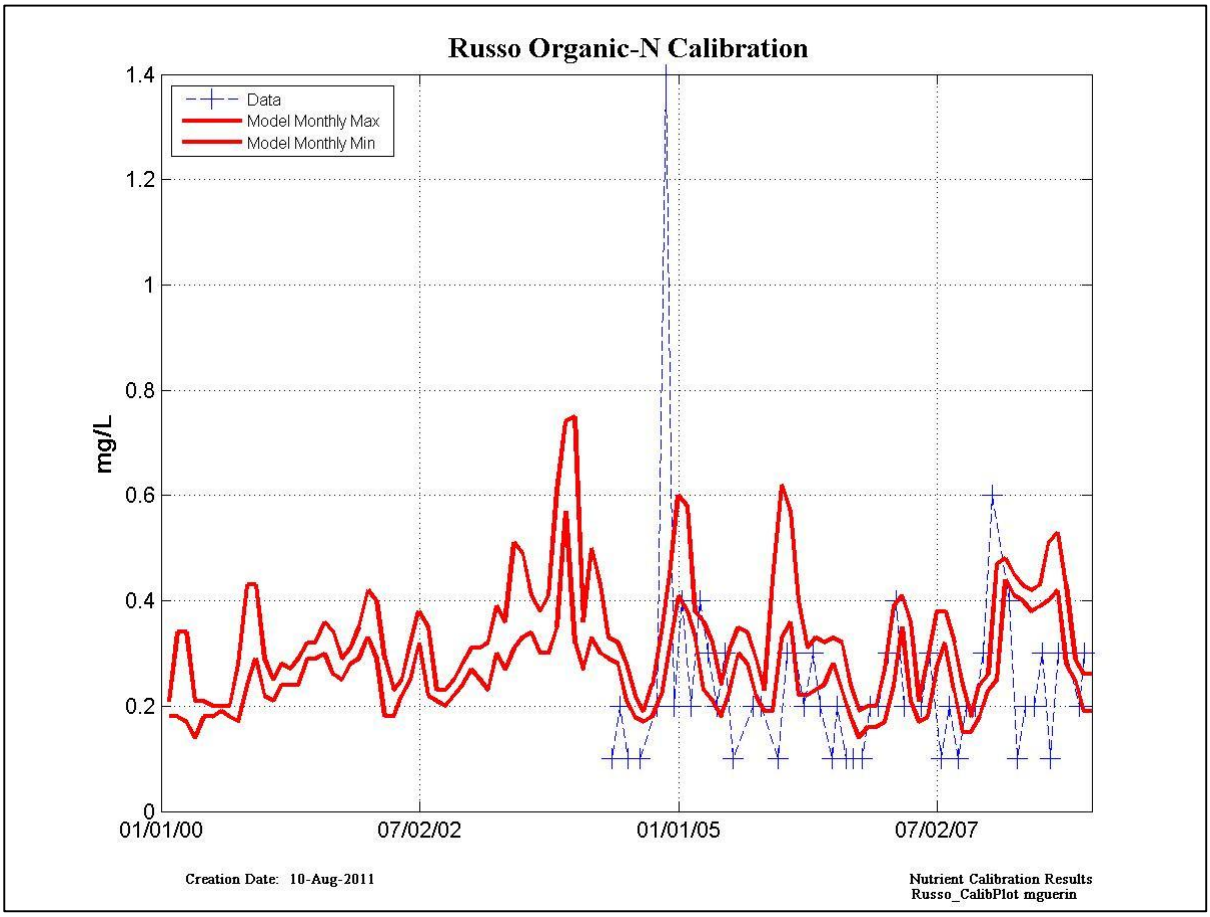


Figure 26-74Organic-N calibration results at Russo – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines

Table 26-74 (Intentionally left blank) Insufficient data to calculate calibration statistics.

26.6 PO4

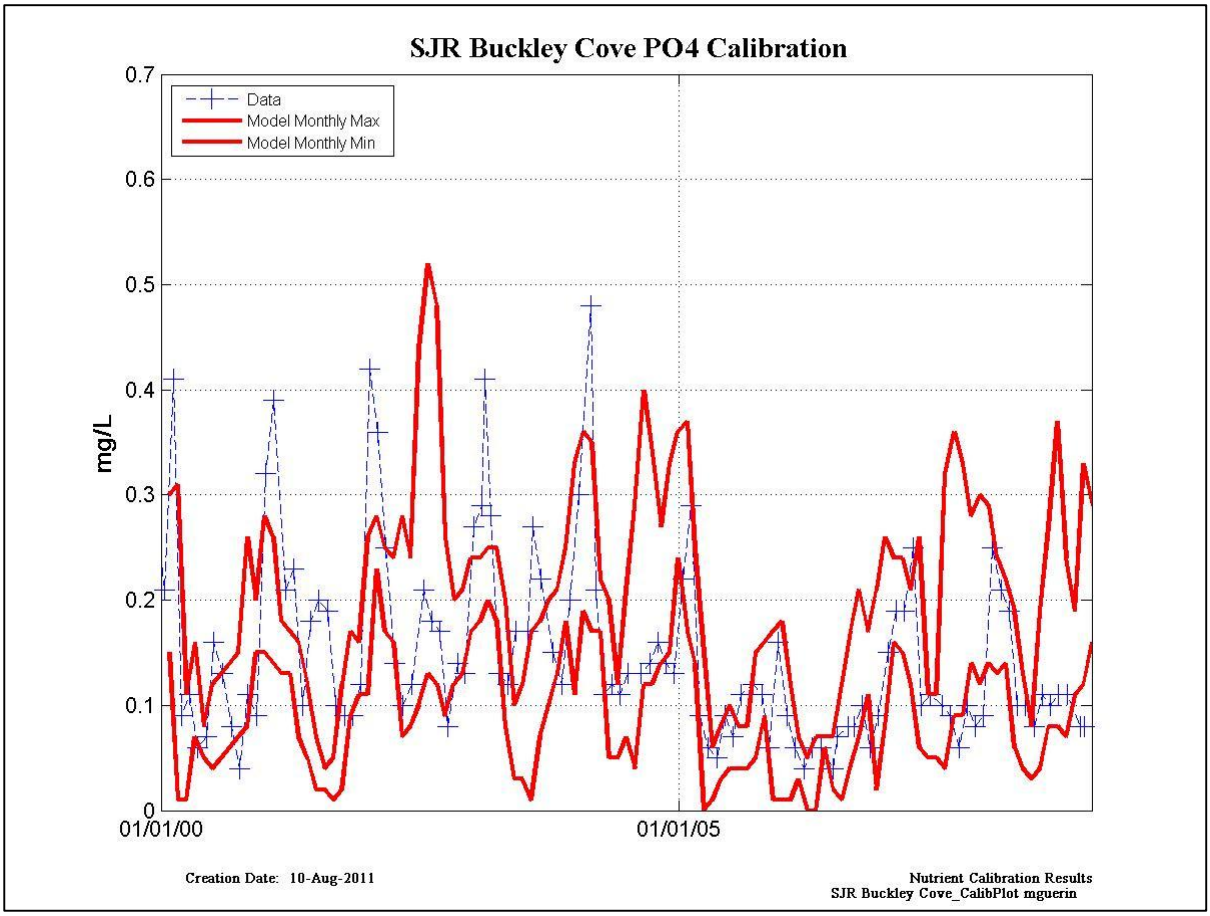


Figure 26-75 Modeled PO_4 calibration results at SJR Buckley Cove – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-75 Model calibration/validation statistics at SJR Buckley Cove for $PO_4$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG

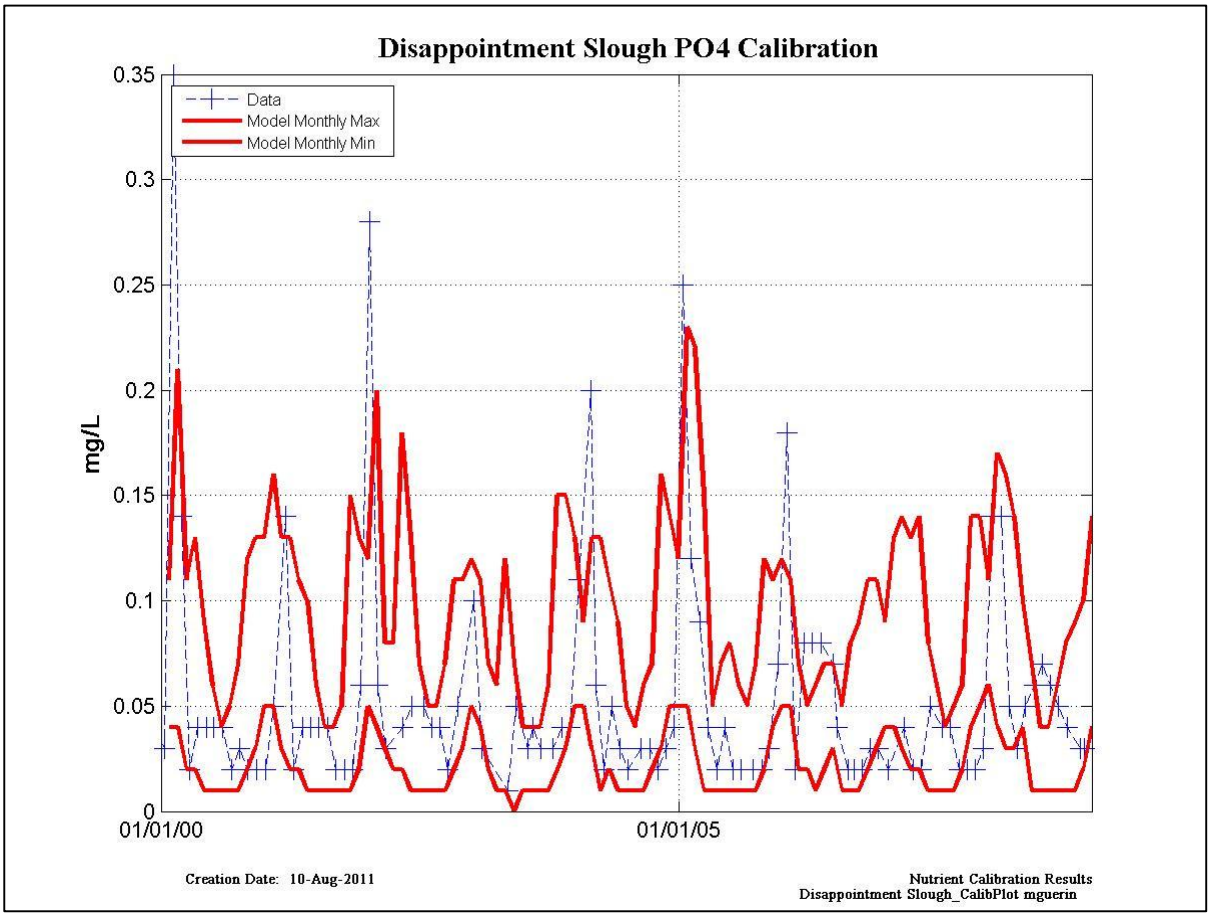


Figure 26-76 Modeled PO_4 calibration results at Disappointment Sl. – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-76 Model calibration/validation statistics at Disappointment Sl. for $PO_4$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG

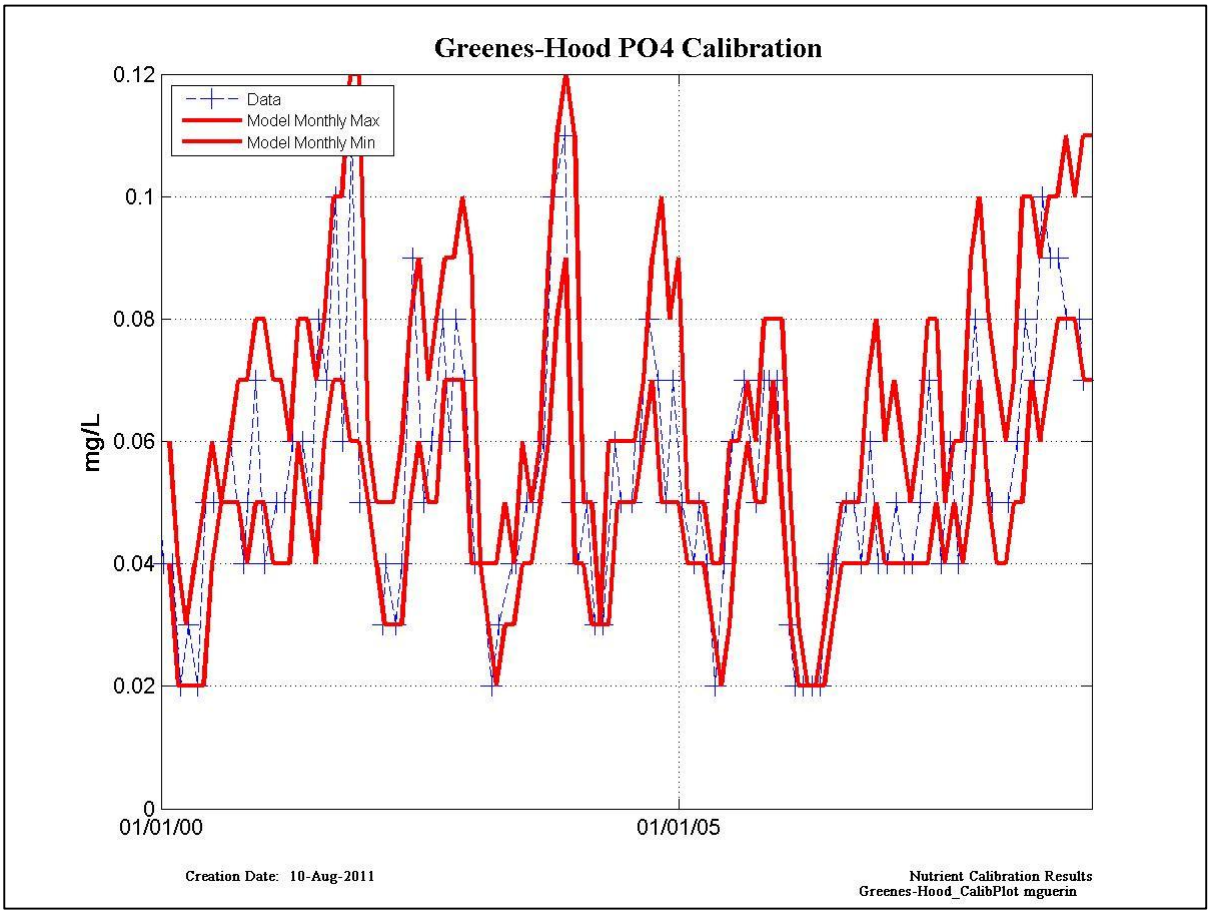


Figure 26-77 Modeled PO_4 calibration results at Greens-Hood – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-77 Model calibration/validation statistics at Greens-Hood for $PO_4$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

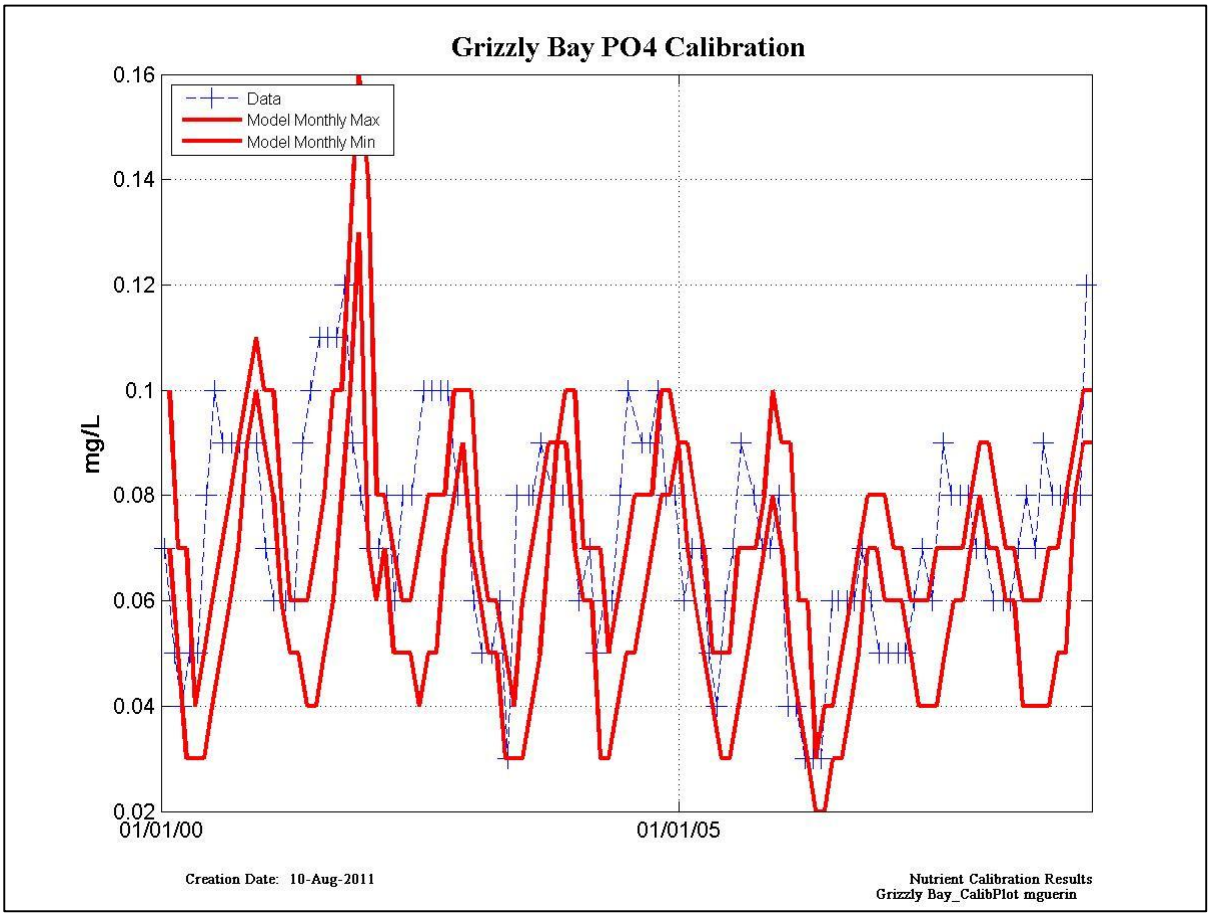


Figure 26-78 Modeled PO_4 calibration results at Grizzly Bay – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-78 Model calibration/validation statistics at Grizzly Bay for $PO_4$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	VG	VG	Underestimate	G
Dry WY Validation	S	VG	Underestimate	S
Wet WY Validation	VG	VG	Underestimate	VG

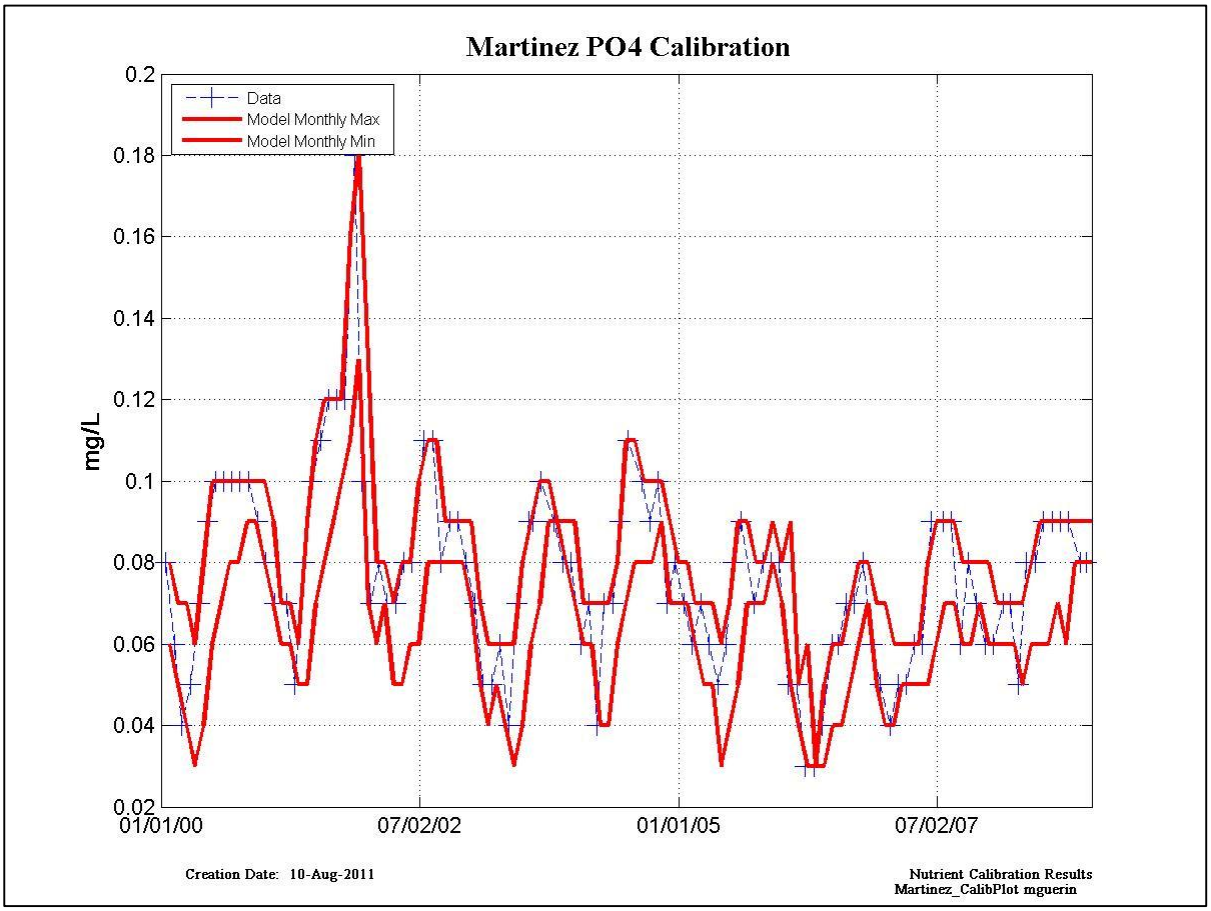


Figure 26-79 Modeled PO_4 calibration results at Martinez – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-79 Model calibration/validation statistics at Martinez for $PO_4$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG

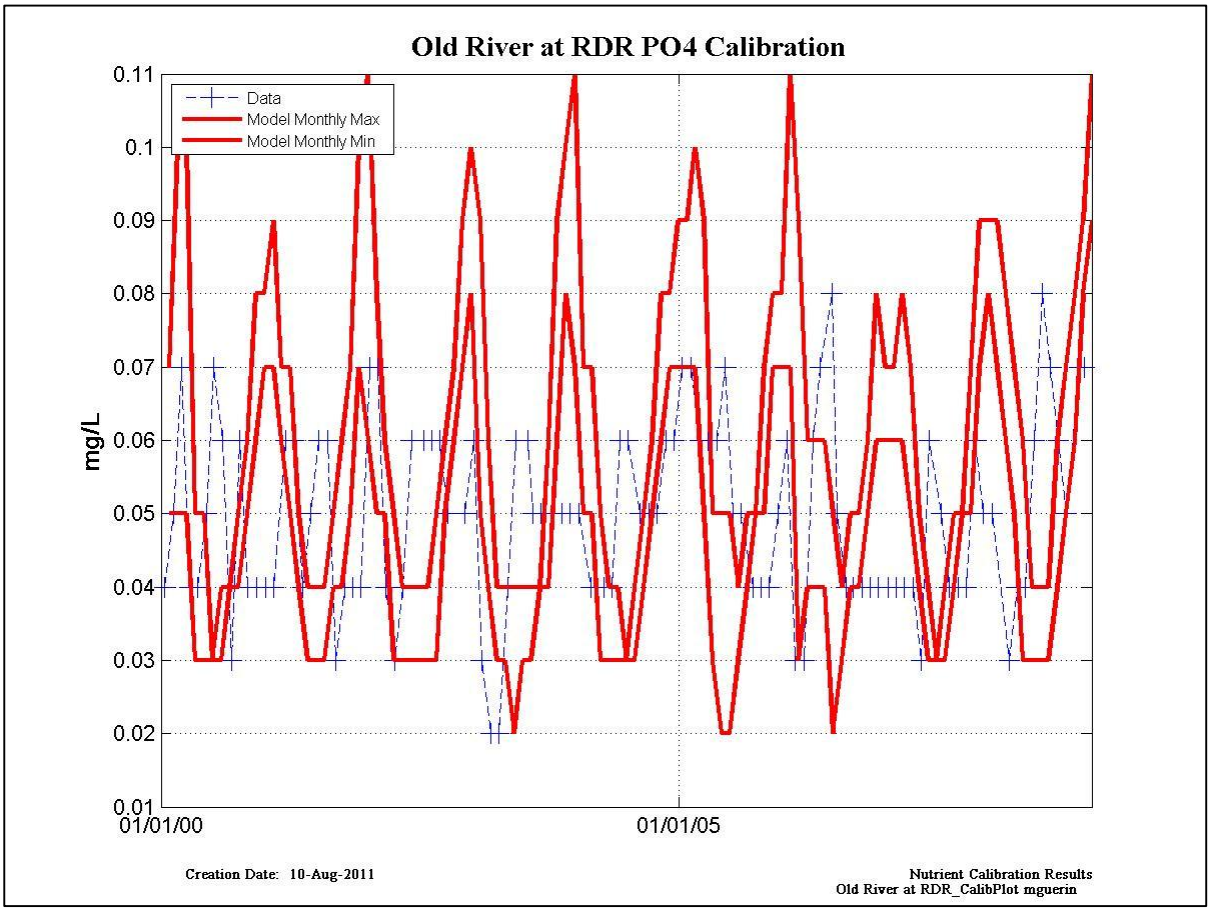


Figure 26-80 Modeled PO_4 calibration results at Old R. at Rancho Del Rio – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-80 Model calibration/validation statistics at Old R. at Rancho Del Rio for $PO_4$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	U	VG	Overestimate	U
Wet WY Calibration	U	VG	Overestimate	U
Dry WY Validation	U	VG	Overestimate	U
Wet WY Validation	S	VG	Overestimate	U

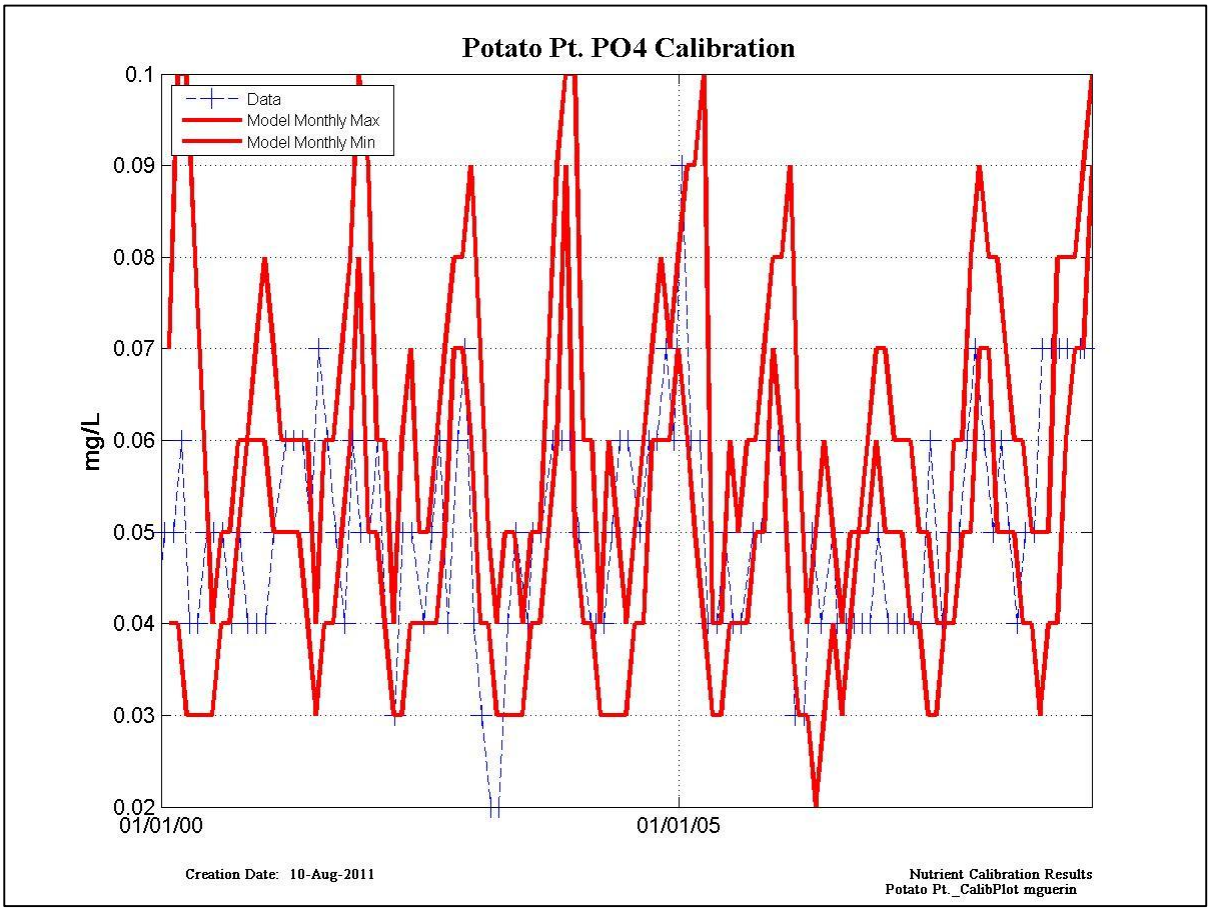


Figure 26-81 Modeled PO_4 calibration results at Potato Pt. – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-81 Model calibration/validation statistics at Potato Pt. for $PO_4$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	S	VG	Overestimate	U
Wet WY Calibration	S	VG	Overestimate	U
Dry WY Validation	S	VG	Overestimate	S
Wet WY Validation	VG	VG	Overestimate	VG

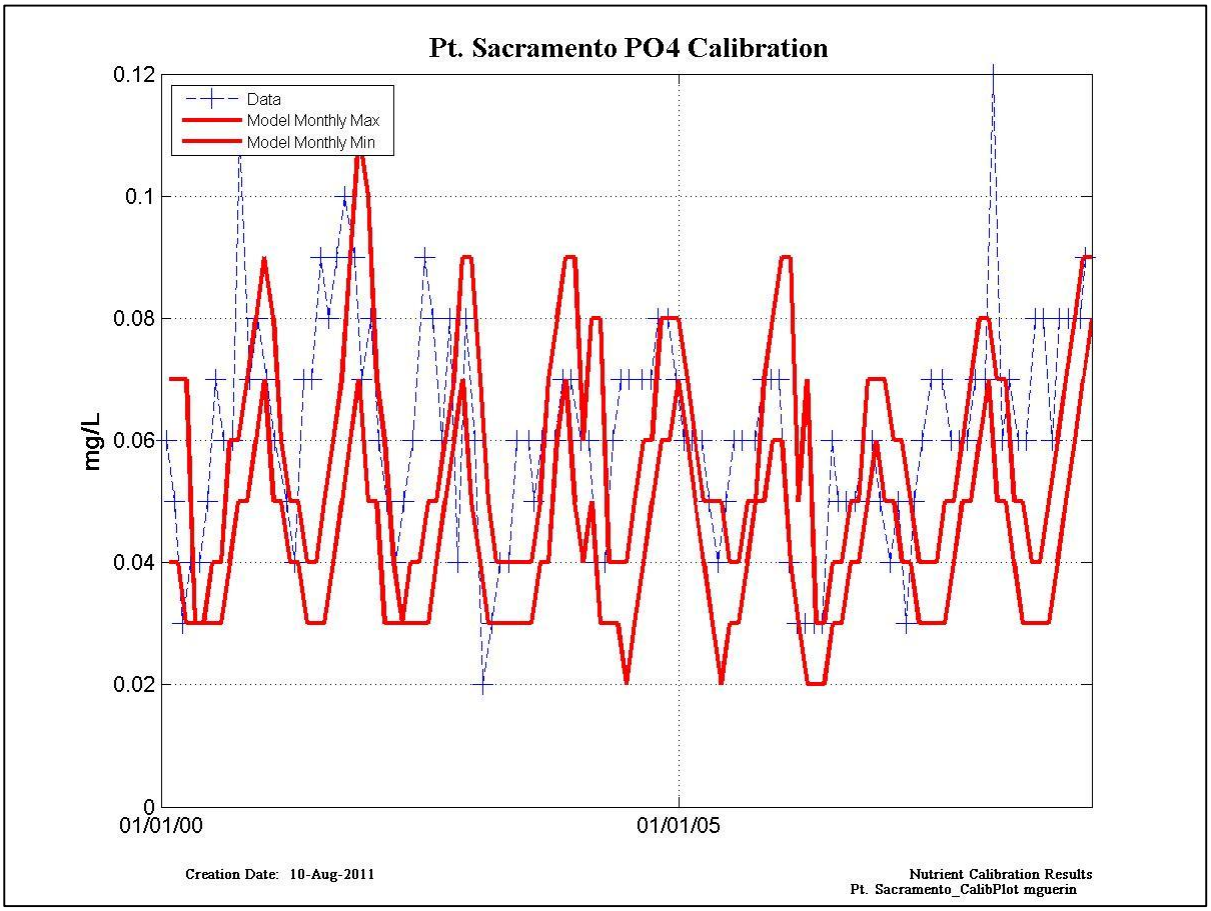


Figure 26-82 Modeled PO_4 calibration results at Pt. Sacramento – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-82 Model calibration/validation statistics at Pt. Sacramento for $PO_4$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	S	VG	Underestimate	S
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	G	VG	Underestimate	G

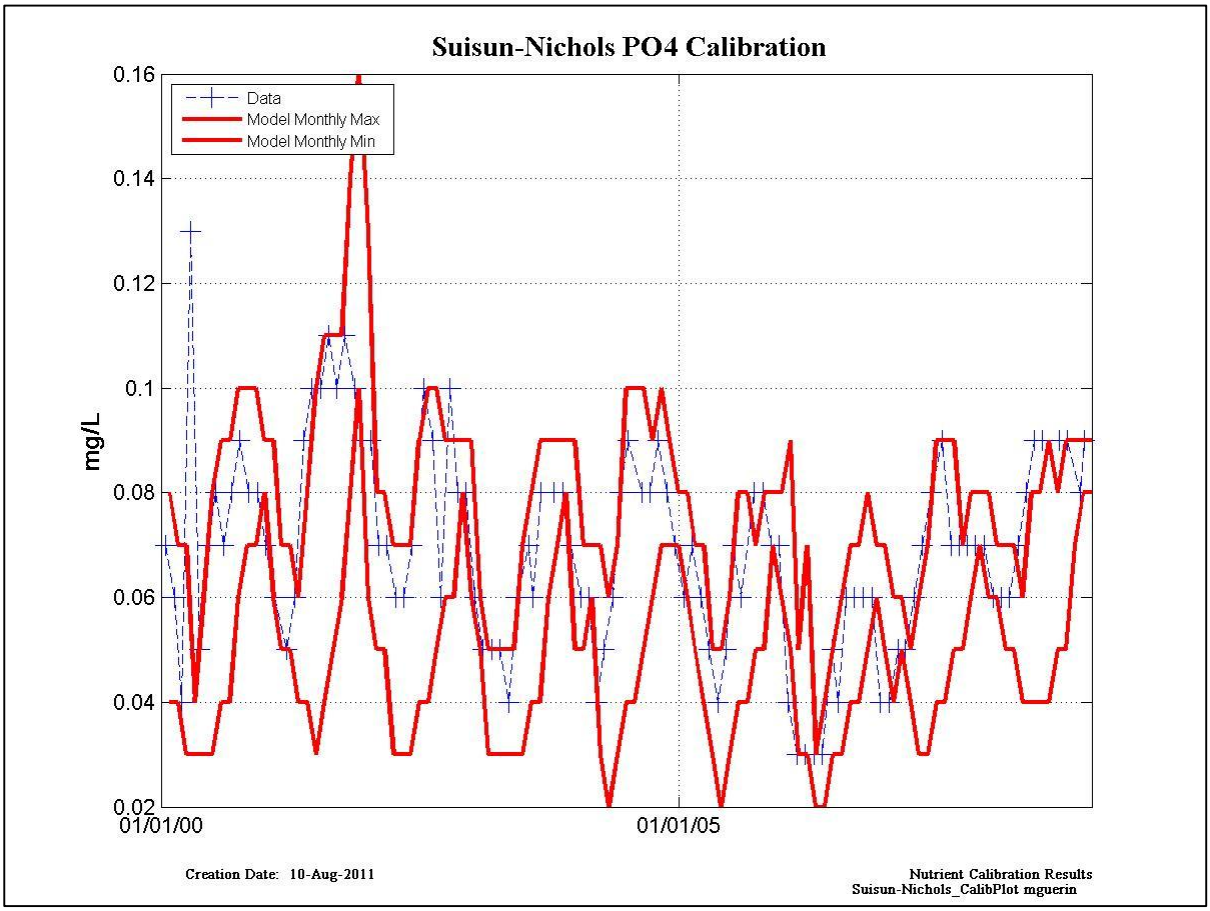


Figure 26-83 Modeled PO_4 calibration results at Suisun-Nichols – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-83 Model calibration/validation statistics at Suisun-Nichols for $PO_4$for the entire modeled period ("All"); Calibration for Dry Years (2001, 2002) and Wet Years (2000, 2003); and Validation for Dry Years (2007, 2008) and Wet Years (2005, 2006).

	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	S	VG	Underestimate	U
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

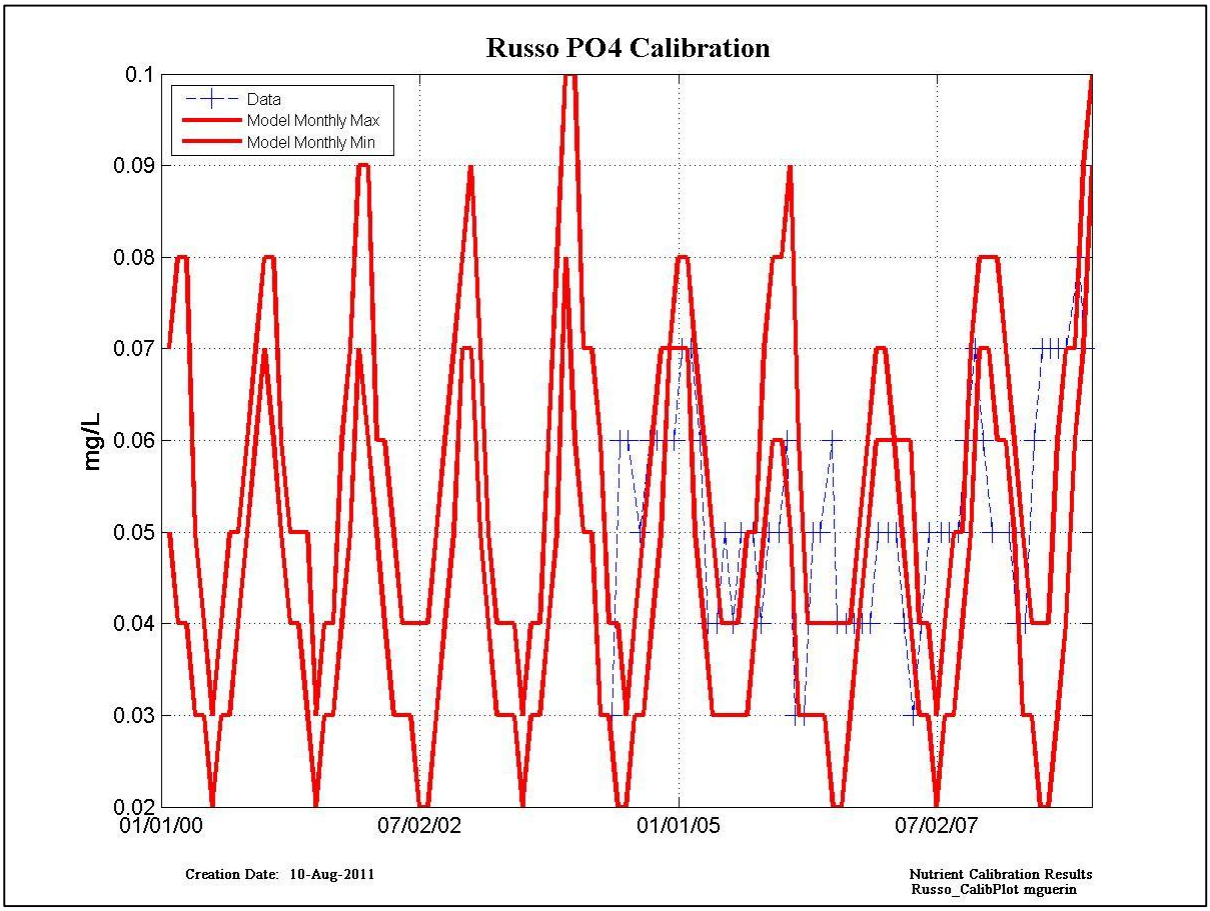


Figure 26-84Modeled PO_4 calibration results at Russo – data points are located at blue symbols, monthly modeled maximum and minimum are denoted by solid red lines.

Table 26-84 (Intentionally left blank) Insufficient data to calculate calibration statistics.

27 Analysis of Revised Categorical Intervals for Nutrient Statistics(Version 8.0.6)

The methodology adopted for calculating calibration statistics from residuals for the nutrient model employed an "envelope" of model values to incorporate the uncertainty in monthly boundary conditions and calibration data (see Section 12 in the main document). The monthly maximum and minimum values calculated from 15minute model output were used to create this envelope. At each location where calibration statistics were calculated, the figures in Chapter 25 illustrate the data plotted with these monthly time series of modeled maximums and minimums. Residual calculations were made for "All" eight calibration+validation years, plus individual calculations for each two-year Dry or Wet Calibration or Validation data set.

In this chapter, we extend the "envelope" analysis to narrower envelopes with widths at 95%, 90%, 80% and 75% of the original (100%) monthly maximums and minimums. For example, to calculate the concentration width of the envelope at a given data point, the "Distance" between the monthly maximum and minimum time series at each data point was calculated as:

$$Distance(i) := Monthly\ Max\ (i) - Monthly\ Min\ (i), \qquad i \in \{Days \mid data(i)\ exists\}$$

For the 100% envelope width, residuals (data – model) would be calculated as zero of the data point fell within this envelope, as a positive value (Data –Max) if the data was greater than the monthly maximum, and as a negative value (Data – Min) if the data was less than the monthly minimum. Note that some constituents had more than measurement day recorded in a given month.

For the 90% envelope, at each point the width was of the envelope was reduced as follows:

$$90\%\ Maximum(i) = (Monthly\ Maximum(i) - 0.1 * Distance(i))$$

$$90\%\ Minimum(i) = (Monthly\ Minimum(i) + 0.1 * Distance(i))$$

The same strategy for calculated residuals was employed. For each of the six constituent types with calibration data, several plots are included below to illustrate the change in envelope width in comparison with data. In addition, Tables with the calculated categories of NSE, PBIAS and RSR statistics are presented to illustrate how the categorical analysis changed under the reduced envelopes. For some of the locations and constituents (such as PO_4 at Martinez), only selected reduced envelope categories were calculated. In the

Tables, purple font indicates a switch between underestimate and overestimate, or *vice-versa*, red font indicates the statistic deteriorated as the envelope width decreased, and blue font indicates the statistic improved as the envelope width decreased.

27.1 Algae

Figure 27-1illustrates the 95%, 90%, 80% and 75% envelopes (note that these correspond to 5%, 10%, 20% and 25% reductions in modeled monthly maximums and minimums) for Algae/chl-a at the Twitchell measurement location, and Table 27-1through Table 27-10 illustrate the change in categorical residual statistics at many of the measurement locations

Only three out of the twenty locations exhibited deterioration in category, and that initially occurred at the 80% envelope width. In one of the three locations (Antioch), there was also an improvement in one category at the 75% envelope width.

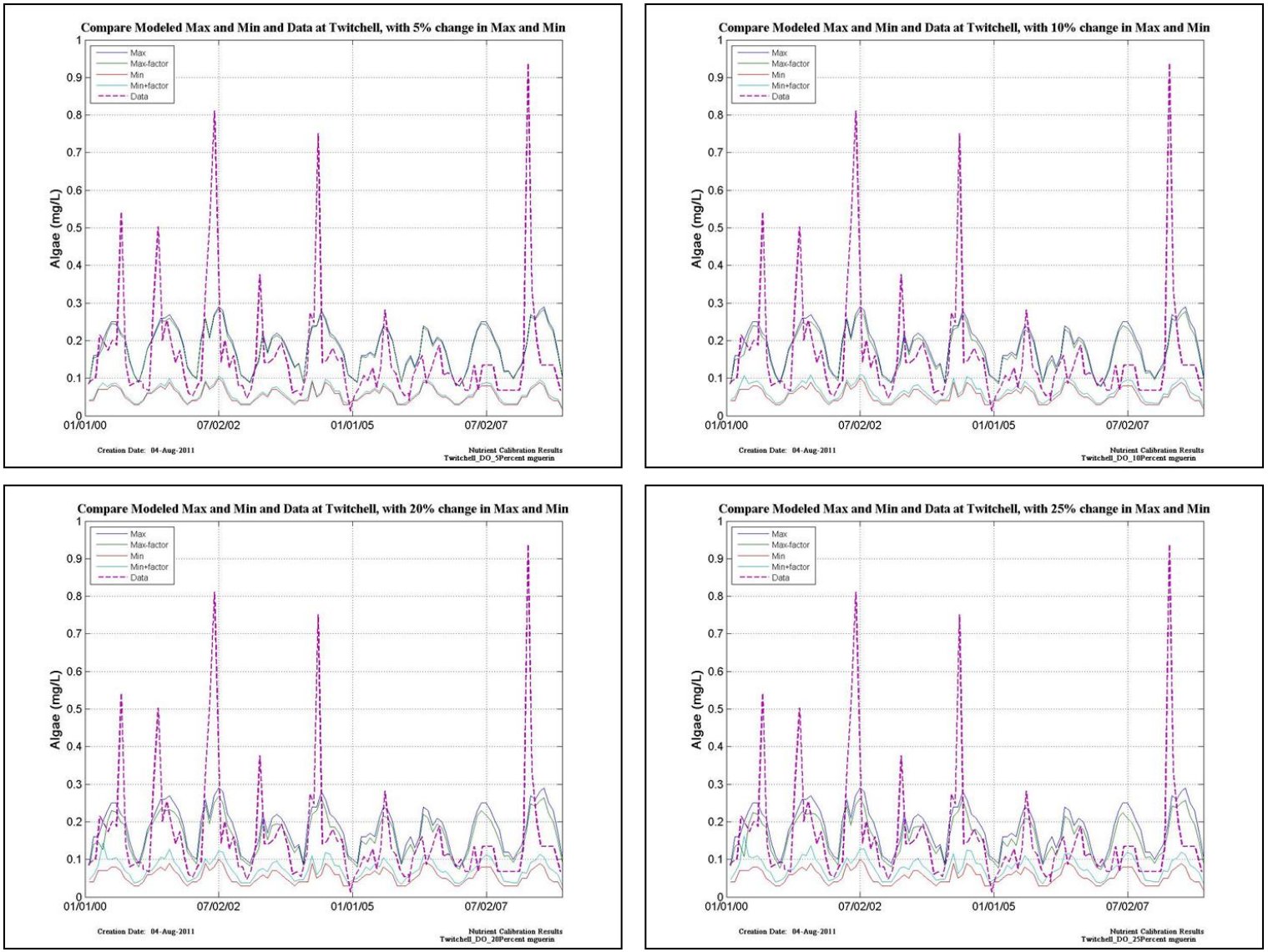


Figure 27-1Comparison of data and the 95%, 90%, 80% and 75% envelope max/min widths for Algae/chl-a at Twitchell.

Table 27-1Categorical statistics for several envelope ranges at Greens-Hood (left) and Pt. Sacramento (right). Colors indicate change from the 100% envelope range.

Greens-Hood

75%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	S	VG	Overestimate	S
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
80%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	S	VG	Overestimate	S
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
90%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	S	VG	Overestimate	S
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
95%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	S	VG	Overestimate	S
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	S	VG	Overestimate	S
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

Pt. Sacramento

75%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
80%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
90%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
95%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
100%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG

Table 27-2 Categorical statistics for several envelope ranges at Potato Point (left) and Old River at Rancho del Rio (right). Colors indicate change from the 100% envelope range.

Potato Point

75%	NSE	PBIAS	Bias	RSR
ALL	S	VG	Underestimate	U
Dry WY Calibration	G	VG	Underestimate	G
Wet WY Calibration	S	G	Underestimate	U
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	G	VG	Underestimate	G
80%				
ALL	S	VG	Underestimate	U
Dry WY Calibration	G	VG	Underestimate	G
Wet WY Calibration	S	G	Underestimate	U
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	G	VG	Underestimate	G
90%				
ALL	S	VG	Underestimate	U
Dry WY Calibration	G	VG	Underestimate	G
Wet WY Calibration	S	G	Underestimate	U
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	G	VG	Underestimate	G
95%				
ALL	S	VG	Underestimate	U
Dry WY Calibration	G	VG	Underestimate	G
Wet WY Calibration	S	G	Underestimate	U
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	G	VG	Underestimate	G
100%				
ALL	S	VG	Underestimate	U
Dry WY Calibration	G	VG	Underestimate	G
Wet WY Calibration	S	G	Underestimate	U
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	G	VG	Underestimate	G

Old River at Rancho del Rio

75%	NSE	PBIAS	Bias	RSR
ALL	S	VG	Underestimate	U
Dry WY Calibration	G	VG	Underestimate	G
Wet WY Calibration	S	S	Underestimate	U
Dry WY Validation	S	VG	Underestimate	S
Wet WY Validation	VG	VG	Underestimate	VG
80%				
ALL	S	VG	Underestimate	U
Dry WY Calibration	G	VG	Underestimate	G
Wet WY Calibration	S	S	Underestimate	U
Dry WY Validation	S	VG	Underestimate	S
Wet WY Validation	VG	VG	Underestimate	VG
90%				
ALL	S	VG	Underestimate	U
Dry WY Calibration	G	VG	Underestimate	G
Wet WY Calibration	S	S	Underestimate	U
Dry WY Validation	S	VG	Underestimate	S
Wet WY Validation	VG	VG	Overestimate	VG
95%				
ALL	S	VG	Underestimate	U
Dry WY Calibration	G	VG	Underestimate	G
Wet WY Calibration	S	S	Underestimate	U
Dry WY Validation	S	VG	Underestimate	S
Wet WY Validation	VG	VG	Overestimate	VG
100%				
ALL	S	VG	Underestimate	U
Dry WY Calibration	G	VG	Underestimate	G
Wet WY Calibration	S	S	Underestimate	U
Dry WY Validation	S	VG	Underestimate	S
Wet WY Validation	VG	VG	Overestimate	VG

Table 27-3 Categorical statistics for several envelope ranges at SJR Buckley Cove (left) and Disappointment Sl. (right). Colors indicate change from the 100% envelope range.

SJR Buckley Cove

75%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	G
Wet WY Calibration	S	G	Underestimate	U
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	VG	VG	Underestimate	G
80%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	G
Wet WY Calibration	S	G	Underestimate	U
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	VG	VG	Underestimate	G
90%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	G
Wet WY Calibration	S	G	Underestimate	U
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	VG	VG	Underestimate	G
95%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	G
Wet WY Calibration	S	G	Underestimate	U
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	VG	VG	Underestimate	G
100%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	G
Wet WY Calibration	S	G	Underestimate	U
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	VG	VG	Underestimate	G

Disappointment Sl.

75%	NSE	PBIAS	Bias	RSR
ALL	S	G	Underestimate	U
Dry WY Calibration	S	S	Underestimate	U
Wet WY Calibration	G	VG	Underestimate	G
Dry WY Validation	S	S	Underestimate	U
Wet WY Validation	G	VG	Underestimate	G
80%				
ALL	S	G	Underestimate	U
Dry WY Calibration	S	S	Underestimate	U
Wet WY Calibration	G	VG	Underestimate	G
Dry WY Validation	S	S	Underestimate	U
Wet WY Validation	G	VG	Underestimate	G
90%				
ALL	S	G	Underestimate	U
Dry WY Calibration	S	S	Underestimate	U
Wet WY Calibration	G	VG	Underestimate	G
Dry WY Validation	S	S	Underestimate	U
Wet WY Validation	G	VG	Underestimate	G
95%				
ALL	S	G	Underestimate	U
Dry WY Calibration	S	S	Underestimate	U
Wet WY Calibration	G	VG	Underestimate	G
Dry WY Validation	S	S	Underestimate	U
Wet WY Validation	G	VG	Underestimate	G
100%				
ALL	S	G	Underestimate	U
Dry WY Calibration	S	S	Underestimate	U
Wet WY Calibration	G	VG	Underestimate	G
Dry WY Validation	S	S	Underestimate	U
Wet WY Validation	G	VG	Underestimate	G

Table 27-4 Categorical statistics for several envelope ranges at Montezuma Sl. (left) and Suisun-Volanti (right). Colors indicate change from the 100% envelope range.

Montezuma Sl.

75%	NSE	PBIAS	Bias	RSR
ALL	S	VG	Overestimate	U
Dry WY Calibration	S	G	Overestimate	U
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	S	VG	Underestimate	G
80%				
ALL	S	VG	Overestimate	U
Dry WY Calibration	S	G	Overestimate	U
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	S	VG	Underestimate	G
90%				
ALL	S	VG	Overestimate	U
Dry WY Calibration	S	G	Overestimate	U
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	G	VG	Overestimate	G
95%				
ALL	S	VG	Overestimate	U
Dry WY Calibration	S	G	Overestimate	U
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	G	VG	Overestimate	G
100%				
ALL	S	VG	Overestimate	U
Dry WY Calibration	S	G	Overestimate	U
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	G	VG	Overestimate	G

Suisun Volanti

75%	NSE	PBIAS	Bias	RSR
ALL	S	G	Overestimate	U
Dry WY Calibration	U	S	Overestimate	U
Wet WY Calibration	S	VG	Overestimate	U
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	S	VG	Overestimate	U
80%				
ALL	S	G	Overestimate	U
Dry WY Calibration	U	S	Overestimate	U
Wet WY Calibration	S	VG	Overestimate	U
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	S	VG	Overestimate	U
90%				
ALL	S	G	Overestimate	U
Dry WY Calibration	U	S	Overestimate	U
Wet WY Calibration	S	VG	Overestimate	U
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	S	VG	Overestimate	U
95%				
ALL	S	G	Overestimate	U
Dry WY Calibration	U	S	Overestimate	U
Wet WY Calibration	S	VG	Overestimate	U
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	S	VG	Overestimate	U
100%				
ALL	S	G	Overestimate	U
Dry WY Calibration	U	S	Overestimate	U
Wet WY Calibration	S	VG	Overestimate	U
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	S	VG	Overestimate	U

Table 27-5 Categorical statistics for several envelope ranges at Suisun-Nichols (left) and Grizzly Bay (right). Colors indicate change from the 100% envelope range.

Suisun-Nichols

75%	NSE	PBIAS	Bias	RSR
ALL	G	VG	Underestimate	G
Dry WY Calibration	G	VG	Underestimate	G
Wet WY Calibration	S	G	Underestimate	U
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	G
80%				
ALL	G	VG	Underestimate	G
Dry WY Calibration	G	VG	Underestimate	G
Wet WY Calibration	S	G	Underestimate	U
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	G
90%				
ALL	G	VG	Underestimate	G
Dry WY Calibration	G	VG	Underestimate	G
Wet WY Calibration	S	G	Underestimate	U
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	G
95%				
ALL	G	VG	Underestimate	G
Dry WY Calibration	G	VG	Underestimate	G
Wet WY Calibration	S	G	Underestimate	U
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	G
100%				
ALL	G	VG	Underestimate	G
Dry WY Calibration	G	VG	Underestimate	G
Wet WY Calibration	S	G	Underestimate	U
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	G

Grizzly Bay

75%	NSE	PBIAS	Bias	RSR
ALL	S	VG	Overestimate	U
Dry WY Calibration	S	VG	Overestimate	U
Wet WY Calibration	S	VG	Underestimate	U
Dry WY Validation	G	VG	Overestimate	S
Wet WY Validation	G	VG	Underestimate	G
80%				
ALL	S	VG	Overestimate	U
Dry WY Calibration	S	VG	Overestimate	U
Wet WY Calibration	S	VG	Underestimate	U
Dry WY Validation	G	VG	Overestimate	G
Wet WY Validation	G	VG	Underestimate	G
90%				
ALL	S	VG	Overestimate	U
Dry WY Calibration	S	VG	Overestimate	U
Wet WY Calibration	S	VG	Underestimate	U
Dry WY Validation	G	VG	Overestimate	G
Wet WY Validation	G	VG	Overestimate	G
95%				
ALL	S	VG	Overestimate	U
Dry WY Calibration	S	VG	Overestimate	U
Wet WY Calibration	S	VG	Underestimate	U
Dry WY Validation	G	VG	Overestimate	G
Wet WY Validation	G	VG	Underestimate	G
100%				
ALL	S	VG	Overestimate	U
Dry WY Calibration	S	VG	Overestimate	U
Wet WY Calibration	S	VG	Underestimate	U
Dry WY Validation	G	VG	Overestimate	G
Wet WY Validation	G	VG	Underestimate	G

Table 27-6 Categorical statistics for several envelope ranges at Twitchell (left) and Rio Vista (right). Colors indicate change from the 100% envelope range.

Twitchell

75%	NSE	PBIAS	Bias	RSR
ALL	S	VG	Underestimate	U
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	S	VG	Underestimate	S
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	VG	VG	Underestimate	VG
80%				
ALL	S	VG	Underestimate	U
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	S	VG	Underestimate	S
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	VG	VG	Underestimate	VG
90%				
ALL	S	VG	Underestimate	U
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	S	VG	Underestimate	S
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	VG	VG	Underestimate	VG
95%				
ALL	S	VG	Underestimate	U
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	S	VG	Underestimate	S
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	VG	VG	Underestimate	VG
100%				
ALL	S	VG	Underestimate	U
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	S	VG	Underestimate	S
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	VG	VG	Underestimate	VG

Rio Vista

75%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	G
Wet WY Calibration	S	G	Overestimate	U
Dry WY Validation	U	VG	Overestimate	U
Wet WY Validation	G	VG	Overestimate	G
80%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	S	G	Overestimate	U
Dry WY Validation	U	VG	Overestimate	U
Wet WY Validation	G	VG	Overestimate	G
90%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	S	G	Overestimate	U
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	VG	VG	Overestimate	VG
95%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	S	G	Overestimate	U
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	VG	VG	Overestimate	VG
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	S	G	Overestimate	U
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	VG	VG	Overestimate	VG

Table 27-7 Categorical statistics for several envelope ranges at Chipps (left) and RSAC077-Pittsburg (right). Colors indicate change from the 100% envelope range.

Chipps

75%	NSE	PBIAS	Bias	RSR
ALL	S	VG	Underestimate	U
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	G	VG	Underestimate	S
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	S	VG	Underestimate	U
80%				
ALL	S	VG	Underestimate	U
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	G	VG	Underestimate	S
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	S	VG	Underestimate	U
90%				
ALL	S	VG	Underestimate	U
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	G	VG	Underestimate	S
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	S	VG	Underestimate	U
95%				
ALL	S	VG	Underestimate	U
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	G	VG	Underestimate	S
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	S	VG	Underestimate	U
100%				
ALL	S	VG	Underestimate	U
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	G	VG	Underestimate	S
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	S	VG	Underestimate	U

RSAC077 - Pittsburg

75%	NSE	PBIAS	Bias	RSR
ALL	G	G	Underestimate	G
Dry WY Calibration	S	G	Underestimate	U
Wet WY Calibration	G	VG	Underestimate	S
Dry WY Validation	S	G	Underestimate	U
Wet WY Validation	G	VG	Underestimate	S
80%				
ALL	G	G	Underestimate	G
Dry WY Calibration	S	G	Underestimate	U
Wet WY Calibration	G	VG	Underestimate	S
Dry WY Validation	S	G	Underestimate	U
Wet WY Validation	VG	VG	Underestimate	S
90%				
ALL	G	G	Underestimate	G
Dry WY Calibration	S	G	Underestimate	U
Wet WY Calibration	G	VG	Underestimate	S
Dry WY Validation	S	G	Underestimate	U
Wet WY Validation	G	VG	Underestimate	S
95%				
ALL	G	G	Underestimate	G
Dry WY Calibration	S	G	Underestimate	U
Wet WY Calibration	G	VG	Underestimate	S
Dry WY Validation	S	G	Underestimate	U
Wet WY Validation	G	VG	Underestimate	S
100%				
ALL	G	G	Underestimate	G
Dry WY Calibration	S	G	Underestimate	U
Wet WY Calibration	G	VG	Underestimate	S
Dry WY Validation	S	G	Underestimate	U
Wet WY Validation	G	VG	Underestimate	S

Table 27-8 Categorical statistics for several envelope ranges at Antioch (left) and Emmaton (right). Colors indicate change from the 100% envelope range.

Antioch

75%	NSE	PBIAS	Bias	RSR
ALL	S	VG	Underestimate	U
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	G	VG	Underestimate	S
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	S	VG	Underestimate	U
80%				
ALL	S	VG	Underestimate	U
Dry WY Calibration	S	G	Underestimate	U
Wet WY Calibration	S	VG	Underestimate	U
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	S	VG	Overestimate	S
90%				
ALL	S	VG	Underestimate	U
Dry WY Calibration	S	G	Underestimate	U
Wet WY Calibration	S	VG	Underestimate	U
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	G	VG	Overestimate	S
95%				
ALL	S	VG	Underestimate	U
Dry WY Calibration	S	G	Underestimate	U
Wet WY Calibration	S	VG	Underestimate	U
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	G	VG	Overestimate	S
100%				
ALL	S	VG	Underestimate	U
Dry WY Calibration	S	G	Underestimate	U
Wet WY Calibration	S	VG	Underestimate	U
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	G	VG	Overestimate	S

Emmaton

75%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	S	VG	Overestimate	G
80%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	S	VG	Overestimate	G
90%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	S	VG	Overestimate	G
95%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	S	VG	Overestimate	G
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	S	VG	Overestimate	G

Table 27-9 Categorical statistics for several envelope ranges at RSAC075-Mallard (left) and RSAC063-Stockton (right). Colors indicate change from the 100% envelope range.

RSAC075 - Mallard

75%	NSE	PBIAS	Bias	RSR
ALL	S	G	Underestimate	U
Dry WY Calibration	S	G	Underestimate	U
Wet WY Calibration	S	G	Underestimate	U
Dry WY Validation	-	-	-	-
Wet WY Validation	S	VG	Overestimate	U
80%				
ALL	S	G	Underestimate	U
Dry WY Calibration	S	G	Underestimate	U
Wet WY Calibration	S	G	Underestimate	U
Dry WY Validation	-	-	-	-
Wet WY Validation	S	VG	Overestimate	U
90%				
ALL	S	G	Underestimate	U
Dry WY Calibration	S	G	Underestimate	U
Wet WY Calibration	S	G	Underestimate	U
Dry WY Validation	-	-	-	-
Wet WY Validation	S	VG	Overestimate	U
95%				
ALL	S	G	Underestimate	U
Dry WY Calibration	S	G	Underestimate	U
Wet WY Calibration	S	G	Underestimate	U
Dry WY Validation	-	-	-	-
Wet WY Validation	S	VG	Overestimate	U
100%				
ALL	S	G	Underestimate	U
Dry WY Calibration	S	G	Underestimate	U
Wet WY Calibration	S	G	Underestimate	U
Dry WY Validation	-	-	-	-
Wet WY Validation	S	VG	Overestimate	U

RSAC063-Stockton

75%	NSE	PBIAS	Bias	RSR
ALL	S	G	Overestimate	U
Dry WY Calibration	S	VG	Overestimate	U
Wet WY Calibration	U	G	Overestimate	U
Dry WY Validation	-	-	-	-
Wet WY Validation	S	VG	Overestimate	U
80%				
ALL	S	G	Overestimate	U
Dry WY Calibration	S	VG	Overestimate	U
Wet WY Calibration	U	G	Overestimate	U
Dry WY Validation	-	-	-	-
Wet WY Validation	S	VG	Overestimate	U
90%				
ALL	S	G	Overestimate	U
Dry WY Calibration	S	VG	Overestimate	U
Wet WY Calibration	U	G	Overestimate	U
Dry WY Validation	-	-	-	-
Wet WY Validation	S	VG	Overestimate	U
95%				
ALL	S	G	Overestimate	U
Dry WY Calibration	S	VG	Overestimate	U
Wet WY Calibration	U	G	Overestimate	U
Dry WY Validation	-	-	-	-
Wet WY Validation	S	VG	Overestimate	U
100%				
ALL	S	G	Overestimate	U
Dry WY Calibration	S	VG	Overestimate	U
Wet WY Calibration	U	G	Overestimate	U
Dry WY Validation	-	-	-	-
Wet WY Validation	S	VG	Overestimate	U

Table 27-10 Categorical statistics for several envelope ranges at RSAC054-Martinez (left) and Roe Island (right). Colors indicate change from the 100% envelope range.

RSAC054 - Martinez

75%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
80%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
90%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
95%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
100%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG

Roe Island

75%	NSE	PBIAS	Bias	RSR
ALL	S	VG	Underestimate	U
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	S	VG	Underestimate	S
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	S	G	Underestimate	U
80%				
ALL	S	VG	Underestimate	U
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	S	VG	Underestimate	S
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	S	G	Underestimate	U
90%				
ALL	S	VG	Underestimate	U
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	S	VG	Underestimate	S
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	S	G	Underestimate	U
95%				
ALL	S	VG	Underestimate	U
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	S	VG	Underestimate	S
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	S	G	Underestimate	U
100%				
ALL	S	VG	Underestimate	U
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	S	VG	Underestimate	S
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	S	G	Underestimate	U

27.2 Dissolved Oxygen

Figure 27-2illustrates the 95%, 90%, 80% and 75% envelopes (note that these correspond to 5%, 10%, 20% and 25% reductions in modeled monthly maximums and minimums) for DO at the Twitchell measurement location, and Table 27-11 through Table 27-20 illustrate the change in categorical residual statistics at many of the measurement locations.

Only five out of the nineteen locations exhibited deterioration in category - that initially occurred at the 95% in one instance and 90% envelope width in one instance, and otherwise at the 80% or 75% envelope widths.

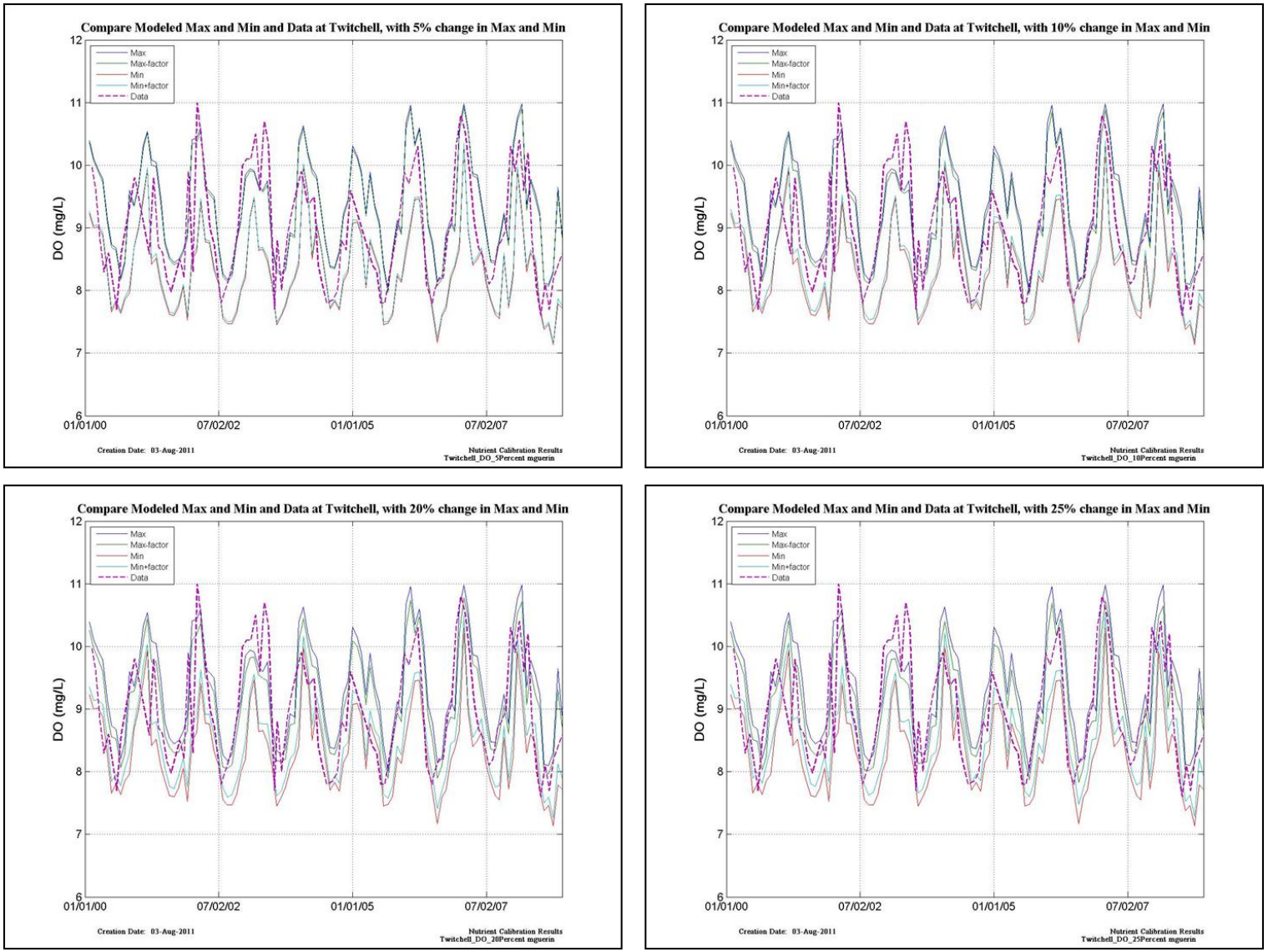


Figure 27-2Comparison of data and the 95%, 90%, 80% and 75% envelope max/min widths for DO at Twitchell.

Table 27-11 Categorical statistics for several envelope ranges at Greens-Hood (left) and Pt. Sacramento (right). Colors indicate change from the 100% envelope range.

Greens-Hood

75%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	S	VG	Overestimate	S
Wet WY Validation	VG	VG	Overestimate	VG
80%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	S	VG	Overestimate	S
Wet WY Validation	VG	VG	Overestimate	VG
90%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	S	VG	Overestimate	S
Wet WY Validation	VG	VG	Overestimate	VG
95%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	S	VG	Overestimate	S
Wet WY Validation	VG	VG	Overestimate	VG
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	S	VG	Overestimate	S
Wet WY Validation	VG	VG	Overestimate	VG

Pt. Sacramento

75%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
80%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
90%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
95%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
100%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

Table 27-12 Categorical statistics for several envelope ranges at Potato Pt. (left) and Old River at Rancho del Rio (right). Colors indicate change from the 100% envelope range.

Potato Pt.

75%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
80%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
90%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
95%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
100%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG

Old River at Rancho del Rio

75%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	G
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
80%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	G
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
90%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	G
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
95%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	G
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
100%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG

Table 27-13 Categorical statistics for several envelope ranges at Twitchell (left) and Rio Vista (right). Colors indicate change from the 100% envelope range.

Twitchell

75%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Underestimate	G
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
80%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	G
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
90%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	G
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
95%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	G
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
100%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	G
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG

Rio Vista

75%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
80%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
90%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
95%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

Table 27-14 Categorical statistics for several envelope ranges at Chipps (left) and RSAC077-Pittsburg (right). Colors indicate change from the 100% envelope range.

Chipps

75%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	G	VG	Underestimate	G
Wet WY Calibration	G	VG	Underestimate	G
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
80%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	G	VG	Underestimate	G
Wet WY Calibration	G	VG	Underestimate	G
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
90%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	G	VG	Underestimate	G
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
95%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	G
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
100%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	G
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG

RSAC077 - Pittsburg

75%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	S	VG	Overestimate	U
80%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	S	VG	Overestimate	U
90%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	S	VG	Overestimate	U
95%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	S	VG	Overestimate	U
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	S	VG	Overestimate	U

Table 27-15 Categorical statistics for several envelope ranges at RSAC054-Martinez. Colors indicate change from the 100% envelope range.

RSAC054 - Martinez

75%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	G	VG	Underestimate	G
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
80%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	G	VG	Underestimate	G
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
90%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
95%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
100%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG

Table 27-16 Categorical statistics for several envelope ranges at SJR Buckley Cove (left) and Disappointment Sl. (right). Colors indicate change from the 100% envelope range.

SJR Buckley Cove

75%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
80%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

Disappointment Sl.

75%	NSE	PBIAS	Bias	RSR
ALL	S	VG	Underestimate	S
Dry WY Calibration	G	VG	Underestimate	VG
Wet WY Calibration	G	VG	Underestimate	G
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	G	VG	Overestimate	G
80%				
ALL	S	VG	Underestimate	S
Dry WY Calibration	G	VG	Underestimate	VG
Wet WY Calibration	G	VG	Underestimate	G
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	G	VG	Overestimate	G
100%				
ALL	S	VG	Underestimate	S
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	G	VG	Underestimate	G
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	G	VG	Overestimate	G

Table 27-17 Categorical statistics for several envelope ranges at Montezuma Sl. (left) and Suisun-Volanti (right). Colors indicate change from the 100% envelope range.

Montezuma Sl.

75%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	S	VG	Overestimate	U
80%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	S	VG	Overestimate	U
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	S	VG	Overestimate	U

Suisun-Volanti

75%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	G
Dry WY Calibration	S	VG	Overestimate	S
Wet WY Calibration	G	VG	Overestimate	G
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	S	VG	Overestimate	U
80%				
ALL	VG	VG	Overestimate	G
Dry WY Calibration	S	VG	Overestimate	S
Wet WY Calibration	G	VG	Overestimate	G
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	S	VG	Overestimate	U
100%				
ALL	VG	VG	Overestimate	G
Dry WY Calibration	S	VG	Overestimate	S
Wet WY Calibration	G	VG	Overestimate	G
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	S	VG	Overestimate	U

Table 27-18 Categorical statistics for several envelope ranges at Suisun-Nichols (left) and Grizzly Bay (right). Colors indicate change from the 100% envelope range.

Suisun-Nichols

75%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	G	VG	Underestimate	G
Wet WY Calibration	G	VG	Underestimate	G
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
80%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	G	VG	Underestimate	G
Wet WY Calibration	G	VG	Underestimate	G
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
100%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	G	VG	Underestimate	G
Wet WY Calibration	G	VG	Underestimate	G
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG

Grizzly Bay

75%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
80%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
100%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG

Table 27-19 Categorical statistics for several envelope ranges at Antioch (left) and Emmaton (right). Colors indicate change from the 100% envelope range.

Antioch

75%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
80%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
100%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

Emmaton

75%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	G	VG	Overestimate	G
Wet WY Calibration	G	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	G
Wet WY Validation	-	-	-	-
80%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	G	VG	Overestimate	G
Wet WY Calibration	G	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	G
Wet WY Validation	-	-	-	-
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	G	VG	Overestimate	G
Wet WY Calibration	G	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	G
Wet WY Validation	-	-	-	-

Table 27-20 Categorical statistics for several envelope ranges at Roe Island (left) and Little Potato Sl. At Terminous (right). Colors indicate change from the 100% envelope range.

Roe Island

75%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	G	VG	Overestimate	G
80%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	G	VG	Overestimate	G
100%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	G	VG	Overestimate	G

Little Potato Sl. at Terminous

75%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	G	VG	Underestimate	S
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
80%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	G	VG	Underestimate	G
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
100%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	G	VG	Underestimate	G
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

27.3 NH3

Figure 27-3illustrates the 95%, 90%, 80% and 75% envelopes (note that these correspond to 5%, 10%, 20% and 25% reductions in modeled monthly maximums and minimums) for NH_3 at the Pt. Sacramento measurement location, and Table 27-21 through Table 27-24 illustrate the change in categorical residual statistics at many of the measurement locations.

In one of the seven locations exhibited deterioration in category - that initially occurred at the 80% envelope width.

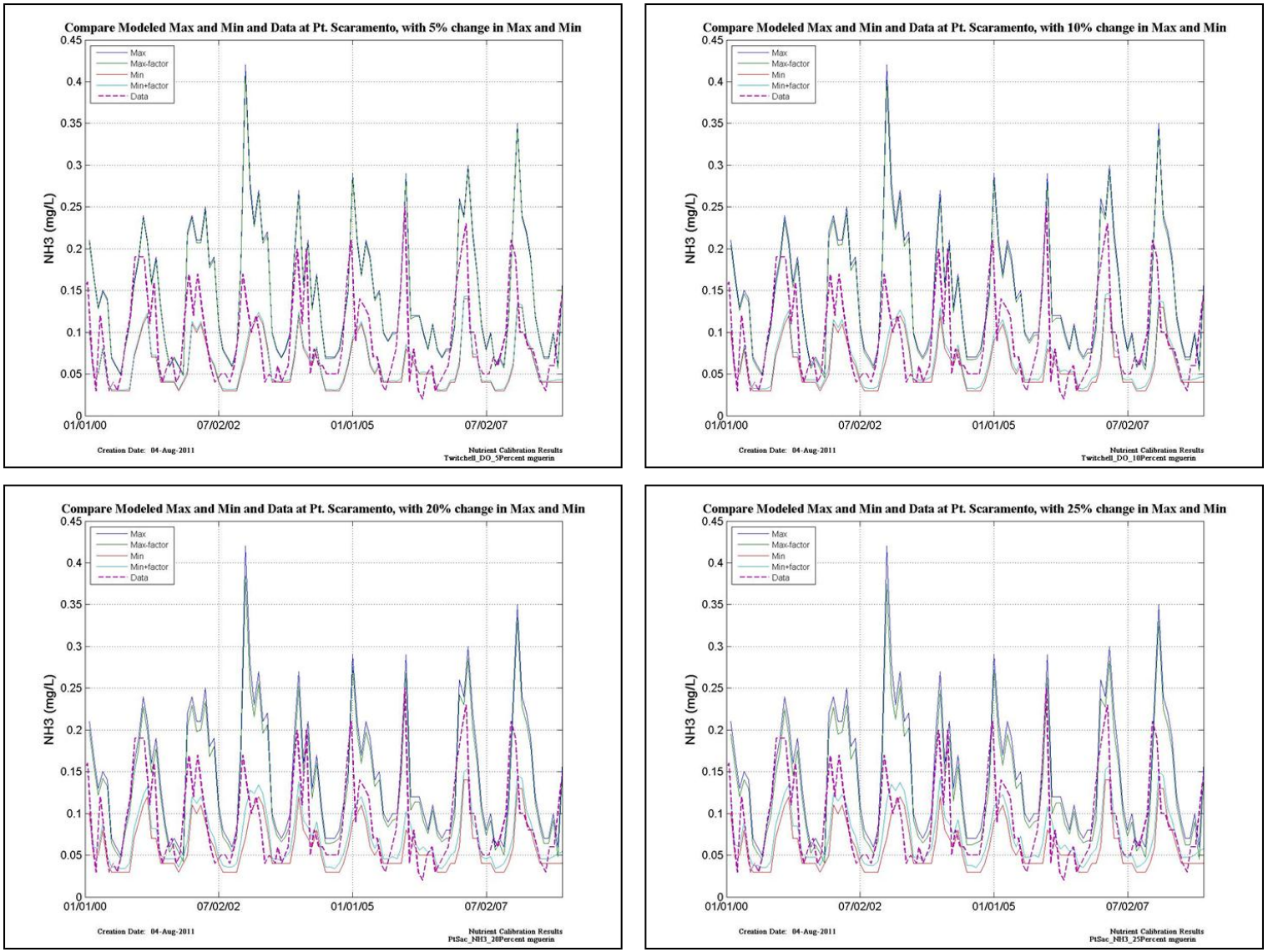


Figure 27-3Comparison of data and the 95%, 90%, 80% and 75% envelope max/min widths for NH3 at Pt. Sacramento.

Table 27-21 Categorical statistics for several envelope ranges at Roe Island (left) and Little Potato Sl. At Terminous (right). Colors indicate change from the 100% envelope range.

Greens-Hood

75%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	VG	VG	Underestimate	VG
80%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	VG	VG	Underestimate	VG
90%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
95%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

Pt. Sacramento

75%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
80%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
90%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
95%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

Table 27-22 Categorical statistics for several envelope ranges at Potato Pt. (left) and Old River at Rancho del Rio (right). Colors indicate change from the 100% envelope range.

Potato Pt.

75%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
80%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
90%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
95%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

Old River at Rancho del Rio

75%	NSE	PBIAS	Bias	RSR
ALL	VG	G	Overestimate	G
Dry WY Calibration	VG	VG	Overestimate	G
Wet WY Calibration	S	VG	Overestimate	U
Dry WY Validation	G	G	Overestimate	S
Wet WY Validation	S	S	Overestimate	U
80%				
ALL	VG	G	Overestimate	G
Dry WY Calibration	VG	VG	Overestimate	G
Wet WY Calibration	S	VG	Overestimate	U
Dry WY Validation	G	G	Overestimate	S
Wet WY Validation	S	S	Overestimate	U
90%				
ALL	VG	G	Overestimate	G
Dry WY Calibration	VG	VG	Overestimate	G
Wet WY Calibration	S	VG	Overestimate	U
Dry WY Validation	G	G	Overestimate	S
Wet WY Validation	S	S	Overestimate	U
95%				
ALL	VG	G	Overestimate	G
Dry WY Calibration	VG	VG	Overestimate	G
Wet WY Calibration	S	VG	Overestimate	U
Dry WY Validation	G	G	Overestimate	S
Wet WY Validation	S	S	Overestimate	U
100%				
ALL	VG	G	Overestimate	G
Dry WY Calibration	VG	VG	Overestimate	G
Wet WY Calibration	S	VG	Overestimate	U
Dry WY Validation	G	G	Overestimate	S
Wet WY Validation	S	S	Overestimate	U

Table 27-23 Categorical statistics for several envelope ranges at Suisun-Nichols (left) and Grizzly Bay (right). Colors indicate change from the 100% envelope range.

Suisun-Nichols

75%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
80%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
90%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
95%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

Grizzly Bay

75%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
80%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
90%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
95%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

Table 27-24 Categorical statistics for several envelope ranges at RSAC054-Martinez. Colors indicate change from the 100% envelope range.

RSAC054 - Martinez

75%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
80%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
90%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
95%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
100%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG

27.4 NO3+NO2

Figure 27-4Figure 27-3 illustrates the 90% and 80% envelopes (note that these correspond to 10% and 20% reductions in modeled monthly maximums and minimums) for NO_3+ NO_2 at the Pt. Sacramento measurement location, and Table 27-25 through Table 27-30 illustrate the change in categorical residual statistics at many of the measurement locations.

Ten of the twelve locations exhibited deterioration in category - that initially occurred at the 90% envelope width. The other two locations did not experience a decrease or an increase in residual category.

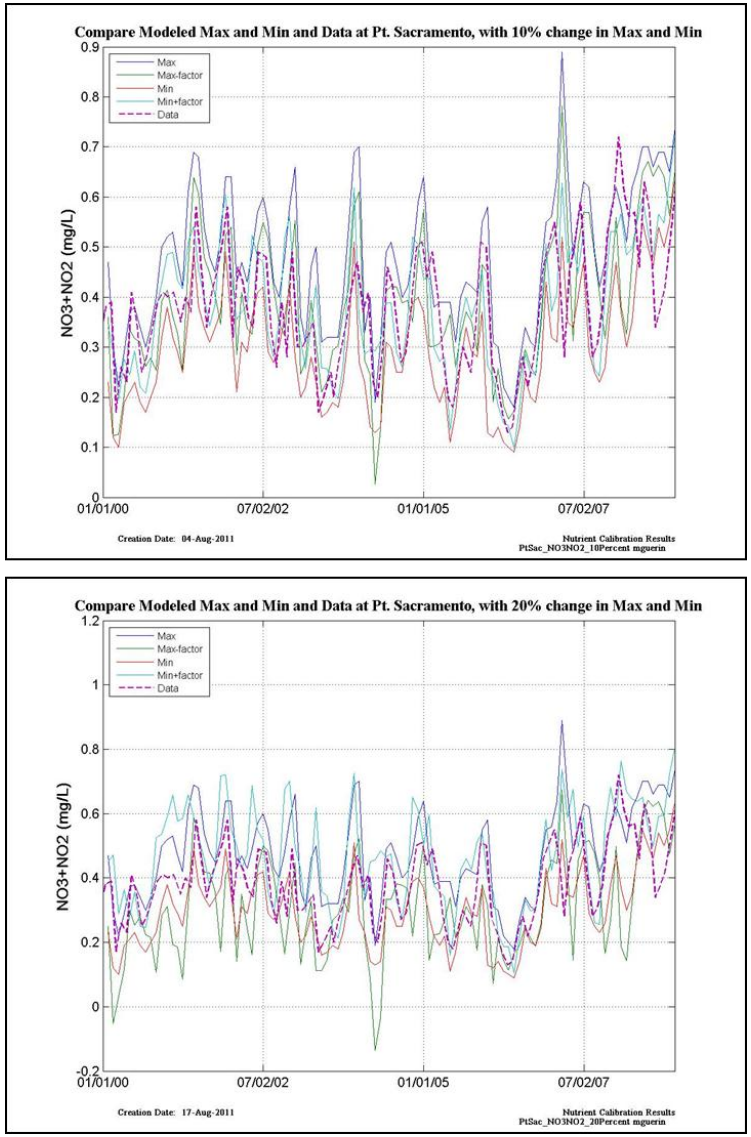


Figure 27-4Comparison of data and the 90% and 80% envelope max/min widths for NO_3+NO_2at Pt. Sacramento.

Table 27-25 Categorical statistics for several envelope ranges at Greens-Hood (left) and Pt. Sacramento (right). Colors indicate change from the 100% envelope range.

Greens-Hood

80%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	S	G	Overestimate	U
Wet WY Calibration	S	G	Overestimate	U
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	S	VG	Overestimate	U
90%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	G	VG	Overestimate	S
Wet WY Calibration	VG	VG	Overestimate	S
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	G	VG	Overestimate	S
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

Pt. Sacramento

80%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	S	VG	Overestimate	U
Wet WY Calibration	S	VG	Overestimate	U
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	VG	VG	Overestimate	G
90%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	S	VG	Overestimate	U
Wet WY Calibration	S	VG	Overestimate	S
Dry WY Validation	G	VG	Overestimate	S
Wet WY Validation	VG	VG	Overestimate	VG
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	G	VG	Overestimate	S
Wet WY Validation	VG	VG	Underestimate	VG

Table 27-26 Categorical statistics for several envelope ranges at Potato Point (left) and Old River at Rancho del Rio (right). Colors indicate change from the 100% envelope range.

Potato Point

80%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	S	G	Overestimate	U
Wet WY Calibration	U	VG	Overestimate	U
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	G	VG	Overestimate	G
90%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	S	VG	Overestimate	U
Wet WY Calibration	S	VG	Overestimate	U
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	VG	VG	Overestimate	VG
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	G	VG	Overestimate	U
Wet WY Calibration	G	VG	Overestimate	U
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	VG	VG	Overestimate	VG

Old River at Rancho del Rio

80%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	G
Dry WY Calibration	S	VG	Overestimate	U
Wet WY Calibration	S	VG	Overestimate	U
Dry WY Validation	S	G	Overestimate	U
Wet WY Validation	VG	VG	Overestimate	G
90%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	S	VG	Overestimate	U
Wet WY Calibration	S	VG	Overestimate	U
Dry WY Validation	S	G	Overestimate	U
Wet WY Validation	VG	VG	Overestimate	G
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	S	VG	Overestimate	S
Wet WY Calibration	S	VG	Overestimate	U
Dry WY Validation	S	G	Overestimate	U
Wet WY Validation	VG	VG	Overestimate	G

Table 27-27 Categorical statistics for several envelope ranges at Disappointment Sl. (left) and SJR Buckley Cove (right). Colors indicate change from the 100% envelope range.

Disappointment Sl.

80%	NSE	PBIAS	Bias	RSR
ALL	G	S	Overestimate	G
Dry WY Calibration	G	S	Overestimate	U
Wet WY Calibration	S	S	Overestimate	U
Dry WY Validation	G	S	Overestimate	U
Wet WY Validation	VG	G	Overestimate	VG
90%				
ALL	G	S	Overestimate	G
Dry WY Calibration	G	S	Overestimate	U
Wet WY Calibration	S	S	Overestimate	U
Dry WY Validation	G	S	Overestimate	U
Wet WY Validation	VG	G	Overestimate	VG
100%				
ALL	G	S	Overestimate	G
Dry WY Calibration	G	S	Overestimate	U
Wet WY Calibration	S	S	Overestimate	U
Dry WY Validation	G	S	Overestimate	U
Wet WY Validation	VG	G	Overestimate	VG

SJR Buckley Cove

80%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
90%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG

Table 27-28 Categorical statistics for several envelope ranges at Suisun-Nichols (left) and Grizzly (right). Colors indicate change from the 100% envelope range.

Suisun-Nichols

80%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	S	VG	Overestimate	U
Wet WY Calibration	S	VG	Overestimate	U
Dry WY Validation	G	VG	Overestimate	S
Wet WY Validation	VG	VG	Overestimate	G
90%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	S	VG	Overestimate	U
Wet WY Calibration	S	VG	Overestimate	S
Dry WY Validation	VG	VG	Overestimate	G
Wet WY Validation	VG	VG	Overestimate	VG
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

Grizzly

80%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	G
Wet WY Calibration	S	VG	Overestimate	U
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	VG	VG	Overestimate	S
90%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	S	VG	Overestimate	U
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	VG	VG	Overestimate	VG
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	VG	VG	Overestimate	VG

Table 27-29 Categorical statistics for several envelope ranges at Rio Vista (left) and RSAC077-Pittsburg (right). Colors indicate change from the 100% envelope range.

Rio Vista

80%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	U	VG	Overestimate	U
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	VG	VG	Overestimate	VG
90%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	S	VG	Underestimate	S
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	G	VG	Overestimate	G
Wet WY Validation	VG	VG	Overestimate	VG
100%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	No Bias	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	No Bias	VG

RSAC077 - Pittsburg

80%	NSE	PBIAS	Bias	RSR
ALL	G	VG	Overestimate	S
Dry WY Calibration	U	VG	Overestimate	U
Wet WY Calibration	U	VG	Overestimate	U
Dry WY Validation	G	VG	Overestimate	S
Wet WY Validation	S	VG	Overestimate	U
90%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	U	VG	Overestimate	U
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	G	VG	Overestimate	S
Wet WY Validation	VG	VG	Overestimate	VG
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	G	VG	Overestimate	S
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

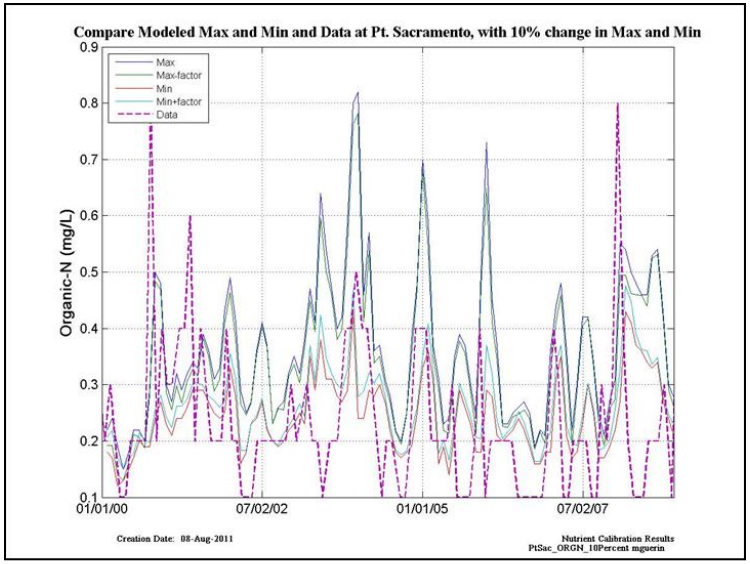
Table 27-30 Categorical statistics for several envelope ranges at RSAC054-Martinez (left) and Roe Island (right). Colors indicate change from the 100% envelope range.

RSAC054 - Martinez					Roe Island				
80%	**NSE**	**PBIAS**	**Bias**	**RSR**	**80%**	**NSE**	**PBIAS**	**Bias**	**RSR**
ALL	VG	VG	Overestimate	G	ALL	G	VG	Overestimate	S
Dry WY Calibration	VG	VG	Overestimate	VG	Dry WY Calibration	S	G	Overestimate	U
Wet WY Calibration	S	VG	Overestimate	U	Wet WY Calibration	G	G	Overestimate	U
Dry WY Validation	S	VG	Overestimate	U	Dry WY Validation	U	VG	Overestimate	U
Wet WY Validation	VG	VG	Overestimate	U	Wet WY Validation	VG	VG	Overestimate	S
90%					**90%**				
ALL	VG	VG	Overestimate	VG	ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG	Dry WY Calibration	U	VG	Overestimate	U
Wet WY Calibration	S	VG	Overestimate	U	Wet WY Calibration	VG	VG	Overestimate	G
Dry WY Validation	VG	VG	Overestimate	VG	Dry WY Validation	U	VG	Overestimate	U
Wet WY Validation	VG	VG	Overestimate	G	Wet WY Validation	VG	VG	Overestimate	VG
100%					**100%**				
ALL	VG	VG	Overestimate	VG	ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG	Dry WY Calibration	VG	VG	Overestimate	G
Wet WY Calibration	VG	VG	Overestimate	VG	Wet WY Calibration	VG	VG	Overestimate	G
Dry WY Validation	VG	VG	Overestimate	VG	Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	VG	VG	Overestimate	VG	Wet WY Validation	VG	VG	Overestimate	VG

27.5 Organic-N

Figure 27-5illustrates 90% and 80% envelopes (note that these correspond to 10% and 20% reductions in modeled monthly maximums and minimums) for NH_3 at the Pt. Sacramento measurement location, and Table 27-31through Table 27-33illustrate the change in categorical residual statistics at many of the measurement locations.

One of the nine locations exhibited deterioration in category, and one location experienced an increase in category– those both initially occurred at the 80% envelope width.



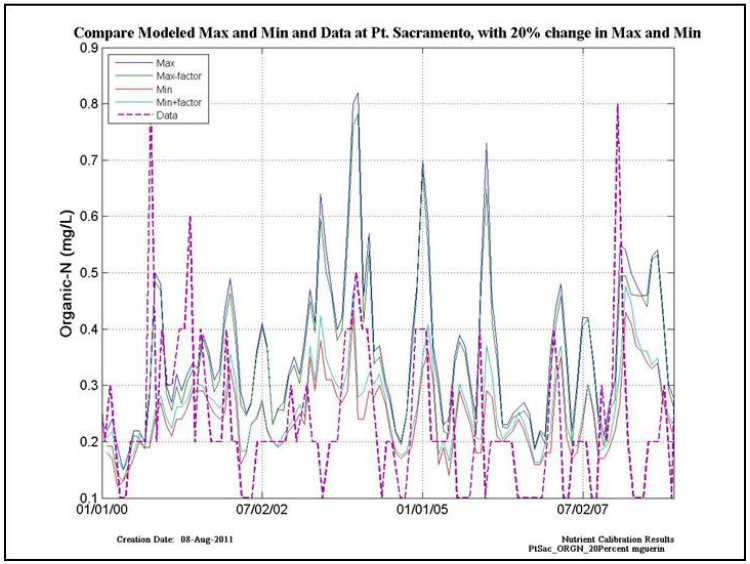


Figure 27-5Comparison of data and the 90% and 80% envelope max/min widths for organic-N at Pt. Sacramento.

Table 27-31 Categorical statistics for several envelope ranges at Green-Hoods (upper left), Potato Point (lower left), Pt. Sacramento (upper right), and Old River at Rancho del Rio (lower right). Colors indicate change from the 100% envelope range.

Greens-Hood

80%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

Pt. Sacramento

80%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	S	VG	Overestimate	S
Wet WY Calibration	S	VG	Overestimate	S
Dry WY Validation	S	G	Overestimate	U
Wet WY Validation	S	G	Overestimate	U
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	S	VG	Overestimate	S
Wet WY Calibration	S	VG	Overestimate	S
Dry WY Validation	S	G	Overestimate	U
Wet WY Validation	S	G	Overestimate	U

Potato Point

80%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	S	VG	Overestimate	U
Wet WY Calibration	S	VG	Overestimate	U
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	S	VG	Overestimate	U
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	S	VG	Overestimate	U
Wet WY Calibration	S	VG	Overestimate	U
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	S	VG	Overestimate	U

Old River at Rancho del Rio

80%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	S	VG	Underestimate	S
Wet WY Calibration	U	VG	Overestimate	U
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	S	VG	Overestimate	U
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	S	VG	Underestimate	S
Wet WY Calibration	U	VG	Overestimate	U
Dry WY Validation	S	VG	Overestimate	U
Wet WY Validation	S	VG	Overestimate	U

Table 27-32 Categorical statistics for several envelope ranges at SJR Buckley Cove (upper left), Grizzly (lower left), Disappointment Sl. (upper right), and Suisun-Nichols (lower right). Colors indicate change from the 100% envelope range.

SJR Buckley Cove

80%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	G	VG	Overestimate	G
Wet WY Calibration	G	VG	Underestimate	G
Dry WY Validation	G	VG	Overestimate	G
Wet WY Validation	VG	VG	Overestimate	VG
100%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Overestimate	G
Wet WY Calibration	G	VG	Underestimate	G
Dry WY Validation	G	VG	Overestimate	G
Wet WY Validation	VG	VG	Overestimate	VG

Disappointment Sl.

80%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	G	VG	Overestimate	G
Wet WY Calibration	VG	VG	Overestimate	S
Dry WY Validation	S	VG	Overestimate	S
Wet WY Validation	VG	VG	Overestimate	VG
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	G	VG	Overestimate	G
Wet WY Calibration	G	VG	Overestimate	S
Dry WY Validation	S	VG	Overestimate	S
Wet WY Validation	VG	VG	Overestimate	VG

Grizzly

80%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	S	G	Underestimate	U
Dry WY Validation	S	VG	Underestimate	S
Wet WY Validation	S	VG	Underestimate	U
100%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	S	G	Underestimate	U
Dry WY Validation	S	VG	Underestimate	S
Wet WY Validation	S	VG	Underestimate	U

Suisun-Nichols

80%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	G	VG	Underestimate	G
Wet WY Calibration	S	VG	Underestimate	S
Dry WY Validation	S	VG	Overestimate	S
Wet WY Validation	S	VG	Overestimate	S
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	G	VG	Underestimate	G
Wet WY Calibration	S	VG	Underestimate	S
Dry WY Validation	S	VG	Overestimate	S
Wet WY Validation	S	VG	Overestimate	S

Table 27-33 Categorical statistics for several envelope ranges at RSAC054-Martinez. Colors indicate change from the 100% envelope range.

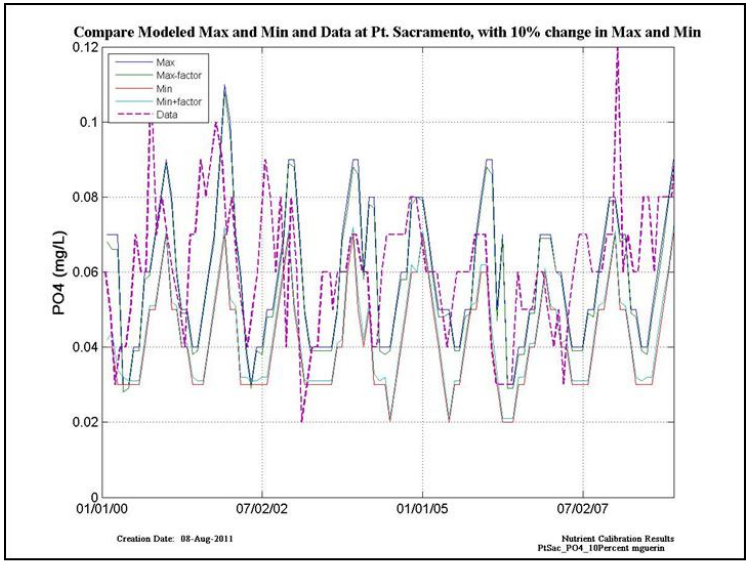
RSAC054 - Martinez

80%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
100%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

27.6 PO4

Figure 27-6illustrates 90% and 80% envelopes (note that these correspond to 10% and 20% reductions in modeled monthly maximums and minimums) for PO_4 at the Pt. Sacramento measurement location, and Table 27-34 through Table 27-36 illustrate the change in categorical residual statistics at many of the measurement locations.

None of the nine locations exhibited deterioration in category (only listed up to the 80% range).



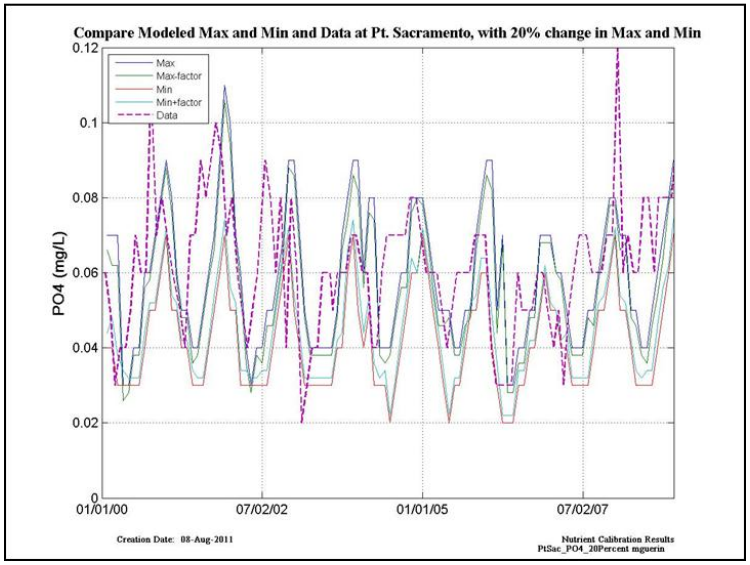


Figure 27-6Comparison of data and the 90% and 80% envelope max/min widths for PO_4 at Pt. Sacramento.

Table 27-34 Categorical statistics for several envelope ranges at Green-Hoods (upper left), SJR Buckley Cove (lower left), Pt. Sacramento (upper right), and Disappointment Sl. (lower right). Colors indicate change from the 100% envelope range.

Greens-Hood

80%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	VG	VG	Overestimate	VG
Wet WY Calibration	VG	VG	Overestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

Pt. Sacramento

80%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	S	VG	Underestimate	S
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	G	VG	Underestimate	G
100%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	S	VG	Underestimate	S
Dry WY Validation	S	VG	Underestimate	U
Wet WY Validation	G	VG	Underestimate	G

SJR Buckley Cove

80%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
100%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG

Disappointment Sl.

80%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG
100%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Overestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG

Table 27-35 Categorical statistics for several envelope ranges at Old River at Rancho del Rio (upper left), Grizzly Bay (lower left), Potato Pt. (upper right), and Suisun-Nichols (lower right). Colors indicate change from the 100% envelope range.

Old River at Rancho del Rio

80%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	U	VG	Overestimate	U
Wet WY Calibration	U	VG	Overestimate	U
Dry WY Validation	U	VG	Overestimate	U
Wet WY Validation	S	VG	Overestimate	U
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	U	VG	Overestimate	U
Wet WY Calibration	U	VG	Overestimate	U
Dry WY Validation	U	VG	Overestimate	U
Wet WY Validation	S	VG	Overestimate	U

Potato Point

80%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	S	VG	Overestimate	U
Wet WY Calibration	S	VG	Overestimate	U
Dry WY Validation	S	VG	Overestimate	S
Wet WY Validation	VG	VG	Overestimate	VG
100%				
ALL	VG	VG	Overestimate	VG
Dry WY Calibration	S	VG	Overestimate	U
Wet WY Calibration	S	VG	Overestimate	U
Dry WY Validation	S	VG	Overestimate	S
Wet WY Validation	VG	VG	Overestimate	VG

Grizzly Bay

80%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	VG	VG	Underestimate	G
Dry WY Validation	S	VG	Underestimate	S
Wet WY Validation	VG	VG	Underestimate	VG
100%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	S	VG	Underestimate	U
Wet WY Calibration	VG	VG	Underestimate	G
Dry WY Validation	S	VG	Underestimate	S
Wet WY Validation	VG	VG	Underestimate	VG

Suisun-Nichols

80%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	S	VG	Underestimate	U
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
100%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	S	VG	Underestimate	U
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG

Table 27-36 Categorical statistics for several envelope ranges at RSAC054-Martinez. Colors indicate change from the 100% envelope range.

RSAC054 - Martinez

80%	NSE	PBIAS	Bias	RSR
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Overestimate	VG
100%				
ALL	VG	VG	Underestimate	VG
Dry WY Calibration	VG	VG	Underestimate	VG
Wet WY Calibration	VG	VG	Underestimate	VG
Dry WY Validation	VG	VG	Underestimate	VG
Wet WY Validation	VG	VG	Underestimate	VG

28 Calibration Statistics and Histograms (Version 8.0.6)

28.1 Algae

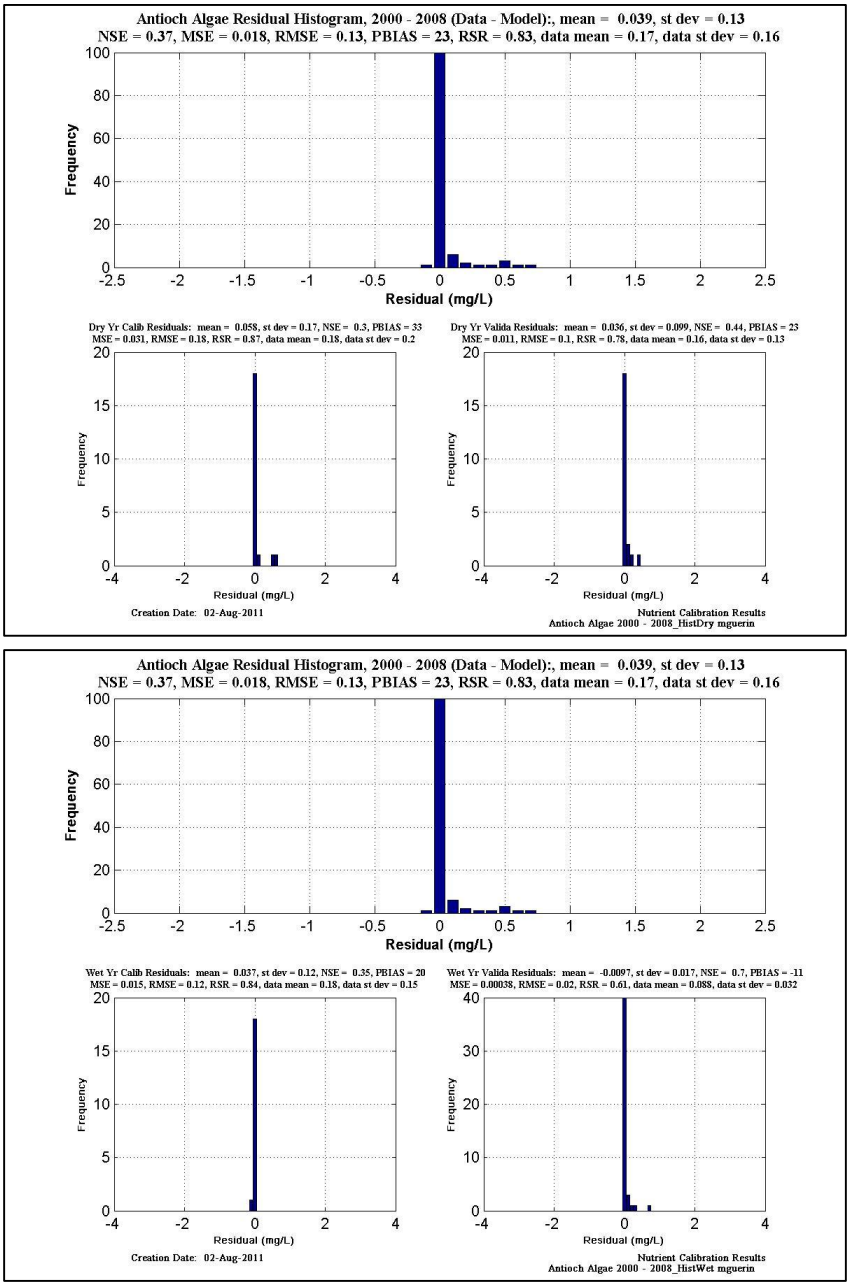


Figure 28-1 Calibration/validation statistics for Algae at Antioch. Upper figure is calibration & validation statistics for dry years; lower figure is calibration &validation statistics for wet years.

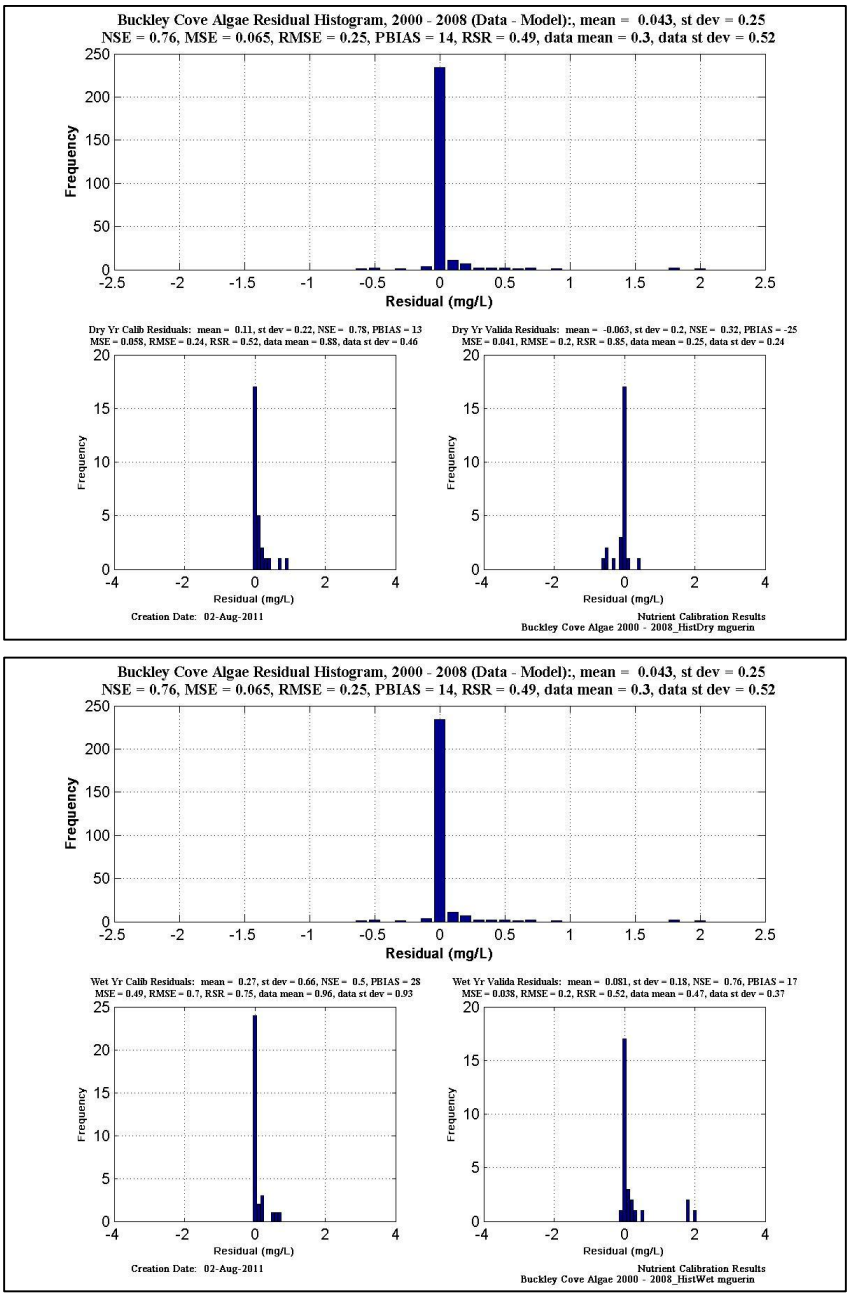


Figure 28-2 Calibration/validation statistics for Algae at Buckley Cove. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

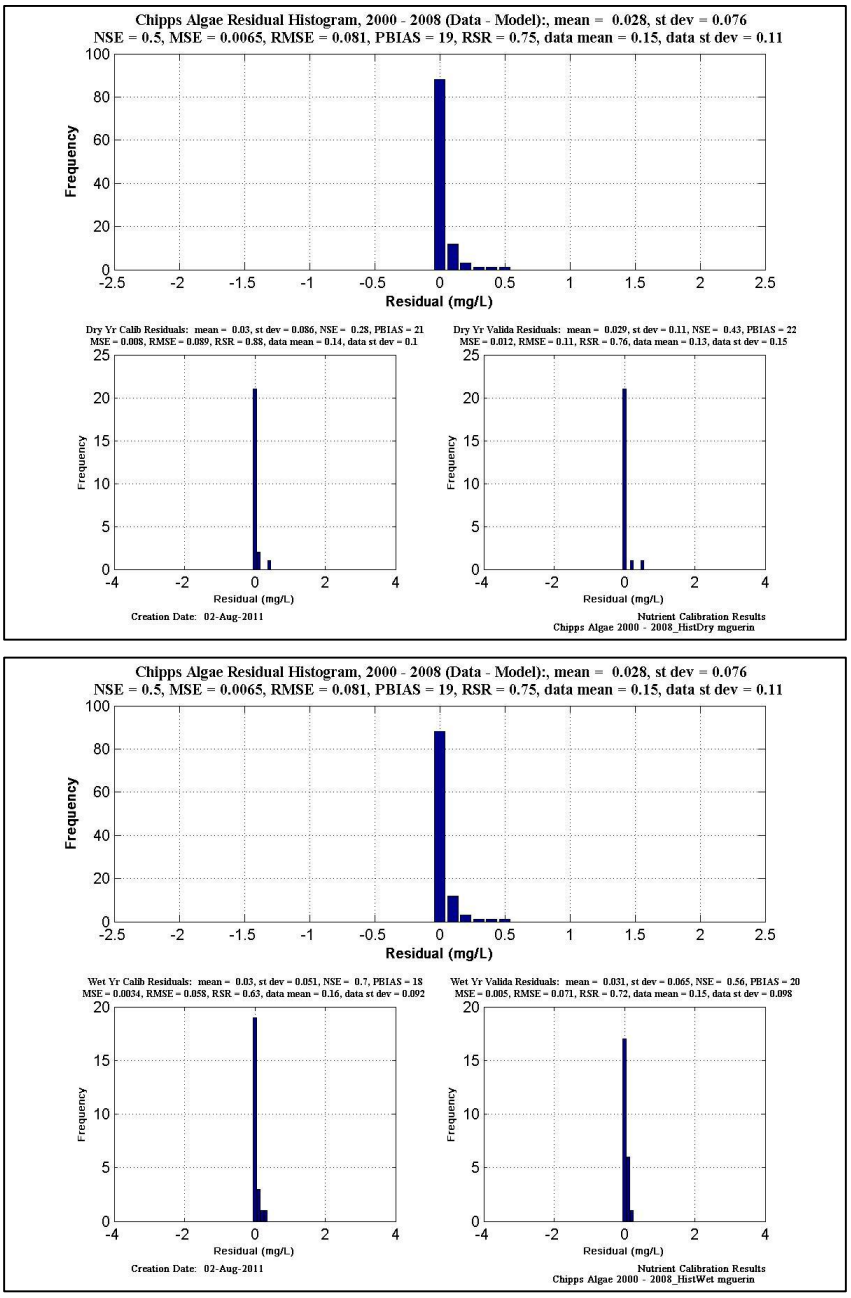


Figure 28-3 Calibration/validation statistics for Algae at Chipps. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

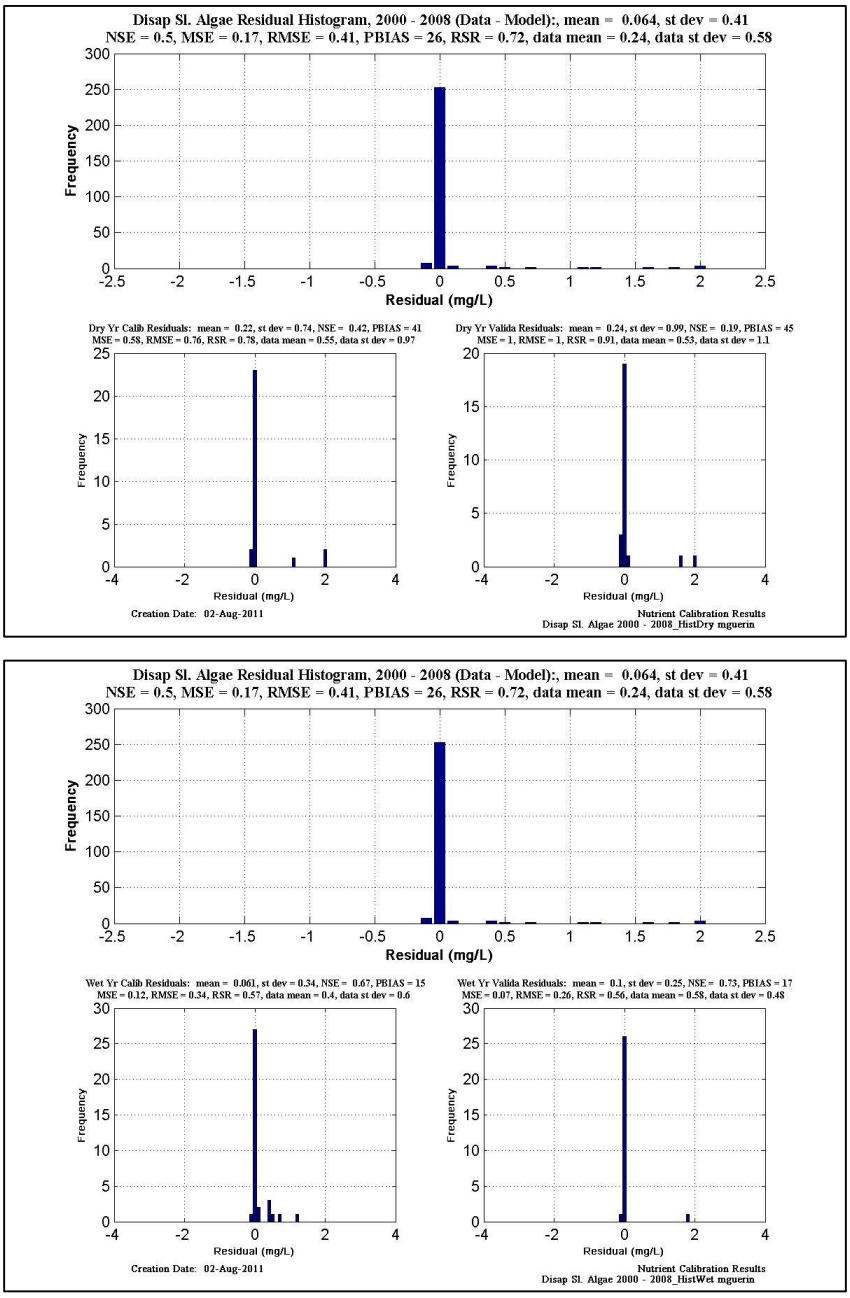


Figure 28-4 Calibration/validation statistics for Algae at Disappointment Sl. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

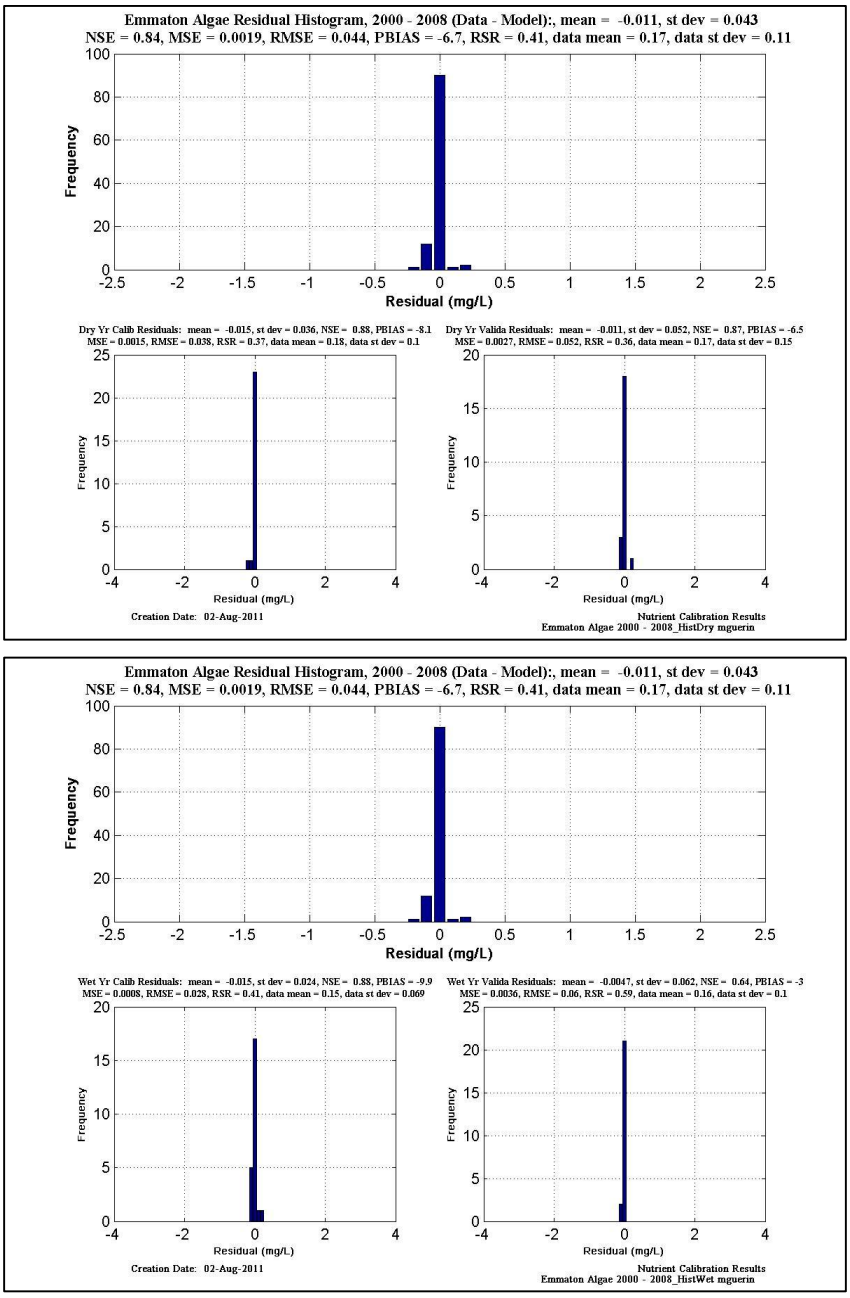
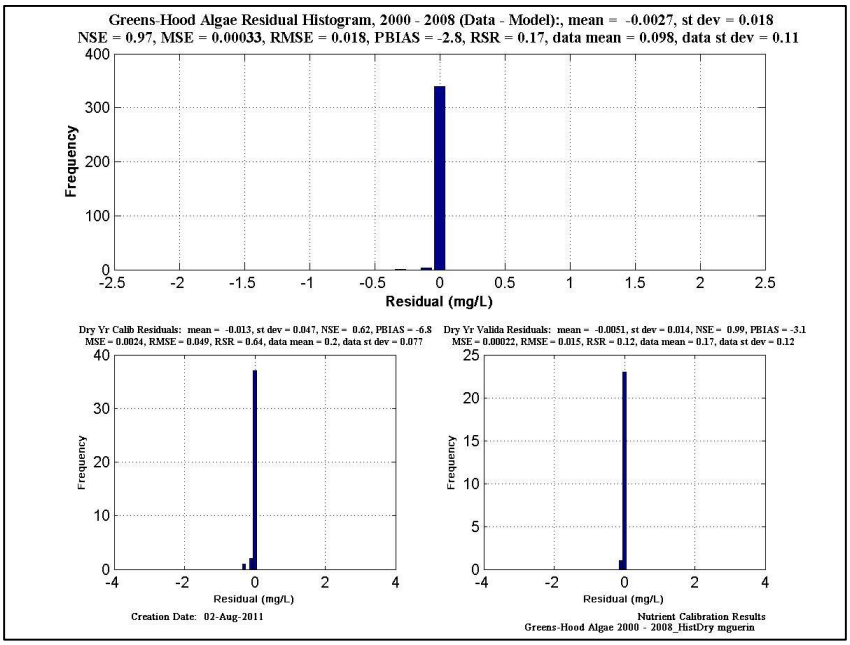


Figure 28-5 Calibration/validation statistics for Algae at Emmaton. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.



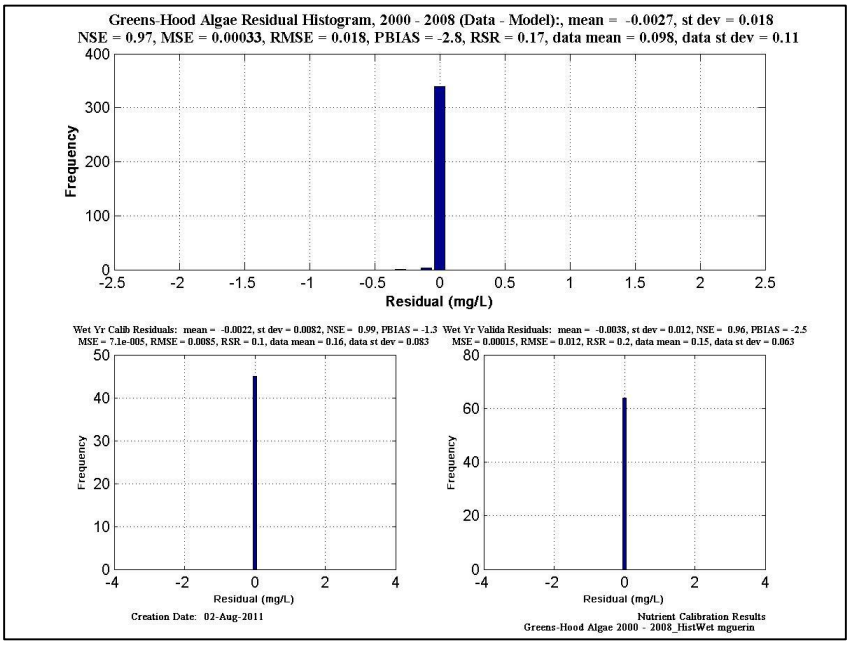


Figure 28-6 Calibration/validation statistics for Algae at Greens-Hood. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

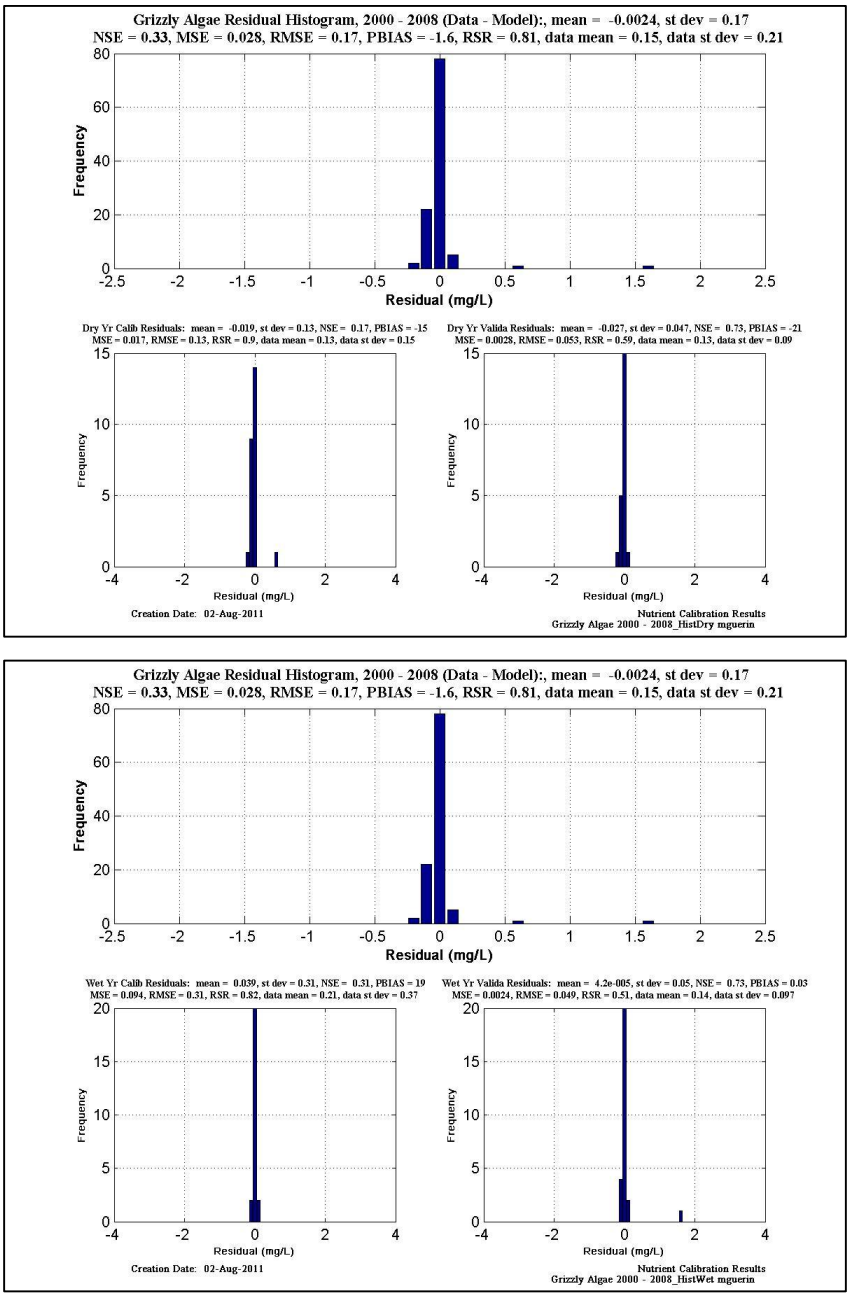


Figure 28-7 Calibration/validation statistics for Algae at Grizzly Bay. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

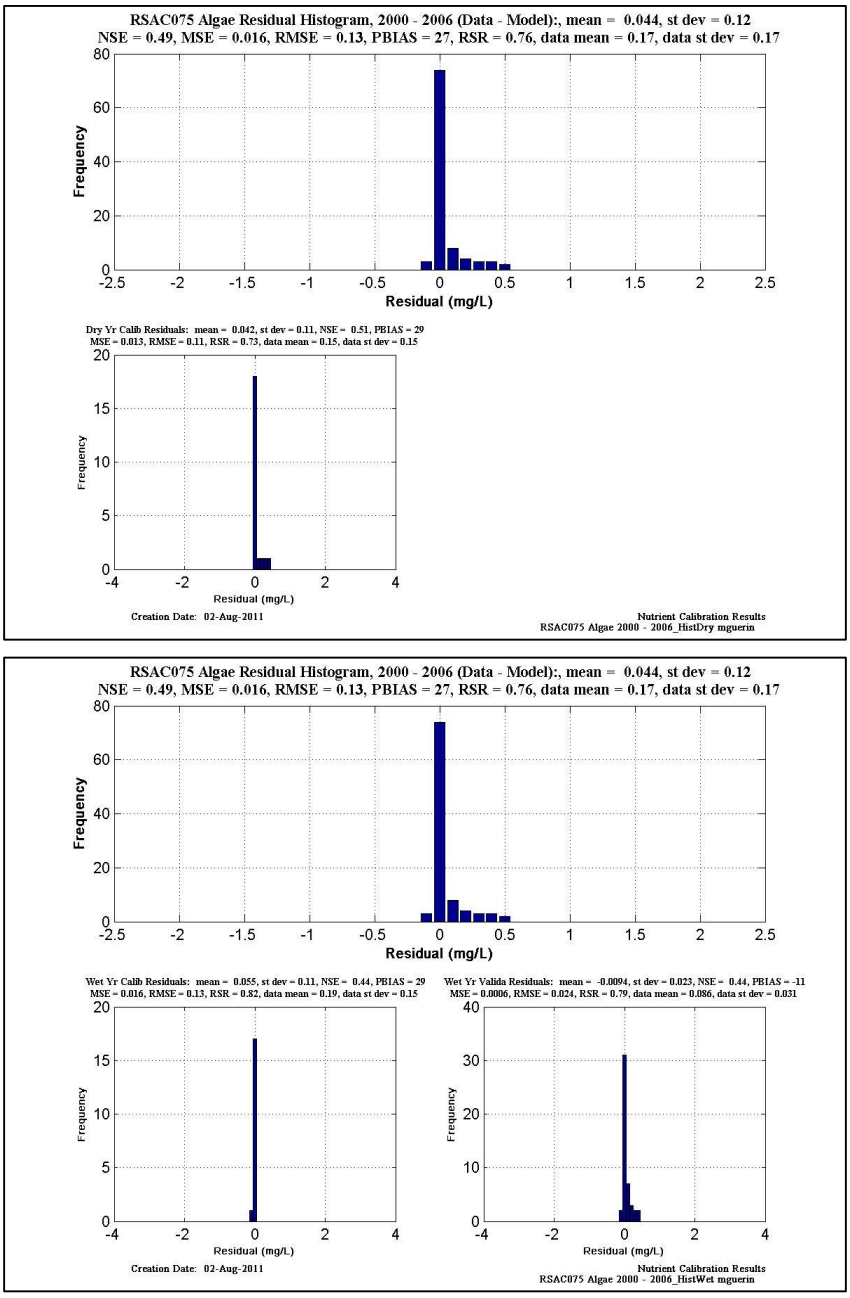


Figure 28-8 Calibration/validation statistics for Algae at Mallard-RSAC075. Upper figure is calibration & validation statistics for dry years, Validation for Dry Years (2007, 2008) missing due to lack of data; lower figure is calibration & validation statistics for wet years.

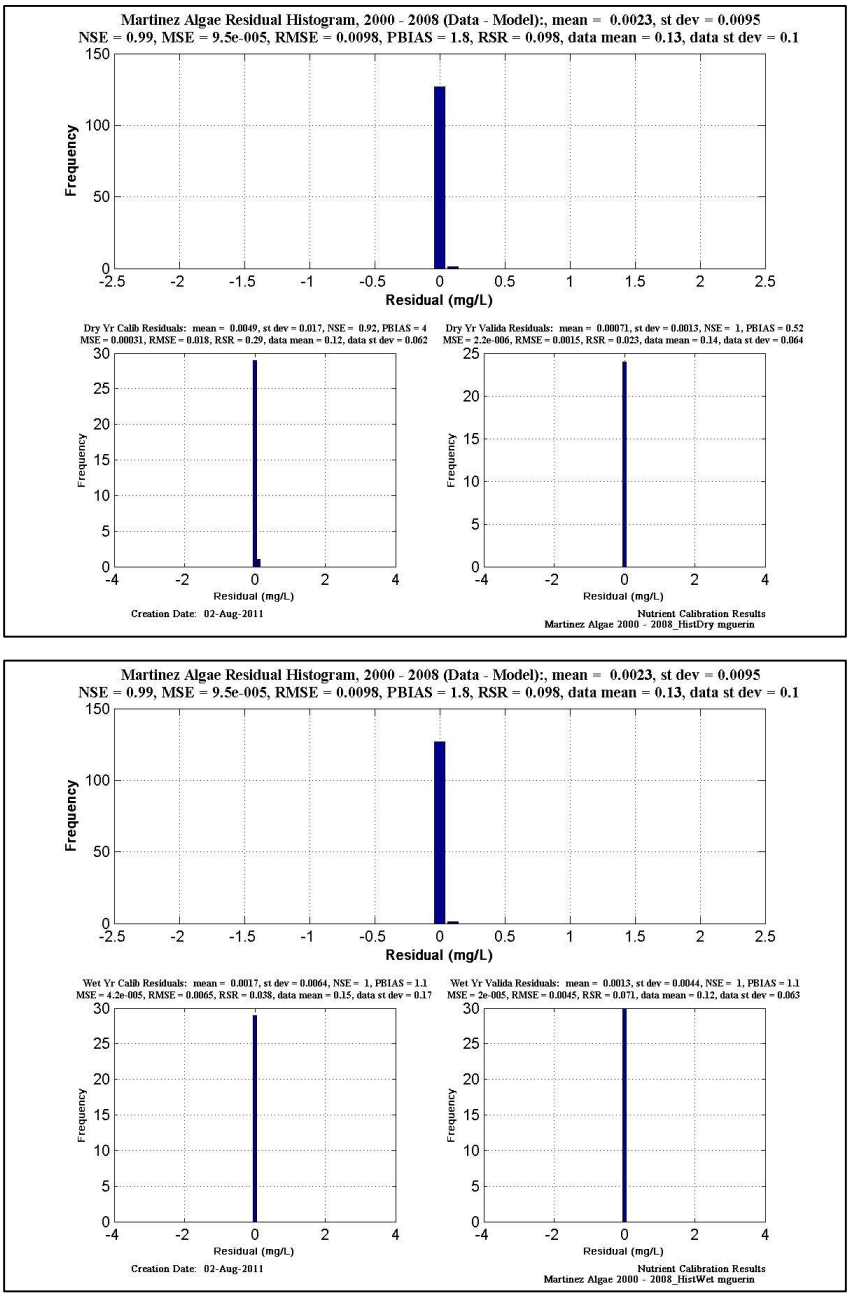


Figure 28-9 Calibration/validation statistics for Algae at Martinez. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

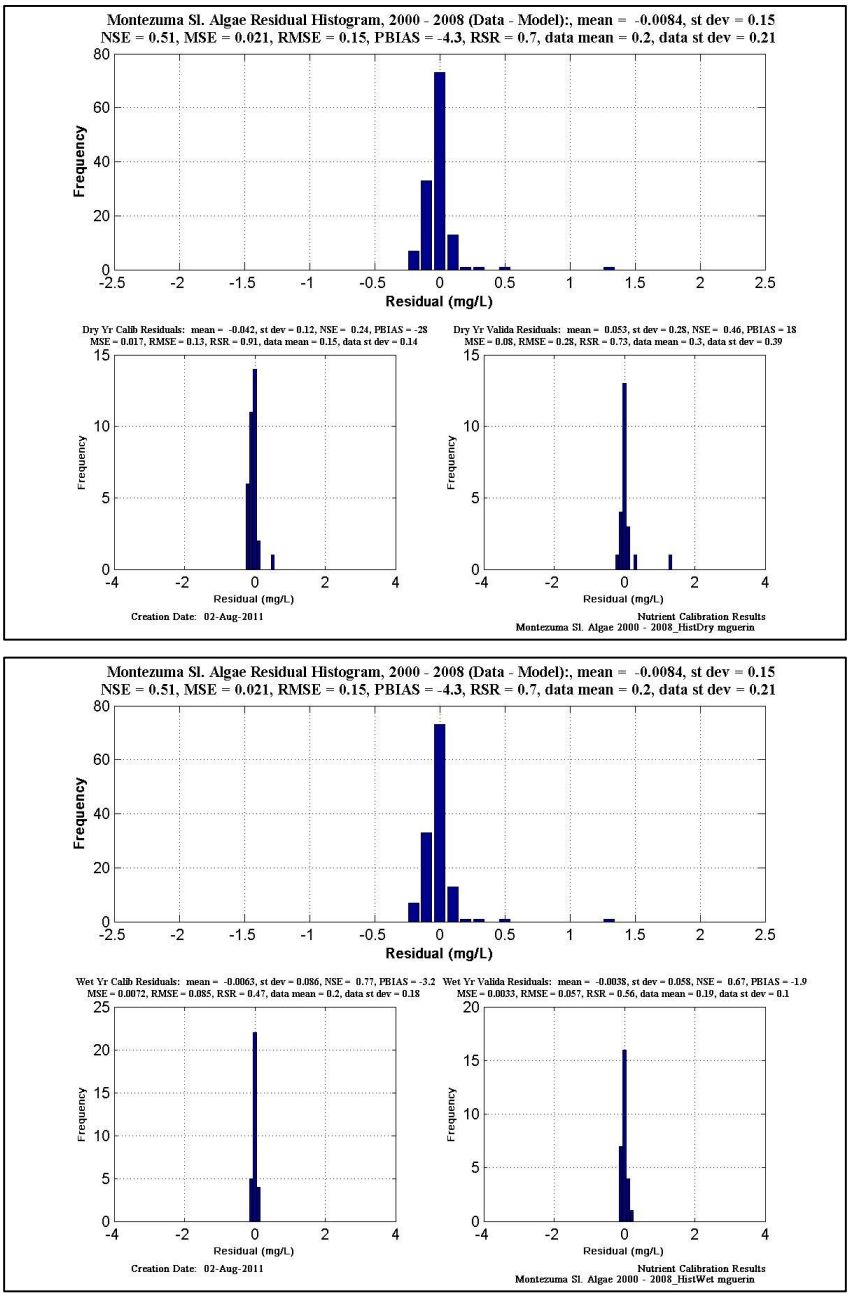


Figure 28-10 Calibration/validation statistics for Algae at Montezuma Sl. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

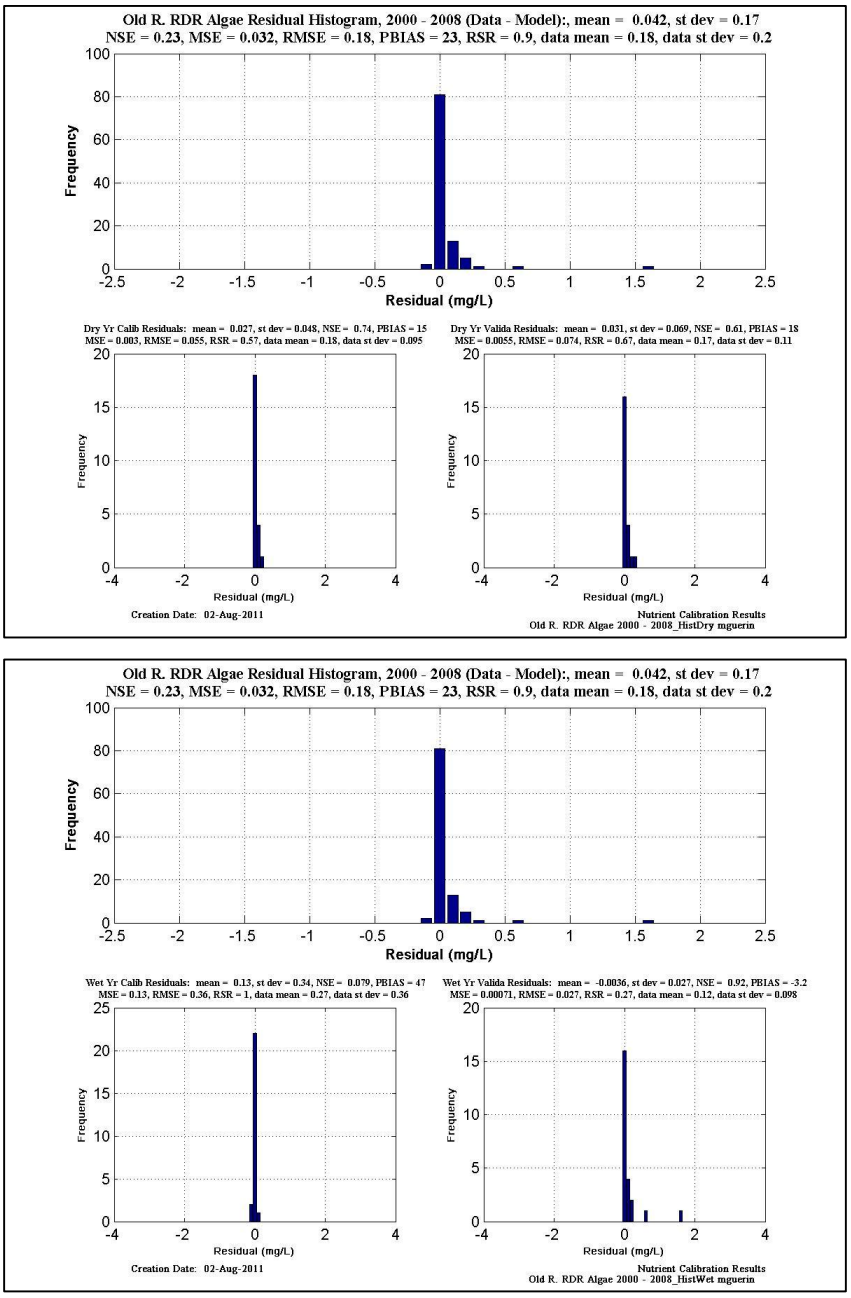


Figure 28-11 Calibration/validation statistics for Algae at Old R. Rancho Del Rio. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

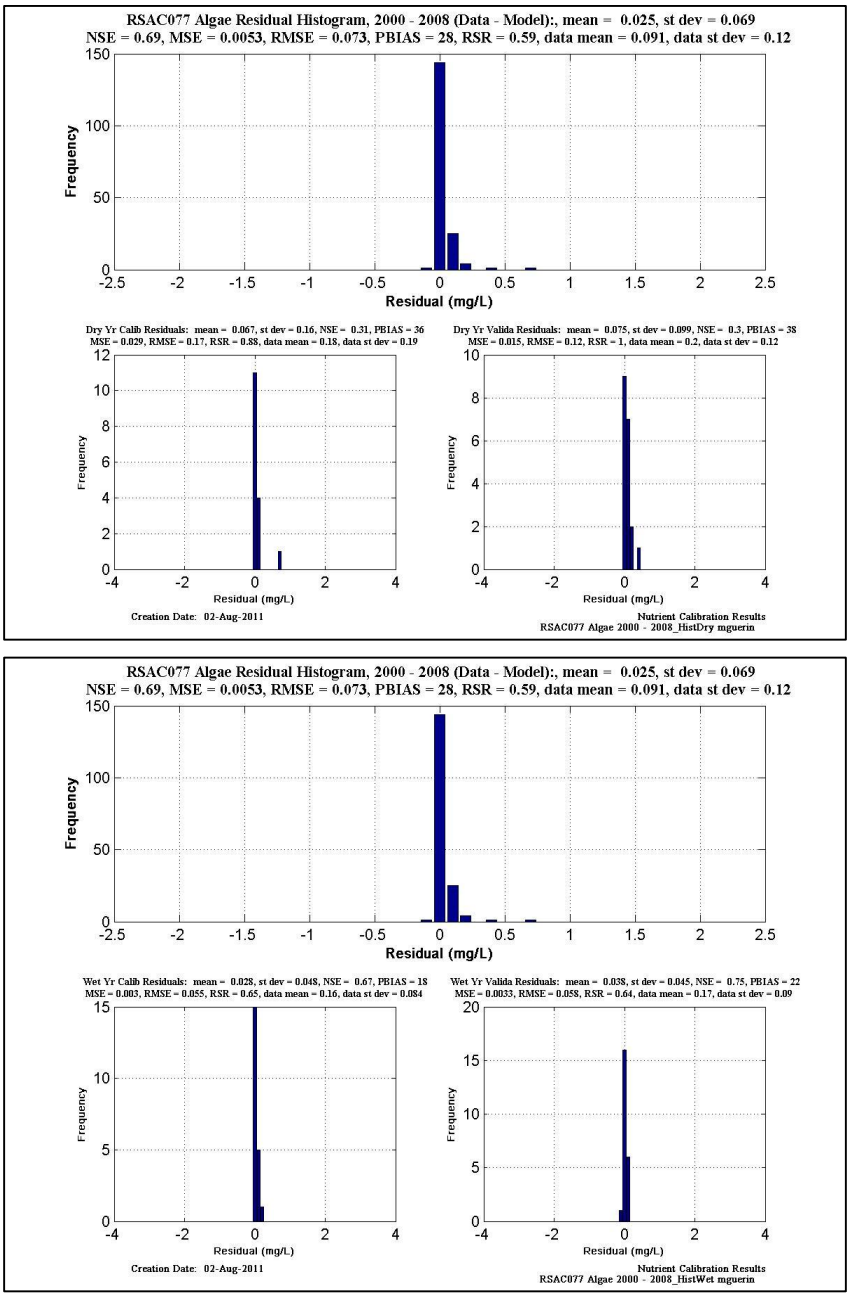


Figure 28-12 Calibration/validation statistics for Algae at Pittsburg, RSAC077. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

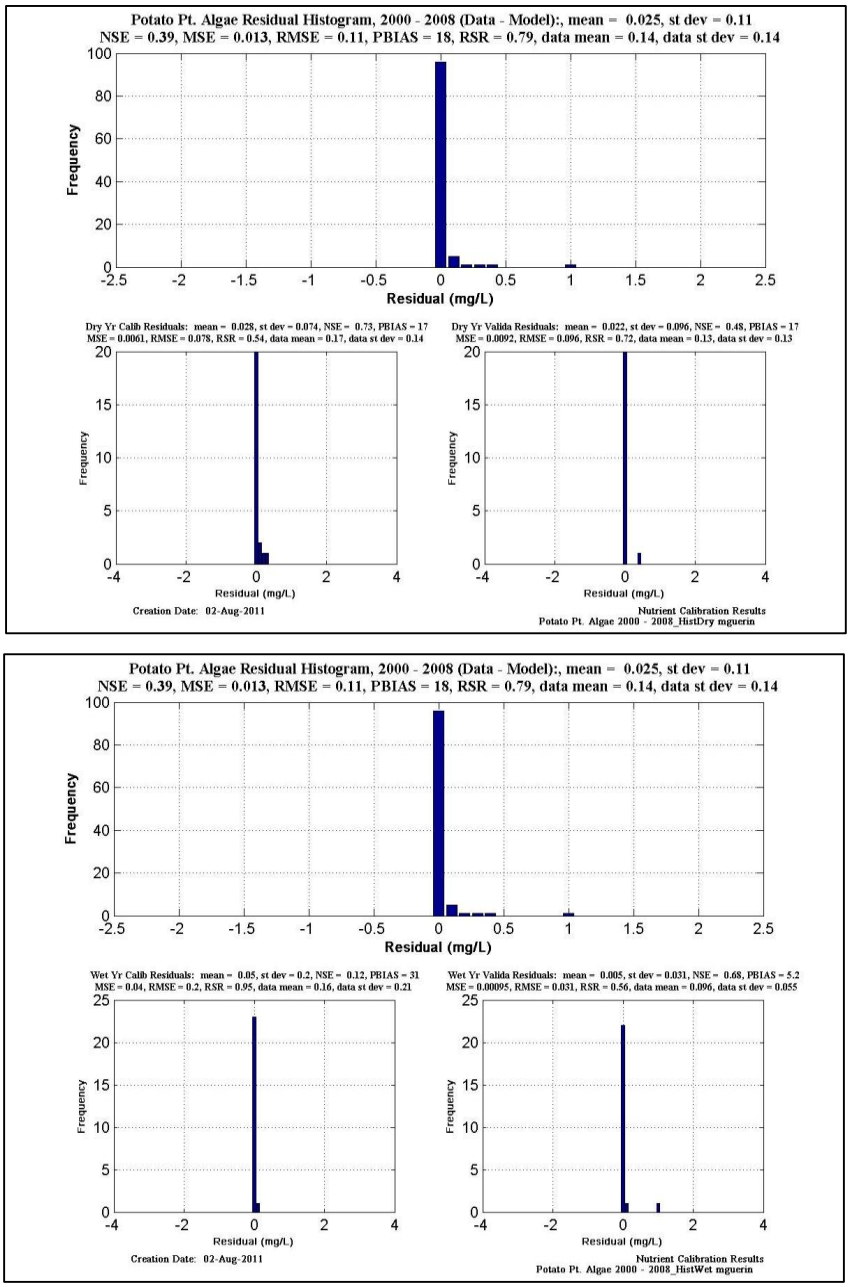


Figure 28-13 Calibration/validation statistics for Algae at Potato Pt. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

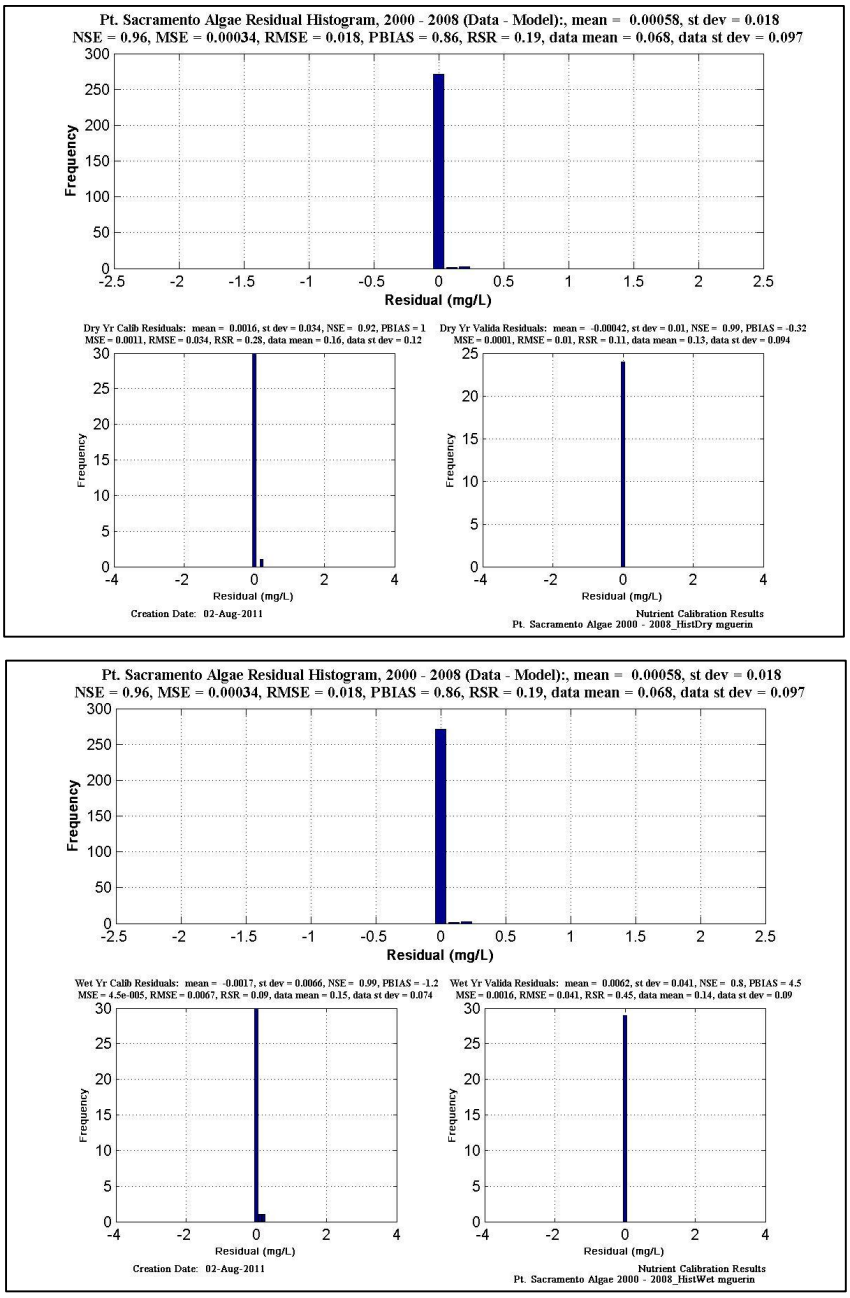


Figure 28-14 Calibration/validation statistics for Algae at Pt. Sacramento. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

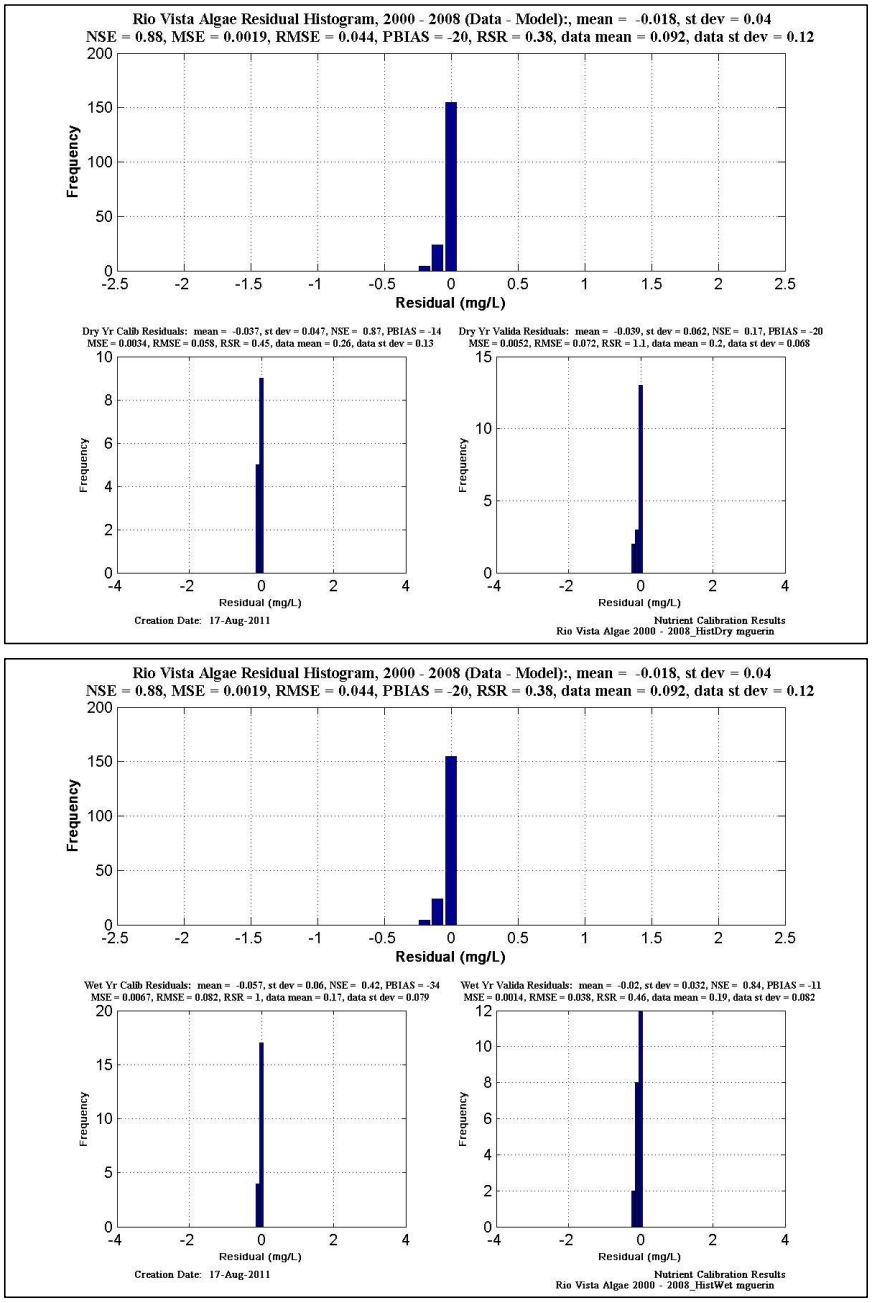


Figure 28-15Calibration/validation statistics for Algae at Rio Vista. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

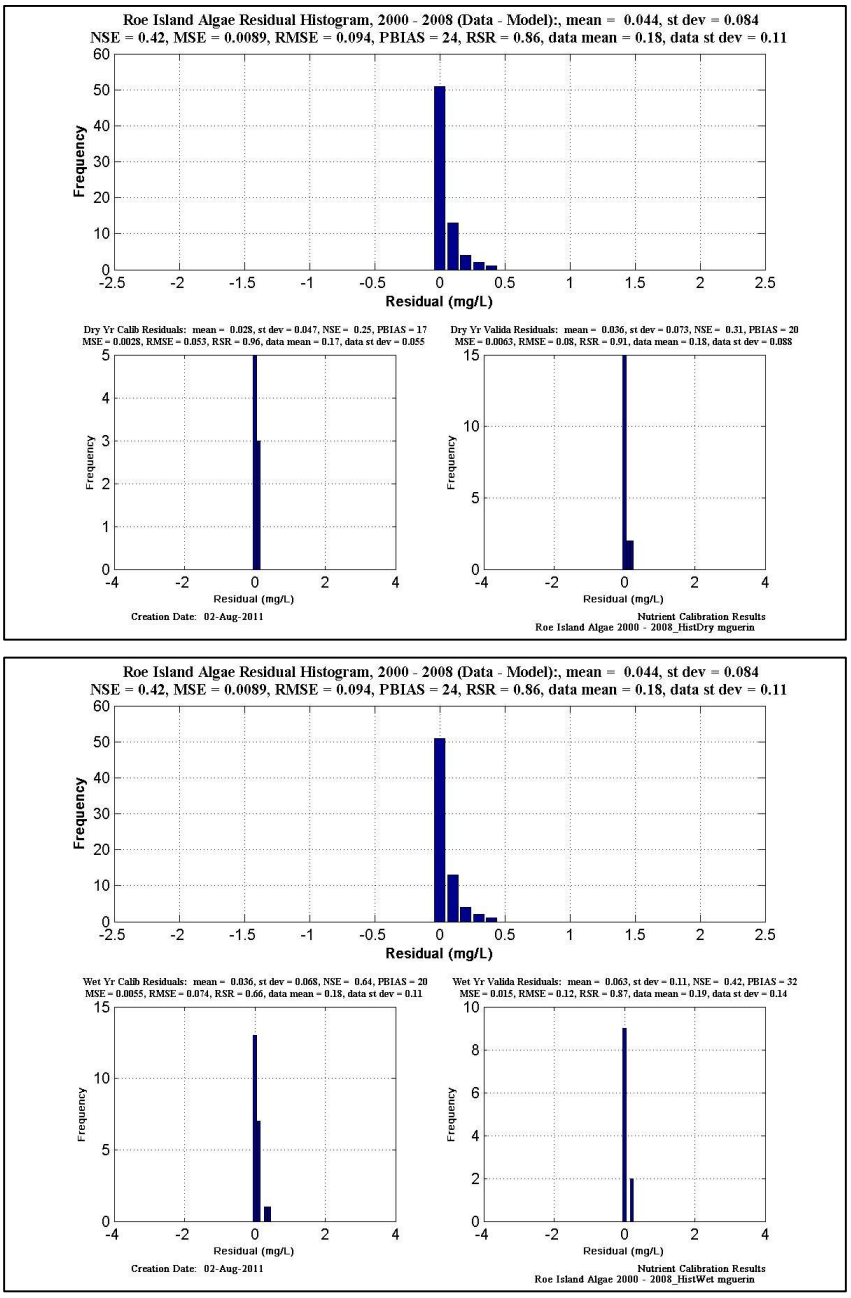
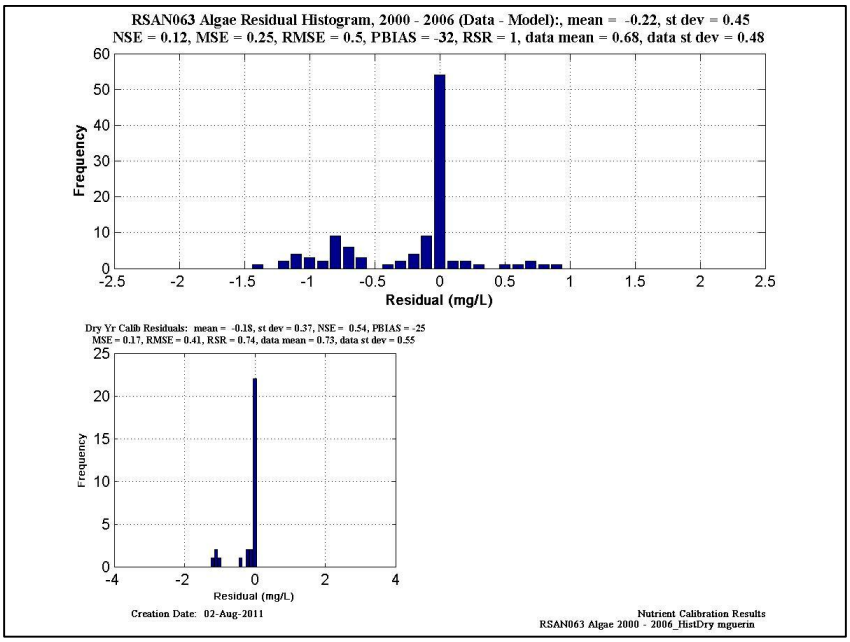


Figure 28-16 Calibration/validation statistics for Algae at Roe Island. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.



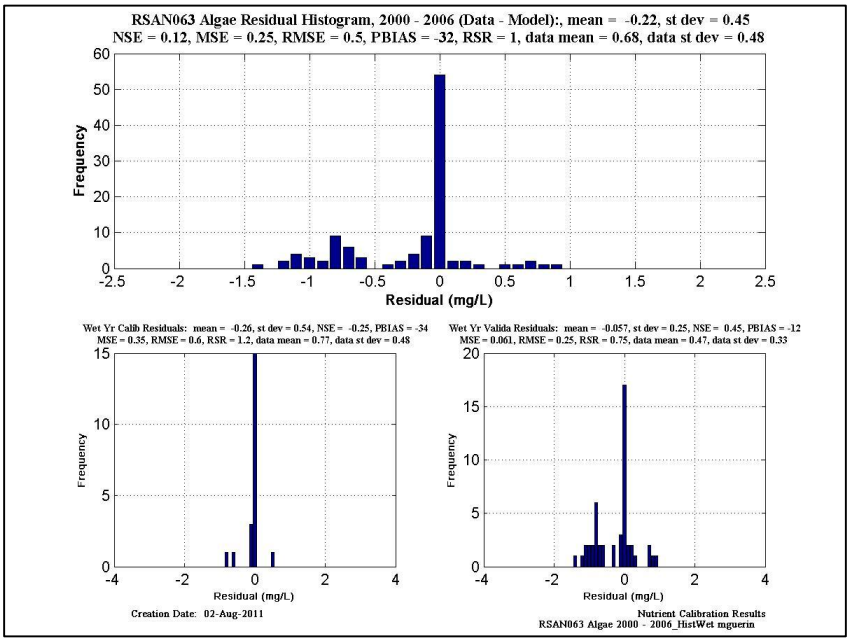


Figure 28-17 Calibration/validation statistics for Algae at Stockton-RSAN063. Upper figure is calibration & validation statistics for dry years, Validation for Dry Years (2007, 2008) is missing due to lack of data; lower figure is calibration & validation statistics for wet years.

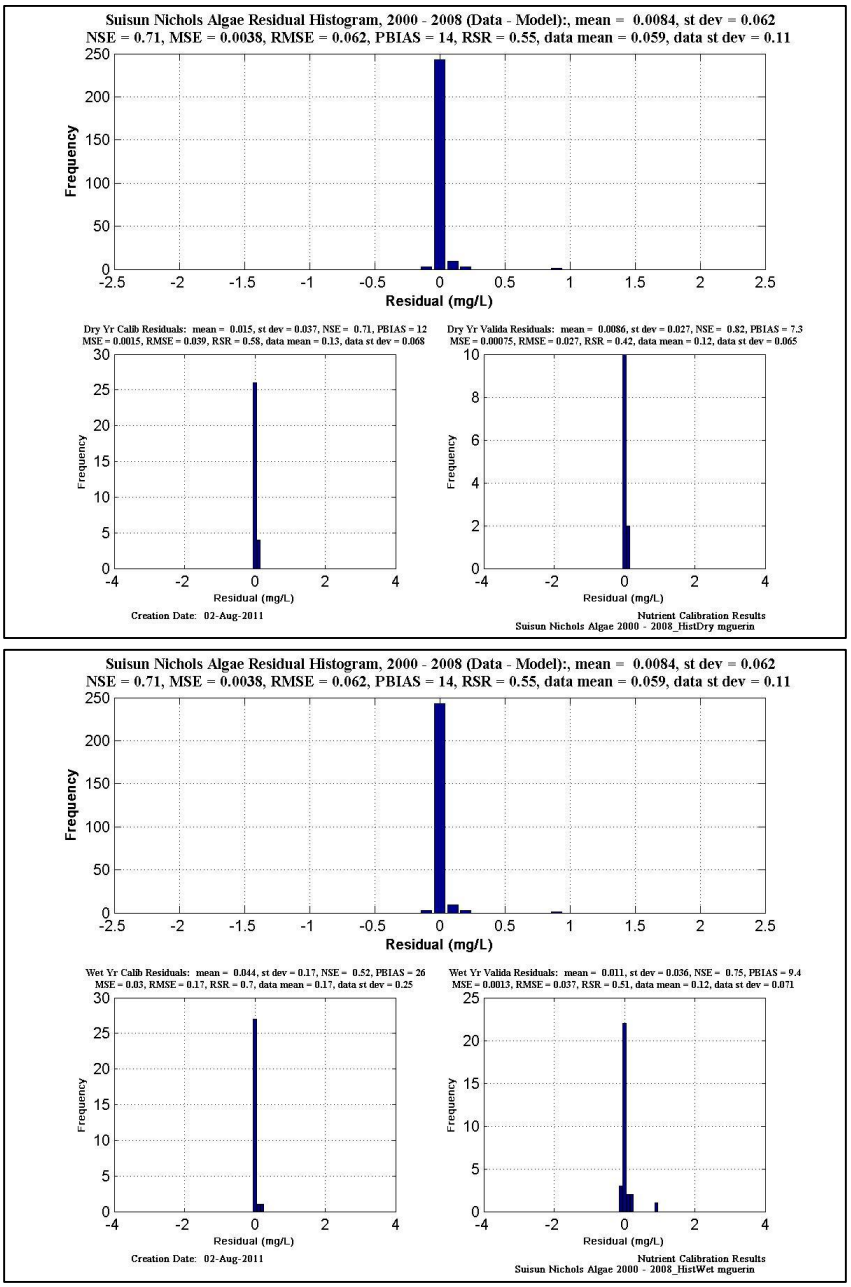


Figure 28-18 Calibration/validation statistics for Suisun-Nichols. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

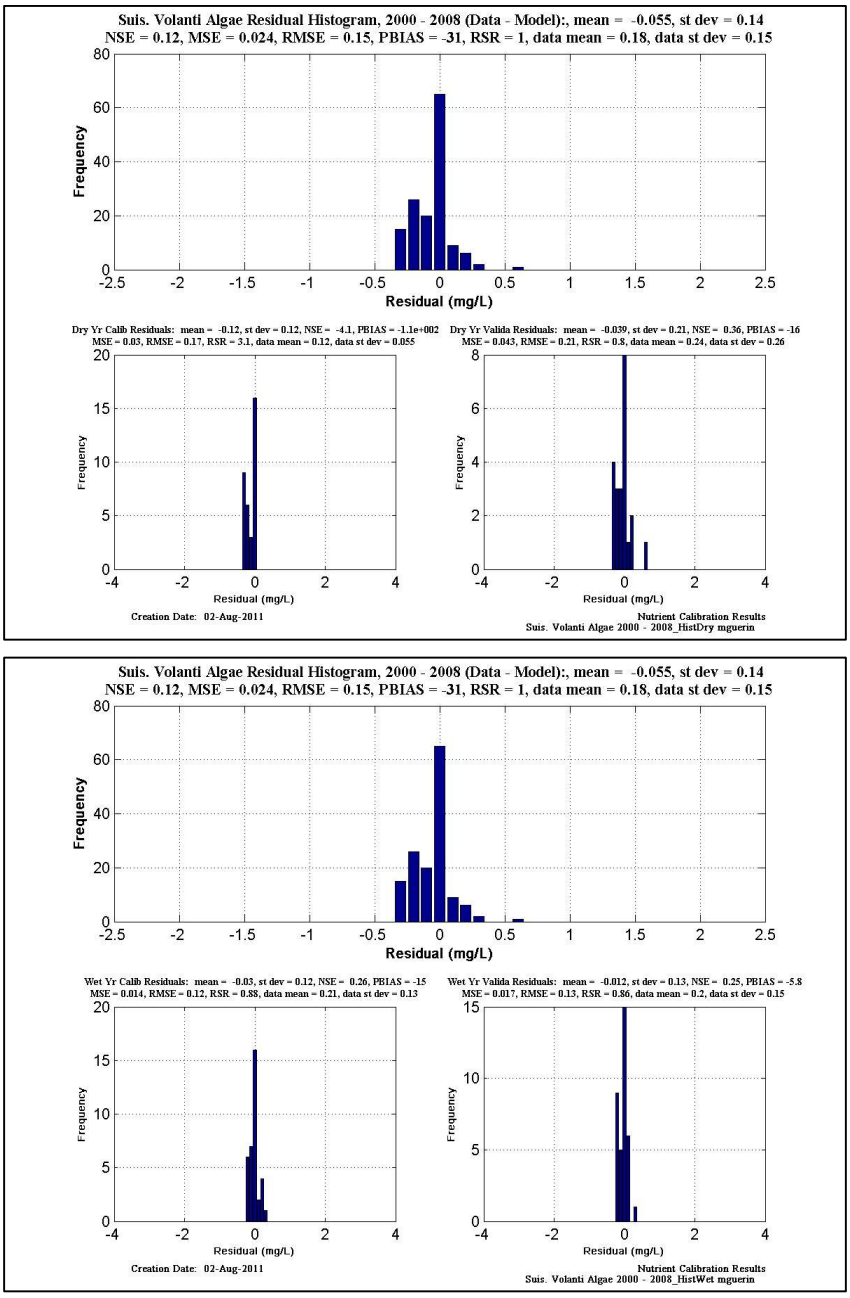
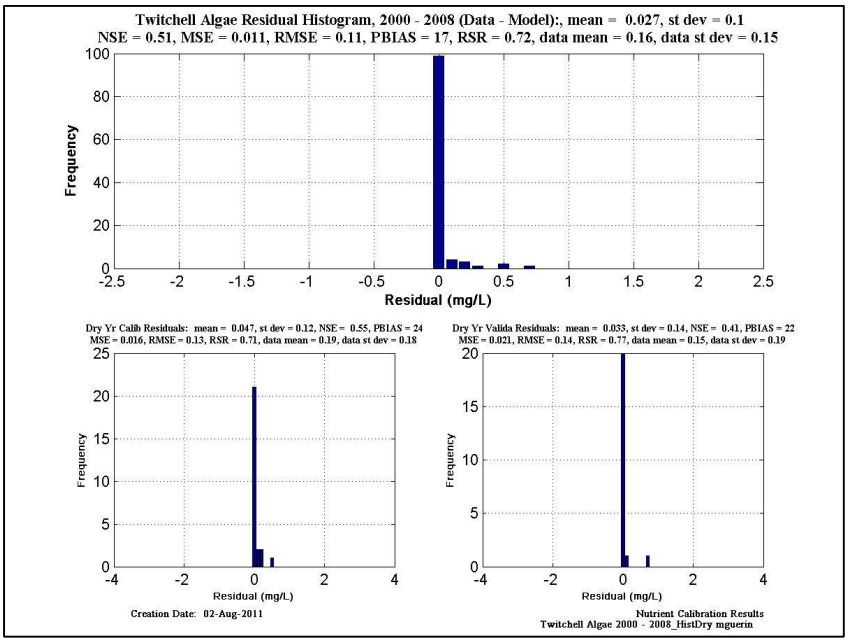


Figure 28-19 Calibration/validation statistics for Algae at Suisun-Volanti. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.



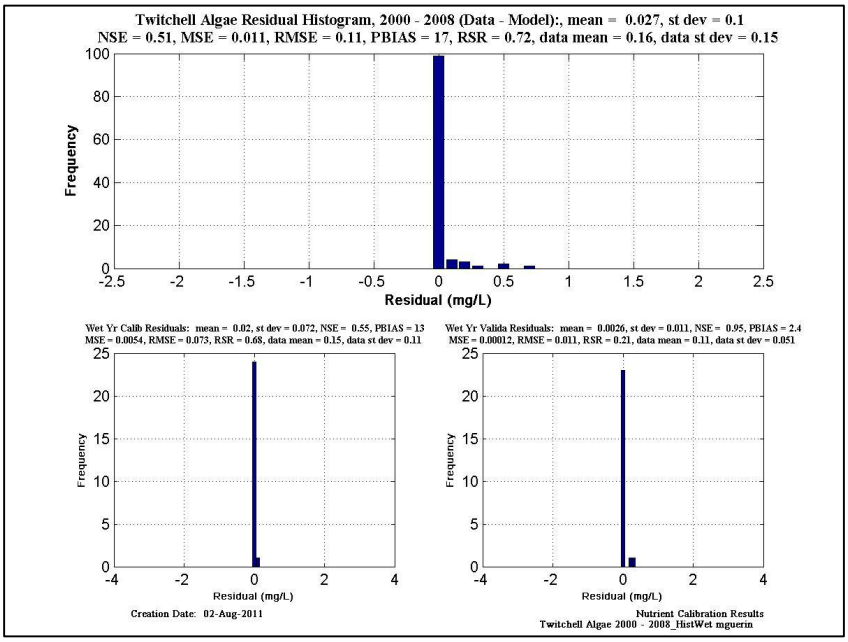


Figure 28-20 Calibration/validation statistics for Algae at Twitchell. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

Figure 28-21 (intentionally left blank) Insufficient data to calculate calibration statistics for Russo.

28.2 Dissolved Oxygen

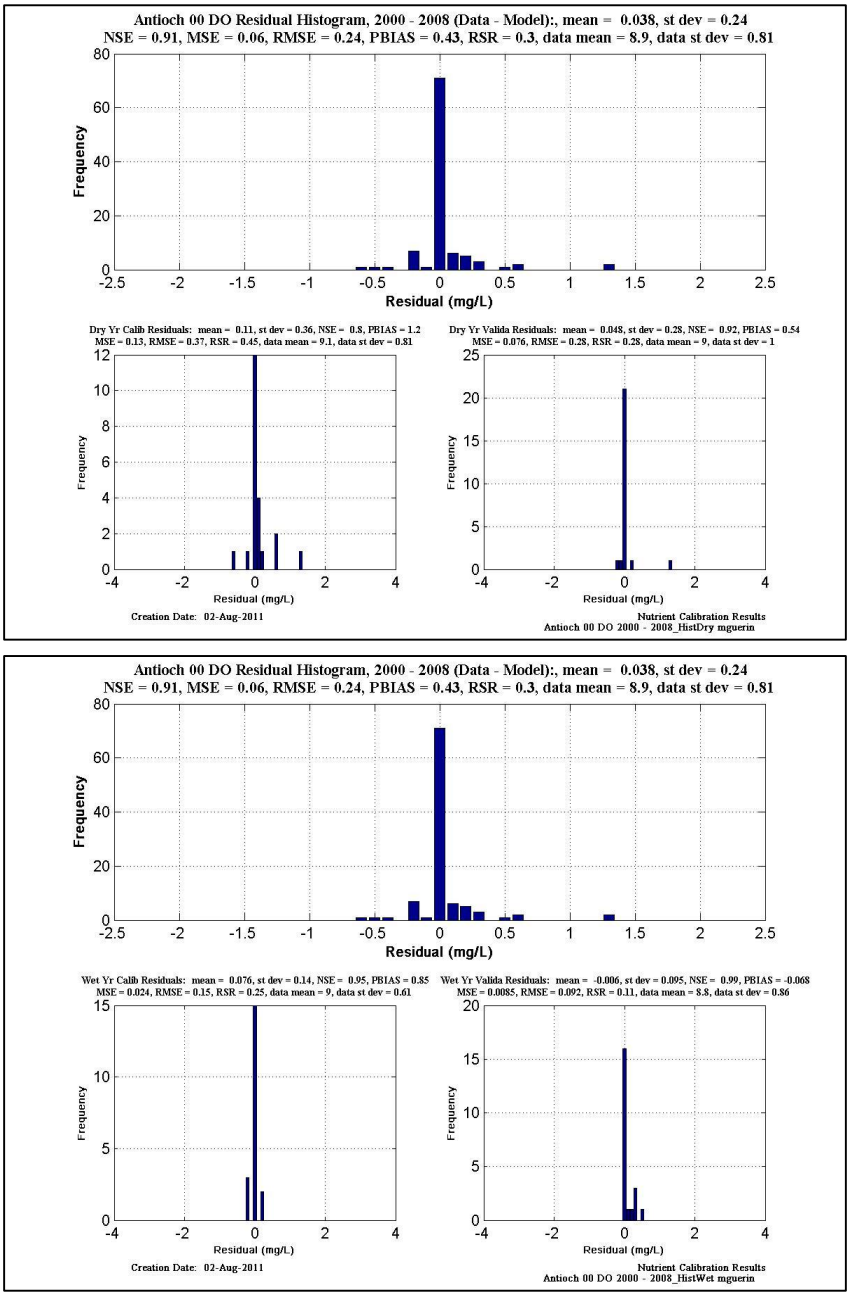


Figure 28-22 Calibration/validation statistics for DO at Antioch. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

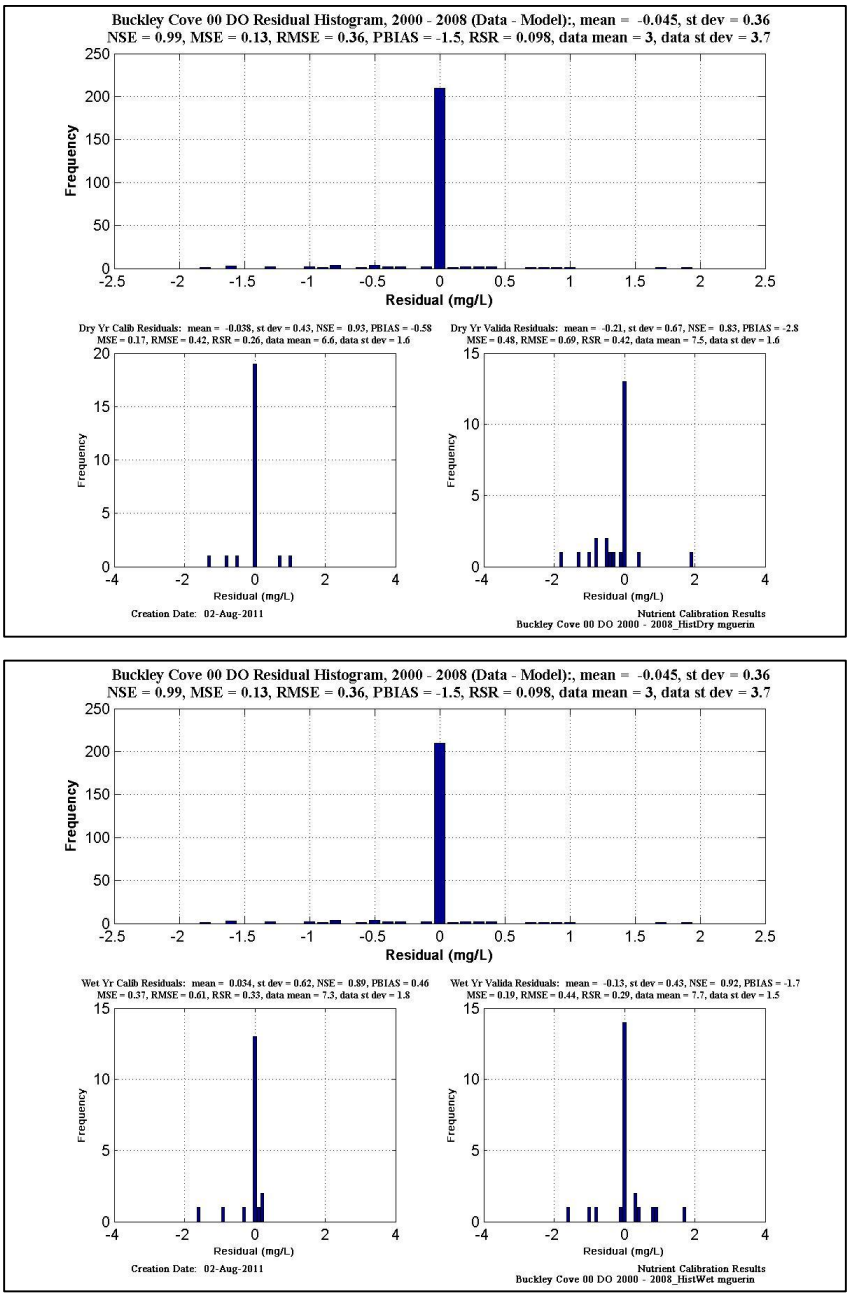


Figure 28-23 Calibration/validation statistics for DO at Buckley Cove. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

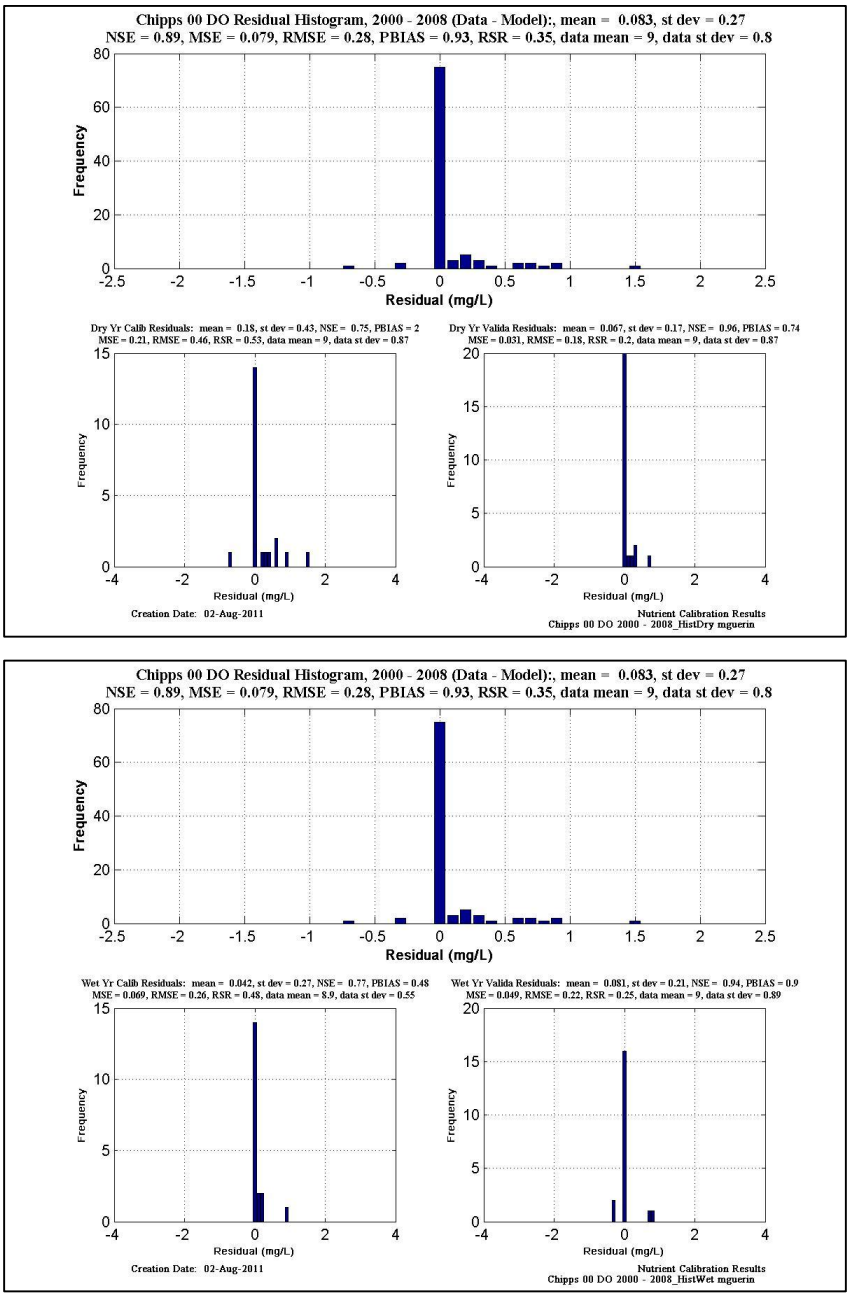


Figure 28-24 Calibration/validation statistics for DO at Chipps. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

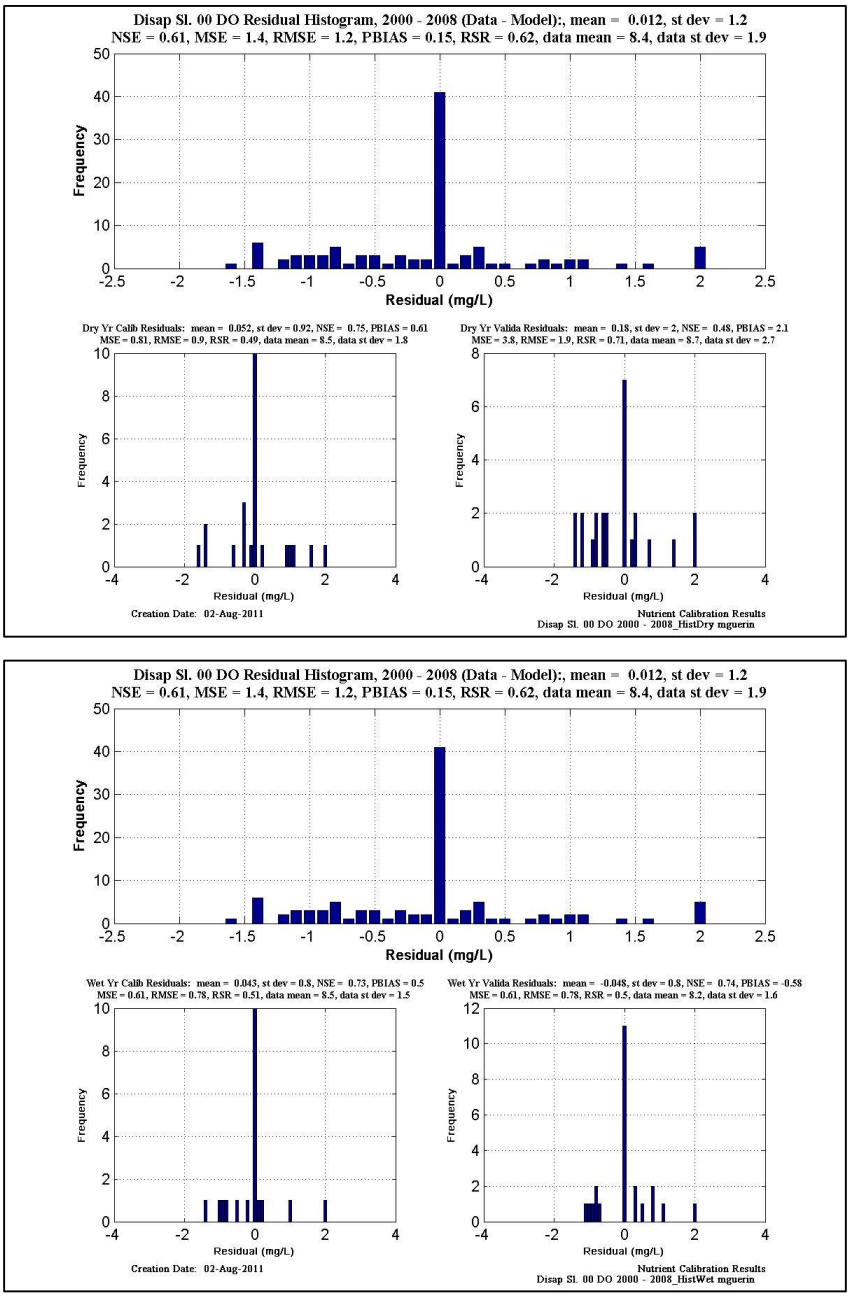


Figure 28-25 Calibration/validation statistics for DO at Disappointment Sl. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

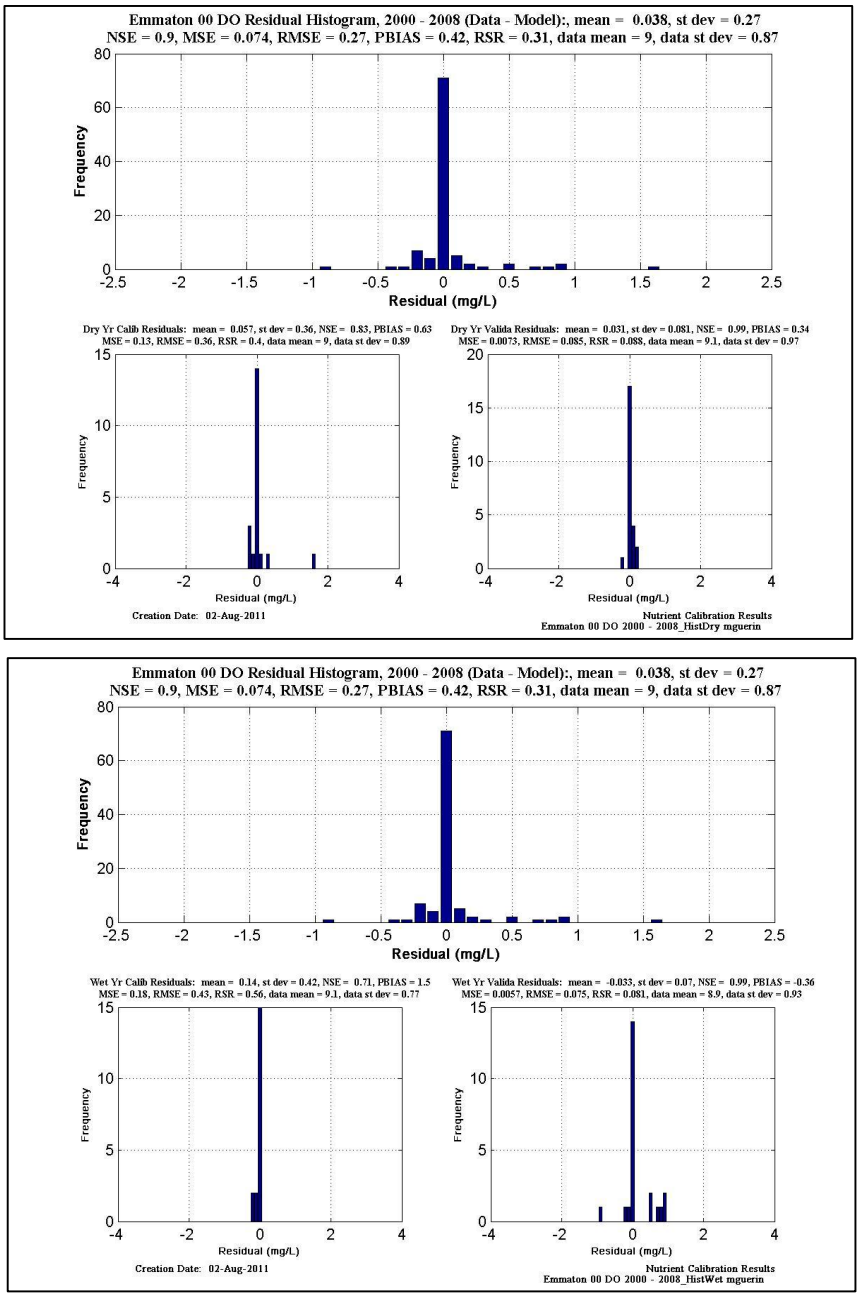


Figure 28-26 Calibration/validation statistics for DO at Emmaton. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

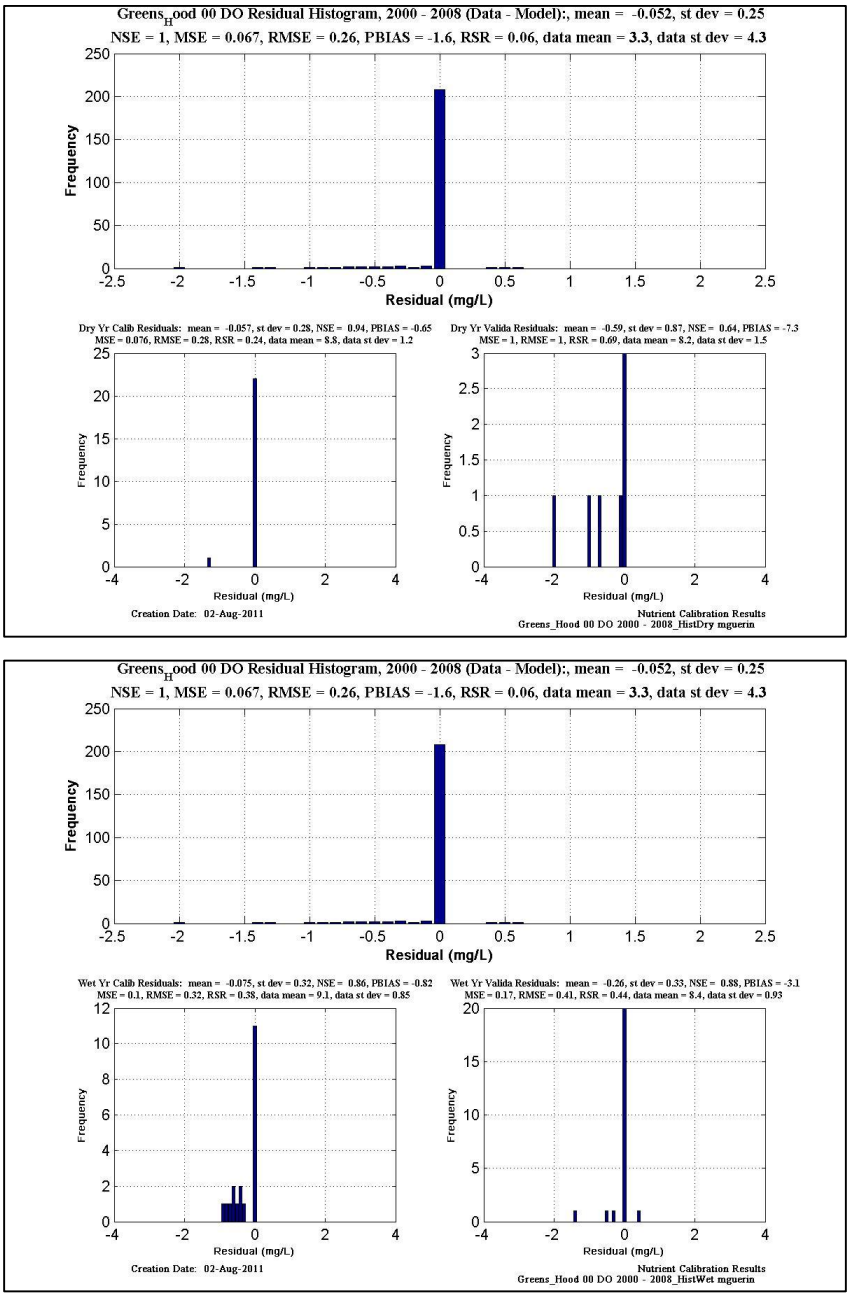


Figure 28-27 Calibration/validation statistics for DO at Greens-Hood. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

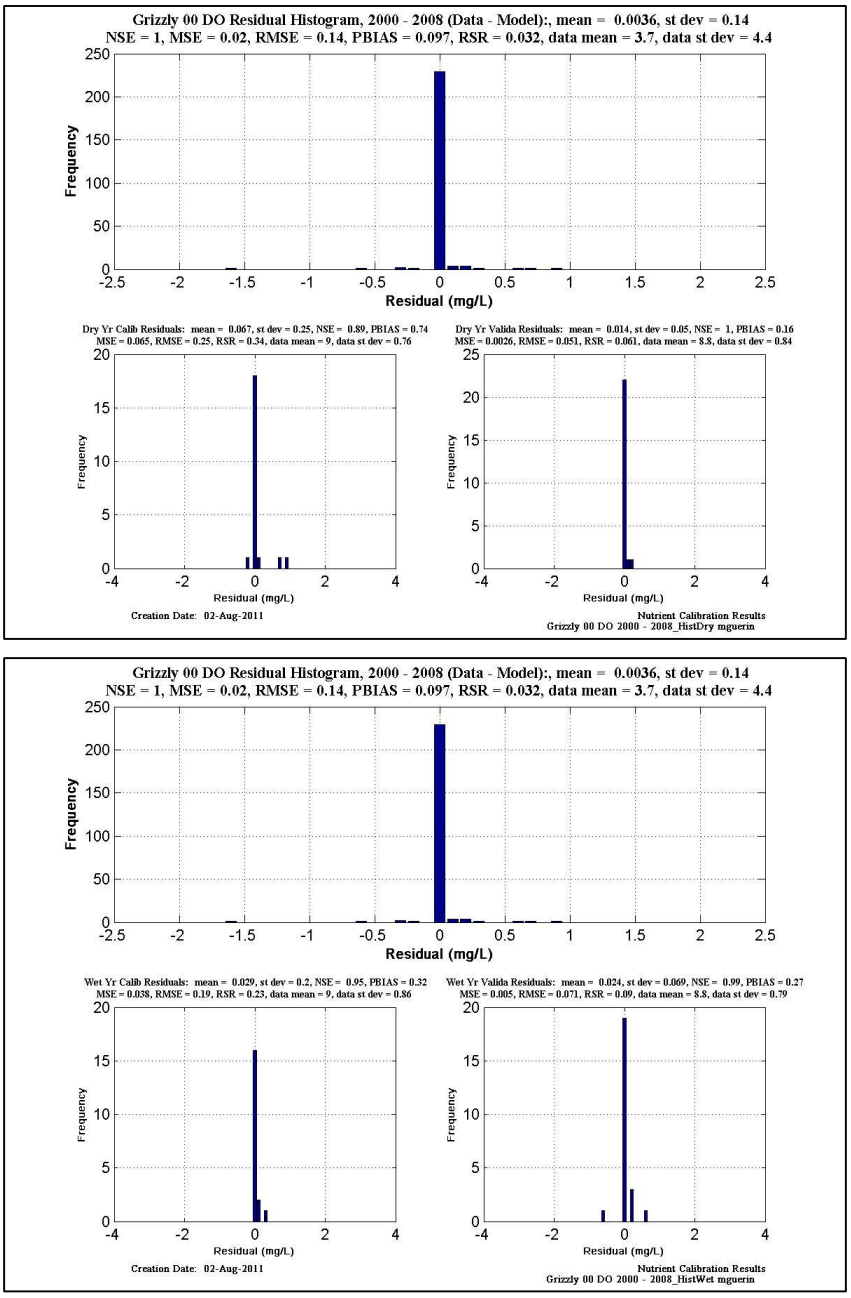


Figure 28-28 Calibration/validation statistics for DO at Grizzly Bay. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

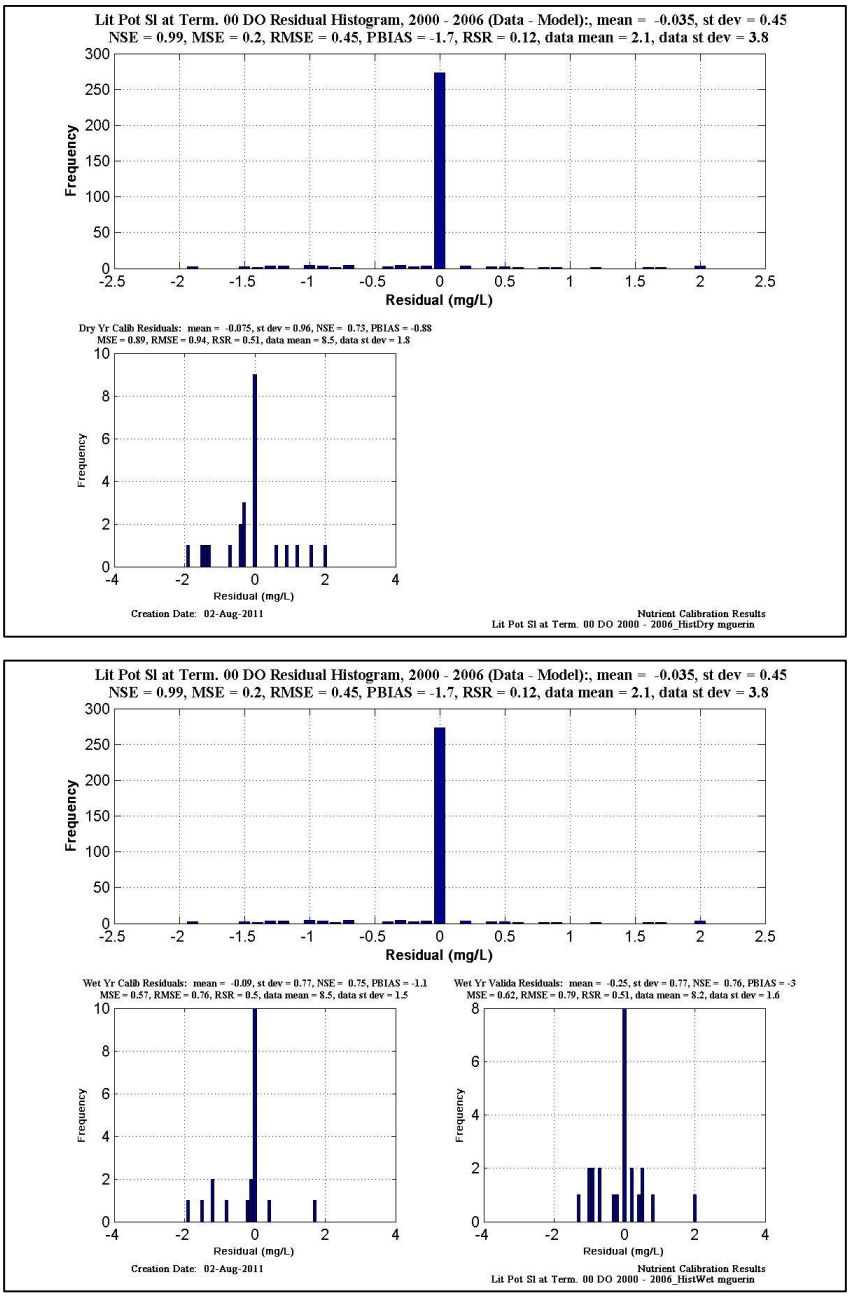


Figure 28-29 Calibration/validation statistics for DO at Little Potato Sl. at Terminous. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years. Validation for Dry Years missing due to lack of data.

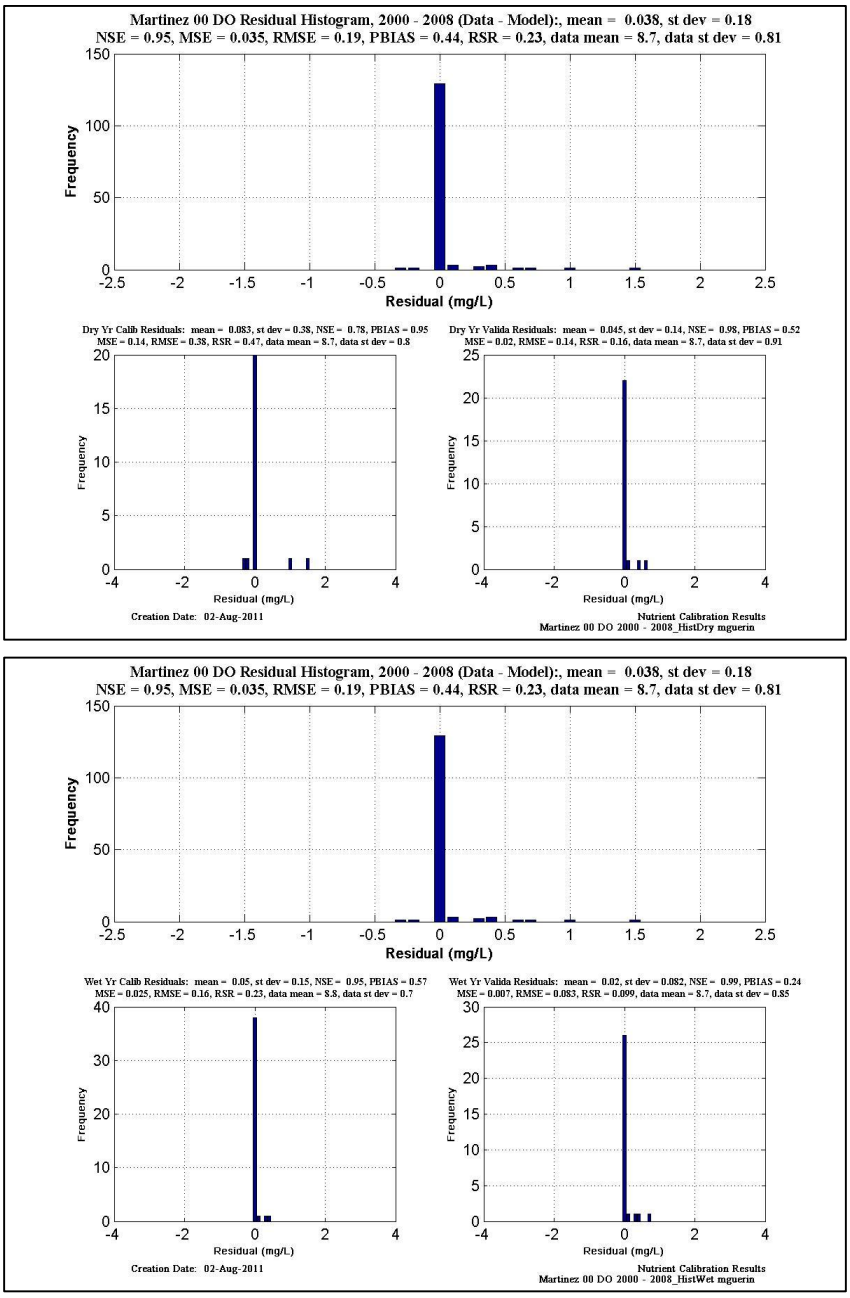


Figure 28-30 Calibration/validation statistics for DO at Martinez. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

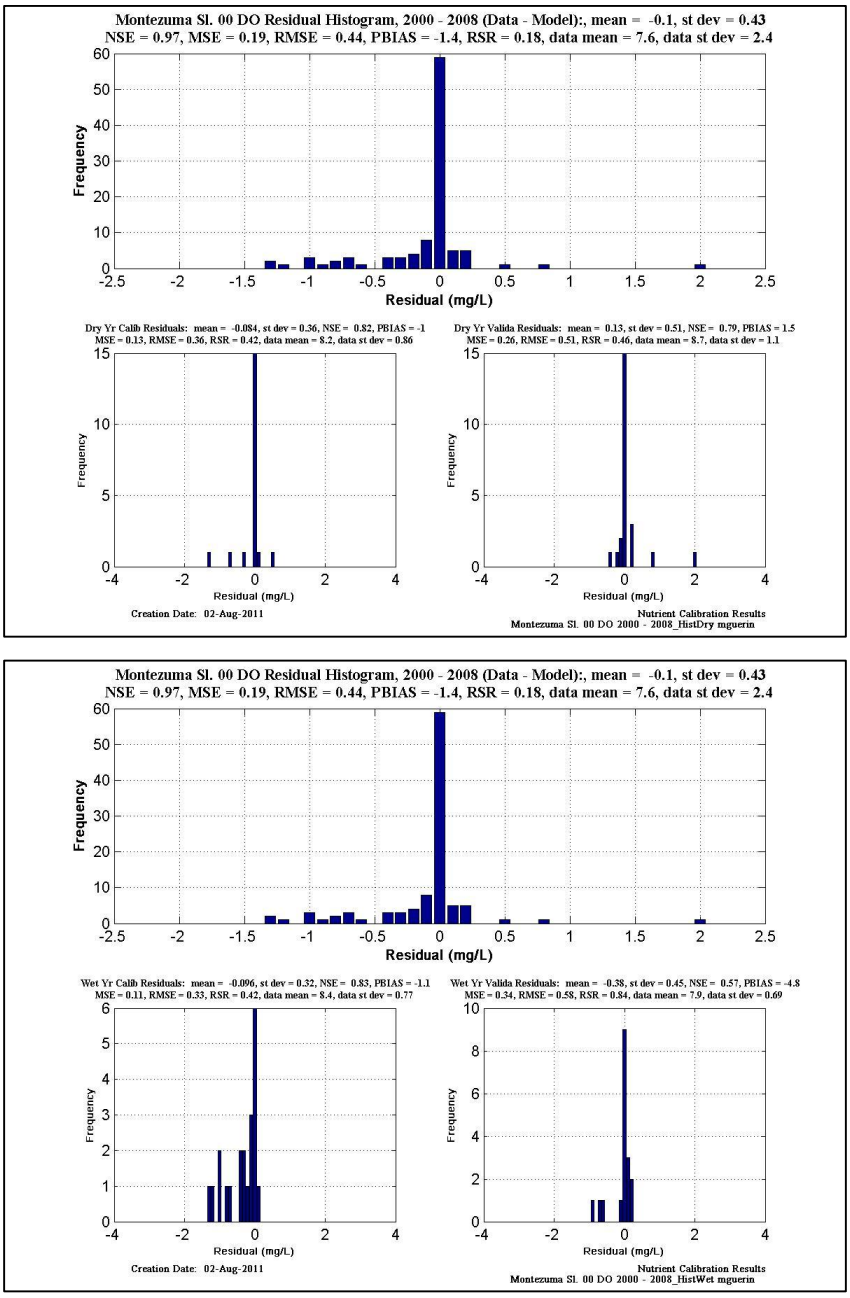


Figure 28-31 Calibration/validation statistics for DO at Montezuma Sl. Bend 2. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

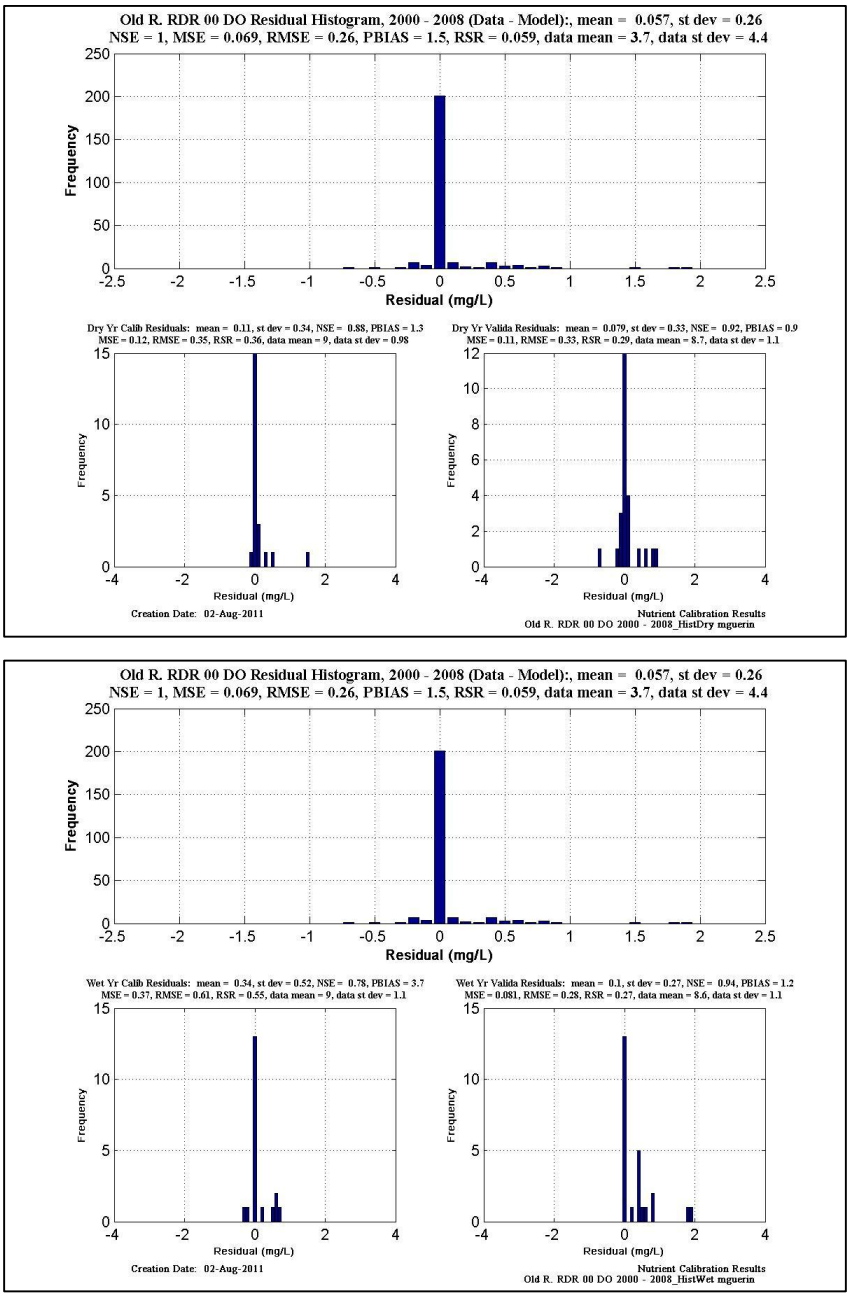


Figure 28-32 Calibration/validation statistics for DO at Old R. Rancho Del Rio. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

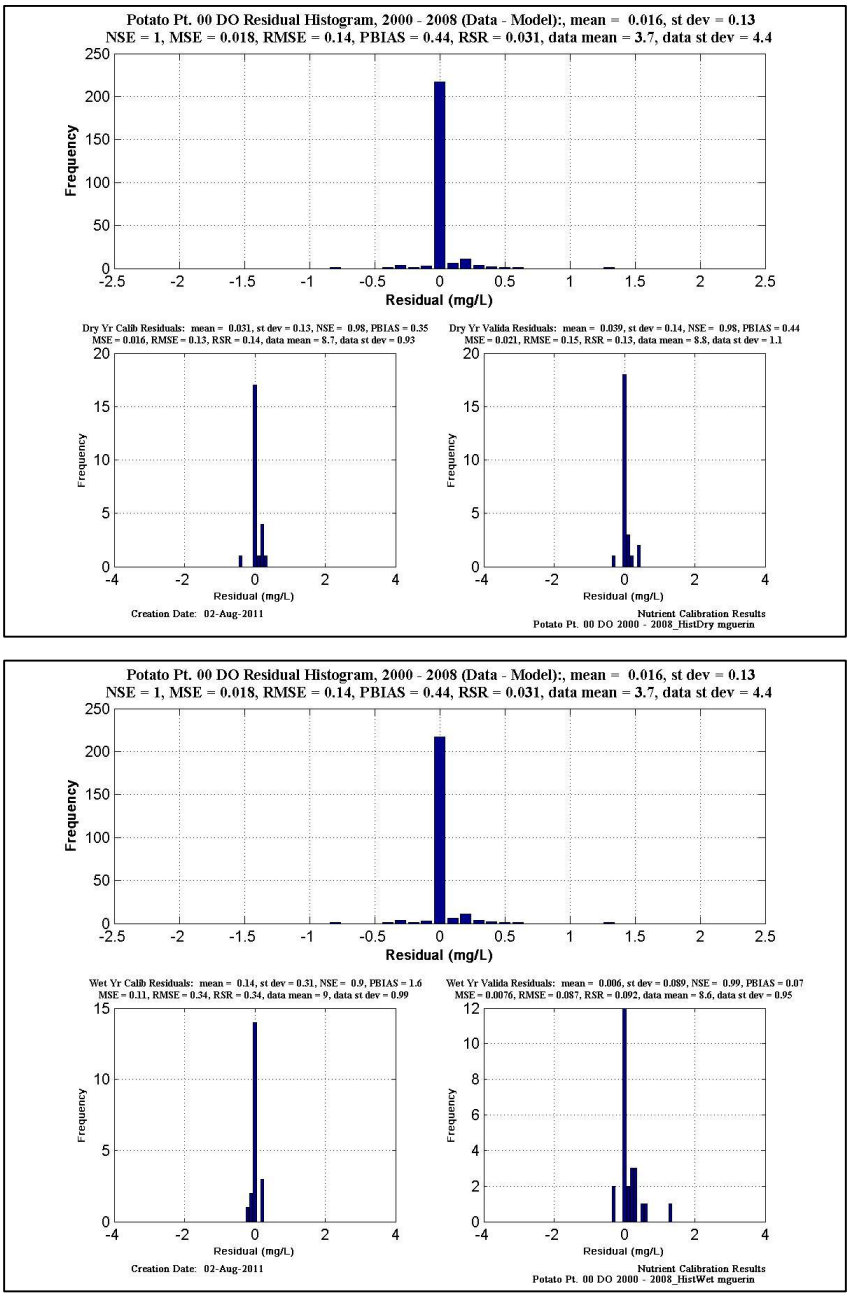


Figure 28-33 Calibration/validation statistics for DO at Potato Pt. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

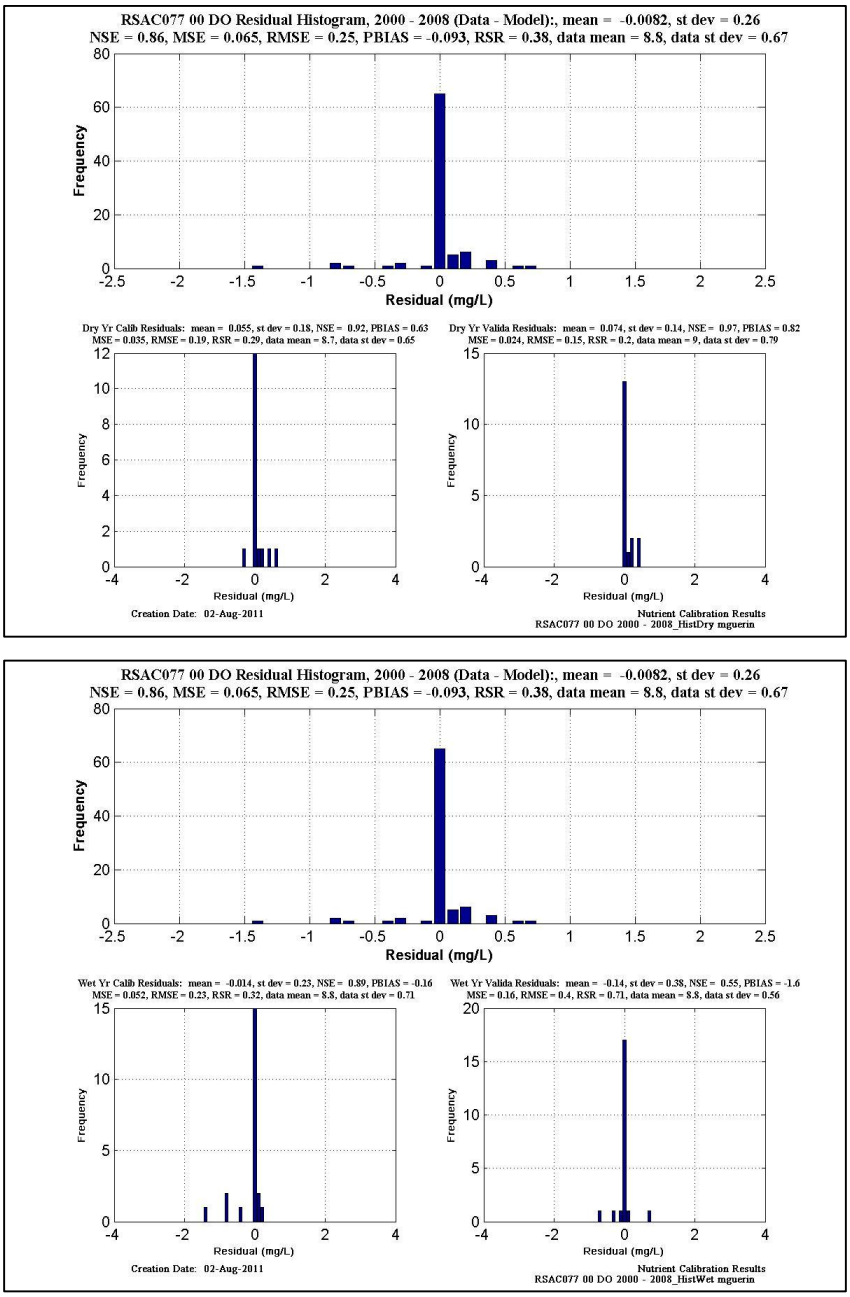


Figure 28-34 Calibration/validation statistics for DO at Pittsburg-RSAC077. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

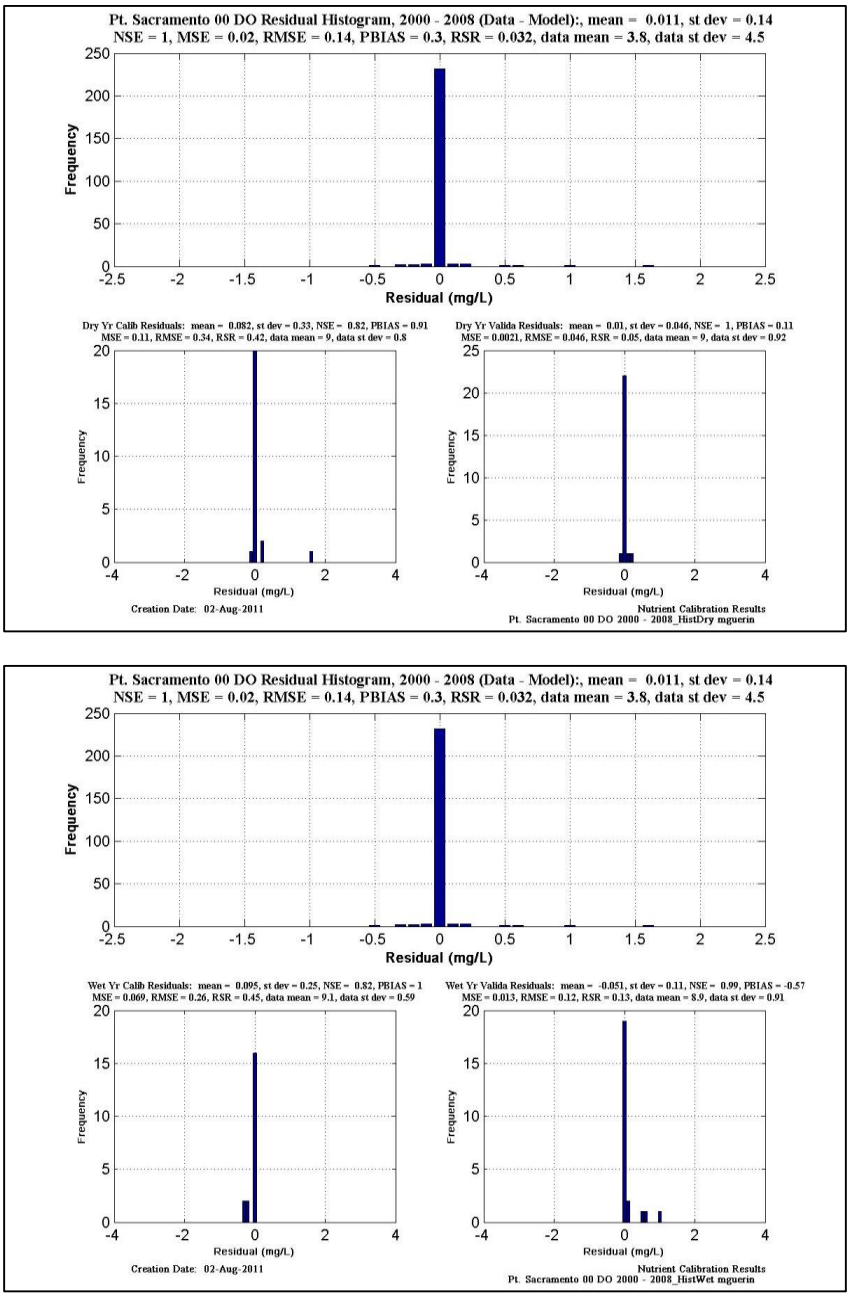


Figure 28-35 Calibration/validation statistics for DO at Pt. Sacramento. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

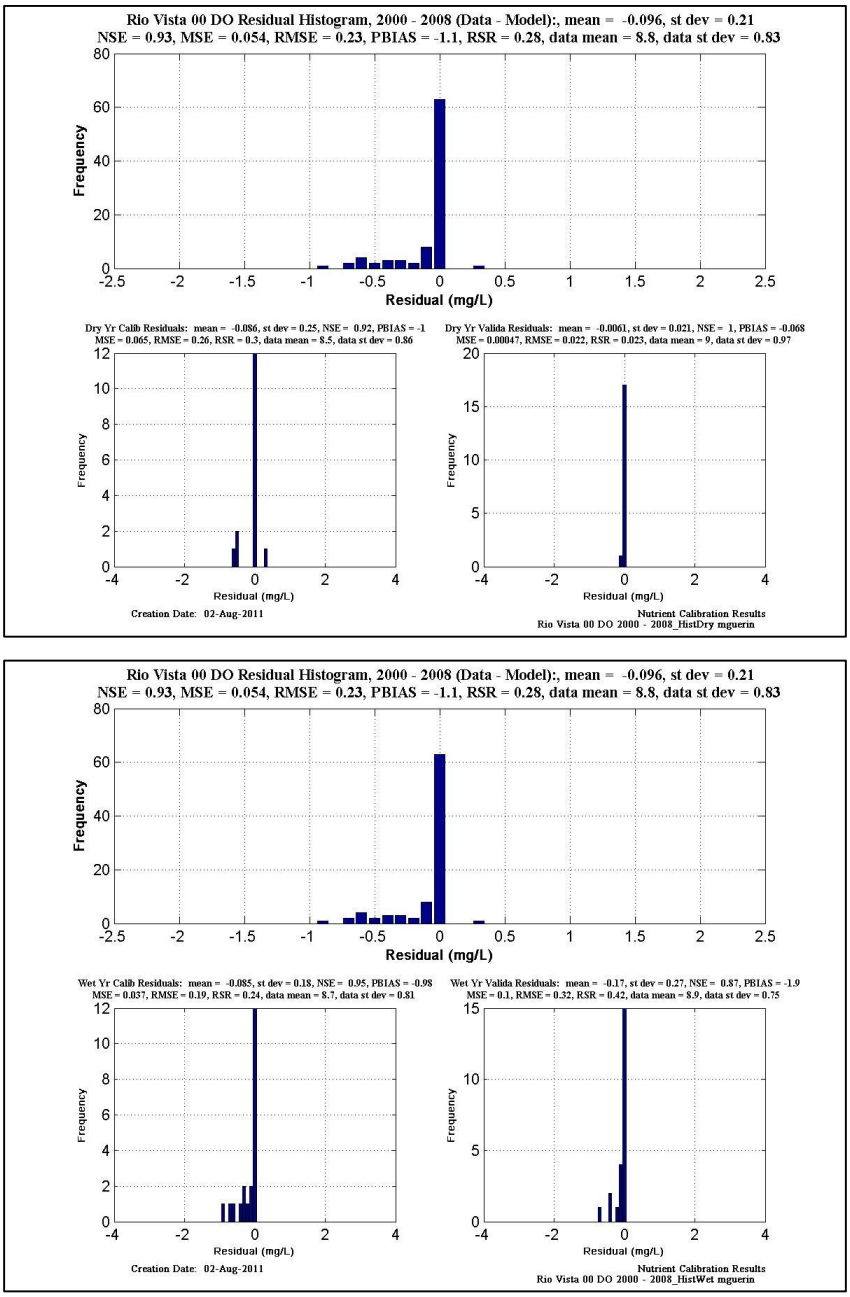


Figure 28-36 Calibration/validation statistics for DO at Rio Vista. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

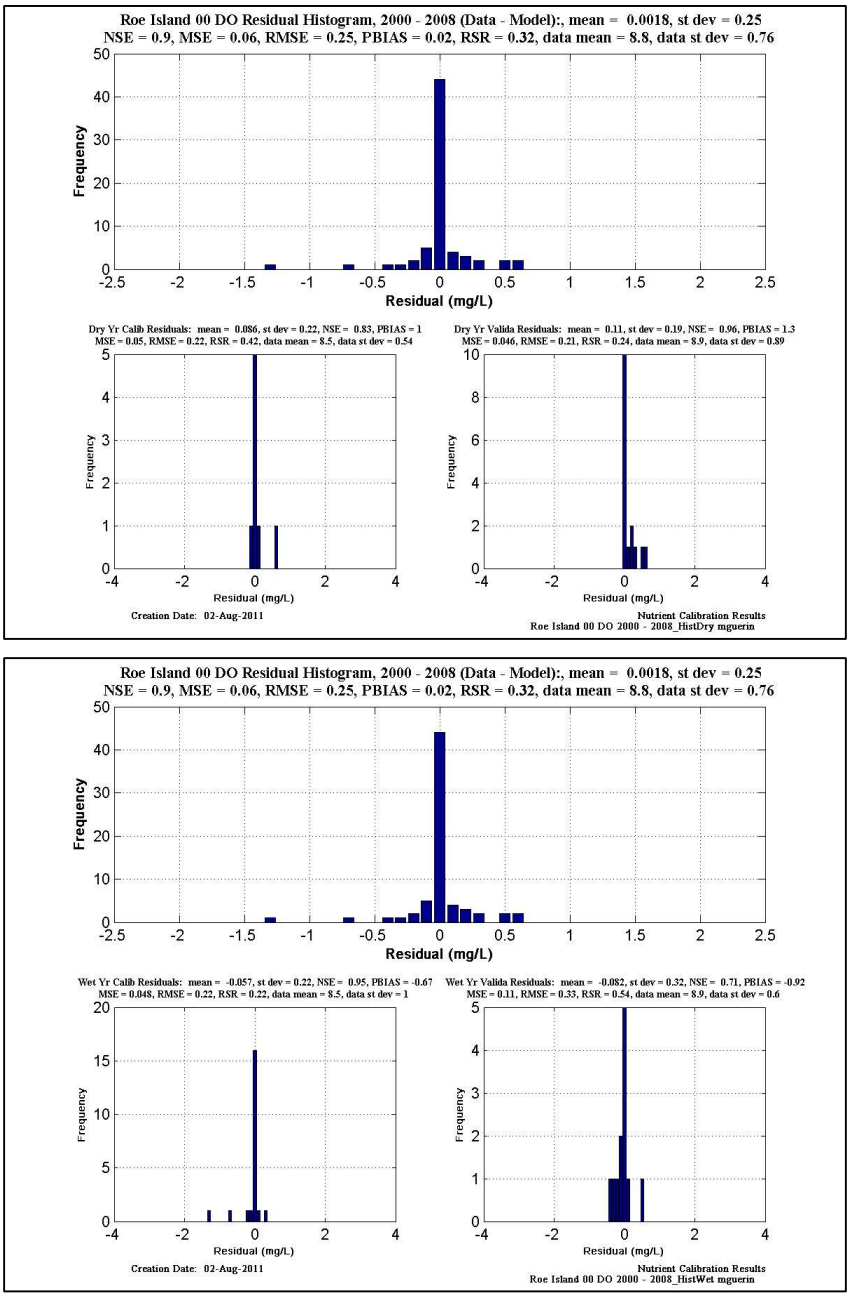


Figure 28-37 Calibration/validation statistics for DO at Roe Island. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

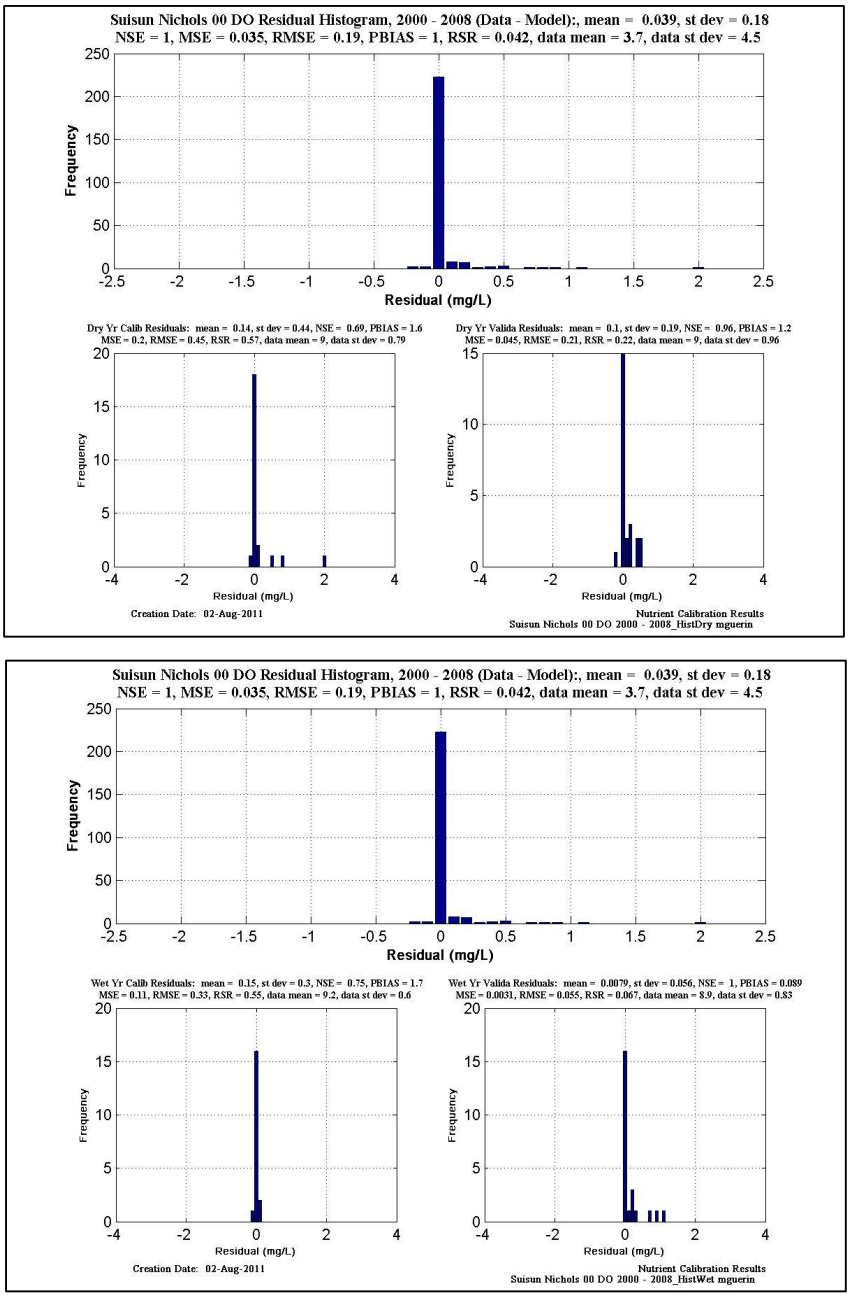


Figure 28-38 Calibration/validation statistics for DO at Suisun-Nichols. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

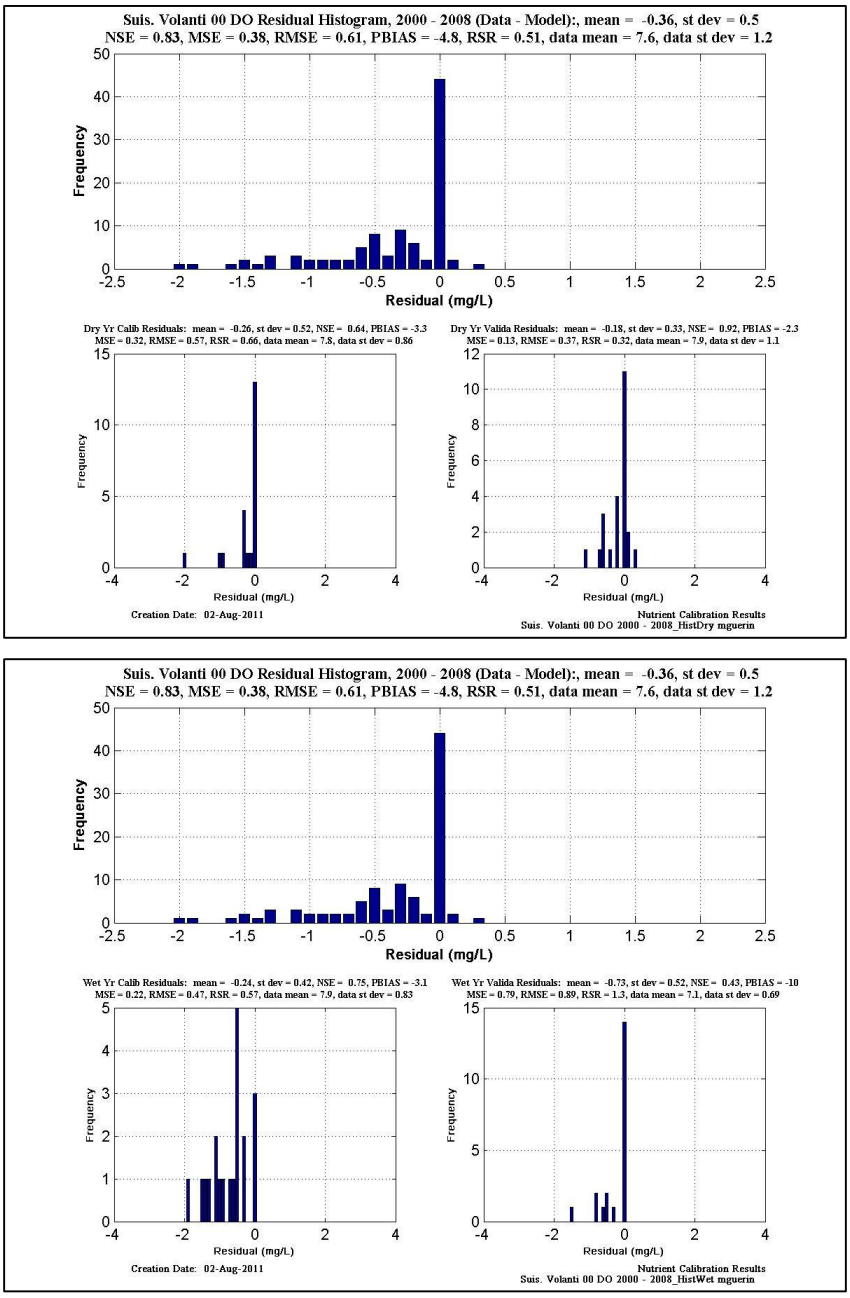


Figure 28-39 Calibration/validation statistics for DO at Suisun-Volanti. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

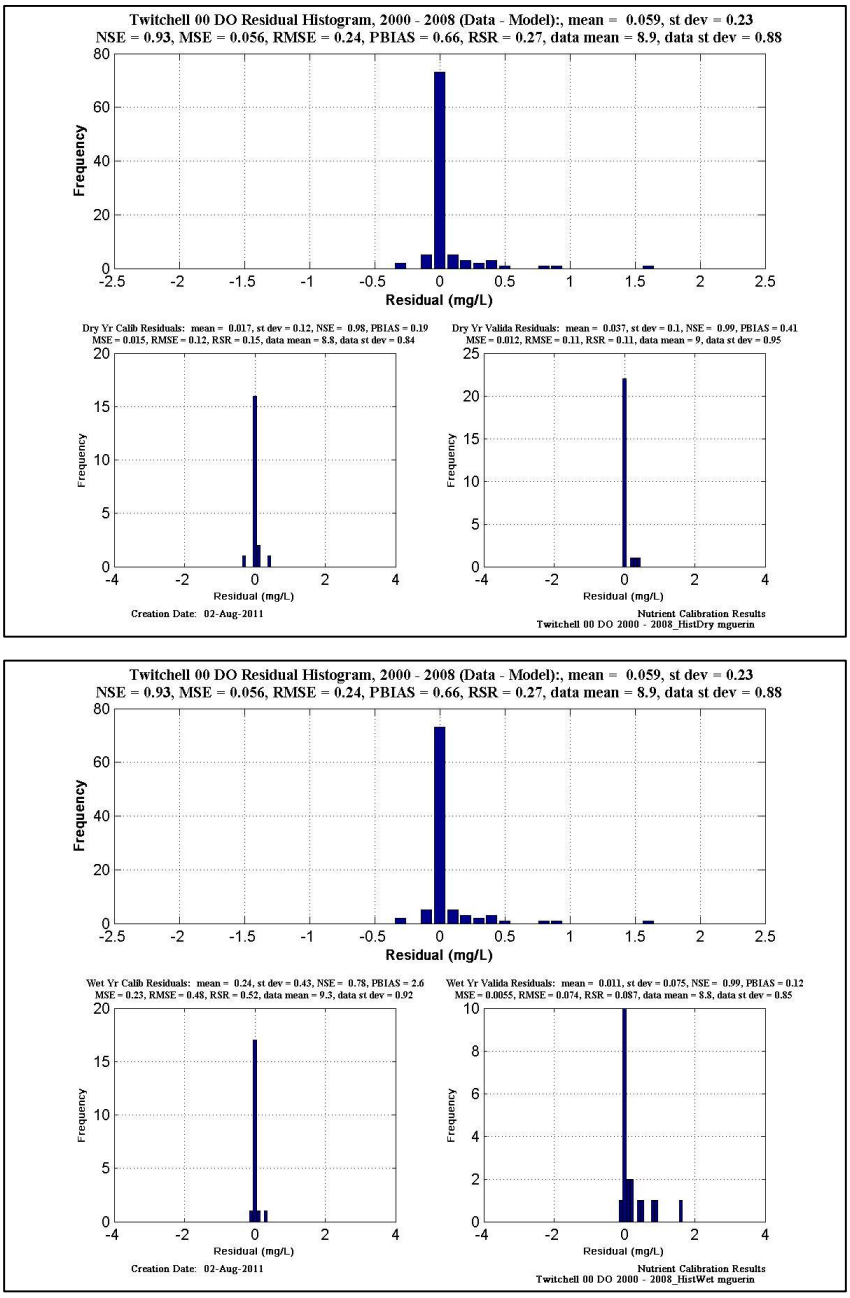


Figure 28-40 Calibration/validation statistics for DO at Twitchell. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

Figure 28-41 (Intentionally left blank) Insufficient data at Russo to calculate calibration statistics.

28.3 NH3

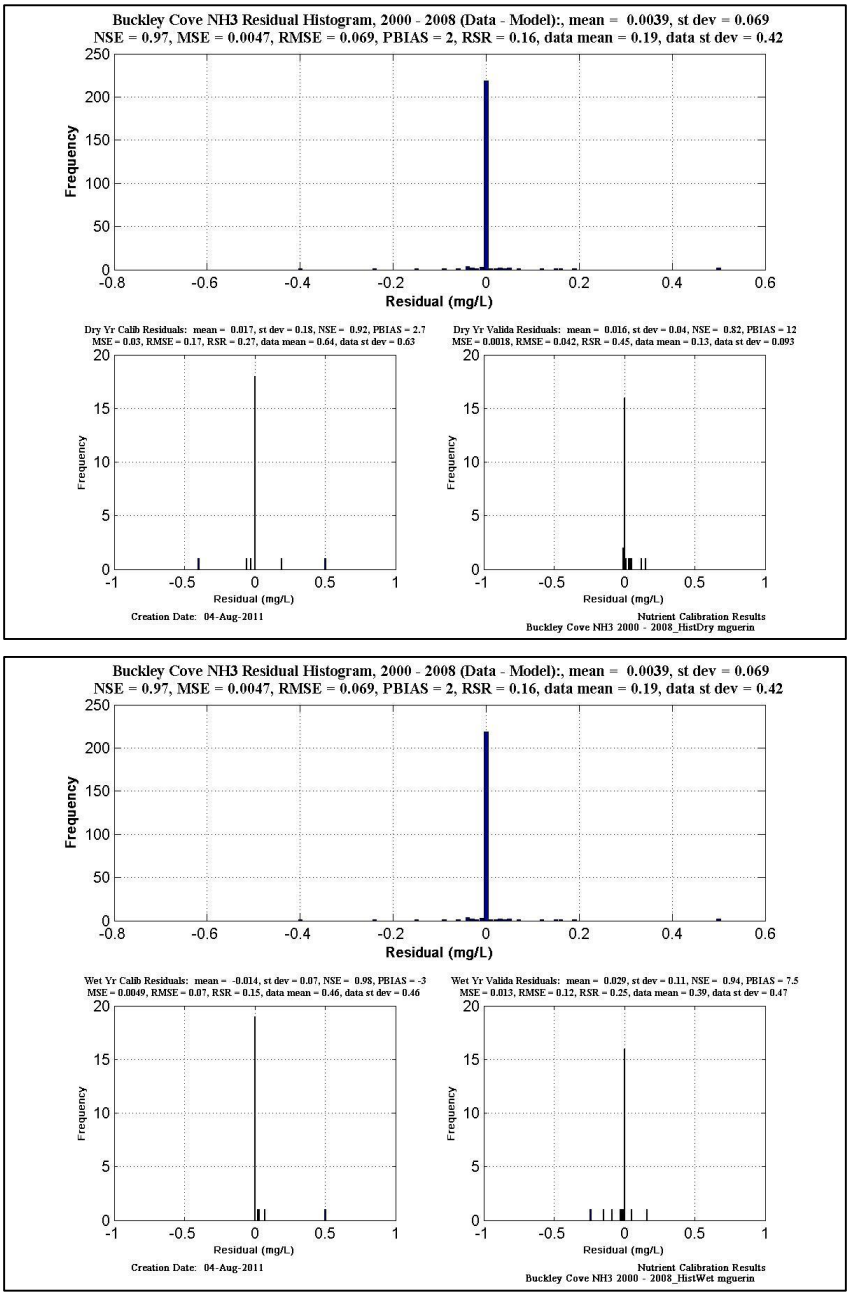


Figure 28-42 Calibration/validation statistics for NH3 at Buckley Cove. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

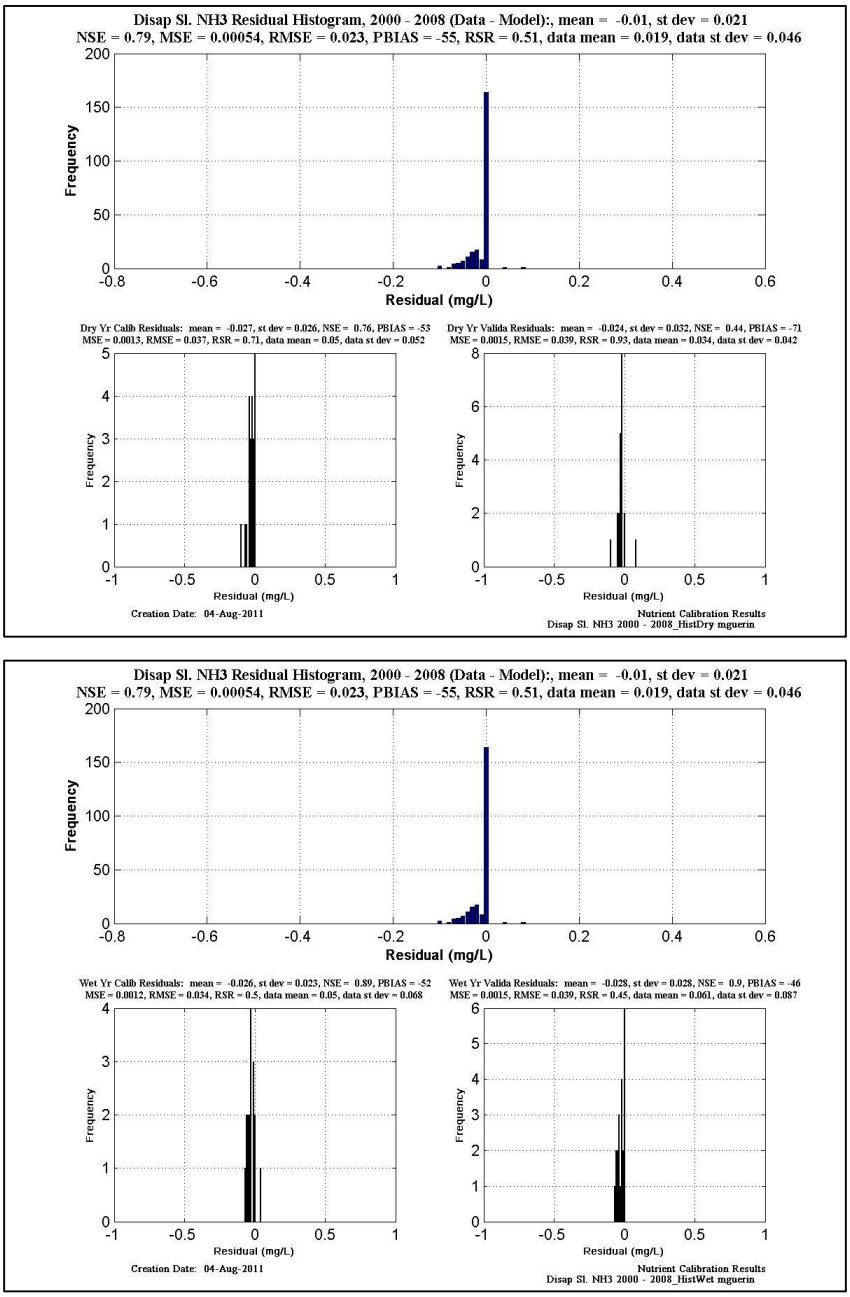
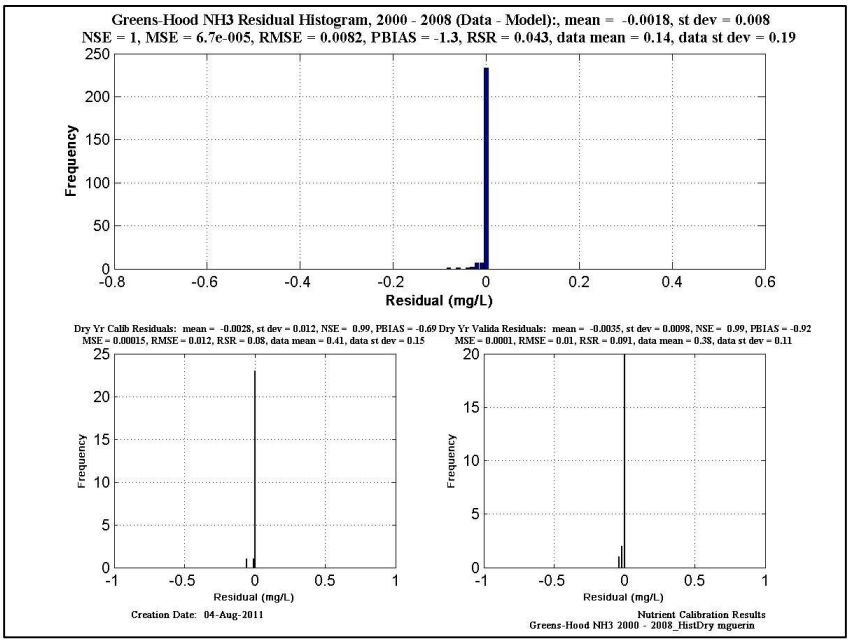


Figure 28-43 Calibration/validation statistics for NH3 at Disappointment Sl. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.



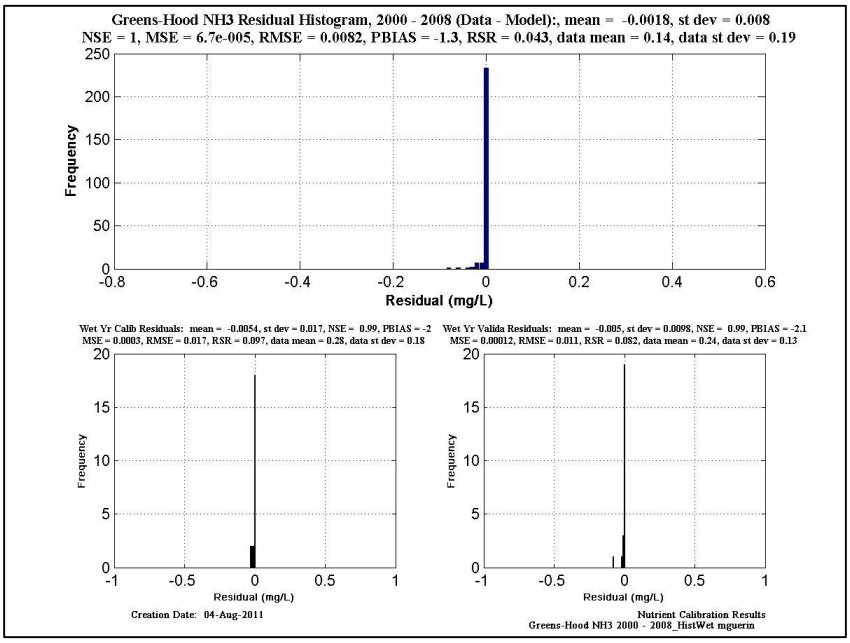


Figure 28-44 Calibration/validation statistics for NH3 at Greens-Hood. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

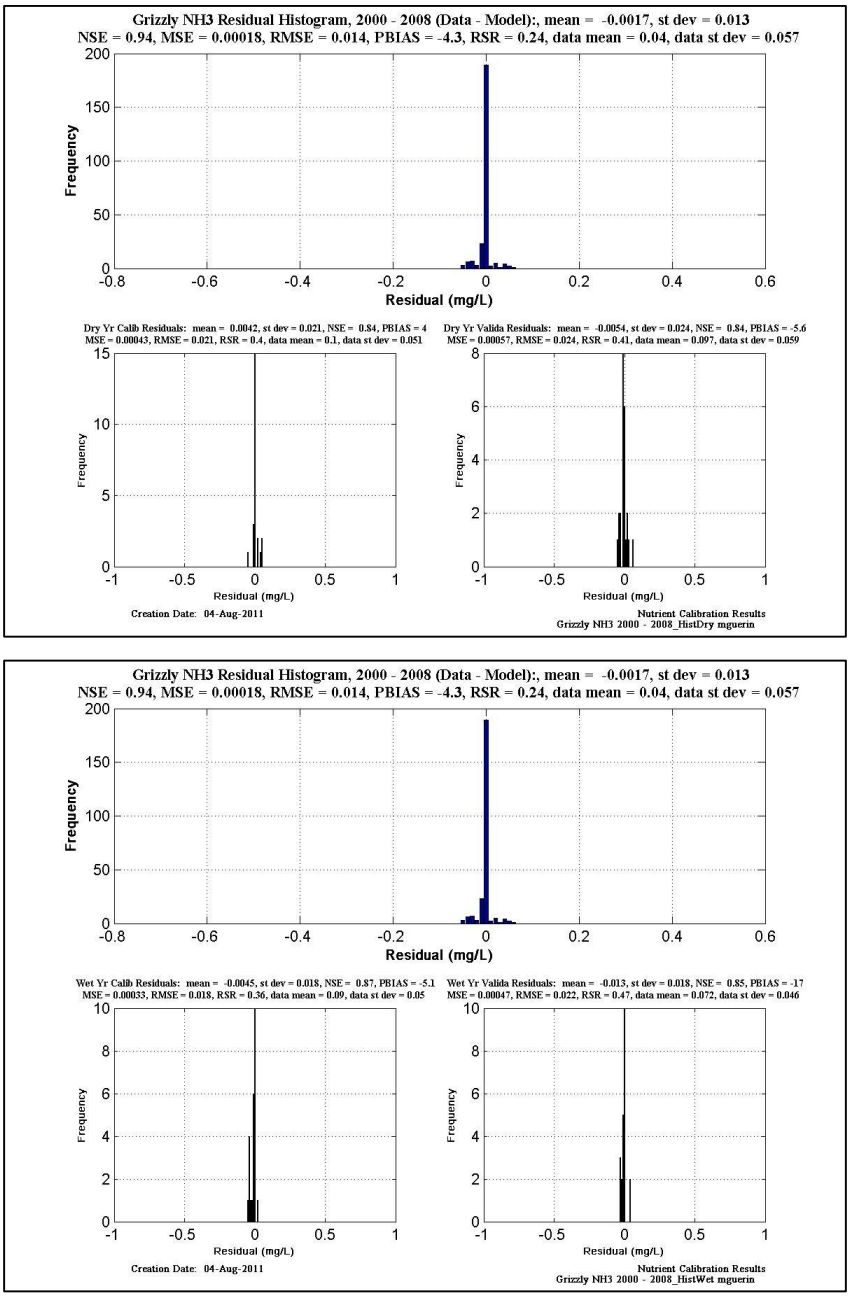


Figure 28-45 Calibration/validation statistics for NH3 at Grizzly Bay. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

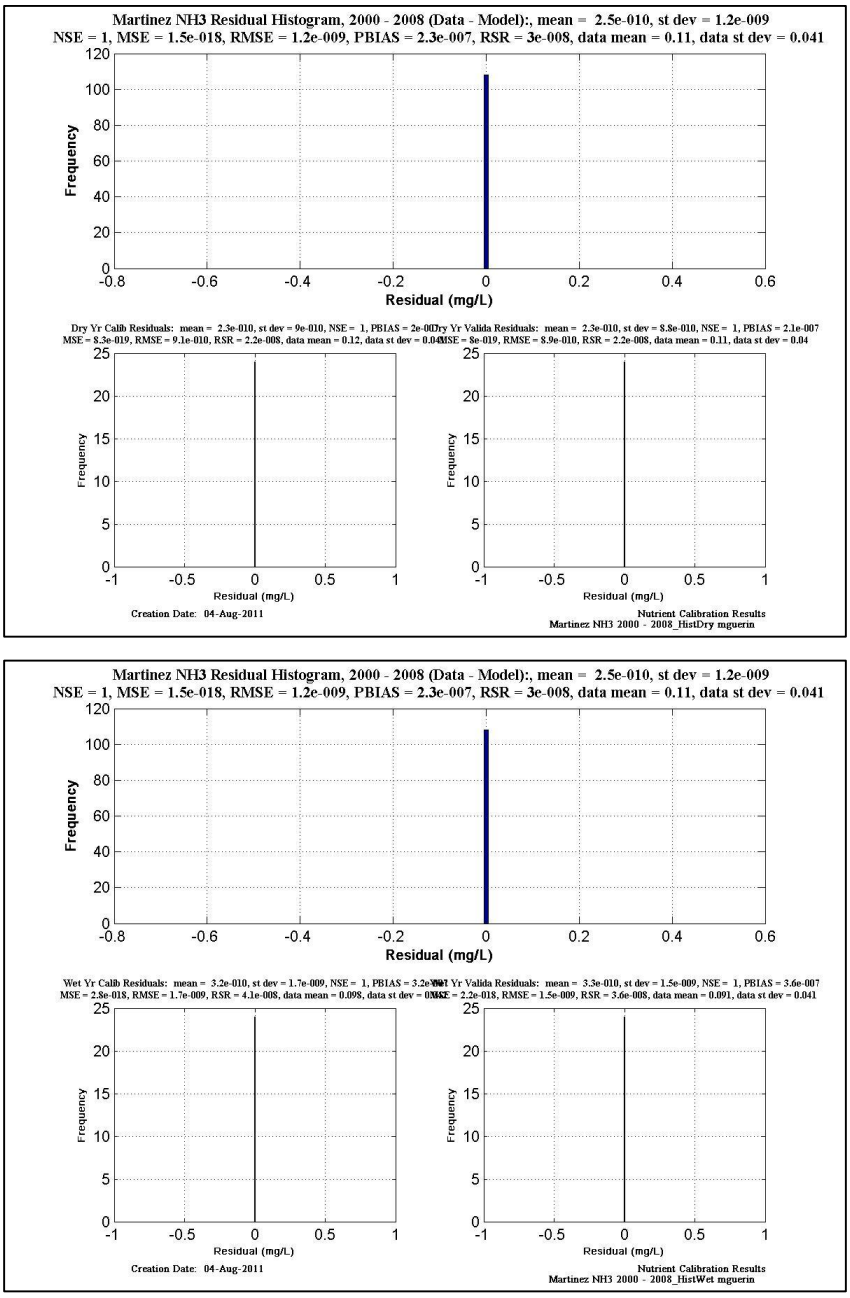


Figure 28-46 Calibration/validation statistics for NH3 at Martinez. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

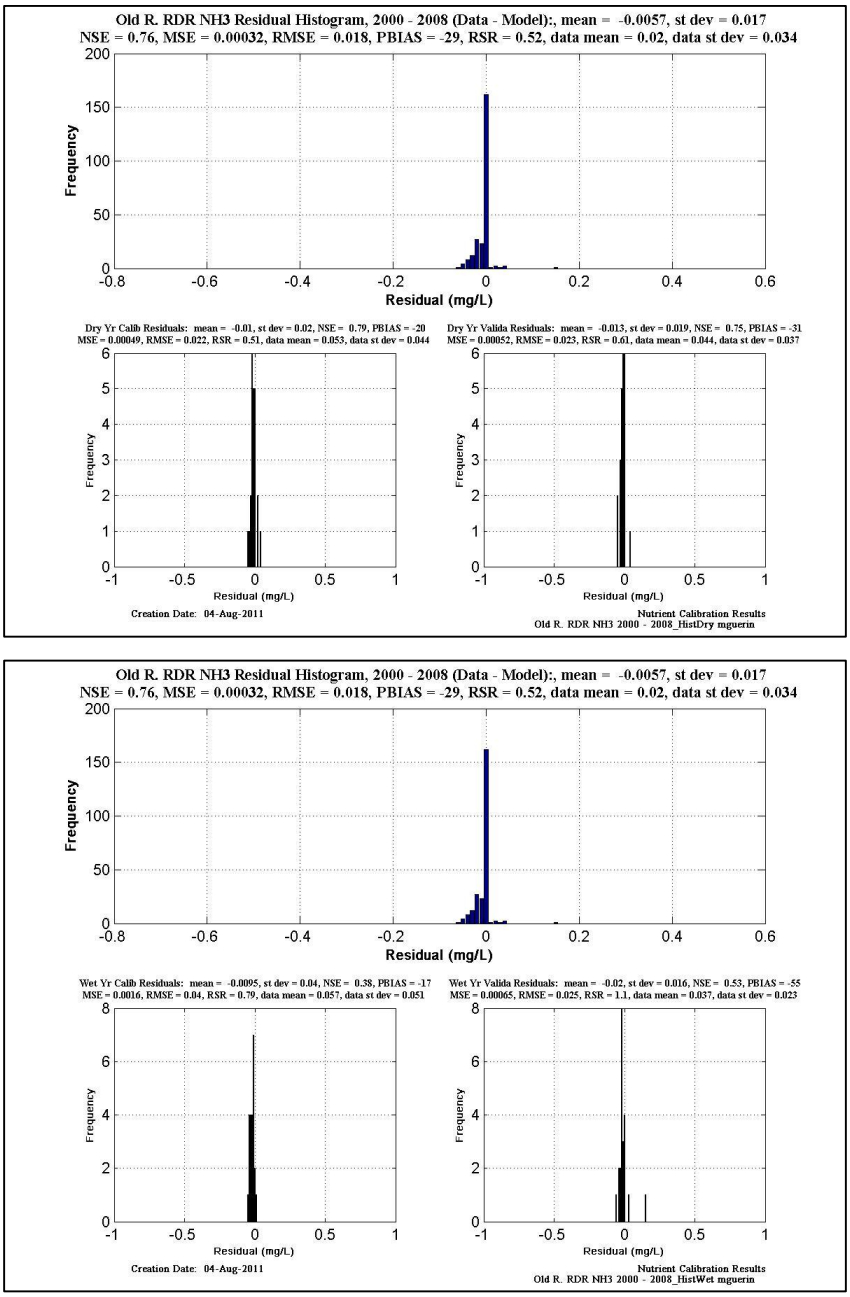


Figure 28-47 Calibration/validation statistics for NH3 at Old R. at Rancho Del Rio. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

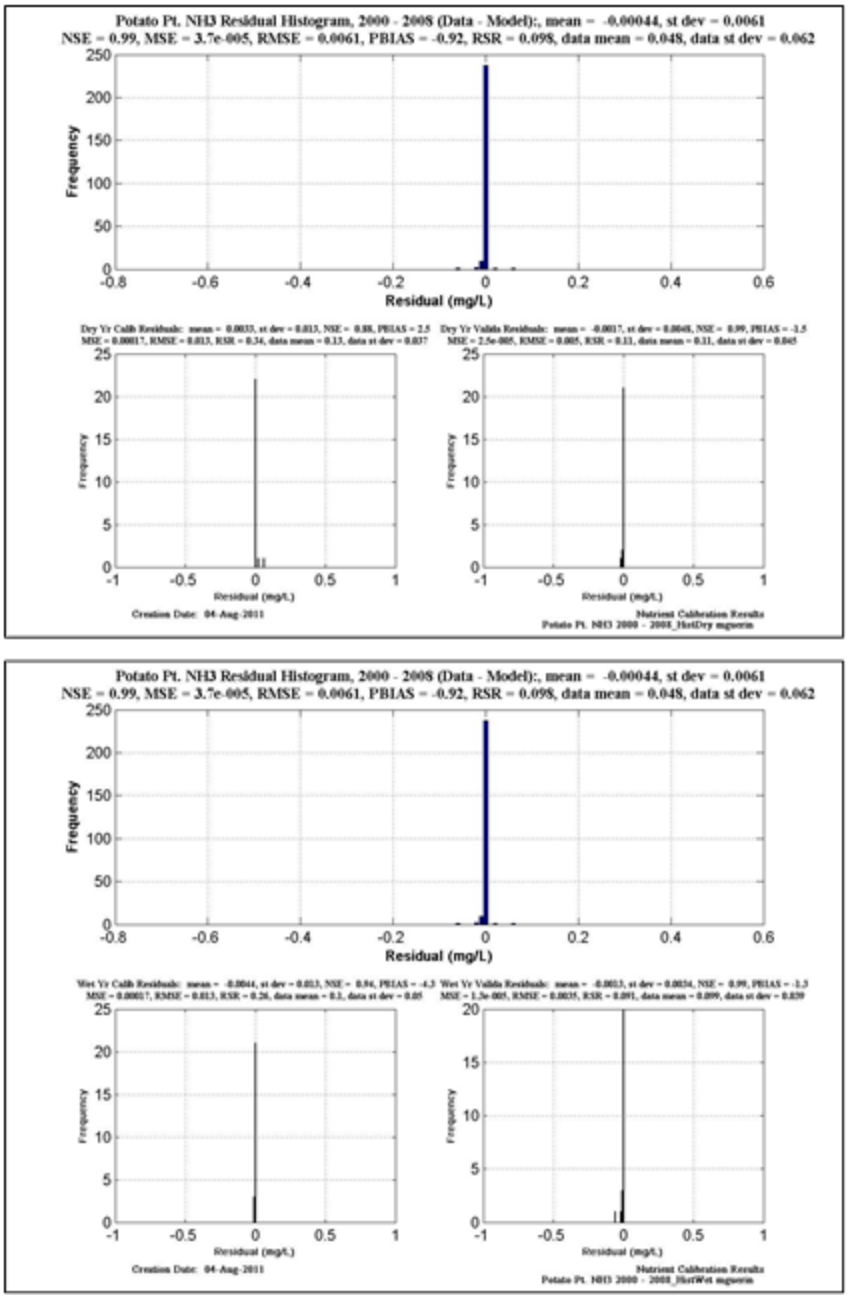


Figure 28-48 Calibration/validation statistics for NH3 at Potato Pt. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

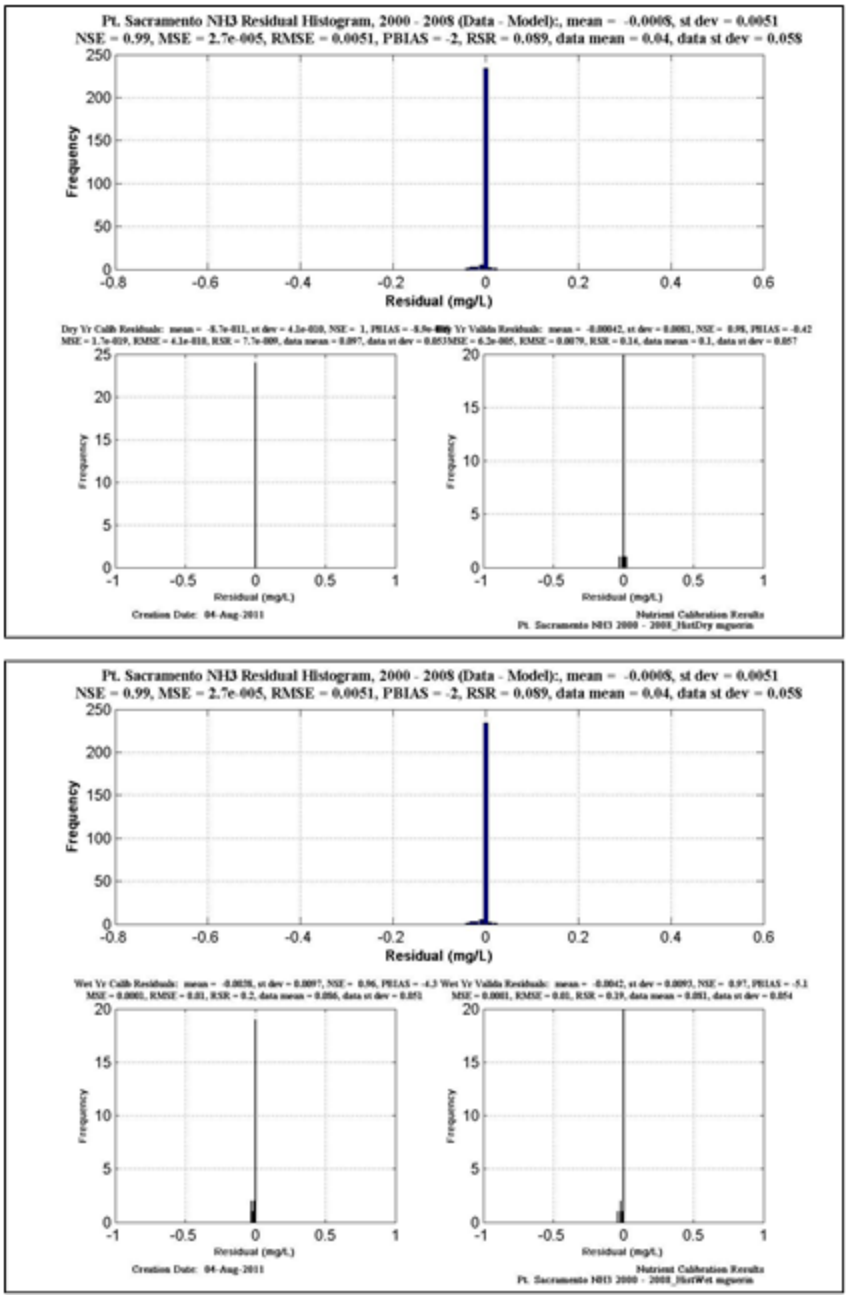


Figure 28-49 Calibration/validation statistics for NH3 at Pt. Sacramento. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

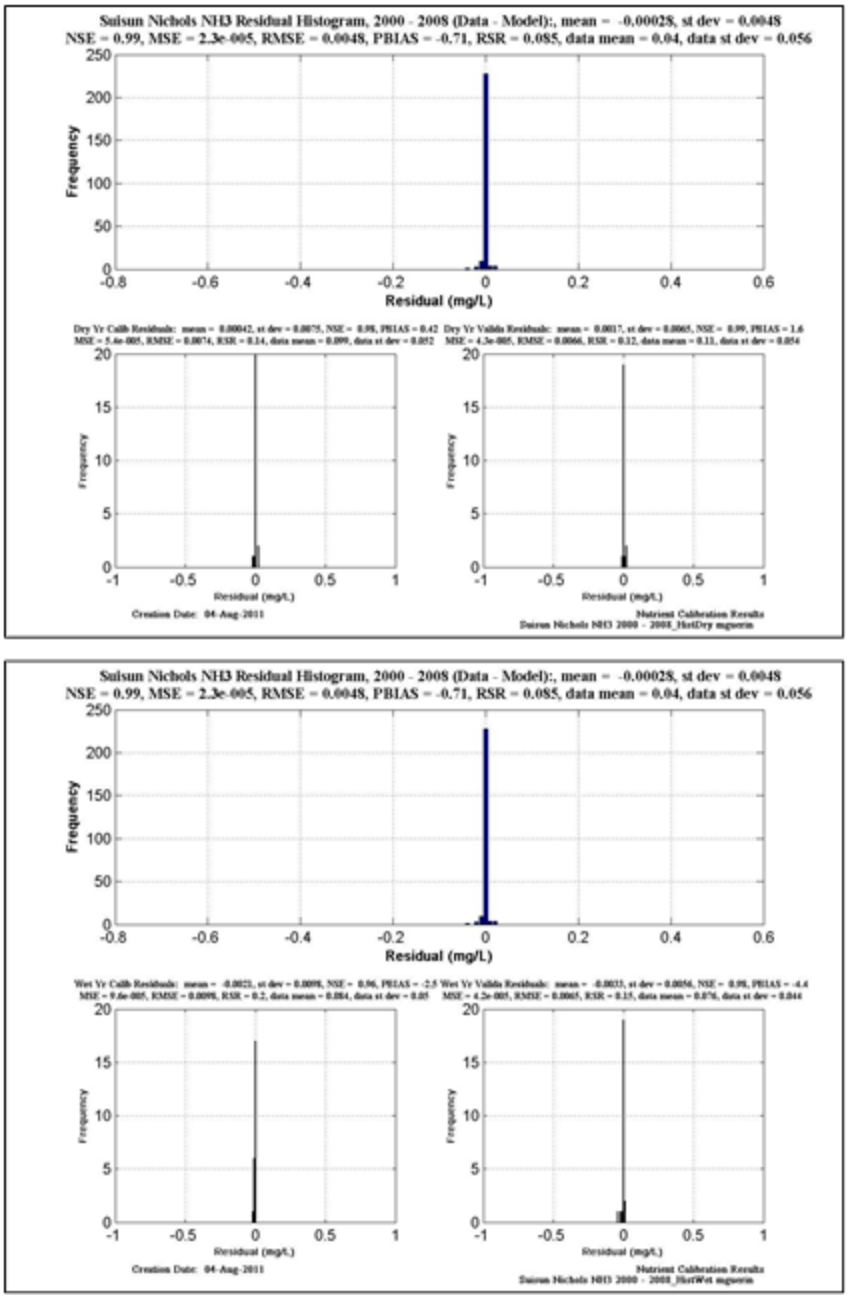


Figure 28-50 Calibration/validation statistics for NH3 at Suisun-Nichols. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

Figure 28-51 (Intentionally left blank) Insufficient data at Russo to calculate calibration statistics.

28.4 NO3+NO2

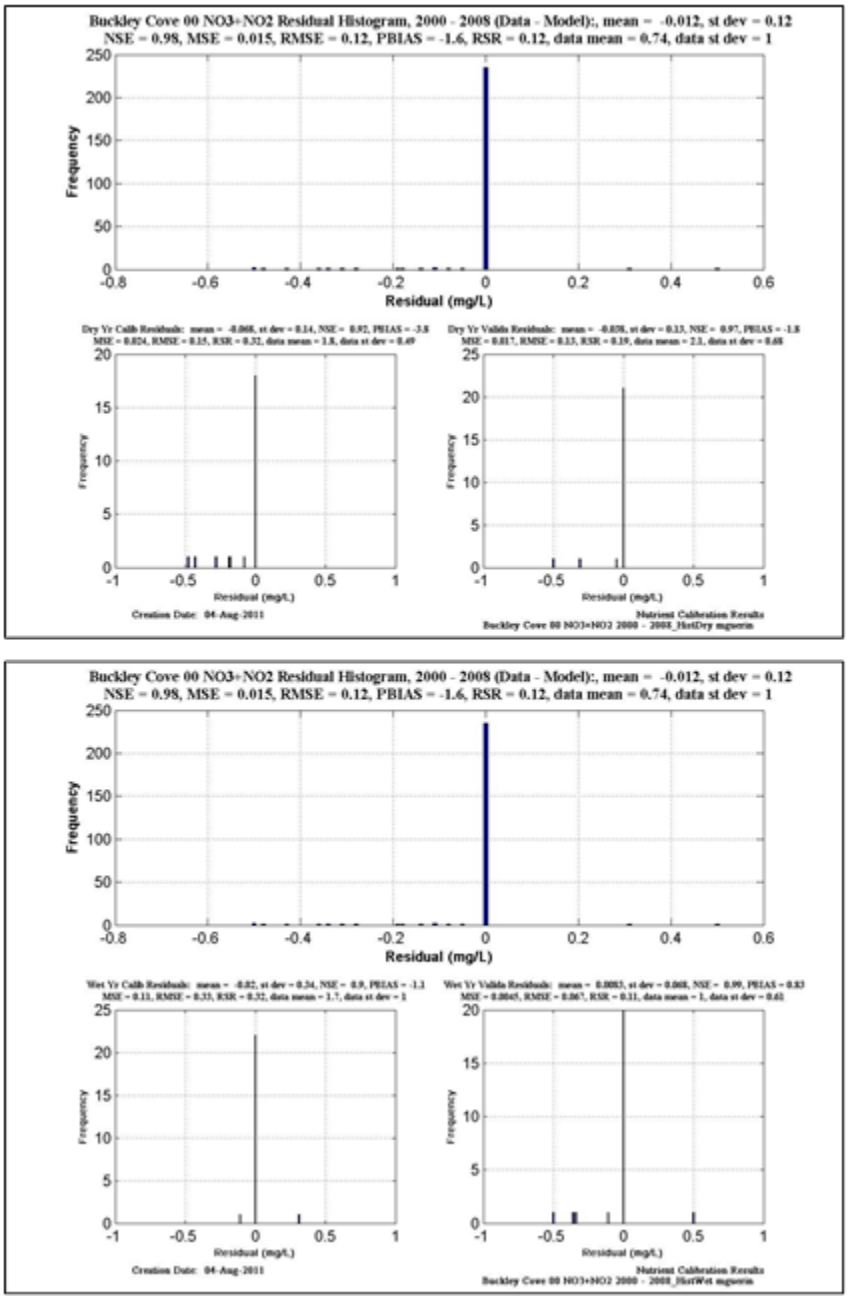


Figure 28-52 Calibration/validation statistics for NO3+NO2 at Buckley Cove. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

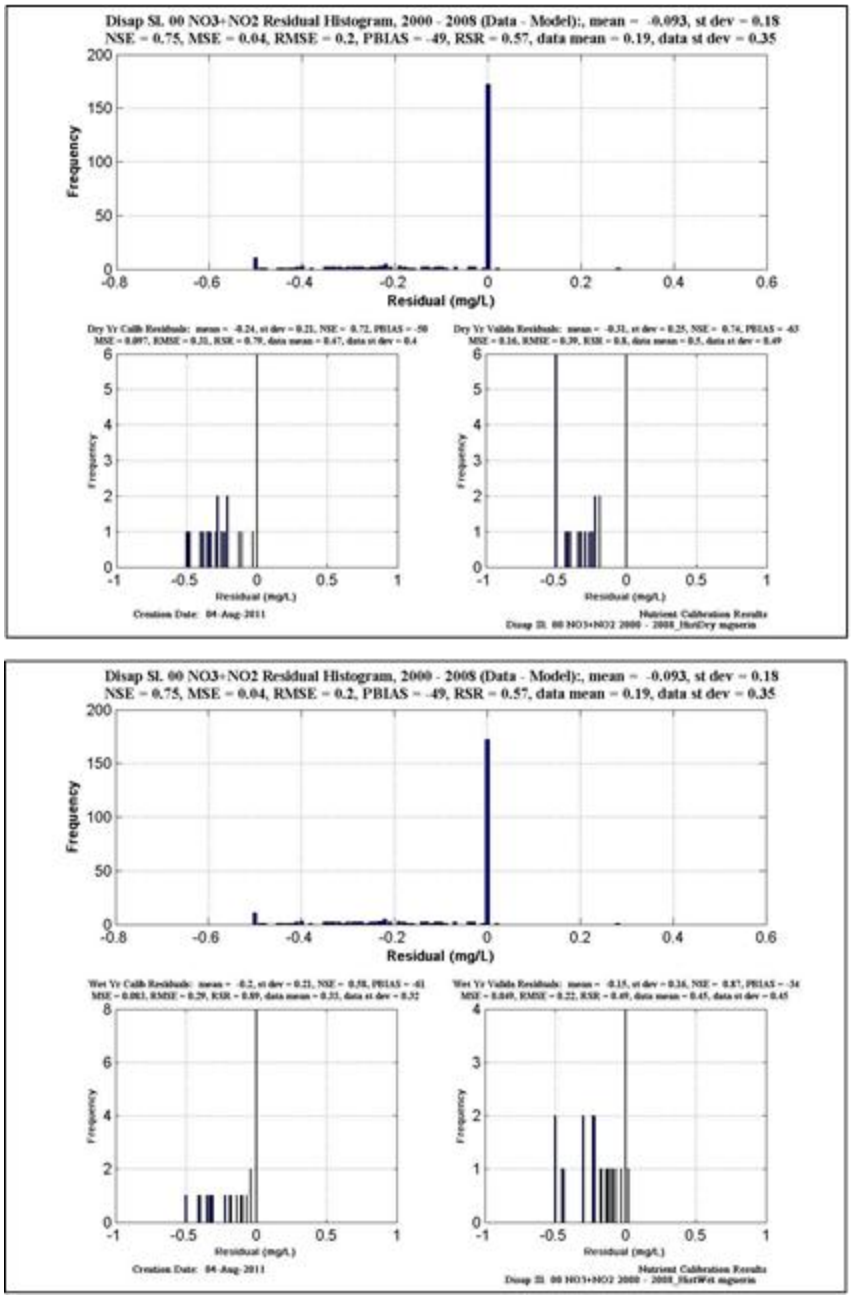


Figure 28-53 Calibration/validation statistics for NO3+NO2 at Disappointment Sl. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

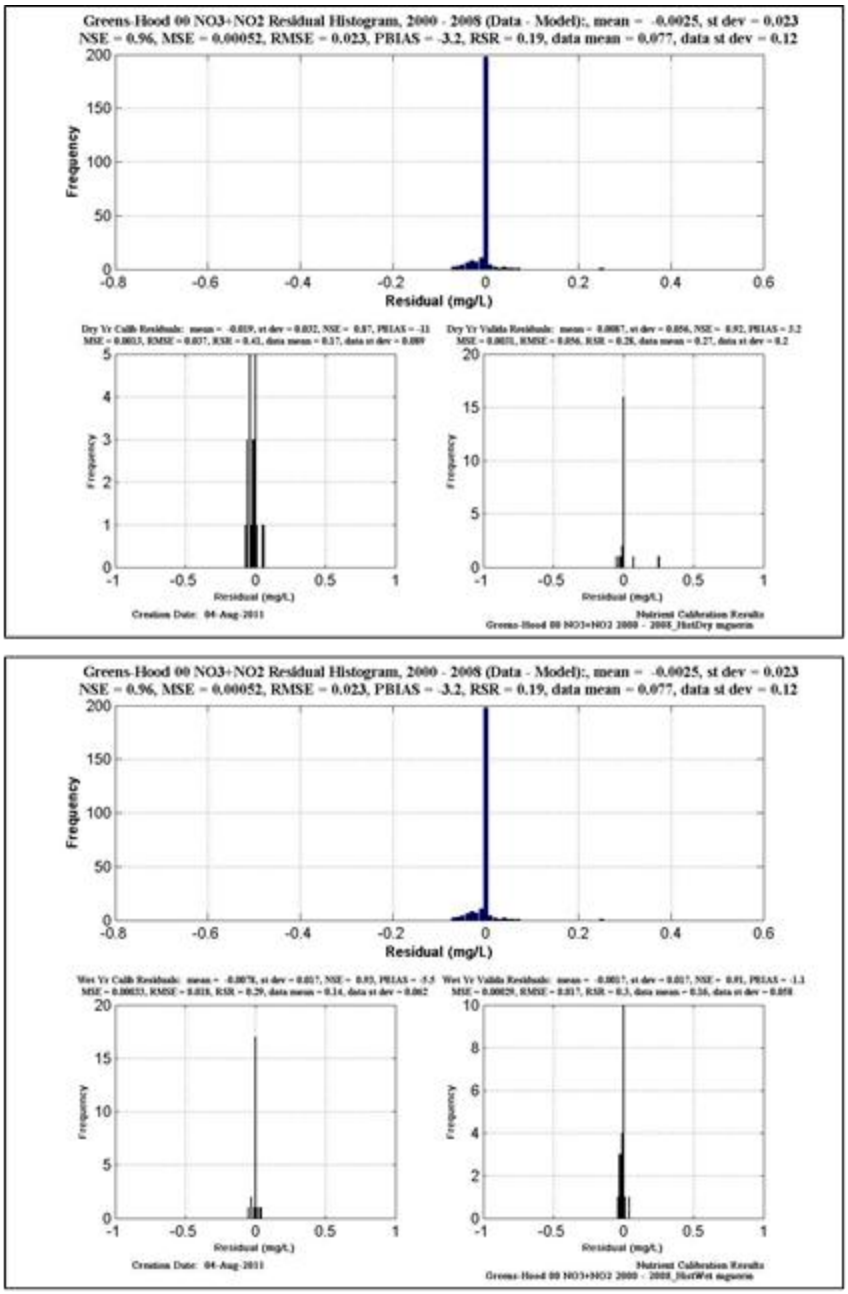


Figure 28-54 Calibration/validation statistics for NO3+NO2 at Greens-Hood. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

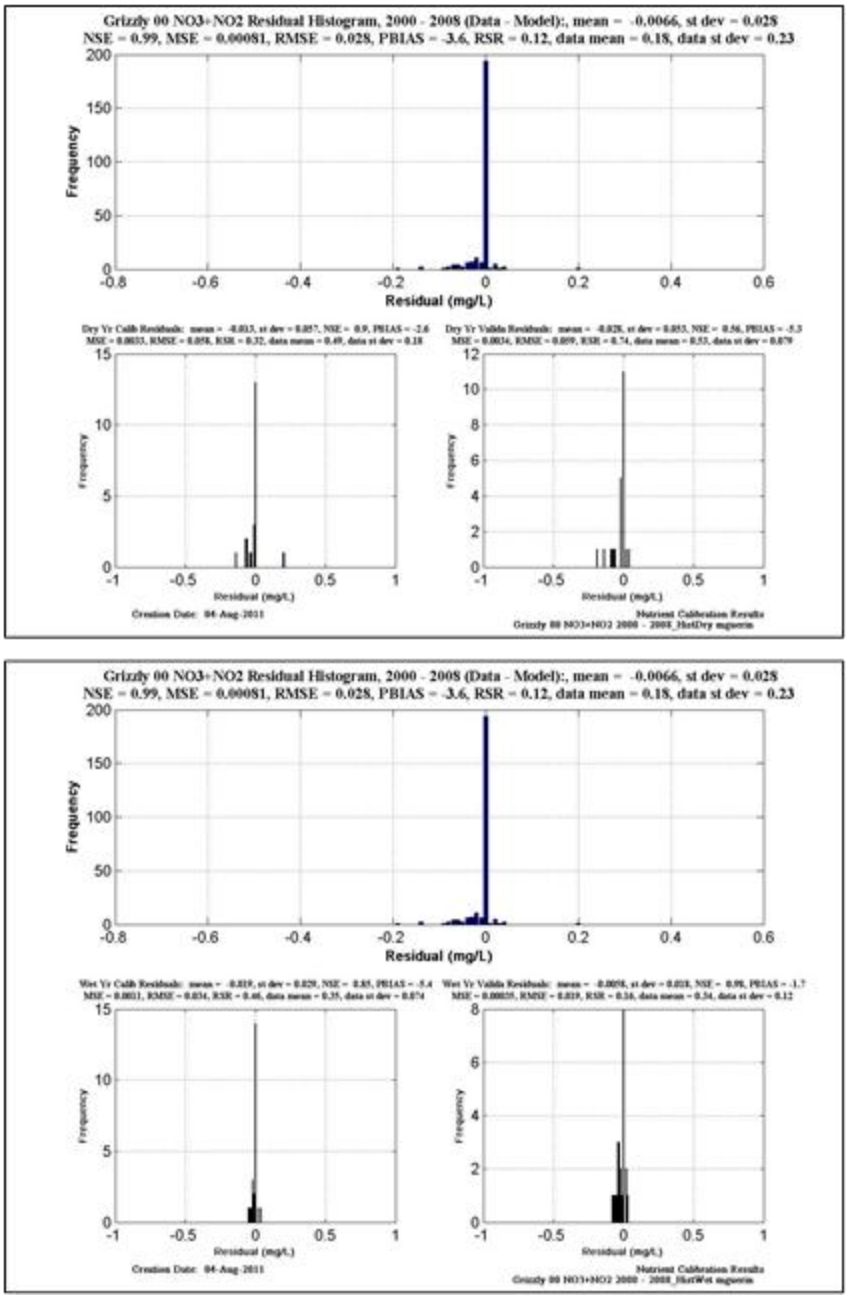


Figure 28-55 Calibration/validation statistics for NO3+NO2 at Grizzly Bay. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

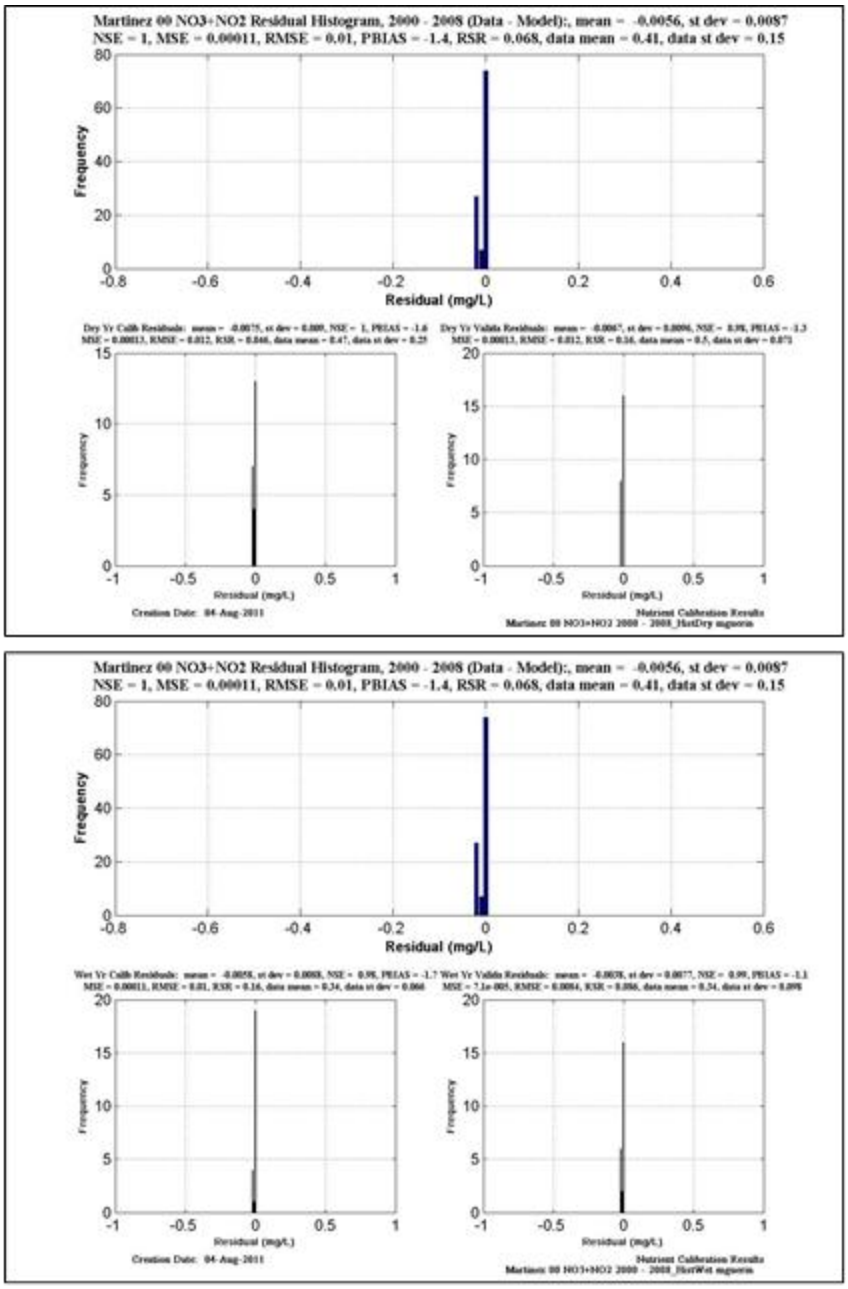


Figure 28-56 Calibration/validation statistics for NO3+NO2 at Martinez. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

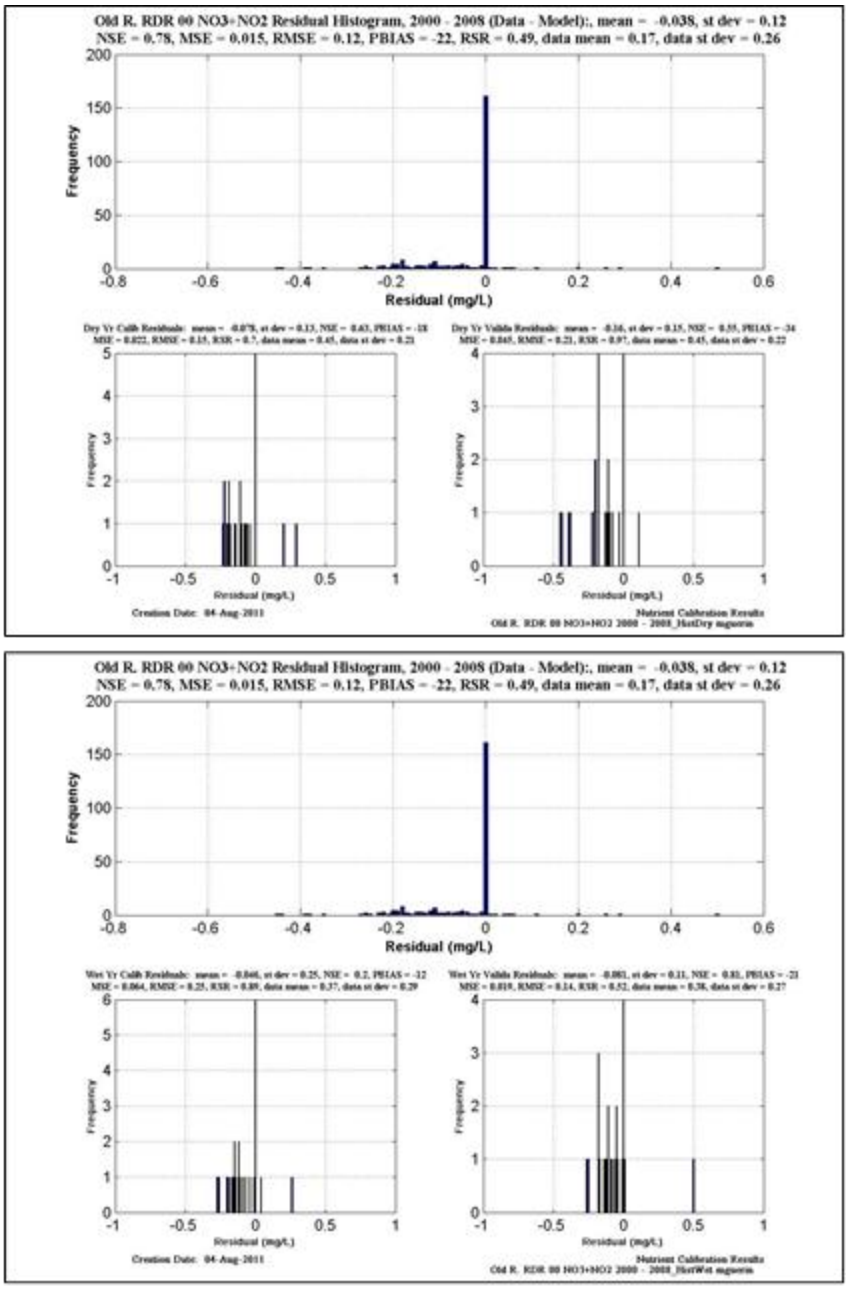


Figure 28-57 Calibration/validation statistics for NO3+NO2 at Old R. at Rancho Del Rio. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

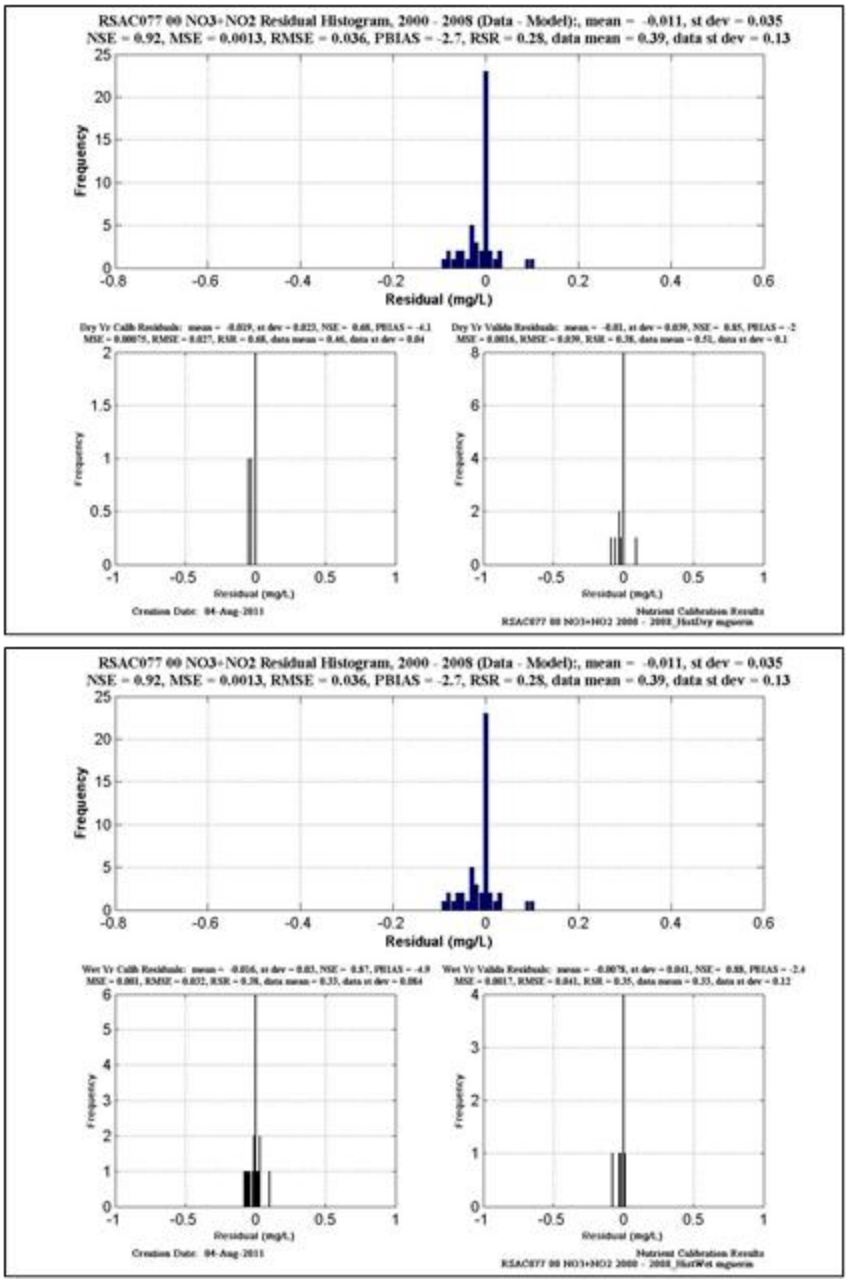


Figure 28-58 Calibration/validation statistics for NO3+NO2 at Pittsburg,-RSAC077. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

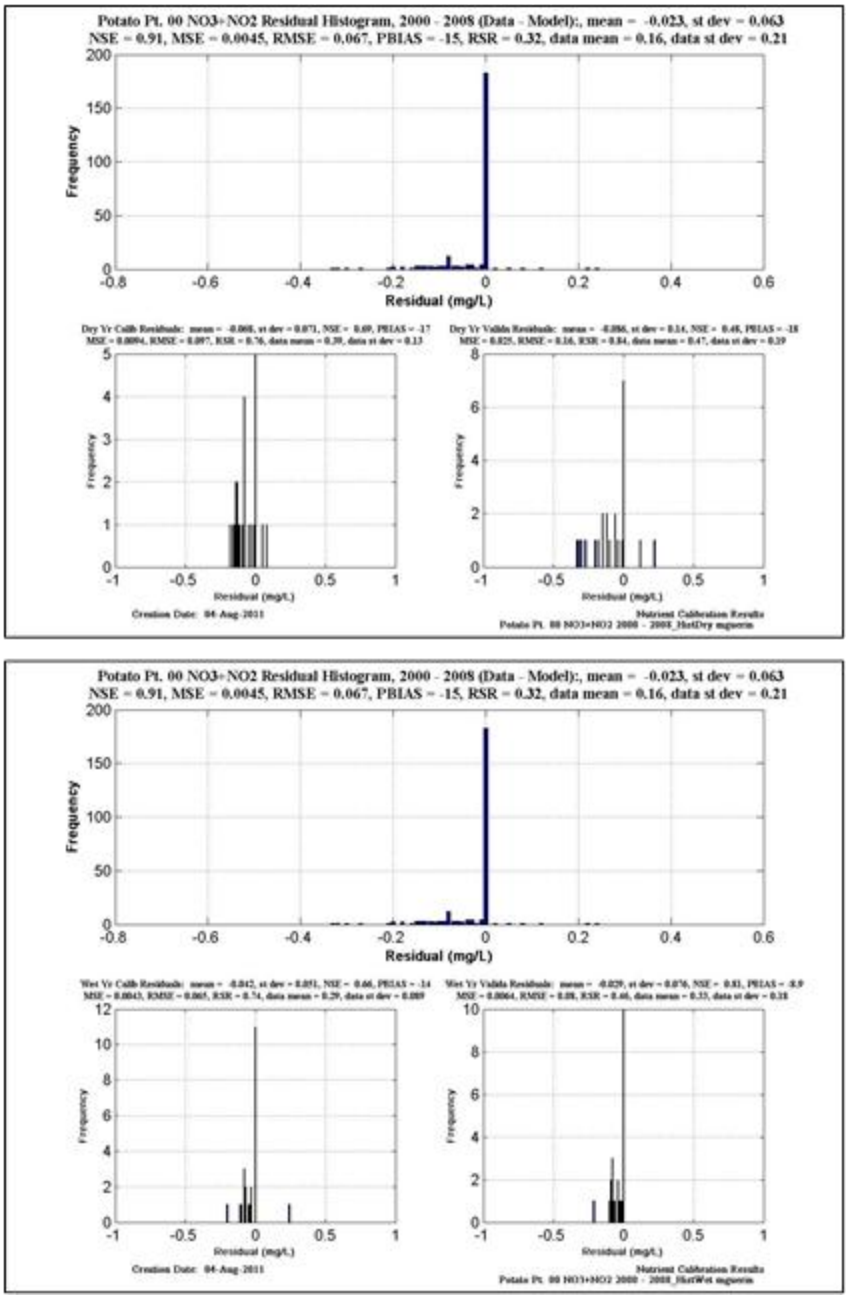


Figure 28-59 Calibration/validation statistics for NO3+NO2 at Potato Pt. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

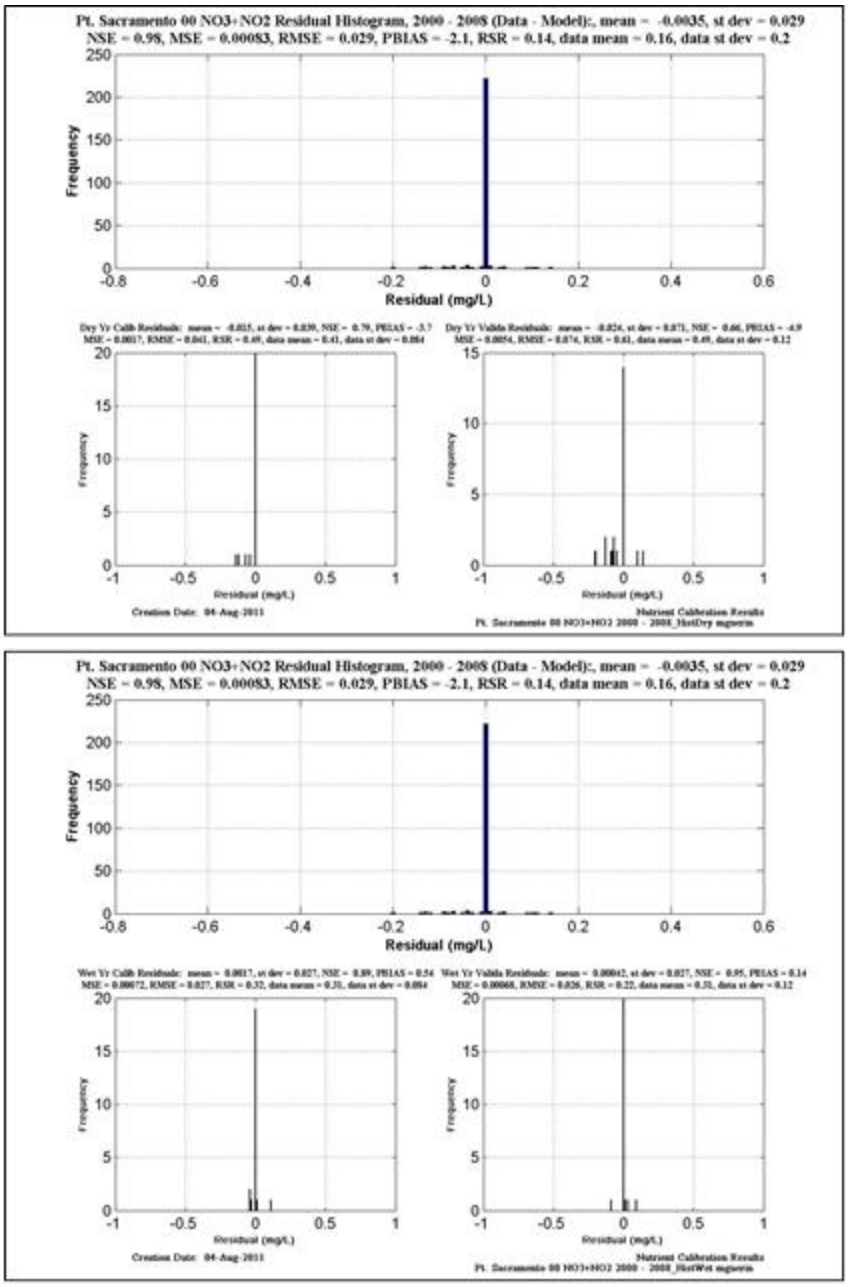


Figure 28-60 Calibration/validation statistics for NO3+NO2 at Pt. Sacramento. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

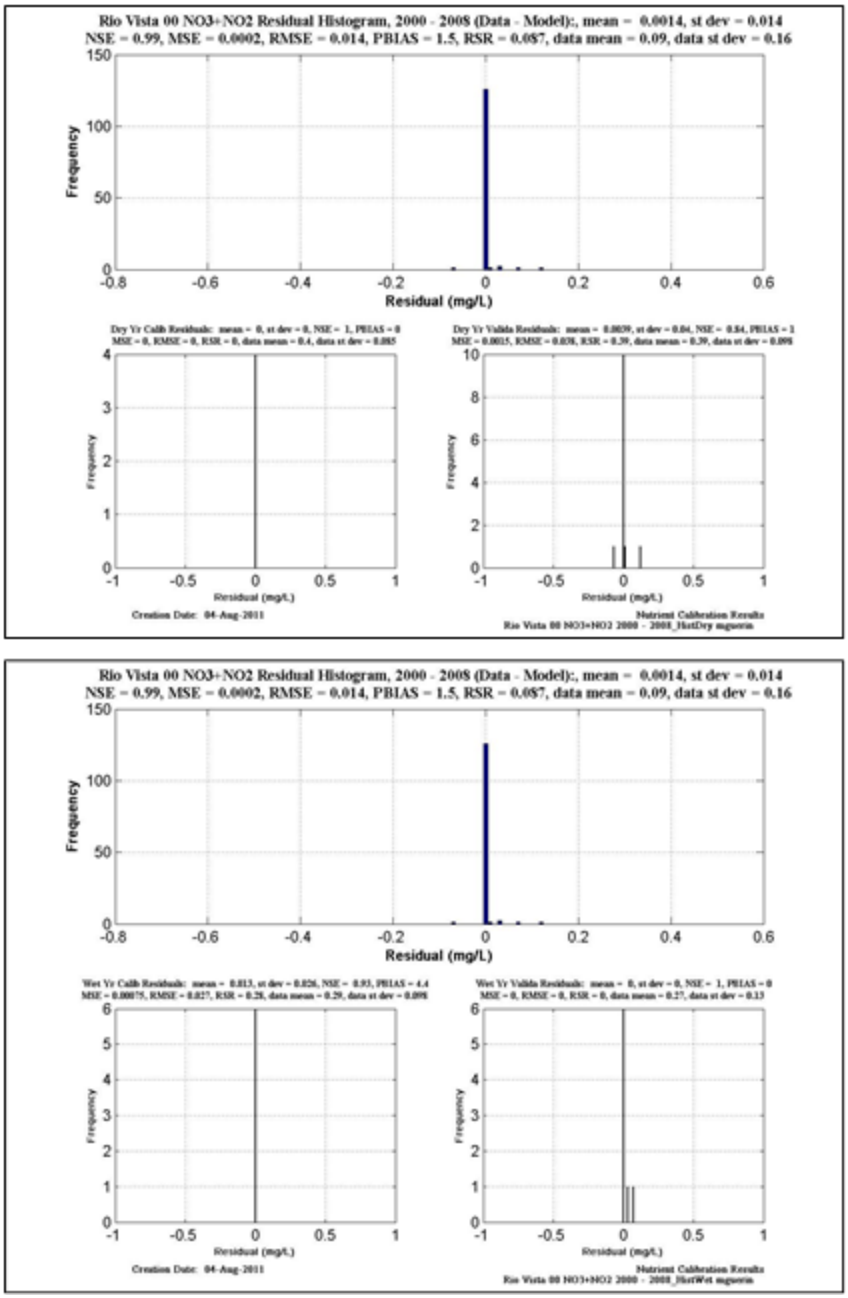


Figure 28-61 Calibration/validation statistics for NO3+NO2 at Rio Vista. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

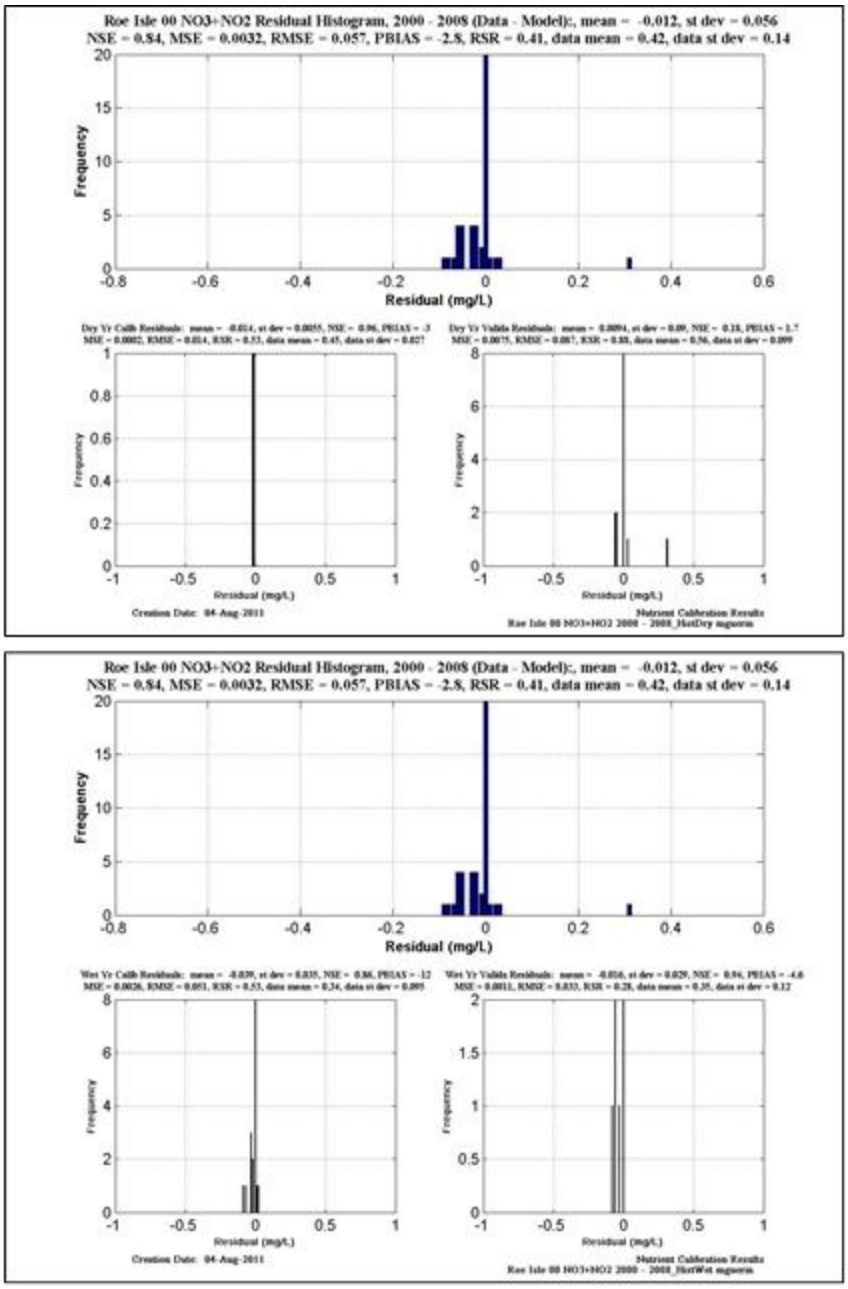


Figure 28-62 Calibration/validation statistics for NO3+NO2 at Roe Island. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

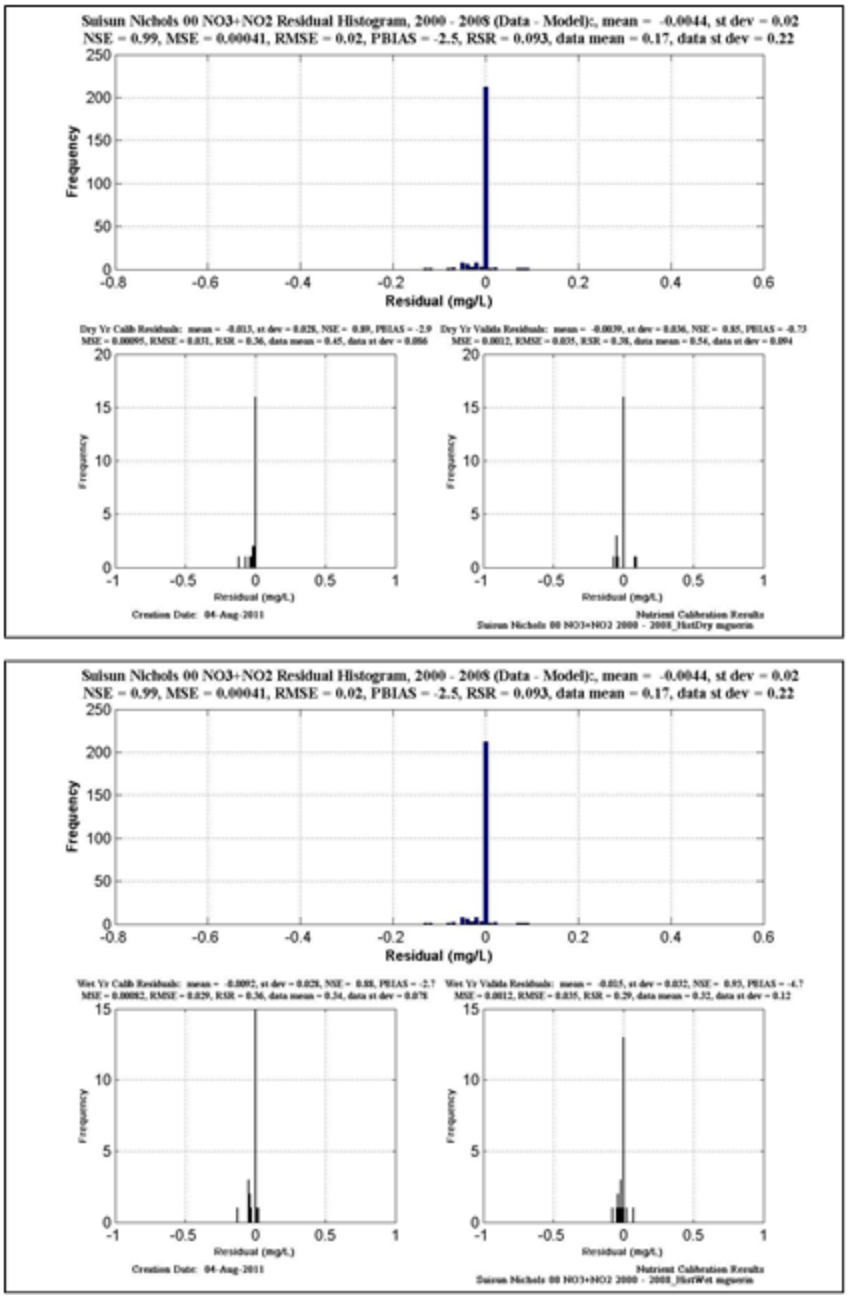


Figure 28-63 Calibration/validation statistics for NO3+NO2 at Suisun-Nichols. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

Figure 28-64 (Intentionally left blank) Insufficient data for Russo to calculate calibration statistics.

28.5 Organic-N

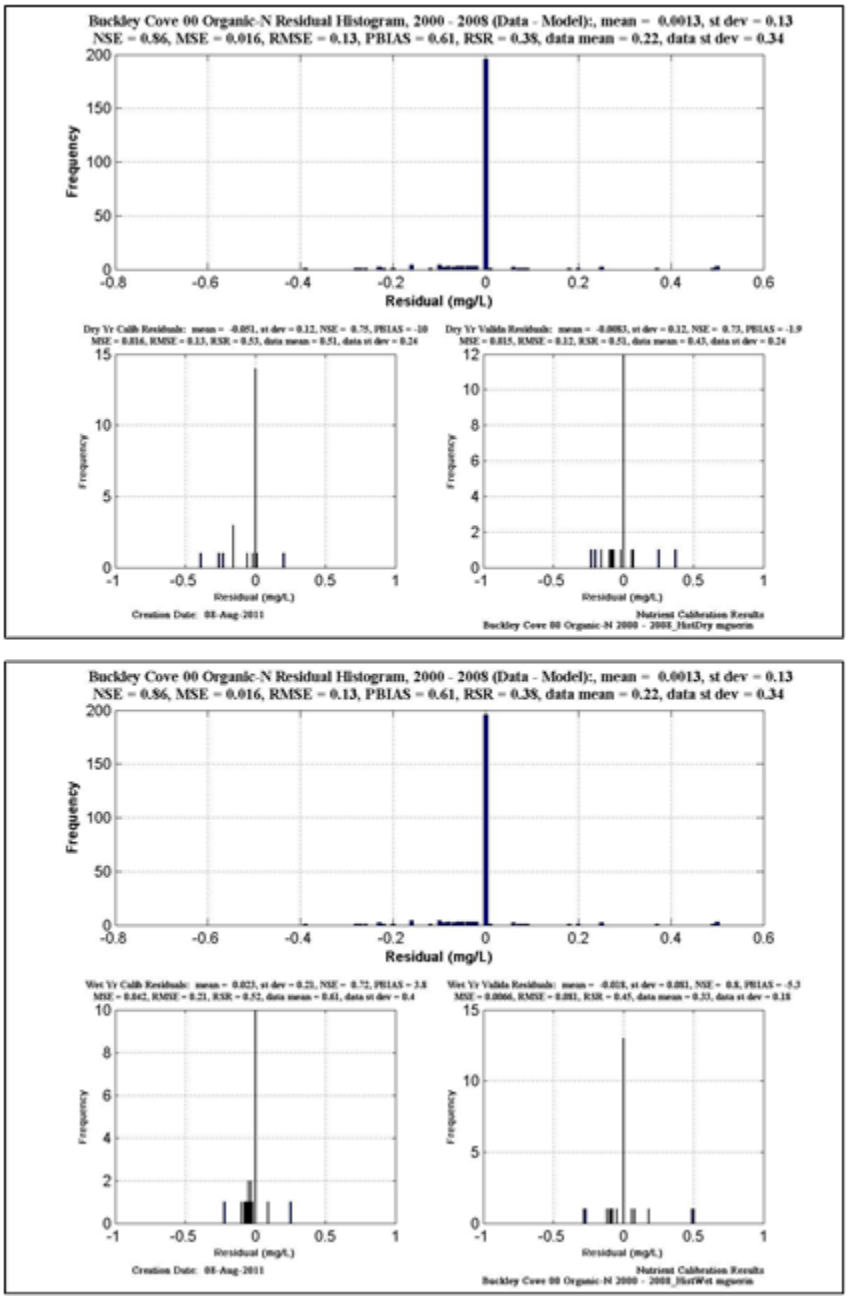


Figure 28-65 Calibration/validation statistics for Organic N at Buckley Cove. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

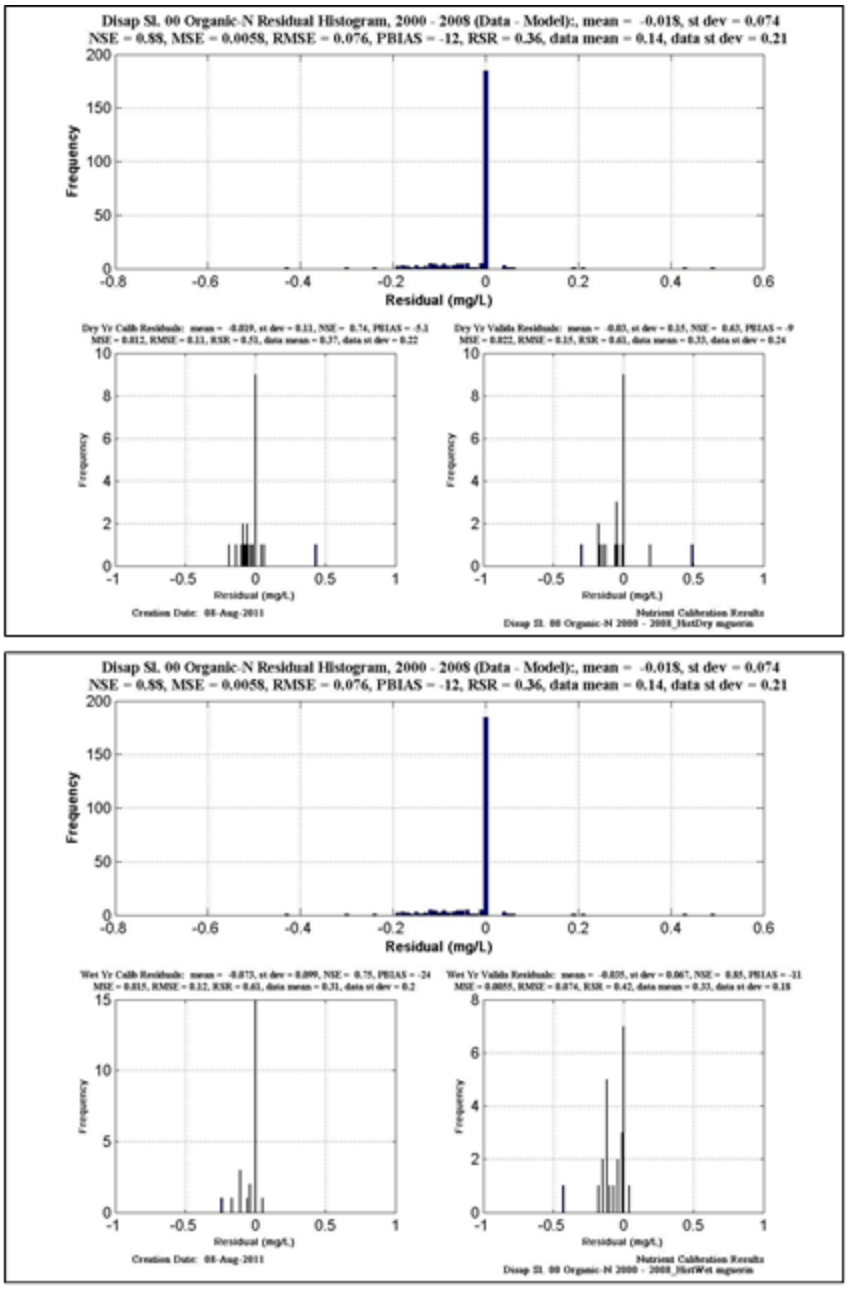


Figure 28-66 Calibration/validation statistics for Organic N at Disappointment Sl. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

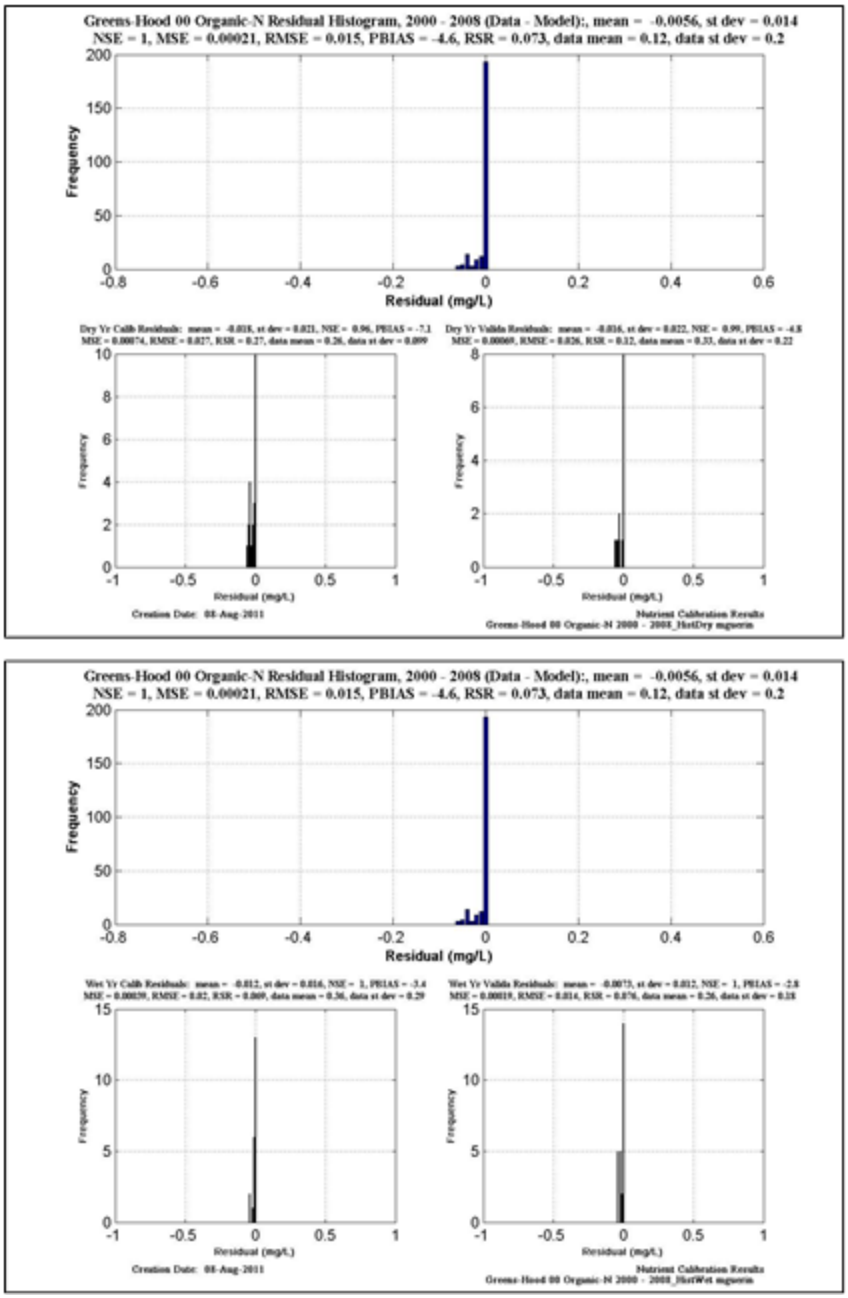


Figure 28-67 Calibration/validation statistics for Organic N at Greens-Hood. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

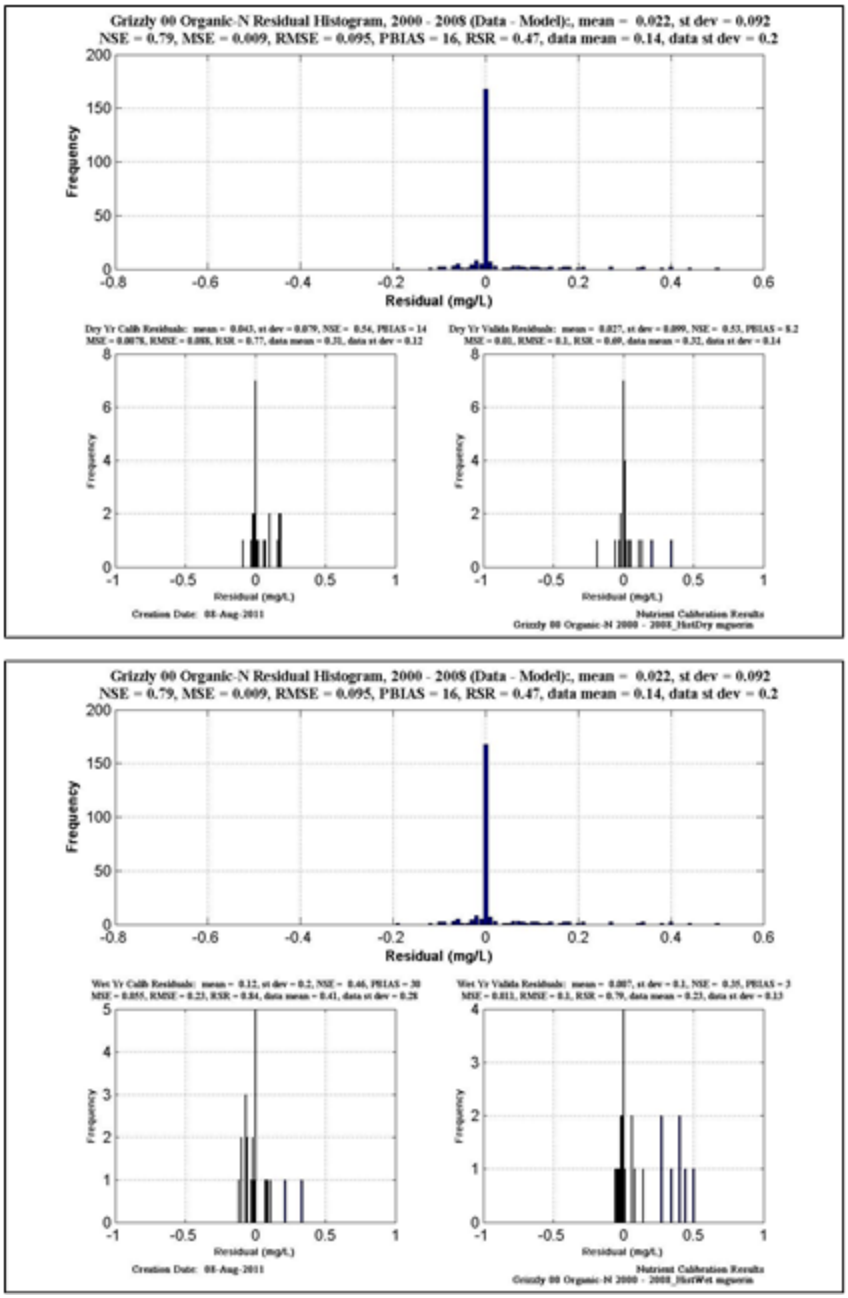


Figure 28-68 Calibration/validation statistics for Organic N at Grizzly Bay. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

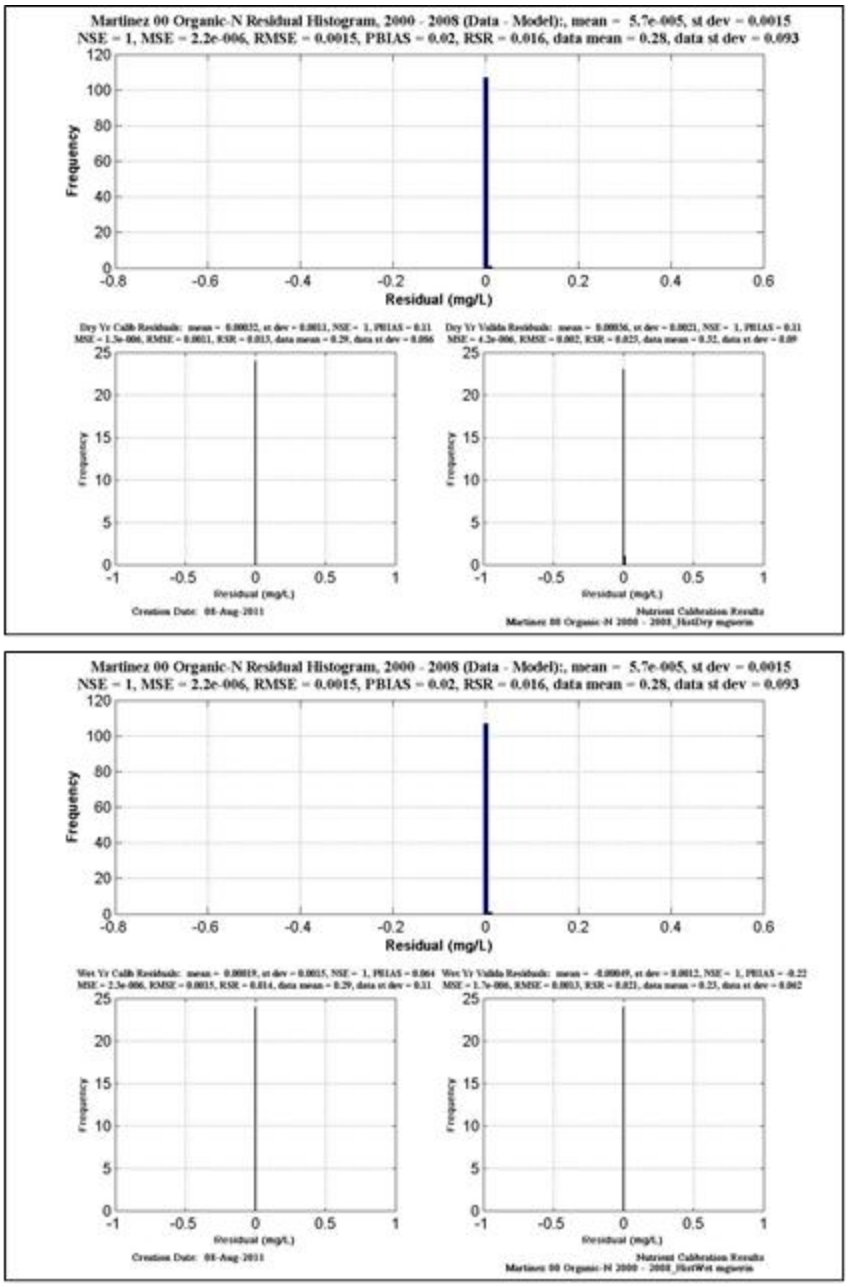


Figure 28-69 Calibration/validation statistics for Organic N at Martinez. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

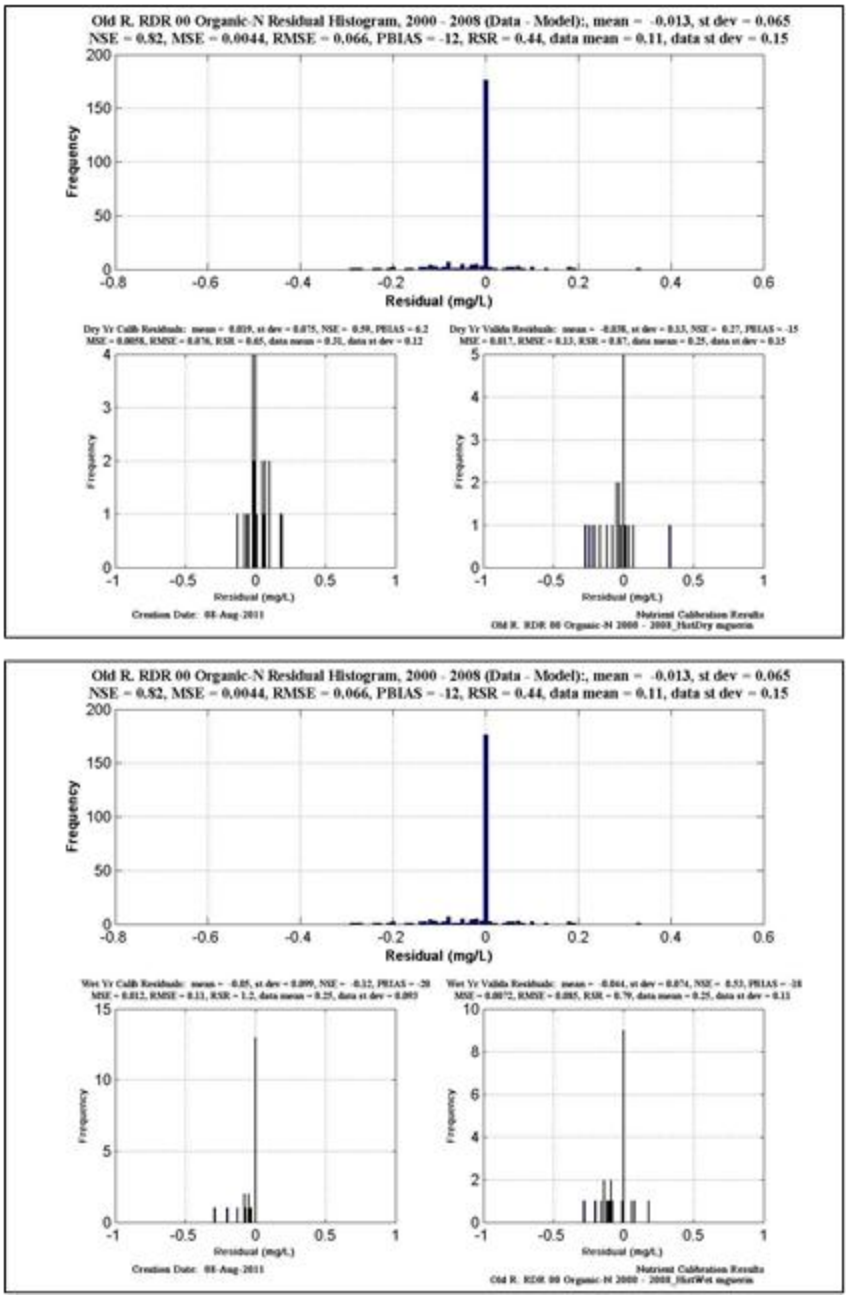


Figure 28-70 Calibration/validation statistics for Organic N at Old R. at Rancho Del Rio. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

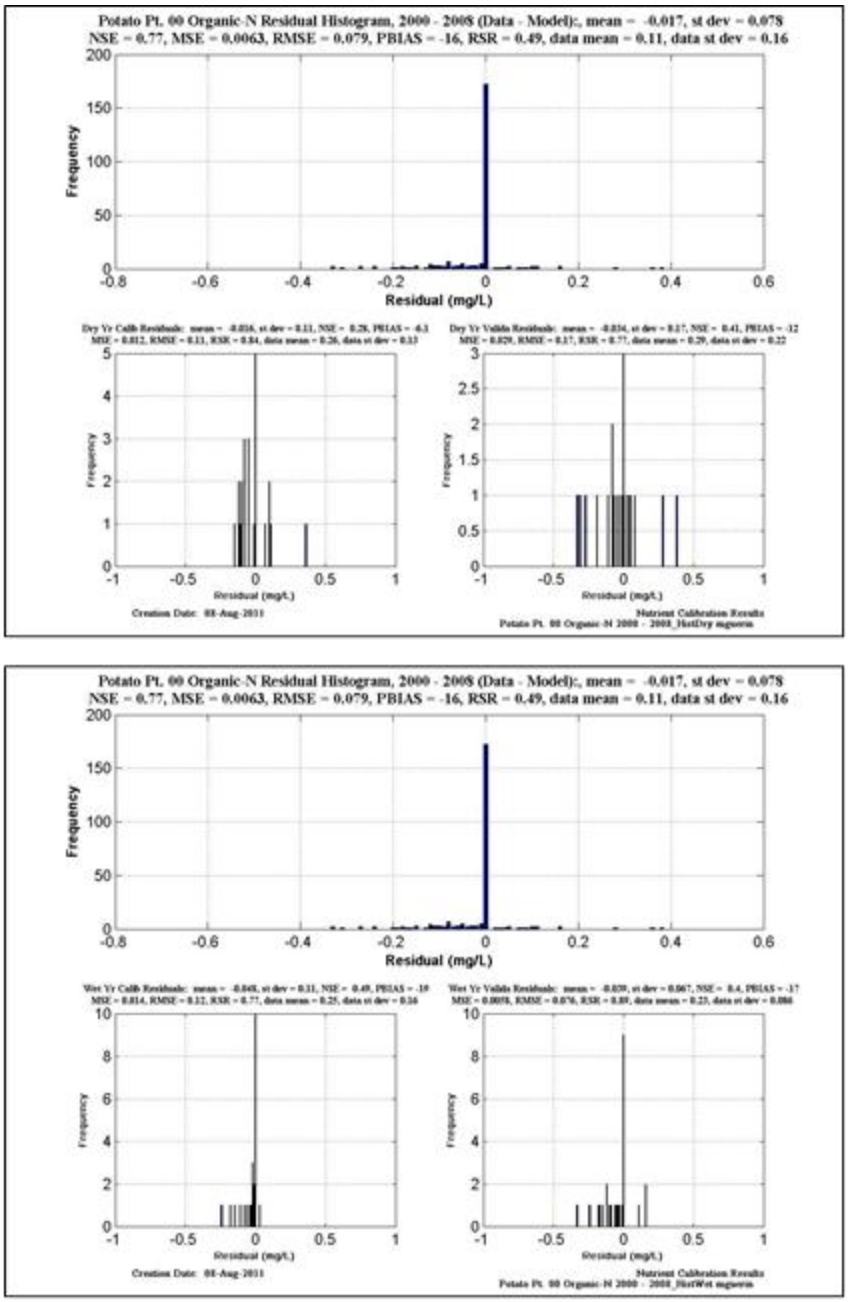


Figure 28-71 Calibration/validation statistics for Organic N at Potato Pt. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

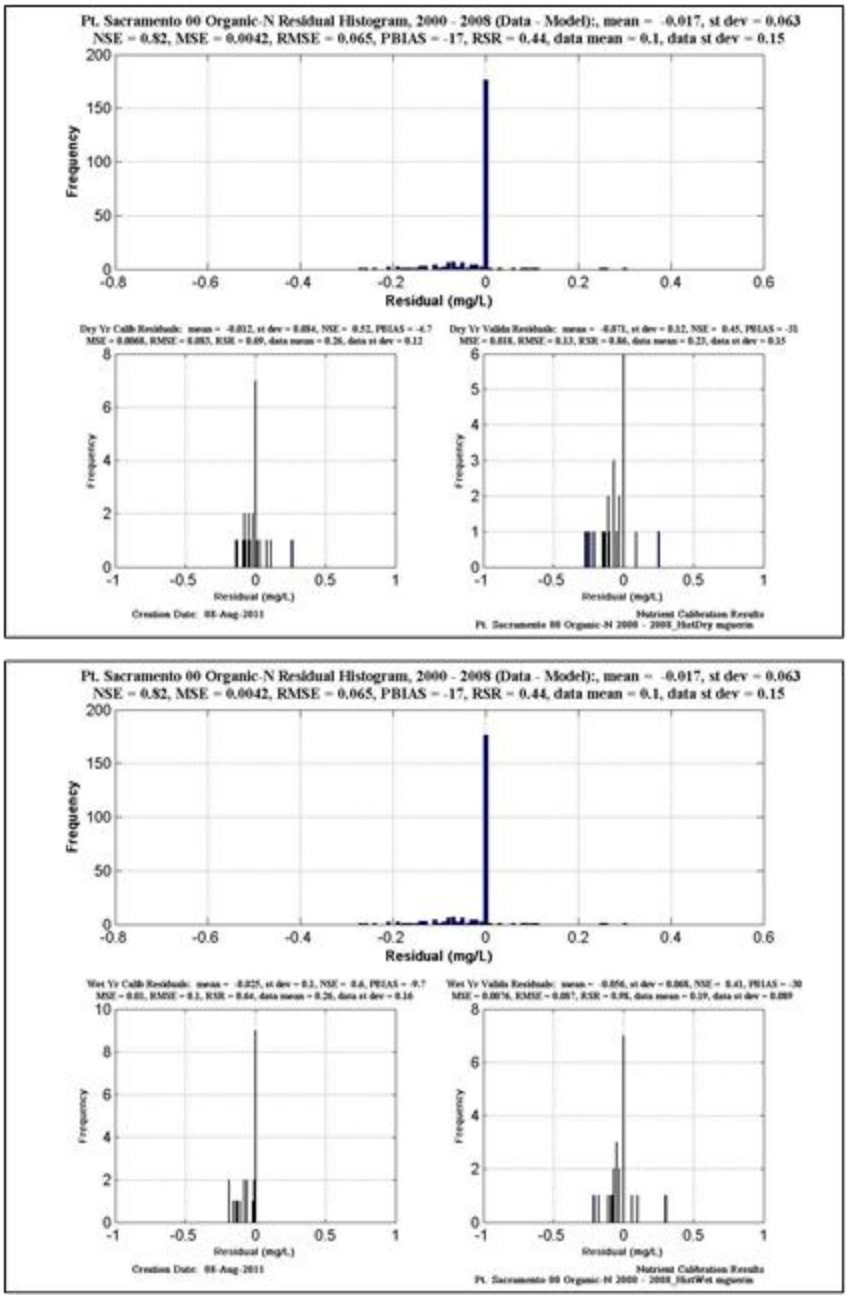


Figure 28-72 Calibration/validation statistics for Organic N at Pt. Sacramento. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

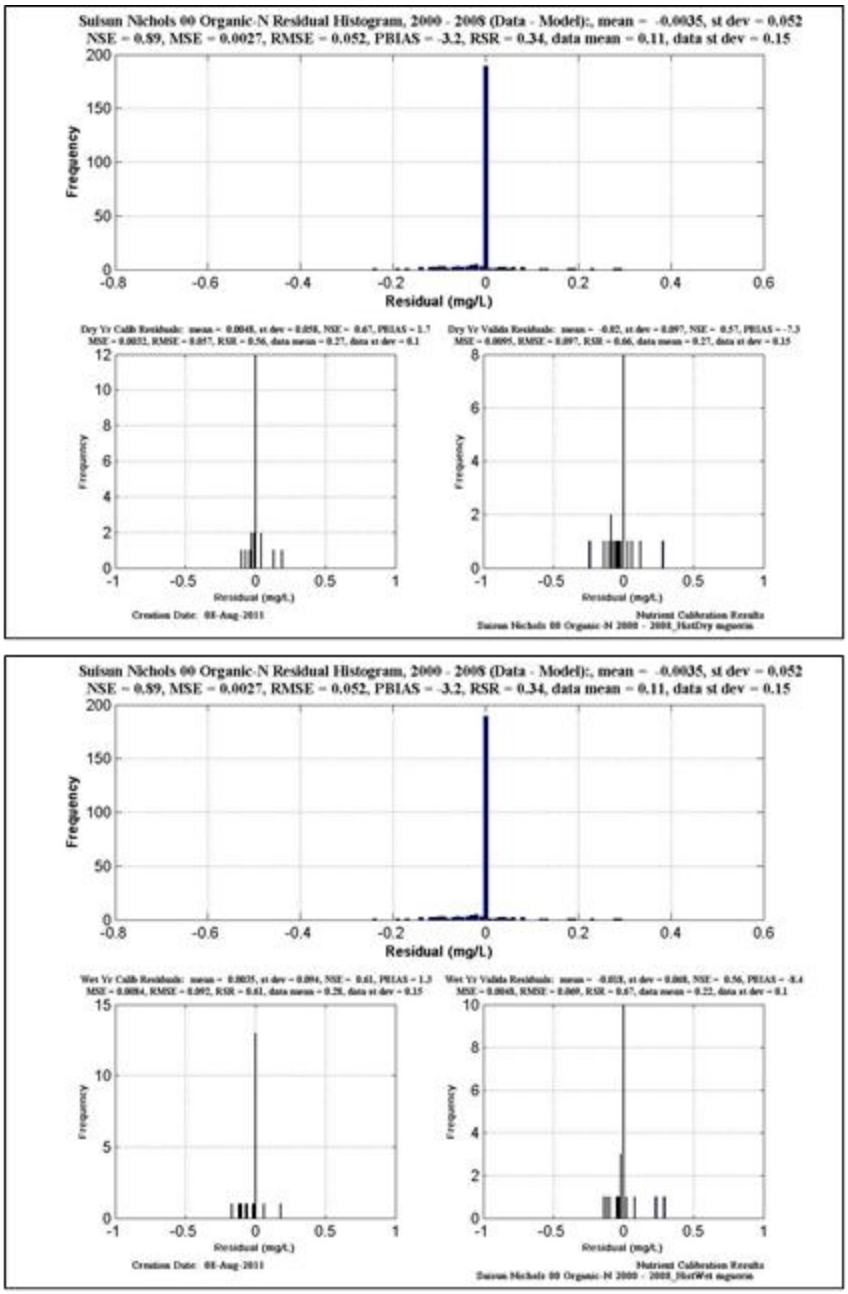


Figure 28-73 Calibration/validation statistics for Organic N at Suisun-Nichols. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

Figure 28-74 (Intentionally left blank) Insufficient data to Russo calculate calibration statistics.

28.6 PO4

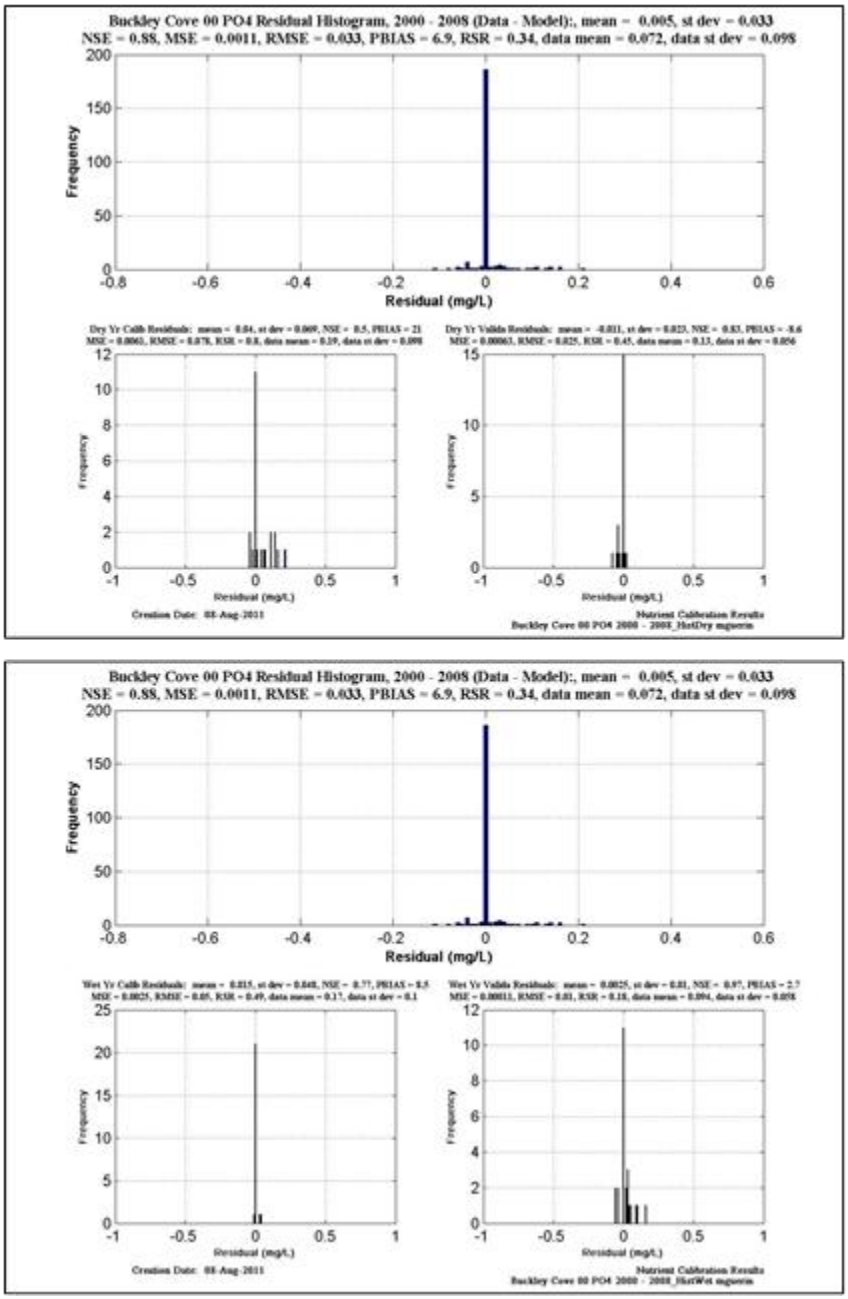


Figure 28-75 Calibration/validation statistics for PO4 at Buckley Cove. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

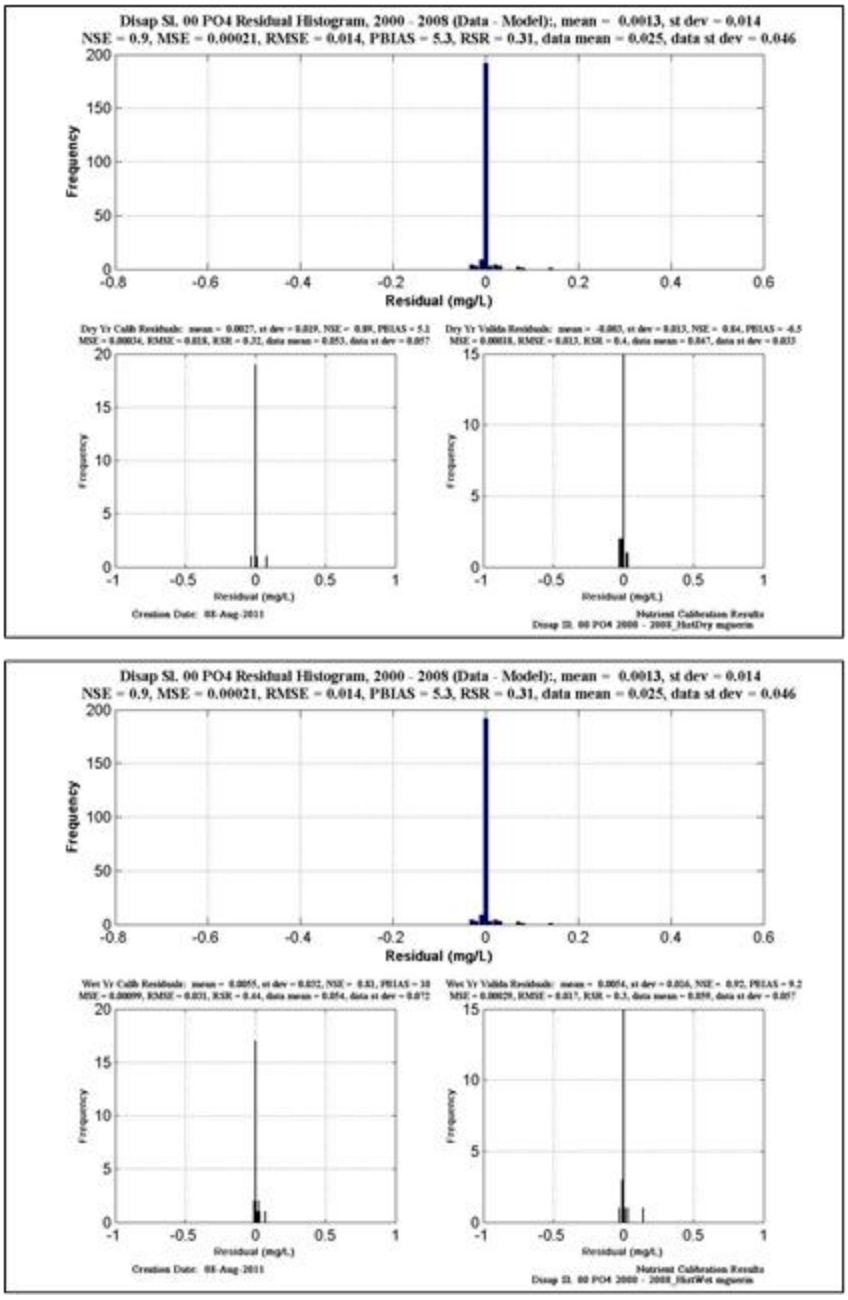


Figure 28-76Calibration/validation statistics for PO4 at Disappointment Sl. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

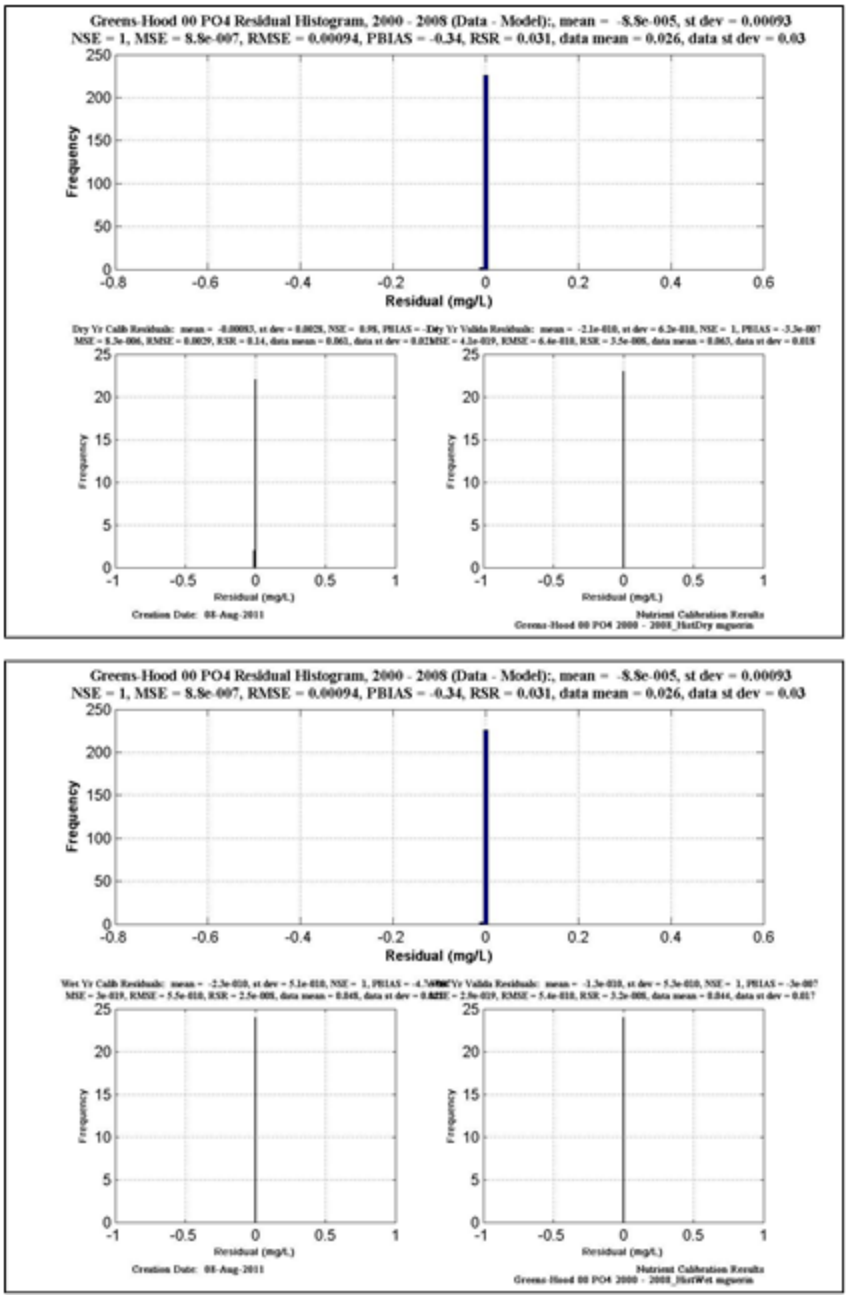


Figure 28-77 Calibration/validation statistics for PO4 at Greens-Hood. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

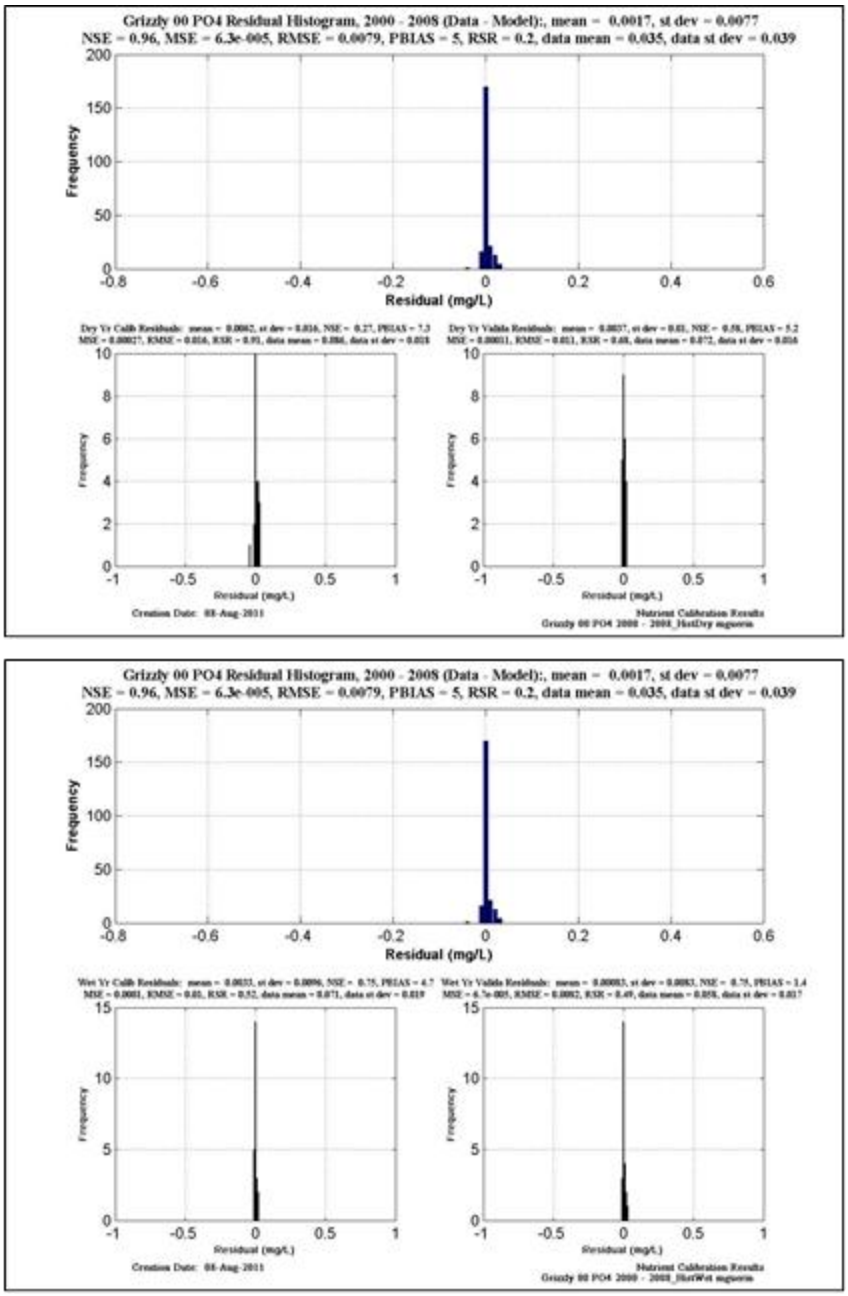


Figure 28-78 Calibration/validation statistics for PO4 at Grizzly Bay. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

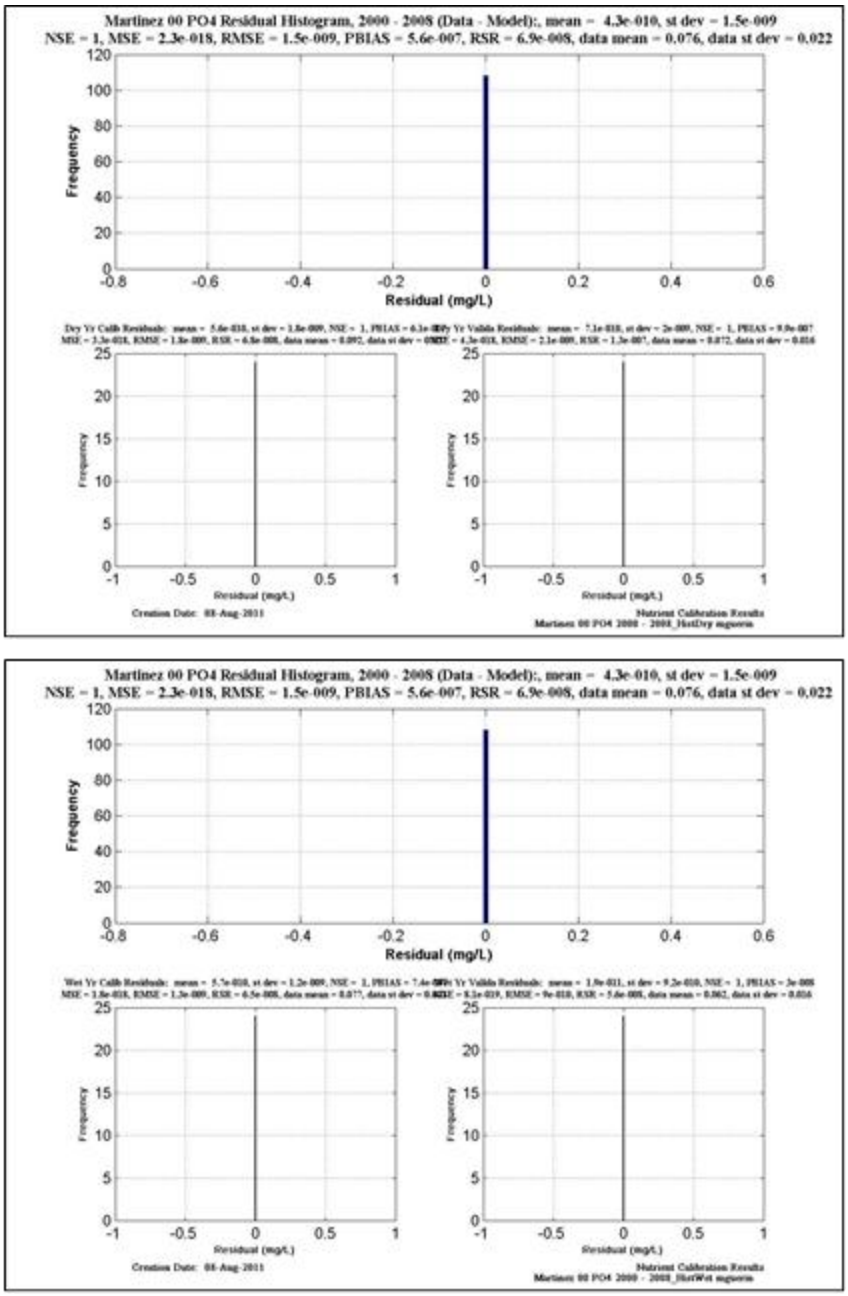


Figure 28-79 Calibration/validation statistics for PO4 at Martinez. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

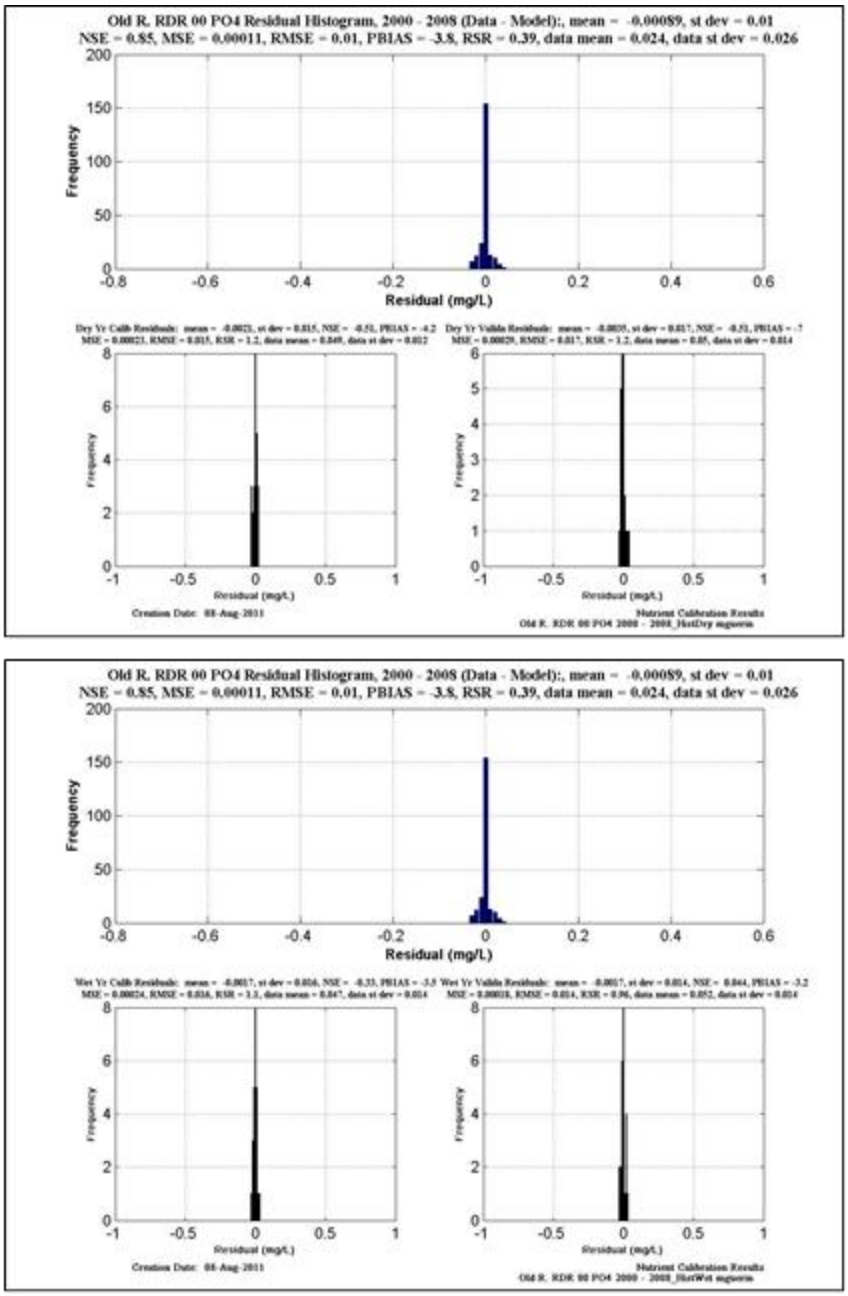


Figure 28-80 Calibration/validation statistics for PO4 at Old R. Rancho Del Rio. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

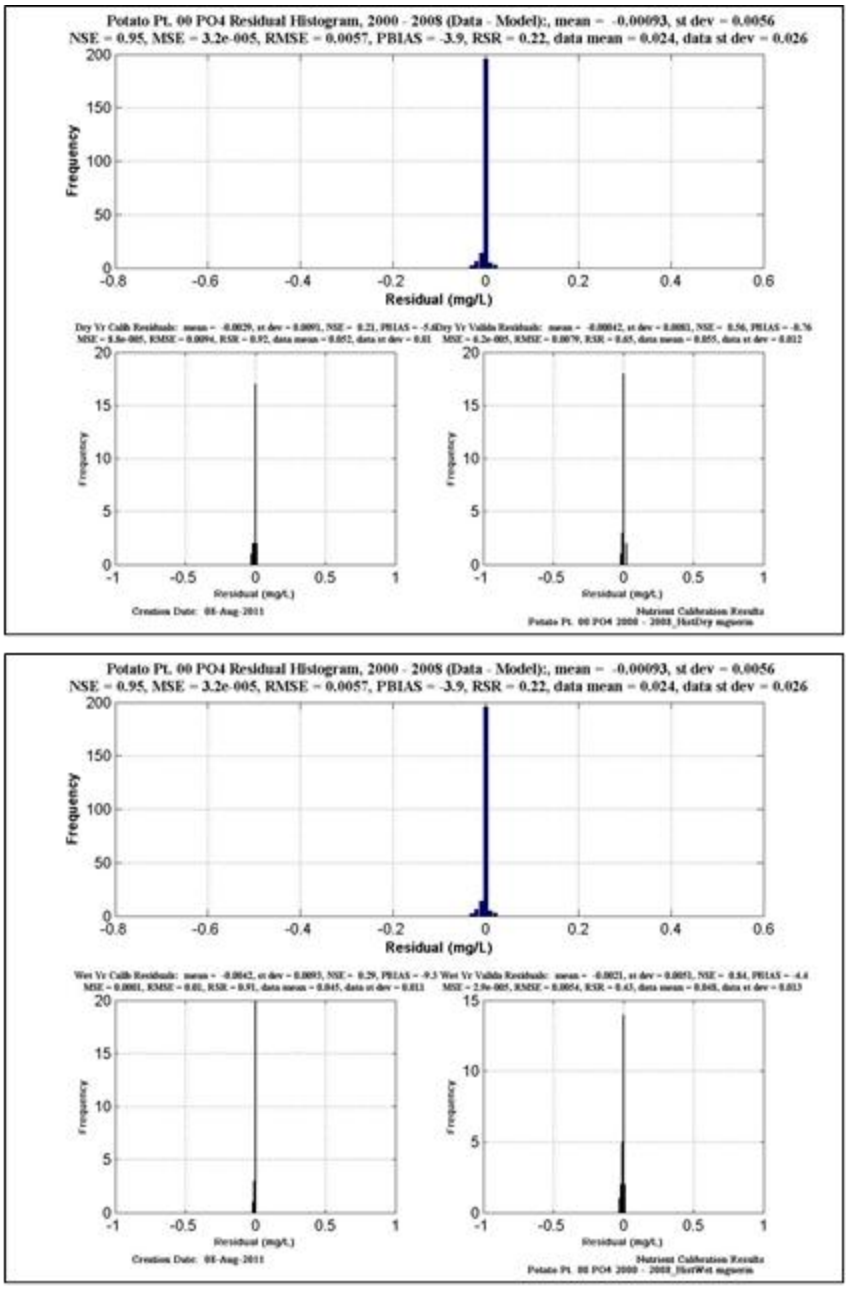


Figure 28-81 Calibration/validation statistics for PO4 at Potato Pt. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

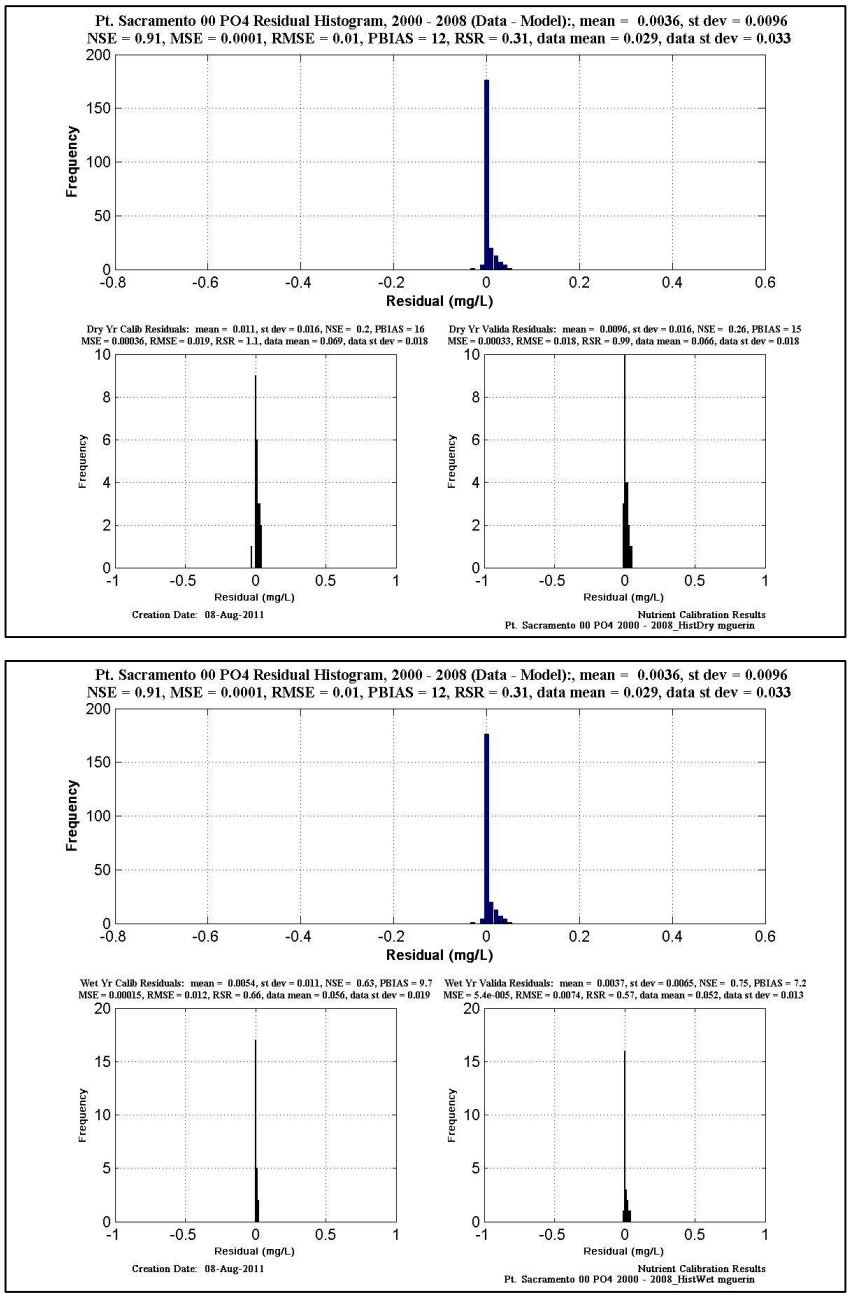
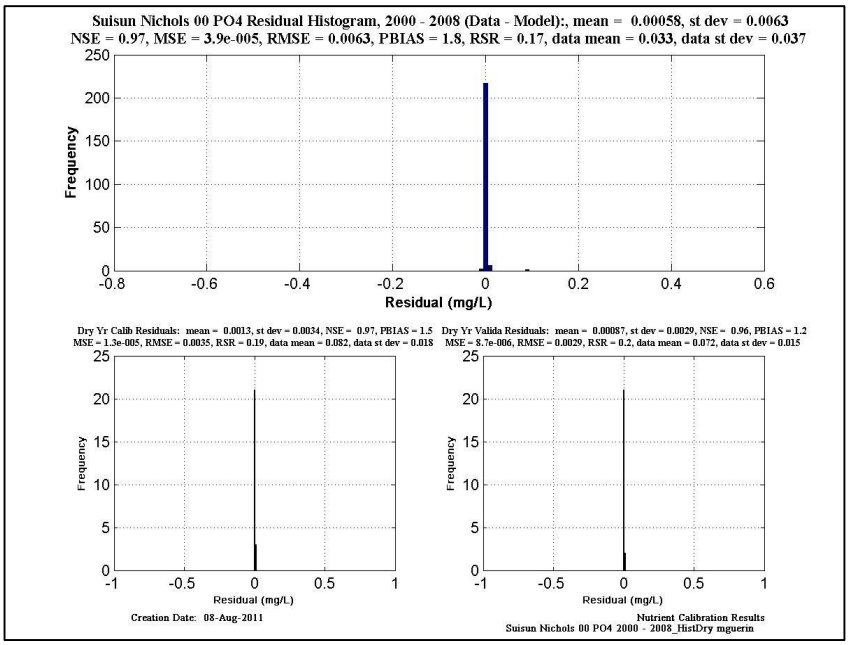


Figure 28-82 Calibration/validation statistics for PO4 at Pt. Sacramento. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.



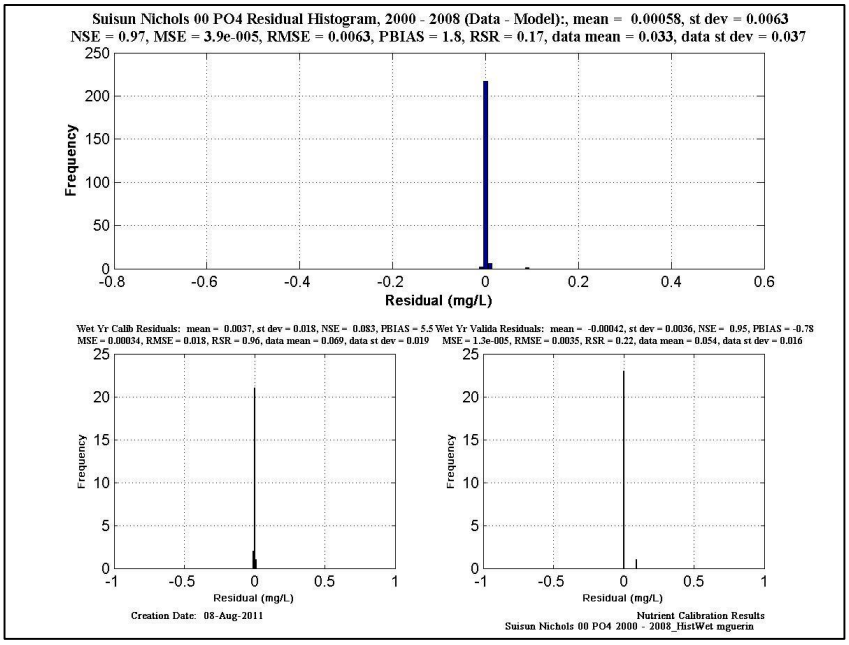


Figure 28-83 Calibration/validation statistics for PO4 at Suisun-Nichols. Upper figure is calibration & validation statistics for dry years; lower figure is calibration & validation statistics for wet years.

Figure 28-84 (Intentionally left blank) Insufficient data at Russo to calculate calibration statistics.