

Florida Department of Environmental Protection

Section 5
SITE SPECIFIC MODEL SELECTION, PREPARATION,
VERIFICATION, CALIBRATION, AND VALIDATION

CALOOSAHATCHEE RIVER BASIN
TMDL MODEL SUPPORT
MAY 30, 2008

Prepared for:

Division of Water Resource Management
Watershed Assessment Section
Tallahassee, Florida

Prepared by:

Dynamic Solutions, LLC (DSLLC)

And

Camp Dresser & McKee, Inc. (CDM)

Table of Contents

FIGURES	v
TABLES.....	xiii
APPENDICIES	xvi
ABBREVIATIONS AND ACRONYMS.....	xvii
5. SITE SPECIFIC MODEL SELECTION, PREPARATION, VERIFICATION, CALIBRATION, AND VALIDATION	1
5.1 MODEL SELECTION AND DESCRIPTION.....	1
5.2 HSPF MODEL	11
5.2.1 HSPF Model Development.....	11
5.2.1.1 Model Simulation Period	12
5.2.1.2 Model Constituents	12
5.2.1.3 Model Discretization.....	12
5.2.1.4 Land Use	16
5.2.1.5 Meteorological Data	20
5.2.1.6 Boundary Conditions.....	22
5.2.1.7 Point Source Discharges.....	30
5.2.1.8 Groundwater Withdrawals.....	34
5.2.1.9 Atmospheric Deposition	36
5.2.1.10 Best Management Practices	37
5.2.1.11 Model Coefficients.....	43
5.2.1.12 Initial Conditions	43
5.2.2 Verification of HSPF Model.....	43
5.2.3 Sensitivity Analysis.....	43
5.2.4 HSPF Model Calibration And Validation	45
5.2.4.1 Hydrologic Calibration	45
5.2.4.2 Hydrologic Validation	54
5.2.4.3 Water Quality Calibration	61
5.2.4.4 HSPF Model Validation	72
5.2.4.5 HSPF Output for EFDC Boundary Condition	82
5.3 EFDC Model.....	84
5.3.1 EFDC MODEL DEVELOPMENT	84
5.3.1.1 Topographic, Shoreline and Bathymetry Data	84
5.3.1.2 Grid Development	86
5.3.1.3 Parameters Simulated and Kinetic Option	89
5.3.1.4 Model Simulation Period	90
5.3.1.5 Model Initial Conditions	90
5.3.1.6 Model Boundary Conditions	90
5.3.1.6.1 Fresh Water Flows	91
5.3.1.6.2 HSPF – EFDC Linkage Approach.....	93
5.3.1.6.3 Use of HSPF versus Data	98

5.3.1.6.4 Open Boundaries	99
5.3.1.6.5 Large Scale Model	99
5.3.1.7 Meteorological Data	101
5.3.1.8 Sediment Diagenesis	101
5.3.2 Goodness of Fit Approach	102
5.3.2.1 Model Comparison Statistic	102
5.3.2.2 Available Data for Calibration/Validation.....	102
5.3.2.2.1 Hydrodynamic Calibration/Validation Stations	102
5.3.2.2.2 Water Quality Calibration/Validation Stations	103
5.3.3 Tidal Exchange and Boundary Flow Summary.....	105
5.3.3.1 Tidal Prism Ratio.....	106
5.3.4 EFDC Model Calibration	108
5.3.4.1 Model Simulation Period	108
5.3.4.2 Boundary Conditions.....	108
5.3.4.2.1 Flow Boundaries.....	108
5.3.4.2.2 Open Boundary Conditions	112
5.3.4.2.3 Sediment Diagenesis	112
5.3.4.2.4 Atmospheric/Wind Forcing	112
5.3.4.3 Tide Signal Calibration	115
5.3.4.4 Salinity Calibration	115
5.3.4.5 Water Temperature Calibration.....	120
5.3.4.6 Calibration Period Velocity Patterns	124
5.3.4.7 Water Quality Calibration	125
5.3.5 EFDC Model Validation	132
5.3.5.1 Model Simulation Period	132
5.3.5.2 Boundary Conditions.....	132
5.3.5.2.1 Flow Boundaries.....	132
5.3.5.2.2 Atmospheric / Wind Forcing	133
5.3.5.3 Tide Signal Validation	137
5.3.5.4 Salinity Validation	137
5.3.5.5 Water Temperature Validation	142
5.3.5.6 Water Quality Calibration	146
5.4 WASP MODEL	151
5.4.1 Model Development of WASP Model and EFDC/WASP linkage.....	151
5.4.1.1 Model Parameters.....	151
5.4.1.2 Model Boundary Locations.....	152
5.4.1.2.1 Flow, temperature and salinity Boundary Conditions.....	154
5.4.1.2.2 Water Quality Boundary Conditions	157
5.4.1.3 Model Simulation Periods	160
5.4.2 WASP Model Verification	160
5.4.2.1 Conservation of Mass	164
5.4.2.2 Numerical Stability	164
5.4.3 Preliminary Sensitivity Analysis.....	165

5.4.4 Overview of the WASP7 Water Quality Model	167
5.4.5 Methodology for Development of the WASP7 Model for the Caloosahatchee Estuary.....	167
5.4.5.1 Data Set Description and Model Control Parameters	167
5.4.5.2 Systems.....	167
5.4.5.3 Segments	168
5.4.5.4 Flows and Exchanges	170
5.4.5.5 Boundary Conditions.....	172
5.4.5.6 Point Source Loads.....	174
5.4.5.7 Parameters.....	175
5.4.5.7.1 Wind Forcing	175
5.4.5.7.2 Water Temperature	176
5.4.5.7.2 Light Extinction	176
5.4.5.7.3 Sediment Oxygen Demand and Benthic Nutrient Fluxes	178
5.4.5.7.4 Canopy Shading.....	181
5.4.5.8 Time Functions.....	181
5.4.5.8.1 Daily Solar Radiation and Fraction of Daily Light as Photoperiod	183
5.4.5.8.1 Wind Speed.....	183
5.4.5.8.1 Light Extinction Function #1.....	183
5.4.5.8.1 Time Variable Benthic Ammonia and Phosphate Fluxes.....	183
5.4.5.8.1 Air Temperature	184
5.4.5.9 Initial Conditions	185
5.4.6 Results of the Wasp7 Model	185
5.4.6.1 Model Calibration	185
5.4.6.1.1 Algal Biomass.....	185
5.4.6.1.2 Dissolved Oxygen	186
5.4.6.2 Model Validation.....	189
5.4.6.2.1 Algal Biomass.....	189
5.4.6.2.2 Dissolved Oxygen	191
5.5 WMM Calibration Refinement	194
5.5.1 WMM Calibration Parameters	194
5.5.1.1 Land Use	194
5.5.1.2 Hydrologic Data.....	195
5.5.1.2.1 Rainfall	195
5.5.1.2.2 Impervious Runoff Coefficient.....	195
5.5.1.2.3 Baseflow.....	196
5.5.1.3 Point Sources.....	196
5.5.2 BMPs.....	197
5.5.2.1 Urban BMPs.....	197
5.5.2.2 Agricultural BMPs.....	198
5.5.3 EVALUATION OF WMM RESULTS WITH CALIBRATION REFINEMENTS	202
5.6 Comparison of HSPF and WMM Caloosahatchee Watershed Models	211
5.6.1 Introduction.....	211
5.6.2 Methodology	216

5.6.3	Results.....	217
5.6.3.1	Tributary Area.....	217
5.6.3.2	Flow.....	218
5.6.3.3	Total Nitrogen.....	219
5.6.3.4	Total Phosphorus	219
5.6.3.5	Total Suspended Solids	219
5.6.3.6	Carbonaceous BOD	219
5.6.4	Summary and Recommendations.....	219
5.7	EFDC and WASP7: A Comparison	221
5.7.1	Introduction.....	221
5.7.1.1	Overview of EFDC	221
5.7.1.2	Overview of WASP7.....	221
5.7.2	Methodology.....	222
5.7.3	Results	222
5.7.3.1	Pre-Processing, Post-Processing and Data Visualization Tools	222
5.7.3.2	Resource Requirements	223
5.7.3.3	Availability of Model Software	224
5.7.3.4	Coupling of Water Column and Sediment Bed	224
5.7.4	Comparison of EFDC and WASP7 Water Quality Model Results	224
5.7.4.1	Model Calibration	225
5.7.4.1.1	Algal Biomass.....	225
5.7.4.1.2	Dissolved Oxygen	227
5.7.4.2	Model Validation.....	230
5.7.4.2.1	Algal Biomass.....	230
5.7.4.2.2	Dissolved Oxygen	231
5.7.5	Summary and Recommendations.....	233
5.7.5.1	Issue #1: Resource Requirements.....	234
5.7.5.2	Issue #2: Availability of Model Software	234
5.7.5.3	Issue #3: Coupling of Water Column and Sediment Bed	234
5.7.5.4	Recommendations	235
5.8	Recommended Data Needs and Model Refinements.....	236

FIGURES

Figure 5-1 Delineated hydrologic units for HSPF Modeling	13
Figure 5-2 Distribution of land uses in the Caloosahatchee River watershed.	17
Figure 5-3 Distribution of land uses in the lower and the upper Caloosahatchee River watershed	19
Figure 5-4 Zones defining the areas of equal precipitation time series developed from hourly NEXRAD data.	21
Figure 5-5 Daily average flow at S77	24
Figure 5-6 Hourly heat flux at S77	24
Figure 5-7 Hourly total suspended solids flux at S77.....	25
Figure 5-8 Hourly NH ₃ /NH ₄ flux at S77	25
Figure 5-9 Hourly nitrate + nitrite flux at S77	26
Figure 5-10 Hourly nitrite flux at S77.....	26
Figure 5-11 Hourly organic nitrogen flux at S-77	27
Figure 5-12 Hourly TKN flux at S77	27
Figure 5-13 Hourly total phosphate flux at S-77	28
Figure 5-14 Hourly ortho-phosphate flux at S77	28
Figure 5-15 Hourly dissolved oxygen flux at S77.....	29
Figure 5-16 Hourly Chl-a flux at S77.....	29
Figure 5-17 Location of permitted wastewater treatment facilities in the Caloosahatchee River watershed	31
Figure 5-18 Location of groundwater withdrawals in the Caloosahatchee River watershed	35
Figure 5-19. Cumulative historic groundwater pumpage rates in areas upstream and downstream of S-79	36
Figure 5-20 Best Management Practices by Type with Hydrologic Unit Numbers Shown	42
Figure 5-21 Impact of 20% increase in rainfall intensity on streamflow at the USGS gage 02292900	44
Figure 5-22 Impact of 50% increase in evapotranspiration rate on streamflow at the USGS gage 02292900	44
Figure 5-23 Impact of reduction of infiltration rate on streamflow at the USGS gage 02292900	45
Figure 5-24 Flow gages in the Caloosahatchee River watershed that have long-term daily flow records	47
Figure 5-25 Modeled and observed flows at S-79 for the calibration period	48

Figure 5-26 Modeled and observed flows at S-78 for the calibration period	48
Figure 5-27 Modeled and observed flows at the San Carlos Canal gage for the calibration period	49
Figure 5-28 Comparison of monthly average modeled and observed flows at S-79 for the calibration period	49
Figure 5-29 Comparison of monthly average modeled and observed flows at S-78 for the calibration period.	51
Figure 5-30 Comparison of monthly average modeled and observed flows at the San Carlos Canal gage for the calibration period	51
Figure 5-31 Probability of exceedance of observed and modeled daily flows at S-79 for the calibration period	52
Figure 5-32 Probability of exceedance of observed and modeled daily flows at S-78 for the calibration period	52
Figure 5-33 Probability of exceedance of observed and modeled daily flows at San Carlos for the calibration period	53
Figure 5-34 Modeled and observed flows at S-79 for the validation period.....	55
Figure 5-35 Modeled and observed flows at S-78 for the validation period.....	56
Figure 5-36 Modeled and observed flows at the San Carlos Canal gage for the validation period.....	56
Figure 5-37 Probability of exceedance of observed and modeled daily flows at S79 for the validation period	57
Figure 5-38 Probability of exceedance of observed and modeled daily flows at S78 for the validation period	57
Figure 5-39 Probability of exceedance of observed and modeled daily flows at San Carlos for the validation period	58
Figure 5-40 Comparison of monthly average modeled and observed flows at S-79 for the validation period.	58
Figure 5-41 Comparison of monthly average modeled and observed flows at S-78 for the validation period	59
Figure 5-42 Comparison of monthly average modeled and observed flows at the San Carlos Canal gage for the validation period.	59
Figure 5-43 Water quality monitoring stations in the Caloosahatchee River watershed that were used for model calibration and validation.	62
Figure 5-44 Modeled and observed water temperature at the S-79 station for the model calibration period	63
Figure 5-45 Modeled and observed TSS concentrations at the S-79 station for the model calibration period	63

Figure 5-46 Modeled and observed nitrate plus nitrite concentrations at the S-79 station for the model calibration period	64
Figure 5-47 Modeled and observed TKN concentrations at the S-79 station for the model calibration period	64
Figure 5-48 Modeled and observed ammonia concentrations at the S-79 station for the model calibration period.	65
Figure 5-49 Modeled and observed phosphate concentrations at the S-79 station for the model calibration period.	65
Figure 5-50 Modeled and observed dissolved oxygen concentrations at the S-79 station for the model calibration period	66
Figure 5-51 Modeled and observed water temperature at the S-78 station for the model calibration period	66
Figure 5-52 Modeled and observed total suspended solids concentrations at the S-78 station for model calibration period	67
Figure 5-53 . Modeled and observed nitrate plus nitrite concentrations at the S-78 station for the model calibration period.	67
Figure 5-54 Modeled and observed TKN concentrations at the S-78 station for the model calibration period	68
Figure 5-55 Modeled and observed ammonia concentrations at the S-78 station for the model calibration period.	68
Figure 5-56 Modeled and observed phosphate concentrations at the S-78 station for the model calibration period.	69
Figure 5-57 . Modeled and observed dissolved oxygen concentrations at the S-78 station for the model calibration period	69
Figure 5-58 Modeled and observed water temperature at the Whiskey Creek station for the model calibration period	70
Figure 5-59 Modeled and observed total suspended solids concentrations at the Whiskey Creek station for the model calibration period	70
Figure 5-60 Modeled and observed nitrate plus nitrite concentrations at the Whiskey Creek station for the model calibration period	71
Figure 5-61 Modeled and observed ammonia concentrations at the Whiskey Creek station for the model calibration period	71
Figure 5-62 . Modeled and observed water temperature at the S-79 station for the model validation period.	72
Figure 5-63 Modeled and observed total suspended solids concentrations at the S-79 station for the model validation period	73

Figure 5-64. Modeled and observed nitrate plus nitrite concentrations at the S-79 station for the model validation period	73
Figure 5-65 Modeled and observed TKN concentrations at the S-79 station for the model validation period	74
Figure 5-66 Modeled and observed ammonia concentrations at the S-79 station for the model validation period.	74
Figure 5-67 Modeled and observed phosphate concentrations at the S-79 station for the model validation period.	75
Figure 5-68 Modeled and observed dissolved oxygen concentrations at the S-79 station for the model validation period.	75
Figure 5-69 Modeled and observed water temperature at the S-78 station for the model validation period.	76
Figure 5-70 Modeled and observed total suspended solids concentrations at the S-78 station for the model validation period	76
Figure 5-71 Modeled and observed nitrate plus nitrite concentrations at the S-78 station for the model validation period	77
Figure 5-72 Modeled and observed TKN concentrations at the S-78 station for the model validation period	77
Figure 5-73 Modeled and observed ammonia concentrations at the S-78 station for the model validation period.	78
Figure 5-74 Modeled and observed phosphate concentrations at the S-78 station for the model validation period	78
Figure 5-75 Modeled and observed dissolved oxygen concentrations at the S-78 station for the model validation period	79
Figure 5-76 Modeled and observed water temperature at the Whiskey Creek station for the model validation period	79
Figure 5-77 Modeled and observed total suspended solids concentrations at the Whiskey Creek station for the model validation period	80
Figure 5-78 Modeled and observed nitrate plus nitrite concentrations at the Whiskey Creek station for the model validation period	80
Figure 5-79 Modeled and observed ammonia concentrations at the Whiskey Creek station for the model validation period	81
Figure 5-80 Locations of HSPF model output to be used as EFDC boundary condition.....	83
Figure 5-81 Digital Terrain Model of the Caloosahatchee water quality model domain (elevations in feet relative to MSL).	85
Figure 5-82 Caloosahatchee model grid with representative cell indices.....	87

Figure 5-83 Caloosahatchee model domain with model bathymetry	88
Figure 5-84 Location of tidal and HSPF boundary conditions relative to the Caloosahatchee grid	91
Figure 5-85 Observed flows and temperature versus HSPF at S79.....	93
Figure 5-86 Large scale model grid and bathymetry	100
Figure 5-87 Ft Myers International Airport wind rose for 2003-2004	104
Figure 5-88 Stations used for hydrodynamic and water quality model calibration/validation	105
Figure 5-89 Time series of the Gulf of Mexico tide data used for the TPR computations	107
Figure 5-90 Time series of dye and volume in the Caloosahatchee River during the TPR tidal cycle	107
Figure 5-91 Time series of flow and constituent concentrations for S79 for 2003.....	108
Figure 5-92 Total Organic Carbon mass loading time series for 2003	109
Figure 5-93 Total Phosphorus mass loading time series for 2003	110
Figure 5-94 Total Nitrogen mass loading time series for 2003	110
Figure 5-95 Sediment diagenesis TOC G3 initial conditions	113
Figure 5-96 Ft Myers wind stick plot for 2003	114
Figure 5-97 Water surface elevation calibration at Ft Myers	115
Figure 5-98 Salinity calibration at BR31 - Bottom	116
Figure 5-99 Salinity calibration at BR31 – Top	116
Figure 5-100 Salinity calibration at CCORAL - Bottom.....	117
Figure 5-101 Salinity calibration at CCORAL – Top	117
Figure 5-102 Salinity calibration at CES09	118
Figure 5-103 Temperature calibration at BR31 – Bottom	120
Figure 5-104 Temperature calibration at BR31 – Top	121
Figure 5-105 Temperature calibration at CCORAL – Top	121
Figure 5-106 Temperature calibration at CES09	122
Figure 5-107 Velocity pattern near ebb tide on May 15, 2003.....	124
Figure 5-108 Velocity pattern near flood tide on May 16, 2003	125
Figure 5-109 Dissolved oxygen calibration time series for CES04, surface layer	126
Figure 5-110 Dissolved oxygen calibration time series for CES04, bottom layer	126

Figure 5-111 Dissolved oxygen calibration time series for CES06, surface layer	127
Figure 5-112 Dissolved oxygen calibration time series for CES06, bottom layer	127
Figure 5-113 Dissolved oxygen calibration time series for PI-01, surface layer	128
Figure 5-114 Chlorophyll-a calibration time series for CES04, surface layer	128
Figure 5-115 Chlorophyll-a calibration time series for CES06, surface layer	129
Figure 5-116 Chlorophyll-a calibration time series for PI-01, surface layer	129
Figure 5-117 Time series of flow and constituent concentrations for S79 for 2004.....	132
Figure 5-118 Total Organic Carbon mass loading time series for 2004	133
Figure 5-119 Total Phosphorus mass loading time series for 2004	134
Figure 5-120 Total Nitrogen mass loading time series for 2004	134
Figure 5-121 Ft Myers wind stick plot for 2004	136
Figure 5-122 Water surface elevation validation at Ft Myers	137
Figure 5-123 Salinity validation at BR31 - Bottom	138
Figure 5-124 Salinity validation at BR31 – Top.....	138
Figure 5-125 Salinity validation at CCORAL - Bottom	139
Figure 5-126 Salinity validation at CCORAL – Top.....	139
Figure 5-127 Salinity validation at CES09	140
Figure 5-128 Temperature validation at BR31 – Bottom	142
Figure 5-129 Temperature validation at BR31 – Top.....	143
Figure 5-130 Temperature validation at CCORAL – Top.....	143
Figure 5-131 Temperature validation at CES09	144
Figure 5-132 Dissolved oxygen validation time series for CES04, surface layer	146
Figure 5-133 Dissolved oxygen validation time series for CES04, bottom layer	147
Figure 5-134 Dissolved oxygen validation time series for CES06, surface layer	147
Figure 5-135 Dissolved oxygen validation time series for CES06, bottom layer	148
Figure 5-136 Dissolved oxygen validation time series for PI-01, surface layer	148
Figure 5-137 Chlorophyll-a validation time series for CES04, surface layer	149
Figure 5-138 Chlorophyll-a validation time series for CES06, surface layer	149

Figure 5-139 Chlorophyll-a validation time series for PI-01, surface layer	150
Figure 5-140 Caloosahatchee River Estuary WASP Modeling boundary location	153
Figure 5-141 Caloosahatchee River upstream EFDC volume derived boundary conditions	154
Figure 5-142 Caloosahatchee River upstream EFDC temperature derived boundary conditions.....	155
Figure 5-143 Caloosahatchee River Open Boundary EFDC volume derived boundary conditions	155
Figure 5-144 Caloosahatchee River Open Boundary EFDC temperature derived boundary conditions	156
Figure 5-145 Caloosahatchee River Open Boundary EFDC salinity derived boundary conditions.....	156
Figure 5-146 Caloosahatchee River upstream DO boundary concentration	157
Figure 5-147 Caloosahatchee River upstream Nitrate boundary concentration.....	158
Figure 5-148 Coastal DO boundary concentration	159
Figure 5-149 Coastal Nitrate boundary concentration	159
Figure 5-150 Spatial Nitrate distribution (in mg/l) after 1 month simulation	161
Figure 5-151 Spatial DO distribution (in mg/l) after 1 month simulation	162
Figure 5-152 Station CES07 time series dissolved oxygen simulation.....	163
Figure 5-153 Station CES07 time series Nitrate simulation.....	164
Figure 5-154 Sensitivity of Nitrate to variations in SOD.....	166
Figure 5-155 Sensitivity of Dissolved Oxygen to variations in SOD	166
Figure 5-156 Seasonal median levels of salinity, apparent color and dissolved oxygen in the Caloosahatchee River Estuary with distance from S-79 to San Carlos Bay. Data from Crean (2007).	177
Figure 5-157 Water quality zones assigned for EFDC and WASP7	180
Figure 5-158 Station CES-04 surface Chlorophyll, Calibration year of 2003.....	186
Figure 5-159 Station CES-06 surface Chlorophyll, Calibration year of 2003.....	186
Figure 5-160 Dissolved oxygen, Station CES-04, Surface layer, Calibration year of 2003.....	187
Figure 5-161 Dissolved oxygen, Station CES-04, Bottom layer, Calibration year of 2003.....	188
Figure 5-162 Dissolved oxygen, Station CES-06, Surface layer, Calibration year of 2003.....	188
Figure 5-163 Dissolved oxygen, Station CES-06, Bottom layer, Calibration year of 2003.....	189
Figure 5-164 Chlorophyll, Station CES-04, Surface layer, Validation year of 2004	190
Figure 5-165 Chlorophyll, Station CES-06, Surface layer, Validation year of 2004	190

Figure 5-166 Dissolved oxygen, Station CES-04, Surface layer, Validation year of 2004	192
Figure 5-167 Dissolved oxygen, Station CES-04, Bottom layer, Validation year of 2004	192
Figure 5-168 Dissolved oxygen, Station CES-06, Surface layer, Validation year of 2004	193
Figure 5-169 Dissolved oxygen, Station CES-06, Bottom layer, Validation year of 2004	193
Figure 5-170 Urban BMP coverage developed based on historical land use change method.....	201
Figure 5-171 Agricultural BMP coverage developed based on FDACS' NOIs database	204
Figure 5-172 Station CES-04 surface Chlorophyll, Calibration year of 2003.....	226
Figure 5-173 Station CES-06 surface Chlorophyll, Calibration year of 2003.....	227
Figure 5-174 Dissolved Oxygen, Station CES-04, Surface layer, Calibration year of 2003	228
Figure 5-175 Dissolved Oxygen, Station CES-04, Bottom layer, Calibration year of 2003	228
Figure 5-176 Dissolved Oxygen, Station CES-06, Surface layer, Calibration year of 2003	229
Figure 5-177 Dissolved Oxygen, Station CES-06, Bottom layer, Calibration year of 2003	229
Figure 5-178 Chlorophyll, Station CES-04, Surface layer, Validation year of 2004	230
Figure 5-179 Chlorophyll, Station CES-06, Surface layer, Validation year of 2004	231
Figure 5-180 Dissolved Oxygen, Station CES-04, Surface layer, Validation year of 2004	231
Figure 5-181 Dissolved Oxygen, Station CES-04, Bottom layer, Validation year of 2004	232
Figure 5-182 Dissolved Oxygen, Station CES-06, Surface layer, Validation year of 2004	232
Figure 5-183 Dissolved Oxygen, Station CES-06, Surface layer, Validation year of 2004	233

TABLES

Table 5-1 Candidate Hydrologic/Watershed Runoff and Models	4
Table 5-2 Candidate Receiving Water Models.....	4
Table 5-3 Reach Characteristics used to Develop F-Tables (rating curves) for the HSPF Model	14
Table 5-4 Distribution of areas and estimated DCIA by land use in the upper, lower and entire Caloosahatchee River watershed .	18
Table 5-5 Total annual precipitation by NEXRAD zone and its statistics.....	22
Table 5-6 Correlation of Datasets.....	23
Table 5-7 Wastewater treatment facilities and their discharge information	32
Table 5-8 Average concentrations of water quality constituents in point source effluents based on DMR data	33
Table 5-9 Average water quality concentrations in groundwater based on analysis of DBHydro data.....	36
Table 5-10 Monthly average nutrient concentrations in wet atmospheric deposition	37
Table 5-11 Urban and Agricultural BMP Removal Efficiencies by Constituent and BMP Type.....	38
Table 5-12 Acreage of BMP by Hydrologic Unit and Type.	38
Table 5-13 Observed and modeled annual average flows and associated errors at S-79 during model calibration	54
Table 5-14 Observed and modeled annual average flows and associated errors at S-79 during model validation.	60
Table 5-15 Calculated statistics for water quality simulation over the entire simulation period at S-79.	82
Table 5-16 Datum Elevations in MSL Feet at Ft. Myers (NOAA#8725520)	85
Table 5-17 EFDC parameters simulated.....	89
Table 5-18 Annual freshwater contribution to the Caloosahatchee from S79	92
Table 5-19 Location of discharge for the Caloosahatchee WWTF's.....	93
Table 5-20 HSPF Water Quality Model State Variables	94
Table 5-21 EFDC parameter to FDEP data correspondence used for calibration	103
Table 5-22 Nutrient mass loadings for the Year 2003 in tons.....	111
Table 5-23 Calibration period summary statistics for Salinity (PPT)	119
Table 5-24 Calibration period summary statistics for Temperature (°F)	123
Table 5-25 Summary of the water quality statistics: calibration period	130
Table 5-26 Nutrient mass loadings for the Year 2004 in tons.....	135
Table 5-27 Validation period summary statistics for Salinity (PPT)	141

Florida Department of Environmental Protection
Caloosahatchee River Basin TMDL Model Support
Task Assignment CDM07-04, May 2008

Table 5-28 Validation period summary statistics for Temperature (°F).....	145
Table 5-29 Summary of the water quality statistics: validation period	150
Table 5-30 WASP7 systems (state variables) of the eutrophication model.....	168
Table 5-31 WASP7 surface layer model segments for the Caloosahatchee Estuary.....	169
Table 5-32 WASP7 flows and settling for solids fields 1, 2 and 3.....	171
Table 5-33 WASP7 subsurface layer model segments for the Caloosahatchee Estuary	172
Table 5-34 WASP7 state variables and units	173
Table 5-35 WASP7 spatial parameters	175
Table 5-36 Summary statistics of water quality for four regions of the Caloosahatchee River and Estuary from 1994 to 2006. Region 1=0-10 km; Region 2=10-30 km; Region 3=30-40 km and Region 4 (estimated)= San Carlos Bay/Pine Is. Sound/Gulf of Mexico. Apparent color data from Crean (2007).....	178
Table 5-37 Time functions for WASP7 model.....	182
Table 5-38 Proposed Percent Imperviousness for Selected Land Use Categories.....	195
Table 5-39 Average Annual Rainfall per Sub-watershed for the Period 1997-2005.	195
Table 5-40 Annual Baseflow per Sub-watershed for the Period 1997-2005.....	196
Table 5-41 Flow and Concentrations from Lake Okeechobee Releases (S-77) to Downstream Calibration Points for the Period 1997-2005.....	197
Table 5-42 Urban BMP Based on Historical Land Use Change Method (1988 vs 2004)	199
Table 5-43 Agricultural BMP Coverage and Assigned Set of Removal Efficiencies.	203
Table 5-44 Assigned Removal Efficiencies for Set 1 and 2 per Constituent.....	205
Table 5-45 Average Annual Loads for the East Caloosahatchee Sub-watershed (Existing Land Use, Year 2004) with Delivery Ratios Set to S-78.	206
Table 5-46 Average Annual Loads for the East Caloosahatchee Sub-watershed (Existing Land Use, Year 2004) with Delivery Ratios Set to S-79.	206
Table 5-47 Average Annual Loads for the West Caloosahatchee Sub-watershed (Existing Land Use, Year 2004).	207
Table 5-48 Average Annual Loads for the Tidal Caloosahatchee Sub-watershed (Existing Land Use, Year 2004).....	207
Table 5-49 Comparison of WMM Average Annual Loads for the Whiskey Creek Hydrologic Unit and Estimated Loads from Available Data.....	210
Table 5-50 Comparison of WMM and HSPF land-based flow calculation methods.....	212
Table 5-51 Comparison of WMM and HSPF land-based sediment calculation methods.....	213
Table 5-52 Comparison of WMM and HSPF land-based nutrients and BOD calculation methods.....	214

Table 5-53 Comparison of WMM and HSPF land-based water temperature and DO calculation methods 215

Table 5-54 Comparison of WMM and HSPF transport network flow and water quality calculation methods..... 216

Table 5-55 Comparison of WMM and HSPF average annual flows and loads 1997-2005 217

APPENDICES

Appendix 5-A	References
Appendix 5-B	Summary of NEXRAD rainfall data and comparisons to NOAA gage data
Appendix 5-C	Table of BMP Pollutant Load Reductions by Parameters
Appendix 5-D	HSPF Hydrologic Parameters for Agricultural Land Uses
Appendix 5-E	EFDC Calibration Plots
Appendix 5-F	EFDC Validation Plots
Appendix 5-G	WASP Calibration Plots
Appendix 5-H	WASP Validation Plots
Appendix 5-I	Comparison of EFDC and WASP Plots for Calibration
Appendix 5-J	Comparison of EFDC and WASP Plots for Validation

ABBREVIATIONS AND ACRONYMS

1D	One Dimensional
2D	Two Dimensional
3D	Three Dimensional
ARS	Agricultural Research Service
ASER	Atmospheric Time series
BASINS	Better Assessment Science Integrating Point and Nonpoint Sources
BMP	Best Management Practice
BOD ₅	5-day Biochemical Oxygen Demand
C	Centigrade
CBOD	Carbonaceous Biochemical Oxygen Demand
cfs	cubic feet per second
CH3D	Curvilinear Hydrodynamics in 3-Dimensions
DBHYDRO	SFWMD Hydrologic database
DLG	Digital Line Graph
DO	Dissolved Oxygen
DTM	Digital Terrain Model
EFDC	Environmental Fluid Dynamics Code
EMC	Event Mean Concentrations
EPA	United States Environmental Protection Agency
F-Tables	Hydraulic Function Tables
F	Fahrenheit
FDACS	Florida's Department of Agricultural and Consumer Services
FDEP	Florida Department of Environmental Protection
Ft	Foot
GIS	Geographic Information System
GUI	Graphic User Interface
HSPF	Hydrological Simulation Program FORTRAN
ID	Identification
IFAS	University of Florida, Institute of Food and Agricultural Sciences
m	meters
µg/l	micrograms per liter
mg/l	milligrams per liter
MPH	Miles per hour
MSL	Mean Sea Level
NAD83	North Atlantic Datum 1983
NED	National Elevation Dataset
NEXRAD_	NEXt Generation RADar
NGVD	National Geodetic Vertical Datum
NGDC	National Geophysical Data Center
NH ₃	Ammonia
NH ₄	Ammonium
NHD	National Hydrographic Dataset
NO ₃	Nitrate

Florida Department of Environmental Protection
 Caloosahatchee River Basin TMDL Model Support
 Task Assignment CDM07-04, May 2008

NO4	Nitrite
NOAA	National Oceanic and Atmospheric Administration
NOI	Notice of Intent
NPDES	National Pollution Discharge Elimination System
OWW	Okeechobee Waterway
PET	Potential Evapotranspiration
ppt	parts per thousand
PCS	<i>EPA</i> Permit Compliance System
PET	Potential Evapotranspiration
RMS	Root Mean Square
SANDS	System for Accurate Nearshore Depth Surveying
SFWMD	South Florida Water Management District
STORET	STOrage and RETrieval
SWAT	Soil and Water Assessment Tool
Texas A&M	Texas Agricultural and Mechanical University
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TOC	Total Organic Carbon
TON	Total Organic Nitrogen
TOP	Total Organic Phosphorus
TP	Total Phosphorus
TPR	Tidal Prism Ratio
TSS	Total Suspended Solids
URL	Uniform Resource Locator
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USGS	United States Geologic Survey
UTM	Universal Transverse Mercator
WAM	Watershed Assessment Model
WASP	Water Quality Analysis Simulation Program
WBAN	Weather Bureau Army Navy
WBID	Water Body Identification
WDM	Watershed Data Management Utility
WLA	Waste Load Allocation
WMM	Watershed Management Model
WOD	World Ocean Database
WQBELS	Water Quality Based Effluent Limits
WSER	Wind Time Series
WSR-88D	Weather Surveillance Radar-1988 Doppler
WWTF	Waste Water Treatment Facility
WWTP	Waste Water Treatment Plant

5. SITE SPECIFIC MODEL SELECTION, PREPARATION, VERIFICATION, CALIBRATION, AND VALIDATION

5.1 MODEL SELECTION AND DESCRIPTION

In the previous modeling studies of Caloosahatchee River Basin, the major limitations of the CH3D and Mike-She applications were that time variable conditions, including simulations of long-term historical time series, could not be represented with the steady-state models. Spatial resolution was also constrained with these models to a one-dimensional analysis for the Caloosahatchee River estuary. Three-dimensional time variable simulations of water quality in the estuary were thus not available with these earlier water quality models of the estuary.

Model Criteria. The following criteria need to be met in the next set of coupled hydrologic, hydrodynamic and water quality models developed for the Caloosahatchee River watershed and Caloosahatchee River estuary. As identified by Florida Department of Environmental Protection (FDEP), the model(s) must be capable of:

- Simulating dynamic conditions over both short time periods (one week) and long time periods (over one year). Time steps between hydrodynamic and water quality simulations must be compatible.
- Spatial resolution (3D), where needed, to include the complex hydrodynamics of streams, estuaries, wetlands, and provide boundary conditions for the Gulf of Mexico.
- Capable of being calibrated and verified using large historical data sets.
- Capable of simulating both time variable point source and nonpoint source inputs. The nonpoint source inputs may be measured, or simulated, based on land uses of historical, present, and future conditions. These inputs may include atmospheric, surface runoff, groundwater, sediment, or tidal data or measurements.
- Developing Water Quality Based Effluent Limits (WQBELs) and Total Maximum Daily Loads (TMDLs) for a variety of water quality parameters including: Dissolved Oxygen (DO), Nutrients, Bacteria, Sediments, and Toxics. Model should include provision for representation of various point source treatment options and BMPs to reduce nonpoint source loads.
- Candidate models include, but are not limited to: HSPF, BASINS-HSPF, WMM, or WAM for hydrologic runoff and watershed-based land use loadings and QUAL2K (1D river); WASP7 or EFDC (3D rivers, estuaries) for receiving water models. The model(s) selected must be in the public domain and have associated user-friendly pre- and post-processing tools that allow for input of data, grid generation, and presentation of results. Consultant should be able to modify these tools based on the needs of the model(s) selected.

Categories of Surface Water Models. The transport pathways and fate of naturally occurring constituents and synthetic organic chemicals in a drainage basin are driven by complex interactions of several factors including precipitation, land uses, urban/rural watershed runoff, groundwater and surface water transport, wastewater inputs, and chemical transformations and biological processes in both the water column and sediment bed. Hydrologic and watershed

runoff models, based on a description of topography, land uses and hydrology, are used to determine streamflow and the quantity of pollutant loading delivered from the land surface of a watershed to the surface waters of a receiving stream, river, lake or estuary. Receiving water models are used to determine the fate and transport of pollutants in surface waters, as well as to predict the interacting effects of the pollutant on other water quality constituents of interest. Watershed and waterbody models of pollutant transport and fate provide decision makers with tools to understand, and compare, the relative significance of the effect of natural processes and human activities on water quality conditions. Models are used to support the development of water pollution control/water quality management plans, including TMDLs, based on quantitative comparisons of the effectiveness of alternative point and nonpoint source control policies.

Surface water models can be differentiated according to how the open boundaries of the physical domain are defined and by the corresponding specification of terms in the model equations. Pollutant loads, physical transport processes, and kinetic interactions can be defined as (a) externally provided input data to a model or as (b) internally calculated by the model. As water quality management issues have become increasingly complex over the past decade, the domain boundaries of water quality models have expanded. Transport pathways and mass loading of pollutants, such as nitrogen in the Chesapeake Bay Program model (<http://www.chesapeakebay.net/model.htm>), are computed and coupled internally through watershed runoff models, regional air quality models, groundwater models, hydrodynamic models, eutrophication and aquatic ecosystem models, sediment diagenesis models and sediment transport models.

Watershed and surface receiving water models can be further differentiated according to the level of complexity, of the spatial and temporal scales, the state variables used, and the kinetic interactions and processes considered in a model framework. To account for these distinguishing features between models, three levels of models are used to assist in the review and selection of appropriate models for the Caloosahatchee Bay study: Level 1- simple screening models; Level 2-mid-range or intermediate models; and Level 3-complex or advanced models. An overview of each level of model follows.

Level 1- Simple Screening Models. Screening-level water quality models are designed to represent only a few selected pollutants as state variables with limited interactions and processes considered and minimal, if any, calibration to observed data. Screening models provide preliminary engineering estimates of wastewater discharge quantities and water quality conditions. Simplified screening models can be performed inexpensively to quickly identify watersheds, geographic areas, or river reaches that may have major pollution sources and related water quality problems. The results of screening-level analyses, evaluated relative to each management alternative investigated, can then be used to identify where monitoring efforts are needed or where more detailed modeling investigations may be required. An example of this type of model is the WMM, which is an annual and seasonal loading model that can be used to evaluate relative changes in runoff volume and pollutant loads due to changes in land use (e.g., historic to existing to future) and/or implementation of BMPs. WMM has quick run times (seconds vs. hours) and was used in this project for comparison with HSPF for total annual and seasonal loads for different land use conditions and to screen different BMP options for Basin Management Action Plan (BMAP) support.

Level 2- Mid-Range Intermediate Models. Mid-range, or intermediate planning-level, models generally include a more detailed characterization of transport processes and pollutant loads that determine transport and fate of multiple pollutants with consideration given to multiple processes and kinetic interactions. Mid-range models, often developed with GIS or GUI interfaces, require calibration and validation to observed data sets. Mid-range watershed models can be used to target sub-areas within a larger drainage basin and to support relative comparisons of point source treatment or BMP management alternatives.

Level 3- Complex or Advanced Models. Complex watershed and surface water quality models represent state-of-the-art scientific understanding of a wide range of watershed and aquatic ecosystem processes and kinetic interactions of numerous chemical and biological constituents in the water column including exchange of constituents between the water column and sediment bed. Level 3 models are designed to provide assessments of the interrelationships between physical transport, biological and chemical processes. These processes interact to generate the quantity and quality of surface waters in response to pollutant loading from both natural and human related activities such as land use changes and point source discharges of wastewater to receiving waters. Level 3 models, typically requiring assignment of numerous model coefficients and parameters, are often developed initially for applied research purposes before widespread adoption for practical water quality management evaluations such as TMDLs. Complex water quality models, linked with watershed runoff models and hydrodynamic models, have been developed to address issues related to oxygen depletion, nutrients and eutrophication, sediment transport, toxic chemical fate and bioaccumulation of toxics.

The candidate watershed runoff and receiving water models reviewed for the selection of models for the Caloosahatchee Bay study are listed in **Tables 5-1 and 5-2**. An overview description of the features of each of the candidate models follows.

Table 5-1 Candidate Hydrologic/Watershed Runoff and Models

Hydrologic and Watershed Runoff Models					
Model	Name	Sponsor & Developer	Level	Space	Time
HSPF	Hydrological Simulation Program Fortran	USGS AQUA TERRA	3	sub-basin	hourly
BASINS-HSPF	Better Assessment Science Integrating Point & Nonpoint Sources-HSPF	EPA AQUA TERRA TetraTech	3	sub-basin	Hourly & daily
WMM	Watershed Management Model	FDEP	1	sub-basin	Annual & seasonal
WAM	Watershed Assessment Model	FDEP EPA SWET	2	grid-based	Hourly/ daily
SWAT	Soil and Water Assessment Tool	USDA ARS Texas A&M	3	sub-basin	daily

Level 1=methods; Level 2=mid-range intermediate; Level 3= advanced/complex

Table 5-2 Candidate Receiving Water Models

Receiving Water Models						
Model	Name	Sponsor & Developer	Level	Space	Time	Transport
QUAL2K		Tufts U (Chapra)	2.	1D(x)	steady	internal
QUAL2E		EPA Athens ERL			state	hydraulics
WASP7	Water Analysis Simulation Program	EPA Athens ERL Wool et al.	3	3D	hourly daily	external linked hydro-dynamic.
CE-QUAL-W2		USACE WES Portland State U Cole & Wells, (2000).	3	2D(xz)	hourly daily	internal hydro-dynamic.
EFDC	Environmental Fluid Dynamics Code	EPA Tetra Tech	3	3D	Hourly & daily	internal hydro-dynamic.

Level 1=methods; Level 2=mid-range intermediate; Level 3= advanced/complex

HSPF. The Hydrological Simulation Program FORTRAN (HSPF), supported by EPA and the USGS as a public domain model, is a lumped parameter watershed runoff model that simulates watershed hydrology and non-point source pollutant loadings for organic matter, nutrients, sediments, bacteria and toxic chemicals within a watershed network of delineated sub-basins. The internal stream model routes flow and water quality constituents through a network of river reaches for each sub-basin of the watershed. The HSPF hydrologic sub-model provides for simulation of water balances in each sub-basin based on precipitation, evaporation, water withdrawals, irrigation, diversions, wastewater discharges, infiltration, and active and deep groundwater reservoirs. Empirical model parameters are assigned for each sub-basin land use through model calibration to simulate the water balance and pollutant loading from a sub-basin. HSPF is designed as a time variable model with results generated on an hourly or daily basis. Hundreds of applications of HSPF over the past two decades have included short-term storm events and/or continuous simulations over annual and decadal cycles. BMP alternatives designed to reduce pollutant loads to receiving waters can be represented in HSPF by adjustments of land use-based yield coefficients for a pollutant. Windows-based user-friendly GUI software tools such as WinHSPF (Duda et al., 2001), GenScn (Kittle et al., 1998) and HSPFParm (Donigian et al., 1999) have been developed to facilitate pre- and post-processing tasks for HSPF. Time series results for streamflow and pollutant loads generated by HSPF have been linked for input to hydrodynamic (e.g., EFDC) and water quality models (e.g., EFDC, WASP7) in numerous applications over the past decade. HSPF is considered a Level 3 Complex or Advanced Model. The URL for HSPF is <http://www.epa.gov/ceampubl/swater/hspf/index.htm>.

BASINS-HSPF. The Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) surface water modeling system was developed by EPA as a public domain modeling framework to facilitate the (a) extraction of environmental data from national databases (e.g., STORET, PCS, digital elevation, USGS streamflow, RF1, NHD, land use, soils); (b) setup and configuration of watershed runoff and surface water quality models; and (c) provide an integrated framework for model execution including comparison and evaluation of management alternatives, including the development of TMDLs, for improving surface water quality conditions (Lahlou et al., 1998). The ArcView Geographic Information System (GIS) provides an integrating framework for organizing, display and analysis of data and model results. Watershed runoff models integrated into the BASINS software package include HSPF (described above) and the Soil and Water Assessment Tool (SWAT) (described below). BASINS-HSPF is considered a Level 3 Complex or Advanced Model. The URL for BASINS is <http://www.epa.gov/athens/wwqtsc/html/basins.html>.

WMM. The Watershed Management Model (WMM) for Windows is the latest version of the WMM originally developed by CDM using Lotus 123. The WMM, developed specifically to estimate annual and/or seasonally averaged nonpoint source pollutant loads derived from direct runoff on watersheds and sub-basins, was modified to address watershed management needs. WMM estimates loads based on local hydrology and non-point loading factors (Event Mean Concentrations, EMCs) which relate land use patterns and percent imperviousness in a watershed to drainage area normalized pollutant loadings (mass/time-area). Options are also available for calculating combined sewer overflow (CSO) and point source wastewater loads. WMM for Windows (a) provides a more robust and user-friendly interface than the previous versions of WMM and (b) functions as a stand-alone application requiring no additional software. WMM can evaluate urban and rural runoff and point source wastewater discharges; use runoff

and baseflow (if known) and evaluate BMP options. Since nonpoint source loads can only be estimated as annual or seasonal averages, WMM is considered a Level 1 Simplified Screening Model.

WAM. The Watershed Assessment Model (WAMView), supported by EPA's Watershed and Water Quality Modeling Center as a public domain model, is a continuous simulation, grid-based watershed scale modeling tool that has been shown to be useful in the assessment of watershed-related properties on water quality (Bottcher et al., 1998; 2005). WAM was developed to allow engineers and planners to assess the water quality of both surface water and groundwater based on topography, land use, soils, climate, and other factors. Using a physically-based spatial grid, the model simulates the key physical processes important for watershed hydrology and pollutant transport. The WAM GIS-based data sets include land use, soils, topography, hydrography, basin and sub-basin boundaries, point source wastewater facilities and service area coverages and climate data. WAM simulates surface water and ground water flow allowing for the assessment of flow and pollutant loading for a tributary reach at both daily and hourly time increments as necessary. Water quality constituents represented in WAM include particulate and soluble phosphorus, particulate and soluble nitrogen (NO₃, NH₄, and organic N), total suspended solids, and biological oxygen demand. The results of WAM are generated as time series outputs located at the source cells, sub-basins, and individual tributary reaches. Results can be displayed as source load maps (surface water and groundwater), attenuated sub-basin and basin loads, ranking of land uses by load source, daily time series of flows and pollutants, and comparative displays showing the effects of different BMP/Management Scenarios. Windows-based user-friendly GUI software tools have been developed to facilitate pre- and post-processing tasks for WAM. WAM is considered a Level 2 Mid-Range or Intermediate Model. The EPA URL for WAMView is <http://www.epa.gov/athens/wwqtsc/html/wamview.html>.

SWAT. The Soil and Water Assessment Tool (SWAT), developed in the early 1990's at Texas Agricultural and Mechanical University by the USDA Agricultural Research Service (ARS) as a public domain model, has many of the same functions as HSPF. Unlike HSPF, however, SWAT incorporates a coupled ground water sub-model as a component of the hydrologic water balance. SWAT differs from HSPF also in that since SWAT uses a daily time step, SWAT is not designed to be applied for storm event analyses. SWAT was developed as a tool to predict water, soil, and chemical runoff yield due to land management practices including agriculture. SWAT is a continuous model and was designed to model large-scale complex watersheds or river basins. The watershed, or river basins, can be subdivided into smaller homogeneous sub-basin parts that can be analyzed separately, or how they interact as a whole. SWAT interfaces with ArcView, Visual Basic, and GRASS to provide user-friendly pre- and post-processing tools to facilitate development and application of the model. With many of the same features as HSPF, SWAT is also considered a Level 3 Complex or Advanced Model. The Texas A&M URL for SWAT is <http://www.brc.tamus.edu/swat/index.html>.

QUAL2K and QUAL2E. QUAL2K is a river and stream water quality model (Pelletier and Chapra, 2005) designed to upgrade and replace QUAL2E (Brown and Barnwell 1987) which is a well-known model with numerous applications to streams and rivers, including Elevenmile Creek in the Perdido River basin (EPA, 1988; HydroQual, 1992). Like QUAL2E, QUAL2K represents a stream or river as a one-dimensional (1D) channel that is considered well-mixed over depth and

across the cross-section of the river. QUAL2K and QUAL2E represent transport with non-uniform steady-state hydraulics based on Manning's equation. QUAL2K and QUAL2E both represent time variability with a diurnal heat budget for water temperature and dissolved oxygen. State variables of QUAL2K include water temperature, organic carbon (BOD), dissolved oxygen, nutrients, algae and benthic algae, pH and alkalinity. As an upgrade of QUAL2E, deposition of particulate organic matter and the resulting sediment water exchange of nutrients and oxygen is incorporated in QUAL2K with an internally coupled steady state sediment flux model (Di Toro, 2001). In contrast to QUAL2E, which is executed from the MS-DOS screen, QUAL2K is implemented within the Microsoft Windows environment. The model is programmed in Visual Basic for Applications (VBA) and Excel is used as a user-friendly graphical user interface to facilitate pre-processing data input and post-processing graphical and tabular display of model results (Pelletier and Chapra, 2005). Although the water quality kinetics of QUAL2K represent an advanced model framework, the QUAL2K model, since it is limited to steady state applications in one-dimensional rivers and streams, is considered to be a Level 2- Mid-Range Intermediate model. The EPA URL for QUAL2K is (<http://www.epa.gov/athens/wwwqtsc/html/qual2k.html>)

WASP7. The current version (7.3) of the eutrophication module of the Water Quality Analysis Simulation Program (WASP7), supported by EPA as a public domain model, represents a Windows-based upgrade and kinetic enhancement of earlier versions of the original WASP model (WASP3: Di Toro et al., 1983; WASP4: Ambrose et al., 1988; WASP5: Ambrose et al. 1993; and **WASP**: Wool et al., undated). The Water Analysis Simulation Program (WASP) is a time variable model that allows for the flexible spatial representation of a water body as 1D, 2D or 3D domains. The water column and the sediment bed are coupled via particulate deposition and exchange of materials across the sediment water interface. In comparison to WASP5 and WASP6, WASP7 includes a more complex representation of water quality kinetics and the addition of periphyton (benthic algae) as an additional state variable. Using the same approach that is available in earlier versions of WASP (e.g., WASP5 and WASP6), sediment-water exchange of nutrients and dissolved oxygen (i.e., sediment oxygen demand) is included in the model based on user-defined empirical representations of benthic forcing function fluxes that can be defined to be dependent on both time and space. It is expected that future releases of WASP will incorporate the internally coupled sediment flux model of Di Toro (2001). The coupling of the sediment flux model with the water column model will then improve the predictive capability of the WASP model to represent alternative management scenarios that would alter external nutrient and organic matter loads to a waterbody. The fifteen (15) state variables of the eutrophication module for WASP7 include three classes of CBOD; particulate (non-living detrital) organic matter as carbon (POC), nitrogen (PON) and phosphorus (POP); dissolved organic matter as nitrogen (DON) and phosphorus (DOP); dissolved oxygen, inorganic nutrients as ammonia; nitrate and ortho-phosphate; algae biomass (as chlorophyll-a); salinity; inorganic suspended solids (non-volatile solids); and benthic algae. Separate modules for WASP7 incorporate suspended solids and toxic chemicals and mercury. Transport and grid geometry data must be externally input to WASP7 either as (a) user-supplied data or (b) data provided by linkage with hydrodynamic models (e.g., EFDC) that can provide flow, depth, volume, velocity, salinity and water temperature. As a Windows-based model, WASP7 provides table based pre-processing capabilities and graphical post-processing to display time series results. Computational grid generation, grid display and animation of results is not included in WASP7. With advanced water quality kinetics and the internal sediment flux model,

WASP7 represents a Level 3- Complex or Advanced water quality model framework. The EPA URL for WASP7 is <http://www.epa.gov/athens/wwwqtsc/html/wasp.html>

CE-QUAL-W2. Originally developed by the US Army Corps of Engineers Waterways Experiment Station for applications to narrow lakes, reservoirs and estuaries, CE-QUAL-W2 is a longitudinal/vertical time variable hydrodynamic and water quality model that has received extensive use throughout the US and the world as a management and research tool with more than 300 applications worldwide. Version 3.0 is a significant update to Version 2 (Cole and Buchak, 1995) that now includes the ability to model multiple waterbodies and the river reaches in between them (Cole and Wells, 2000; Wells and Cole, 2000). The model can now be applied to entire drainage basins including rivers, reservoirs, and estuaries. State variables of CE-QUAL-W2 include water temperature, TDS or salinity, BOD/organic carbon, dissolved oxygen, nutrients, algae, iron, coliform bacteria, suspended solids, inorganic carbon, pH and alkalinity. Sediment-water exchange of nutrients and dissolved oxygen is included as user-defined forcing function fluxes. With internal linkage to a hydrodynamics model and advanced water quality kinetics, CE-QUAL-W2 is considered to be a Level 3- Complex or Advanced model. The Portland State University URL for CE-QUAL-W2 is <http://www.ce.pdx.edu/w2>.

EFDC. The Environmental Fluid Dynamics Code (EFDC) is a general-purpose modeling package designed to simulate 1D/2D or 3D flow, transport, and biogeochemical processes in surface water systems including rivers, lakes, estuaries, reservoirs, wetlands, and near shore to shelf scale coastal regions. The public domain EFDC model, originally developed at the Virginia Institute of Marine Science for estuarine and coastal applications, is now supported by EPA and maintained by Tetra Tech, Inc. The hydrodynamic model is comparable to the Princeton Ocean Model (Blumberg and Mellor, 1987) while the water quality and eutrophication model is functionally equivalent to the Chesapeake Bay Model (CE-QUAL-ICM) developed by the US Army Corps of Engineers, Waterways Experiment Station (Cercio and Cole, 1993; 1995). In addition to hydrodynamics, salinity and water temperature, EFDC includes sub-models to simulate sediment transport, eutrophication, toxic contaminants and sediment diagenesis. EFDC is unique among advanced surface water models since it is designed to use a single source code to interface hydrodynamics (Hamrick, 1992) with sediment transport (Tetra Tech, 2000), toxic chemicals (Tetra Tech, 1999b), eutrophication (Park et al., 1995) and sediment diagenesis (Di Toro, 2001) within a single source code (Hamrick, 1996). EFDC has provided an advanced modeling framework for hundreds of applications worldwide, including Mobile Bay (Wool et al., 2003), to support the simulation of hydrodynamic transport and the interpretation and prediction of water quality responses to natural phenomena and manmade pollution for TMDLs and other evaluations of alternative management scenarios for point source (wastewater) and nonpoint source (BMP) controls. As a public domain model with source code readily available, EFDC has been modified and improved over the years to support various modeling projects. The Dynamic Solutions URL for EFDC is http://www.ds-intl.biz/fs_ee.html

The availability and capabilities of pre- and post-processing software tools is critical for efficient applications of EFDC. To meet our needs to efficiently test, setup and calibrate EFDC models, Dynamic Solutions developed the EPA-licensed EFDC_Explorer pre- and post processor. EFDC_Explorer, developed to support the EFDC sub-models for hydrodynamics, sediment transport, toxic chemicals, water quality and sediment diagenesis, is public domain, Windows-

based GUI software available from Dynamic Solutions. EFDC_Explorer is designed to support EFDC model set-up and configuration, grid generation (cartesian or curvilinear), model testing, calibration and validation. EFDC_Explorer provides the capability for data visualization, including display of the computational grid, map overlays, spatial results, time series and vertical profile plots. Animation of results can easily be generated and saved to an AVI file (Craig, 2004). The URL for EFDC_Explorer is http://www.ds-intl.biz/fs_ee.html; the URL for a description is http://www.ds-intl.biz/Programs/EFDC_Explorer%20Overview.pdf

Models Not Meeting Criteria. Watershed models that did not meet the criteria for watershed model selection include WMM and SWAT. The WMM is designed as a Level 1 screening model to compute annual or seasonal loading estimates. SWAT, although it is a Level 3 complex model, does not support the high frequency simulation of storm events since it is designed for a daily time step. WAM, although it meets the criteria, was not selected since it is considered to be a Level 2- Mid-Range or Intermediate model.

Receiving water models that did not meet the criteria for water quality model selection include QUAL2E, QUAL2K and CE-QUAL-W2. QUAL2E and QUAL2K did not meet the criteria since both models are limited to steady-state and one-dimensional stream and river applications. CE-QUAL-W2 did not meet the criteria for this study since it is designed for two-dimensional, laterally averaged representations of hydrodynamics and water quality of a waterbody.

Watershed Model Selection. The watershed runoff model selected for the Caloosahatchee River basin modeling study is HSPF and BASINS-HSPF. The HSPF model framework meets all the criteria established for the Caloosahatchee River Basin modeling study. HSPF, applied for many watersheds in the southeastern states, has been accepted as the technical basis for numerous TMDL evaluations. In addition to the technical features of HSPF, the Dynamic Solutions and CDM team has extensive experience with the development of HSPF models and the HSPF source code is available for modification, if needed, for this study.

Receiving Water Model Selection. The primary receiving water model selected for the Caloosahatchee Bay hydrodynamic and water quality model is EFDC. The EFDC model meets all the criteria established for the Caloosahatchee River Basin modeling study. Over the past decade, the EFDC model has been used worldwide for hundreds of applications for rivers, lakes, reservoirs, wetlands, estuaries and coastal waters. As one of EPA's most advanced surface water modeling system for hydrodynamics and water quality studies, EFDC has been accepted as the technical basis for numerous TMDL evaluations. In addition to the outstanding technical features and capabilities of EFDC, Dynamic Solutions has extensive experience with the development of EFDC models, modification and enhancement of the EFDC code and development and modification of EFDC_Explorer, the innovative pre- and post-processor developed by Dynamic Solutions to support EFDC applications (Craig, 2004). In addition to the selection of EFDC as the receiving water model for the development of the hydrodynamic and water quality model of the Caloosahatchee estuary, WASP7 has also been selected as a receiving water model where the hydrodynamic linkage needed for WASP7 will be provided by the EFDC model. The selection of both EFDC and WASP7 as water quality model frameworks for the Caloosahatchee estuary model will provide FDEP with a unique opportunity for a comparison of the results obtained with each water quality model and an evaluation of the similarities and differences in the kinetics

employed for each of these well-known and highly-respected advanced surface water modeling tools.

These peer reviewed model frameworks (HSPF, EFDC and WASP7) have been applied for hundreds of applications worldwide, including numerous TMDL studies in rivers and estuaries of the US. Many of the TMDL applications, in fact, have been developed using all three of these public domain models where HSPF results have been linked for input to the EFDC hydrodynamic model and the EFDC and WASP7 water quality models.

5.2 HSPF MODEL

This section describes the Hydrologic Simulation Program – FORTRAN (HSPF) model setup for the Caloosahatchee River (HUC 03090205), model output, and verification. For this TMDL model support project, the model was used to simulate surface and ground water flows, total suspended solids (TSS), total phosphorus (TP), total nitrogen (TN), Nitrate plus Nitrite ($\text{NO}_2 + \text{NO}_3$), TKN, organic nitrogen, ammonia nitrogen (NH_3/NH_4), ortho-phosphate (O-PO_4), water temperature, ultimate biochemical oxygen demand (UBOD), chlorophyll-a (Chl-a), and dissolved oxygen (DO). It also provides pollutant load time-series that are used as input to the EFDC hydrodynamic and water quality model.

The Caloosahatchee River watershed was divided into 102 hydrologic units that included major tributaries and point source discharges. The model was progressively calibrated for flow, temperature, TSS, nutrients, BOD, and DO. HSPF generates non-point source runoff and loads from land sources and drains them to adjacent stream segments. Flow in the stream segments is routed downstream along with water quality constituents. Appropriate land based and in-stream processes were selected and parameterized through model calibration and sensitivity analyses. Modeled streamflow and pollutant concentrations are compared with observed data from flow gages and water quality monitoring stations for model calibration and validation. Finally, time series of flow, temperature, and water quality constituent concentrations computed at different boundary locations of the lower and tidally influenced segment of the Caloosahatchee River serve as input to the EFDC model.

5.2.1 HSPF Model Development

The Caloosahatchee HSPF model simulates rainfall, evapotranspiration, runoff, infiltration, surface storage, and ground and surface water flows and water quality constituent (parameter) loads from various land uses in each hydrologic unit. It then transports water and water quality constituents through stream/lake segments to points of interest for “loading” to the receiving water model (EFDC) for hydrodynamic and water quality evaluations.

The upstream boundary of the Caloosahatchee River is defined by the Moorehaven Lock (S-77), which controls the flow from Lake Okeechobee to the river. There are 93 permitted point source WWTP / WWTF's, most of which are small facilities in the watershed. The discharge and pollutant loads from these wastewater treatment plants were incorporated in the model. The watershed also includes over 3,900 permitted wells that may withdraw water from surface and ground water sources. Withdrawal of ground and surface water through pumping and wastewater plant effluent discharged to surface water affect the flow and water quality in stream reaches.

The model consists of physical data describing the distribution and characteristics of various land uses, physical attributes of stream and lake reaches, time series input data and model parameters. Many input data are derived from spatial data using standard geographic information system (GIS) software. Time series input data, such as rainfall, temperature, upstream boundary conditions, point source discharge, and groundwater pumpage data were analyzed in Microsoft EXCEL to perform data quality checks and to estimate data for missing values. Processed time series data were stored in the HSPF WDM utility format for efficient use by the HSPF model. The final and site specific parameter values were obtained through model calibration.

5.2.1.1 Model Simulation Period

The HSPF hydrologic model was calibrated using data from January 1, 2001 through December 31, 2005 and validated using data from January 1, 1997 through December 31, 1999. The HSPF water quality model was calibrated using the ambient water quality data from January 1, 2004 through December 31, 2005 and validated using the ambient water quality data from January 1, 2002 through December 31, 2003.

5.2.1.2 Model Constituents

Flow and the following water quality constituents were modeled using HSPF:

- Water temperature
- Total suspended solids
- 5-day biochemical oxygen demand (BOD₅) from ultimate BOD (UBOD)
- Nitrogen (TN, TKN, NO₂+NO₃, organic N, NH₃/NH₄)
- Phosphorus (TP, organic P, Ortho-Phosphate)
- Phytoplankton (as Chl-a)
- Dissolved oxygen (DO)

With the exception of Chl-a, all of these constituents were modeled for the tributary land area, and loaded to the HSPF reaches in the watershed.

5.2.1.3 Model Discretization

The smallest discrete hydrologic unit in a HSPF model application is a hydrologic unit and associated receiving water reach. The model requires the acreage of various land uses in each hydrologic unit and the stream reach to which the land segment discharges. The Caloosahatchee River watershed was divided into 102 hydrologic units and the stream network was divided into 97 reaches (**Figure 5-1**). The hydrologic unit boundaries were delineated using existing WBID boundaries, topographic data (Composite Topography for SW Florida, 100-ft), and the drainage network (High Resolution National Hydrography Dataset, USGS) in a GIS. Tributary confluences, hydraulic structures, and flow gages were used to define the segmentation locations. Major changes in slope, channel cross-section, depth, and other physical characteristics were also considered in model segmentation. One F-Table (a depth-discharge relationship or rating curve) was developed for each reach using an equivalent trapezoidal cross-section and obtaining reach characteristics data.

A previous modeling effort conducted by SFWMD developed a Mike-SHE model of the Caloosahatchee River watershed, compiled the stream cross-section data from various sources, and estimated reach characteristics using equivalent trapezoidal cross-sections. According to the report, the SFWMD provided the cross sections for parts of C-43, Jack's Branch, County Line Ditch, Canal 1, Canal 2, C-19, 42-foot canal, and Hilliard Canal. The cross-sections for other stream segments were estimated from the topographic data. **Table 5-3** lists the reach characteristics used to develop the F-Tables for the HSPF model.

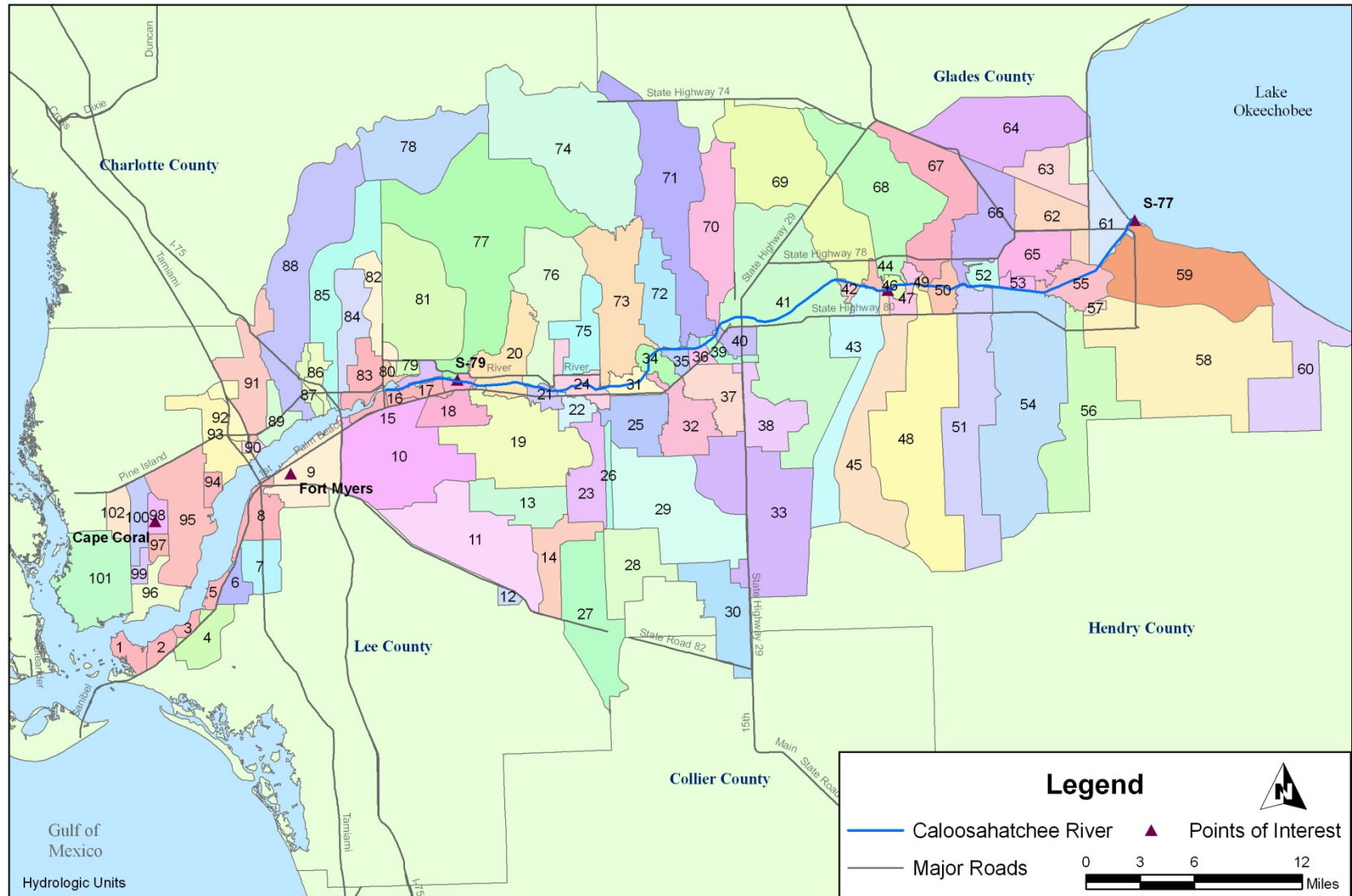


Figure 5-1 Delineated hydrologic units for HSPF Modeling

Table 5-3 Reach Characteristics used to Develop F-Tables (rating curves) for the HSPF Model

Reach ID (HSPF)	Reach Name	Length (mile)	Bottom Width (ft)	Side Slope (ft/ft)	Manning's Roughness
4	Hendry Creek	1.94	75	4.0	0.034
6	WC L-Canal	0.62	30	5.0	0.034
7	WC L-Canal	2.22	30	5.0	0.034
9	Billy Creek	4.13	15	3.5	0.034
10	Able Canal	9.73	250	2.0	0.034
11	Sailfish	8.41	45	2.0	0.034
12	57-19-1	1.18	20	3.0	0.034
13	Able Canal	5.68	50	2.0	0.034
14	Bellwest	4.91	50	3.2	0.034
18	C-43	2.36	164	6.2	0.030
19	Hickey Creek	10.19	46	1.4	0.022
20	C-43	2.13	118	7.1	0.030
21	C-43	2.01	72	5.3	0.030
22	Bedman Creek	2.98	33	1.2	0.022
23	Dog Canal	5.85	26	1.0	0.022
24	C-43	2.50	52	4.9	0.030
25	LPDD Header Canal1	2.83	27	0.7	0.022
26	Duda Canal	4.78	50	3.0	0.022
27	Hendry Canal Ext	6.08	53	0.8	0.022
28	Duda Canal	4.00	50	3.0	0.022
29	Townsend Canal	8.61	66	0.5	0.022
30	Townsend Canal	4.18	66	0.5	0.022
31	C-43	2.81	223	1.0	0.030
32	Roberts Canal	5.24	32	0.5	0.022
33	Roberts Canal	8.45	13	1.0	0.022
34	C-43	1.48	223	1.0	0.030
35	C-43	2.32	219	1.1	0.030
36	Crawford	1.10	30	0.8	0.022
37	Crawford	4.16	15	1.0	0.022
38	SR-29 Ditch	7.41	30	0.7	0.022
39	C-43	1.06	94	4.5	0.030
40	C-43	0.48	85	4.7	0.030
41	C-43	7.53	111	4.0	0.030
42	C-43	1.49	190	1.9	0.030
43	Canal 1	14.33	50	1.0	0.022
44	C-43	1.45	298	3.9	0.030
45	Canal 2	13.32	65	0.6	0.022
46	C-43	1.07	298	3.9	0.030
47	C-43	0.57	298	3.9	0.030

Florida Department of Environmental Protection
Caloosahatchee River Basin TMDL Model Support
Task Assignment CDM07-04, May 2008

Reach ID (HSPF)	Reach Name	Length (mile)	Bottom Width (ft)	Side Slope (ft/ft)	Manning's Roughness
48	Canal 3	15.59	56	3.6	0.022
49	C-43	0.81	298	3.9	0.030
50	C-43	1.91	298	3.9	0.030
51	42-Foot Canal	16.07	14	0.5	0.022
52	C-43	1.78	227	4.5	0.030
53	C-43	1.97	44	6.1	0.030
54	Hilliard Canal	15.59	52	0.6	0.022
55	C-43	3.87	659	6.2	0.030
56	Left HH Canal	13.29	36	0.8	0.022
57	Flaghole Canal	2.56	52	2.8	0.022
58	FlagHole5	13.72	37	1.0	0.022
59	Disston Main Canal	10.05	72	0.8	0.022
60	Industrial Canal	8.80	52	1.0	0.022
61	C-43	3.20	72	3.3	0.030
62	C-19	4.47	20	3.0	0.022
63	C-19	3.16	10	3.0	0.022
64	C-19	6.28	2	3.0	0.022
65	(No name)	3.17	30 ^[1]	1.0 ^[1]	0.034 ^[1]
66	Meanderline Ditch	5.35	9	0.2	0.022
67	Citrus Center Canal	6.77	30	0.7	0.022
68	Lindens Pen Marsh	14.91	20	1.0	0.022
69	Cypress Branch	11.34	20	1.7	0.074
70	Polywog Branch	13.52	10	1.0	0.022
71	Bee Branch	14.22	10	0.6	0.022
72	Ft. Denaud	7.25	3	1.0	0.022
73	Jacks Branch	8.68	20	0.9	0.022
74	Jacks Branch	8.45	20	0.9	0.022
75	County Line	3.23	13	0.9	0.022
76	Cypress Creek	9.72	10	0.6	0.022
77	Big Island Canal	13.09	35	0.5	0.022
79	Big Island Canal	4.23	35	0.5	0.022
80	Owl Creek	0.50	13	1.5	0.034
81	Trout Creek	4.51	50	5.0	0.034
82	Owl Creek	1.99	13	0.9	0.034
84	Stroud Creek	4.40	20	3.3	0.034
85	Popash Creek	5.98	20	3.0	0.034
86	Bayshore Creek	4.81	20	5.0	0.034
87	Chapel Creek	3.88	20	2.5	0.034
88	Daughtrey Branch1	10.51	13	2.0	0.034
89	Marshpoint	3.62	13	3.0	0.034

Reach ID (HSPF)	Reach Name	Length (mile)	Bottom Width (ft)	Side Slope (ft/ft)	Manning's Roughness
90	Powell Creek	0.91	100	4.0	0.034
91	Powell Creek	4.68	30	4.0	0.034
92	(No name)	3.81	30 ^[1]	4.0 ^[1]	0.034 ^[1]
93	Yellow Fever Creek	4.66	50	4.0	0.034
95	Mackinac	7.09	162	2.0	0.034
96	San Carlos	2.94	133	2.0	0.034
97	San Carlos	2.23	90	2.0	0.034
98	San Carlos	2.60	90	2.0	0.034
99	Courtney	2.92	70	2.1	0.034
100	Courtney	4.73	70	2.1	0.034
101	Aries	10.18	130	2.0	0.034
102	Aries	3.62	130	2.0	0.034
124	Bedman Creek	1.96	33	1.4	0.022
126	Townsend Canal	1.28	66	0.5	0.037
131	C-43	0.26	223	1.0	0.030
150	C-43	0.47	284	4.0	0.030
172	Jacks Branch	0.32	20	0.9	0.022
501	C-43	3.28	262	4.5	0.030
559	Disston Main Canal	8.75	77	0.7	0.022

[1] Estimated using topographic data and aerial photo

5.2.1.4 Land Use

The seamless GIS coverage of a 2004 land use data provided by the SFWMD was considered appropriate for the development of the existing condition model. Since the year of the land use data coincided with the model calibration period, the data was considered representative of watershed conditions. The land uses were grouped into ten different classes to capture the variation of watershed characteristics affecting the flow and pollutant loads. Distribution of these land uses are shown in **Figure 5-2**. The figure shows that urban areas (e.g. commercial, and high, medium and low density residential areas) are more concentrated in lower Caloosahatchee River watershed along shores and a larger percentage of croplands are located in the upper part of the watershed. Land use area percentages for each hydrologic unit were computed in a GIS. Percent of directly connected impervious area (DCIA) for each land use was initially estimated based on previous modeling efforts and similar studies and the pervious and impervious area of various land uses in each hydrologic unit was incorporated in the model. The DCIA values were refined and finalized through model calibration. A summary of land use distribution in the areas upstream and downstream of the Franklin Lock & Dam (S-79) is provided in **Table 5-4** and graphically shown in **Figure 5-3**. The table also includes the distribution of land uses for the entire watershed as well as the DCIA values.

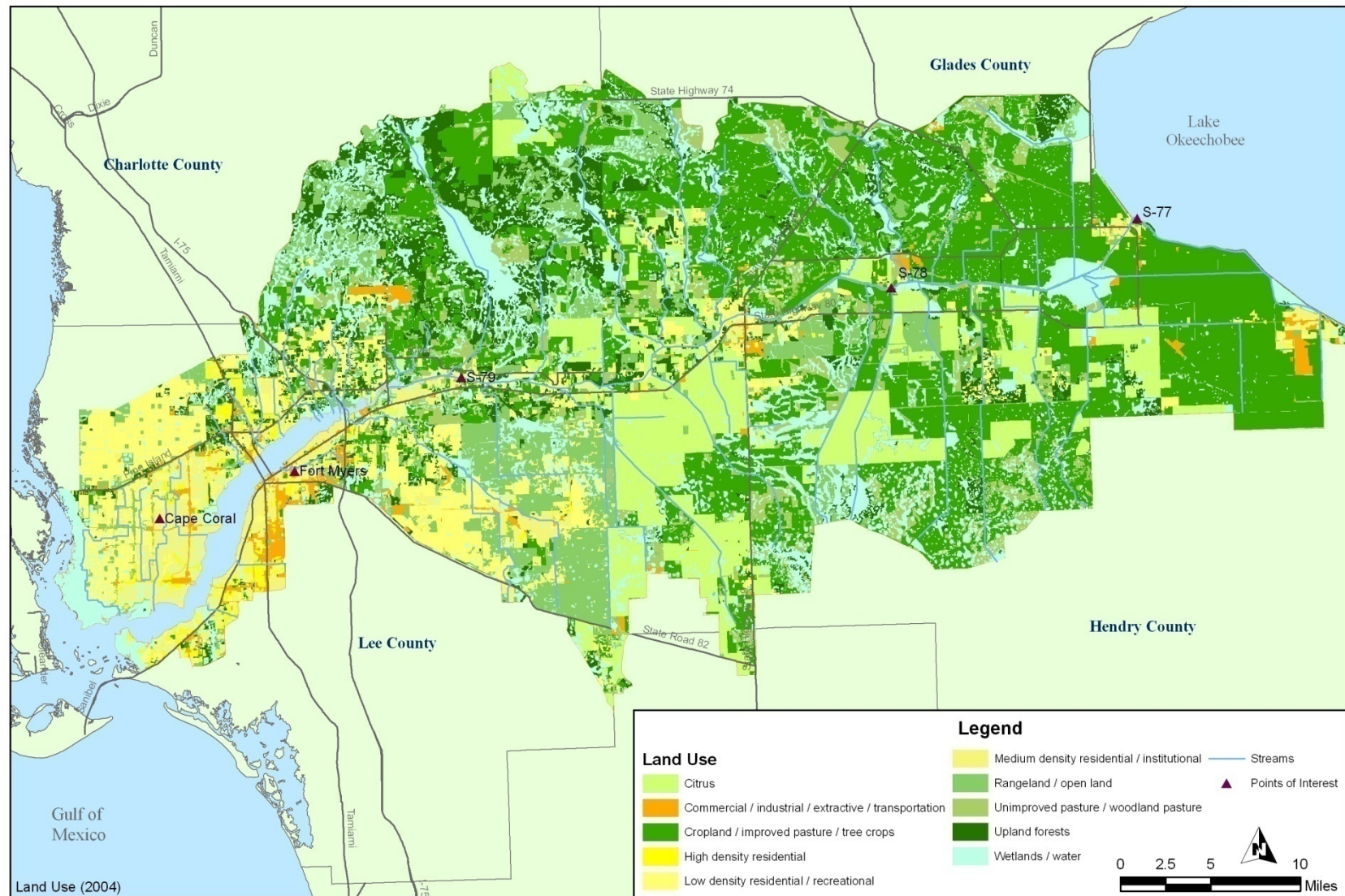


Figure 5-2 Distribution of land uses in the Caloosahatchee River watershed.

Table 5-4 Distribution of areas and estimated DCIA by land use in the upper, lower and entire Caloosahatchee River watershed

Location	Land Use	Area (acres)	Percent of Total Area (%)	DCIA (%)
Downstream of Franklin Lock & Dam (S-79)	Citrus	976	0.4	1
	Commercial / industrial / extractive / transportation	11,944	4.6	66
	Cropland / improved pasture / tree crops	29,269	11.3	1
	High density residential	8,727	3.4	49
	Medium density residential / institutional	29,500	11.4	26
	Low density residential / recreational	39,092	15.1	10
	Rangeland / open land	35,516	13.7	1
	Unimproved pasture / woodland pasture	9,908	3.8	1
	Upland forests	38,295	14.8	1
	Wetlands / water	56,257	21.7	0
	Total Area/Average DCIA	259,484		10
Upstream of Franklin Lock & Dam (S-79)	Citrus	97,645	15.7	1
	Commercial / industrial / extractive / transportation	6,384	1.0	66
	Cropland / improved pasture / tree crops	246,376	39.7	1
	High density residential	558	0.1	49
	Medium density residential / institutional	4,302	0.7	26
	Low density residential / recreational	19,824	3.2	10
	Rangeland / open land	61,069	9.8	1
	Unimproved pasture / woodland pasture	41,636	6.7	1
	Upland forests	34,909	5.6	1
	Wetlands / water	107,820	17.3	0
	Total Area/Average DCIA	620,524		2
Entire Caloosahatchee River Watershed	Citrus	98,621	11.2	1
	Commercial / industrial / extractive / transportation	18,329	2.1	66
	Cropland / improved pasture / tree crops	275,645	31.3	1
	High density residential	9,285	1.1	49
	Medium density residential / institutional	58,916	3.8	26
	Low density residential / recreational	33,803	6.7	10
	Rangeland / open land	96,585	11.0	1
	Unimproved pasture / woodland pasture	51,544	5.6	1
	Upland forests	73,205	8.3	1
	Wetlands / water	164,077	18.6	0
	Total Area/Average DCIA	880,009		5

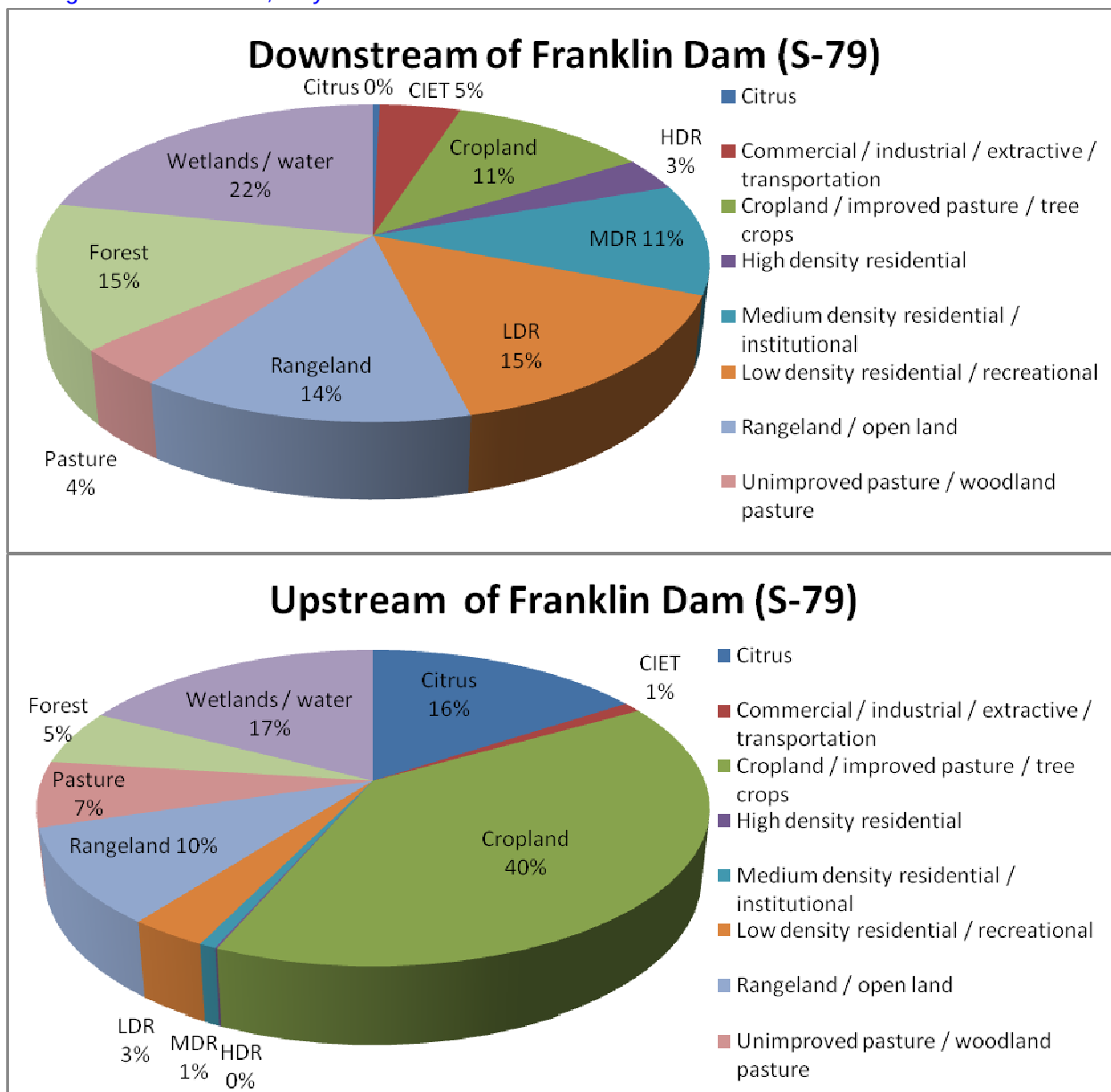


Figure 5-3 Distribution of land uses in the lower and the upper Caloosahatchee River watershed

5.2.1.5 Meteorological Data

HSPF uses meteorological data to generate runoff and pollutant loads. Modeled runoff and pollutant loads from point and nonpoint sources were routed through stream reaches. Representative hourly rainfall and potential evapotranspiration (PET) are the key meteorological inputs to HSPF. Hourly precipitation data for the desired simulation period (January 1996 through December 2006) is available from many Lee County, the SFWMD and NOAA rain gages in the Caloosahatchee River watershed. But none of the gages has a complete data set covering the entire simulation period. Because of missing data at the precipitation gages, large watershed area and significant spatial variation in storm intensity, it was necessary to use precipitation data derived from the NEXt Generation RADar (NEXRAD) data. NOAA's National Weather Service maintains 159 Weather Surveillance Radar-1988 Doppler (WSR-88D) sites throughout the United States and some overseas locations that comprise the NEXRAD network. From three meteorological base data quantities (reflectivity, mean radial velocity, and spectrum width) hourly precipitation data are computed on a seamless 1.1x1.1 nautical mile grid. The time series data for all the grid cells located in the Caloosahatchee River watershed were obtained and aggregated into fifteen area-weighted precipitation time series representing different parts of the watershed. Fifteen time series were selected to attain the maximum spatial resolution in precipitation data without exceeding the model limits for the total number of operations in one model. These areas were defined by grouping multiple hydrologic units as shown in **Figure 5-4**. The total annual precipitation for each NEXRAD precipitation zone and their variability are provided in **Table 5-5**. Precipitation is higher near the coast and gradually reduces towards Lake Okeechobee. The NEXRAD data were compared to the closest hourly NOAA-NWS stations.

Observed daily temperature and evapotranspiration data were available from the SFWMD meteorological station S78W. However, the observed evapotranspiration data was not available for the entire simulation period. Therefore, daily PET data was computed in WDMUtil using Hamon's method (Hamon, 1961). Hamon's method was selected because it required only the daily maximum and the minimum temperatures, and latitude of the location as input. Total annual PET was then compared with available evapotranspiration data at S78W and adjusted to ensure that the computed PET time series was representative of the Caloosahatchee River watershed. The computed annual PET was used in the model as an input. The model computed evapotranspiration. The average annual PET for the Caloosahatchee River watershed was 54.3 inches. Daily PET was then desegregated to hourly values using WDMUtil. Zones defining the areas of equal precipitation time series as developed from hourly NEXRAD data.

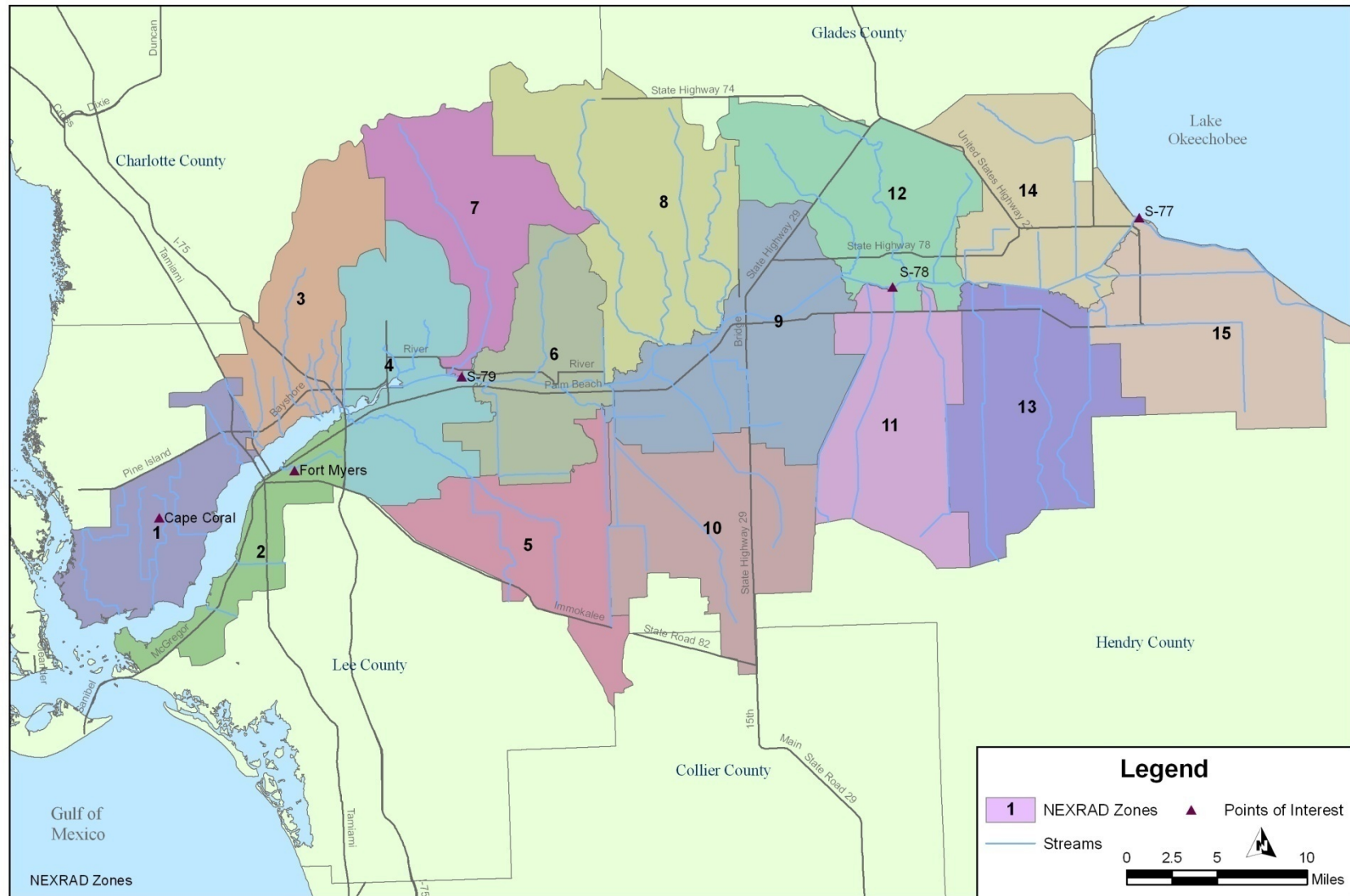


Figure 5-4 Zones defining the areas of equal precipitation time series developed from hourly NEXRAD data.

Table 5-5 Total annual precipitation by NEXRAD zone and its statistics.

Location	Total Precipitation (in) by Year								
	1997	1998	1999	2000	2001	2002	2003	2004	2005
NEXRAD Zone 01	69.0	67.6	69.1	58.9	64.1	83.8	80.4	61.9	75.6
NEXRAD Zone 02	68.1	65.0	69.0	54.8	62.7	76.5	79.1	63.9	80.6
NEXRAD Zone 03	59.8	63.4	66.0	41.5	50.2	66.1	70.0	54.4	67.8
NEXRAD Zone 04	61.6	64.9	61.5	42.2	53.3	70.7	69.5	55.1	70.3
NEXRAD Zone 05	59.0	59.4	63.1	58.3	66.2	64.9	72.7	55.0	68.8
NEXRAD Zone 06	63.8	65.1	63.0	44.6	59.3	69.7	69.3	57.2	73.4
NEXRAD Zone 07	64.7	64.1	60.4	42.9	54.1	71.6	64.7	53.6	67.1
NEXRAD Zone 08	62.6	58.9	58.3	40.8	55.6	67.2	60.3	50.8	65.8
NEXRAD Zone 09	56.4	61.8	60.2	41.7	57.2	69.6	65.8	47.4	69.8
NEXRAD Zone 10	51.0	54.8	65.5	58.1	69.1	62.5	60.2	48.0	68.1
NEXRAD Zone 11	45.6	54.4	59.6	40.7	57.9	59.9	61.1	43.1	71.5
NEXRAD Zone 12	53.8	52.6	57.9	37.1	49.2	65.9	65.3	45.4	65.3
NEXRAD Zone 13	45.4	54.0	57.3	39.6	51.5	56.5	56.2	43.6	67.6
NEXRAD Zone 14	49.8	56.9	58.2	33.8	44.9	53.0	56.4	39.3	59.2
NEXRAD Zone 15	47.1	56.5	59.0	36.6	47.8	50.0	53.0	49.5	62.6
<i>Average</i>	57.2	60.0	61.9	44.8	56.2	65.9	65.6	51.2	68.9
<i>Minimum</i>	45.4	52.6	57.3	33.8	44.9	50.0	53.0	39.3	59.2
<i>Maximum</i>	69.0	67.6	69.1	58.9	69.1	83.8	80.4	63.9	80.6
<i>Standard Deviation</i>	8.0	4.9	3.9	8.4	7.1	8.8	8.0	7.0	5.2

5.2.1.6 Boundary Conditions

The Caloosahatchee River originates from Lake Okeechobee and flows to the southwest, emptying into the estuary. There are three major control structures – Moorehaven Lock (S-77), Ortona Lock (S-78), and Franklin Lock and Dam (S-79) along the Caloosahatchee River. These three locks are operated to maintain the water level in the Caloosahatchee River and used for navigational purposes. The Moorehaven Lock (S-77) is located at the upstream end of the Caloosahatchee River and, therefore, defines the upstream boundary of the HSPF model. Flow and ambient water quality measurements at S-77 were used to develop time series input data for the boundary condition. The Franklin Lock and Dam (S-79), located 43 miles downstream of the Lake Okeechobee, separates the upper, freshwater portion the river from the lower, tidally influenced portion of the river. The Ortona Lock (S-78) is located between the other two locks, 16 miles downstream of Lake Okeechobee. The HSPF model includes multiple river reaches between the Moorehaven Lock (S-77) and the Franklin Lock (S-79), and tributaries draining to these reaches. The model also includes streams contributing to the tidal part of the Caloosahatchee River, but excludes the lower tidal part of the Caloosahatchee River (i.e. downstream of S-79). The tidal lower part of the Caloosahatchee River is included in the EFDC modeling domain as it constitutes the receiving water segment. Discharge through the Ortona and Franklin Locks are computed using specific rating curves (i.e. F-Tables) and modeled flows in the upstream reaches. A complete record of discharge is necessary at S-77 to define the boundary condition for the simulation period, and at S-78 and S-79 for model calibration and validation. The

data from the gages at these locks were analyzed and the data gaps were filled as discussed below.

Daily mean flow data are available from two SFWMD gages, S77-S at Moorehaven Lock and S78-T at Ortona Lock. These flow data span from 5/1/1996 to 5/6/2006 at the S77-S gage and from 1/1/1995 to 9/30/2003 at the S78-T gage. Additionally, three USGS flow gages (02292000, 02292480 and 02292900) are located at or near the S-77, S-78 and S-79 locks. An analysis of flow data from all the gages revealed that the flow data from the S78-T and 02292480 gages are essentially the same except that the S78-T flow data reports six missing values. **Table 5-6** shows the strong correlations that exist between different data sets. The simple linear regression equations presented in **Table 5-6** were used to populate the missing values and obtain complete flow time series data between Jan 1, 1995 and May 5, 2006. No data was available at any station after May 5, 2006. All negative values in the final flow time series were replaced by 0.0 since the HSPF model can directly simulate flows in only one direction. The negative flows represent flow from the river to Lake Okeechobee.

Table 5-6 Correlation of Datasets

Average Daily Flow (cfs)		Regression Equation	Coefficient of Determination (r^2)
Independent Variable (X)	Dependent Variable (Y)		
USGS 02292000	S77-S	$Y = 1.0563(X) - 24.789$	0.9852
S77-S	S78-T	$Y = 1.0329(X) - 41.889$	0.9076
S78-T	USGS 0229290	$Y = 1.3225(X) + 340.15$	0.8406

Observed water quality constituent concentrations at S-77 were obtained from the SFWMD's DBHydro database. Monthly average concentrations were calculated using the long-term (1996-2005) measurements of water quality constituents. Then the daily concentrations were determined by linearly interpolating the monthly average values and multiplied by daily flow to develop daily load (flux) time series of heat, total suspended solids, ammonia, nitrate plus nitrite, organic nitrogen, TKN, TP, phosphate and dissolved oxygen. These data were used to define the loads at the upstream boundary of the Caloosahatchee River. Time varying flow and fluxes of heat, total suspended solids, ammonia, nitrate, nitrite, organic nitrogen, phosphate and dissolved oxygen are shown in **Figures 5-5 through 5-16**, respectively. No BOD₅ measurements were available at S-77.

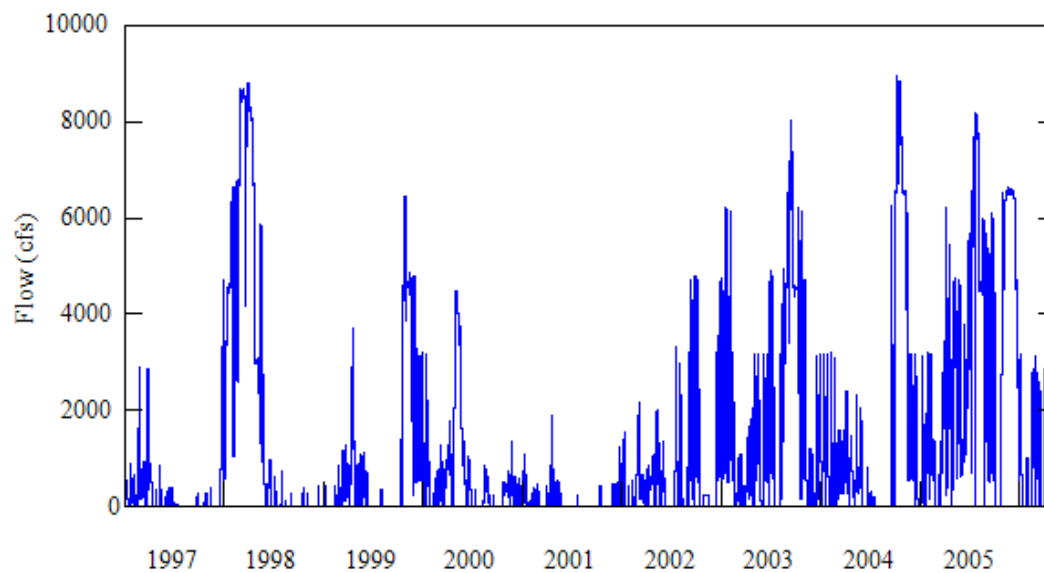


Figure 5-5 Daily average flow at S77

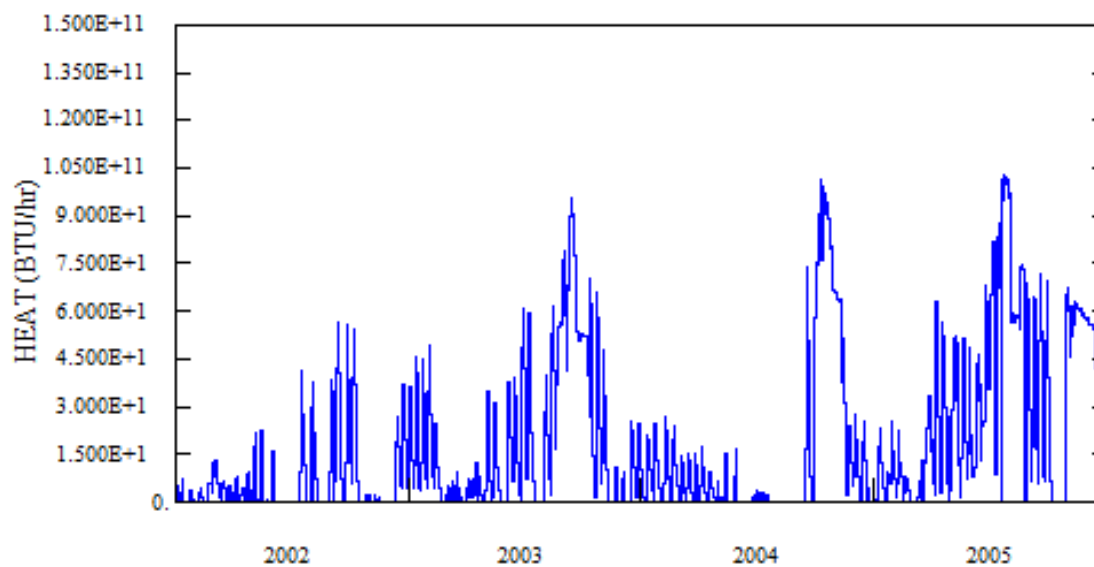


Figure 5-6 Hourly heat flux at S77

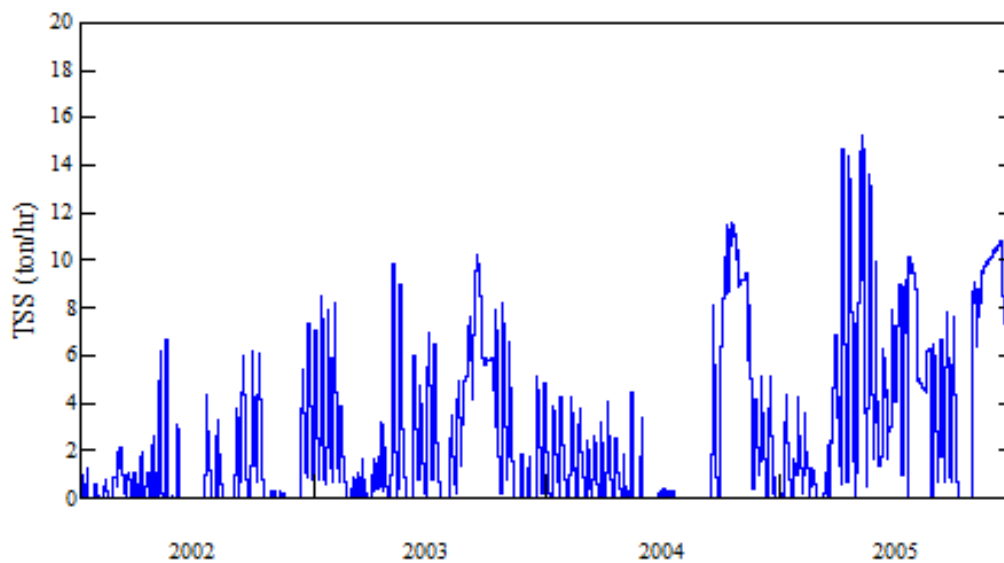


Figure 5-7 Hourly total suspended solids flux at S77

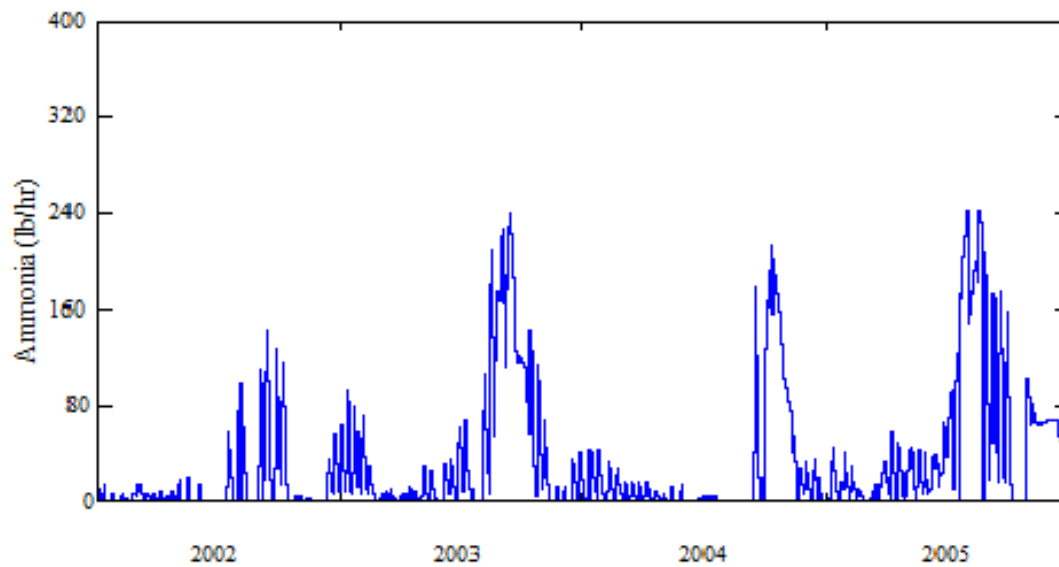


Figure 5-8 Hourly NH₃/NH₄ flux at S77.

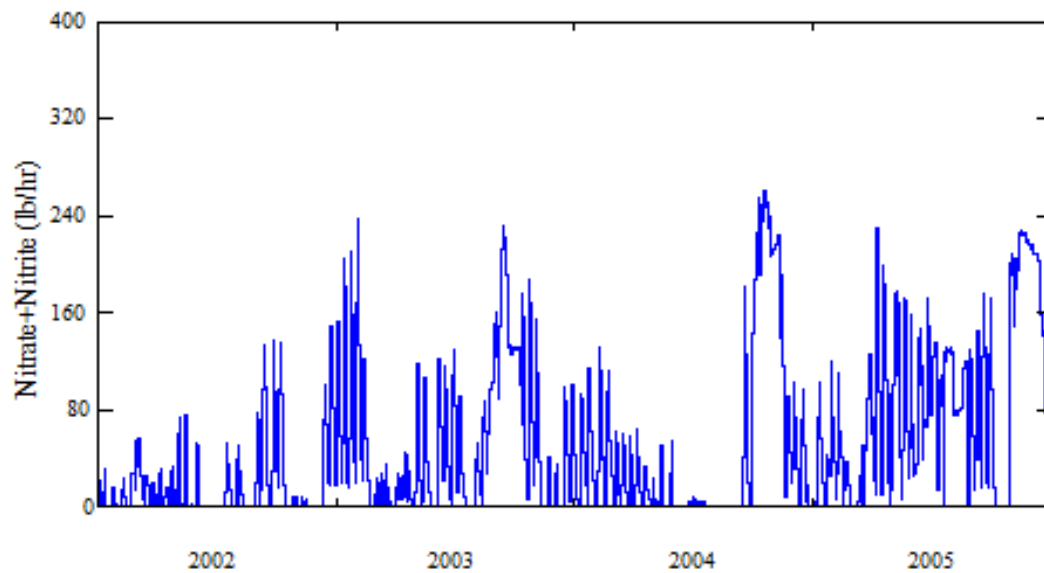


Figure 5-9 Hourly nitrate + nitrite flux at S77

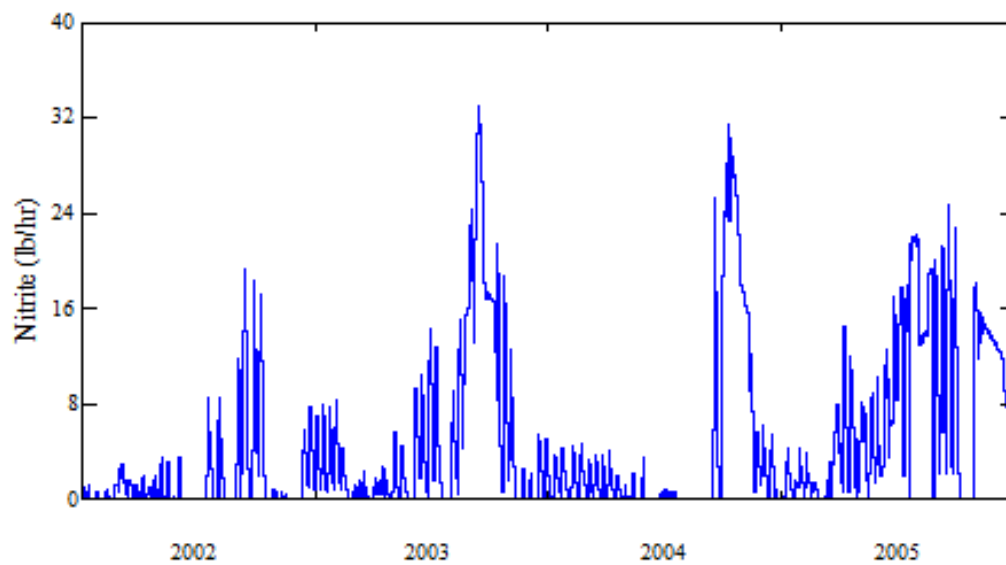


Figure 5-10 Hourly nitrite flux at S77

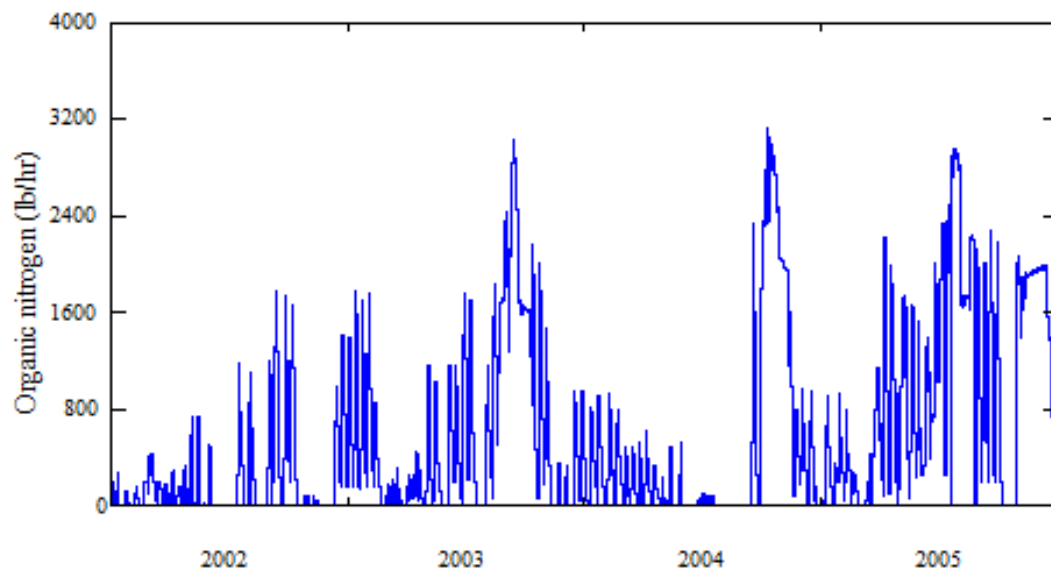


Figure 5-11 Hourly organic nitrogen flux at S-77

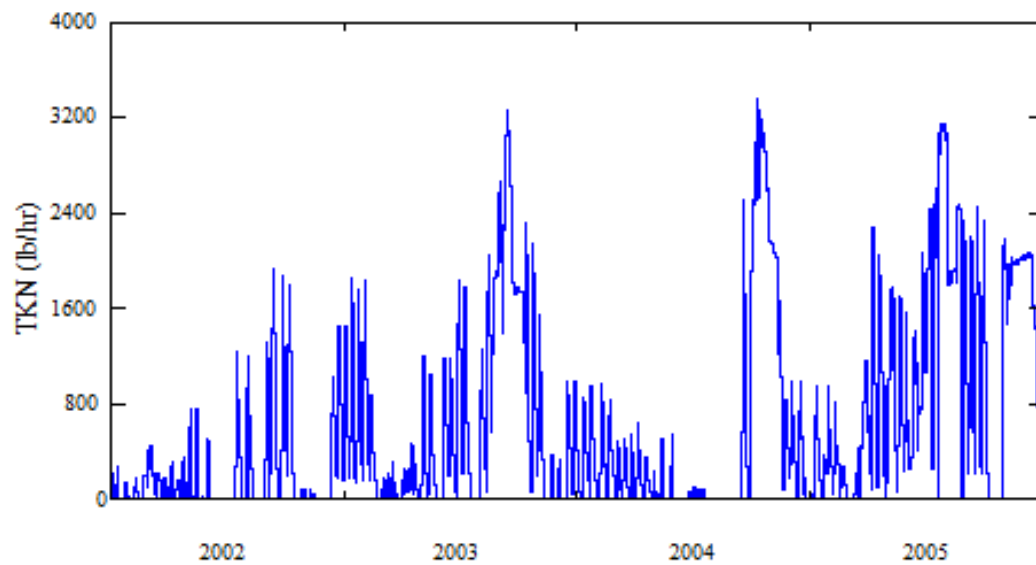


Figure 5-12 Hourly TKN flux at S77

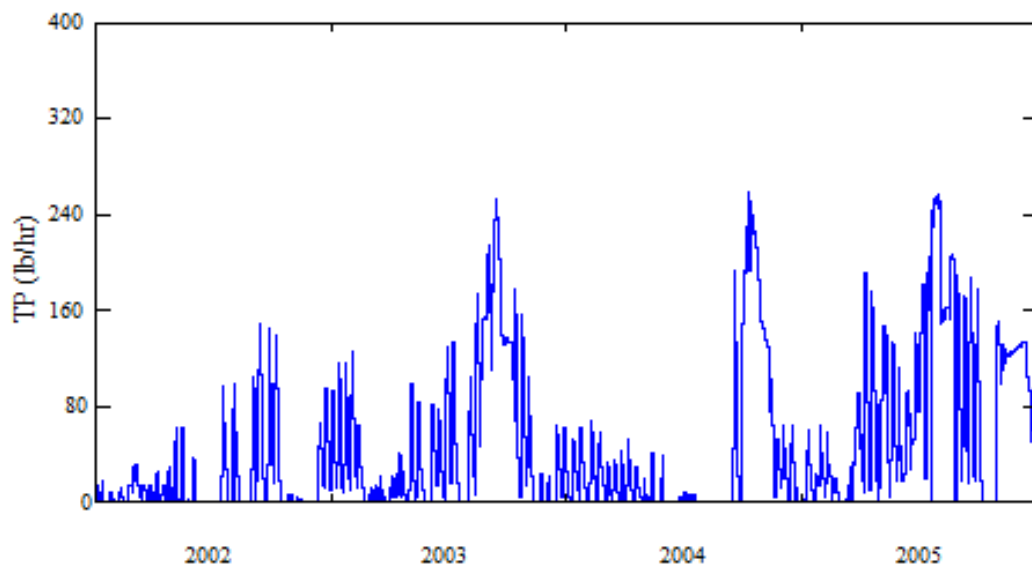


Figure 5-13 Hourly total phosphate flux at S-77

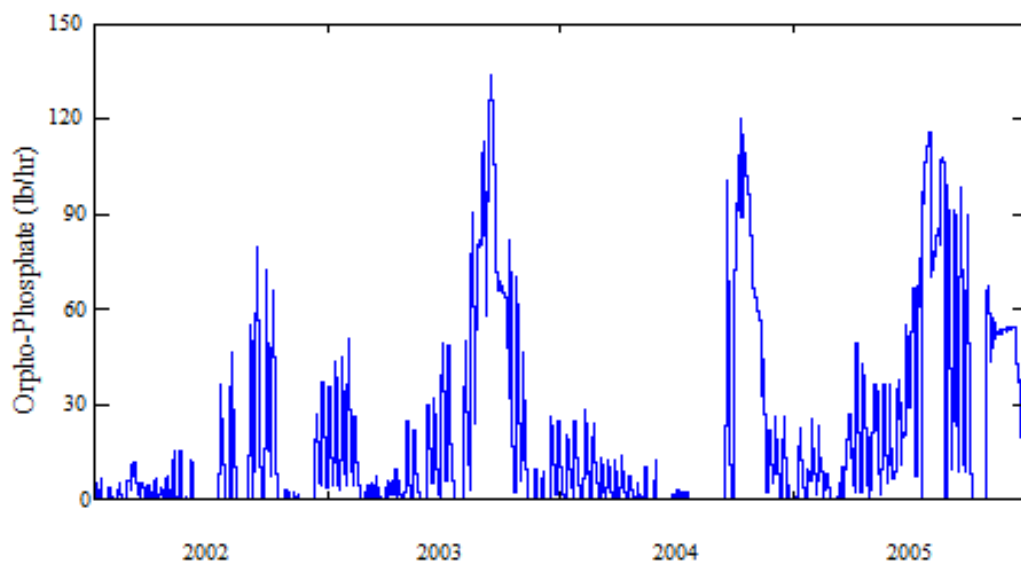


Figure 5-14 Hourly ortho-phosphate flux at S77

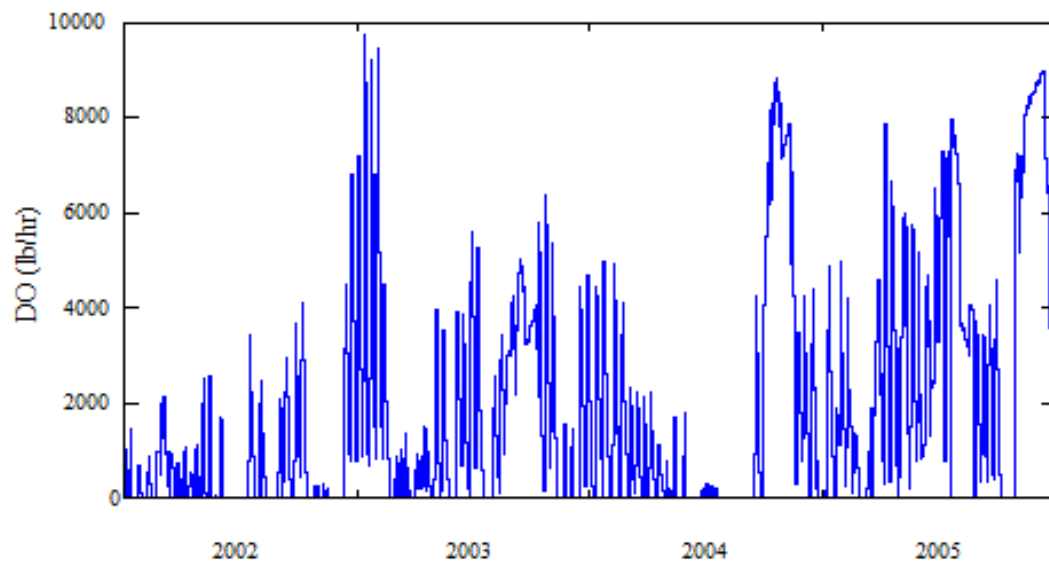


Figure 5-15 Hourly dissolved oxygen flux at S77

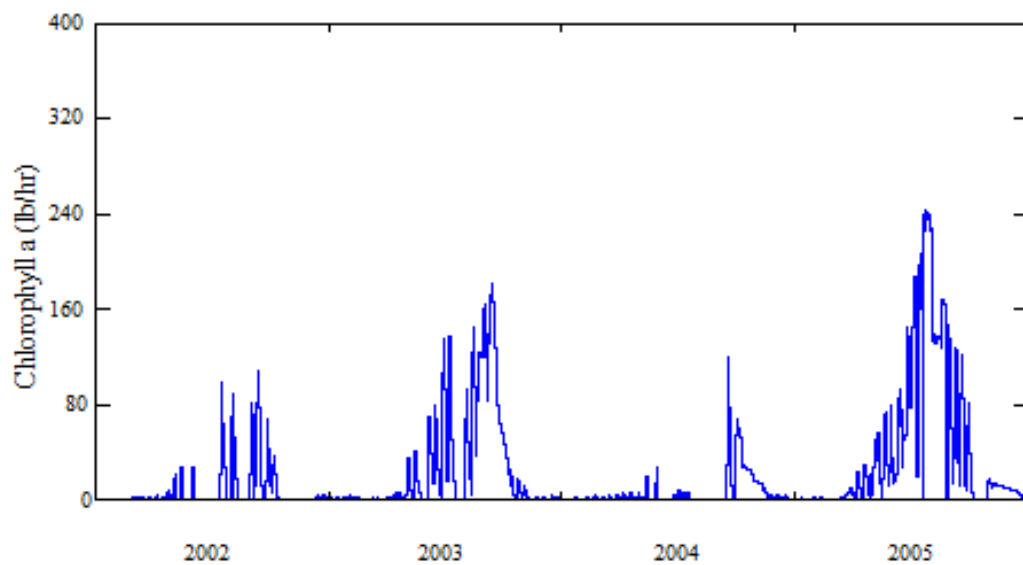


Figure 5-16 Hourly Chl-a flux at S77.

5.2.1.7 Point Source Discharges

Point source discharge data are needed to develop a comprehensive water quality model and compute waste load allocation (WLA) portion of the TMDL. Data obtained from FDEP indicate that there are 93 National Pollution Discharge Elimination System (NPDES) permitted facilities in the watershed. Geographic locations of these point sources are shown in **Figure 5-17**. Forty-four of these facilities were identified as domestic or industrial wastewater treatment facilities having effluent measurements in Discharge Monitoring Report (DMR) data. DMR data for these point sources were obtained from the FDEP and average flow and pollutant loads were computed. The waterbody (HSPF reach ID) receiving the effluent from each point source was identified using either the EPA's Permit Compliance System (PCS) data or their geographic location using a GIS. Information about the facility, flow, receiving waterbody, and the type of wastewater source are provided in **Table 5-7**. Average concentrations of water quality constituents in the point source effluents as determined from the DMR data are listed in **Table 5-8**. Average flow and concentrations were used to determine the pollutant loads from individual point sources and entered in the model.

Five of other wastewater treatment facilities (NPDES permit numbers: FL0021270, FL0021261, FL0030325, FL0039829 and FL0030007) discharge to the Caloosahatchee River estuary downstream of S-79. Discharges from these five facilities are included in the EFDC receiving water model.

Florida Department of Environmental Protection
 Caloosahatchee River Basin TMDL Model Support
 Task Assignment CDM07-04, May 2008

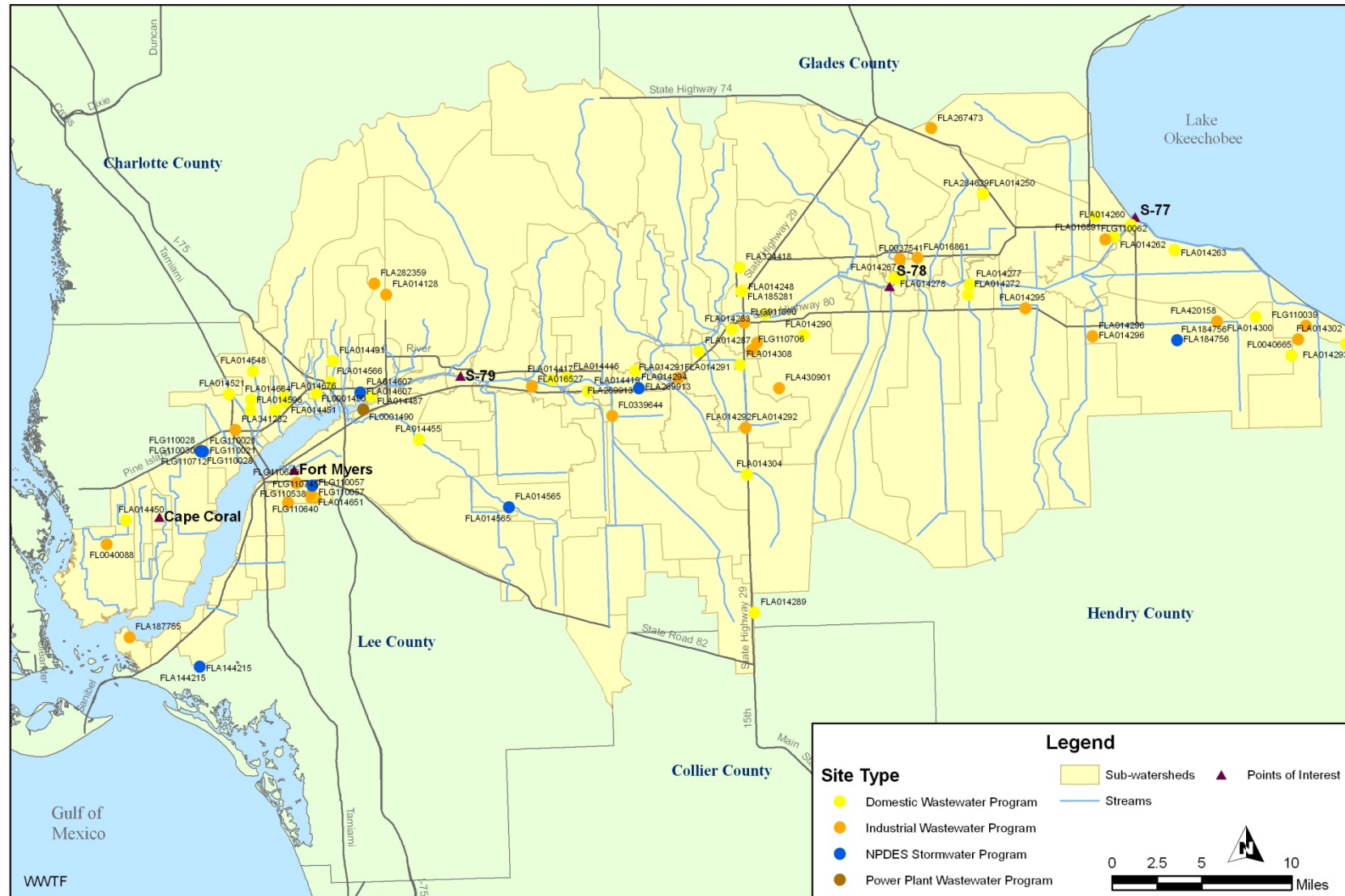


Figure 5-17 Location of permitted wastewater treatment facilities in the Caloosahatchee River watershed

Table 5-7 Wastewater treatment facilities and their discharge information

Facility ID	Facility Name	Receiving HSPF Reach	Design Flow (MGD)	Avg Flow (MGD)	Type
FLA014565	Lehigh Acres WWTP	13	2.48	1.7746	Domestic
FL0040665	Clewiston, City of - WWTF	58	1.5	1.6875	Domestic
FLA014548	North Fort Myers Utility	90	3.5	1.3385	Domestic
FLA014290	Port Labelle	41	0.25	0.1995	Domestic
FLA014283	Labelle, City of	40		0.1944	Domestic
FLA016891	Glades County WWTP	61		0.1020	Domestic
FLA014676	River Trails Mobile Home Park	87	0.097	0.0598	Domestic
FLA014661	Pioneer Village WWTP	86	0.045	0.0483	Domestic
FLA014263	Benbow WWTP	59		0.0449	Domestic
FLA014651	Crews Sanitation Co - Regional Residual Management Facility	9	0.045	0.0284	Domestic
FLA014248	Whisper Creek RV Resort	41	0.044	0.0216	Domestic
FLA014487	Bay Pointe Condominium	82	0.04	0.0211	Domestic
FLA014552	Spring Woods Home Owners Assn	88	0.02	0.0196	Domestic
FLA014304	Labelle Labor Village	33	0.055	0.0183	Domestic
FLA014419	Charleston Park STP	24	0.015	0.0159	Domestic
FLA014451	Julia Park	87	0.015	0.0149	Domestic
FLA014260	Sportsmans Village RV Condo WWTP	59	0.025	0.0144	Domestic
FLA014446	Oak Park Mobile Home Village	24	0.02	0.0144	Domestic
FLA014607	Upriver Campgrounds	82	0.03	0.0127	Domestic
FLA269913	River Bend Motorcoach Resort	31		0.0127	Domestic
FLA014278	River Oaks Subdivision	46	0.015	0.0119	Domestic
FLA014308	Greentree South	38	0.02	0.0118	Domestic
FLA184756	Airglades Industrial Park	58	0.025	0.0113	Domestic
FLA014287	Grandma's Grove RV Park	36	0.025	0.0108	Domestic
FLA014288	Riverbend Estates	41		0.0102	Domestic
FLA014267	Meadowlark Campground	46	0.015	0.0102	Domestic
FLA014491	High Point WWTP	84	0.025	0.0097	Domestic
FLA014417	Alva Schools - Elementary and Middle	76	0.02	0.0083	Domestic
FLA014566	Seminole Campground	84	0.01	0.0080	Domestic
FLA014250	Robin's Nest RV Resort	66	0.03	0.0071	Domestic
FLA185281	Maple Corner WWTP	41		0.0063	Domestic
FLA014277	Hendry Isles Resort	51	0.0075	0.0062	Domestic
FLA014300	Holiday Trav - L - Park KOA	58	0.015	0.0057	Domestic
FLA014596	Swan Lake Mobile Home Park	90	0.025	0.0055	Domestic
FLA014272	Golfer's Heaven At Hendry Isles	51	0.025	0.0048	Domestic

Facility ID	Facility Name	Receiving HSPF Reach	Design Flow (MGD)	Avg Flow (MGD)	Type
FLA014294	South Florida United Methodist Camp	31	0.012	0.0046	Domestic
FLA014450	Whispering Pines Condo Association	101	0.01	0.0040	Domestic
FLA014664	Garden RV Park WWTP	90	0.005	0.0038	Domestic
FLA014455	Hut Restaurant	10	0.005	0.0020	Domestic
FLA014262	River Gardens	61	0.035	0.0015	Domestic
FLA324418	Muse School - West Glades Elementary	41		0.0014	Domestic
FLA014302	US Sugar Corp - Clewiston Mill	60	37.6	2.4478	Industrial
FLA014292	Citrus Belle Packing Plant	33	0.5	0.3003	Industrial
FLA014291	Jack M Berry Inc	32	0.49	0.0799	Industrial

Table 5-8 Average concentrations of water quality constituents in point source effluents based on DMR data

Facility ID	mg/L									Fecal Coli. (#/100 mL)
	TSS	CBOD5	TKN	NO ₃	NO ₂	TON	TN	TP	DO	
FLA014302	1620	1974	14.7	0.7	0.0	15.8				
FLA014565	43	68					4.8			1
FL0040665	68	58					15.7	1.4	4.9	30
FLA014548	89	80								3
FLA014292				0.4				14.5		
FLA014290	74	78		2.8						9
FLA014283	213	223		1.9						10
FLA016891	85	77		5.3			22.9			49
FLA014291		60					5.8			
FLA014676	80	83		5.6						1
FLA014661	87	85		2.9			10.4			7
FLA014263	38	33		5.3						21
FLA014651										
FLA014248	100	145								1
FLA014487	84	107		3.7						1
FLA014552	64	126		0.8						5
FLA014304	104	102		2.6			3.0			1
FLA014419	90	87		2.4			3.8			1
FLA014451	76	79		4.3			3.9			2
FLA014260	60	56		6.3						14
FLA014446	82	78		2.5			5.0			2
FLA014607	124	115		2.4						1
FLA269913	73	32		8.4						2

Facility ID	mg/L								Fecal Coli.	
	TSS	CBOD5	TKN	NO ₃	NO ₂	TON	TN	TP	DO	(#/100 mL)
FLA014278	88	89		14.1						29
FLA014308	74	80		2.5						1
FLA184756	84	265		6.4			11.3			71
FLA014287	108	80		0.1			19.5			2
FLA014288	102	82		2.0						45
FLA014267	136	363								4
FLA014491	75	61		3.1						1
FLA014417	74	49		2.8			15.6			1
FLA014566	104	97		5.6			2.9			2
FLA014250	103	116		10.3						41
FLA185281	72	375		2.6						1
FLA014277	172	125					1.8			7
FLA014300	62	62		2.6						63
FLA014596	103	79		3.4						1
FLA014272	67	73					0.4			4
FLA014294	69	85		2.4			7.9			2
FLA014450	134	68		3.9						1
FLA014664	116	104					4.8			1
FLA014455	201	120		3.4						1
FLA014262	100	109		8.4			6.2			111
FLA324418	48	50		6.0						18

5.2.1.8 Groundwater Withdrawals

The SFWMD issues water withdrawal permits and maintains a database of pumpage information. Data obtained from the SFWMD included GIS data showing the locations of surface water and groundwater withdrawal permits. Only the groundwater withdrawals information were processed and incorporated in the model to account for additional flow and pollutant loads to the surface water system. Groundwater flows/loads are input into the nearest tributary by a time series of flow and pollutant load. Historic flow data were analyzed to determine the monthly average pumpage in each hydrologic unit. Pollutant loads were estimated based on observed groundwater concentrations in the area wells and average pumpage. Locations of these groundwater withdrawal pumps are shown in **Figure 5-18**. Average pumpage and groundwater water quality concentrations used in the model are provided in **Figure 5-19** and **Table 5-9**, respectively.

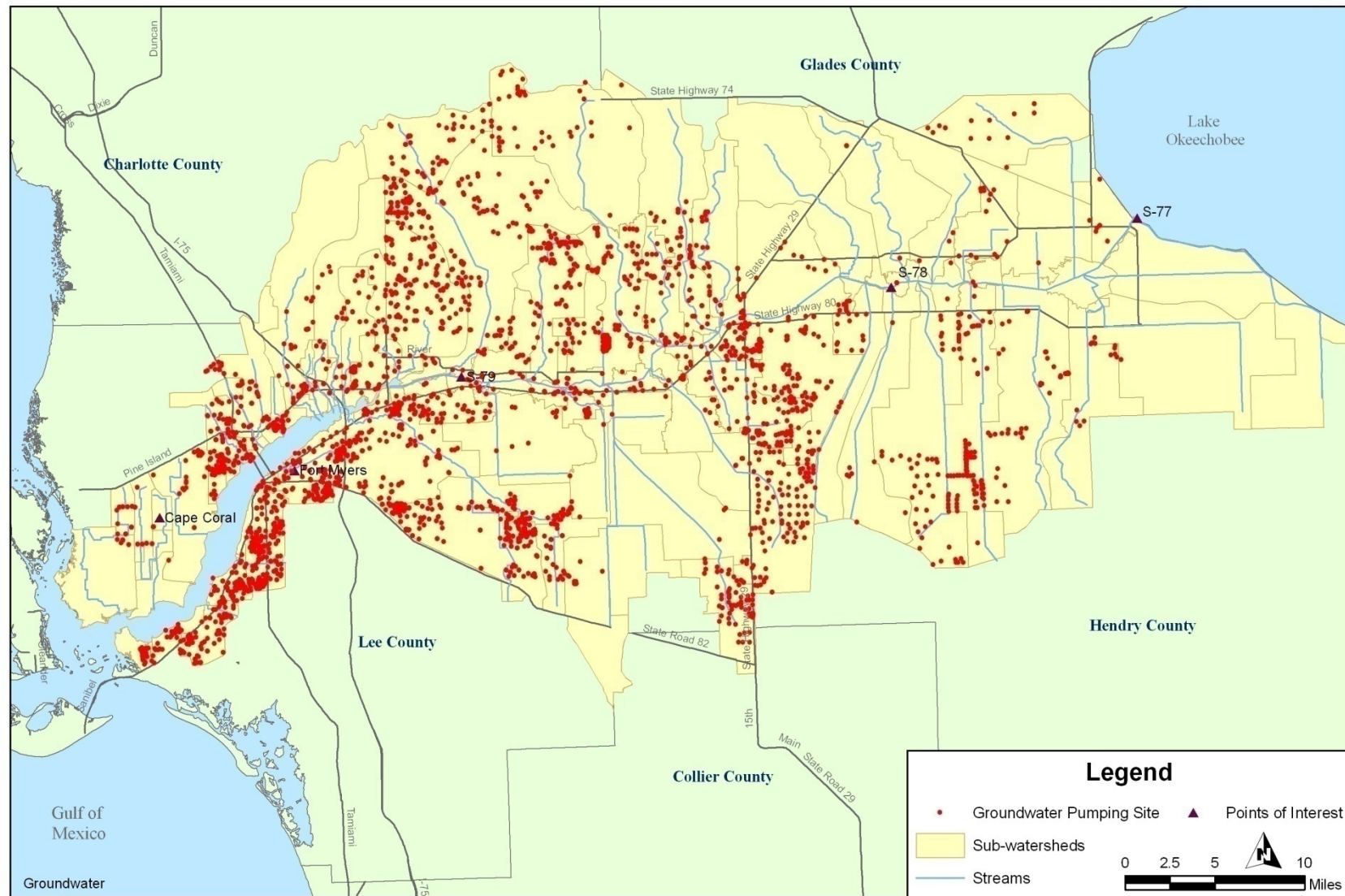


Figure 5-18 Location of groundwater withdrawals in the Caloosahatchee River watershed

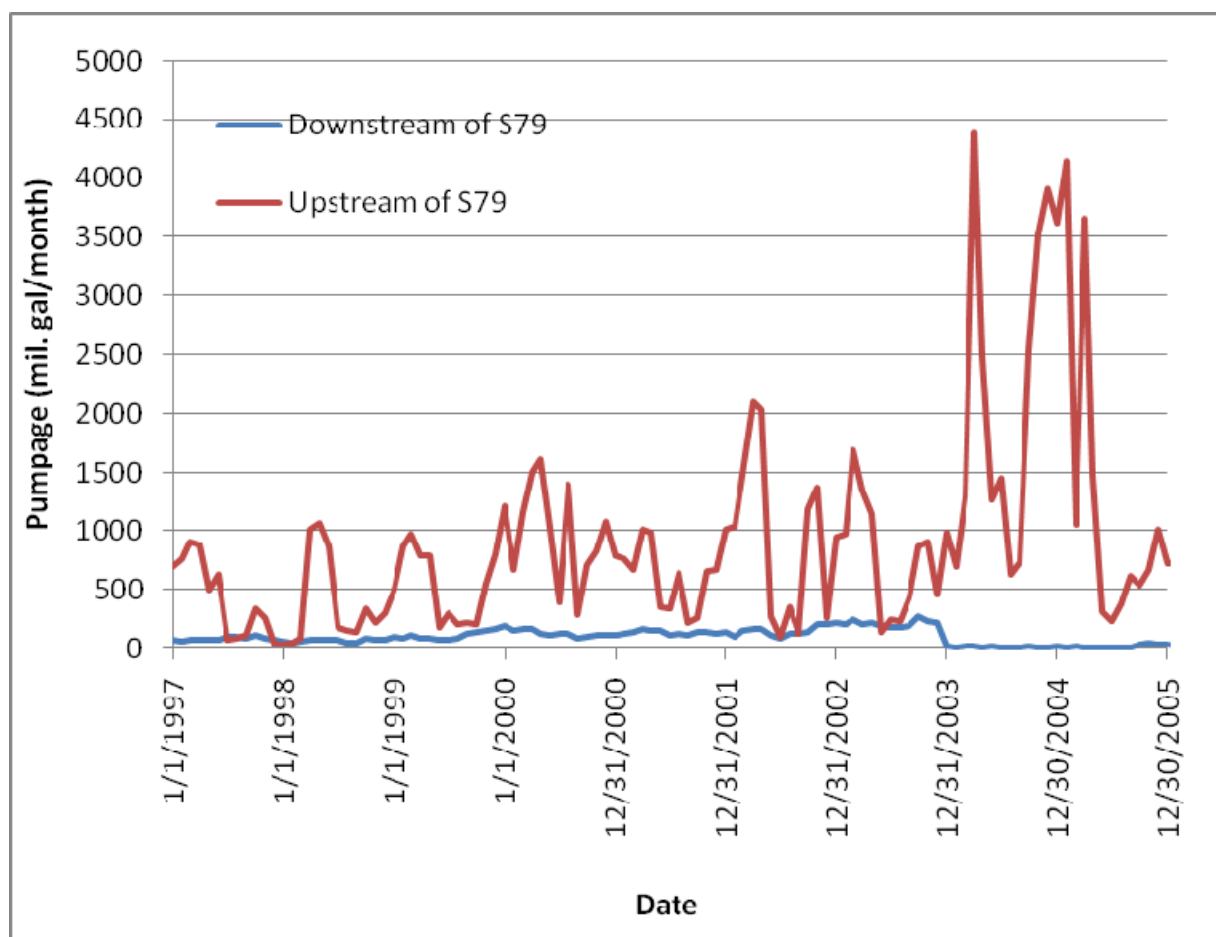


Figure 5-19. Cumulative historic groundwater pumpage rates in areas upstream and downstream of S-79

Table 5-9 Average water quality concentrations in groundwater based on analysis of DBHydro data.

Constituent	Concentration (mg/L)
Ammonia Nitrogen	0.83
Dissolved Oxygen	0.74
Total Kjeldahl Nitrogen	1.64
Nitrate plus nitrite	0.07
Organic Nitrogen	0.81
Phosphate	0.27
Total Phosphorus	0.39

5.2.1.9 Atmospheric Deposition

HSPF accepts both dry and wet deposition of atmospheric pollutants. The dry deposition can be specified as mass flux whereas the wet deposition can be specified as concentration in rain water. In Florida there are 7 National Atmospheric Deposition Program/National Trends Network

(NADP/NTN) stations that monitor wet atmospheric deposition of nutrients. However, none of these stations are located in the study area. The nearest station, F41, is approximately 60 miles north of the Caloosahatchee River watershed. Lee County maintains an atmospheric deposition monitoring site at Lover's Key (site ID LKATMDEP) that recorded data from March 2005 through June 2007. The wet atmospheric deposition of nitrogen and phosphorus were obtained from this Lee County site to calculate monthly average concentrations. Computed average monthly concentrations are presented in **Table 5-10**. The wet atmospheric deposition data for organic nitrogen (ON) were not available and, therefore, calculated by subtracting ammonia from TKN. The dry atmospheric deposition data were not available at the Lee County and the NADP/NTN sites. Hence, the nutrient loads from dry atmospheric deposition were assumed to be negligible.

Table 5-10 Monthly average nutrient concentrations (mg/l) in wet atmospheric deposition monitored at Lover's Key, Lee County.

Month	Ammonia	Nitrite +Nitrate	TKN	Phosphate	Total P
Jan	0.175	0.227	1.000	0.003	0.008
Feb	0.188	0.357	0.530	0.002	0.005
Mar	0.204	0.157	0.563	0.063	0.011
Apr	0.244	0.182	0.278	0.007	0.033
May	0.451	0.280	0.716	0.062	0.080
Jun	0.168	0.181	0.420	0.013	0.017
Jul	0.108	0.169	0.184	0.003	0.008
Aug	0.139	0.295	0.283	0.005	0.011
Sep	0.097	0.169	0.212	0.002	0.006
Oct	0.082	0.110	0.327	0.012	0.023
Nov	0.107	0.156	1.335	0.005	0.020
Dec	0.103	0.090	0.285	0.002	0.008

5.2.1.10 Best Management Practices

The HSPF model utilized Best Management Practice (BMP) data from several sources to account for pollutant load reduction in urban and agricultural areas in the Caloosahatchee River Basin watershed. This information consisted of the type of BMP, classified as urban or agricultural, the removal efficiency, and the spatial extent of these BMPs.

The local jurisdictions of Lee County, City of Fort Myers, and City of Cape Coral were contacted to obtain stormwater related data that would be useful in establishing a spatial coverage of BMP treated areas. The City of Fort Myers provided 57 hard copies of permit files which, in some cases, included locations of stormwater treatment areas within the City. For the City of Cape Coral, dominated by canals, it was decided that freshwater canals provide sufficient residence time and treatment volume storage to be treated as wet detention pond BMPs in HSPF.

The Institute of Food and Agricultural Sciences (IFAS) from the University of Florida has collected the Notices of Intent (NOI) State-wide for the Florida's Department of Agricultural and Consumer Services (FDACS). FDACS provided the NOI database for the Study Area. The NOI database constitutes the best information available on spatial coverage of agricultural BMP implementation. The database identifies a number of practices oriented to reduce stormwater runoff pollution per

parcel. **Tables 5-11 and 5-12** present urban and agricultural BMP removal efficiencies by constituent and BMP type, and acreage of BMP by Hydrologic Unit number. **Figure 5-20** depicts best management practices by type with hydrologic unit numbers for the Caloosahatchee River watershed. Site-specific BMPs are beyond the level of detail for these TMDL models. Therefore, BMPs were considered by reducing the loading factors based upon the percentage of BMP coverage and its relative efficiency by parameter.

Table 5-11 Urban and Agricultural BMP Removal Efficiencies by Constituent and BMP Type.

Urban and Agricultural BMP Removal Efficiencies	Urban BMP	Agricultural BMP 1	Agricultural BMP 2	Agricultural BMP 3	Agricultural BMP 4
Total Suspended Solids	0.85	0.80	0.30	0.50	0.10
BOD5	0.30	0.40	0.13	0.23	0.07
Nitrate+Nitrite	0.35	0.30	0.10	0.18	0.05
Total Kjeldahl Nitrogen (TKN)	0.25	0.30	0.10	0.18	0.05
Dissolved Phosphorus	0.65	0.60	0.20	0.35	0.10
Total Phosphorus	0.50	0.60	0.20	0.35	0.10

Agricultural BMP 1 Water Management Activities
Agricultural BMP 2 Water Control Structures Maintenance
Agricultural BMP 3 Pest Management Activities
Agricultural BMP 4 Nutrient Management Activities

Table 5-12 Acreage of BMP by Hydrologic Unit and Type.

Hydrologic Unit	Urban BMP Treatment Areas				Agricultural BMP Treatment Areas		
	Commercial / industrial / extractive / transportation (acres)	High density residential (acres)	Low density residential / recreational (acres)	Medium density residential / institutional (acres)	Citrus (acres)	Cropland / improved pasture / tree crops (acres)	Ag BMP Type
1	23.3	50.1	197.7	93.8			
2	4.3	75.2	112.2	296.1			
3	0.8	5.9	6.6	71.1			
4	134.4	397.4	121.5	459.0			
5	9.6	61.0	65.0	82.7			
6	71.0	67.0	12.7	109.6			
7	737.2	123.2	129.2	21.1			
8	152.1	13.1	117.7	63.1			
9	590.2	35.5	87.6	236.8			
10	353.0	240.0	2,687.1	472.7			
11	352.3	35.7	7,474.4	437.1			
12	0.0	0.0	0.0	331.0			
13	84.4	52.5	1,549.5	179.8			
14	3.2	3.0	180.4	317.1			

Hydrologic Unit	Urban BMP Treatment Areas				Agricultural BMP Treatment Areas		
	Commercial / industrial / extractive / transportation (acres)	High density residential (acres)	Low density residential / recreational (acres)	Medium density residential / institutional (acres)	Citrus (acres)	Cropland / improved pasture / tree crops (acres)	Ag BMP Type
15	155.9	0.0	10.5	3.3			
16	7.9	0.0	0.1	5.4			
17	15.8	0.0	20.1	9.7			
18	15.6	0.0	211.0	54.9			
19	4.9	0.0	2,332.5	0.0			
20	17.4	0.0	388.3	0.0			
21	36.3	0.0	74.3	0.0			
22	14.5	0.0	64.6	5.8			
23	0.0	0.0	1,008.8	0.0			
24	51.6	0.0	386.5	165.4			
25	0.0	0.0	17.2	0.0			
26	0.0	0.0	0.0	0.0			
27	207.1	0.0	475.3	6.8			
28	106.8	0.0	0.0	0.0			
29	15.6	0.0	0.0	0.0	6,260.2	1,879.5	Ag BMP 1
30	46.2	0.0	108.5	3.5			
31	57.5	69.4	336.9	0.0			
32	58.7	0.0	24.2	0.0			
33	64.2	0.0	51.1	5.2	82.0	829.6	Ag BMP 1
34	10.8	0.0	122.1	0.0			
35	0.6	0.0	114.7	0.0	4.3	2.7	Ag BMP 2
36	36.3	21.3	65.2	0.0			
37	17.3	0.0	0.0	0.0			
38	7.9	24.4	198.2	46.0	113.0	325.5	Ag BMP 1
39	37.1	0.0	112.0	0.0			
40	463.9	31.2	176.8	480.2	39.1	0.1	Ag BMP 1
41	316.0	114.8	2,158.4	461.6	39.6	665.4	Ag BMP 1
42	0.0	0.0	46.2	0.0			
43	0.2	0.0	0.0	0.0	95.1	134.3	Ag BMP 1
44	0.0	6.0	133.6	0.0			
45	0.0	3.0	13.6	0.0	459.5	312.1	Ag BMP 1
46	0.0	4.4	13.1	5.2			
47	102.0	0.8	0.0	0.0			
48	10.6	0.0	7.3	0.0	579.2	1,399.8	Ag BMP 1
49							
50	2.4	0.0	39.5	0.0			
51	16.4	0.0	331.9	0.0	13.2	223.8	Ag BMP 3
52	0.0	0.0	8.0	0.0			

Florida Department of Environmental Protection
Caloosahatchee River Basin TMDL Model Support
Task Assignment CDM07-04, May 2008

Hydrologic Unit	Urban BMP Treatment Areas				Agricultural BMP Treatment Areas		
	Commercial / industrial / extractive / transportation (acres)	High density residential (acres)	Low density residential / recreational (acres)	Medium density residential / institutional (acres)	Citrus (acres)	Cropland / improved pasture / tree crops (acres)	Ag BMP Type
53	0.0	0.0	0.0	0.0			
54	28.2	0.0	317.5	0.0	1,166.6	1,717.1	Ag BMP 3
55	0.0	0.0	0.4	0.0	0.0	5.5	Ag BMP 1
56	10.3	0.0	14.3	0.0	604.6	2,790.3	Ag BMP 4
57	0.0	0.0	0.0	0.0	10.1	49.3	Ag BMP 1
58	577.4	0.0	40.0	61.9	2,435.3	6,446.4	Ag BMP 2
59	297.0	14.7	40.6	8.3			
60	1,149.0	7.3	356.9	149.7			
61	110.9	0.0	172.7	51.9			
62	124.4	0.0	0.0	0.0			
63	0.0	0.0	11.6	0.0			
64	233.7	0.0	0.0	0.0			
65	2.2	0.0	0.0	0.0			
66	100.2	0.0	113.2	0.0			
67	288.6	0.0	4.5	3.5			
68	225.6	0.0	26.5	4.2			
69	0.0	0.0	13.8	0.0	37.0	594.2	Ag BMP 1
70	0.0	0.0	413.6	60.8			
71	28.5	0.0	651.4	0.5			
72	23.5	0.0	547.0	7.3			
73	24.2	0.0	424.6	6.2			
74	22.8	0.0	170.2	0.0	1,241.5	2,327.1	Ag BMP 1
75	0.0	0.0	21.7	0.0			
76	20.7	0.0	169.8	0.0			
77	6.6	0.0	162.1	15.0	0.0	5.2	Ag BMP 1
78	0.0	0.0	0.0	0.0			
79	0.0	0.0	124.2	0.0			
80	0.2	0.0	54.8	0.0			
81	564.1	0.0	123.4	0.0			
82	23.4	0.0	152.1	0.0			
83	20.5	9.8	96.2	9.3			
84	258.4	0.0	414.6	0.1			
85	20.6	0.0	336.4	17.3			
86	48.8	0.0	122.3	0.0			
87	33.7	27.5	102.3	13.2			
88	83.5	11.8	553.5	29.7			
89	34.9	105.5	200.0	91.2			
90	18.7	0.0	0.0	0.0			

Florida Department of Environmental Protection
Caloosahatchee River Basin TMDL Model Support
Task Assignment CDM07-04, May 2008

Hydrologic Unit	Urban BMP Treatment Areas				Agricultural BMP Treatment Areas		
	Commercial / industrial / extractive / transportation (acres)	High density residential (acres)	Low density residential / recreational (acres)	Medium density residential / institutional (acres)	Citrus (acres)	Cropland / improved pasture / tree crops (acres)	Ag BMP Type
91	94.4	164.5	125.5	33.0			
92	140.5	165.6	73.6	9.4			
93	194.0	169.6	576.0	136.7			
94	3.1	24.1	147.7	75.8			
95	172.1	85.7	144.0	242.0			
96	0.0	8.0	66.5	36.8			
97							
98	0.0	2.0	8.8	28.9			
99	0.0	49.8	6.0	131.3			
100	38.5	0.6	436.9	183.7			
101	64.3	172.8	4,301.7	411.2			
102	24.1	6.5	1,042.5	140.4			

Agricultural BMP 1 Water Management Activities
Agricultural BMP 2 Water Control Structures Maintenance
Agricultural BMP 3 Pest Management Activities
Agricultural BMP 4 Nutrient Management Activities

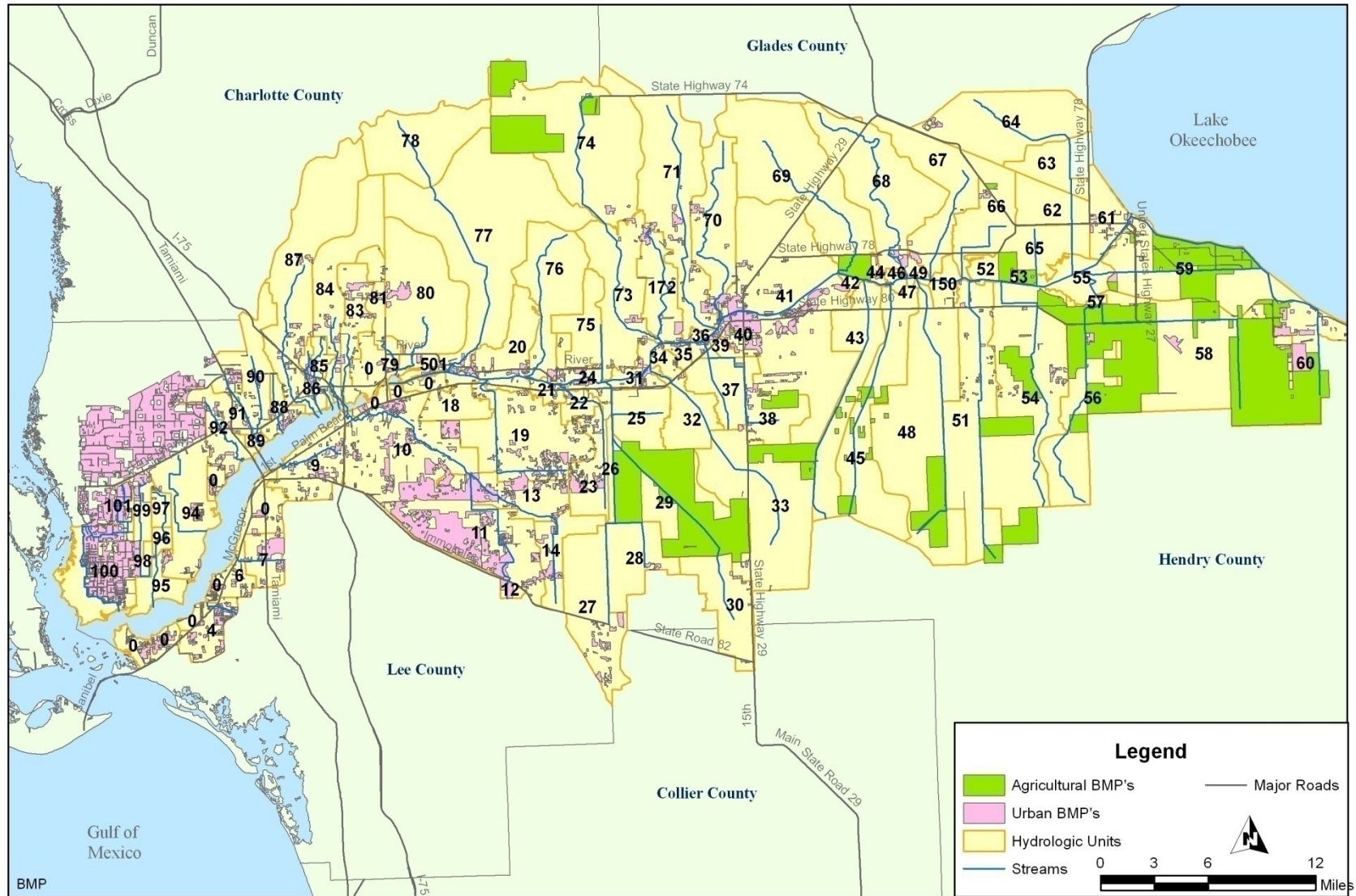


Figure 5-20 Best Management Practices by Type with Hydrologic Unit Numbers Shown

5.2.1.11 Model Coefficients

Model coefficients are required to fully represent the components of hydrologic cycle (e.g., surface and subsurface flows and storages, infiltration, evapotranspiration, etc), pollutant loads from land segments, routing of flow and pollutants in receiving water bodies, and in-stream processes involving water quality constituents. Model coefficients were initially selected from the body of literature (USEPA, 2000; USEPA 1978; Tellis, 2001; Bowie, 1985) and further refined through model calibration.

5.2.1.12 Initial Conditions

In a continuous simulation model it is necessary to specify the state of the system at the start of the simulation. In HSPF initial conditions are specified by assigning values to a number of state variables. HSPF input for initial hydrologic conditions (such as lower zone nominal storage and interception storage) are not directly measurable quantities. Therefore, the variables that determine the initial hydrologic condition of the watershed were estimated by adjusting their values to match modeled flow with observed data. Initial conditions for the water quality variables were assigned based on the observed water quality data.

5.2.2 Verification of HSPF Model

The Caloosahatchee River HSPF model consists of a network of stream reaches and associated land segments. Reach connectivity, distribution of land uses, and connectivity of land segments and reaches were manually checked using a custom spreadsheet as well as the ArcView GIS software. Also the error/warning log file generated by HSPF during the model execution was checked to ensure that no errors or significant warnings were reported in the log file.

5.2.3 Sensitivity Analysis

In order to evaluate the impact of changes in hydrologic input data on streamflows three scenarios were modeled and compared with calibrated hydrologic model results. These scenarios include

- A 20 percent increase in precipitation intensity and amount
- A 50 percent increase in evapotranspiration
- Infiltration rates reduced by a factor of 10

Changes in HSPF input data resulted in changes in streamflow as shown in **Figures 5-21 through 5-23**. An increase in precipitation, a reduction in infiltration and an increase in hydrologically connected imperviousness increased peak flows whereas an increase in evapotranspiration reduced streamflow. The impacts caused by the changes in hydrologic input data are reasonable and, therefore, the model is considered responsive. It is important to note that the impact of changes in input data are less pronounced at USGS gage 02292900 as the inflow from Lake Okeechobee to Caloosahatchee River and subsequent discharge at gage S-78 constitute a significant part of the flow in the Caloosahatchee River.

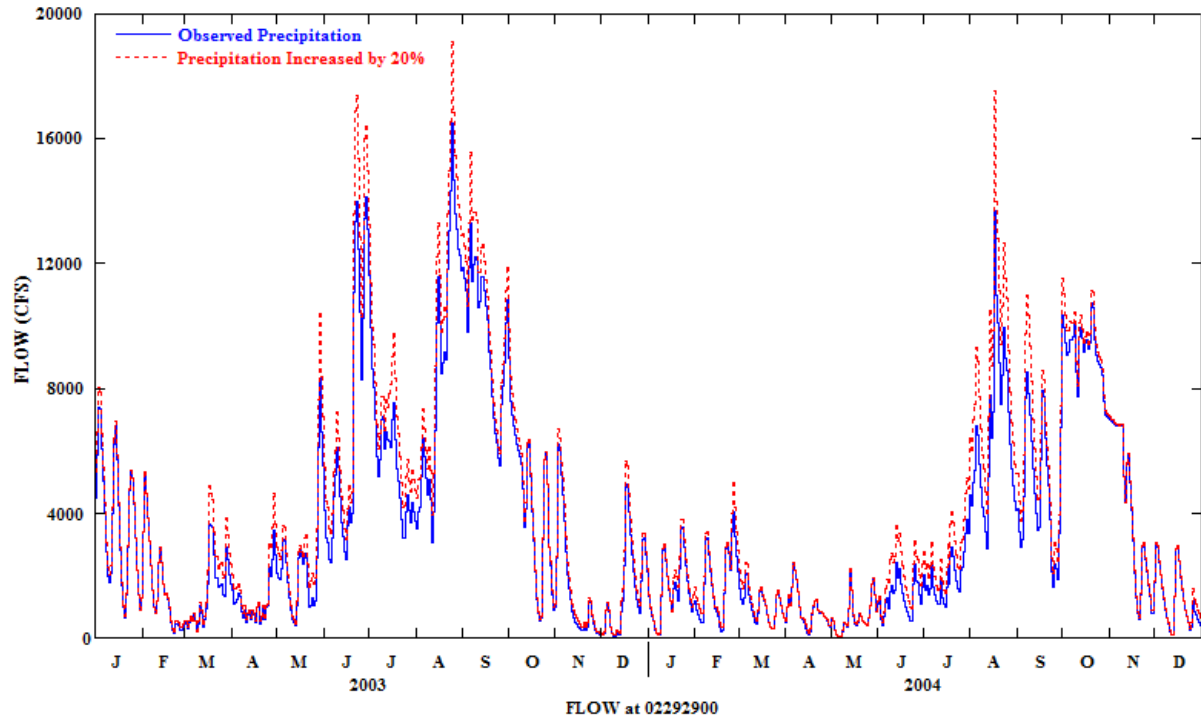


Figure 5-21 Impact of 20% increase in rainfall intensity on streamflow at the USGS gage 02292900

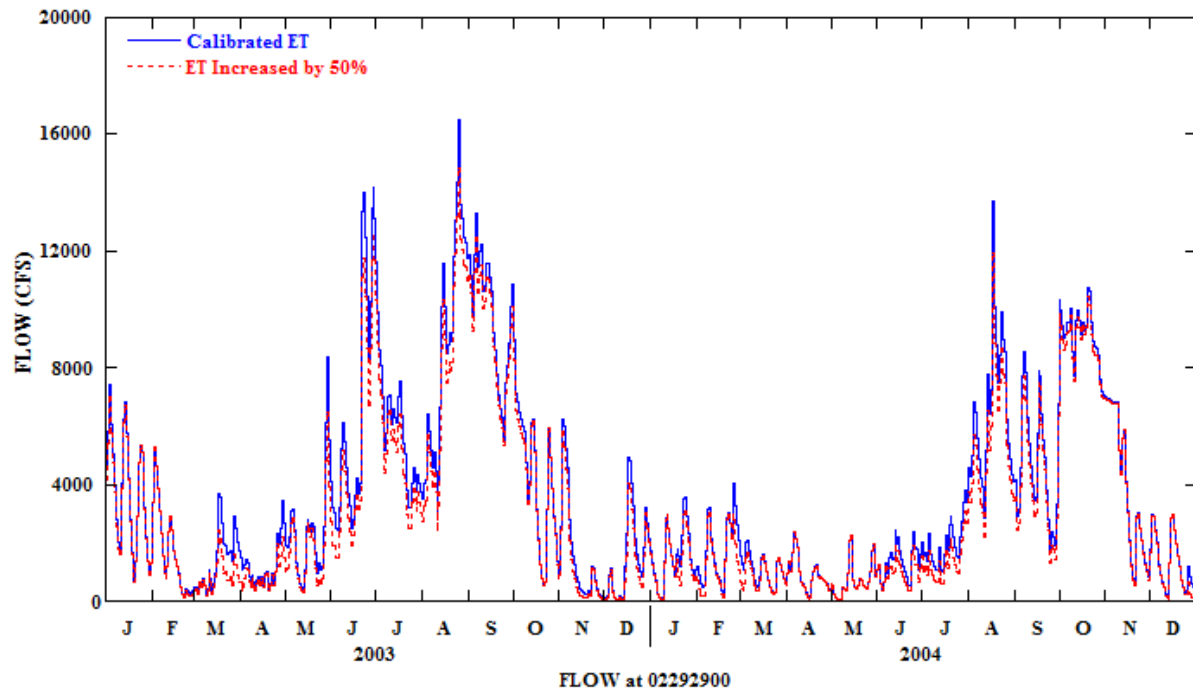


Figure 5-22 Impact of 50% increase in evapotranspiration rate on streamflow at the USGS gage 02292900

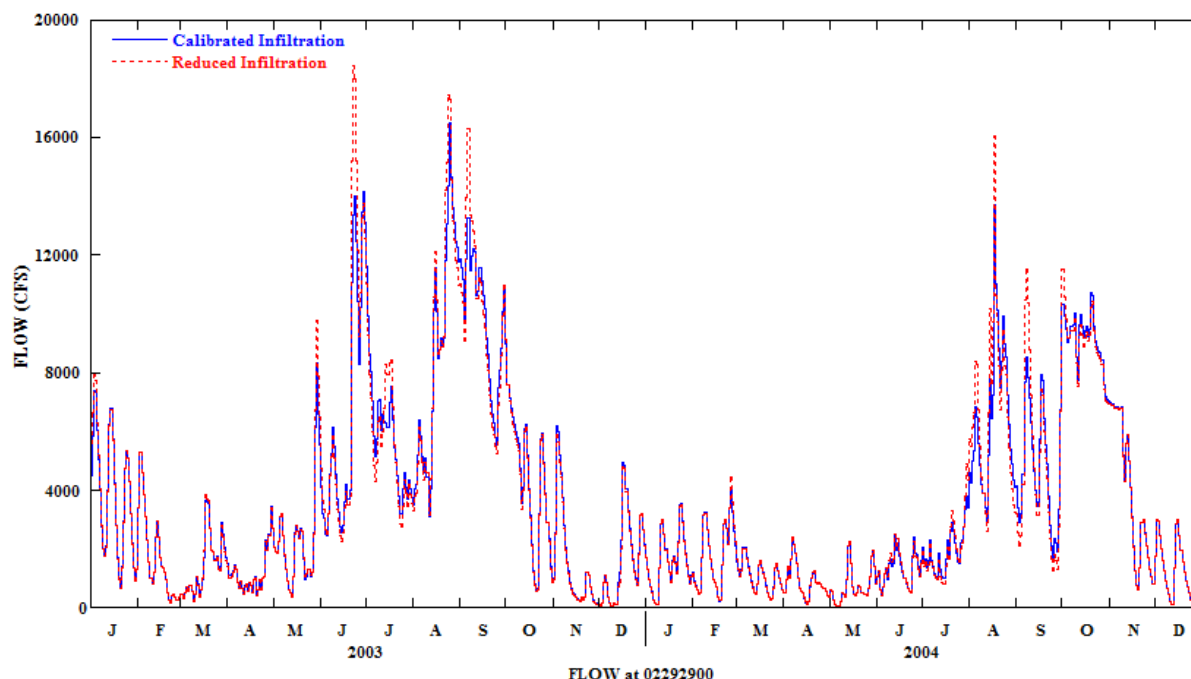


Figure 5-23 Impact of reduction of infiltration rate on streamflow at the USGS gage 02292900

5.2.4 HSPF Model Calibration And Validation

5.2.4.1 Hydrologic Calibration

Two USGS gages on the main stem of the Caloosahatchee River and three USGS gages on small tributaries in Ft. Myers and the City of Cape Coral have long-term flow data available. These gages are:

- Caloosahatchee River at S-79, near Olga (02292900)
- Caloosahatchee Canal at Ortona Lock, near La Belle (02292480)
- Whiskey Creek at Ft. Myers (02293230)
- San Carlos Canal at Cape Coral (02293241)
- Courtney Canal at Cape Coral (02293243)

The locations of these gages are shown in **Figure 5-24**. The daily average flow from the gages at S-79, S-78 (Ortona Lock), and San Carlos Canal were used to calibrate and validate the model. The quality of daily flow data recorded at the San Carlos Canal and the Courtney Canal gages is considered poor by USGS (<http://pubs.usgs.gov/wdr/2004/wdr-fl-04-2a/pdf/p344-345.pdf> and <http://pubs.usgs.gov/wdr/2004/wdr-fl-04-2a/pdf/p342-343.pdf>). According to the USGS measured flows at these gages are impacted by heavy debris buildup on the carp grates installed on top of the weir. Estimated daily flows at the Whiskey Creek at Ft. Myers are also considered poor by USGS. Therefore, the daily flows at the San Carlos Canal gage were used with caution for model calibration and validation. During the model calibration effort, flows were computed at the same locations as the gages and compared with observed flows to estimate appropriate model parameters providing a good match.

Flow calibration of the model was performed using January 2001 through December 2005 flow data. Daily average modeled and observed flows at S-79, S-78 and the San Carlos Canal gages are plotted in **Figures 5-25 through 5-27**. Scatter plots of monthly mean modeled versus observed flows (**Figures 5-28 and 5-30**) show that the model output are in good agreement at S-79 while at the San Carlos Canal gage the match is not as good. The relatively poor match at the San Carlos Canal gage is attributed to the errors in observed data (frequent 0.0 flows) as discussed earlier. A comparison of average annual flows at S-79 (**Table 5-13**) shows only a 3% error in flow calibration over the entire simulation period. The errors in annual flows calibration at S78 and San Carlos were 9.0% and -9.0%.

For calibration period, the observed and modeled probability of exceedances for daily flows at S-79, S-78, and San Carlos are given by **Figures 5-31 through 5-33**. Generally, the hydrological model performed better in simulating high flow events than low flow events. This could be attributed to the inaccuracies in precipitation data. A slight error in rainfall data could result in large discrepancies between observed and simulated flows for low flow events. The results also indicated that the model performed better in S-79 and S-78 than in San Carlos. The possible reasons have been discussed above.

Nash-Sutcliffe efficiency coefficient (NSE) is calculated by the equation below to evaluate the fit between observed and modeled daily flows. The values of the NSE vary from negative infinite to 1. The simulated flows would exactly match the observed flow when NSE is equal to 1. The NSE coefficient is a better criterion to evaluate model fitness when simulated flows are constantly higher or lower than observed flows (Laroche et al, 1996).

$$NASH = 1 - \frac{\sum_{i=1}^n (Q_{oi} - Q_{si})^2}{\sum_{i=1}^n (Q_{oi} - \bar{Q}_s)^2}$$

where Q_{oi} is the i th observed flow value (cfs); Q_{si} is the i th simulated flow value (cfs); $\bar{Q}_s$ is the mean simulated flow value (cfs); n is the number of observed values; and i is the index for observed value (Nash and Sutcliffe, 1970).

At calibration period, the calculated NSE coefficients for S-79, S-78, and San Carlos, were 0.81, 0.85, and 0.45, which indicated very good modeling performance at S-79 and S-78 and fair modeling performance at San Carlos.

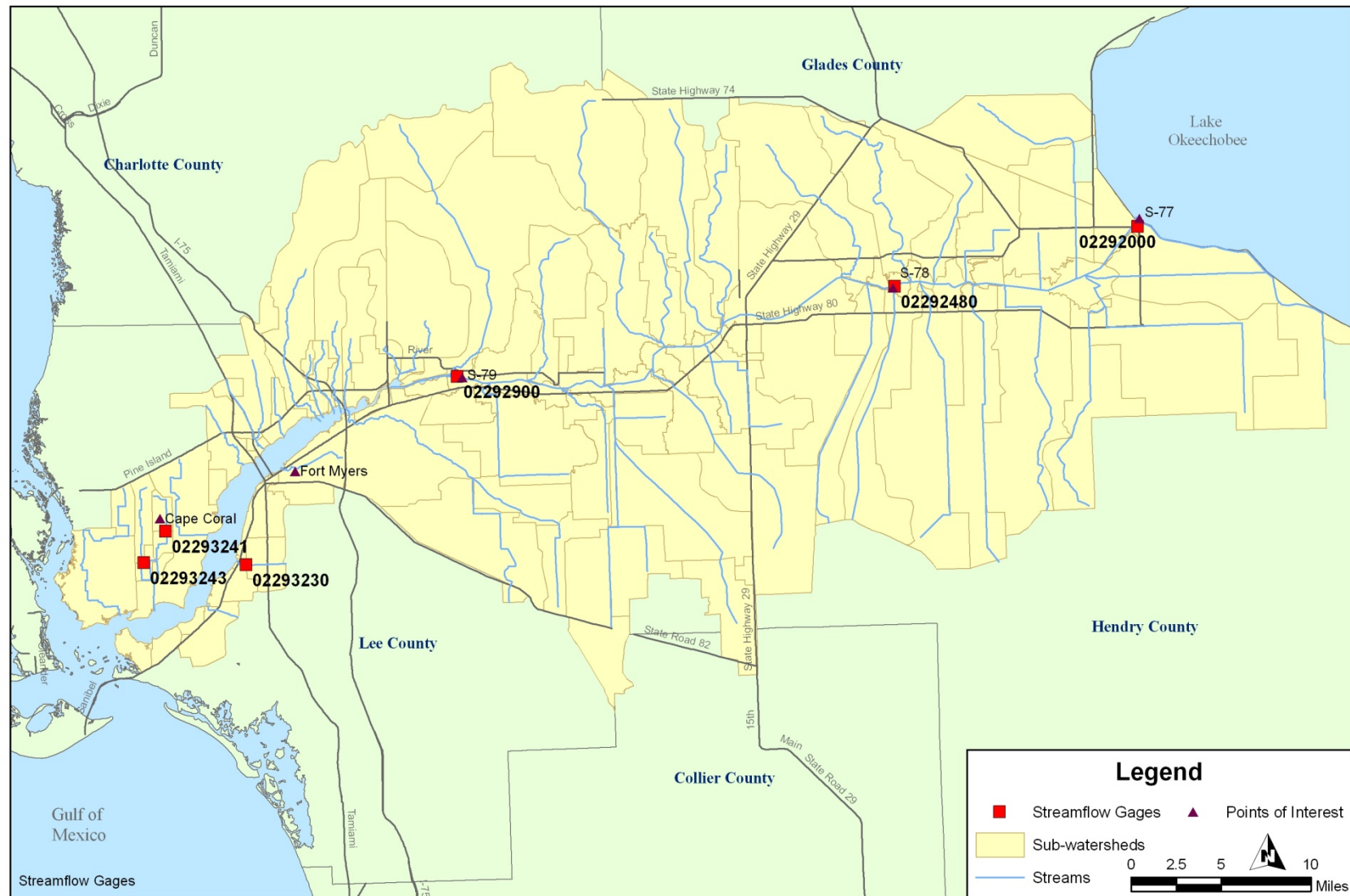


Figure 5-24 Flow gages in the Caloosahatchee River watershed that have long-term daily flow records

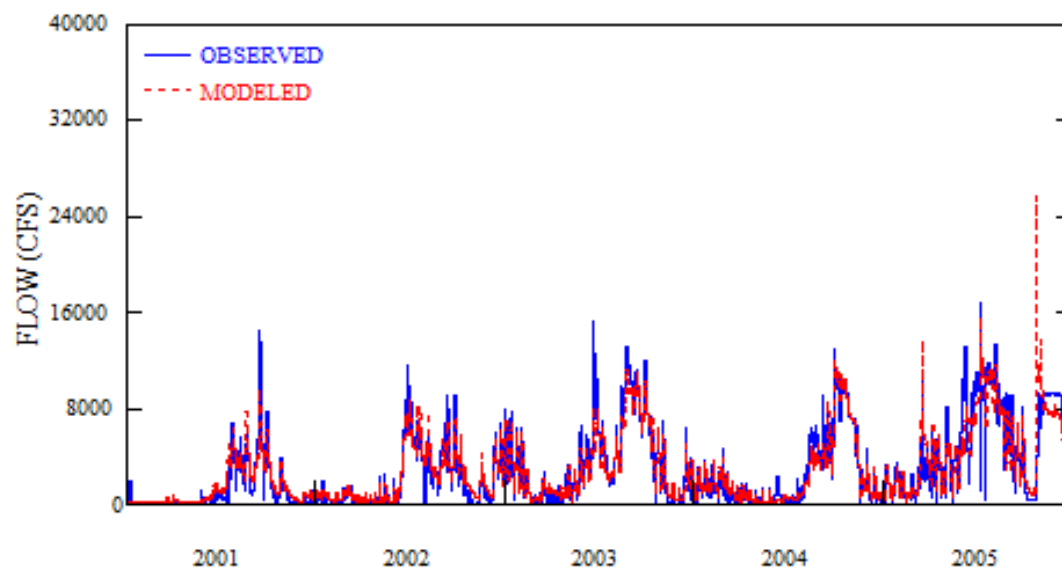


Figure 5-25 Modeled and observed flows at S-79 for the calibration period

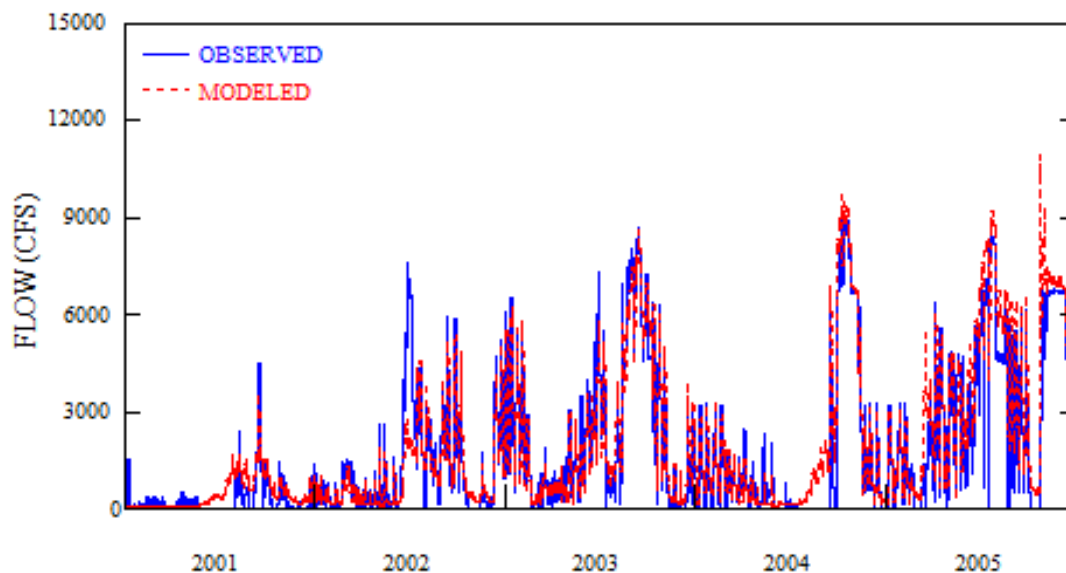


Figure 5-26 Modeled and observed flows at S-78 for the calibration period

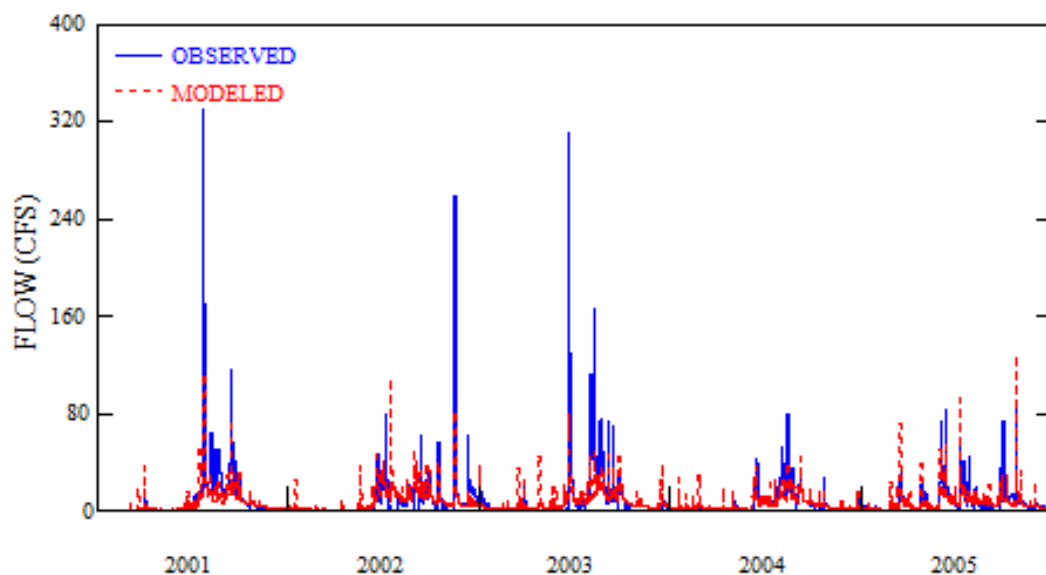


Figure 5-27 Modeled and observed flows at the San Carlos Canal gage for the calibration period

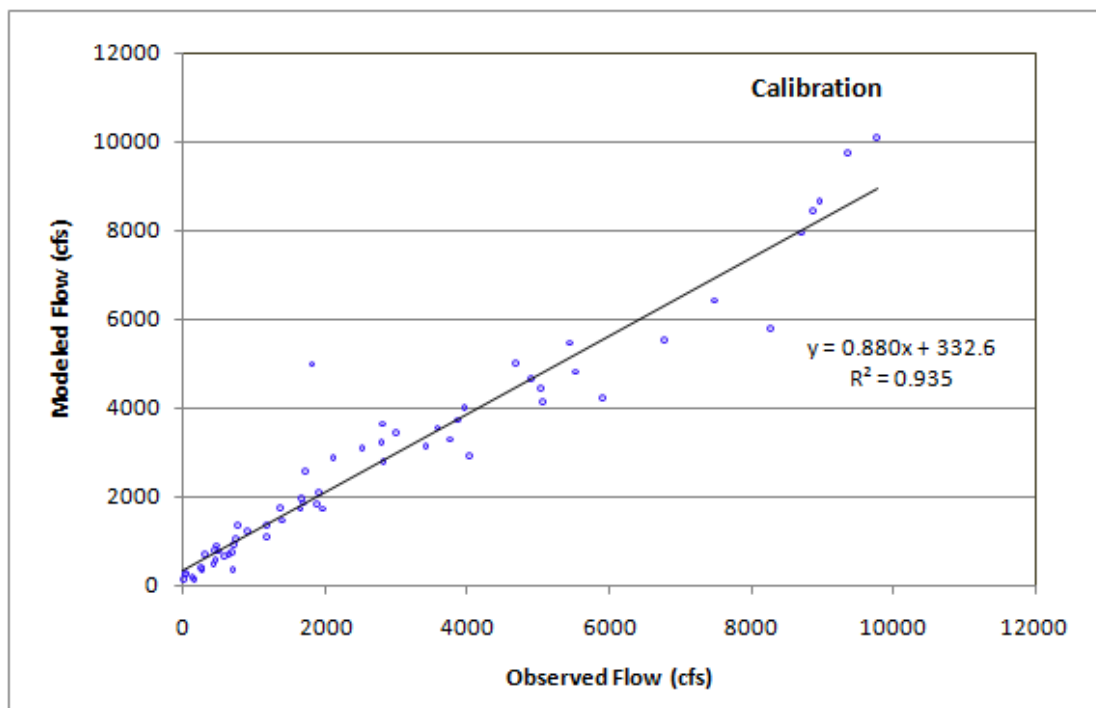


Figure 5-28 Comparison of monthly average modeled and observed flows at S-79 for the calibration period

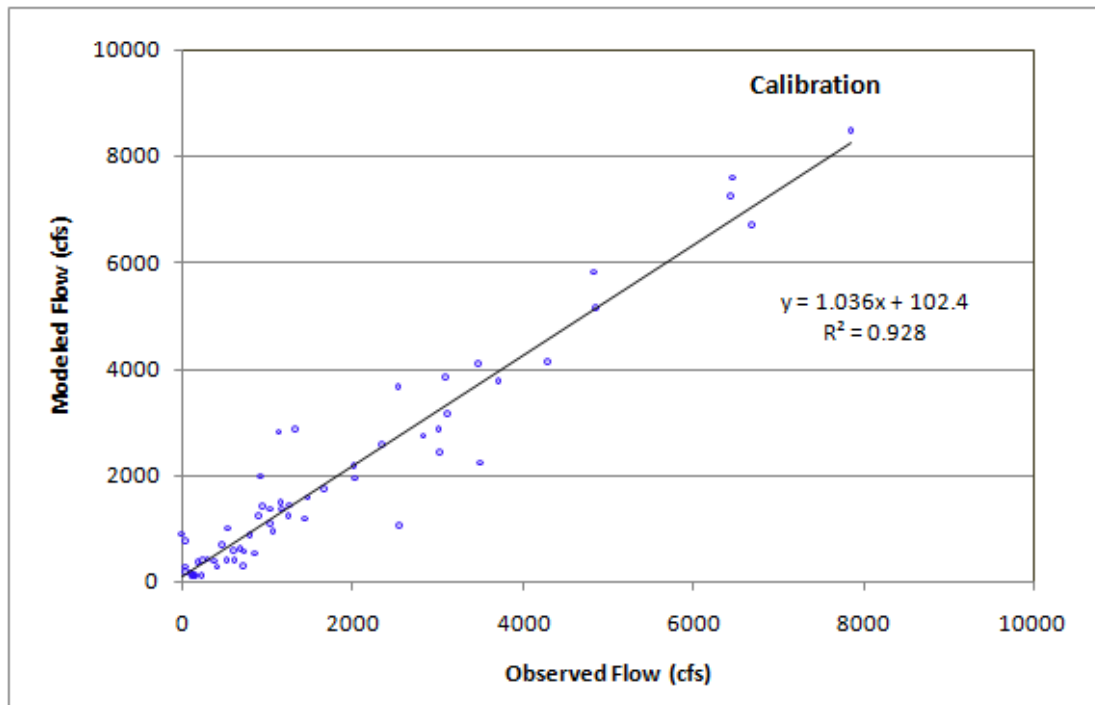


Figure 5-29 Comparison of monthly average modeled and observed flows at S-78 for the calibration period.

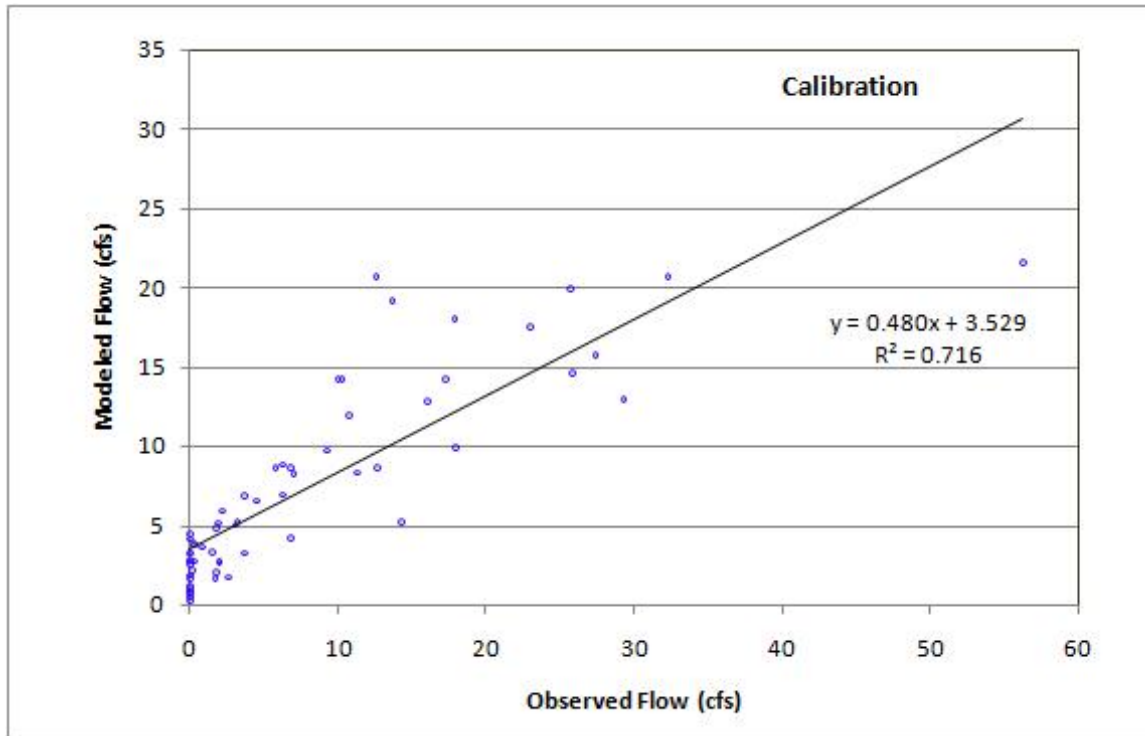


Figure 5-30 Comparison of monthly average modeled and observed flows at the San Carlos Canal gage for the calibration period

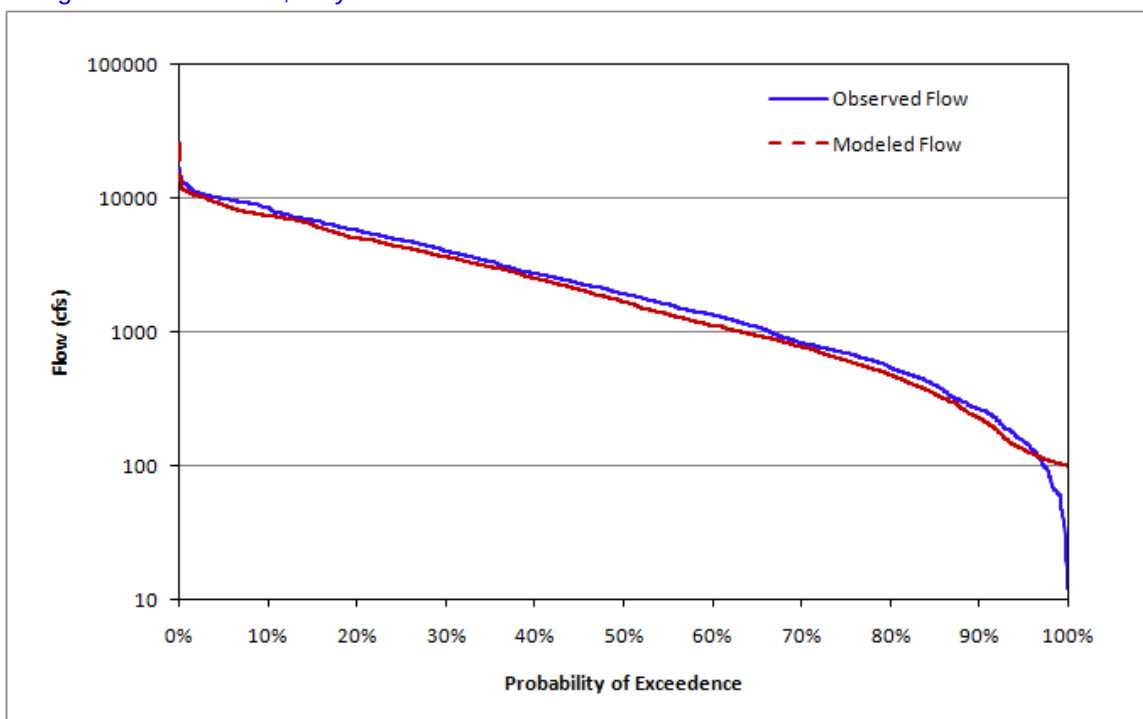


Figure 5-31 Probability of exceedance of observed and modeled daily flows at S-79 for the calibration period

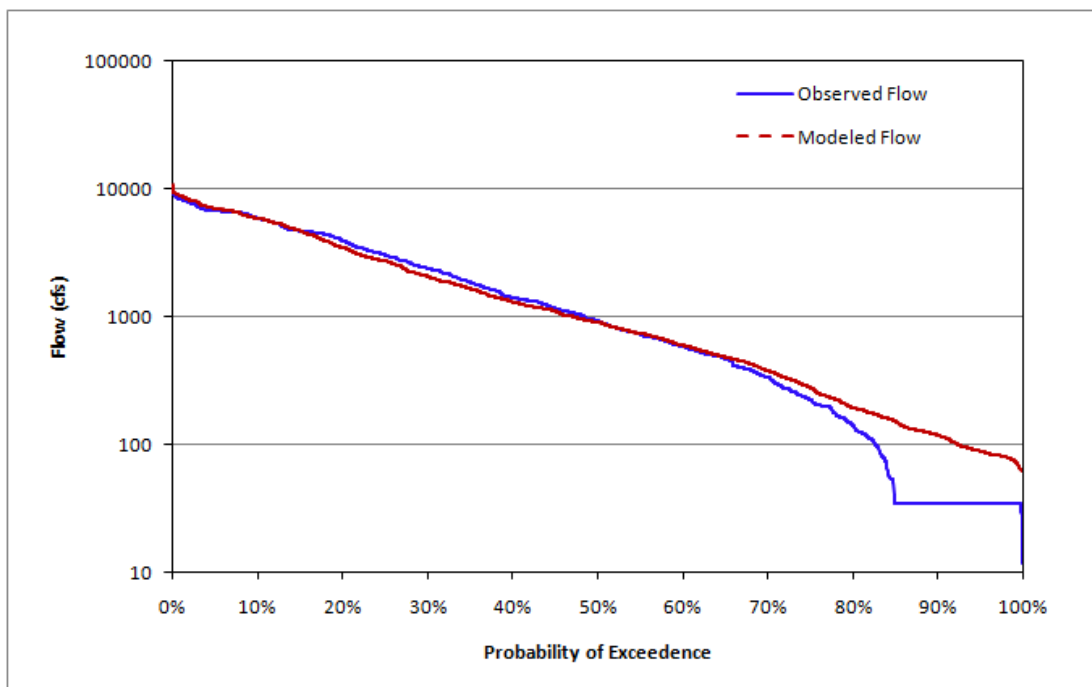


Figure 5-32 Probability of exceedance of observed and modeled daily flows at S-78 for the calibration period

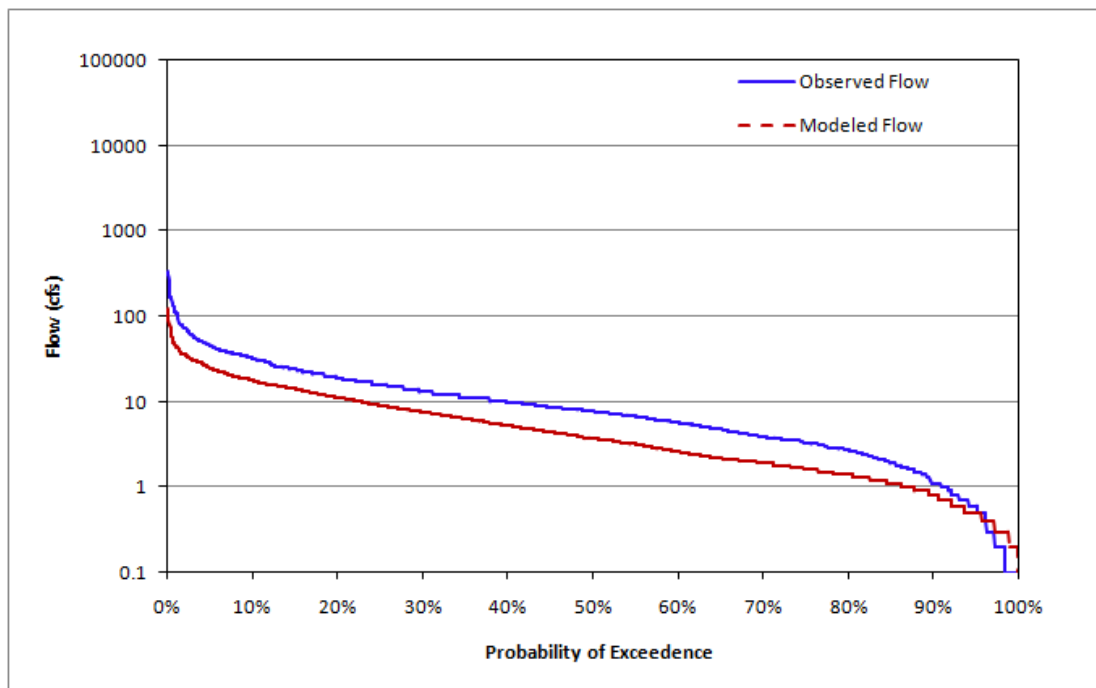


Figure 5-33 Probability of exceedance of observed and modeled daily flows at San Carlos for the calibration period

Table 5-13 Observed and modeled annual average flows and associated errors at S-79 during model calibration

Station	Year	Annual Average Flow (cfs)		
		Observed	Modeled	Percent Difference
S79	2001	1,120	1,300	14%
	2002	2,060	2,170	5%
	2003	3,580	3,390	-6%
	2004	2,560	2,480	-3%
	2005	5,060	5,000	-1%
	Average	2,876	2,868	2%
S78	2001	291	446	35%
	2002	1,350	1,120	-21%
	2003	2,420	2,440	1%
	2004	1,570	1,820	14%
	2005	3,170	3,820	17%
	Average	1,760	1,929	9%
San Carlos	2001	8.20	6.31	-30%
	2002	7.40	8.49	13%
	2003	10.20	8.27	-23%
	2004	6.00	5.89	-2%
	2005	7.70	7.66	-1%
	Average	7.90	7.32	-9%

5.2.4.2 Hydrologic Validation

Model validation using an independent dataset confirms that a calibrated model can reliably simulate the conditions outside the calibration domain without further adjustment of the parameter values. Hydrologic validation of the Caloosahatchee River watershed model was performed using the observed flows from January 1997 through December 1999. Daily average modeled and observed flows at S-79, S-78 and the San Carlos Canal gages for the validation period are plotted in **Figures 5-34 through 5-36**.

For the validation period, the observed and modeled probability of exceedances for daily flows at S-79, S-78, and San Carlos are given by **Figures 5-37 through 5-39**. For the validation period, the calculated NSE coefficients for S-79, S-78, and San Carlos, were 0.94, 0.94, and 0.31, which indicated very good modeling performance at S-79 and S-78 and fair modeling performance at San Carlos.

Scatter plots of monthly mean modeled versus observed flows (**Figures 5-40 through 5-42**) show that the model output are in good agreement at S-79 while at the San Carlos Canal gage the match is not as good. As discussed earlier the relatively poor match at the San Carlos Canal gage may be attributed to the errors in observed data (frequent 0.0 flows). A comparison of average annual flows at S-79 (**Table 5-14**) shows only a 3% difference in hydrologic validation over the

entire simulation period. The errors in annual flow validation at S78 and San Carlos were -1.0% and 24%.

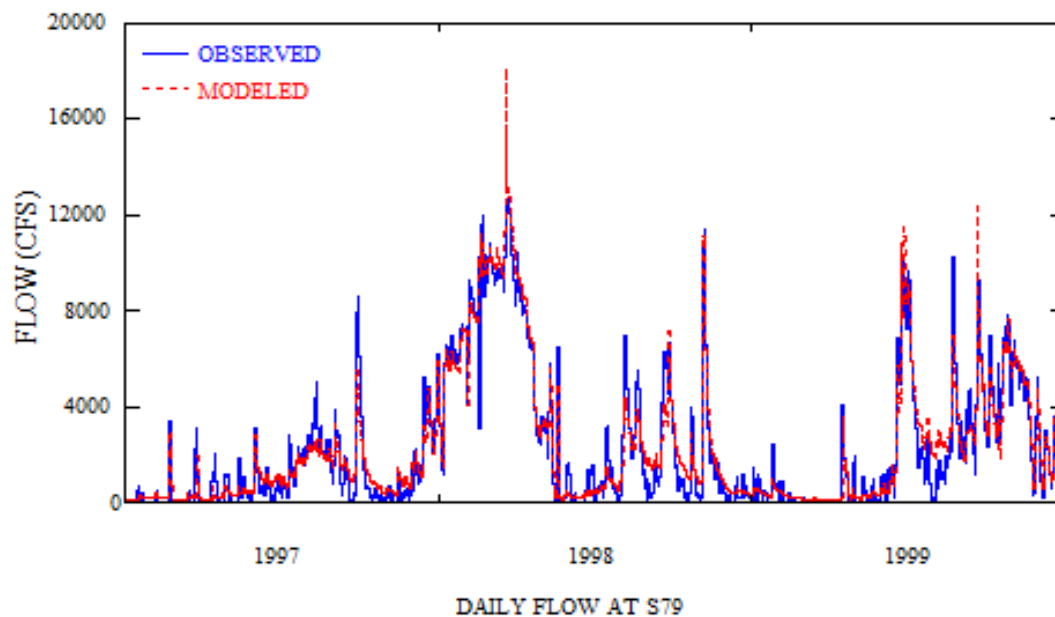


Figure 5-34 Modeled and observed flows at S-79 for the validation period

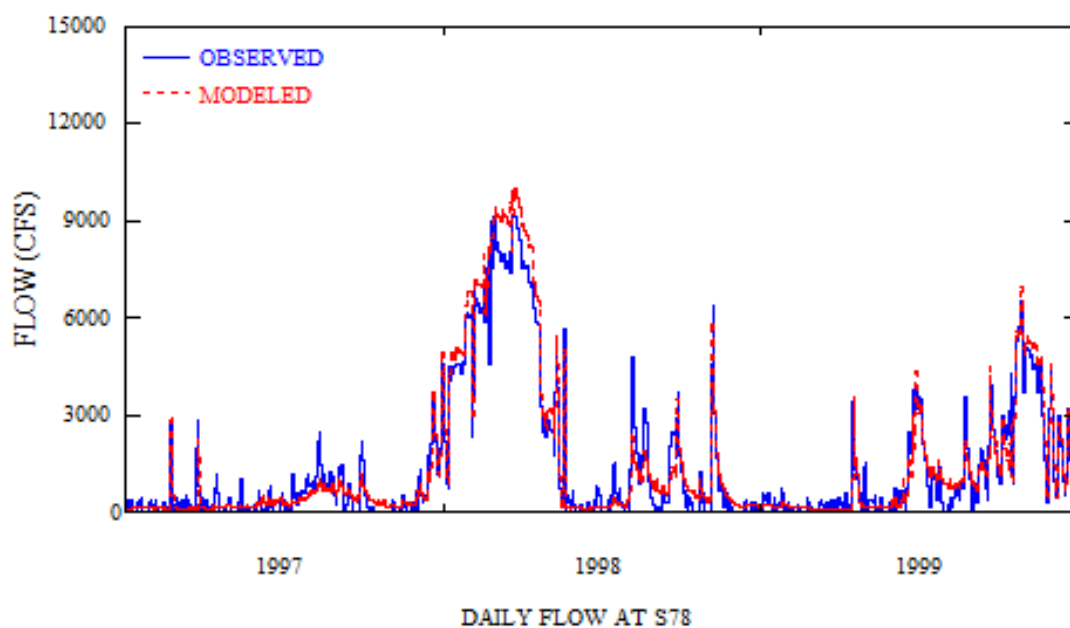


Figure 5-35 Modeled and observed flows at S-78 for the validation period

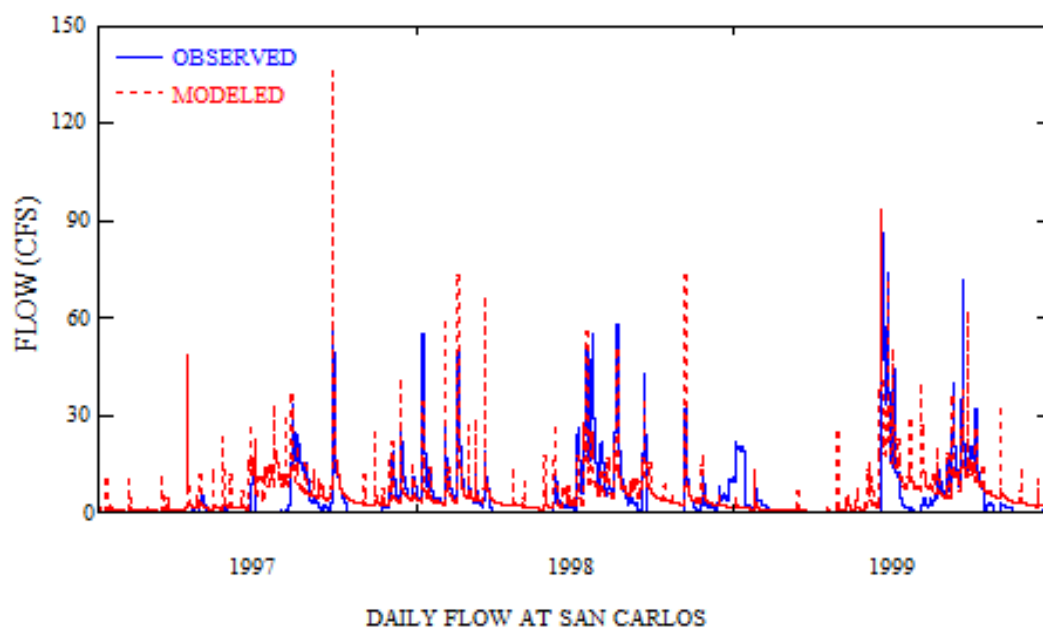


Figure 5-36 Modeled and observed flows at the San Carlos Canal gage for the validation period

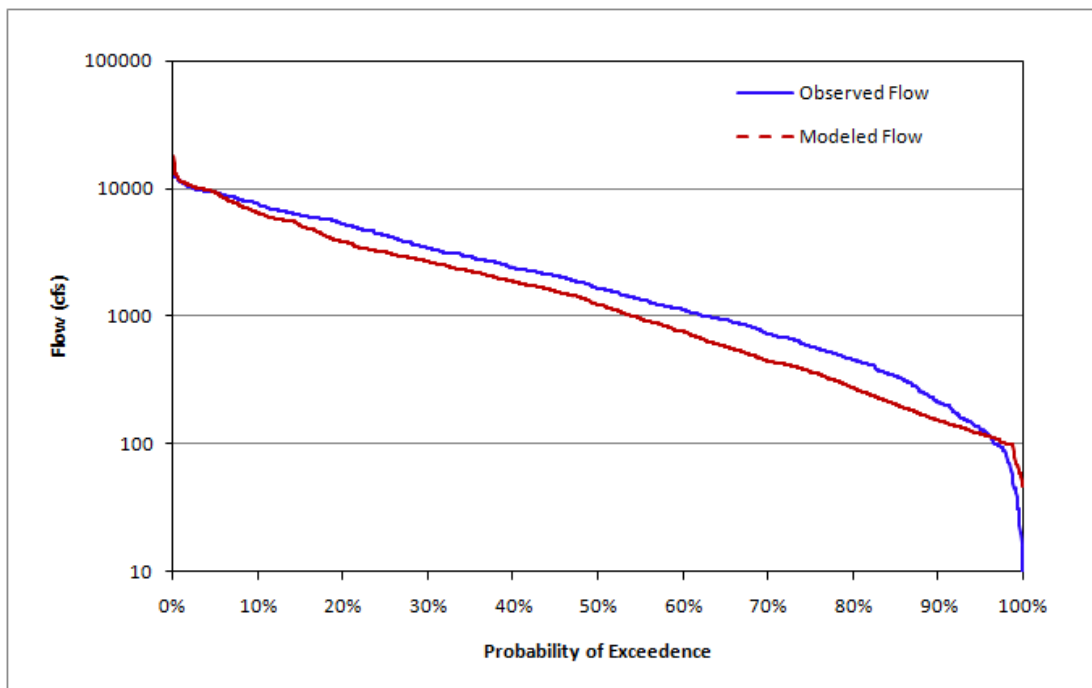


Figure 5-37 Probability of exceedance of observed and modeled daily flows at S79 for the validation period

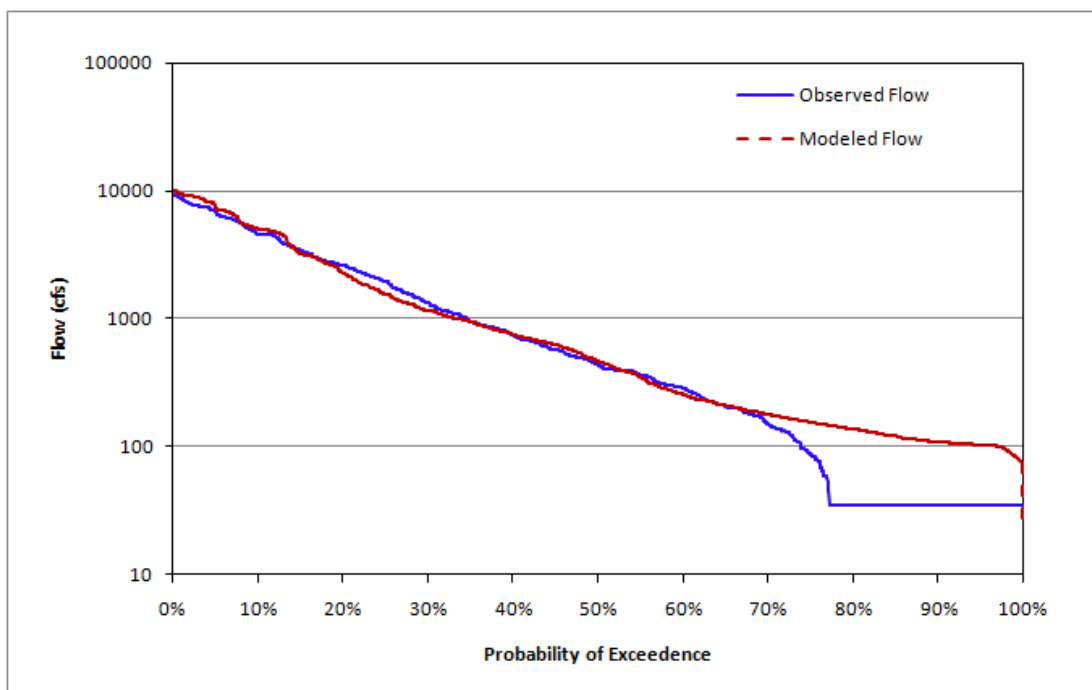


Figure 5-38 Probability of exceedance of observed and modeled daily flows at S78 for the validation period

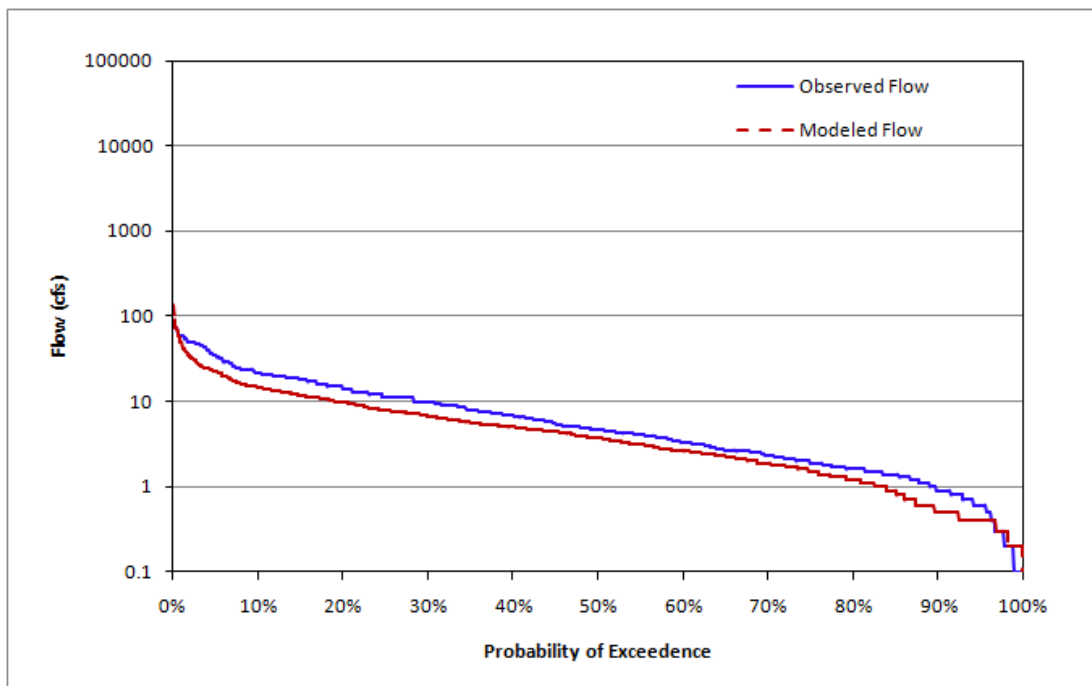


Figure 5-39 Probability of exceedance of observed and modeled daily flows at San Carlos for the validation period

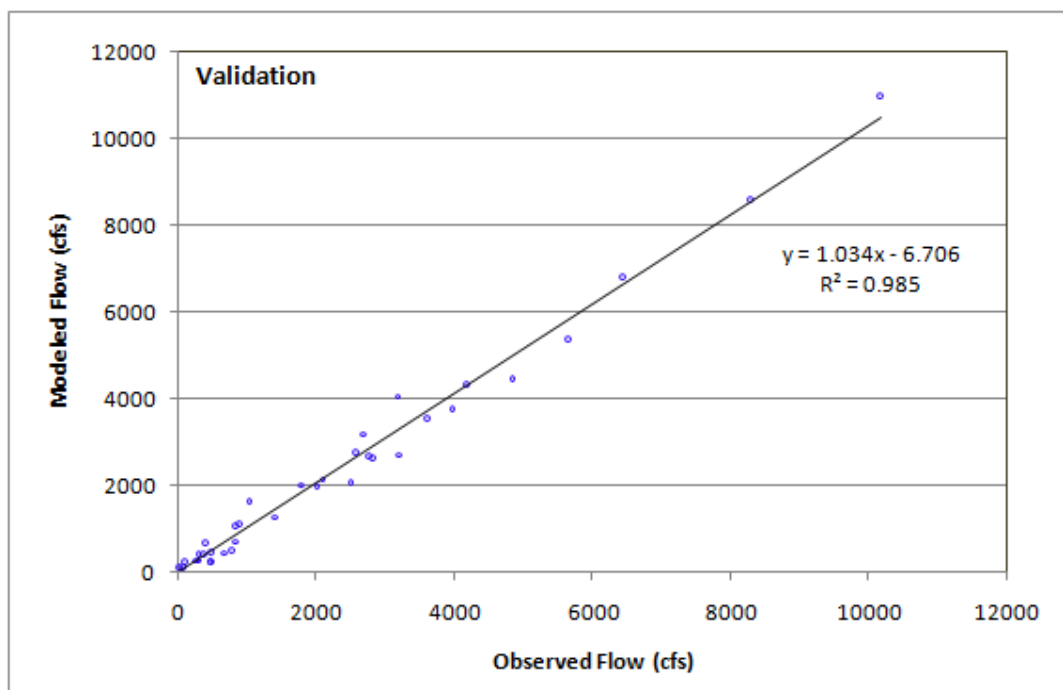


Figure 5-40 Comparison of monthly average modeled and observed flows at S-79 for the validation period.

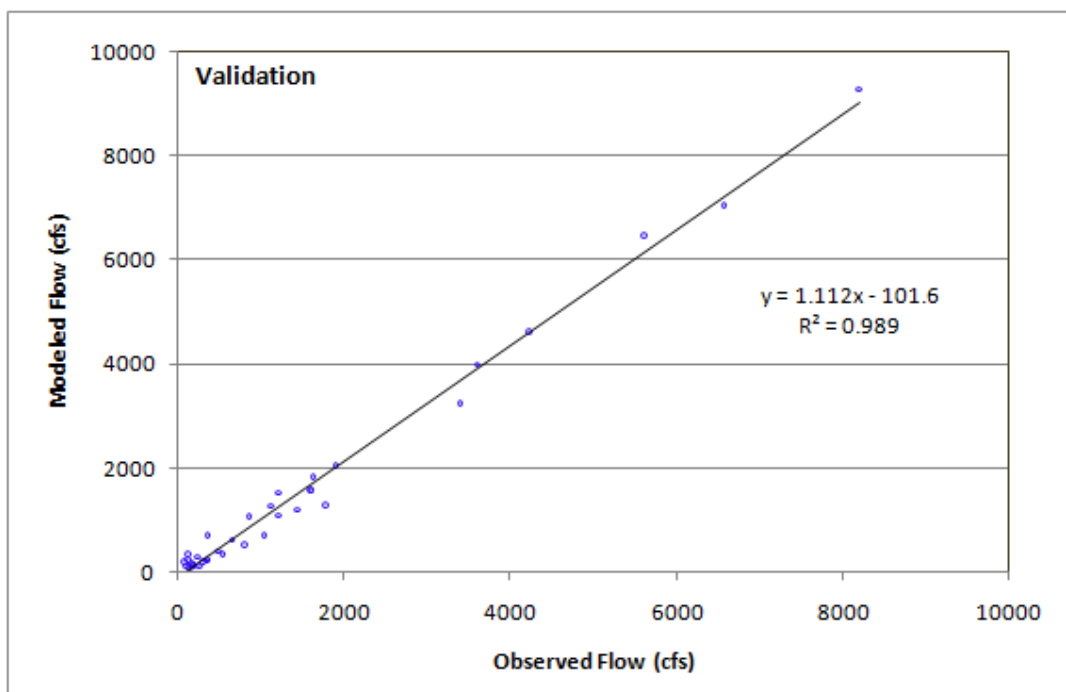


Figure 5-41 Comparison of monthly average modeled and observed flows at S-78 for the validation period

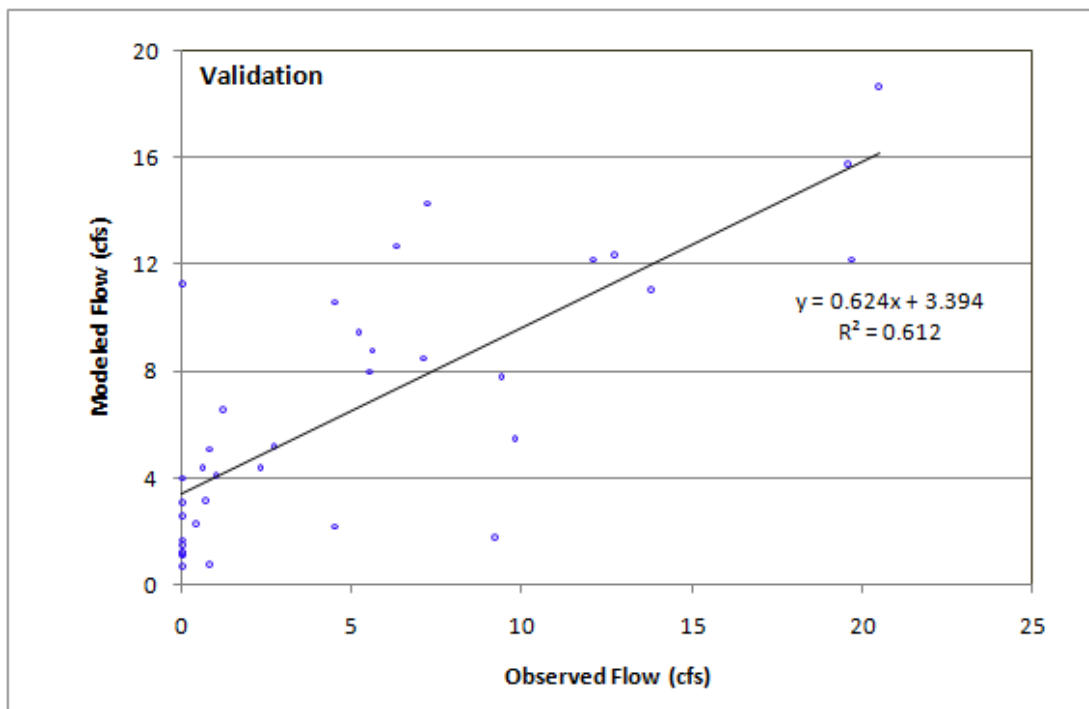


Figure 5-42 Comparison of monthly average modeled and observed flows at the San Carlos Canal gage for the validation period.

Table 5-14 Observed and modeled annual average flows and associated errors at S-79 during model validation.

Station	Year	Annual Average Flow (cfs)		
		Observed	Modeled	Percent Difference
S79	1997	1,040	1,050	1%
	1998	3,620	3,740	3%
	1999	2,180	2,260	4%
	Average	2,280	2,350	3%
S78	1997	480	432	-11%
	1998	2,610	2,830	8%
	1999	1,280	1,300	2%
	Average	1,457	1,521	-1%
San Carlos	1997	2.87	5.97	52%
	1998	6.58	6.95	5%
	1999	5.84	6.81	14%
	Average	5.10	6.58	24%

5.2.4.3 Water Quality Calibration

The Caloosahatchee River HSPF model simulates water quality constituents in the main stem of the river and also in the tributaries. Surface and sub-surface flows and loads from the watershed land segments are discharged into the stream reaches. The in-stream advective processes transport flow and loads from upstream to downstream reaches and the kinetic processes act as sources or sinks of water quality constituents in the reaches. The HSPF model simulates the in-stream processes and computes the concentrations of water quality constituents in each reach. Each reach is considered a completely mixed reactor. Modeled and observed water quality data from January 2004 through December 2005 were compared at S-79, S-78 and the Whiskey Creek (WHISGR10) water quality stations (**Figure 5-43**) to perform model calibration. It should be noted that the water quality data are ambient data that are routinely taken monthly at various locations. These do not necessarily reflect the wet weather response of flows, concentrations, and loads in the system, especially for smaller tributaries that are less well-mixed.

Model calibration results for water temperature, TSS, nutrients (nitrate + nitrite, NH_3/NH_4 , and phosphate), 5-day biochemical oxygen demand (available only at the Whiskey Creek station) and dissolved oxygen at the S-79, S-78 and the Whiskey Creek stations are presented in **Figures 5-44 through Figure 5-61**. The modeled dissolved oxygen concentration at the Whiskey Creek station was significantly higher than the observed data and excluded from the model calibration. The low observed DO concentration at the Whiskey Creek station could be caused by local sources and/or processes (e.g. algal bloom in storm water ponds) that could not be successfully modeled without the detailed characteristics of the reaches/ponds and wet weather sampling data. Additionally, an effort to model such local phenomenon using the Caloosahatchee River HSPF model would easily exceed the operational limits of the model.

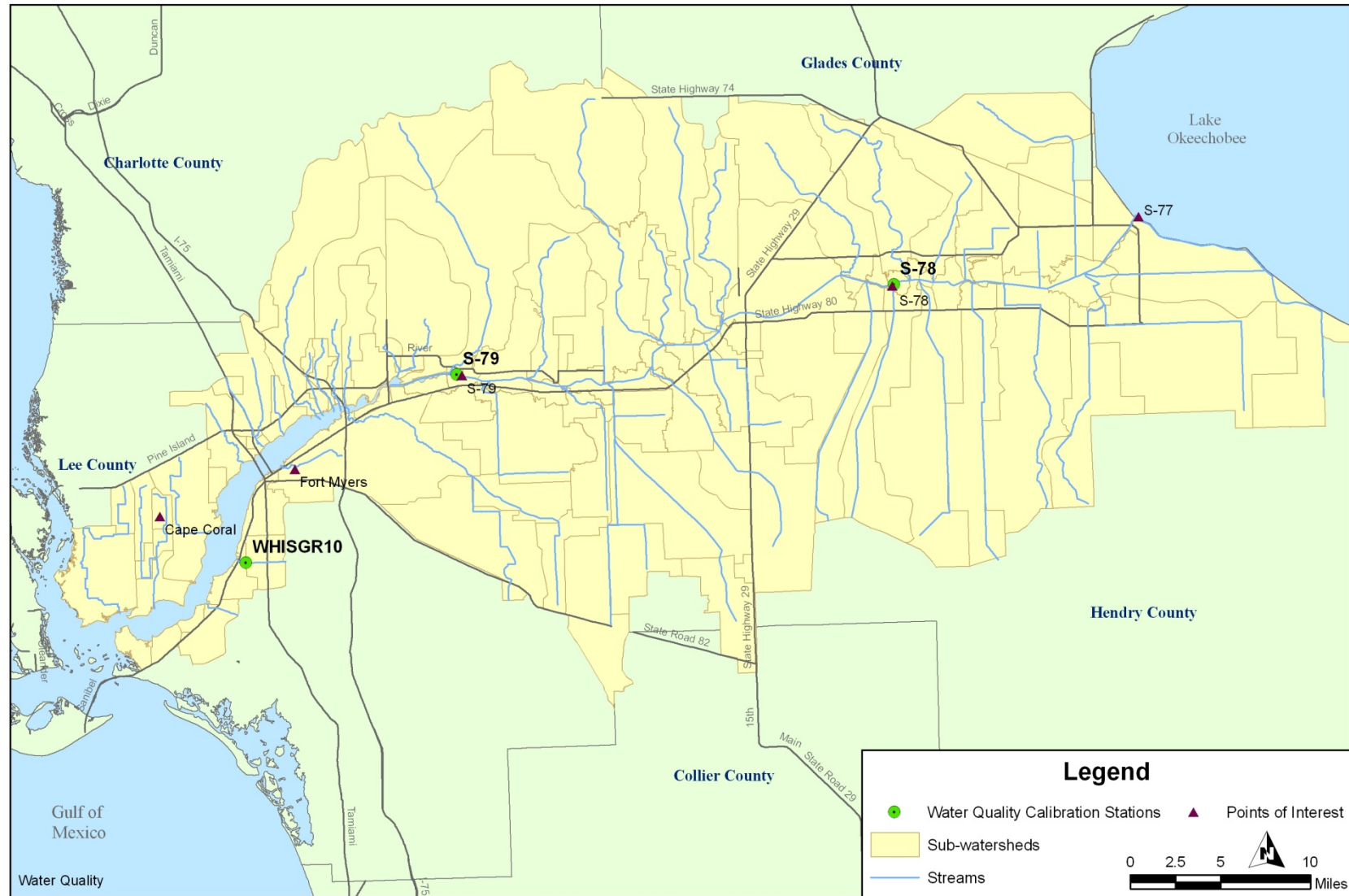


Figure 5-43 Water quality monitoring stations in the Caloosahatchee River watershed that were used for model calibration and validation.

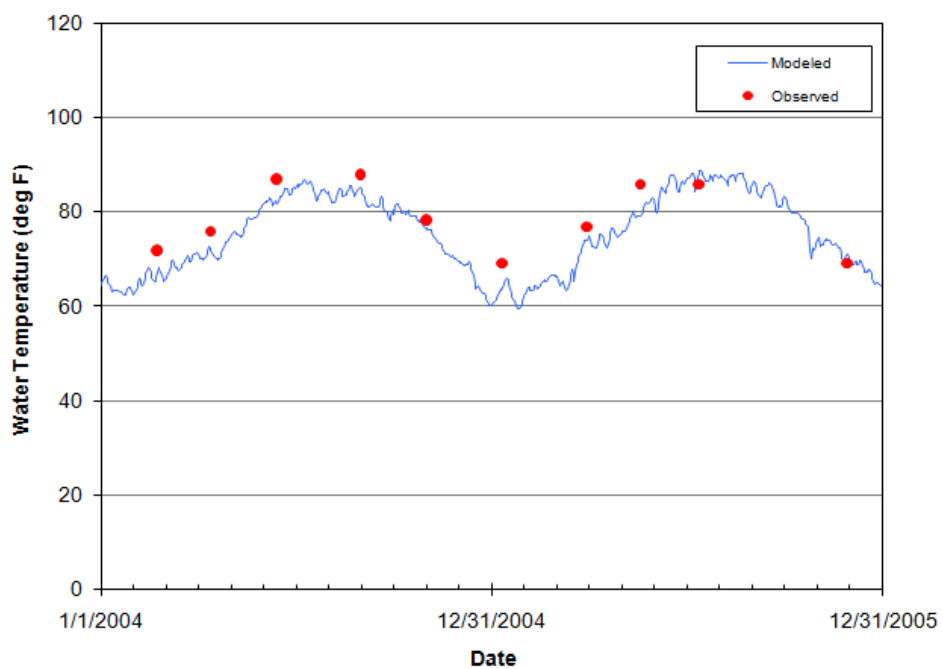


Figure 5-44 Modeled and observed water temperature at the S-79 station for the model calibration period

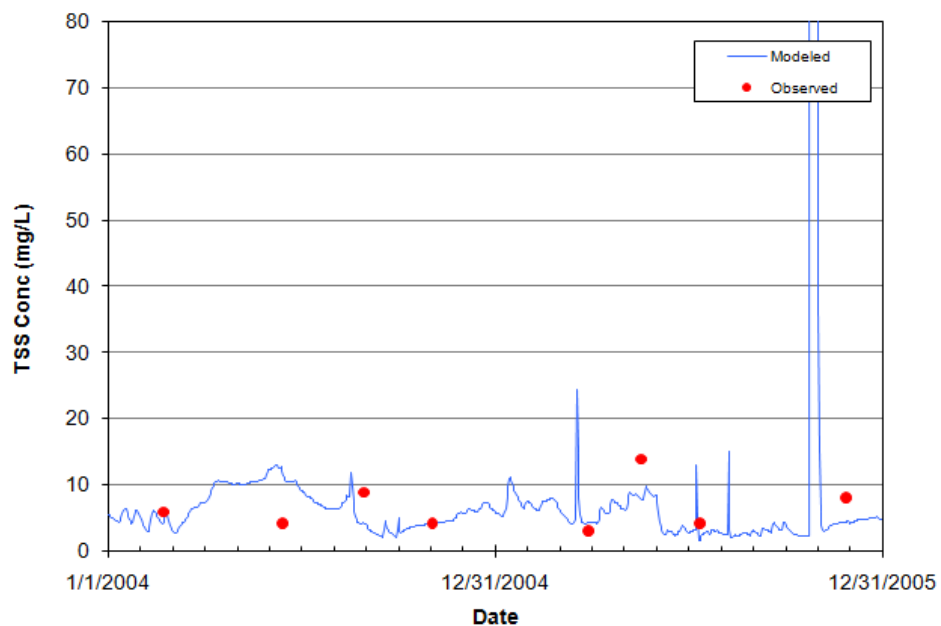


Figure 5-45 Modeled and observed TSS concentrations at the S-79 station for the model calibration period

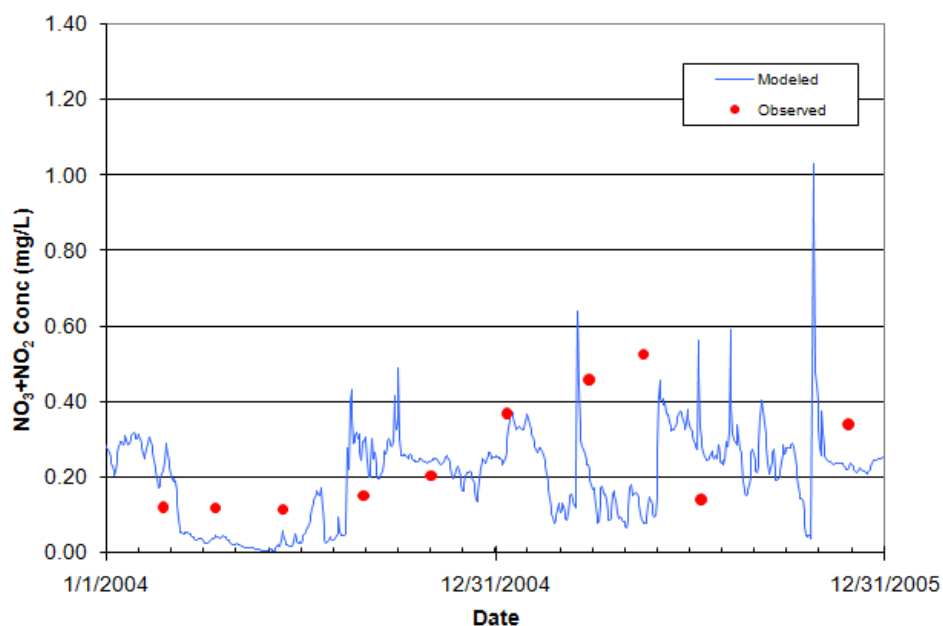


Figure 5-46 Modeled and observed nitrate plus nitrite concentrations at the S-79 station for the model calibration period

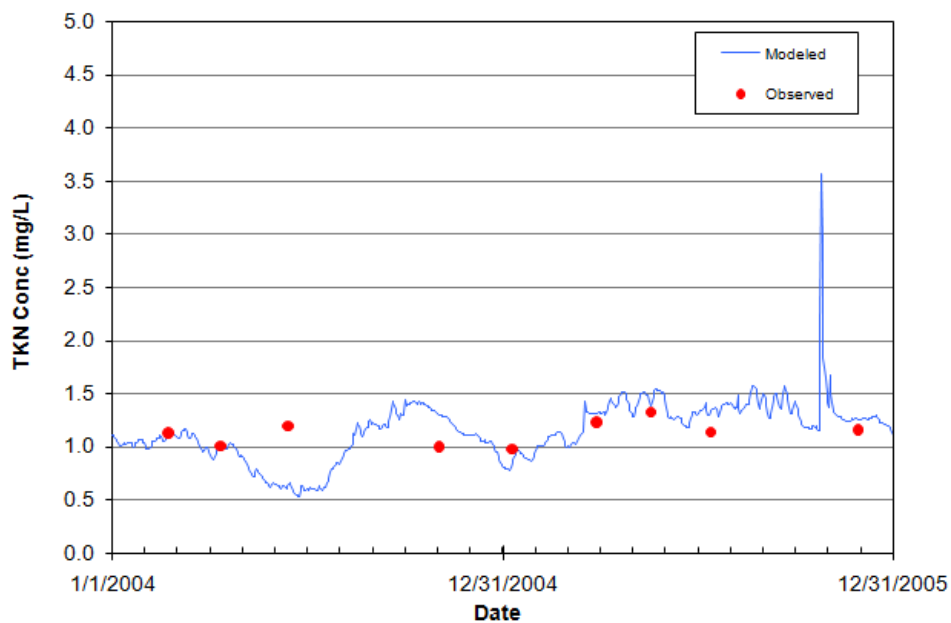


Figure 5-47 Modeled and observed TKN concentrations at the S-79 station for the model calibration period

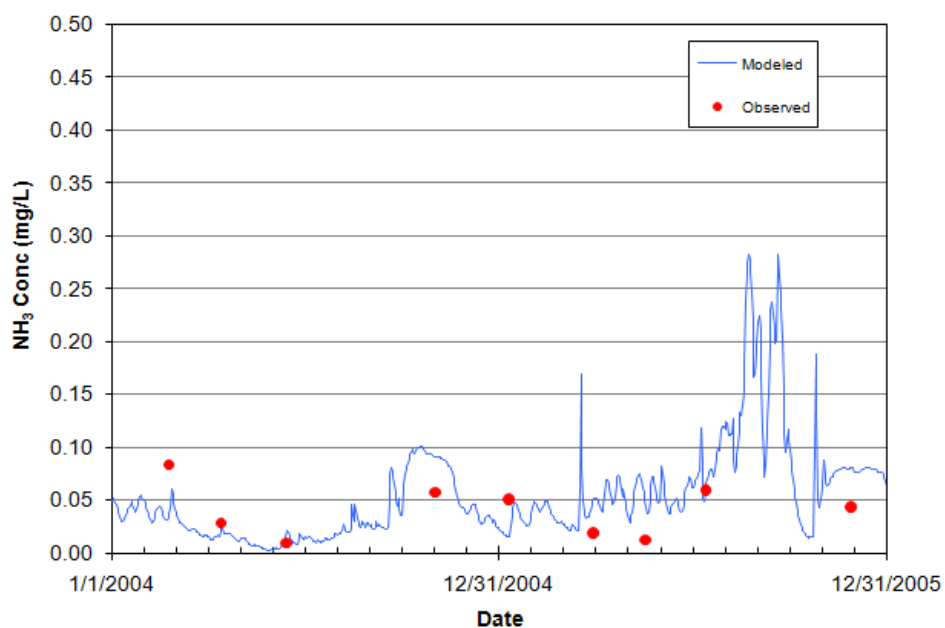


Figure 5-48 Modeled and observed ammonia concentrations at the S-79 station for the model calibration period.

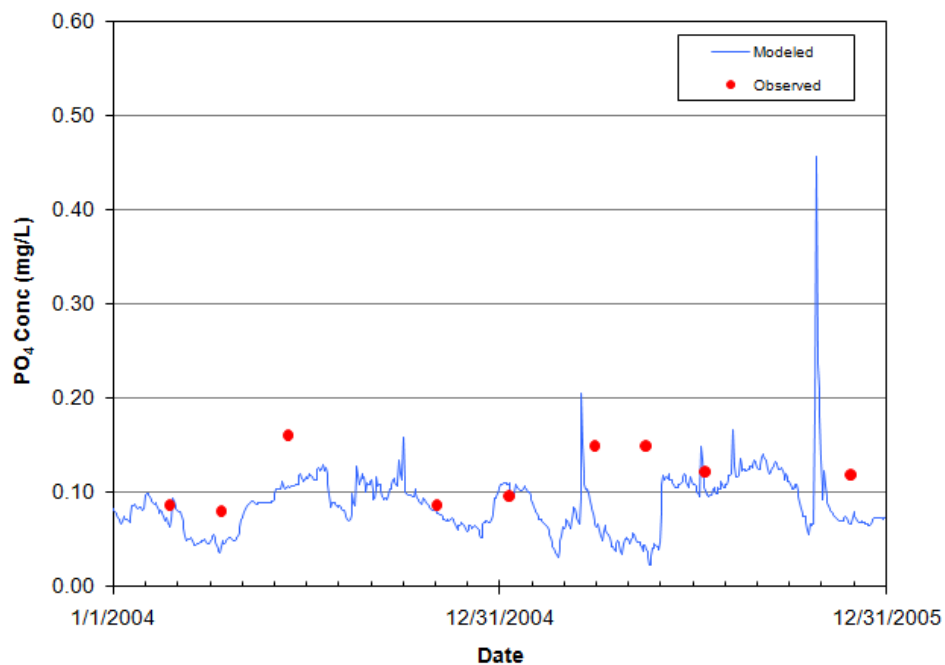


Figure 5-49 Modeled and observed phosphate concentrations at the S-79 station for the model calibration period.

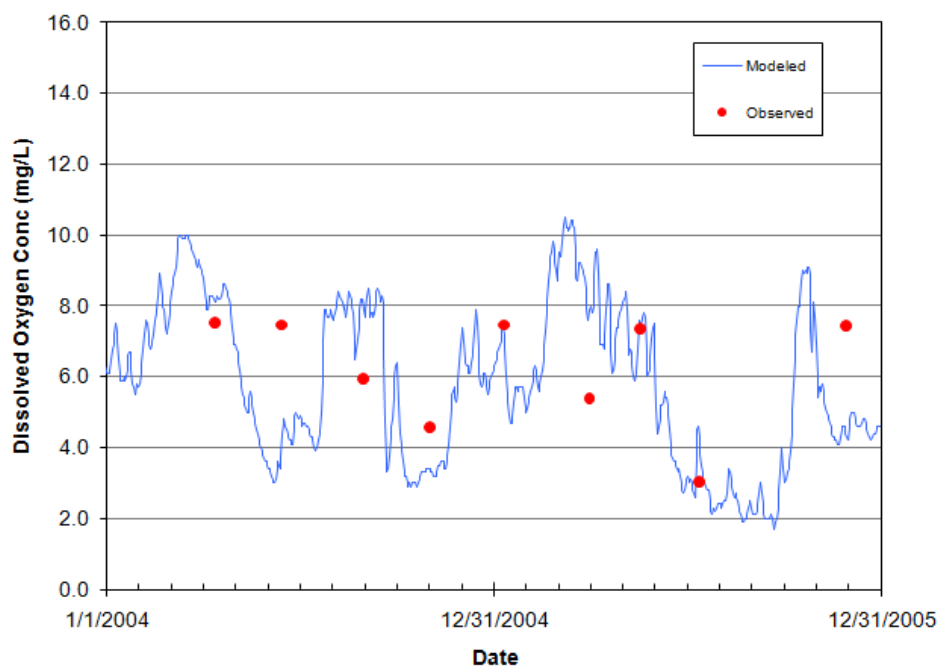


Figure 5-50 Modeled and observed dissolved oxygen concentrations at the S-79 station for the model calibration period

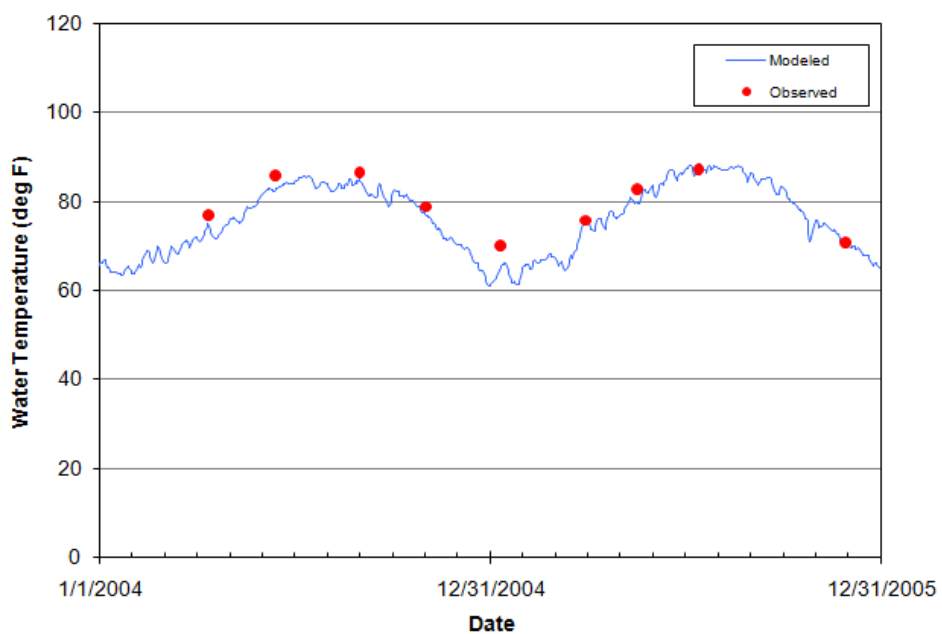


Figure 5-51 Modeled and observed water temperature at the S-78 station for the model calibration period

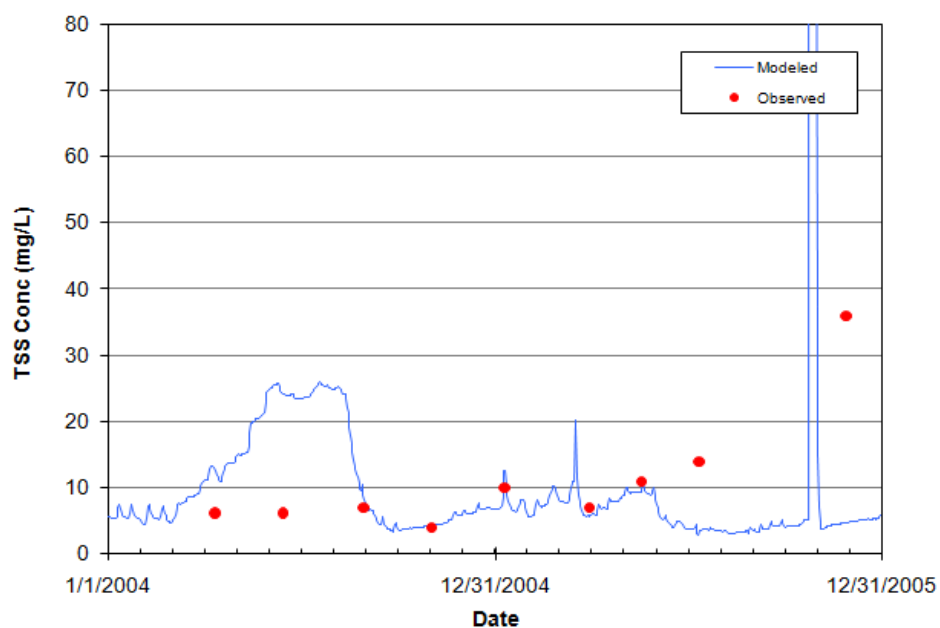


Figure 5-52 Modeled and observed total suspended solids concentrations at the S-78 station for model calibration period

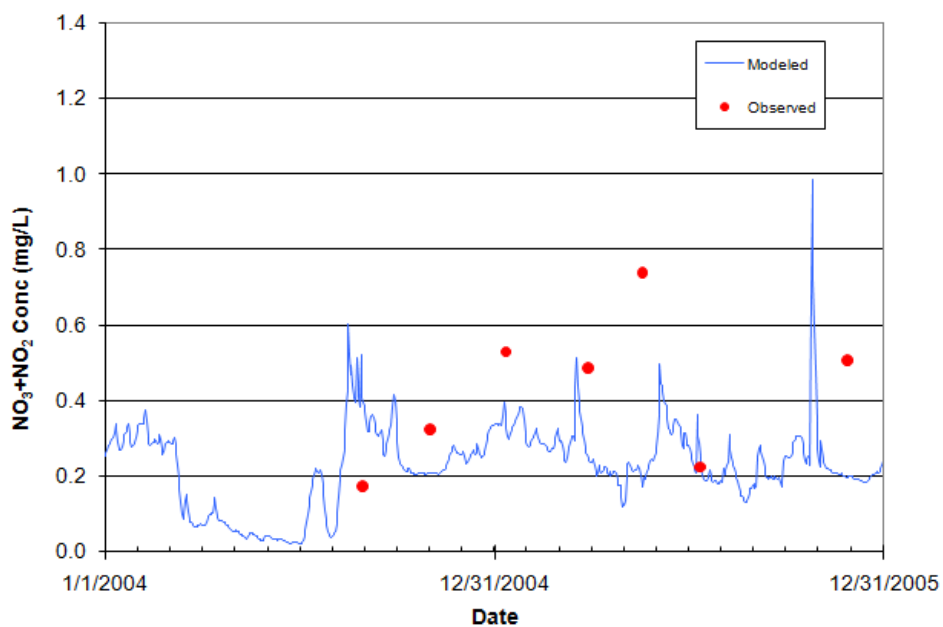


Figure 5-53 . Modeled and observed nitrate plus nitrite concentrations at the S-78 station for the model calibration period.

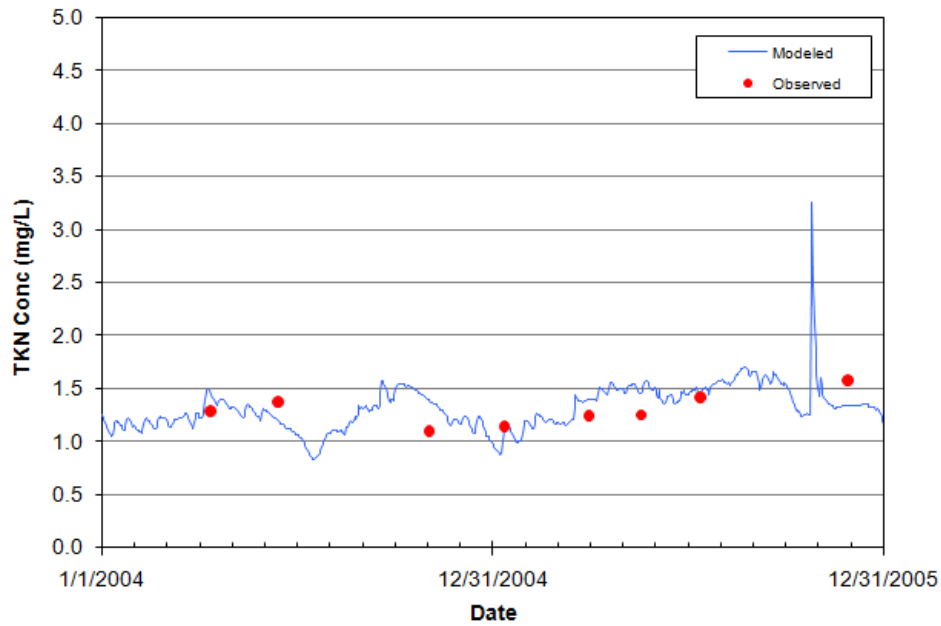


Figure 5-54 Modeled and observed TKN concentrations at the S-78 station for the model calibration period

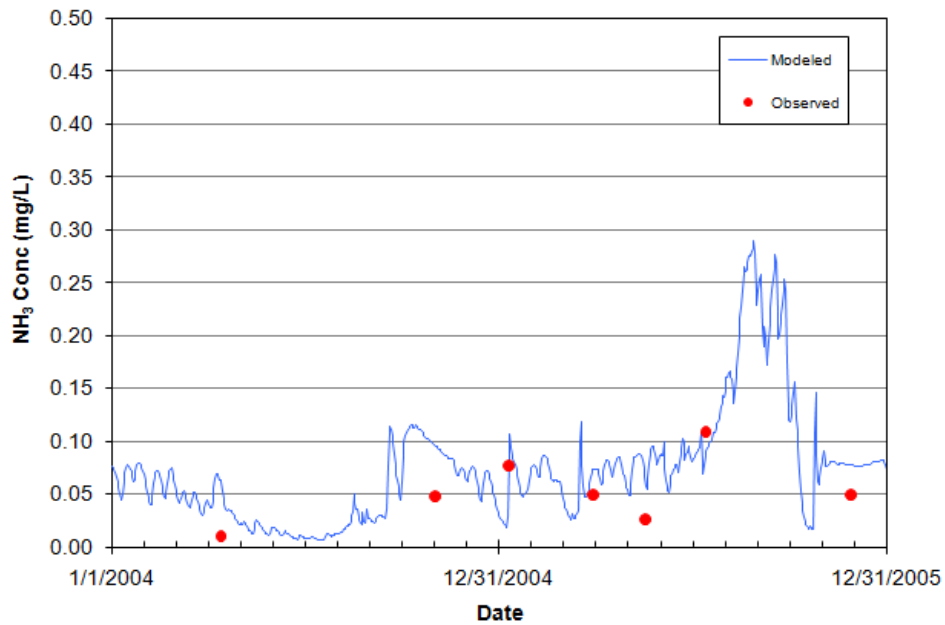


Figure 5-55 Modeled and observed ammonia concentrations at the S-78 station for the model calibration period.

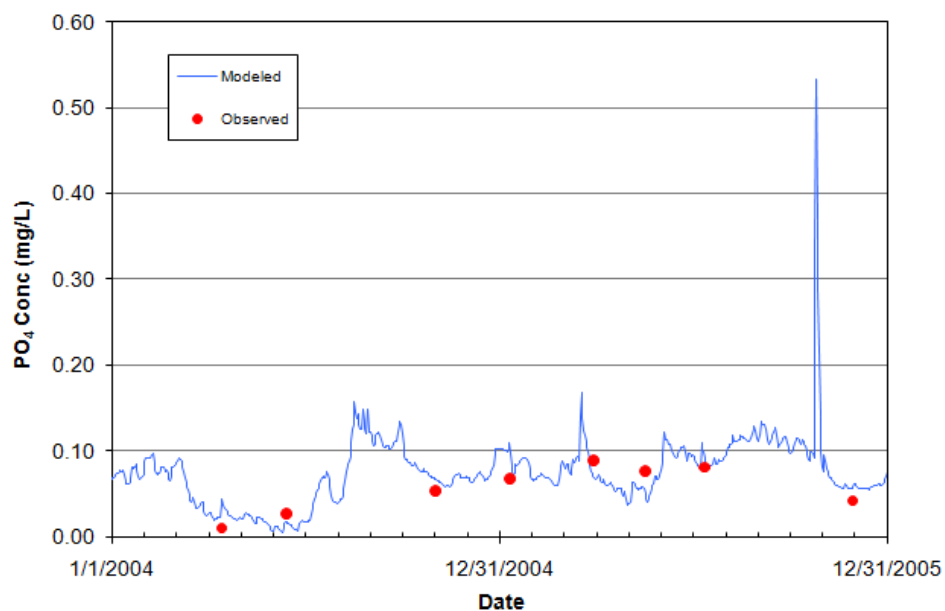


Figure 5-56 Modeled and observed phosphate concentrations at the S-78 station for the model calibration period.

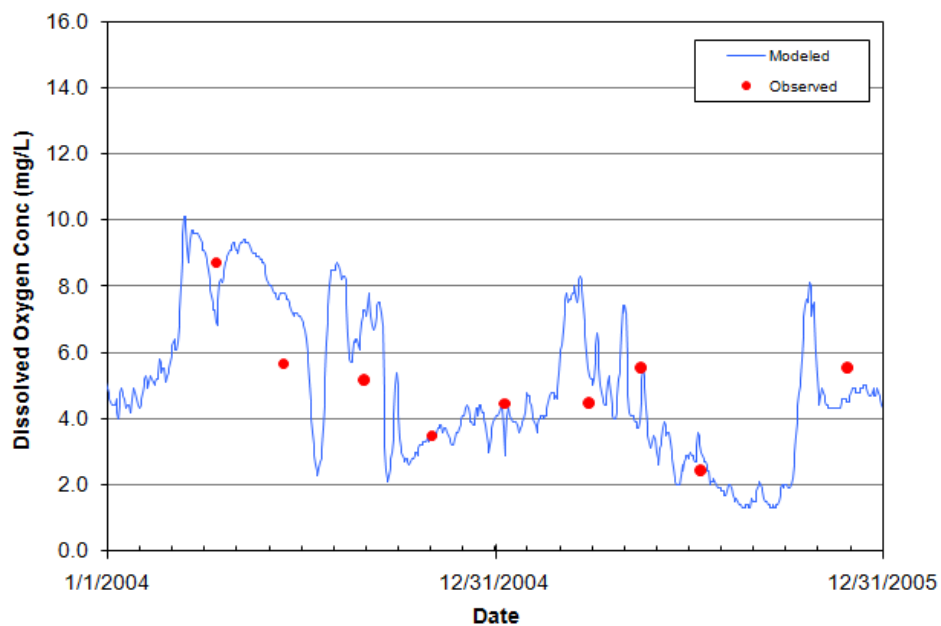


Figure 5-57 . Modeled and observed dissolved oxygen concentrations at the S-78 station for the model calibration period

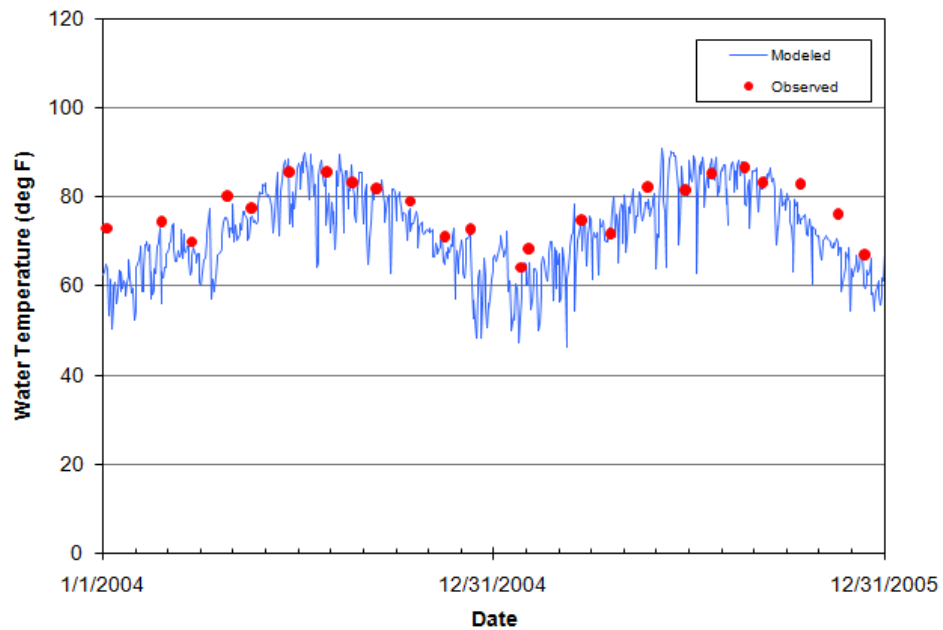


Figure 5-58 Modeled and observed water temperature at the Whiskey Creek station for the model calibration period

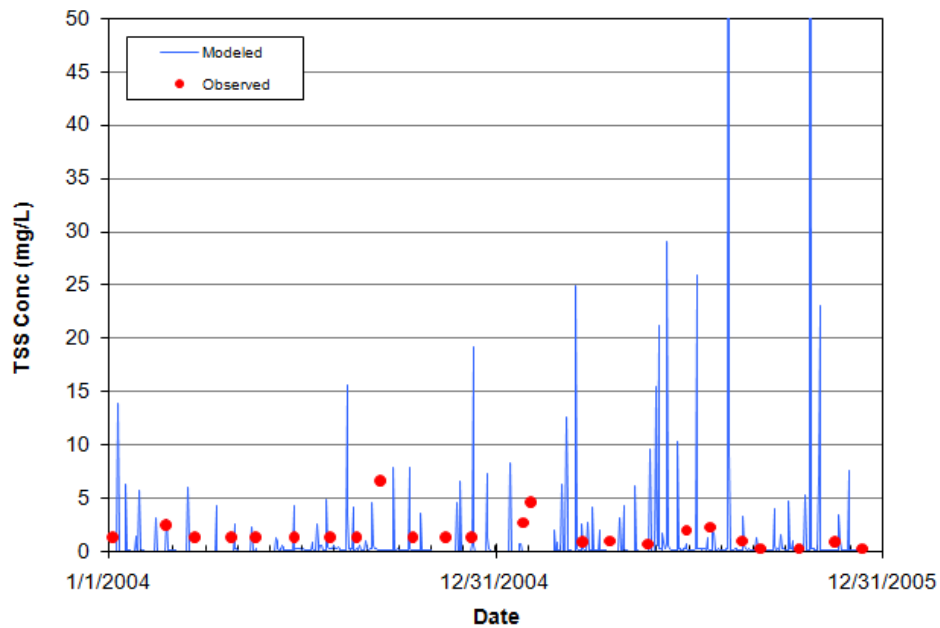


Figure 5-59 Modeled and observed total suspended solids concentrations at the Whiskey Creek station for the model calibration period

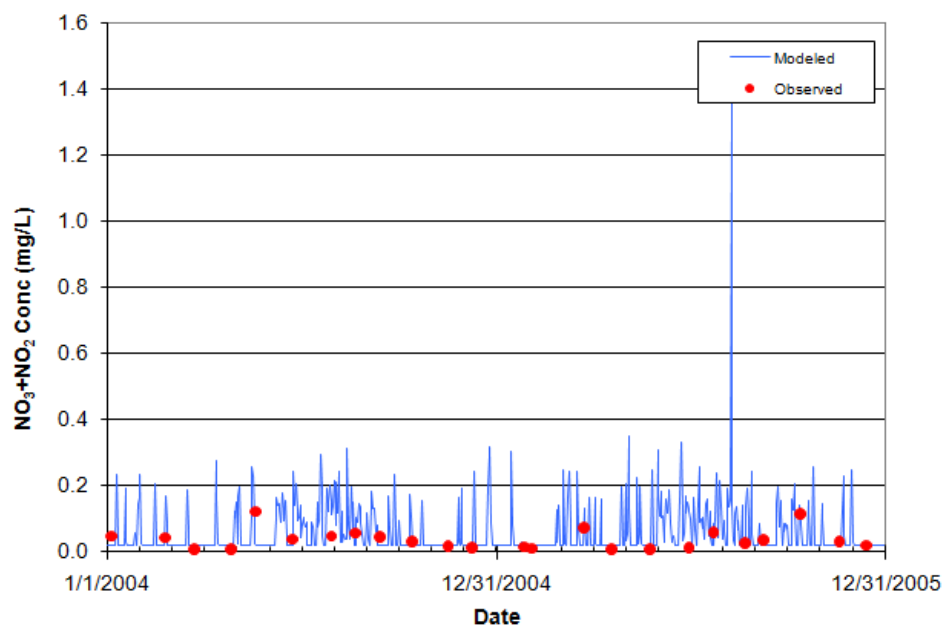


Figure 5-60 Modeled and observed nitrate plus nitrite concentrations at the Whiskey Creek station for the model calibration period

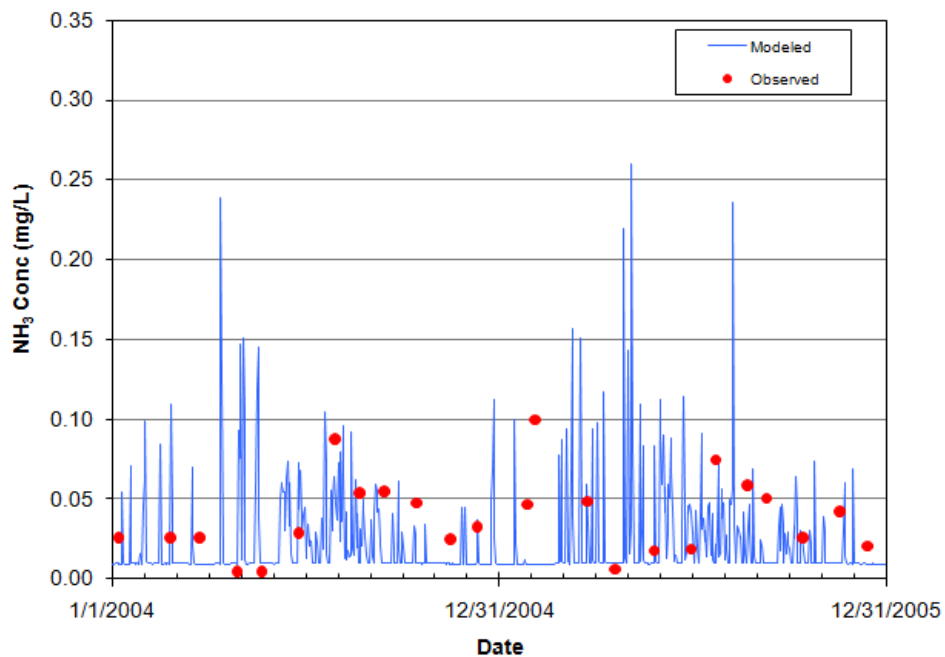


Figure 5-61 Modeled and observed ammonia concentrations at the Whiskey Creek station for the model calibration period

5.2.4.4 HSPF Model Validation

Validation of the model was performed using the data collected at the same water quality stations as those used for model calibration, but for a different period (January 2001 through December 2003). The model validation results at S-79, S-78 and the Whiskey Creek stations for various water quality constituents are shown in **Figures 5-62 through 5-79**.

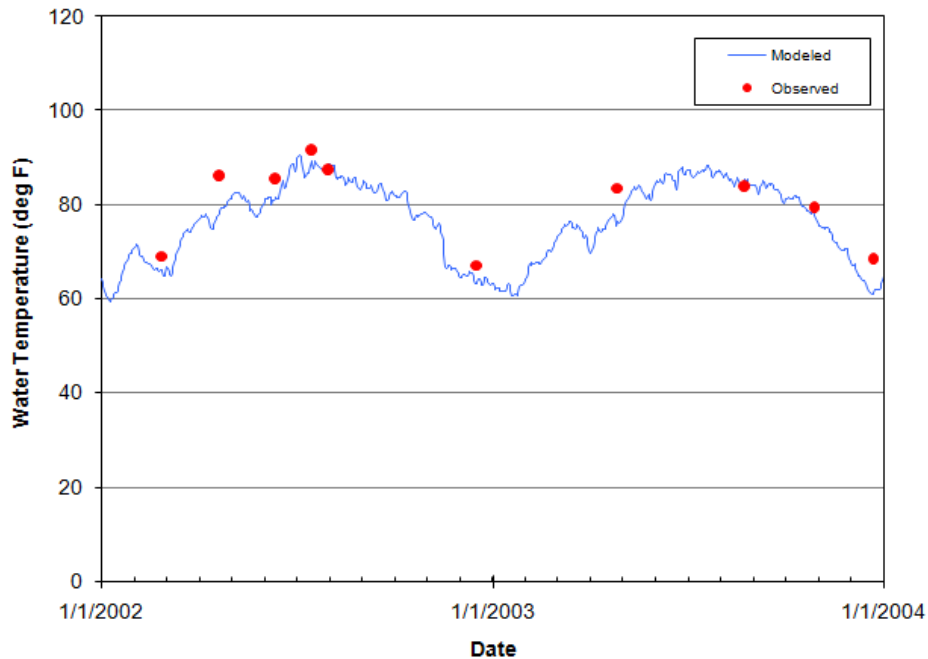


Figure 5-62 . Modeled and observed water temperature at the S-79 station for the model validation period.

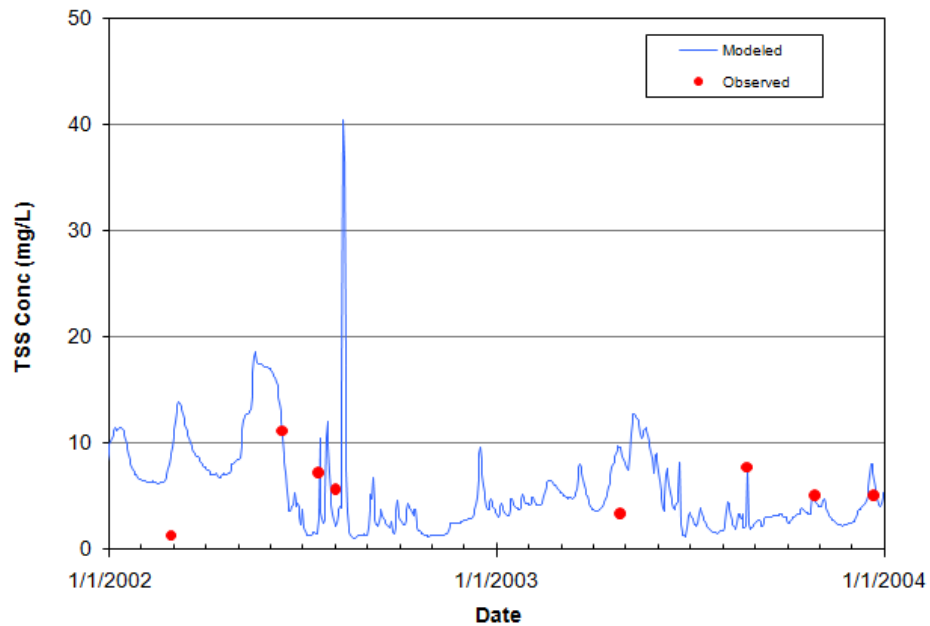


Figure 5-63 Modeled and observed total suspended solids concentrations at the S-79 station for the model validation period

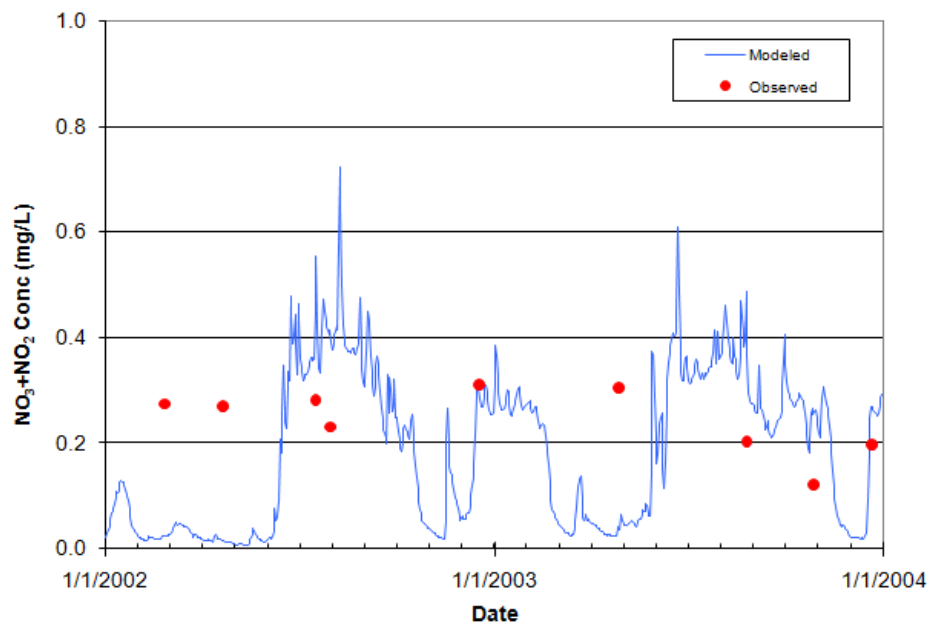
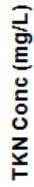
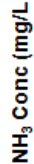


Figure 5-64. Modeled and observed nitrate plus nitrite concentrations at the S-79 station for the model validation period



period



validation period.

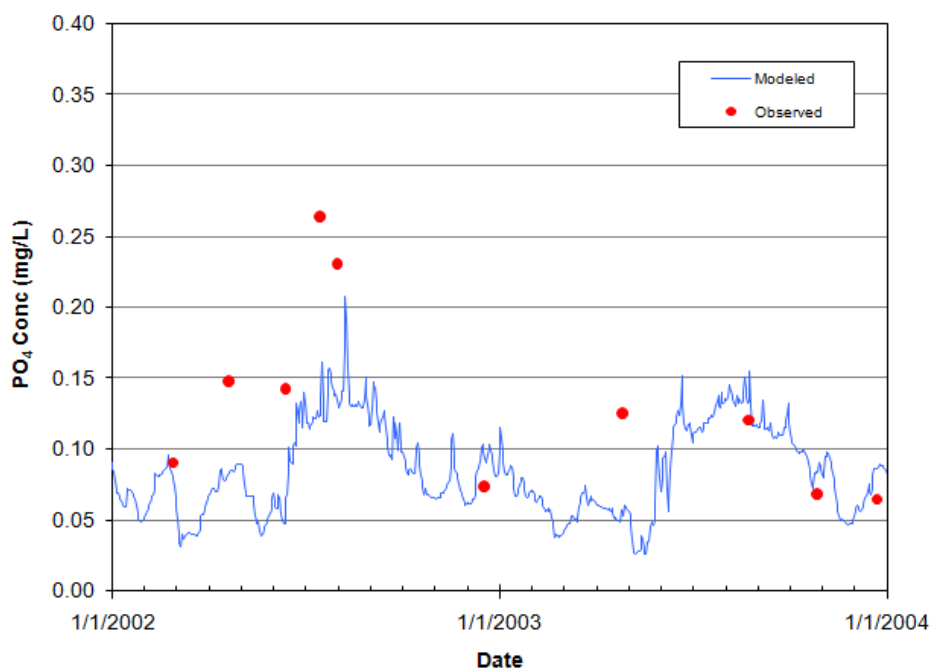


Figure 5-67 Modeled and observed phosphate concentrations at the S-79 station for the model validation period.

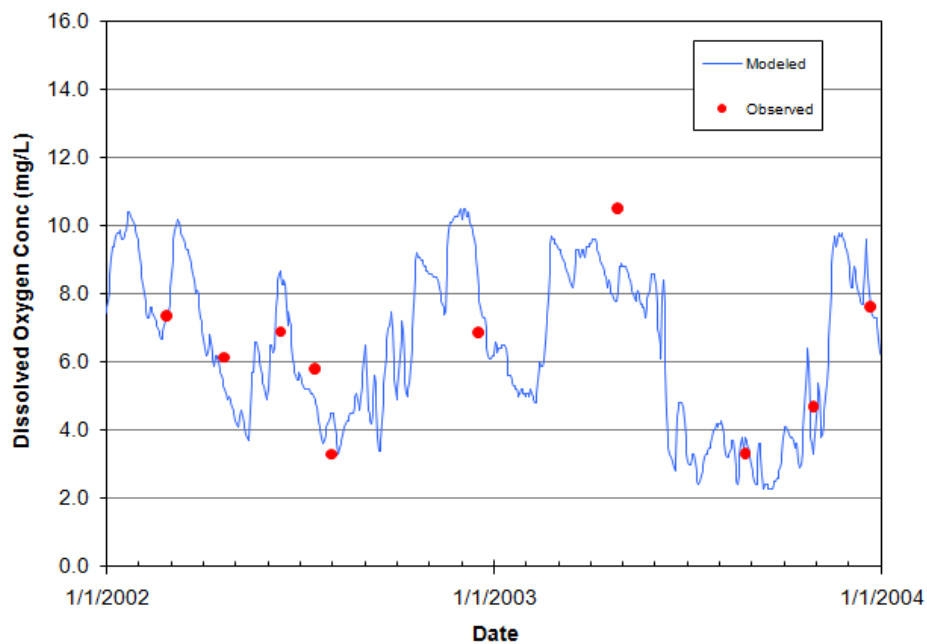


Figure 5-68 Modeled and observed dissolved oxygen concentrations at the S-79 station for the model validation period.

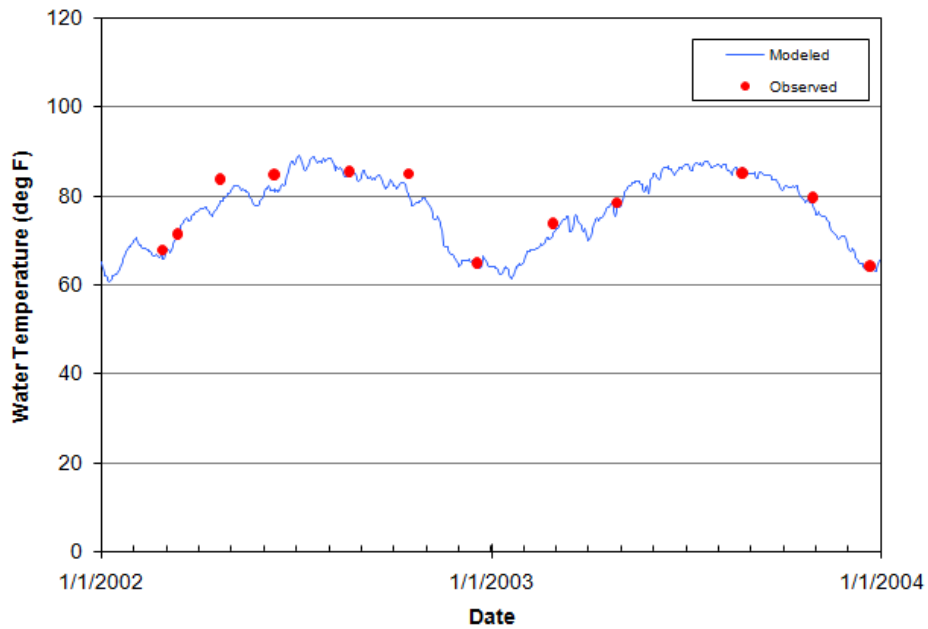


Figure 5-69 Modeled and observed water temperature at the S-78 station for the model validation period

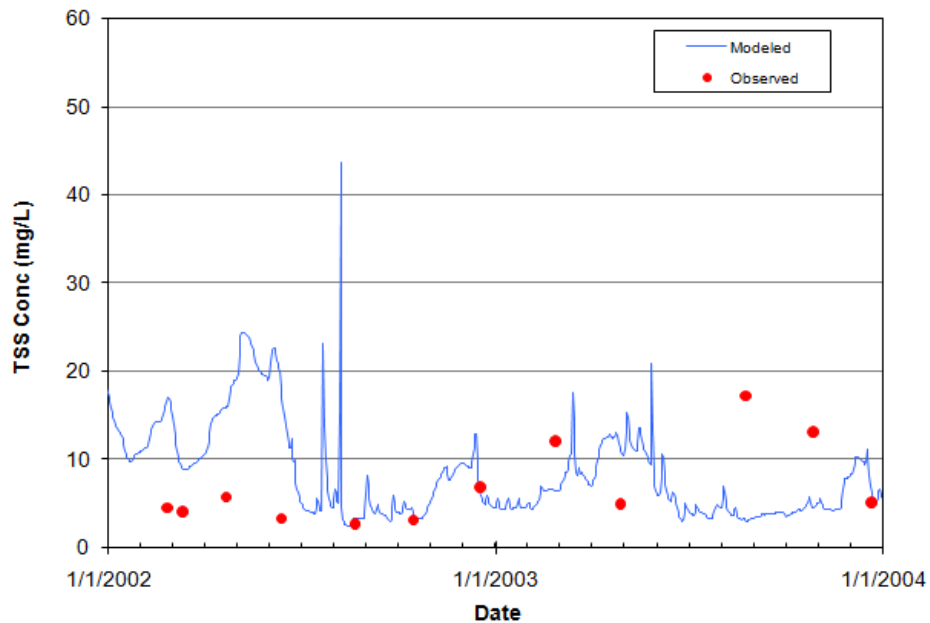


Figure 5-70 Modeled and observed total suspended solids concentrations at the S-78 station for the model validation period

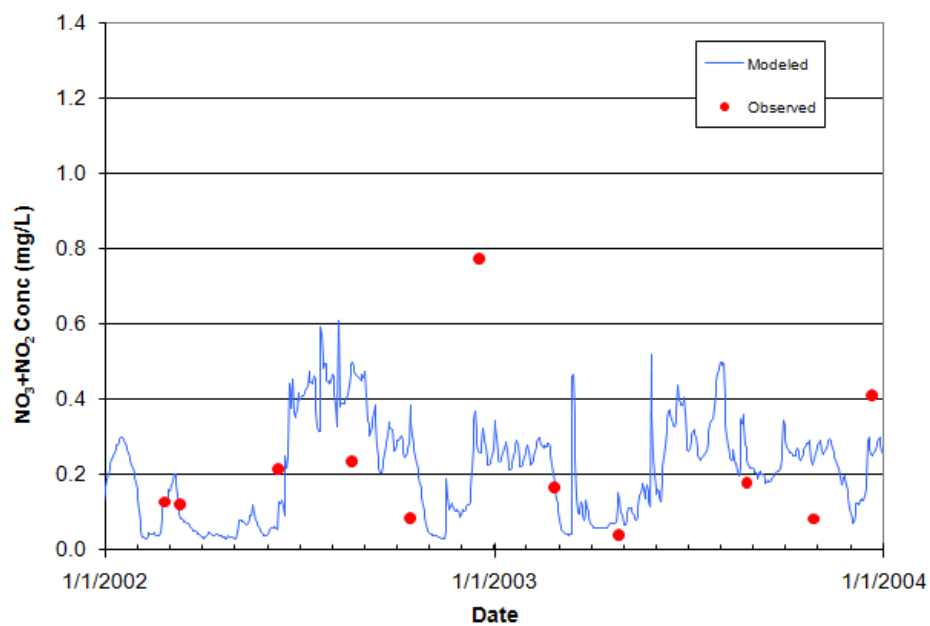


Figure 5-71 Modeled and observed nitrate plus nitrite concentrations at the S-78 station for the model validation period

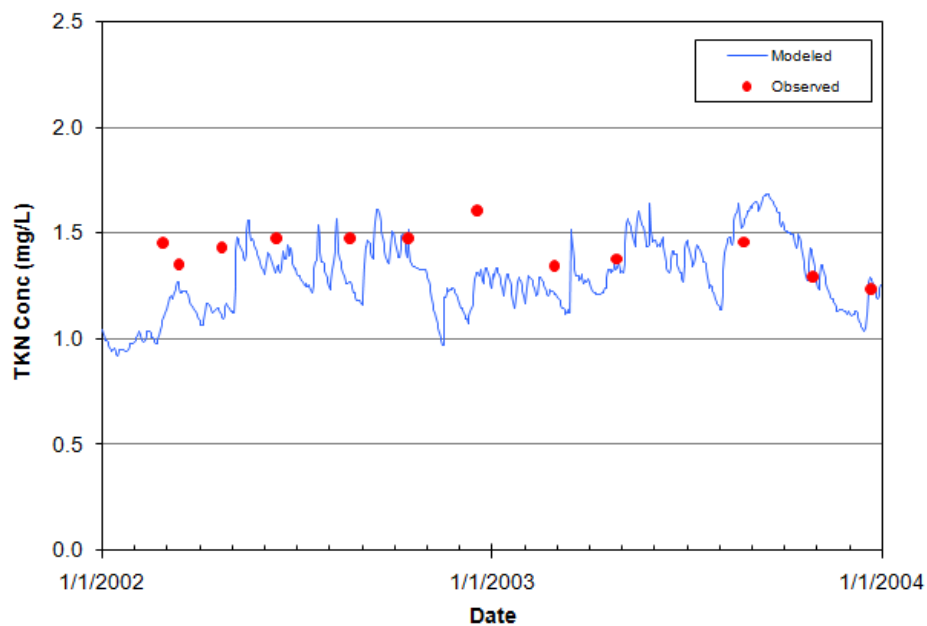


Figure 5-72 Modeled and observed TKN concentrations at the S-78 station for the model validation period

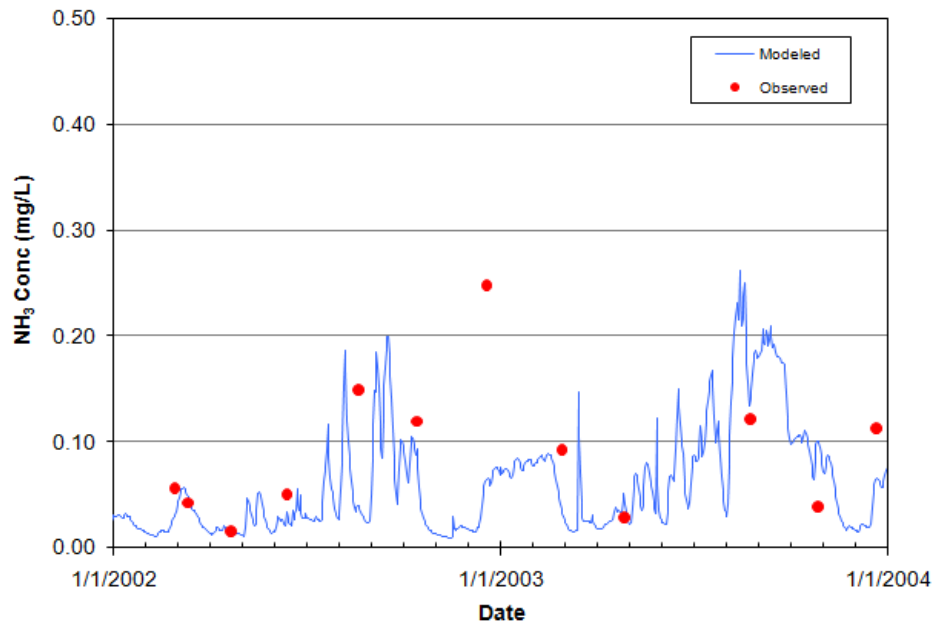


Figure 5-73 Modeled and observed ammonia concentrations at the S-78 station for the model validation period.

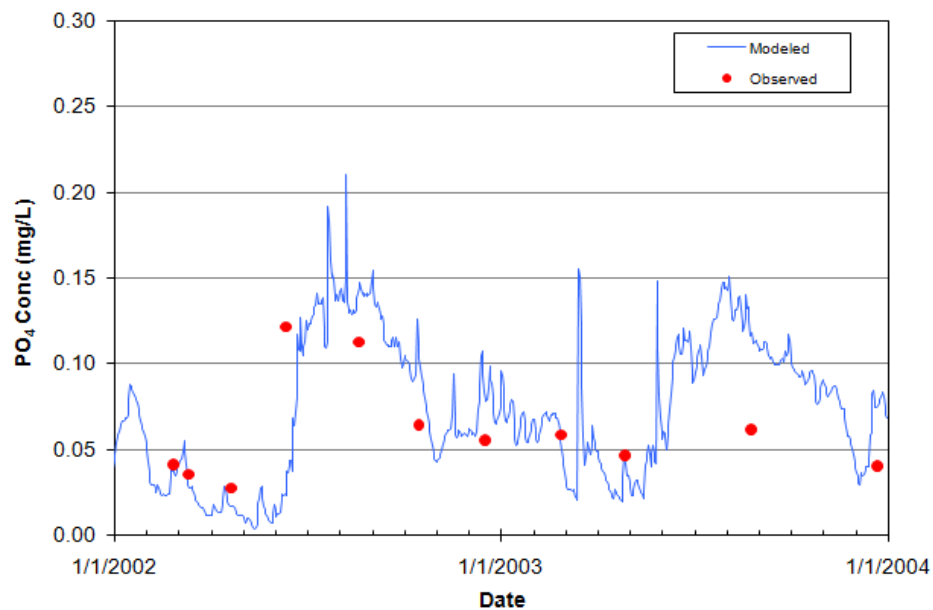


Figure 5-74 Modeled and observed phosphate concentrations at the S-78 station for the model validation period

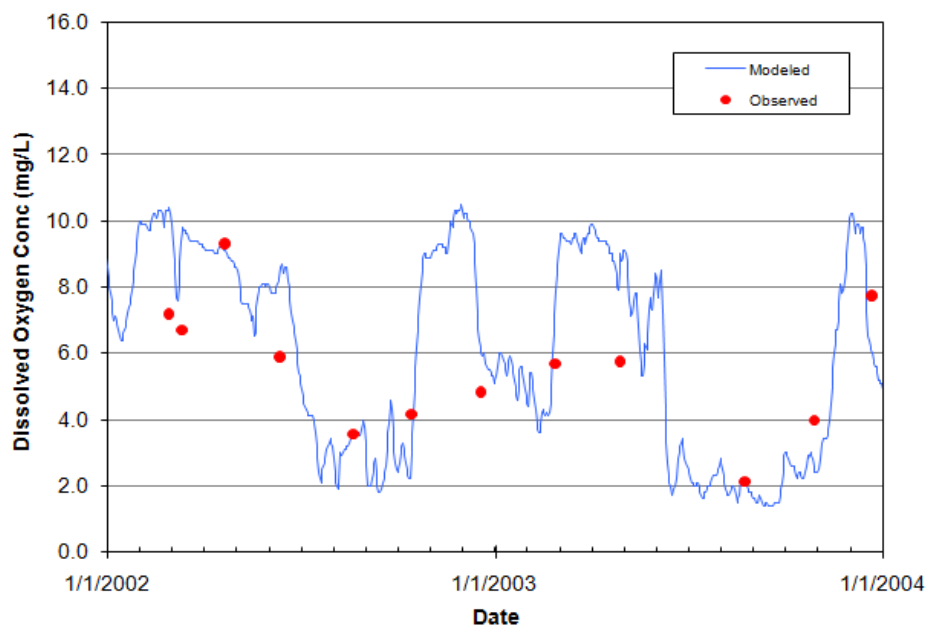


Figure 5-75 Modeled and observed dissolved oxygen concentrations at the S-78 station for the model validation period

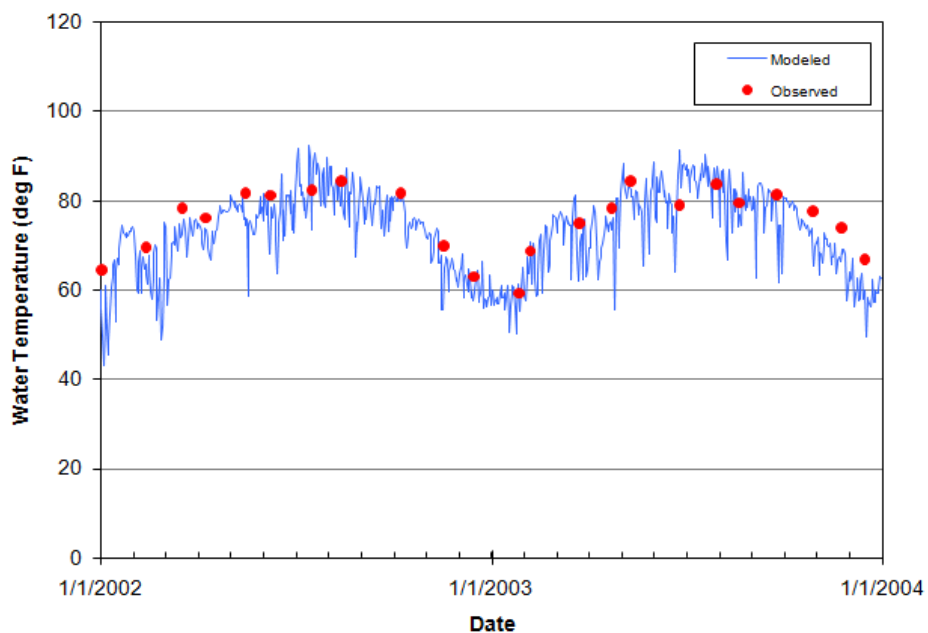


Figure 5-76 Modeled and observed water temperature at the Whiskey Creek station for the model validation period

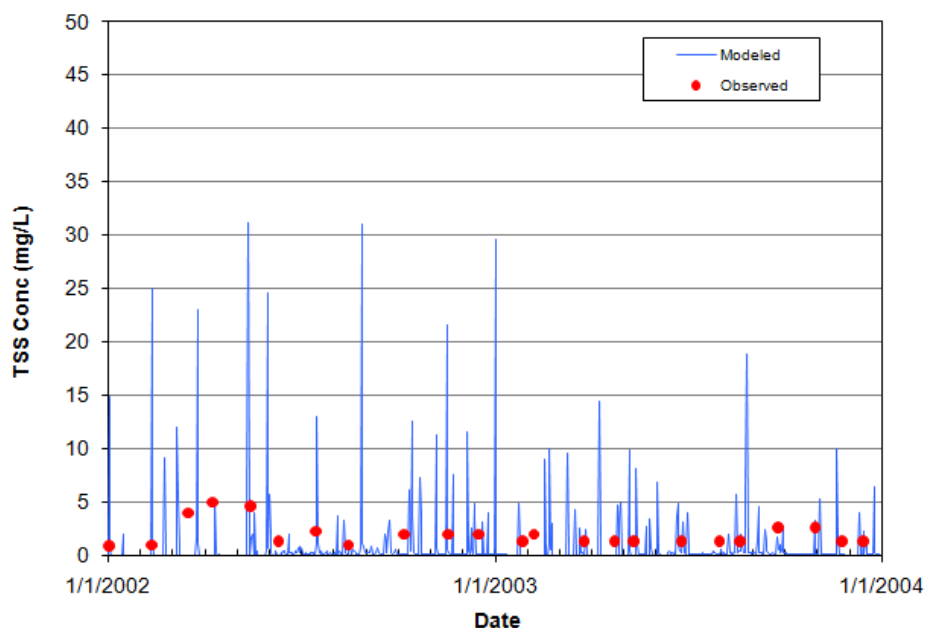


Figure 5-77 Modeled and observed total suspended solids concentrations at the Whiskey Creek station for the model validation period

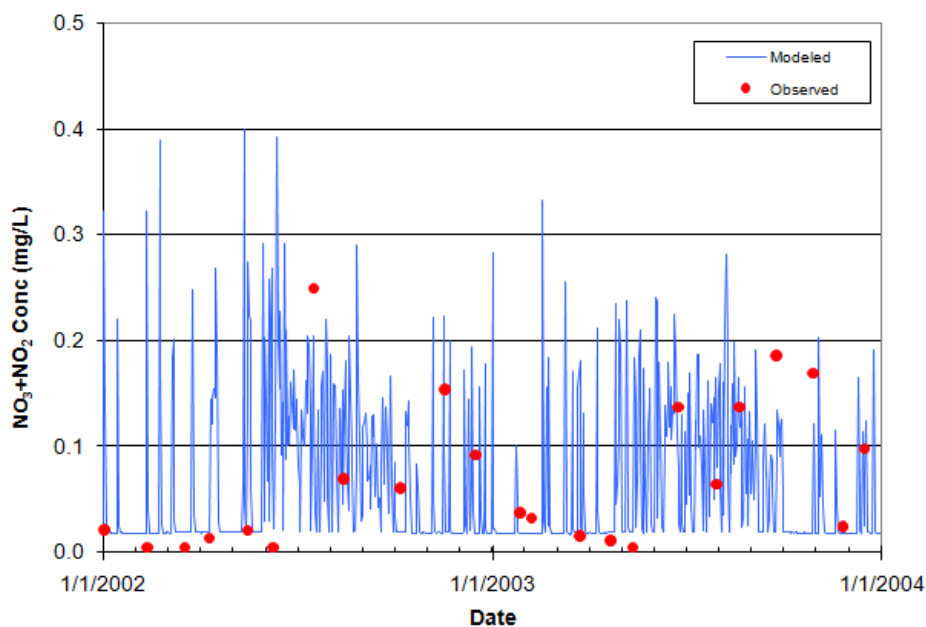


Figure 5-78 Modeled and observed nitrate plus nitrite concentrations at the Whiskey Creek station for the model validation period

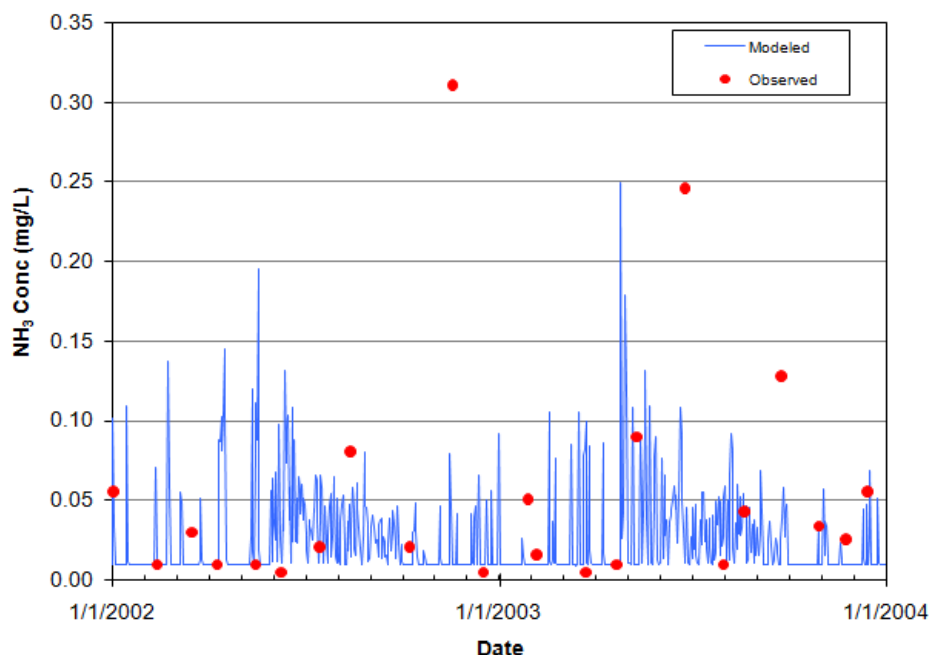


Figure 5-79 Modeled and observed ammonia concentrations at the Whiskey Creek station for the model validation period

Paired values of measured and modeled concentrations were compared using the Wilcoxon and 2-Sided Kolmogorov-Smirnoff (K-S) nonparametric tests. These tests were applied to determine whether or not the measured and modeled data have statistically similar means (Wilcoxon test) and distributions (K-S test). For evaluation purposes, a level-of-significance of 0.05 was used to make the determination of similarity.

The calculated statistics for water quality modeling results are shown in Table 5-15. Based on the 2-sided Kolmogorov-Smirnov Test, the distributions of measured and modeled water temperature, TSS, DO, PO₄, TKN and NO₃ plus NO₂ are all considered similar. Based on the Wilcoxon Rank Sum Test, water temperature, TKN, and PO₄ exhibit statistically different means for the measured and modeled data, whereas TSS, DO, and NO₃ plus NO₂ show statistically similar means.

Table 5-15 Calculated statistics for water quality simulation over the entire simulation period at S-79.

Statistics	P-value for Wilcoxon Rank Sum Test	P-value for 2-Sided Kolmogorov-Smirnov Test
Water temperature	0.0%	45.0%
TSS	66.4%	55.2%
DO	52.7%	>99.9%
TKN	3.0%	12.4%
PO ₄	0.0%	5.9%
NO ₃ +NO ₂	75.7%	12.4%

5.2.4.5 HSPF Output for EFDC Boundary Condition

Upon completion of the HSPF model calibration and the validation, the model was then used to simulate the water quality constituents and provide time series output that would be used to specify the boundary conditions for the EFDC model. **Figure 5-80** shows the locations at which HSPF output were generated to use as the EFDC boundary conditions.

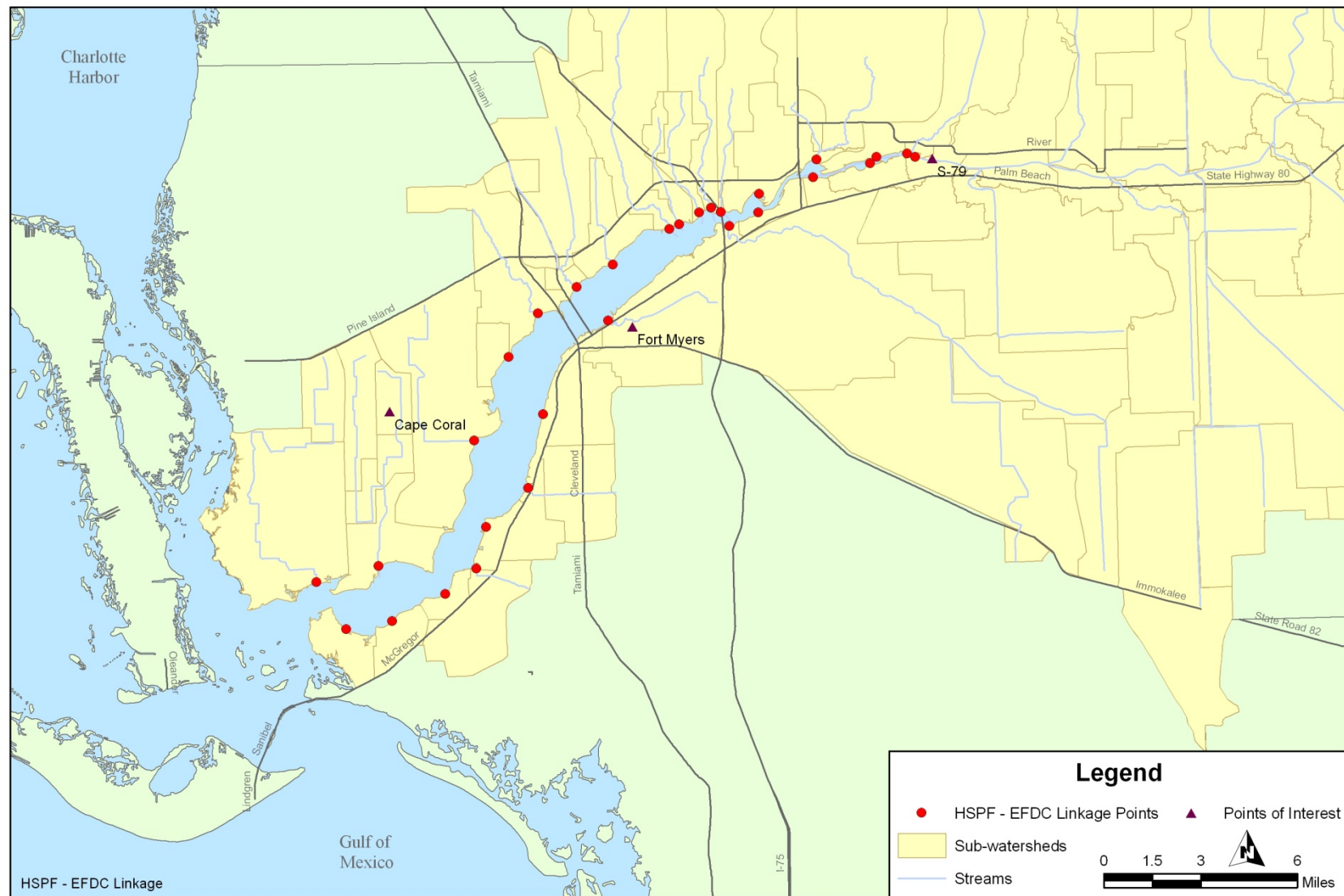


Figure 5-80 Locations of HSPF model output to be used as EFDC boundary condition.

5.3 EFDC MODEL

5.3.1 EFDC MODEL DEVELOPMENT

This Section summarizes the development of the site-specific hydrodynamic and water quality model using the Environmental Fluid Dynamics Code (EFDC) (Hamrick, 1995) for the Caloosahatchee River tidal estuary. The water quality model used for this application is the coupled water quality model internal to EFDC (Park, et.al., 1995), sometimes referred to as HEM3D.

The EFDC water quality model being developed for the TMDL process for the Caloosahatchee River tidal estuary (hereafter simply called the Caloosahatchee) was initially based on the EFDC model of the Caloosahatchee for the U.S. Army Corps of Engineers (USACE) (DSLCC, 2007). The USACE Caloosahatchee model was developed to evaluate release scenarios from Lake Okeechobee and as a water management tool. The model was calibrated for salinity for the year 2000. Where appropriate, the model parameterization and lessons learned from that study were used to setup the FDEP TMDL model of the Caloosahatchee.

The Caloosahatchee water quality model needed to be configured to allow for multiple year simulations in a reasonable time frame (i.e. < 8 CPU hours per year). This would allow management scenarios to be analyzed in a timely manner. This issue impacted the selection of the model domain and grid resolution due to computational issues and simulation productivity.

5.3.1.1 Topographic, Shoreline and Bathymetry Data

Topographic elevation data and map coordinates for the shoreline of the physical domain of the Model were obtained from the USGS Digital Line Graph (DLG). Shoreline data were obtained from NOAA's National Geophysical Data Center (NGDC) Coastline Extractor. Map coordinates (xy) are defined for the project as North Atlantic Datum 1983 (NAD83) Universal Transverse Mercator (UTM) northing's and easting's (meters) for UTM Zone 17. All elevations in the Model have been adjusted so that their reference point (or zero datum) is mean sea level (MSL) at Ft. Myers for the current Epoch as defined by NOAA. **Table 5-16** is provided by NOAA and shows the relationship between mean sea level and various other datum elevations at Ft. Myers.

Table 5-16 Datum Elevations in MSL Feet at Ft. Myers (NOAA#8725520)

Highest Observed Water Level (11/23/1988)	4.09
Mean Higher High Water (MHHW)	0.68
Mean High Water (MHW)	0.47
North American Vertical Datum-1988 (NAVD)	0.41
Mean Sea Level (MSL)	0.00
Mean Tide Level (MTL)	-0.01
Mean Low Water (MLW)	-0.48
Mean Lower Low Water (MLLW)	-0.63
National Geodetic Vertical Datum-1929 (NGVD)	-0.76
Lowest Observed Water Level (09/08/1965)	-3.49

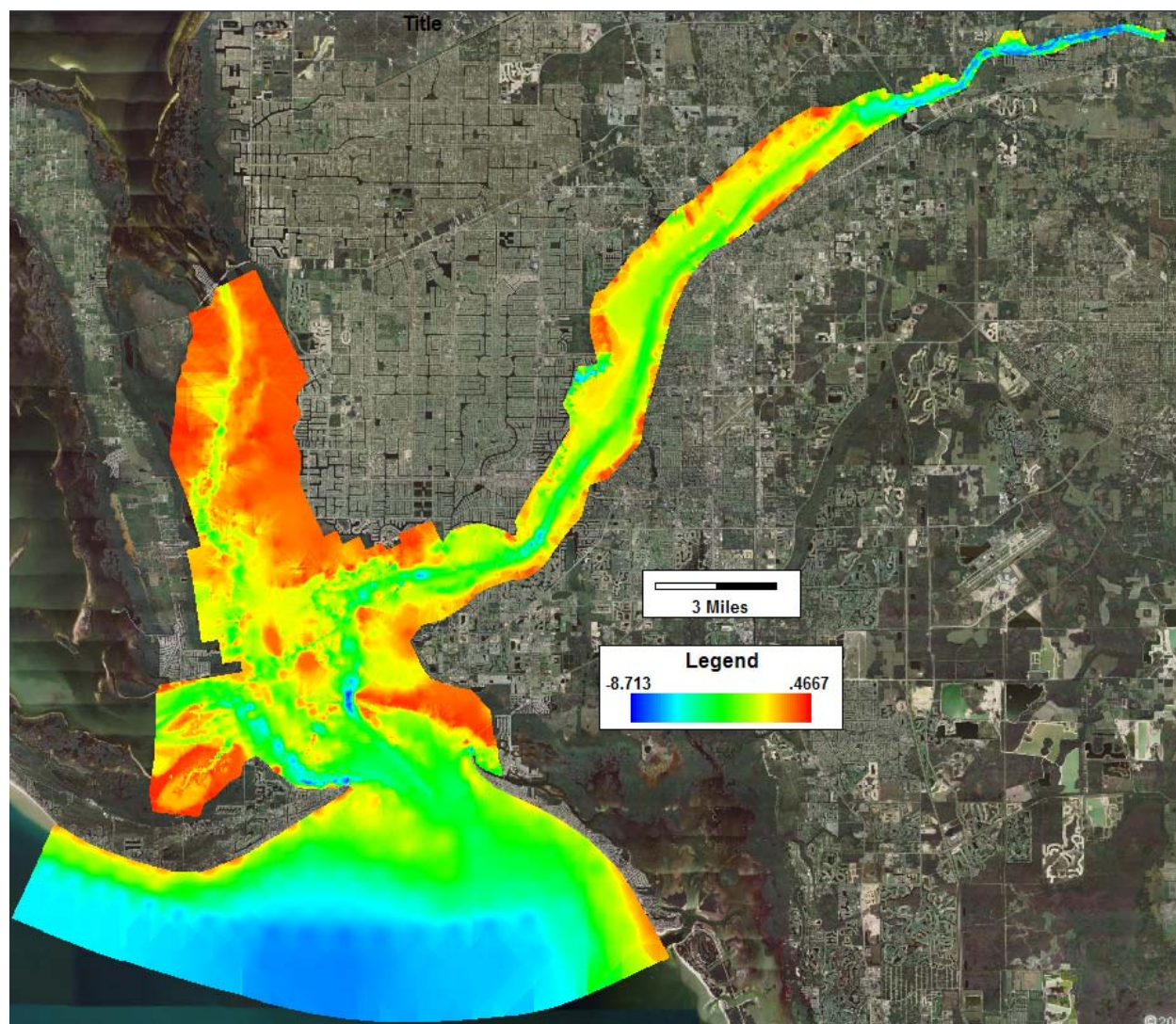


Figure 5-81 Digital Terrain Model of the Caloosahatchee water quality model domain (elevations in feet relative to MSL).

The bathymetric data used to process the DTM shown in **Figure 5-81** is a composite from several data sources. The origins of these data were NOAA and the USGS (SFWMD, 2007). The data was supplied in four files/data sets. They were:

- NOAA NED 2004
- OWW 2003
- USGS 2003
- USGS SANDS 2003

These data represent the latest and most complete bathymetric data for the model domain.

The original vertical datum for these files was NAVD88. The elevations were adjusted to MSL by:

$$Elev_{MSL} = Elev_{NAVD88} + (Datum_{NAVD88} - Datum_{MSL})$$

Substituting the datums from Table 1 we obtain:

$$Elev_{MSL} = Elev_{NAVD88} + (0.41 - 0.0) = Elev_{NAVD88} + 0.41$$

The elevations are in feet so the offset is +0.41 feet (0.125 meters).

5.3.1.2 Grid Development

Grid development is a critical component of the hydrodynamic model. A model grid is the result of a balance of spatial resolution, site conceptual model and modeling objectives against the computational time and resources. High resolution grids can produce great horizontal and vertical detail, but if the run times are excessive, then the model will be limited due to the inability to produce enough runs to obtain good calibration, validation and target scenarios.

The final Caloosahatchee River tidal estuary grid is shown in **Figure 5-82**. The grid has 733 horizontal cells and four vertical layers. The grid was developed using the Delft RGFGGrid program (Delft, 2006). The grid created by RGFGGrid was then configured for EFDC by importing the GRD file into EFDC_Explorer (Craig, 2008). Final minor editing to the grid was performed using EFDC_Explorer. The average of the absolute orthogonality deviation for the final grid was 0.4 degrees. This is less than the target deviation of less than 2-3 degrees (Delft, 2006).

This grid addresses all of the critical components needed for the Caloosahatchee River water quality modeling. The upstream boundary of the model is located at the S79 Franklin Lock & Dam. This structure limits the tidal influence up the Caloosahatchee. All of the fresh water discharge points to Caloosahatchee River have been addressed in the HSPF modeling effort. Therefore, the EFDC model grid does not extend up these catchments. HSPF will provide the flow and water quality loadings at the boundaries of the Caloosahatchee EFDC model.

Figure 5-82 shows the grid with some cells labeled with the EFDC's grid numbering scheme of I (generally the X/Easting component) and the J (generally the Y/Northing component). The Gulf

of Mexico is located along the model boundary with the smallest J's and the eastern edge of model domain (near S79) has the largest I.

The EFDC model grid was configured with four layers to address the density dependent dynamics due to salinity and temperature profiles. For this case, each layer represents 25% of the water depth for each cell.

The processed bathymetric data discussed in the previous section was then used to develop the model bathymetry for each cell. **Figure 5-83** shows the model grid with the resulting bathymetry for each cell.

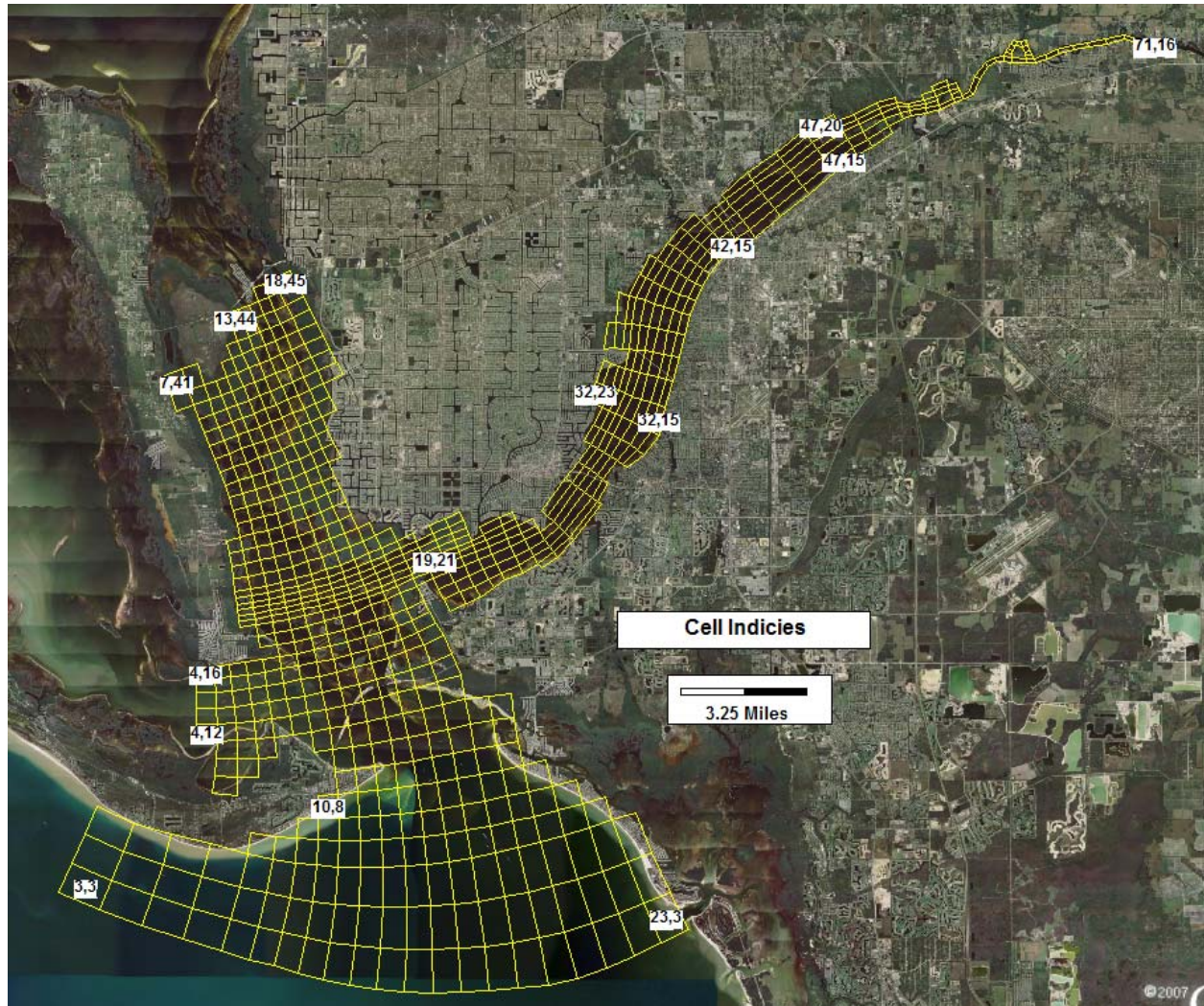


Figure 5-82 Caloosahatchee model grid with representative cell indices

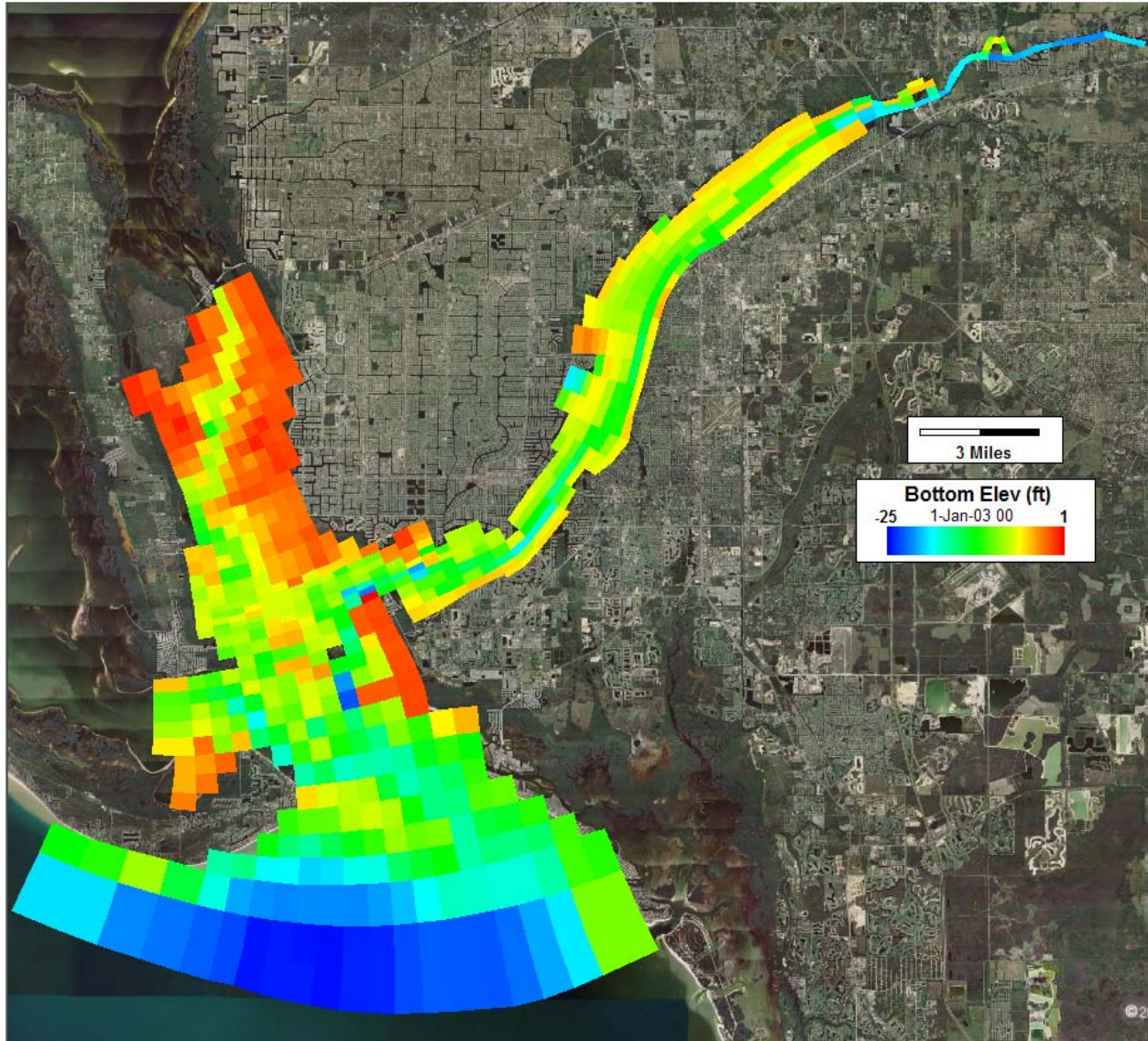


Figure 5-83 Caloosahatchee model domain with model bathymetry

5.3.1.3 Parameters Simulated and Kinetic Option

For the Caloosahatchee, the EFDC/HEM3D kinetic option 1 was used. This essentially mimics the CE-QUAL-ICM (Cерco & Cole, 1994) kinetics. This option has been the most tested and stable of the EFDC water quality kinetic options. Within this option, the user can activate or inactivate the kinetics and transport of individual parameters. The parameters modeled for the Caloosahatchee Estuary water quality model are listed in **Table 5-17**.

Table 5-17 EFDC parameters simulated

Code	EFDC Parameter	EFDC Parameter ID	EFDC Units	Used in Model
NA	Water Surface	WS	M	Yes
NA	Salinity	SAL	ppt	Yes
NA	Temperature	TEM	°C	Yes
NA	Inorganic Cohesive Sediments	COH	mg/l	Yes
Water Quality Sub-Model (HEM3D Parameters)				
1	Cyanobacteria	CHC	mg C/l	No
2	Diatoms	CHD	mg C/l	No
3	Green Algae	CHG	mg C/l	Yes
4	Refractory Particulate Organic Carbon	RPOC	mg C/l	Yes
5	Labile Particulate Organic Carbon	LPOC	mg C/l	Yes
6	Dissolved Organic Carbon	DOC	mg C/l	Yes
7	Refractory Particulate Organic Phosphorus	RPOP	mg P/l	Yes
8	Labile Particulate Organic Phosphorus	LPOP	mg P/l	Yes
9	Dissolved Organic Phosphorus	DOP	mg P/l	Yes
10	Total Phosphate	TPO4	mg P/l	Yes
11	Refractory Particulate Organic Nitrogen	RPON	mg P/l	Yes
12	Labile Particulate Organic Nitrogen	LPON	mg N/l	Yes
13	Dissolved Organic Nitrogen	DON	mg N/l	Yes
14	Ammonia Nitrogen	NHX	mg N/l	Yes
15	Nitrate Nitrogen	NOX	mg N/l	Yes
16	Particulate Biogenic Silica	SUU	mg Si/li	No
17	Dissolved Available Silica	SAA	mg Si/l	No
18	Chemical Oxygen Demand	COD	mg O ₂ /l	No
19	Dissolved Oxygen	DOX	mg O ₂ /l	Yes
20	Total Active Metals	TAM	mol/m ³	No
21	Fecal Coliform	FCB	mpn/100mL	No

The water quality parameters needed by the EFDC model were all initialized with the defaults as indicated in the user's manual (Park, et.al., 1995). These defaults are mostly identical to the factors determined in the Chesapeake Bay CE-QUAL-ICM application and reported in the ICM user's manual (Cерco & Cole, 1994).

5.3.1.4 Model Simulation Period

Based on the availability of time series of atmospheric forcing, tidal forcing and flow data needed for construction of the hydrodynamic Model, the period where the required data are the most complete and coincide with appropriate water quality data is the period from October 2002 through December of 2004. The model will be calibrated to one year of data for 2003. The validation period will be for the year 2004.

5.3.1.5 Model Initial Conditions

For salinity and temperature the model was initialized to the measured data at the beginning of the simulation periods. For water quality a constant value was applied for each constituent over the entire model domain. For a system as dynamic as the Caloosahatchee the initial conditions were not particularly critical, especially given that the starting times were on January 1. Within a few days the system responded to the boundary and internal forcings.

5.3.1.6 Model Boundary Conditions

The locations of the boundary conditions are shown in **Figure 4**. The Caloosahatchee model used two types of boundary conditions, flow and open boundaries. A flow boundary type is defined using a time series of flows and the water column parameters simulated. On open boundary is defined by a water surface elevation time series and the water column parameters. The flows at an open boundary are computed based on the water surface boundary condition specified and the adjacent water surface. This boundary allow for flows to enter and leave the model domain as required by the hydrodynamics.

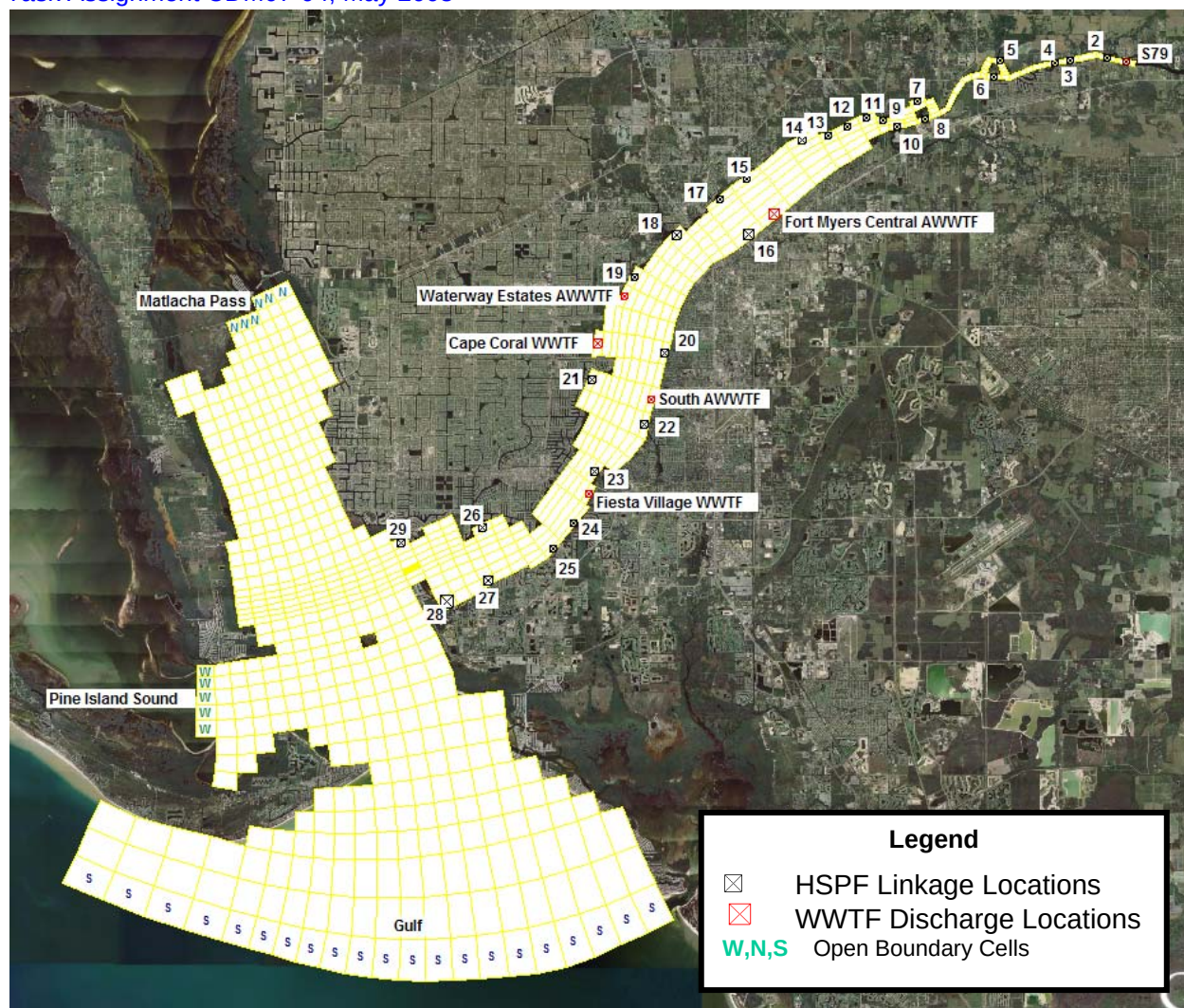


Figure 5-84 Location of tidal and HSPF boundary conditions relative to the Caloosahatchee grid

5.3.1.6.1 Fresh Water Flows

The flow boundaries for the Caloosahatchee model represented two types of sources. The first type of flow boundaries were for the tributary network that drains to the Caloosahatchee Estuary. The second type of flow boundary condition was the permitted waste water treatment plants that discharge to the Caloosahatchee.

The tributary flow boundaries were defined using the flows and water quality results from the HSPF modeling efforts (see Section 5.2). The numbered points shown on **Figure 5-84** refer to the HSPF linkage ID corresponding to the HSPF sub-watersheds. The Linkage ID 1 has been renamed to “S79” as it corresponds to the discharge from the S79 structure. This is the primary source of fresh water into the Caloosahatchee River tidal system. For each sub-basin the flows,

water temperature and water quality parameters were taken from the HSPF simulation results. A constant salinity of 0.25 ppt was used for all freshwater flows. This value was derived from an analysis of salinity data from the water upstream of S79 (21FLSFWM CES01). As an example, the time series of the flows, salinity and temperatures assigned to the S79 structure for year 2003 are shown in **Figure 5-85**. The other smaller watersheds contribute about 25 percent of the total inflows. The annual average S79 flow contribution to the Caloosahatchee is shown in **Table 5-18**. Even though measured S79 flows were available, the ratios in Table 5-18 were derived from the HSPF simulated flows for all the tributaries and S79.

Table 5-18 Annual freshwater contribution to the Caloosahatchee from S79

Year	S79 Contribution (%)
2001	71.9
2002	70.8
2003	75.8
2004	71.0
2005	82.3

The waste water facilities that directly discharge to the Caloosahatchee Estuary are listed in **Table 5-19**. The flows and pollutant discharges for these facilities were taken from the monthly reporting for each facility.

The mass loading results of the HSPF and WWTF approaches discussed in this section will be presented in the respective sections for the model calibration and validation.

Table 5-19 Location of discharge for the Caloosahatchee WWTF's

Discharge Location		NPDES Permit Number	Name of Facility
Easting (m)	Northing (m)		
409905	2936047	FL0039829	Fiesta Village WWTF
415536	2948171	FL0021261	Fort Myers Central AWWTF
406740	2943193	FL0030007	Cape Coral WWTF
409514	2946726	FL0030325	Waterway Estates Advanced WWTP
412479	2941080	FL0021270	South AWWT Facility

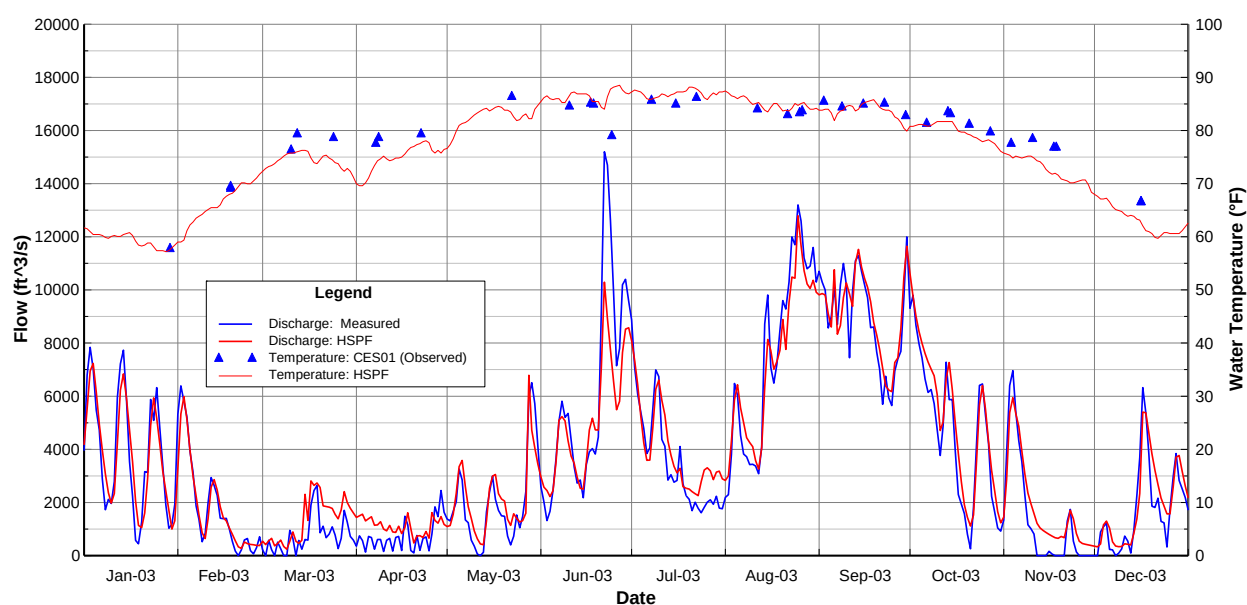


Figure 5-85 Observed flows and temperature versus HSPF at S79

5.3.1.6.2 HSPF – EFDC Linkage Approach

The complete specification of boundary conditions for input to EFDC and WASP7 include boundary inputs from (1) tributaries and distributed runoff from HSPF sub-watersheds, (2) wastewater treatment facilities and (3) open water boundaries. A description of the procedures used to link the time series data sets obtained from these three different types of boundary groups is presented in this section.

(1) Tributaries and Distributed Runoff from HSPF Sub-Watersheds

The HSPF model framework consists of a network of sub-watersheds that generate flow and pollutant loading from runoff over the land uses of sub-watersheds defined within a larger watershed domain for a project. Some, but not all, sub-watershed are defined by an in-stream reach where flow and pollutant loads simulated as land use dependent runoff are input and routed through a reach that is defined by length, volume, surface area, depth and hydraulic residence time. A sub-watershed that is defined by a reach generates flow and water quality concentrations at a specific downstream outlet location of the sub-watershed. A sub-watershed that does not include a reach generates water volume and loads as distributed runoff over the entire sub-watershed. The state variable groups of the HSPF water quality model are shown in **Table 5-20**.

Suspended solids are represented in HSPF as inorganic solids with specified particle size fractions assigned to characterize solids as silts, clays and sands.

Table 5-20 HSPF Water Quality Model State Variables

HSPF State Variable	HSPF Code	Notes
Streamflow	HSPF_Q	
Water temperature	HSPF_T	
Dissolved Oxygen	HSPF_DO	
Suspended Solids	HSPF_TSS	Inorganic clay, silts and sands
Algae Biomass	HSPF_Algae	
Biochemical Oxygen Demand	HSPF_BOD	All labile organic matter is lumped into BOD (ultimate).
Ammonia-Nitrogen	HSPF_NH3	
Nitrate-Nitrogen	HSPF_NO3	
Nitrite-Nitrogen	HSPF_NO2	
	HSPF_ORN	Organic Nitrogen: Refractory organic Nitrogen derived from HSPF_TOC
Total Orthophosphate-Phosphorus	HSPF_PO4	
	HSPF_ORP	Organic Phosphorus: Refractory organic Phosphorus derived from HSPF_TOC
Organic Carbon	HSPF_ORC	Refractory Organic Carbon

Water column algae is represented in HSPF as a single functional group of phytoplankton. Algae results can be written out at the discretion of the HSPF modeling team as either dry weight (DW) biomass (mg DW/L) or biomass converted for output to chlorophyll-a (ug Chl/L).

Biochemical oxygen demand (BOD) is represented in HSPF as the labile, or reactive, component of organic matter. Runoff loading from land uses and in-stream BOD in HSPF is considered to be BOD-Ultimate rather than the commonly measured 5-day BOD (BOD5).

Carbon is represented in HSPF as the inorganic and organic forms of carbon. Inorganic carbon is accounted for in HSPF by the carbon dioxide, alkalinity and pH sub-model. Organic carbon is represented in HSPF as the non-living refractory form of organic matter. It is important to understand that the non-living labile form of organic carbon is represented in the HSPF model as the oxygen equivalent of labile organic matter that is defined by the BOD state variable. The representation of labile organic matter as either labile organic carbon or BOD is described by the stoichiometric ratio of oxygen to carbon (O₂/C). The refractory form of organic carbon is included as a state variable in the HSPF model and is considered to be non-living organic matter with a very slow rate of decay.

Nitrogen is represented as the inorganic and organic forms of nitrogen in HSPF. Inorganic nitrogen is represented as ammonia-N, nitrite-N and nitrate-N with the complete nitrification cycle considered by the nitrogen sub-model. Organic nitrogen is represented as a state variable in HSPF as the non-living refractory form of organic nitrogen with a very slow decay rate.

Phosphorus is represented as the inorganic and organic forms of phosphorus. Inorganic phosphorus is represented as total orthophosphate with partitioning between the dissolved and particulate forms of orthophosphate considered. Total organic phosphorus is represented as a state variable in HSPF as the non-living refractory form of organic-P with a very slow decay rate.

It is important to understand that the labile form of organic-N and organic-P is not explicitly accounted for in the HSPF model as explicit state variables for labile organic-N and organic-P. The labile component of organic-N and organic-P is represented instead as the N and P stoichiometric equivalent of labile organic matter that is defined by the BOD state variable for labile organic matter.

Since HSPF represents labile and refractory organic matter as separate state variables, wastewater discharges of organic matter (as C,N,P) that are explicitly input as loads to an HSPF reach must first be “filtered” to correctly specify the loading of only the refractory components of organic C,N,P by splitting out the labile component of the organic matter as C,N,P that is accounted for by the input load of BOD assigned for the effluent. This procedure is needed to prevent “double counting” of the input of labile organic matter present in an effluent discharge.

The procedures used for linkage of HSPF results for input to EFDC are described below.

Flow: The internal EFDC units for flow is m³/s. For the Caloosahatchee, the HSPF flows generated were in 1000's ft³/day. These were converted to m³/s.

Temperature: The internal EFDC units of temperature is degrees Celsius. HSPF reported the water temperature as degrees Fahrenheit. These were converted to Celsius.

Suspended Solids. Suspended solids are assigned for input to EFDC as either cohesive or non-cohesive inorganic solids classes. For the Caloosahatchee project, 100% of suspended solids generated by HSPF are represented as inorganic cohesive solids for input to EFDC.

Algae: EFDC represents algae as three functional groups with biomass units of mg-C/L. Algal biomass generated by HSPF must be converted to organic carbon for input to EFDC. For the Caloosahatchee project, algal biomass is output from the HSPF model as dry weight with 100% of the algal biomass assigned to the Green algae group (CHG). Algal biomass is converted from dry weight to carbon using a carbon-to-dry weight ratio of 0.45 mg-C/mg-DW.

$$\text{CHG (mg-C/L)} = \text{HSPF_Algae (mg-DW/L)} * (\text{C/DW})$$

Organic Carbon: EFDC represents organic carbon as dissolved organic carbon (DOC), and the non-living (detrital) forms of refractory particulate organic carbon (RPOC) and labile particulate organic carbon (LPOC). Total organic carbon (TOC) (non-living) is the sum of the three components of organic carbon. As described above, HSPF represents labile organic matter as BOD (ultimate) and refractory organic matter as organic carbon (HSPF_ORC). Linkage of HSPF BOD and organic carbon for input of total organic carbon (HSPF_TOC) to EFDC is defined as follows.

$$\begin{aligned}\text{HSPF_LOC} &= \text{HSPF_BOD} * (\text{BODU/BOD5}) * \text{C/O2} \\ \text{HSPF_TOC} &= \text{HSPF_LOC} + \text{HSPF_ORC}\end{aligned}$$

The non-living Total Organic Carbon (HSPF_TOC), computed as the sum of the labile (HSPF_LOC) and refractory (HSPF_ORC) organic matter simulated by HSPF. BODU/BOD5 is the ratio of BOD-Ultimate to BOD5. For the Caloosahatchee the BOD was modeled as BOD Ultimate so the ratio of BODU/BOD5 = 1.0. The stoichiometric ratio for carbon to oxygen has a value of C/O2 = 12/32 = 0.375 mg C/mg-O2.

The HSPF_TOC is then split into dissolved organic carbon (DOC) and refractory particulate organic carbon (RPOC) and labile particulate organic carbon (LPOC) components for input to EFDC. For the Caloosahatchee project, organic carbon splits of HSPF results are based on field data collected for the Lower St. Johns River watershed (Hendrickson et al., 2007). The splits are 25%, 40% and 35% respectively for RPOC, LPOC and the DOC fractions.

Phosphorus. EFDC represents inorganic phosphorus as total orthophosphate (TPO4) and organic phosphorus as dissolved organic phosphorus (DOP), and the non-living (detrital) forms of refractory particulate organic phosphorus (RPOP) and labile particulate organic phosphorus (LPOP). Total organic phosphorus (TORP) (non-living) is the sum of the three components of organic phosphorus. As described above, HSPF represents labile organic matter as BOD (ultimate) and refractory organic matter as organic phosphorus. Total Phosphorus (HSPF_TP) is the sum of the organic (HSPF_TOP) and inorganic (HSPF_PO4) components. Linkage of HSPF BOD and organic phosphorus for input of total organic phosphorus (HSPF_TOP) to EFDC is defined as :

$$\begin{aligned}\text{HSPF_TOP} &= \text{HSPF_TOC} * \text{P/C} \\ \text{HSPF_TP} &= \text{HSPF_PO4} + \text{HSPF_TOP}\end{aligned}$$

The stoichiometric ratio for Phosphorus to Carbon is based on the Redfield (1963) ratio of carbon to phosphorus where C/P = 41.1 mg C/mg-P and P/C= 0.0243 mg-P/mg-C (Di Toro, 2000).

The non-living Total Organic Phosphorus (HSPF_TOP) is then split into dissolved organic phosphorus (DOP) and refractory particulate organic phosphorus (RPOP) and labile particulate

organic phosphorus (LOPOP) components for input to EFDC. For the Caloosahatchee project, organic phosphorus splits of HSPF results are based on field data collected for the Lower St. Johns River watershed (Hendrickson et al., 2007). The splits used were 10%, 37% and 53% respectively for RPOP, LPOP and the DOP fractions. Total orthophosphate (TPO4) is directly input to EFDC.

Nitrogen. EFDC represents inorganic nitrogen as ammonia-N (NHX) and nitrite+nitrate-N (NOX) and organic nitrogen as dissolved organic nitrogen (DON), and the non-living (detrital) forms of refractory particulate organic nitrogen (RPON) and labile particulate organic nitrogen (LPON). Total organic nitrogen (TORN) (non-living) is the sum of the three components of organic nitrogen. As described above, HSPF represents labile organic matter as BOD (ultimate) and refractory organic matter as organic nitrogen. Linkage of HSPF BOD and organic nitrogen for input of total non-living organic nitrogen (HSPF_TON) to EFDC is defined as follows:

$$\begin{aligned}\text{HSPF_TON} &= \text{HSPF_TOC} * \text{N/C} \\ \text{HSPF_TN} &= \text{HSPF_NH3} + \text{HSPF_NO3} + \text{HSPF_NO2} + \text{HSPF_TON}\end{aligned}$$

The stoichiometric ratio for Nitrogen to Carbon is based on the Redfield (1963) ratio of carbon to nitrogen where C/N = 5.7 mg C/mg-N and N/C= 0.1754 mg-N/mg-C (Di Toro 2000).

Non-living Total Organic Nitrogen (HSPF_TON), computed as the sum of the labile and refractory organic matter simulated by HSPF, is then split into dissolved organic nitrogen (DON) and refractory particulate organic nitrogen (RPON) and labile particulate organic nitrogen (LPON) components for input to EFDC. For the Caloosahatchee project, organic nitrogen splits of HSPF results are based on field data collected for the Lower St. Johns River watershed (Hendrickson et al., 2007). The splits used were 30%, 35% and 35% respectively for RPON, LPON and the DON fractions. The inorganic forms of nitrogen are assigned for input to EFDC directly as

$$\begin{aligned}\text{NHX} &= \text{HSPF_NH3} \\ \text{NOX} &= \text{HSPF_NO3} + \text{HSPF_NO2}\end{aligned}$$

Dissolved Oxygen. Dissolved oxygen is assigned for input to EFDC directly.

(2) Wastewater Treatment Facilities and (3) Open Water Boundary Conditions

Procedures used to assign organic matter boundary condition data for input to EFDC from wastewater facilities and open water monitoring stations differ somewhat from the procedures described above that are used to link results generated by HSPF. The approach was different because the data obtained to describe inputs to the water quality model from either wastewater effluent or open water conditions were based on measurements of whole water samples. A whole water samples from will contain inorganic solids, inorganic nutrients, non-living (detrital) particulate organic matter, dissolved organic matter and particulate organic matter from algal biomass while a whole water sample from wastewater will not include any algal biomass.

Lung (2001) describes “filtering” procedures needed to prepare data for boundary inputs to a water quality model where organic matter is represented in the model as the non-living forms of carbon, nitrogen and phosphorus. Particulate organic matter associated with algal biomass

from an observed whole water sample must be “filtered” to subtract out the algal component from the measured concentration of organic matter.

Observed open water measurements of total organic carbon (TOC), total organic nitrogen (TON) and total organic phosphorus (TOP) were “filtered” to define boundary inputs of the non-living forms of TOC, TON and TOP as:

$$\begin{aligned}\text{TOC (non-living)} &= \text{TOC (measured)} - \text{Algae (ug Chl/L)} * \text{C/Chl} \\ \text{TON (non-living)} &= \text{TON (measured)} - \text{Algae (ug Chl/L)} * \text{C/Chl} * \text{N/C} \\ \text{TOP (non-living)} &= \text{TOP (measured)} - \text{Algae (ug Chl/L)} * \text{C/Chl} * \text{P/C}\end{aligned}$$

Stoichiometric parameters for C/CHL, C/N and C/P are described above under HSPF linkage procedures.

The non-living components of TOC, TOP and TON were then split for input to EFDC based on assignment of the dissolved, refractory and labile fractions as described above for linkage of the HSPF results.

Suspended solids measurements from either wastewater effluent or open water monitoring stations include both inorganic solids and organic solids. Since EFDC represents cohesive and non-cohesive solids as inorganic solids, the organic component that is included in observed TSS data must be “filtered” out for specification of boundary condition input data to EFDC.

$$\text{TSS (inorganic)} = \text{TSS (measured)} * (1 - \text{Org_Fraction})$$

For wastewater effluent, Metcalf & Eddy (1991) indicate that 65% of TSS in secondary effluent is comprised of particulate organic matter. The parameter value for Org_Fraction is assigned for wastewater sources as 0.65. For open water monitoring station data, estimates of the organic fraction of TSS measurements will be based on estimates of both the non-living detrital organic matter and algal biomass components.

5.3.1.6.3 Use of HSPF versus Data

The S79 structure on the Caloosahatchee River has on ongoing monitoring programs for discharge and water quality parameters. While the observed data could be used to define the boundary condition for the S79 inflows the decision was made to use HSPF simulation results for S79 instead. The rationale for this decision was:

- Most of the inflows to the Caloosahatchee Estuary are ungaged and/or have incomplete data sets.
- Using a rainfall/runoff simulator allows the modeler to “fill” the data gaps in infrequent data set. This enables the user to capture unusual rainfall events that measured data may miss.
- The use of HSPF simulation results allows for the “what if” scenario analysis required for the modeling study.

That said, in using simulated results there is an implicit acceptance of the impacts of model versus data discrepancies in the HSPF results on the receiving water quality model. While one goal of the modeling study is to minimize these discrepancies, they do exist. **Figure 5-85** also shows the measured S79 flows and temperatures compared to the calibrated HSPF results used

for the water quality modeling of the Caloosahatchee Estuary for the year 2003. On average the flow and temperature match is acceptable. The measured annual average discharge was 3572 cfs compared to 3724 cfs for the HSPF model (~ 4%). The observed water temperature was 79.7 °F compared to 76.3 °F for the HSPF model (~ -4%). On average the HSPF model does a good job. However, on a short term basis (i.e. March and April), the flows can be quite different.

5.3.1.6.4 Open Boundaries

The cells in **Figure 5-84** that have been labeled with a compass point direction indicate that those cells have been assigned as an open (i.e. tidal) boundary condition. Within the EFDC_Explorer modeling system, the boundary cells are managed as groups of cells that correspond to a physical boundary. For this application the cells along the northern edge of the model near the FL 78 bridge (labeled with a "N") make up the Matlacha Pass boundary group. The western open boundary of the model opens into the Pine Island Sound. The southern boundary represents the Gulf of Mexico conditions. The development of the tidal boundary conditions used for the Caloosahatchee water quality model is provided in the following section.

5.3.1.6.5 Large Scale Model

As mentioned above, the model domain and grid used for the Caloosahatchee water quality model is a balance of computational speed and required resolution. However, the computational constraints required the open boundaries (i.e. tidal boundaries) of the model to be limited to boundaries in Matlacha Pass and Pine Island Sound. There were insufficient data available at those locations to properly drive the tidal signal at those locations. Therefore, the approach used for this study was to develop a larger scale but coarser grid model of a large area in order to use regional/ocean data and approximate fresh water flows to compute the tidal, temperature and salinity series at the Caloosahatchee model boundaries. **Figure 5-86** provides a plot of the model bathymetry and grid of the large scale model. The USACE report (DSLLC, 2007) provides a more complete description of the model construction, calibration and application.

Time series of water surface elevation, temperature and salinity were then extracted from the model runs of the large scale model for the period(s) of interest. For the Caloosahatchee water quality model, the open boundaries at Matlacha Pass, Pine Island Sound and the Gulf of Mexico were configured with the corresponding time series from the large scale mode. One exception was for the Gulf boundary's salinity concentration. During the model calibration it was found that applying a constant salinity boundary salinity of 28 and 33 PPT at the surface and bottom, respectively provided better salinity results.

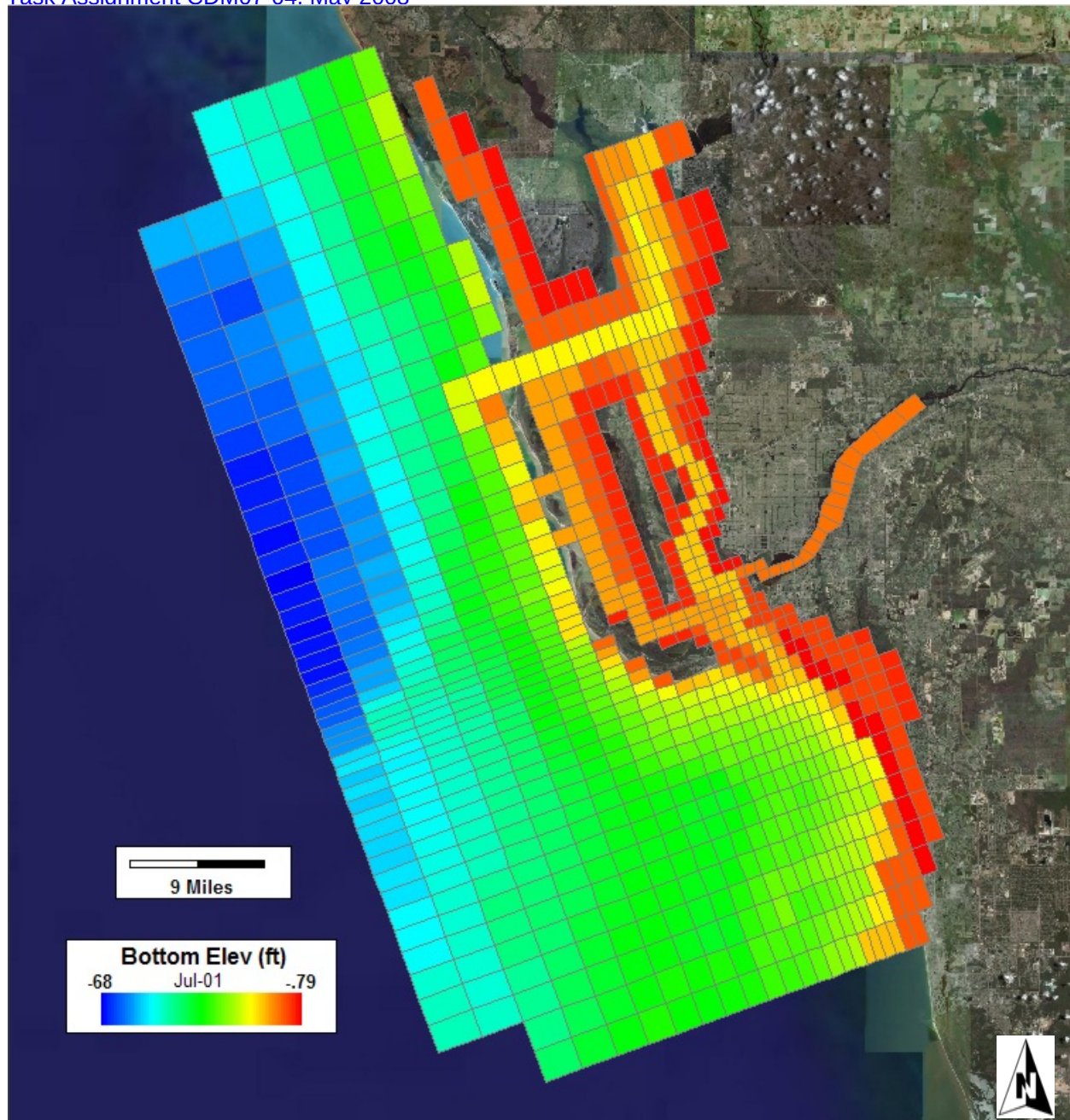


Figure 5-86 Large scale model grid and bathymetry

5.3.1.7 Meteorological Data

Atmospheric forcing data are used to model hydrodynamic processes and water temperature. Parameters include barometric pressure, air temperature, relative humidity, wind speed and direction, precipitation, evaporation, incident solar radiation and cloud cover. Atmospheric forcing data was available from historical archives maintained by NOAA NCDC. Hourly records of barometric pressure, air temperature, relative humidity, rainfall, wind speed and direction, and cloud cover were obtained from NOAA NCDC for the station located at the Ft. Myers International Airport (Page Field, WBAN ID 12835). During that process it was determined that the Page Field data had several significant data gaps in wind speed, direction and temperature. A search was conducted of the nearby meteorological stations that had the same period of record and the parameters needed. It was found that the Ft Myers SW Florida Regional Airport (WBAN ID 19894) provided the data required. The WSER and ASER files were generated using Page Field as the primary station and the SW Florida Regional airport as the "filler" station. **Figure 5-87** shows the wind rose for the period of 2003 and 2004.

5.3.1.8 Sediment Diagenesis

The EFDC water quality model currently has three options for defining the sediment/water column interactions for water quality parameters. They are:

- Spatially and Temporally Constant Fluxes
- Spatially and Temporally Variable Fluxes
- Full Sediment Diagenesis

The water quality parameters that have an interaction with the sediments are phosphate, ammonia, nitrate, silica, chemical oxygen demand and oxygen (i.e. sediment oxygen demand). The first two options require the fluxes to be set to some predefined flux rate in g/m²/day. The full diagenesis (Park, et al, 1995 & DiToro, 2001) option uses a sediment diagenesis sub-model to compute the fluxes from some basic physical properties and typical/reference rates and factors.

For the Caloosahatchee the sediment/water column interaction option chosen was the Full Sediment Diagenesis option. There were no sediment nutrient flux data to calibrate the model with. However, the sediment diagenesis sub-model has given good results (principally judged by predicting reasonable sediment oxygen demands, SOD's) with a minimum of site specific data. The literature values (Park, et al, 1995 & DiToro, 2001) for the diagenesis parameters and coefficients can be used with little to no adjustments.

What is necessary is an approach to initialize the organic nutrients in the sediment bed. The diagenesis model requires particulate organic carbon, particulate organic nitrogen and particulate organic phosphorus for three reactive sediment classes, i.e. G1, G2 and G3. Typically the G3 class contains the largest fraction of nutrients but is configured as inert. The G1 class is the more reactive (i.e. labile) while the G2 class as slower reacting (i.e. refractory)

For the Caloosahatchee a set of sediment TOC data was available. This data was used to assign the initial organic carbon fractions in the sediments. The splits between the G1, G2 and

G3 classes used the approach of 1:10:100 ratios, respectively. The organic phosphorus and nitrogen sediment concentrations were derived from the TOC concentrations using the P/C and N/C Redfield ratios

5.3.2 Goodness of Fit Approach

5.3.2.1 Model Comparison Statistic

The model-data comparison statistic selected for the calibration and validation was the Root Mean Square (RMS) error.

The RMS is calculated by the following:

$$RMS = \sqrt{\frac{\sum_{i=1}^N (O_i - X_i)^2}{N}}$$

Where:

O – The observed value,

X – The corresponding model value in space and time, and

N – The number of valid data/model pairs.

5.3.2.2 Available Data for Calibration/Validation

The data needed for calibration of a model is slightly different than that needed for definition of boundary conditions. The model boundaries must have data or a defensible approach (e.g. the HSPF simulation results used for this study) for all boundaries for the entire period of the simulation. However, for calibration, the data can be either sparse or robust, but it must be internal to the model domain, or at least not negatively impacted by a boundary condition.

5.3.2.2.1 Hydrodynamic Calibration/Validation Stations

For Caloosahatchee, there are 17 stations that meet the various data requirements for calibration and validation of the EFDC hydrodynamic model. The stations are MarkerH, CES02-÷CES 11, 242, 350, MPV002, BR31, FMYER and CCORAL. Given these stations, three stations were selected as being representative of the overall system. These stations are described below and their positions are shown in **Figure 5-88**.

- FMYER is the Ft Myers, FL NOAA tide station (ID 8725520).
- BR31 is representative of the upper end of the Caloosahatchee Estuary.
- CCORAL is located roughly in the middle of the Caloosahatchee Estuary.
- CES09 representative of San Carlos Bay waters and the channel between the Caloosahatchee and the Gulf of Mexico.

The BR31 and CCORAL stations are SFWMD stations with continuous data collection at two fixed depths near the top and bottom of the water column are their respective sites. These high resolution data sets provide a better understanding of the salinity and temperature dynamics in the estuary than monthly data collection programs (e.g. the CES## stations). However, the monthly data programs can collect a much larger set of parameters.

5.3.2.2.2 Water Quality Calibration/Validation Stations

For water quality, the CES (21FLSFWM) and PI (21FLEECO) stations provided a good set of parameters and coverage of the simulation periods for both calibration and validation. All of the CES stations have vertical profiles of salinity, temperature, DO, pH, in addition to Secchi depth. However, only CES03, CES04 and CES06 have a more complete suite of water quality parameters. For the parameters needing laboratory analysis only top and bottom samples were analyzed. All the PI stations in the area of interest had useful water quality data, but only for the top (0.5 meters below the surface) of the water column.

For this application the following stations were selected for the water quality calibration and validation. These stations are shown on **Figure 5-88**.

- CES04 - representative of the middle to upper section of the Caloosahatchee.
- CES06 - representative of the middle section of the Caloosahatchee.
- PI-01 - representative of San Carlos Bay waters and the channel between the Caloosahatchee and the Gulf of Mexico.

A table of the model to measured parameter correspondence is provided in **Table 5-21**.

Table 5-21 EFDC parameter to FDEP data correspondence used for calibration

Derived Data From	Corresponding EFDC Parameter(s)
Dissolved Oxygen	Dissolved Oxygen (DOX)
Chlorophyll a	Green Algae (CHG) ¹
Total Organic Carbon	Sum of DOC, LPOC and RPOC fractions and Algal C
Total Phosphorus	Sum of DOP, LPOP and RPOP fractions and Total Phosphate (TPO4)
Orthophosphate	Total Phosphate (TPO4)
Total Nitrogen	Sum of DON, LPON and RPON fractions, Nitrate-Nitrite (NOX) and Ammonia (NHX)
Nitrate-Nitrite Nitrogen	Nitrate-Nitrite (NOX)
Ammonia Nitrogen	Ammonia (NHX)
TSS	Cohesive Class 1

¹ Algae concentration converted to Chlorophyll a by the ratio 0.065 mg C/μg Chla.

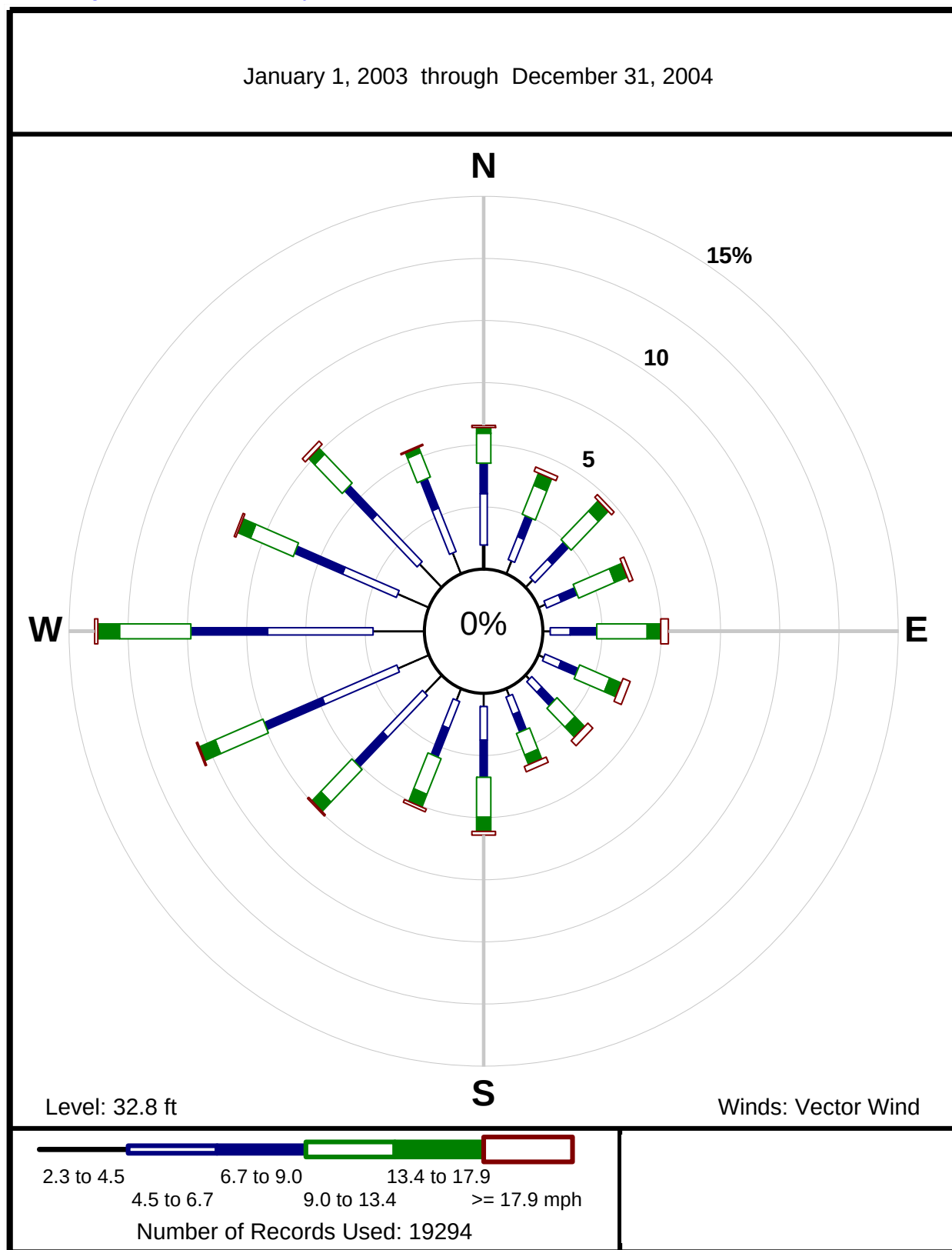


Figure 5-87 Ft Myers International Airport wind rose for 2003-2004

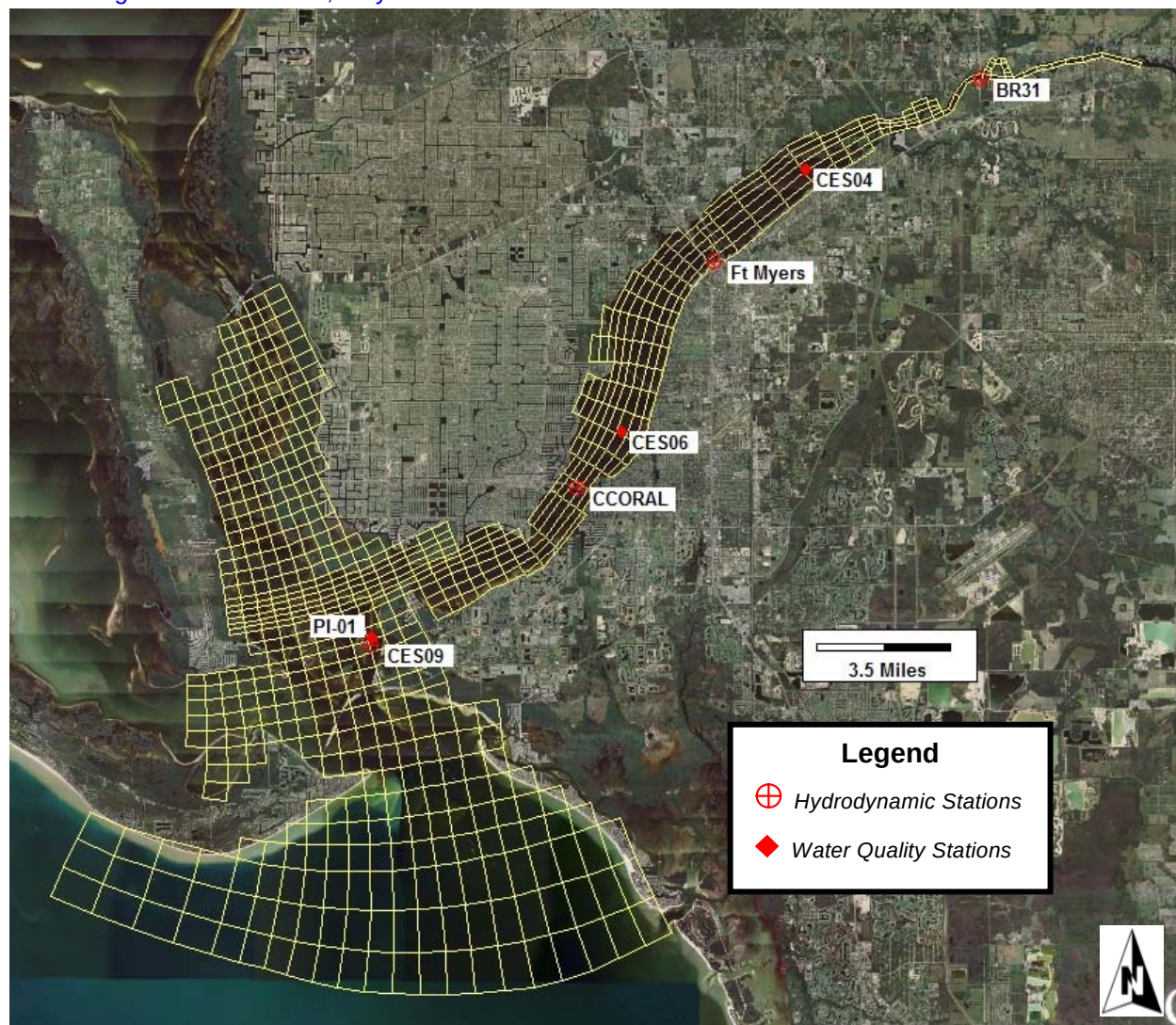


Figure 5-88 Stations used for hydrodynamic and water quality model calibration/validation

5.3.3 Tidal Exchange and Boundary Flow Summary

In general, the boundary condition impacts in the model are as follows:

- During the dry season (typically November through May), the hydrodynamics and water quality are largely controlled by the open ocean boundary. The small freshwater inflows from the surface drainage networks and wastewater dischargers have little impact on the hydrodynamics during this period.
- During the wet season and other wet-weather periods, the freshwater reaches (HSPF reaches) have greater impact in the tidal creek, from which S79 typically contributes more than 50% of the total freshwater flow.
- The tidal portion of Caloosahatchee is relatively long (about 150,000 ft). With a daily tide fluctuation magnitude of up to about 5 feet, the hydrodynamic regime of the tidal creek is

somehow controlled by the tidal boundary as it is expressed through the following tidal prism ratio.

5.3.3.1 Tidal Prism Ratio

In order to understand the Caloosahatchee tidal dynamics and fresh/saline water mixing the tidal prism ratio (TPR) was computed. The TPR is defined as the change of water volume during one tidal exchange divided by the volume of water at high tide. The TPR can be computed using the following equation:

$$TPR_{Vol} = \frac{dVol_{Tide}}{Vol_{HighTide}}$$

The numerator is referred to as the tidal prism.

It is also possible to calculate the TPR from mass weighted concentrations in the area of interest. The TPR from concentrations is computed using the following:

$$TPR_{Conc} = 1 - \frac{C_{HighTide}}{C_{LowTide}}$$

The procedure is to assign an initial dye concentration to the area of interest of 100 mg/l. The area of interest is just the Caloosahatchee River and tidal estuary. The area outside of the Caloosahatchee is assigned an initial concentration of 0.0 mg/l. One tide cycle is then simulated. EFDC_Explorer is then used to generate a time series of the mass weighed dye concentrations of the Caloosahatchee. The dye concentration at low tide is then estimated from the time series and then the TPR is computed using the equation above.

For the Caloosahatchee a tidal range of 4.92 feet (1.5 meters) at the Gulf boundary (i.e. a typical large diurnal range) was used. **Figure 5-89** shows the tide data for several days around the period used for the TPR computations. The actual period used for the computation is shown in as the thick red line. The time series of the dye and water volume during the TPR simulation is shown in **Figure 5-90**. The resulting TPR is 0.16. In other words, without any fresh water input, the 16% of the water in the Caloosahatchee is exchanged with the water in Matlacha Pass. With fresh water inflows during storms, the flushing of the estuary will be higher.

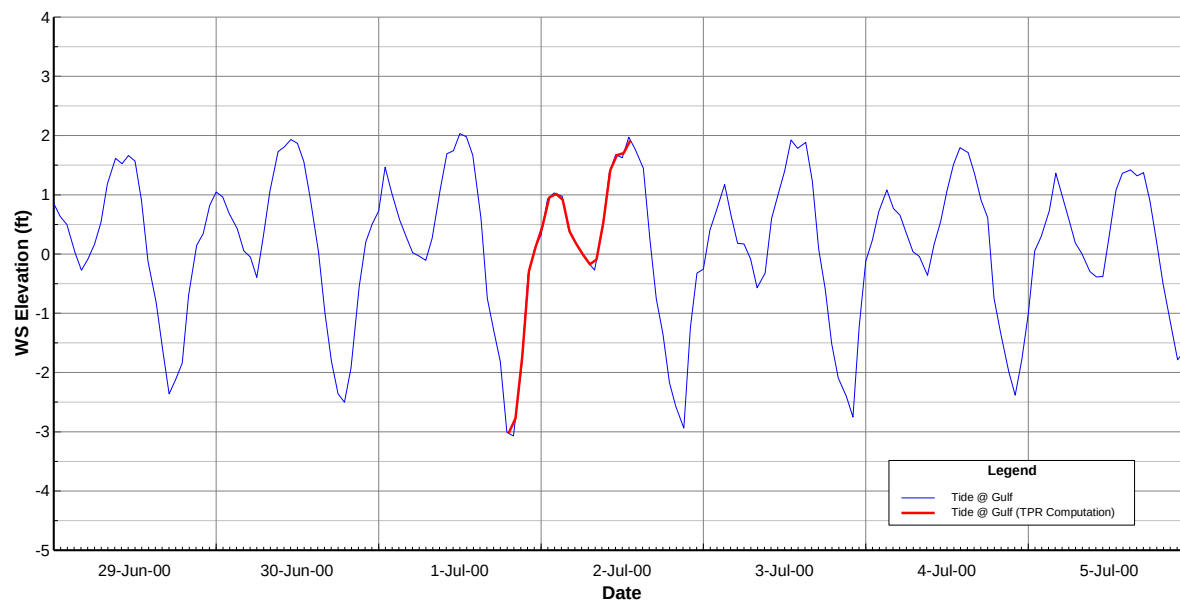


Figure 5-89 Time series of the Gulf of Mexico tide data used for the TPR computations

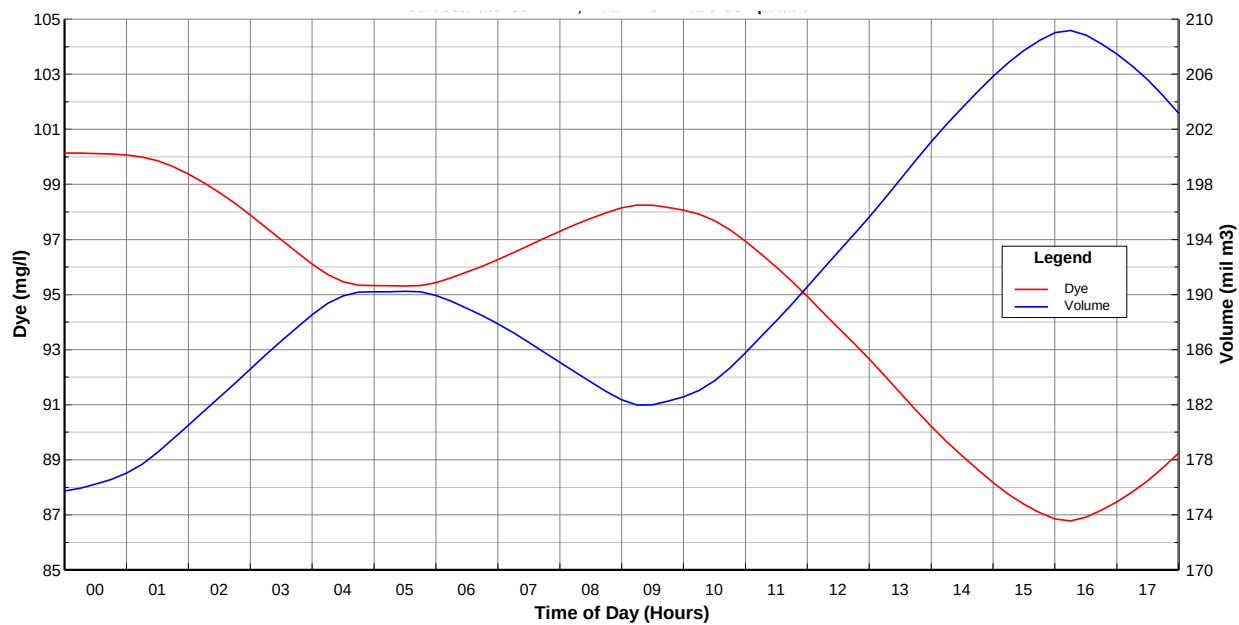


Figure 5-90 Time series of dye and volume in the Caloosahatchee River during the TPR tidal cycle

5.3.4 EFDC Model Calibration

5.3.4.1 Model Simulation Period

The period selected for hydrodynamic model calibration was from January 1, 2003 to December 31, 2003. This period has an adequate set of salinity, temperature, meteorology, and water quality data for setting boundary conditions and calibrating the model.

The general approaches for assigning the model initial conditions and boundary conditions are discussed in Section 5.3.1. The specifics of the EFDC hydrodynamic and water quality model calibration are presented in the following sections.

5.3.4.2 Boundary Conditions

5.3.4.2.1 Flow Boundaries

Using the approaches for linking the HSPF model results and constructing the WWTF loads, the boundary condition time series for the hydrodynamic and water quality parameters were developed for the calibration period. As shown in **Table 3**, the flows from S79 account for 70 to 80 percent of the freshwater inflows into the Caloosahatchee. Therefore, to streamline the reporting, only the inflows for S79 will be presented here. **Figure 5-91** provides the time series of flows, temperature, total suspended solids, dissolved oxygen (DO), total organic carbon (TOC), total phosphorus (TP) and total nitrogen (TN) for S79. While this figure is a little busy, it provides a good summary of the temporally varying flow and concentrations at S79. The average flow for S79 for 2003 was 3733 ft³/s with the largest inflow period between July and October.

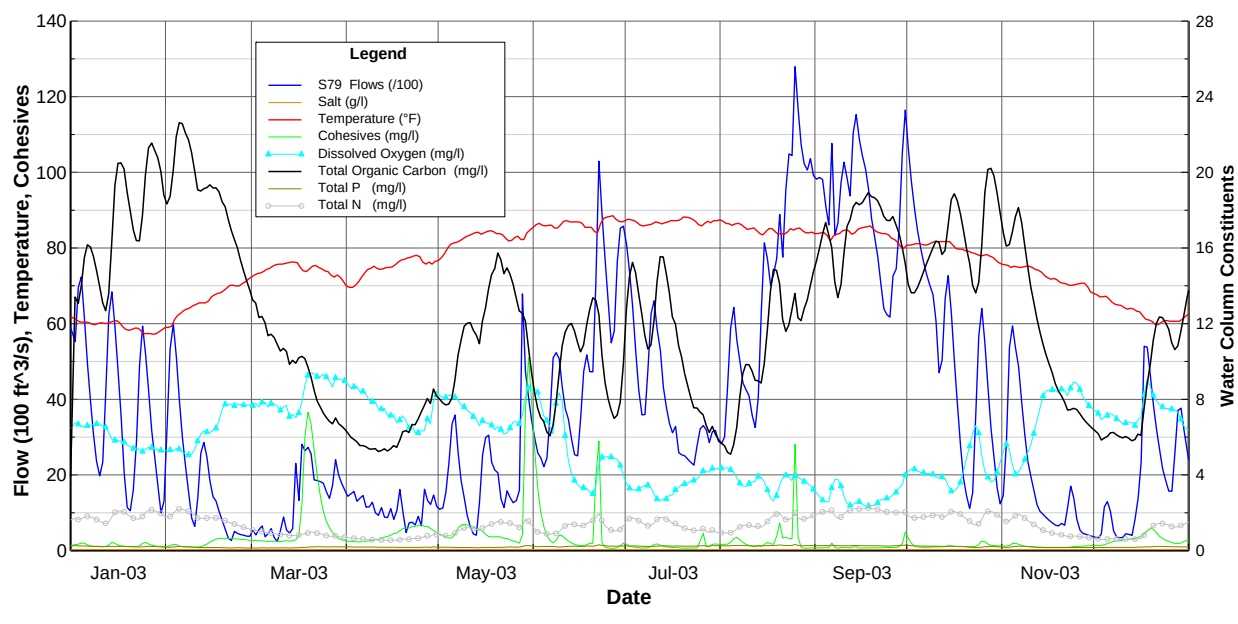


Figure 5-91 Time series of flow and constituent concentrations for S79 for 2003

Table 5-22 provides a summary the annual mass loading of all of the other freshwater boundaries, including the WWTF's, for TOC, TP and TN. Similarly to the water flux, S79 provides 68 to 90 percent of the nutrient loadings to the Caloosahatchee. S79 inflows have a dominant impact on the resulting nutrient concentrations in estuary.

Figures 5-92 to 5-94 provide a graphical summary of the mass loadings for S79, HSPF02 (a representative HSPF tributary for the smaller downstream inputs), and the WWTF's for TOC, TP and TN, respectively. The S79 mass loadings are generally three orders of magnitude higher than the WWTF's.

The patterns of mass loadings for TOC, TP and TN can be seen in the water quality concentrations in the Caloosahatchee, as shown in the time series calibration plots discussed later.

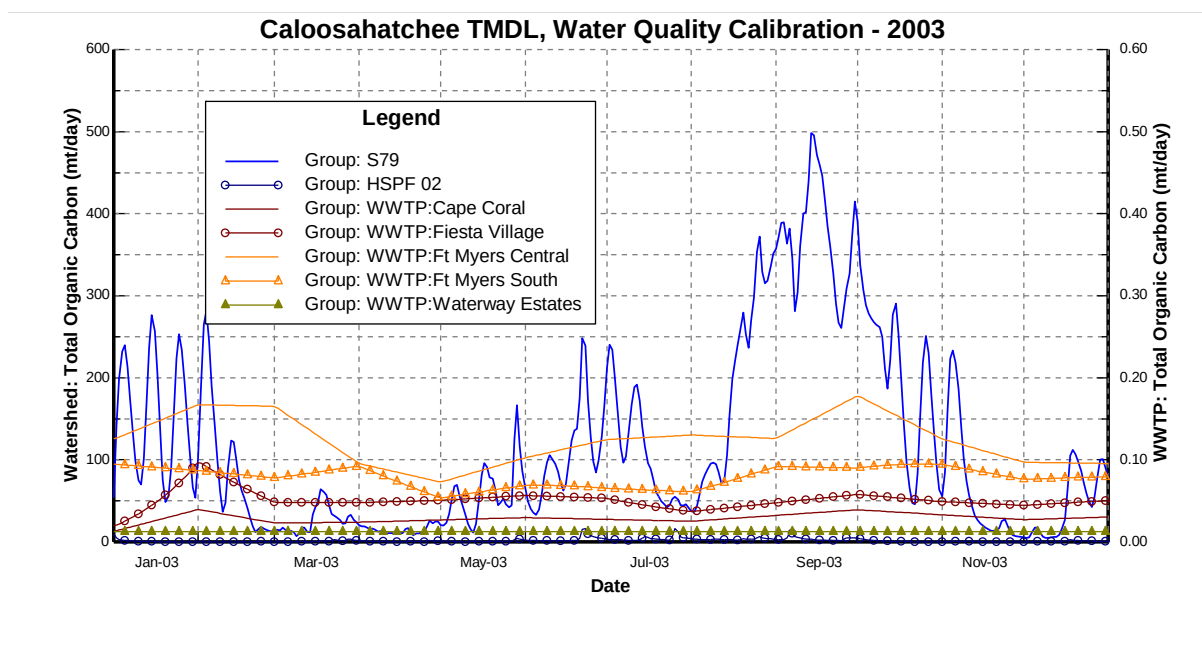


Figure 5-92 Total Organic Carbon mass loading time series for 2003

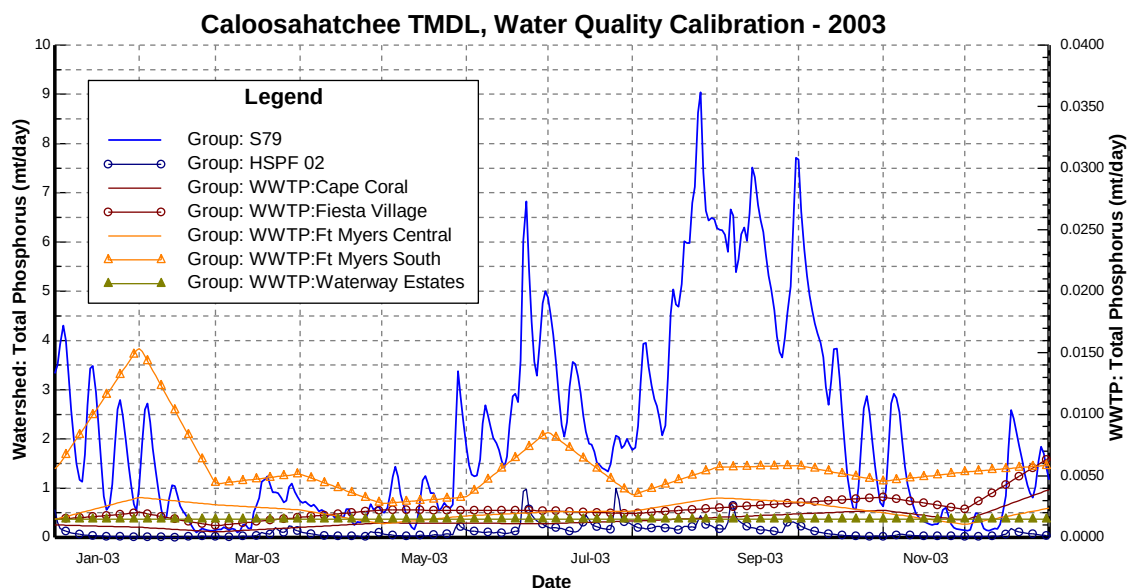


Figure 5-93 Total Phosphorus mass loading time series for 2003

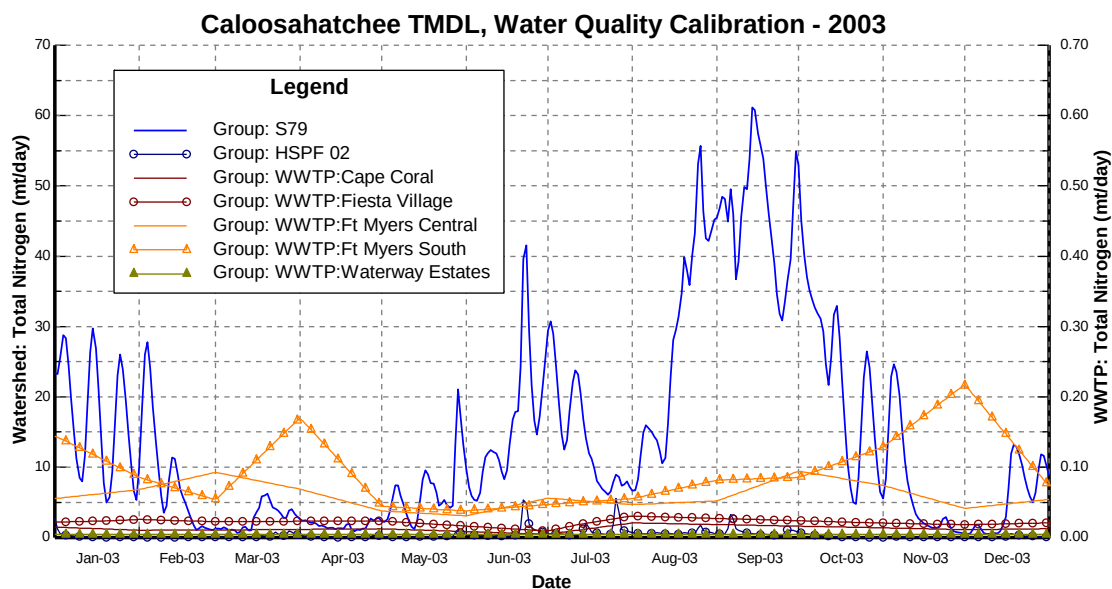


Figure 5-94 Total Nitrogen mass loading time series for 2003

Table 5-22 Nutrient mass loadings for the Year 2003 in tons

HSPF Tributaries	TOC	TN	TP
HSPF 01 (S79)	49,138	5,626	484
HSPF 02	481.6	113.4	26.0
HSPF 03	13.9	2.9	0.6
HSPF 04	26.9	5.9	1.2
HSPF 05	373.4	63.0	13.7
HSPF 06	15.1	3.3	0.7
HSPF 07	57.0	11.8	2.4
HSPF 08	16.1	3.6	0.6
HSPF 09	121.7	18.1	3.6
HSPF 10	1,098.3	181.0	36.6
HSPF 11	167.0	36.0	7.0
HSPF 12	41.1	7.0	1.5
HSPF 13	37.6	6.1	1.2
HSPF 14	341.0	72.4	14.1
HSPF 15	68.9	10.5	2.2
HSPF 16	318.3	51.7	10.9
HSPF 17	438.8	76.6	13.7
HSPF 18	201.5	32.5	6.7
HSPF 19	27.0	6.3	1.2
HSPF 20	142.7	32.1	6.7
HSPF 21	306.0	68.0	15.8
HSPF 22	324.7	44.9	9.3
HSPF 23	24.4	5.6	1.1
HSPF 24	178.2	24.4	4.7
HSPF 25	20.7	4.9	0.9
HSPF 26	219.5	50.0	12.0
HSPF 27	36.4	8.3	1.5
HSPF 28	35.8	9.8	1.5
HSPF 29	306.3	55.8	10.0

Point Source Dischargers

WWTP:Cape Coral	11.7	5.1	0.6
WWTP:Fiesta Village	18.7	8	0.85
WWTP:Ft Myers Central	50.1	24.0	0.9
WWTP:Ft Myers South	31.6	37.5	2.3
WWTP:Waterway Estates	5.1	1.8	0.6

Summaries

Total	54,695.7	6,708.3	696.85
S79 Fraction	89.8%	83.9%	69.5%

5.3.4.2.2 Open Boundary Conditions

The open boundary time series for stage, temperature and salinity were defined using the large scale model (see Section 5.3.1.6.5). The water column constituents for the remaining parameters listed in **Table 5-17** were derived from ambient water quality data. For the Matlacha Pass the primary data source was PI-03 (21FLEECO) and PI-13 (21FLEECO) for Pine Island Sound. There was more difficulty in determining the water quality boundary conditions for the Gulf. The data from station CHARHB0003FTM (21FLFTM) was used as a guide but the data was not for the period of simulation. The data from this station along with professional judgment was used to define the water quality time series use for the Gulf. These concentrations were lower than those inside Pine Island Sound and Charlotte Harbor/Matlacha Pass.

5.3.4.2.3 Sediment Diagenesis

Using the TOC data and approach outlined in Section 5.3.1.8, the initial conditions for the organic sediments were assigned. A plot of the G3 class for organic carbon is shown in **Figure 5-95**. The plot has been overlaid with the measured TOC sediment data in g/m³. The data show an organic enrichment of sediments in Estero Bay and in the upper Caloosahatchee. For the Caloosahatchee this is the result of direct POC S79 loads being carried into the tidal section and then settling as well as algal detrital matter subsequently generated due to the nutrient loads and the algal dynamics.

5.3.4.2.4 Atmospheric/Wind Forcing

Figure 5-96 provides a visualization of wind speed, direction and dry bulb temperature for the processed wind and atmospheric data for the calibration period.

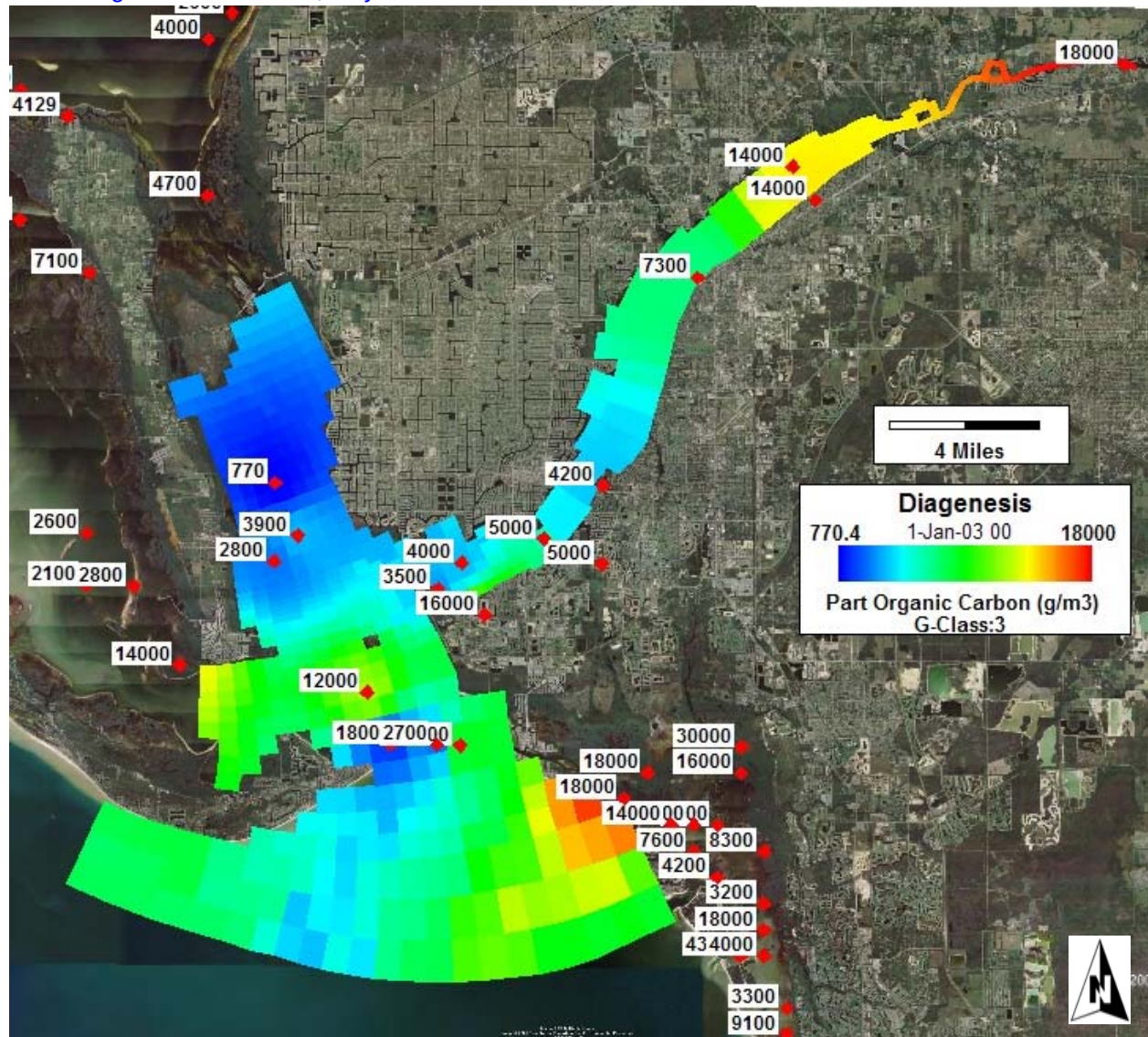


Figure 5-95 Sediment diagenesis TOC G3 initial conditions

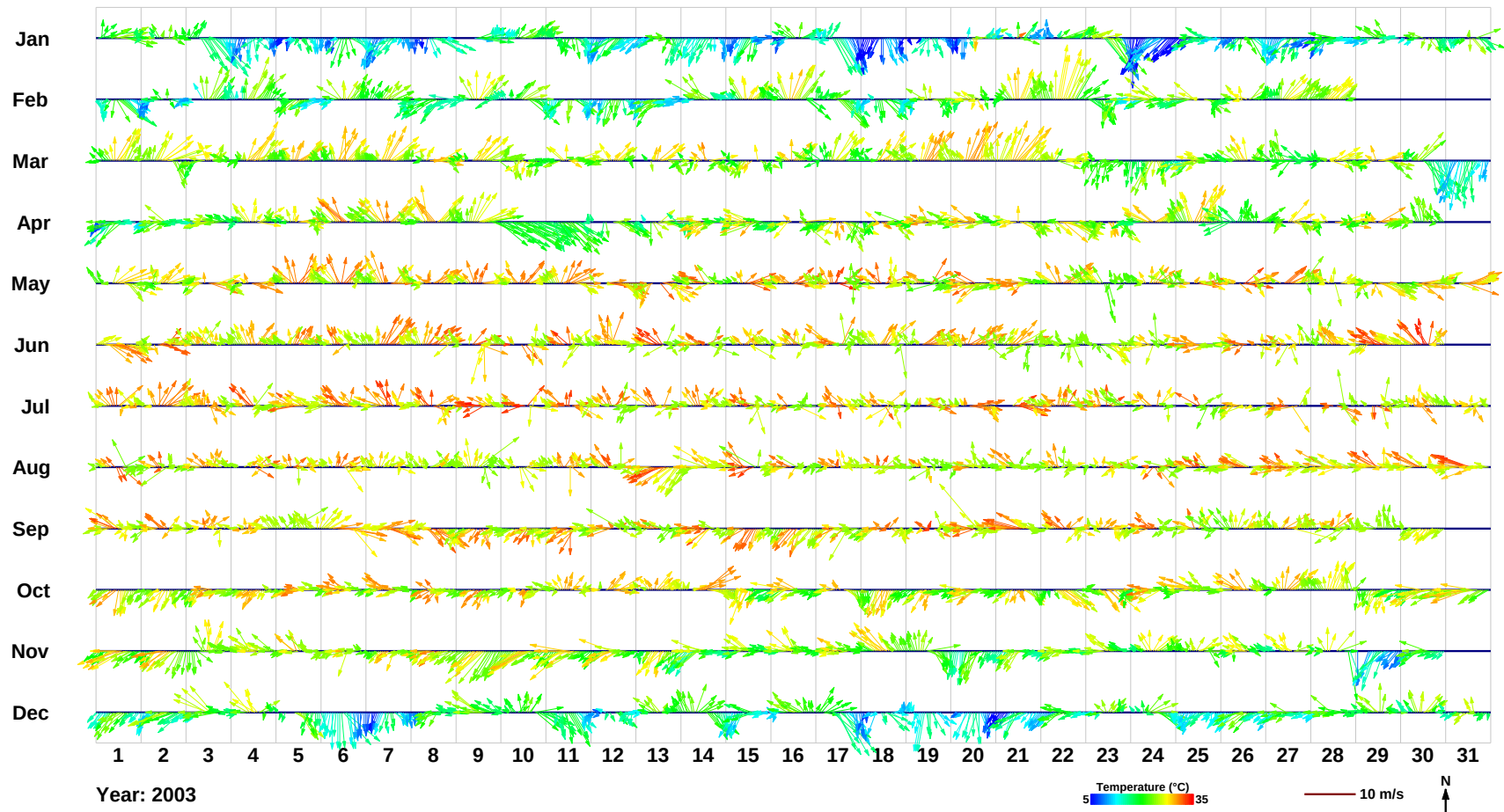


Figure 5-96 Ft Myers wind stick plot for 2003

5.3.4.3 Tide Signal Calibration

The model was first calibrated for water surface elevations. The data used for the calibration was the Ft Myers, FL NOAA tide station (8725520). The location of the station is shown in **Figure 8**. The model-data comparison plot is shown in **Figure 17**. The RMS for the water surface elevation was 0.252 ft (7.6 cm).

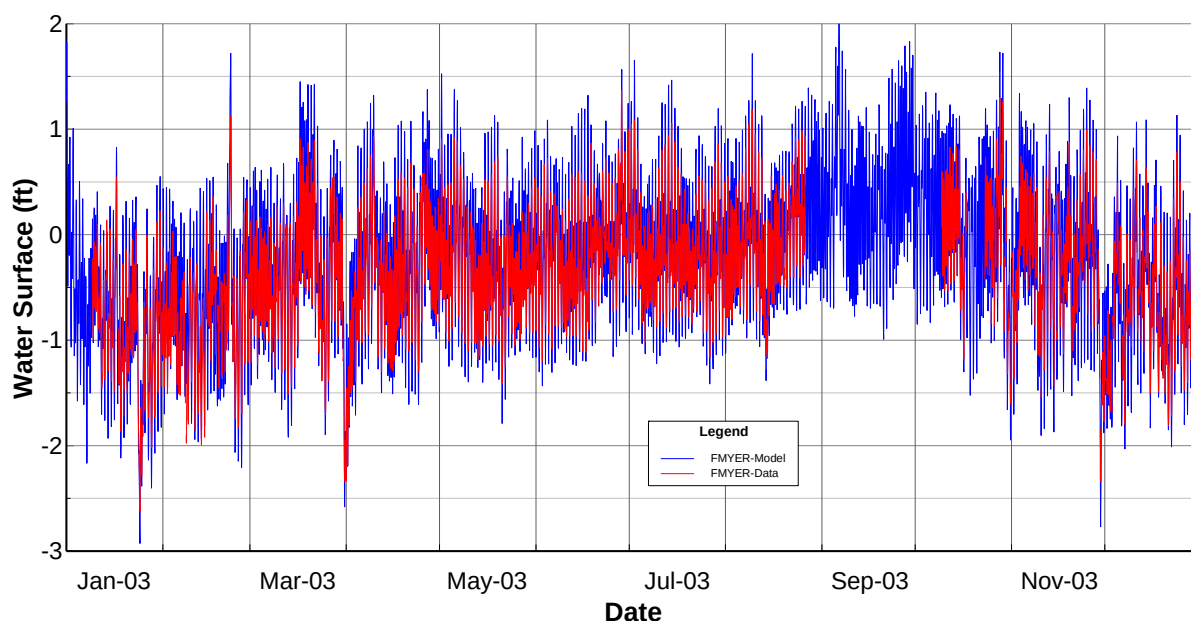


Figure 5-97 Water surface elevation calibration at Ft Myers

5.3.4.4 Salinity Calibration

The **Figures 5-98 -102** show the model-data comparisons for salinities in the Caloosahatchee model for the calibration year of 2003. The BR31 and CCORAL stations are fixed stations with two salinity probes mounted near the top and bottom of the water column. These data help determine the amount of salinity stratification at those locations, as well as a high resolution time series to pick up the variability of salinity at these locations.

At BR31 in the March-April time period, the model under predicts the salinity at both the top and bottom sensors. It was found that during this period the HSPF model was providing flows that were nearly double the measured flows at S79 (see Section 5.3.1.6.3). Later in the year, the model did a better job of picking up the salinity migration back up the estuary.

Table 8 contains a summary of the RMS (see Section 5.3.2 for a definition) error statistics for salinity. Overall, the model-data comparisons were considered very good.

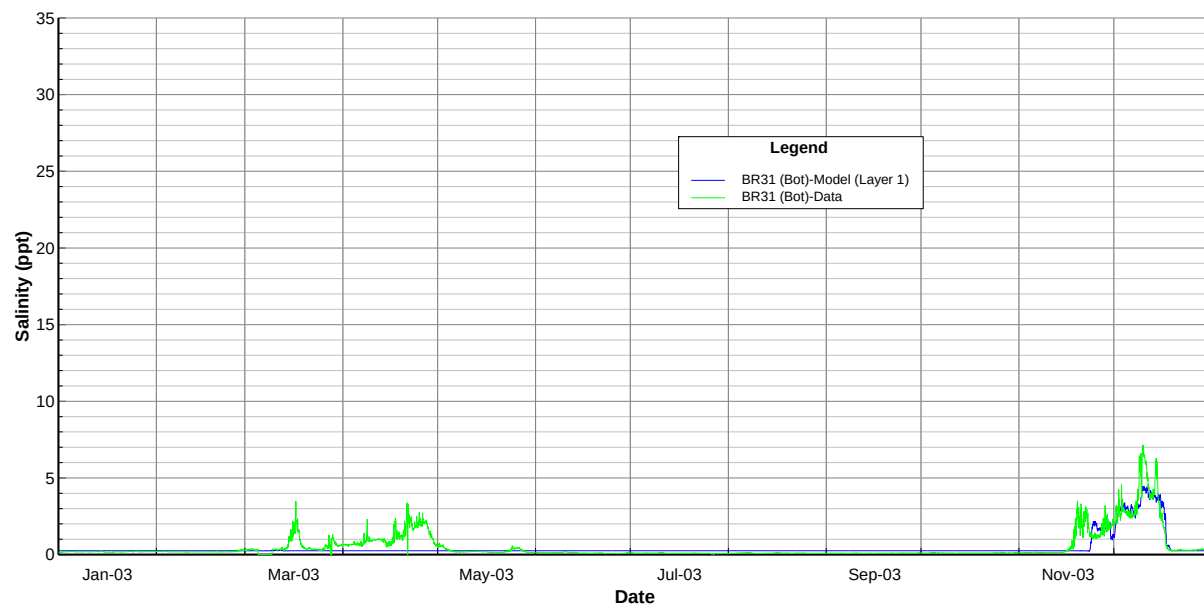


Figure 5-98 Salinity calibration at BR31 - Bottom

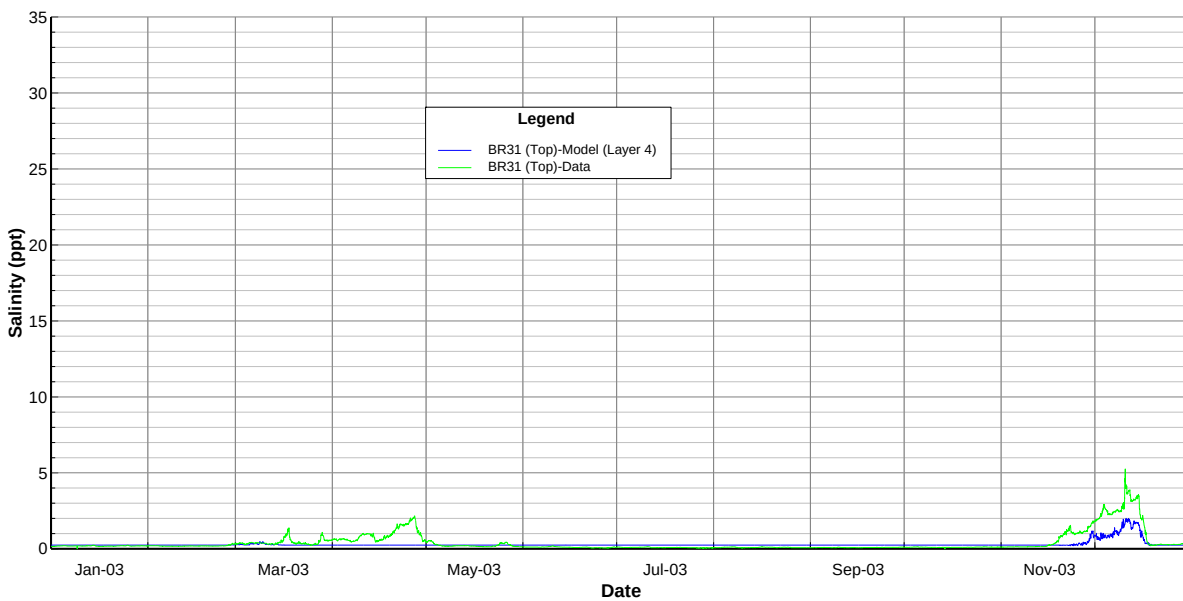


Figure 5-99 Salinity calibration at BR31 – Top

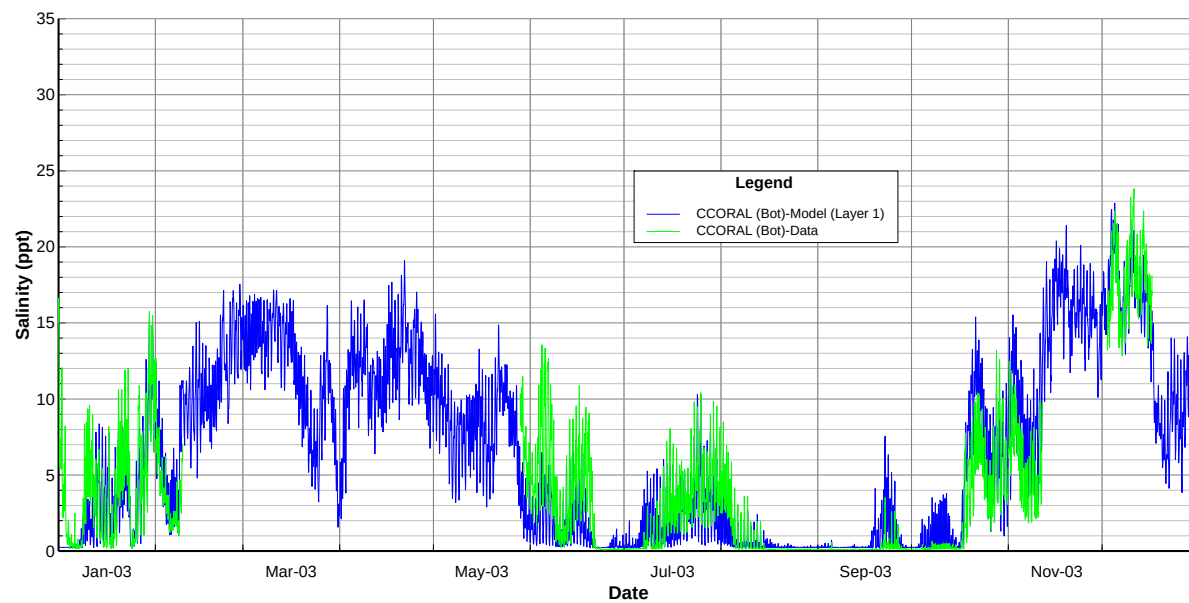


Figure 5-100 Salinity calibration at CCORAL - Bottom

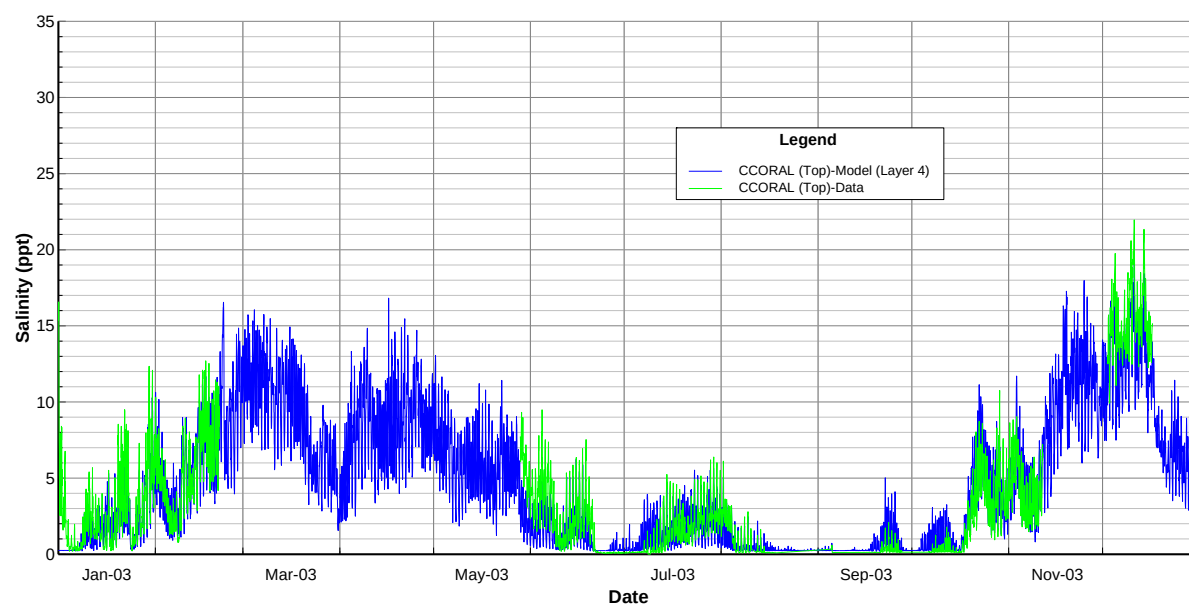


Figure 5-101 Salinity calibration at CCORAL – Top

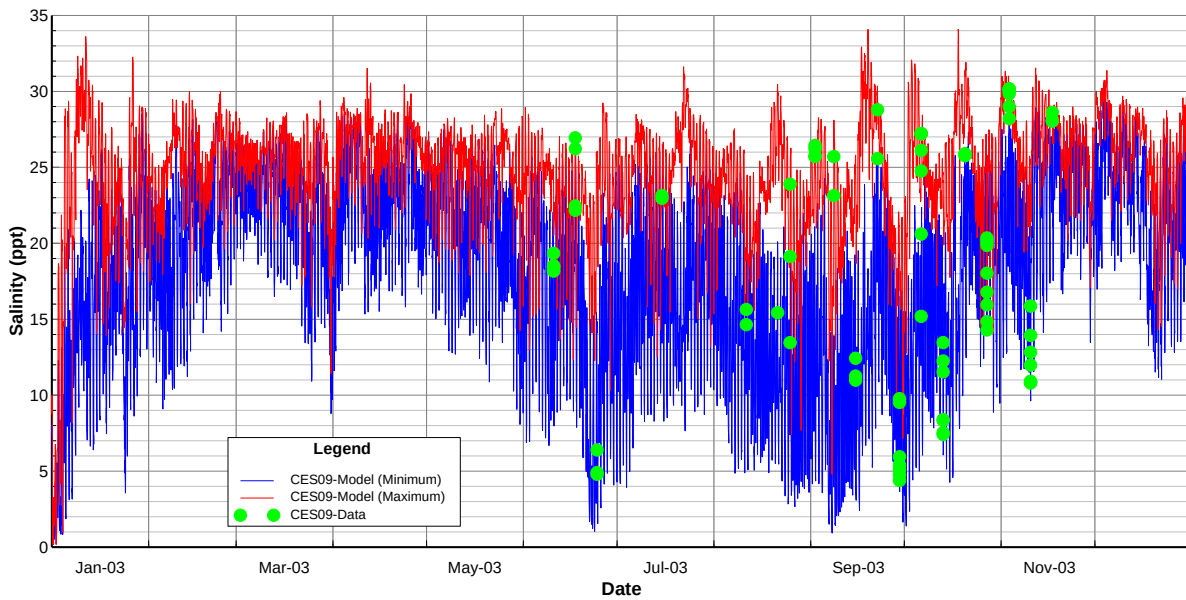


Figure 5-102 Salinity calibration at CES09

Table 5-23 Calibration period summary statistics for Salinity (PPT)

Station ID	Layer/ Type	Starting Date/Time	Ending Date/Time			Data Average	Model Average
				# Pairs	RMS		
CES09	Minimum	10-Jun-03 16:10	17-Nov-03 09:37	19	5.197	17.429	15.694
CES09	Maximum	10-Jun-03 16:10	17-Nov-03 09:37	19	7.563	20.816	25.198
BR31 (Bot)	Layer 1	1-Jan-03 01:00	31-Dec-03 22:00	8,758	0.506	0.476	0.416
BR31 (Top)	Layer 4	1-Jan-03 01:00	31-Dec-03 22:00	8,758	0.449	0.383	0.297
CCORAL (Bot)	Layer 1	1-Jan-03 01:00	16-Dec-03 23:00	5,290	2.211	3.525	3.478
CCORAL (Top)	Layer 4	1-Jan-03 01:00	16-Dec-03 23:00	4,530	1.547	3.429	3.158
Composite				27,374	0.998		

5.3.4.5 Water Temperature Calibration

The **Figures 5-103-5-106** show the model-data comparisons for temperatures in the Caloosahatchee model for the calibration year of 2003. The BR31 and CCORAL stations are fixed stations with two temperature probes mounted near the top and bottom of the water column. These data helped determine the amount of thermal stratification at those locations, as well as a high resolution time series to pick up the variability of temperatures at these locations. During the calibration period there were no data available from the CCORAL bottom temperature probe.

The BR31 station is significantly impacted by the flows from S79. This can be clearly seen when reviewing the both the top and bottom temperature plots for BR31 (**Figures 5-103 & 5-104**). The under prediction of temperatures during the March to May period can be directly related to the HSPF under prediction of temperatures and over prediction of flows for that same period. That said, the overall comparisons at BR31 are considered acceptable.

Table 5-24 contains a summary of the RMS (see Section 5.3.2 for a definition) error statistics for temperature. Overall, the model-data comparisons were considered very good.

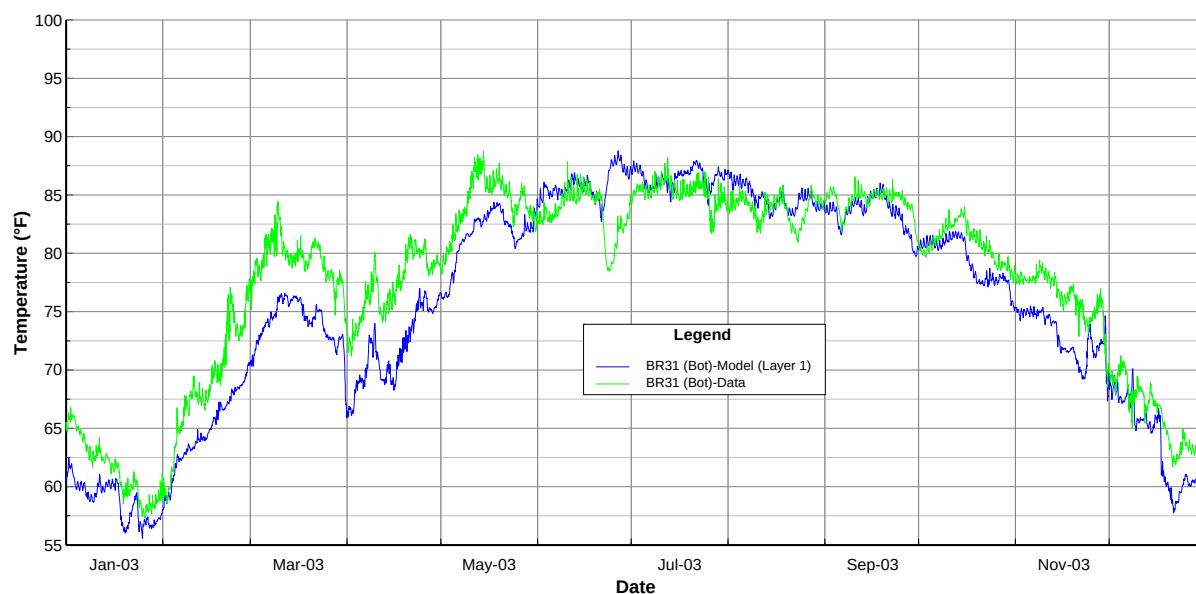


Figure 5-103 Temperature calibration at BR31 – Bottom

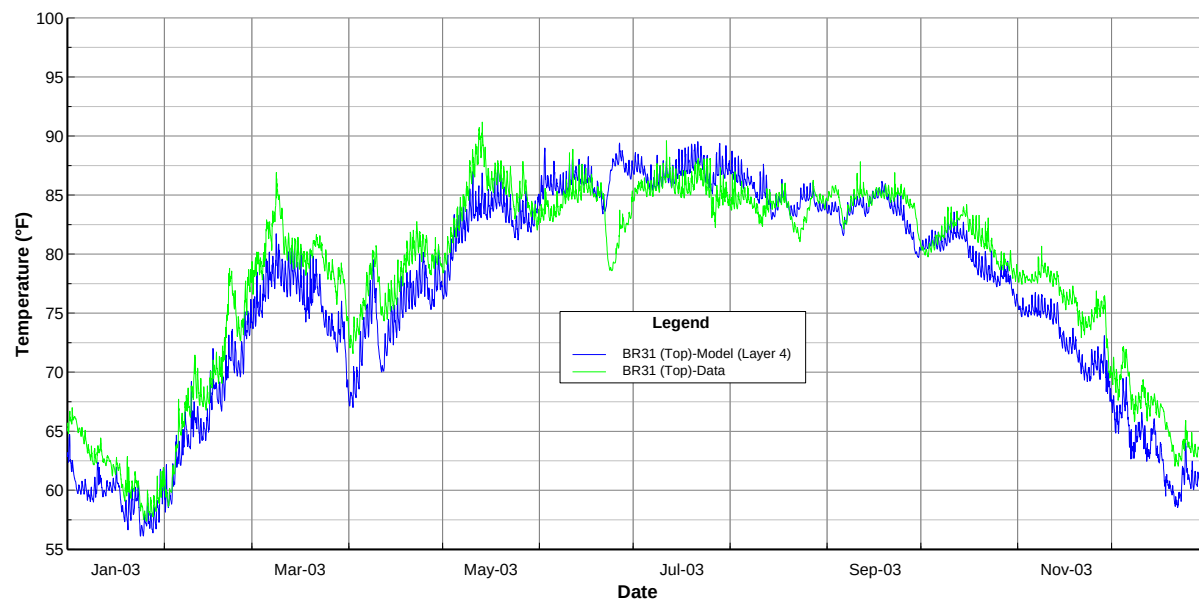


Figure 5-104 Temperature calibration at BR31 – Top

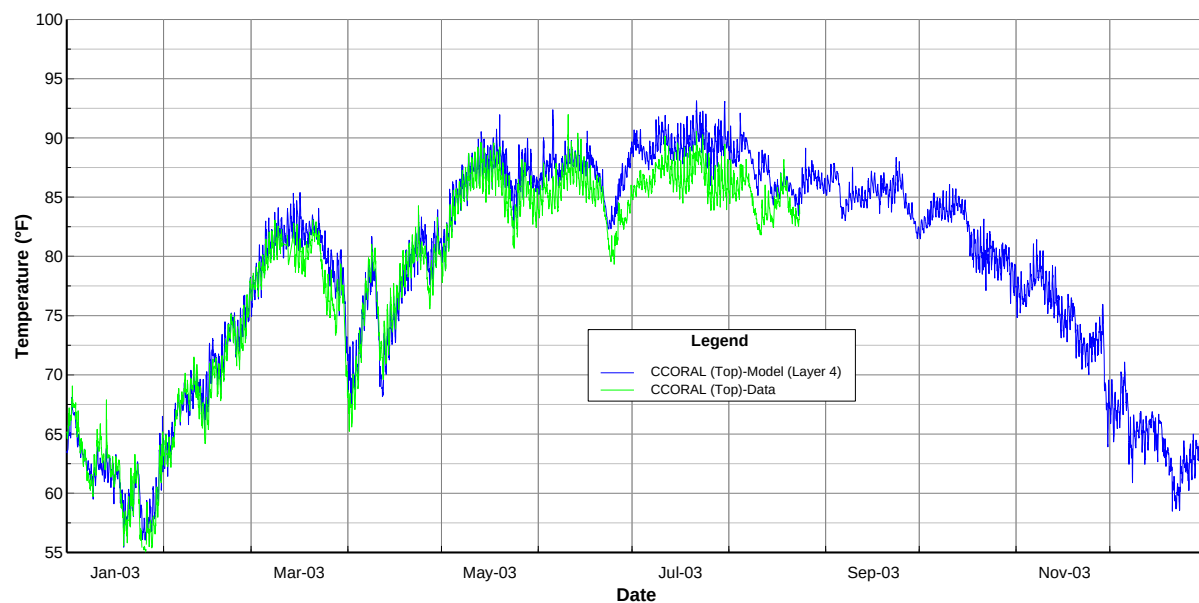


Figure 5-105 Temperature calibration at CCORAL – Top

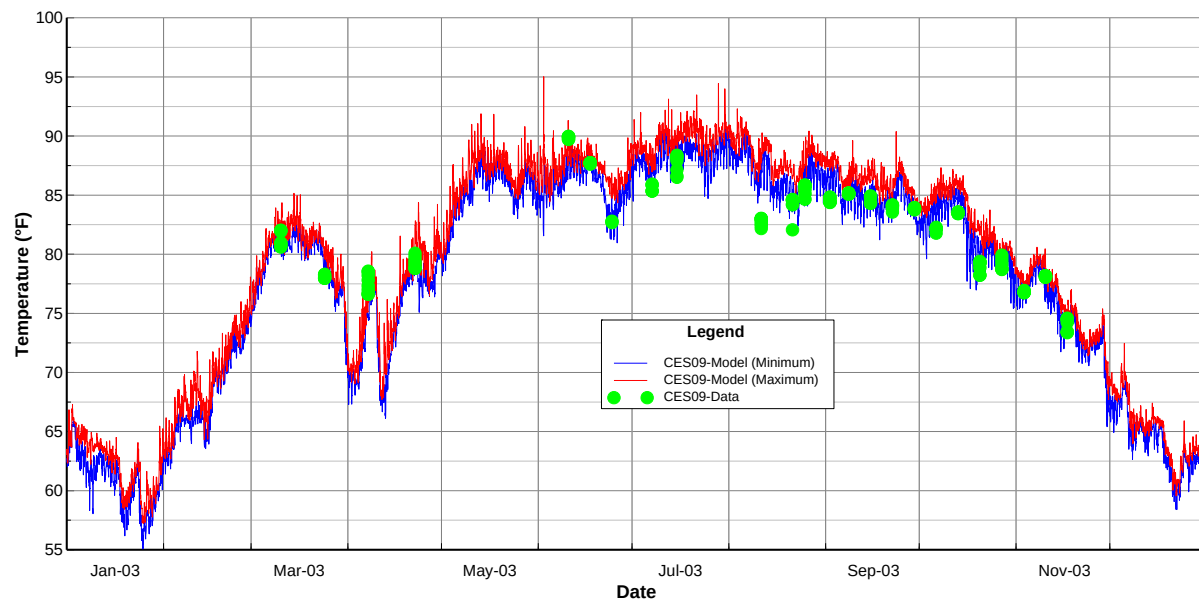


Figure 5-106 Temperature calibration at CES09

Table 5-24 Calibration period summary statistics for Temperature (°F)

Station ID	Layer/	Starting	Ending			Data	Model
	Type	Date/Time	Date/Time	# Pairs	RMS	Average	Average
CES09	Minimum	10-Mar-03 13:00	17-Nov-03 09:37	24	1.615	81.919	82.696
CES09	Maximum	10-Mar-03 13:00	17-Nov-03 09:37	24	2.006	82.715	84.072
BR31 (Bot)	Layer 1	1-Jan-03 01:00	31-Dec-03 22:00	8,758	3.446	77.637	75.678
BR31 (Top)	Layer 4	1-Jan-03 01:00	31-Dec-03 22:00	8,758	2.823	78.016	76.544
CCORAL (Top)	Layer 4	1-Jan-03 01:00	23-Aug-03 17:00	5,541	2.002	78.315	79.605
Composite				23,105	2.860		

5.3.4.6 Calibration Period Velocity Patterns

Another important component of the hydrodynamic conditions is the flow velocity. At this time, there is not any available flow or velocity data to calibrate to. However, the flow velocity patterns in this calibrated model are consistent with the basic conceptual model for the Caloosahatchee in terms of the velocity magnitudes and directions in response to tidal fluctuations. As examples of the Caloosahatchee velocities, **Figures 5-107 & 108** present velocity patterns in typical ebb (**Fig. 5-107**) and flood (**Fig. 5-108**) tide conditions

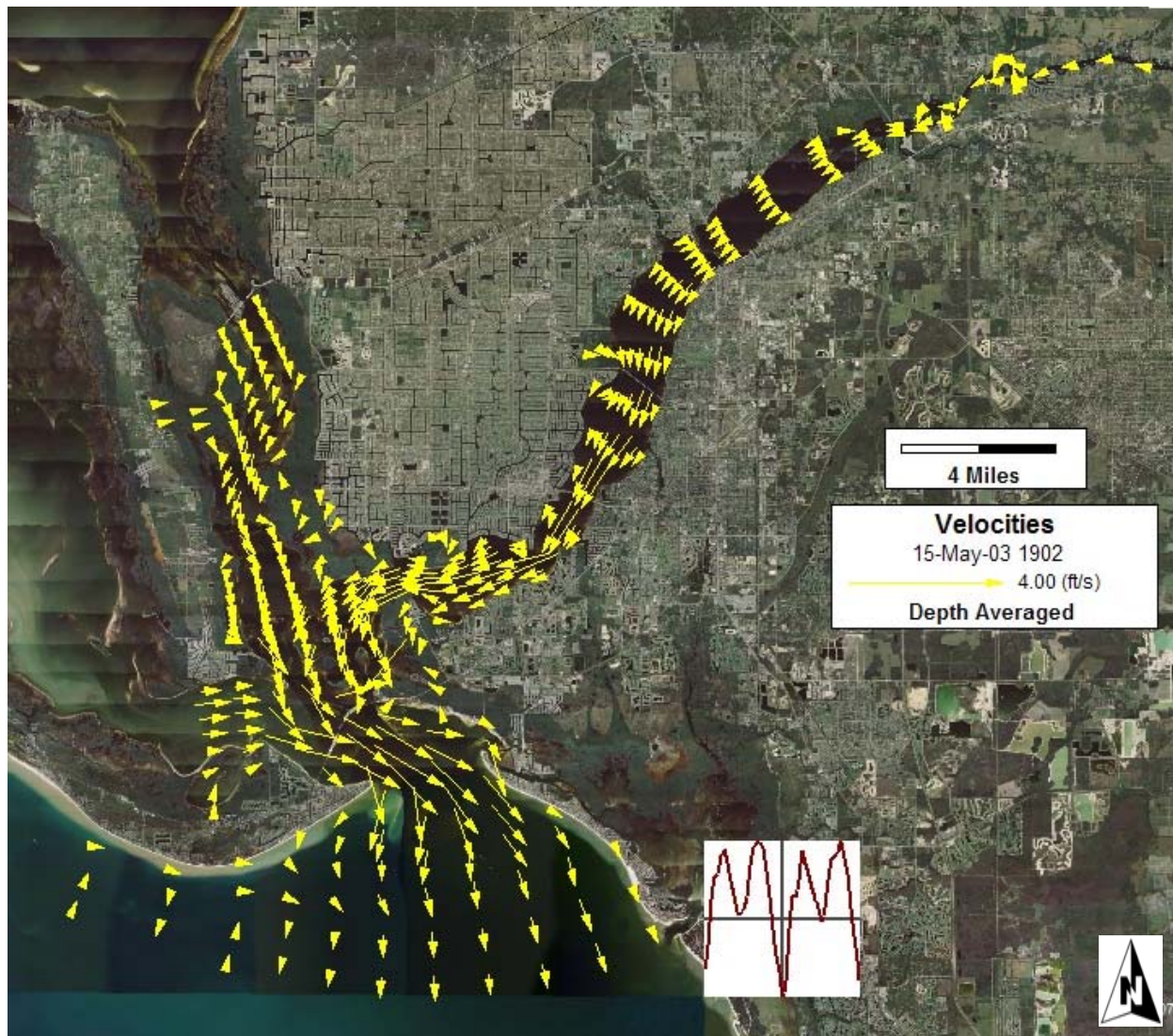


Figure 5-107 Velocity pattern near ebb tide on May 15, 2003

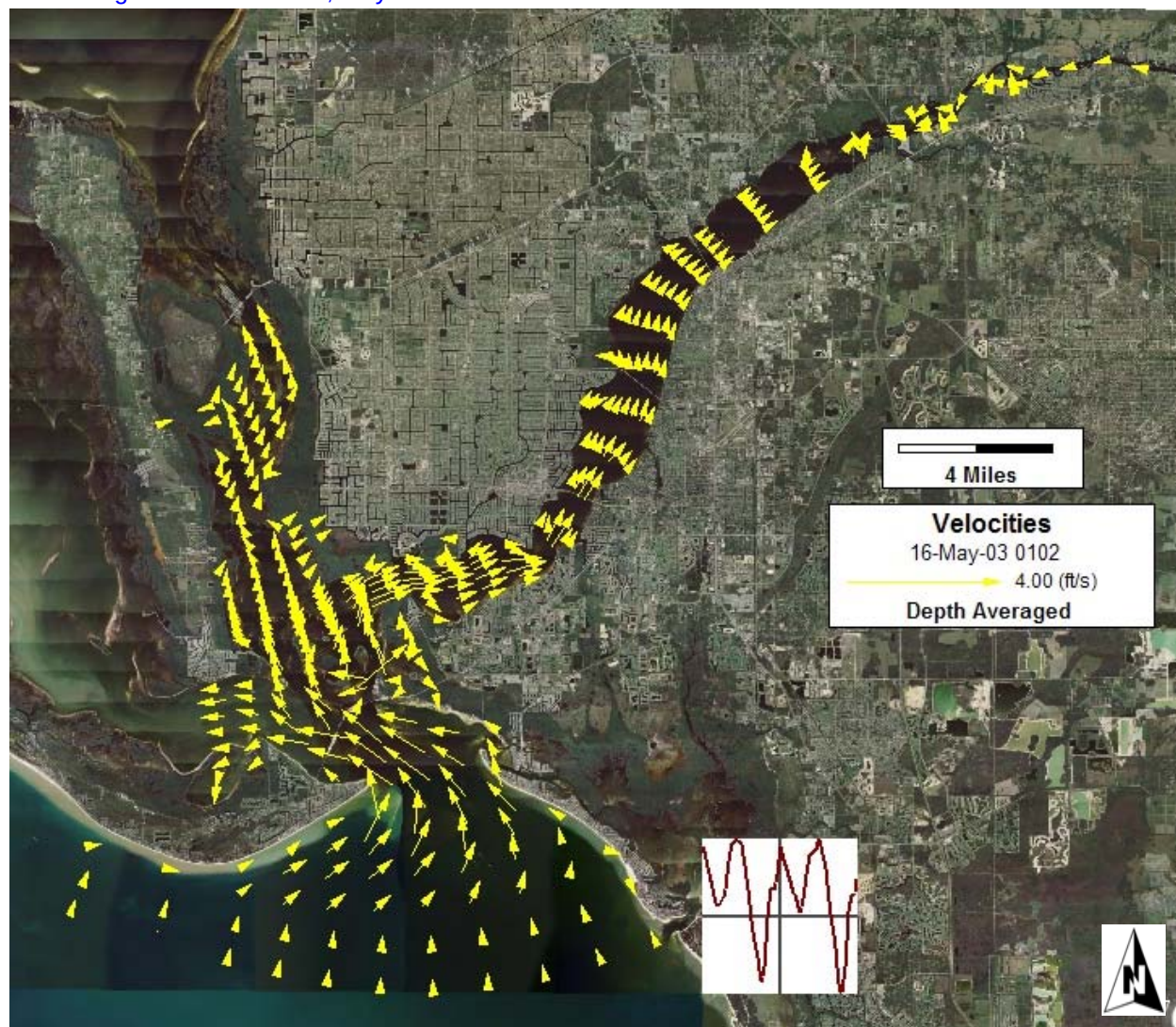


Figure 5-108 Velocity pattern near flood tide on May 16, 2003

5.3.4.7 Water Quality Calibration

The **Figures 5-109 to 116** show the model-data comparisons for dissolved oxygen in the Caloosahatchee model for the calibration year of 2003. **Figures 5-117 to 5-119** provide the model-data comparisons for Chlorophyll-a for the calibration period. A complete set of calibration time series plots for all of the parameters listed in **Table 5-21** are included in **Appendix E**. Also included in Appendix E are the station by station calibration statistics. **Table 5-25** contains a summary of the calibration statistics for the calibration parameters.

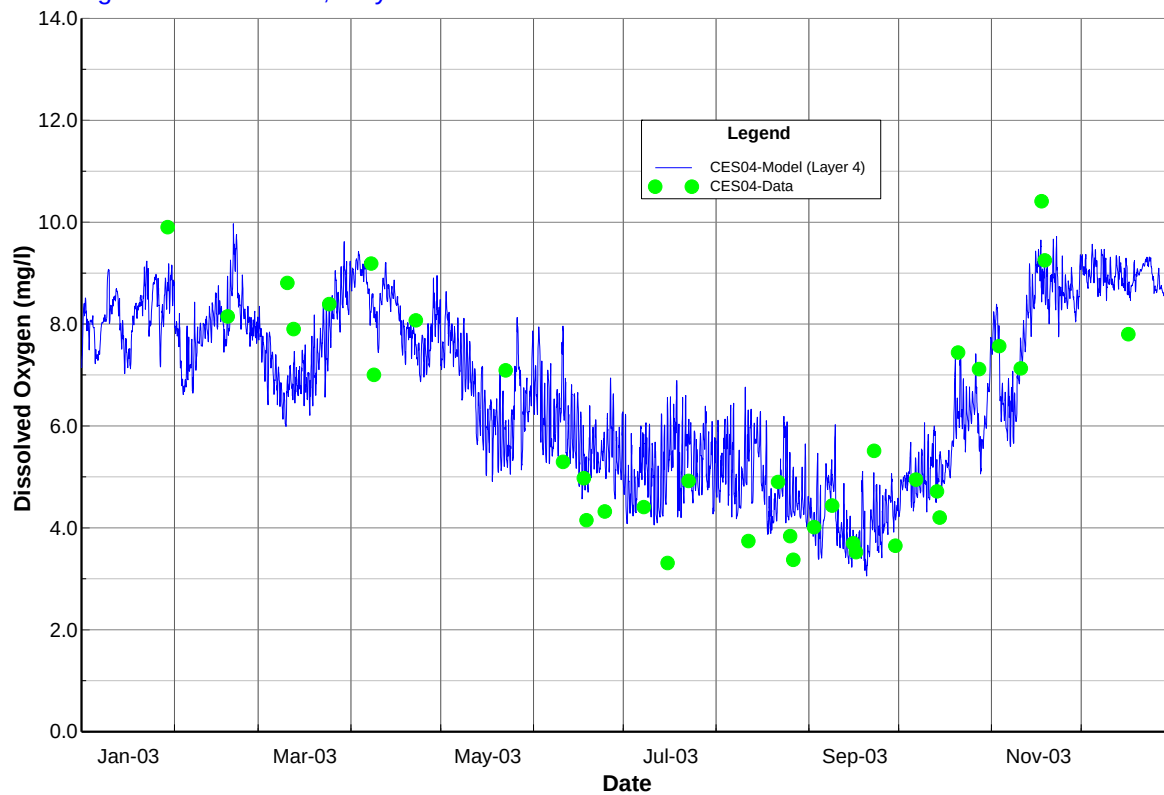


Figure 5-109 Dissolved oxygen calibration time series for CES04, surface layer

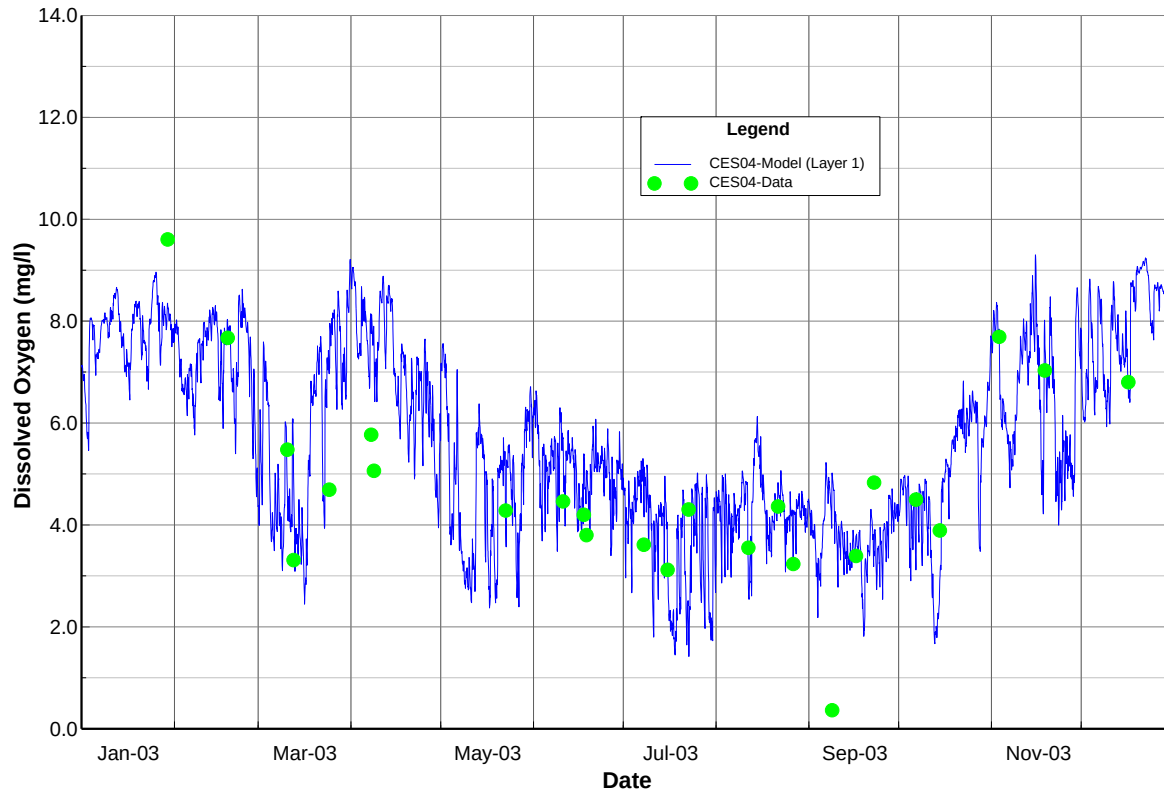


Figure 5-110 Dissolved oxygen calibration time series for CES04, bottom layer

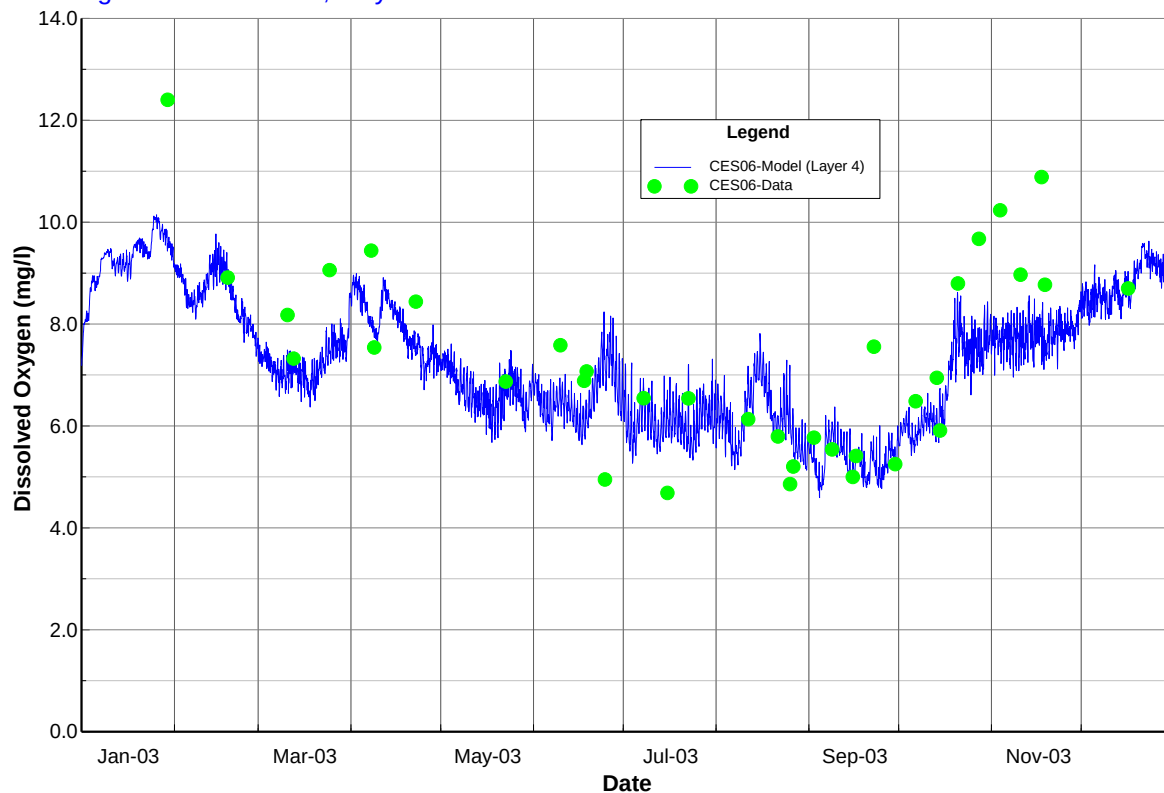


Figure 5-111 Dissolved oxygen calibration time series for CES06, surface layer

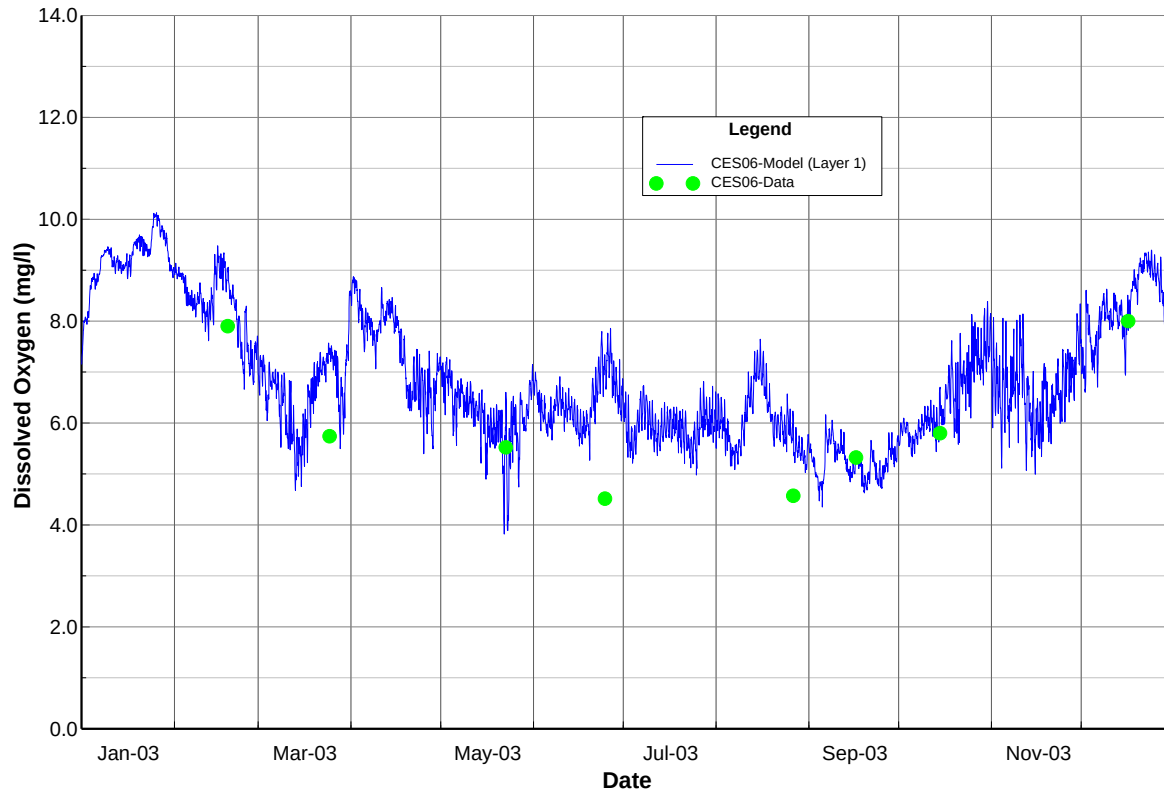


Figure 5-112 Dissolved oxygen calibration time series for CES06, bottom layer

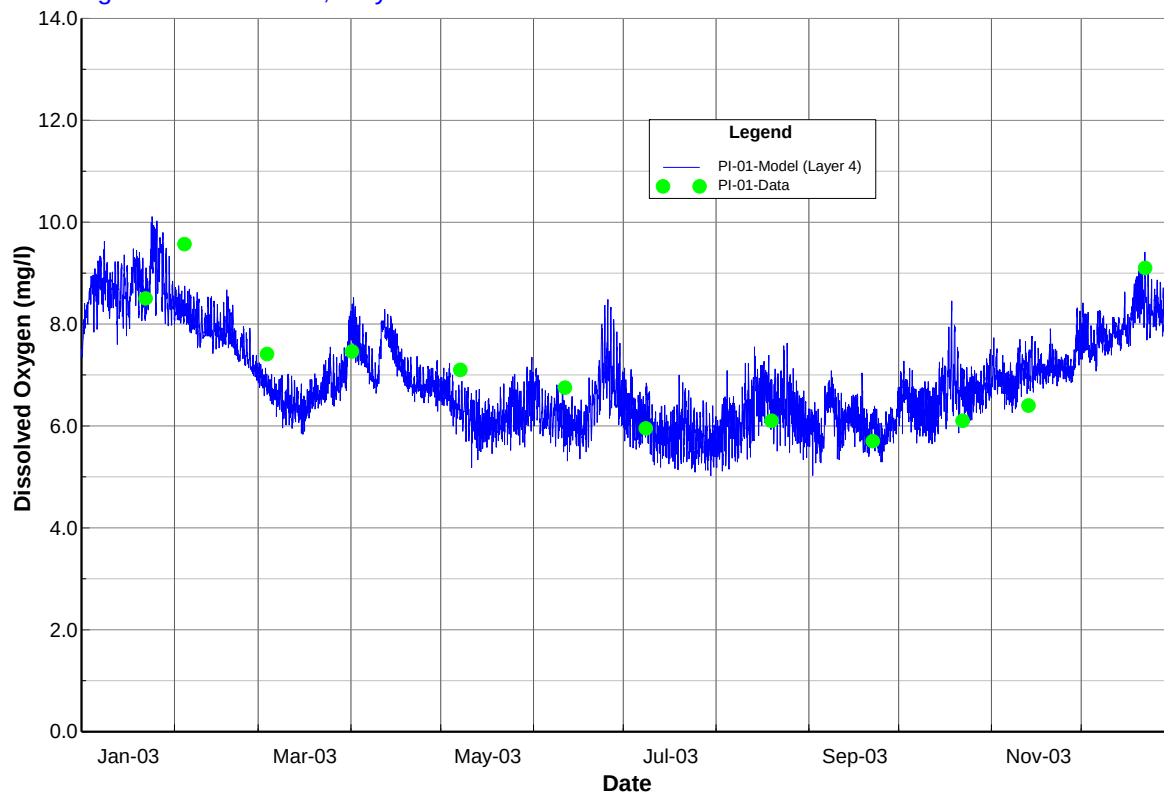


Figure 5-113 Dissolved oxygen calibration time series for PI-01, surface layer

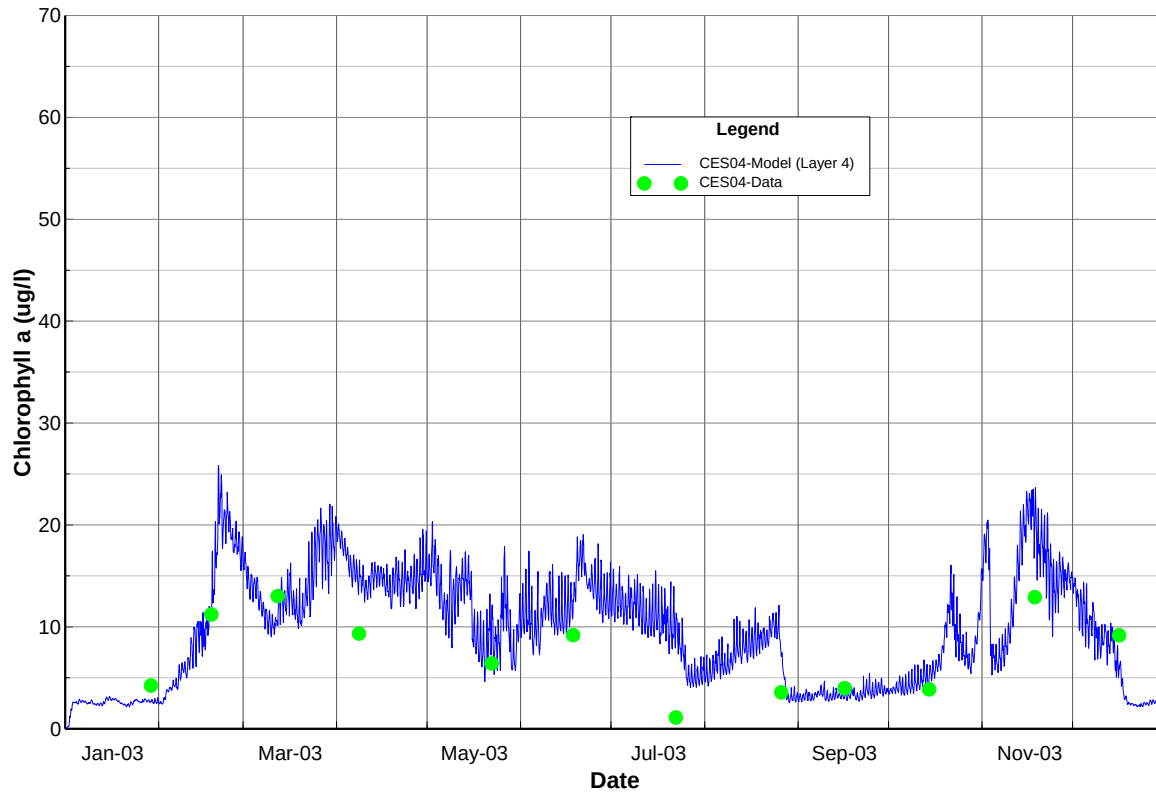


Figure 5-114 Chlorophyll-a calibration time series for CES04, surface layer

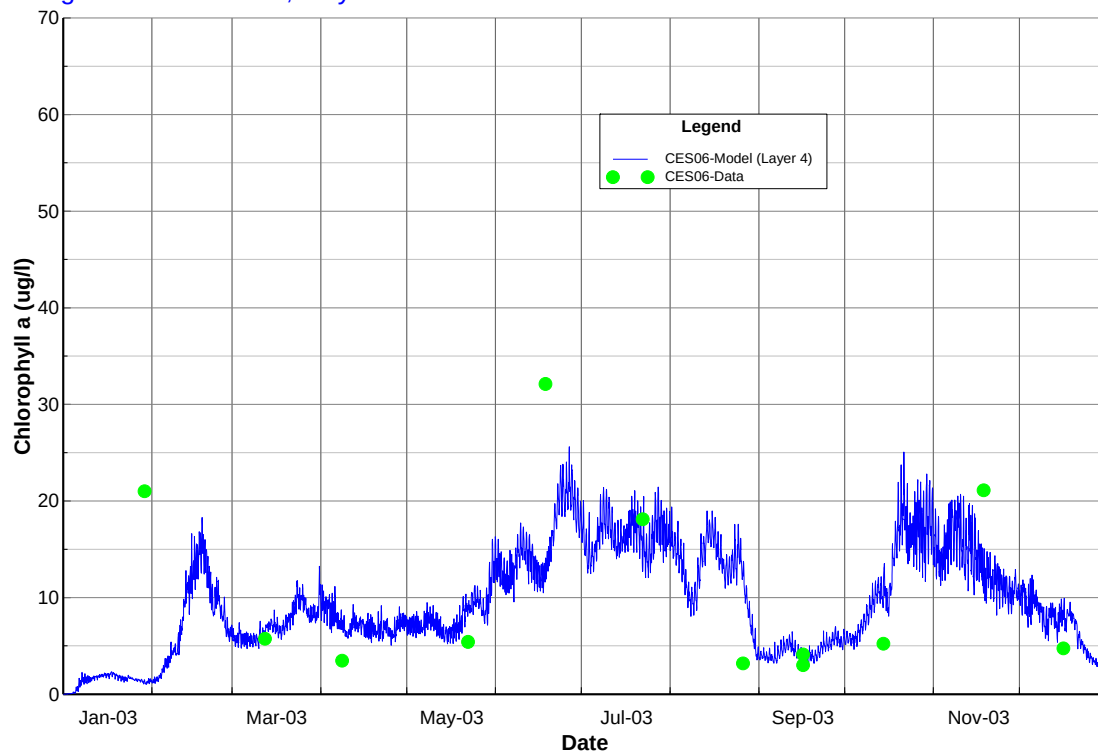


Figure 5-115 Chlorophyll-a calibration time series for CES06, surface layer

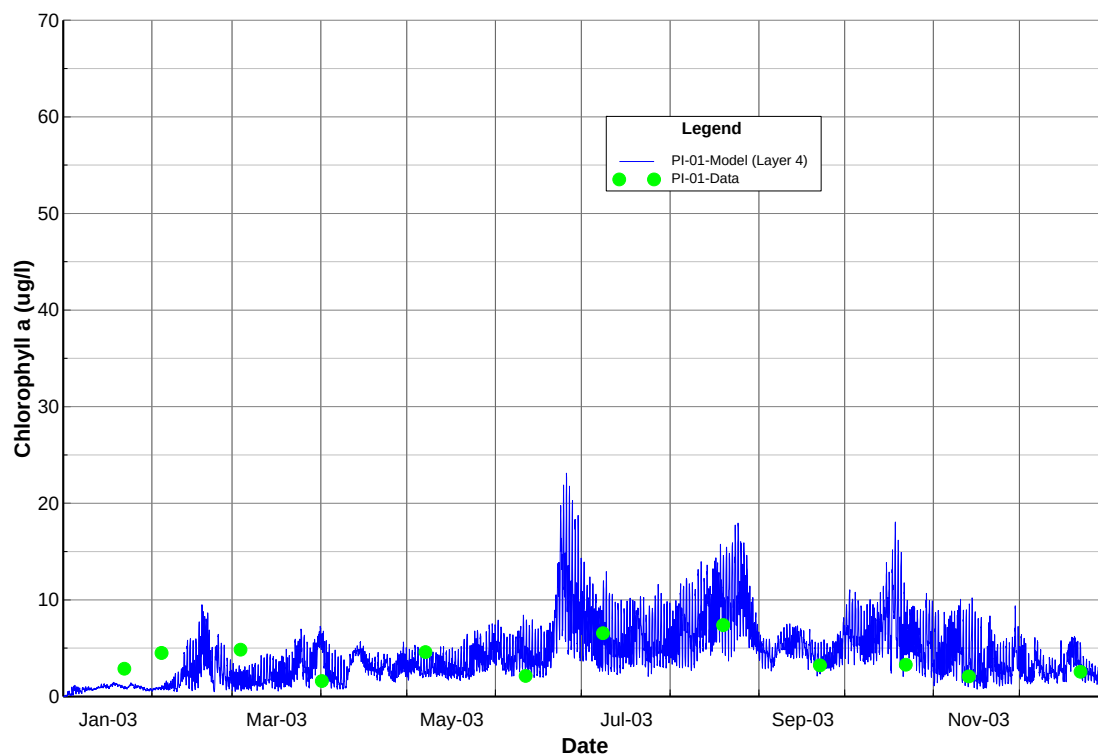


Figure 5-116 Chlorophyll-a calibration time series for PI-01, surface layer

Table 5-25 Summary of the water quality statistics: calibration period

Parameter	# of Data/ Model Pairs	RMS	Data Average (mg/l)	Model Average (mg/l)
Dissolved Oxygen (mg/l)	117	1.29	6.27	6.42
Chlorophyll a (ug/l)	36	5.66	7.24	7.48
Total Phosphorus (mg/l)	62	0.08	0.10	0.07
Total Phosphate (mg/l)	63	0.06	0.06	0.04
Total Nitrogen (mg/l)	47	0.29	0.99	1.02
Ammonia Nitrogen (mg/l)	42	0.06	0.05	0.08
Nitrate Nitrogen (mg/l)	50	0.11	0.12	0.14
Total Organic Carbon (mg/l)	46	5.61	13.80	11.11
Total Suspended Solids (mg/l)	47	10.30	9.41	5.82

The S79 flow and related nutrient loadings dominate the spatial and temporal distribution of nutrients in the Caloosahatchee estuary. A clear pattern can be seen in the TP, TPO4, TOC and TN nutrients with CES04 matching the S79 loadings the best. As the water from the Caloosahatchee River moves downstream it is subject to transformation and uptake resulting in a lower concentration, generally, but the S79 loading patterns are readily discernible in the EFDC model results and observed data for both CES04 and CES06. The San Carlos Bay station, PI-01, appears to exhibit only remnants of the S79 loadings of nutrients.

As shown in the table of the summary statistics of the observed data and the EFDC model results for dissolved oxygen in Appendix 5E, Station CES06 average values for the observed data for the calibration year (2003) are 7.34 mg/L for the surface layer with a lower concentration of 5.92 mg/L for the bottom layer. The EFDC results, however, do not seem to conform to expectations related to typical patterns of surface and bottom layer oxygen levels in an estuary since the EFDC surface and bottom layer results are essentially identical with an average of 6.929 mg/L in the surface layer and 6.995 mg/L in the bottom layer. Graphical overlays (not shown) of the surface and bottom layer EFDC results reveal that DO levels are lower in the bottom than the surface layer during the months of February through May and November through December 2003. During the period from June through October, however, surface and bottom oxygen levels simulated in EFDC are essentially identical. Inspection of the inflow time series from S79 (see Figure 5-25) shows that during February through May and again in November -December, flow from S79 is relatively low (< 1,500 to 2,500 cfs) while during the summer-fall period from June through October, flow increases to highs ranging from ~8,500 to 12,000 cfs. Under the lower flow conditions, the water column stratifies, vertical mixing is inhibited and oxygen in the bottom layer is less than oxygen in the surface layer. Under the higher flow conditions of summer-fall, freshwater dominates this water body and

stratification is minimal in this shallow region. The water column is well mixed and there is negligible difference between surface and bottom layer oxygen levels.

During model calibration the sediment diagenesis decay rates and reaction rates had to be lowered to achieve calibration. In general, the Caloosahatchee organic components are more refractory than the initialized case (i.e. Chesapeake Bay). This make sense conceptually as the Caloosahatchee system is on average warmer than the Virginia/Maryland climate. The organic matter should have been subject to more decay resulting in a larger refractory component and, possibly, a less reactive refractory component.

Based on a review of the calibration plots and statistics in Appendix A, the DO and Chl-a plots shown in the body of the report and the statistics shown in Table 10, the model is considered calibrated.

5.3.5 EFDC Model Validation

5.3.5.1 Model Simulation Period

The period selected for hydrodynamic model validation was from January 1, 2004 to December 31, 2004. This period has an adequate set of salinity, temperature, meteorology, and water quality data for setting boundary conditions and validating the model.

The model initial conditions and boundary conditions are discussed in Section 5.3.1. The EFDC hydrodynamic and water quality validation results are presented in the following sections.

5.3.5.2 Boundary Conditions

5.3.5.2.1 Flow Boundaries

Using the approaches for linking the HSPF model results and constructing the WWTF loads, the boundary condition time series for the hydrodynamic and water quality parameters were developed for the validation period. **Figure 5-117** provides the time series of flows, temperature, total suspended solids, dissolved oxygen (DO), total organic carbon (TOC), total phosphorus (TP) and total nitrogen (TN) for S79. The average flow for S79 for 2004 was 2662 ft³/s with the flows picking up in August and peaking in early October. This year's inflows are approximately 71% of the inflows for 2003, representing a little drier condition than the calibration year.

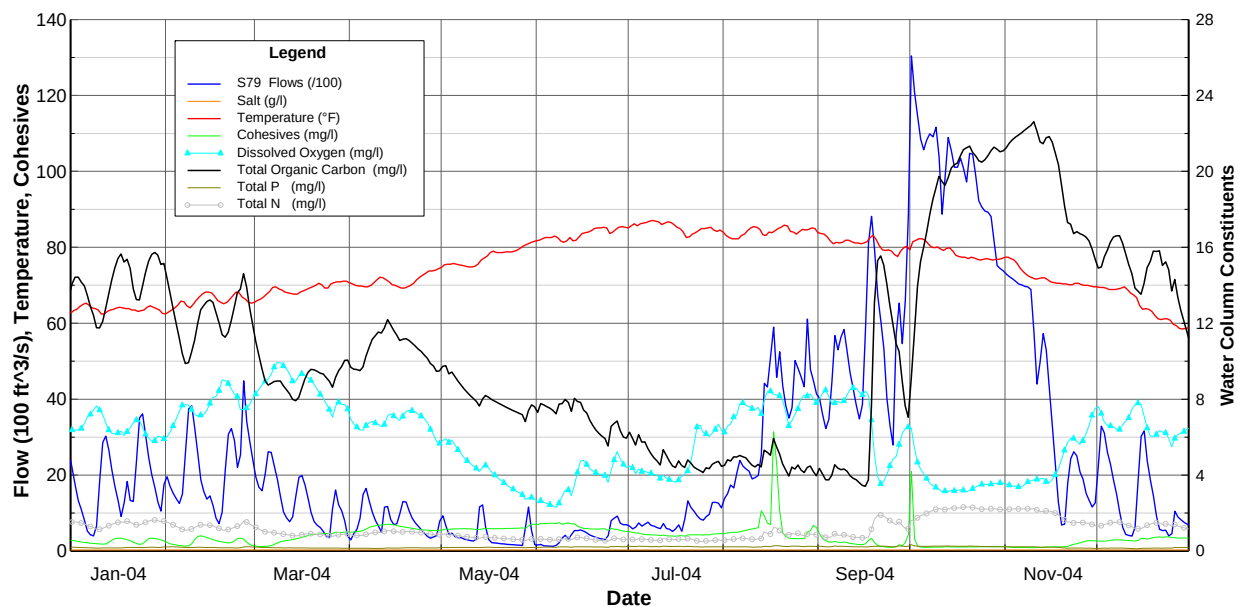


Figure 5-117 Time series of flow and constituent concentrations for S79 for 2004

Table 5-26 provides a summary the annual mass loading of all of the other freshwater boundaries, including the WWTF's, for TOC, TP and TN. Similarly to the water flux and the calibration year, S79 provides 64 to 85 percent of the nutrient loadings to the Caloosahatchee. Again, S79 inflows have a dominant impact on the resulting nutrient concentrations in estuary but to a lesser degree than during 2003.

Figures 5-118 to 5-120 provide a graphical summary of the mass loadings for S79, HSPF02 and the WWTF's for TOC, TP and TN, respectively. The S79 mass loadings are generally three orders of magnitude higher than the WWTF's.

5.3.5.2.2 Atmospheric / Wind Forcing

Figure 5-121 provides a visualization of wind speed, direction and dry bulb temperature for the processed atmospheric data for the validation period.

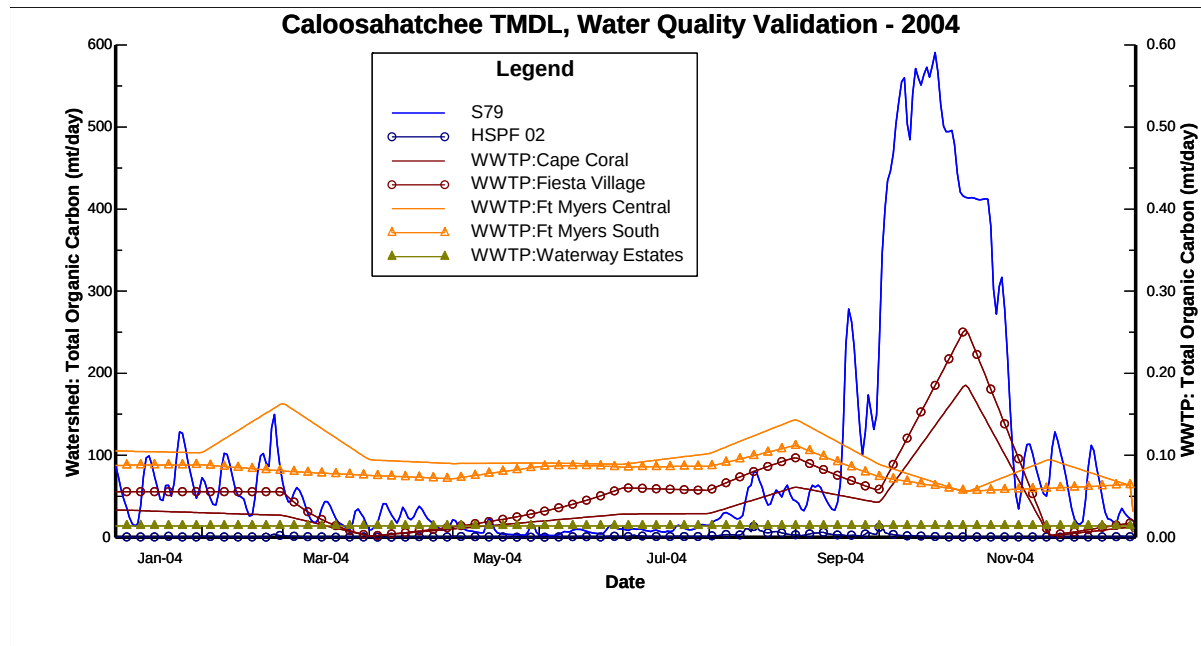


Figure 5-118 Total Organic Carbon mass loading time series for 2004

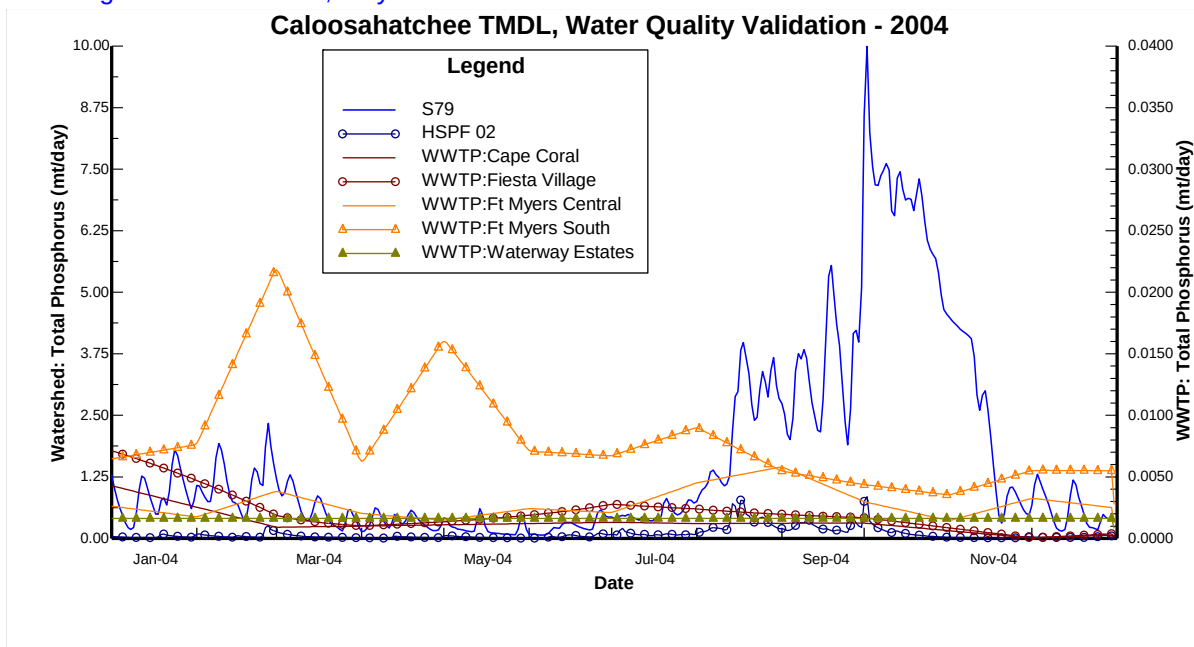


Figure 5-119 Total Phosphorus mass loading time series for 2004

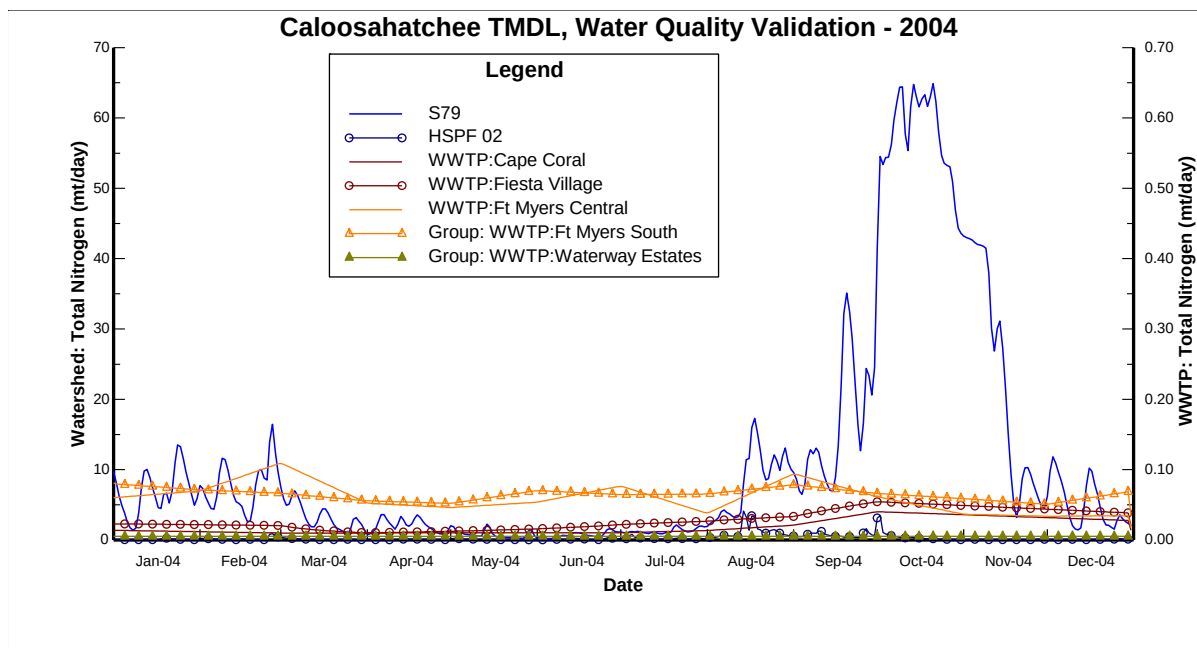


Figure 5-120 Total Nitrogen mass loading time series for 2004

Table 5-26 Nutrient mass loadings for the Year 2004 in tons

HSPF Tributaries	TOC	TN	TP
HSPF 01 (S79)	34,993	3,711	320
HSPF 02	333.1	75.9	18.3
HSPF 03	9.6	2.0	0.4
HSPF 04	20.1	4.4	0.9
HSPF 05	268.5	43.3	9.8
HSPF 06	11.6	2.5	0.6
HSPF 07	40.5	8.4	1.8
HSPF 08	11.7	2.6	0.4
HSPF 09	91.3	12.7	2.7
HSPF 10	840.7	138.4	27.0
HSPF 11	108.7	22.1	4.6
HSPF 12	33.8	5.5	1.2
HSPF 13	32.5	5.1	1.0
HSPF 14	222.7	44.6	9.3
HSPF 15	55.5	8.1	1.8
HSPF 16	266.8	42.0	9.2
HSPF 17	378.9	64.1	11.6
HSPF 18	158.2	23.7	4.9
HSPF 19	19.8	4.4	0.9
HSPF 20	117.8	26.5	5.7
HSPF 21	536.2	48.6	12.1
HSPF 22	604.1	37.5	8.0
HSPF 23	43.7	4.4	0.9
HSPF 24	327.4	19.0	3.9
HSPF 25	36.9	3.7	0.8
HSPF 26	377.9	34.0	8.8
HSPF 27	65.5	6.6	1.3
HSPF 28	61.0	6.5	1.1
HSPF 29	523.7	33.7	6.8

Point Source Dischargers

WWTP:Cape Coral	25.7	6.9	0.4
WWTP:Fiesta Village	19.7	9.4	0.7
WWTP:Ft Myers Central	86.5	21.9	1.0
WWTP:Ft Myers South	162.3	23.6	3.0
WWTP:Waterway Estates	10.1	1.8	0.6

Summaries

Total	40,895.5	4,504.6	481.6
S79 Fraction	85.6%	82.4%	66.4%

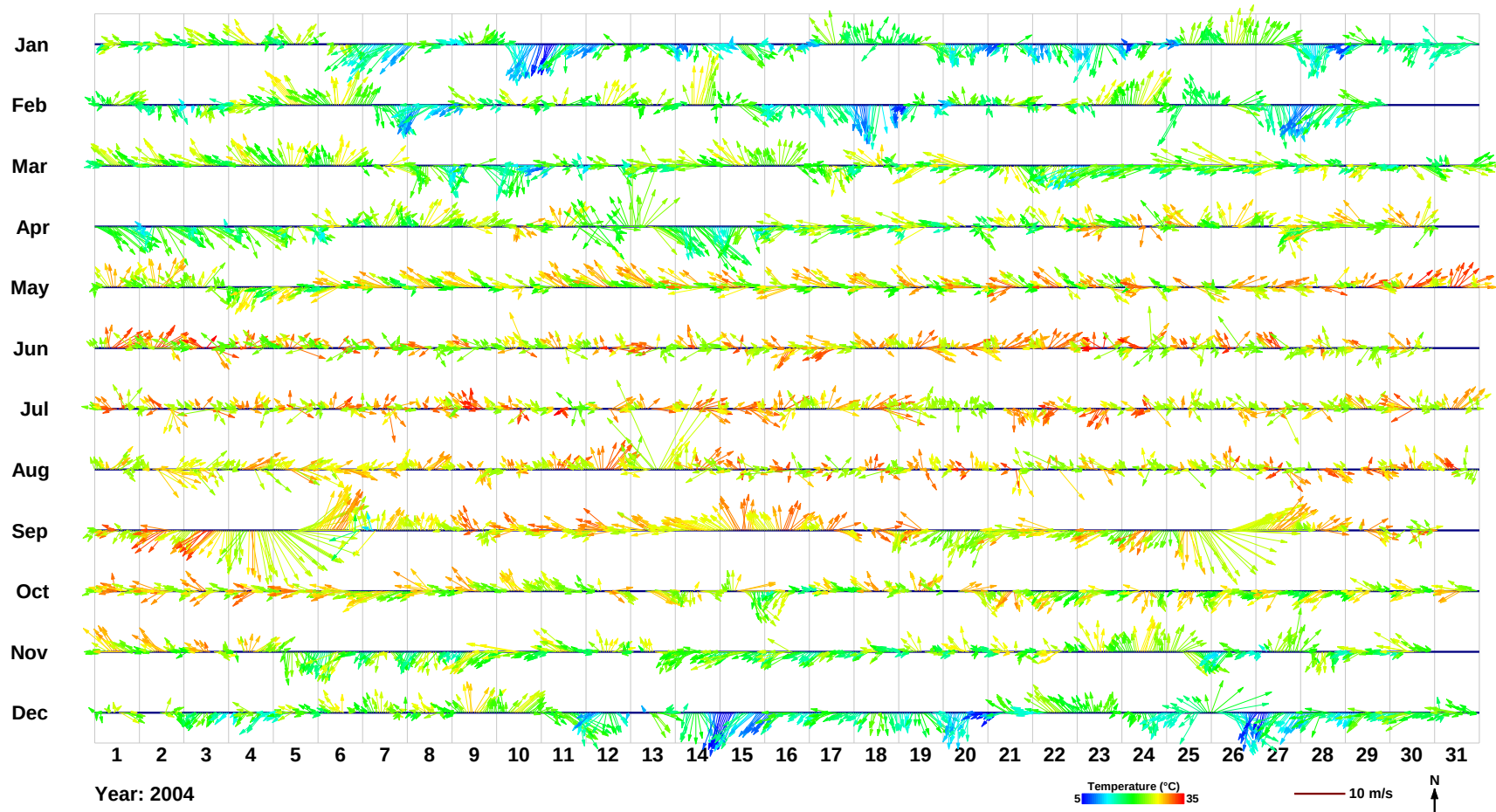


Figure 5-121 Ft Myers wind stick plot for 2004

5.3.5.3 Tide Signal Validation

The computed water surface elevations were compared to the NOAA Ft Myers tidal data for the validation period. The location of the station is shown in **Figure 5-88**. The model-data comparison plot is shown in **Figure 5-122**. The RMS for the water surface elevation was 0.249 ft (7.6 cm). The water surface elevation RMS for the validation period was nearly the same as for the calibration period.

5.3.5.4 Salinity Validation

The **Figures 5-123-127** show the model-data comparisons for salinities in the Caloosahatchee model for the validation year of 2004. **Table 5-27** contains a summary of the RMS (see Section 5.3.2 for a definition) error statistics for salinity. Overall, the model-data comparisons were considered good, though not as good as those for the calibration period. The RMS errors for CES09 are not good but they represent only a few data points as there were no salinity data available for this station later in 2004.

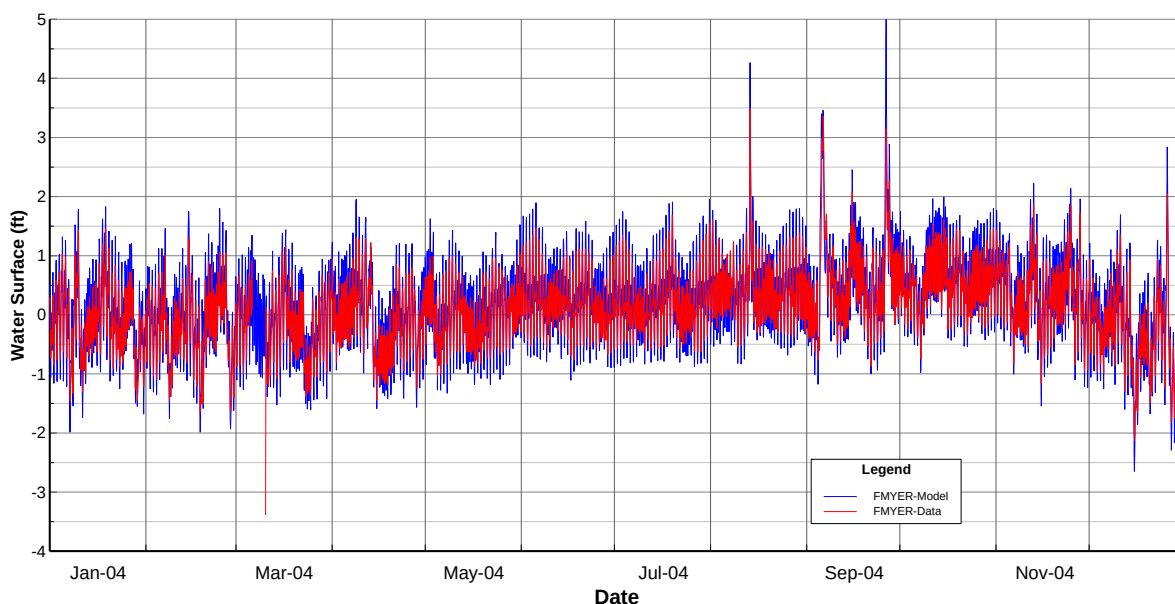


Figure 5-122 Water surface elevation validation at Ft Myers

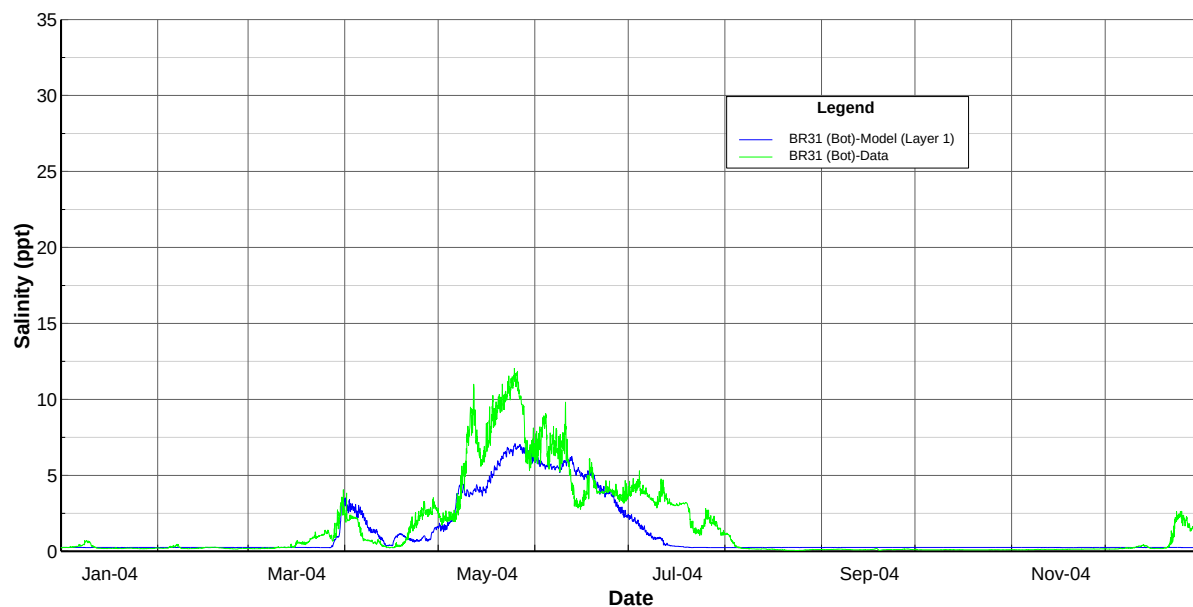


Figure 5-123 Salinity validation at BR31 - Bottom

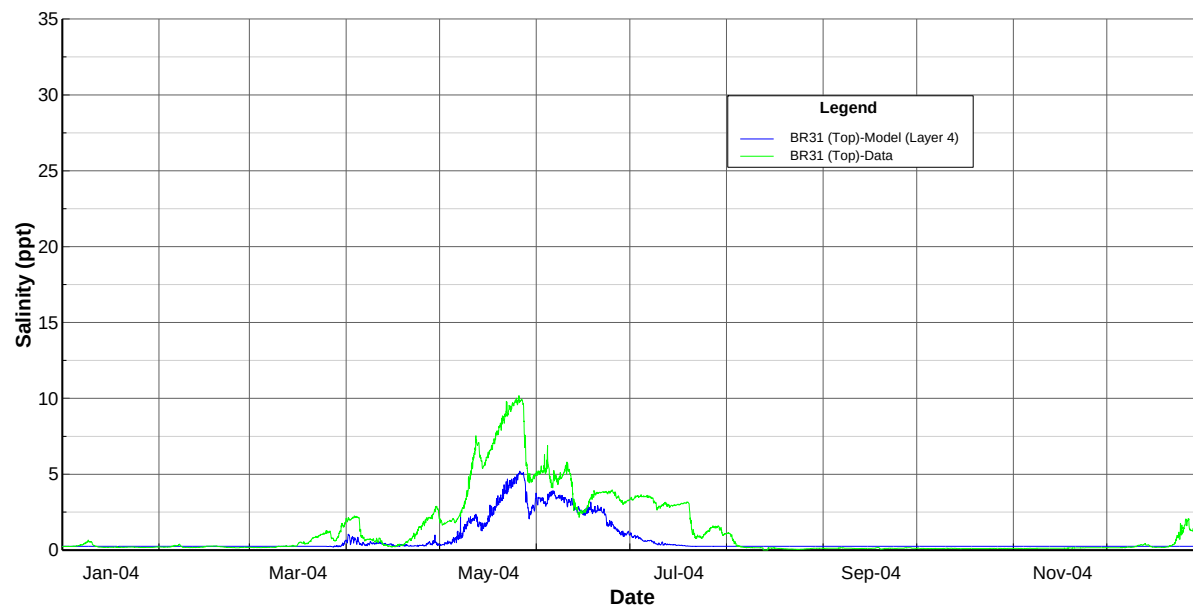


Figure 5-124 Salinity validation at BR31 – Top

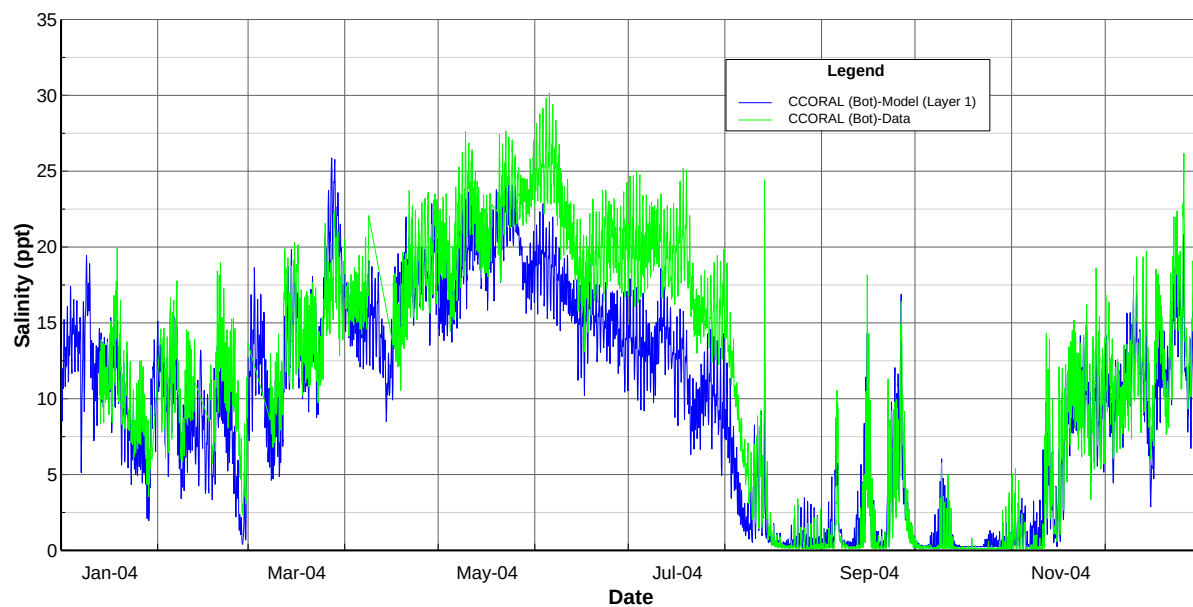


Figure 5-125 Salinity validation at CCORAL - Bottom

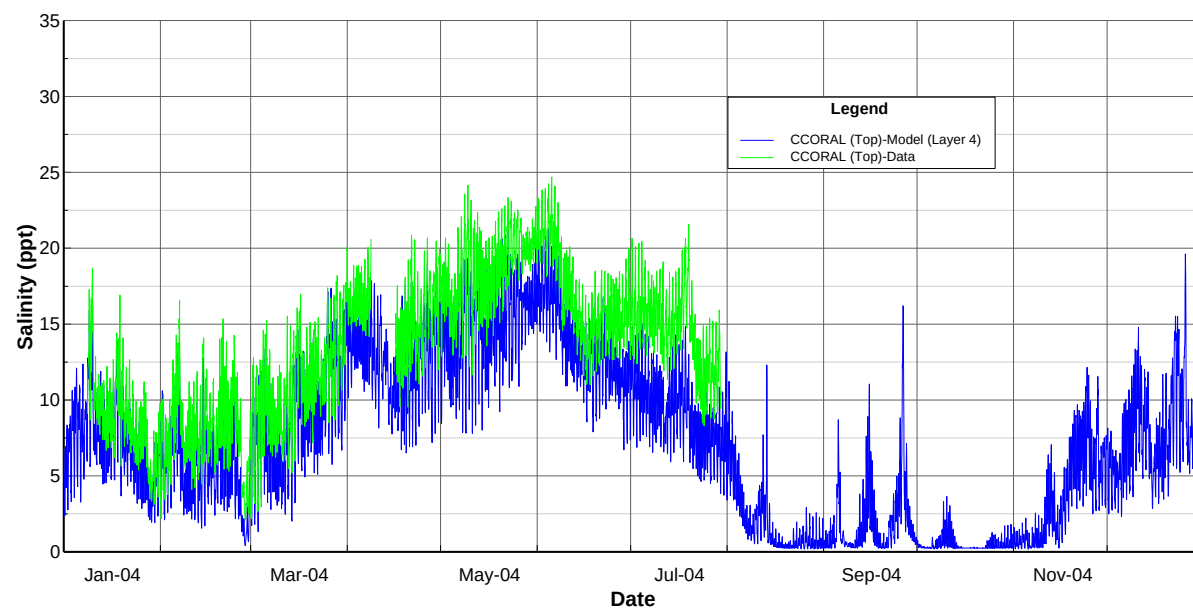


Figure 5-126 Salinity validation at CCORAL – Top

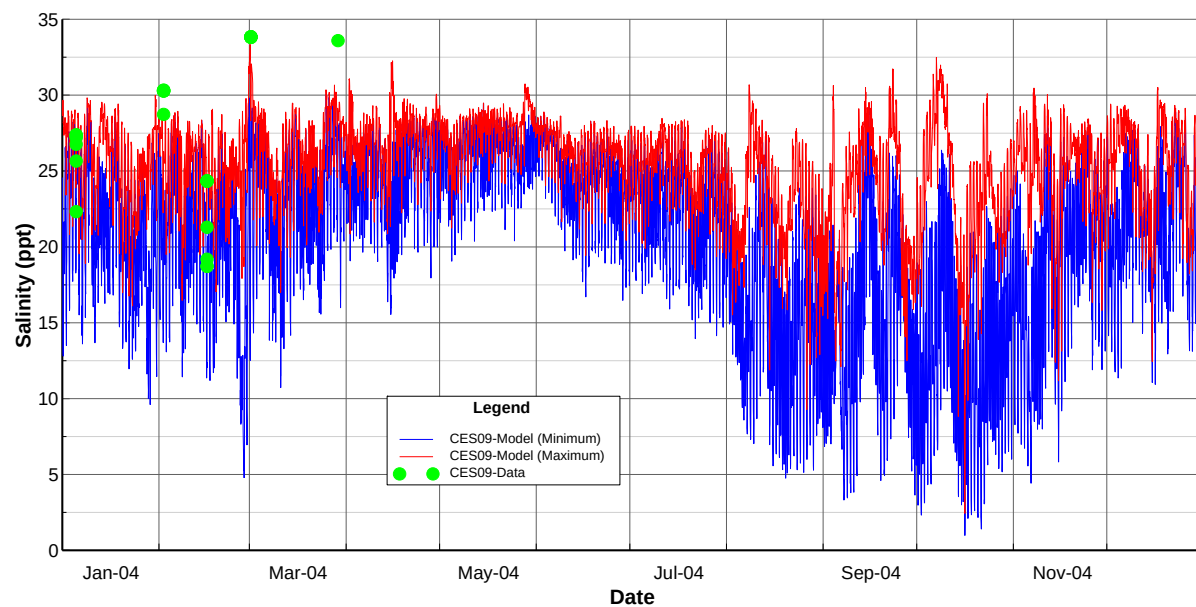


Figure 5-127 Salinity validation at CES09

Table 5-27 Validation period summary statistics for Salinity (PPT)

Station ID	Layer/ Type	Starting Date/Time	Ending Date/Time			Data Average	Model Average
				# Pairs	RMS		
CES09	Minimum	5-Jan-04 11:02	29-Mar-04 10:15	5	6.609	27.432	21.462
CES09	Maximum	5-Jan-04 11:02	29-Mar-04 10:15	5	4.317	30.282	26.619
BR31 (Bot)	Layer 1	1-Jan-04 00:00	30-Dec-04 21:00	8,757	1.234	1.566	1.136
BR31 (Top)	Layer 4	1-Jan-04 00:00	30-Dec-04 21:00	8,757	1.385	1.292	0.656
CCORAL (Bot)	Layer 1	13-Jan-04 12:00	30-Dec-04 21:00	7,878	3.397	11.499	9.618
CCORAL (Top)	Layer 4	8-Jan-04 13:00	30-Jul-04 02:00	4,696	3.508	13.386	10.437
Composite				30,098	2.200		

5.3.5.5 Water Temperature Validation

The **Figures 5-101-104** show the model-data comparisons for temperatures in the Caloosahatchee model for the validation year of 2004. **Table 5-28** contains a summary of the RMS (see Section 5.3.2 for a definition) error statistics for temperature. Overall, the model-data comparisons were considered good, though not as good as for the calibration period.

The impact of the S79 temperatures can be seen in the temperature calibration plots between BR31 and CCORAL. The temperatures at BR31 are nearly match the S79 inflows, but as the water moves downstream and the natural heating/cooling processes impact the waters the temperatures come more in line with the data. This is evidenced by the good match at CCORAL.

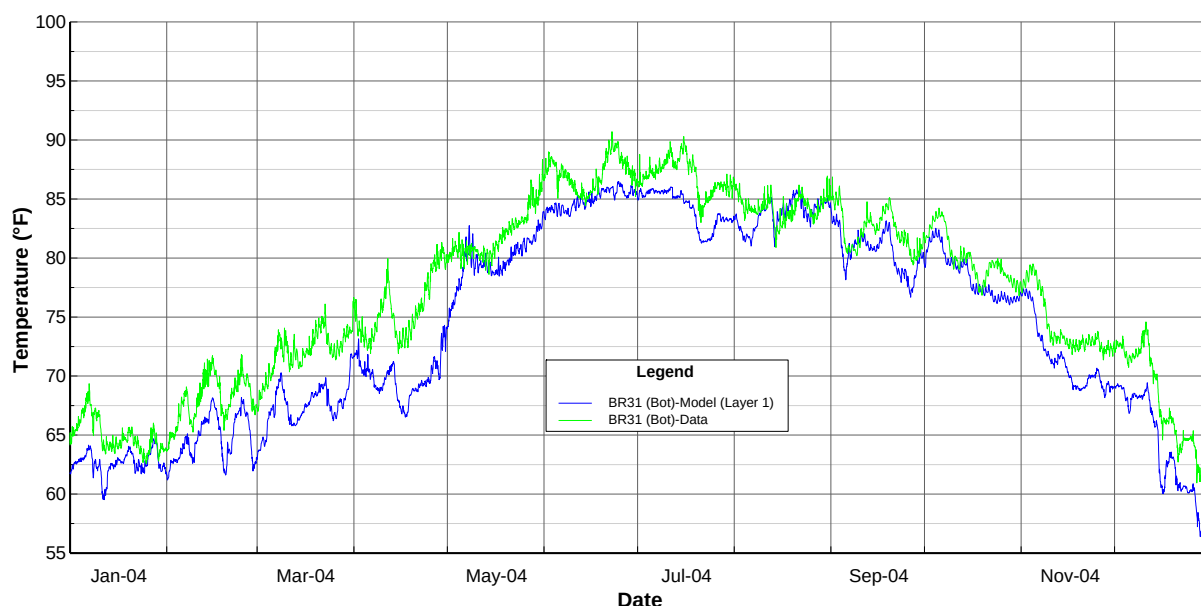


Figure 5-128 Temperature validation at BR31 – Bottom

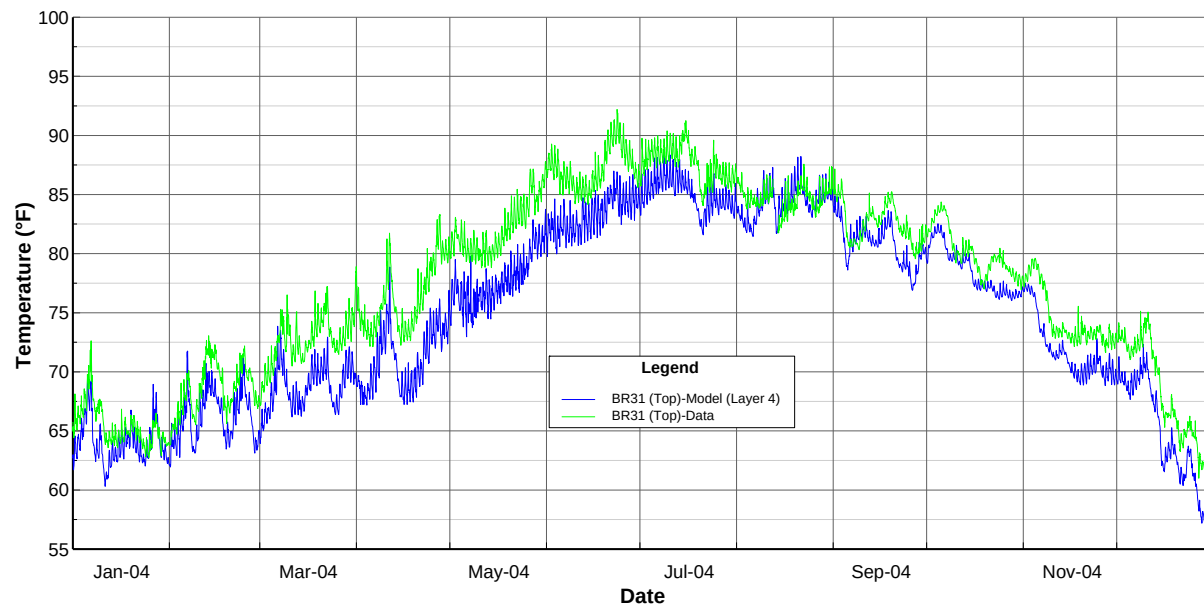


Figure 5-129 Temperature validation at BR31 – Top

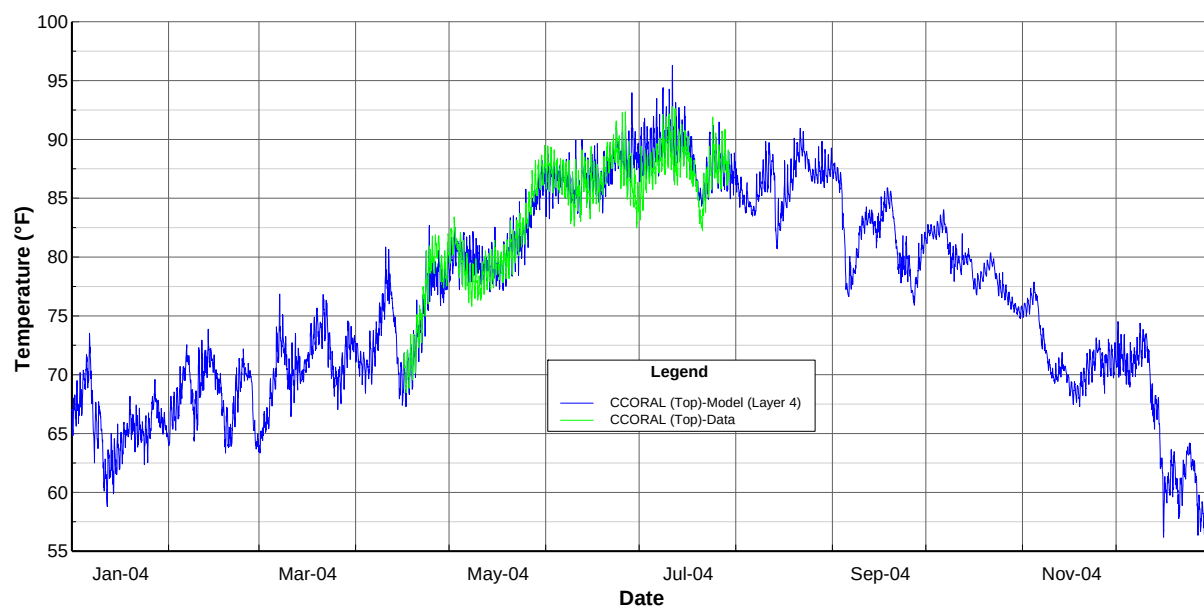


Figure 5-130 Temperature validation at CCORAL – Top

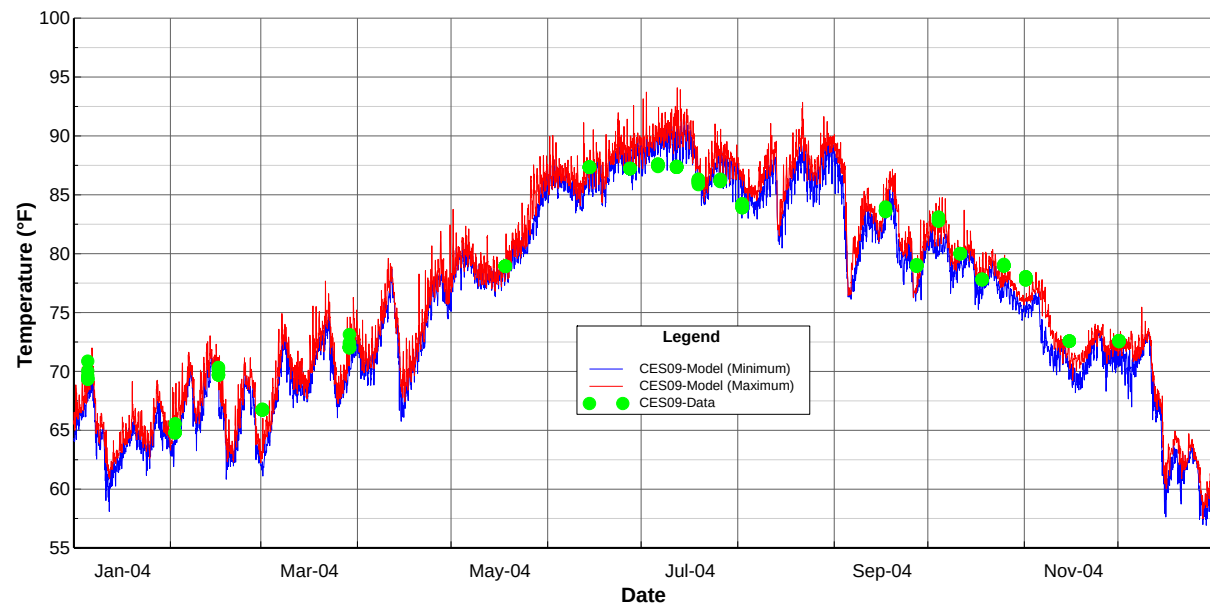


Figure 5-131 Temperature validation at CES09

Table 5-28 Validation period summary statistics for Temperature (°F)

Station ID	Layer/	Starting	Ending			Data	Model
	Type	Date/Time	Date/Time	# Pairs	RMS	Average	Average
CES09	Minimum	5-Jan-04 11:02	1-Dec-04 09:28	22	1.833	78.702	77.537
CES09	Maximum	5-Jan-04 11:02	1-Dec-04 09:28	22	1.497	79.019	78.479
BR31 (Bot)	Layer 1	1-Jan-04 00:00	30-Dec-04 21:00	8,692	3.37	77.133	74.311
BR31 (Top)	Layer 4	1-Jan-04 00:00	30-Dec-04 21:00	8,691	3.302	77.494	74.705
CCORAL (Top)	Layer 4	16-Apr-04 13:00	30-Jul-04 01:00	2,506	1.452	83.843	84.132
Composite				19,933	3.095		

5.3.5.6 Water Quality Calibration

The **Figures 5-132 to 136** show the model-data comparisons for dissolved oxygen in the Caloosahatchee model for the validation year of 2004. **Figures 5-137 to 139** provide the model-data comparisons for Chlorophyll-a for the validation period. A complete set of validation time series plots for all of the parameters listed in **Table 5-21** are included in Appendix B. Also included in Appendix B are the station by station calibration statistics. **Table 5-29** contains a summary of the validation statistics for the calibration parameters.

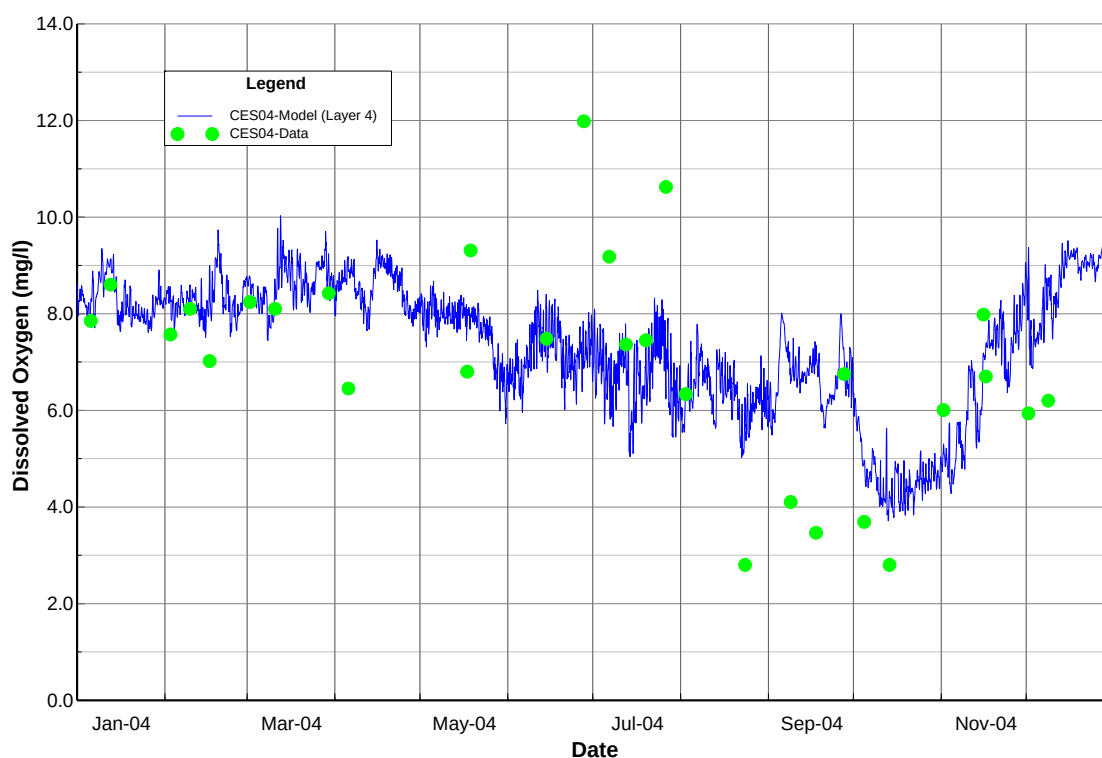


Figure 5-132 Dissolved oxygen validation time series for CES04, surface layer

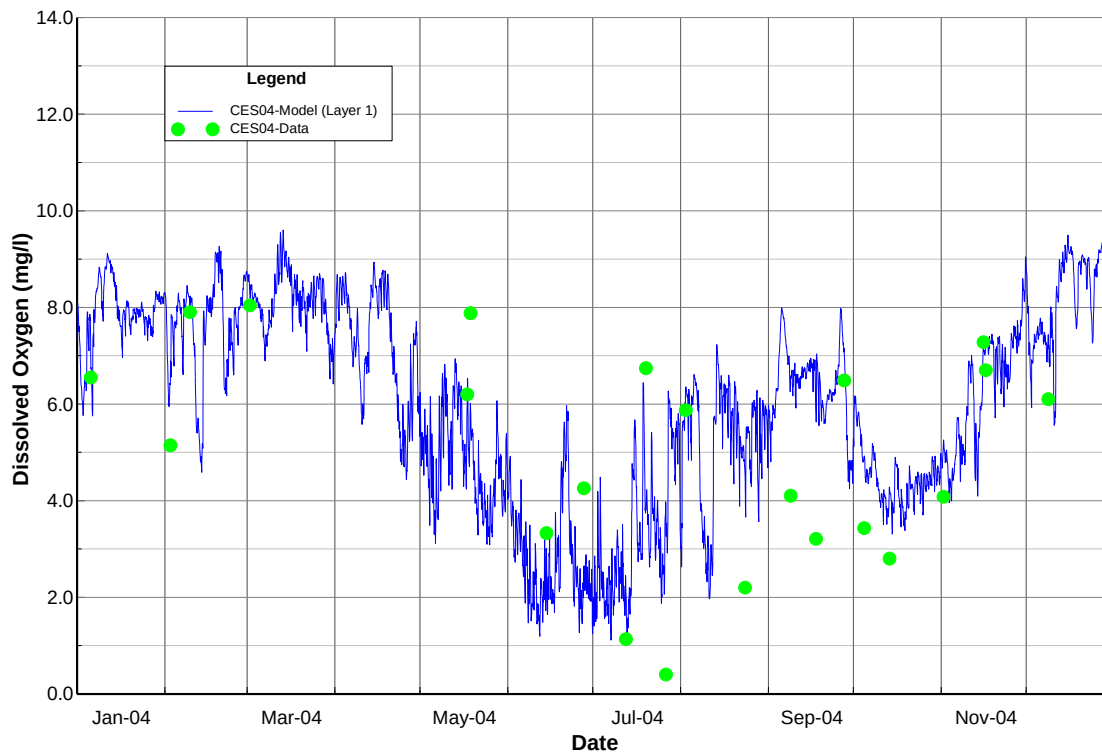


Figure 5-133 Dissolved oxygen validation time series for CES04, bottom layer

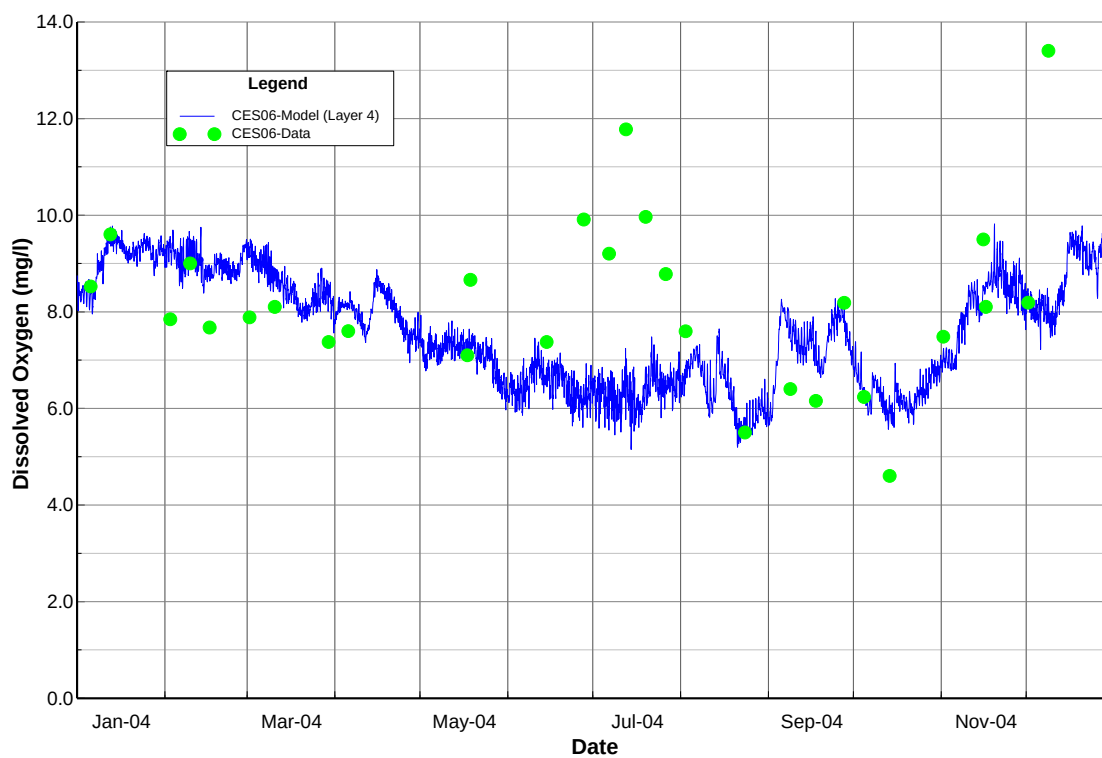


Figure 5-134 Dissolved oxygen validation time series for CES06, surface layer

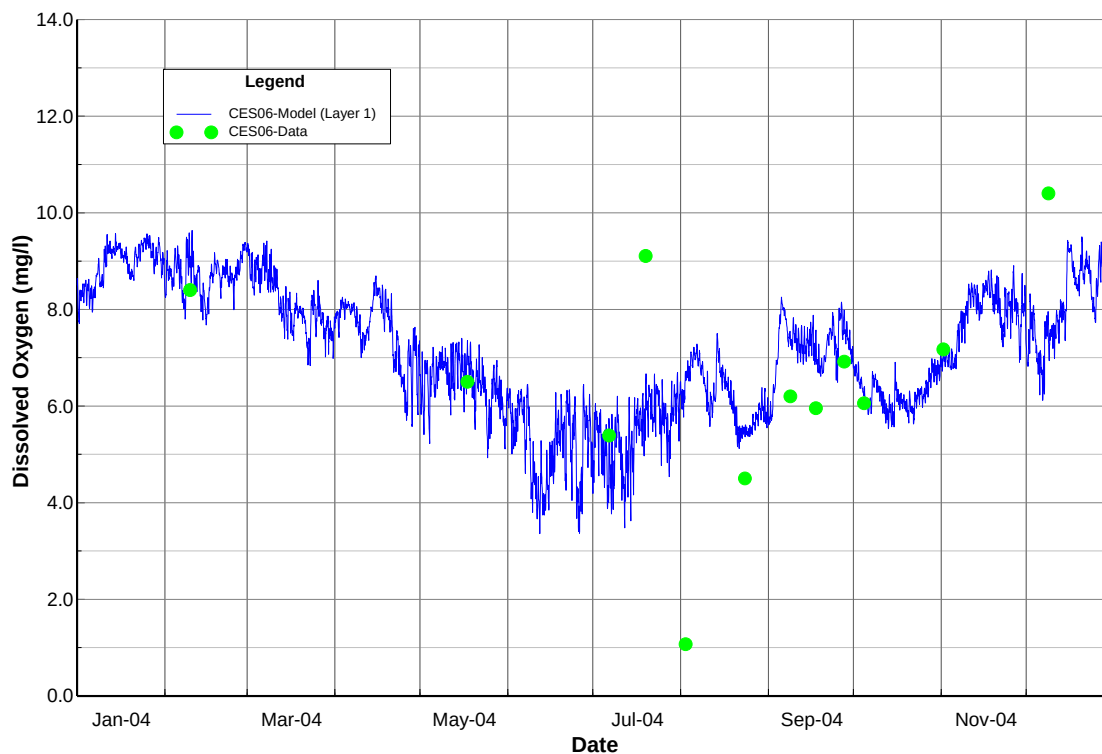


Figure 5-135 Dissolved oxygen validation time series for CES06, bottom layer

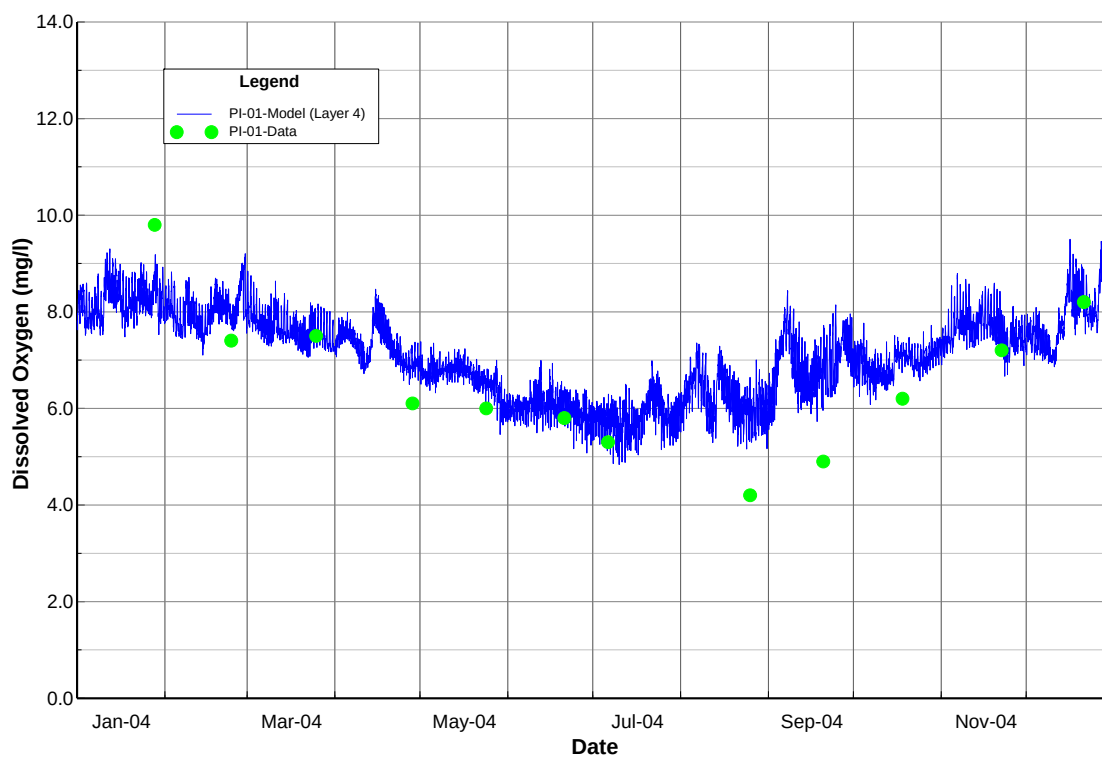


Figure 5-136 Dissolved oxygen validation time series for PI-01, surface layer

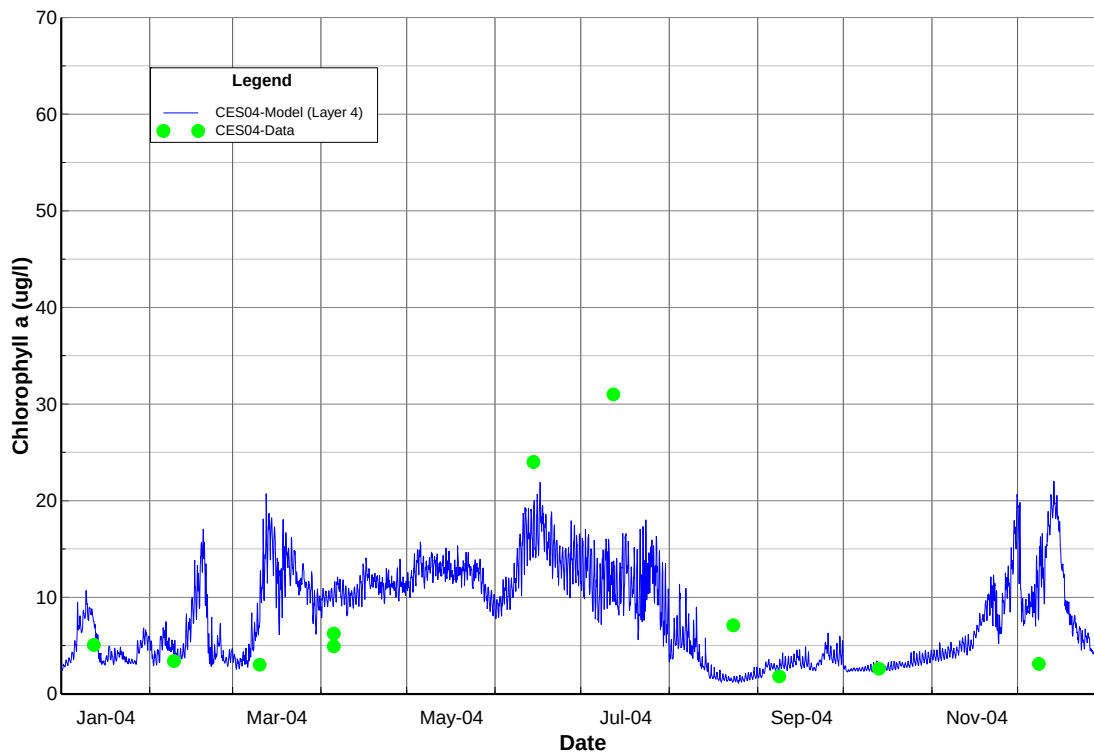


Figure 5-137 Chlorophyll-a validation time series for CES04, surface layer

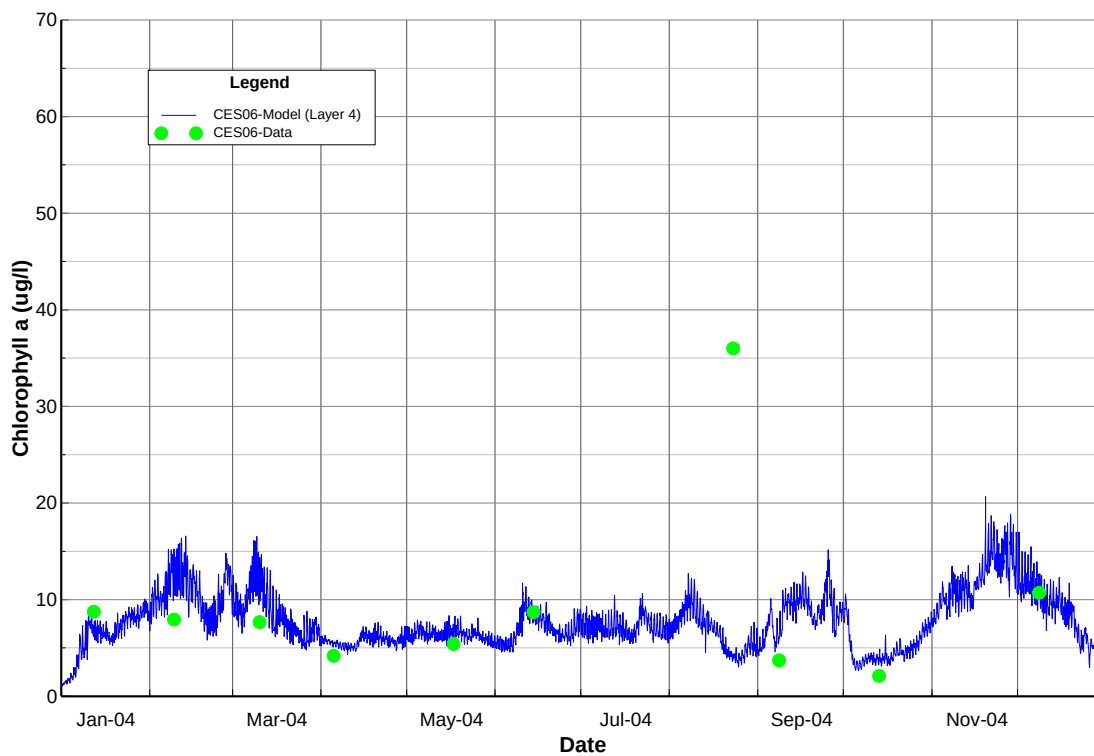


Figure 5-138 Chlorophyll-a validation time series for CES06, surface layer

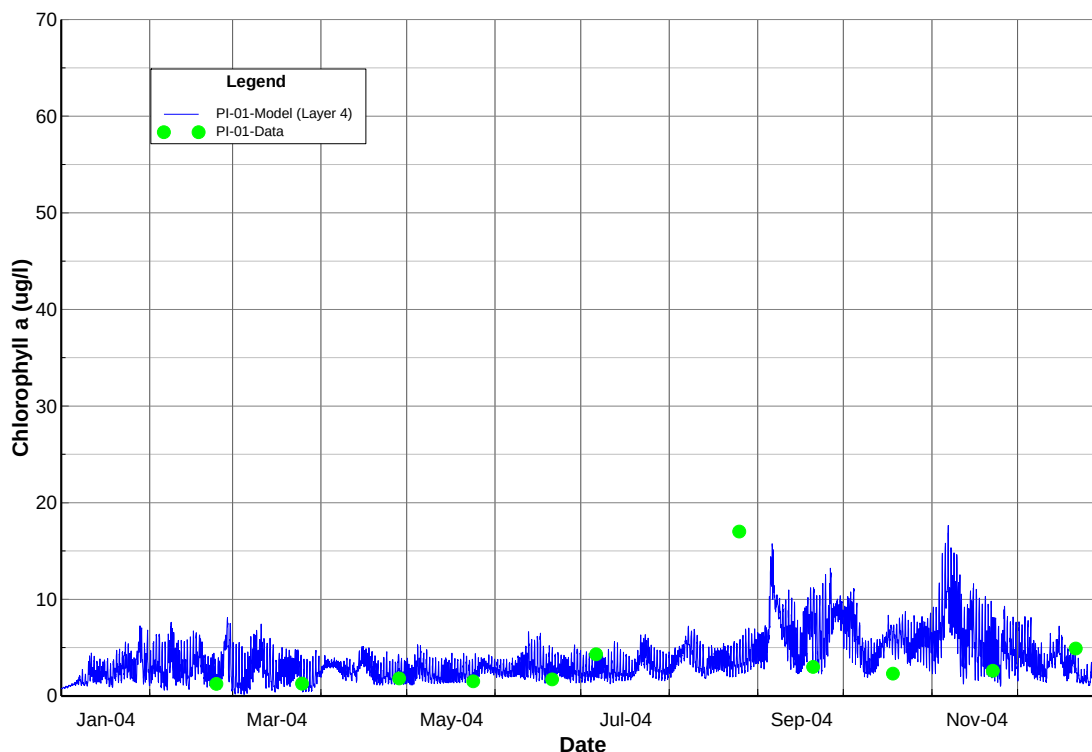


Figure 5-139 Chlorophyll-a validation time series for PI-01, surface layer

Table 5-29 Summary of the water quality statistics: validation period

Parameter	# of Data/ Model Pairs	RMS	Data Average (mg/l)	Model Average (mg/l)
Dissolved Oxygen (mg/l)	104	1.81	6.80	7.05
Chlorophyll a (ug/l)	33	11.71	9.30	6.53
Total Phosphorus (mg/l)	51	0.06	0.09	0.06
Total Phosphate (mg/l)	48	0.04	0.05	0.05
Total Nitrogen (mg/l)	53	0.28	1.05	0.86
Ammonia Nitrogen (mg/l)	57	0.07	0.07	0.06
Nitrate Nitrogen (mg/l)	51	0.09	0.13	0.13
Total Organic Carbon (mg/l)	45	8.01	12.63	9.28
Total Suspended Solids (mg/l)	57	9.21	10.22	5.87

A review of the DO and Chl-a plots as well as the nutrient plots in Appendix B indicate that the model does not perform as well as for the calibration period. However, the overall seasonal trends are well represented and the average nutrient levels are in range. It is clear that the model misses a major bloom in mid summer in the surface layer but tracks better in the bottom layer, even during this bloom event(s).

On whole, this model is considered both calibrated and validated.

5.4 WASP MODEL

5.4.1 Model Development of WASP Model and EFDC/WASP linkage

This section summarizes the development of the WASP model for application to the Caloosahatchee River tidal estuary. The hydrodynamic element of the Environmental Fluids Dynamics Code (EFDC) model of the Caloosahatchee River tidal estuary was used to “drive” the WASP model by providing volume, flow, velocity, salinity and water temperature data to simulate water quality conditions in the tidal Caloosahatchee River. EFDC is an advanced three-dimensional hydrodynamic model (Hamrick, 1992; 1996) that has often been applied for linkage with the WASP water quality model.

The WASP model includes separate sub-models to simulate surface water transport and fate of (a) water quality (nutrients, algae and dissolved oxygen); (b) toxic chemicals and solids; and (c) mercury. Since WASP does not include an internal three-dimensional sub-model to simulate hydrodynamics, segment geometry, transport and mixing is either (a) specified by the modeler as input data or is (b) provided by external linkage to a hydrodynamic model such as EFDC (EPA, 2006).

Hydrodynamic linkage from the EFDC model was developed using EFDC_Explorer to generate the hydrodynamics files required for input to run WASP (Version 7.2). EFDC_Explorer is a Windows-based graphic user interface for pre- and post processing of the EFDC model (Craig, 2004). The data generated by the EFDC to WASP linkage automatically defines the spatial and vertical location of each WASP segment by mapping the EFDC grid cells to the WASP segments. In order to develop the input data for the WASP model, it is essential for the modeler to know the spatial location and depth information of each WASP segment that corresponds to the matching EFDC grid cell. The time series modeling results for flow, volume, velocity, salinity and temperature are passed from EFDC to WASP with the hydrodynamic linkage file generated by EFDC. Utilizing this linkage procedure greatly improves the water quality simulation results since it eliminates any potential error from the manual input of numerous temperature and salinity time series generated by EFDC. Computation time for the WASP model is also saved by linkage of the EFDC generated salinity and temperature results since WASP doesn't need to simulate salinity processes. An ArcGIS based post-processing file was also generated during this process to assist in visualizing the spatial distributions of the model results.

5.4.1.1 Model Parameters

Flow volume, velocity, temperature and salinity simulated by the EFDC hydrodynamic model are passed to, and utilized by, the WASP model to provide segment geometry, transport and temperature and salinity data. The water quality sub-model of WASP includes the following state variables:

- Ammonia;
- Nitrate
- Organic Nitrogen
- Organic Phosphate

- Orthophosphate
- Phytoplankton (Chl-a)
- Dissolved Oxygen;
- CBOD1; CBOD2 and CBOD3
- Detrital Carbon;
- Detrital Nitrogen, and;
- Detrital Phosphorous.

In the application of the WASP model to the tidal Caloosahatchee River, the state variables for CBOD2 and CBOD3 are not used (i.e., “bypassed”) in the WASP simulation. The WASP state variable for CBOD1 is defined by boundary condition data describing CBOD provided by either wastewater facilities or results generated by the HSPF watershed model.

5.4.1.2 Model Boundary Locations

The domain of the WASP model is shown in **Figure 5-141**. The USGS Station S-79 and SFWMD Station CES01 monitoring stations are within the upstream river boundary cell at the Franklin Lock & Dam S-79 . The upstream boundary conditions for the water quality variables of the WASP model are assigned using time series from these two stations. The yellow grid cells bounded with a red outline identify the open water boundary cells for the south, west and north boundaries where tide stage, temperature and salinity represent that of the Gulf of Mexico (south); Pine Island Sound (west) and Matalacha Pass (north).

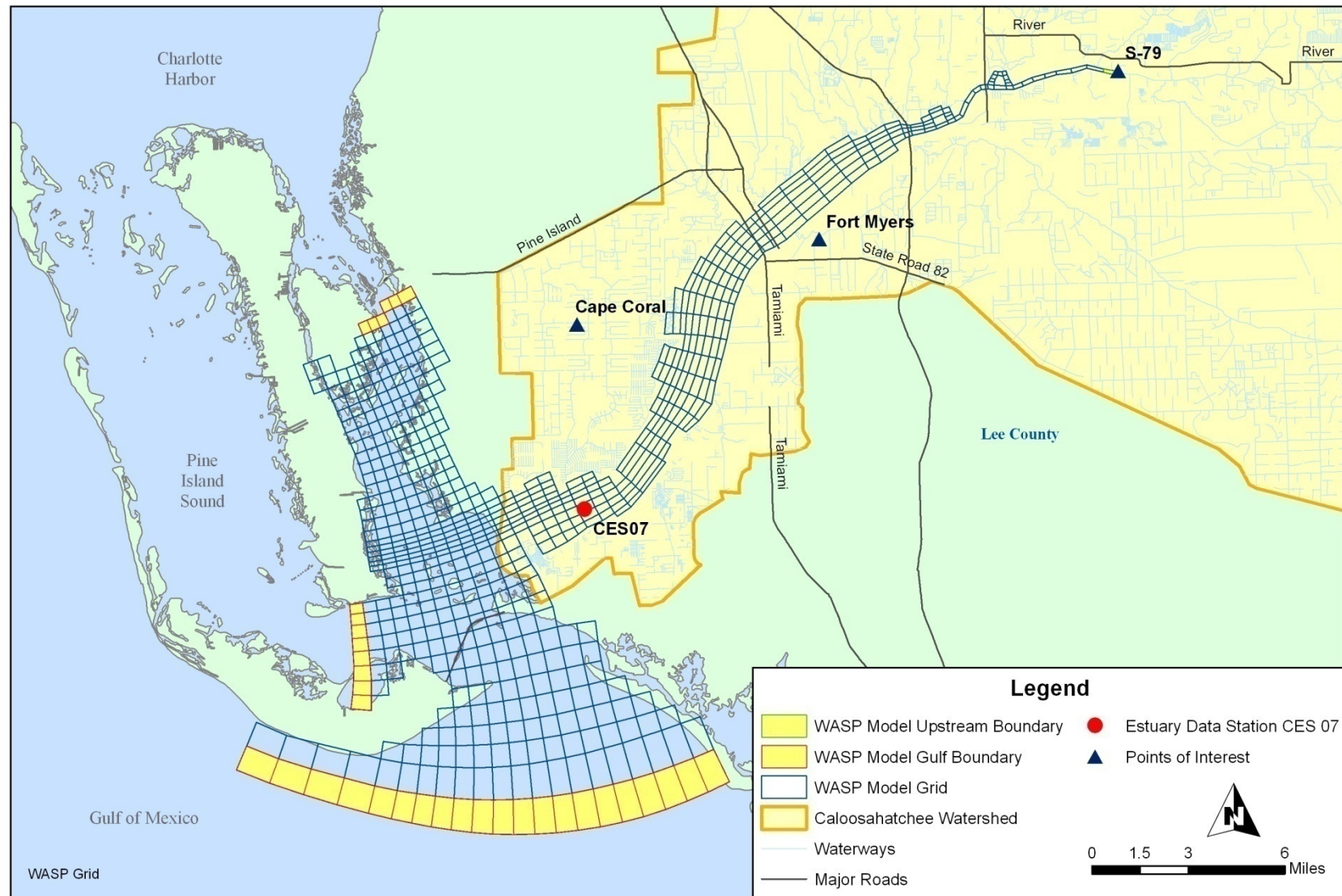


Figure 5-140 Caloosahatchee River Estuary WASP Modeling boundary location

5.4.1.2.1 Flow, temperature and salinity Boundary Conditions

The EFDC model results were linked to the WASP model for the following model parameters for all the WASP segments: flow, volume, velocity, dispersive mixing, temperature, and salinity.

The EFDC model generates hydrodynamic linkage files that provide temperature, salinity, segment volume and flow information for the boundary segments and all the interior segments of the WASP model. Thus, the WASP model does not need additional input data to describe volume, flow, temperature and salinity for the boundary conditions and the initial conditions of the interior segments.

The EFDC model supplied flow data as boundary conditions to the Caloosahatchee River tidal estuary WASP model for the (a) upstream boundary location at the S-79 Franklin Lock & Dam and (b) open water boundaries to the south, west, and north for the Gulf of Mexico, Pine Island Sound and Matalacha Pass. These flows have been linked to the WASP model for use as boundary conditions for the incoming freshwater Caloosahatchee River and the Gulf of Mexico open water boundary. The use of simulated flows, salinity and temperature are necessary to provide complete temporal and spatial coverage for all of the incoming flows for the simulation periods of interest.

As an example of the EFDC volume information provided as linked input to the WASP model, the Caloosahatchee River upstream location (S-79) surface layer volume and temperature for the calibration period of January 2003 to December 2003 is shown in **Figures 5-141 and 5-142**.

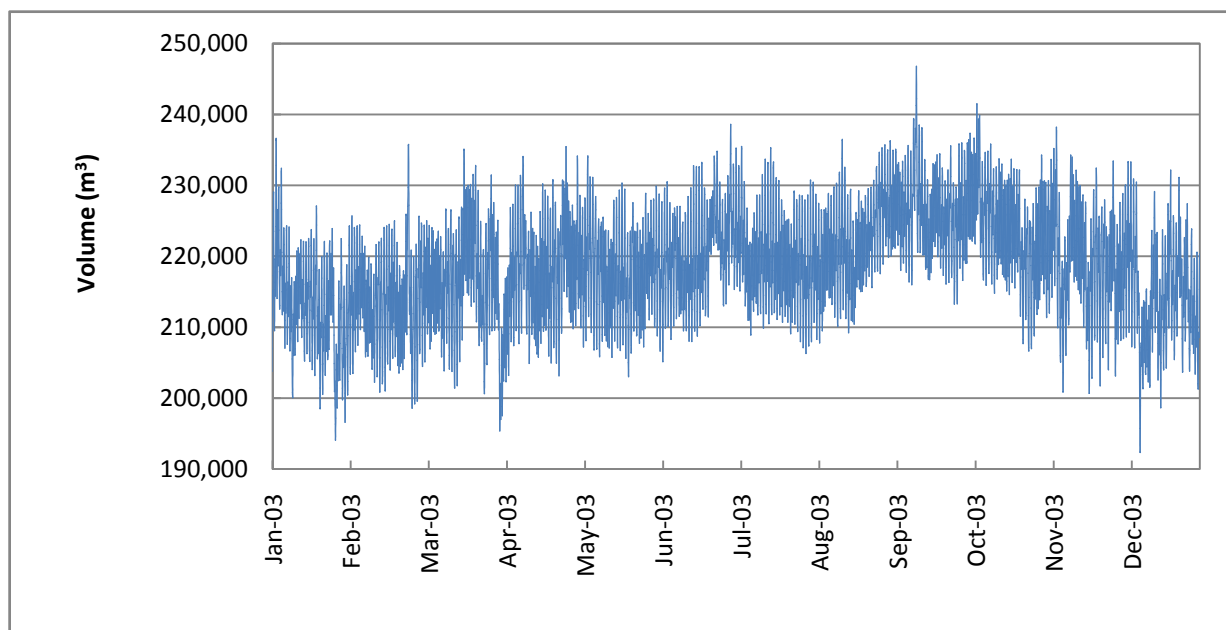


Figure 5-141 Caloosahatchee River upstream EFDC volume derived boundary conditions

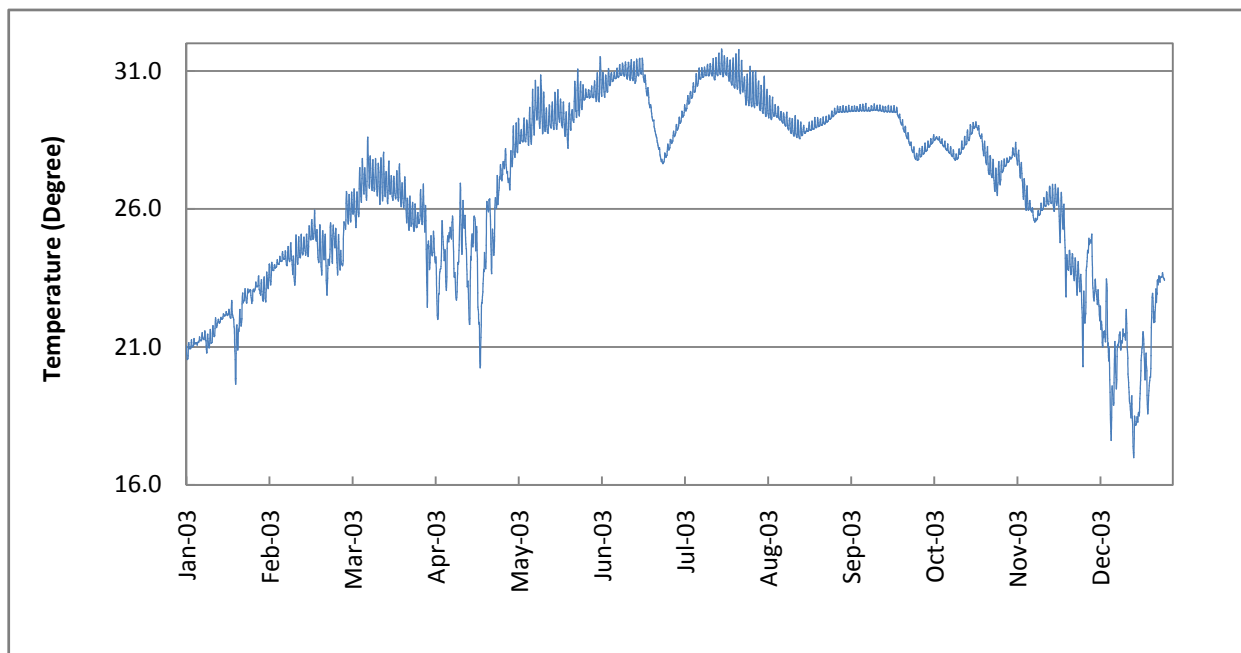


Figure 5-142 Caloosahatchee River upstream EFDC temperature derived boundary conditions

In addition to the upstream boundary location at S-79, the WASP model requires similar boundary conditions for assignment from the EFDC model at the south, west and north open boundaries. Segment volume, temperature, and salinity time series for a surface segment on the South Gulf of Mexico boundary condition are shown in **Figures 5-143 through 5-145**.

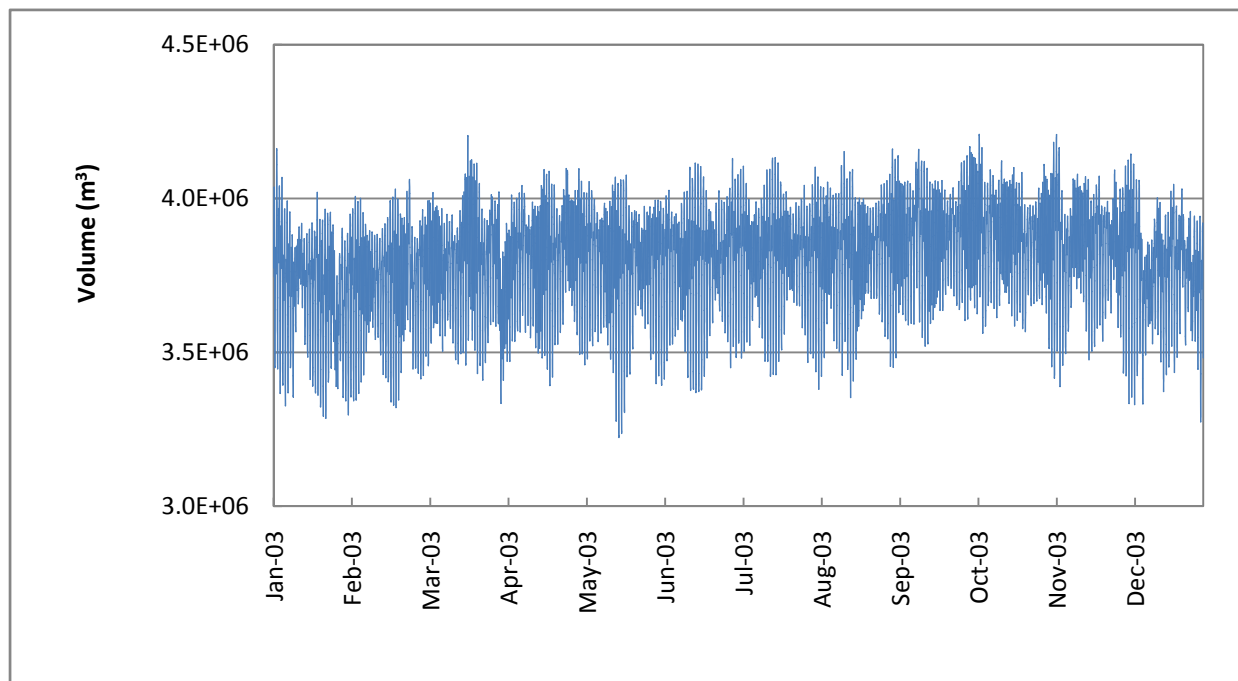


Figure 5-143 Caloosahatchee River Open Boundary EFDC volume derived boundary conditions

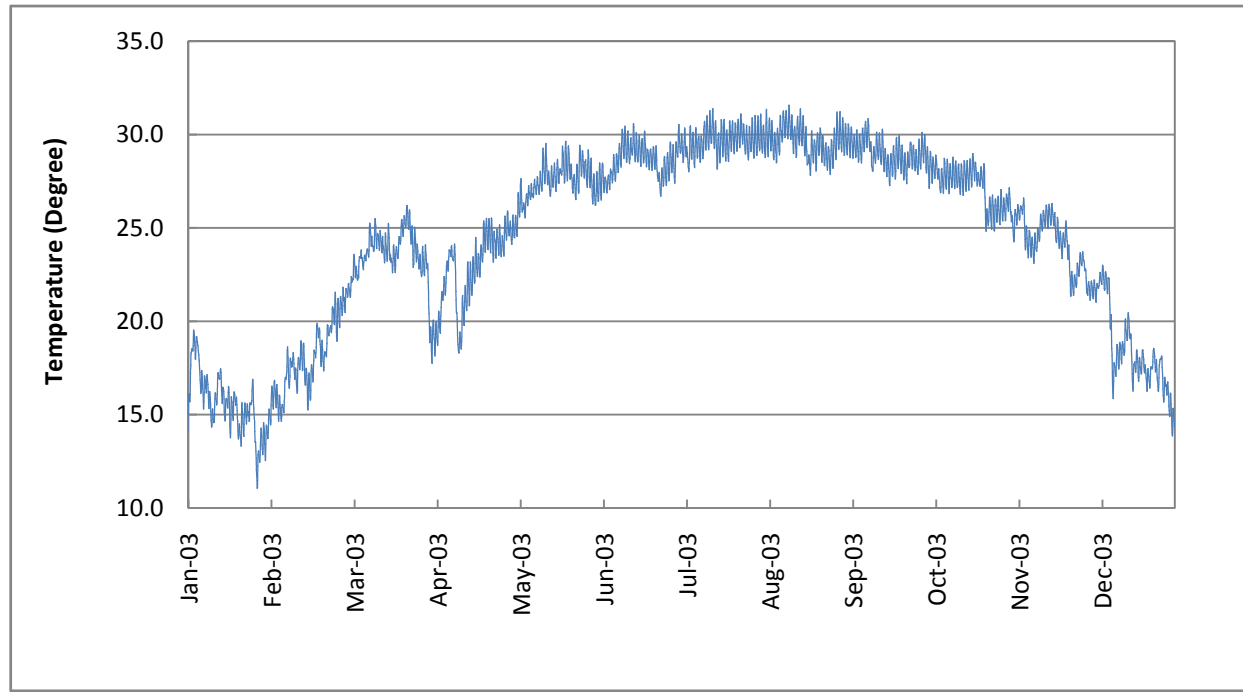


Figure 5-144 Caloosahatchee River Open Boundary EFDC temperature derived boundary conditions

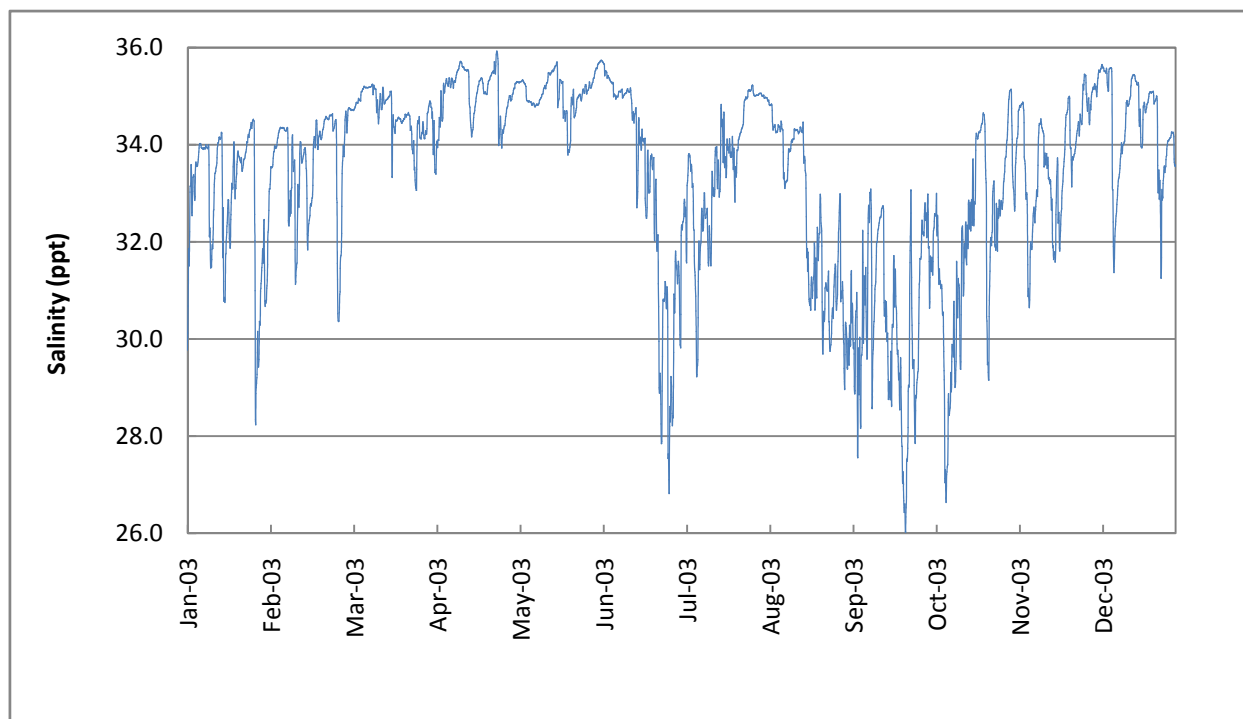


Figure 5-145 Caloosahatchee River Open Boundary EFDC salinity derived boundary conditions

5.4.1.2.2 Water Quality Boundary Conditions

The water quality boundary information required for input to the WASP model includes time series concentrations of Ammonia, Nitrate, Organic Nitrogen, Organic Phosphate, Orthophosphate, Phytoplankton Chl-a, Dissolved Oxygen, CBOD1, Detrital Carbon, Detrital Nitrogen, and Detrital Phosphorous. Water quality boundary conditions are assigned for the upstream boundary at the S-79 Franklin Lock & Dam and the open water boundary for the Gulf of Mexico, Pine Island Sound and Matalacha Pass.

The Caloosahatchee River tidal estuary WASP model uses the water quality information from both the S-79 and CES01 monitoring stations to assign the upstream river boundary conditions. As examples of the WASP upstream boundary inputs, **Figures 5-146 and 5-147** show the surface layer boundary conditions of Dissolved Oxygen and Nitrate concentrations at the upstream segment at S-79.

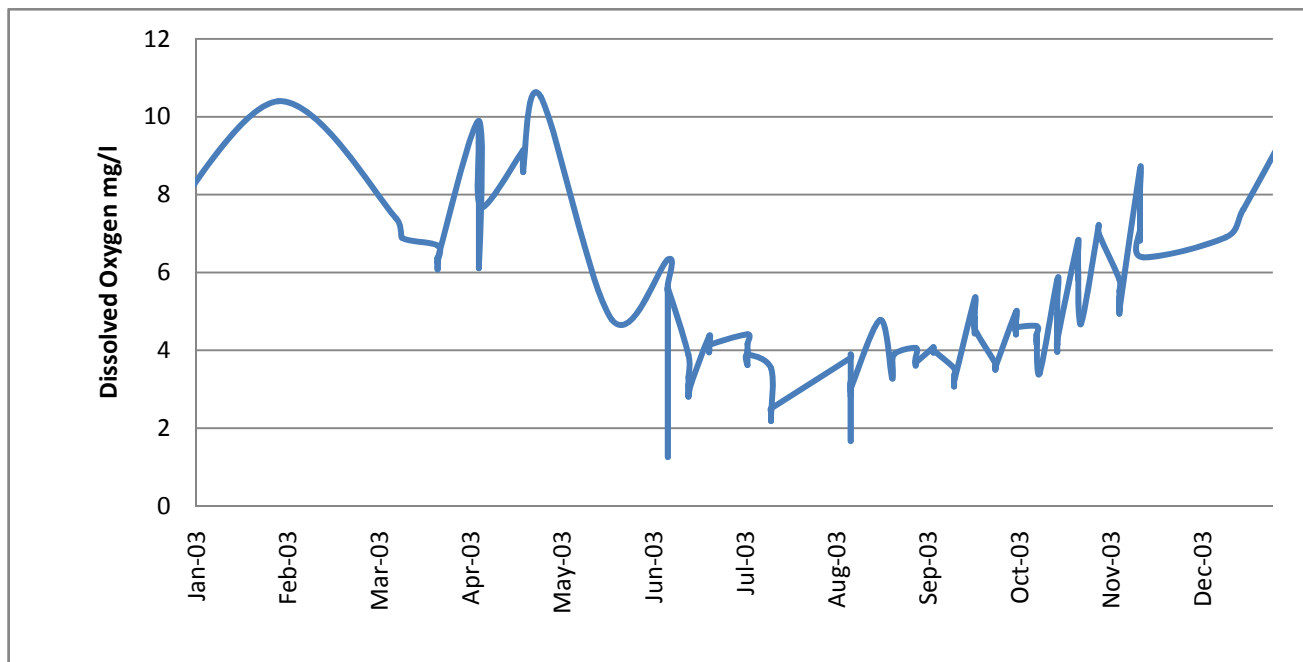


Figure 5-146 Caloosahatchee River upstream DO boundary concentration

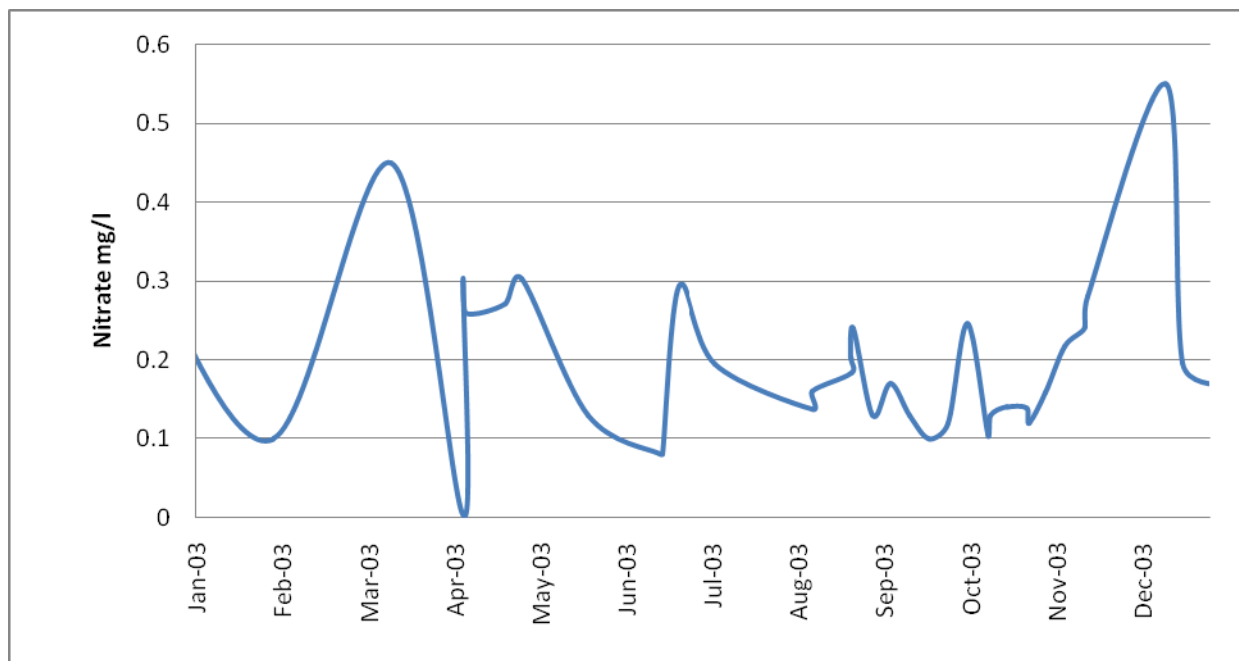


Figure 5-147 Caloosahatchee River upstream Nitrate boundary concentration

For the coastal open water boundary of the Gulf of Mexico, limited data are available. The water quality boundary information was derived from data extracted from the NOAA NODC World Ocean database (WOD05) for the Gulf of Mexico in the vicinity of the Caloosahatchee estuary (http://www.nodc.noaa.gov/OC5/WOD05/pr_wod05.html). As an example of the open water boundary conditions, the time series concentrations for the calibration period of October 2002 to November 2003 are plotted for Dissolved Oxygen (**Figure 5-148**) and Nitrate (**Figure 5-149**).

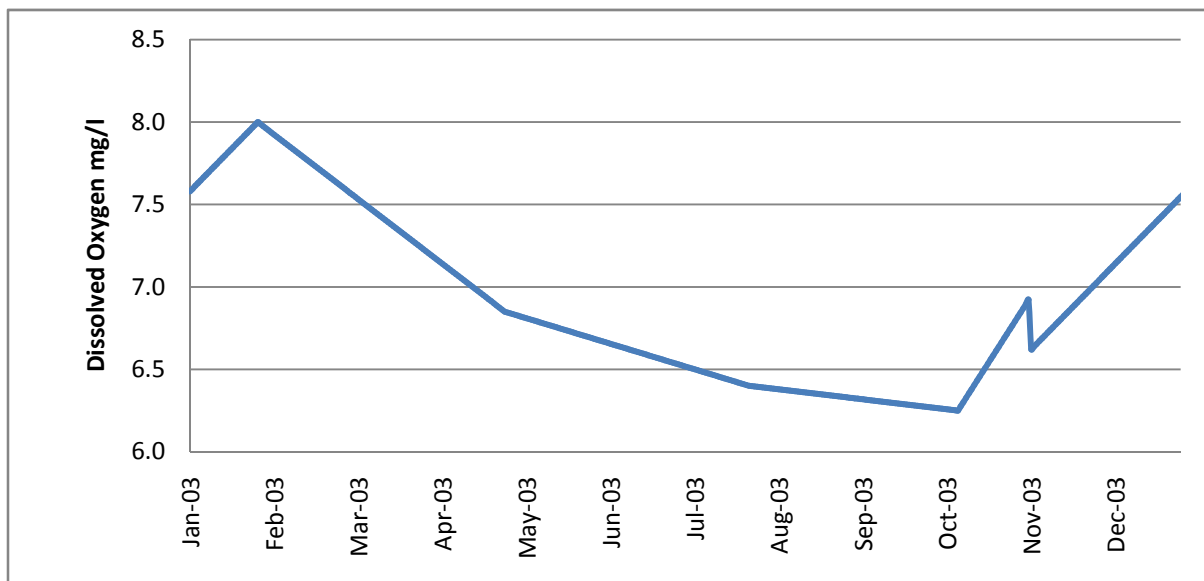


Figure 5-148 Coastal DO boundary concentration

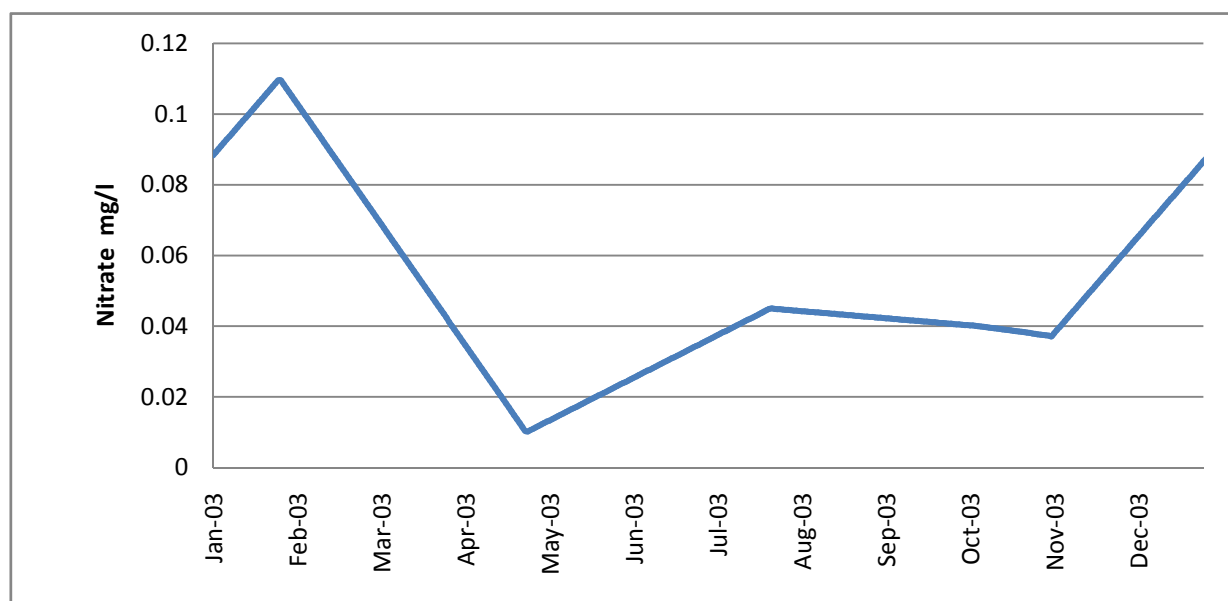


Figure 5-149 Coastal Nitrate boundary concentration

5.4.1.3 Model Simulation Periods

The period selected for WASP model simulation was from January 1, 2003 to December 31, 2003. During this period there exists a good overlap of all the salinity, temperature, and water quality and meteorology data to define both the initial conditions and boundary conditions. Data are also available for this period to support model calibration.

5.4.2 WASP Model Verification

Initial conditions were set as a fixed constant value for each WASP state variable at all segments in the domain from the upstream boundary to the coastal open water boundary at each layer. The model required several days “spin-up” to allow the initial conditions assigned for all model state variables to become well distributed by circulation processes. A map of the spatial nitrate distribution after one month simulation is presented as **Figure 5-150**. The figure shows that a high concentration of upstream water could influence the nutrients and dissolved oxygen concentration in the lower reaches of the estuary. It is very clear that the WASP model is setup and running correctly with the hydrodynamic linkage and water quality forcing from observed data sets. The model responds well to the hydrodynamics and flow boundary information provided by the EFDC linkage. If there is no flow information, the WASP model won't run and the concentration values of all the segments would be the same value for each simulated water quality variable, such as nitrate and Dissolved Oxygen. The spatial distribution of Dissolved Oxygen was also plotted and is presented as **Figure 5-151**.

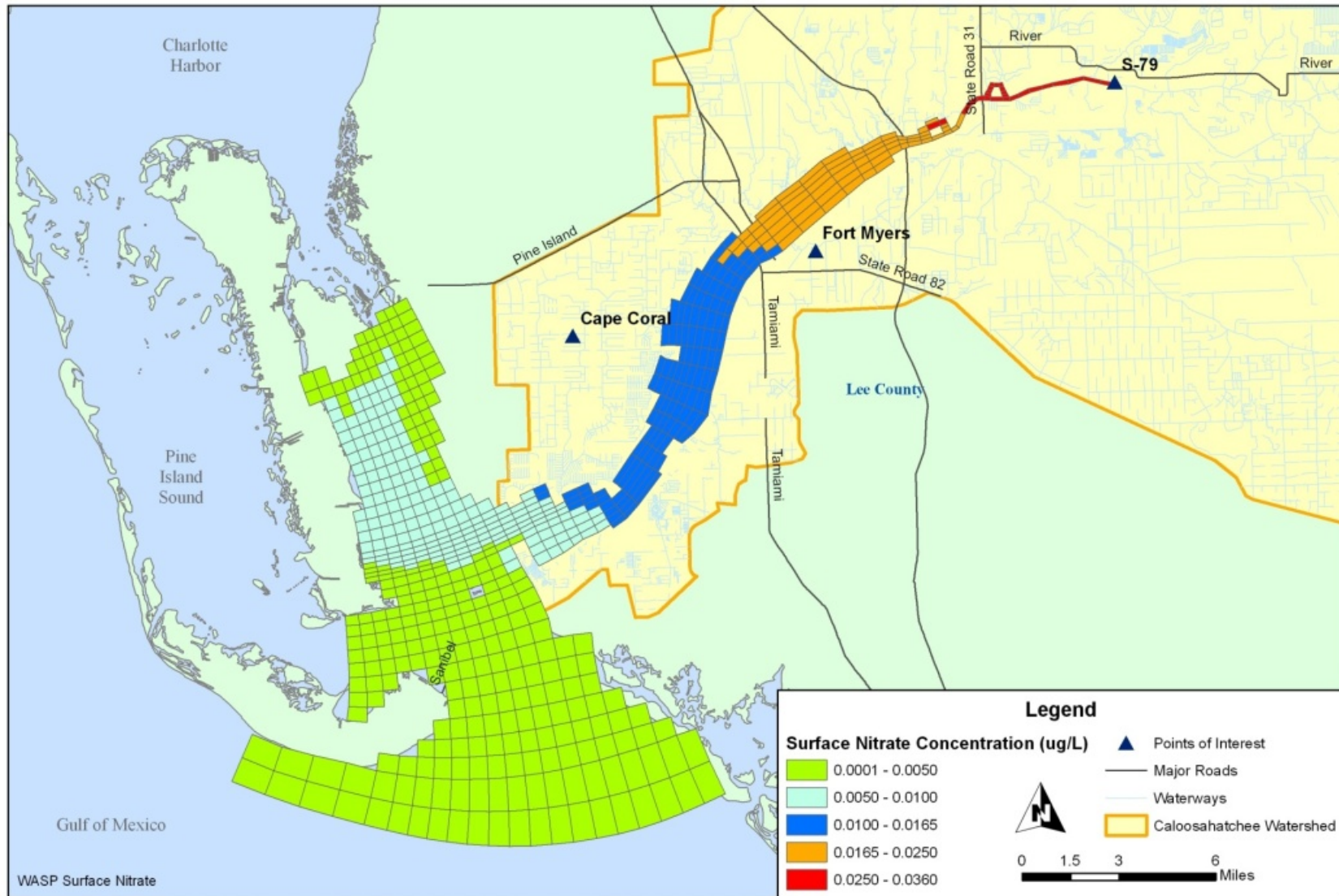


Figure 5-150 Spatial Nitrate distribution (in mg/l) after 1 month simulation

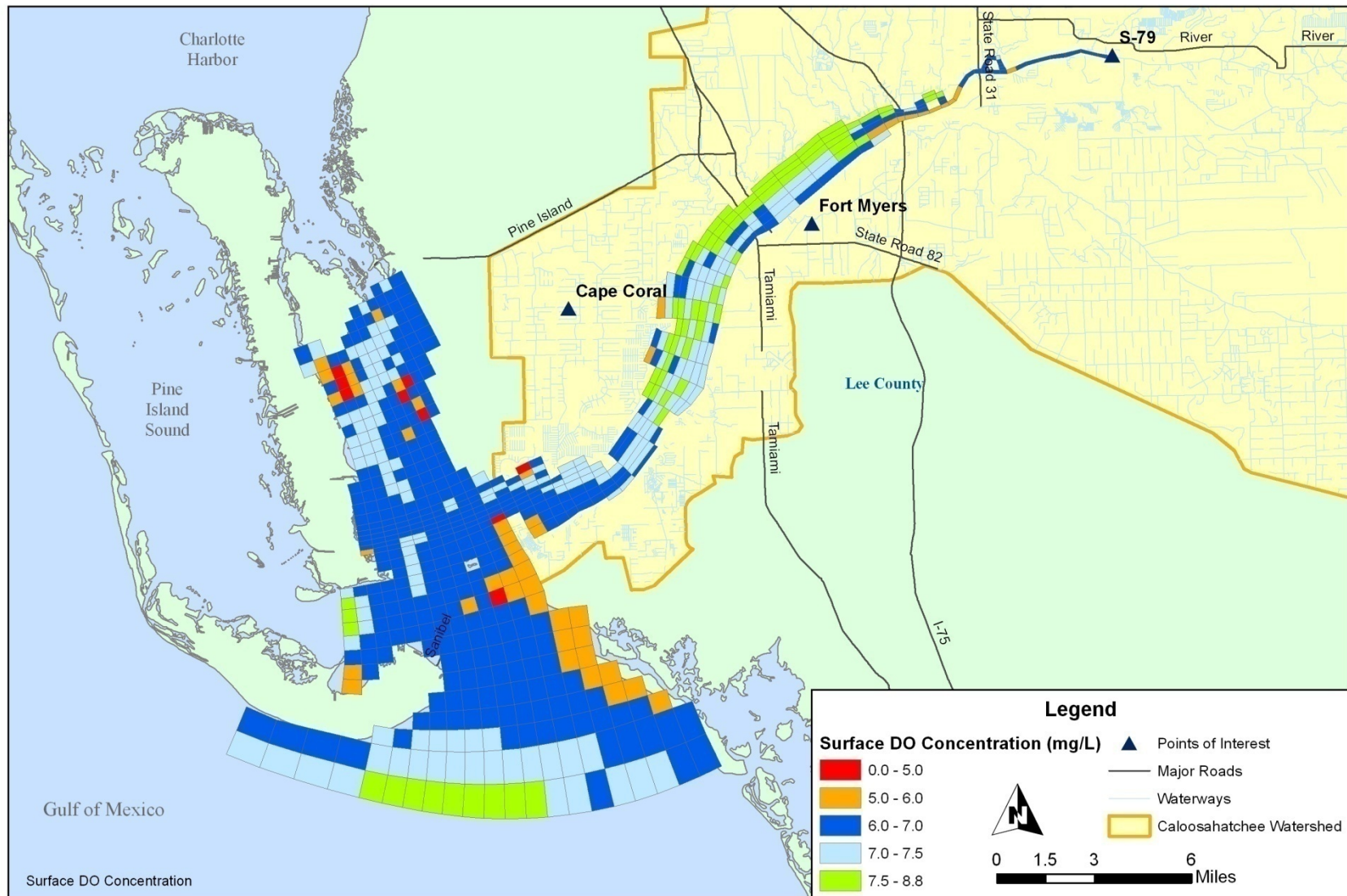


Figure 5-151 Spatial DO distribution (in mg/l) after 1 month simulation

In addition to the spatial distributions of these constituents shown above, time series plots of dissolved oxygen and nitrate are shown in **Figures 5-152 and 5-153** for the SFWMD CES-07 monitoring station. The location of CES-07 in the model domain is shown on the map of the entire model grid (see **Figure 5-140**). Based on these example time series results generated with the WASP model, it is clear that the WASP model is setup and running correctly with the hydrodynamic linkage and the water quality boundary conditions and other input data required to drive the WASP water quality model. If there were no source or sink terms for nutrients or dissolved oxygen, the time series values for these state variables would continue to decrease continuously with time. The dissolved oxygen values are seen to decrease in the summer and begin to increase again in the fall and winter, which is consistent with typical observations in an estuary such as the Caloosahatchee. The nitrate concentration is seen to fluctuate seasonally and depicts the WASP model responding to the water quality inputs and hydrodynamics forcing. These example spatial maps and time series plots for nitrate and dissolved oxygen demonstrate that that the (a) hydrodynamic information is passing correctly from EFDC to the WASP model and (b) the WASP model is receiving the nutrient and DO input data as expected.

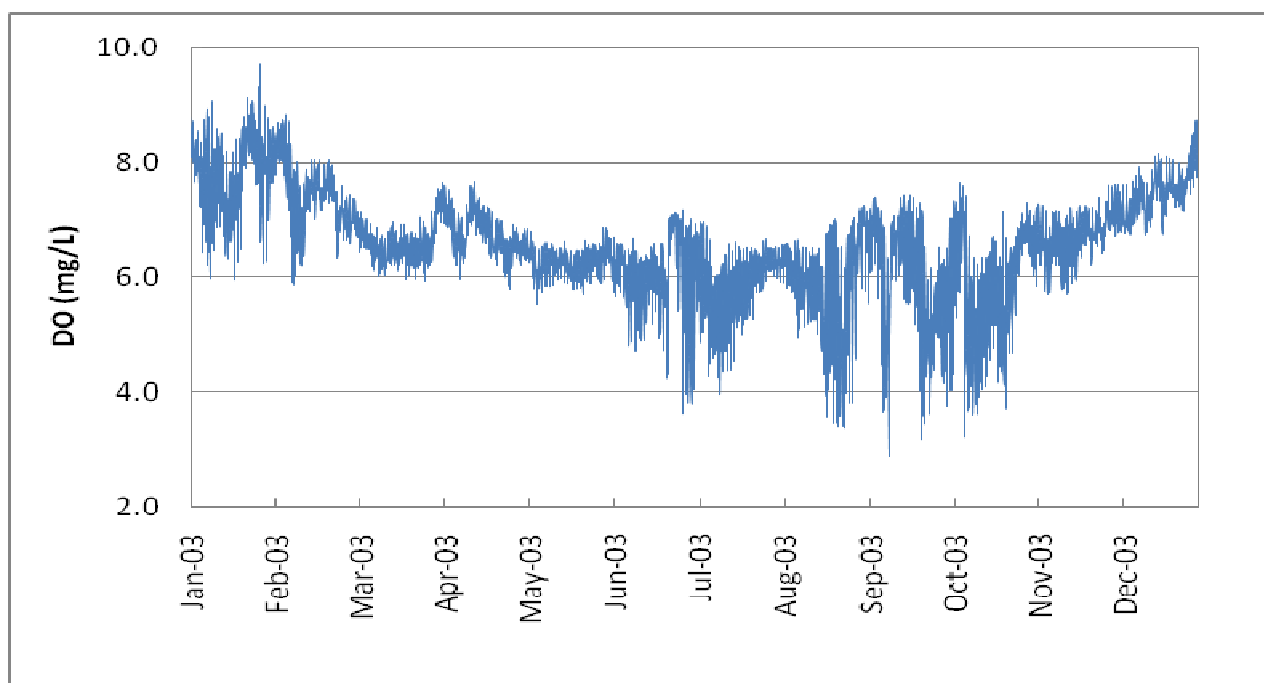


Figure 5-152 Station CES07 time series dissolved oxygen simulation.

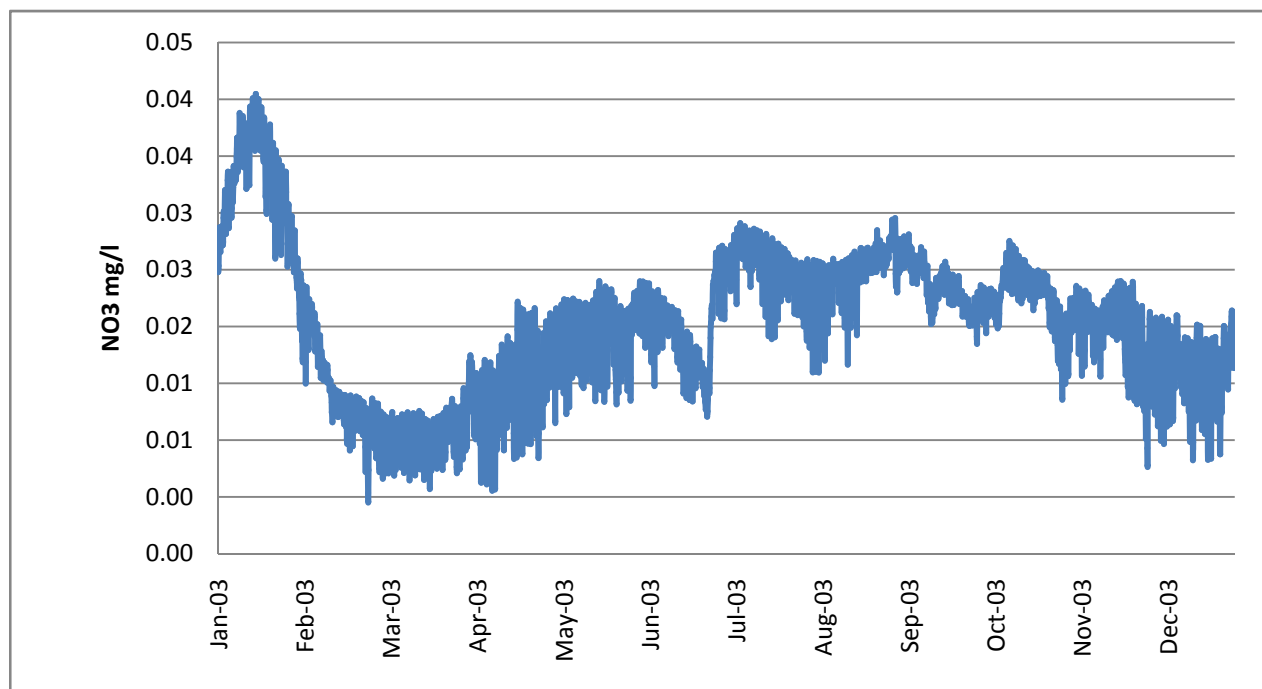


Figure 5-153 Station CES07 time series Nitrate simulation

5.4.2.1 Conservation of Mass

The hydrodynamic results from the EFDC model provide flow, volume, salinity and temperature data for linked input to the WASP model. Since mass conservation has already been checked for the EFDC model, mass conservation will also be satisfied for the WASP model.

5.4.2.2 Numerical Stability

The computational stability of the numerical solution techniques used in both EFDC and WASP is controlled by (a) the simulated distribution of velocity and dispersive mixing generated by the EFDC hydrodynamic model and (b) the modeler's specifications of the integration time step and the length, width and depth of each grid segment. In building the EFDC model, the integration step was adjusted as needed to achieve a stable solution with the hydrodynamic model.

In the WASP model, numerical stability of the model results are tested by comparison of the model results to "maximum allowed" values assigned by the modeler for each water quality state variable. If the WASP simulation results exceed the "maximum allowed" concentration at any time during the model run, the model stops and a warning message is provided to the modeler to check the setup of the WASP model. If the WASP model results, were, in fact, unstable but simulated concentrations did not exceed the "maximum allowed" concentration for a state variable the model would not stop with a warning message. The time series results for an unstable model would, however, exhibit erratic oscillations with concentrations fluctuating

from very high to very low values in the characteristic “sawtooth” pattern indicative of numerical instability.

In the simulations presented here, the maximum concentration for each water quality state variable was set to an arbitrary value of 100 units. As can be seen in the example time series plots, the WASP model is stable for the one year simulation period. The numerical stability is acceptable for a WASP model that has been driven using the hydrodynamic linkage file generated by the EFDC model of the Caloosahatchee estuary.

5.4.3 Preliminary Sensitivity Analysis

An initial analysis was conducted to evaluate sensitivity of predicted water quality in the Caloosahatchee to various parameters and loadings. For this preliminary sensitivity analysis, three different sediment oxygen demand (SOD) values were tested. These three cases were for 0.5 g/square meter/day SOD, 1 g/square meter/day SOD, and 2 g/square meter/day SOD. It was found that phytoplankton Chl a, ammonia, and orthophosphate experienced relatively small changes under these three cases. Both nitrate and dissolved oxygen were found to be responsive to varying levels of SOD. **Figure 5-154**, below, depicts the model's nitrate concentration response to the three SOD settings. DO was found to be very sensitive to variation in the setting of SOD. **Figure 5-155**, below, depict this sensitivity.

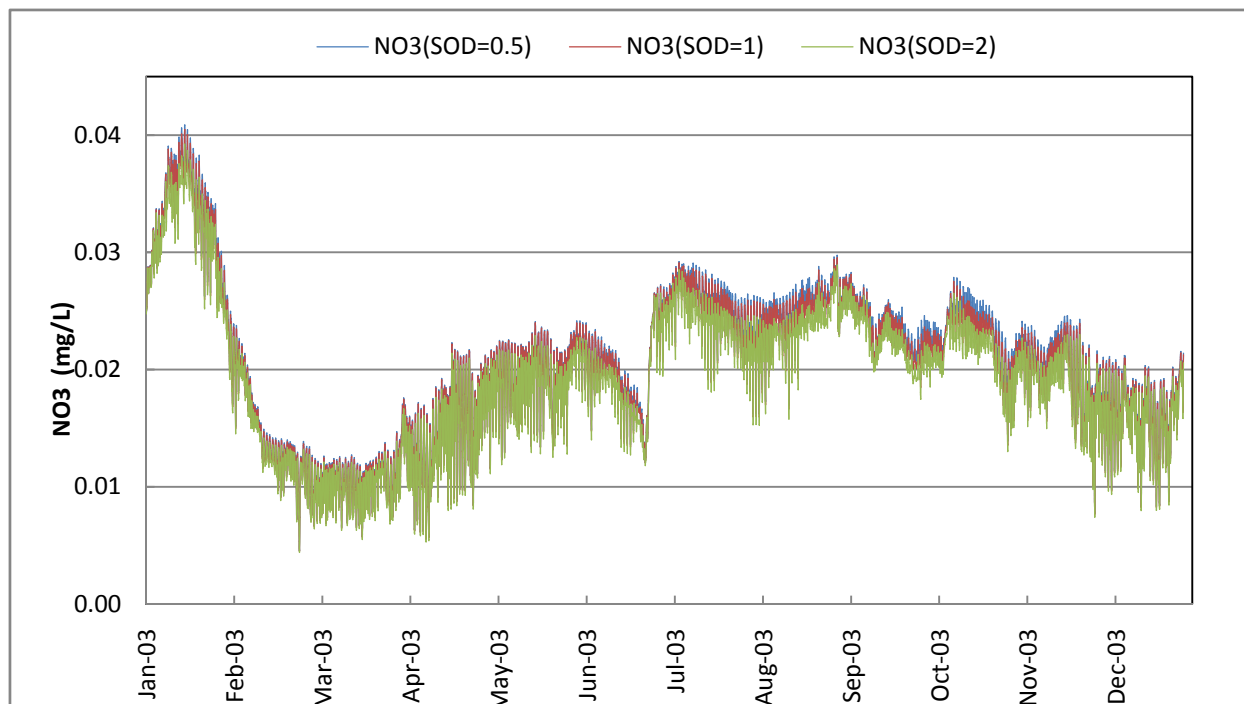


Figure 5-154 Sensitivity of Nitrate to variations in SOD

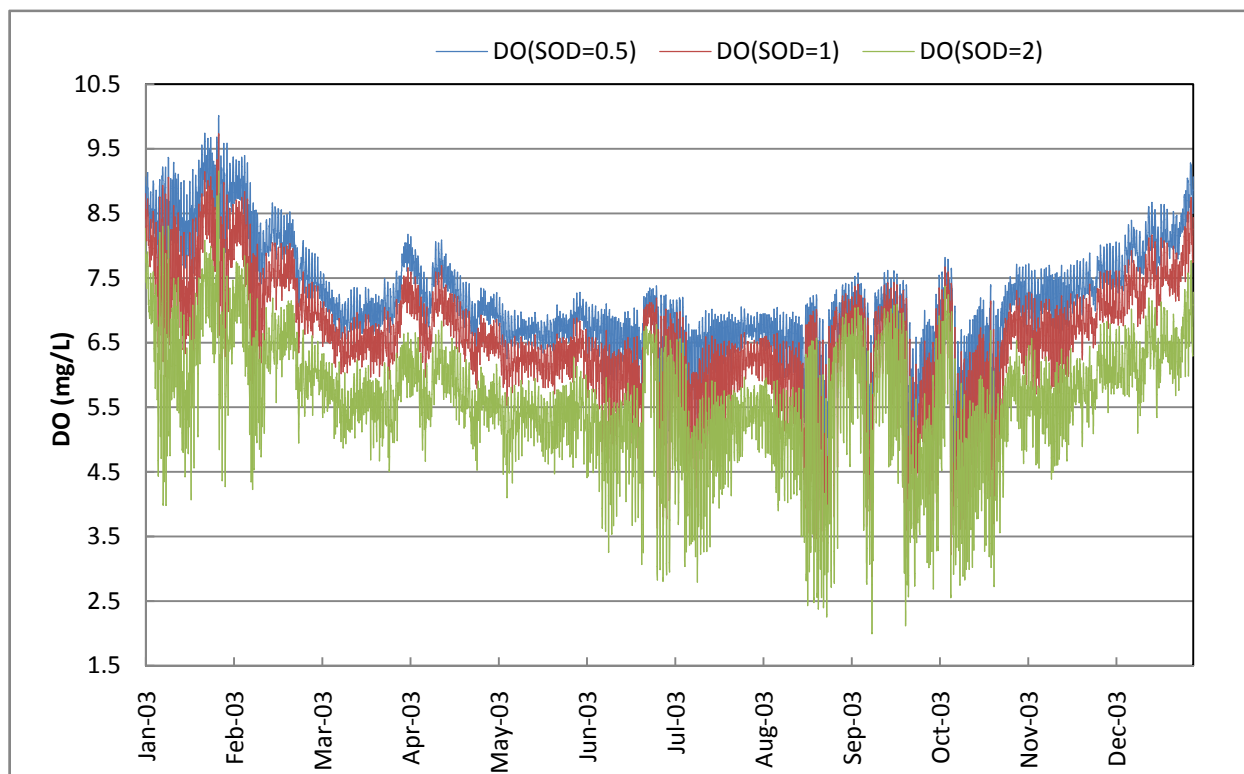


Figure 5-155 Sensitivity of Dissolved Oxygen to variations in SOD

5.4.4 Overview of the WASP7 Water Quality Model

The current version (7.2) of the eutrophication module of the Water Quality Analysis Simulation Program (WASP) represents a Windows-based upgrade and kinetic enhancement of earlier versions of the original WASP models (WASP3: Di Toro et al., 1983; WASP4: Ambrose et al., 1988; WASP5: Ambrose et al. 1993; and WASP6: Wool et al., undated). The time variable WASP model allows for the spatial representation of a water body as 1D, 2D or 3D network of horizontal segments and vertical layers. Although WASP7 does include an internal 1D kinematic wave model to simulate stream and river hydrodynamics, 2D and 3D hydrodynamic transport data must be provided by linkage with the EFDC hydrodynamic model to input flow, segment depths, interface areas and volumes, velocity and dispersive mixing.

5.4.5 Methodology for Development of the WASP7 Model for the Caloosahatchee Estuary

Development of the WASP7 model for the Caloosahatchee Estuary requires input data for the following categories of information:

- Data Set Description and Model Control Parameters
- Systems
- Segments
- Flows
- Exchanges
- Boundary Conditions
- Parameters
- Point Source Loads
- Time Functions
- Kinetic Constants
- Output Controls
- Initial Conditions

5.4.5.1 Data Set Description and Model Control Parameters

Model control parameters specify the beginning and ending calendar date and 24 hr clock /times for the simulation model; the source of the hydrodynamic data; and the numerical solution method. For the Caloosahatchee estuary model, 3D hydrodynamic data is simulated with EFDC with the results linked for input to WASP7.

5.4.5.2 Systems

In WASP7, systems are the state variables of the model. The eutrophication module of WASP7 includes the state variables shown in **Table 5-30**. The table shows the status of the state variable (simulated or bypassed) and the solids field (1,2, or 3) that is used to represent particle settling for the state variable. As shown in the table, the sixteen (16) systems of the WASP7 eutrophication model include non-living detrital particulate organic matter as carbon (POC),

nitrogen (PON) and phosphorus (POP); dissolved organic matter as CBOD (CBOD1, CBOD2, and CBOD3); nitrogen (DON) and phosphorus (DOP); dissolved oxygen, inorganic nutrients as ammonia; nitrate + nitrite and total orthophosphate; algae biomass (as chlorophyll-a); salinity; and inorganic suspended solids. The state equations, interactions and kinetics of the state variables represented in the eutrophication model are documented in the user's manuals for WASP5 (Ambrose et al., 1993) and WASP6 (Wool et al., undated). Enhancements to the WASP7 model that are not included in WASP5 or WASP6 are documented in technical release notes for WASP7 (EPA, 2006; 2007).

Table 5-30 WASP7 systems (state variables) of the eutrophication model

System Data			
	System	Option	Particulate
			Transport Field
1	Ammonia (mg/L)	Simulated	Solids 1
2	Nitrate (mg/L)	Simulated	Solids 1
3	Organic Nitrogen (mg/L)	Simulated	Solids 1
4	Orthophosphate (mg/L)	Simulated	Solids 1
5	Organic Phosphorus (mg/L)	Simulated	Solids 1
6	Phytoplankton Chla (ug/L)	Simulated	Solids 2
7	Dissolved Oxygen (mg/L)	Simulated	Solids 1
8	CBOD 1 (Ultimate) (mg/L)	Simulated	Solids 1
9	CBOD 2 (Ultimate) (mg/L)	Bypassed	Solids 1
10	CBOD 3 (Ultimate) (mg/L)	Bypassed	Solids 1
11	Detrital Carbon (mg/L)	Simulated	Solids 3
12	Detrital Nitrogen (mg/L)	Simulated	Solids 3
13	Detrital Phosphorus (mg/L)	Simulated	Solids 3
14	Solids (mg/L)	Simulated	Solids 1
15	Salinity (ppt)	Simulated	Solids 1
16	(not used)	Simulated	Solids 1

5.4.5.3 Segments

Control volumes, or model segments, are developed to represent the shoreline, open boundaries and bathymetric characteristics of a waterbody as a connected network of 'boxes'

defined by length, width, depth, interface areas and volume of each segment. WASP7 is designed to allow a model developer to construct a network of completely mixed segments to represent the horizontal and vertical domain of a waterbody. WASP7 is considered flexible in that the connectivity of segments within the network are specified by the model developer. Although segment properties are obviously defined and compiled from spatial outlines and bathymetric data taken from physical maps and charts, the segment network data used in WASP7 is not defined on the basis of a real-world XYZ coordinate systems (e.g., UTM Northing and Easting data; bottom elevation).

For the WASP7 model of the Caloosahatchee estuary, the results linked from the EFDC hydrodynamic model provide the data needed by WASP7 to assign model control parameters for starting/ending date and time of the simulation; hydrodynamic time step; segment volumes; interface areas and layer thicknesses; and the segment connectivity of the Caloosahatchee estuary model. The EFDC domain for the Caloosahatchee estuary model was represented with 733 horizontal grids and 4 vertical layers for a total of 2,932 grid cells (see Figure 2 and 3). Since the WASP7 model excludes the outer rows of the open water boundary grid cells included in the EFDC domain, the WASP7 model includes 701 horizontal segments and 4 vertical layers for a total of 2,804 segments. **Table 5-31** shows a representative data table for the first 11 of the 2,804 segments defined by the EFDC Caloosahatchee estuary hydrodynamic model. A discussion of the hydrodynamic linkage between EFDC and WASP7 is given in Section 5.4.1 of this report.

Table 5-31 WASP7 surface layer model segments for the Caloosahatchee Estuary

Segments									
Segments Parameters Initial Concentrations Fraction Dissolved									
Segment	Description	Volume	Velocity Multiplier	Velocity Exponent	Depth Multiplier	Depth Exponent	Segment Type	Bottom Segment	
1	I=3 J=4 K=4	3.58259E+6	0.0000	0.0000	1.5990	0.0000	Surface	702: I=3 J=4 K=3	
2	I=4 J=4 K=4	3.65337E+6	0.0000	0.0000	1.6027	0.0000	Surface	703: I=4 J=4 K=3	
3	I=5 J=4 K=4	4.1044E+6	0.0000	0.0000	1.7728	0.0000	Surface	704: I=5 J=4 K=3	
4	I=6 J=4 K=4	4.05281E+6	0.0000	0.0000	1.8285	0.0000	Surface	705: I=6 J=4 K=3	
5	I=7 J=4 K=4	3.03433E+6	0.0000	0.0000	1.8655	0.0000	Surface	706: I=7 J=4 K=3	
6	I=8 J=4 K=4	2.80792E+6	0.0000	0.0000	1.9188	0.0000	Surface	707: I=8 J=4 K=3	
7	I=9 J=4 K=4	2.93682E+6	0.0000	0.0000	2.0155	0.0000	Surface	708: I=9 J=4 K=3	
8	I=10 J=4 K=4	3.03726E+6	0.0000	0.0000	2.0048	0.0000	Surface	709: I=10 J=4 K=3	
9	I=11 J=4 K=4	3.26352E+6	0.0000	0.0000	2.0160	0.0000	Surface	710: I=11 J=4 K=3	
10	I=12 J=4 K=4	3.45625E+6	0.0000	0.0000	2.0322	0.0000	Surface	711: I=12 J=4 K=3	
11	I=13 J=4 K=4	3.51228E+6	0.0000	0.0000	1.9935	0.0000	Surface	712: I=13 J=4 K=3	

Fill/Calc

Copy

Paste

Volume Scale Factor

1.0000000

Volume Conversion Factor

1.0000000

Insert

Delete

OK

Cancel

5.4.5.4 Flows and Exchanges

Surface water flows, velocities and dispersive exchanges in the horizontal and vertical domain that are simulated by the EFDC hydrodynamic model (see Figures 27 and 28) are linked for input to WASP7 with the EFDC-generated *.HYD file. In EFDC, water column mixing processes accounted for by molecular diffusivity and turbulent diffusion are simulated to compute concentration gradient based mass fluxes of a constituent across the horizontal and vertical interfaces of the model domain. The EFDC hydrodynamic model computes horizontal and vertical dispersion coefficients that are linked for input to WASP7 in the *.HYD file as 'exchange' data.

The time step of 11 seconds that is used for the EFDC Caloosahatchee model to satisfy numerical stability criteria must also be used for the WASP7 eutrophication model. Hydrodynamic data is provided to WASP7 based on an averaging of EFDC hydrodynamic results for 600 time steps of 11 seconds (110 minutes). With a 600:1 hydrodynamic to water quality averaging interval, transport data is updated in the WASP7 model at an interval of 1.83 hrs. On a modern fast PC (dual core Pentium processor with a chip speed of 2.67 GHz), a one-year simulation for the EFDC hydrodynamic, sediment transport and water quality model requires a runtime of 7.5 to 8 hrs. The same one-year simulation for the WASP7 water quality model required a much longer runtime of about 27 to 28 hrs.

WASP7 represents settling of particulate materials in the water quality model as a component of the transport sub-model for state variables assigned to Solids Fields 1, 2 and 3. Constant settling velocities are assigned for the Caloosahatchee estuary model as follows: (1) Solids Field 1 $Ws1=0.086$ m/day (inorganic suspended solids); (2) Solids Field 2 $Ws2=0.04$ m/day (algae); and (3) Solids Field 3 $Ws3=0.4$ m/day (detrital organic matter). **Table 5-32** shows a portion of the data table used to define Solids 2 settling from the bottom water column layer to a surface sediment bed layer.

Table 5-32 WASP7 flows and settling for solids fields 1, 2 and 3

Flow Fields				
Field	Used	Scale	Conversion	
Surface Water	☒	1.0000000	1.0000000	
Pore Water	☒	1.0000000	1.0000000	
Solids 1	☒	1.0000000	0.0000116	
Solids 2	☒	1.0000000	0.0000116	
Solids 3	☒	1.0000000	0.0000116	
Evaporation/Precipitation	☒	1.0000000	1.0000000	

Solids 2 functions		
Function		
Flow Function		

Segment pairs for Solids 2, Flow Function			
From	To	Frac. of flow	
2797: I=14 J=43 K=1	2805: Surface Bed	276700.000000	
2798: I=15 J=43 K=1	2805: Surface Bed	275800.000000	
2799: I=16 J=43 K=1	2805: Surface Bed	277100.000000	
2800: I=17 J=43 K=1	2805: Surface Bed	311100.000000	
2801: I=18 J=43 K=1	2805: Surface Bed	474700.000000	
2802: I=16 J=44 K=1	2805: Surface Bed	270300.000000	
2803: I=17 J=44 K=1	2805: Surface Bed	297000.000000	
2804: I=18 J=44 K=1	2805: Surface Bed	468600.000000	

Time/value pairs for Solids 2, Flow Function		
Date	Time	Value
1/1/2003	0:00	4E-2
1/1/2005	0:00	4E-2

Data required to simulate particle settling include the upper/lower layer segment pair and the horizontal surface area of the upper/lower interface. A linkage file was written for this project to provide the segment pair and surface area data needed to represent solids settling. The solids transport data is automatically imported into the WASP7 project file using a hardwired filename (WASPD.MRM) that must be located in the same sub-directory as the EFDC *.HYD linkage file. The solids transport file must be written in the same "Data Group D" record structure format used in Wasp5 for solids (see Ambrose et al., 1993). A surface sediment bed layer that underlies the entire model domain must also be added to the segment table to provide a destination pathway for solids settled out of the water column to the sediment bed. **Table 5-33** shows the portion of the WASP7 segment table where Segment 2805 (N=2804 +1) is defined in the data table as a surface benthic layer segment. The volume and depth multiplier values shown in the table are computed from the horizontal surface of the entire model domain and a thickness of 0.1 meters.

Table 5-33 WASP7 subsurface layer model segments for the Caloosahatchee Estuary

Segments								
Parameters Initial Concentrations Fraction Dissolved								
Segment	Description	Volume	Velocity	Velocity	Depth	Depth	Segment	Bottom
			Multiplier	Exponent	Multiplier	Exponent	Type	Segment
2794	I=17 J=42 K=1	1.20411E+5	0.0000	0.0000	0.3753	0.0000	Subsurface	None
2795	I=18 J=42 K=1	6.3115E+3	0.0000	0.0000	0.0132	0.0000	Subsurface	None
2796	I=13 J=43 K=1	2.46998E+4	0.0000	0.0000	0.0885	0.0000	Subsurface	None
2797	I=14 J=43 K=1	6.46844E+4	0.0000	0.0000	0.2338	0.0000	Subsurface	None
2798	I=15 J=43 K=1	6.48783E+4	0.0000	0.0000	0.2352	0.0000	Subsurface	None
2799	I=16 J=43 K=1	1.57919E+5	0.0000	0.0000	0.5700	0.0000	Subsurface	None
2800	I=17 J=43 K=1	1.0174E+5	0.0000	0.0000	0.3270	0.0000	Subsurface	None
2801	I=18 J=43 K=1	7.59542E+3	0.0000	0.0000	0.0160	0.0000	Subsurface	None
2802	I=16 J=44 K=1	1.60742E+5	0.0000	0.0000	0.5947	0.0000	Subsurface	None
2803	I=17 J=44 K=1	1.03867E+5	0.0000	0.0000	0.3498	0.0000	Subsurface	None
2804	I=18 J=44 K=1	1.54646E+4	0.0000	0.0000	0.0330	0.0000	Subsurface	None
2805	Surface Bed	1.289E+8	0.0000	0.0000	0.1000	0.0000	Surface benthic	None

Fill/Calc Copy Paste Volume Scale Factor 1.0000000 Volume Conversion Factor 1.0000000
 + Insert - Delete OK Cancel

5.4.5.5 Boundary Conditions

Boundary conditions are defined for the Caloosahatchee model to describe external loading from the Caloosahatchee River at S-79, tributaries of the watershed; wastewater loading from wastewater treatment plants with effluent discharges directly to the Caloosahatchee estuary; and open water exchange with the nearshore Gulf of Mexico on the south, Matlacha Pass to the north and Pine Island Sound to the west. With the four layers of the model and the HSPF and wastewater inflows and the open water boundary groups, there are a total of 264 boundary segments defined for input to the Caloosahatchee estuary EFDC and WASP7 models. Boundary groups for individual segment inflows are defined for 29 HSPF locations and 5 wastewater discharges (see Table 4). Boundaries for the three open water boundary groups are defined with multiple grid cells for the south Gulf of Mexico boundary (N=21 cells); west Pine Island Sound boundary (N=5 cells); and north Matlacha Pass boundary (N=6 cells). The location of these 37 boundary groups is shown in Figure 4 in the discussion of the EFDC hydrodynamic model in Section 5.3.1.6. A discussion of the data sources, procedures and assumptions used for the linkage of HSPF results, wastewater effluent and open water boundary data sets for input to EFDC is given in Section 5.3.1.6.2 of this report.

The state variables and units of the WASP7 eutrophication model are listed in **Table 5-34**.
 WASP7 State Variables and Units

Table 5-34 WASP7 state variables and units

Sys#	State Variable Group	Description	Name	Units
0	Flow	EFDC HYD linkage	FLOW	m**3/sec
0	Water Temperature	EFDC HYD linkage	WTEM	Deg-C
1	Inorganic-Nitrogen	Ammonia-N	NH4N	mg-N/L
2	Inorganic-Nitrogen	Nitrate-N+Nitrite-N	NO23N	mg-N/L
3	Inorganic-Phosphorus	OrthoPhosphate-P	TPO4	mg-P/L
4	Total Water Column Algae	Water Column Algae Biomass	ALGAE	ug-Chl/L
5	BiochemicalOxygenDemand(Ultimate)	CBOD1	CBOD1	mg-O2/L
6	Dissolved Oxygen	Oxygen	DO	mg-O2/L
7	Organic-Nitrogen	Org-N	OrgN	mg-N/L
8	Organic-Phosphorus	Org-P	OrgP	mg-P/L
9	Salinity	EFDC HYD linkage	SAL	ppt
11	Detrital-Organic-Carbon	Detrital-Organic-Carbon	DETR_C	mg-C/L
12	BiochemicalOxygenDemand(Ultimate)	CBOD2	CBOD2	mg-O2/L
13	BiochemicalOxygenDemand(Ultimate)	CBOD3	CBOD3	mg-O2/L
14	Detrital-Organic-Nitrogen	Detrital-Organic-Nitrogen	DETR_N	mg-N/L
15	Detrital-Organic-Phosphorus	Detrital-Organic-Phosphorus	DETR_P	mg-P/L
16	Suspended Solids	Inorg SS(Cohesive+NonCohesive)	TSS	mg/L
10	Not Used	Not Used	Not Used	Not Used

The linkage, or mapping, of the HSPF and EFDC state variables as boundary condition input for the WASP7 state variables is as follows:

- System #1 WASP_NH3 = EFDC_NH3 = HSPF_NH3
- System #2 WASP_NO3 = EFDC_NO3 = HSPF_NO3
- System #3 WASP_TPO4 = EFDC_TPO4 = HSPF_PO4

Algae (HSPF results as dry weight (DW) biomass)

- System #4 WASP_ALGAE = HSPF_ALGAE (mg DW/L) * C/DW * 1/ (C/CHL)

Algae (Open boundary observed data as chlorophyll-a)

- System #4 WASP_ALGAE = OBS_ALGAE (ug Chl/L)
- System #5 WASP_CBOD1 = EFDC_DOC * O2/C (dissolved organic-C)
- System #6 WASP_Oxygen = EFDC_DOX = HSPF_Dissolved Oxygen
- System #7 WASP_ORGN = EFDC_DON (dissolved organic-N)
- System #8 WASP_ORGP = EFDC_DOP (dissolved organic-P)
- System #9 WASP_SALINITY = simulated in EFDC; linked with EFDC HYD file
- System #10 WASP_NOT_USED = 0.0
- System #11 WASP_DETRC = EFDC_RPOC + EFDC_LPOC (refractory + labile POM)
- System #12 WASP_CBOD2 = 0.0 (bypassed)

- System #13 WASP_CBOD3 = 0.0 (bypassed)
- System #14 WASP_DETRN = EFDC_RPON + EFDC_LPON (refractory + labile POM)
- System #15 WASP_DETRP = EFDC_RPOP + EFDC_LPOP (refractory + labile POM)
- System #16 WASP_TSS = EFDC [Cohesive +NonCohesive] SS = HSPF_SS [inorg SS]

Daily time series for the boundary condition data sets are written for the 264 boundary segments for the 16 state variables using an ASCII file format that must match the WASP5 format for boundary conditions (see Ambrose et al., 1993). Date and time assigned for the time series must be converted to time as Julian days relative to the start date/time for the WASP7 model run. The first entry for the boundary condition time series data sets must therefore be t=0. The boundary condition file is automatically imported into WASP7 if the boundary condition file is named BOUND.TXT and if the file is located in the same sub-directory as the EFDC *.HYD hydrodynamic linkage file.

5.4.5.6 Point Source Loads

As described above for boundary conditions, wastewater discharges are included as external boundary conditions in the linkage of HSPF, wastewater and open water boundary data. Wastewater loads are represented by the effluent flow rates and effluent concentrations extracted from Florida DEP effluent monitoring files. Point source loads (as mass/time) are thus not defined for the WASP7 model of the Caloosahatchee estuary.

5.4.5.7 Parameters

Parameters in WASP7 are used to specify spatial forcing functions for each segment of the model domain. **Table 5-35** identifies all the parameters available in the WASP7 eutrophication model. The boxes with 'X' shown in the table indicate those parameters "used" for the Caloosahatchee estuary model:

Table 5-35 WASP7 spatial parameters

Parameter data			
	Parameter	Used	Scale Factor
1	Segment Scale Factor for Wind	☒	1.0000
2	Wind Speed Time Function to use for Segment (1 or 2)	☐	1.0000
3	Water Velocity Function (1-4) for Segment (m/sec)	☐	1.0000
4	Temperature of Segment (Degrees C or Multiplier)	☒	1.0000
5	Temperature Time Function for Segment Temperature (1 - 4)	☒	1.0000
6	Light Extinction for Segment (Per Day or Multiplier)	☒	1.0000
7	Light Extinction Time Function to use for Segment	☒	1.0000
8	BOD(1) Decay Rate Scale Factor	☐	1.0000
9	BOD(2) Decay Rate Scale Factor	☐	1.0000
10	BOD(3) Decay Rate Scale Factor	☐	1.0000
11	Benthic Ammonia Flux (mg/m2/day)	☒	1.0000
12	Benthic Phosphate Flux (mg/m2/day)	☒	1.0000
13	Sediment Oxygen Demand (g/m2/day)	☒	1.0000
14	Sediment Oxygen Demand Temperature Correction Factor	☒	1.0000
15	Incoming Solar Radiation (Langleys/day)	☐	1.0000
16	Measured Segment Reaeration Rate (per day)	☐	1.0000
17	Zooplankton Population	☐	1.0000
18	Fraction Light Intercept by Canopy	☒	1.0000
19	Tsvigolo Escape Coefficient	☐	1.0000
20	Dam Elevation (meters)	☐	1.0000
21	Dam Pool W/Q Coefficient	☐	1.0000
22	Dam Type Coefficient	☐	1.0000

5.4.5.7.1 Wind Forcing

The segment scale factors for adjustment of surface wind are taken directly from input data for "wind sheltering" from the EFDC hydrodynamic model. A single wind time series function #1, taken from the wind data used for the EFDC hydrodynamic model, is applied for all surface layer segments.

5.4.5.7.2 Water Temperature

Water temperature is represented by time series for the upper two layers and the lower two layers in WASP7 using EFDC results extracted for the surface (k=4) and bottom (k=1) layer. Results were taken from EFDC for a grid cell that matches Station CES-06 in the middle region of the estuary. The surface and bottom layer water temperature data is applied to the entire model domain for WASP7.

5.4.5.7.2 Light Extinction

Incident solar radiation is adsorbed and scattered in the water column by detritus, algal biomass, inorganic solids and dissolved organic matter. In the Caloosahatchee estuary, the water is highly colored from naturally occurring processes within the watershed. In WASP7, light extinction in the water column is represented as the sum of extinction coefficients calculated for (a) detritus and inorganic solids, (b) algal biomass, (c) dissolved organic carbon and (d) background light extinction which can be related to color.

Crean (2007) has summarized water quality data in the Caloosahatchee estuary using data collected during the period from October 1994 through December 2006. **Figure 5-156** shows the spatial distributions of the median values of salinity, apparent color and dissolved oxygen with the data compiled for wet and dry seasons. Although there is a seaward gradient of decreasing color in both the wet and dry seasons, there is also a pronounced difference in the distributions of color in the wet and dry seasons. **Table 5-36** presents data compiled by Crean (2007, Table 2) giving summary statistics based on a composite of dry and wet season data sets.

Background extinction coefficients are estimated for input to WASP7 as a function of apparent color (as PCU) based on a coefficient derived from a field study in Tampa Bay and Charlotte Harbor (McPherson and Miller, 1994). Using data collected in these waters, the extinction coefficient was estimated as $K_e(\text{color}) = 0.014 * \text{Color (PCU)}$ where the extinction coefficient (K_e) has the units of 1/meter. The median values for the spatial distribution of color for the three regions compiled by Crean (2007) are used to estimate the spatial distribution of the background extinction coefficient for input to WASP7 and EFDC. The time function for background color is assigned a constant value of 1.0. The time dependency of apparent color and light extinction is therefore not represented in the WASP7 model.

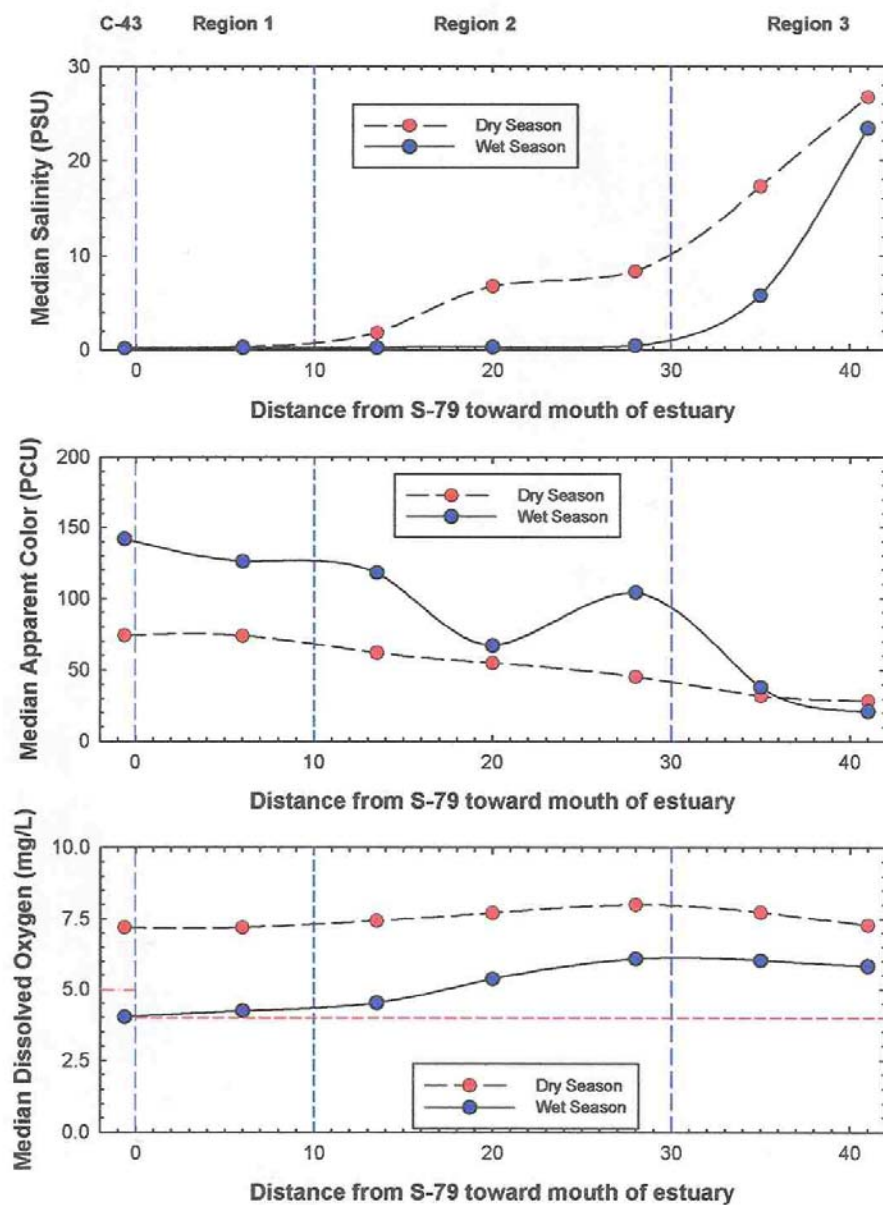


Figure 5-156 Seasonal median levels of salinity, apparent color and dissolved oxygen in the Caloosahatchee River Estuary with distance from S-79 to San Carlos Bay. Data from Crean (2007).

Table 5-36 Summary statistics of water quality for four regions of the Caloosahatchee River and Estuary from 1994 to 2006. Region 1=0-10 km; Region 2=10-30 km; Region 3=30-40 km and Region 4 (estimated)= San Carlos Bay/Pine Is. Sound/Gulf of Mexico. Apparent color data from Crean (2007)

Statistic	Color (PCU)			0.8
	Region1	Region2	Region3	Region 4 (estimated)
Mean	103	88	45	36.0
stddev	57	59	44	35.2
5%ile	42	27	8	6.4
25%ile	61	44	19	15.2
50%ile	80	68	30	24.0
75%ile	138	118	53	42.4
95%ile	222	208	136	108.8
Statistic	Ke (Color) =0.014 * Color (units 1/meter)			
	Region1	Region2	Region3	Region4 (estimated)
Mean	1.44	1.23	0.63	0.50
stddev	0.80	0.83	0.62	0.49
5%ile	0.59	0.38	0.11	0.09
25%ile	0.85	0.62	0.27	0.21
50%ile	1.12	0.95	0.42	0.34
75%ile	1.93	1.65	0.74	0.59
95%ile	3.11	2.91	1.90	1.52

5.4.5.7.3 Sediment Oxygen Demand and Benthic Nutrient Fluxes

Although preliminary work was completed in 2004 by EPA to couple the sediment diagenesis model of Di Toro (2000) with the WASP eutrophication model (Martin, 2004), the sediment diagenesis model has not yet been incorporated in WASP7. Sediment oxygen demand (SOD) and benthic fluxes of ammonia and phosphate are represented instead in WASP7 using user-assigned segment and time dependent empirical functions. For unknown reasons, benthic flux of nitrate is not included in WASP7. Since the sediment diagenesis model is incorporated in EFDC, however, and is applied for the Caloosahatchee water quality model, the comparison of EFDC results and WASP7 results for dissolved oxygen and nutrients is expected to be different simply because the methodology used in WASP7 for representation of sediment oxygen

demand and benthic fluxes of ammonia and phosphate is based on empirical data rather than internally coupled deterministic sub-models.

Assignment of user-specified empirical functions based on either observed data sets or best estimates based on the literature has been the approach used in all previous versions of WASP for over two decades [WASP3: Di Toro et al., (1983); WASP4: Ambrose et al., (1988); WASP5: Ambrose et al., (1993) and WASP6: Wool et al., (undated)]. In this empirical approach, SOD rates and benthic flux rates for ammonia and phosphate are assigned for each bottom layer segment with the rates based on a reference water temperature of 20 Deg-C. A temperature dependence coefficient is assigned to describe how the reference rate for SOD at 20 Deg-C [(SOD(20)] changes in response to bottom water temperature which implicitly also specifies a time varying functional relationship for SOD since seasonal water temperature cycles are typically similar from year to year. Time varying multipliers can be assigned to describe how benthic ammonia and phosphate fluxes change during the course of a year. Rather than assign different rates for every bottom layer segment, it has been typical practice to define groups of bottom layer segments as spatial “zones” where a “zone” is defined on the basis of common characteristics that might control sediment decomposition such as depth, surface sediment bed properties, turbidity maximum regions, proximity to a wastewater discharge etc. In many rivers and estuaries spatial “zones” are defined to characterize upper, middle and lower regions of a waterbody.

For the Caloosahatchee estuary six zones are defined in EFDC (**Figure 5-157**) and WASP7 for the upper (Zone 1), middle (Zone 2 and Zone 3), and Lower (Zone 4) regions of the estuary from the upstream boundary at S79 to the mouth of the river at San Carlos Bay. Zone 5 is defined for the open water areas of San Carlos Bay, Pine Island Sound, Matlacha Pass and the nearshore Gulf of Mexico. Zone 6 is defined for wetland area grid cells. SOD values are assigned on the basis of a preliminary analysis of the results generated by the EFDC sediment diagenesis model for selected grid cells within each spatial zone. Benthic flux rates for ammonia and phosphate are assigned for each zone as a function of the SOD rates and Redfield weight based stoichiometric ratios for O:C:N:P (Di Toro 1986; Di Toro et al, 1990).

Using results extracted from preliminary EFDC results for selected grid cells in each of the zones, SOD values (at a reference temperature of 20 Deg-C) are assigned for input to WASP7 as follows: Zone 1 = 1.5; Zone 2 & 3 = 1.5; Zone 4 = 0.85; and Zone 5 & 6 = 0.75. A scale factor of 2.0 is then used to double the SOD rates listed above used for model calibration and validation. The SOD values have units of g O₂/square-meter/day. WASP7 allows for the input of a bottom water temperature correction factor for SOD to estimate seasonal changes in SOD. WASP7 allows for the assignment of time functions to describe seasonal changes in benthic ammonia and phosphate fluxes as multipliers for the flux rates assigned for each water quality zone and bottom layer segment. The use of a temperature dependent coefficient for SOD and the specification of time varying multipliers for benthic ammonia and phosphate fluxes effectively parameterizes seasonal variability in both water temperature, primary productivity and deposition of detrital particulate organic matter (POM) and algal biomass to the sediment bed.

For the Caloosahatchee estuary model, seasonal dependence of SOD and benthic nutrient fluxes is estimated using EFDC-simulated bottom water temperature representative of the middle estuary (Station CES-06) and appropriate temperature dependence coefficients for SOD, benthic ammonia and benthic phosphate fluxes. Temperature dependent functions are then multiplied by the SOD and benthic ammonia and phosphate release rates assigned for each spatial water quality zone where the benthic flux rates are referenced to a water temperature of 20 Deg-C.

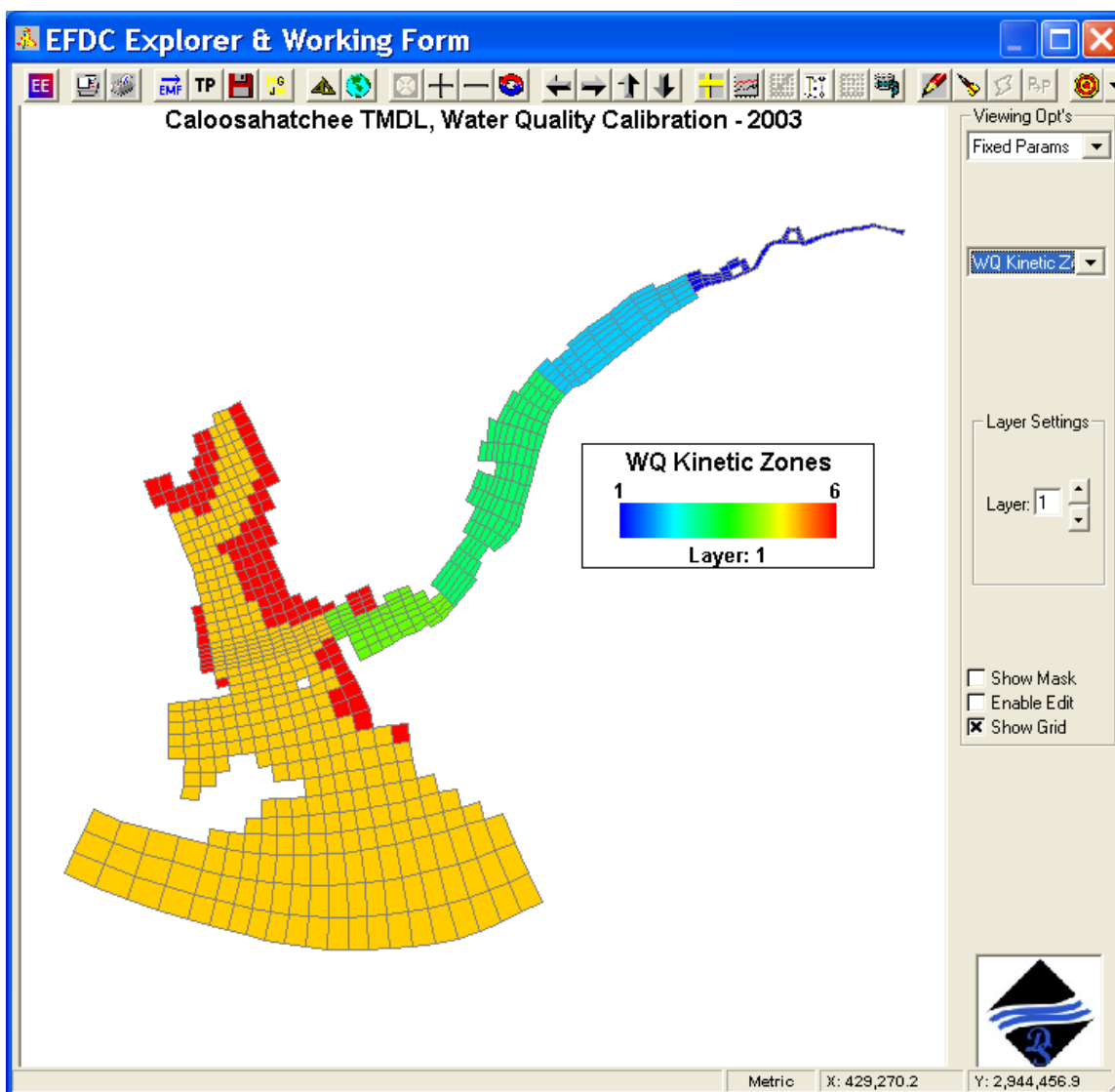


Figure 5-157 Water quality zones assigned for EFDC and WASP7

The benthic ammonia flux rate (J_N) be estimated from the SOD rate using Redfield stoichiometry on a weight basis (Di Toro 2000; pp 78) as follows:

$$J_N(20) = \frac{1}{a_{CN} a_{O2C}} SOD(20) \times 1000$$

SOD (20) = SOD rate (as g O₂/sq-m/day) at 20 Deg-C reference temperature

a_{CN} = carbon to nitrogen Redfield ratio of 5.68 mg C/mg N

a_{O2C} = oxygen to carbon Redfield ratio of 2.67 mg O₂/mg N

1000 = conversion factor of 1000 mg O₂/ g O₂

J_N(20)= benthic ammonia flux rate as mg N/m²-day at 20 Deg-C reference temperature

The benthic phosphate flux rate (J_P) can be similarly estimated from SOD and the benthic ammonia flux using Redfield stoichiometry (Di Toro 2000) as follows:

$$J_P(20) = \frac{1}{a_{CP} a_{O2C}} SOD(20) \times 1000$$

a_{CP} = carbon to phosphorus Redfield ratio of 41.1 mg C/mg P

J_P(20) = benthic phosphate flux rate as mg P/m²-day at 20 Deg-C reference temperature

5.4.5.7.4 Canopy Shading

The segment multiplier factors for the adjustment of surface light intensity are taken directly from input data (PSHADE.INP) for “shading” from the EFDC hydrodynamic model.

5.4.5.8 Time Functions

Time functions in WASP7 are used to specify temporal forcing functions for either (a) all of the segments as a global function or for (b) specific groups of segments defined by spatial water quality zones of the model domain. Time functions selected for the Caloosahatchee WASP7 model are shown in **Table 5-37**.

As discussed under “Parameters”, time series of water temperature extracted from EFDC hydrodynamic results for a grid cell near Station CES-06 are used to represent the surface layer (time function #1) and the bottom layer (time function #2). The upper two layers are assigned the “surface layer” function #1 and the lower two layers are assigned the “bottom layer” function #2.

Time Functions

	Time Function	Used
▶	Water Temperature Function 1 (°C)	☒
	Water Temperature Function 2 (°C)	☒
	Water Temperature Function 3 (°C)	☐
	Water Temperature Function 4 (°C)	☐
	Daily Solar Radiation (Langley's)	☒
	Fraction Daily Light (fraction)	☒
	Wind Speed Time Function 1 (m/sec)	☒
	Wind Speed Time Function 2 (m/sec)	☐
	Light Extinction Function 1	☒
	Light Extinction Function 2	☐
	Light Extinction Function 3	☐
	Light Extinction Function 4	☐
	Light Extinction Function 5	☐
	Time Variable Ammonia Benthic Flux (mg/m2-day)	☒
	Time Variable Phosphorus Benthic Flux (mg/m2-day)	☒
	Velocity Function 1 (m/sec)	☐
	Velocity Function 2 (m/sec)	☐
	Velocity Function 3 (m/sec)	☐
	Zooplankton Population (count)	☐
	Air Temperature (°C)	☒
	Ice Cover (fraction ice free)	☐
	Reaeration Function (per day)	☐

Time/value pairs for Water Temperature Function 1 (°C)

	Date	Time	Value
1	1/ 1/2003	0:00	1.68138E+1
2	1/ 1/2003	4:47	1.67162E+1

+ Insert
 Copy
 Import

- Delete
 Paste
 Graph

Delete All
 Fill/Calc

OK
 Cancel

Table 5-37 Time functions for WASP7 model

5.4.5.8.1 Daily Solar Radiation and Fraction of Daily Light as Photoperiod

Daily averaged incident solar radiation data is computed from the hourly input data used for the EFDC hydrodynamic model. Daily incident solar radiation is then attenuated by an adjustment factor of 0.75 to assign the Photosynthetic Active Radiation (PAR) component of visible light for calculation of the algal growth rate. The seasonal variation of the photoperiod, or the fraction of a day that is daylight, is computed as a function of latitude and the day of year using an equation from Duffie and Beckman (1974) as reported by Thomann and Fitzpatrick (1982).

5.4.5.8.1 Wind Speed

Daily averaged wind speed data is computed from the hourly input data used for the EFDC hydrodynamic model. Wind data is used in WASP7 to estimate wind-driven reaeration of dissolved oxygen in the surface layer.

5.4.5.8.1 Light Extinction Function #1

The time variability of background light extinction that may result from temporal changes in color are not represented in the WASP7 model of the Caloosahatchee estuary. Although color data is available that could be used to define a time function for color and background light extinction due to color in WASP7, the EFDC water quality model does not allow for the specification of a time function for changes in the background light extinction. In order to develop an unbiased comparison of the results obtained with EFDC and WASP7, the results should be based on comparable formulations and forcing functions for both models where comparable approaches can be defined in EFDC and WASP7. The time function for background light extinction is thus assigned a constant value of 1.0 for each segment of each water quality zone for WASP7.

5.4.5.8.1 Time Variable Benthic Ammonia and Phosphate Fluxes

Water quality zones are used to assign the spatial dependence of benthic ammonia and phosphate flux rates at a reference temperature of 20 Deg-C for each bottom layer segment. Temperature dependence coefficients and bottom water temperature data, extracted from EFDC hydrodynamic results, are used to compute time series multipliers for benthic fluxes of ammonia and phosphate and SOD.

Temperature dependence of benthic ammonia flux [$J_N(T)$] is described as

$$J_N(T) = J_N(20)\Theta^{(T-20)}$$

$\Theta = 1.125$ (from Di Toro 2000; page 73)
 T = bottom water temperature (Deg-C)

Temperature dependence of benthic phosphate flux [$J_P(T)$] is described as

$$J_P(T) = J_P(20)\Theta^{(T-20)}$$

$\Theta = 1.125$ (assume same value as ammonia flux temperature coefficient)
 T = bottom water temperature (Deg-C)

The time varying multipliers for benthic ammonia and phosphate flux are computed and assigned for input to WASP7 as time functions based on bottom water temperature and the temperature dependence coefficients.

$$J_N \text{Multiplier}(t) = \Theta^{(T-20)}$$

$$J_P \text{Multiplier}(t) = \Theta^{(T-20)}$$

A single time series of bottom water temperature, assigned as a representative bottom water temperature data set for the entire model domain, is used to compute the ammonia and phosphate flux time series multipliers for input to WASP7.

Temperature dependence of SOD is described as:

$$SOD(T) = SOD(20)\Theta^{(T-20)}$$

$\Theta = 1.065$ (see Thomann & Mueller, 1987)

T = bottom water temperature (Deg-C)

The temperature coefficient of $\Theta = 1.065$ is assigned as a segment dependent parameter with the same value assigned for all bottom layer segments. Bottom water temperature is then used to compute the time dependence of water temperature as it controls SOD for each segment.

In summary SOD rates and stoichiometrically related benthic fluxes for ammonia and phosphate are empirically specified in WASP7 as a function of bottom layer segment (x) and time (t) as follows:

$$SOD(x, t, T) = SOD_x(20)\Theta^{(T-20)}$$

$SOD(x, t, T)$ is the SOD rate for a segment assigned to spatial zone "x" as a function of time (t), bottom water temperature (T) and the SOD rate assigned to a zone "x" for a reference temperature of 20 Deg-C. The temperature coefficient Θ is assigned in WASP7 as a spatial parameter for each segment.

Benthic fluxes of ammonia and phosphate are empirically specified in WASP7 as function of spatial zone and bottom layer segment (x) and time (t) with spatial parameter and time functions as follows:

$$J_N(x, t) = J_N \text{Multiplier}(t) J_N(x, 20)$$

$$J_P(x, t) = J_P \text{Multiplier}(t) J_P(x, 20)$$

5.4.5.8.1 Air Temperature

Daily averaged air temperature data is computed from the hourly input data used as atmospheric forcing for the EFDC hydrodynamic model.

5.4.5.9 Initial Conditions

The initial conditions for each segment for the water quality variables of the WASP7 model are mapped directly from the input data for the initial conditions from the EFDC water quality model. For the calibration run (2003), constant values are assigned for each segment to startup the model. For the validation run (2004), restart values for each state variable are assigned from the end time of the calibration run results.

5.4.6 Results of the Wasp7 Model

Time series plots are presented for surface and bottom layer results for algal biomass (as chlorophyll-a) and dissolved oxygen. Results are first presented for the model calibration period from 1-Jan-2003 through 31-Dec-2003. Results are then presented for the model validation period from 1-Jan-2004 through 31-Dec-2004. Observed data points are marked by solid red circles.

5.4.6.1 Model Calibration

5.4.6.1.1 Algal Biomass

As can be seen in **Figures 5-158** and **5-159**, the WASP7 results for Station CES-04, although higher than the observations, tends to follow the timing shown by the observations. The WASP7 results at Station CES-06, however, are much higher than the observed levels of algal biomass during the spring and summer months.

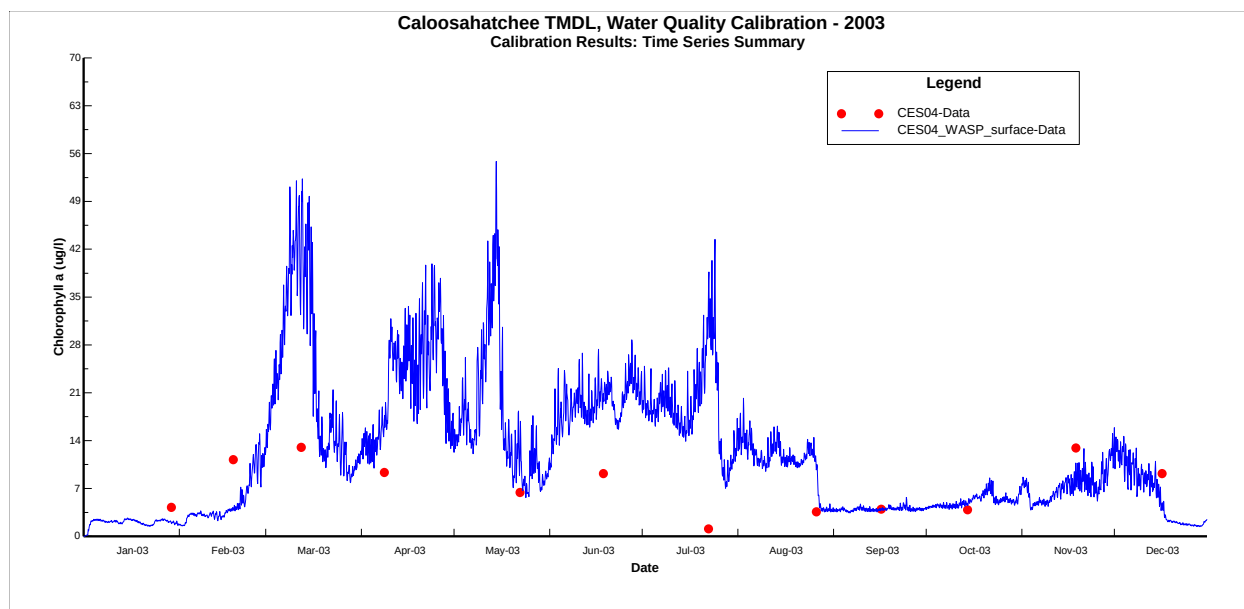


Figure 5-158 Station CES-04 surface Chlorophyll, Calibration year of 2003

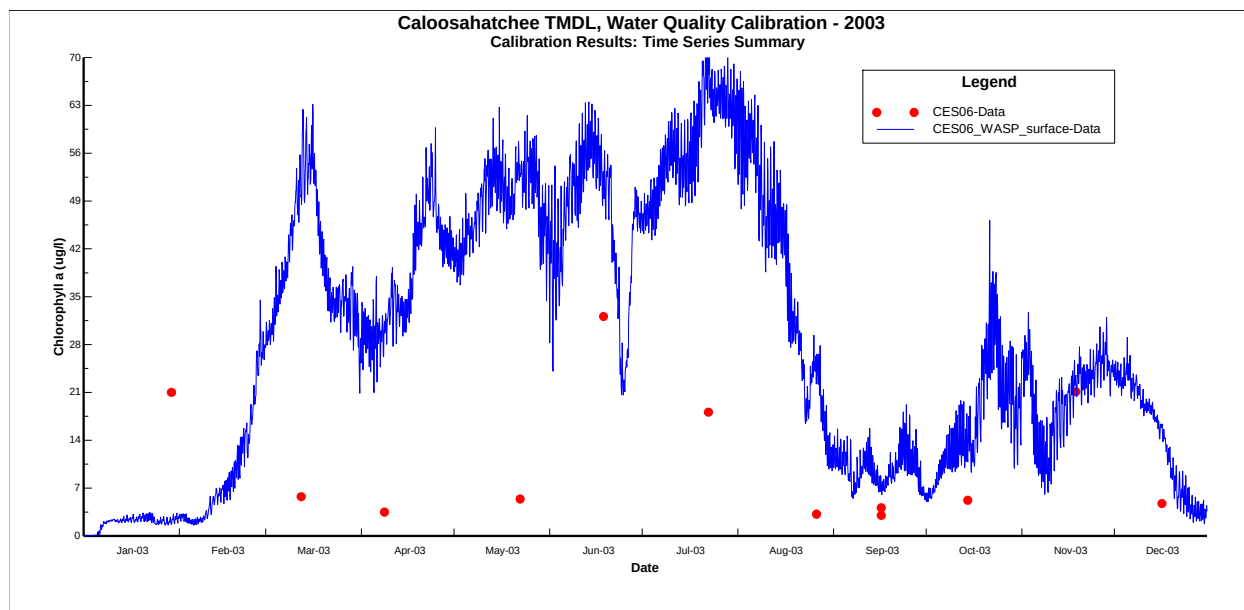


Figure 5-159 Station CES-06 surface Chlorophyll, Calibration year of 2003

5.4.6.1.2 Dissolved Oxygen

As can be seen in **Figures 5-160 to 5-163**, the WASP7 results show a fairly good match between simulated oxygen and the observed data for the surface and bottom layers of Stations CES-04 and CES-06. The WASP7 results for both stations, however, do not match the

observed data for the time period characterized by cooler water temperature during January-February and November-December. The WASP7 results for Station CES-06 simulate much higher levels of dissolved oxygen than is seen in the observed data for both the surface and bottom layer. The high levels of oxygen are the result of the over simulation of algae chlorophyll during the spring and summer months at CES-06. There is an apparent consistent pattern at Stations CES-04 and CES-06 where the WASP7 dissolved oxygen results are much lower than the observed data during cooler water conditions. As an empirical user-defined function, sediment oxygen demand varies over time as a function of the bottom water temperature over time. Bottom water temperature therefore serves as a surrogate to characterize the seasonal variability of SOD. The seasonal variation of winter and summer water temperature, however, is not necessarily synchronized with the seasonal variability of the deposition of particulate organic matter from algal blooms and influxes of organic matter loading from the watershed to the sediment bed.

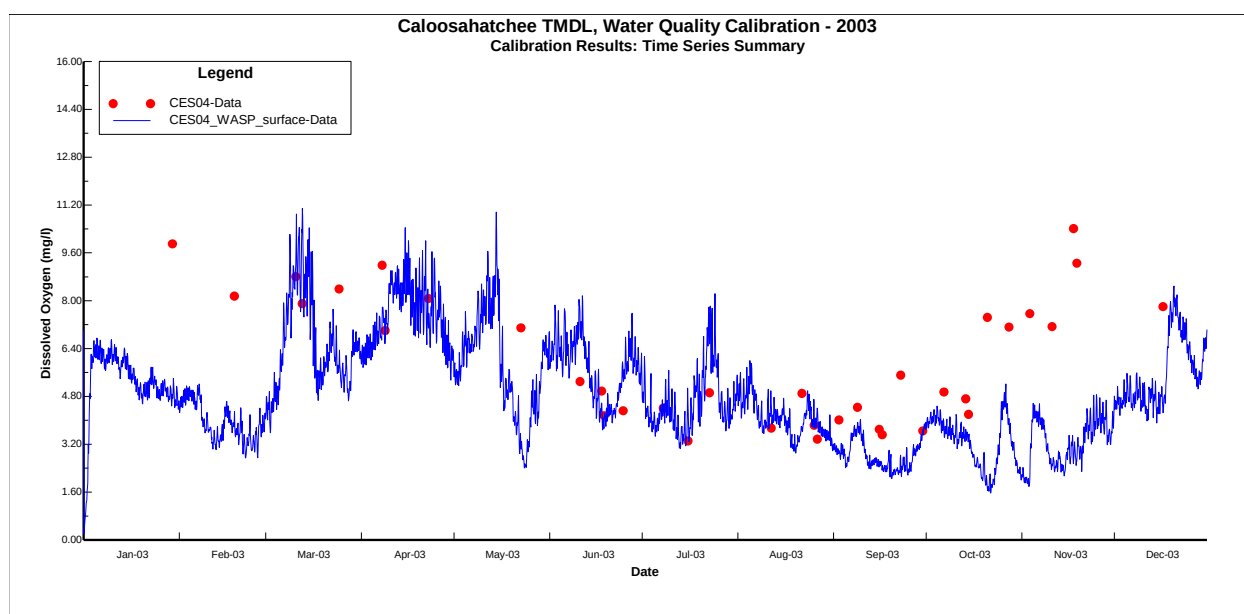


Figure 5-160 Dissolved oxygen, Station CES-04, Surface layer, Calibration year of 2003

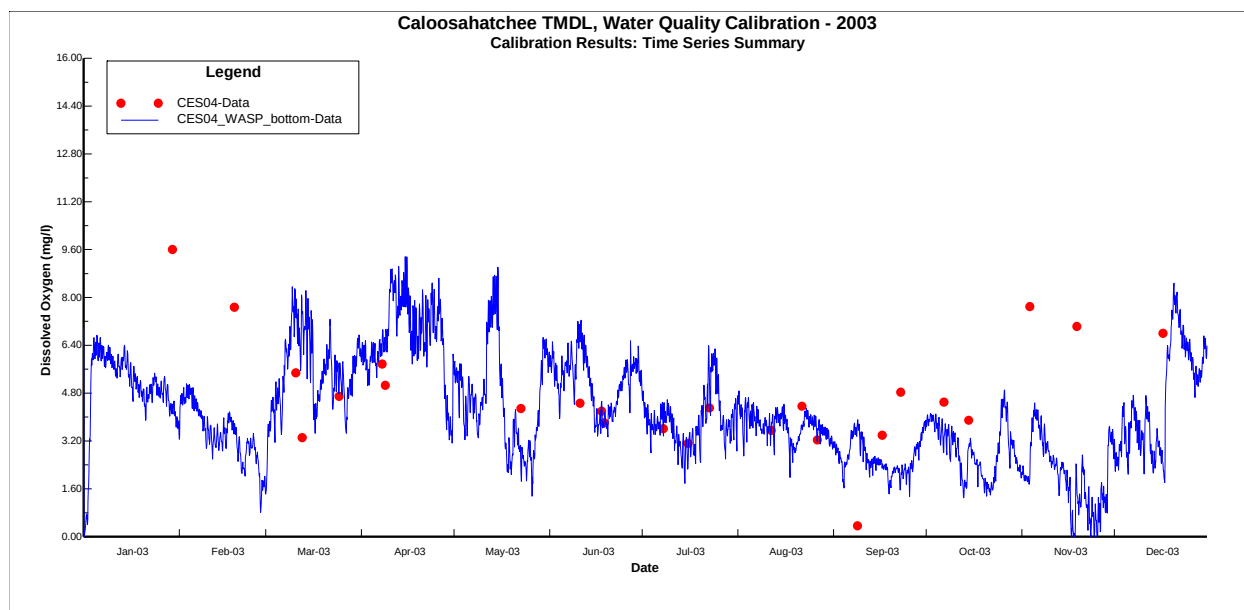


Figure 5-161 Dissolved oxygen, Station CES-04, Bottom layer, Calibration year of 2003

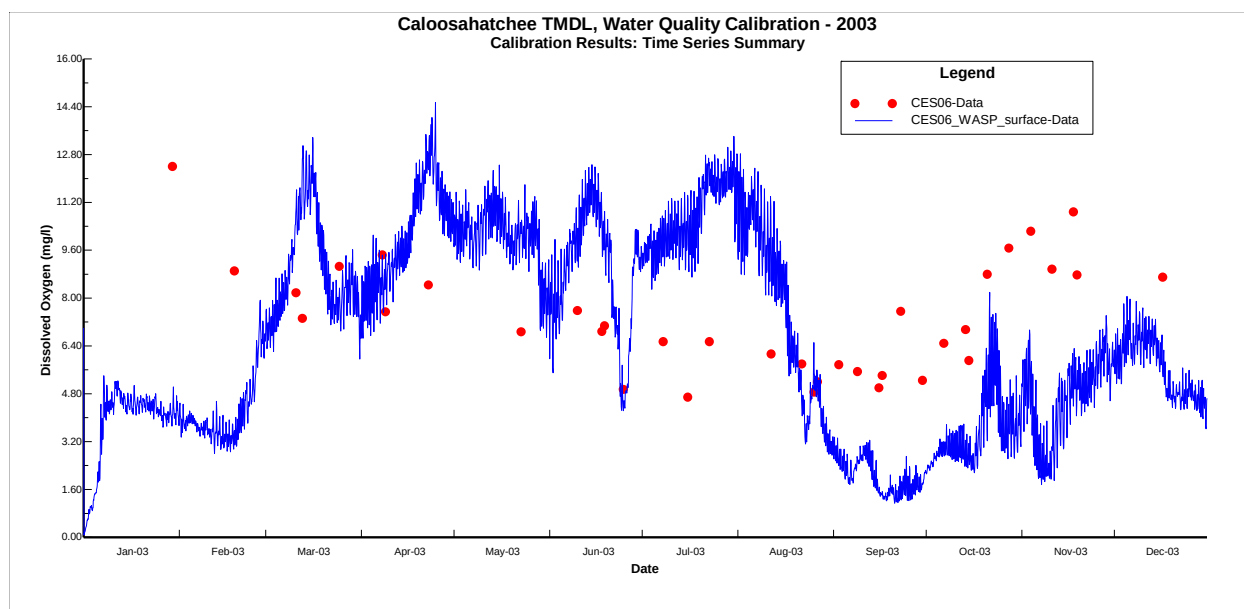


Figure 5-162 Dissolved oxygen, Station CES-06, Surface layer, Calibration year of 2003

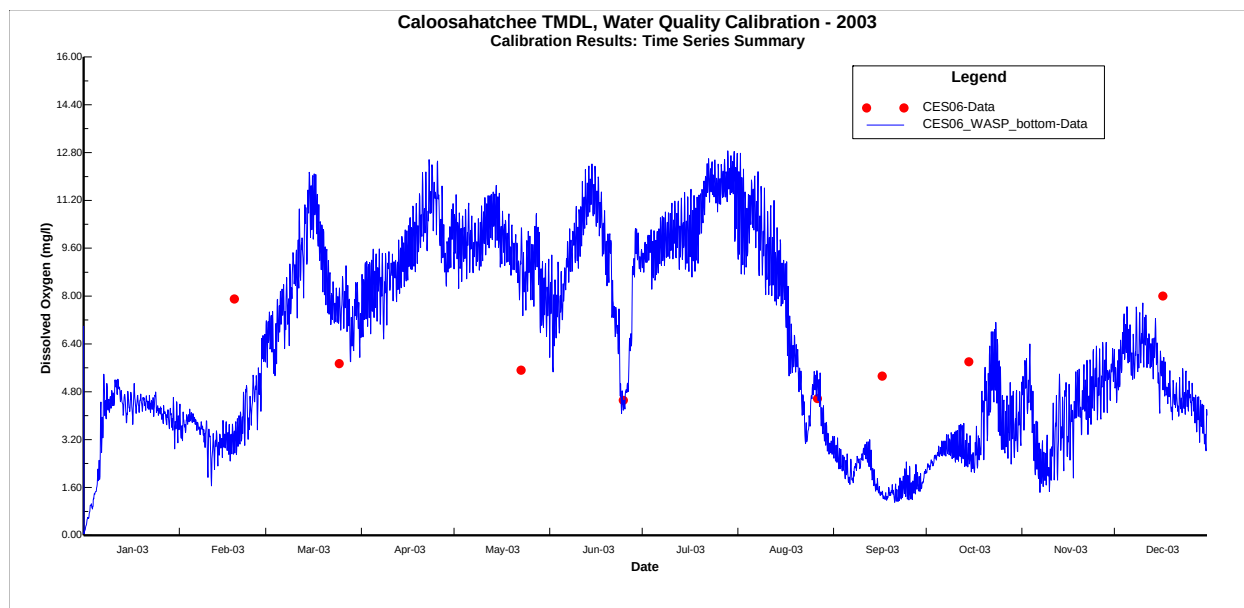


Figure 5-163 Dissolved oxygen, Station CES-06, Bottom layer, Calibration year of 2003

5.4.6.2 Model Validation

5.4.6.2.1 Algal Biomass.

As can be seen in **Figures 5-164** and **5-165**, the WASP7 results show fair agreement between simulated algal biomass and observed chlorophyll measurements for the surface layer of Stations CES-04 and CES-06 for the validation year of 2004. In particular, the WASP7 results for CES-06 pick up the peak chlorophyll level of ~ 80 ug/L during July 2004.

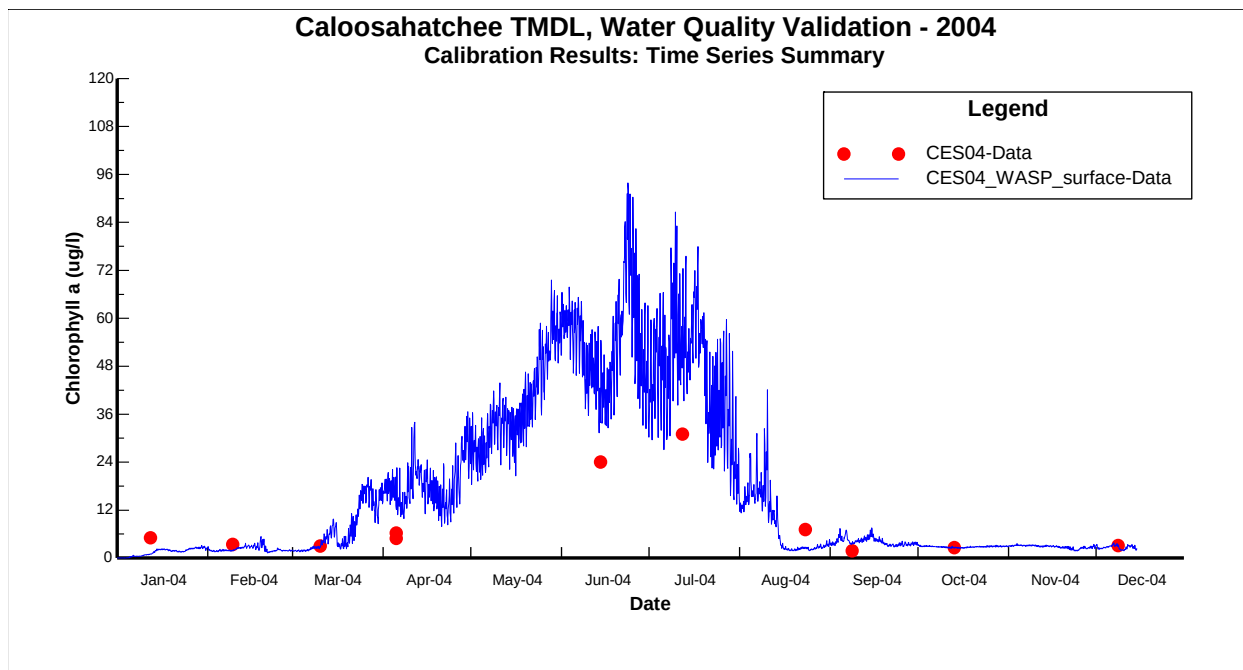


Figure 5-164 Chlorophyll, Station CES-04, Surface layer, Validation year of 2004

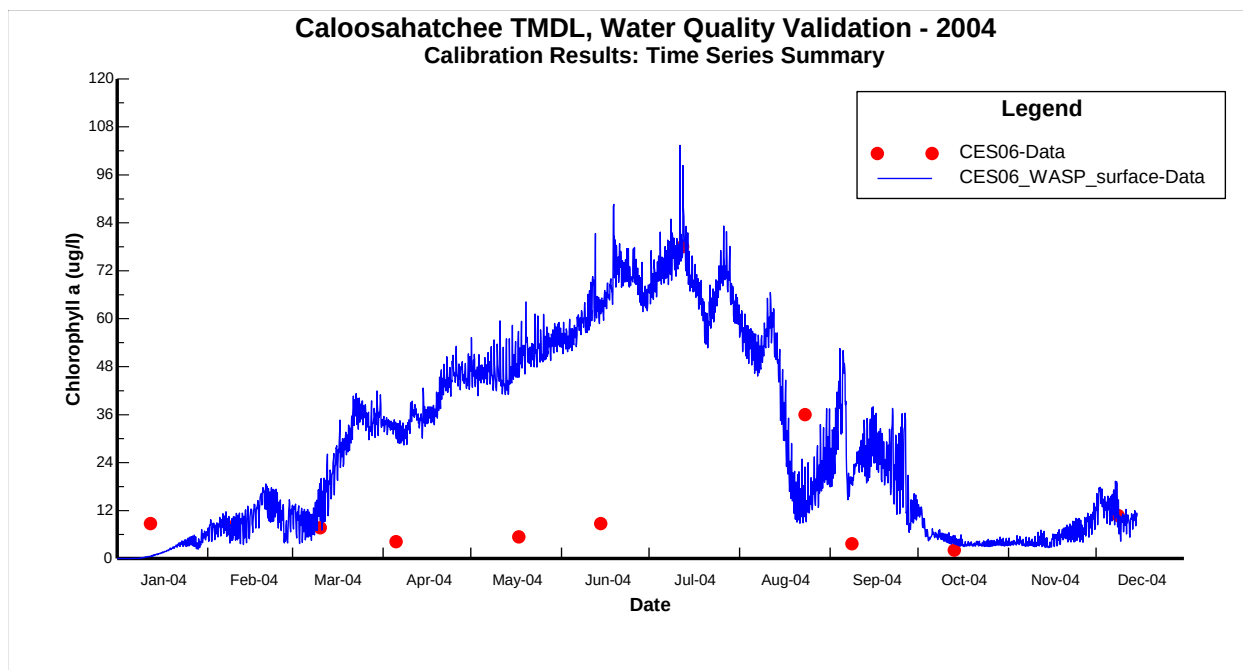


Figure 5-165 Chlorophyll, Station CES-06, Surface layer, Validation year of 2004

5.4.6.2.2 Dissolved Oxygen

As can be seen in **Figures 5-166** to **Figures 5-169**, the WASP7 results, although not as good as the calibration results, show a fair match between simulated oxygen and observed data for the surface and bottom layers of Stations CES-04 and CES-06 in 2004. With the exception of simulated oxygen during periods of cooler water temperatures, as discussed above under model calibration, the WASP7 results for Station CES-04 and CES-06 appear to track the observed data fairly well.

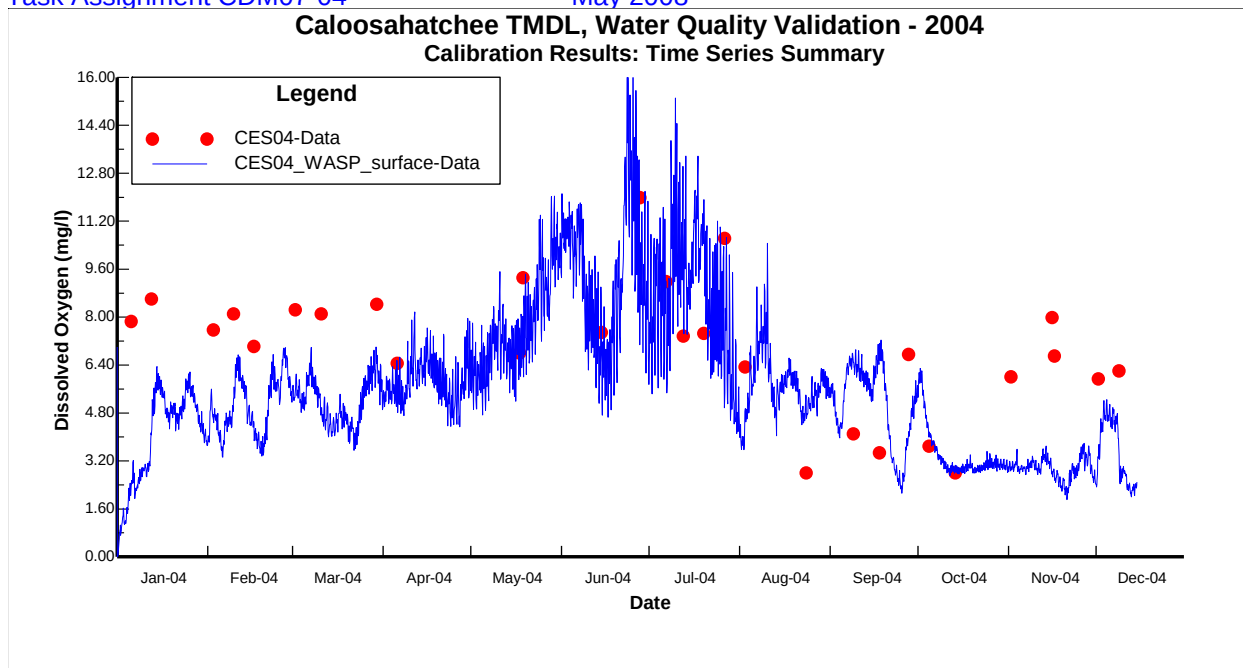


Figure 5-166 Dissolved oxygen, Station CES-04, Surface layer, Validation year of 2004

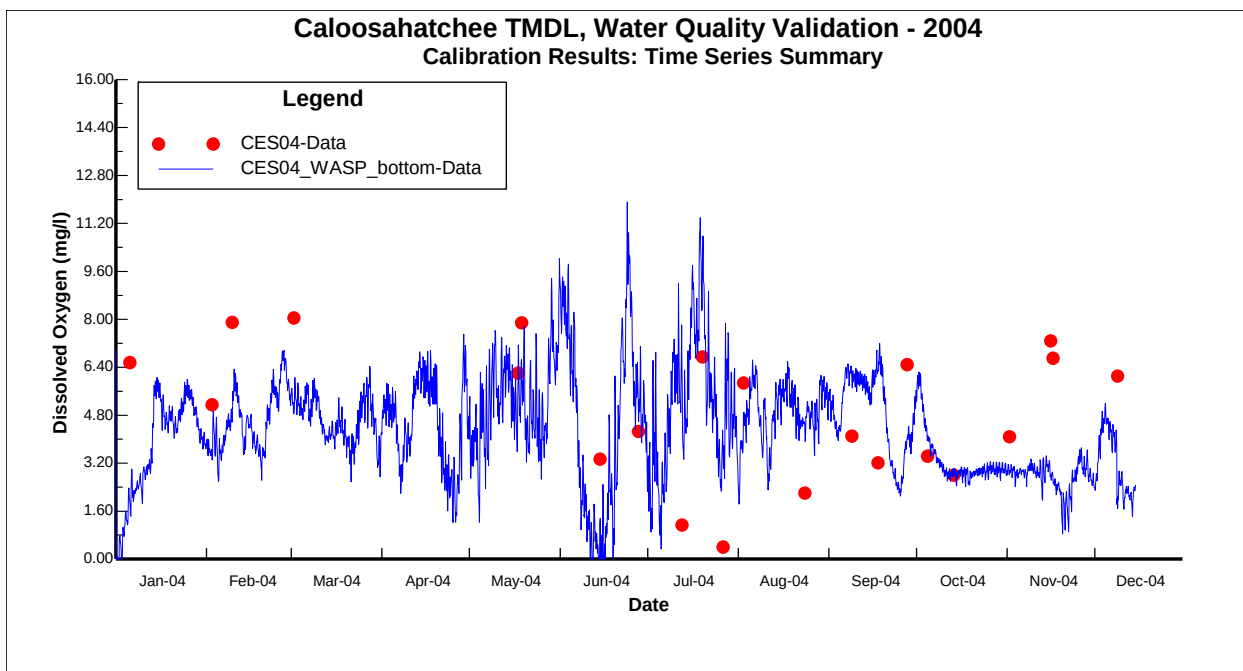


Figure 5-167 Dissolved oxygen, Station CES-04, Bottom layer, Validation year of 2004

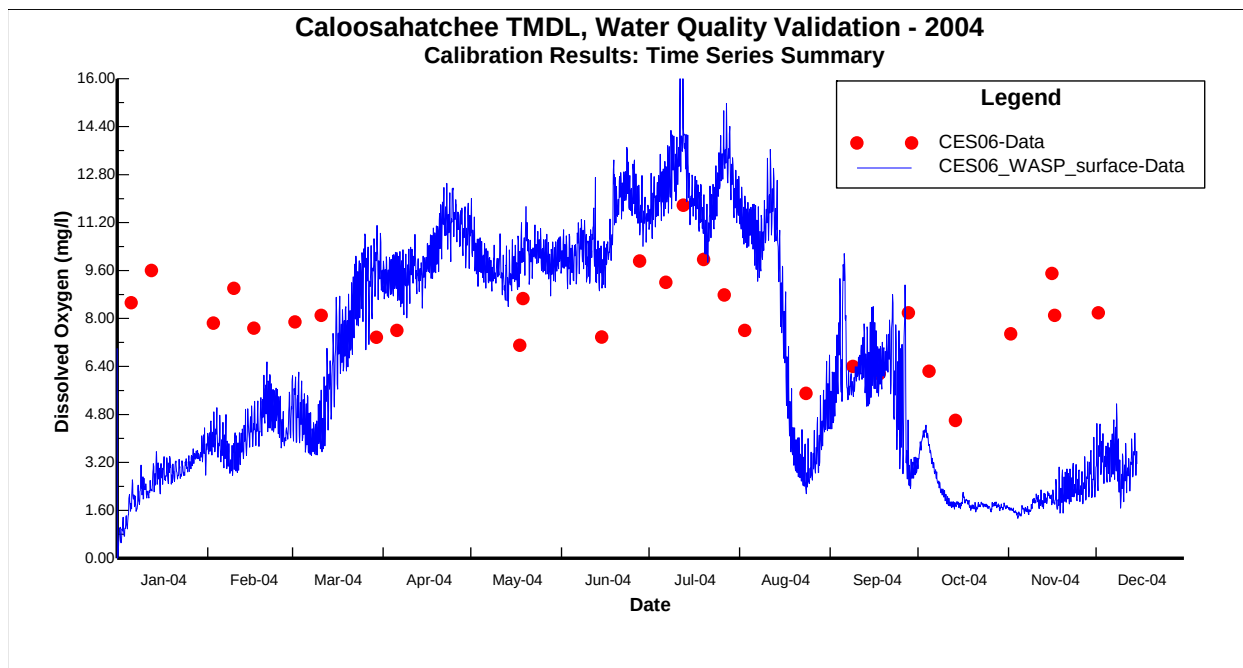


Figure 5-168 Dissolved oxygen, Station CES-06, Surface layer, Validation year of 2004

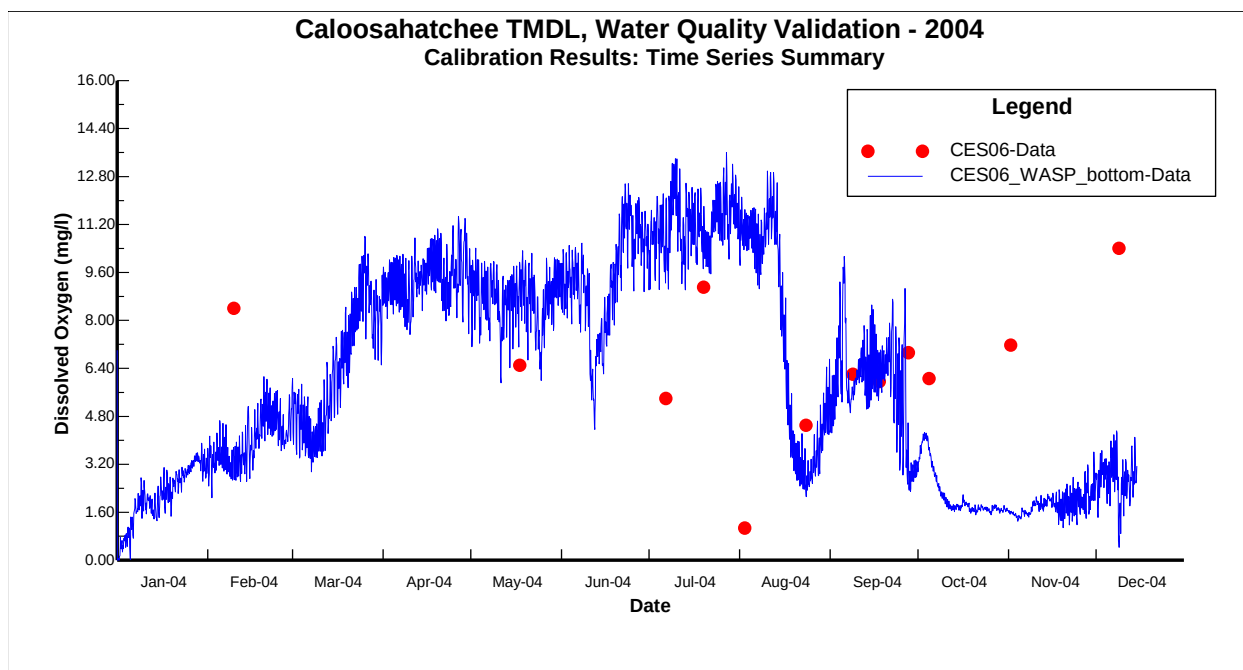


Figure 5-169 Dissolved oxygen, Station CES-06, Bottom layer, Validation year of 2004

5.5 WMM CALIBRATION REFINEMENT

For the Estero Bay and Caloosahatchee River Nutrient Load Assessment (EBCRNLA) project that CDM completed for the SFWMD (CDM, 2007), calibration of the WMM was performed by comparing WMM-estimated loads with observed loads calculated at the S-78 and S-79 control structures for the period 1991-1995. Results from the calibrated WMM closely matched the observed values for flow, TP, TN, and TSS at S-79 and S-78, with the largest percent difference (approximately 20%) noted for TN at S-78. As discussed in the report, these results were considered to be reasonable, particularly considering that the measured loads were based on a limited number of ambient water quality samples and did not necessarily include wet weather events; therefore, the measured values may be considered only an approximation of the actual loads.

For this Caloosahatchee River TMDL Model project, the WMM calibration was refined to match observed values at S-78 and S-79 for the period 1997-2005. Results for Whiskey Creek are also presented, though the limited tributary area and sampling data makes the measured loads very approximate. The following sections outline the changes that were made to the existing WMM (as used in the EBCRNLA project) and present the calibration results.

5.5.1 WMM Calibration Parameters

Changes in land use characteristics, hydrologic data, and point sources were implemented as part of the calibration.

5.5.1.1 Land Use

The percent directly connected impervious area (DCIA) for some urban land use categories was modified during HSPF calibration, and, therefore, modified in WMM for consistency. Data updates indicate that the percent imperviousness for the wetlands / water land use category could be reduced, depending on available storage for the wetlands and water. This was discussed with the HSPF team after comparing preliminary runs of baseline and existing conditions. In order to physically explain a lower percent imperviousness, wetlands and waterbodies were visually inspected using aerial photography. Two major patterns were identified:

- Large interconnected wetlands ; and
- Isolated wetlands, which are not directly connected to canals, ditches or streams. Two types of wetlands were identified under this category: wetlands located within agricultural lands, which are most likely expected to be depressionial; and, typical isolated wetlands. Both could be connected to an adjacent canal or stream only during strong rainfall events.

A GIS procedure was used to estimate the predominance of this type of feature. By selecting those wetland features with an area equal to or less than 50 acres, it corresponded to 26% of the total wetland acreage within the Study Area. The selected features with this criterion captured most of the isolated wetlands. Therefore, 26% of the total wetland acreage was used as an estimate of the percent coverage of the isolated wetland features. This significant percentage together with the expected low conveyance of any wetland, led to reducing its percent imperviousness to 5 percent.

Table 5-38 presents a list of the proposed percent imperviousness associated with land use categories that should be used for model calibration.

Table 5-38 Proposed Percent Imperviousness for Selected Land Use Categories.

Land Use Category	Initial Model Percent Imperviousness	Modified Percent Imperviousness
Commercial/industrial/ transportation	88%	66%
High Density Residential	65%	49%
Medium Density Residential	35%	26%
Wetlands / water	25%	5%

5.5.1.2 Hydrologic Data

5.5.1.2.1 Rainfall

The original WMM had two rainfall values: 53.8 inches/year and 48.4 inches/year, which were used for the Tidal and for the East and West Caloosahatchee River, respectively. These values represented long-term average annual rainfall totals in the study area. The current study incorporates NEXRAD data into the modeling, with 15 different rainfall zones created within the study area. In order to account for this new rainfall distribution in WMM, the distribution of the 15 rainfall zones was established for each of the three WMM areas (East, West and Tidal), and area-weighted average annual rainfall data for the 1997-2005 modeling period were developed. The results of these analyses are presented in **Table 5-39**.

Table 5-39 Average Annual Rainfall per Sub-watershed for the Period 1997-2005.

Sub-watershed	Average Annual Rainfall (inches/year)
East Caloosahatchee	52.3
West Caloosahatchee	58.9
Tidal Caloosahatchee	63.1

5.5.1.2.2 Impervious Runoff Coefficient

Based on HSPF calibration, the impervious runoff coefficient was reduced from 0.95 to 0.75. This reduction may reflect existing onsite storage and exfiltration from BMP ponds.

5.5.1.2.3 Baseflow

Using the new average annual rainfall values for each subwatershed and the proposed pervious and impervious runoff coefficients, calculations were performed to estimate the annual baseflow value for each subwatershed for the period 1997-2005. **Table 5-40** presents the annual baseflow values for each subwatershed. The values in Table 5-40 reflect an actual evapotranspiration (ET) of 35 to 40 inches per year, which is reasonable for Florida.

Table 5-40 Annual Baseflow per Sub-watershed for the Period 1997-2005.

Sub-watershed	Annual Baseflow (inches/year)
East Caloosahatchee	9.3
West Caloosahatchee	12.3
Tidal Caloosahatchee	14.2

5.5.1.3 Point Sources

Point sources included in the current model correspond to flows and concentrations reported in Discharge Monitoring Reports (DMR) that each domestic WWTP submitted to FDEP for the period 2003-2004. None of these values are changed for this calibration except for those loads observed at S-77 (i.e., Lake Okeechobee releases), which were updated with flows and concentrations for the period 1997-2005.

Constituent concentrations included in WMM were based on flow-weighting each observed concentration at S-77 on a daily basis. For those days where no concentration for a given constituent is available, the concentration of the most recent sampling event was used to estimate the daily load to the Caloosahatchee River. The average annual load of each constituent was then divided by the average annual flow at S-77 to determine its average annual concentration. **Table 5-41** presents the average annual flow and concentration of measured constituents at S-77. WMM does not adjust point source loads by delivery ratios, so the concentrations included in WMM were modified by their respective reduction factor, which is based on delivery ratio to downstream calibration points and suspended fraction of each constituent.

Table 5-41 Flow and Concentrations from Lake Okeechobee Releases (S-77) to Downstream Calibration Points for the Period 1997-2005.

Parameter	Value Measured at S-77	Value. To Include in WMM (DR to S-78) ¹	Value. To Include in WMM (DR to S-79) ²
Flow (MGD)	745	745	745
BOD (mg/L)	2.0	1.62	1.60
COD (mg/L)	NA	NA	NA
TSS (mg/L)	19.0	7.22	6.46
TDS (mg/L)	314.8	314.8	314.8
TP (mg/L)	0.097	0.079	0.078
DP (mg/L)	0.034	0.034	0.034
TKN (mg/L)	1.463	1.33	1.32
NO ₂ +NO ₃ (mg/L)	0.140	0.14	0.14
Pb (mg/L)	3.7x10 ⁻⁴	1.6x10 ⁻⁴	1.5x10 ⁻⁴
Cu (mg/L)	9.5x10 ⁻⁴	5.7x10 ⁻⁴	5.4x10 ⁻⁴
Zn (mg/L)	2.2x10 ⁻³	1.52x10 ⁻³	1.48x10 ⁻³
Cd (mg/L)	1.5x10 ⁻⁴	0.7x10 ⁻⁴	0.6x10 ⁻⁴

¹ Affected by delivery ratio (DR) to S-78 (0.38, from previous study) and respective constituent suspended fraction.

² Affected by delivery ratio (DR) to S-79 (0.34, from previous study) and respective constituent suspended fraction.

5.5.2 BMPs

5.5.2.1 Urban BMPs

In the 2007 EBCRNLA, CDM and the SFWMD found that there was no available urban BMP database in the Study Area. Therefore, BMP coverages were estimated by the change in land use since the implementation of the stormwater rule (post 1984).

For this Study, the stakeholders were informed of this important data gap at the public meetings and several follow-up conference calls and meetings were held to further investigate what BMP data was available or could be developed to assist with this TMDL program. BMP data are important to the program and especially to the stakeholders, and it is in their interest to inventory them. The CDM team discussed the need for the following information:

1. BMP type,
2. location,
3. sizing information (design criteria),
4. tributary area,
5. maintenance condition, and
6. removal efficiency estimates for the parameters of interest.

It was confirmed in the meetings that this level of information is generally not available. However, several stakeholders are actively working to provide initial and ultimate information for TMDL program use. Therefore, the project team used the same method to determine urban BMP, however, for this project the historical land use comparison was updated with the existing land use coverage (year 2004, unlike year 2000 used in the 2007 EBCRNLA) with respect to the year 1988 land use coverage. **Table 5-42** presents the urban BMP coverage for the study area. **Figure 5-170** shows the spatial distribution of urban BMP coverage.

5.5.2.2 Agricultural BMPs

Agricultural BMPs have been implemented in the study area for many years. They are used to reduce stormwater runoff loadings of nutrients, pesticides, and sediment. The implementation of these stormwater reduction strategies remains unregulated. However, certain agencies have set coverage goals for implementation strategies to be in compliance with the federal Clean Water Act (USEPA, 1972), with farm owner participation on a voluntary basis. These strategies include the reinforcement of BMP implementation on farmers who have submitted a notice of intent (NOI) to be covered by the Department of Consumer Affairs (DCA) BMP rule to reduce agricultural pollution.

The Institute of Food and Agricultural Sciences (IFAS) from the University of Florida has collected the NOIs State-wide for the Florida's Department of Agricultural and Consumer Services (FDACS). FDACS provided CDM with the NOI database for the study area. The NOI database constitutes the best information available on spatial coverage of BMP implementation. The database identifies a number of management practices that target the reduction of stormwater runoff pollution per parcel. This information, however, has certain limitations:

- The extent to which each one of the practices is applied within each parcel is not specified.
- There is no guarantee that an intention to implement BMPs has been followed through and corresponded in the actual implementation of a BMP.
- Expected removal efficiencies from the implementation of each one of the management practices are not provided in the database.

Florida Department of Environmental Protection
 Caloosahatchee River Basin TMDL Model Support
 Task Assignment CDM07-04 May 2008

Table 5-28 Urban BMP Coverage Based on Historical Land Use Change Method (1988 vs. 2004).

ID	Hydrologic Unit	Sub-watershed	Commercial/ind/ transportation	High Density Residential	Low Density Residential	Medium Density Residential	Total BMP Treated Area (acres) ⁽¹⁾	% Area Treated by BMPs ⁽²⁾
2. 42-foot Canal		East	51%		28%		398.2	28%
11. C-19		East	98%				124.4	95%
16. Canal 3		East	100%	90%	92%		23.1	95%
21. Citrus Center		East	100%		100%	100%	308.0	100%
23. Clewiston		East	46%	12%	72%	11%	836.6	32%
34. Disston Island WCD		East	74%	100%	31%	12%	386.2	57%
37. Flaghole WCD		East	99%		3%		477.5	56%
48. Hendry Hilliard WCD		East	100%		100%		24.6	100%
50. Hilliard		East	100%		64%		335.9	66%
52. Industrial Canal		East	82%			100%	826.3	82%
54. Jack Spratt (Myrtle Slough)		East	100%		100%		9.8	100%
57. L-42		East			100%		11.6	100%
61. Lake Hicpochee		East	100%		33%		14.5	36%
63. Linden Pens Marsh		East	89%		40%	22%	377.6	69%
67. Meander Ditch		East	100%		100%		213.4	100%
70. Moore Haven		East	54%		38%	12%	298.2	29%
71. Nicodemus Slough		East	100%				233.7	100%
72. Ninemile Canal		East	100%				10.2	96%
89. Sugarland WCD		East	64%		13%	23%	191.5	29%
5. Bayshore Creek		Tidal	40%		21%		174.4	24%
8. Billy's Creek		Tidal	34%	5%	34%	11%	909.9	20%
9. Blackstone		Tidal				100%	331.0	100%
13. Caloosahatchee South Shore		Tidal	16%	21%	44%	14%	871.4	20%
17. Cape Coral Freshwater Stream 3F		Tidal	22%	4%	45%	11%	2,460.9	28%
18. Cape Coral Tidal Estuary 3M		Tidal	10%	26%	66%	9%	2,009.9	17%
19. Carrol Canal		Tidal	21%	10%	83%	6%	209.5	21%
20. Chapel Branch		Tidal	59%	32%	30%	88%	176.7	36%
24. Cohn Branch		Tidal	91%	100%	76%	71%	141.2	78%
31. Daughtrey Creek (With WWTP)		Tidal	54%	16%	32%	18%	678.5	32%
33. Deep Lagoon (With WWTP)		Tidal	42%	57%	90%	49%	617.9	54%
38. Fort Myers Shores		Tidal	67%	0%	26%	2%	191.6	17%
43. Gator Slough Fresh 3F		Tidal	24%	47%	77%		1,762.8	62%
46. Hancock Creek (WBID3240E1)		Tidal	55%	41%	92%	20%	2,116.0	67%
51. Horseshoe/Hermosa Canal Stream 3F		Tidal	56%		96%	24%	9,876.3	94%
53. Iona		Tidal	25%	32%	50%	60%	871.3	45%
56. Kickapoo Creek		Tidal	19%		16%	11%	61.5	15%
65. Manuel's Branch		Tidal	1%				3.6	0%
66. Marsh Point		Tidal	33%	27%	13%	19%	290.4	19%
74. Olga		Tidal	24%		21%	22%	123.9	22%
75. Orange River (With WWTP)		Tidal	55%	40%	67%	30%	14,422.4	59%
76. Otter Creek		Tidal			86%		124.2	86%
77. Owl Creek		Tidal	12%		34%		175.6	27%
78. Palm Creek		Tidal	78%		4%	10%	52.2	6%
80. Piggot Bridge		Tidal	100%		58%		59.5	48%

⁽¹⁾ Total area treated by urban BMPs.

⁽²⁾ Percent of the total area treated by urban BMPs with respect to the total urban area.

Florida Department of Environmental Protection
Caloosahatchee River Basin TMDL Model Support
Task Assignment CDM07-04 May 2008

Table 5-28 Urban BMP Coverage Based on Historical Land Use Change Method (1988 vs. 2004) (Continued)

ID	Hydrologic Unit	Sub-watershed	Commercial/ind/ transportation	High Density Residential	Low Density Residential	Medium Density Residential	Total BMP Treated Area (acres) ⁽¹⁾	% Area Treated by BMPs ⁽²⁾
82. Popash Creek		Tidal	14%		27%	44%	359.2	27%
84. Powell Creek -mod (With WWTP)		Tidal	30%	33%	13%	4%	701.7	19%
86. South Urban Cape Coral Estuary 3M		Tidal	67%	100%	76%	61%	5,099.5	75%
88. Stroud Creek		Tidal	67%		34%	2%	682.2	42%
90. Telegraph Creek		Tidal	95%		94%	100%	183.7	95%
91. Thompson Cutoff		Tidal	100%	43%	6%		16.0	19%
93. Trout Creek		Tidal	75%		94%		691.8	78%
94. Whiskey Creek (With WWTP)		Tidal	44%	14%	47%	7%	1,266.2	24%
95. Winkler Canal		Tidal	18%			2%	84.9	9%
96. Yellow Fever Creek (WBID3240E)		Tidal	46%	14%	79%	12%	1,408.0	51%
4. Banana Branch		West	43%		45%		200.0	44%
6. Bedman Creek		West	84%		41%	74%	402.7	56%
7. Bee Branch		West	100%		82%	2%	726.4	80%
14. Canal 1		West	100%				0.2	100%
15. Canal 2		West		100%	96%		22.7	98%
22. City Ditch		West	100%	100%	53%	100%	534.3	70%
25. County Line Drainage District1		West			80%		21.7	80%
26. County Line Drainage District2		West			33%		60.2	26%
27. Cow Slough		West	79%		84%	100%	158.2	81%
28. Crawford Canal		West	97%	100%	100%		122.5	99%
29. Cypress Branch		West			94%		135.1	94%
30. Cypress Creek		West	100%		78%		215.4	74%
32. Deadmans Branch		West	100%		100%		33.3	100%
35. Dog Canal		West			61%		1,257.8	60%
36. Fichter Branch		West			73%		174.0	66%
39. Franklin Run		West			96%		171.6	92%
40. Ft. Denaud Branch		West	89%		61%	100%	588.4	62%
41. Ft. Simmons		West	53%	82%	67%		265.8	67%
45. Greenbriar Swamp		West			100%		26.3	100%
47. Hendry Canal		West	92%				106.8	42%
49. Hickey's Creek		West	49%		68%		1,642.1	65%
55. Jacks Branch		West	100%		89%	100%	879.8	89%
58. LaBelle		West	81%	81%	77%	73%	1,263.8	77%
59. LaBelle East		West	36%	78%	78%	45%	1,139.5	71%
60. LaBelle Private Drainage District		West	64%		10%		79.1	32%
62. LeHigh SE		West	97%		95%	100%	689.2	96%
64. Mackerel Canal		West			100%		540.4	100%
68. Messer		West	65%	100%	44%	35%	386.8	45%
69. Miller's Gulley		West			87%		166.6	87%
73. North LaBelle		West	95%	89%	77%	93%	878.2	83%
79. Park Branch		West			82%		197.0	82%
81. Polywog		West			68%	80%	481.4	69%
83. Port LaBelle		West			100%		424.8	100%
85. Roberts		West	58%		20%	18%	120.4	30%
87. Spanish Creek		West			83%		85.2	82%
92. Townsend Canal		West	100%				15.6	70%
Grand Total			52%	27%	65%	19%	68,520	49%

⁽¹⁾ Total area treated by urban BMPs.

⁽²⁾ Percent of the total area treated by urban BMPs with respect to the total urban area.

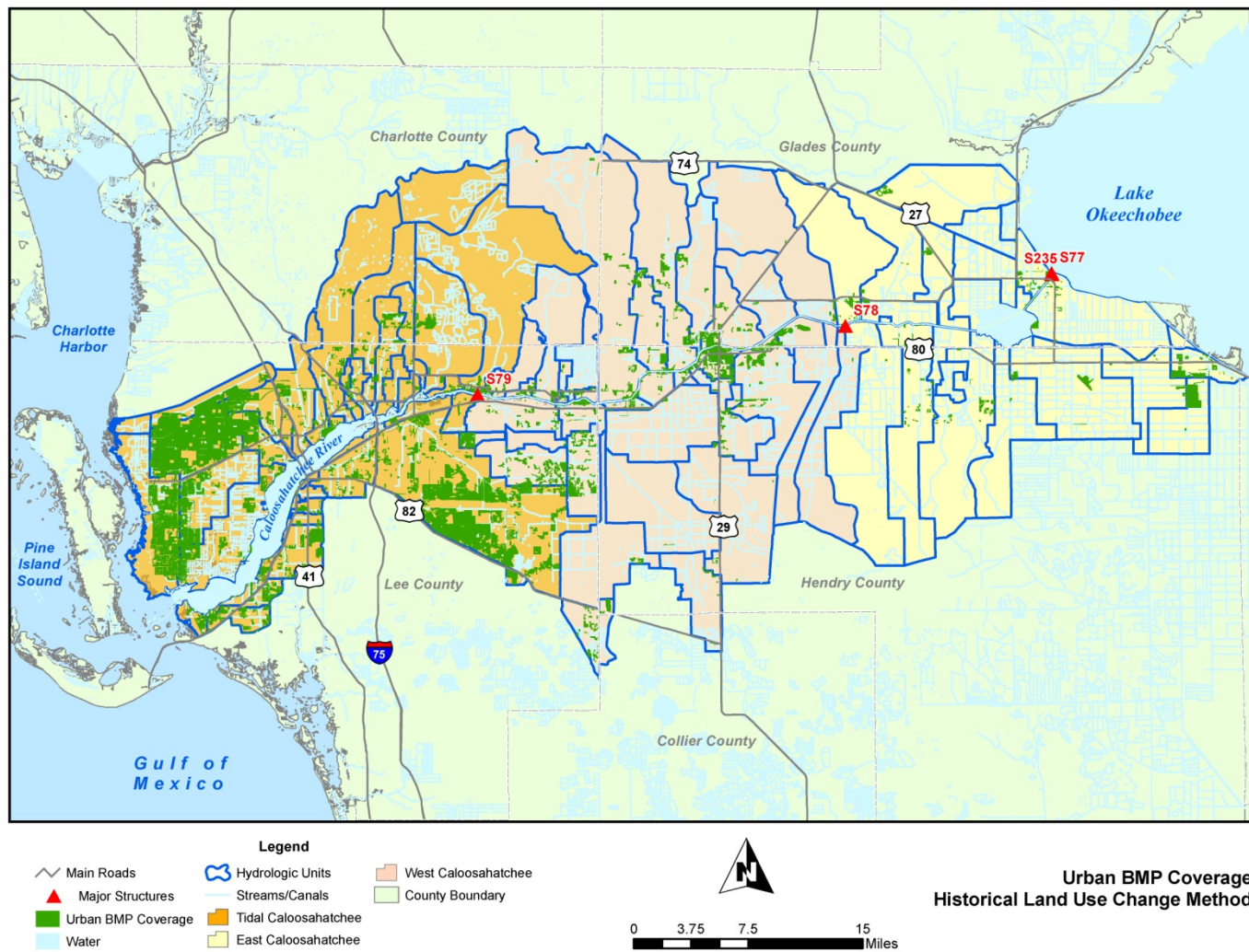


Figure 5-170 Urban BMP coverage developed based on historical land use change method

Based on the above limitations, best estimates were made in order to define the spatial distribution of agricultural BMPs with the available information and include them in the watershed pollutant loading models used in this project. These best estimates incorporated the following premises:

- Each practice is applied to an area equivalent to fifty percent (50%) of the parcel indicated in the NOI database,
- Since constant numbers and types of practices were usually applied to parcels, removal efficiencies were assigned to specific number of practices and types. Two sets of removal efficiencies were defined based on the number of parcels that applied common practices such as: stormwater management, fertilizer management, and other less common practices (e.g., erosion control, pesticide management, and administrative practices). Each set of removal efficiencies assigns different ranges of efficiencies: in Set 1, removal efficiencies vary from 10 to 70%; whereas, in Set 2, they vary from 30 - 90%, depending upon the constituent.

Table 5-43 presents agricultural land use acreage with BMPs, percentage of land use with agricultural BMPs, and assigned set of removal efficiencies per subbasin. **Figure 5-171** displays the spatial distribution of the agricultural BMPs in the study area. **Table 5-44** presents pollutant removal efficiencies per constituent for two sets referenced in Table 5-43.

5.5.3 EVALUATION OF WMM RESULTS WITH CALIBRATION REFINEMENTS

After incorporating the changes described above, WMM was run independently for each sub-watershed. Two model runs for the East sub-watershed were necessary to compare WMM estimates to downstream points: one with delivery ratios to S-78, and another with delivery ratios to S-79. Load contributions from the East Caloosahatchee River sub-watershed and the Lake Okeechobee releases (S-77) were compared to observed flows and concentrations at S-78. Likewise, load contributions from East and West sub-watersheds to S-79, which also included Lake Okeechobee releases (S-77), were compared to observed concentrations and flows. **Tables 5-44 through 5-49** present WMM estimates of annual loads for the East to S-78, East to S-79, West, and Tidal sub-watersheds. Total WMM estimated loads at S-78 and S-79 are provided at the bottom of Table 5-32 and Table 5-33, respectively.

Table 5-29. Agricultural BMP Coverage and Assigned Set of Removal Efficiencies.

Jurisd	Hydrologic Unit	Set of Removal Efficiencies ²	Citrus ¹	Citrus (1/2 Area) ²	Cropland / improved pasture / tree crops ¹	Cropland / improved pasture (1/2 Area) ²	Rangeland / unimproved pasture / open land ¹	Rangeland / unimproved pasture (1/2 Area) ²	Grand Total
East	42-foot Canal	Set 1	11.74	1.1%	28.74	0.1%	172.06	2.6%	212.54
	Canal 3	Set 2	75.37	0.6%	2,470.11	9.1%	456.38	4.5%	3,001.87
	Flaghole WCD	Set 2	7,211.32	43.3%	535.02	2.4%	206.02	15.1%	7,952.35
	Grassy Marsh	Set 2	1,010.80	28.4%	2.08	0.4%	6.35	10.6%	1,019.23
	Hilliard	Set 1	2,187.56	22.6%	1,453.68	6.3%	425.21	5.1%	4,066.45
Tidal	Telegraph Creek	Set 2			10.05	0.1%	0.00	0.0%	10.05
West	Banana Branch	Set 1	13.79	0.8%			0.11	0.0%	13.90
	Canal 1	Set 2	307.98	5.7%	9.81	0.1%	42.30	0.7%	360.08
	Canal 2	Set 2	998.67	10.2%	1.97	0.0%	68.12	1.0%	1,068.75
	Cypress Branch	Set 2	1,150.74	49.7%	17.33	0.0%	59.57	1.1%	1,227.64
	Jacks Branch	Set 2	3,827.11	26.2%	1,272.82	5.3%	346.33	2.1%	5,446.26
	LaBelle	Set 2	71.73	28.2%					71.73
	LaBelle East	Set 2			755.92	11.6%	22.84	0.2%	778.76
	Messer	Set 2	0.21	0.0%	456.25	10.5%	86.41	4.8%	542.87
	Roberts	Set 2	253.00	11.0%	1,016.04	4.4%	36.40	0.4%	1,305.45
	Townsend Canal	Set 2	11,927.80	44.4%	2,231.48	27.7%	705.85	33.0%	14,865.13
Grand Total			29,047.8		10,261.3		2,634.0		41,943.05

¹ Acreage of land use category with agricultural BMPs.

² Percentage with respect to the total land use acreage per subbasin for the half (50%) of the agricultural BMP coverage, which was the assumed spatial coverage per parcel.

³ See Table 6-6 for assigned set of removal efficiencies per constituent.

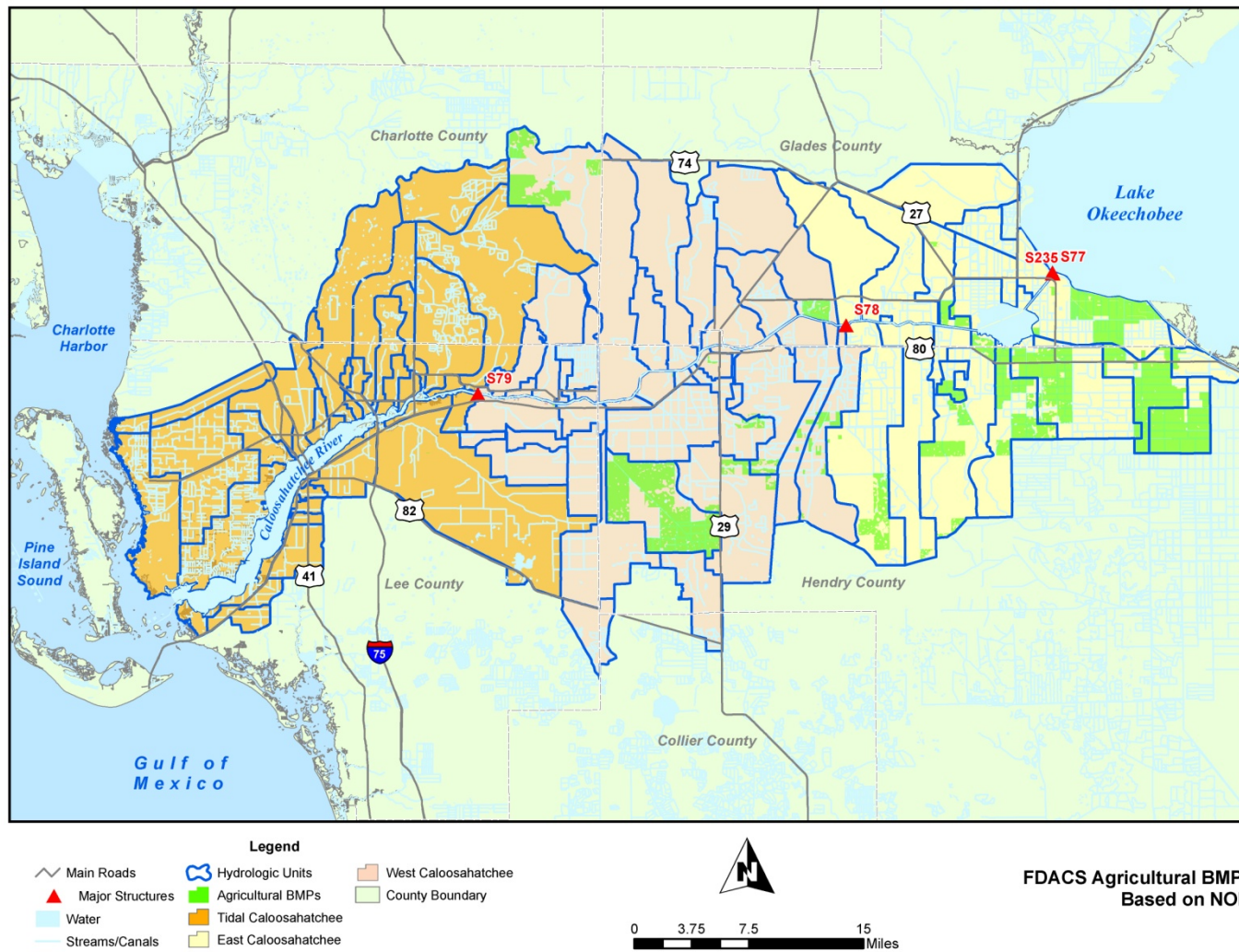


Figure 5-171 Agricultural BMP coverage developed based on FDACS' NOIs database

Table 5-44 Assigned Removal Efficiencies for Set 1 and 2 per Constituent.

Constituent	Removal Efficiencies Set 1	Removal Efficiencies Set 2
BOD	25%	40%
COD	25%	40%
TSS	80%	90%
TDS	10%	40%
TP	30%	60%
DP	30%	70%
TKN	20%	30%
NO23	15%	40%
Pb	70%	80%
Cu	60%	70%
Zn	45%	70%
Cd	70%	80%

Table 5-49 presents a comparison between observed and modeled loads (TN, TP, and TSS) and flows at S-78 and S-79. In comparing observed and modeled loads, it is important to consider that observed loads are based on grab samples and flow measurements that are subject to measurement error. In general, flow measurements are fairly accurate for which it is anticipated that the actual flow be within $\pm 10\%$ of the measured value. Water quality samples collected at these sites are grab samples collected once every one to two months at best, depending upon the constituent. Disregarding the possible but present hourly variability of a given constituent, daily variability is expected to be significant between sampling events. Therefore, the flow-weighted method used to estimate average annual loads based on daily loads is expected to have cumulative error from flow, daily constituent concentration variability, and constituent concentration determination. It is possible that the estimate of measured load based on the limited number of water quality samples may differ from the actual load by 25 to 50% or more.

Results at S-78 and S-79 indicate that all compared parameters fall within the expected range ($< \pm 10\%$) of measuring uncertainty for flow. In addition, the loads of TSS, TN and TP are also within 10% of the estimated measured load, except for TSS at S-79, for which the WMM load is significantly greater than the estimate of measured load. The

Florida Department of Environmental Protection
 Caloosahatchee River Basin TMDL Model Support
 Task Assignment CDM07-04 May 2008

Table 5-32. Average Annual Loads for the East Caloosahatchee Sub-watershed (Existing Land Use, Year 2004) with Delivery Ratios Set to 5-79.

ID	Hydrologic Unit	Area	Imperv. Area (%)	Imperv. Area (acres)	Flow (ac-ft/yr)	BOD lbs/yr	Cd lbs/yr	COD lbs/yr	Cu lbs/yr	DP lbs/yr	NO23 lbs/yr	Pb lbs/yr	TDS lbs/yr	TKN lbs/yr	TP lbs/yr	TSS lbs/yr	Zn lbs/yr
1 .	30-foot Canal	186	1.1%	2	270	1,338	0	16,735	1	88	183	1	86,974	937	161	6,637	4
2 .	42-foot Canal	21,928	2.4%	525	32,295	170,000	6	2,000,000	113	8,688	20,405	95	10,000,000	94,805	14,646	520,000	444
10 .	Bronson	1,810	1.6%	29	2,641	13,631	0	160,000	9	927	1,825	8	850,000	9,312	1,623	51,684	41
11 .	C-19	6,783	2.5%	168	10,000	60,824	0	620,000	44	4,006	7,549	32	3,200,000	37,924	6,795	170,000	228
12 .	C20 Canal	911	4.4%	40	1,375	4,826	0	84,829	2	160	546	2	440,000	2,548	230	10,742	2
16 .	Canal 3	31,839	1.8%	581	46,559	210,000	4	2,900,000	151	11,357	30,551	117	15,000,000	140,000	20,056	840,000	611
21 .	Citrus Center	17,796	2.6%	468	26,288	150,000	3	1,700,000	115	8,918	18,015	97	8,500,000	90,913	15,708	620,000	553
23 .	Clewiston	4,509	20.6%	929	8,152	110,000	4	770,000	112	3,231	7,115	51	2,700,000	25,553	4,117	130,000	594
34 .	Disston Island WCD	19,626	2.6%	519	28,995	180,000	2	1,800,000	132	11,831	22,341	93	9,400,000	110,000	19,848	470,000	699
37 .	Flaghole WCD	23,840	2.7%	650	35,256	190,000	2	2,100,000	138	9,970	25,643	88	11,000,000	110,000	16,218	420,000	696
44 .	Grassy Marsh	2,186	1.2%	27	3,174	13,989	0	180,000	11	584	2,472	6	980,000	8,708	975	36,627	48
48 .	Hendry Hilliard WCD	16,882	1.6%	269	24,614	120,000	1	1,500,000	79	7,794	17,517	58	7,900,000	81,884	13,191	340,000	358
50 .	Hilliard	26,331	1.9%	492	38,525	180,000	3	2,300,000	119	9,882	25,631	89	12,000,000	110,000	16,624	510,000	487
52 .	Industrial Canal	9,505	8.0%	759	16,390	150,000	38	1,100,000	121	6,313	17,280	94	8,700,000	58,128	10,388	250,000	1,005
54 .	Jack Spratt (Myrtle Slough)	3,294	1.6%	54	4,805	21,802	0	290,000	16	1,002	3,634	9	1,500,000	13,498	1,674	59,887	71
57 .	L-42	4,829	1.3%	62	7,013	37,736	0	410,000	25	2,771	5,220	19	2,300,000	26,516	4,740	110,000	118
61 .	Lake Hicpochee	10,224	3.0%	304	15,166	70,166	0	920,000	39	4,034	8,779	33	4,900,000	43,536	6,677	200,000	150
63 .	Linden Pens Marsh	20,829	3.1%	641	30,940	170,000	6	2,100,000	129	8,341	19,045	110	10,000,000	93,214	14,599	690,000	562
67 .	Meander Ditch	6,547	2.5%	163	9,654	57,530	1	620,000	42	3,455	6,891	35	3,100,000	34,246	5,990	210,000	208
70 .	Moore Haven	3,888	8.3%	323	6,150	54,469	1	460,000	49	2,329	4,924	27	2,000,000	20,572	3,478	94,675	243
71 .	Nicodemus Slough	17,298	3.0%	514	25,660	110,000	3	1,600,000	76	5,638	14,146	59	8,300,000	67,783	9,289	310,000	295
72 .	Ninemile Canal	913	2.1%	20	1,341	7,478	0	81,197	5	499	966	4	430,000	4,841	842	20,398	25
89 .	Sugarland WCD	11,202	2.9%	320	16,593	110,000	1	1,000,000	79	6,862	13,008	53	5,400,000	63,394	11,391	260,000	399
	Lake Okeechobee	0	na	na	830,000	3,600,000	136	1	1,226	77,184	320,000	341	710,000,000	3,000,000	180,000	15,000,000	3,360
	TOTAL (East to S-79)	263,158	3.0%	7,858	1,221,856	5,793,789	212	24,712,762	2,833	195,864	593,686	1,521	838,686,974	4,248,312	379,260	21,330,650	11,201

Notes: 1. Existing Urban BMPs are included. Agricultural BMPs based on FDACS' Notice of Intent (NOI) database are also included.

2. "With WWTP" denotes Hydrologic Units with Wastewater Treatment Plant permitted flows and loads included; however, data are not available for COD and DP.

3. Flow includes baseflow, septic tank flows, stormwater runoff, Wastewater Treatment Plant permitted flows, and Lake Okeechobee releases (under eponymus Hydrologic Unit).

4. The total percent impervious is an area-weighted composite that includes changes on the percent imperviousness to selected land use categories as part of the calibration process.

Florida Department of Environmental Protection
Caloosahatchee River Basin TMDL Model Support
Task Assignment CDM07-04 May 2008

Table 5-34. Average Annual Loads for the Tidal Caloosahatchee Sub-watershed (Existing Land Use, Year 2004)

ID	Hydrologic Unit	Area	Imperv. Area (%)	Imperv. Area (acres)	Flow (ac-ft/yr)	BOD lbs/yr	Cd lbs/yr	COD lbs/yr	Cu lbs/yr	DP lbs/yr	NO23 lbs/yr	Pb lbs/yr	TDS lbs/yr	TKN lbs/yr	TP lbs/yr	TSS lbs/yr	Zn lbs/yr
3 . Balcock		13,880	1.9%	268	27,900	120,000	14	1,900,000	97	5,510	13,452	107	9,100,000	75,406	11,039	960,000	272
5 . Bayshore Creek		2,071	8.2%	170	4,420	50,154	7	410,000	55	1,210	2,848	61	1,500,000	12,265	2,064	220,000	243
8 . Billy's Creek		6,732	29.3%	1,972	17,164	320,000	42	2,200,000	635	6,449	14,802	507	5,600,000	58,104	10,285	1,900,000	2,593
9 . Blackstone		695	13.8%	96	1,561	13,808	1	130,000	21	373	983	14	490,000	4,267	600	52,483	74
13 . Caloosahatchee South Shore		6,427	23.0%	1,480	15,593	240,000	26	1,800,000	509	5,677	13,380	369	5,000,000	51,236	9,264	1,400,000	1,691
17 . Cape Coral Freshwater Stream 3F		11,039	17.9%	1,978	25,670	380,000	37	2,600,000	575	9,568	22,315	438	8,400,000	78,836	14,286	1,400,000	2,110
18 . Cape Coral Tidal Estuary 3M		15,387	23.8%	3,657	42,024	620,000	130	4,400,000	1,352	14,881	35,306	1,017	19,000,000	130,000	25,050	3,600,000	4,931
19 . Carrol Canal		1,075	33.7%	362	2,834	61,391	8	400,000	121	1,281	2,772	98	940,000	10,467	2,027	350,000	489
20 . Chapel Branch		1,369	9.9%	135	2,966	32,668	4	270,000	47	814	2,074	42	960,000	8,537	1,436	160,000	162
24 . Cohn Branch		472	8.2%	39	1,008	9,953	1	87,710	13	240	640	12	330,000	2,625	406	41,117	42
31 . Doughtrey Creek (With WWTP)		23,263	3.8%	873	47,666	270,000	40	3,600,000	241	8,133	22,906	251	16,000,000	110,000	14,479	1,300,000	720
33 . Deep Lagoon (With WWTP)		1,777	27.2%	483	4,659	68,451	13	500,000	165	1,464	4,461	108	1,900,000	16,293	2,890	430,000	537
38 . Fort Myers Shores		2,072	20.2%	419	4,913	71,719	9	560,000	141	1,678	3,834	110	1,600,000	15,637	2,669	420,000	535
42 . Gator Slough Estuarine 3M		1,691	4.8%	80	3,494	25,171	3	280,000	19	629	1,724	23	1,100,000	7,712	1,007	77,754	59
43 . Gator Slough Fresh 3F		5,861	9.0%	527	12,933	140,000	25	1,100,000	165	3,144	9,167	147	5,000,000	34,572	5,510	450,000	617
46 . Hancock Creek (WBID3240E1)		4,933	15.2%	749	11,206	160,000	21	1,200,000	250	3,452	8,642	213	3,600,000	32,809	5,709	710,000	917
51 . Horseshoe/Hermosa Canal Stream 3F		12,791	9.4%	1,204	27,599	340,000	21	2,100,000	206	6,466	18,256	195	8,500,000	66,667	10,383	460,000	1,003
53 . Iona		3,285	22.7%	745	7,946	120,000	14	870,000	256	2,608	6,776	178	2,500,000	25,847	4,499	700,000	821
56 . Kickapoo Creek		956	6.6%	63	2,009	22,532	3	180,000	24	576	1,460	25	670,000	5,708	982	83,027	92
65 . Mannef's Branch		885	40.9%	362	2,460	58,179	7	370,000	122	1,162	2,500	97	820,000	9,372	1,803	350,000	497
66 . Marsh Point		1,961	20.7%	406	4,669	78,114	10	520,000	148	1,745	4,426	112	1,500,000	15,377	2,956	380,000	461
74 . Olga		2,370	7.2%	170	5,010	42,596	6	430,000	60	1,165	2,975	54	1,700,000	13,465	2,001	230,000	215
75 . Orange River (With WWTP)		50,340	9.6%	4,819	110,000	1,200,000	167	9,400,000	1,405	30,364	77,346	1,272	39,000,000	300,000	49,793	4,000,000	5,591
76 . Otter Creek		1,051	3.0%	32	2,135	14,785	1	160,000	12	556	1,236	15	700,000	6,333	1,088	88,161	46
77 . Owl Creek		3,870	6.4%	248	8,121	67,758	9	690,000	76	1,808	4,509	79	2,700,000	21,403	3,174	350,000	323
78 . Palm Creek		1,969	6.1%	120	4,119	45,465	7	360,000	45	1,153	2,793	53	1,400,000	11,258	1,954	160,000	172
80 . Piggot Bridge		586	5.6%	33	1,221	10,066	1	96,797	12	334	765	11	390,000	3,635	638	55,848	36
82 . Popash Creek		11,357	3.7%	419	23,222	140,000	20	1,800,000	110	3,968	11,036	125	7,600,000	53,778	6,863	590,000	323
84 . Powell Creek -mod (With WWTP)		9,193	14.8%	1,361	22,718	260,000	80	2,100,000	485	5,905	19,158	397	12,000,000	72,939	12,770	1,400,000	1,553
86 . South Urban Cape Coral Estuary 3M		17,034	7.9%	1,341	36,235	290,000	7	2,400,000	163	8,281	20,908	105	12,000,000	79,648	10,747	320,000	720
88 . Stroud Creek		5,591	8.8%	489	11,991	130,000	17	1,100,000	142	2,970	7,182	153	4,000,000	31,600	4,952	550,000	638
90 . Telegraph Creek		39,308	2.3%	895	79,284	330,000	43	5,600,000	249	13,486	35,719	269	26,000,000	200,000	25,956	2,300,000	588
91 . Thompson Cutoff		583	5.1%	30	1,208	7,645	1	93,604	10	214	631	8	390,000	2,916	382	39,599	25
93 . Trout Creek		18,373	4.4%	803	37,818	240,000	31	2,900,000	272	8,421	19,942	280	12,000,000	110,000	16,256	1,700,000	1,150
94 . Whiskey Creek (With WWTP)		5,817	41.4%	2,407	16,218	360,000	44	2,300,000	781	6,883	16,577	577	5,100,000	60,609	11,351	2,100,000	2,982
95 . Winkler Canal		977	43.3%	423	2,762	67,927	9	480,000	133	1,248	2,702	109	920,000	10,234	1,921	390,000	583
96 . Yellow Fever Creek (WBID3240E)		5,717	16.9%	966	13,179	180,000	25	1,400,000	319	3,738	9,922	254	4,200,000	38,245	6,286	920,000	1,135
Estuary		0	na	na	16,232	99,786	411	1	163	0	21,635	296	40,000,000	100,000	8,389	180,000	3,872
TOTAL (Tidal)		292,760	10.5%	30,626	662,167	6,688,168	1,315	56,738,112	9,599	167,554	447,760	8,181	264,610,000	1,887,800	293,865	30,817,989	38,818
TOTAL (Caloosahatchee River)		646,142	7.5%	40,348	1,303,808	10,216,165	1,578	100,397,836	12,696	306,824	831,523	10,905	472,550,000	3,660,121	546,936	48,008,712	50,547

Notes: 1. Existing Urban BMPs are included. Agricultural BMPs based on FDACS' Notice of Intent (NOI) database are also included.

2. *With WWTP* denotes Hydrologic Units with Wastewater Treatment Plant permitted flows and loads included; however, data are not available for COD and DP.

3. Flow includes baseflow, septic tank flows, stormwater runoff, Wastewater Treatment Plant permitted flows, and Lake Okeechobee releases (under eponymus Hydrologic Unit).

4. The total percent impervious is an area-weighted composite that includes changes on the percent imperviousness to selected land use categories as part of the calibration process.

Table 5-35. Comparison of WMM Average Annual Loads and Loads Estimated from Available Flow and Water Quality Data.

Constituent	S-78 ¹			S-79 ³		
	Observed ²	Modeled	% Difference	Observed ⁴	Modeled	% Difference
Flow (cfs)	1,531.73	1,688	10%	2,484.32	2,574	4%
Total Nitrogen (Tons/yr)	2,528	2,435	-4%	3,524	3,499	-1%
Total Phosphorus (Tons/yr)	178	196	10%	311	316	2%
Total Suspended Solids (Tons/yr)	13,891 ⁽⁵⁾	13,091	-6%	11,883 ⁽⁵⁾	19,261	62%

¹ Structure S-78 is located downstream of structures S-77 and S-235. Its tributary area corresponds to the East Caloosahatchee sub-watershed.

² Observed load at S-78 is based on daily flows and grab sample data. Loads were estimated by flow-weighting observed concentrations for the period 1997-2005.

³ Structure S-79 is located downstream of structure S-78. Its tributary area corresponds to the East and West Caloosahatchee sub-watersheds.

⁴ Observed load at S-79 is based on daily flows and grab sample data. Loads were estimated by flow-weighting observed concentrations for the period 1997-2005.

⁵ Observed loads for TSS at S-79 seem suspect for being lower than that at S-78.

estimate of observed TSS load at S-78 is greater than the downstream TSS load observed at S-79 for the period of 1997-2005, which makes the observed load estimate at S-79 rather suspect, particularly because the estimated observed load for the EBCRNLA WMM effort (1990-1995 data) showed a significant increase in TSS load between S-78 and S-79. At these two locations, TSS concentrations were measured approximately six times every year to account for a total of 52 samples during the modeling period of 1997 through 2005. Both the WMM load estimate and the estimate of observed load reflect a low flow-weighted TSS concentration of 5 to 10 mg/l. No further model adjustments were made to achieve better agreement between the WMM TSS load and the estimate of observed TSS load at S-79.

WMM model results for Whiskey Creek are compared to measured Whiskey Creek data in **Table 5-49**. This comparison has a number of limitations:

- WMM models Whiskey Creek as a single subbasin with a tributary area of 5,817 acres (9.1 square miles)
- The USGS gage at Whiskey Creek has a tributary area of approximately 3.7 square miles. Consequently, the flow from WMM was reduced by a factor of 0.41 (3.7/9.1) to compare the WMM flow and USGS flow.
- The rainfall applied in WMM (63.1 inches per year) to the entire Tidal Caloosahatchee area may not be consistent with the quantity of rainfall on the small 3.7 square mile area. In fact, the rainfall used by HSPF for the Whiskey Creek subbasin is 68.8 inches per year for the 1997-2005 period.
- The pollutant loads are estimated based on concentrations that do not come from the same branch of Whiskey Creek as the location of the USGS gage.
- Concentrations of TP and TN at a water quality station on the same branch as the USGS station are significantly higher than the data used as the basis for the observed load estimation. This sampling was done on a more frequent basis (as opposed to monthly ambient sampling) but was limited to a single wet season month and dry season month.
- Pollutant load estimates based on ambient monthly sampling may be expected to be low because the sampling may not capture the effects of storm events which tend to move quickly through small urbanized tributary areas.

The results in Table 5-36 show an underestimation in flow by WMM, which may in part be the result of differences between the rainfall data used in WMM and the actual rainfall in the relatively small tributary area. The table also shows that the TP, TN and TSS loads estimated by WMM are much higher than the estimated observed loads. As discussed earlier, this may be due to the limited sampling data (ambient monthly water quality samples) missing the larger concentration and load events in a small, flashy urban watershed. The average concentrations of measured TN and TP are 0.65 mg/l and 0.06 mg/l, respectively, and these values are at or below (in the case of TN) the concentration of baseflow that was used in the WMM. This may indicate that the sampling is not capturing major storm flows that are likely to have higher pollutant concentrations.

Table 5-49 Comparison of WMM Average Annual Loads for the Whiskey Creek Hydrologic Unit and Estimated Loads from Available Data

Constituent	WHISKEY CREEK ¹		
	Observed ²	Modeled	% Difference
Flow (cfs)	12.00	9	-25%
Total Nitrogen (Tons/yr)	8	16	87%
Total Phosphorus (Tons/yr)	0.7	2	206%
Total Suspended Solids (Tons/yr)	56	423	661%

In summary, though the WMM estimated pollutant loads are significantly different than the estimated observed loads in Whiskey Creek, there are a number of reasons that might explain that the observed loads are not representative of the overall loads from the small urban watershed. Consequently, no further model adjustments were made.

5.6 COMPARISON OF HSPF AND WMM CALOOSAHATCHEE WATERSHED MODELS

5.6.1 Introduction

This section documents the comparison between the Hydrological Simulation Program – FORTRAN (HSPF) and Watershed Management Model (WMM) representations of the Caloosahatchee River watersheds. Both models were used in parallel in this project to estimate the flows and loads of several water quality constituents from the watershed to the tidal Caloosahatchee River.

Tables 5-50 through 5-54 compare features of HSPF and WMM related to simulation of flows and loads from the watershed, and transport/transformation occurring in the watershed transport network. Tables 5-50 through 5-53 focus on the watershed flows and loads, whereas Table 5-54 focuses on the transport network.

The generation of land-based flows is addressed in Table 5-50. In WMM, the average annual surface runoff from pervious and impervious land areas is calculated based on the average annual rainfall, and runoff coefficients for pervious and impervious lands. Baseflow in WMM is calculated based on an assigned average annual baseflow value, presuming that only pervious lands are contributing baseflow. In contrast, HSPF utilizes the Stanford Watershed Model approach to determining quantities of surface runoff, interflow and baseflow from pervious lands. The simulation is driven by hourly time series of rainfall and potential evapotranspiration (PET). As noted in the table, there are a number of soil storage, interception storage, and infiltration parameters that are used to determine whether rainfall is converted to streamflow or lost to evapotranspiration (ET).

Table 5-51 summarizes the model characteristics for sediment simulation. For WMM, the surface runoff quantity is assigned an average Event Mean Concentration (EMC) value (which can vary by land use type) to determine the average annual sediment load from the watershed. A single EMC value is specified for each land use (separate EMCs for the pervious and impervious fractions of a particular land use are not specified). In contrast, HSPF does separate calculations for pervious and impervious land elements. For the pervious elements, HSPF calculates the amount of soil detachment occurring during rain events due to rain impact on the soil surface, and calculates the rate of sediment re-attachment during dry periods, with the rate of both processes depending on input detachment and re-attachment parameter values. For impervious areas, HSPF calculated sediment buildup during dry periods and washoff during wet periods, again based on input buildup and washoff parameters.

Table 5-50 Comparison of WMM and HSPF land-based flow calculation methods

FLOW COMPONENT	WMM	HSPF
Surface runoff - pervious area	Annual rainfall Runoff coefficient	Rainfall time series Potential evapotranspiration time series Soil storage parameters Interception storage Infiltration parameter Evapotranspiration parameters
Surface runoff - impervious area	Annual rainfall Runoff coefficient	Rainfall time series Hourly potential evaporation Surface retention parameter
Interflow - pervious area	None	Rainfall time series Potential evapotranspiration time series Soil storage parameters Interception storage Infiltration parameter Evapotranspiration parameters
Baseflow - pervious area	Annual baseflow	Rainfall time series Potential evapotranspiration time series Soil storage parameters Interception storage Infiltration parameter Evapotranspiration parameters

Table 5-51 Comparison of WMM and HSPF land-based sediment calculation methods

SEDIMENT COMPONENT	WMM	HSPF
Surface runoff - pervious area	Runoff concentration ¹	Sediment buildup parameters AND/OR Sediment detachment parameters Sediment re-attachment parameters PLUS Sediment washoff parameters
Surface runoff - impervious area	Runoff concentration ¹	Sediment buildup parameters Sediment washoff parameters
Interflow - pervious area	None	None
Baseflow - pervious area	Baseflow concentration	None

¹ Single runoff concentration is applied in WMM to total runoff from pervious and impervious land area

The model evaluations of nutrients (nitrogen, phosphorus) and biochemical oxygen demand (BOD) are characterized in Table 5-52. For WMM, the modeling of nutrients and BOD are exactly the same as any other water quality parameter, with EMCs assigned to surface runoff and baseflow. In contrast, the nutrients and BOD have been modeled in HSPF as “general constituents”, either applying buildup and washoff algorithms or applying “potency factors” (i.e., pounds of constituent per ton of sediment washoff). Concentrations of nutrients and BOD in the pervious land interflow and baseflow is based on assigned concentrations, which can vary monthly and can vary by land use type.

Table 5-52 Comparison of WMM and HSPF land-based nutrients and BOD calculation methods

NUTRIENT/BOD COMPONENT	WMM	HSPF
Surface runoff - pervious area	Runoff concentration ¹	Pollutant buildup parameters Pollutant washoff parameters AND/OR Potency factor
Surface runoff - impervious area	Runoff concentration ¹	Pollutant buildup parameters Pollutant washoff parameters AND/OR Potency factor
Interflow - pervious area	None	Interflow concentration
Baseflow - pervious area	Baseflow concentration	Baseflow concentration

¹ Single runoff concentration is applied in WMM to total runoff from pervious and impervious land area

Table 5-53 summarizes the model characteristics for simulation of dissolved oxygen (DO) and water temperature. WMM is typically not applied to constituents such as DO and water temperature, because receiving water concentrations are generally more a function of receiving water processes (e.g., reaeration, sediment oxygen demand for DO, and heat transfer mechanisms for water temperature). HSPF calculates water temperature for surface runoff and interflow based on relationship to air temperature, with relationship defined by input water temperature parameters. The baseflow water temperature is typically defined directly based on input monthly baseflow temperature values.

Modeling considerations of flow and water quality in the watershed transport network are presented in Table 5-54. In WMM, average annual or seasonal calculations of flow and load are evaluated on a subwatershed basis, and the total watershed flow and load is the sum of the subwatershed flows and loads. The only consideration of constituent loss in the watershed transport network in WMM is the specification of a “delivery ratio”, which defines how much of the particulate fraction of each constituent is delivered to a specific point of interest (e.g., watershed outlet). For example, specifying a delivery ratio of 0.6 means that 60% of the particulate fraction will get to the point of interest, and 40% will not (settles in the transport network). In contrast, HSPF routes the flows through a defined reach network, and evaluates specific processes that decrease (or increase) constituent loads and concentrations. For sediment, the potential for

Table 5-53 Comparison of WMM and HSPF land-based water temperature and DO calculation methods

WATER TEMPERATURE / DO COMPONENT	WMM	HSPF
Surface runoff - pervious area	None	Air temperature time series Water temperature parameters DO assumed at saturation concentration
Surface runoff - impervious area	None	Air temperature time series Water temperature parameters DO assumed at saturation concentration
Interflow - pervious area	None	Air temperature time series Water temperature parameters Interflow DO concentration
Baseflow - pervious area	None	Monthly water temperature Baseflow DO concentration

sediment deposition (loss) or scour (gain) is based on calculated reach shear stress values and input scour and deposition parameters (e.g., silt and clay settling rates, and critical shear stress values for scour and deposition). HSPF also includes full eutrophication simulation, accounting for phytoplankton growth/respiration/death processes and related impacts on concentrations of DO, BOD and nutrients. Heat budget calculations are also done in HSPF to simulate water temperature, which in turn affects the rate of kinetic processes as well as the saturation DO concentration in the reach.

With respect to wastewater point sources and the benefits of Best Management Practices (BMPs), the WMM and HSPF models evaluate the impacts in a similar way. In both models, the wastewater point sources are defined based on a flow rate and concentrations of the various water quality constituents. For BMPs, both models account for the reduction in surface runoff loads associated with the BMP implementation by defining the amount of land served by BMPs, and the presumed BMP removal efficiency for the various constituents. WMM accounts for the BMP benefits directly based on the defined percentage of land treated and BMP efficiency. In HSPF, the user must define the acreage of land treated by BMPs (rather than percentage). The uncontrolled loads from the treated lands must either be routed to a "BMP module" where loads are reduced based on the presumed efficiency, or the load reduction can be applied by specifying a scaling factor when the watershed loads are mapped to the reach in the "SCHEMATIC" block of the HSPF input.

Table 5-54 Comparison of WMM and HSPF transport network flow and water quality calculation methods

TRANSPORT NETWORK COMPONENT	WMM	HSPF
Flow	None	Reach storage-outflow relationship Direct rainfall and evaporation time series
Sediment	Delivery ratio	Scour parameters Deposition parameters
Nutrients, BOD	Delivery ratio	Full eutrophication kinetics
Dissolved oxygen (DO)	None	Full eutrophication kinetics
Water temperature		Solar radiation time series Cloud cover time series Air temperature time series Dewpoint temperature time series Wind speed time series Heat transfer parameters

5.6.2 Methodology

For this analysis, results from the WMM and HSPF models have been compared for the period of 1997 through 2005. For WMM, the model was calibrated based on the average annual rainfall for that period. As discussed previously, WMM calculations were done for three distinct geographical areas: (1) between S-77 and S-78, (2) between S-78 and S-79, and (3) tidal (downstream of S-79). The rainfall data time series input used by HSPF (15 distinct rainfall zones) was processed to determine an appropriate area-weighted rainfall for the three WMM geographical areas. In contrast, HSPF hydrologic calibration and validation focused on the years 2001 through 2005 (calibration) and 1997 through 1999 (validation), and HSPF water quality calibration and validation focused on the years 2004 through 2005 (calibration) and 2002 through 2003 (validation). To directly compare HSPF and WMM results, the HSPF model was run for the period of 1996 through 2005, with one year (1996) representing “start-up” conditions.

The average annual flow and load results from WMM (based on average annual rainfall and baseflow for the period 1997-2005) and HSPF (generated based on time series rainfall from 1996 to 2005) were tabulated and compared to the measured flow and load at structures S-77,

S-78 and S-79, as well as the total watershed discharge in the tidal area (downstream of S-79). The total load to the tidal river (tidal watershed discharge plus discharge at S-79) is also presented. The comparison at S-77 (headwater boundary of the model) was done to show that the WMM and HSPF models accurately represent the measured boundary flows and loads at that location. Similarly, results are compared at S-78 and S-79 to evaluate differences between the models, and differences between the model results and the measured flows and loads. Keep in mind that the “measured” loads are based on daily flows and grab sample concentrations (typically monthly) so the “measured” load is actually an estimate that is subject to potential significant error.

5.6.3 Results

Table 5-55 lists the long-term (1997-2005) load estimates based on measured data, WMM results, and HSPF results. The results are presented for the following constituents:

- Tributary area
- Flow
- Total nitrogen (total N)
- Total phosphorus (total P)
- Total suspended solids (TSS)
- Carbonaceous BOD (CBOD)

A summary of the findings for each constituent is presented below.

5.6.3.1 Tributary Area

The values in Table 5-55 indicate that the WMM and HSPF models are based on comparable tributary areas, with some further analysis of the tidal watershed area. As noted in the footnotes below the table, the HSPF model accounts for 242,225 acres of land associated with a routing reach (e.g., well-defined stream), and an additional 17,260 acres discharges to the tidal river without routing through a well-defined reach. Thus, the total HSPF land area downstream of S-79 is 259,485 acres. For WMM, the total area downstream of S-79 is 292,760 acres, but WMM includes several areas (e.g., Gator Slough) that do not contribute to the tidal river. The footnotes to Table 6 indicate the WMM subwatersheds (or parts of subwatersheds) that are not considered to be tributary to the tidal river. Without these areas, the WMM tributary area below S-79 is 259,730 acres, which is almost identical to the HSPF tributary area. As noted below the table, the flow and loads from these “excluded” WMM subwatersheds have been excluded from the WMM flows and loads in Table 6 for the tidal area, so that the comparisons between WMM and HSPF are based on similar tributary areas.

Table 5-55 Comparison of WMM and HSPF average annual flows and loads 1997-2005

Constituent	Calculation Method	Location				
		S-77	S-78	S-79	Tidal	Total to Tidal River
Area (acres)	Measured	NA	NA	NA	NA	NA
	WMM	NA	263,158	616,540	259,730	876,270
	HSPF	NA	263,651	620,526	259,485	880,011
Flow (acft/yr)	Measured ¹	834,512	1,109,153	1,799,566	NA	NA
	WMM	834,954	1,221,856	1,863,497	590,797	2,454,294
	HSPF	835,599	1,193,928	1,816,467	602,588	2,419,055
Total N (ton/yr)	Measured ²	1,820	2,528	3,524	NA	NA
	WMM	1,816 ³	2,435	3,489	1,058	4,547
	HSPF	1,924	2,657	3,699	739	4,438
Total P (ton/yr)	Measured ²	110	178	311	NA	NA
	WMM	110 ³	196	316	134	450
	HSPF	131	229	369	165	534
TSS (ton/yr)	Measured ²	21,040	13,891	11,883	NA	NA
	WMM	21,559 ³	13,091	19,260	14,642	33,902
	HSPF	4,921 ⁴	37,463	62,485	15,986	78,471
CBOD (ton/yr)	Measured ²	NA	NA	NA	NA	NA
	WMM (5-day)	2,269 ^{3,5}	3,013	4,661	3,344	8,005
	HSPF (ultimate)	8591 ⁵	5,793	5,363	2,789	8,152

¹ Measured flow is based on daily measurements at structure locations

² Measured loads are estimated based on daily flows and periodic (e.g., monthly) grab sample concentrations

³ WMM loads at S-77 are adjusted by “delivery ratios” to account for particulate pollutant loss between S-77 and downstream locations S-78 and S-79. Values of 0.38 and 0.34 were used for delivery to S-78 and S-79, respectively, based on previous SFWMD Caloosahatchee Basin study by CDM

⁴ The HSPF load of TSS at S-77 was reduced at the loading point to account for loss between S-77 and S-78.

⁵ BOD loads at S-77 are strictly an estimate because measured BOD data are not available.

5.6.3.2 Flow

As shown in the table, the results from the WMM and HSPF models produce long-term average flow results that are similar to each other, and similar to measured long-term flow. At all three locations, both WMM and HSPF average annual volumes are within 10% of the measured values.

5.6.3.3 Total Nitrogen

A review of the total N results in Table 5-55 indicates that the HSPF model has a slightly higher headwater total N load from Lake Okeechobee at structure S-77. At the other C-43 Canal stations, the results indicate that WMM and HSPF have comparable loads, and both are close to the estimate of measured total N load. The WMM load in the tidal area is higher than the corresponding HSPF load, with the overall total N load to the tidal river being very similar for the WMM and HSPF models.

5.6.3.4 Total Phosphorus

Like total N, the total P results in Table 5-55 indicates that the HSPF model has a slightly higher headwater total P load from Lake Okeechobee at structure S-77. At the other stations, the results indicate that HSPF produces a somewhat higher average annual total P load than WMM. Given the level of uncertainty in the estimation of the measured total P load, both the WMM and HSPF results appear reasonable.

5.6.3.5 Total Suspended Solids

The results presented in Table 5-55 show that the average annual TSS loads at stations S-78 and S-79 are much higher than the estimate of measured load and the WMM results. Previously, it was discussed that the TSS load results in the freshwater C-43 Canal are skewed by a large storm event in October 2005 (Hurricane Wilma). If the year 2005 is excluded, the average annual TSS load calculated by HSPF at S-78 and S-79 is 12,718 and 19,808 tons per year, respectively. These values are very close to the average annual WMM values for the entire period. It should be recalled that the estimate of measured load for TSS is subject to significant error because of the limited number of observed TSS concentration data during this period. It should also be noted that the WMM and HSPF loads for TSS in the tidal area are very close as well. Because TSS concentrations in the C-43 Canal are typically low (5 mg/l or less), it is expected that watershed TSS loads will have limited impact on water quality in the tidal river, and further model refinement will not be merited.

5.6.3.6 Carbonaceous BOD

Because there are no measured BOD data at the C-43 Canal stations, comparisons between estimated measured loads and modeled loads cannot be made. Comparison of WMM loads (based on 5-day BOD) and HSPF (based on ultimate BOD) shows that the headwater S-77 loads show a ratio of about 4 to 1, which may be slightly high, but the other stations show a ratio of 0.8 to 1.9. Normally, the ratio of 5-day to ultimate CBOD would be expected to be in the range of 2 or 3 to 1, so it is possible that WMM is overestimating the 5-day BOD load and/or HSPF is underestimating the ultimate BOD load. Again, without measured data, no conclusions can be drawn.

5.6.4 Summary and Recommendations

For this analysis, results from the WMM and HSPF models have been compared for the period of 1997 through 2005. For WMM, the model was calibrated based on the average annual rainfall for that period. As discussed previously, WMM calculations were done for three distinct

geographical areas: (1) between S-77 and S-78, (2) between S-78 and S-79, and (3) tidal (downstream of S-79). The results suggest that the two models are generating comparable average annual flows and loads that are reasonable with respect to the estimated average annual loads in the watershed.

These models appear to be appropriate for the evaluation of alternative management strategies to reduce pollution loads to the tidal Caloosahatchee River. The relatively simple WMM model is well-suited to evaluate a number of pollution-reduction alternatives quickly in terms of average annual load reductions. WMM could be applied to identify one or more desirable management alternatives, which could then be evaluated in more detail using the HSPF model. Only the HSPF model can generate time series of flows and loads over a continuous simulation period. Continuous simulation can evaluate impacts over a range of conditions, helping to identify the “critical conditions” for the tidal river impairment and evaluating whether the management alternatives will be sufficient to eliminate the impairment.

5.7 EFDC AND WASP7: A COMPARISON

5.7.1 Introduction

The model framework selected for the Caloosahatchee estuary TMDL project includes a watershed runoff model (HSPF), a hydrodynamic model (EFDC) and water quality models (EFDC and WASP7). The primary water quality model selected for the Caloosahatchee modeling study is the EFDC hydrodynamic and water quality model. In addition to the selection of EFDC, WASP7 has also been selected as a water quality model for the Caloosahatchee estuary study. The selection of EFDC and WASP7 as water quality model frameworks for the Caloosahatchee estuary study provides Florida DEP with a unique opportunity for a comparison of the results obtained with each water quality model. The objective of the comparison is to provide Florida DEP with an unbiased evaluation of the similarities, differences, strengths and weaknesses of these well-known and highly-respected surface water quality modeling tools.

5.7.1.1 Overview of EFDC

The Environmental Fluid Dynamics Code (EFDC) is an advanced modeling package designed to simulate 1D/2D or 3D hydrodynamics and biogeochemical processes in a wide variety of surface water systems including rivers, lakes, estuaries, reservoirs, wetlands, coastal and open ocean waters. EFDC is unique among advanced surface water models because it is designed to internally couple the hydrodynamic model with sediment transport, toxic chemicals, eutrophication and sediment diagenesis models within a single source code (Hamrick, 1996). Over the past decade, EFDC has served as an advanced modeling framework to support hundreds of hydrodynamic, sediment transport, toxic chemicals and water quality applications worldwide (see Ji, 2008).

5.7.1.2 Overview of WASP7

The Water Quality Analysis Simulation Program (WASP) is a compartment-based modeling framework for surface water systems. The time variable WASP model allows for the spatial representation of a waterbody as a 1D, 2D or 3D network of horizontal segments and vertical layers. Pollutants represented in the WASP model include water quality parameters related to (a) eutrophication; (b) toxic chemicals; and (c) mercury. The current version of the eutrophication module of WASP (Vers 7.2; USEPA, 2007) represents a Windows-based upgrade and kinetic enhancement of earlier versions of WASP (WASP3: Di Toro et al., 1983; WASP4: Ambrose et al., 1988; WASP5: Ambrose et al. 1993; 1995; and WASP6: Wool et al., undated). In comparison to WASP5 and WASP6, WASP7 includes enhanced representations of some of the water quality kinetics and the addition of benthic algae as a state variable. Over the past two decades, WASP has served as a modeling framework to support hundreds of toxic chemical and water quality applications worldwide (see Lung, 2001).

5.7.2 Methodology

EFDC and WASP7 are compared qualitatively on the basis of general criteria related to model support, documentation and usage and technical criteria related to the theory and formulations of the models. General criteria include: (a) availability of a user's manual and documentation of the theoretical principles and governing equations of the model; (b) technical support for model development (c) pre-processing, post-processing and data visualization tools to support development of a model; (d) application history; (e) resource requirements; and (f) availability of model software. Technical criteria considered include (a) numerical methods; (b) initial conditions; (c) external loading and boundary conditions; (d) state variables and kinetic processes; (e) coupling of water column and sediment bed; (f) linkage with HSPF.

WASP7 results and observed data are presented in Section 5.4.5.1 (calibration) and Section 5.4.5.2 (validation) for dissolved oxygen and algae as chlorophyll-a. In order to evaluate the agreement between EFDC and WASP7 results, calibration (2003) and validation (2004) year results for EFDC and WASP7 are compared to observed data dissolved oxygen and algae biomass (as chlorophyll) for Stations CES-04 and CES-06. A complete set of EFDC and WASP7 comparison plots for Stations CES-04 and CES-06 for nitrogen, phosphorus, TSS and TOC are given in Appendix 5-I and 5-J for the calibration and validation results.

5.7.3 Results

In relation to the general and technical criteria identified above, the major differences between EFDC and WASP7 are presented as follows:

5.7.3.1 Pre-Processing, Post-Processing and Data Visualization Tools

The availability and capabilities of pre- and post-processing software tools is critical for the efficient development and application of any surface water model. The ability to display maps of the watershed, streams and rivers, shoreline, station locations, and relevant landmarks that can be superimposed on the model computational grid is essential for a complete picture of the model domain for a study. The ability to display time series, spatial transects, horizontal maps and vertical profiles of water quality constituents is essential for model development and comparison of model results to observed data.

Pre-processing and post-processing software tools are available for EFDC from EPA (EFDCView) and from Dynamic Solutions LLC (EFDC_Explorer). Dynamic Solutions developed the EPA-licensed EFDC_Explorer software to support the development and application of EFDC sub-models for hydrodynamics, sediment transport, toxic chemicals, water quality and sediment diagenesis. EFDC Explorer is a public domain, Windows-based GUI software available at no cost by downloading setup files from Dynamic Solutions. EFDC_Explorer is designed to support EFDC model set-up and configuration, grid generation (cartesian or curvilinear), model testing and calibration and validation comparison to observed data sets. EFDC_Explorer provides the capability for data visualization, including display of the computational grid, map overlays, spatial transects, time series and vertical profile plots. Animation of results can easily be generated and saved to an AVI file (Craig, 2004).

Pre-processing and post-processing tools are also available for WASP7 from EPA as integrated components of the WASP software package. The WASP7 pre- and post processor is public domain, Windows-based GUI software available by downloading setup files from the EPA website. The post-processing tool that is part of the WASP7 software package (MOVEM) allows for the display of model results as (a) X/Y line plots for selected segments as time series and/or spatial transects and (b) 2D spatial grid showing color coded results as time snapshots and/or animated results that can easily be saved to an AVI file. The display of maps related to the model domain and any geographical references for a modeling project such as station locations or the model computational grid, however, is not available as an option within the WASP7 software package. It is difficult therefore to identify the location of a WASP grid segment that relates to a station location or wastewater discharge for example within the WASP7 package since the only data available to characterize segments is a table list of segment numbers and descriptions and volumes. Map software, such as ArcView GIS, must be used as an external standalone tool to prepare and display segment grid maps as overlays on the variety of maps typically needed for a modeling project.

5.7.3.2 Resource Requirements

Both models require considerable scientific/engineering background related to surface water quality and eutrophication as well as overall data processing expertise to setup and apply a water quality model for a 3D waterbody such as the Caloosahatchee estuary. The lack of availability of a map display of the computational grid and any relevant geographic landmarks for a modeling project in the WASP7 software is a weakness that tends to increase the labor effort needed for setup of a model. For the Caloosahatchee project, map displays that were readily available in EFDC_Explorer were used to facilitate setup of the WASP7 model.

Perhaps the most significant resource requirement difference between WASP7 and EFDC is the run time required to execute the two models with an identical computational grid, identical numerical time step for integration and a comparable number of state variables. The EFDC domain for the Caloosahatchee model was represented with 733 horizontal grids and 4 vertical layers for a total of 2,932 grid cells. Since the WASP7 model excludes the outer rows of the open water boundary grid cells, the WASP7 domain is represented with 701 horizontal segments and 4 vertical layers for a total of 2,804 segments. The time step that is used for EFDC to obtain numerical stability must also be used for WASP7 because of the hydrodynamic linkage file. Hydrodynamic data is provided to WASP7 based on an averaging of hydrodynamic results over 600 time steps of 11 seconds (110 minutes). On a 2.67 GHz Intel Core 2 Duo, a one-year simulation for the EFDC hydrodynamic, sediment transport and water quality model required a runtime of about 7.5 to 8 hrs. Using the same computer, the runtime required for WASP7 on the same computer, at 27 to 28 hrs, was considerably longer than the runtime required for EFDC.

5.7.3.3 Availability of Model Software

Both EFDC and WASP7 are public domain models. Fortran source code for EFDC has been made freely available for the past decade from EPA. Fortran source code, however, is not distributed with the windows-based WASP7 software package. EPA's reason for this policy is to maintain version control for the WASP model. Any modifications needed for the WASP7 code must be performed by EPA Region IV as the developer of the software. For the Caloosahatchee project, source code modifications were needed to increase the size of arrays for the number of boundary conditions, decrease the number of discrete time series data points to reduce memory requirements and modify the transport data table for defining bottom water column segment pathways to the sediment bed segment for solids deposition. Changes were requested and promptly made by EPA Region IV. The lack of availability of the Fortran source code, however, is an important issue for a model development team when, during the construction of a model, the team has difficulties understanding how the WASP7 model actually operates with the input data, model options and model formulations. The documentation manuals and information given in the data tables in the WASP7 interface, although generally adequate, does not always provide answers to questions that can only be answered sometimes by reading the source code.

5.7.3.4 Coupling of Water Column and Sediment Bed

The EFDC model includes an internal coupling of the water column and sediment bed with Di Toro's (2001) sediment flux model. The present version of WASP7 does not include the sediment diagenesis model that allows for internal coupling of particulate organic matter deposition to the sediment bed and the resulting sediment oxygen demand and the sediment bed release of nutrients to the water column. Since the sediment diagenesis model is not yet incorporated in WASP7, the sediment-water exchange of nutrients and sediment oxygen demand is accounted for in WASP with user-defined empirical representations of benthic forcing function fluxes that can vary in space and time. This is the identical methodology used in WASP5 and WASP6. It is anticipated that future releases of WASP will include the sediment diagenesis model. The coupling of the sediment flux model with the water column model will then greatly improve the predictive capability of the WASP model framework to represent alternative management scenarios that would potentially alter external loading to a waterbody.

5.7.4 Comparison of EFDC and WASP7 Water Quality Model Results

Selected results are presented for comparison of observed data to EFDC and WASP7 results at Station CES-04 and Station CES-06 in the Caloosahatchee estuary (see Figure 8 for station location map). These stations were selected because of the availability of a complete suite of water quality data for comparison to model results for both WASP7 and EFDC. Time series plots are presented for surface and bottom layer results for algal biomass (as chlorophyll-a) and dissolved oxygen. Results are first presented for the model calibration period from 1-Jan-2003 through 31-Dec-2003. Results are then presented for the model validation period from 1-Jan-2004 through 31-Dec-2004. EFDC results are shown as the magenta colored line while the WASP7 results are shown with the blue line. Observed data points are marked by solid red

circles. A complete set of EFDC and WASP7 model vs. observed data plots for the calibration and validation years for Station CES-04 and CES-06 is presented in Appendix 5-I and 5-J.

5.7.4.1 Model Calibration

5.7.4.1.1 Algal Biomass

As can be seen in **Figures 5-172** and **5-173**, the EFDC results show a good match between simulated algal biomass and observed chlorophyll measurements for the surface layer of Stations CES-04 and CES-06 for 2003. The WASP7 results for Station CES-04, although somewhat higher than the observations and the EFDC results, tends to follow the timing shown with the observations and the EFDC results. The WASP7 results at Station CES-06, however, are not as good as EFDC and simulate much higher levels of algal biomass during the spring and summer months than is indicated by the observed data.

In both EFDC and WASP7, algae biomass is governed by growth, basal metabolism and respiration, settling from the water column and mortality loss. Identical parameter values are used in EFDC and WASP7 for the assignment of the settling and mortality rates. WASP7 allows for the input of a global maximum growth rate for algae while EFDC allows for the assignment of maximum growth rates for each of the six water quality zones defined for the Caloosahatchee model. The reduction of the maximum algal growth in both models is dependent on incident light, water temperature and the availability of nutrients. WASP7 and EFDC use similar formulations for nutrient limitation based on half-saturation constants for nitrogen and phosphorus. Water temperature dependence in WASP7 uses a somewhat different formulation than EFDC but the overall temperature effect on algae growth for WASP7 and EFDC should be similar. There are differences, however, in the light dependence formulations of WASP7 and EFDC for the (a) estimation of light extinction in the water column and (b) the specification of the optimal light saturation level for algal photosynthesis.

Light extinction in EFDC accounts for the background light extinction from color, algal biomass, detrital organic matter and inorganic solids with different coefficients used for algae, detritus and inorganic solids (see Di Toro, 1978; Lung, 2001). Light extinction in WASP7 accounts for background extinction from color, extinction from algae chlorophyll, extinction from dissolved organic carbon and extinction from the sum of detrital organic matter and inorganic solids. Unlike EFDC, WASP7 does not allow for the use of different coefficients to describe the extinction of detritus and inorganic solids. Since the coefficient for detritus is 0.174 and the coefficient for inorganic solids is 0.052 there is about a three-fold difference in the estimation of the extinction coefficient given the same concentration of detritus and inorganic solids.

WASP7 and EFDC also differ in the formulations used to compute the light limitation factor for algal growth. Light limitation in WASP7 is based on the input of a constant optimal saturating light intensity considered appropriate for the dominant phytoplankton assemblage. Light limitation in EFDC, based on an approach used by Kremer and Nixon (1978), uses a computed saturation light level that is derived from a weighted average of the incident solar radiation for the previous three days.

Additional evaluations of the light, nutrient and water temperature limitation factors that control the overall growth rates of algae in WASP7 and EFDC are needed to fully understand why there are differences in simulated algal biomass.

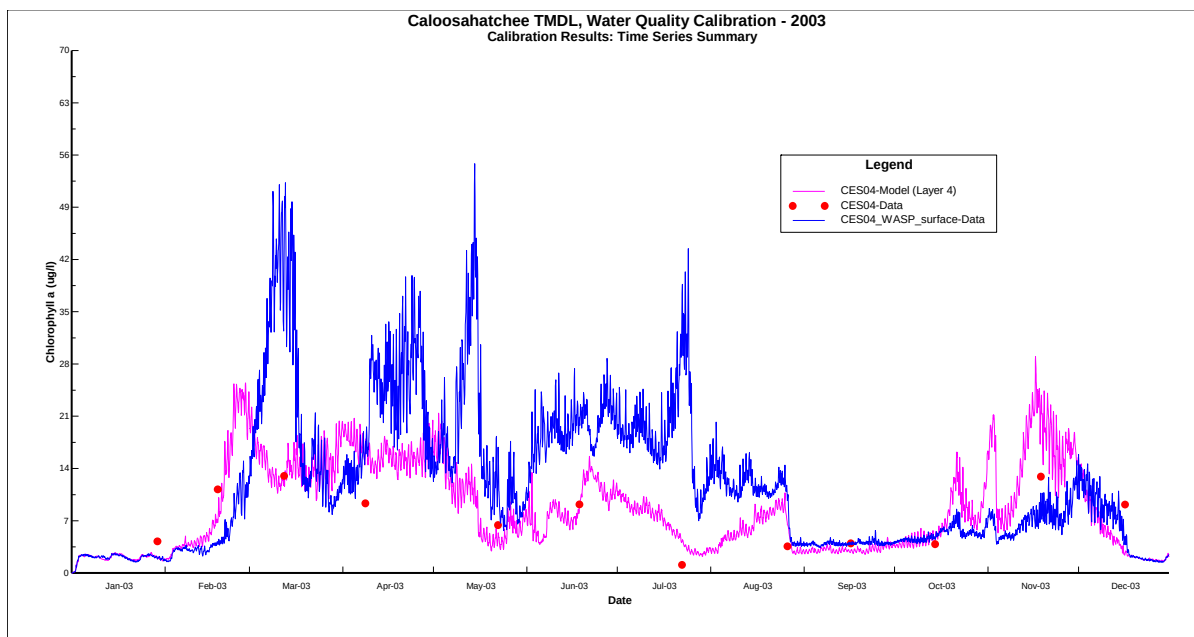


Figure 5-172 Station CES-04 surface Chlorophyll, Calibration year of 2003

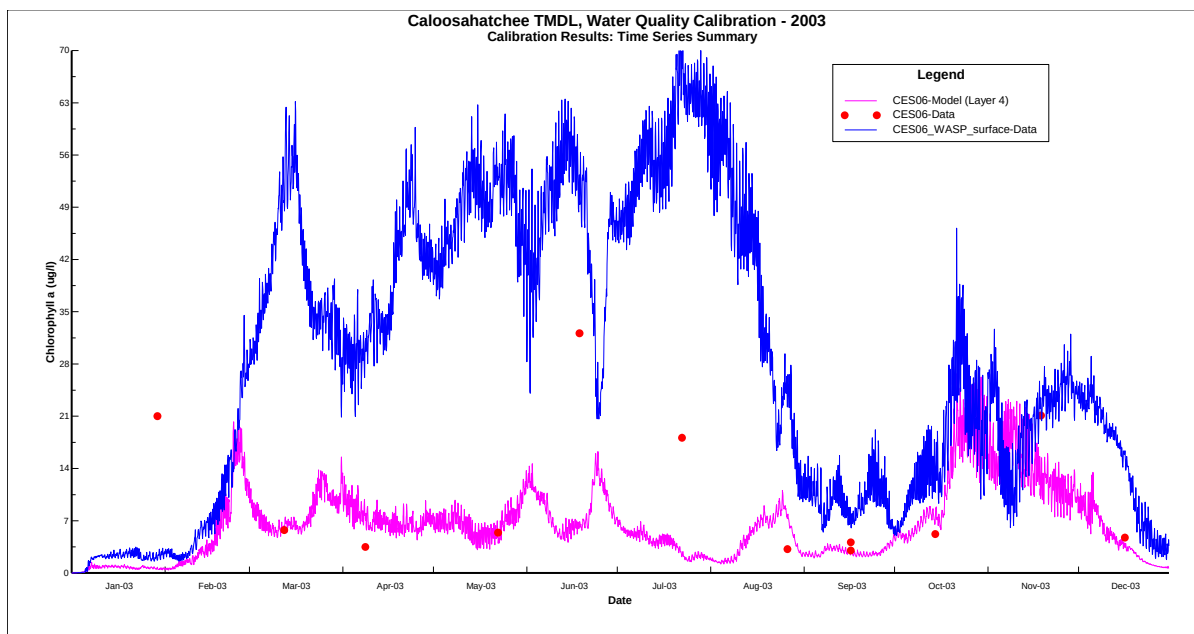


Figure 5-173 Station CES-06 surface Chlorophyll, Calibration year of 2003

5.7.4.1.2 Dissolved Oxygen

As can be seen in **Figures 5-174 to 5-177**, the EFDC results show a fairly good match between simulated oxygen and the observed data for the surface and bottom layers of Stations CES-04 and CES-06. The WASP7 results for Station CES-04 are similar to the EFDC results for the surface and bottom layers with the exception of the time period characterized by cooler water temperature during January-February and November-December. The WASP7 results for Station CES-06, however, simulate much higher levels of dissolved oxygen than is seen in the observed data. The high levels of oxygen are the result of the over simulation of algae chlorophyll during the spring and summer months at CES-06. There is an apparent consistent pattern at Stations CES-04 and CES-06 where the WASP7 dissolved oxygen results are much lower than the observed data or the EFDC results during cooler water conditions. As an empirical user-defined function, sediment oxygen demand varies over time as a function of the bottom water temperature over time. Bottom water temperature therefore serves as a surrogate to characterize the seasonal variability of SOD. The seasonal variation of winter and summer water temperature, however, is not necessarily synchronized with the seasonal variability of the deposition of particulate organic matter from algal blooms and influxes of organic matter loading from the watershed to the sediment bed. Since EFDC incorporates the sediment diagenesis model, any temporal variability in particulate organic matter deposition is internally coupled and reflected in the simulation of sediment oxygen demand.

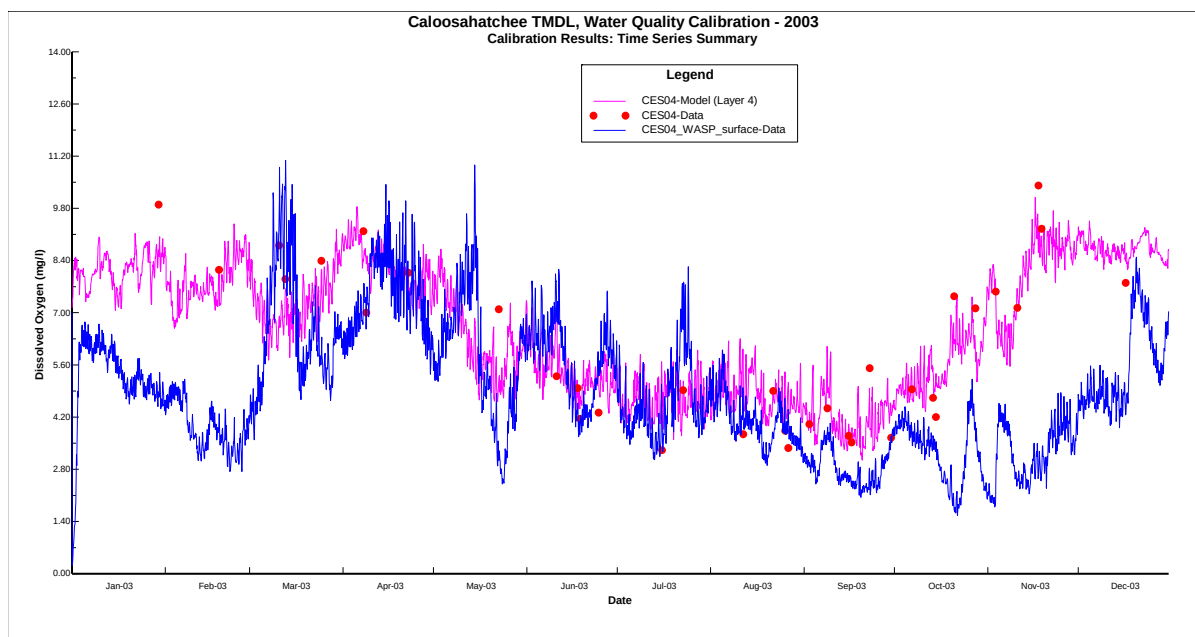


Figure 5-174 Dissolved Oxygen, Station CES-04, Surface layer, Calibration year of 2003

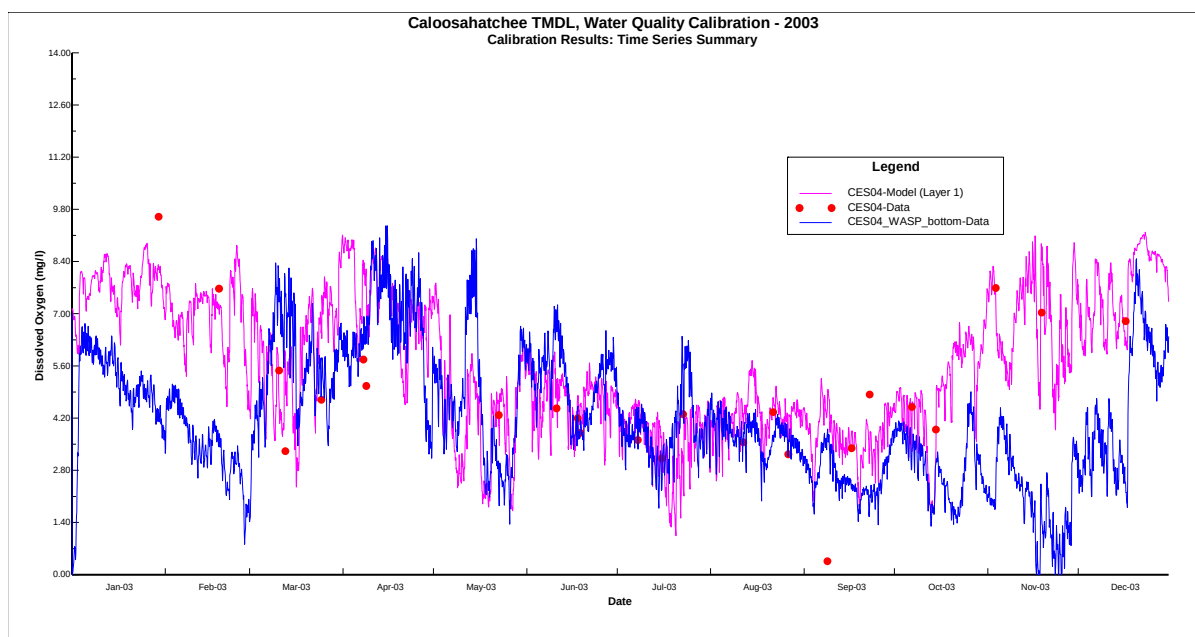


Figure 5-175 Dissolved Oxygen, Station CES-04, Bottom layer, Calibration year of 2003

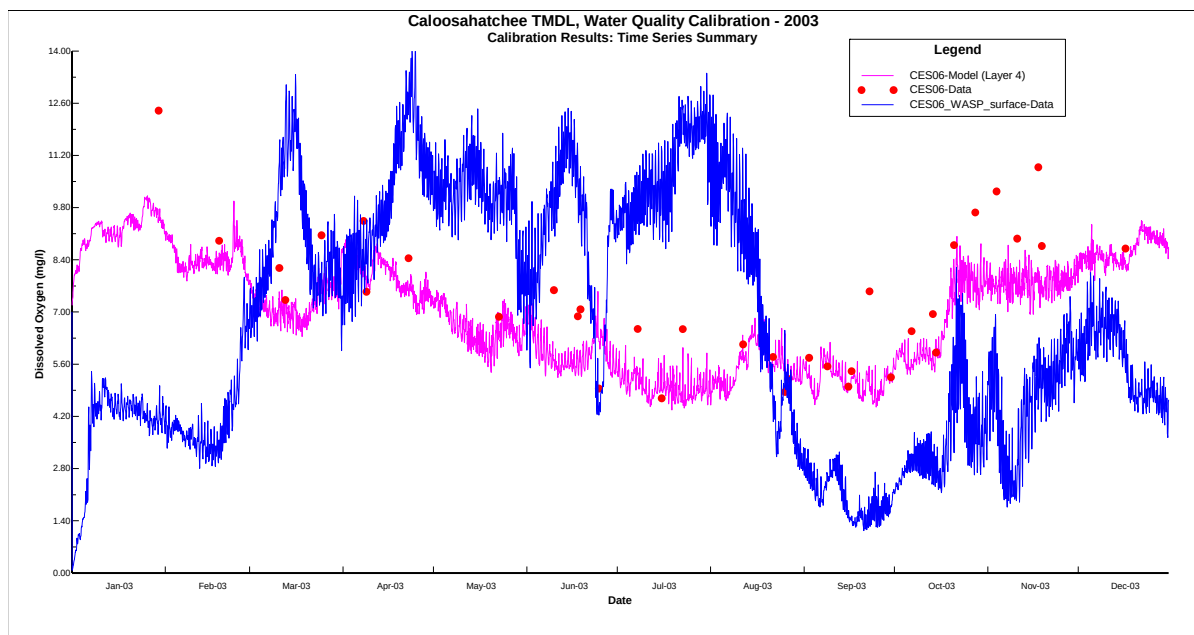


Figure 5-176 Dissolved Oxygen, Station CES-06, Surface layer, Calibration year of 2003

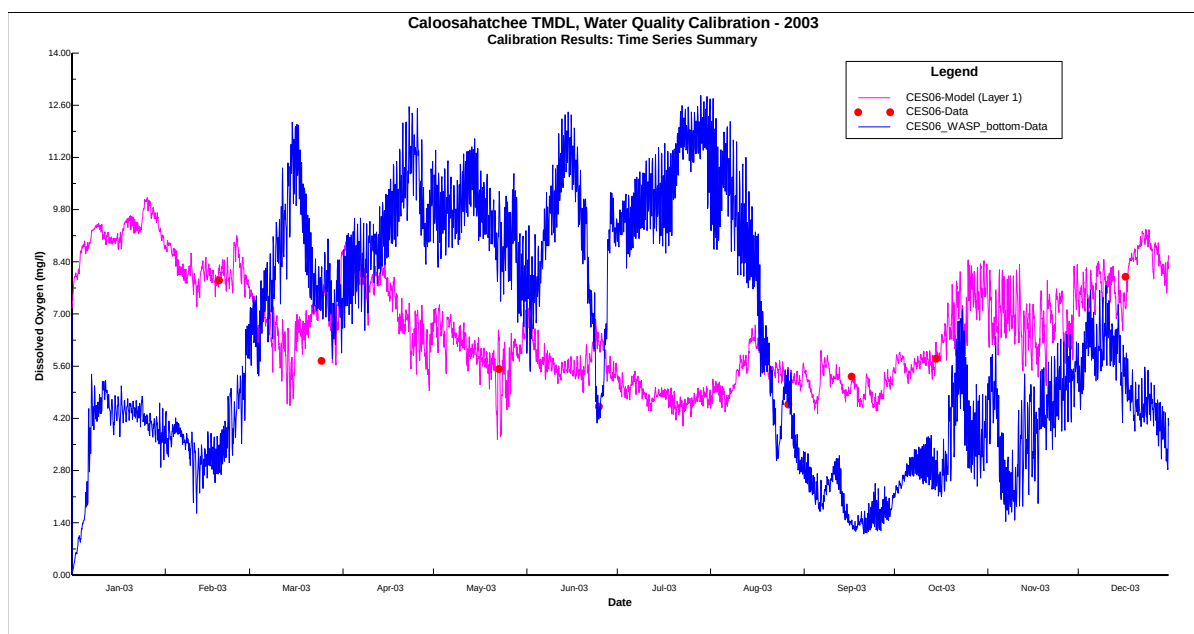


Figure 5-177 Dissolved Oxygen, Station CES-06, Bottom layer, Calibration year of 2003

5.7.4.2 Model Validation

5.7.4.2.1 Algal Biomass

As can be seen in **Figures 5-178** and **5-179**, the EFDC results show fair agreement between simulated algal biomass and observed chlorophyll measurements for the surface layer of Stations CES-04 and CES-06 for the validation year of 2004. The WASP7 results for Station CES-04 and CES-06, unlike the results for the calibration year, are much higher than the EFDC results for these two stations. The WASP7 results for Station CES-06, however, are much higher than the observed chlorophyll data while the EFDC results show a better match with the observed data. As discussed above for the calibration results, additional evaluations of the light, nutrient and water temperature limitation factors that control algal growth in WASP7 and EFDC are needed to fully understand why there are differences in simulated algal biomass between the two models.

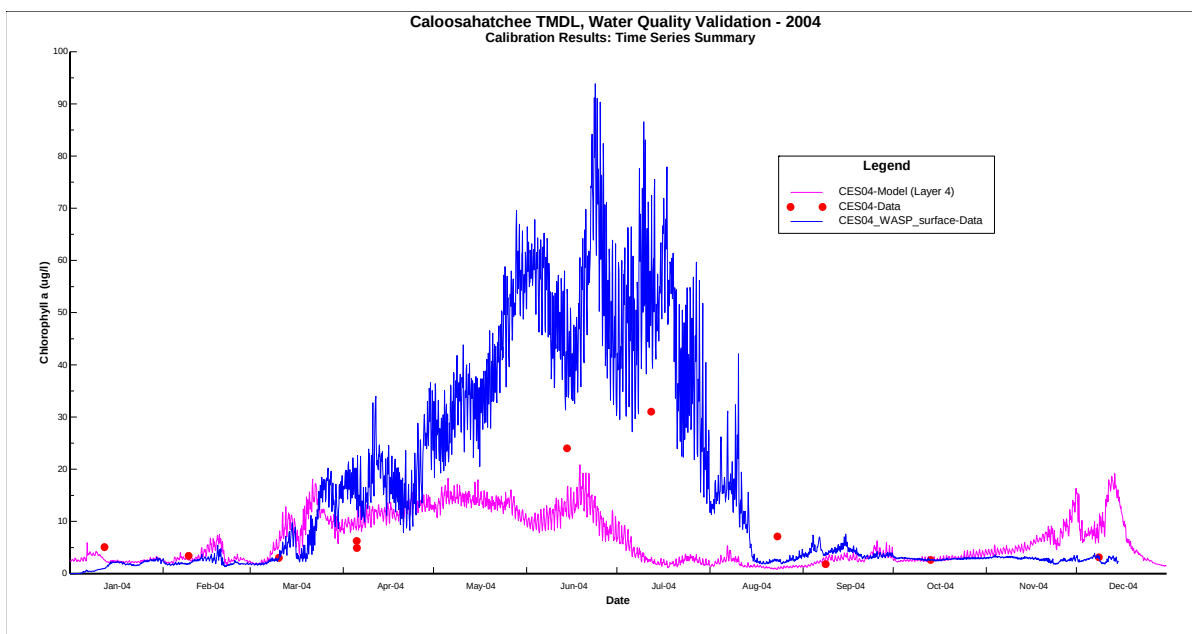


Figure 5-178 Chlorophyll, Station CES-04, Surface layer, Validation year of 2004

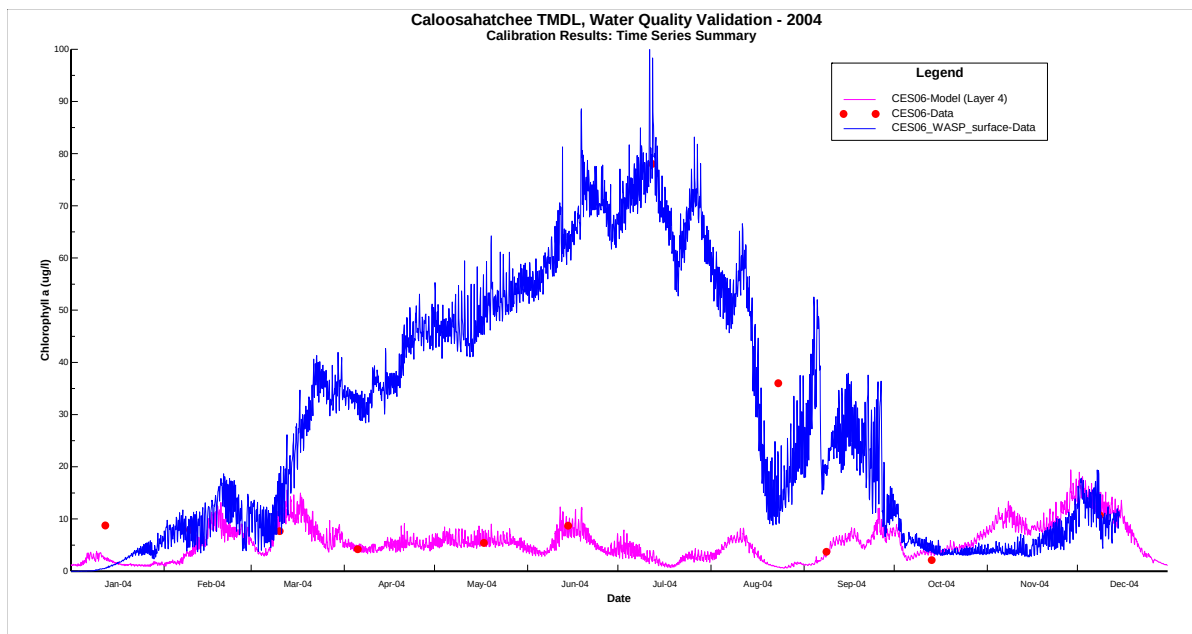


Figure 5-179 Chlorophyll, Station CES-06, Surface layer, Validation year of 2004

5.7.4.2.2 Dissolved Oxygen

As can be seen in **Figures 5-180 to 5-183** the EFDC validation results, although not as good as the calibration results, show a fair match between simulated oxygen and observed data for the surface and bottom layers of Stations CES-04 and CES-06 in 2004. With the exception of simulated oxygen during cooler water temperatures, as discussed above under model calibration, the WASP7 results for Station CES-04 and CES-06 appear to track the observed data, as well as, or better than, the EFDC results.

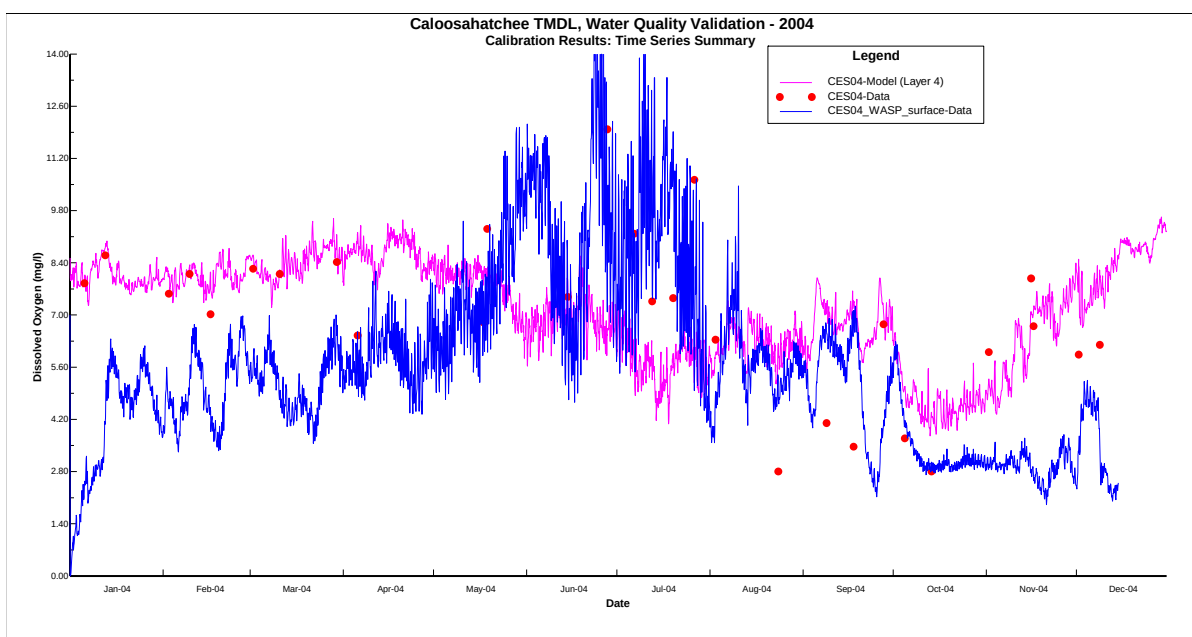


Figure 5-180 Dissolved Oxygen, Station CES-04, Surface layer, Validation year of 2004

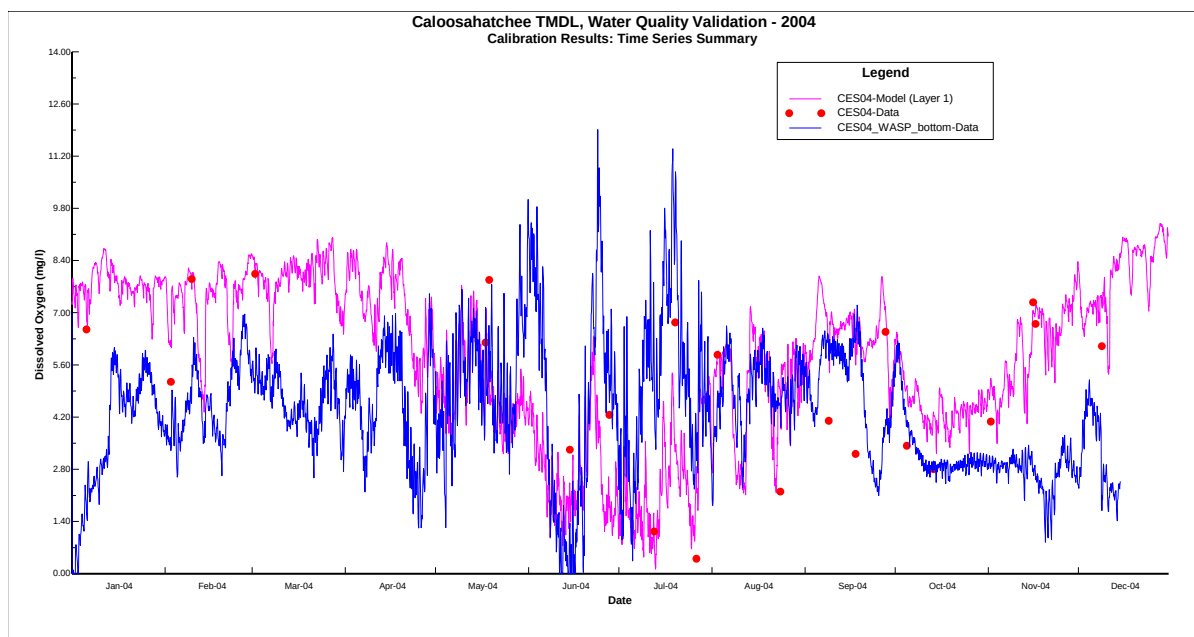


Figure 5-181 Dissolved Oxygen, Station CES-04, Bottom layer, Validation year of 2004

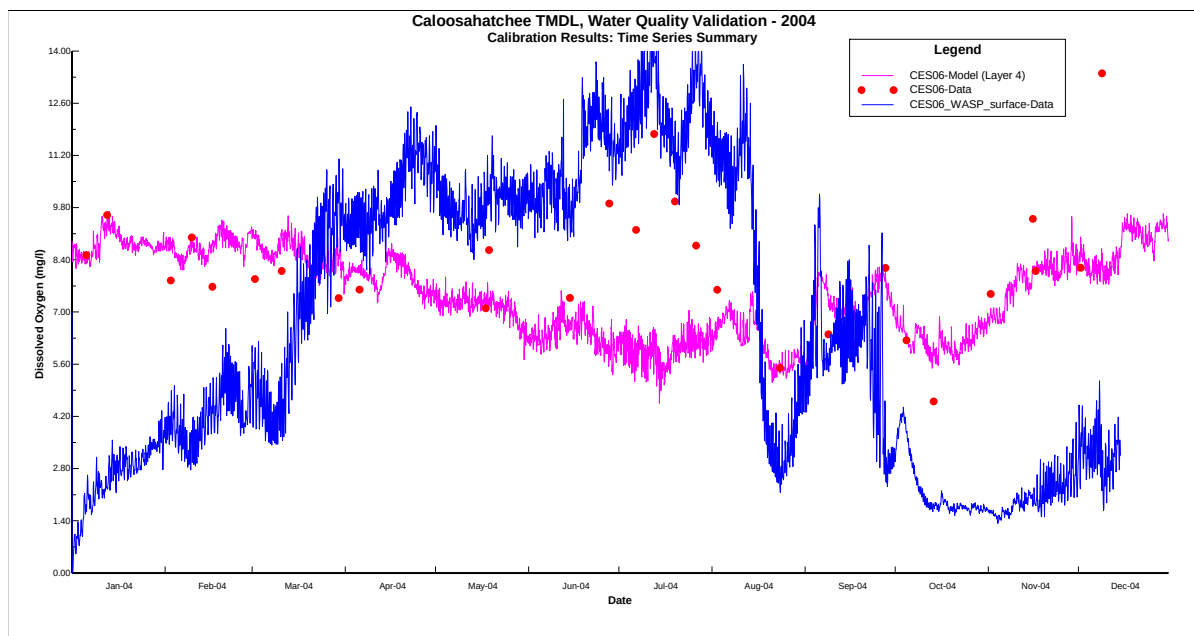


Figure 5-182 Dissolved Oxygen, Station CES-06, Surface layer, Validation year of 2004

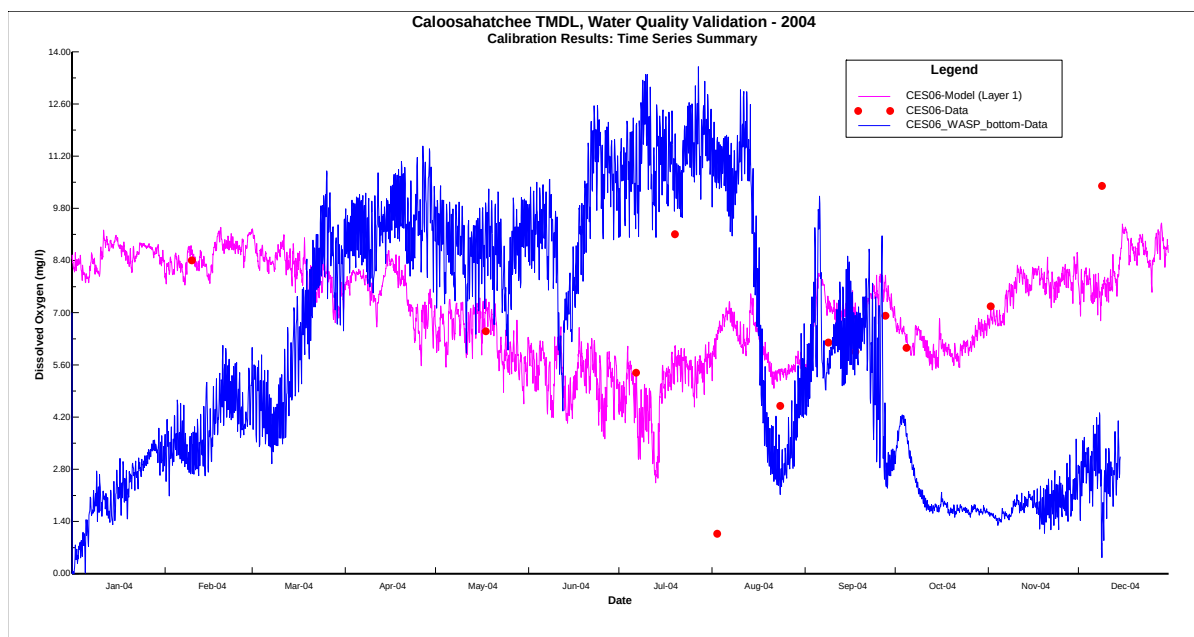


Figure 5-183 Dissolved Oxygen, Station CES-06, Surface layer, Validation year of 2004

5.7.5 Summary and Recommendations

While additional calibration / validation efforts may improve the comparisons, there are considerable differences in the results for dissolved oxygen and algae biomass (as chlorophyll) simulated by WASP7 and EFDC. The most significant difference between the two models is the approach used in each model to represent sediment oxygen demand and the benthic fluxes of nutrients across the sediment-water interface. WASP7 uses an empirical methodology based on the user's assignment and calibration of appropriate parameter values for SOD and benthic fluxes of ammonia and orthophosphate. The empirical methodology, although useful for comparison of model results to observed historical water quality data sets, does not provide any predictive capability needed for the assessment of the water quality impact of alternative management scenarios intended to control runoff or wastewater loading. EFDC, by contrast, can internally simulate the coupled response of the benthic fluxes of nutrients and sediment oxygen demand to the deposition of particulate organic matter to the sediment bed.

The sediment diagenesis model that is incorporated in EFDC provides the predictive capability needed to assess the water quality impact of proposed management scenarios to control external loads to a waterbody.

The other key differences between the two models are the formulations used to represent algal growth and the light limitation of photosynthetic growth of algae. WASP7 allows for the input of a global parameter value to define the maximum growth rate for algae. EFDC, by contrast, allows for the input of spatially varying parameter values to define algal growth rates based on the six water quality zones defined for the Caloosahatchee model (see Figure 5-157). In the six water quality zones used for the EFDC model, algal growth rates ranged from 1.75 per day to 2.75 per

day while the global algal growth rate of 2.0 per day assigned in WASP7 was somewhat less than the mean of the growth rates assigned in EFDC.

WASP7 uses a constant parameter value to define the optimal, or saturating, light intensity for algal growth. EFDC, however, uses an adaptive saturating light intensity formulation, rather than a constant optimal light level, as a time weighted acclimation to available light over two day periods. A detailed comparison of the light limitation factors computed by each model is needed to more fully understand how these different approaches control the simulated time series of algae biomass as shown in Figures 5-172 and 5-173 for the calibration periods and Figures 5-178 and 5-179 for the validation period.

Three key issues related to the general and technical criteria discussed above have been identified in our comparison of the differences between EFDC and WASP7.

5.7.5.1 Issue #1: Resource Requirements

The runtime for a one-year simulation for the EFDC hydrodynamic and water quality model of the Caloosahatchee estuary is 7.5 to 8.0 hrs on a 2.67 GHz Intel Core 2 Duo. The runtime for a one-year simulation for the WASP7 water quality model is 27 to 28 hrs on the same computer.

5.7.5.2 Issue #2: Availability of Model Software

Although WASP7 is a public domain model, the Fortran source code is not made available to users by the model development team at EPA Region IV. The fact that code modifications must be made upon request to the WASP development EPA Region IV is not a major issue since EPA is more than willing to provide the technical assistance needed to resolve problems related to the configuration of a site-specific model such as the Caloosahatchee estuary. The central issue, however, is that, without access to the source code, it is impossible for a modeling team to properly evaluate model formulations or understand how input data or option switches are used in the WASP7 model. Although documentation manuals for WASP are available that describe input data and some model formulations there are always questions that arise in a project about how the input data is actually applied or how a model formulation or option switch is written to derive some result. The lack of availability of Fortran source code is an important issue for the use of WASP7.

5.7.5.3 Issue #3: Coupling of Water Column and Sediment Bed

The current release of WASP7 (Vers 7.2) does not include the sediment diagenesis model of Di Toro (2000). It is anticipated that future releases of WASP will include the sediment diagenesis model since preliminary work related to incorporating this sub-model into WASP was completed in 2004 (Martin, 2004). With appropriate user-specified benthic flux rates for SOD and nutrients, the existing version of WASP7 is adequate for calibration and validation of a model for historical conditions with an observed database. In the absence of an internally coupled sediment flux model, however, the predictive capability of the WASP7 model framework for assessments of

the water quality impact of alternative management scenarios based on changes to the external loading to a waterbody is significantly limited.

5.7.5.4 Recommendations

The present comparison of EFDC and WASP7 results, is not a quantitative comparison of the results that can be generated by the two models. The model results presented in this document are based on different choices made in how to structure input for the models as well as the constraints imposed by limitations of each model for assigning input data during calibration and validation.

It is recommended that benchmark input data sets be developed for WASP7 and EFDC based on identical approaches where the models allow for similar approaches to be adopted. The benchmark cases are not intended for further calibration and validation of the model to observed data sets. The benchmark cases, instead, are intended to provide a platform for additional comparisons of the results obtained with WASP7 and EFDC if both models use comparable data sets for input. Specifically, EFDC should be setup to select the option to empirically assign sediment oxygen demand and benthic nutrient flux rates for ammonia and phosphate based on the six water quality zones so that this component of the EFDC model is consistent with the limitation of the WASP7 model. In addition, EFDC should be setup to assign the same algal growth rate for all six water quality zones so that this component of the EFDC model is also consistent with the limitations of the WASP7 model.

5.8 RECOMMENDED DATA NEEDS AND MODEL REFINEMENTS

The following recommendations are made for the future Caloosahatchee River Basin watershed and receiving water hydrodynamic and water quality model improvements. These recommendations are grouped into two categories the first involving data and the other regarding the models themselves.

Recommended Data Needs

- Collect sediment samples for TOC, TON and TOP to enable the use of the full sediment diagenesis sub-model in EFDC to represent the spatial temporal variations in nutrient fluxes;
- Collect data about Sediment Oxygen Demand (SOD) from the Caloosahatchee River and Estuary itself. The current available data is for Estero Bay and Charlotte Harbor;
- Gather improved data about the major structures, including cross-sections, on the Caloosahatchee River and tributaries, to enable refine of the F-Tables for these structures;
- Develop a consistent program of periodic water quality sample collection in the Caloosahatchee River at fixed locations to enable better monitoring of water quality trends and enable refinements in the water quality modeling; and
- Collect data about BOD5, TOC, and fecal coliform in the Caloosahatchee River immediately upstream of S-79, S-78 and S-77.

Recommended Model Refinements

- The WMM, HSPF, and EFDC public domain models may be increased in level of detail as necessary in future applications to simulate regional and/or site-specific BMPs for the BMAP process.
- It may be appropriate to add explicit consideration of cyanobacteria nitrogen-fixation from the atmosphere to EFDC and WASP
- To minimize the off-shore boundary effect, the EFDC model grid should be extended an extra of 6~7 miles more further into the gulf.