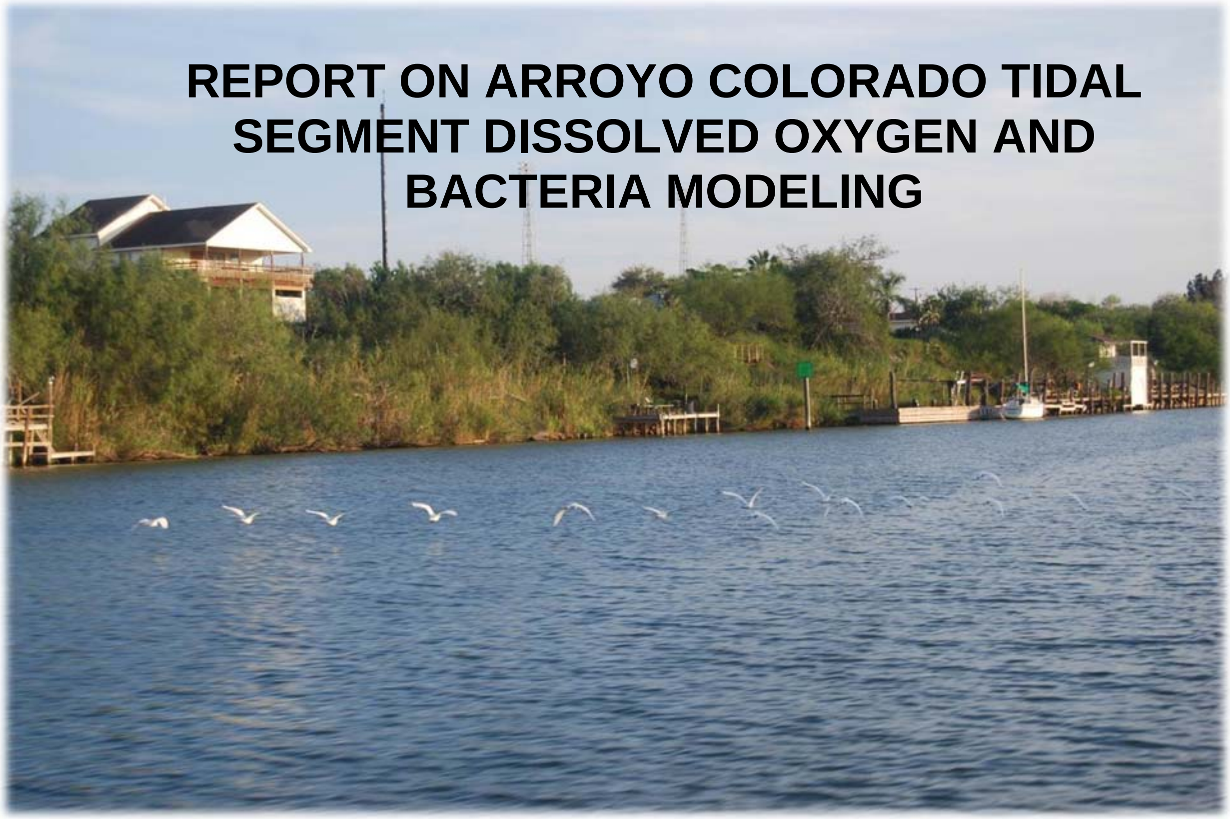
REPORT ON ARROYO COLORADO TIDAL SEGMENT DISSOLVED OXYGEN AND BACTERIA MODELING



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Texas A&M University

and

Texas Commission on Environmental Quality

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LIST OF ABBREVIATIONS AND ACRONYMS

AU	Assessment unit
BMP	best management practice
BREC	Blackland Research and Extension Center
CBOD	carbonaceous biochemical oxygen demand
cms	cubic meters per second
CHL-A	chlorophyll-α
°C	degrees Centigrade
DO	dissolved oxygen
EPA	United States Environmental Protection Agency
ft	feet
gpm	gallons per minute
H/WQ	hydrodynamic and water quality
kg	kilogram
LDOM	labile dissolved organic matter
LPOM	labile particulate organic matter
µg/L	micrograms/liter
m	meter
MAE	mean absolute error
mg/L	milligrams/liter
m^3	cubic meter
MGD	million gallons per day
mL	milliliter
NH_4	ammonia as nitrogen (or ammonium)
NO_{23}	nitrite plus nitrate as nitrogen
Org-N	organic nitrogen
Org-P	organic phosphorus
OSSF	on-site sewage facility
PO_4	orthophosphate phosphorus
ppt	parts per thousand
PS	point source
r^2	coefficient of determination
RDOM	refractory dissolved organic matter
RE	relative error
RMSE	root mean square error
RPOM	refractory particulate organic matter
SOD	sediment oxygen demand
SWAT	Soil & Water Assessment Tool
SWQM	Surface Water Quality Monitoring
SWQMIS	Surface Water Quality Monitoring Information System
TCEQ	Texas Commission on Environmental Quality
TCOON	Texas Coastal Ocean Observation Network

TDS	total dissolved solids
TIAER	Texas Institute for Applied Environmental Research
TMDL	total maximum daily load
TN	total nitrogen
TPDES	Texas Pollutant Discharge Elimination System
TP	total phosphorus
TSS	total suspended solids
USACE	United States Army Corps of Engineers
USEPA	U.S. Environmental Protection Agency
USGS	United States Geological Survey
UTRGV	University of Texas Rio Grande Valley
WPP	watershed protection plan
WWTF	Wastewater Treatment Facility

CHAPTER 1

INTRODUCTION

1.1 Background on Project Area and Water Quality Issues

The Arroyo Colorado is a former channel of the Rio Grande that flows through Hidalgo, Cameron and Willacy counties in the Lower Rio Grande Valley of South Texas (Figure 1-1). The following general information on the waterway and its watershed are provided in the watershed protection plan for the Arroyo Colorado (ACWP, 2007). Much of the flow in the Arroyo Colorado originates from wastewater discharges, agricultural return flows, urban runoff, and shallow groundwater interactions. The Arroyo Colorado is divided by the Texas Commission on Environmental Quality (TCEQ) into two classified segments – Arroyo Colorado Tidal (Segment 2201) and Arroyo Colorado Above Tidal (Segment 2202). The Tidal segment 2201 is further subdivided into five assessments units (AUs) 2201_01, 2201_02, 2201_03, 2201_04 and 2201_05. Many factors are attributed to the depressed dissolved oxygen (DO) concentrations that occur predominately in the upper portion of the tidal segment 2201 at AUs 2201_04 and 2201_05, which are located in the vicinity of the Port of Harlingen (see zone of impairment on Figure 1-1). Modification of the hydrology, dredging, streambank destabilization, channelization, and loss or degradation of wetlands and riparian environments are among the physical habitat factors thought to negatively impact DO as well as direct sources of organic matter and nutrients, such as wastewater infrastructure (including wastewater treatment facility (WWTF) discharges), agricultural practices, and urban stormwater. Additional water quality issues in the Arroyo Colorado include elevated fecal bacteria in the tidal and non-tidal segments and concerns regarding high nutrient levels in both segments.

The two segments defining the Arroyo Colorado are defined by TCEQ as follows:

- **Segment 2201:** Arroyo Colorado Tidal - From confluence with Laguna Madre in Cameron/Willacy County to a point 100 meters (110 yards) downstream of Cemetery Road south of Port Harlingen in Cameron County.
- **Segment 2202:** Arroyo Colorado Above Tidal - From a point 100 meters (110 yards) downstream of Cemetery Road south of Port Harlingen in Cameron County to FM 2062 in Hidalgo County.

The Arroyo Colorado Tidal has been included on the Clean Water Act list of impaired water bodies for low DO since 1998. The upstream part of the Arroyo Colorado Tidal and the entirety of the Arroyo Colorado Above Tidal are on the 303(d) impaired list for bacteria (TCEQ, 2015a). In 2002, TCEQ completed the first phase of a total maximum daily load (TMDL) study that showed that extensive physical modifications of the Arroyo Colorado along with excessive nutrients from urban, agricultural and wastewater sources lowered DO in the water body. In 2007, local stakeholders developed and published "A Watershed Protection Plan for the Arroyo Colorado Phase I," which identified strategies to address water quality issues (ACWP, 2007). It recommended municipalities to improve or plan to improve their wastewater collection and treatment systems to reduce nutrients and suspended solids in their effluent. Many agricultural best management practices (BMP), such as land leveling, soil fertility testing, nutrient management, improved irrigation management, and others listed in the Natural Resources Conservation Service Field Office Technical Guide, were recommended to control the nutrients from agriculture. Since then most of these strategies are currently being implemented throughout the watershed (ACWP, No Date).

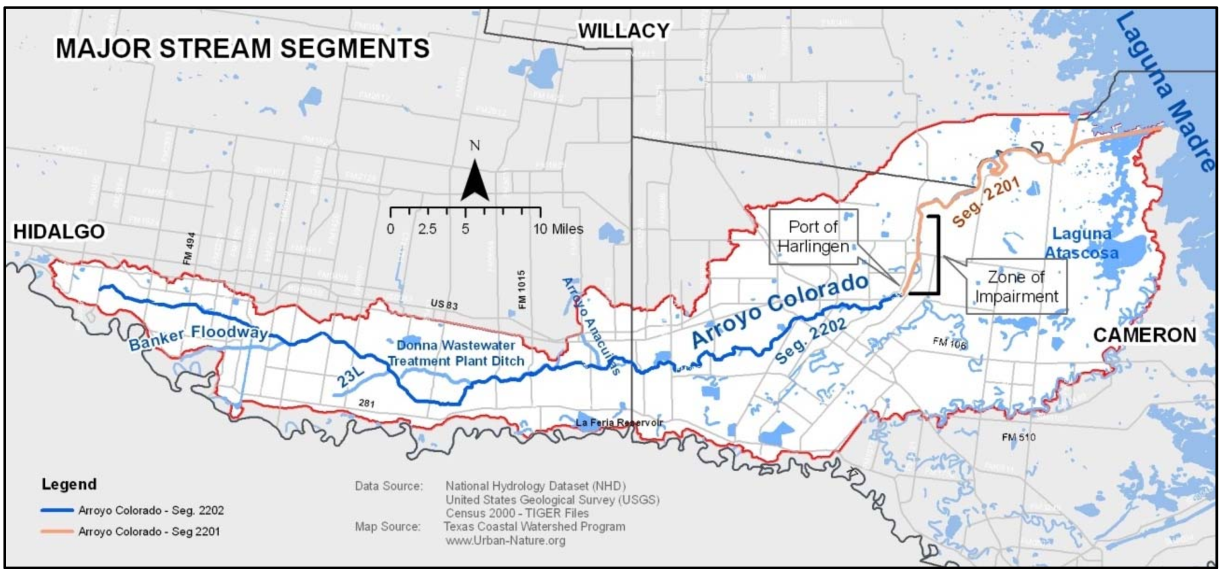

Figure 1-1. Map of Arroyo Colorado Watershed.

Source: TWRI (2012)

1.2 Report Overview

The contents of this report provide information on development and application of a computer model of the Arroyo Colorado Tidal that was designed to address the DO and bacteria impairments of the segment. This report is the cumulative effort of work tasks and funding in two Clean Water Act § 319(h) grants through the TCEQ that involved the updating of the Arroyo Colorado watershed protection plan (WPP), which included DO and bacteria modeling of the Arroyo Colorado Watershed. The modeling effort was a multi-year and two-institute effort of the Blackland Research and Extension Center (BREC) of AgriLife Research and the Texas Institute for Applied Environmental Research (TIAER) of Tarleton State University. The watershed and above tidal modeling of the Arroyo Colorado was performed by BREC and the results of those efforts are provided in a separate report (Jeong, 2017). The results of the watershed and above tidal modeling of the Arroyo Colorado were critical inputs to the modeling of the Arroyo Colorado Tidal segment discussed herein.

Chapter 2

Arroyo Colorado Modeling System

2.1 Overview of Modeling System Framework

Two models with complementary capabilities were selected to provide a modeling system for evaluating water quality conditions and to assess control measures and BMPs aimed at restoring water quality in the Arroyo Colorado watershed and in both the tidally influenced and above tidal influence portions of the Arroyo Colorado, *i.e.*, Segments 2201 and 2202. The two models are the Soil & Water Assessment Tool (SWAT) and CE-QUAL-W2. The hydrologic and pollutant loads from the upland watersheds and hydrologic and water quality transport processes of the Segment 2202 (Arroyo Colorado Above Tidal) were simulated using the SWAT model. The hydrodynamics and water quality of the in-stream tidal waters of the Arroyo Colorado (Segment 2201) were simulated with the CE-QUAL-W2 model.

As introduced above, the linked modeling system includes a watershed and basic stream transport model (SWAT) and a two-dimensional hydrodynamic and water quality (H/WQ) model (CE-QUAL-W2; Figure 2-1). Development and application of this modeling system were important parts of the efforts to update the WPP for the Arroyo Colorado. The modeling system was applied to evaluate the water quality benefits, especially to DO and bacteria, from reducing pollutant loadings within the Arroyo Colorado watershed. For the application of CE-QUAL-W2, SWAT provided daily streamflow and water-quality constituent loadings as input to the model of the tidal segment. To correctly simulate conditions within the tidal segment required a model, such as CE-QUAL-W2 capable of simulating tidal fluctuations; salinity variations in the longitudinal direction along the Arroyo Colorado and in the vertical direction (*i.e.*, salt wedge dynamics); sediment-water column interactions of nutrients and oxygen demanding substances; and kinetic, advective, and dispersive processes for a complex array of water quality constituents that included DO, various forms of nitrogen and phosphorus, organic and inorganic forms of dissolved and particulate matter, phytoplankton and bacteria. The modeling system, both SWAT and CE-QUAL-W2, required extensive calibration and validation against monitoring data collected within the Arroyo Colorado watershed. Monitoring data were critical to honing the predictive capabilities of the linked modeling system and in determining the accuracy of its predictions (or, in other words, assessing the uncertainty associated with model predictions) by providing the basis of comparison of model predictions to observed data from the real-world system. A myriad of data sources and data types are required as input to the modeling system (*e.g.*, meteorological data, soils, land use/land cover, topographic information, streamflow, pollutant loadings associated with the streamflow, and tidal data in the Laguna Madre). Additionally, numerous types of measured data are required to determine if model-system predictions (or outputs) match observed conditions in the Arroyo Colorado watershed and tidal and above tidal segments of the Arroyo Colorado and to evaluate the degree of reliability of the predictions

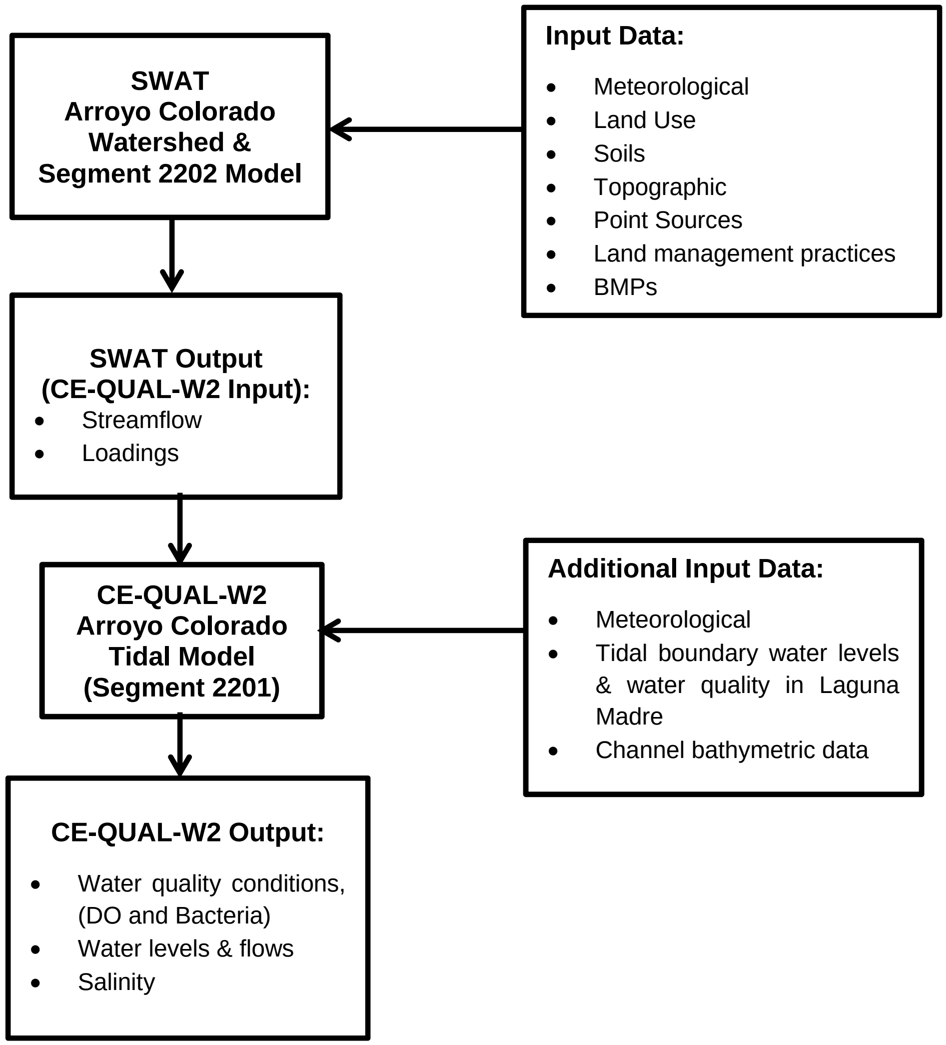

Figure 2-1. Schematic of SWAT and CE-QUAL-W2 modeling system showing major data linkages

2.2 Interface Tool

An interfacing procedure tool was developed by BREC to couple SWAT and the CE-QUAL- W2 model. The Visual Basic Application in Microsoft Excel 2010 was the platform for the development of this semi-automated procedural tool. Basically the interface procedure takes SWAT generated output files and restructured them into the required CE-QUAL-W2 input format. Current versions of these models (SWAT2012 v.588 and CE-QUAL -W2 v.3.7) as of May 2015 were coupled for this project. Both SWAT and CE-QUAL-W2 implement on ASCII type input/output systems. SWAT model and CE-QUAL-W2 model are spatially coordinated such that SWAT reaches and CE-QUAL-W2 segments are geometrically aligned well enough to transfer SWAT output into CE-QUAL-W2 input at the appropriate boundaries.

The SWAT model runs on a daily time step and the Arroyo Colorado SWAT model was composed of 17 subbasins/reaches. SWAT output for stream flow (output.rch) contains stream discharge and instream water quality variables for all reaches. The stream outputs were used to set up the upstream boundary conditions of the CE-QUAL-W2 model at the transition of the Arroyo Colorado water body from its tidal and above-tidal portions. Inflows from tributary channels are another set of boundary conditions defined in CE-QUAL-W2. In SWAT, the contribution of tributary channels can be found in the subbasin output (output.sub).

Some of the water quality output variables in SWAT match those used in CE-QUAL-W2 as input to describe inflows; however, there are several variables that do not exactly correspond (Table 2-1). In the SWAT model, non-living organic matter are stated as organic nitrogen (ORGN), organic phosphorus (ORGP) and carbonaceous biochemical oxygen demand (CBOD), whereas CE-QUAL-W2 models non-living organic matter as labile dissolved organic matter (LDOM), refractory dissolved organic matter (RDOM), labile particulate organic matter (LPOM), refractory particulate organic matter (RPOM), and multiple carbonaceous biochemical oxygen demand (CBOD) groups. In order to link the two models, relationships and stoichiometric ratios were used to match SWAT output variables into CE-QUAL-W2 input variables as indicated in Table 2-1. This conversion was performed in such a way that mass balances of all constituents are maintained.

Table 2-1. Matching of SWAT output variables to active CE-QUAL-W2 variables for the Arroyo Colorado Tidal

SWAT Output Variables	Active in CE-QUAL-W2 for Arroyo Colorado	List of All Potentially Active CE-QUAL-W2 Variables (from Cole and Wells, 2011)
No	Yes	TDS (g/m3 or mg/l) or salinity (kg/m3)
Yes	Yes	Generic constituents, such as bacteria, water age, tracer, etc.
No	Yes	Inorganic suspended solids, mg/l
Yes	Yes	PO4-P, mg/l as P
Yes	Yes	NH4-N, mg/l as N
Yes	Yes	NO3-N + NO2-N, mg/l as N
No	No	Dissolved silica, mg/l as Si
No	No	Particulate silica, mg/l as Si
No	No	Iron, mg/l as Fe or divalent metal
No	Yes, from stoichiometry	LDOM, mg/l as organic matter
No	Yes, from stoichiometry	RDOM, mg/l as organic matter
No	Yes, from stoichiometry	LPOM, mg/l as organic matter
No	Yes, from stoichiometry	RPOM, mg/l as organic matter
Yes	Yes, from stoichiometry	CBOD - user defined number of groups, mg/l as O2, set by NBOD

SWAT Output Variables	Active in CE-QUAL-W2 for Arroyo Colorado	List of All Potentially Active CE-QUAL-W2 Variables (from Cole and Wells, 2011)
No	No	CBOD-P – user defined number of groups, mg/l as P, set by NBOD
No	No	CBOD-N – user defined number of groups, mg/l as N, set by NBOD
No	Yes	Algae - user defined number of groups
Yes	Yes	Dissolved oxygen, mg/l
No	No	TIC, mg/l as C
No	No	Alkalinity, mg/l as CaCO3
No	No	Zooplankton
No	No	LDOM-P, mg/l as P
No	No	RDOM-P, mg/l as P
No	No	LPOM-P, mg/l as P
No	No	RPOM-P, mg/l as P
No	No	LDOM-N, mg/l as N
No	No	RDOM-N, mg/l as N
No	No	LPOM-N, mg/l as N
No	No	RPOM-N, mg/l as N
Yes	Yes	Water Temperature, C
Yes	Yes	Flow, cms

CHAPTER 3

CE-QUAL-W2 Overview and Data Requirements

3.1 Overview

CE-QUAL-W2 is a two-dimensional, longitudinal/vertical, H/WQ model developed by Portland State University (Cole and Wells, 2011). Version 3.7 of CE-QUAL-W2, which was the most recent version of the model available at the time of the model development, was used for this study. The model has been applied to rivers, estuaries, lakes, and reservoirs. It has capabilities of predicting longitudinal-vertical hydrodynamics and water quality in stratified and non-stratified systems, multiple algae, epiphyton/periphyton, zooplankton, macrophyte, biochemical oxygen demand, and generic water quality groups that include bacteria, internal dynamic pipe/culvert model, hydraulic structures (weirs, spillways) algorithms including for submerged and 2-way flow over submerged hydraulic structures, dynamic shading algorithm based on topographic and vegetative cover. In the model any combination of constituents can be included/excluded from a simulation. The main model limitations are that it assumes conditions are well-mixed in the lateral direction (but can be used in a Quasi-3-D mode by use of additional model branches), and hydrostatic assumption for vertical momentum equation (Cole and Wells, 2011).

3.2 Input Data to Model

CE-QUAL-W2 is a comprehensive H/WQ model in two dimensions necessitating extensive input data to define conditions for proper simulation of the Arroyo Colorado Tidal segment. The model input data are characterized into six major categories:

1. Geometric data,
2. Initial conditions,
3. Boundary conditions,
4. Meteorological conditions,
5. Hydraulic, and kinetic parameters, and
6. Verification data.

Discussion of each of these data categories for the Arroyo Colorado Tidal model follows.

3.2.1 Geometric Data

An initial and critical activity of development of the Arroyo Colorado CE-QUAL-W2 model was the delineation of the Arroyo Colorado Tidal into longitudinal segments and vertical layers. It is through these segments and layers that a two-dimensional representation of the selected section of the Arroyo Colorado Tidal is formed, which is comprised of grid cells. The model computes horizontal and vertical velocities and water quality constituent concentrations for each grid cell. A hypothetical representation of longitudinal segments, vertical layers, and the individual grid cells taken from Cole and Wells (2011) is provided in Figure 3-1. Note that in the longitudinal plane that the segments can vary in length, though the lengths of adjacent segments should not vary abruptly, but the vertical layers must be kept at a uniform depth for each layer. Figure 3-1 depicts a longer main water body (segments 2-9) with three smaller tributary branches (segments 12-15, 18 & 19 and 22-24). For the representation of the selected portion of the Arroyo Colorado for this study, no tributaries were of sufficient size to warrant their inclusion in the segmentation.

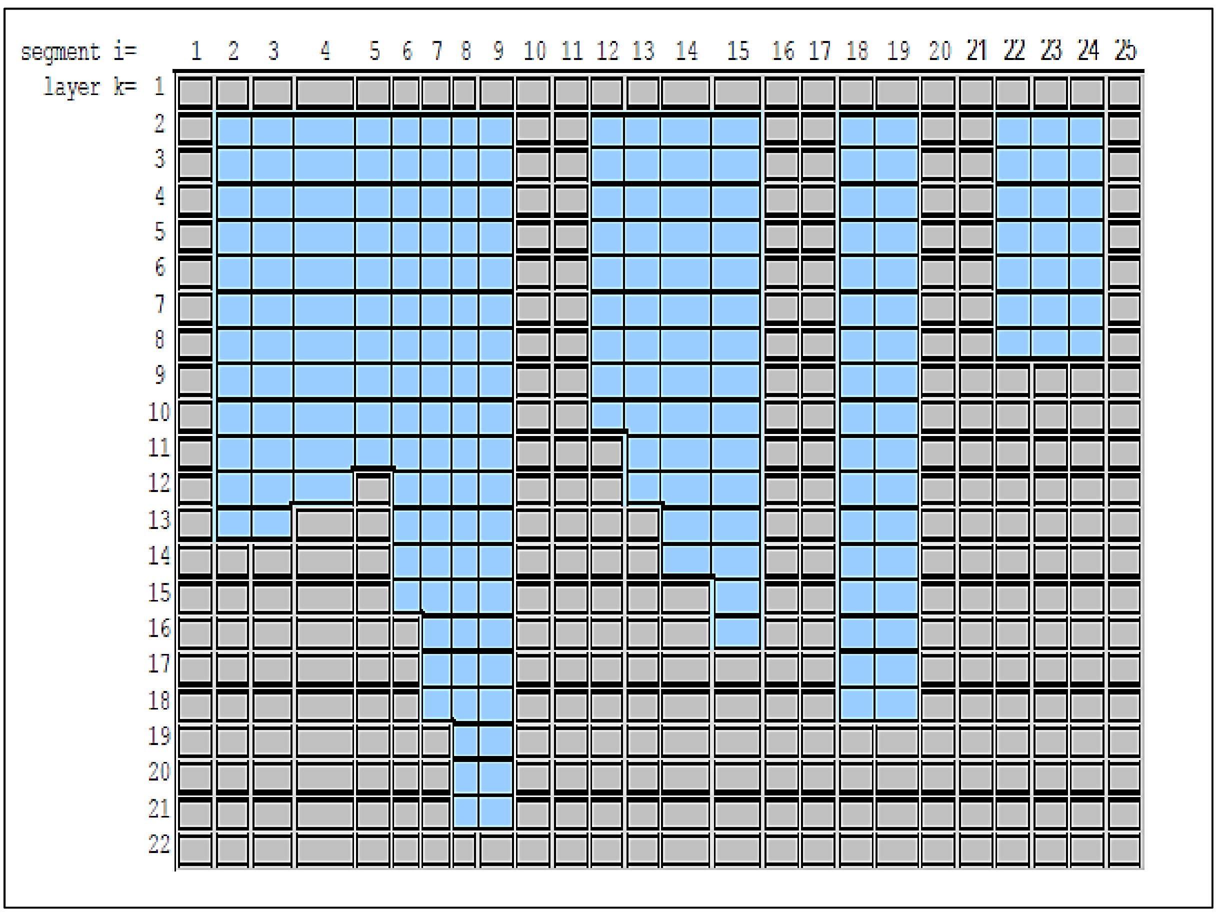

Figure 3-1. **Hypothetical computation grid in the x-z plane showing active cells in blue and inactive cells in gray.**

Source: Cole and Wells (2011).

The CE-QUAL-W2 model requires a large amount of data to replicate the physical dimensions of the stream into the model. In this project, the bathymetric data collected by United States Army Corps of Engineers (USACE), cross-sectional survey data conducted by the University of Texas at Brownsville (now the University of Texas Rio Grande Valley (UTRGV)), and United States Geological Survey (USGS) topographical maps were used to develop the longitudinal and the vertical segmentation of the Arroyo Colorado. USACE conducted the bathymetric survey of the Arroyo Colorado Tidal section on March 2012 for the purpose of obtaining post-dredging information on the Arroyo Colorado barge channel. In July and August 2013, UTRGV performed the flow measurement with the cross-sectional survey at the upstream boundary of the tidal segment for the purpose of providing additional data for this project. The USACE and UTRGV bathymetric data were projected onto USGS topographical maps using ArcGIS, and the needed three-dimensional coordinates were determined for the cross-sections used to define the model segmentation. Next, the three-dimensional feature of Auto-CAD was used to calculate the width of each vertical layer for each selected cross section incorporated into the model, providing the required dimensional input to create the segmentation representation of the Arroyo Colorado in CE-QUAL-W2.

Using this cross-sectional information, the Arroyo Colorado Tidal was divided into longitudinal segments (Figure 3-2) and the vertical layers (Figure 3-3). There were 170 longitudinal segments (excluding inactive layers at the beginning and the end) with length 250 meters (m) each with the exception of segment 20 which is 300-m long. The first 12 segments define above-tidal segments representing the downstream portion of the Arroyo Colorado Above Tidal (Segment 2202). The remaining segments are located in the tidal segment (Segment 2201) and extend from the upstream terminus of the segment, downstream into the Laguna Madre. Each segment was divided into multiple equal depth layers of 0.5 m (1.6 ft.). There were a maximum of 15 vertical layers (excluding 2 inactive layers at the top and the bottom, as required in the model) at the deepest section of the Arroyo Colorado and minimum of 8 vertical layers at the shallow portion. Smoothing of the Arroyo Colorado bottom was necessary in the segments in the vicinity of the above tidal segment to minimize model numerical instabilities (Figures 3-3 and 3-4).

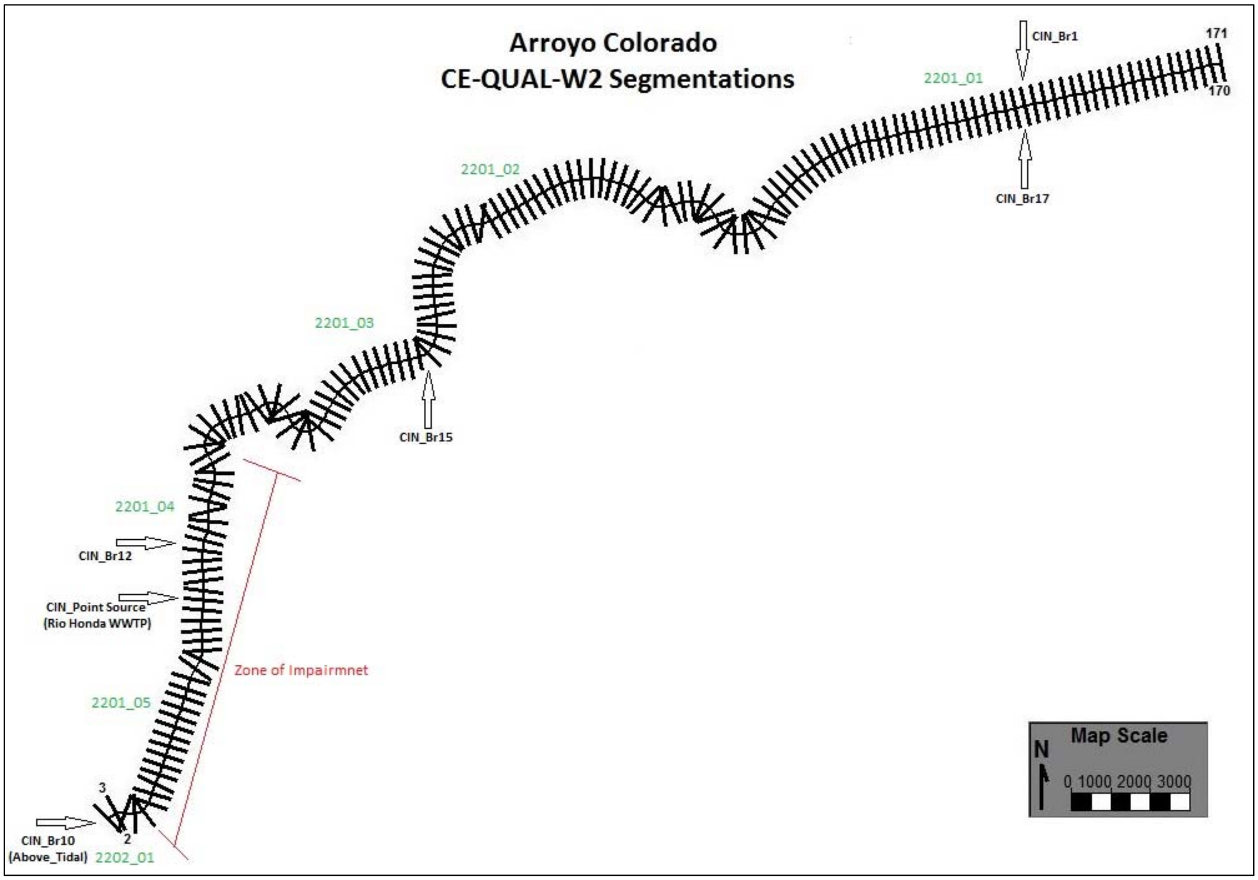

Figure 3-2. **Plan view of CE-QUAL-W2 model segmentation of Arroyo Colorado Tidal Segment 2201**

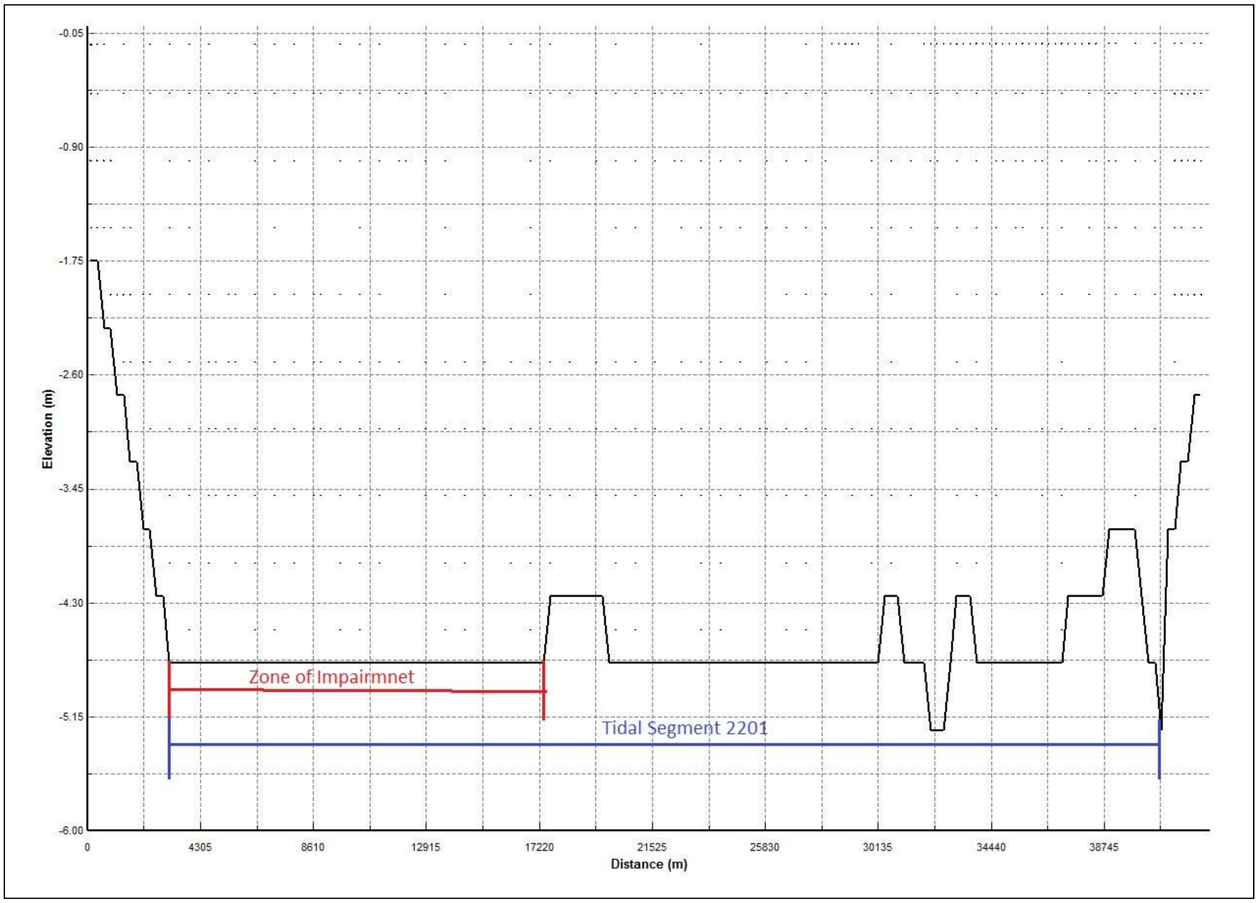

Figure 3-3. Vertical profile view of CE-QUAL-W2 model segmentation of Arroyo Colorado Tidal Segment 2201

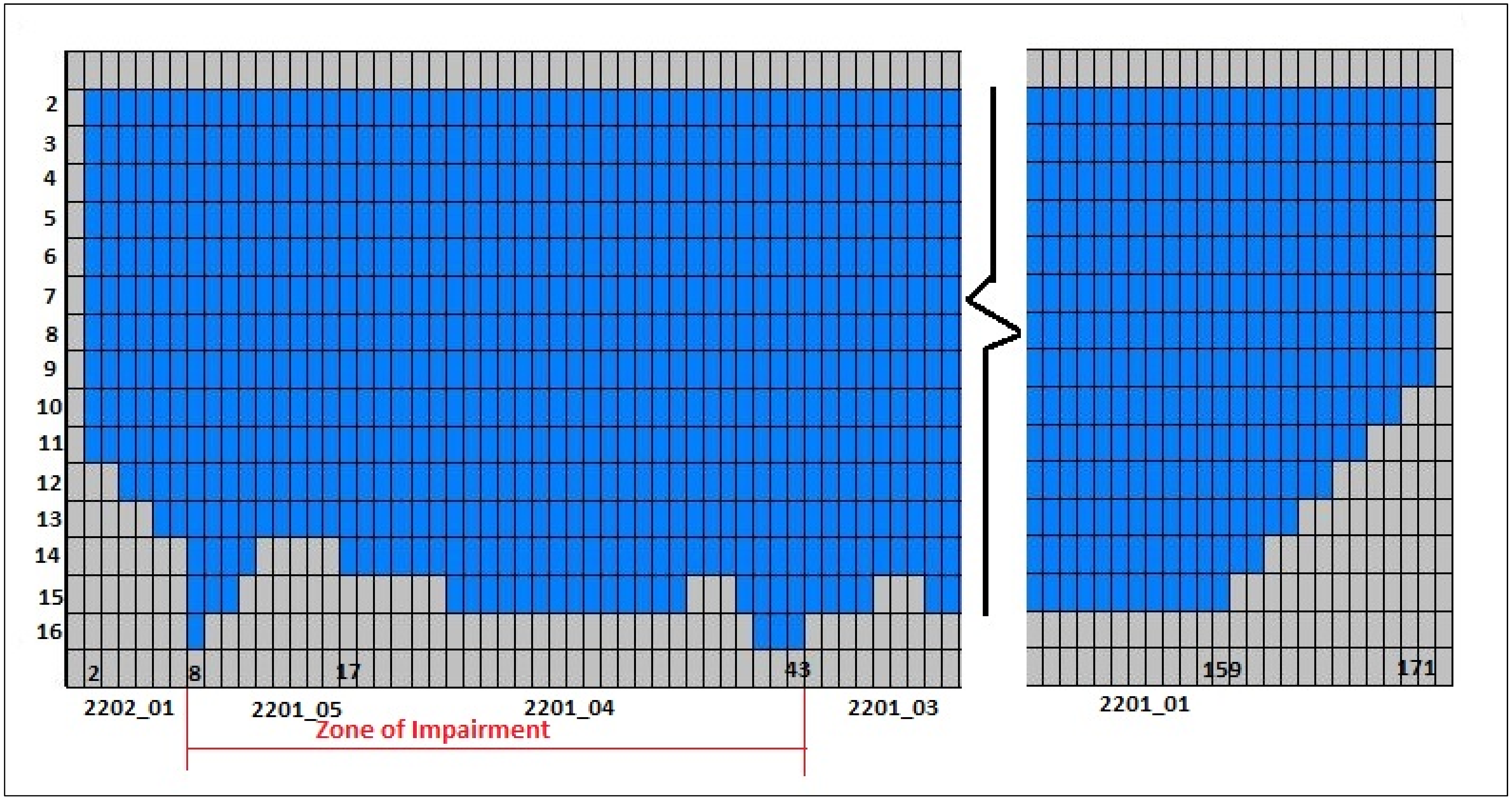

Figure 3-4. **Sample of the vertical and the longitudinal segmentation of CE-QUAL-W2 model of Arroyo Colorado Tidal Segment 2201**

3.2.2 Initial Conditions

The CE-QUAL-W2 model must be initialized with temperatures and concentrations of the water quality constituents for the beginning of a simulation. In essence the specification of initial conditions provides a starting point for the model. The model includes a number of means of specifying the initial conditions including setting the entire segmentation to a single value for each constituent to providing vertical profiles allowing vertical and longitudinal variation in the initial values for each constituent and in each segment.

For this application, constant vertical profiles of temperature, algae, and DO were used to set initial conditions along the Arroyo Colorado Tidal, while for total dissolved solids (TDS; referred to as salinity hereafter) both longitudinal and vertical profiles were used. For all other constituents, one representative concentration of each was used for initializing the initial condition for both the vertical and longitudinal distances of the Arroyo Colorado Tidal. The measured data at TCEQ Station 13074 at Cemetery Road, located immediately above the tidal segment, were used to create the initial conditions for the CE-QUAL-W2 model. To overcome inaccuracies in specification of initial conditions, the model was operated for typically six months before predictions were considered as reflective of true conditions

3.2.3 Boundary Conditions

Specification of upstream or downstream boundary conditions is essential to the operation of CE-QUAL-W2. Time-varying boundary conditions are used to drive the external conditions imposed upon the Arroyo Colorado. The boundary conditions used in this application included: 1) Arroyo Colorado Above Tidal segment inflows and water quality conditions at the upstream terminus of the model, 2) smaller tributary/point source inflows and water quality conditions, and 3) tidal boundary conditions of water level and water quality at the downstream terminus of the model in the Laguna Madre. For the operation of the Arroyo Colorado Tidal model, these boundary conditions were created for the period of January 1, 2000 through December 31, 2013.

The CE-QUAL-W2 inputs for the stream flows, water quality, and water temperature boundary conditions for the upstream boundary on the Arroyo Colorado and tributaries entering into the Arroyo Colorado Tidal were obtained from output of the SWAT model (see the information in Chapter 2). The water quality constituents derived from SWAT output after processing by the interface tool were previously listed in Table 2-1. For each inflow point into the CE-QUAL-W2, separate time series input files were developed for 1) stream flow, 2) water temperature, and 3) the water quality constituents defined in Table 2-1. The inflow points are shown on the segmentation plan view (Figure 3-2).

Even though the City of Rio Honda WWTF is included in the SWAT model, because of the location of its discharge directly into the Arroyo Colorado Tidal, SWAT output reflecting only the WWTF could not be readily obtained. That is the SWAT model output would include the combined effects of the WWTF discharge and runoff from SWAT Subbasin 15 in which it was located. Therefore, the flow and water quality of the City of Rio Hondo WWTF was included as input into CE-QUAL-W2 by obtaining the actual input data file for the facility in SWAT and using those data as the required input into the Arroyo Colorado Tidal model.

For downstream tidal boundary conditions, water-level data were obtained from Texas Coastal Ocean Observation Network (TCOON). The time series of water-level data (or tidal-elevation data) from the TCOON Station Arroyo-047 (latitude 26° 21' 7" N, longitude 97° 19' 32" W) was used to setup downstream tidal boundary condition. Station Arroyo-047 is the closest tidal gauging station to the most downstream segments of the CE-QUAL-W2 model. Unfortunately, Station Arroyo-047 only had water-level measurements through December 2005. Fortunately, the tide gage had been operated sufficiently long to allow harmonic components of the tide to be developed through data analysis. These harmonic component constants allow accurate predictions of the astronomical tide at the location of Station Arroyo-047 beyond the time period of the measured data based on very accurate astronomical predictions of the location of the sun and moon as their position and distance vary with time relative to the station location. The results of the harmonic components analysis were provided on the TCOON website for the station, as well, as the time-series predictions of the astronomical tide for the period required ending December 31, 2013.

The actual tidal elevations at any location, however, are defined not only by the astronomical tide but also by water-level variations caused by meteorological forcing based on wind velocity and barometric pressure variations. Based on the information in the paragraph immediately above, the time series of tidal fluctuations at the lower boundary of the Arroyo Colorado Tidal model were provided directly from the measured data at TCOON Station Arroyo-047 for the period of January 2000 through December 2005. Being measured data, the water levels for the period included both the astronomical tide and imposed modifications to that tide caused by meteorological forcing. For the period from January 2006 through December 2013, the tidal fluctuations at the lower model boundary consisted of the astronomical tide predicted from the harmonic constants for Station Arroyo-047 with corrections to those data to account for the influences of meteorological forcing. These temporal varying corrections were developed using nearby TCOON Station Port Isabel -018, for which a complete dataset of measured water levels exist for the period 2000 – 2013. The relationship of the meteorological forcing water-level component for Stations Arroyo-047 and Port Isabel-018 was computed for the available common time periods. This computed relation/equation of the meteorological forcing was then used to estimate the needed modification to the predicted astronomical tidal at Station Arroyo-047 providing the needed additional time series of water levels for the period of 2006 - 2013.

The water quality and temperature data used to define the downstream boundary water-quality conditions were downloaded from TCEQ Surface Water Quality Monitoring Information System (SWQMIS) website for TCEQ Surface Water Quality Monitoring (SWQM) Station 13447 located in the Laguna Madre at the intersection of the Intracoastal Waterway and the Arroyo Colorado barge canal. The Station 13447 is the closest available station in the Laguna Madre to the Arroyo Colorado Tidal and this station has been routinely monitored for water quality for many years. The water quality data at Station 13447 were analyzed and found to contain some season variations. Therefore, the needed water quality boundary conditions at the Laguna Madre were set with two seasonal components, which consisted of a warm season (May – October) and a cool season (November – April) with transition between seasons that were 14 days in duration (a week in each season).

3.2.4 Meteorological Conditions

In order to simulate water temperature and the influences of wind shear on water level and hydrodynamics and water circulation, CE-QUAL-W2 requires as input various time series of meteorological data. These data include air temperature, dew point temperature, cloud cover, wind speed, and wind direction. The required metrological data were obtained from the National Oceanic and Atmospheric Administration, National Climatic Data Center for the Harlingen Valley International Airport (WBAN ID 12904). This location was the most reliable station with the most complete set of data near the study area.

CE-QUAL-W2 input also requires specification of spatially varying wind-sheltering coefficients, which typically vary from 0 to 1. The wind-sheltering coefficients are multiplied by the wind speed, resulting in an effective wind experienced at the water surface. The coefficients account for the local effects of vegetation and terrain on the wind that reduce the measured wind speed collected at a height of 10 meters above the ground at the Valley International Airport. The upper portion of the Arroyo Colorado Tidal has more and higher streambank vegetation and higher streambanks than the lower portion, which provides for more wind sheltering in a relative sense. In contrast, the lower portion close towards the Laguna Madre is more open with sparser and shorter vegetation and the banks are shorter, which provides less sheltering and more wind effect on the surface water. The spatially varying wind-sheltering coefficient input was estimated for each CE-QUAL-W2 segment based on the Google Earth maps and the pictures taken during the TIAER reconnaissance trip conducted on October 16-19, 2012.

3.2.5 Hydraulic and Kinetic Parameters

The next two datasets required as input to CE-QUAL-W2 are the hydraulic and kinetic parameters. These two datasets include parameters that impact the internal model computations affecting the predictions of water velocities (vertical and horizontal), water levels, water temperatures, and various water quality parameters. The hydraulic parameters include vertical and horizontal dispersion/diffusion coefficient and bottom friction. The CE-QUAL-W2 user manual indicates that there are over 120 kinetic parameters affecting constituent kinetics, e.g., algal growth and nitrification of ammonia (NH_4). The hydraulic and kinetic parameter input used in the calibration of the Arroyo Colorado CE-QUAL-W2 model is provided in Appendix A.

3.2.6 Verification Data

Mechanistic models such as CE-QUAL-W2 require extensive observational data to assess model performance through a process typically referred to as model verification. The verification process will be explained in greater detail in the next chapter, but succinctly the process involves comparison of model predictions to data collected within the prototype system, in this case, Arroyo Colorado Tidal. The comparisons occur through separate calibration and validation steps. The ability of the model to reasonably predict what was measured in Arroyo Colorado tidal as investigated through the verification process is a direct measure of the reliability and robustness of applications of the Arroyo Colorado model.

Due to difference in time periods of data availability, different time periods were chosen for the calibration of the different variables. The water level and tidal fluctuation monitoring data were available for various periods within 2006 – 2007 when TCEQ operated two continuous recording water-level stations along the Arroyo Colorado Tidal. The hydrodynamic calibration was therefore conducted for the period of January 2006 through December 2008. The water quality calibration was performed for the period of January 2005 through December 2006 due to fact that the 2006 has more intensive water quality monitoring data relative to other years. As DO calibration needs longer periods of data for better representation of the daily and seasonal fluctuation of the data, DO and algae calibration was performed for the period January 2003 through December 2006. The bacteria calibration was conducted for the period January 2002 to December 2006. The CE-QUAL-W2 validation was performed with the data provided by UTRGV during their monitoring study period for this project in 2013. All the validations were performed for the period January 2012 to December 2013.

The TCEQ monitoring stations used for the verification of the CE-QUAL-W2 model in this project are shown in the Figure 3-5. Stations C730 and C739 in Figure 3-5 are the TCEQ tidal gages at Rio Hondo and Rio City, respectively, which were used to calibrate the tidal fluctuation of the water level. The other locations are TCEQ SWQM stations for which there are various amounts of water quality data.

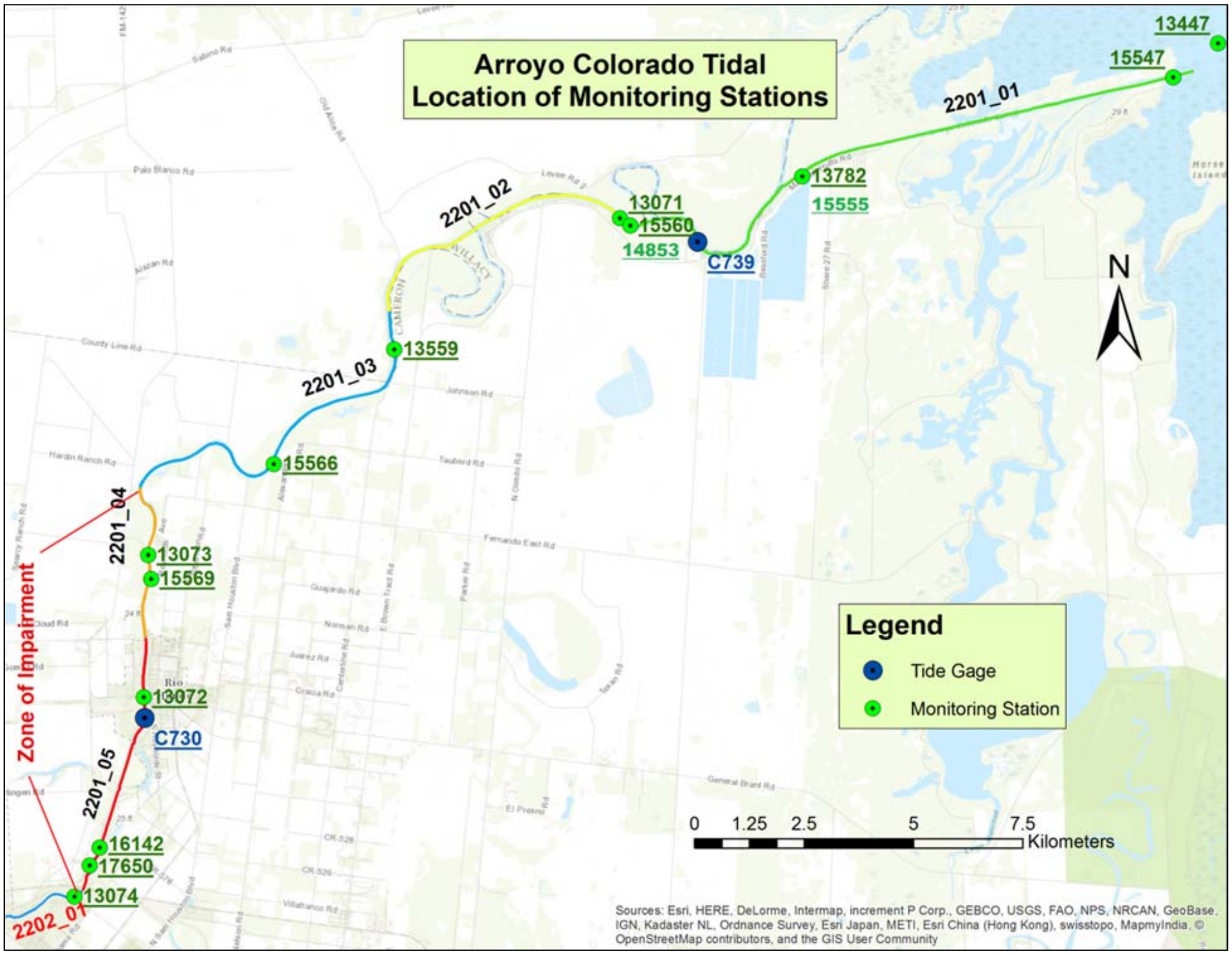

Figure 3-5. Arroyo Colorado Tidal Segment 2201 by AU showing major monitoring stations used in model verification

Chapter 4

Verification of Arroyo Colorado Tidal Model

4.1 Model Verification

Model verification is the process where the model input parameters are adjusted until the simulated data from the model match with observed data. CE-QUAL-W2 inputs and parameters were adjusted to match observed and predicted water levels, salinities, water temperatures, and water-quality constituents at key locations in the Arroyo Colorado Tidal segment. The verification process is the combination of the model calibration and validation process which are defined as follows:

- Calibration — The first stage testing and tuning of a model to a set of observational data, such that the tuning results in a consistent and rational set of theoretically defensible input parameters.
- Validation — Subsequent testing of a calibrated model to additional observational data to further examine the model validity and preferably under different external conditions from those used during calibration (Thomann and Mueller, 1987).

During the calibration process, all model hydraulic and kinetic parameters were adjusted within the literature recommended ranges for the most sensitive parameters first, followed by the next most sensitive, and so on. Sources of the literature recommended ranges included the CE-QUAL-W2 user's manual (Cole and Wells, 2001) and Bowie *et al.* (1985), which remains a definitive source of rates, constants and kinetics for surface water quality modeling despite the date of its publications. Model calibration is an iterative procedure that is achieved using a combination of best professional judgment and quantitative comparison with a subset of the observed data. In case the matching between simulated and observed data does not meet the targets of performance, the calibration and validation processes will be revisited until a best fit between simulated and observed data is obtained. Visual and quantitative analysis measures were used to evaluate the performance of models during calibration and validation. Further information on the model verification process is provided in the modeling QAPP (TWRI *et al.*, 2016)

4.2 Statistical Measures of Model Performance

The model verification processes will be iterated until the simulated data from the revised model match with measured data at a satisfactory level. Then only the calibrated parameters are transferred to the future scenario models for a BMP assessment.

At first the model performance was evaluated visually at several stations along the Arroyo Colorado Tidal. The time-series of the model simulated and measured data for different variables were plotted to visually evaluate the prediction (performance) of the model during calibration. Then, model performance statistics including relative error (RE), the coefficient of determination (r^2), and root-mean-square error (RMSE) were used as quantitative measures of model fit to supplement the visual evaluation of fit. The formulas for model fit statistics are provided below, where y_i is the measured value, $\hat{y}_i$ is the model predicted value, an overscore indicates a mean value, and n is the number of measurements.

Relative Error
$$RE = \left(\sum_{i=1}^{n} \left| y_i - \hat{y}_i \right| / y_i \right) / n$$

Coefficient of Determination
$$r^2 = \left\{ \frac{\sum_{i=1}^{n} (y_i - \bar{y})(\hat{y}_i - \bar{\hat{y}})}{\left[\sum_{i=1}^{n} (y_i - \bar{y})^2 \right]^{0.5} * \left[\sum_{i=1}^{n} (\hat{y}_i - \bar{\hat{y}})^2 \right]^{0.5}} \right\}^2$$

Root Mean Square Error
$$RMSE = \left\{ \left[\sum (y_i - \hat{y}_i)^2 \right] / n \right\}^{0.5}$$

4.3 Hydrodynamic Verification

The hydrodynamic verification process involved comparing model predictions and observed data of water-level fluctuations, near surface salinity and temperature, vertical salinity profiles, and vertical temperature profiles. Ideally, the hydrodynamic verification process would have also included comparisons of velocities (speed and direction); however, observed data of this nature did not exist for the Arroyo Colorado Tidal. The purpose of this verification process was to confirm model performance in predictions of tide propagation, salinity wedge definition, and temperature stratification. The Arroyo Colorado Tidal segment experiences density stratification, mainly as a result of the presence of a salinity wedge originating in the Laguna Madre and propagating along the bottom of the channel in an upstream direction. This stratification results in the freshwater from the Arroyo Colorado Above Tidal and other tributaries that flow into the Arroyo Colorado Tidal remaining above the denser salinity wedge. This salinity wedge phenomenon is important to be captured in the model because it causes an isolation of the bottom waters often resulting in low DOs along the deeper portions of the barge channel of the Arroyo Colorado Tidal.

4.3.1 Verification of Surface Water Level

The surface water-level calibration was performed through comparison of model predicted water surface levels and tidal range to the measured surface water level data from TCEQ Stations C730 and C739 near Rio Honda and Arroyo City, respectively (Figure 3-5). The objective of this calibration is to adjust relevant input parameters until the model provides reasonable predictions of water-level fluctuations, which infers that tidal propagation from the Laguna Madre is reasonable predicted by the model. The model calibration was performed first by visual inspections of time-series plots of model predicted and measured surface levels. Then, the model input was adjusted modifying hydraulic and bottom friction coefficient, and refining the channel geometry. The project modeling QAPP defined the following model performance targets for the surface water level calibration and validation:

- The tidal water level should be calibrated and then validated so that the average RMSE is less than 33 % of the daily observed tidal range and the average RE is less than 50%.

Representative results of the surface water level calibration at Rio Honda and Arroyo City are shown in Figure 4-1. The time period of these selected sample plots were chosen within the calibration period when there is minimum fluctuation of wind and inflow of freshwater. The tidal water level RE and RMSE statistics are shown on the right top corner of the plot. Similarly, the results of the surface water level validation at Station 13782 are shown in Figure 4-2. Tidal fluctuation data were obtained for model validation at the location of Station 13782 during the project specific sampling conducted by UTRGV. Station 13782 is located towards the downstream end of the segment (Figure 3-5). All the water-level calibration and validation results were acceptable and the tidal ranges were within the model performance targets as defined by the project QAPP.

A second surface water-level model performance target in the QAPP was defined as the time of day of simulated daily tidal maximum and minimum must calibrate within ±1 hour. This performance statistic provided to be unworkable and was not used. It proved to be very difficult to develop a methodology to define the daily maximum and minimum for comparison, because the actual astronomical tidal period is 24.8 hours (slightly more than 1 day), meteorological forcing of water level complicated when maximum and minimum water levels actually occurred on a given day, and the tides propagating from the Gulf of Mexico are complex and continually transitioning from one high and one low per tidal period to two highs and two lows per tidal period on roughly a 2-week cycle. This performance measure proved to be very difficult to implement and was therefore not used as a measure of model performance. Visual critique of Figures 4-1 and 4-2 does indicate that the timing by the model of the occurrence of tidal highs and lows were fairly consistent and the predictions were at least visually reasonable.

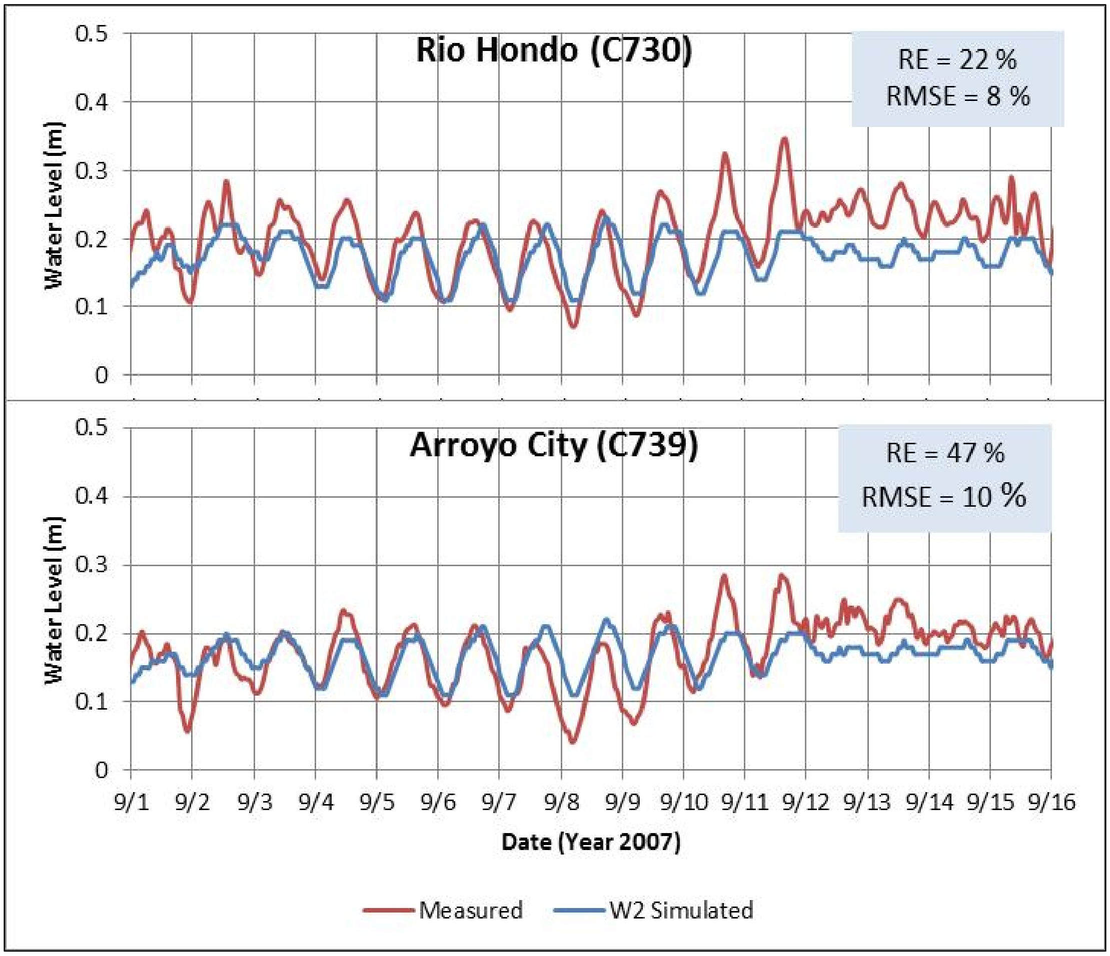

Figure 4-1. Water Level calibration at Rio Honda and Arroyo City in Arroyo Colorado Tidal Segment 2201

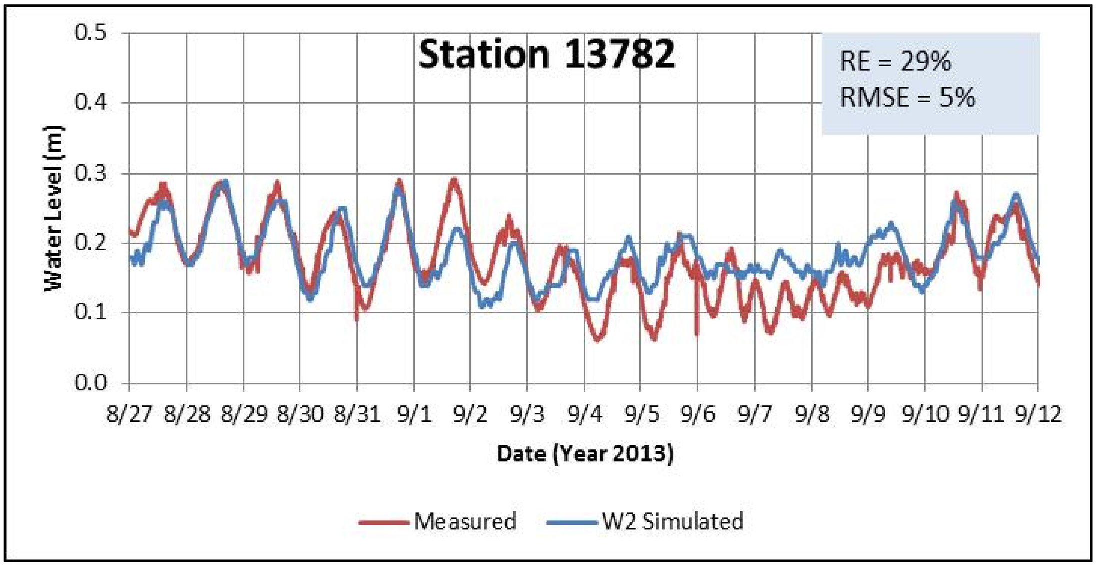

Figure 4-2. Water Level Validation at Station 13782 in Arroyo Colorado Tidal Segment 2201

4.3.2 Temperature and Salinity

Next the CE-QUAL-W2 model was calibrated for vertical and longitudinal variation in water temperature and the salinity. The temperature and, especially, the salinity affect the density gradient and tidal exchange within the Arroyo Colorado Tidal. The calibration of the temperature and the salinity involved adjustments to the hydraulic parameters such as longitudinal eddy viscosity [AX][1], longitudinal eddy diffusivity [DX] , Chezy coefficient [FRICT], wind sheltering coefficient [WSC], solar radiation absorbed in surface later [BETA], and extinction coefficient for pure water [EXH2O]. In addition to these coefficients, temperature predictions are also affected by the surface heat exchange algorithm, mainstem and tributary inflows, inflow temperatures and their placement, outlet and withdrawal specifications, the numerical solution scheme, and the bathymetric and the meteorological data. After developing acceptable water level performance by the model, there was minimal effort required to calibrate temperature and salinity. There is, however, somewhat of a feedback where water surface elevation and tidal flows are affected by the adequacy of the temperature and salinity calibration.

The project QAPP defines the following performance targets for water temperature and salinity for both model calibration and validation:

- The salinity of the mixed surface layer within the zone of impairment should be calibrated so that the overall RMSE is ≤ 1.5 parts per thousand (ppt) and outside the zone of

[1] Throughout this report the name or abbreviation used in the CE-QUAL-W2 model for various input constants are provided in brackets, e.g.., [AX], and these abbreviations are the same as used in Appendix A.

impairment the overall RMSE of mixed surface layer salinities should be ≤ 2.0 ppt. For both the zone of impairment and the area outside of the zone of impairment, the average RE of the mixed surface layer salinities should be ≤ 0.50. In practice, the performance statistic was applied to the near-surface measurements of temperature and salinity rather than the mixed surface layer (see more details given for this on the third bullet of this list).

- The water temperature at the surface should be calibrated so that the RMSE is ≤ 2°C and RE ≤ 0.50.

- The depth of the mixed surface layer should be calibrated so the RMSE is ≤ 1.5 meter and RE ≤ 0.50. This statistical measure of performance was not applied for two distinct reasons: 1) the bacteria measurements and 24-hour deployments of multiprobes to measure DO were all made near the water surface (typically 0.3 m below the surface), which made it more relevant to simulate the near-surface salinity and water temperature correctly than salinity and temperature within the mixed surface layer, and 2) the model did simulate a strong salinity wedge along the Arroyo Colorado Tidal, but the model was not able to consistently simulate the dynamics of temporal variations in the depth of the salinity wedge and mixed surface layer.

The model performance statistics of CE-QUAL-W2 predictions during the calibration and validation periods for the temperature and the salinity are shown in the Table 4-1. The calibration and the validation statistics of the model are presented for the zone of impairment, below the zone of impairment, and the overall system of the Arroyo Colorado Tidal. The TCEQ defined AUs 2201_04 and 2201_05 comprise the zone of impairment while other AUs 2201_01, 2201_02, and 2201_03 are located below the zone of impairment.[2] Model performance statistics were met for surface water temperature during both the calibration and validation periods. For salinity the performance measures were close to being met for the calibration period, but were grossly missed for the validation periods.

To provide visual and graphical indications of model performance for surface temperature and salinity, a series of graphs are provided of model predicted and observed data for TCEQ SWQM Station 13072, which is located on the Arroyo Colorado at Rio Hondo (Figure 3-5). Station 13072 is the location on the Arroyo Colorado Tidal with the most consistent set of observed water quality data. Several other SWQM stations had observed data for which graphs could have been developed. Station 13072 is, however, located in the zone of DO impairment, and comparisons at this location provide representative indications of model performance without burdening the reader with numerous graphics. Figures 4-3 and 4-4 provide the model predicted and observed surface temperature for Station 13072 (model

[2] The description of the zone of impairment used in this report is based on the 2012 Texas Integrated Report – Texas 303(d) List and the AUs with depressed DO defined in that document. (TCEQ, 2013).

segment 25) during a portion of the calibration and validation periods, respectively. Note that during the calibration period, the USGS conducted intensive data collection efforts on February 22-23, 2006 and May 23-24, 2006 and these are the two periods depicted on Figure 4-3. On Figure 4-4 the temperature data collected by UTRGV during their three data collection efforts during July and August 2013 are depicted with model predictions. Visual review of these two figures indicated that the surface temperatures were well predicted during both the calibration and validation periods.

Table 4-1. Model performance of near-surface temperature and salinity predictions evaluation with RE and RMSE at Arroyo Colorado Tidal Segment 2201. (Yellow highlighted is the model performance targets and results.)

Statistical Parameters		Zone of Impair.		Below Zone of Impair.		Overall System	
		Calib.*	Valid.**	Calib.*	Valid.**	Calib.*	Valid.**
Temperature (°C)	RE (target ≤0.5)	0.03	0.03	0.05	0.04	0.04	0.03
	RMSE	1.04	1.10	1.29	1.32	1.13	1.22
	RMSE Target	–	–	–	–	2.00	2.00
Salinity (ppt)	RE (target ≤0.5)	0.42	0.38	0.38	0.62	0.40	0.50
	RMSE	1.87	6.86	1.66	11.21	1.80	9.29
	RMSE Target	1.50	1.50	2.00	2.00	–	–

**Calibration period is 2006-2008, ** Validation period is 2010-2013*

The same sampling location and dates were used to develop graphs of near-surface predictions and observations of salinity (Figures 4-5 and 4-6). Visual inspection of these two figures indicates that near-surface salinity predictions were not as good as temperature. The model predictions for July 29, 2013 during the validation period are particularly poor. This poor model performance on July 29, 2013 was not unique to Station 13072 and it was the widespread poor comparison of the model predictions on this date to the observed data that resulted in the very poor performance statistics of the validation period. No explanation could be found or adjustments made to model input of meteorological and freshwater inflow conditions to give predictions of the observed high salinities on July 29th that were not observed during the other two UTRGV intensive surveys that occurred in close temporal proximity.

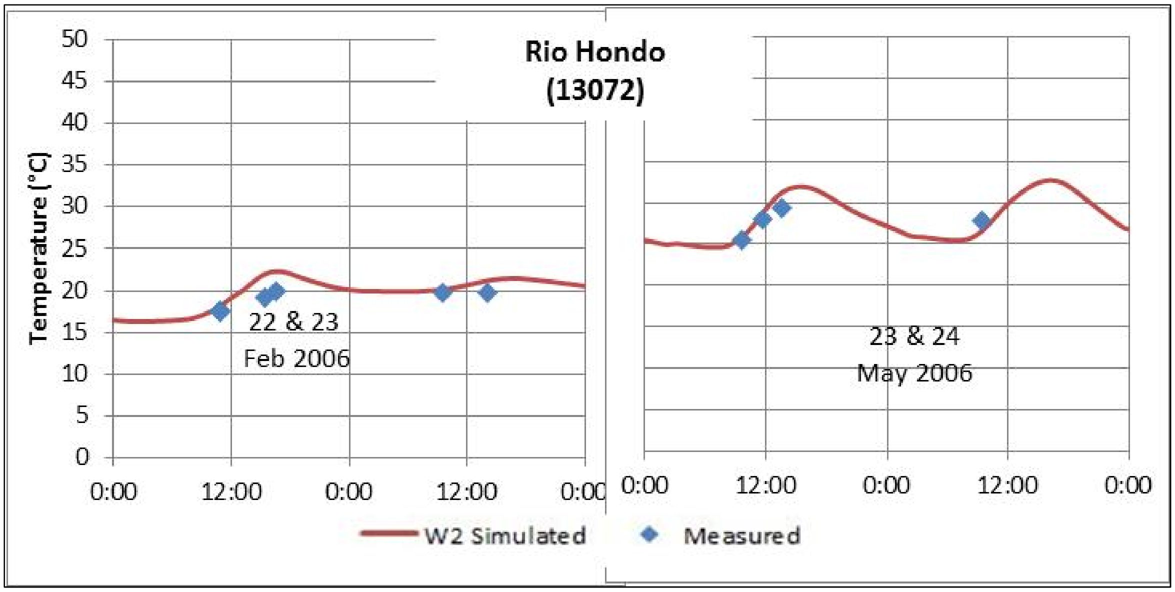

Figure 4-3. **Model predicted near-surface temperature time series during the calibration period at Segment 25 and observed near-surface temperature data for Station 13072.**

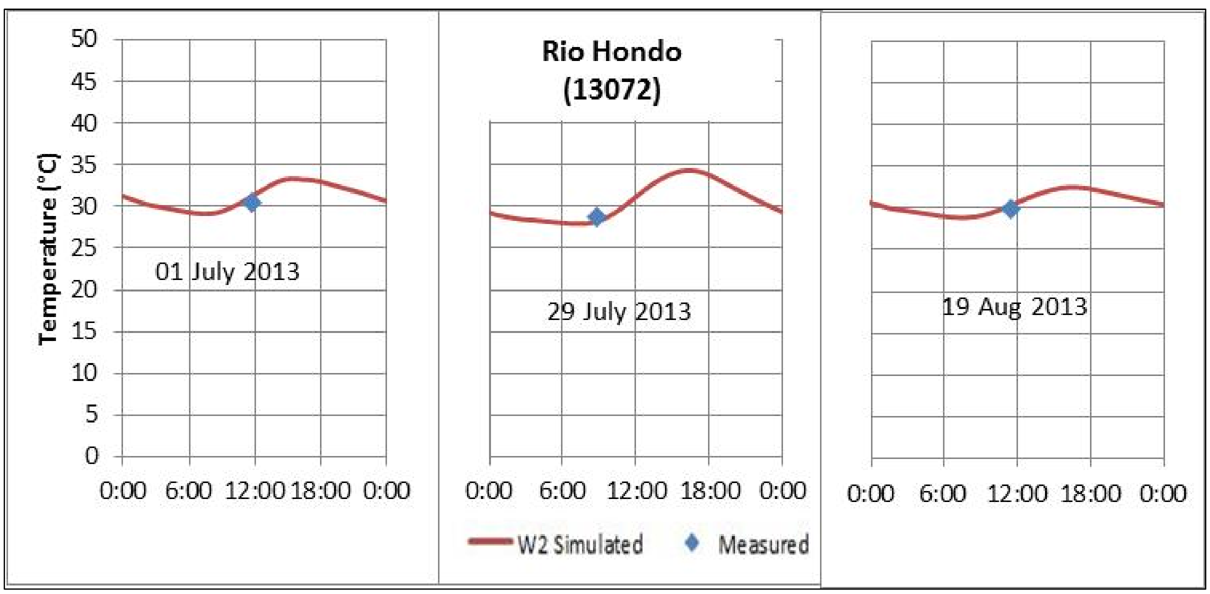

Figure 4-4. **Model predicted near-surface temperature time series during the validation period at Segment 25 and observed near-surface temperature data for Station 13072.**

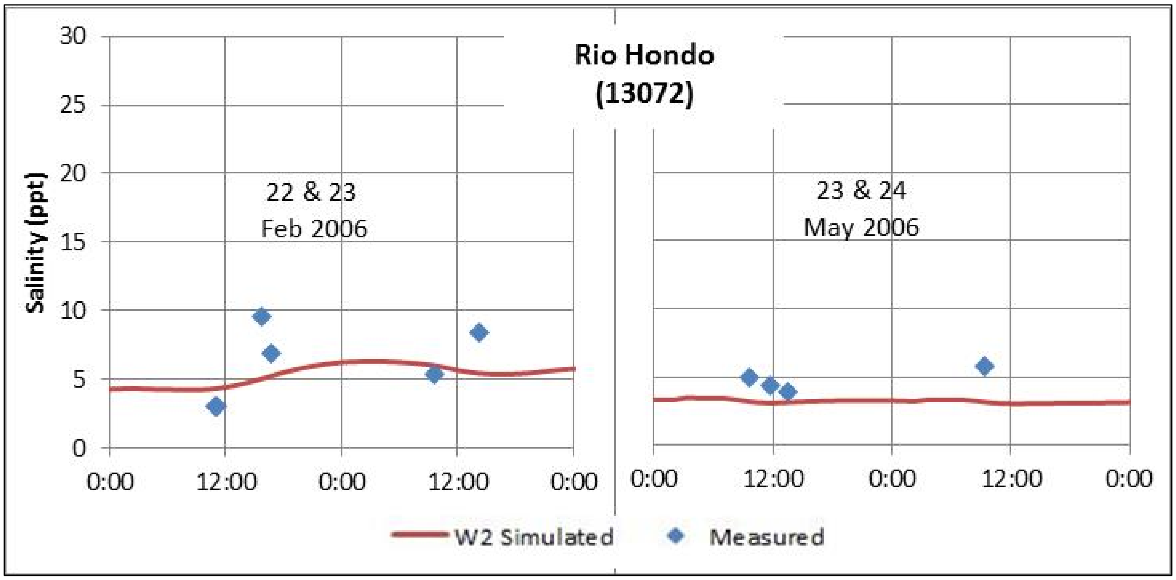

Figure 4-5. **Model predicted near-surface salinity time series during the calibration period at Segment 25 and observed near-surface salinity data for Station 13072.**

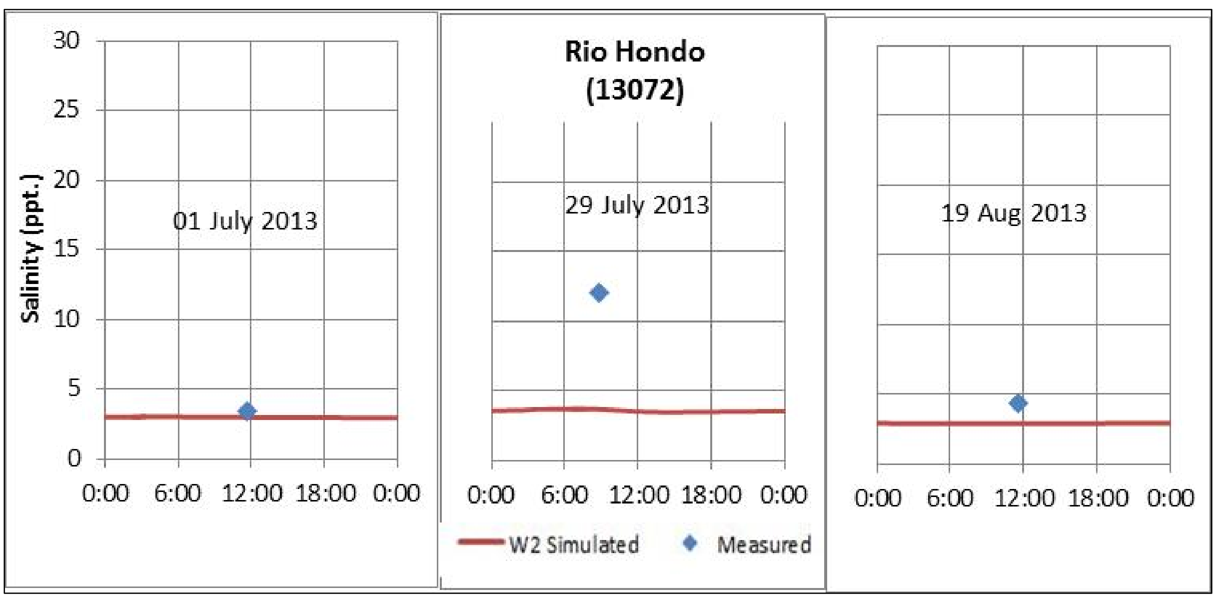

Figure 4-6. **Model predicted near-surface salinity time series during the validation period at Segment 25 and observed near-surface salinity data for Station 1307.**

The model was additionally evaluated for performance in predicting temperature and salinity vertical profiles through visually evaluation. Numerous graphs of model predicted and observed profile data of the temperature and the salinity were developed at the different stations along the Arroyo Colorado Tidal (Figure 3-5). Station 13072, a key station with a relative abundance of data in the zone of impairment, is again used as the location for graphical data presentation. Figures 4-7 and 4-8 shows the vertical profiles for the temperature during the calibration and validation periods, respectively. The temperature profiles were generally well predicted by the model. The comparisons of model predicted and observed salinity vertical profiles are provided in Figures 4-9 and 4-10 for the calibration and validation periods. The degree to which the model could simulate the salinity wedge and overlying fresher water is particularly depicted in these figures. The model generally under predicted the depth of the fresher top water layer during the calibration period, but over predicted this layer during the validation period. It is of interest to note the last two vertical profiles of salinity in Figure 4-9, which show both a predicted and observed response to high freshwater inflows that totally removed the salinity wedge during the August and October 2008 periods.

4.3.3 Discussion of Hydrodynamic Model Performance

While the Arroyo Colorado Tidal model predictions did not provide results that met all performance statistics regarding water levels, near-surface water temperature, and near-surface salinity; overall the model was showing proper response to forcing functions of tidal fluctuations and freshwater inflows. It would be incorrect to dismiss all the shortcomings in the hydrodynamic verification process as being the results of having measured tide data for the Laguna Madre downstream boundary only through December 2005 and inaccuracies in SWAT predictions of streamflow used as input. Likewise, it is inappropriate to not take into account that these two areas of model input are very important and any inaccuracies in either will diminish performance of the Arroyo Colorado Tidal model. These CE-QUAL-W2 hydrodynamic performance results were made available to the project team and interested parties of TWRI, TCEQ and the Texas State Soil and Water Conservation Service (TSSWCB) as the project progressed. There was a consensus amongst these parties that while it would have been preferred to have better model performance as measured by the evaluative statistics in the QAPP, nonetheless, the Arroyo Colorado Tidal model was considered as acceptably verified for use in hydrodynamic predictions.

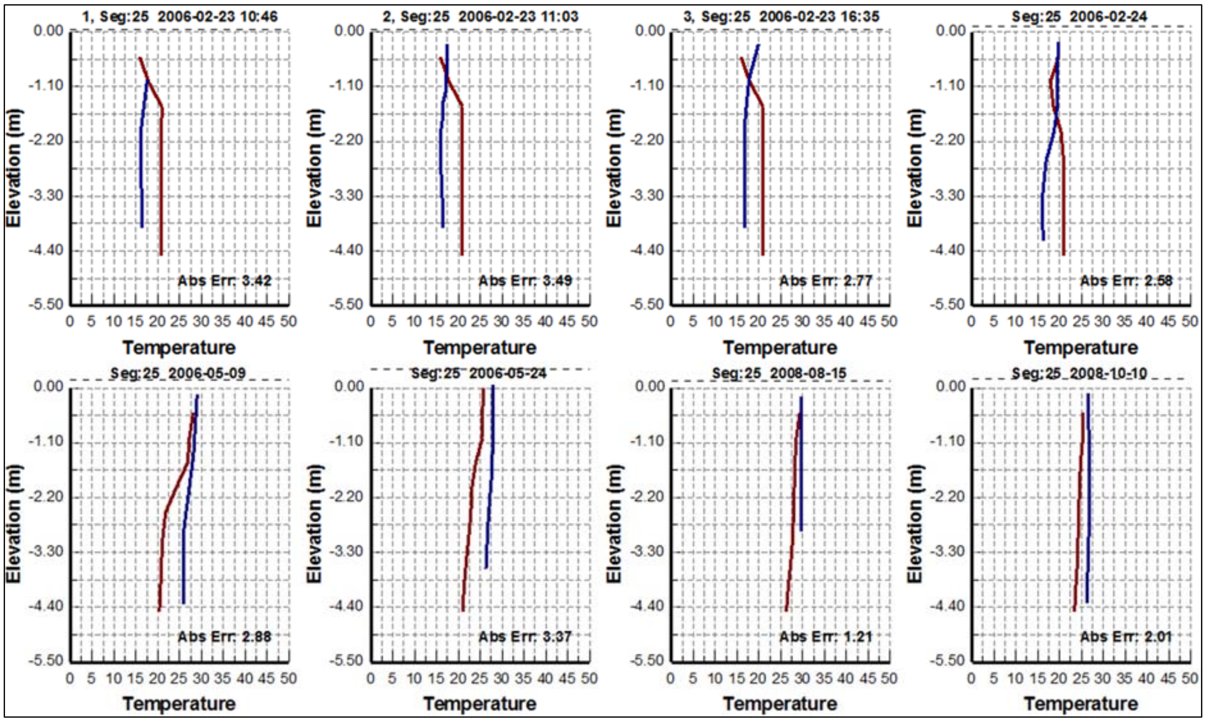

Figure 4-7. **Model predicted and observed vertical temperature profiles during the calibration period at Segment 25 and Station 13072.**

(Model predictions in red and observational data in blue.)

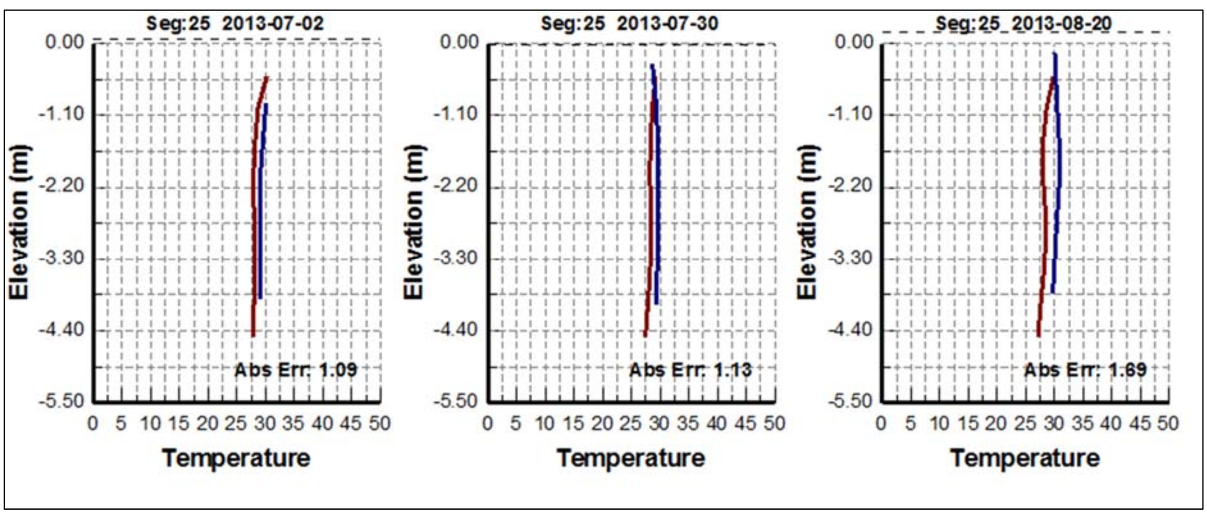

Figure 4-8. **Model predicted and observed vertical temperature profiles during the validation period at Segment 25 and Station 13072.**

(Model predictions in red and observational data in blue.)

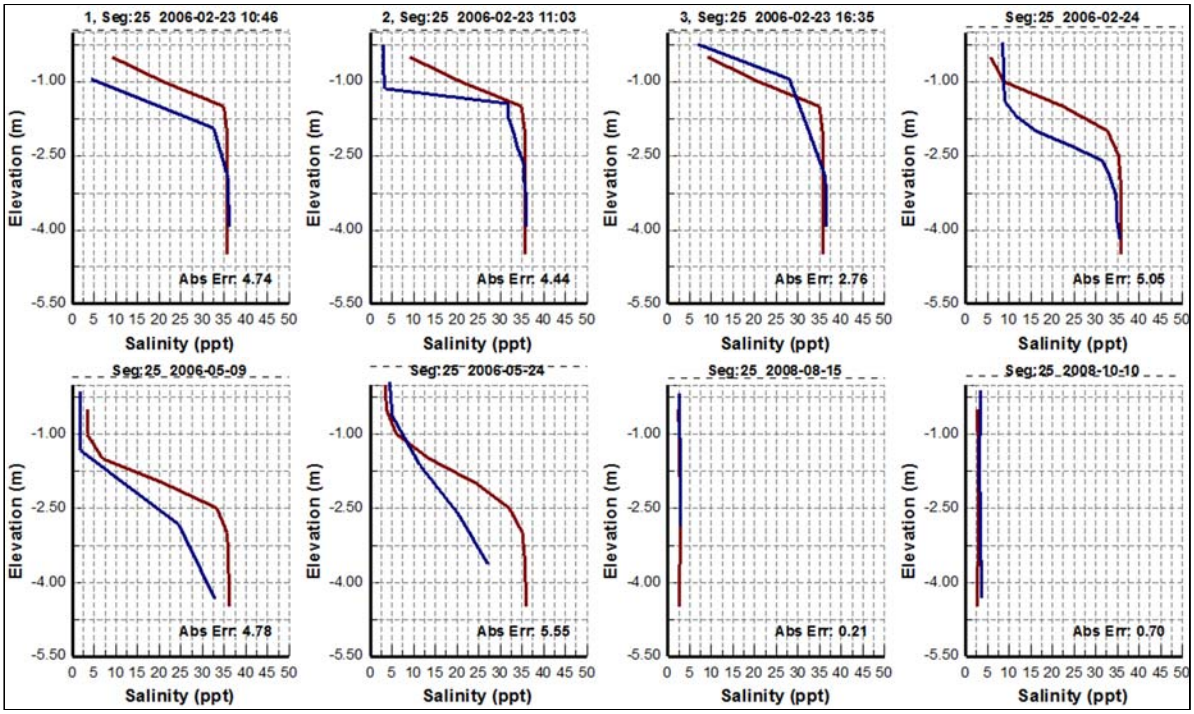

Figure 4-9. Model predicted and observed vertical salinity profiles during the calibration period at Segment 25 and Station 13072.

(Model predictions in red and observational data in blue.)

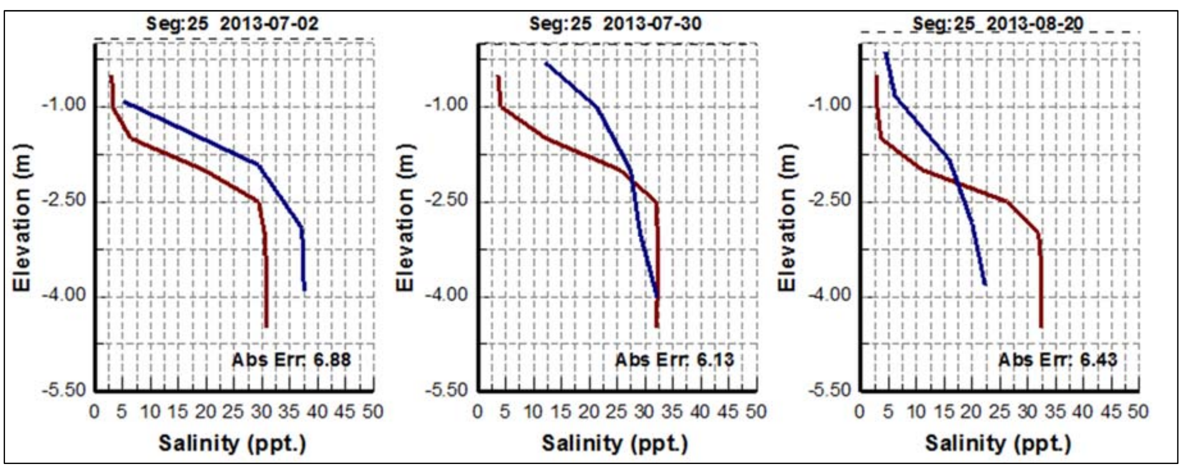

Figure 4-10. Model predicted and observed vertical salinity profiles during the validation period at Segment 25 and Station 13072.

(Model predictions in red and observational data in blue.)

4.4 Water Quality Verification

The usual sequence for model development is to first verify the hydrodynamics (including water surface elevation, salinity, and temperature) and finally water quality. While the water quality calibration process can affect temperature and salinity, usually these impacts are minor enough that significant re-verification of the hydrodynamics is not required. For water quality simulations, it is important to provide accurate initial and time-varying boundary conditions. If nutrient loadings are not adequately characterized, then it will be impossible for the model to accurately reproduce water quality parameters. There are more than 120 coefficients affecting constituent kinetics, although less than 10 are normally adjusted during water-quality calibration. The calibration process for the water-quality constituents involves an iterative process of adjusting key input parameters describing kinetic rates and constants. Due to the interaction of the constituents, the calibration process is very much an art based on visual evaluation of graphics comparing predicted and observational data as well as evaluating improvements in statistical measures of model performance. Since water quality constituents are coupled (*e.g.*, algal growth, though uptake and incorporation in cell biomass, reduces inorganic forms of nitrogen and phosphorus), calibration of one constituent often affects other constituents to various degrees making calibration a difficult and tedious process. An understanding of the processes modeled as well as knowledge of the system is necessary for the successful model calibration.

As with the hydrodynamic verification process, a plethora of plots comparing model predictions to observational data were generated. Only a few representative graphics are presented herein to keep the amount of information displayed manageable.

4.4.1 Verification of Total Suspended Solids

The total suspended solids (TSS) is the combination of the inorganic and volatile (or organic) suspended solids. High TSS concentrations reduce light availability in the water column slowing down of photosynthesis, which also causes less DO production in the system. Also, high TSS causes an increase in surface water temperature, because the suspended particles absorb heat from sunlight, which cause DO levels to fall even further (because warmer waters can hold less DO), and harm aquatic life in many other ways. The verification of the TSS in the CE-QUAL-W2 model involved a focus on the inorganic suspended solids and the adjustment of the settling rate for each of three user defined inorganic suspended solids state variables (*i.e.*, clay, silt, and sand). CE-QUAL-W2 also has the ability to simulate resuspension of inorganic suspended solids due to wind shear and the resulting wind-generated waves.

The upper non-tidal Segment 2202 of the Arroyo Colorado carries high TSS that originates from the different sources, such as, urban runoff and agricultural runoff. The abrupt changes in water depth and channel width from the shallower non-tidal segment to the deeper barge channel of tidal Segment 2201 results in the settling of inorganic suspended sediments in the upper section of the tidal segments.

The model simulated average and the median TSS for the calibration and the validation periods at different AUs along the Arroyo Colorado Tidal (Segment 2201) are shown in Table 4-2. The AUs are listed from upstream towards the downstream in the right to left direction in the Table 4-2. As expected, the model generated higher TSS at the upstream AUs and concentrations decreases in downstream direction within both the calibration and validation periods.

Table 4-2. Model simulated TSS concentrations for the calibration and validation periods for AUs of the Arroyo Colorado Tidal (Segment 2201).

All units in mg/L

Conditions	Statistic	Zone of Imp. AUs		Below Zone of Imp. AUs		
		2201_05	2201_04	2201_03	2201_02	2201_01
Calibration (2005-2007)	Average	38.9	24.4	15.7	12.4	10.7
	Median	29.0	16.7	11.0	9.0	8.6
Validation (2010-2013)	Average	43.9	27.4	18.0	14.0	11.4
	Median	29.9	17.1	10.8	8.6	8.3

The project QAPP defined the following model performance target for TSS calibration and validation:

- Concentrations of the TSS should be calibrated so that the overall RMSE is less than 50% of the observed average concentration or 5 mg/L, whichever is greater. Wherein "overall" means the average of the near-surface TSS across time and the longitudinal domain of Segment 2201.

The RE and the RMSE statistics for the calibration and validation periods are shown in Table 4-3. The RE statistic is provided for information purposes only. Also contained in Table 4-3 is the performance target for RMSE as defined in the above bullet. The RMSE target was met for the predictions in the zone of impairment, but not met for the Arroyo Colorado Tidal below the zone of impairment. For both the calibration and validation periods, the overall RMSE targets were met as stipulated in the QAPP. Graphical presentations of the simulated time series of near-surface TSS with observed data for the calibration and the validation periods at Rio Honda are provided in Figures 4-11 and 4-12. The times series plots of the model predicted TSS against the measured data for both calibration and the validation periods seem visually acceptable.

Table 4-3. Evaluation of model performance for near-surface TSS during the calibration and validation periods, Arroyo Colorado Tidal, Segment 2201.

(Yellow highlighted is the model performance targets and results.)

Statistical Parameters	Zone of Impair.		Below Zone of Impair.		Overall System	
	Calib.*	Valid.**	Calib.*	Valid.**	Calib.*	Valid.**
RE (no target in QAPP)	0.38	0.09	0.42	0.46	0.39	0.27
RMSE (mg/L)	8.18	2.75	7.99	13.91	8.09	10.03
RMSE Target (mg/L)	10.78	16.98	6.95	11.96	9.05	14.47

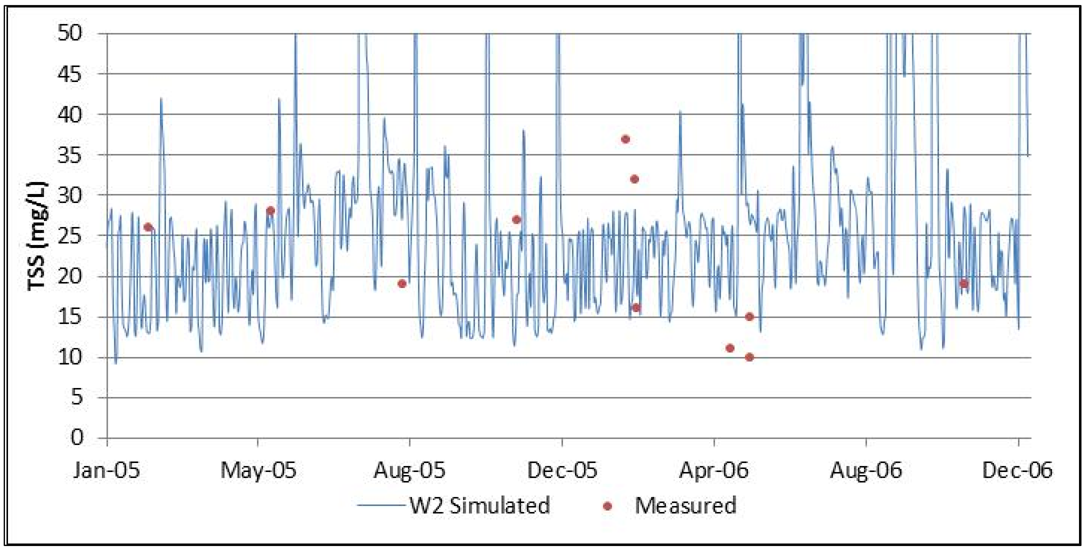

Figure 4-11. Time series of model predicted TSS and observed data for the calibration period, Segment 25 and Station 13072.

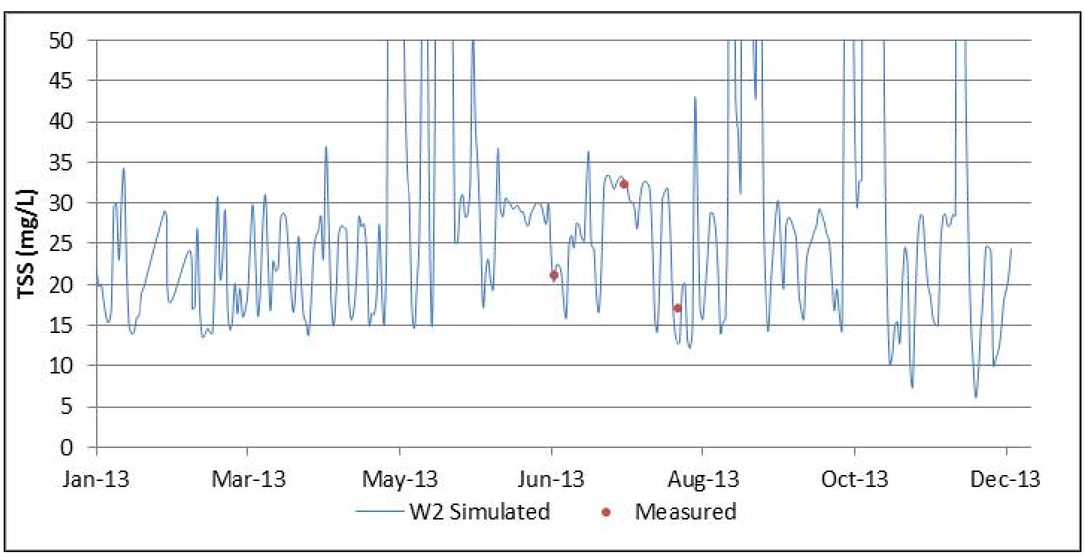

Figure 4-12. Time series of model predicted TSS and observed data for the validation period, Segment 25 and Station 13072.

4.4.2 Verification of Nitrogen Forms

The verification results are provided for various the forms of nitrogen, *i.e.*, NH_4, nitrite plus nitrate (NO_{23}), and total nitrogen (TN) which is the sum of these two inorganic nitrogen forms and organic nitrogen (Org-N).[3] The focus of the verification was on the near-surface predicted concentrations of forms of nitrogen, because of the absence of sufficient observed data collected at depth to allow any meaningful comparisons and because of the overall emphasis of model response to the upper layers of the model. Note that the model predicted Org-N is the sum of LDOM-N, RDOM-N, LPOM-N, and RPOM-N components plus the nitrogen in the three algal species in the model, and that there were no observational data for these component forms of Org-N. The major sources of the nitrogen in the system are nutrient loading from municipal WWTFs and agricultural and urban stormwater. The high nitrogen loadings can result in low DO and excessive growth of aquatic vegetation, which would be in the form of suspended algae in the Arroyo Colorado Tidal. All AUs of the Arroyo Colorado Tidal and Above Tidal have concerns regarding high levels of NO_{23} based upon TCEQ's recent biennial assessments of water quality data (TCEQ, 2015a). Concentrations of nitrogen forms generally decrease from upstream end of the Arroyo Colorado Tidal to its downstream terminus in the Laguna Madre, though the decrease is not always monotonic (Berthold *et al.*, 2013). For example, in the upper portion of the Tidal segment within the zone of impairment (Stations 13072 and 13073), lower NO_{23} and higher NH_4 concentrations were observed than would be anticipated with a strict monotonic decrease. It is speculated that this contrary trend might be due to the abrupt change in water depth from the shallower non-tidal segment to the deeper barge channel of the tidal segment.

The CE-QUAL-W2 calibration of the inorganic forms of the nitrogen involved adjustments of the NH_4 preference factor for algal update of nitrogen [ANPR], the sediment release rate of NH_4 [NH4R], NH_4 oxidation rate to NO_{23} [NH4DK], the water column denitrification rate of NO_{23} [NO3DK], and the sediment NO_{23} uptake rate [NO3S]. Near-surface NH_4 and NO_{23} levels can be difficult to reproduce as some phytoplankton show a preference for ammonium over nitrate and the degree to which they exhibit this preference is different between groups. In addition, water column nitrate undergoes denitrification when the water column goes anoxic, and nitrates also diffuses into the sediments where they undergo denitrification in the anaerobic layer under both oxic and anoxic conditions. The calibration of the forms of organic forms of nitrogen involved adjustments of decay rates of LDOM [LDOMDK], RDOM

[3] For observed data, TN = total Kjeldahl nitrogen + nitrite + nitrate. CE-QUAL-W2 combines nitrite and nitrate forms of nitrogen into one parameter, which herein is referred to as NO_{23}. Based on stoichiometric constants provided through input into CE-QUAL-W2, the amount of carbon, nitrogen and phosphorus in organic matter is defined in the model's four pools of organic matter (LDOM, RDOM, LPOM, and RPOM, see Table 2-1).

[RDOMDK], LPOM [LPOMDK], and RPOM [RPOMDK] and the settling rate of particulate organic matter [POMS].

The project QAPP defined the following model performance targets for nitrogen calibration and validation:

- Concentrations of inorganic forms of nitrogen (NH_4 and NO_{23}), and TN should be calibrated so that the overall RMSE of each is less than 50% of the observed average concentration or 0.25 mg/L, whichever is greater. (This performance target applied to the entire Arroyo Colorado Tidal model domain, though results are provided below at a more spatially refined level of detail.)

The statistical measures of model performance based on near-surface predictions and observational data at stations in the zone of impairment, below the zone of impairment, and for the entire Arroyo Colorado Tidal are presented in Table 4-4. The RMSE statistics met the performance targets for NH_4, NO_{23}, and TN in the calibration and validation periods. For Station 13072 during both the calibration and validation periods, graphical presentations of the predicted time series of near-surface concentrations of NH_4, NO_{23}, and TN with observed data are provided in Figures 4-13 through 4-18. The model performed reasonably well in reproducing the temporal trends of NH_4, NO_{23}, and TN as depicted in these six figures. Overall the model was considered successfully verified for all nitrogen forms, despite some slightly unfavorable results during the validation period.

Table 4-4. Evaluation of model performance for near-surface for NH_4, NO_{23} and TN during the calibration and validation periods, Arroyo Colorado Tidal, Segment 2201.

(Yellow highlighted is the model performance targets and results.)

Parameter	Statistical Parameters	Zone of Impair.		Below Zone of Impair.		Overall System	
		Calib.*	Valid.**	Calib.*	Valid.**	Calib.*	Valid.**
NH_4	RE (no target in QAPP)	1.27	1.31	0.67	1.10	0.97	1.21
	RMSE (mg/L)	0.21	0.30	0.22	0.16	0.22	0.24
	RMSE Target (mg/L)	0.25	0.25	0.25	0.25	0.25	0.25
NO_{23}	RE (no target in QAPP)	0.38	0.28	0.29	0.82	0.33	0.49
	RMSE (mg/L)	1.71	0.93	0.94	1.31	1.40	1.10
	RMSE Target (mg/L)	1.82	1.54	1.60	0.90	1.72	1.28
TN	RE (no target in QAPP)	0.40	0.19	0.25	0.15	0.33	0.17
	RMSE (mg/L)	2.24	1.08	1.29	0.59	1.86	0.91
	RMSE Target (mg/L)	2.33	2.25	2.23	1.72	2.28	2.04

**Calibration period is 2005-2007, ** Validation period is 2010-2013*

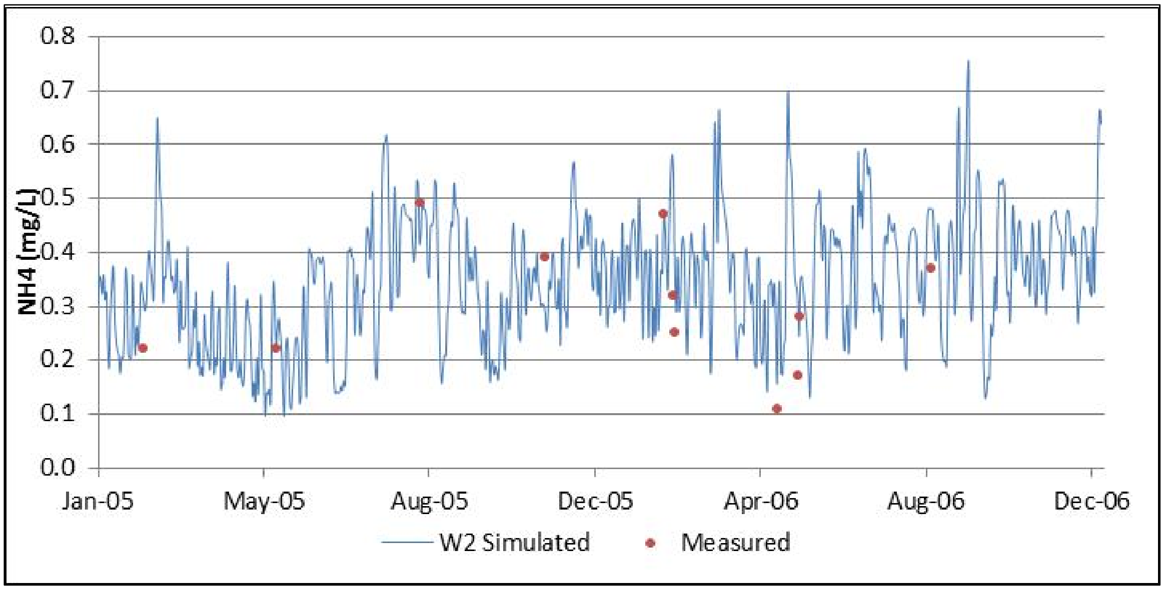

Figure 4-13. Time series of model predicted NH_4 and observed data for the calibration period, Segment 25 and Station 13072.

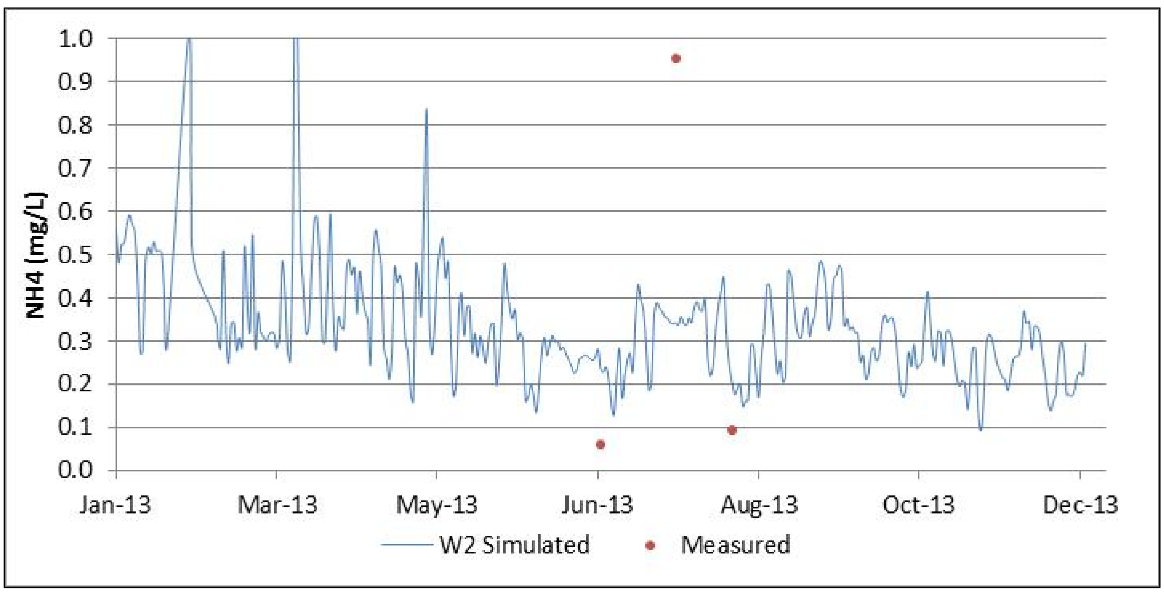

Figure 4-14. Time series of model predicted NH_4 and observed data for the validation period, Segment 25 and Station 13072.

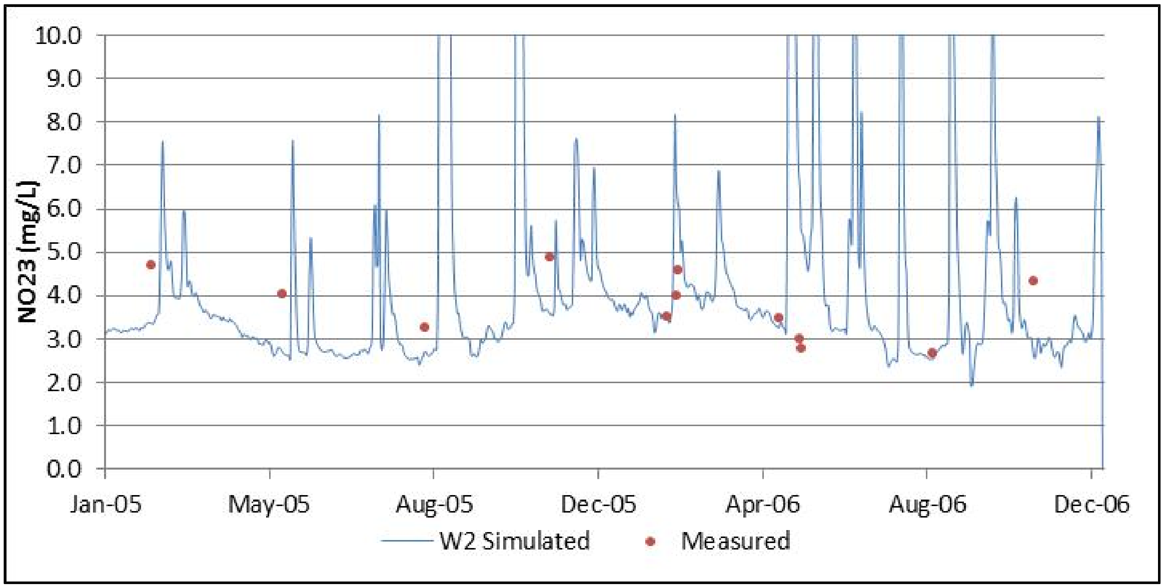

Figure 4-15. Time series of model predicted NO_{23} and observed data for the calibration period, Segment 25 and Station 13072.

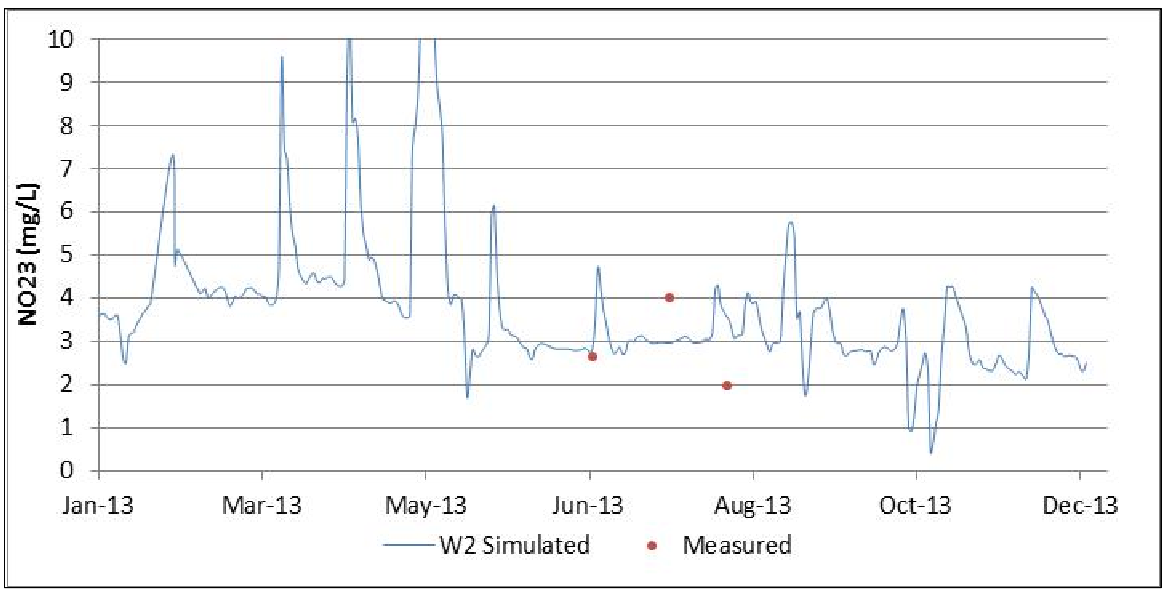

Figure 4-16. Time series of model predicted NO_{23} and observed data for the validation period, Segment 25 and Station 13072.

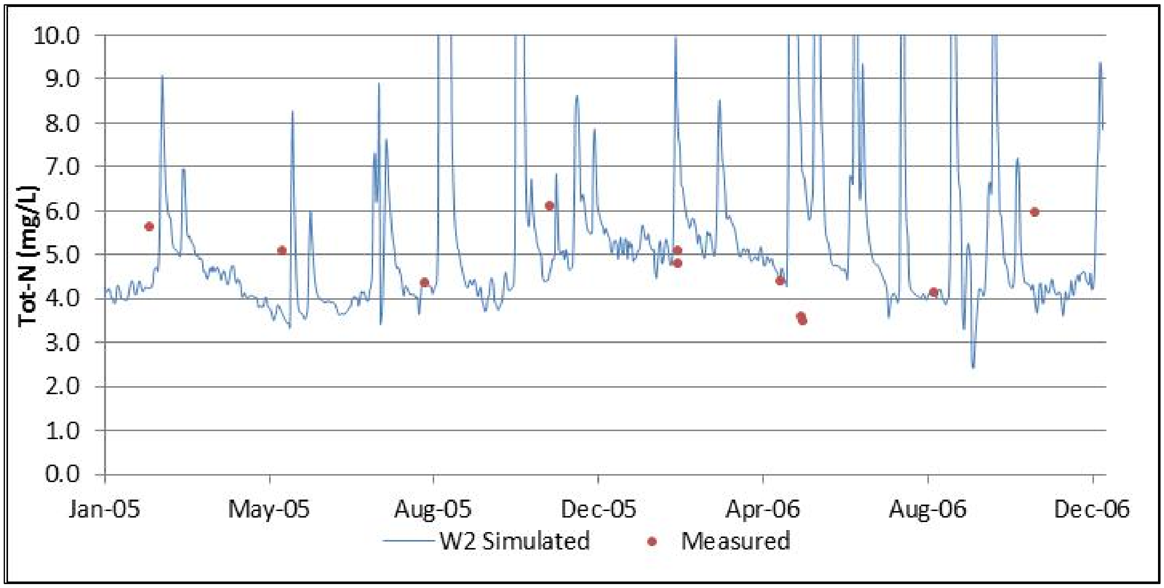

Figure 4-17. **Time series of model predicted TN and observed data for the calibration period, Segment 25 and Station 13072.**

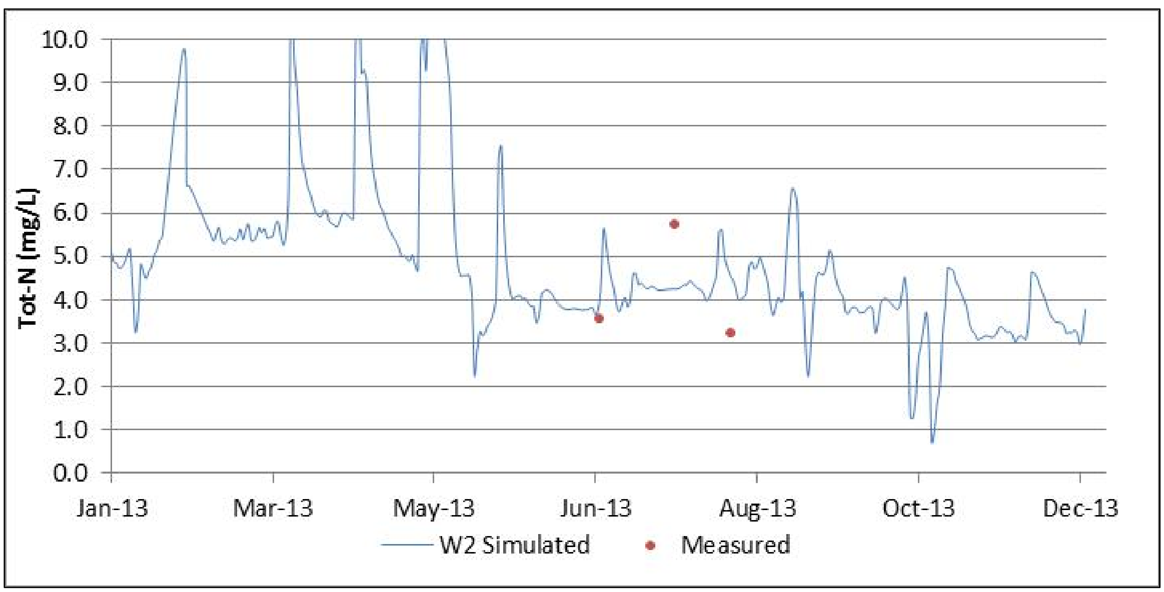

Figure 4-18. **Time series of model predicted TN and observed data for the validation period, Segment 25 and Station 13072.**

4.4.3 Verification of Phosphorus Forms

The verification results for the forms of phosphorus included, inorganic phosphorus or orthophosphate phosphorous (PO_4), and total phosphorus (TP), which is the sum of the inorganic and organic phosphorus (Org-P) forms plus the phosphorus bound to suspended sediments. Note that similar to Org-N, Org-P is the sum of the LDOM-P, RDOM-P, LPOM-P, and RPOM-P components plus the phosphorus in the three modeled algal species, and that there were no observational data for these component forms of Org-P. Like nitrogen, the major sources of the phosphorous in the system are nutrient loadings from municipal wastewater and agricultural and urban stormwater. High phosphorus loadings can result in low DO and excessive growth of aquatic vegetation, which would be in the form of suspended algae in the Arroyo Colorado Tidal. The levels of TP in the Arroyo Colorado Tidal do not exceed the TCEQ screening levels based on the most recent biennial assessment; however, the same assessment indicates that TP screening levels are exceeded in every AU of the Arroyo Colorado Above Tidal (TCEQ, 2015a). Phosphorous concentrations in the Arroyo Colorado Tidal show similar spatial trends to nitrogen with concentrations generally decreasing from upstream to the downstream terminus in the Laguna Madre (Berthold *et al.*, 2013).

The CE-QUAL-W2 model calibration of PO_4 involved adjustments of the sediment release rate of phosphorous [PO4R] and responses to the uptake of phosphorus through algal growth.

The project QAPP defined the following performance target for phosphorus model calibration and validation:

- Concentrations of inorganic forms of phosphorous and total phosphorous should be calibrated so that the overall RMSE of each is less than 50% of the observed average concentration or 0.25 mg/L, whichever is greater. (This performance target applied to the entire Arroyo Colorado Tidal model domain, though results are provided below at a more spatially refined level of detail.)

This statistical measure of model performance were calculated using near-surface predictions and observational data at station locations in the zone of impairment, below zone of impairment, and for the overall Arroyo Colorado Tidal segment. Based on the overall system statistics, the model was considered successfully verified for all phosphorous forms, despite some slightly unfavorable results for the validation period (Table 4-5). Graphical presentations of the predicted time series of surface predictions of PO_4 and TP with observed data for calibration and validation periods at Station 10372 are provided in Figures 4-19 through 4-22. The model performed reasonably well in reproducing the temporal trends of PO_4 and TP.

Table 4-5. Evaluation of model performance for near-surface for PO4 and TP during the calibration and validation periods, Arroyo Colorado Tidal, Segment 2201.

(Yellow highlighted is the model performance targets and results.)

Statistical Parameters		Zone of Impair.		Below Zone of Impair.		Overall System	
		Calib.*	Valid.**	Calib.*	Valid.**	Calib.*	Valid.**
PO_4 (mg/L)	RE (no target in QAPP)	0.43	0.15	0.18	0.25	0.30	0.20
	RMSE (mg/L)	0.24	0.13	0.09	0.10	0.18	0.11
	RMSE Target (mg/L)	0.25	0.29	0.25	0.25	0.25	0.25
TP (mg/L)	RE (no target in QAPP)	0.50	0.25	0.18	0.22	0.34	0.19
	RMSE (mg/L)	0.30	0.25	0.11	0.13	0.23	0.20
	RMSE Target (mg/L)	0.27	0.19	0.26	0.27	0.26	0.16

**Calibration period is 2005-2007, ** Validation period is 2010-2013*

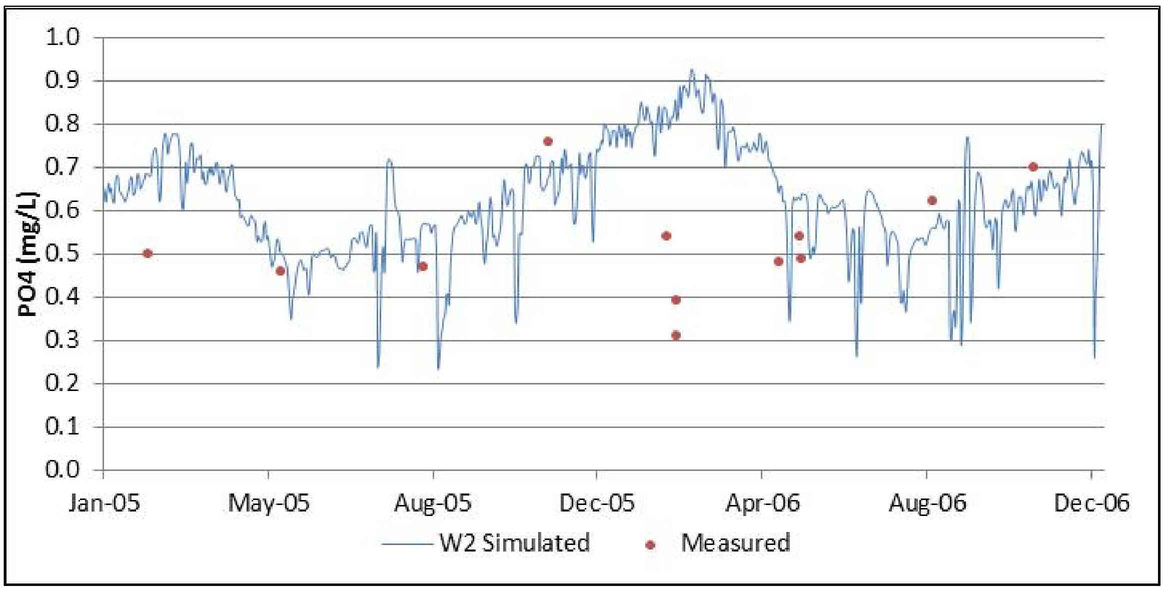

Figure 4-19. Time series of model predicted PO_4 and observed data for the calibration period, Segment 25 and Station 13072.

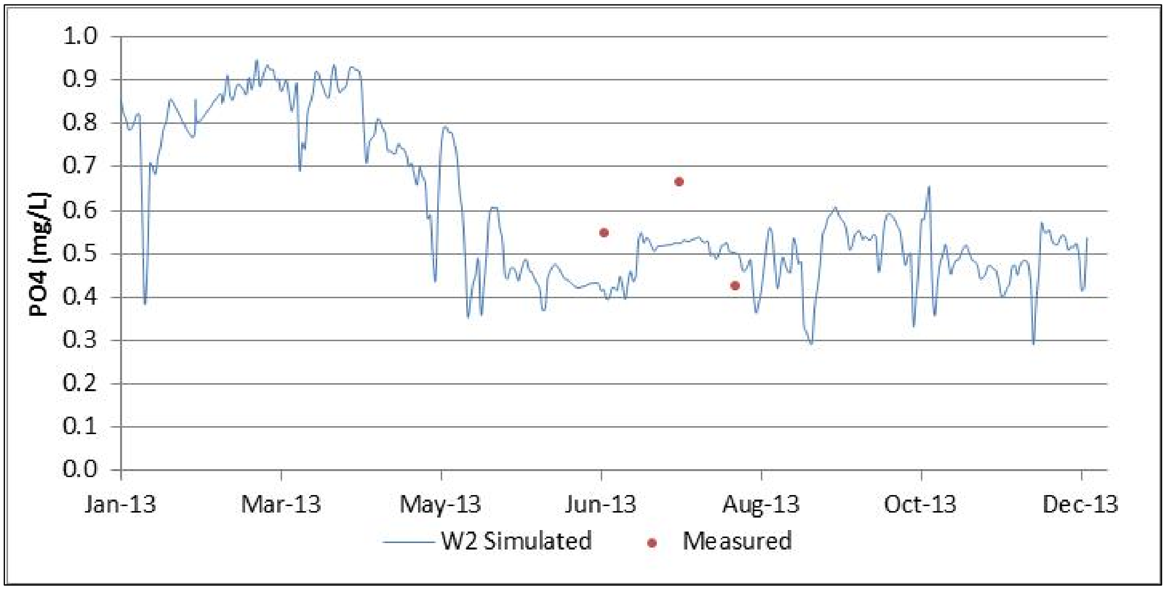

Figure 4-20. Time series of model predicted PO_4 and observed data for the validation period, Segment 25 and Station 13072.

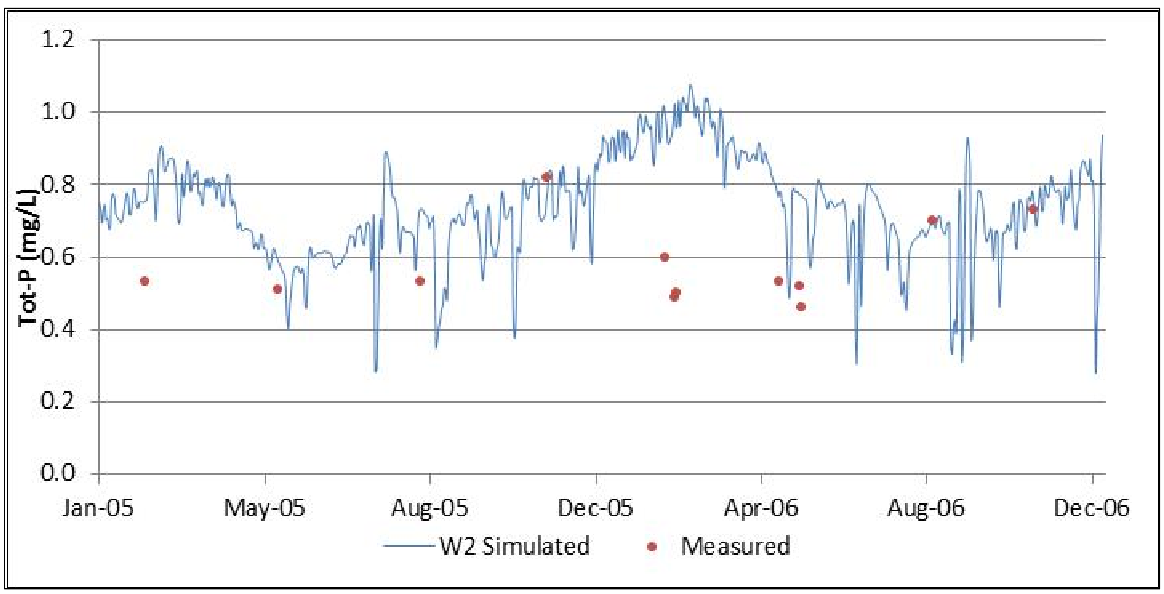

Figure 4-21. Time series of model predicted TP and observed data for the calibration period, Segment 25 and Station 13072.

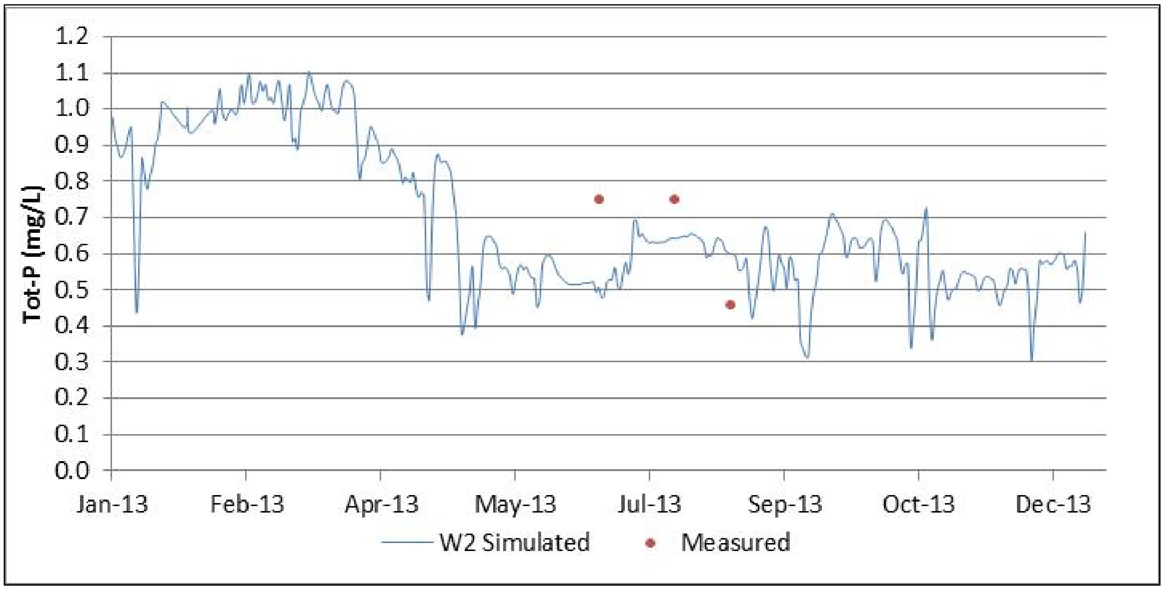

Figure 4-22. Time series of model predicted TP and observed data for the validation period, Segment 25 and Station 13072.

4.4.4 Verification of Dissolved Oxygen and Algal Biomass

Once the model has been verified adequately for other water quality parameters, then the DO and algal biomass were calibrated and validated. In practice, while the nitrogen and phosphorus forms were calibrated, to a degree, prior to the calibration of DO and algal biomass, the feedback on nutrients from algal dynamics makes it impossible to, in practice, apply a strict sequential process to the calibration process for the full suite of water quality parameters in the model. Therefore, while the nutrients were generally calibrated prior to and partially independent of the DO and algal biomass calibrations, there was also a refining of the nutrient calibration that occurred with the DO and algae calibrations. The nutrient results provided immediately above are the final calibration and validation results reflecting the needed adjustments after the DO and algal biomass verification process.

The DO and algal biomass calibration involved several model inputs: defining a proper reaeration equation based on water velocity and wind speed; balancing the oxygen uptake and production rates of algae [O2AR, O2AG]; refining longitudinal variation in sediment oxygen demand [SOD]; adjusting sediment nutrient recycling [SEDK]; specifying algal biomass growth rates, respiration rates, and settling velocities [AG, AR, AS]; and adjusting organic matter decay rates [DOMK, POMK, KBOD]. Much of the art in water quality modeling is involved in calibrating DO and algal biomass dynamics, which involves balancing and adjusting algae biomass, organic matter, and the nutrients in the system. Further, the magnitude of these processes is influenced by definition of the temperature rate multipliers applied to the majority of the kinetic parameters input into CE-QUAL-W2 and specified for each kinetic parameter.

Algal biomass is a property of water quality that is not routinely measured in many water bodies, and the Arroyo Colorado Tidal is not exception to this norm. Instead, the more common measurement, as a surrogate for algal biomass, is chlorophyll-a (Chl-a), which is a green pigment in all green plants and cyanobacteria. While the amount of Chl-a in algae is not a constant, its measurement does provide a relative indication of the amount of algal biomass present at the time of measurement. In CE-QUAL-W2, the relationship between Chl-a and algal biomass is defined through stoichiometric relations specified through input. The CE-QUAL-W2 model provides good flexibility in the number and kinds of algal groups that can be included in the simulation through careful specification of the kinetic rate parameters that define the characteristics of each algal group. For this project, the algae community was broken into diatoms (algae group 1), green (algae group 2), and blue-greens (cyanobacteria; algae group 3).

Initial attempts to calibrate DO and Chl-a led to the conclusion that a different approach would have to be used to guide the calibration process than the performance targets defined in the modeling QAPP. The timing and spatial variability of algal blooms and the related dynamics of DO could not be totally replicated by CE-QUAL-W2 for the Arroyo Colorado Tidal. The inability of CE-QUAL-W2 to replicate the timing of algal biomass and DO dynamics was partially, but far from entirely, the result of driving the model with input from SWAT, which contains its own limitations in being able to provide an entirely accurate description of inflows and loadings of water quality parameters, including algal biomass. The different approach taken and agreed to by TWRI, TCEQ, and TSSWCB involved calibrating the model to replicate the overall rate of occurrences of depressed DO and using visual inspection of time series graphs of model predicted and observed Chl-a.

To put this calibration approach into proper context necessitates some specifics on the DO criteria defined for the Arroyo Colorado Tidal and an understanding of the assessment data available for DO in the Arroyo Colorado Tidal. Based on the 2014 Texas Surface Water Quality Standards (TCEQ, 2014), the Arroyo Colorado Tidal is a saltwater body with an assigned High aquatic life use with these associated dissolved oxygen criteria to protect that use:

- 24-hour average DO ≥ 4.0 mg/L, and
- 24-hour minimum DO ≥ 3.0 mg/L.

Support of the High aquatic life use is achieved if these criteria are met at least 90% of the time.

Assessment of these criteria necessitates the collection of DO data involving the deployment of a multiprobe for a 24 hours with data internally stored in the unit at usually a 15-minute interval. Because 24-hour data collection requires a trip to deploy the multi-probe and another trip the next day to retrieve the multi-probe, these data are expensive to collect and not routinely collected. Until a few years ago TCEQ directed 24-hour data collection to occur during the time of the year when depressed DO was most likely to occur, which for the majority of water bodies in Texas is the warm season. Therefore, data collection efforts were focused on the TCEQ defined Index Period of March 15 through October 15, with a portion of the data collection needing to occur within the Critical Period of July 1 through September 30. TCEQ recognized that restricting sampling to the Index Period provided good information regarding whether or not a water body was experiencing depressed DO, but this sampling scheme obviously biased the data collection. Therefore the collected data were not representative of other times of the year when depressed DO was less likely to occur. Consequentially this constraint on sampling did not result in an observed dataset that provided an optimal means to assess if DO criteria were being met 90% of the time. More recently, the TCEQ assessment methodology contains the following information on 24-hour DO data collection:

> **Seasonal Requirements for 24-hour Dissolved Oxygen Data Sets.** Twenty-four hour dissolved oxygen sampling is resource intensive, so only samples from an index period were required in past assessments. Requirements for balance between years are the same as those for other methods. At least one half of the 24-hour DO monitoring events must be spaced over an index period representing warm-weather seasons of the year (March 15-October 15). One-fourth to one-third of the measurements must be made during the critical period (July 1-September 30). Approximately one month must separate each 24-hour sampling event. Although samples over the entire year are not required at this time, current monitoring guidance encourages year-round sampling. (TCEQ, 2105b)

The timing of the majority of the 24-hour DO data collection efforts for the Arroyo Colorado Tidal reflect the earlier seasonally-focused methodology, since the majority of the data were collected 2009 and earlier. Table 4-6 provides a summary of 24-hour DO data collected from 1998 through 2009 and the model-verification sampling performed by UTRGV in 2013, which shows that the majority of the extant data were collected from March through October.

Table 4-6. Distribution by month of 24-hour data collection in the zone of impairment from 1998 through 2009 and in 2013.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	4	0	2	8	1	10	12	0	4	0	0
0.0%	9.8%	0.0%	4.9%	19.5%	2.4%	24.4%	29.3%	0.0%	9.8%	0.0%	0.0%
Percent of Data:				Index Period =		90.2%					
				Critical Period =		53.7%					

All the 24-hour DO data were collected in the zone of impairment and these data are summarized in Table 4-7. The observed 24-hour DO data indicate a water body (*i.e.*, the zone of impairment in the Arroyo Colorado Tidal) meeting the 24-hour average criterion but experiencing sufficient occurrences of depressed 24-hour minimum DO to not support the 24-hour minimum DO criterion. Generally, excessive organic loadings and their decay would result in depressed 24-hour average DO concentrations, and, perhaps, depressed 24-hour minimum DO concentrations. However, the zone of impairment of the Arroyo Colorado Tidal appears to be experiencing relatively large diurnal fluctuations in DO that cause the minimum DO criterion to not to be met. Occurrences of depressed 24-hour minimum DO are predominately caused by nutrient enrichment, sometimes exacerbated by hydrologic modification resulting in more frequent occurrences of algal blooms. Under algal bloom conditions there is an exaggeration of the normal diurnal fluctuations in DO experienced in many water bodies, which follow a cyclic patter of maximum DO concentrations in the afternoon as a result of oxygen generation from photosynthesis and minimum DOs around the time of sunrise in response to domination of respiration processes in the absence of sunlight.

Note: Only limited 24-hour data were collected below the zone of impairment. These data were largely collected prior to the period of interest for this study and were too few in number to be used in this study.

The revised approach to evaluate model performance was then for the model to replicate the overall percent of time that observed 24-hour and 24-hour minimum DO concentrations were above the relevant DO criterion. A numeric range was not set on how close the model predictions needed to be to the percentages in Table 4-7 for the model to be declared successfully calibrated; however, the goal was to focus the modeling on predicting the occurrences of the 24-hour minimum DO within a few percentage points of the observed value of 75%. This evaluation of model predicted concentrations involved an overall analysis of the near-surface predictions within and below the zone of impairment. More importantly for evaluating model performance, a time- and location-weighted averaging of the model prediction data was conducted so that the performance evaluation was comparing model results only for the time of year (*i.e.*, month) and station locations of the observed data, which provides more accurate comparisons to the observed data. To complete this analysis, CE-QUAL-W2 predicted DO concentrations were saved as output for the needed locations at an hourly interval over the period simulated. The model data were then processed to determine the average and minimum DO for every simulated day at every needed model segment. In hindsight, this model performance approach should have either replaced those in the QAPP or have been added to those in the QAPP.

Table 4-7. Summary of observed 24-hour DO data for zone of impairment collected 1998 through 2009 and in 2013

Number of Observations	41
Average of 24-hour Averages (mg/L)	7.32
Average of 24-hour Minimums (mg/L)	4.38
Average Range [Maximum – Minimum] (mg/L)	2.93
Percent of Measurement with Average DO > 4.0 mg/L	95%
Percent of Measurement with Minimum DO > 3.0 mg/L	75%

The comparison of model predicted and observed DO results are provided in Table 4-8 based on percentage of days that the DO was above the 24-hour DO average of 4 mg/L and the 24-hour DO minimum of 3 mg/L. Along the Arroyo Colorado Tidal almost all of the observed 24-hour DO measurement were collected at Stations 13072 and 13073 during the selected calibration and validation periods. Also, many of the measurements were collected during May, July and August (Table 4-6). In Table 4-9 is provided an indication of the longitudinal variation in the percentage of time that the 24-hour minimum DO criterion is met for model segment locations aligned with the TCEQ monitoring station provided in Figure 3-5.

Visual inspections of graphical results were used to further evaluate model performance for algal biomass and DO. Figures 4-23 and 4-24 provide the model predicted Chl-a and all observed Chl-a data for the location of Station 13072 during the calibration and validation period. To demonstrate the temporal predictions of biomass for the three algal groups represented in CE-QUAL-W2, the location of Station 13072 again is used for the time series plot of portions of the calibration and validation periods (Figures 4-25 and 4-26). Finally, Station 13072 is again used for time series of DO predictions during portions of the calibration and validation periods (Figures 4-27 and 4-28) where in the model-predicted diurnal fluctuations in DO are obvious.

Based on the visual inspections of many graphs on Chl-a and DO similar to those displayed in this report, and more importantly, the ability of the model to very reasonably represent the percent of time the 24-hour minimum DO criterion was met, it was concluded that the model was working with a sufficient level of performance to be considered verified for DO and algal biomass.

Table 4-8. Comparison of model predicted and observed 24-hour DO concentrations based on percent of time DO criteria were meet or exceeded.

(Yellow highlighted is the model performance results.)

Condition	Zone of Imp.		Below Zone of Imp.		Weighted by stations & months	
	24 hr. Avg DO	24 hr. Min DO	24 hr. Avg DO	24 hr. Min DO	24 hr. Avg DO	24 hr. Min DO
Measured (1998-2009 & 2013)	Not applicable	Not applicable	Not applicable	Not applicable	95%	75%
Calibration (2003-2007)	98%	82%	99%	98%	98%	72%
Validation (2010-2013)	98%	82%	99%	98%	97%	75%

Table 4-9. Predicted percent of time by model segment and TCEQ monitoring station location that the 24-hour minimum DO concentration was above the 24-hour minimum DO criterion of 3 mg/L.

Percent Exceedance for 24 hour minimum DO Criterion (3.0 mg/L)												
Condition	Zone of Impairment (station/ model segment)					Below Zone of Impairment (station/ model segment)						
	17650 Seg 9	16142 Seg 10	13072 Seg 25	15569 Seg 35	13073 Seg 38	13559 Seg 77	14853 Seg 92	13071 Seg 107	15560 Seg 108	15555 Seg 128	13782 Seg 129	15547 Seg 165
Calibration (2003-2007)	85%	83%	76%	87%	89%	95%	97%	98%	98%	98%	98%	99%
Validation (2010 – 2013)	84%	82%	76%	88%	92%	95%	98%	98%	98%	98%	98%	99%

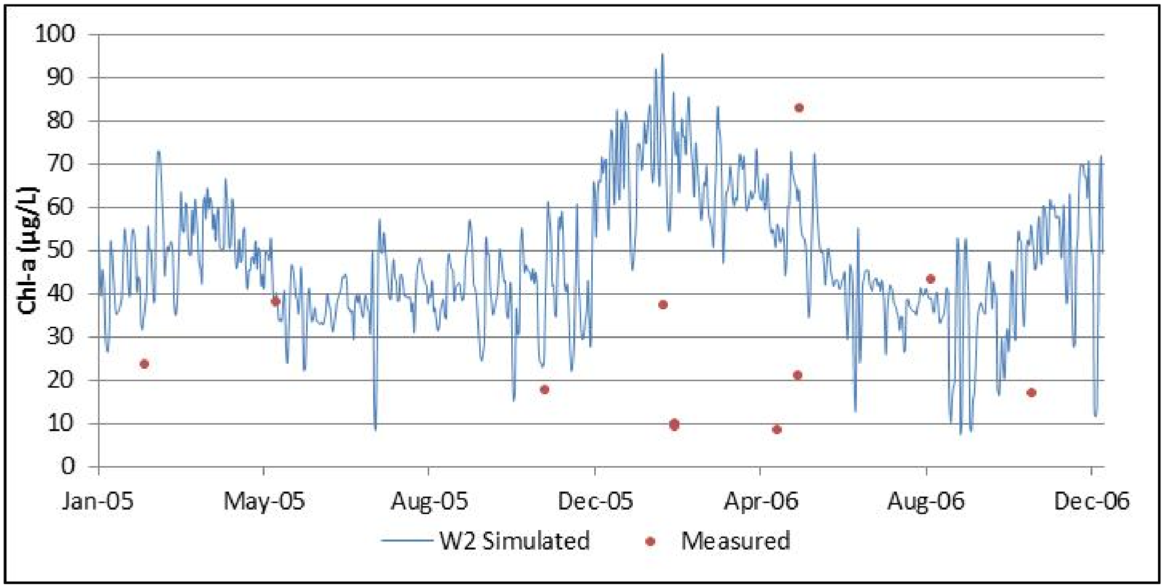

Figure 4-23. **Time series of model predicted Chl-a and observed data for a portion of the calibration period, Segment 25 and Station 13072.**

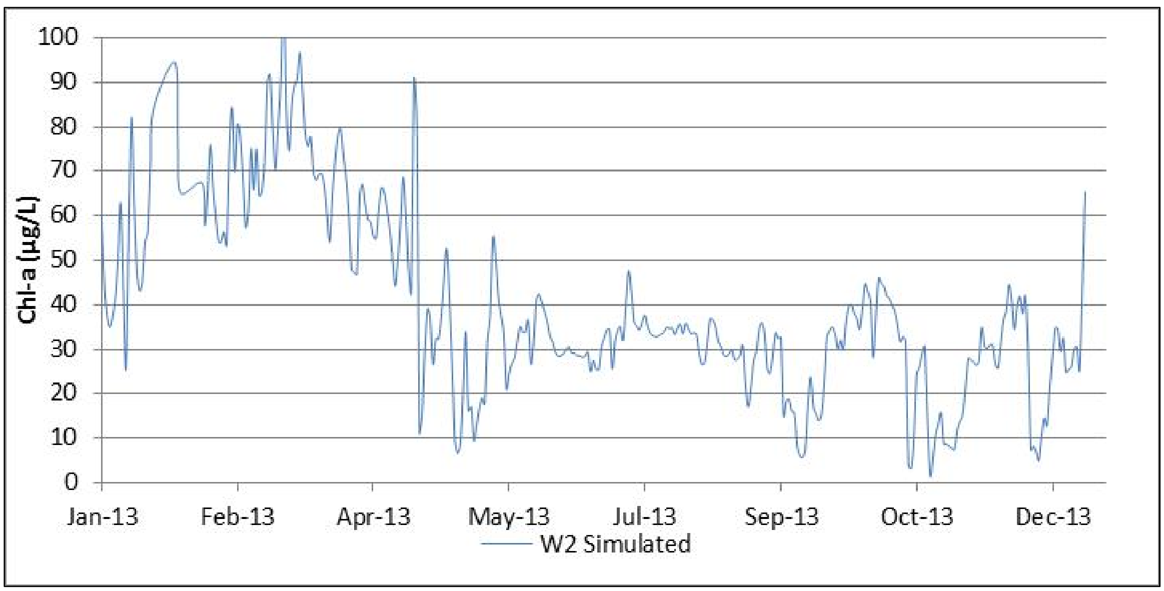

Figure 4-24. **Time series of model predicted Chl-a for a portion of the validation period, Segment 25 and Station 13072.**

Note: No observed Chl-a data existed for this period of time, so the time series is provided to show typical model response.

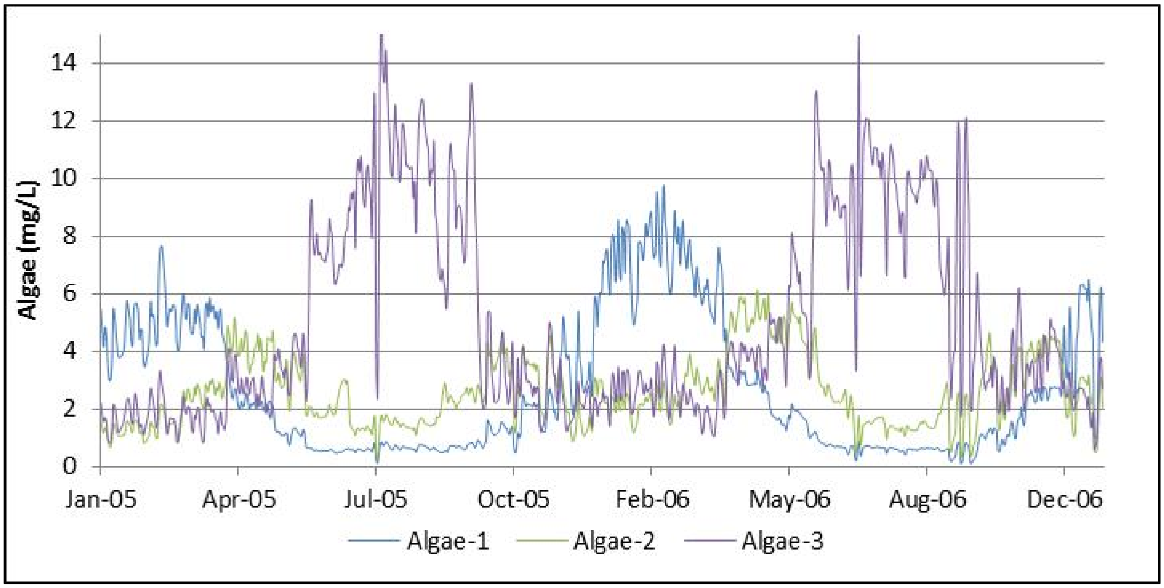

Figure 4-25. Time series of model predicted algal biomass for a portion of the calibration period, Segment 25 and Station 13072.

Note: No observed biomass data existed, so the time series is provided to show typical model response.

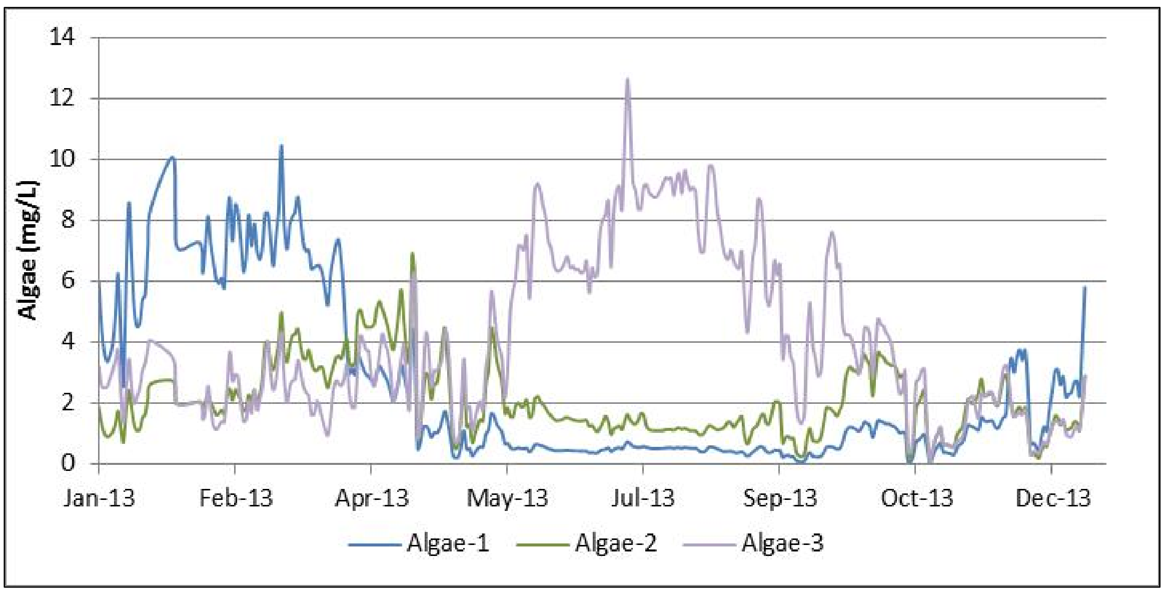

Figure 4-26. Time series of model predicted algal biomass during a portion of the validation period, Segment 25 and Station 13072.

Note: No observed biomass data existed, so the time series is provided to show typical model response.

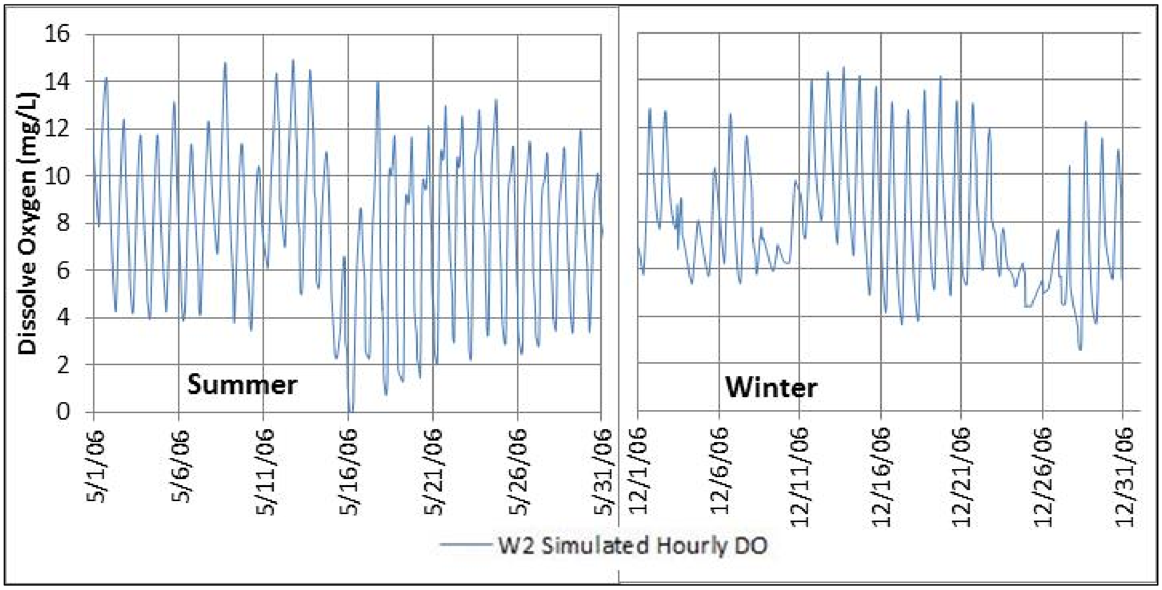

Figure 4-27. Time series of model predicted DO for a portion of the calibration period, Segment 25 and Station 13072.

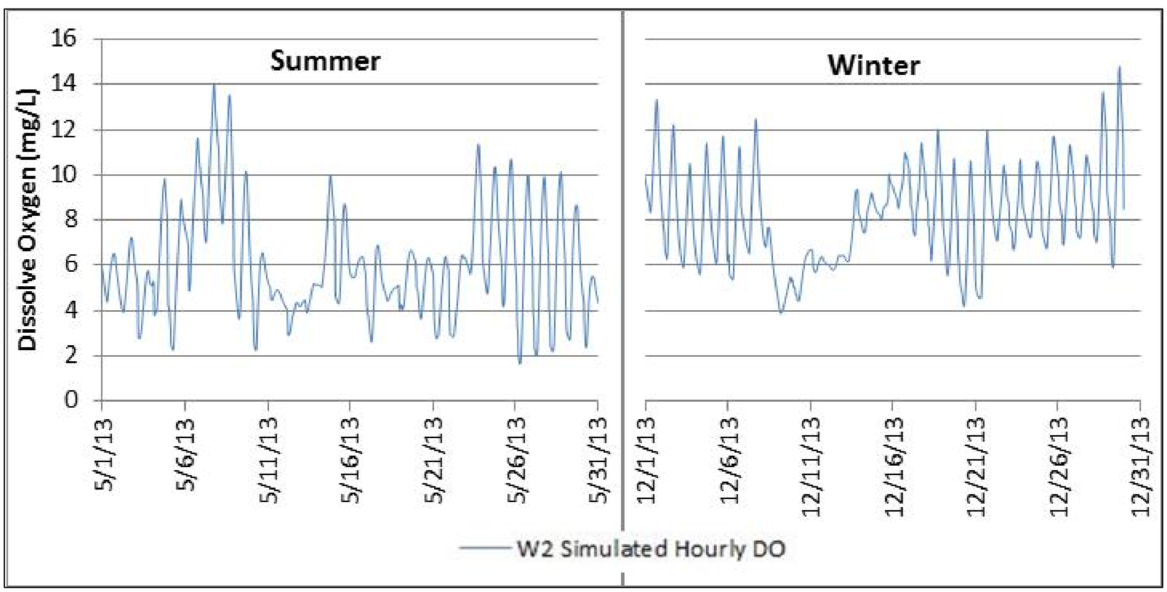

Figure 4-28. Time series of model predicted DO during a portion of the validation period, Segment 25 and Station 13072.

4.4.5 Verification of Bacteria

Before embarking on a description of the verification results for bacteria modeling of the Arroyo Colorado Tidal, an important assumption to the modeling must be described in some detail. For freshwater systems, such as the Arroyo Colorado Above Tidal, the relevant indicator bacteria to evaluate recreation use is *Escherichia* coli (*E. coli*) and for saltwater systems, such as the Arroyo Colorado Tidal, the relevant indicator bacteria is Enterococci. The applicable standards for recreation use are found in the 2010 Texas Surface Water Quality Standards (TCEQ, 2010).[4] Both of these waterbodies are designated for primary contact recreation use which stipulates an *E. coli* geometric mean criterion of 126 colonies/100 mL and an Enterococci geometric mean criterion of 35 colonies/100 mL. The SWAT model simulated *E. coli*, because it is the relevant indicator bacteria for assessing recreation use in the Arroyo Colorado Above Tidal and observed *E. coli* concentrations provided the data for verification of model predictions. Since Enterococci was not simulated by SWAT, an immediate challenge was how to take the bacteria results from SWAT and use them as the needed input of time-series Enterococci bacteria loadings into the CE-QUAL-W2 model.

A common conversion factor used, which is accepted in some analysis in watershed planning, is a simple ratio of the geometric mean criterion for the two indicator bacteria, *i.e.*, to convert from *E. coli* to Enterococci apply this relationship: Enterococci = 35/126 * *E. coli*. While defensible as a conversion factor between the two indicator bacteria, this ratio when applied to SWAT bacteria predictions resulted in gross under predictions of Enterococci in the CE-QUAL-W2. As an alternative for the needed conversion factor, the results of two bacteria sampling programs were used. The earlier study was conducted by the Nueces River Authority that included simultaneous sample collection for analysis of *E. coli* and Enterococci at 6 stations along the Arroyo Colorado Above Tidal on 12 occasions from January 2009 through December 2009. The other study was conducted for bacterial source tracking as part of the updating of the Arroyo Colorado watershed protection plan and included water sampling conducted from June 2014 through May 2015 (Flores *et al.*, 2017). In this study, 113 water samples were analyzed for *E. coli* and Enterococci after collection at 10 stations along both the Tidal and Above Tidal segments of the Arroyo Colorado. The average ratio of the paired *E. coli* and Enterococci measurements from the two studies was calculated to be 3.0. So, for the CE-QUAL-W2 modeling effort, the *E.coli* predicted by the SWAT model was multiplied by 3.0 to convert *E. coli* into Enterococci through the Interface Tool and then that was used to define the bacteria loading input into the CE-QUAL-W2 model.

The CE-QUAL-W2 model was verified for the bacteria after the model has been adequately verified for the hydrodynamic, and water quality parameters. The bacteria calibration does not affect the hydrodynamic and other water quality parameters of the model and vice-versa. The CE-QUAL-W2 model has the capability to model any number of user defined arbitrary generic constituents defined by a decay rate, settling rate, and temperature rate multiplier. Enterococci was defined as a generic constituent in CE-QUAL-W2 model to simulate bacteria

[4] The United States Environmental Protection Agency has not approved the recreation use standards in the 2014 Texas Surface Water Quality Standards, so the relevant standards revert to the approved recreational use standards in the 2010 Texas Surface Water Quality Standards.

in the Arroyo Colorado Tidal. As discussed in the preceding paragraph, the bacteria verification depends extensively on the input time series data from the linked watershed model SWAT. The calibration of the CE-QUAL-W2 model to Enterococci was performed through adjustment of the temperature rate multiplier [CGQ10], the settling rate [CGS], and primarily the decay rate [CG1DK] of Enterococci.

The project QAPP defied the following performance target for the bacteria calibration:

- Concentrations of near-surface (0.3 m depth) Enterococci will be calibrated so that the logarithm base 10 of model predicted and observed concentrations have RE ≤ 0.50. A logarithm transformation is used because of the extremely large natural variability of all types of bacteria data.

The comparison of the CE-QUAL-W2 predicted Enterococci concentrations and computed RE statistic during the calibration and the validation periods are provided in Table 4-10. The RE statics for the calibration period just meets the performance target of 0.5, if comparison of data for Station 13782 on September 12, 2007 is not considered (the measured data was <10 colonies/100 mL and the predicted value was 457 colonies/100 mL; without the removal of these data, RE = 1.36). For the validation period and overall period considering both periods together, the RE statistics somewhat exceeded the performance target with values of 0.66 and 0.58 respectively. As shown in the Table 4-10, the measured Enterococci concentrations during the calibration period along the Arroyo Colorado Tidal are much lower than the Enterococci measurements during the validation period, while the model predictions are roughly the same at each station during both periods. The model was unable to capture the large difference in observed concentrations between the calibration and validation periods. The reason for this was attributed to the time-series input of Enterococci. As an example, the SWAT bacteria (*E. coli*) output from the outlet of Subbasin 10 before conversion to Enterococci is provided in Figure 4-29. The outlet of Subbasin 10 in SWAT is the combined outflow from the Arroyo Colorado Above Tidal watershed representation in the model. It is readily apparent in Figure 4-29 that this critical input to the CE-QUAL-W2 model did not reflect the large increase in bacteria concentrations during the validation period indicated in the observed data. Given the restrictions imposed by input loading of Enterococci, the approach taken was not to try a strict calibration independent of the validation, but rather to minimize the error in prediction for both periods by adjusting the bacteria decay rate to overestimate during the calibration period and to underestimate during the validation period.

Time series plots of model predicted Enterococci at segment 25 and observed data for Station 13072 are provided for the calibration and validation periods in Figures 4-30 and 4-31. The overestimation of predicted Enterococci concentrations is somewhat apparent in Figure 4-30 for the calibration period, but the underestimation during the verification period is more readily apparent in Figure 4-31.

Based on the limitations of the time-series of Enterococci loadings as input to the model and the relatively close values of the RE statistic to the performance target, CE-QUAL-W2 was considered verified to the best degree possible.

Table 4-10. Model performance statistic (RE) and comparison of measured and predicted geometric mean concentrations for stations with Enterococci data during the calibration (2002-2004) period, validation (2005-2008) period, and overall (2002-2008).

All values are geometric means in units in colonies/100 mL, except RE which is unitless.

Condition	Period	Sta 13072 Seg 25	Sta 13073 Seg 38	Sta 13559 Seg 77	Sta 13071 Seg 107	Sta 13782 Seg 129	RE
Measured	**Calibration**	37.4	44.7	30.1	18.5	18.3	0.50£
Predicted	**Calibration**	96.8	80.2	44.8	37.5	30.0	
Measured	**Validation**	180.2	123.4	107.0	92.0	81.7	0.66
Predicted	**Validation**	83.8	68.2	37.2	31.8	26.5	
Measured	**Overall**	85.5	74.3	52.2	39.6	40.0	0.58
Predicted	**Overall**	89.2	73.1	40.3	34.1	27.9	

£ The following comparative measurement was removed from the analysis: Station 13782 on Sept. 12, 2002, measured value of <10 colonies/100 mL and predicted of 457 colonies/100 mL. If this data point is not removed, RE = 1.36.

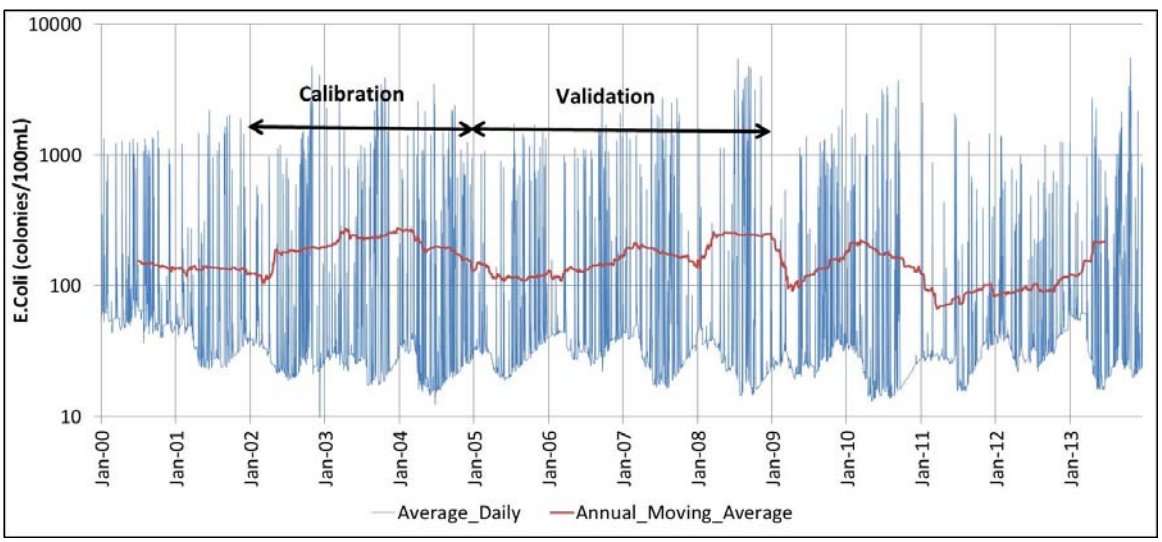

Figure 4-29. Time series of SWAT *E. coli* output before conversion to Enterococci for the outlet of Subbasin 10 representing the total outflow from the Arroyo Colorado Above Tidal.

(The red line is an annual moving average providing one measure of central tendency of the model predictions.)

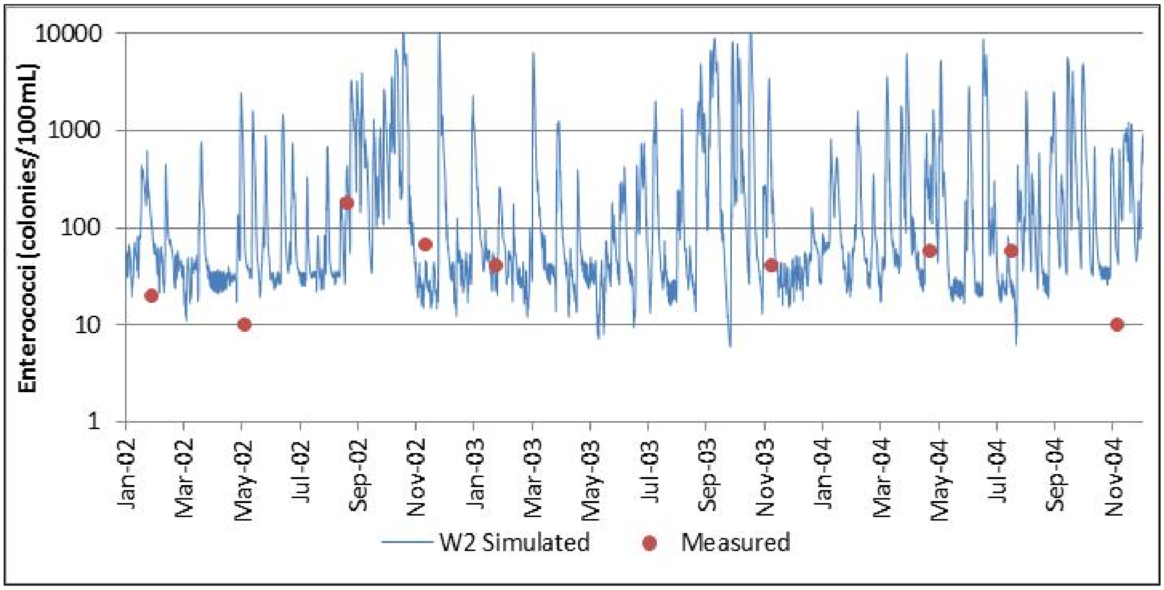

Figure 4-30. **Time series of model predicted Enterococci during the calibration period, Segment 25 and Station 13072.**

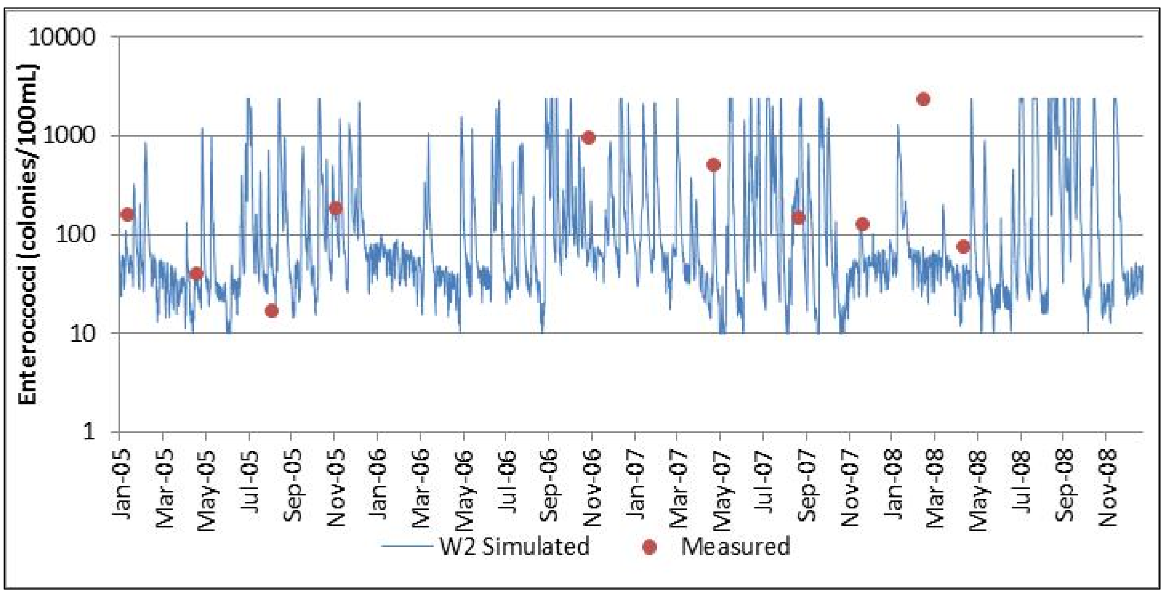

Figure 4-31. **Time series of model predicted Enterococci during the validation period, Segment 25 and Station 13072.**

4.4.6 Discussion of Water Quality Verification

Calibrating and validating the water quality portion of the CE-QUAL-W2 model of the Arroyo Colorado Tidal was an imposing challenge. Anytime the modeling effort necessitates the use of linked models where one model uses the output from another models to define key input, there is the possibility of compounding of errors. This application of SWAT and CE-QUAL-W2 proved to be not exception to this general rule. Both SWAT and CE-QUAL-W2 are excellent, state-of-the-art tools representing the physical, chemical, and biological processes of their respective domains as well, if not better, than any other suitable models. Nonetheless, both models provide only approximation of the complexities of the real world or prototype systems they are representing through simulation. Given the inherent approximations of the true mechanisms driving the environmental processes represented in these models, they do provide surprisingly good approximation of the prototype systems. In this application, the two prototype systems were the watershed area of the entire Arroyo Colorado watershed and the Arroyo Colorado Above Tidal as represented in SWAT, and the Arroyo Colorado Tidal as represented in CE-QUAL-W2.

While some of the performance targets were not met for the water quality verification process of CE-QUAL-W2,a majority of target statistics were successfully met, such as for TSS, NH_4, NO_{23}, TN, PO_4, and TP. The more important water quality parameters of DO, algal biomass, and Enterococci, however, proved more challenging regarding the results of verification. The temporal and spatial variability and dynamics of algal blooms and their impacts on a key model output of 24-hour minimum DO proved too challenging for the CE-QUAL-W2 model based on the initially specified model performance targets, which focused on comparison of specific model output to observed data on the same day and at the same time. The alternative approach was to calibrate and validate model response to a key model output by focusing on achieving reasonable agreement to the percent of time the 24-hour minimum DO criterion was exceeded. By focusing on overall percent time the 24-hour minimum DO criterion was met, and to a lesser degree the 24-hour average DO being met, rather than focusing on matching individual minimum DOs on specific days, the model was tuned so that it very reasonably represented the overall pattern of occurrences of depressed DO and visually reasonably represented Chl-a as a measure of biomass. The bacteria verification, likewise, suffered from an inability to match the stipulated performance target statistic. In this case, a significant increase in the observed geometric mean concentrations of Enterococci bacteria concentrations from the calibration period to validation period could not be replicated by the model. In the end the problem with representing this increase was the bacteria loading input to the model, which did not reflect this temporal increase. Given the constraint on model input, the best that could be achieved was to over predict concentrations during the calibration period and under predict them for the validation period. Nonetheless, model response came close to the relevant statistical measure for RE.

In the end, the success of the level of verification achieved depends upon acceptance by interested parties. The level of verification for water quality was discussed in a couple of conference calls between TIAER, BREC, TWRI, TCEQ and TSSWCB. The consensus was that CE-QUAL-W2 was performing acceptably for the purposes of assessing BMP performance.

4.5 Sensitivity Analysis

A sensitivity analysis was carried out to evaluate CE-QUAL-W2 performance and the variability of results. During the calibration process the sensitivity or responsiveness of the model predictions to various assumptions and kinetic rate constants specified in model output was evaluated. The setup of the CE-QUAL-W2 includes kinetic parameters based on literature recommendations and best professional judgment, and estimates in the absence of data. The sensitivity analysis was performed by changing one kinetic parameter by a fixed percentage higher and lower than the value determined during model verification, re-running the model, and the resulting predictions compared to understand whether a factor has a discernible effect on water quality predictions. Given the large number of model calibration parameters and lengthy model run times, only a few selected kinetic parameters were tested for the model sensitivity.

For the Arroyo Colorado Tidal model, the sensitivity analysis was performed to investigate the impact on average 24-hour average DO, average 24-hour minimum DO, average Chl-a, and average Enterococci bacteria by TCEQ defined AUs along the Arroyo Colorado Tidal, Segment 2201. The parameters selected for the sensitivity analysis were maximum algal growth rate [AG], maximum algal respiration rate [AR], half-saturation coefficient for nitrogen limitation on growth [AHSN], half-saturation coefficient for phosphorous limitation on algal growth [AHSP], CBOD decay rate [KBOD], oxygen stoichiometry for algal primary production [O2AG], oxygen stoichiometry for algal respiration [O2AR], sediment oxygen demand [SOD], and first-order decay rate of bacteria [CG1DK]. The sensitivity analysis was performed for a four-year simulation period of January 2003 through December 2007. Alteration of either +/- 10% or +/- 25% on each kinetic parameters was performed through individual simulation, one at a time. The amount of change selected (10% or 25%) was based on the amount of variability and range of acceptable values associated with each parameter.

The summary of the sensitivity analysis effects on the average near-surface 24-hour average and minimum DO concentrations are presented in Table 4-11. Because of the high levels of nutrients in the Arroyo Colorado, varying the half saturation coefficients for nitrogen and phosphorus had no effect on DO concentrations, *i.e.*, nutrients are not limiting algal growth nearly as much as light and thus not impacting DO either. Similarly, varying the decay rate of CBOD had only very minor impacts of DO concentrations. Variation in sediment oxygen demand had almost no impact on DO, which is contrary to many water bodies. The explanations regarding sediment oxygen demand are that the sensitivity analysis was performed on near-surface predictions of DO and the Arroyo Colorado Tidal is subject to a strong and largely persistent salinity wedge which isolates the lower waters, where sediment oxygen demand is most exerted, from the overlying waters. As anticipated for a water body with nutrient enrichment, varying the parameters impacting algal growth (*i.e.*, algal maximum growth rate and respiration rate) and the oxygen produced during photosynthesis and consumed during respiration had the greatest impact on near-surface DO concentrations. Very roughly, for each 1% increase or decrease in any of these algal related parameters, averages of 24-hour average and minimum DO concentration also changed 1%,

Table 4-11. Summary of sensitivity analysis on overall averages of near-surface 24-hour average and minimum DOs by AU for a simulated period of January 2003 – December 2007.

All DO concentrations in units of mg/L

Sensitivity Parameter			Zone of Imp. AUs				Below Zone of Imp. AUs					
			2201_05		2201_04		2201_03		2201_02		2201_01	
Base Case		Avg	7.44		8.52		9.57		10.13		10.45	
		Min	4.46		5.76		7.31		8.32		8.70	
Max algal growth rate [AG]	+10%	Avg	8.06	+ 8%	9.41	+ 10%	10.58	+ 11%	11.20	+ 11%	11.48	+ 10%
		Min	4.68	+ 5%	6.14	+ 7%	7.73	+ 6%	8.74	+ 5%	9.01	+ 4%
	-10%	Avg	6.85	- 8%	7.67	- 10%	8.56	- 11%	9.06	- 11%	9.35	- 11%
		Min	4.23	- 5%	5.35	- 7%	6.81	- 7%	7.79	- 6%	8.23	- 5%
Max algal respiration rate [AR]	+10%	Avg	7.04	- 5%	7.99	- 6%	8.98	- 6%	9.53	- 6%	9.86	- 6%
		Min	4.20	- 6%	5.46	- 5%	7.02	- 4%	8.05	- 3%	8.48	- 3%
	-10%	Avg	7.88	+ 6%	9.09	+ 7%	10.16	+ 6%	10.73	+ 6%	11.00	+ 5%
		Min	4.75	+ 6%	6.08	+ 6%	7.58	+ 4%	8.55	+ 3%	8.85	+ 2%
Half-saturation coefficient for nitrogen [AHSN]	+25%	Avg	7.44	+ 0%	8.52	+ 0%	9.57	+ 0%	10.13	+ 0%	10.45	+ 0%
		Min	4.46	+ 0%	5.76	+ 0%	7.31	+ 0%	8.32	+ 0%	8.70	+ 0%
	-25%	Avg	7.44	+ 0%	8.52	+ 0%	9.57	+ 0%	10.13	+ 0%	10.45	+ 0%
		Min	4.46	+ 0%	5.76	+ 0%	7.31	+ 0%	8.32	+ 0%	8.70	+ 0%
Half-saturation coefficient for phosphorous [AHSP]	+25%	Avg	7.44	+ 0%	8.52	+ 0%	9.57	+ 0%	10.13	+ 0%	10.45	+ 0%
		Min	4.46	+ 0%	5.76	+ 0%	7.31	+ 0%	8.32	+ 0%	8.70	+ 0%
	-25%	Avg	7.44	+ 0%	8.52	+ 0%	9.57	+ 0%	10.13	+ 0%	10.45	+ 0%
		Min	4.46	+ 0%	5.76	+ 0%	7.31	+ 0%	8.32	+ 0%	8.70	+ 0%
CBOD decay rate [KBOD]	+25%	Avg	7.37	- 1%	8.47	- 1%	9.55	- 0%	10.14	+ 0%	10.45	+ 0%
		Min	4.37	- 2%	5.70	- 1%	7.29	- 0%	8.32	+ 0%	8.70	+ 0%
	-25%	Avg	7.54	+ 1%	8.59	+ 1%	9.59	+ 0%	10.13	+ 0%	10.45	+ 0%
		Min	4.57	+ 2%	5.85	+ 2%	7.35	+ 1%	8.33	+ 0%	8.71	+ 0%
Oxygen stoichiometry for algal primary production [O2AG]	+10%	Avg	8.01	+ 8%	9.28	+ 9%	10.44	+ 9%	10.95	+ 8%	11.25	+ 8%
		Min	4.80	+ 8%	6.34	+ 10%	8.04	+ 10%	9.02	+ 8%	9.36	+ 8%
	-10%	Avg	6.89	- 7%	7.77	- 9%	8.69	- 9%	9.32	- 8%	9.66	- 8%
		Min	4.13	- 7%	5.19	- 10%	6.58	- 10%	7.63	- 8%	8.04	- 8%
Oxygen stoichiometry for algal respiration [O2AR]	+10%	Avg	7.04	- 5%	8.05	- 6%	9.06	- 5%	9.71	- 4%	10.06	- 4%
		Min	4.03	- 10%	5.21	- 10%	6.74	- 8%	7.85	- 6%	8.28	- 5%
	-10%	Avg	7.87	+ 6%	9.02	+ 6%	10.08	+ 5%	10.56	+ 4%	10.85	+ 4%
		Min	4.92	+ 10%	6.32	+ 10%	7.88	+ 8%	8.79	+ 6%	9.13	+ 5%

Sensitivity Parameter			Zone of Imp. AUs				Below Zone of Imp. AUs					
			2201_05		2201_04		2201_03		2201_02		2201_01	
Sediment oxygen demand [SOD]	+25%	Avg	7.44	+ 0%	8.51	- 0%	9.55	- 0%	10.12	- 0%	10.44	- 0%
		Min	4.45	- 0%	5.75	- 0%	7.29	- 0%	8.31	- 0%	8.69	- 0%
	-25%	Avg	7.45	+ 0%	8.53	+ 0%	9.58	+ 0%	10.15	+ 0%	10.47	+ 0%
		Min	4.47	+ 0%	5.78	+ 0%	7.33	+ 0%	8.34	+ 0%	8.72	+ 0%

The summary of the sensitivity analysis on Chl-a is presented on Table 4-12, based on averages of near-surface model predictions by AU. As with the sensitivity analysis on DO and due to sufficient abundance of nutrients in the Arroyo Colorado, varying the half saturation coefficients for nitrogen and phosphorus had no impact on average Chl-a concentrations in any AUs. The maximum algal growth rate and maximum algal respiration rate had significant impacts on average Chl-a concentrations. The changes in Chl-a increased in the downstream direction (*i.e.*, with decreasing AU number). This increased sensitivity in the downstream direction reflects the ever increasing residence time of parcels of water with Chl-a present as these parcels are transported down the Arroyo Colorado Tidal from the major freshwater input at the upstream end of the Arroyo Colorado Tidal until these waters eventually exit the system into the Laguna Madre.

Table 4-12. Summary of sensitivity analysis on overall average near-surface Chl-a concentrations by AU for a simulated period of January 2003 – December 2007.

All Chl-a concentrations in units of µg/L

Sensitivity Parameter		Zone of Imp. AUs				Below Zone of Imp. AUs					
		2201_05		2201_04		2201_03		2201_02		2201_01	
Base Case		45.18		37.99		34.2		30.96		33.55	
Max algal growth rate [AG]	+10%	48.58	+ 8%	43.15	+ 14%	41.36	+ 21%	39.90	+ 29%	44.43	+ 32%
	-10%	42.05	- 7%	33.28	- 12%	27.58	- 19%	22.59	- 27%	22.83	- 32%
Max algal respiration rate [AR]	+10%	42.21	- 7%	33.95	- 11%	29.05	- 15%	24.96	- 19%	26.28	- 22%
	-10%	48.48	+7%	42.51	+ 12%	39.93	+ 17%	37.54	+ 21%	41.17	+ 23%
Algal half-saturation for nitrogen limited growth [AHSN]	+25%	45.18	+ 0%	37.99	+ 0%	34.20	+ 0%	30.96	+ 0%	33.55	+ 0%
	-25%	45.18	+ 0%	37.99	+ 0%	34.20	+ 0%	30.96	+ 0%	33.56	+ 0%
Algal half-saturation for phosphorous limited growth [AHSP]	+25%	45.18	+ 0%	37.99	+ 0%	34.20	+ 0%	30.96	+ 0%	33.55	+ 0%
	-25%	45.18	+ 0%	37.99	+ 0%	34.20	+ 0%	30.97	+ 0%	33.56	+ 0%

The final part of the sensitivity analysis is provided in Table 4-13 for Enterococci. The model was found to be fairly sensitive to varying the first-order bacteria decay rate [CG1DK]. As used in this modeling application the decay rate is a disappearance rate for Enterococci bacteria reflecting several processes, including settling, predation, solar radiation induced die-off, response to nutrient deficiencies, and effects of bacterial toxins to name some of the most important factors.

Table 4-13. Summary of sensitivity analysis on the geometric mean of near-surface Enterococci concentrations by AU for a simulated period of January 2003 – December 2007.

All geometric mean concentrations in units of colonies/100 mL of Enterococci

Sensitivity Parameter		Zone of Imp.				Below Zone of Imp.					
		2201_05		2201_04		2201_03		2201_02		2201_01	
Base Case		113		85		53		36		27	
1st-order decay rate [CG1DK]	**+25%**	101	- 11%	71	- 16%	42	- 20%	28	- 22%	22	- 19%
	-25%	128	+ 13%	104	+ 22%	71	+ 35%	49	+ 36%	37	+ 37%

The sensitivity analysis results are provided graphically for the parameters that caused the greater response when varied from their values assigned through the verification process. These graphics are provided as a series of figures (Figures 4-32 through 4-37) without repetition of the explanatory text provided with the tabular results of the sensitivity analysis.

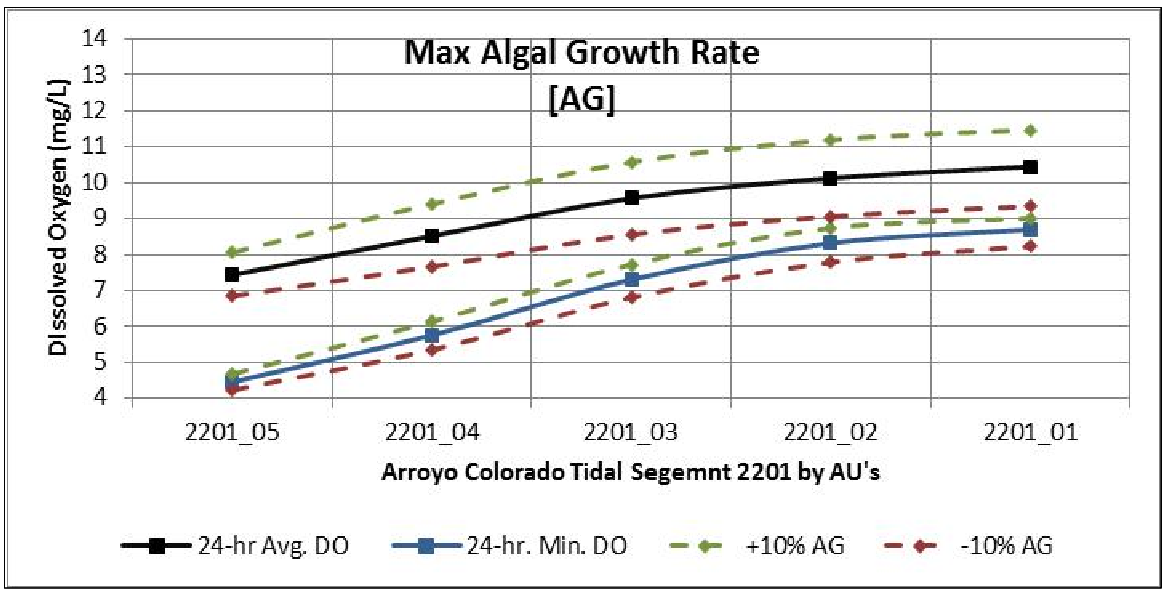

Figure 4-32. Sensitivity results of maximum algal growth rate on average 24-hour average and average 24-hour minimum DO concentrations by AUs along the Arroyo Colorado Tidal, Segment 2201.

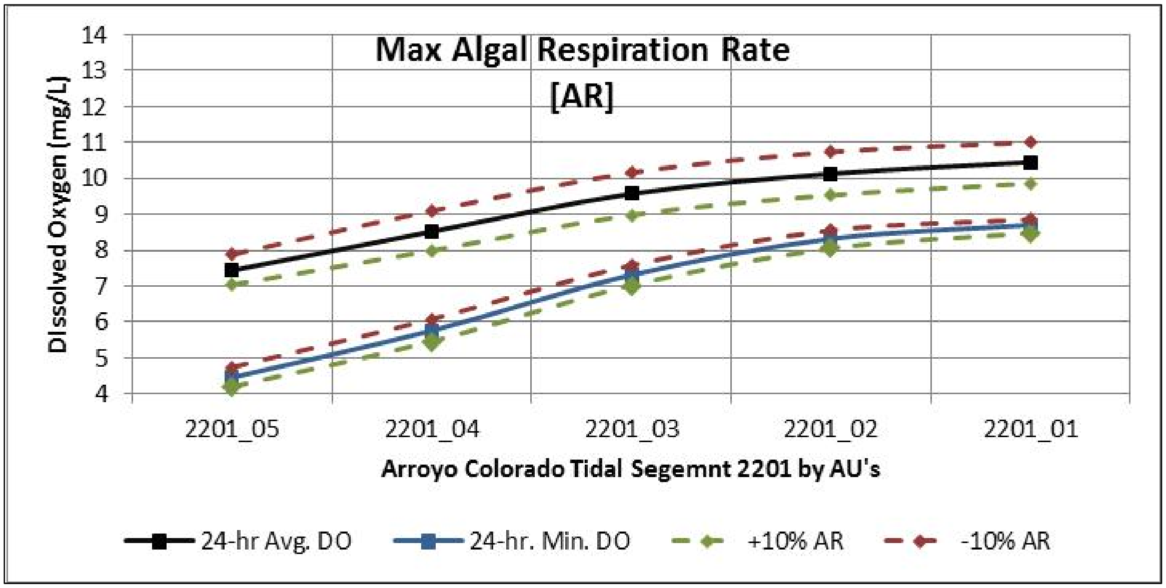

Figure 4-33. **Sensitivity results of maximum algal respiration rate on average 24-hour average and average 24-hour minimum DO concentrations by AUs along the Arroyo Colorado Tidal, Segment 2201.**

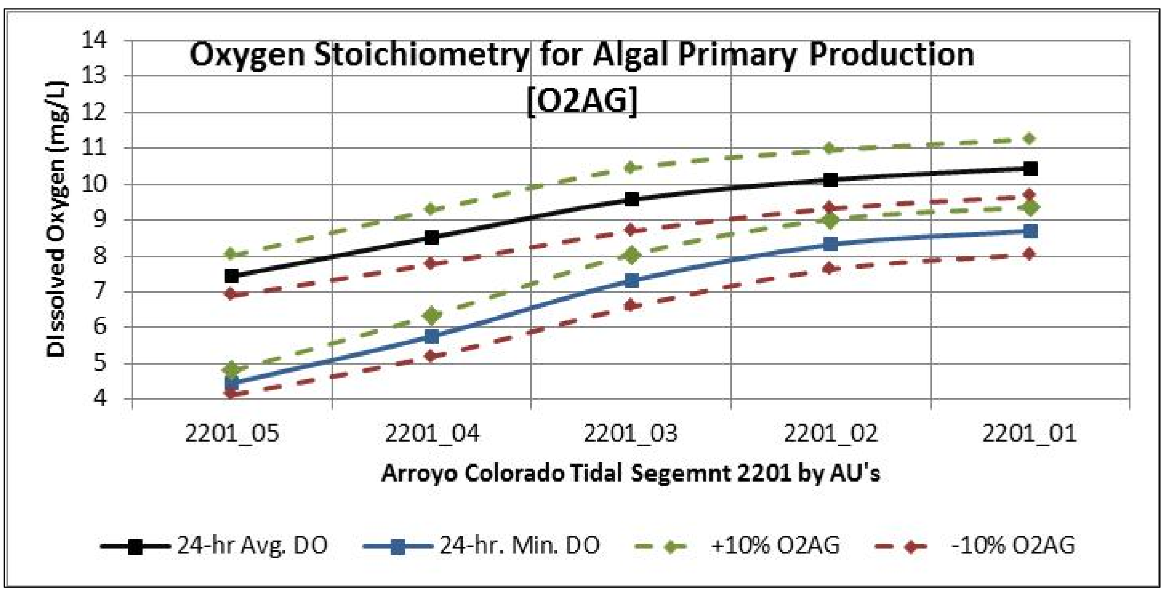

Figure 4-34. **Sensitivity results of oxygen stoichiometry for algal primary production on average 24-hour average and average 24-hour minimum DO concentrations by AUs along the Arroyo Colorado Tidal, Segment 2201.**

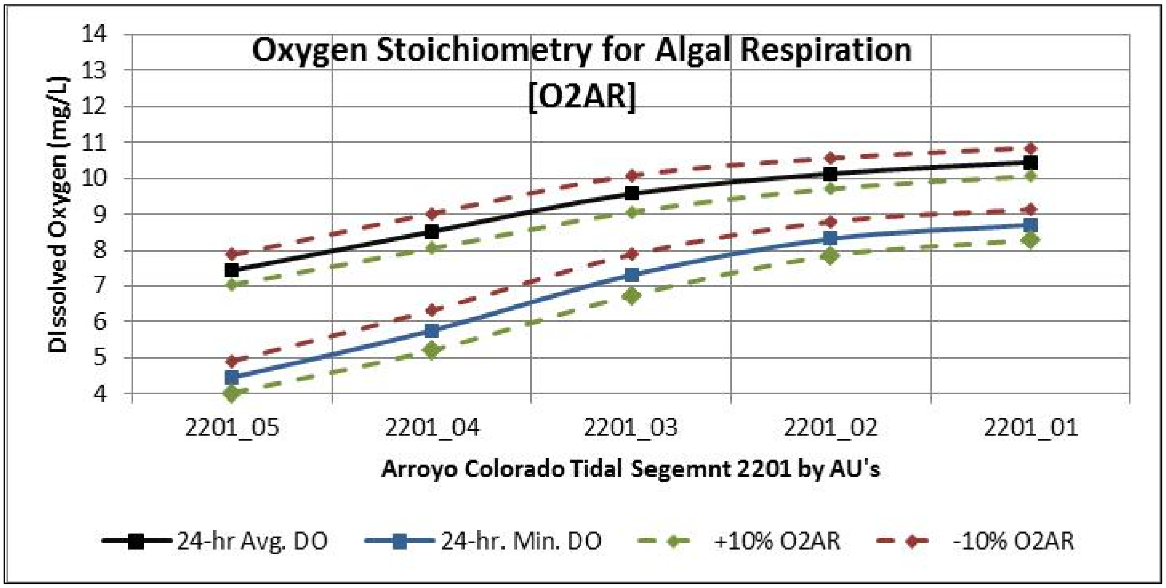

Figure 4-34. **Sensitivity results of oxygen stoichiometry for algal primary respiration on average 24-hour average and average 24-hour minimum DO concentrations by AUs along the Arroyo Colorado Tidal, Segment 2201.**

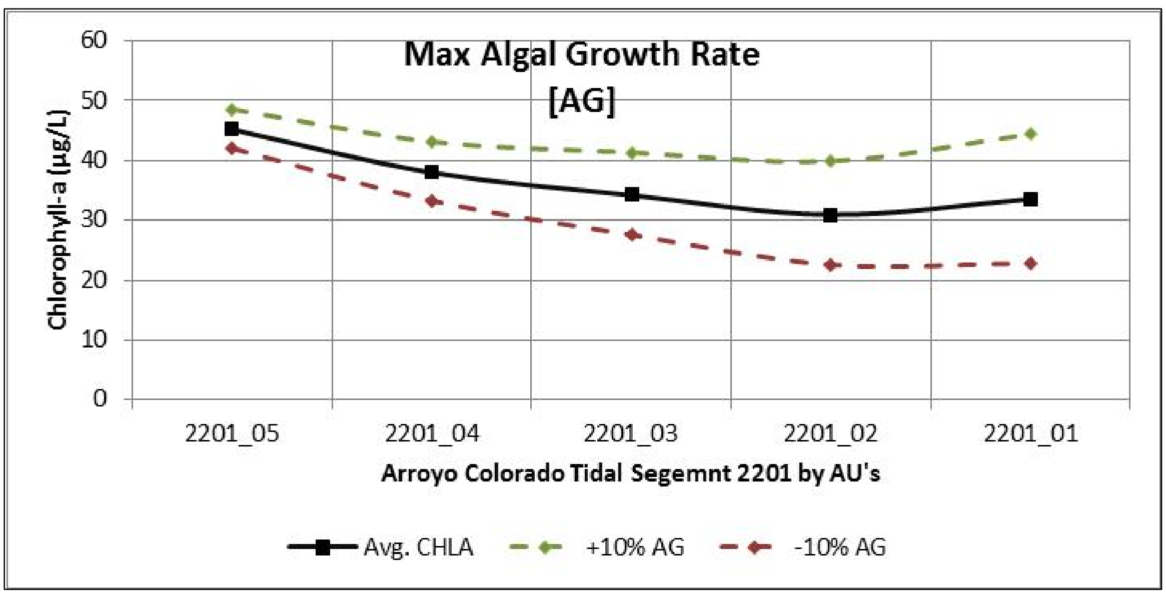

Figure 4-35. **Sensitivity results of maximum algal growth rate on Chl-a by AUs along the Arroyo Colorado Tidal, Segment 2201.**

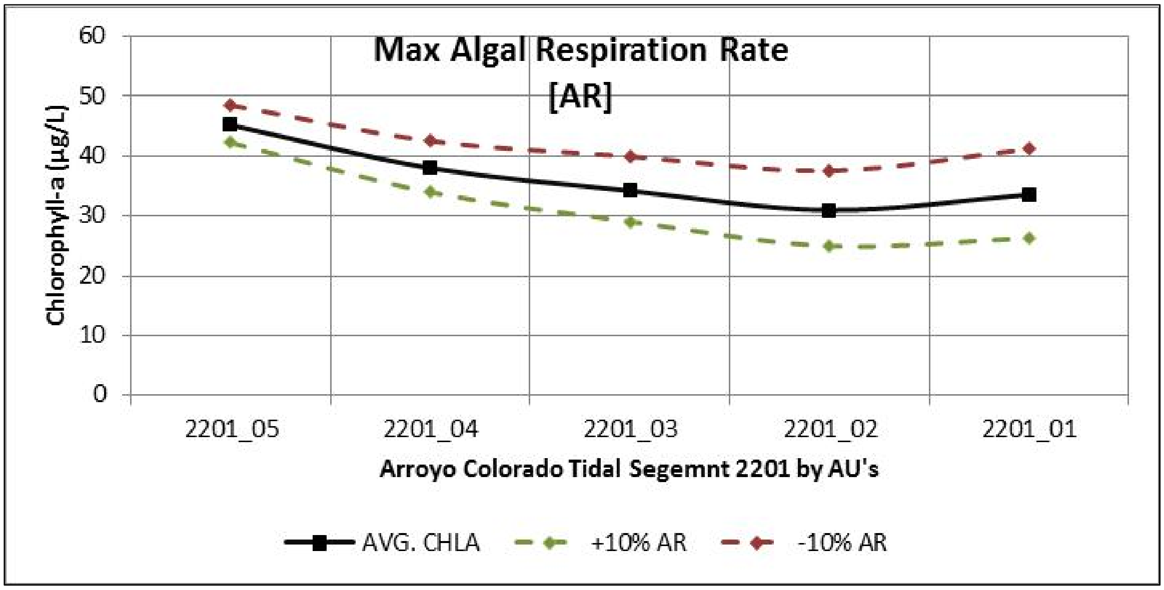

Figure 4-36. **Sensitivity results of maximum algal respiration rate on Chl-a by AUs along the Arroyo Colorado Tidal, Segment 2201.**

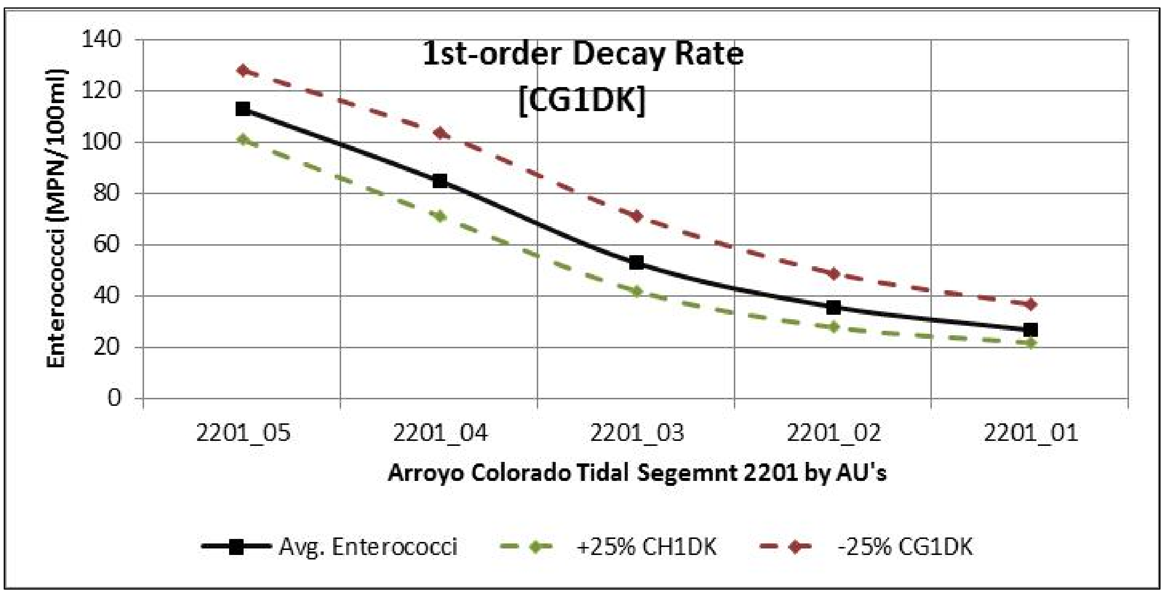

Figure 4-37. **Sensitivity results of first order decay rate on the geometric mean concentration of Enterococci by AUs along the Arroyo Colorado Tidal, Segment 2201.**

Chapter 5

Evaluation of Management Options

The SWAT and CE-QUAL-W2 modeling system was used to evaluate future scenarios and estimate water quality improvements from these scenarios. With the exception of the scenario to evaluate placement of aerators in the Arroyo Colorado Tidal, each scenario with its management practices was first simulated in SWAT and then SWAT output through the Interface Tool was used as input to CE-QUAL-W2. The CE-QUAL-W2 model then simulated the DO dynamics and fate and transport of bacteria in terms of Enterococci within the Arroyo Colorado Tidal segment to evaluate the effectiveness of the selected suites of management measures.

5.1 Modeling Scenarios

The selected scenarios of management measures considered for evaluation are outlined below. As explained above, most management measures were applied by changing the input variables of the SWAT model, so the details on the SWAT modeling efforts are provided in Jeong (2017) and Flores *et al*. (2017). Within CE-QUAL-W2 current and future baseline conditions and four different management scenarios were simulated for the five-year period of 2003 – 2007. Operation of the model actually began July 1, 2002 to allow six months of simulation time before results were considered allows the simulation time to overcome effects of any inaccuracies in specification of initial conditions in the model. While SWAT was operated from 2000 - 2013, the extremely high computational time required to operate CE-QUAL-W2 necessitated operating the model for only a subset of the total time. The selected period of 2003 - 2007 included two years with above average freshwater flows from the watershed of the Arroyo Colorado Above Tidal (2003 and 2004), two below average inflow years (2005 and 2006), and one generally average inflow year (2007), and therefore does include a reasonable variation of hydrologic conditions from SWAT imposed into CE-QUAL-W2.

5.1.1 Scenario 1 - Implement Management Measures

This description of Scenario 1 and its implementation measures was heavily borrowed from the wording in Flores *et al.* (2017) and details on Scenario 1 are provided in that report.

The implementation of management measures under Scenario 1 are subdivided into agricultural management, WWTF, on-site sewage facilities (OSSFs), urban, and instream. Agricultural management included in the model scenario consisted of increasing the cropland under conservation plan by 35,000 acres (*i.e.*, 75% of cropland will be under a conservation plan) and developing conservation plans on 10,000 acres of pasture and 7,500 acres of rangeland.

Major WWTFs were modeled in SWAT to discharge wastewater at concentrations of 10 mg/L CBOD, 15 mg/L TSS, and 63 colonies/100 mL *E. coli* by 2020; and then 7 mg/L CBOD, 12 mg/L TSS, 3 mg/L NH_4, and 0-32 colonies/100 mL *E. coli* by 2027. Small WWTFs were modeled to stay at 20 mg/L BOD and 20 mg/L TSS until their discharge exceeded 1 million gallons per day (MGD) at which time their discharge was modified to 10 mg/L CBOD, 15 mg/L TSS, and 3 mg/L NH_4. Texas Water Development Board Water Plan numbers were used to calculate percent increases in WWTF flow. Additionally, planned wastewater reuse in McAllen, Pharr, Harlingen, and San Benito was reflected in Scenario 1. For OSSFs, 300 failing OSSFs (nearest the Arroyo and its tributaries) were repaired/replaced in this scenario. Three instream BMPs/aeration structures in the non-tidal segment were included.

Increasing urbanization (via conversion of agricultural land to urban) was modeled along with implementation of key urban stormwater BMPs (*i.e.*, construction of several stormwater detention structures). The primary detention projects modeled include the restoration of Llano Grande Lake and the construction of the Hickery Hill detention facility in SWAT. Additional urban BMPs in SWAT include:

- 20% landscaping/low impact development/green infrastructure/urban forestry ordinance for new development
- 10% reduction in pet waste through education and outreach

5.1.2 Scenario 2 - Implement Management Measures and Advanced Wastewater Treatment

The implementation of advanced wastewater treatment in conjunction with watershed management measures described in the previous section (Scenario 1) was also assessed. This consisted of reducing TP in wastewater effluent to 0.10 mg/L and TN to 4 mg/L, where >90% of the TP was in the form of PO_4 and >90% of the TN was in the form of NH_4 and NO_{23}. Implementation of such a scenario is unlikely; however, it provided helpful insight regarding the levels of watershed implementation that may be necessary to achieve water quality standards.

5.1.3 Scenario 3 - Implement Management Measures and Restore Llano Grande Lake Spring

Restoration of spring flow from Llano Grande Lake in conjunction with the implementation of watershed management measures described previously (Scenario 1) was also assessed.

This consisted of restoring 1,000 gallons per minute (gpm) in spring flow from the lake, adding 1.44 MGD (with zero sediment, N, P, and *E. coli*) to the main channel in SWAT Subbasin 6.

5.1.4 Scenario 4 - Implement Aerators in Zone of Impairment

The final scenario evaluated was the implementation of aerators in the tidal segment's zone of DO impairment (Figure 5-1). Using CE-QUAL-W2, two scenarios were modeled:

- operating three aerators thought the entire year (Scenario 4a);
- operating three aerators only for the months of July and August (Scenario 4b).

These aerator scenarios used the Future Baseline results from SWAT.

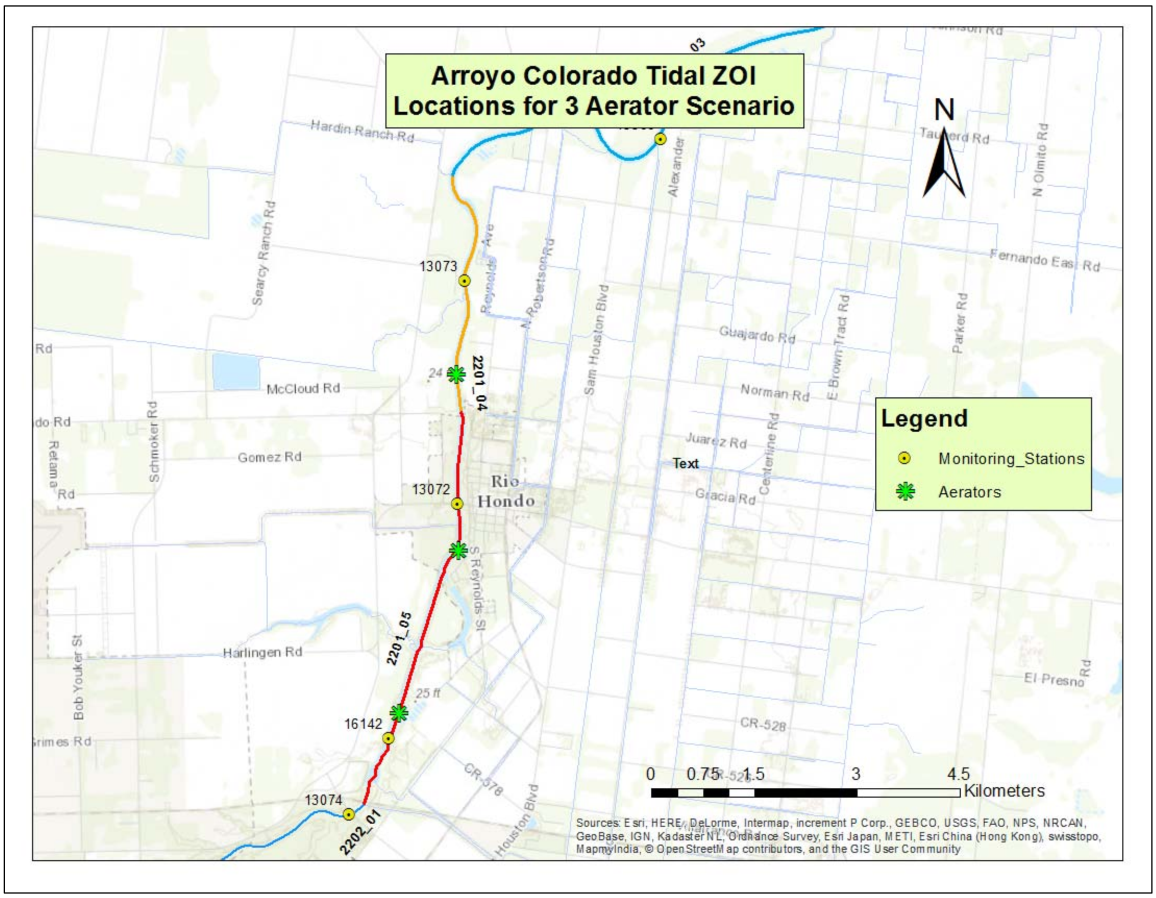

Figure 5-1. Assumed location of aerators along the zone of impairment of the Arroyo Colorado Tidal (Scenario 4)

5.2 Evaluation of Management Scenarios by CE-QUAL-W2

As explained earlier, the CE-QUAL-W2 model was used to predict the impacts of selected management scenarios on DO and bacteria levels in the Arroyo Colorado Tidal. CE-QUAL-W2 is strictly an H/WQ model, and freshwater inflows and loadings of nutrients, sediment, organic matter, DO and bacteria were obtained from SWAT model output. Table 5-1 provides the average and median concentrations of key water quality variables feeding into CE-QUAL-W2 model from SWAT model at the outlet of Subbasin 10 (the downstream terminus of the Arroyo Colorado Above Tidal segment). The conditions summarized in Table 5-1 include two baseline conditions and the three scenarios discussed above. The first baseline is the representation of present (or existing) conditions in SWAT and the future baseline represents conditions reflecting increased urbanization of land use and increased amount of discharge from WWTFs.

Table 5-1. Summary of SWAT output from Subbasin 10 (downstream end of the Arroyo Colorado Above Tidal) used in CE-QUAL-W2 for the period of 2003-2007

Conditions	Statistic	Flow (cms)	*E. coli* (colonies /100 mL) £	NO_{23} (mg/L)	NH_4 (mg/L)	PO_4 (mg/L)	Chl-a (µg/L)	CBOD (mg/L)
Current Baseline	Average	7.01	50.5	4.20	0.27	0.56	68.06	8.57
	Median	4.70	31.6	2.91	0.23	0.56	64.48	3.44
Future Baseline	Average	8.03	49.8	3.94	0.42	0.66	57.60	12.48
	Median	4.93	31.5	3.01	0.38	0.67	57.01	4.76
Scenario 1	Average	7.04	43.6	3.31	0.27	0.47	55.81	9.53
	Median	4.23	27.9	2.24	0.24	0.47	51.44	1.36
Scenario 2	Average	7.04	43.6	2.45	0.20	0.01	3.57	9.53
	Median	4.23	27.9	1.33	0.17	0.01	0.19	1.36
Scenario 3	Average	7.10	36.7	1.30	0.10	0.03	59.39	9.91
	Median	4.22	23.8	0.54	0.09	0.02	55.42	1.36

£ *For E. coli* the average concentrations presented are geometric means.

5.2.1 Evaluation of Scenario 1 - Implement Management Measures

The CE-QUAL-W2's results for the selected management measures of Scenario 1 by CE-QUAL-W2 indicated only slight improvement in the geometric mean concentration of the Enterococci in the five AUs comprising the Arroyo Colorado Tidal (Table 5-2). The implementation of the management measures under Scenario 1, however, did result in significant improvements in DO concentrations and fully attained the 24-hour minimum DO criterion. Table 5-3 contain the results for Scenario 1 showing percent of time that both the 24-hour average and minimum DO criteria were met in each of the AUs comprising the Arroyo Colorado DO. It can be noted that model predictions also indicated significant improvement in meeting the 24-hour minimum DO criterion under the increased flows from WWTFs as contained in the Future Baseline as compared to the Current Baseline. This Future Baseline somewhat unanticipated improvement in DO appeared to be a result of the increased flows, which increased water velocities and decreased the amount of residence time of algae, which resulted in less time for growth of algal biomass in SWAT (see Chl-a in Table 5-1). These increased freshwater flows entering into the Arroyo Colorado Tidal also decreased residence time simulated by CE-QUAL-W2 in the Arroyo Colorado Tidal and further decreased algal biomass predicted in the Tidal segment. Now under Scenario 1 the algal biomass from SWAT entering the tidal segment was further reduced from the Future Baseline and also a significant decrease in the median concentrations of CBOD was predicted (again shown in Table 5-1). In Table 5-1, the median CBOD is considered a measure of the typical concentration of CBOD entering into the Arroyo Colorado Tidal under baseflow conditions, while the average reflects the influence of elevated concentrations during stormwater runoff events. Thus, the CBOD from the Arroyo Colorado Above Tidal flowing into the Tidal segment under baseflow conditions was predicted to be greatly reduced under Scenario 1 compared to the two baseline conditions. Therefore Scenario 1 predicted conditions indicated that the two DO criteria would be met over 90% of the time throughout the Arroyo Colorado Tidal (Table 5-3). An additional insight supporting the large reductions in baseflow CBOD entering the Arroyo Colorado Tidal as the cause of the DO improvement is provided in Table 5-4. Review of the summary statistics of DO concentrations provided in Table 5-4 indicate the diurnal fluctuations in DO (denoted as range in the table) did not changed much between Scenario 1 and the baseline conditions. But especially in AUs 2201_04 and 2201_05, both the 24-hour average and minimum DOs increased roughly 1.5 mg/L, presumably as a response to the notable reduction in CBOD in the inflows from SWAT.

Table 5-2. CE-QUAL-W2 Enterococci geometric mean results for modeled scenarios by AUs along Arroyo Colorado Tidal.

(Non-attainment shown in Red font) £

Conditions (2003-2007)	Zone of Imp.		Below Zone of Imp.		
	2201_05	2201_04	2201_03	2201_02	2201_01
Current Baseline (CB)	103	74	42	35	24
Future Baseline (FB)	130	97	60	54	34
Scenario 1 (Conservation practices)	102	73	45	43	28
Future Scenario 2 (Low N/P loads for point source [PS])	102	73	45	45	27
Future Scenario 3 (Llano Reservoir Spring water 1000 gpm)	80	58	37	40	26

£ Scenario 4 was not used to evaluate bacteria, since the processes included in CE-QUAL-W2 for aerators would not change simulated bacteria values.

Table 5-3. CE-QUAL-W2 24-hour DO results for modeled scenarios showing the % time each criterion is met by AUs along Arroyo Colorado Tidal.

(Non-attainment shown in Red font)

Condition	24 Hr. DO Criterion	Zone of Imp.		Below Zone of Imp.		
		2201_05	**2201_04**	**2201_03**	**2201_02**	**2201_01**
Current Baseline	Average (>4mg/L)	98%	97%	98%	99%	99%
	Minimum (>3mg/L)	76%	90%	96%	98%	99%
Future Baseline	Average (>4mg/L)	98%	97%	97%	98%	98%
	Minimum (>3mg/L)	85%	94%	96%	97%	98%
Scenario 1 *(Conservation practices)*	Average (>4mg/L)	99%	98%	97%	98%	99%
	Minimum (>3mg/L)	96%	97%	97%	98%	98%
Scenario 2 *(Low N/P loads for PS)*	Average (>4mg/L)	99%	97%	97%	98%	99%
	Minimum (>3mg/L)	96%	95%	95%	97%	98%
Scenario 3 *(Llano Reservoir Spring 1000 gpm)*	Average (>4mg/L)	98%	97%	97%	98%	98%
	Minimum (>3mg/L)	93%	95%	96%	97%	98%
Scenario 4a *(3 aerators in ZOI)*	Average (>4mg/L)	99%	99%	98%	98%	98%
	Minimum (>3mg/L)	97%	98%	97%	98%	98%
Future Scenario 4b *(July-Aug running 3 aerators in ZOI)*	Average (>4mg/L)	98%	97%	97%	98%	98%
	Minimum (>3mg/L)	92%	95%	96%	97%	98%

5.2.2 Evaluation of Scenario 2 - Implement Management Measures and Advanced Wastewater Treatment

As anticipated, the implementation of advanced wastewater treatment had no significant effect on geometric mean Enterococci concentrations in the tidal segment (Table 5-2), since this did not alter the bacteria loadings from the WWTFs. The slight changes in Enterococci concentrations in AUs 2201_1 and 2201_02 are small and difficult to explain based on the changes implemented in Scenario 2. However, under this unlikely scenario of advanced treatment, SWAT predictions indicated a very significant reductions (>20 fold) in phosphorus (PO_4) and commensurate very large reduction in algae (or Chl-A). Under this scenario, nutrients and especially phosphorus were indicated to seriously limit growth of algae. Further, under Scenario 2, the low inflow loadings of phosphorus and Chl-a, resulted in low algal biomass predictions in the Arroyo Colorado Tidal with commensurate greatly reduced daily ranges in DO indicted (Table 5-4) and the two DO criteria being easily met (Table 5-3).

Table 5-4. CE-QUAL-W2 results for different scenarios showing the average and median DO concentrations of daily average, minimum and range by AUs along Arroyo Colorado Tidal.

Condition	24 Hr. DO (mg/L) by AU	Zone of Imp.				Below Zone of Imp.					
		2201_05		2201_04		2201_03		2201_02		2201_01	
		Avg.	Med.	Avg.	Med.	Avg.	Med.	Avg.	Med.	Avg.	Med.
Current Baseline	Average	7.3	7.1	8.2	8.2	9.3	9.5	9.9	10.1	10.3	10.6
	Minimum	4.5	4.5	5.7	5.7	7.2	7.4	8.2	8.5	8.6	8.8
	Range	2.8	2.7	2.6	2.5	2.1	2.9	1.7	1.7	1.7	1.7
Future Baseline	Average	7.9	7.8	8.7	8.9	9.4	9.9	9.9	10.2	10.2	10.6
	Minimum	5.0	5.0	6.2	6.3	7.3	7.7	8.2	8.5	8.5	8.8
	Range	2.9	2.8	2.5	2.5	2.1	2.1	1.7	1.7	1.7	1.6
Scenario 1 (Conservation practices)	Average	9.4	9.6	10.1	10.6	10.3	10.9	10.2	10.7	10.3	10.8
	Minimum	6.7	6.6	7.8	8.1	8.3	8.9	8.6	9.0	8.7	8.9
	Range	2.7	2.7	2.4	2.3	2.0	2.0	1.7	1.6	1.6	1.6
Scenario 2 (Low N/P loads for PS)	Average	7.5	7.5	7.5	7.6	7.8	7.9	8.0	8.1	8.5	8.6
	Minimum	7.0	7.2	7.0	7.3	7.3	7.6	7.5	7.8	8.0	8.1
	Range	0.5	0.2	0.5	0.2	0.5	0.2	0.5	0.3	0.6	0.4
Scenario 3 (Llano Reservoir Spring 1,000 gpm)	Average	9.2	9.6	9.9	10.5	10.0	10.6	9.8	10.2	9.8	10.1
	Minimum	6.6	6.8	7.6	8.2	8.2	8.7	8.4	8.7	8.5	8.7
	Range	2.7	2.6	2.2	2.2	1.9	1.9	1.4	1.4	1.3	1.3
Scenario 4a (3 aerators in ZOI)	Average	10.1	10.1	11.2	11.5	10.3	10.7	10.1	10.4	10.2	10.7
	Minimum	7.4	7.2	8.9	9.1	8.3	8.7	8.4	8.7	8.6	8.9
	Range	2.7	2.7	2.3	2.3	2.0	2.0	1.7	1.6	1.7	1.6
Scenario 4b (July-Aug running 3 aerators in ZOI)	Average	8.0	8.0	8.9	9.3	9.5	10.0	9.9	10.2	10.2	10.6
	Minimum	5.3	5.2	6.6	6.7	7.5	7.9	8.2	8.6	8.5	8.8
	Range	2.7	2.6	2.4	2.3	2.0	2.0	1.7	1.6	1.7	1.6

5.2.3 Evaluation of Scenario 3- Implement Management Measures and Restore Llano Grande Lake Spring

The restoration of the Llano Grande Lake spring flows had significant effect on Enterococci, nutrients, Chl-a, and CBOD concentrations in the tidal segment (Table 5-1). The Enterococci concentrations decreased significantly through the Arroyo Colorado Tidal segment, but still not sufficiently to attain the recreational use criterion (Table 5-2).

SWAT predicts significant decrease of nutrient, chlorophyll α, and CBOD with the restoration of the Llano Grande Lake spring (Table 5-1). The decrease in the nutrients resulted in less algal growth within the Arroyo Colorado Tidal and some reductions in the range of DO (Table 5-4), but still the 24-hour minimum DO criterion was still met (Table 5-3).

5.2.4 Evaluation of Scenario 4- Implement Aerators in Zone of Impairment

Results from CE-QUAL-W2 predicted that installation of three aerators in the zone of impairment would be effective in meeting the 24-hour minimum DO criterion under other conditions as described under the Future Baseline. Operating the aerators continuously was designated as Scenario 4a, which resulted predictions that that the 24-hour average and minimum DO criterion would be met. Simulating operation of the aerators for just the peak summer months of July and August was also predicted to be adequate to result in DO water quality standards attainment (Table 5-3).

5.3 Discussion and Conclusions

Several management options were identified for achieving "full attainment" of the DO criteria in the tidal segment's zone of impairment. Both implementation of advanced wastewater treatment (Scenario 2) and installation of aerators in the zone of impairment (Scenarios 4a and 4b) resulted in attainment of the DO criterion in the tidal segment. The various management measures implemented under Scenario 1 were also predicted by CE-QUAL-W2 to result in attainment of the DO criteria, as did the restoration of spring flow from Llano Grande Lake with the Scenario 1 management measures (Scenario 3).

Finally, despite greater than 30% reductions in Enterococci, none of the proposed measures resulted in full attainment of recreational use standards throughout the tidal segment according to CE-QUAL-W2, except the lowermost AU 2201_01. The simulation of bacteria and resulting predictions by CE-QUAL-W2 are highly contingent on the conversion factor used to translate *E. coli* loadings predicted from SWAT into the saltwater indicator bacteria of Enterococci. The accuracy of the conversion factor of 3.0 that was selected is undoubtedly one of the more problematic assumptions made in the modeling of the Arroyo Colorado Tidal. Therefore, the bacteria simulations by CE-QUAL-W2 are subject to a substantial amount of uncertainty.

Chapter 6

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Appendix A

CE-QUAL-W2 user control interface file used for the Dissolved Oxygen Calibration

PSU W2 Model Version 3.7
TITLE C ....TITLE..................................

GRID	NWB	NBR	IMX	KMX	NPROC	CLOSEC
	1	1	172	17	2	OFF

IN/OUTFL	NTR	NST	NIW	NWD	NGT	NSP	NPI	NPU
	5	0	0	0	0	0	0	0

CONSTITU	NGC	NSS	NAL	NEP	NBOD	NMC	NZP
	1	3	3	0	2	0	0

MISCELL	NDAY	SELECTC	HABTATC	ENVIRPC	AERATEC	INITUWL
	100	OFF	OFF	OFF	OFF	OFF

TIME CON	TMSTRT	TMEND	YEAR
	913	2557	2000

DLT CON	NDT	DLTMIN	DLTINTR
	1	0.10	ON

DLT DATE	DLTD
	913.0

DLT MAX	DLTMAX
	100.0

DLT FRN	DLTF
	0.90

DLT LIMI	VISC	CELC
WB 1	ON	ON

BRANCH G	US	DS	UHS	DHS	UQB	DQB	NLMIN	SLOPE	SLOPEC
BR1	2	171	0	-1	0	0	1	0	0

LOCATION	LAT	LONG	EBOT	BS	BE	JBDN
WB 1	26.40	97.33	-5.50	1	1	1

INIT CND	T2I	ICEI	WTYPEC	GRIDC
WB 1	-1.0	0.0	SALT	RECT

CALCULAT	VBC	EBC	MBC	PQC	EVC	PRC
WB 1	ON	ON	ON	ON	OFF	OFF

DEAD SEA WINDC QINC QOUTC HEATC

```
WB 1                  ON     ON      ON      ON

INTERPOL         QINIC  DTRIC  HDIC
BR1                 ON     ON     ON

HEAT EXCH        SLHTC   SROC  RHEVAP  METIC  FETCHC   AFW   BFW   CFW  WINDH
WB 1              TERM    OFF     OFF     ON     OFF    9.2   0.46   2.0   10.0

ICE COVE         CEC  SLICEC  ALBEDO  HWICE  BICE  GICE  ICEMIN  ICET2
WB 1              OFF

TRANSPOR         SLTRC    THETA
WB 1         ULTIMATE     0.55

HYD COEF         AX    DX   CBHE   TSED    FI   TSEDF   FRICC      Z0
WB 1           15.0  45.0   0.30   20.0  0.01    1.0   CHEZY   0.0001

EDDY VISC        AZC   AZSLC  AZMAX   FBC     E    ARODI  STRCKLR  BOUNDFR  TKECAL
WB 1            NICK    IMP   0.0001    3  9.535   0.431    24.0     10.0      IMP

N STRUC          NSTR  DYNELEV
BR1                 0      OFF

STR INT          STRIC  STRIC  STRIC  STRIC  STRIC  STRIC  STRIC  STRIC  STRIC
BR 1

STR TOP          KTSTR  KTSTR  KTSTR  KTSTR  KTSTR  KTSTR  KTSTR  KTSTR
BR1

STR BOT          KBSTR  KBSTR  KBSTR  KBSTR  KBSTR  KBSTR  KBSTR  KBSTR  KBSTR
BR1

STR SINK         SINKC  SINKC  SINKC  SINKC  SINKC  SINKC  SINKC  SINKC  SINKC
BR1

STR ELEV         ESTR   ESTR   ESTR   ESTR   ESTR   ESTR   ESTR   ESTR   ESTR
BR1
STR WIDT         WSTR   WSTR   WSTR   WSTR   WSTR   WSTR   WSTR   WSTR   WSTR
BR1

PIPES            IUPI  IDPI  EUPI  EDPI   WPI  DLXPI   FPI  FMINPI  WTHLC  DYNPIPE

PIPE UP          PUPIC  ETUPI  EBUPI  KTUPI  KBUPI

PIPE DOWN        PDPIC  ETDPI  EBDPI  KTDPI  KBDPI

SPILLWAY         IUSP  IDSP   ESP  A1SP  B1SP  A2SP  B2SP  WTHLC

SPILL UP         PUSPC  ETUSP  EBUSP  KTUSP  KBUSP

SPILL DOWN       PDSPC  ETUSP  EBUSP  KTDSP  KBDSP
```

SPILL GAS	GASSPC	EQSP	AGASSP	BGASSP	CGASSP					
GATES	IUGT	IDGT	EGT	A1GT	B1GT	G1GT	A2GT	B2GT	G2GT	WTHLC
GATE WEIR	GTA1	GTB1	GTA2	GTB2	DYNVAR	GTIC				
GATE UP	PUGTC	ETUGT	EBUGT	KTUGT	KBUGT					
GATE DOWN	PDGTC	ETDGT	EBDGT	KTDGT	KBDGT					
GATE GAS	GASGTC	EQGT	AGASGT	BGASGT	CGASGT					
PUMPS 1	IUPU	IDPU	EPU	STRTPU	ENDPU	EONPU	EOFFPU	QPU	WTHLC	DYNPUMP
PUMPS 2	PPUC	ETPU	EBPU	KTPU	KBPU					
WEIR SEG	IWR	IWR	IWR	IWR	IWR	IWR	IWR	IWR	IWR	
WEIR TOP	KTWR	KTWR	KTWR	KTWR	KTWR	KTWR	KTWR	KTWR	KTWR	
WEIR BOT	KBWR	KBWR	KBWR	KBWR	KBWR	KBWR	KBWR	KBWR	KBWR	
WD INT	WDIC	WDIC	WDIC	WDIC	WDIC	WDIC	WDIC	WDIC	WDIC	
WD SEG	IWD	IWD	IWD	IWD	IWD	IWD	IWD	IWD	IWD	
WD ELEV	EWD	EWD	EWD	EWD	EWD	EWD	EWD	EWD	EWD	
WD TOP	KTWD	KTWD	KTWD	KTWD	KTWD	KTWD	KTWD	KTWD	KTWD	
WD BOT	KBWD	KBWD	KBWD	KBWD	KBWD	KBWD	KBWD	KBWD	KBWD	
TRIB PLA	PTRC DENSITY	PTRC DENSITY	PTRC DENSITY	PTRC DENSITY	PTRC DENSITY	PTRC	PTRC	PTRC	PTRC	
TRIB INT	TRIC ON	TRIC ON	TRIC ON	TRIC ON	TRIC ON	TRIC	TRIC	TRIC	TRIC	
TRIB SEG	ITR 28	ITR 33	ITR 89	ITR 150	ITR 150	ITR	ITR	ITR	ITR	
TRIB TOP	ELTRT	ELTRT	ELTRT	ELTRT	ELTRT	ELTRT	ELTRT	ELTRT	ELTRT	

```
                0.0     0.0     0.0     0.0     0.0

TRIB BOT        ELTRB   ELTRB   ELTRB   ELTRB   ELTRB   ELTRB   ELTRB   ELTRB   ELTRB
                    0.0     0.0     0.0     0.0     0.0

DST TRIB        DTRC    DTRC    DTRC    DTRC    DTRC    DTRC    DTRC    DTRC    DTRC
BR 1              OFF

HYD PRIN        HPRWBC  HPRWBC  HPRWBC  HPRWBC  HPRWBC  HPRWBC  HPRWBC
NVIOL           OFF
U               ON
W               ON
T               ON
RHO             ON
AZ              OFF
SHEAR           OFF
ST              OFF
SB              OFF
ADMX            OFF
DM              OFF
HDG             OFF
ADMZ            OFF
HPG             OFF
GRAV            OFF

SNP PRINT       SNPC    NSNP    NISNP
WB 1              OFF       0       0

SNP DATE        SNPD    SNPD    SNPD    SNPD    SNPD    SNPD    SNPD    SNPD    SNPD
WB 1

SNP FREQ        SNPF    SNPF    SNPF    SNPF    SNPF    SNPF    SNPF    SNPF    SNPF
WB 1

SNP SEG         ISNP    ISNP    ISNP    ISNP    ISNP    ISNP    ISNP    ISNP    ISNP
WB 1

SCR PRINT       SCRC    NSCR
WB 1              ON        1

SCR DATE        SCRD    SCRD    SCRD    SCRD    SCRD    SCRD    SCRD    SCRD    SCRD
WB 1              913

SCR FREQ        SCRF    SCRF    SCRF    SCRF    SCRF    SCRF    SCRF    SCRF    SCRF
WB 1              1.0

PRF PLOT        PRFC    NPRF    NIPRF
WB 1              OFF       0       0

PRF DATE        PRFD    PRFD    PRFD    PRFD    PRFD    PRFD    PRFD    PRFD    PRFD
WB 1
```

```
PRF FREQ        PRFF   PRFF   PRFF   PRFF   PRFF   PRFF   PRFF   PRFF   PRFF
WB 1

PRF SEG         IPRF   IPRF   IPRF   IPRF   IPRF   IPRF   IPRF   IPRF   IPRF
WB 1

SPR PLOT        SPRC   NSPR  NISPR
WB 1              ON      1     12

SPR DATE        SPRD   SPRD   SPRD   SPRD   SPRD   SPRD   SPRD   SPRD   SPRD
WB 1           913.0

SPR FREQ        SPRF   SPRF   SPRF   SPRF   SPRF   SPRF   SPRF   SPRF   SPRF
WB 1           0.042

SPR SEG         ISPR   ISPR   ISPR   ISPR   ISPR   ISPR   ISPR   ISPR   ISPR
WB 1               9     10     25     35     38     77     92    107    108
                 128    129    165

VPL PLOT        VPLC   NVPL
WB 1              ON      1

VPL DATE        VPLD   VPLD   VPLD   VPLD   VPLD   VPLD   VPLD   VPLD   VPLD
WB 1           913.0

VPL FREQ        VPLF   VPLF   VPLF   VPLF   VPLF   VPLF   VPLF   VPLF   VPLF
WB 1         0.20833

CPL PLOT        CPLC   NCPL   TECPLOT
WB 1             OFF      0       OFF

CPL DATE        CPLD   CPLD   CPLD   CPLD   CPLD   CPLD   CPLD   CPLD   CPLD
WB 1

CPL FREQ        CPLF   CPLF   CPLF   CPLF   CPLF   CPLF   CPLF   CPLF   CPLF
WB 1

FLUXES          FLXC   NFLX
WB 1             OFF      0

FLX DATE        FLXD   FLXD   FLXD   FLXD   FLXD   FLXD   FLXD   FLXD   FLXD
WB 1

FLX FREQ        FLXF   FLXF   FLXF   FLXF   FLXF   FLXF   FLXF   FLXF   FLXF
WB 1

TSR PLOT        TSRC   NTSR  NITSR
                  ON      1     14

TSR DATE        TSRD   TSRD   TSRD   TSRD   TSRD   TSRD   TSRD   TSRD   TSRD
               913.0
```

TSR FREQ	TSRF	TSRF	TSRF	TSRF	TSRF	TSRF	TSRF	TSRF	TSRF
	0.042								
TSR SEG	ITSR	ITSR	ITSR	ITSR	ITSR	ITSR	ITSR	ITSR	ITSR
	9	10	24	25	35	38	77	92	107
	108	116	128	129	165				
TSR LAYE	ETSR	ETSR	ETSR	ETSR	ETSR	ETSR	ETSR	ETSR	ETSR
	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
	0.30	0.30	0.30	0.30	0.30				
WITH OUT	WDOC	NWDO	NIWDO						
	OFF	0	0						
WITH DAT	WDOD	WDOD	WDOD	WDOD	WDOD	WDOD	WDOD	WDOD	WDOD
WITH FRE	WDOF	WDOF	WDOF	WDOF	WDOF	WDOF	WDOF	WDOF	WDOF
WITH SEG	IWDO	IWDO	IWDO	IWDO	IWDO	IWDO	IWDO	IWDO	IWDO
RESTART	RSOC	NRSO	RSIC						
	OFF	0	OFF						
RSO DATE	RSOD	RSOD	RSOD	RSOD	RSOD	RSOD	RSOD	RSOD	RSOD
RSO FREQ	RSOF	RSOF	RSOF	RSOF	RSOF	RSOF	RSOF	RSOF	RSOF
CST COMP	CCC	LIMC	CUF						
	ON	ON	10						

CST ACTIVE	CAC
TDS	ON
GEN1	ON
ISS1	ON
ISS2	ON
ISS3	ON
PO4	ON
NH4	ON
NO3	ON
DSI	OFF
PSI	OFF
FE	OFF
LDOM	ON
RDOM	ON
LPOM	ON
RPOM	ON
BOD1	ON

BOD2	ON								
BODP1	OFF								
BODN1	OFF								
BODP2	OFF								
BODN2	OFF								
ALG1	ON								
ALG2	ON								
ALG3	ON								
DO	ON								
TIC	OFF								
ALK	OFF								
LDOM-P	ON								
RDOM-P	ON								
LPOM-P	ON								
RPOM-P	ON								
LDOM-N	ON								
RDOM-N	ON								
LPOM-N	ON								
RPOM-N	ON								
CST DERI	CDWBC	CDWBC	CDWBC	CDWBC	CDWBC	CDWBC	CDWBC	CDWBC	CDWBC
DOC	OFF								
POC	OFF								
TOC	ON								
DON	OFF								
PON	OFF								
TON	ON								
TKN	ON								
TN	ON								
DOP	OFF								
POP	OFF								
TOP	ON								
TP	ON								
APR	OFF								
CHLA	ON								
ATOT	OFF								
%DO	OFF								
TSS	ON								
TISS	ON								
CBOD	ON								
pH	OFF								
CO2	OFF								
HCO3	OFF								
CO3	OFF								
CST FLUX	CFWBC	CFWBC	CFWBC	CFWBC	CFWBC	CFWBC	CFWBC	CFWBC	CFWBC
TISSIN	OFF								
TISSOUT	OFF								
PO4AR	OFF								
PO4AG	OFF								
PO4AP	OFF								
PO4ER	OFF								

PO4EG	OFF
PO4EP	OFF
PO4POM	OFF
PO4DOM	OFF
PO4OM	OFF
PO4SED	OFF
PO4SOD	OFF
PO4SET	OFF
NH4NITR	OFF
NH4AR	OFF
NH4AG	OFF
NH4AP	OFF
NH4ER	OFF
NH4EG	OFF
NH4EP	OFF
NH4POM	OFF
NH4DOM	OFF
NH4OM	OFF
NH4SED	OFF
NH4SOD	OFF
NO3DEN	OFF
NO3AG	OFF
NO3EG	OFF
NO3SED	OFF
DSIAG	OFF
DSIEG	OFF
DSIPIS	OFF
DSISED	OFF
DSISOD	OFF
DSISET	OFF
PSIAM	OFF
PSINET	OFF
PSIDK	OFF
FESET	OFF
FESED	OFF
LDOMDK	OFF
LRDOM	OFF
RDOMDK	OFF
LDOMAP	OFF
LDOMEP	OFF
LPOMDK	OFF
LRPOM	OFF
RPOMDK	OFF
LPOMAP	OFF
LPOMEP	OFF
LPOMSET	OFF
RPOMSET	OFF
CBODDK	OFF
DOAP	ON
DOAR	ON
DOEP	OFF
DOER	OFF

DOPOM	ON						
DODOM	ON						
DOOM	OFF						
DONITR	ON						
DOCBOD	ON						
DOREAR	ON						
DOSED	ON						
DOSOD	ON						
TICAG	OFF						
TICEG	OFF						
SEDDK	OFF						
SEDAS	OFF						
SEDLPOM	OFF						
SEDSET	OFF						
SODDK	OFF						
CST ICON	C2IWB	C2IWB	C2IWB	C2IWB	C2IWB	C2IWB	C2IWB
TDS	-2.000						
GEN1	48.000						
ISS1	2.4000						
ISS2	3.6000						
ISS3	6.0000						
PO4	0.470						
NH4	0.330						
NO3	3.460						
DSI	0.000						
PSI	0.000						
FE	0.000						
LDOM	0.000						
RDOM	0.000						
LPOM	0.000						
RPOM	0.000						
BOD1	18.020						
BOD2	0.000						
BODP1	0.000						
BODN1	0.000						
BODP2	0.000						
BODN2	0.000						
ALG1	-1.000						
ALG2	-1.000						
ALG3	-1.000						
DO	-1.000						
TIC	0.000						
ALK	0.000						
LDOM-P	0.000						
RDOM-P	0.000						
LPOM-P	0.000						
RPOM-P	0.000						
LDOM-N	0.000						
RDOM-N	0.000						
LPOM-N	0.000						
RPOM-N	0.000						

CST PRIN	CPRWBC	CPRWBC	CPRWBC	CPRWBC	CPRWBC	CPRWBC	CPRWBC	CPRWBC
TDS	ON							
GEN1	ON							
ISS1	OFF							
ISS2	OFF							
ISS3	OFF							
PO4	ON							
NH4	ON							
NO3	ON							
DSI	OFF							
PSI	OFF							
FE	OFF							
LDOM	OFF							
RDOM	OFF							
LPOM	OFF							
RPOM	OFF							
BOD1	OFF							
BOD2	OFF							
BODP1	OFF							
BODN1	OFF							
BODP2	OFF							
BODN2	OFF							
ALG1	ON							
ALG2	ON							
ALG3	ON							
DO	ON							
TIC	OFF							
ALK	OFF							
LDOM-P	OFF							
RDOM-P	OFF							
LPOM-P	OFF							
RPOM-P	OFF							
LDOM-N	OFF							
RDOM-N	OFF							
LPOM-N	OFF							
RPOM-N	OFF							

CIN CON	CINBRC	CINBRC	CINBRC	CINBRC	CINBRC	CINBRC	CINBRC	CINBRC	CINBRC
TDS	ON								
GEN1	ON								
ISS1	ON								
ISS2	ON								
ISS3	ON								
PO4	ON								
NH4	ON								
NO3	ON								
DSI	OFF								
PSI	OFF								
FE	OFF								
LDOM	OFF								
RDOM	OFF								

LPOM	OFF
RPOM	OFF
BOD1	ON
BOD2	ON
BODP1	OFF
BODN1	OFF
BODP2	OFF
BODN2	OFF
ALG1	ON
ALG2	ON
ALG3	ON
DO	ON
TIC	OFF
ALK	OFF
LDOM-P	OFF
RDOM-P	OFF
LPOM-P	OFF
RPOM-P	OFF
LDOM-N	OFF
RDOM-N	OFF
LPOM-N	OFF
RPOM-N	OFF

CTR CON	CTRTRC	CTRTRC	CTRTRC	CTRTRC	CTRTRC	CTRTRC	CTRTRC	CTRTRC	CTRTRC
TDS	ON	ON	ON	ON	ON				
Gen1	ON	ON	ON	ON	ON				
ISS1	ON	ON	ON	ON	ON				
ISS2	ON	ON	ON	ON	ON				
ISS3	ON	ON	ON	ON	ON				
PO4	ON	ON	ON	ON	ON				
NH4	ON	ON	ON	ON	ON				
NO3	ON	ON	ON	ON	ON				
DSI	OFF	OFF	OFF	OFF	OFF				
PSI	OFF	OFF	OFF	OFF	OFF				
FE	OFF	OFF	OFF	OFF	OFF				
LDOM	OFF	OFF	OFF	OFF	OFF				
RDOM	OFF	OFF	OFF	OFF	OFF				
LPOM	OFF	OFF	OFF	OFF	OFFF				
RPOM	OFF	OFF	OFF	OFF	OFF				
BOD1	ON	ON	ON	ON	ON				
BOD2	ON	ON	ON	ON	ON				
BODP1	OFF	OFF	OFF	OFF	OFF				
BODN1	OFF	OFF	OFF	OFF	OFF				
BODP2	OFF	OFF	OFF	OFF	OFF				
BODN2	OFF	OFF	OFF	OFF	OFF				
ALG1	ON	ON	ON	ON	ON				
ALG2	ON	ON	ON	ON	ON				
ALG3	ON	ON	ON	ON	ON				
DO	ON	ON	ON	ON	ON				
TIC	OFF	OFF	OFF	OFF	OFF				
ALK	OFF	OFF	OFF	OFF	OFF				
LDOM-P	OFF	OFF	OFF	OFF	OFF				

RDOM-P	OFF	OFF	OFF	OFF	OFF				
LPOM-P	OFF	OFF	OFF	OFF	OFF				
RPOM-P	OFF	OFF	OFF	OFF	OFF				
LDOM-N	OFF	OFF	OFF	OFF	OFF				
RDOM-N	OFF	OFF	OFF	OFF	OFF				
LPOM-N	OFF	OFF	OFF	OFF	OFF				
RPOM-N	OFF	OFF	OFF	OFF	OFF				
CDT CON	CDTBRC	CDTBRC	CDTBRC	CDTBRC	CDTBRC	CDTBRC	CDTBRC	CDTBRC	CDTBRC
TDS	OFF								
Gen1	OFF								
ISS1	OFF								
ISS2	OFF								
ISS3	OFF								
PO4	OFF								
NH4	OFF								
NO3	OFF								
DSI	OFF								
PSI	OFF								
FE	OFF								
LDOM	OFF								
RDOM	OFF								
LPOM	OFF								
RPOM	OFF								
BOD1	OFF								
BOD2	OFF								
BODP1	OFF								
BODN1	OFF								
BODP2	OFF								
BODN2	OFF								
ALG1	OFF								
ALG2	OFF								
ALG3	OFF								
DO	OFF								
TIC	OFF								
ALK	OFF								
LDOM-P	OFF								
RDOM-P	OFF								
LPOM-P	OFF								
RPOM-P	OFF								
LDOM-N	OFF								
RDOM-N	OFF								
LPOM-N	OFF								
RPOM-N	OFF								
CPR CON	CPRBRC	CPRBRC	CPRBRC	CPRBRC	CPRBRC	CPRBRC	CPRBRC	CPRBRC	CPRBRC
TDS	OFF								
Gen1	OFF								
ISS1	OFF								
ISS2	OFF								
ISS3	OFF								

PO4	OFF
NH4	OFF
NO3	OFF
DSI	OFF
PSI	OFF
FE	OFF
LDOM	OFF
RDOM	OFF
LPOM	OFF
RPOM	OFF
BOD1	OFF
BOD1	OFF
BODP1	OFF
BODN1	OFF
BODP2	OFF
BODN2	OFF
ALG1	OFF
ALG2	OFF
ALG3	OFF
DO	OFF
TIC	OFF
ALK	OFF
LDOM-P	OFF
RDOM-P	OFF
LPOM-P	OFF
RPOM-P	OFF
LDOM-N	OFF
RDOM-N	OFF
LPOM-N	OFF
RPOM-N	OFF

EX COEF	EXH2O	EXSS	EXOM	BETA	EXC	EXIC
WB 1	0.25	0.10	0.10	0.25	OFF	OFF

ALG EX	EXA	EXA	EXA	EXA	EXA	EXA
	0.25	0.25	0.20			

ZOO EX	EXZ	EXZ	EXZ	EXZ	EXZ	EXZ
	0.20					

MACRO EX	EXM	EXM	EXM	EXM	EXM	EXM
	0.01					

GENERIC	CGQ10	CG0DK	CG1DK	CGS
CG 1	1.047	0.0	0.15	0.00

S SOLIDS	SSS	SEDRC	TAUCR
SS# 1	30.0	OFF	1.0
SS# 2	10.0	OFF	1.0
SS# 3	1.0	OFF	1.0

ALGAL RATE	AG	AR	AE	AM	AS	AHSP	AHSN	AHSSI	ASAT

ALG1	3.0	0.60	0.05	0.05	0.15	0.008	0.05	0.0	80.00
ALG2	3.0	0.62	0.05	0.05	0.10	0.008	0.05	0.0	120.00
ALG3	2.5	0.75	0.05	0.05	0.05	0.008	0.01	0.0	150.00

ALGAL TEMP	AT1	AT2	AT3	AT4	AK1	AK2	AK3	AK4
ALG1	3.0	16.0	22.0	36.0	0.20	0.99	0.99	0.10
ALG2	5.0	18.0	30.0	35.0	0.20	0.99	0.99	0.10
ALG3	15.0	26.0	35.0	45.0	0.10	0.99	0.99	0.10

ALG STOI	ALGP	ALGN	ALGC	ALGSI	ACHLA	ALPOM	ANEQN	ANPR
ALG1	0.01	0.08	0.45	0.18	0.15	0.70	2	0.001
ALG2	0.01	0.08	0.45	0.18	0.15	0.70	2	0.001
ALG3	0.01	0.08	0.45	0.18	0.15	0.70	2	0.001

EPIPHYTE	EPIC	EPIC	EPIC	EPIC	EPIC	EPIC	EPIC	EPIC	EPIC
EPI1	OFF								

EPI PRIN	EPRC	EPRC	EPRC	EPRC	EPRC	EPRC	EPRC	EPRC	EPRC
EPI1	OFF								

EPI INIT	EPICI	EPICI	EPICI	EPICI	EPICI	EPICI	EPICI	EPICI	EPICI
EPI1									

EPI RATE	EG	ER	EE	EM	EB	EHSP	EHSN	EHSSI
EPI1								

EPI HALF	ESAT	EHS	ENEQN	ENPR
EPI1				

EPI TEMP	ET1	ET2	ET3	ET4	EK1	EK2	EK3	EK4
EPI1								

EPI STOI	EP	EN	EC	ESI	ECHLA	EPOM
EPI1						

ZOOP RATE	ZG	ZR	ZM	ZEFF	PREFP	ZOOMIN	ZS2P
Zoo1							

ZOOP	ALGP	PREFA	PREFA	PREFA	PREFA	PREFA	PREFA	PREFA	PREFA	PREFA
Zoo1										

ZOOP	ZOOP	PREFZ	PREFZ	PREFZ	PREFZ	PREFZ	PREFZ	PREFZ	PREFZ	PREFZ
Zoo1										

ZOOP TEMP	ZT1	ZT2	ZT3	ZT4	ZK1	ZK2	ZK3	ZK4
Zoo1								

ZOOP STOI	ZP	ZN	ZC
Zoo1			

MACROPHY	MACWBC	MACWBC	MACWBC	MACWBC	MACWBC	MACWBC	MACWBC		
Mac1	OFF								
MAC PRIN	MPRWBC	MPRWBC	MPRWBC	MPRWBC	MPRWBC	MPRWBC	MPRWBC		
Mac1	OFF								
MAC INI	MACWBCI	MACWBCI	MACWBCI	MACWBCI	MACWBCI	MACWBCI	MACWBCI		
Mac1									
MAC RATE	MG	MR	MM	MSAT	MHSP	MHSN	MHSC	MPOM	LRPMAC
Mac1									
MAC SED	PSED	NSED							
Mac1									
MAC DIST	MBMP	MMAX							
Mac1									
MAC DRAG	CDDRAG	DMV	DWSA	ANORM					
Mac1									
MAC TEMP	MT1	MT2	MT3	MT4	MK1	MK2	MK3	MK4	
Mac1									
MAC STOICH	MP	MN	MC						
Mac1									

DOM	LDOMDK	RDOMDK	LRDDK	
WB 1	0.6	0.006	0.001	
POM	LPOMDK	RPOMDK	LRPDK	POMS
WB 1	0.10	0.001	0.01	0.1
OM STOIC	ORGP	ORGN	ORGC	ORGSI
WB 1	0.01	0.08	0.45	0.18
OM RATE	OMT1	OMT2	OMK1	OMK2
WB 1	4.0	35.0	0.1	0.99
CBOD	KBOD	TBOD	RBOD	CBODS
BOD 1	0.50	1.047	1.0	0.0
BOD 2	0.05	1.047	1.0	5.0
CBOD STOIC	BODP	BODN	BODC	
BOD 1	0.007	0.057	0.32	
BOD 2	0.007	0.057	0.32	
PHOSPHOR	PO4R	PARTP		
WB 1	0.001	0.0		
AMMONIUM	NH4R	NH4DK		
WB 1	0.001	0.40		

NH4 RATE	NH4T1	NH4T2	NH4K1	NH4K2
WB 1	5.0	25.0	0.10	0.99

NITRATE	NO3DK	NO3S	FNO3SED
WB 1	0.05	0.0001	0.0

NO3 RATE	NO3T1	NO3T2	NO3K1	NO3K2
WB 1	5.0	25.0	0.1	0.99

SILICA	DSIR	PSIS	PSIDK	PARTSI
WB 1	0.1	1.0	0.3	0.0

IRON	FER	FES
WB 1	0.5	2.0

SED CO2	CO2R
WB 1	1.2

STOICH 1	O2NH4	O2OM
WB 1	4.57	1.4

STOICH 2	O2AR	O2AG
ALG1	1.0	1.55
ALG2	1.0	1.55
ALG3	1.0	1.55

STOICH 3	O2ER	O2EG
EPI1	1.1	1.4

STOICH 4	O2ZR
Zoop1	1.1

STOICH 5	O2MR	O2MG
Mac1	1.1	1.4

O2 LIMIT	O2LIM
	0.5

SEDIMENT	SEDC	SEDPRC	SEDCI	SEDS	SEDK	FSOD	FSED	SEDBR	DYNSEDK
WB 1	OFF	OFF	0.0	0.1	0.1	1.0	1.0	0.01	OFF

SOD RATE	SODT1	SODT2	SODK1	SODK2
WB 1	4.0	35.0	0.1	0.99

S DEMAND	SOD	SOD	SOD	SOD	SOD	SOD	SOD	SOD	SOD
	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40

```
                0.40  0.40  0.40  0.40  0.40  0.40  0.40  0.40  0.40
                0.35  0.35  0.35  0.35  0.35  0.35  0.35  0.35  0.35
                0.35  0.35  0.35  0.35  0.35  0.35  0.35  0.35  0.35
                0.35  0.35  0.35  0.35  0.35  0.35  0.35  0.35  0.35
                0.30  0.30  0.30  0.30  0.30  0.30  0.30  0.30  0.30
                0.30  0.30  0.30  0.30  0.30  0.30  0.30  0.30  0.30
                0.30  0.30  0.30  0.30  0.30  0.30  0.30  0.30  0.30
                0.25  0.25  0.25  0.25  0.25  0.25  0.25  0.25  0.25
                0.25  0.25  0.25  0.25  0.25  0.25  0.25  0.25  0.25
                0.25  0.25  0.25  0.25  0.25  0.25  0.25  0.25  0.25
                0.20  0.20  0.20  0.20  0.20  0.20  0.20  0.20  0.20
                0.20  0.20  0.20  0.20  0.20  0.20  0.20  0.20  0.20
                0.20  0.20  0.20  0.20  0.20  0.20  0.20  0.20  0.20
                0.20

REAERATION      TYPE     EQN#   COEF1   COEF2   COEF3   COEF4
WB 1            ESTUARY    1      0.0     0.0     0.0     0.0

RSI FILE.................................RSIFN................................
    .................................RSIFN................................

QWD FILE.................................QWDFN................................
    .................................QWDFN................................

QGT FILE.................................QGTFN................................
    .................................QGTFN................................

WSC FILE.................................WSCFN................................
        wsc6b.npt

SHD FILE.................................SHDFN................................
        shda.npt

BTH FILE.................................BTHFN................................
WB 1    bth19.npt

MET FILE.................................METFN................................
WB 1    met-2013b1.npt

EXT FILE.................................EXTFN................................
    .................................EXTFN................................

VPR FILE.................................VPRFN................................
WB 1    vpr3.npt

LPR FILE.................................LPRFN................................
WB 1    lpr18.npt

QIN FILE.................................QINFN................................
BR1     qin_br10.npt

TIN FILE.................................TINFN................................
```

BR1 tin_br10.npt

CIN FILE.................................CINFN................................
BR1 cin_br10.npt

QOT FILE.................................QOTFN................................
BR1 ....QOTFN................................

QTR FILE.................................QTRFN................................
TR1 qin_point_2013.npt
TR2 qin_br12.npt
TR3 qin_br15.npt
TR4 qin_br1.npt
TR5 qin_br17.npt

TTR FILE.................................TTRFN................................
TR1 tin_point_2013.npt
TR2 tin_br12.npt
TR3 tin_br15.npt
TR4 tin_br1.npt
TR5 tin_br17.npt

CTR FILE.................................CTRFN................................
TR1 cin_point_2013x.npt
TR2 cin_br12.npt
TR3 cin_br15.npt
TR4 cin_br1.npt
TR5 cin_br17.npt

QDT FILE.................................QDTFN................................
BR1 ....QDTFN................................

TDT FILE.................................TDTFN................................
BR1 ....TDTFN................................

CDT FILE.................................CDTFN................................
BR1 ....CDTFN................................

PRE FILE.................................PREFN................................
BR1 ....PREFN................................

TPR FILE.................................TPRFN................................
BR1 ....TPRFN................................

CPR FILE.................................CPRFN................................
BR1 ....CPRFN................................

EUH FILE.................................EUHFN................................
BR1 ....EUHFN................................

TUH FILE.................................TUHFN................................
BR1 ....TUHFN................................

CUH FILE.................................CUHFN................................
BR1 ....CUHFN................................

EDH FILE.................................EDHFN................................
BR1 edh_20131aa.npt

TDH FILE.................................TDHFN................................
BR1 tdh_2013_bth09.npt

CDH FILE.................................CDHFN................................
BR1 cdh_2013_bth10a_test.npt

SNP FILE................................SNPFN................................
WB 1 snp.opt

PRF FILE.................................PRFFN................................
WB 1 prf.opt

VPL FILE.................................VPLFN................................
WB 1 vpl.w2l

CPL FILE.................................CPLFN................................
WB 1 cpl.opt

SPR FILE.................................SPRFN................................
WB 1 spr.opt

FLX FILE................................FLXFN................................
WB 1 flx.opt

TSR FILE.................................TSRFN................................
tsr.opt

WDO FILE.................................WDOFN................................
wdo.opt