Final Draft
Calibration of the Truckee River HSPF Water Quality Model

Prepared for: **The Cities of Reno and Sparks, Nevada**

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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EXECUTIVE SUMMARY

Water quality is a critical issue for the Truckee River. The management and regulation of water quality will require the use of water quality models to evaluate the effects of various wastewater treatment and storm water management options on water quality in the river. The development of a revised Total Maximum Daily Load (TMDL) for the Truckee River, replacing the one developed in 1994, is of immediate concern. The revised TMDL requires application of a water quality model that can define the interrelationships between river flow, external pollutant loading, and resulting water quality.

Local stakeholders supported development of a water quality model called the Truckee River Hydrological Simulation Program – FORTRAN (TRHSPF) as a long-term river management tool, to evaluate water quality implications of alternative management scenarios and to reexamine the TMDL developed in 1994. The water quality model is designed to generate results consistent with past modeling applications, contain consistent documentation, be publicly available, and provide a stable platform for future modeling activities (LTI, 2003).

LimnoTech (LTI) developed the new integrated model as a long-term management tool for river water quality by enhancing the Hydrological Simulation Program – FORTRAN (HSPF) model with the periphyton routines from the existing DSSAMt model of the Truckee River, and improving other select routines. The selection, development, and enhancements made to HSPF are documented in a separate report (LTI, 2003), which also contains an initial model calibration to observed data from 2000-2001.

This report presents improvements to the TRHSPF model completed since initial development, and presents the final calibration of the model to a larger data set. The primary recent improvements to the model, other than calibration to a larger data set, consist of changes to reach hydraulic representation and addition of explicit consideration of blue-green algae. The new reach hydraulics better represent travel time at a wide range of flow conditions between Reno, Nevada and Marble Bluff Dam. The model calibration was extended to consider water quality and benthic algae data collected between July 2000 and August 2002. Model comparisons were also conducted with three other years to add additional confidence in the model parameters selected. The additional years for model comparison were 1990, 1995, and 1996. These years were selected because they represent a range of Truckee River flow conditions.

Data were collected for boundary conditions and forcing functions that represent external factors acting upon the model and for calibration data against which model predictions were compared. The boundary conditions/forcing function data include meteorological data used for predicting heat and light effects on the river, agricultural and groundwater flows and concentration data, and the upstream and tributary flows and concentrations. Model predictions were compared to water quality and periphyton data at numerous locations between Reno and Marble Bluff Dam.

Model calibration proceeded in a stepwise manner. Constituents simulated by the model and unaffected by the growth and respiration of periphyton were completed first. These were flow, total dissolved solids, temperature, and alkalinity. Second, the calibration for constituents dependent on periphyton growth and respiration were completed together. These included nutrients, dissolved oxygen, pH, and periphyton. The goals of model calibration were to achieve an adequate “goodness of fit” to observed data, while keeping model coefficients within a reasonable range. This was accomplished for all parameters.

The TRHSPF model results provide an exemplary calibration for a large number of stations, parameters and time periods. The resulting TRHSPF model error statistics for the calibration periods were consistent with, and often better than, the error statistics obtained for past modeling of the Truckee River, while considering a more robust data set. Thus, application of TRHSPF to the Truckee River is consistent with the models used previously for a regulatory purpose.

1. INTRODUCTION

Water flow and quality are critical issues for the Truckee River. Management and regulatory factors that influence the river include the established Total Maximum Daily Loads (TMDLs) for total phosphorus (TP), total nitrogen (TN), and total dissolved solids (TDS), the finalization of the Truckee River Operating Agreement (TROA) that will control flow in the river, and the development of a regional wastewater treatment plan by the Cities of Reno and Sparks and Washoe County. These factors will require the use of water quality models to evaluate the effects of various treatment and management options on water quality in the river.

The Truckee River Hydrological Simulation Program – FORTRAN (TRHSPF) has been developed by Reno and Sparks, Nevada, to re-evaluate the Truckee River TMDLs. It incorporates state-of-the science benthic algae routines from the DSSAMt computer model with the stable, well-documented, and publicly supported HSPF framework. The selection, development, and enhancements made to HSPF are documented in a separate report, which also contains an initial model calibration to observed data from 2000-2001 (LTI, 2003).

The purpose of this report is to document recent improvements to the model framework and to present an updated model calibration to a more complete data set. Changes made to the model consisted of modifying reach characteristics to incorporate hydraulic equations more suited and developed for the Truckee River, and adding a separate periphyton group to represent blue-green algae. The model calibration was extended to consider a more complete data set, including water quality and benthic algae data collected between July 2000 and August 2002, and water quality data for the years 1990, 1995, and 1996.

The following sections of this report describe:

- Model updates (Section 2),
- The sources of data used for model inputs (Section 3), and
- Model calibration (Section 4).

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2. MODEL UPDATES

The Cities engaged LTI to develop the TRHSPF model as the long-term management tool for river water quality by enhancing the existing HSPF model with the periphyton and selected other water quality routines from the DSSAMt model used for the previous TMDL.

Development of the enhanced HSPF model was accomplished through seven steps:

1. Literature review to define state-of-the science for periphyton modeling
2. Development of conceptual equations of periphyton
3. Integration of equations into HSPF
4. Testing and pre-calibration to previous DSSAMt model runs
5. Initial model calibration
6. Model improvements
7. Model recalibration

Stages 1 through 5 were the subject of a previous report titled "Calibration of TRHSPF Water Quality Model" (LTI, 2003). That report described the process of developing and testing the TRHSPF water quality model and will be referred to as the October 2003 initial calibration report.

The following subsection describes model improvements implemented since the October 2003 calibration report. Stages 6 and 7 are the subject of this report. Model improvements are covered in the following subsections, while the development of model inputs and model calibration are described in Sections 3 and 4.

Two primary improvements were made to the model since the original October 2003 calibration report. These improvements correspond to: 1) Improvement in the hydraulic representation of the Truckee River, and 2) Addition of a second algal functional group to represent nitrogen-fixing blue-green algae.

2.1 IMPROVED HYDRAULIC REPRESENTATION

The United States Geological Survey (USGS) has developed two hydraulic representations of the Truckee River potentially suitable for supporting the TRHSPF model. Nowlin developed power functions for water quality modeling (Nowlin 1987), and Berris (1996) utilized stream cross-section data for a water quantity model. Berris' hydraulic representation was subsequently used by the USGS for total dissolved solids (TDS) and temperature modeling (Taylor, 1998). For the purpose of this report, these hydraulic representations will be referred to as the Nowlin and Berris hydraulics. Previous water quality and periphyton modeling of the Truckee River have utilized both hydraulic representations. DSSAMt uses Nowlin hydraulics, and earlier versions of TRHSPF used the Berris hydraulics.

Brock (2001) compared and summarized the methods used to calculate the hydrologic properties of each model and the simulated velocities of each, and discussed the impacts of the differences.

The main conclusions of his memo are:

- Reach characteristics developed by Berris and used in HSPF overestimate velocity and underestimate travel time;
- Berris hydraulics are more uniform than Nowlin hydraulics at varying flow;
- Berris hydraulics are biased towards riffles and under-represent pools.

Furthermore, the memorandum states that these differences in hydraulics may result in the uniform growth of benthic algae down the length of the Truckee River and overestimate growth at low and high flows.

Subsequent analyses showed systematic differences between Nowlin and Berris hydraulics and concluded that Nowlin's hydraulics are better suited for water quality modeling of the Truckee River (Naperala and Azad, 2005). Therefore, Nowlin's hydraulic representation was added to the TRHSPF model.

2.2 ADDITION OF NITROGEN-FIXING ALGAE

The original TRHSPF application (LTI, 2003) used a single periphyton group to characterize all types of benthic algae. The current application improves upon that simpler representation by including a second periphyton group to represent nitrogen-fixing blue-green algae. The underlying growth and loss processes between the two algal groups are essentially identical, although different rate coefficients are used between the two groups. The primary difference between the blue-green algal group that was added and the original algal assemblage is the ability of the N-fixing algae to use atmospheric nitrogen (N_2) as a nutrient during periods of low dissolved inorganic nitrogen concentrations (DIN). When DIN levels fall below a specified level, the following rules govern blue-green algae growth and their effect on the nitrogen budget:

1. No consideration is given to nitrogen limitation on growth; it is assumed that an abundant supply of N_2 is available to support blue-green growth.
2. Blue-green algal growth does not consume inorganic nitrogen from the water column. The only effect on the nitrogen budget comes through the release of nitrogen from the blue-green algal (e.g., through respiration).

When available nitrogen concentrations are high enough to suppress nitrogen fixation, the equations defining blue-green algae kinetics and effects on the nitrogen budget are identical to the other algal groups (although specific rate coefficients will differ).

3. MODEL INPUTS AND DATA SOURCES

The final calibration of the enhanced TRHSPF model focused on the data collected by the CMP from July 2000 through August 2002. This data set represents an improvement over previous data sets available for calibration because none of the earlier data sets contain a complete annual set of both water quality data and periphyton data. Additional calibration comparisons were conducted for the years 1990, 1995, and 1996. These years do not have as robust of a data set as 2000-2002, but were added to allow a broader range of flow conditions to be considered during calibration.

Data were collected for two purposes: 1) to describe boundary conditions and forcing functions that represent external factors acting upon the model; and 2) to provide calibration data against which model predictions were compared (Fritsen and Memmott, 2001). The boundary conditions/forcing function data include meteorological data used for predicting heat and light effects on the river, agricultural and groundwater flows and concentration data, and the upstream and tributary flows and concentrations. Model predictions were compared to water quality and periphyton data.

This section describes the sources of data used in the model. It is divided into separate discussions of:

- Model Domain
- Hydrology
- Meteorology
- Diversions and return flows
- Water quality
- Biology

3.1 MODEL DOMAIN

The spatial extent of the model covers an area starting at East McCarran Bridge in Reno and ending at Marble Bluff Dam. TRHSPF divides the river into a series of segments. A total of 43 segments were used for this application, as shown in Figure 3-1. The segments range in length from 0.13 miles to 3.24 miles with an average length of 1.31 miles.

3.2 HYDROLOGY

The Truckee River application of HSPF simulates the hydraulic behavior of each section of the river using a routing method commonly known as storage routing (Bicknell et al., 1997). This method requires that channel properties, and a fixed relationship between flow and volume are defined for each reach. Estimates of surface water inflows, agricultural diversions, and groundwater accretion are also required for the period of simulation.

3.2.1 Channel Properties

As discussed in Section 2.1.1, channel properties were based upon the previous work of Nowlin (1987).

3.2.2 Surface Water Flows

The model required specification of four primary surface water inflows. These are Truckee River flow at Reno, NV; Steamboat Creek; North Truckee Drain; and Truckee Meadows Water Reclamation Facility (TMWRF) effluent. Flows at these locations were estimated using the following methods.

- The upstream model boundary was estimated using daily flows measured at the USGS gauge near Sparks, NV (10348200).
- Steamboat Creek flow was estimated using daily flows measured at the USGS gauge at Cleanwater Way (10349980).
- North Truckee Drain flows were estimated using daily flows measured at the North Truckee Drain Gauge (10348300).
- TMWRF flows were estimated using daily flows measured at the facility.
- Gage locations referenced throughout this report are shown in Figure 3-1.

Figure 3-1

Map of Truckee River from Reno, NV, to Marble Bluff Dam, Showing Water Quality Monitoring and USGS Gauging Stations, and Agricultural Withdrawals and Returns

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3.3 METEOROLOGICAL DATA

Meteorological data are important inputs for the TRHSPF model. Required inputs for the calculation of water quality processes include air temperature, dew point temperature, wind speed, cloud cover, and solar radiation. All meteorological inputs effect the model's prediction of water temperature. Water temperature affects the simulation of dissolved oxygen, nutrient and BOD decay, and periphyton growth and respiration. Solar radiation also influences the growth of periphyton.

Hourly measurements of air temperature, dew point temperature, and wind speed were collected by the Western Regional Climate Center (WRCC) at the Reno, NV airport (WRCC, 2002). These values were used to represent the average condition for each hour. Missing data were filled in using the nearest measured data points or linear interpolation. The method used depended on the number of hourly data points missing. If one hourly data point was missing, an average of the first and last reported hourly data point was used to replace the missing data. If a data gap was greater than one hourly data point, then a simple linear interpolation was applied to the available data to replace the missing data. These data were used to represent the atmospheric conditions for all model reaches.

Cloud cover data are collected each hour at the Reno, NV airport and reported by the WRCC (WRCC, 2002). Cloud cover is reported as clear, few, scattered, broken, or overcast. This qualitative description was transformed into a single hourly value between 0 and 100 to represent percent cloud cover. The observed cloud cover description was assigned a value between 0 and 100 (Table 3-1). The maximum value for each hour was used to represent total cloud cover. These hourly values were used to represent average hourly cloud cover for all model reaches in TRHSPF.

Table 3-1. Numeric Value Assigned to Cloud Cover Description.

Cloud Cover Description	Assigned Numeric Value
Clear	0
Few	10
Scattered	30
Broken	75
Overcast	100

Solar radiation data are measured at two stations in Reno, Nevada. The stations, South and North Reno, are operated by the WRCC. Data for both stations were obtained from the Desert Research Institute (DRI) (Brock, 2002). Data collected from the South Reno station were used as the primary source of observed solar radiation data. Gaps in this data set were filled using observed measurements from the North Reno station. The solar radiation data sets were further modified for each model reach to account for the effects of shading from nearby mountains. This modification to solar radiation accounts for nearby topographic features and was developed for the Truckee River by the USGS (Taylor, 1998).

3.4 AGRICULTURAL DIVERSIONS AND RETURN FLOWS

The Truckee River supplies water to many irrigation ditches between Reno and Marble Bluff Dam. This water is used to irrigate agricultural lands in the region surrounding the river, and then returns to the Truckee River in ditches. For modeling purposes, only diversions monitored by the Federal Water Master were considered. The agricultural diversions and approximate locations are shown in Figure 3-1.

Agricultural return flows were previously estimated (Brock and Caupp, 1998) to be 35% of the rate of diversion. This estimate was used and applied to most agricultural returns in the model. The agricultural return flow estimates were refined for the Gregory, Herman, and Gardella diversions using data collected recently (Wood Rodgers, 2005). Agricultural return flows for the Gregory, Herman, and Gardella diversions were estimated to be 28%, 22%, and 10% respectively, of the rate of diversion. Table 3-2 and Table 3-3 provide a summary of the average agricultural diversion and return flow rates. Averages are based on data provided in the "*Irrigation Ditches on the Lower Truckee River*" report (Wood Rogers, 2005). Active return flows from the Pioneer diversion are upstream of McCarran bridge and are therefore not included in the TRHSPF model. Several diversions were not included in the post-2000 simulations because they are believed to be no longer in service (e.g., Noce, Pierson, Fellnagle, and Olinghouse #3).

Table 3-2. Average Agricultural Diversion and Return Flow (acre-feet) to the Truckee River[1].

Location	Diversion Flow	Return Flow
Murphy	1791 (12)	624 (12)
McCarran	919 (12)	NM
Washburn	358 (13)	837 (1)
Gregory	689 (17)	179 (12)
Herman	3005 (13)	702 (8)
Proctor	188 (7)	NM
Olinghouse 1	1842 (13)	NM
Gardella	461 (12)	47 (12)

[1]Parentheses indicate the number of years of data reported, and NM indicates that the return flow was not measured.

Table 3-3. Average Agricultural Diversion % Return Flow Rate to the Truckee River.

Location	Years of Data[1]	Average Return (%)[2]	Modeled Return (%)
Murphy	12	35	35
McCarran	0	NM	35
Washburn	1	82	35
Gregory	12	28	**28**
Herman	8	22	**22**
Proctor	0	NM	35
Olinghouse 1	0	NM	35
Gardella	12	10	**10**

[1]Years of data indicates the number of years used in the calculation of the average return flow rate.
[2]NM indicates that the return flow was not measured.

The Truckee-Carson Irrigation District (TCID) operates a diversion from the Truckee River to the Carson Basin via the Truckee Canal. Water is diverted at Derby Dam through the Truckee Canal and an ungauged amount of water spills back to the Truckee River upstream of Wadsworth. The Truckee Canal diversion flow was estimated by subtracting Truckee River flow at Wadsworth from Truckee River flow at Vista while accounting for all agricultural diversion and returns present in that stretch of the river. Truckee Canal diversions were estimated using this approach rather than USGS Truckee Canal gage data because the gage location does not account for the spillway returns and other losses back to the Truckee River.

3.4.1 Groundwater Accretion

Several low flow field studies and modeling studies have been conducted to estimate groundwater inflows to the Lower Truckee River. Two studies (Nowlin, 1987; Brock, 1992) estimated an annual average inflow to the lower Truckee River of 23 cfs. This was used as the total groundwater inflow between Wadsworth gauge and Marble Bluff Dam, a 26-mile stretch of river (Reach 328 – 343). The groundwater was assumed to enter the river at the same rate spatially and temporally. Therefore, a constant rate of 0.9 cfs per mile was added between Wadsworth and Marble Bluff Dam for the simulation period.

3.5 WATER QUALITY CONCENTRATION DATA

3.5.1 Upstream Boundary and Tributary Concentrations

Concentration data for temperature, dissolved oxygen (DO), and nutrients were compiled from the TMWRF routine monitoring program and from CMP.

Continuous measurements of temperature, DO, specific conductivity (for total dissolved solids estimates), and pH were measured by YSI data sondes that were placed in the Truckee River between March 2000 and August 2002. A data sonde at the East McCarran Street Bridge provided data for use as upstream boundary conditions for the model. Data sondes at East McCarran, Lockwood, Tracy, Painted Rock, Wadsworth, and Marble Bluff Dam provided calibration data for comparing to model simulations (Figure 3-1).

Data sondes were placed in North Truckee Drain and Steamboat Creek beginning March 1, 2001, and remained instream through 2002. Data collected during 2001 and 2002 were used to estimate temperature, dissolved oxygen, specific conductivity, and pH for July 1, 2000 through August 31, 2002. The months of January and February lacked continuous measurements. During this period averages of samples collected by TMWRF were used as model inputs.

TDS concentrations at the boundary conditions were estimated from continuous specific conductivity measurements recorded by the data sondes. Specific conductivity and TDS measurements taken at East McCarran, Steamboat Creek, and North Truckee were compared, and a relationship was developed. The data were compared separately at each location. The resulting regression equations were similar. Due to the similarity, all measured specific conductivity and TDS data at these locations were lumped together, and a single equation was developed that related TDS to specific conductivity. The resulting relationship ($r^2 = 0.955$) is:

$$\text{TDS (mg/L)} = 0.6485\ \text{EC}\ (u\text{mho/cm})$$

This equation was used to convert continuous specific conductivity measurement to TDS concentrations.

Monthly samples were collected by TMWRF for total phosphorus, orthophosphorus, total Kjeldahl nitrogen (TKN), soluble Kjeldahl nitrogen (SKN), total ammonia nitrogen, nitrate nitrogen, nitrite nitrogen, alkalinity, TDS, and dissolved organic carbon (DOC). The samples were collected from seven locations along the Truckee River within the model domain (Figure 3-1) as well as Steamboat Creek and North Truckee Drain. Samples for the same constituents were collected from the TMWRF effluent at a frequency of either daily or three times a week, depending upon the constituent. DRI also collected nutrient samples and measured turbidity and light attenuation at the same stations where benthic algae data were collected during each of their monthly surveys as part of the CMP. Quarterly samples from McCarran, collected as part of the CMP, were also included in the data set for estimation of upstream boundary conditions.

HSPF simulates a complete mass balance for nitrogen, phosphorus, and carbon. These constituents are tracked by the model in three forms: forms that are immediately available to algae, unavailable forms that readily break down (called “labile”), and unavailable forms that are transported out of the system with no further transformation (called “refractory”). Nutrient forms available for algal growth include total ammonia nitrogen, nitrate nitrogen, orthophosphorus, and carbon dioxide. Labile forms of nutrients consist of a single state variable, “biochemical oxygen demand (BOD)”, which has the same user-specified stoichiometry of nutrients as algae. HSPF uses separate state variables for the refractory forms of nutrients: organic refractory nitrogen (ORN), organic refractory phosphorus (ORP), and organic refractory carbon (ORC). Nutrients contained in algal tissue are accounted for in the nutrient mass balance when death or removal occurs. The nutrients are added to the organic refractory state variables (ORN, ORP, and ORC), or are made available as inorganic nutrients based on user-specified variables.

BOD data were not available for the Truckee River or tributaries, and needed to be estimated from measurements of other parameters. Ultimate (BOD_{ult}) was estimated based upon soluble organic nitrogen (soluble Kjeldahl nitrogen minus total ammonia nitrogen) by using the stoichiometric relationships calculated from the CMP periphyton database (see Section 3.5.4, Table 3-4). This method of estimating ultimate BOD gave results most similar to historical measurements, and results in total nitrogen mass balancing at the upstream model boundary. The relationship used is:

$$BOD_{ult} = (SON) \div (0.045 \text{ mg ON/mg OM}) * (1.07 \text{ mg } O_2\text{/ mg OM})$$

Where:

SON is soluble organic nitrogen (mg/l);

OM is organic matter;

O_2 is oxygen demand; and

ON is organic nitrogen.

Data for organic refractory nitrogen, organic refractory phosphorus, and organic refractory carbon also were not available. ORC concentrations were estimated by subtracting the carbon represented by BOD_{ult} from DOC. Historical data from the TMWRF database in which both TOC and DOC were collected at the same time indicated that DOC represented the majority of TOC. ORN was estimated as the particulate organic nitrogen fraction (total Kjeldahl nitrogen - soluble Kjeldahl nitrogen). ORP was estimated as the difference between total phosphorus and the sum of orthophosphorus and the labile organic phosphorus represented by BOD_{ult}. ORP was set to zero where orthophosphorus and labile organic phosphorus exceeded measured total phosphorus. This is the case for many Truckee River samples at McCarran and North Truckee Drain, although the percentage error is small.

The method used for calculating daily upstream and tributary loads to a model based on less frequent data can have important effects on the subsequent modeling results. To ensure that estimated loads were as accurate as possible, LTI evaluated the appropriateness of three of the primary load calculation methodologies for use with the Truckee River data. These methodologies include a ratio estimator method, a transformation-bias adjusted regression estimator, and a monthly aggregate estimator (Preston et al., 1990). All three methods were developed for use with data from routine sampling programs that also had daily flow records, such as are available for the Truckee River and its main tributaries. The ratio estimator has been found to be the least biased method, but it does not provide daily load estimates that are needed for dynamic water quality modeling. However, it does provide a check of accuracy of the total loads calculated using the other methods. The regression method uses statistical lognormal regression relationships between flow and concentration, and uses an adjustment back-transformation bias when calculating daily loads from the regression. The monthly aggregate method uses the monthly average constituent concentration and daily flow record to calculate loads. This method may under-predict loads from systems that are heavily influenced by storm events, but can provide good estimates of daily load for more stable systems.

Of the three methods, the monthly aggregate estimator was the most suitable for calculating loads for the TRHSPF model. Total load estimates from all three methods for all parameters were in good agreement. The regression estimator was not suitable because there were not significant statistical relationships between flow and concentration for most parameters. Flows in the Truckee River, North Truckee Drain, and Steamboat Creek are all heavily managed and relatively stable over short time periods, and the monthly aggregate method should provide good estimates of loads under these conditions.

3.5.2 Agricultural Return Concentrations

Water quality data for temperature, DO, nutrients, alkalinity, TDS, and pH were collected during the 1999 and 2000 growing seasons at two agricultural returns. Data from both returns were averaged by month and applied to all returns. Estimated monthly concentration values (Table 3-4) were used in conjunction with estimated agricultural flows to calculate loads.

Table 3-4. Monthly Average Concentrations of Agricultural Returns.

	April	May	June	July	August	September	October
Temp (°C)	13.7	17.3	20.9	21.0	19.8	16.1	12.3
DO (mg/L)	11.8	7.9	7.5	6.1	5.7	8.9	10.2
NO_3-N (mg/L)	0.224	0.060	0.073	0.045	0.049	0.178	0.423
NH_3-N (mg/L)	0.050	0.030	0.021	0.022	0.027	0.022	0.036
Ortho-P (mg/L)	0.237	0.172	0.181	0.152	0.098	0.093	0.177
TDS (mg/L)	205.4	192.5	199.2	137.5	179.1	257.0	397.7
ORP (mg/L)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ORN (mg/L)	0.222	0.240	0.300	0.236	0.140	0.126	0.186
ORC (mg/L)	3.088	3.198	3.192	3.173	1.955	0.240	0.625
BOD_{ult} (mg/L)	33.8	29.0	27.2	15.1	18.0	20.9	28.9
Alkalinity (mg/L)	79.8	81.9	86.8	70.7	83.7	109.0	140.7

3.5.3 Groundwater Concentrations

Groundwater concentrations were estimated from well samples near the Truckee River between Wadsworth and Marble Bluff Dam, and from groundwater model predictions. Temperature, nutrients, alkalinity, dissolved oxygen, BOD, CO_2 and TIC were estimated from groundwater well samples. TDS estimates used were from the groundwater modeling report (Pohll et. al., 2001). Estimates of groundwater concentrations used in the model are located in Table 3-5.

Table 3-5. Estimated Groundwater Concentrations.

Constituent	Estimated Groundwater Concentration
Temp (°C)	15.0
DO (mg/L)	5.0
NO_3-N (mg/L)	0.005
NH_3-N (mg/L)	0.001
Ortho-P (mg/L)	0.095
TDS (mg/L)	1100.0 – 2600[1]
Alkalinity (mg/L)	118.0
ORN (mg/L)	0.0
ORP (mg/L)	0.0
ORC (mg/L)	0.0
BOD_{ult} (mg/L)	6.39

[1]TDS concentration varies by reach.

3.5.4 TMWRF Effluent Concentrations

Effluent concentrations were measured by TMWRF staff for the period of calibration. Samples were collected and analyzed on a daily or weekly basis. Daily measurements were available for temperature, DO, orthophosphorus, total phosphorus, nitrate, nitrite, ammonia, pH and flow. Data were collected once or more per week (but not daily) for alkalinity, TDS, SKN, and TKN. Measurements of concentration were assumed to be representative of plant discharge for each day or week, depending on sampling frequency. BOD was estimated from DON using the method described in Section 3.5.1. Table 3-6 reports the average monthly effluent concentrations during the calibration period.

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Table 3-6. Average Monthly Effluent Characteristics from TMWRF during the Calibration Period.

Constituent	Jul-00	Aug-00	Sep-00	Oct-00	Nov-00	Dec-00	Jan-01	Feb-01	Mar-01	Apr-01	May-01	Jun-01	Jul-01	Aug-01	Sep-01	Oct-01	Nov-01	Dec-01	Jan-02	Feb-02	Mar-02	Apr-02	May-02	Jun-02	Jul-02	Aug-02
Flow (MGD)	28.3	30.8	29.2	28.7	28.4	27.8	28.0	28.6	28.0	28.0	27.5	28.0	28.0	28.2	29.5	28.6	28.2	28.4	29.8	28.9	27.9	27.1	27.2	27.5	28.0	28.6
Temp (deg C)	23.0	23.5	22.1	20.3	16.9	15.6	14.4	14.7	16.7	17.4	20.4	21.8	23.1	23.6	22.7	20.8	18.6	15.7	14.7	14.9	15.8	17.9	19.2	21.8	23.7	23.5
TDS (mg/L)	388	387	377	363	356	361	352	341	354	363	376	372	382	384	378	363	371	376	385	374	375	364	347	356	378	378
DON (mg/L)	1.13	1.10	1.02	1.07	1.26	1.04	1.21	1.29	1.13	0.73	2.88	1.24	1.36	1.05	0.99	1.14	1.00	1.41	1.18	1.44	1.41	1.28	0.97	1.10	0.82	0.98
NO3-N (mg/L)	0.090	0.075	0.020	0.054	0.060	0.084	0.589	0.110	0.071	0.057	2.324	0.047	0.185	0.138	0.325	0.027	0.065	0.110	0.116	0.127	0.111	0.030	0.044	0.025	0.045	0.043
NO2-N (mg/L)	0.005	0.004	0.005	0.010	0.006	0.003	0.018	0.005	0.002	0.058	0.476	0.016	0.033	0.011	0.012	0.001	0.003	0.005	0.002	0.002	0.002	0.006	0.004	0.003	0.005	0.004
NH3-N (mg/L)	0.059	0.057	0.074	0.030	0.023	0.035	0.049	0.121	0.054	16.652	10.193	0.076	0.247	0.045	0.015	0.023	0.097	0.047	0.040	0.078	0.066	0.134	0.059	0.098	0.282	0.127
ORN (mg/L)	0.36	0.35	0.32	0.34	0.39	0.33	0.39	0.41	0.35	0.23	0.91	0.39	0.43	0.33	0.32	0.36	0.32	0.44	0.37	0.45	0.45	0.41	0.30	0.35	0.26	0.31
Ortho-P (mg/L)	0.11	0.13	0.09	0.16	0.11	0.18	0.05	0.12	0.20	0.10	0.17	0.16	0.17	0.16	0.13	0.14	0.32	0.12	0.06	0.08	0.10	0.12	0.13	0.19	0.19	0.21
ORP (mg/L)	0.10	0.12	0.14	0.17	0.18	0.16	0.15	0.22	0.19	0.18	0.21	0.15	0.19	0.14	0.14	0.14	0.18	0.18	0.17	0.19	0.21	0.17	0.14	0.13	0.12	0.18
DO (mg/L)	7.3	6.9	6.9	7.4	7.4	7.5	7.5	7.9	7.3	7.6	7.5	6.9	6.7	6.3	6.1	6.2	6.4	6.8	6.9	7.0	6.4	6.2	6.5	6.6	6.2	6.1
Alkalinity (mg/L)	127	129	122	120	126	156	125	123	130	157	157	130	126	120	125	114	133	139	130	127	117	126	121	113	129	125

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3.6 BIOLOGICAL DATA

The Comprehensive Monitoring Program (CMP) was established by the City of Reno, the City of Sparks, and Washoe County to collect data for the calibration of the water quality model in addition to the data collected in the TMWRF routine monitoring program. The CMP was conducted by the stakeholders and DRI, and included monthly surveys over the period of July 2000 through August 2002.

Biological data collection included estimates of algae attached to the stream bottom (periphyton), algae suspended in the water column (phytoplankton), and rooted plants (macrophytes). The periphyton samples included algae attached to rocks (epilithic) and algae attached to soft sediments or sand (epipsammic). Periphyton biomass was measured through analysis of both ash-free dry weight (representing organic matter or biomass) and chlorophyll *a* (the photosynthetic pigment of plants). PhycoTech, Inc., analyzed a subset of samples, approximately one sample per station for each survey. They identified algae to the species level, enumerated algae, and calculated total algal biovolumes represented by each species. Measurements of biovolume are the most direct measure of biomass.

DRI collected samples at eight stations along the Truckee River within the model domain between Glendale Avenue and Marble Bluff Dam (Figure 3-1). A site near Patagonia, upstream of the section of river included in the model, was also sampled. Three to six transects were sampled at each location. Samples were collected from three to eight units along each transect. Each unit represented a different flow/substrate habitat along the transect, and could be dominated by epilithic or epipsammic habitat. Macrophytes could also be present in a unit, or could dominate a unit.

3.6.1 Periphyton Biomass

LTI calculated average transect periphyton biomass by weighting the individual unit sample data according to the proportion of total width represented by the unit. HSPF simulates algae as biomass rather than chlorophyll *a*. For the epilithic periphyton, the ash free dry weight (AFDW) results were assumed to represent algal biomass. The area available for epilithic colonization is greater than represented by a simple two-dimensional area. Cobbles, rocks, and boulders also have vertical faces that increase the habitable area. Based on recommendations from DRI, the area represented by the two-dimensional sample was multiplied by a factor of 2 to represent the actual habitable surface area of the epilithic units. Epipsammic samples had AFDW to chlorophyll *a* ratios that were an order of magnitude or more higher than the epilithic samples. This was likely the result of the organic sediments containing large amounts of degraded detritus and organic matter from other sources. For this reason, the epipsammic chlorophyll *a* data were converted to “equivalent AFDW” by multiplying the chlorophyll *a* data by the median AFDW/chl *a* ratio from the epilithic algae data. Since sand and organic sediments are relatively two-dimensional, there was no correction applied for habitable surface area.

After the equivalent AFDW densities were calculated for each unit, the epilithic and epipsammic data were combined, and average transect biomass was calculated by weighting the individual unit data according to the proportion of total width represented by the unit. It was assumed that the farthest sampled point from the bank represented the units in the middle of a transect that were not wadeable and could not be sampled (DRI, personal communication). This may result in overestimates of the average transect biomass, since it is likely that benthic algal density is less in the deeper, faster water that was not sampled.

3.6.2 Functional Grouping of Periphyton Biomass Data

For taxonomic classification and algal biomass analysis, DRI collected additional periphyton data in the Truckee River under the Truckee River Biomass Monitoring (TRBM) program from November 2001 through August 2002. Samples were collected at six sites (Hershdale, Fleisch, Patagonia, Lockwood, Patrick, Tracy) on the Truckee River. Table 3-7 provides information on sampling locations. The Hershdale, Fleisch, and Patagonia locations are upstream of the model domain. The Lockwood, Patrick, and Tracy locations are within the model domain.

Table 3-7. Truckee River Sampling Stations for Truckee River Biomass Monitoring Program (TRBM)

Stations	Station abbreviations	Distance from Tahoe (km)
Hershdale	HERS	32
Fleisch	FLEI	56
Patagonia	PATA	80
Lockwood	LOCK	106
Patrick	PATR	115
Tracy/Clark	TRAC	122

Samples were collected once a month over a period of several days. Each site was generally sampled once a month on a single day. Data from each sample date includes the taxonomic classification of all periphyton species present in a sample and the relative algal biomass concentration of each periphyton species.

Periphyton data were divided into four functional groups: diatoms, blue-greens, greens, and flagellates. Data were grouped according to the taxonomic grouping given by Canale and Vogel (1974) (Table 3-8). It should be noted that the division *Chrysophyta* referred to in Canale and Vogel (1974) is now *Bacillariophyta,* and the class *Myxophyceae* of the division of *Cyanophyta* is now *Cyanophyceae*. The diatom functional group for this analysis also included the class *Coscinodiscophyceae* and *Fragilariophyceae* of the *Bacillariophyta* division.

Table 3-8. Periphyton Algal Function Group Classification

Algal Functional Group	Division	Class
Diatoms	Bacillariophyta	Bacillariophyceae
Diatoms	Bacillariophyta	Coscinodiscophyceae
Diatoms	Bacillariophyta	Fragilariophyceae
Blue-Greens	Cyanophyta	Cyanophyceae
Greens	Chlorophyta	(all classes)
Flagellates	Chrysophyta	Chrysophyceae

The diatom functional group was the most dominant group throughout the sample period. Diatoms generally dominated the relative algal biomass concentration comprising an average of 86% of the total algal biomass for all sites over the entire sample period. During November, February, and May, diatoms dominated the algal biomass at all sites sampled; making up >80% of the total algal biomass. In contrast, during December, March, and early May, the blue-green functional group dominated the algal biomass at specific sites. Blue-greens were found to dominate the algal biomass in December at Patagonia (54%), in March at Fleisch (82%), and in early May at Hershdale (76%). In addition, blue-greens comprised approximately 10 to 20% of the total algal biomass in November at Fleisch and Patagonia, December at Patrick, and early May at Fleisch. Greens were a dominant periphyton functional group in January at Patrick and Tracy, representing 66% and 45% of the total algal biomass, respectively. In addition, greens totaled 15% of the total algal biomass in March at Patagonia.

3.6.3 Macrophytes

Rooted aquatic plants (macrophytes) were not included in the biomass estimates used for model simulations. Macrophytes obtain a large part of their nutrient requirements from sediments, not the water column. While plant death and decay may release nutrients back to the water column, data were not collected to quantify this source, and it is not expected to be significant relative to other sources. Floating plants such as duckweeds (*Lemna spp.*) and mosquito ferns (*Azolla spp.*) obtain their nutrients from the water column, but were not differentiated from rooted plants in the CMP sampling and thus were not included in the modeling.

3.6.4 Phytoplankton

During the DRI sampling, chlorophyll *a* samples were collected from the water column. Chlorophyll *a* is a measure of the biomass of algae suspended in the water column (phytoplankton). Previous modeling efforts had not included phytoplankton in the simulations because concentrations were low historically. Chlorophyll *a* concentrations found in the CMP sampling were mostly less than 10 ug/L, although some samples were as high as 20 ug/L. Phytoplankton are not expected to have a large impact on nutrient dynamics in a shallow river like the Truckee River where periphyton biomass is many times greater; therefore, phytoplankton were not simulated in TRHSPF.

3.6.5 Benthic Macroinvertebrates

Benthic macroinvertebrate data were collected as part of the CMP. Quarterly samples from the CMP sampling were counted as part of TMWRF's permitting requirements, and these samples were used in the model inputs.

3.6.6 Stoichiometric Ratios

TRHSPF tracks transformations of nutrients and carbon by specifying the ratios of nitrogen, phosphorus, and carbon in algal organic matter. The nutrient composition of organic matter, also called the stoichiometry, was based upon data from the epilithic periphyton samples collected as part of the CMP. Epilithic periphyton are those that grow on rocks, and thus samples are less likely to contain detritus from other sources. As part of the CMP sampling program, representative periphyton samples were collected for analysis of chlorophyll *a*, ash free dry weight (AFDW), particulate carbon, particulate nitrogen, and particulate phosphorus. AFDW is used in the HSPF modeling to represent biomass. Ratios of the nutrients and biomass were calculated, and these values were used as guides when developing inputs to the model (Table 3-9) and in calculating boundary loads and calibration data. The CVBO variable relating oxygen to organic matter was calculated based upon theoretical organic matter oxygen to carbon equivalence (2.67 mg O_2/mg C) and the measured carbon to AFDW ratio. Table 3-10 includes the commonly referenced stoichiometric equivalents based directly upon the median ratios from the CMP data.

Table 3-9. Stoichiometric Inputs for TRHSPF

HSPF input variable	Units	Value
RATCLP	mg chl/mg P	0.8
CVBO	mg O_2/mg OM	1.70
CVBPC	mol C/mol P	158
CVBPN	mol N/mol P	16.2
BPCNTC	mg C/mg OM*100	40

Table 3-10. Nutrient to Organic Matter Ratios

Ratio	Value
mg N / mg OM	0.0475
mg P / mg OM	0.00654
mg C / mg OM	0.40
mg OM / chl *a*	191

4. MODEL CALIBRATION

Model calibration consists of adjusting model coefficients (within an acceptable range dictated by field, laboratory, and literature values) until a model is able to best reproduce site-specific observations. The confidence that can be placed in model predictions based upon model calibration is directly dependent upon: 1) the degree to which model results match observed data, and 2) the quantity of observed data available to support calibration. The greater the amount of data that can be accurately described by the model, the greater amount of confidence that can be placed in model predictions.

The TRHSPF model was calibrated to field data collected from the years 1990, 1995, 1996, 2000, 2001, and 2002. The focus of the calibration effort was the 2000-2002 period, as this period corresponded to a comprehensive monitoring program that provided robust water quality data and was the only period that contained comprehensive periphyton measurements. Kinetic coefficients that were defined during the calibration to the 2000-2002 data were subsequently used in a model confirmation (sometimes called "model verification") step to confirm that their use would acceptably simulate conditions observed in 1990, 1995, and 1996.

The remainder of this section describes the calibration process. It is divided into sections discussing:

- Model configuration
- Calibration process
- Calibration metrics
- Flow calibration
- Temperature calibration
- Total dissolved solids (TDS) calibration
- Nutrient calibration
- Periphyton calibration
- Dissolved oxygen calibration
- Alkalinity and pH calibration
- Model validation to observed data from 1990, 1995, 1996
- Suitability of model calibration for future management use

Each calibration subsection describes the data available for calibration, and the variables modified to improve calibration. Statistics comparing the simulated constituent with measured data are provided in each section.

4.1 MODEL CONFIGURATION

The first step in model application consists of describing the physical characteristics of the system, for use in the model.

TRHSPF was built on the model framework developed by the USGS (Nowlin, 1987; Berris, 1996; Taylor 1998). The USGS flow and water quality model spanned the entire Truckee River from Lake Tahoe to Pyramid Lake. TRHSPF uses the model characteristics developed by the USGS from East McCarran Bridge to Marble Bluff Dam. This section of river corresponds to reach 301 through 343 of Nowlin's (1987) model. It spans approximately 55 miles and the drop in elevation is 550 feet. The physical characteristics developed by USGS include:

- Reach length
- Elevation change for each reach
- Agricultural diversion and return locations (Figure 3-1)
- Topographic shading factors for each reach
- Channel characteristics
- Stage discharge relationships (F-tables) for each reach
- Calibrated model coefficients for temperature and dissolved solids

The above model parameters were used as a starting point for TRHSPF. Minor changes in some of these parameters were made to aid the calibration process.

4.2 CALIBRATION PROCESS

TRHSPF was calibrated to data from the years 1990, 1995, 1996, 2000, 2001, and 2002. The primary focus of the calibration was the data collected during July 2000 through August 2002. This is the only period with benthic algae data, and was used to calibrate and test parameters related to benthic algae growth, respiration, removal, and their impact on other water quality constituents. The kinetic coefficients from this period were used as a starting point for the other calibration periods.

Low, average, and high flow years were selected for the remaining calibration periods. Selecting independent data sets that reflect a range of flow conditions will test the robustness of model calibration. The years 1990, 1995, and 1996 reflect low (10% percent of annual flows less than this value), average (~60% less than), and high (76% less than) flow in the Truckee River at the Vista and Nixon gauging stations. These data sets will provide an adequate confirmation of most of the parameters of interest. They are all missing periphyton data, thus limiting their usefulness.

The calibration process proceeded as follows:

- The model was calibrated to the period between July 2000 through August 2002;

- The model was reconfigured and run for the years 1990, 1995, and 1996 and compared to data for these periods with the kinetic coefficients kept fixed; and

- The model's goodness of fit was assessed for the calibration and confirmation years.

The parameter set that best explains conditions in the river as measured by visual and statistical comparison to observed data, and is within typical ranges for all coefficients, was selected.

4.3 CALIBRATION METRICS

Model calibration is the process of comparing model predicted results to observed data, and adjusting un-measured model coefficients (within accepted ranges) in order to achieve an acceptable comparison between model and data. There are no generally accepted guidelines for what constitutes an "acceptable" model calibration. Model calibration is best conducted on a weight of evidence approach that considers both graphical and statistical comparisons (Thomann, 1982). The answer to the question "how good of a model calibration is required?" depends on the intended use of the model. Reckhow et al. (1997) suggest reversing the question to "what management decisions can be supported, given the current quality of the model calibration?" The approach taken here is to achieve the best fit to a series of metrics, while keeping model parameter values within accepted and measured ranges.

The metrics used for assessing the calibration were:

- Visually comparing time series plots of flow and water quality constituents at all available sampling locations;

- Visually comparing profile plots of flow and water quality constituents for several time periods;

- Regression statistics of predicted vs. observed values (Table 4-1) for flow, TDS, temperature, and DO;

- The residual, relative and average errors (Table 4-1) between the simulated and observed daily maximum, mean, and minimum temperature, and DO; and

- The residual, relative, and average error for total phosphorus, total nitrogen, and alkalinity.

Table 4-1. Equations for Statistics Used during Model Calibration.

Statistic	Equation
*Regression, r^2	$\left[\frac{\sum xy - \sum x \sum y}{\sqrt{[\sum x^2 - (\sum x)^2][\sum y^2 - (\sum y)^2]}}\right]^2$
*Regression, slope	$\frac{\sum xy - (\sum x)(\sum y)}{\sum x^2 - (\sum x)^2}$
*Regression, y-intercept	$\overline{Y}$ - *Slope* $\overline{X}$
Average Error	$\sum_{i=1}^{n} \frac{\lvert Simulated\ Value - Observed\ Value \rvert}{n_{\text{obs}}}$
Relative Error	$\sum_{i=1}^{n} \frac{(Absolute\ Average\ Error / Observed\ Value)}{n_{\text{obs}}}$
Residual Error	$\sum_{i=1}^{n} \frac{(Simulated\ Value - Observed\ Value)}{n_{\text{obs}}}$

*Calculated using built-in Microsoft Excel capabilities

No single error calculation is capable of capturing both the average size of the error as well as the potential for bias, so a suite of error calculations are conducted.

The average error is an average of the absolute value of the difference between predicted and observed data. The average error represents the amount of error in predictions regardless of whether they are higher or lower than the observed data. Relative error converts the average error to a percentage basis, by dividing the error by the observed concentration. Relative error is often useful for purposes of reporting, because it can be compared across parameters with different units. Residual error is the arithmetic average of the predicted minus the observed concentrations. The sign of the residual error (+ or -) indicates whether predictions are higher or lower than observed data, and indicate whether the model results are biased--i.e., whether they tend to be disproportionately positive or negative.

4.4 FLOW CALIBRATION

TRHSPF flow routing is based on the estimated inflows and diversions present in each reach and the estimated stage discharge relationship specified in the format required by HSPF. The use of observed and estimated flows at the upstream boundary, North Truckee Drain, Steamboat Creek, TMWRF, agricultural ditches, and the Truckee Canal resulted in an acceptable fit at three of the five comparison locations. Model results for flow, depth and velocity are presented at the following locations corresponding to USGS gauges (Figure 3-1).

- Sparks, NV (10348200)
- Vista, NV (10350000)
- Tracy, NV (10350340)
- Below Derby Dam, NV (10351600)
- Wadsworth, NV (10351650)
- Nixon, NV (10351700)

Comparisons of simulated and observed flow were acceptable at Reno, Vista, Tracy, Wadsworth and Nixon, NV. Each of these stations showed a close match between simulated and observed flow, and had a high regression value. Detailed comparisons of predicted and observed flows at these stations are shown in Figures A-1 through A-6 of Appendix A. Regression statistics are reported in Table 4-2.

The flow comparison at the gauge below Derby Dam differed by as much as 300 cfs between July 1, 2000 and December 4, 2000. After December 4, 2000, model simulation matches the gauge well (Appendix A, Figure A-4). This difference may be due to operation of Gilpin Spill (personal communication with Roger Leseur, 2002). Gilpin spill is used to regulate the volume of water diverted from the Truckee River by the Truckee Canal. It is located on the Truckee Canal and returns water to the Truckee River in a section of the river below the Derby Dam gauge (USGS 10351600) and above the gauge at Wadsworth, NV (USGS 10351650). Therefore flow measurements at the Derby Dam gauge may be lower than measurements at Wadsworth because they do not include this return flow. As explained in section 3.4, TRHSPF assumes a "net" Truckee Canal flow and does not include the Gilpin Spill return flow in the TCID diversion. The volume of water that will be returned by Gilpin spill just downstream of the diversion is simply left in the river. Therefore, the model may over-predict flow in the reaches (320-321) between the head of the canal and Gilpin spill. The impact of this simulation method is limited to these two reaches.

Table 4-2. Summary of Regression Statistics for Flow.

Location	R^2
McCarran	1.0
Vista	0.99
Tracy	0.98
Below Derby Dam	0.21 (July 1, 2000 – Dec. 4, 2000) and 0.94 (Dec 5, 2000 – Aug. 31, 2002)
Wadsworth	0.99
Nixon	0.98

4.5 TEMPERATURE CALIBRATION

Stream water temperatures were recorded at 10 locations between Reno, NV and Pyramid Lake. Monthly readings were taken during TMWRF's routine sampling program at seven locations, and hourly data were measured using YSI data sondes at eight locations (Table-4-3). These were East McCarran, Lockwood, Tracy, Painted Rock, Wadsworth, Dead Ox, Little Nixon, and Marble Bluff Dam. The hourly measurements from East McCarran were used as model inputs for the upstream boundary. Hourly measurements taken at five additional locations were used for model calibration. These data were supplemented with monthly measurements from TMWRF's routine sampling locations.

Table-4-3. Location and Frequency of Stream Temperature Data Collected between Reno, NV and Marble Bluff Dam.

Location	Frequency of Measurement	Time Period with Hourly Data
East McCarran	Monthly, Hourly	July, 2000 – December, 2000 and March, 2001 – August, 2002
Lockwood	Monthly, Hourly	July, 2000 – December, 2000 and March, 2001 – August, 2002
Tracy	Hourly	July, 2000 – December, 2000 and March, 2001 – August, 2002
Derby Dam	Monthly	Not available
Painted Rock	Monthly, Hourly	July, 2000 – December, 2000 and March, 2001 – August, 2002
Wadsworth	Monthly, Hourly	July, 2000 – December, 2000 and March, 2001 – August, 2002
Little Nixon	Monthly	Not available
Marble Bluff Dam	Hourly	July, 2000 – December, 2000 and March, 2001 – August, 2002

Calibration of temperature was based on work previously completed USGS (Berris, 1996). The calibrated parameters were used in conjunction with meteorological and stream temperature data measured for the period of interest. Using these values resulted in an acceptable model fit to the measured data.

The calibration process for stream temperature included:

- Visually comparing the simulated and measured values;
- Calculating absolute average and residual errors between the daily maximum, mean and minimum observed and predicted values; and
- Performing regression analysis between model results and hourly measured values.

Detailed temperature time series plots are shown in Appendix A for the entire calibration period in Figures A-7 through A-12. These figures show that the model describes the seasonal variation in temperature and follows the diel trend well. The predicted magnitude of the swings, and the time of peak temperature for each day are close to the measured values.

To quantify the comparison between observed and predicted values, the average error, residual error, and regression statistics were calculated at each station with continuous monitoring data. The average and residual errors for daily maximum, mean, and minimum values are reported in Table 4-4. The regression analysis results are reported in Table 4-5. This analysis was conducted at each station where hourly observed data were collected for a significant period of time.

The figures and statistics show that the model closely matches observed data at all locations and times. In general, TRHSPF slightly over-predicts the daily maximum and mean, and under-predicts the daily minimum (Table 4-5). In addition, the calculated errors tend to become greater, and r^2 values smaller at downstream stations. This may be due to lower flows at the downstream stations. Low flows at these stations are associated with shallower depths and slower velocity. These conditions allow for potentially greater daily fluctuations, and may increase the influence of external forces that are not monitored in detail such as agricultural return flows.

Table 4-4. The Average and Residual Error between Observed and Predicted Temperature Values (degrees F) for the Entire Simulation Period at Each Station with Continuous Monitoring Data.

	East McCarran	Lockwood	Tracy	Painted Rock	Wadsworth	Marble Bluff Dam	Avg.
Average Error							
Max	0.78	1.02	1.27	1.74	1.65	1.56	1.18
Mean	0.33	0.54	0.78	1.80	1.91	1.71	1.29
Min	0.99	0.60	0.69	1.57	2.06	1.83	1.29
N	711	701	689	672	677	653	
Residual Error							
Max	-0.67	-0.95	-1.18	-1.37	-0.73	-0.25	-0.91
Mean	0.28	-0.47	-0.61	-1.66	-1.76	-1.25	-0.49
Min	0.98	0.28	0.05	-1.05	-1.90	-1.32	-0.49
N	711	702	689	672	677	653	

Table 4-5. Regression Statistics between Observed and Predicted Temperature Values at Each Sampling Location for the Entire Calibration Period (July 1, 2000 – August 31, 2002).

Location	r^2	Slope	Intercept
McCarran	1.00	1.00	0.04
Lockwood	0.99	1.00	-0.18
Tracy	0.99	1.00	-0.55
Painted Rock	0.96	1.00	-1.63
Wadsworth	0.97	0.98	-0.81
Marble Bluff Dam	0.96	0.97	0.69

4.6 TDS CALIBRATION

Simulated concentrations of TDS are dependent on the loads input to the model and the simulated stream flow. No model coefficients can be adjusted to calibrate the TDS model. The primary mechanism for TDS calibration was varying the estimated groundwater concentration to match the observed increase in TDS below Wadsworth during low flow. Different estimates were used and the subsequent model results were compared to the increased concentration observed at Dead Ox, Little Nixon, Nixon, and Marble Bluff Dam. The estimated TDS concentration that was within the range of observed values and gave the best fit to data was used.

TDS concentrations were measured or estimated using specific conductivity at 12 locations between Reno, NV and Marble Bluff Dam. Time series calibration plots for these locations are shown in Figure A-13 through A-24 in Appendix A.

To quantify the comparison between observed and predicted values, the average, residual, and relative errors, and regression statistics were calculated and are reported in Table 4-6. This analysis was conducted at each station where hourly-observed data were collected. Model relative error was good, averaging less than 8%. Regression statistics were also good at most stations, with r-squared values above 0.85 for all stations.

Table 4-6. Residual, Average, and Relative Error, and Regression Statistics between Observed and Predicted TDS at Each Location for the Entire Simulation Period.

Location	Residual Error	Average Error	Relative Error	r^2	Slope	Intercept
McCarran	-0.04	1.51	3%	0.94	0.96	2.97
Lockwood	-9.21	11.65	8%	0.85	0.81	18.96
Tracy	-8.69	9.83	7%	0.91	0.91	4.84
Painted Rock	-11.11	11.99	8%	0.91	0.98	-7.91
Wadsworth	-9.16	10.90	7%	0.90	1.02	-12.57
Marble Bluff Dam	27.02	29.68	11%	0.93	1.24	-31.48

4.7 NUTRIENT CALIBRATION

TRHSPF simulates a complete mass balance for nitrogen and phosphorus. These constituents are tracked by the model in three forms: Forms that are available to algae, labile forms that readily break down, and refractory forms that are transported out of the system with no further transformation. Nutrient forms available for algal growth include ammonia nitrogen, nitrate nitrogen, and orthophosphorus. Labile organic forms of nutrients are grouped together and added to the state variable, BOD. As noted in Section 3.5, BOD is estimated from dissolved organic nitrogen measurements. The labile nitrogen, phosphorus, and carbon portions of BOD are calculated from the stoichiometric relationship used in HSPF. HSPF uses separate state variables for the refractory forms of nutrients: organic refractory nitrogen (ORN), organic refractory phosphorus (ORP), and organic refractory carbon (ORC). Nutrients contained in algal tissue are accounted for in the nutrient mass balance when death or removal occurs. The nutrients are added to the organic refractory state variables (ORN, ORP, and ORC), or are made available as inorganic nutrients based on user-specified variables. Inorganic, labile, and organic refractory components of nitrogen and phosphorus are summed for total nitrogen and total phosphorus.

Data used for calibration were measured at eleven locations between Reno, NV and Marble Bluff Dam (Table 4-7). Water quality samples were collected at these locations as part of the CMP and TMWRF routine sampling. Each monitoring program collected samples approximately once per month. A direct comparison between model results and observed data can be made for total ammonia (NH_3+NH_4), nitrate (NO_3), orthophosphorus (PO_4), TP, and TN. Figures used to assess calibration are discussed in the following subsections. The average, residual, and relative error calculations for these constituents are reported in Table 4-8.

Table 4-7. Location of Sampling Sites Used for Calibration of Nutrients.

Location	Sampling Program	
	TMWRF	CMP
East McCarran (MCCN)	X	X
Lockwood (LOCK)	X	X
Patrick (PAT)	X	X
Tracy	X	X
Below Derby Dam (DERBY)	X	
Painted Rock (PAINT)	X	X
Wadsworth (WADS)	X	
John's Ranch (JOHN)	X	X
Dead Ox (DEAD)	X	X
Nixon (NIX)	X	
Little Nixon (LNIX)	X	X

The instream concentration of nutrients is dependent on the density, growth, and death of periphyton, as well as external loads. For this reason calibration of nutrients was completed in conjunction with periphyton. Model parameters modified from the preliminary calibration included the stoichiometric constants (Table 3-8), and the nitrification rate of ammonia (KTAM20). The stoichiometric constants were based on algal biomass measurements unavailable during DSSAMt calibrations. The ammonia nitrification rate (KTAM20) was varied depending on the average depth of each reach, based on the relationship used in DSSAMt (Caupp et al., 1998).

Overall the total nitrogen simulation compared well to observed data except for the most downstream end of the system. The relative error for observed and predicted TN was 50%, with the majority of this error coming from the two most downstream stations. The residual error was typically small and negative at all stations, except Dead Ox (Table 4-8, and Figures A-25 through Figure A-34), indicating a slight under-simulation of TN. The calibration of ammonia (Figure A-35 through Figure A-44) and nitrate (Figure A-45 through Figure A-54) tends to follow similar patterns as TN.

Comparisons of simulated and observed dissolved organic nitrogen (DON) are also presented for each station. Since DON is not directly measured, it was estimated by subtracting NH_3 from SKN. The model simulates organic nitrogen as part of the BOD state variable. To perform the DON comparison, the nitrogen portion of BOD was calculated based on stoichiometric coefficients in the model (and estimated from data, see Section 4.5). Time-series plots of the DON comparison are shown in Figure A-55 through Figure A-64.

Total phosphorus simulations compared reasonably well to observed data (Figure A-65 through Figure A-74). In general, TP was over-simulated at most sites. This is the result of using labile nitrogen to estimate ultimate BOD. HSPF lumps labile nutrients into BOD. The ratio of nutrients to BOD is based on a constant stoichiometric relationship. Using nitrogen to estimate BOD resulted in the over-prediction of labile phosphorus. This bias was expected. Using labile nitrogen to estimate BOD allowed for a nitrogen mass balance within the system. The calibration of orthophosphorus shows a much better comparison to observed data than TP (Figure A-75 through Figure A-84).

Table 4-8. Error Statistics for Nutrients at Each Location (July 1, 2000 – August 31, 2002).

Constituent	Statistic	East McCarran	Lockwood	Patrick	Tracy-Clark	Derby Dam	Painted Rock	Wadsworth	Johns Ranch	Dead Ox	Little Nixon	Average
Total Phosphorus	Residual Error	0.011	0.046	0.045	0.037	0.038	0.026	0.026	0.025	0.037	0.027	0.032
	Average Absolute Error	0.012	0.046	0.047	0.038	0.039	0.031	0.029	0.034	0.037	0.030	0.034
	Relative Error	134%	73%	64%	67%	72%	52%	55%	52%	44%	71%	68%
	n	35	47	18	45	27	34	26	18	7	41	
Orthophosphorus	Residual Error	0.001	0.006	0.010	0.006	0.006	0.002	0.006	0.012	0.022	0.014	0.008
	Average Absolute Error	0.002	0.008	0.013	0.010	0.010	0.011	0.011	0.017	0.027	0.016	0.012
	Relative Error	30%	20%	31%	30%	28%	27%	33%	87%	85%	73%	44%
	n	35	46	18	44	27	34	26	18	7	41	
Total Nitrogen	Residual Error	-0.007	0.000	-0.090	-0.003	-0.027	-0.027	-0.070	-0.012	0.069	-0.052	-0.022
	Average Absolute Error	0.039	0.129	0.213	0.110	0.144	0.128	0.161	0.164	0.152	0.147	0.139
	Relative Error	30%	21%	27%	19%	18%	23%	25%	28%	43%	40%	27%
	n	34	45	19	34	27	33	27	17	6	43	
Nitrate-nitrogen	Residual Error	0.000	0.012	-0.025	0.002	0.026	0.021	0.014	0.010	0.041	0.021	0.012
	Average Absolute Error	0.005	0.019	0.068	0.045	0.034	0.032	0.030	0.046	0.041	0.025	0.035
	Relative Error	63%	78%	203%	208%	166%	205%	147%	227%	955%	362%	261%
	n	34	46	20	44	27	33	27	18	6	44	
Total Ammonia	Residual Error	-0.016	0.006	0.008	-0.012	-0.022	-0.001	0.016	0.026	0.007	-0.007	0.000
	Average Absolute Error	0.017	0.024	0.024	0.023	0.027	0.010	0.031	0.040	0.016	0.014	0.023
	Relative Error	84%	56%	51%	36%	34%	32%	133%	58%	78%	61%	62%
	n	35	45	19	44	27	34	27	17	7	44	
Dissolved Organic Nitrogen	Residual Error	0.060	0.162	0.175	0.162	0.159	0.172	0.160	0.255	0.225	0.199	0.173
	Average Absolute Error	0.061	0.177	0.249	0.190	0.184	0.192	0.201	0.255	0.225	0.213	0.195
	Relative Error	61%	75%	136%	105%	83%	108%	106%	115%	58%	92%	94%
	n	30	33	6	32	27	28	27	6	4	33	

4.8 PERIPHYTON CALIBRATION

The CMP collected periphyton data at eight locations within the model domain. These locations were East McCarran, Lockwood, Patrick, Tracy, Painted Rock, John's Ranch, Dead Ox, and Nixon (Figure 3-1). Data were collected at each location as frequently as once per month to once per quarter. Samples were analyzed to determine the type and biomass of periphyton at each transect. The biomass densities observed at each transect varied significantly at a given site. For this reason, model results were compared to the densities estimated for each transect at each site, as well as the average biomass for each transect.

Results for the calibration are summarized across all sampling events in Figure 4-1 and are provided in more detail in Appendix A, Figures A-85 through A-92. Results plotted in Figure 4-1represent the average modeled and observed periphyton densities and the observed data error bars represent ±1 standard deviation. While the observed data show large amounts of variability throughout the system (as evidenced by the error bars in Figure 4-1), predicted periphyton densities match observed densities very well along the entire length of the river.

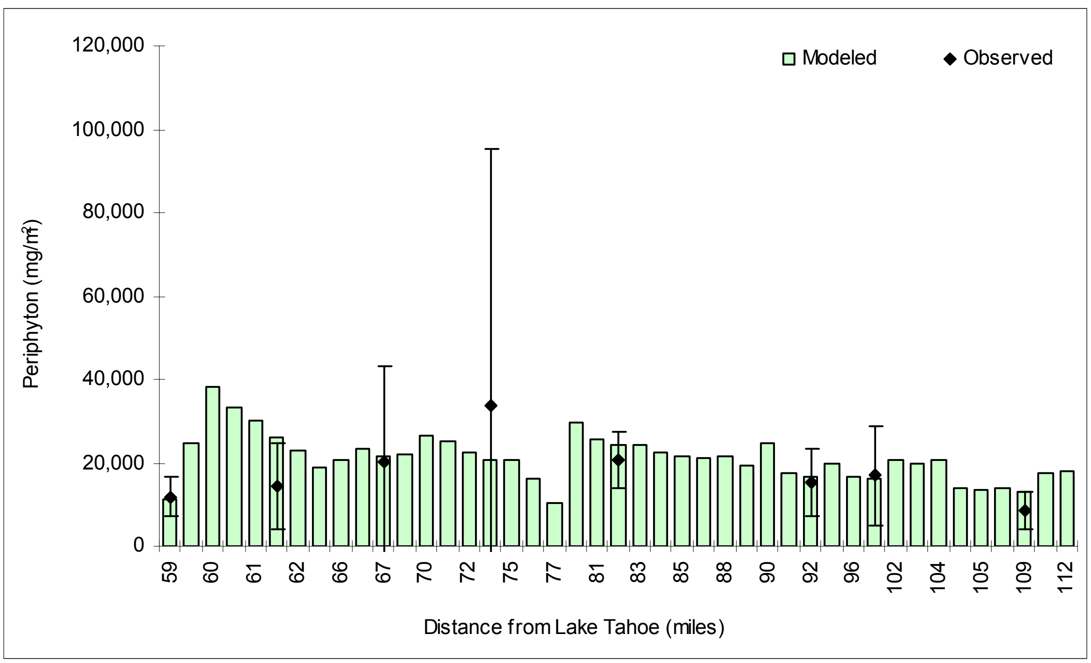

Figure 4-1. Summary of Periphyton Calibration.

Initial model parameters related to periphytion were set to those developed during the preliminary calibration. Parameters adjusted during calibration were done so for three reasons.

1. Direct measurements suggested that the value should be changed.

2. The currently used value is outside that commonly cited in the literature.

3. To provide improved fit to observed data for parameters that had limited data to support them.

The parameters altered during calibration fell into one or more of the above categories.

Table 4-9 lists the HSPF variable name, a description of its function, why it was changed, the new value, and previously used value. The values altered were the light attenuation method (EXTB), grazing macroinvertebrate biomass (BINV), the saturation light level (CSLIT), the half-saturation constant for riffle velocity in the nutrient availability equation (CMMV), and the macroinvertebrate-grazing rate (CREMVL).

Table 4-9. Parameters Used During Periphyton Calibration.

Variable	Description	Reason for difference	TRHSPF value	Preliminary Calibration value
EXTB	Light attenuation factor	Photosynthetically available radiation (KPAR) data did not indicate relationship with turbidity or flow. Averaged measured data were approximately equal to new value.	0.4 ft^{-1}	Correlated factor to turbidity. Thus the value varied spatially and temporally
CREMVL	Biomass removed by grazing macroinvertebrate	Updated to reflect literature values. Estimated mass of benthic invertebrates varied monthly based on TMWRF sampling program.	34.66 mg/mg/yr	19.66
BINV	Biomass of macroinvertebrate	Estimated mass of benthic invertebrates based on TMWRF quarterly sampling program.	Monthly value by reach between 110 and 23,620 mg/m^2	Single value for each reach for entire year between 2410 and 4140 mg/m^2
CSLIT	Saturation light level	Value was used as calibration parameter for preliminary calibration. Changed for final calibration to reflect literature values.	0.278 ly/hour	0.185 ly/hour
CMMV	Half saturation constant for riffle velocity in the nutrient availability equation for benthic algae.	TRHSPF uses the velocity limitation equation to reduce nutrient concentrations available to benthic algae. Variable set fairly low to keep this function from contributing too much to periphyton loss.	.2001 ft/s	1.6 ft/s

4.9 DISSOLVED OXYGEN CALIBRATION

DO predictions from TRHSPF were compared to observed data at seven locations between Reno, NV and Marble Bluff Dam. Each location included a combination of discrete samples and continuous data from YSI data sondes. The locations used for calibration were East McCarran Bridge, Lockwood, Tracy, Painted Rock, Wadsworth, Little Nixon, and Marble Bluff Dam. The data sondes were typically placed instream for the entire calibration period, but were removed from January through March in 2001 due to safe access concerns. Thus, continuous data are not available during that period. Monthly measurements collected as part of the CMP or TMWRF sampling program are available at four of the calibration locations and provide an additional check for periods without continuous monitoring data.

Figures A-93 through A-99 in Appendix A show model predictions compared to observed data at each location. These calibration figures show three lines representing simulated maximum, average, and minimum daily DO concentrations. The measured data are displayed as a solid band that covers the range of values observed each day. Points are plotted to represent the data collected at discrete sampling events.

Primary calibration variables for DO were those that affected periphyton growth or death, and the escape coefficient used for the Tsivoglou reaeration equation. Increased periphyton growth increased the magnitude of the diurnal oxygen swing. Reductions in periphyton had the opposite effect. The escape coefficient modifies the reaeration in each reach. Increasing the escape coefficient increases reaeration, reducing the escape coefficient limits reaeration.

Nowlin (1987) conducted a reaeration study in support of water quality modeling work. He concluded that Tsivoglou's equation best described the reaeration mechanisms that occur in the Truckee River, and estimated an escape coefficient for the river. Nowlin's (1987) estimated escape coefficient was used as a starting point for DO calibration. The escape coefficient was then modified to improve fit by using the escape coefficient used by Brock (1998). The resulting predicted reaeration rates remained within the range of reported values for most model segments. Table 4-10 shows the average reaeration coefficient and Tsivoglou's escape coefficient for each reach.

Two studies have been conducted on the Truckee River to estimate reaeration. Nowlin (1987) conducted oxygen reaeration studies on the Truckee River during October 1979 and July 1980. He calculated reaeration coefficients from Mustang Bridge to Derby Dam (Reaches 308 – 315), and from the Railroad Bridge below Wadsworth to Dead Ox (Reaches 327 – 335). Flow conditions during Nowlin's study were 324 to 372 cfs above Derby Dam, and 50 to 78 cfs below Derby Dam. Lico and Taylor (1999) calculated reaeration rates during August and September of 1999 between Mustang Bridge and Patrick. Flows were 570 cfs during this study. The sections of river used to estimate reaeration for the Nowlin and Lico studies do not correspond exactly to model reaches in TRHSPF. However, for purposes of comparison, Table 4-10 includes estimates of reaeration from both of these studies. The relationship of estimated reaeration to model reach is approximate. In all cases, simulated average reaeration rates compare well to those estimated from the USGS field studies.

The predicted DO provides a very good match to the observed data. All stations show a positive correlation between predicted and observed DO (Table 4-11). Relative error between predicted and observed daily means is typically less than 10%, and the average absolute error for the daily minimum is less than 1.0 mg/L at all stations (Table 4-12). The seasonal trend and diurnal swing in DO concentrations match observed data well (e.g., typically less than 15% difference between observed and predicted daily maximum or minimum) at most locations during the simulation period.

Table 4-9. Escape Coefficient, Predicted Average Reaeration Coefficient, and Measured Reaeration Coefficient for Each Reach.

Model Reach	Escape coefficient (ft^{-1})	Average predicted reaeration coefficient (day^{-1}) at 20 °C	Average Simulated Flow (cfs)	Estimated reaeration rate (Nowlin and Lico) day^{-1}
301	0.029	3.30	393	NA
302	0.029	0.53	409	
303	0.029	0.37	485	
304	0.029	0.35	485	
305	0.029	13.81	482	
306	0.029	10.79	482	
307	0.029	58.21	482	
308	0.029	13.29	482	2.52 – 17.8
309	0.029	5.65	483	
310	0.029	0.49	483	
311	0.029	13.30	483	
312	0.029	7.21	484	
313	0.029	1.71	484	
314	0.029	2.44	484	
315	0.029	3.20	484	
316	0.029	5.73	484	NA
317	0.029	7.05	484	
318	0.029	3.39	483	
319	0.029	0.90	202	
320	0.029	6.12	202	
321	0.029	7.15	202	
322	0.029	10.46	202	
323	0.029	3.55	202	
324	0.029	9.30	201	
325	0.029	3.06	201	
326	0.029	3.07	202	
327	0.029	4.75	202	5.25 – 7.49
328	0.029	3.79	203	
329	0.029	1.13	204	
330	0.029	7.81	208	
331	0.029	5.55	213	
332	0.029	5.79	218	
333	0.029	4.72	218	
334	0.029	4.20	219	
335	0.029	2.03	220	
336	0.029	5.69	221	NA
337	0.029	0.38	221	
338	0.029	4.51	220	
339	0.029	8.40	220	
340	0.029	5.22	222	
341	0.029	8.87	222	
342	0.029	5.14	223	
343	0.029	0.83	223	

Table 4-10. Error and Regression Statistics between Hourly Observed and Predicted DO Measurements between July 1, 2000 and August 31, 2002.

Location	Residual	Average	Relative	r^2	Slope	Intercept
McCarran	-0.10	0.32	3.3%	0.94	0.92	0.70
Lockwood	-0.02	0.40	4.5%	0.89	0.91	0.79
Tracy	-0.18	0.83	9.4%	0.70	0.71	2.50
Painted Rock	0.48	0.73	8.2%	0.79	0.86	1.82
Wadsworth	-0.05	0.94	10.3%	0.65	0.73	2.47
Marble Bluff Dam	0.13	1.02	13.0%	0.64	0.62	3.61

Table 4-11. Average, Residual, and Relative Error for Daily Observed and Predicted Maximum, Mean, and Minimum Dissolved Oxygen between July 1, 2000 and August 31, 2002.

Statistic	East McCarran	Lockwood	Tracy	Painted Rock	Wadsworth	Marble Bluff Dam	Avg.
Average Error							
Max	0.37	0.59	1.01	0.69	0.82	0.91	0.73
Mean	0.12	0.27	0.49	0.58	0.61	0.54	0.44
Min	0.17	0.41	0.57	0.79	0.68	0.77	0.56
n	679	591	567	556	503	568	
Residual Error							
Max	-0.35	-0.22	-0.65	0.09	-0.29	-0.63	-0.34
Mean	-0.10	-0.02	-0.22	0.49	-0.04	0.13	0.04
Min	0.06	0.05	0.42	0.72	0.08	0.66	0.33
n	679	591	567	556	503	568	
Relative Error							
Max	3%	6%	9%	6%	7%	8%	7%
Mean	1%	3%	5%	6%	6%	6%	5%
Min	2%	5%	9%	10%	9%	13%	8%
n	679	591	567	556	503	568	

4.10 ALKALINITY AND pH CALIBRATION

The predicted pH levels are dependent on the provided alkalinity. For this reason, the calibration of the two parameters is discussed in this section together.

No model variables can be adjusted to calibrate alkalinity. Simulation results are dependent on the alkalinity loads input to the model and the simulated stream flow. A mild increase in alkalinity concentration was observed in the data during low flow periods below Wadsworth, NV. This is the only area where groundwater accretion occurs. Since the increase in alkalinity concentrations occurs during low flow, groundwater loading is the suspected cause. For this reason, different assumptions regarding alkalinity concentrations in the groundwater were tested. The estimate that provided the closest fit with the data was used (average relative error < 10%, Table 4-13). This was the only calibration adjustment made for alkalinity. Alkalinity calibration figures for all TMWRF and CMP stations are shown in Figures A-100 through A-109 in Appendix A.

Simulated pH levels are dependent on alkalinity, carbon loads, and two variables. The variables are:

- The ratio of the carbon dioxide invasion rate to the oxygen reaeration rate.
- The benthal release rate of CO_2 (as carbon) for aerobic and anaerobic conditions.

Calibration of pH was conducted last. The primary calibration variables were the benthal release rates. The carbon dioxide invasion ratio was calculated using a relationship developed by Mills et al. (1982) and described in Chapra (1997). The resulting ratio of 0.923 was used in the model. No data were available for the benthal release rates of carbon under aerobic or anaerobic conditions. Both values were set low and increased until a suitable model fit was achieved. Final values of 32 mg/m^2–hr and 36 mg/m^2–hr were used.

Simulated pH results were compared with hourly data collected using YSI data sondes. The locations used for calibration are the same as those used for DO, temperature, and TDS. Calibration figures for pH are shown in Figures A-110 through A-118 in Appendix A.

Table 4-12. Error Calculations between Observed and Predicted Alkalinity for July 1, 2000 and August 31, 2002

	Statistic for Alkalinity			
Station	Residual Error	Average Absolute Error	Relative Error	n
McCarran	1.49	2.25	2%	34
Lockwood	1.17	5.80	6%	46
Patrick	5.98	9.02	9%	19
Tracy-Clark	1.68	5.61	6%	44
Derby Dam	1.59	5.39	4%	27
Painted Rock	0.40	5.84	5%	32
Wadsworth	-0.15	7.21	6%	27
Johns Ranch	4.54	10.20	7%	16
Dead Ox	12.59	21.30	9%	6
Little Nixon	0.11	8.17	8%	42
Total	2.94	8.08	6%	196

4.11 COMPARISON TO OBSERVED DATA FROM 1990, 1995-1996

In addition to the primary calibration period of 2000-2002, TRHSPF was also applied to the years 1990, 1995-1996. These years lack the comprehensive calibration data set that was available for 2000-2002, but do contain sufficient information on environmental forcing functions and observed Truckee River DO to provide additional assessment of the model. This step was often called “model verification” and is now commonly referred to as “model confirmation.”

Observed DO data consisted of continuous measurements from YSI data sondes at Tracy and Wadsworth in 1990. In 1995-1996, continuous measurements were available from YSI data sondes at the following locations: McCarran, Lockwood, Tracy, Painted Rock, and Marble Bluff Dam. The data sondes were typically placed instream from April through December, and removed from January through March due to safety concerns and possible sonde damage from high flows . These specific years were selected because they represent a range of Truckee River flow conditions.

The years 1995 and 1996 reflect average (~60% of annual flows less than this value) and high (76% less than) flow in the Truckee River, respectively. Figures A-119 through A-123 in Appendix A show model predictions compared to observed data at each location. These calibration figures show three lines representing simulated maximum, average, and minimum daily DO concentrations. The measured data are displayed as a solid band that covers the range of values observed each day. Calibration statistics are provided in Table 4-14. These statistics represent an excellent comparison between model and data. Residual errors are consistently less than 0.5 mg/l; average errors are consistently less than 1.0 mg/l; and relative errors are consistently less than 10% across all stations.

Table 4-13. Average, Residual, and Relative Error for Daily Observed and Predicted Maximum, Mean, and Minimum Dissolved Oxygen between January 1, 1995 and December 31, 1996

Statistic	McCarran	Lockwood	Tracy	Painted Rock	Marble Bluff Dam	Average
Residual Error						
Max	-0.13	0.36	0.17	0.28	0.04	0.14
Mean	-0.09	0.17	0.14	0.63	-0.13	0.14
Min	-0.17	0.02	0.16	0.81	-0.11	0.14
N	426	298	403	339	242	
Average Error						
Max	0.35	0.97	1.10	0.89	0.92	0.85
Mean	0.20	0.52	0.65	0.74	0.57	0.54
Min	0.32	0.50	0.69	0.92	0.56	0.60
N	426	298	403	339	242	
Relative Error						
Max	3%	10%	11%	9%	9%	8%
Mean	2%	6%	7%	8%	6%	6%
Min	3%	6%	8%	11%	9%	7%
N	426	298	403	339	242	

The year 1990 reflect low flow conditions in the Truckee River, representing the 10% low flow year. Figures A-124 and A-125 in Appendix A show model predictions compared to observed DO data at each location. Calibration statistics for 1990 are provided in Table 4-15. The calibration statistics, while acceptable, are not as good as observed for the other calibration periods. Much of this discrepancy can be explained by the lack of model input data for forcing functions related to agricultural diversions/returns and groundwater inputs. During the low flow conditions observed in 1990, these un-monitored inputs play a larger role on predicted water quality and contribute greatly to model uncertainty.

Table 4-14. Average, Residual, and Relative Error for Daily Observed and Predicted Maximum, Mean, and Minimum Dissolved Oxygen between January 1, 1990 and December 31, 1990

Statistic	Tracy	Wadsworth	Average
Residual Error			
Max	-1.98	-1.82	-1.90
Mean	-1.11	-0.77	-0.94
Min	-0.44	0.10	-0.17
n	304	302	
Average Error			
Max	2.66	2.14	2.40
Mean	1.67	1.37	1.52
Min	1.18	1.33	1.26
n	304	302	
Relative Error			
Max	20%	18%	19%
Mean	17%	15%	16%
Min	21%	23%	22%
n	304	302	

4.12 SUITABILITY OF MODEL CALIBRATION FOR FUTURE MANAGEMENT USE

As stated previously, there are no generally accepted guidelines for what constitutes an "acceptable" model calibration. The answer to the question "how good of a model calibration is required?" depends on the intended use of the model. Reckhow et al. (1997) suggest reversing the question to "what management decisions can be supported, given the current quality of the model calibration?" Donigian (2000) provides general calibration/validation targets or tolerances for HSPF applications and indicates that an average error less than 15% indicates a "very good" water quality calibration, while errors in the range of 15-25% indicate a "good" calibration. Oreskes et al. (1994) correlate the robustness of a model to the amount of data it can simulate, stating "the greater the number and diversity of confirming observations, the more probable it is that the conceptualization embodied in the model is not flawed."

The TRHSPF model results provide an exemplary calibration for a large number of stations, parameters and time periods. The resulting TRHSPF model error statistics for the calibration periods were consistent with the error statistics obtained for past modeling of the Truckee River, while considering a more robust data set. Thus, application of TRHSPF to the Truckee River is consistent with the models used previously for a regulatory purpose.

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APPENDIX A:

DETAILED GRAPHICAL COMPARISONS OF MODEL OUTPUT AND OBSERVED DATA

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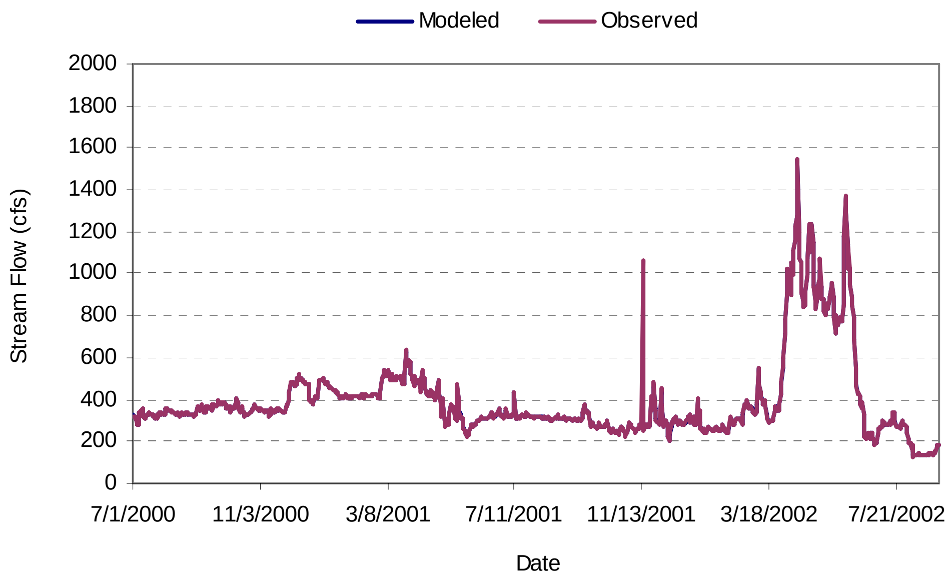


Figure A-1. Comparison of Modeled and Observed Flows (cfs) at East McCarran between July 1, 2000 and August 31, 2002. (Note: modeled and observed flows are identical at this site)

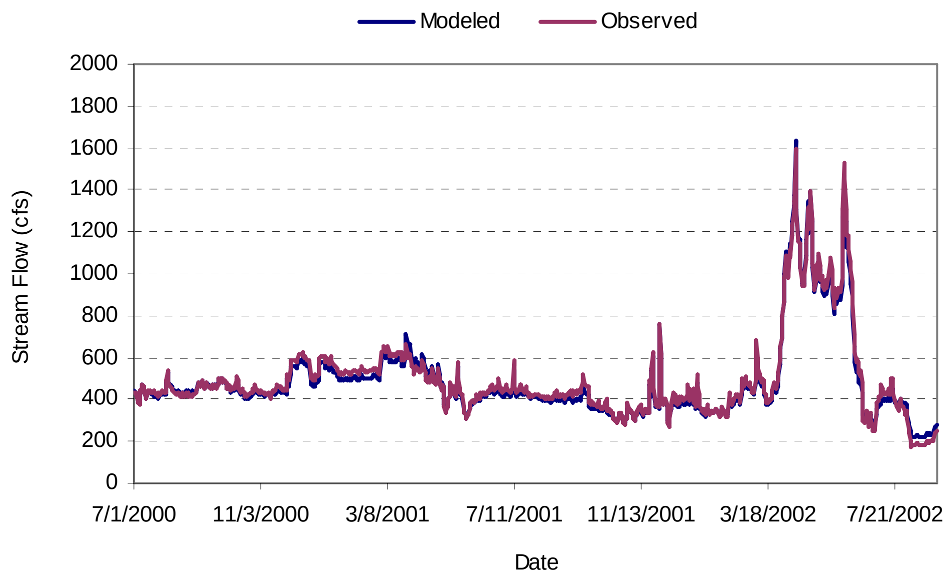


Figure A-2. Comparison of Modeled and Observed Flows (cfs) at Vista between July 1, 2000 and August 31, 2002.

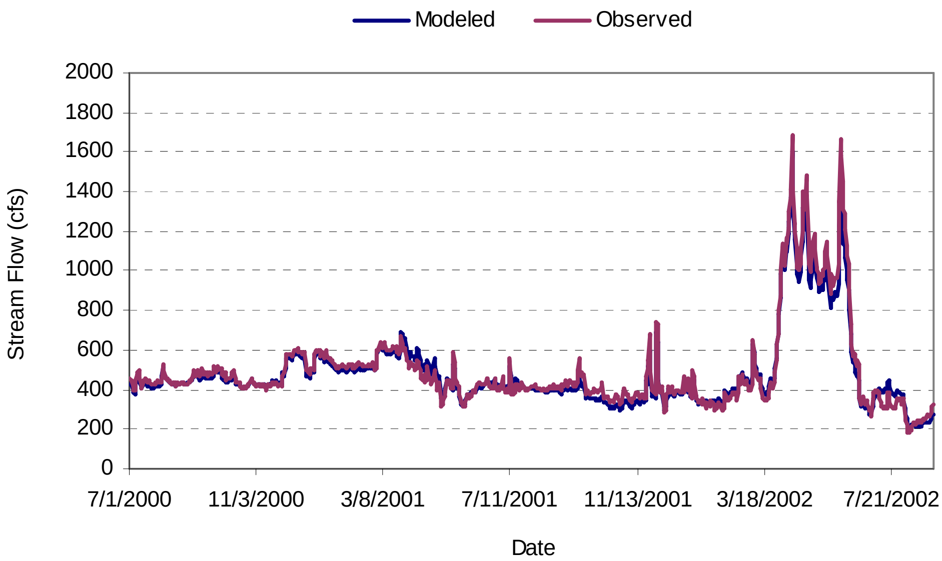


Figure A-3. Comparison of Modeled and Observed Flows at Tracy between July 1, 2000 and August 31, 2002.

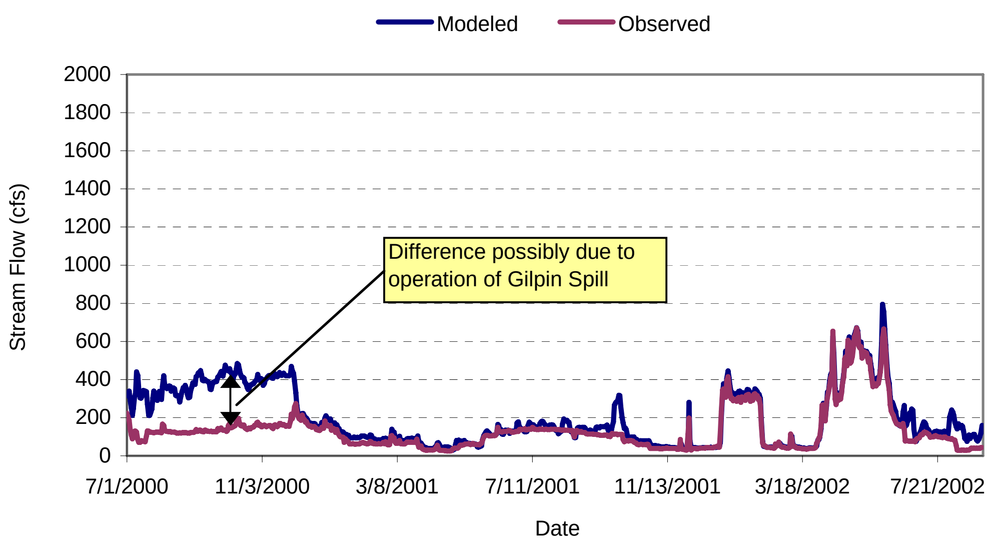


Figure A-4. Comparison of Modeled and Observed Flows below Derby Dam between July 1, 2000 and August 31, 2002.

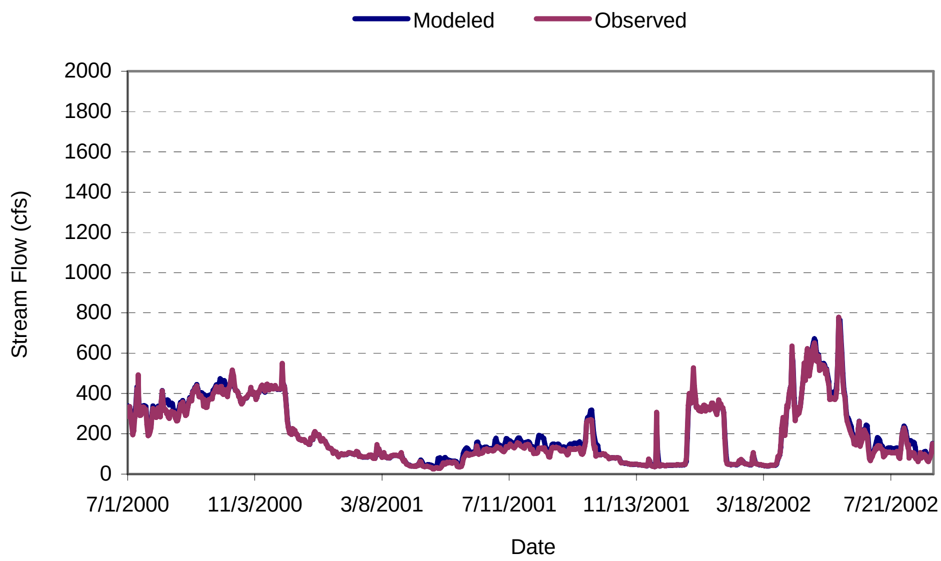


Figure A-5. Comparison of Modeled and Observed Flows (cfs) Wadsworth between July 1, 2000 and August 31, 2002.

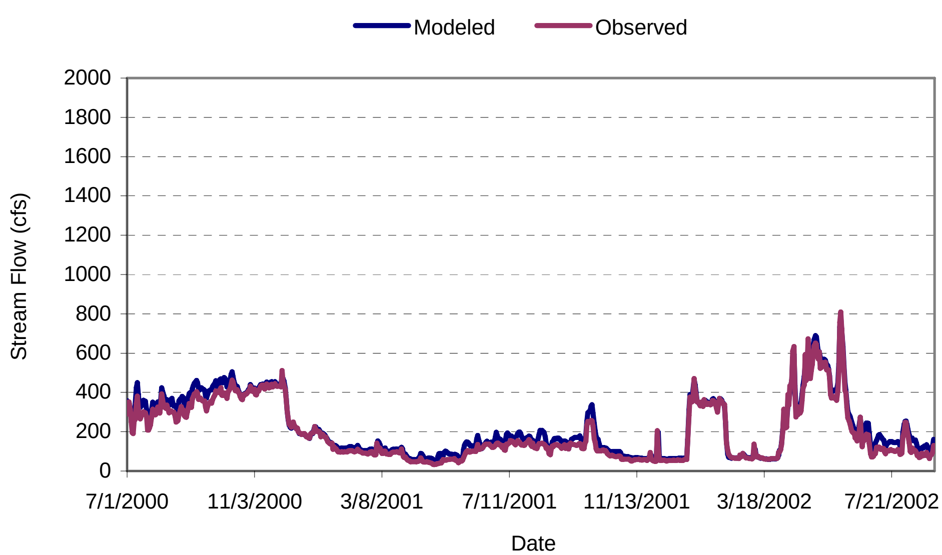


Figure A-6. Comparison of Modeled and Observed Flows (cfs) at Nixon between July 1, 2000 and August 31, 2002.

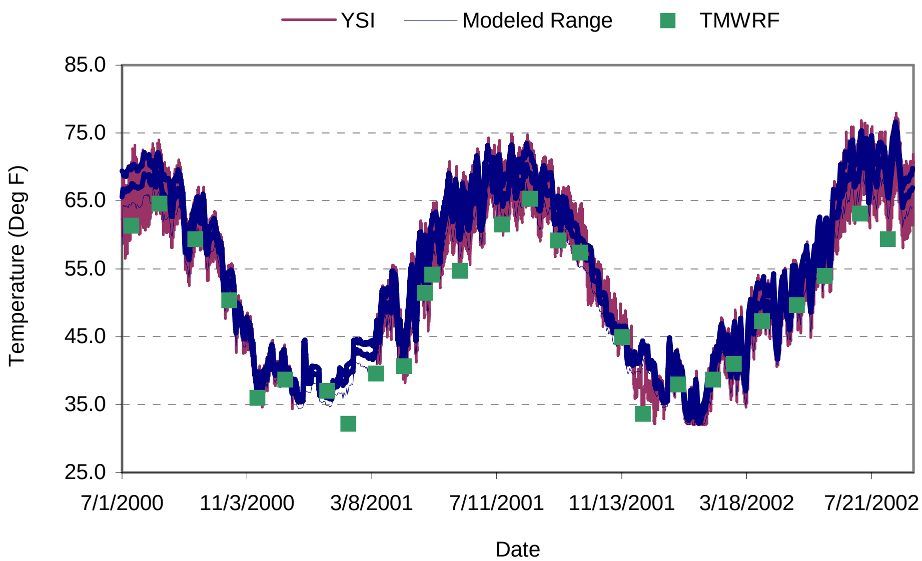


Figure A-7. Comparison of Observed and Modeled Water Temperature at East McCarran Bridge between July 1, 2000 and August 31, 2002.

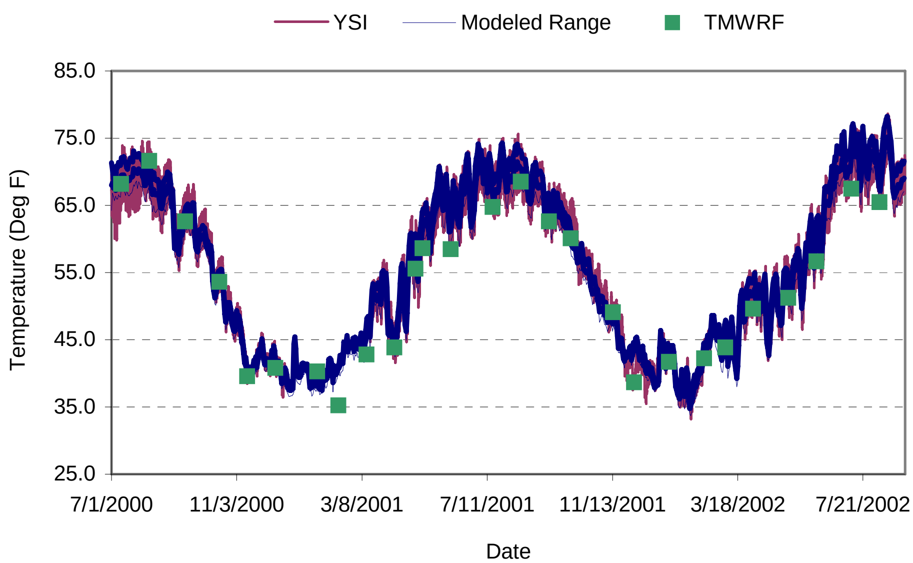


Figure A-8. Comparison of Modeled and Observed Water Temperature at Lockwood between July 1, 2000 and August 31, 2002.

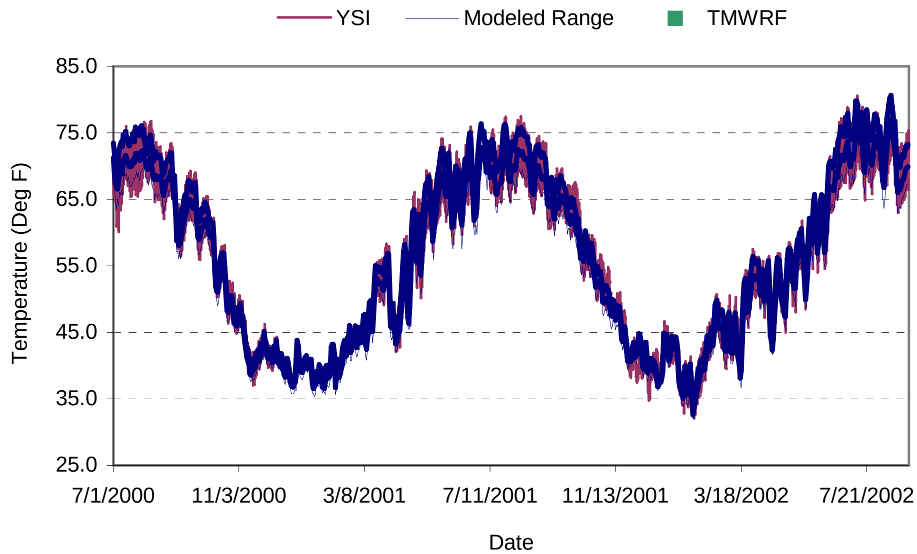


Figure A-9. Comparison of Modeled and Observed Water Temperature at Tracy between July 1, 2000 and August 31, 2002.

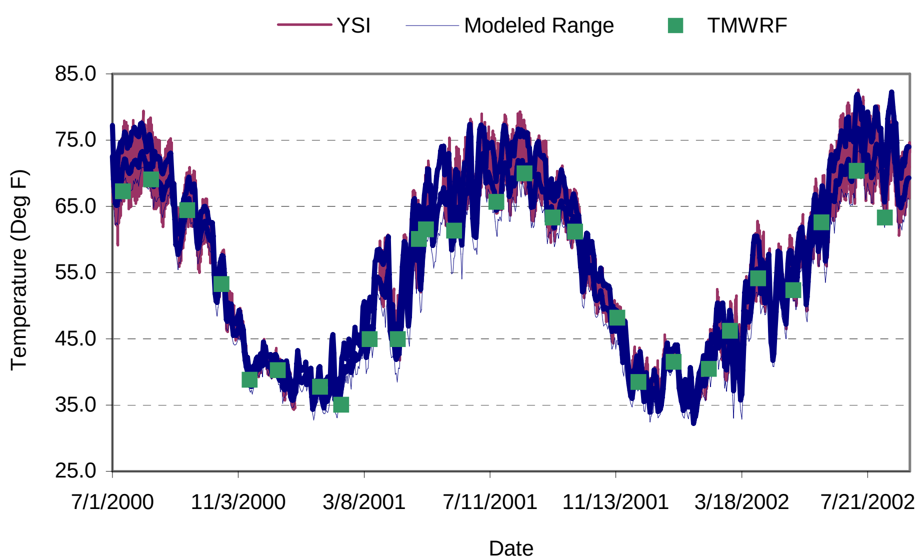


Figure A-10. Comparison of Modeled and Observed Water Temperature at Painted Rock between July 1, 2000 and August 31, 2002.

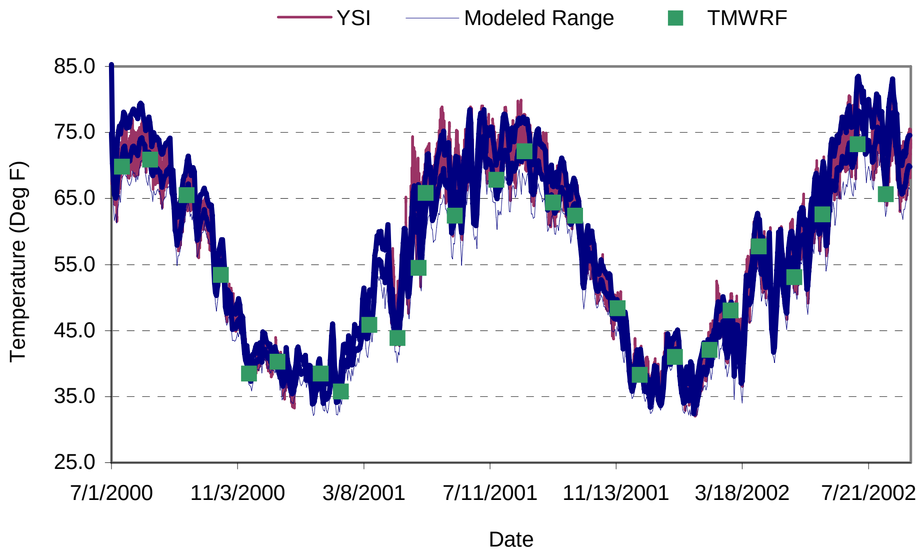


Figure A-11. Comparison of Modeled and Observed Water Temperature Data at Wadsworth between July 1, 2000 and August 31, 2002.

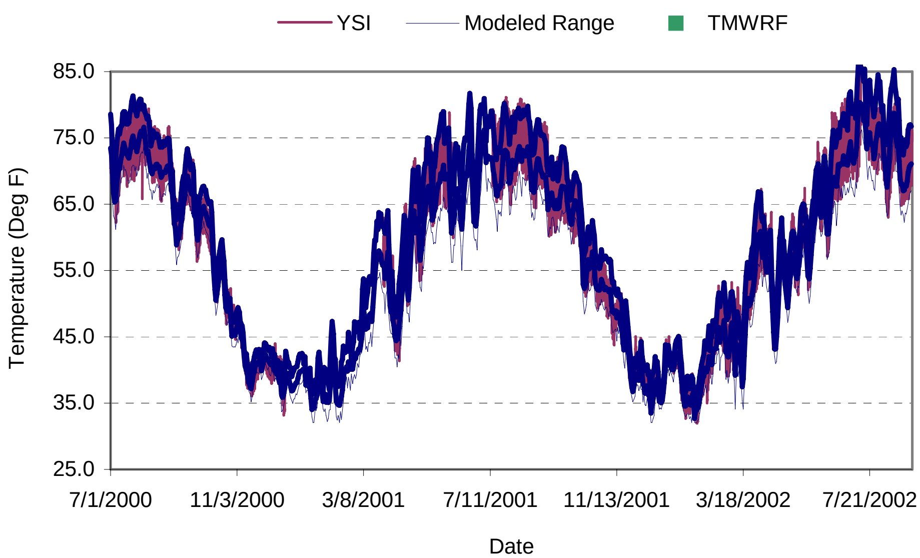


Figure A-12. Comparison of Modeled and Observed Water Temperature Data at Marble Bluff Dam between July 1, 2000 and August 31, 2002.

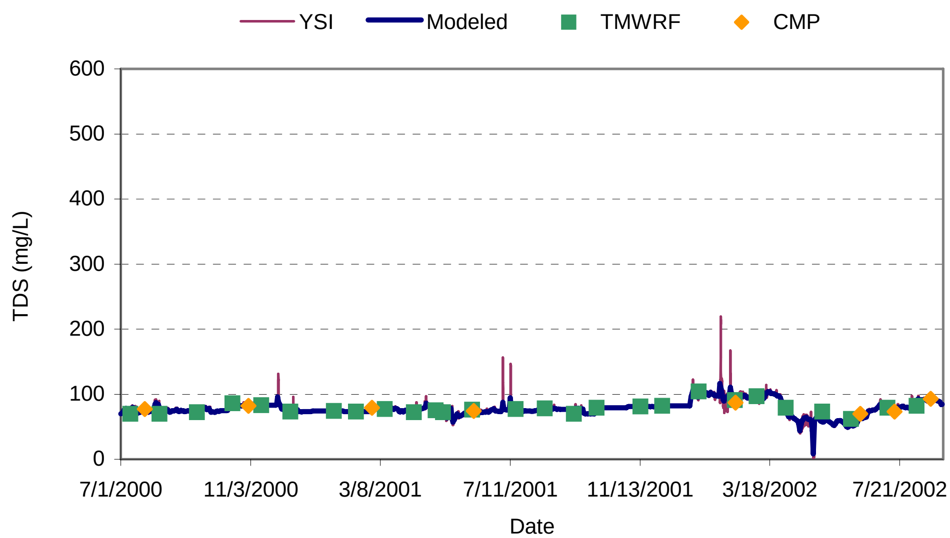


Figure A-13. Comparison of Observed and Modeled Total Dissolved Solids (mg/L) at East McCarran Bridge between July 1, 2000 and August 31, 2002.

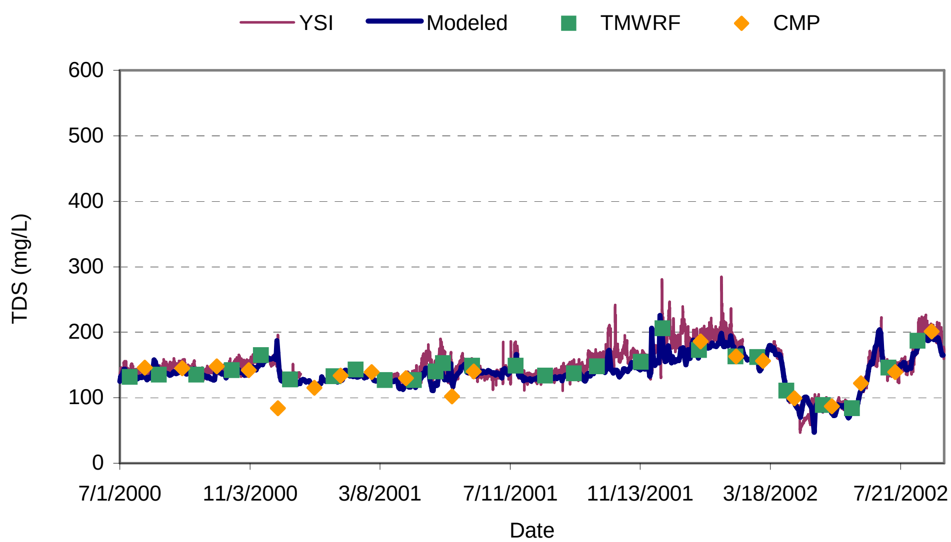


Figure A-14. Comparison of Observed and Modeled Total Dissolved Solids (mg/L) at Lockwood between July 1, 2000 and August 31, 2002.

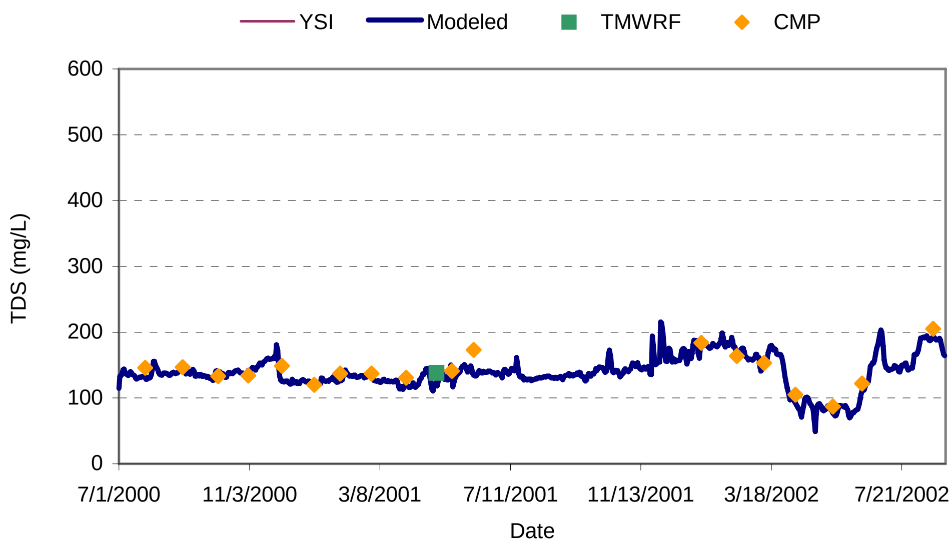


Figure A-15. Comparison of Observed and Modeled Total Dissolved Solids (mg/L) at Patrick between July 1, 2000 and August 31, 2002.

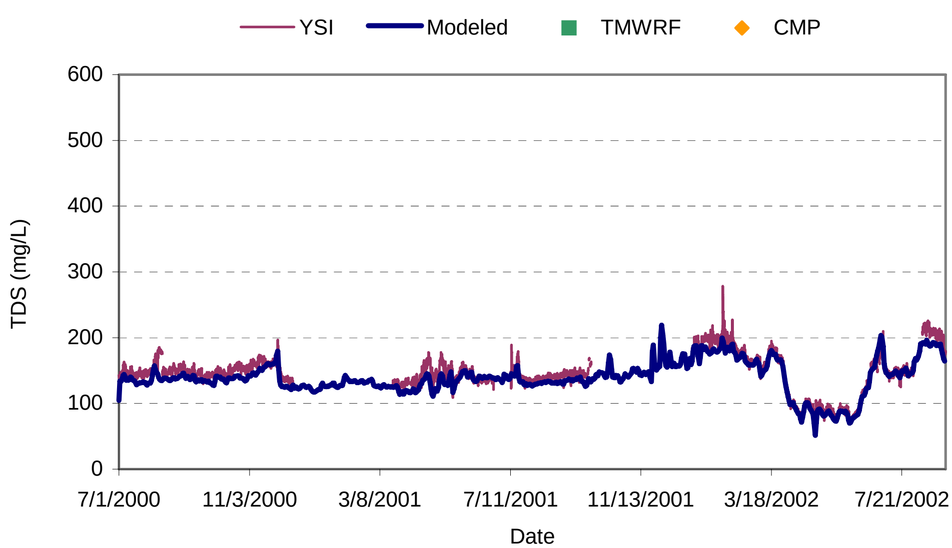


Figure A-16. Comparison of Observed and Modeled Total Dissolved Solids (mg/L) at Tracy between July 1, 2000 and August 31, 2002.

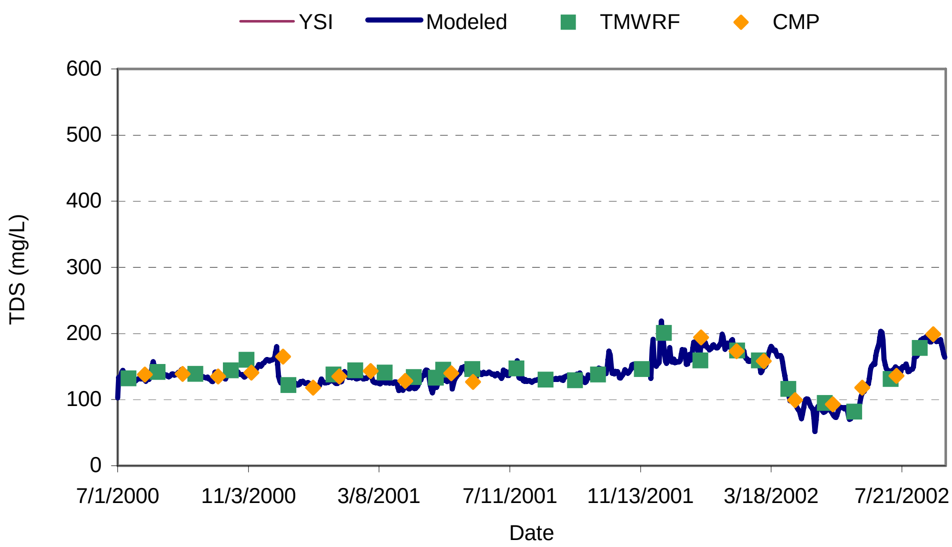


Figure A-17. Comparison of Observed and Modeled Total Dissolved Solids (mg/L) at Tracy-Clark between July 1, 2000 and August 31, 2002.

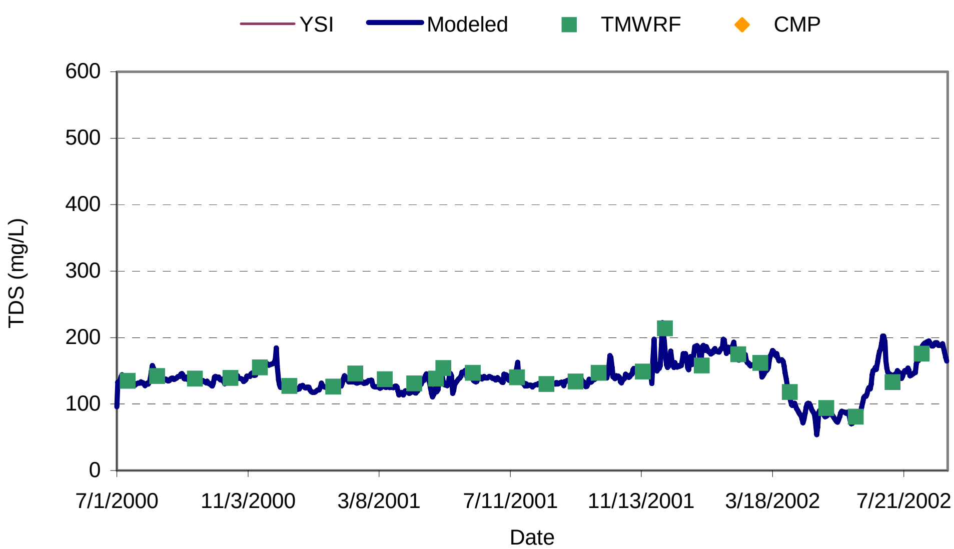


Figure A-18. Comparison of Observed and Modeled Total Dissolved Solids (mg/L) below Derby Dam between July 1, 2000 and August 31, 2002.

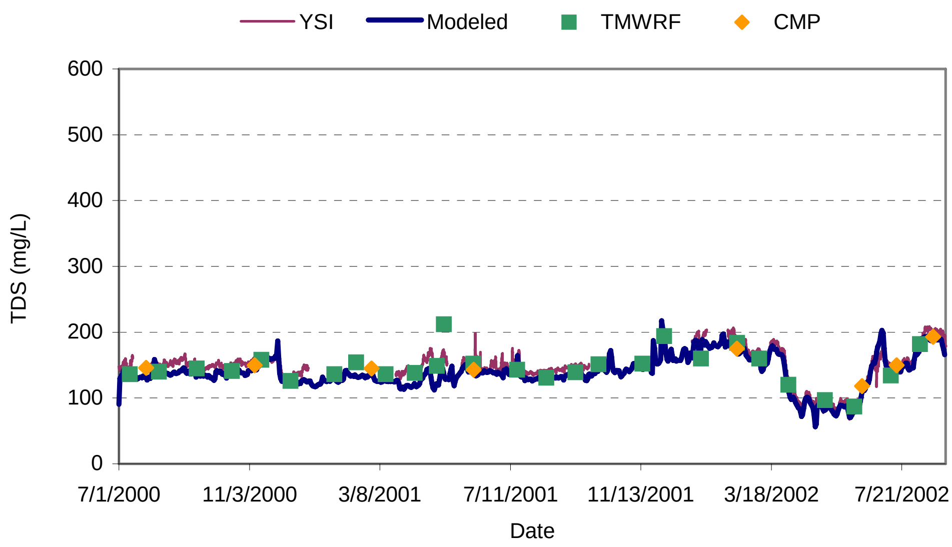


Figure A-19. Comparison of Observed and Modeled Total Dissolved Solids (mg/L) at Painted Rock between July 1, 2000 and August 31, 2002.

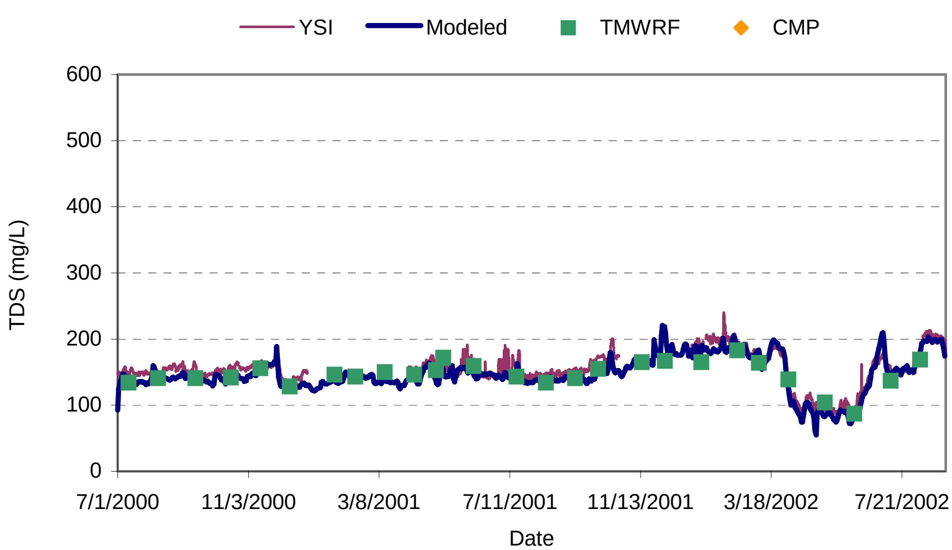


Figure A-20. Comparison of Observed and Modeled Total Dissolved Solids (mg/L) at Wadsworth between July 1, 2000 and August 31, 2002.

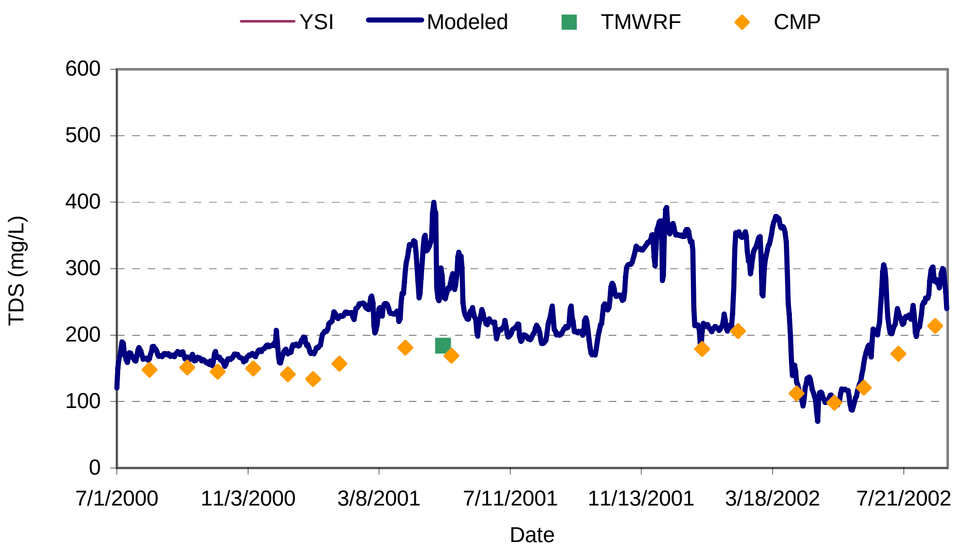


Figure A-21. Comparison of Observed and Modeled Total Dissolved Solids (mg/L) at John's Ranch between July 1, 2000 and August 31, 2002.

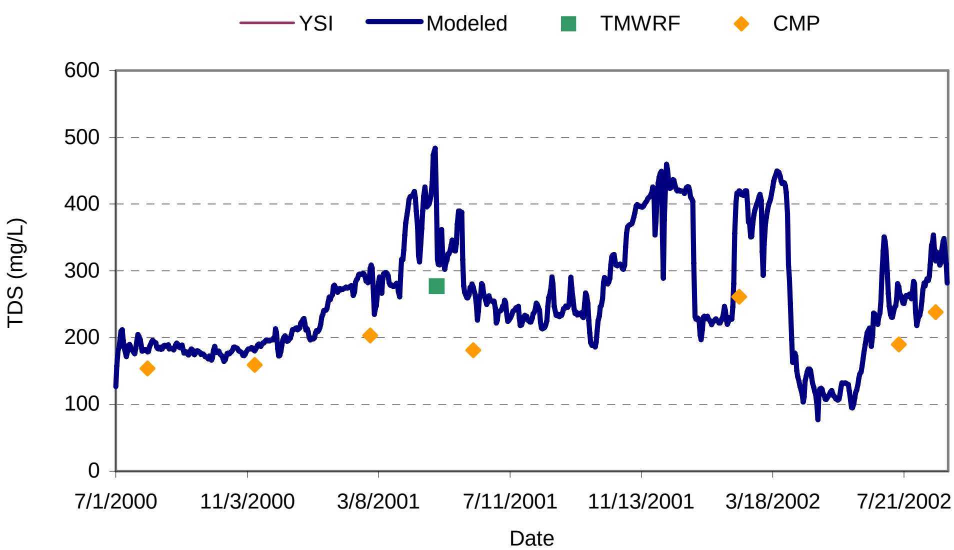


Figure A-22. Comparison of Observed and Modeled Total Dissolved Solids (mg/L) at Dead Ox between July 1, 2000 and August 31, 2002.

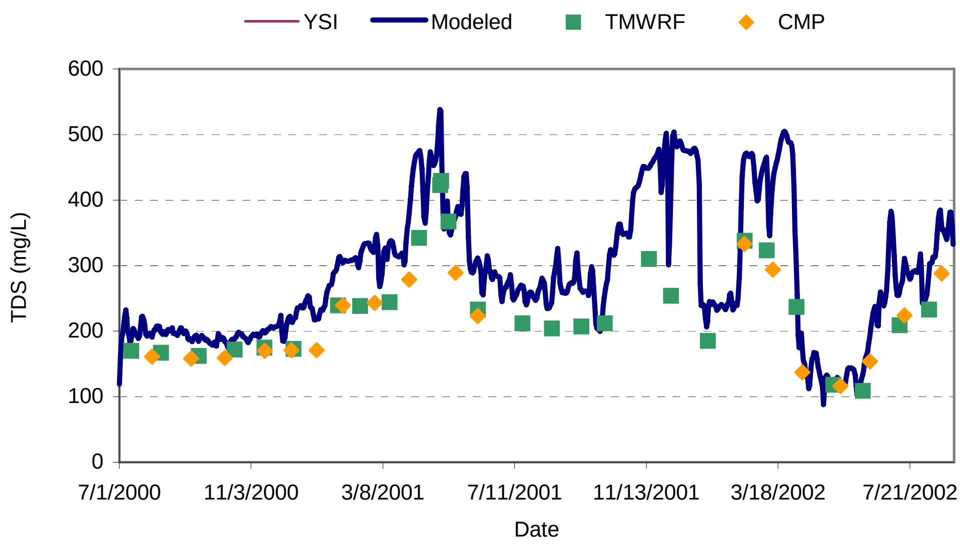


Figure A-23. Comparison of Observed and Modeled Total Dissolved Solids (mg/L) at Little Nixon between July 1, 2000 and August 31, 2002.

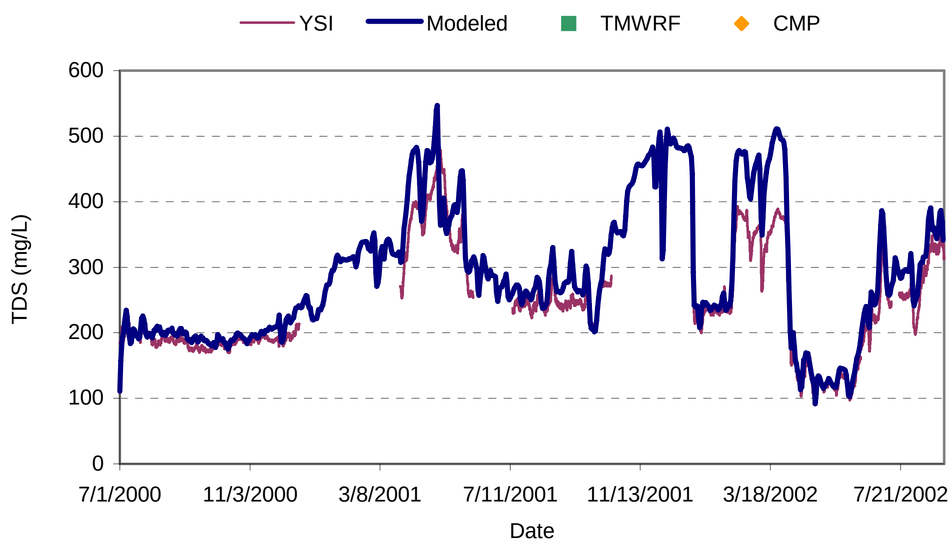


Figure A-24. Comparison of Observed and Modeled Total Dissolved Solids (mg/L) at Marble Bluff Dam between July 1, 2000 and August 31, 2002.

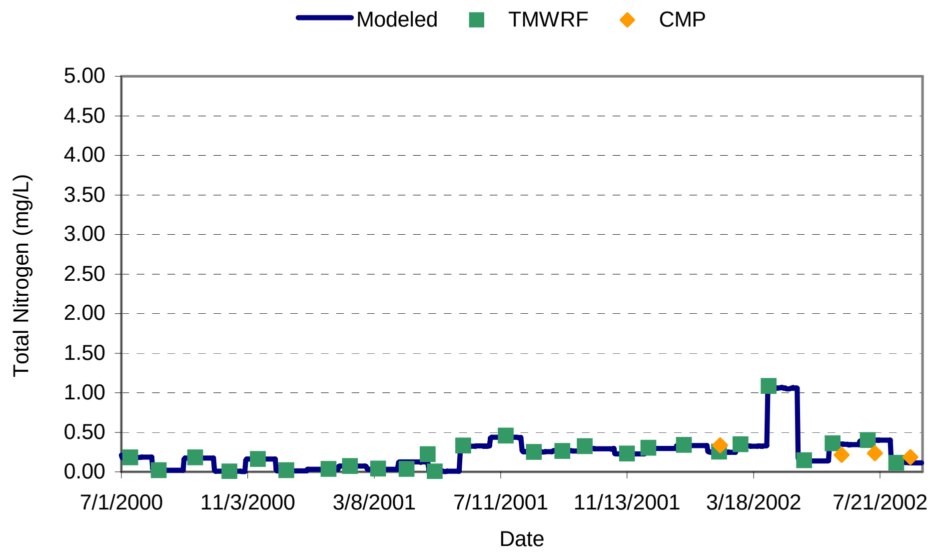


Figure A-25. Comparison of Observed and Modeled Total Nitrogen (mg/L) at East McCarran Bridge between July 1, 2000 and August 31, 2002.

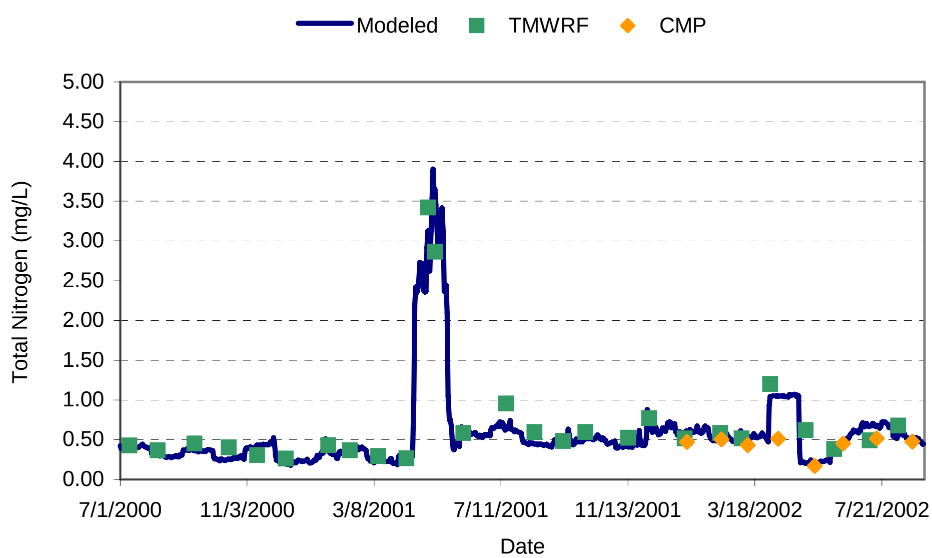
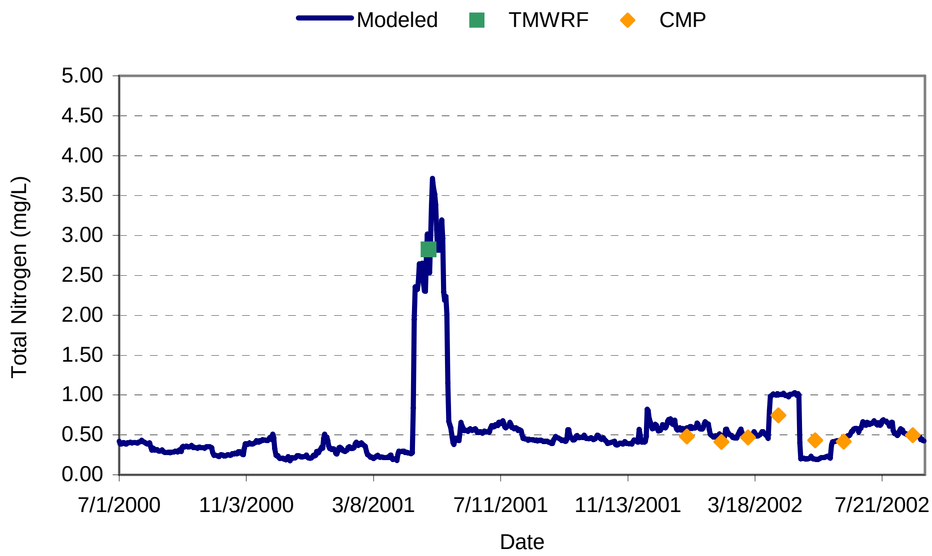


Figure A-26. Comparison of Observed and Modeled Total Nitrogen (mg/L) at Lockwood between July 1, 2000 and August 31, 2002.



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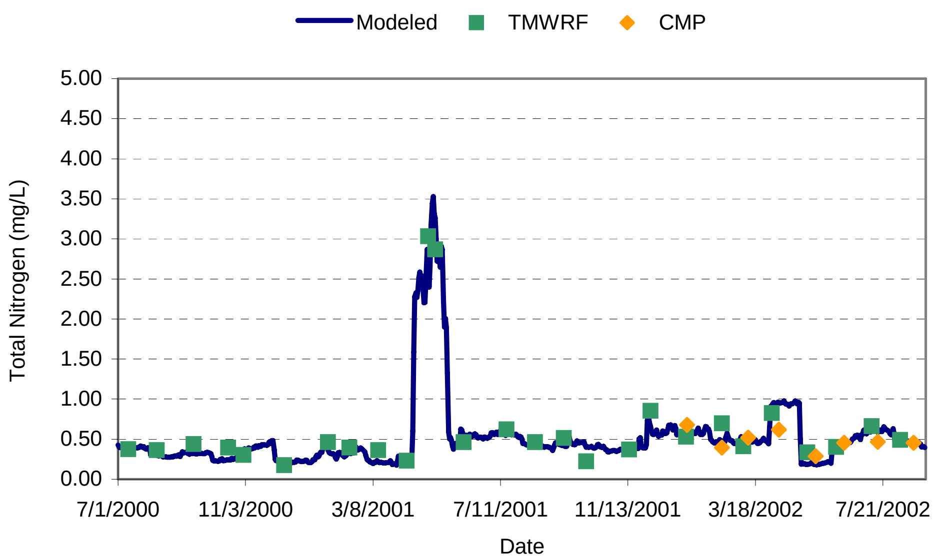

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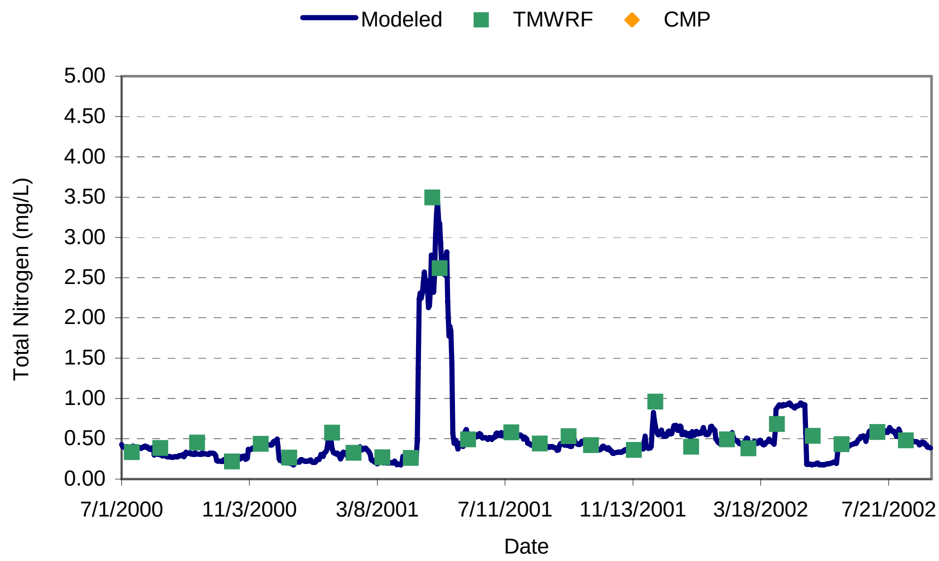

Figure A-29. Comparison of Observed and Modeled Total Nitrogen (mg/L) below Derby Dam between July 1, 2000 and August 31, 2002.

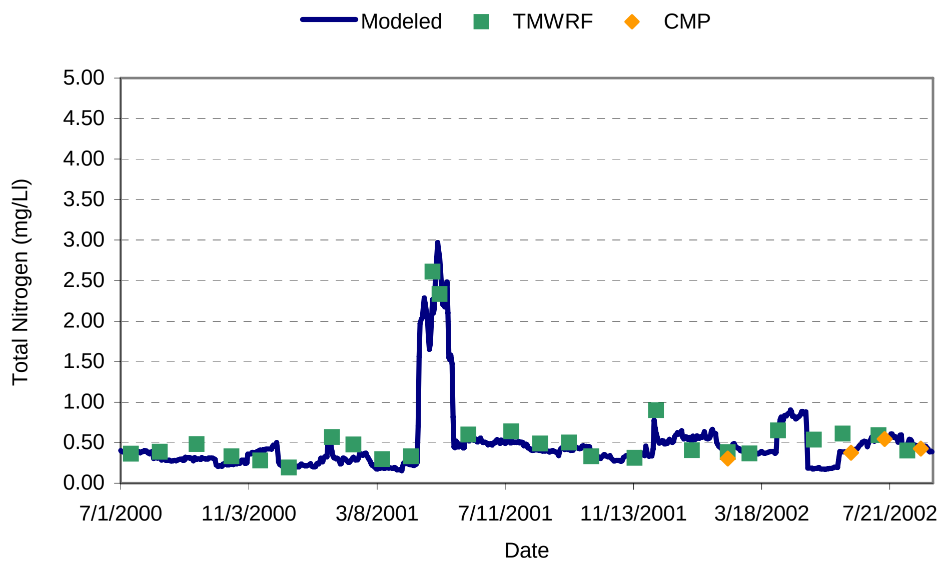

Figure A-30. Comparison of Observed and Modeled Total Nitrogen (mg/L) at Painted Rock between July 1, 2000 and August 31, 2002.

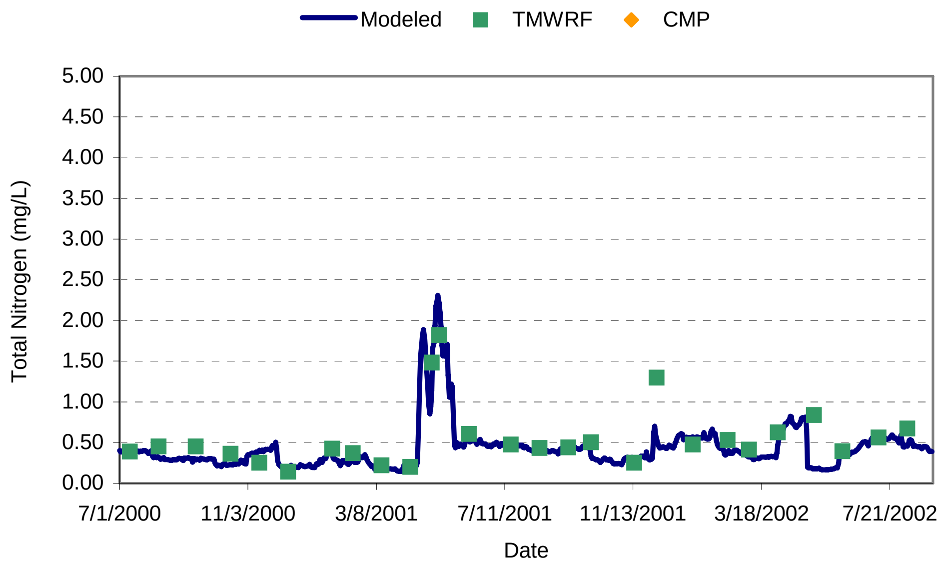

Figure A-31. Comparison of Observed and Modeled Total Nitrogen (mg/L) at Wadsworth between July 1, 2000 and August 31, 2002.

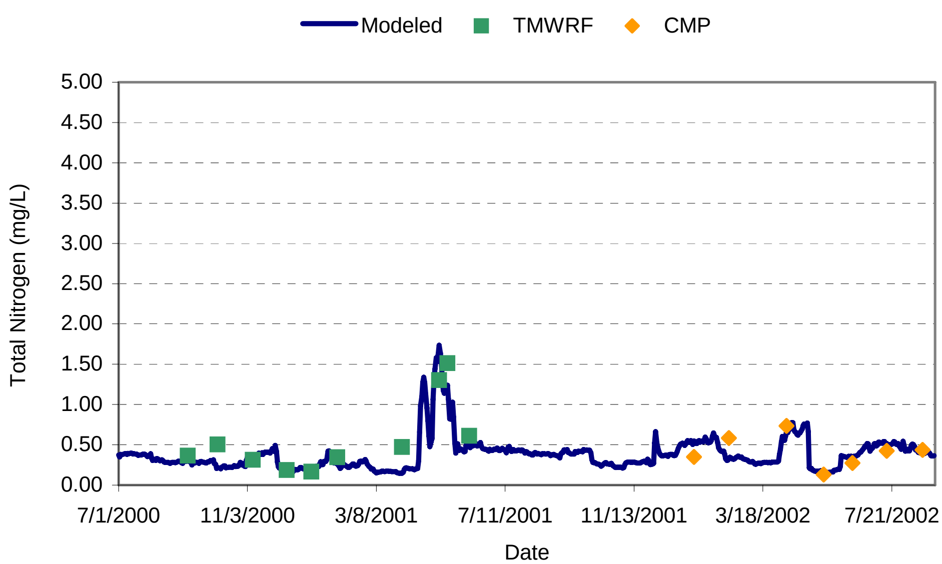

Figure A-32. Comparison of Observed and Modeled Total Nitrogen (mg/L) at John's Ranch between July 1, 2000 and August 31, 2002.

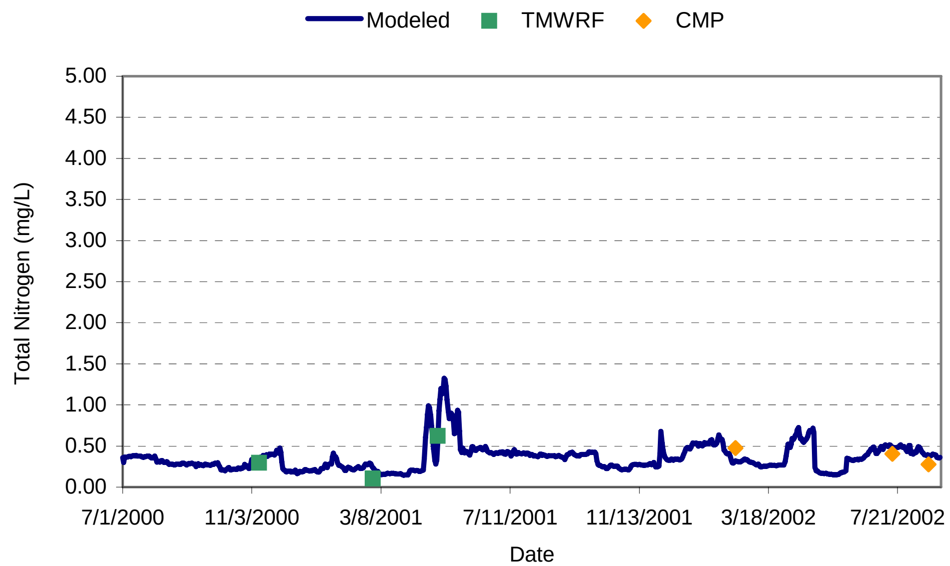

Figure A-33. Comparison of Observed and Modeled Total Nitrogen (mg/L) at Dead Ox between July 1, 2000 and August 31, 2002.

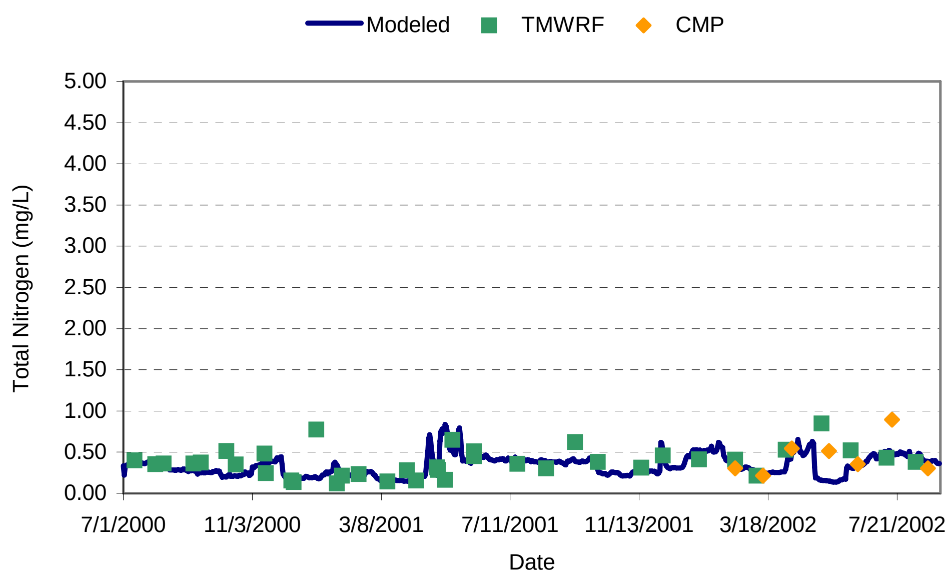

Figure A-34. Comparison of Observed and Modeled Total Nitrogen (mg/L) at Little Nixon between July 1, 2000 and August 31, 2002.

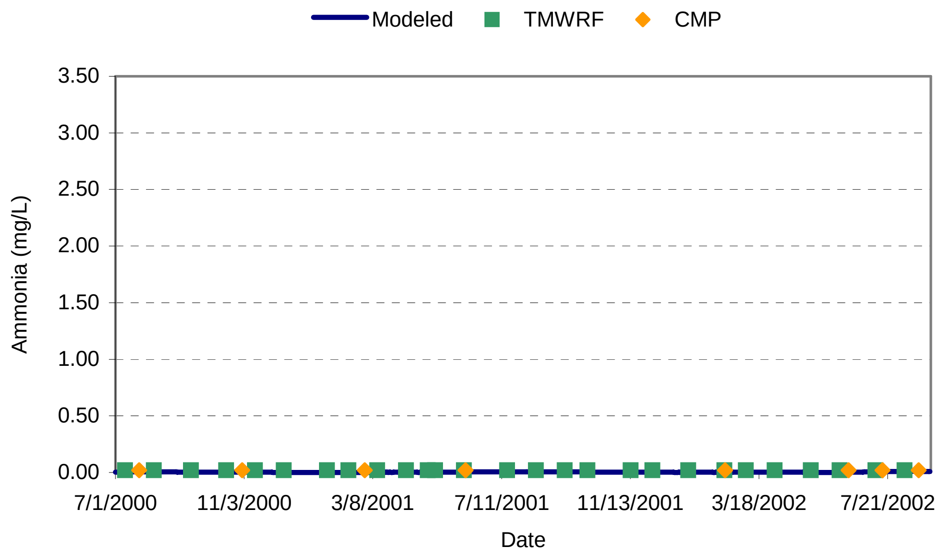

Figure A-35. Comparison of Observed and Modeled Total Ammonia (mg/L) at East McCarran Bridge between July 1, 2000 and August 31, 2002.

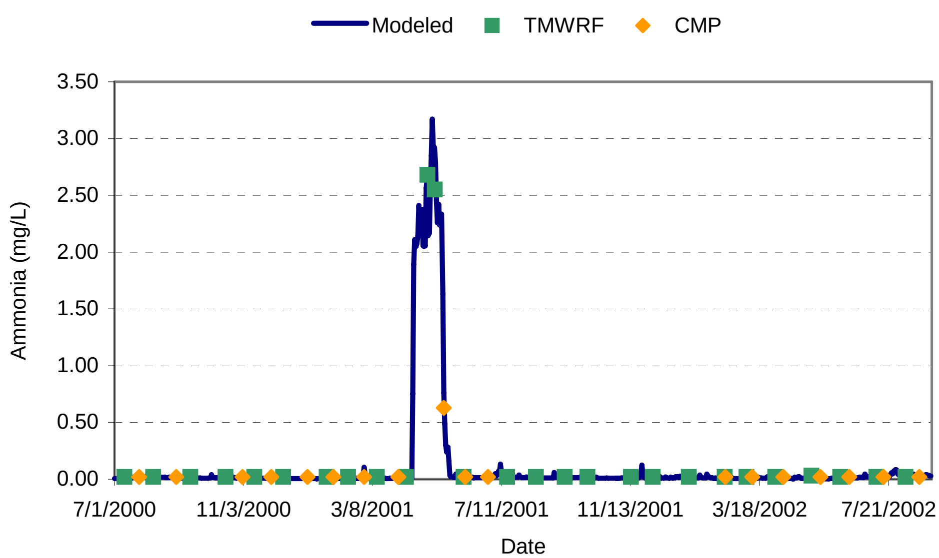

Figure A-36. Comparison of Observed and Modeled Total Ammonia (mg/L) at Lockwood between July 1, 2000 and August 31, 2002. Scaled to Show Peak Observed Concentrations.

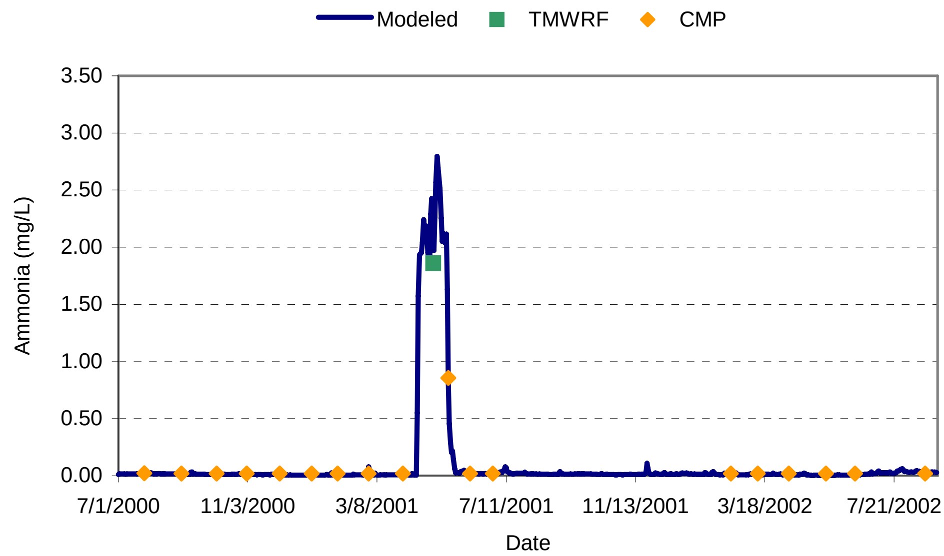

Figure A-37. Comparison of Observed and Modeled Total Ammonia (mg/L) at Patrick between July 1, 2000 and August 31, 2002. Scaled to Show Peak Observed Concentrations.

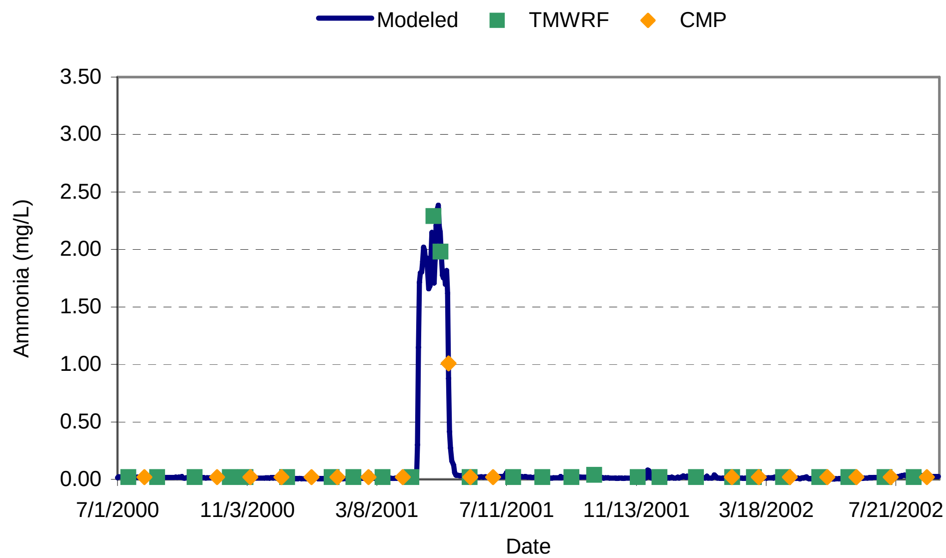

Figure A-38. Comparison of Observed and Modeled Total Ammonia (mg/L) at Tracy-Clark between July 1, 2000 and August 31, 2002. Scaled to Show Peak Observed Concentrations.

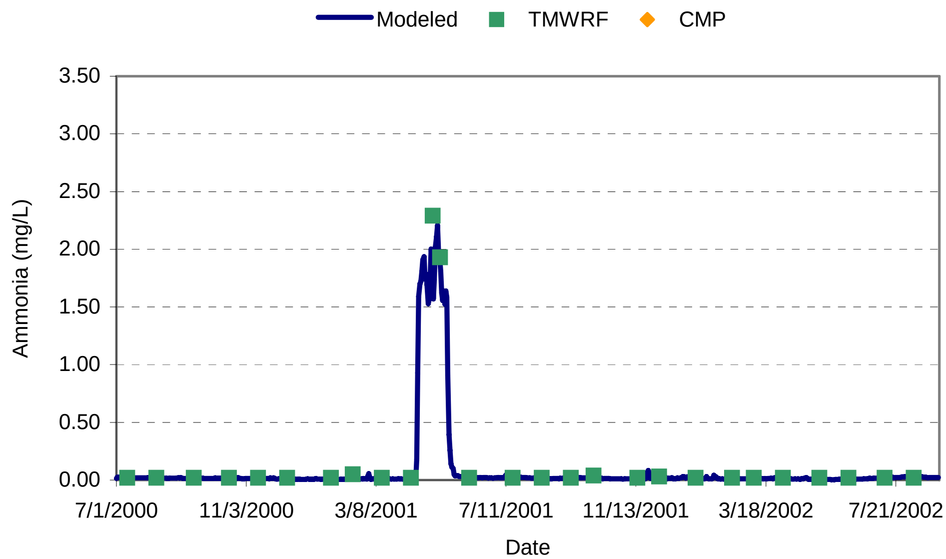

Figure A-39. Comparison of Observed and Modeled Total Ammonia (mg/L) below Derby Dam between July 1, 2000 and August 31, 2002. Scaled to Show Peak Observed Concentrations.

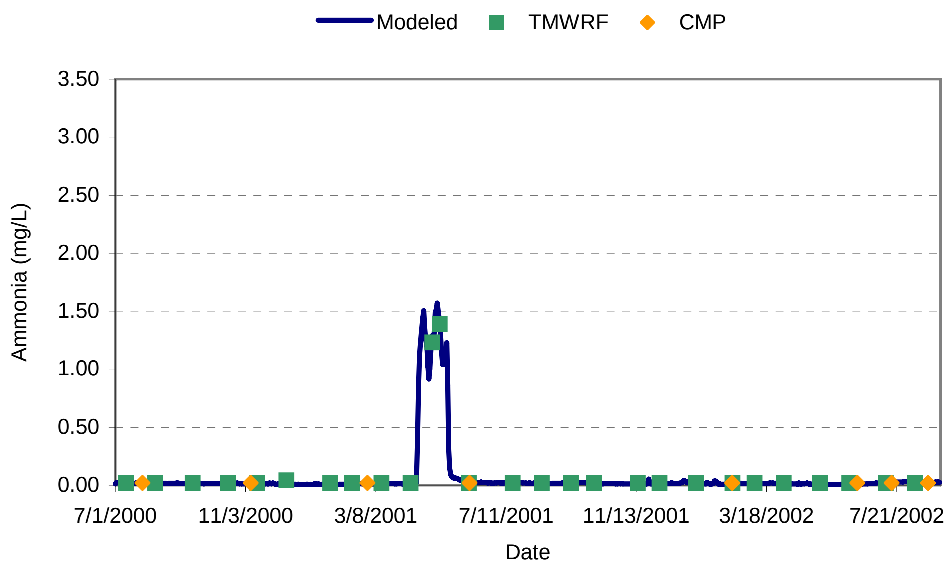

Figure A-40. Comparison of Observed and Modeled Total Ammonia (mg/L) at Painted Rock between July 1, 2000 and August 31, 2002. Scaled to Show Peak Observed Concentrations.

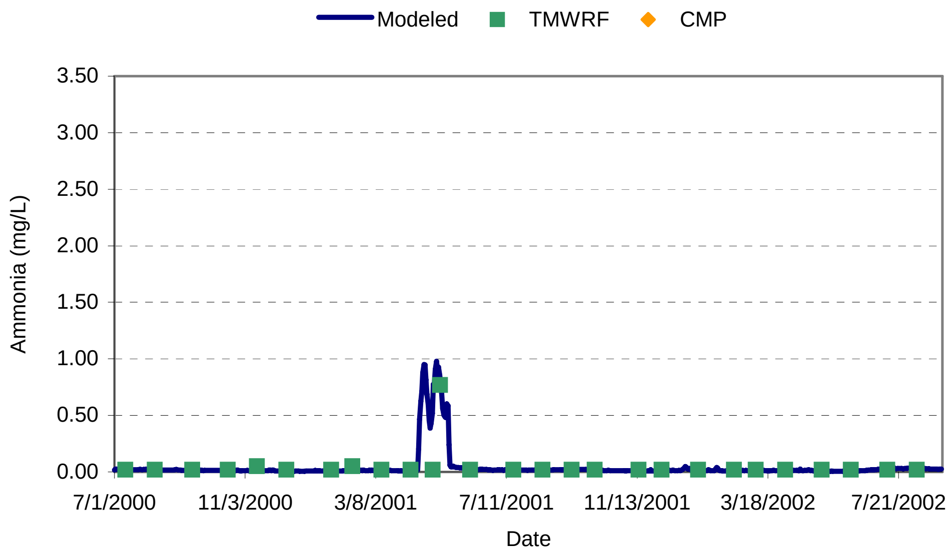

Figure A-41. Comparison of Observed and Modeled Total Ammonia (mg/L) at Wadsworth between July 1, 2000 and August 31, 2002.

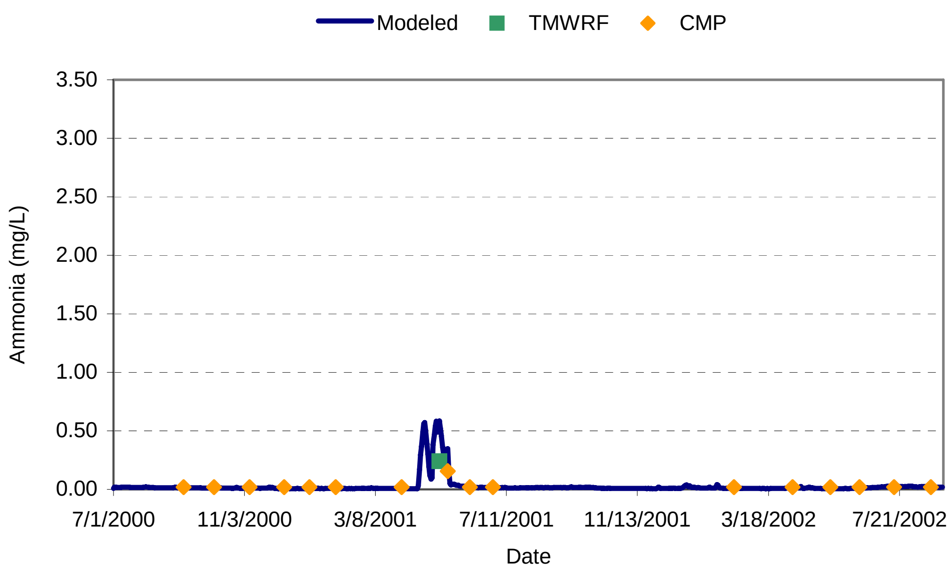

Figure A-42. Comparison of Observed and Modeled Total Ammonia (mg/L) at John’s Ranch between July 1, 2000 and August 31, 2002.

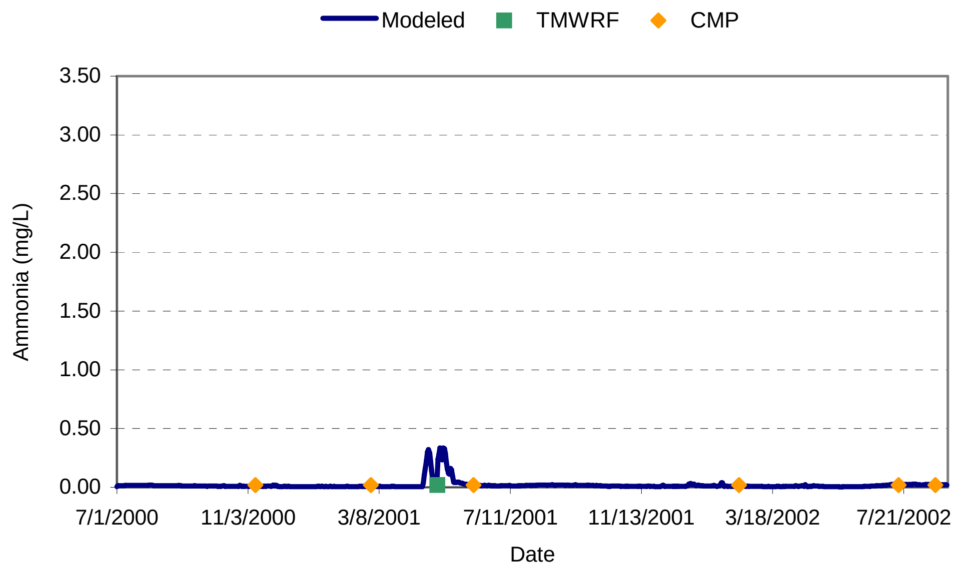

Figure A-43. Comparison of Observed and Modeled Total Ammonia (mg/L) at Dead Ox between July 1, 2000 and August 31, 2002.

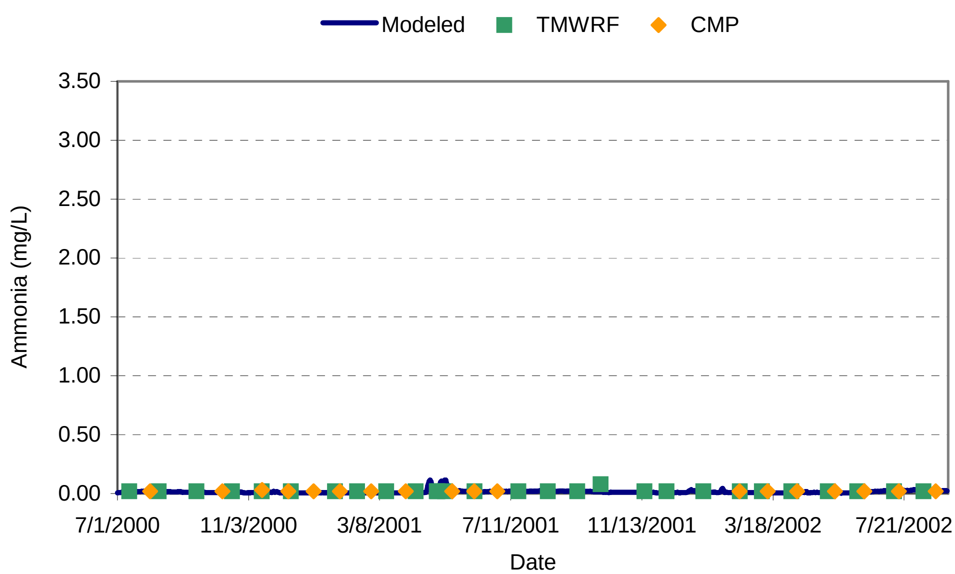

Figure A-44. Comparison of Observed and Modeled Total Ammonia (mg/L) at Little Nixon between July 1, 2000 and August 31, 2002.

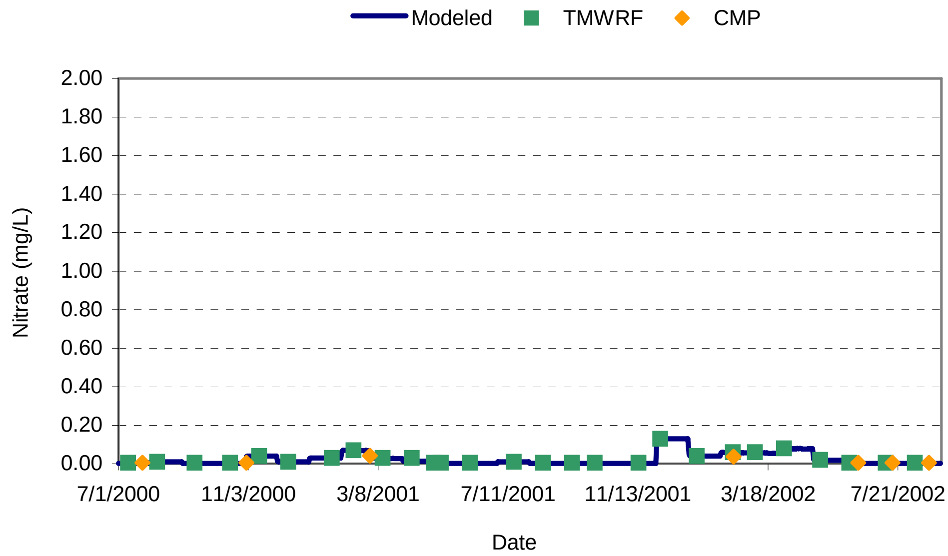

Figure A-45. Comparison of Observed and Modeled Nitrate-Nitrogen (mg/L) at East McCarran Bridge between July 1, 2000 and August 31, 2002.

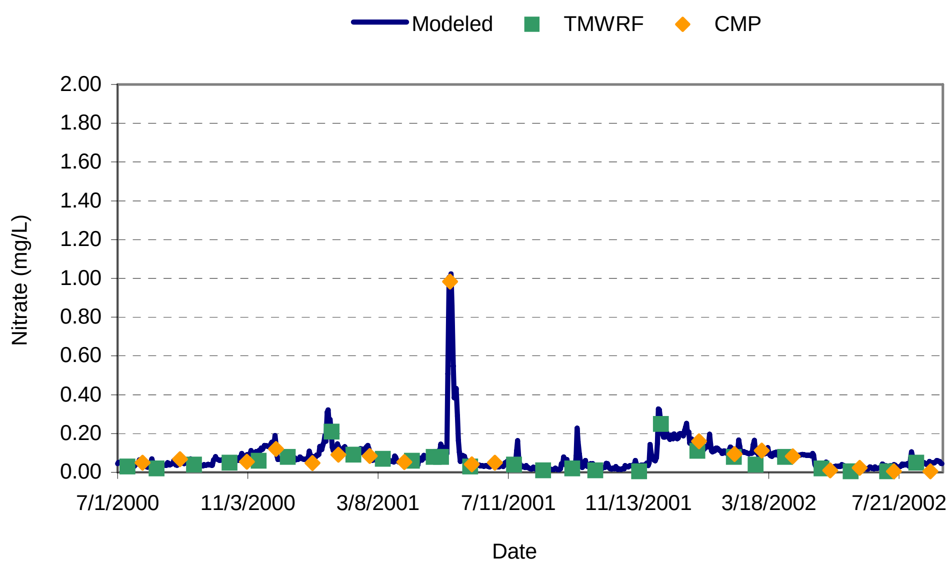

Figure A-46. Comparison of Observed and Modeled Nitrate-Nitrogen (mg/L) at Lockwood between July 1, 2000 and August 31, 2002.

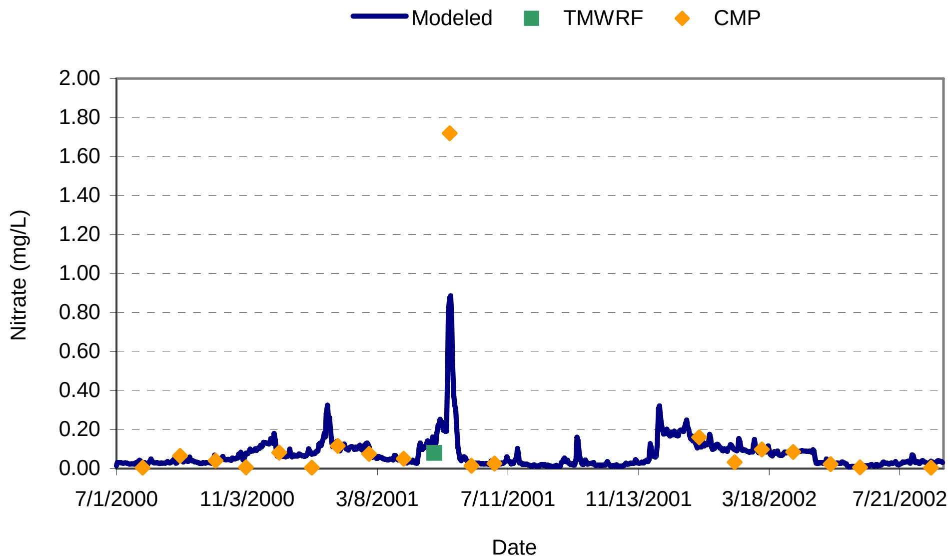

Figure A-47. Comparison of Observed and Modeled Nitrate-Nitrogen (mg/L) at Patrick between July 1, 2000 and August 31, 2002.

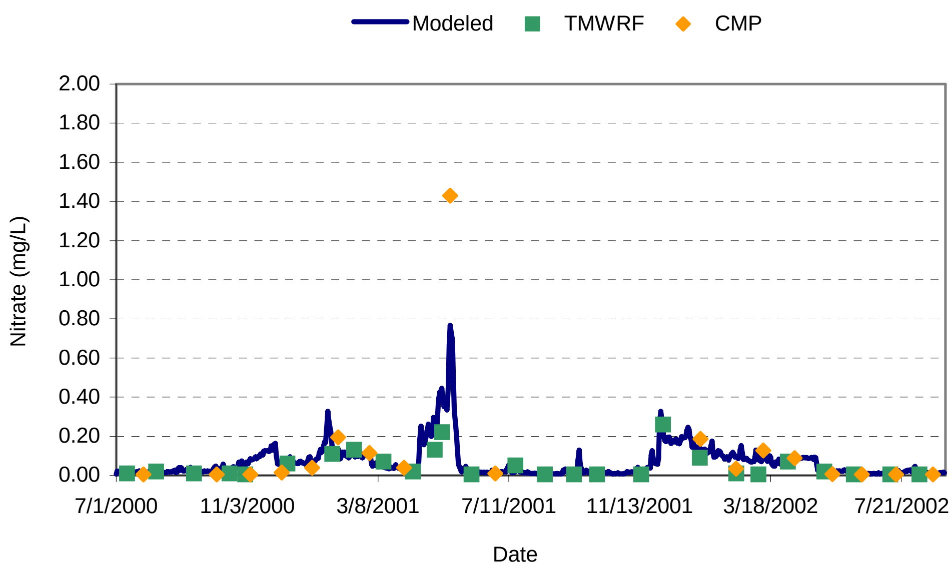

Figure A-48. Comparison of Observed and Modeled Nitrate-Nitrogen (mg/L) at Tracy-Clark between July 1, 2000 and August 31, 2002.

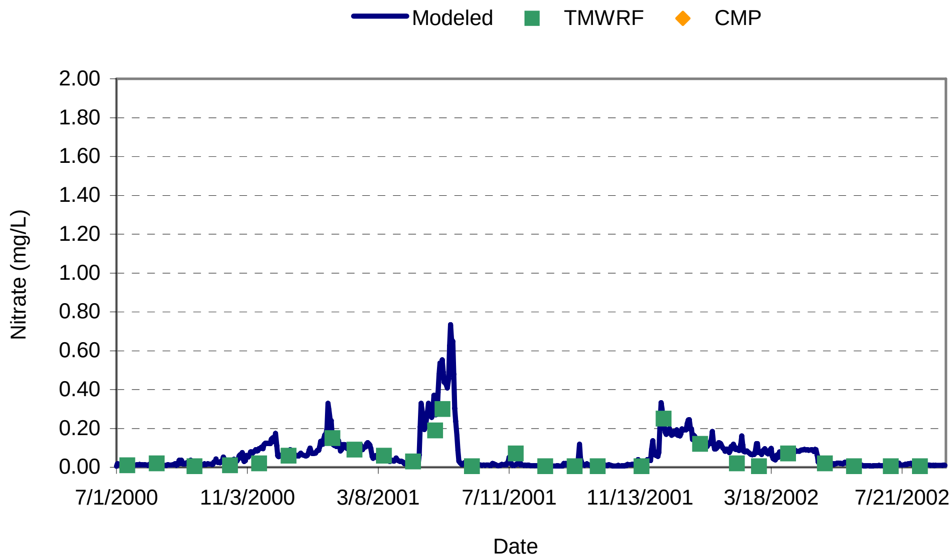

Figure A-49. Comparison of Observed and Modeled Nitrate-Nitrogen (mg/L) below Derby Dam between July 1, 2000 and August 31, 2002.

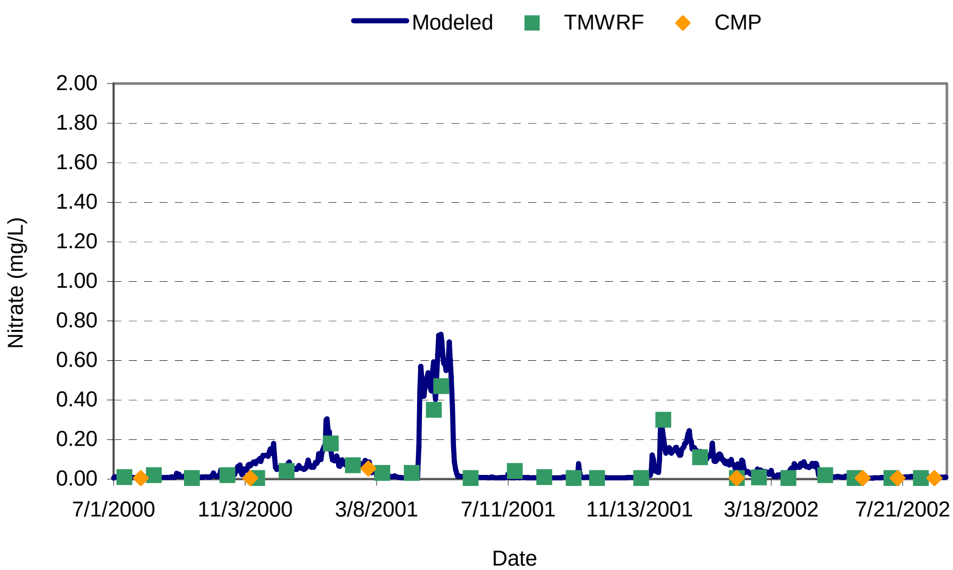

Figure A-50. Comparison of Observed and Modeled Nitrate-Nitrogen (mg/L) at Painted Rock between July 1, 2000 and August 31, 2002.

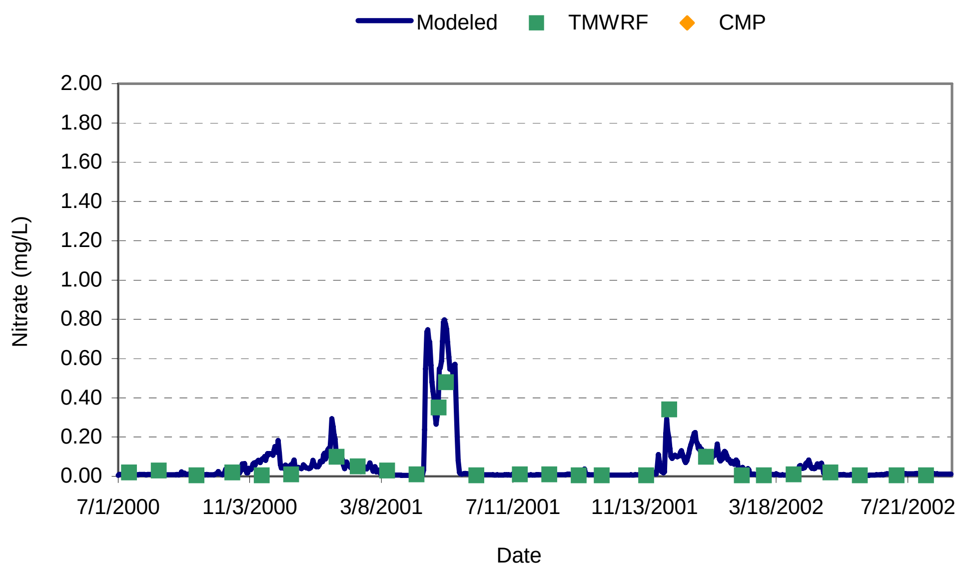

Figure A-51. Comparison of Observed and Modeled Nitrate-Nitrogen (mg/L) at Wadsworth between July 1, 2000 and August 31, 2002.

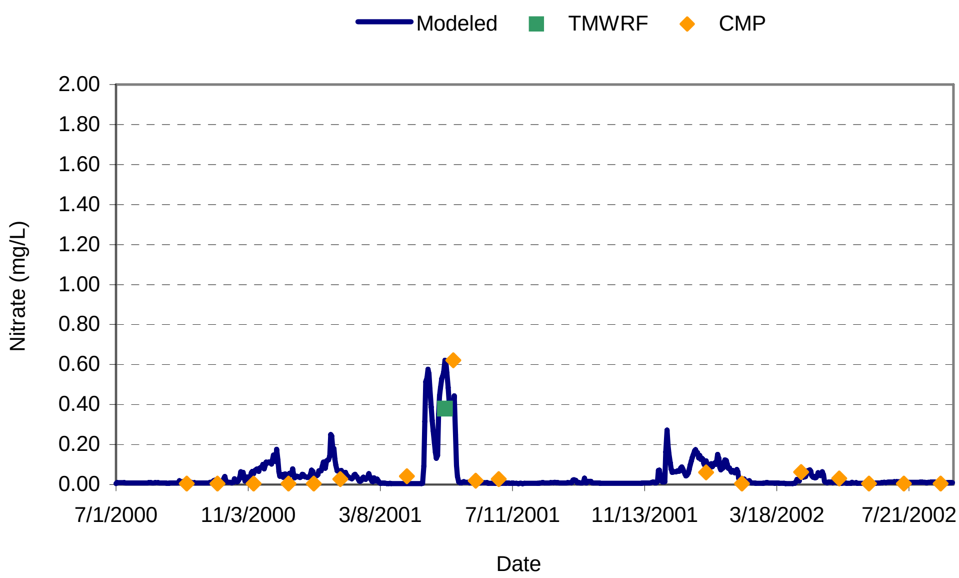

Figure A-52. Comparison of Observed and Modeled Nitrate-Nitrogen (mg/L) at John's Ranch between July 1, 2000 and August 31, 2002.

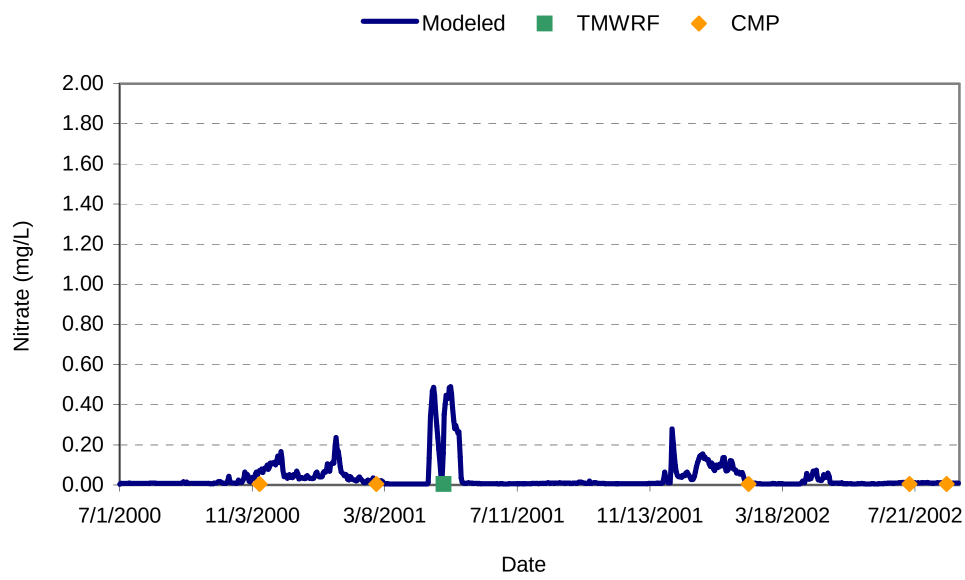

Figure A-53. Comparison of Observed and Modeled Nitrate-Nitrogen (mg/L) at Dead Ox between July 1, 2000 and August 31, 2002.

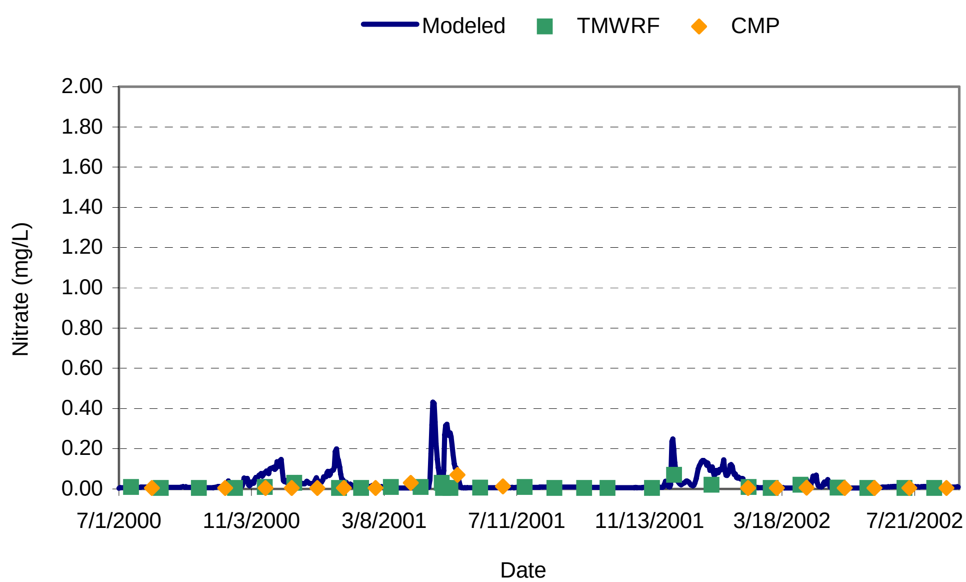

Figure A-54. Comparison of Observed and Modeled Nitrate-Nitrogen (mg/L) at Little Nixon between July 1, 2000 and August 31, 2002.

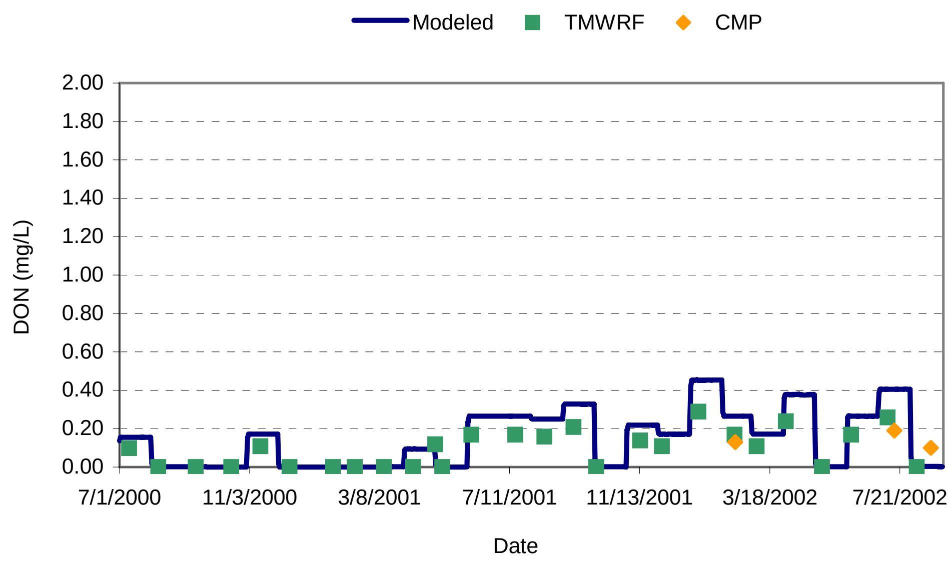

Figure A-55. Comparison of Observed and Modeled Dissolved Organic Nitrogen (mg/L) at East McCarran between July 1, 2000 and August 31, 2002.

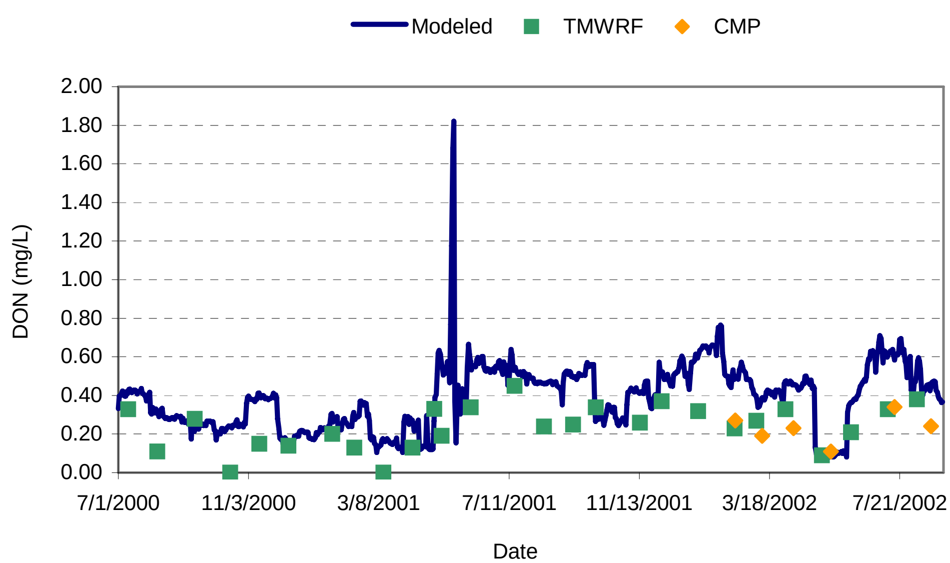

Figure A-56. Comparison of Observed and Modeled Dissolved Organic Nitrogen (mg/L) at Lockwood between July 1, 2000 and August 31, 2002.

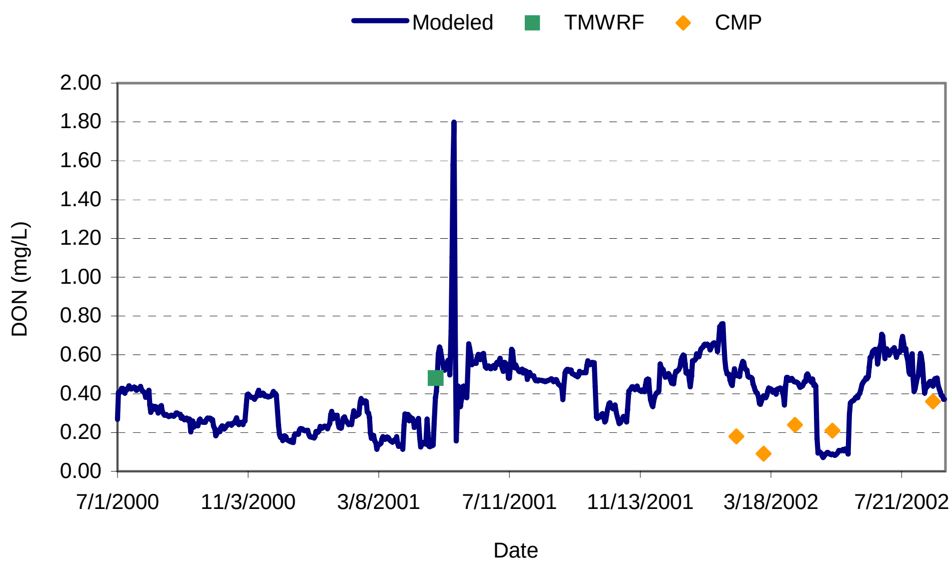

Figure A-57. Comparison of Observed and Modeled Dissolved Organic Nitrogen (mg/L) at Patrick between July 1, 2000 and August 31, 2002.

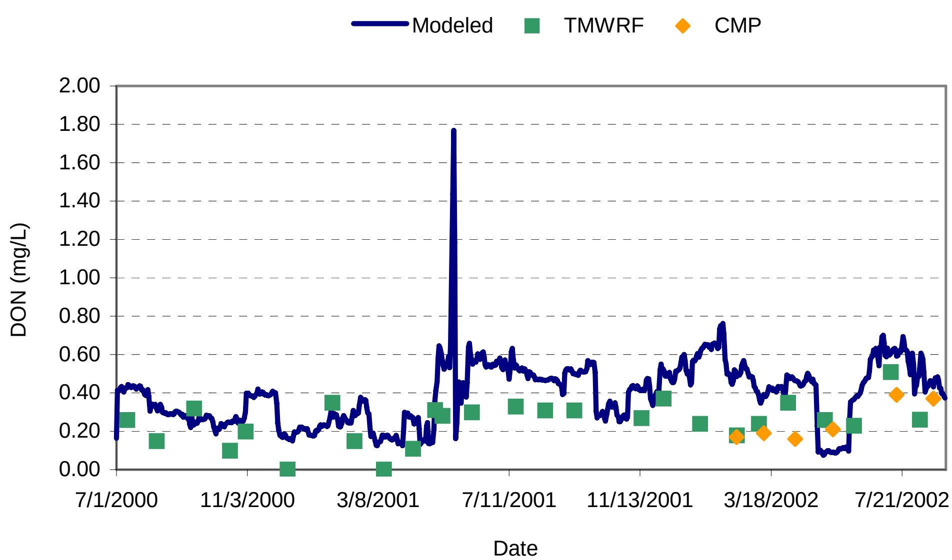

Figure A-58. Comparison of Observed and Modeled Dissolved Organic Nitrogen (mg/L) at Tracy-Clark between July 1, 2000 and August 31, 2002.

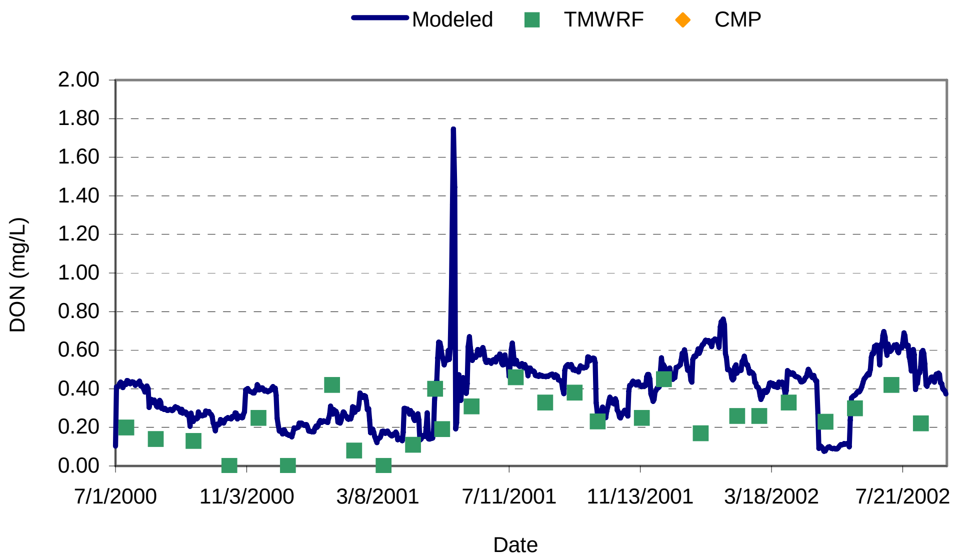

Figure A-59. Comparison of Observed and Modeled Dissolved Organic Nitrogen (mg/L) below Derby Dam between July 1, 2000 and August 31, 2002.

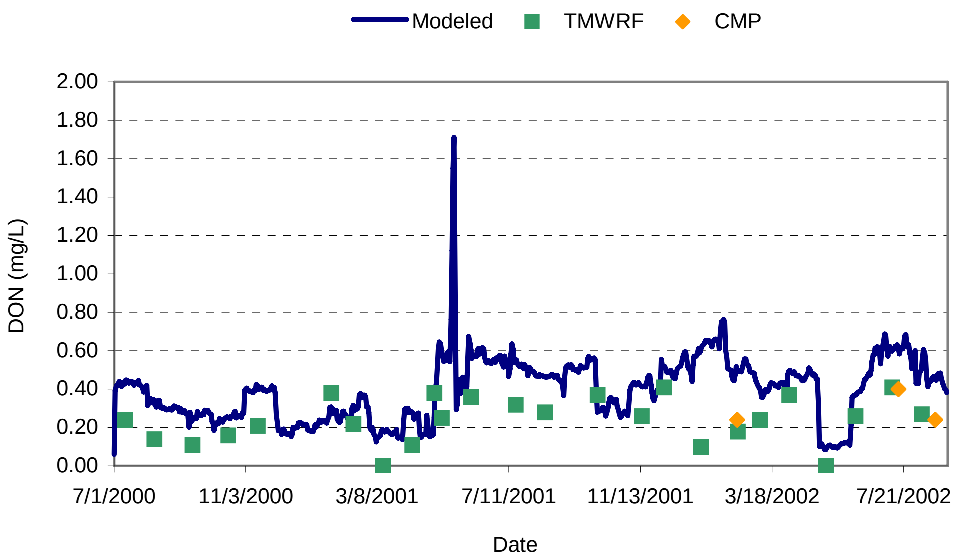

Figure A-60. Comparison of Observed and Modeled Dissolved Organic Nitrogen (mg/L) at Painted Rock between July 1, 2000 and August 31, 2002.

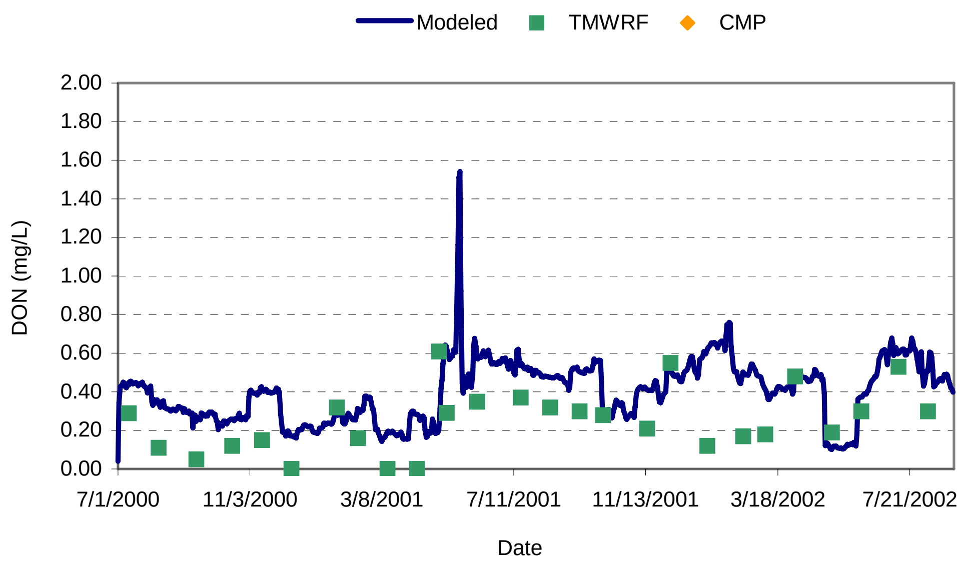

Figure A-61. Comparison of Observed and Modeled Dissolved Organic Nitrogen (mg/L) at Wadsworth between July 1, 2000 and August 31, 2002.

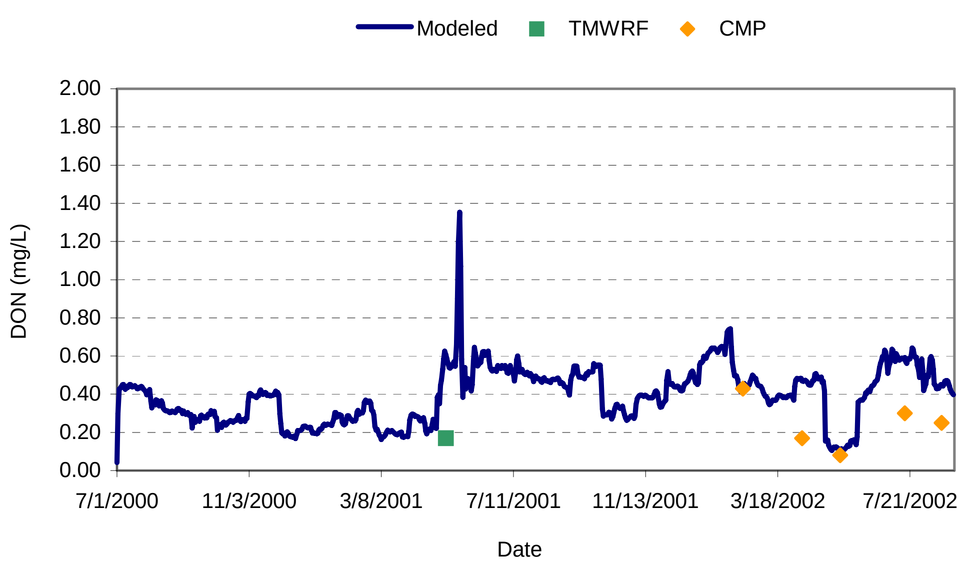

Figure A-62. Comparison of Observed and Modeled Dissolved Organic Nitrogen (mg/L) at John's Ranch between July 1, 2000 and August 31, 2002.

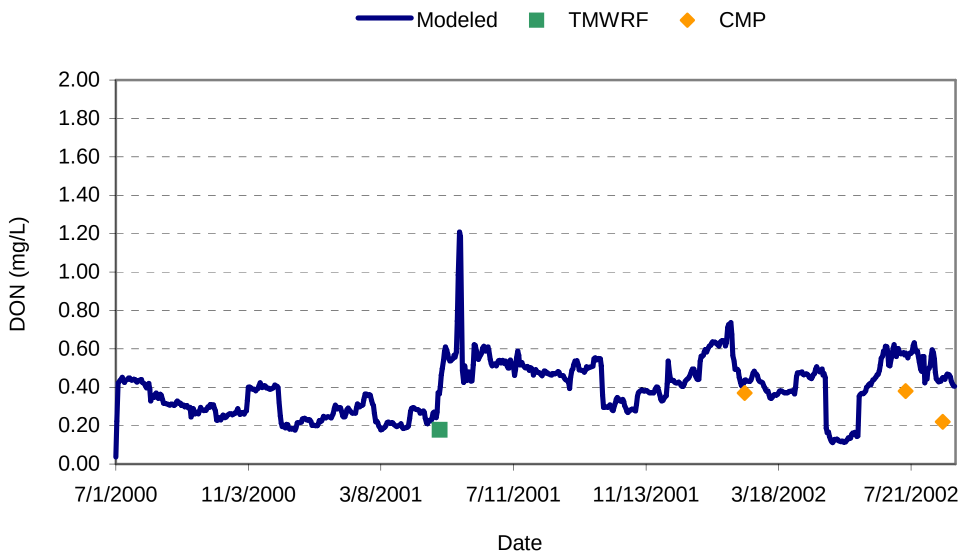

Figure A-63. Comparison of Observed and Modeled Dissolved Organic Nitrogen (mg/L) at Dead Ox between July 1, 2000 and August 31, 2002.

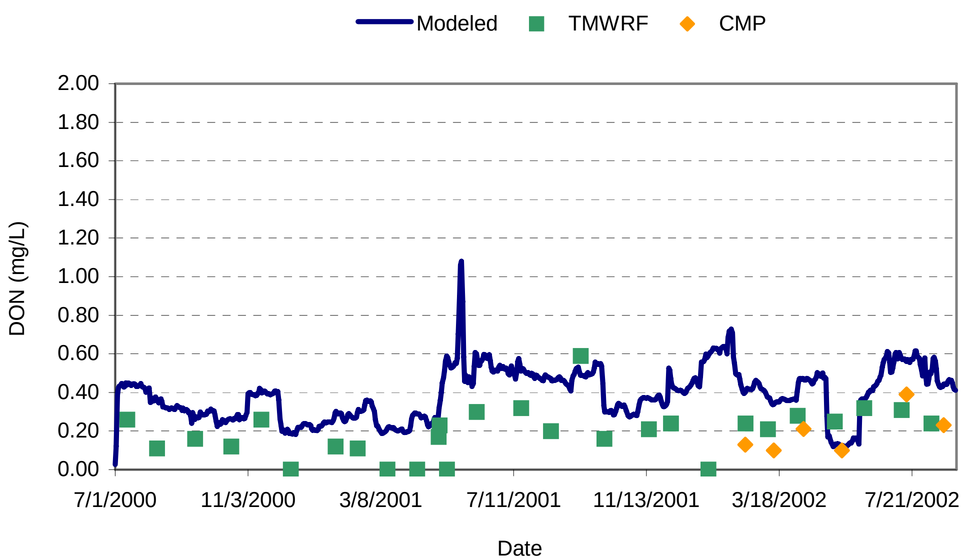

Figure A-64. Comparison of Observed and Modeled Dissolved Organic Nitrogen (mg/L) at Little Nixon between July 1, 2000 and August 31, 2002.

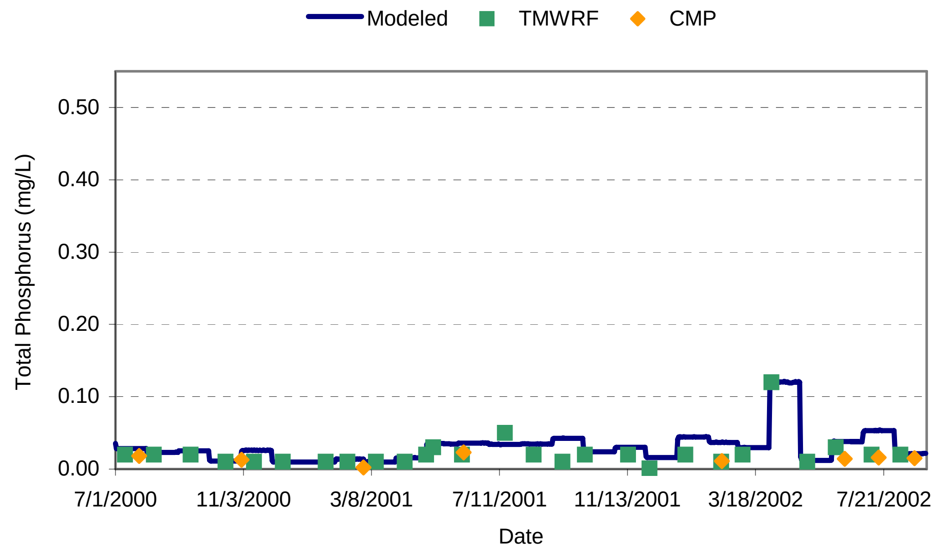

Figure A-65. Comparison of Observed and Modeled Total Phosphorus (mg/L) at East McCarran Bridge between July 1, 2000 and August 31, 2002.

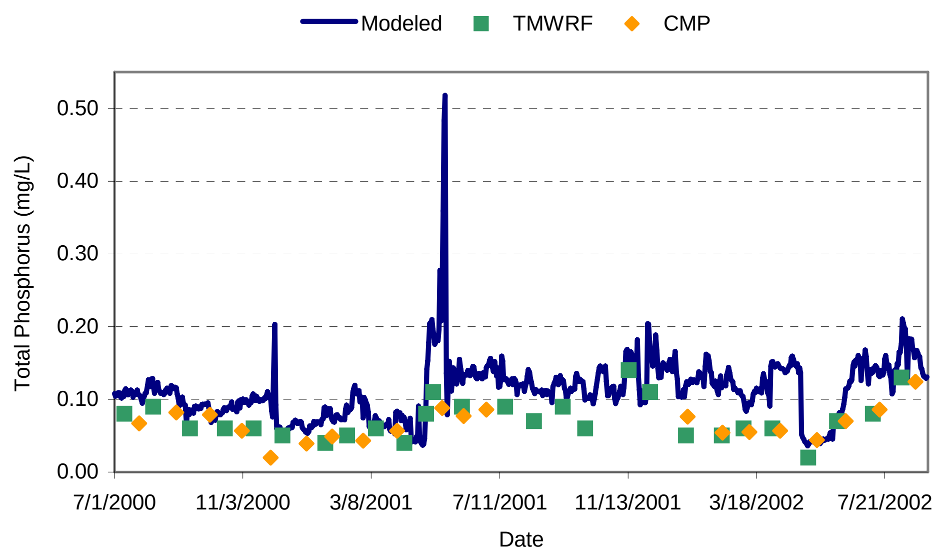

Figure A-66. Comparison of Observed and Modeled Total Phosphorus (mg/L) at Lockwood between July 1, 2000 and August 31, 2002.

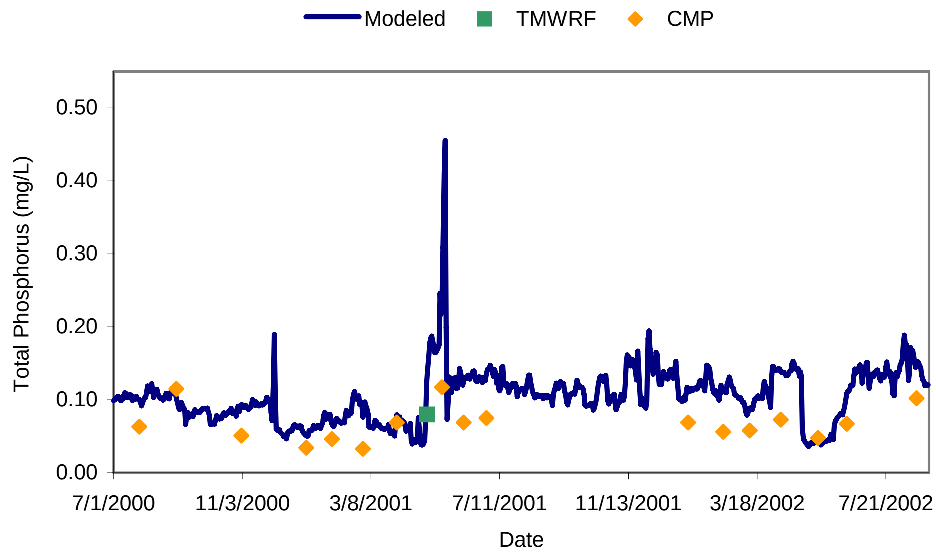

Figure A-67. Comparison of Observed and Modeled Total Phosphorus (mg/L) at Patrick between July 1, 2000 and August 31, 2002.

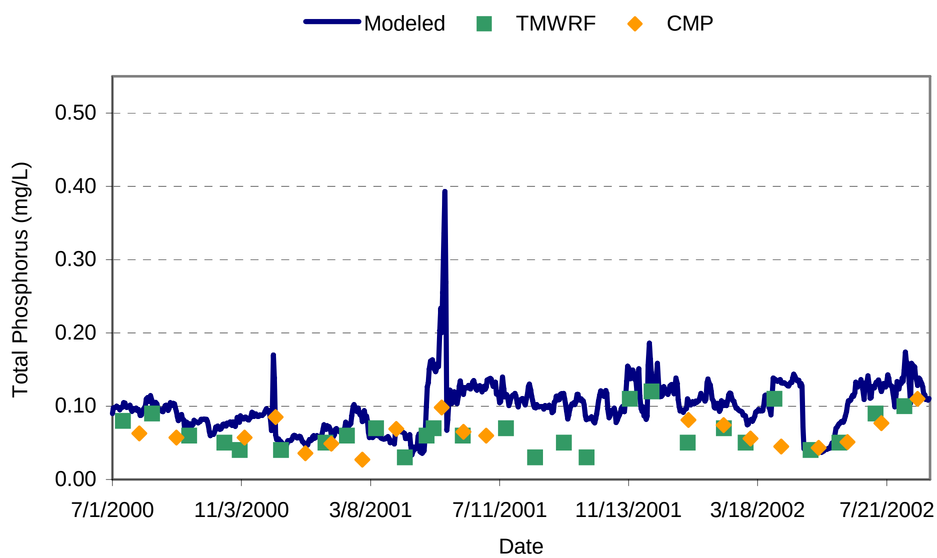

Figure A-68. Comparison of Observed and Modeled Total Phosphorus (mg/L) at Tracy-Clark between July 1, 2000 and August 31, 2002.

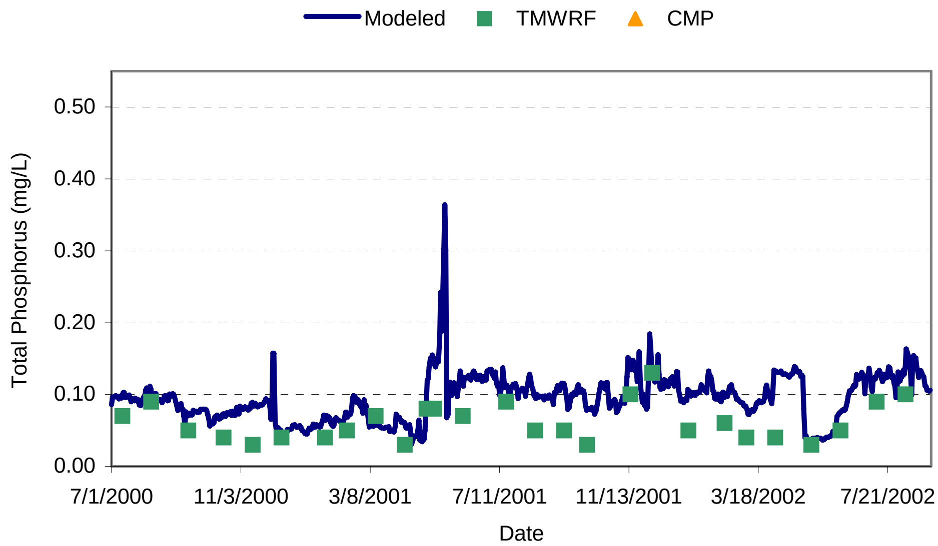

Figure A-69. Comparison of Observed and Modeled Total Phosphorus (mg/L) below Derby Dam between July 1, 2000 and August 31, 2002.

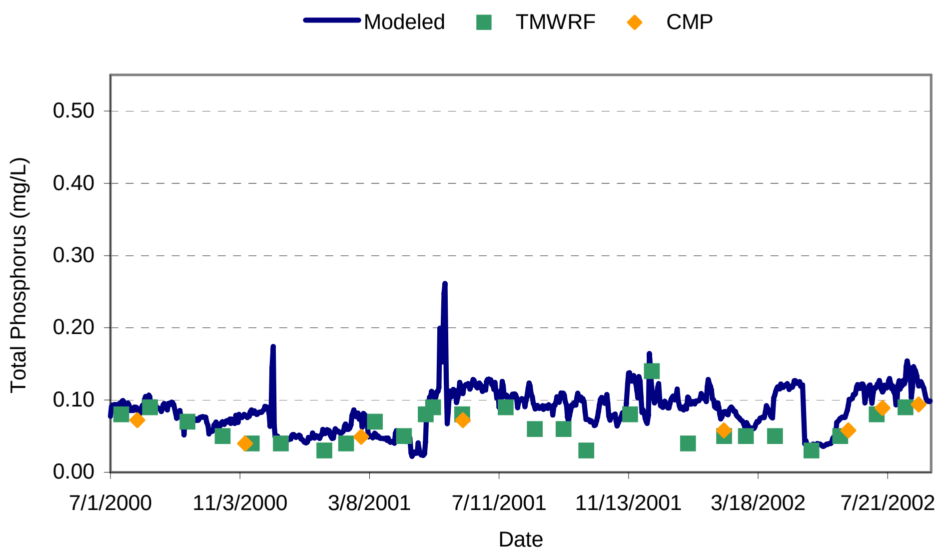

Figure A-70. Comparison of Observed and Modeled Total Phosphorus (mg/L) at Painted Rock between July 1, 2000 and August 31, 2002.

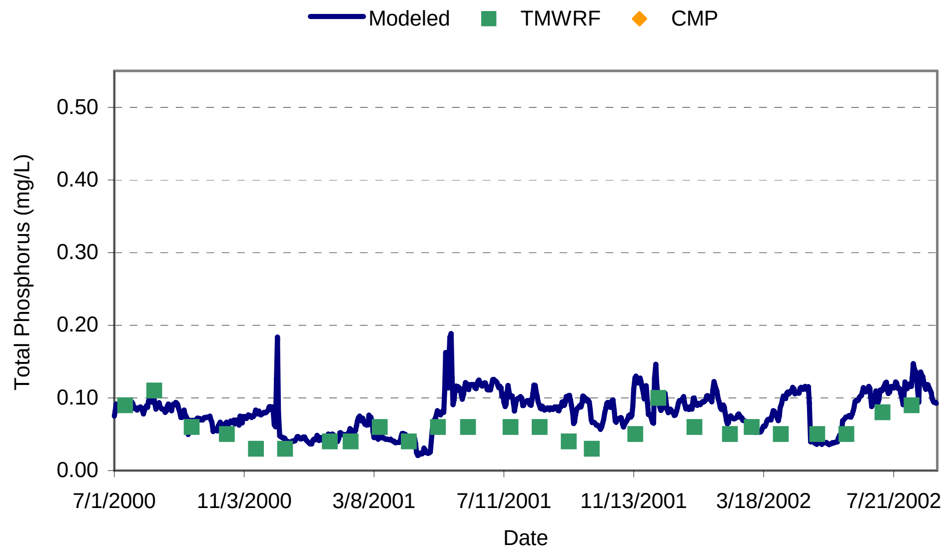

Figure A-71. Comparison of Observed and Modeled Total Phosphorus (mg/L) at Wadsworth between July 1, 2000 and August 31, 2002.

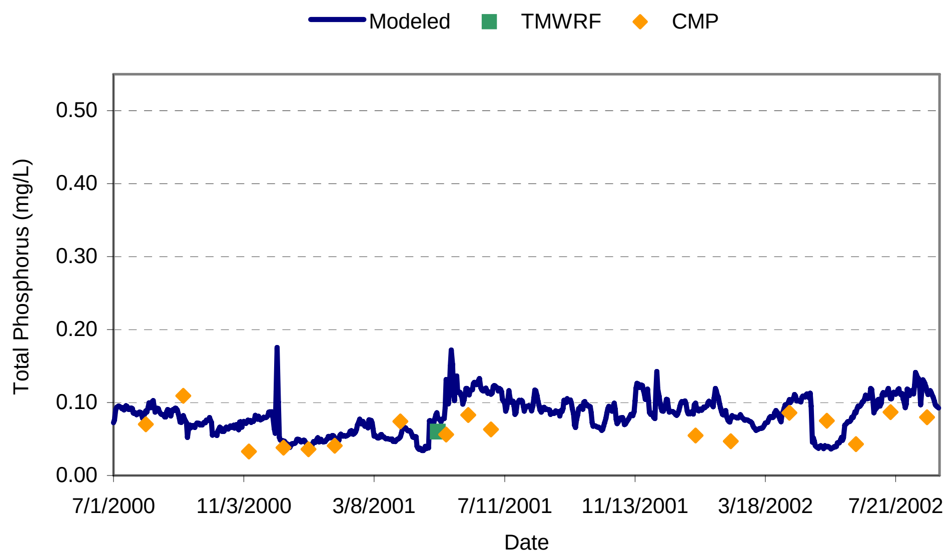

Figure A-72. Comparison of Observed and Modeled Total Phosphorus (mg/L) at John's Ranch between July 1, 2000 and August 31, 2002.

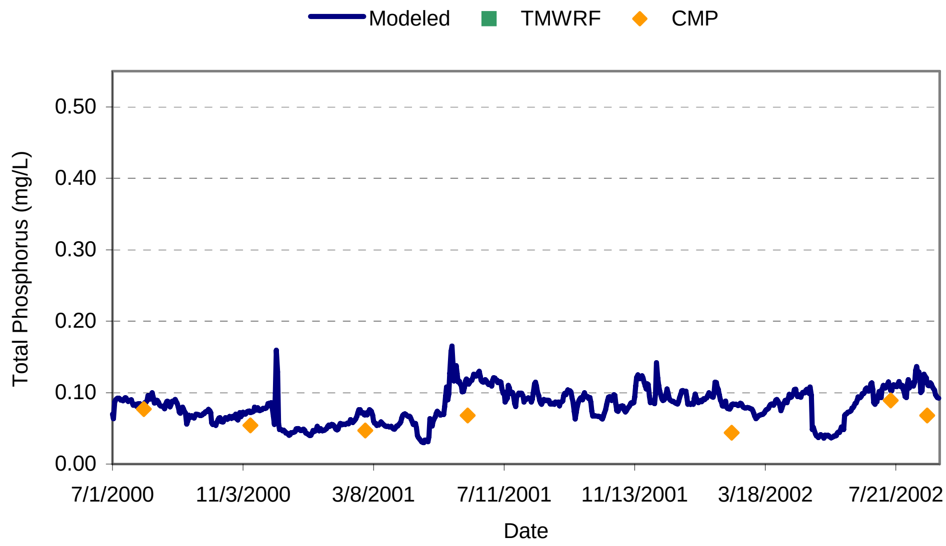

Figure A-73. Comparison of Observed and Modeled Total Phosphorus (mg/L) at Dead Ox between July 1, 2000 and August 31, 2002.

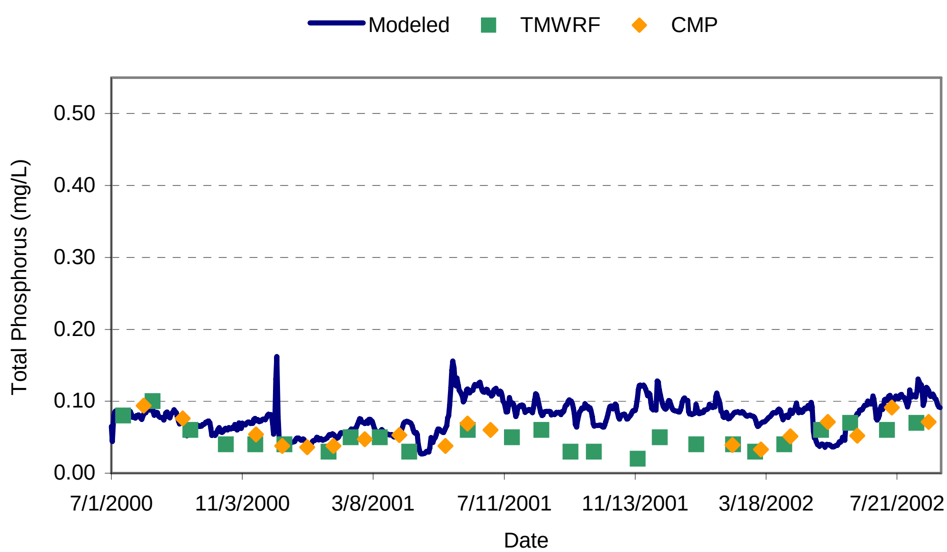

Figure A-74. Comparison of Observed and Modeled Total Phosphorus (mg/L) at Little Nixon between July 1, 2000 and August 31, 2002.

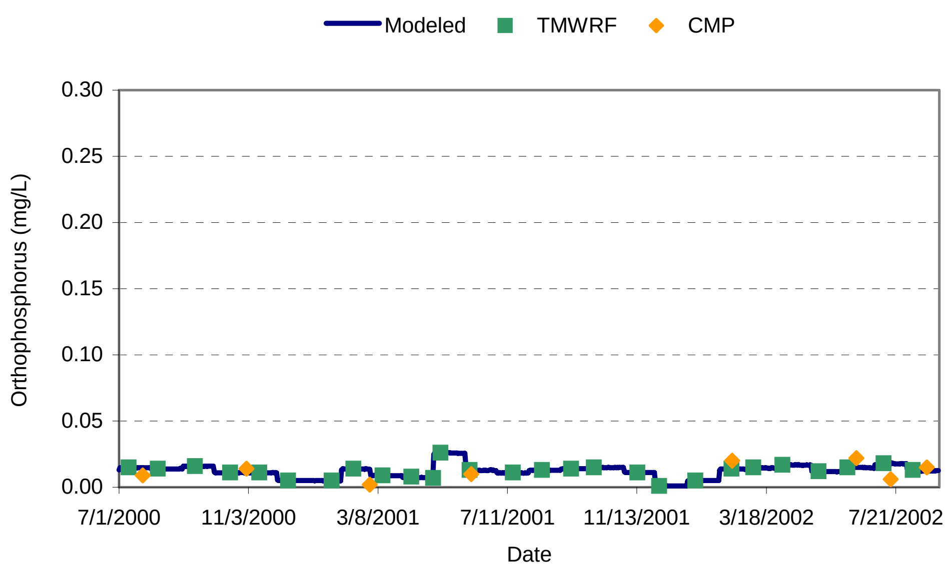

Figure A-75. Comparison of Observed and Modeled Orthophosphorus (mg/L) at East McCarran Bridge between July 1, 2000 and August 31, 2002.

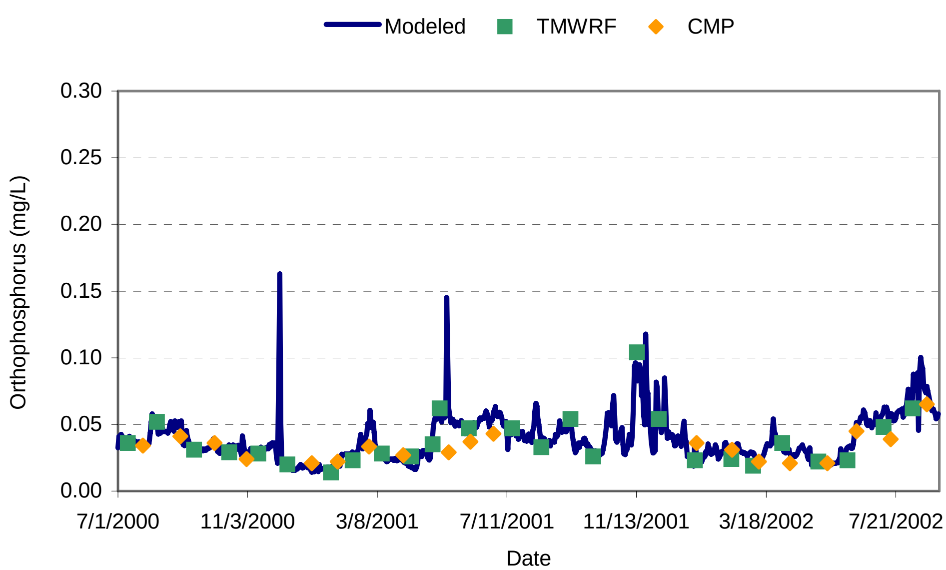

Figure A-76. Comparison of Observed and Modeled Orthophosphorus (mg/L) at Lockwood between July 1, 2000 and August 31, 2002.

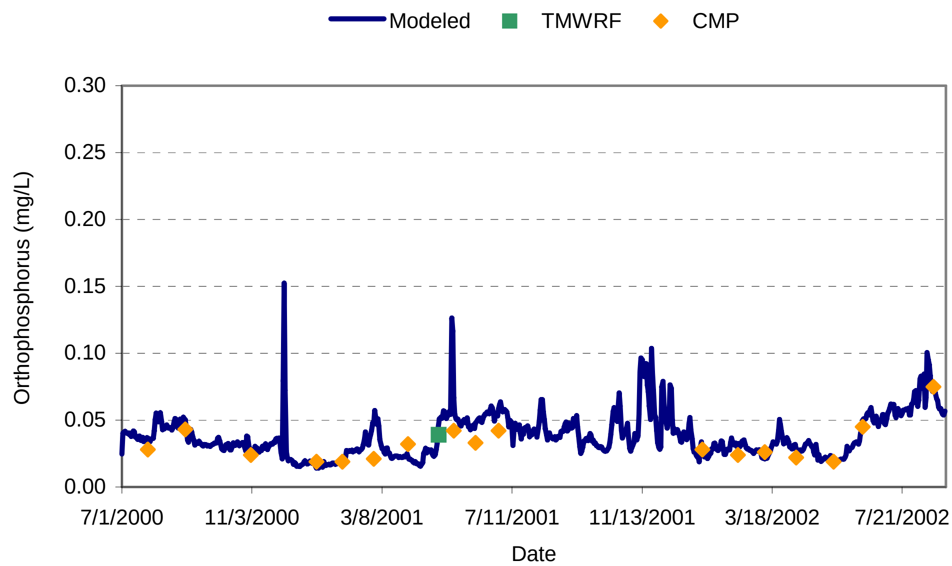

Figure A-77. Comparison of Observed and Modeled Orthophosphorus (mg/L) at Patrick between July 1, 2000 and August 31, 2002.

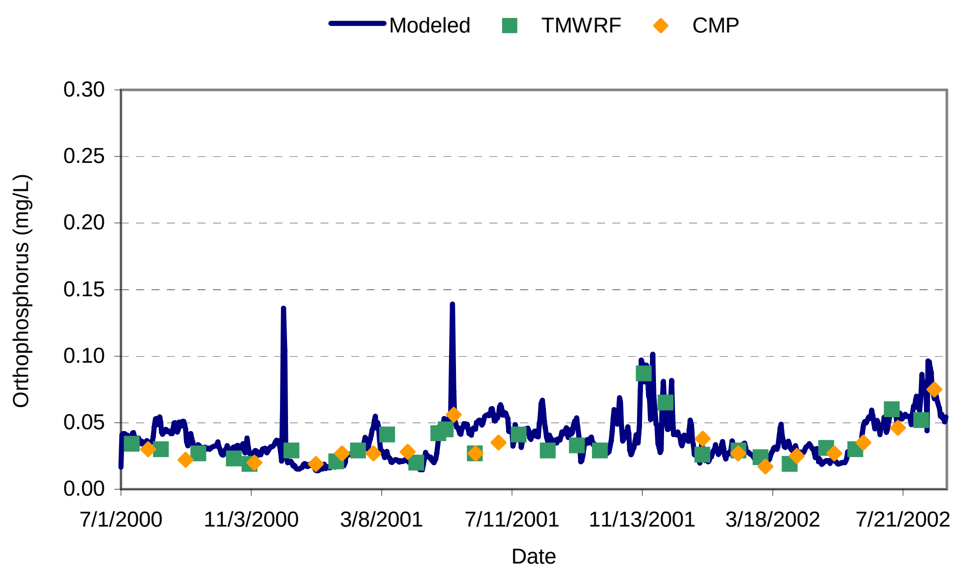

Figure A-78. Comparison of Observed and Modeled Orthophosphorus (mg/L) at Tracy-Clark between July 1, 2000 and August 31, 2002.

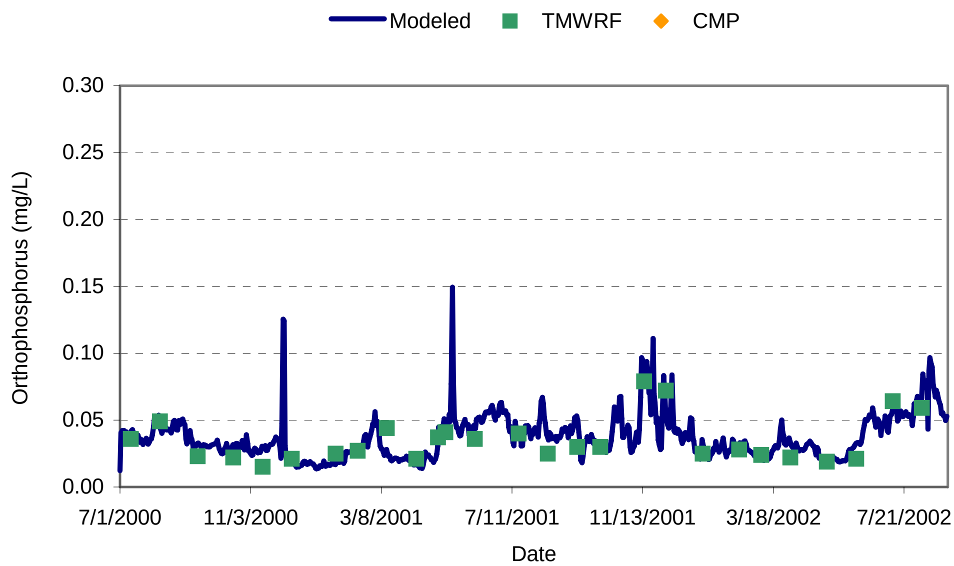

Figure A-79. Comparison of Observed and Modeled Orthophosphorus (mg/L) below Derby Dam between July 1, 2000 and August 31, 2002.

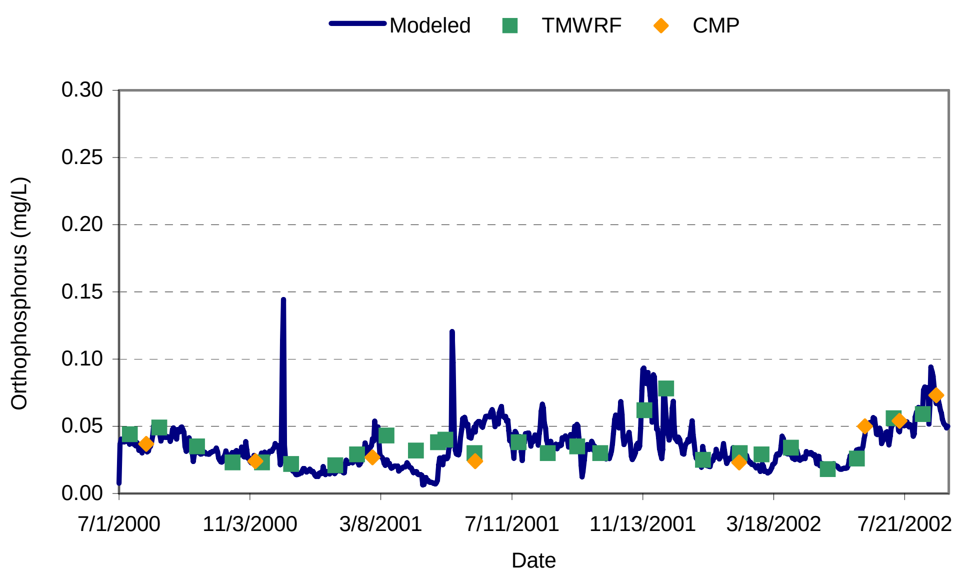

Figure A-80. Comparison of Observed and Modeled Orthophosphorus (mg/L) at Painted Rock between July 1, 2000 and August 31, 2002.

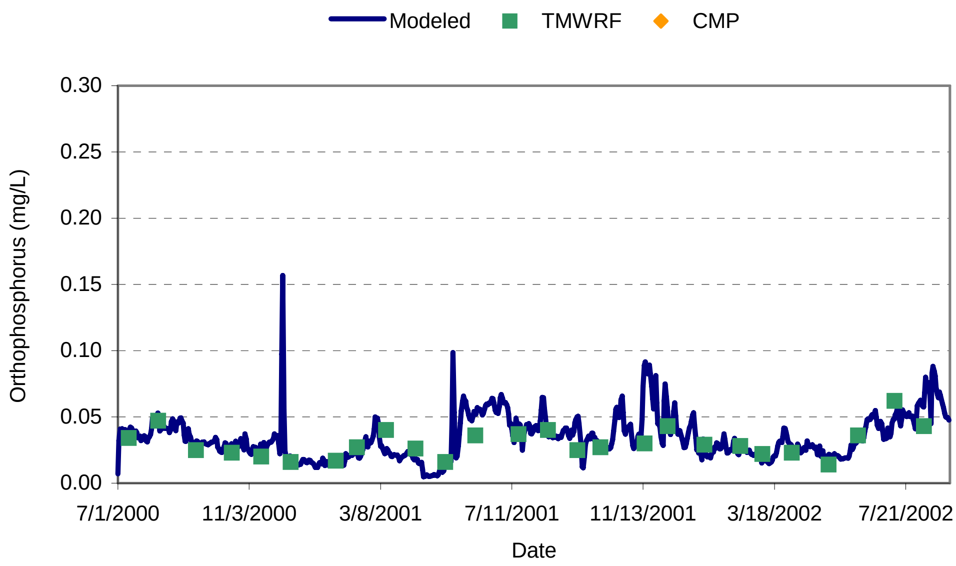

Figure A-81. Comparison of Observed and Modeled Orthophosphorus (mg/L) at Wadsworth between July 1, 2000 and August 31, 2002.

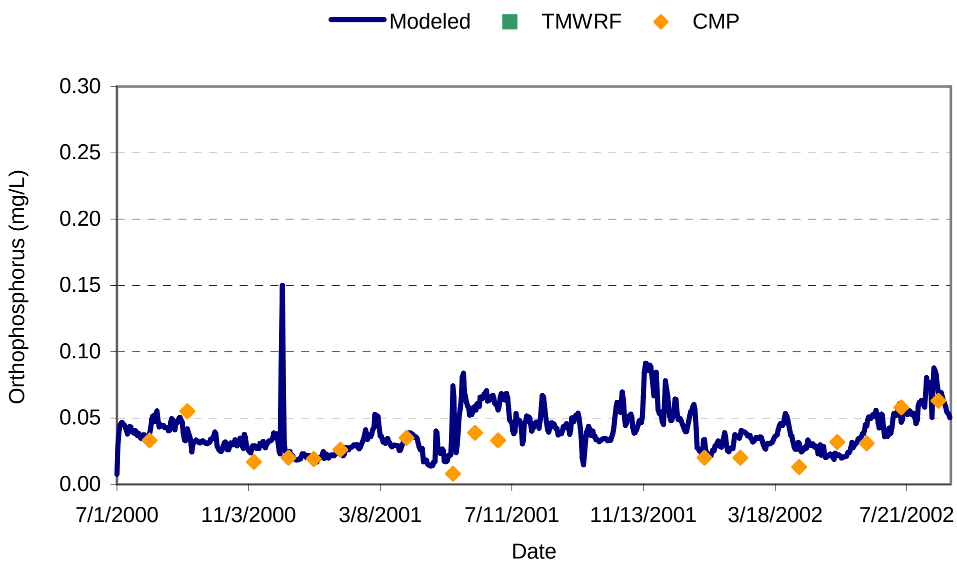

Figure A-82. Comparison of Observed and Modeled Orthophosphorus (mg/L) at John's Ranch between July 1, 2000 and August 31, 2002.

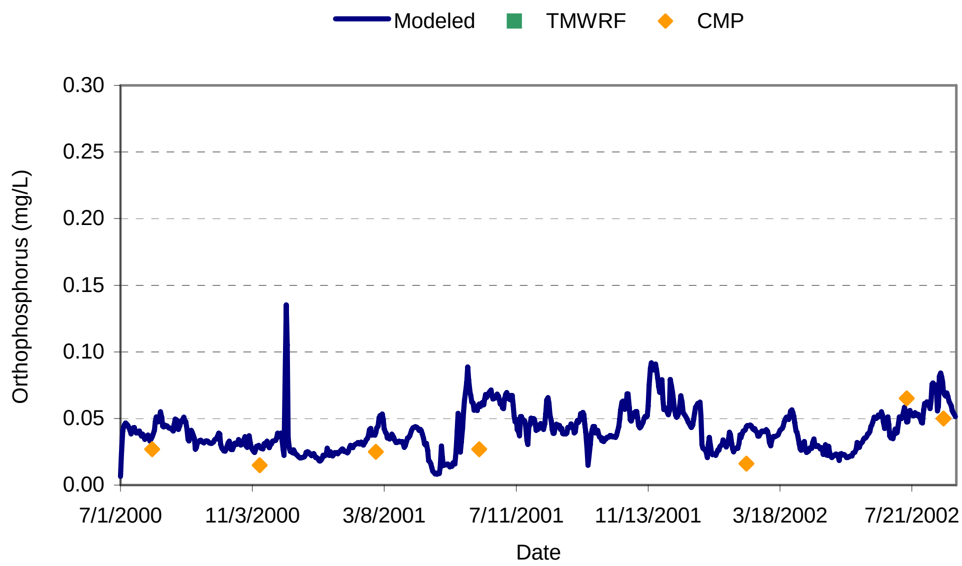

Figure A-83. Comparison of Observed and Modeled Orthophosphorus (mg/L) at Dead Ox between July 1, 2000 and August 31, 2002.

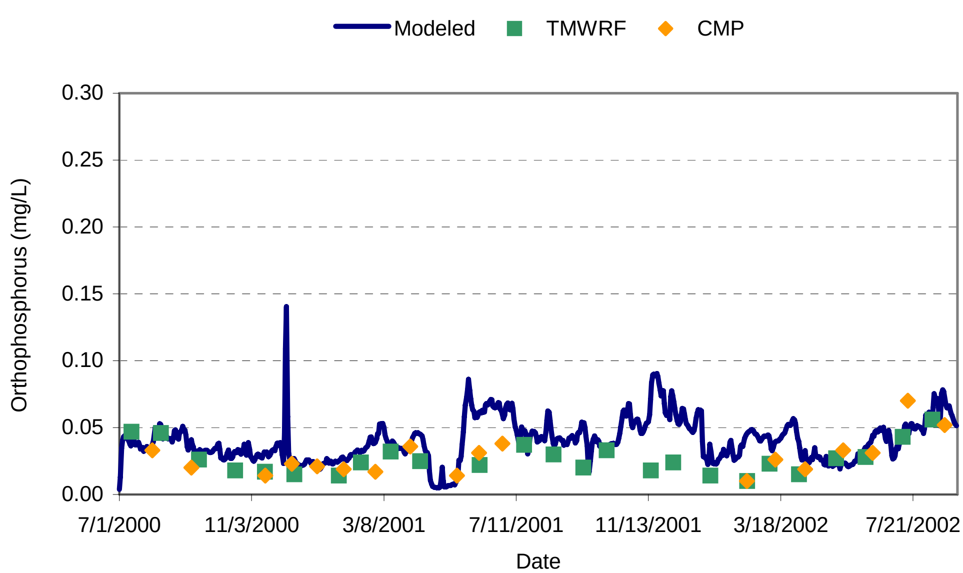

Figure A-84. Comparison of Observed and Modeled Orthophosphorus (mg/L) at Little Nixon between July 1, 2000 and August 31, 2002.

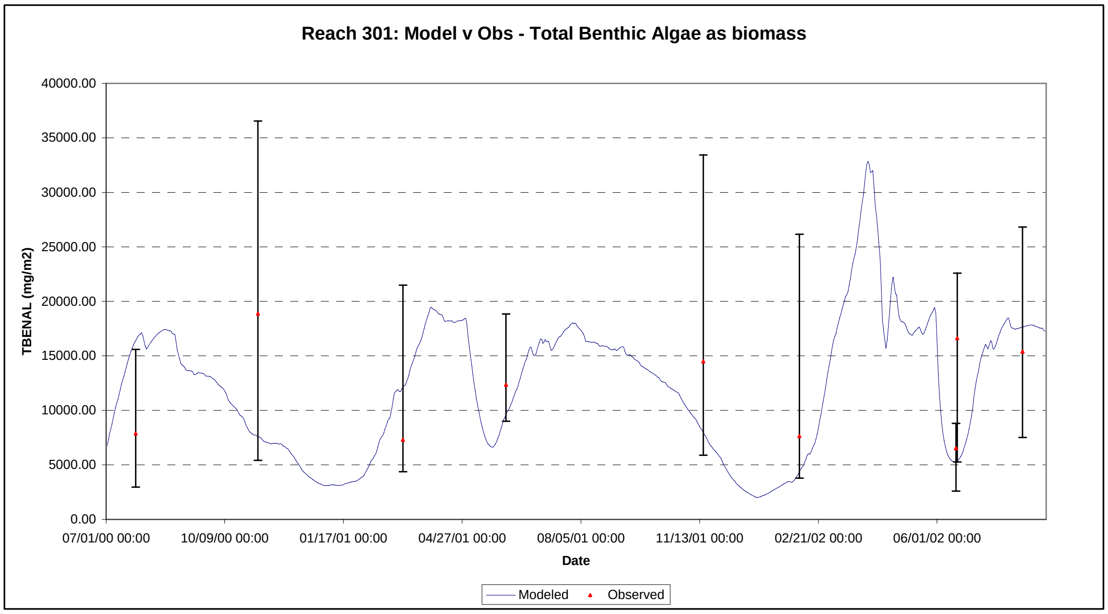

Figure A-85. Comparison of Observed and Modeled Periphtyon Biomass at East McCarran (Reach 301) between July 1, 2000 and August 31, 2002.

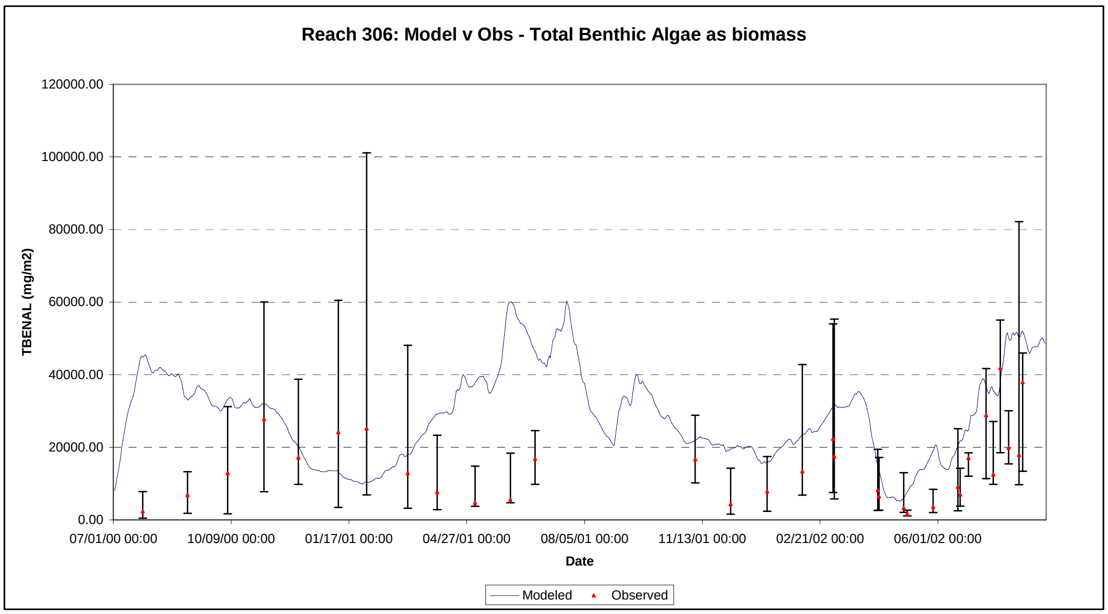

Figure A-86. Comparison of Observed and Modeled Periphtyon Biomass at Lockwood (Reach 306) between July 1, 2000 and August 31, 2002.

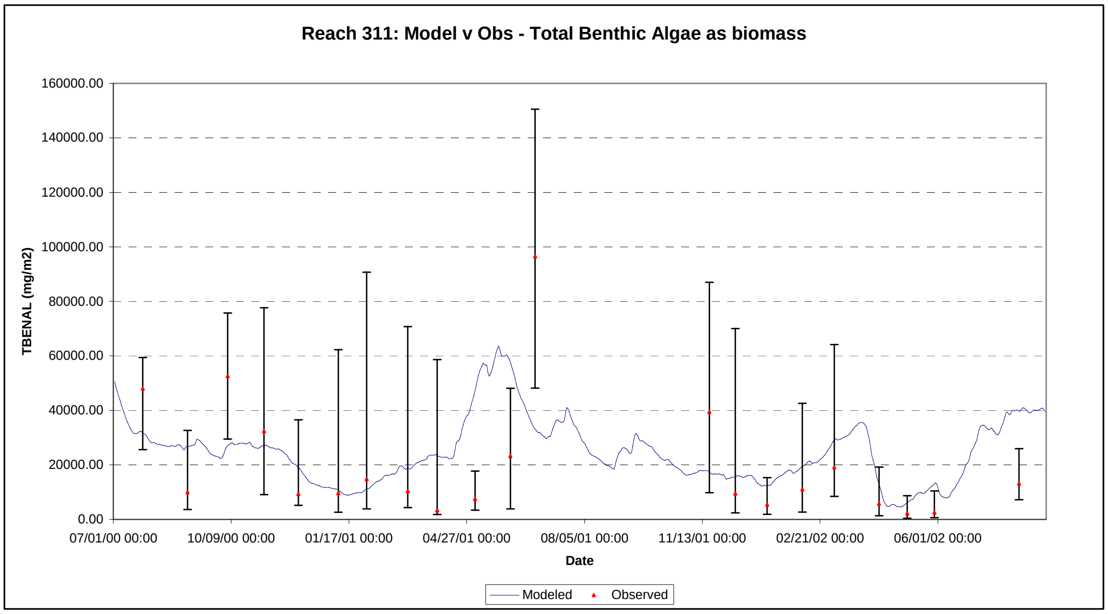

Figure A-87. Comparison of Observed and Modeled Periphtyon Biomass Patrick (Reach 311) between July 1, 2000 and August 31, 2002.

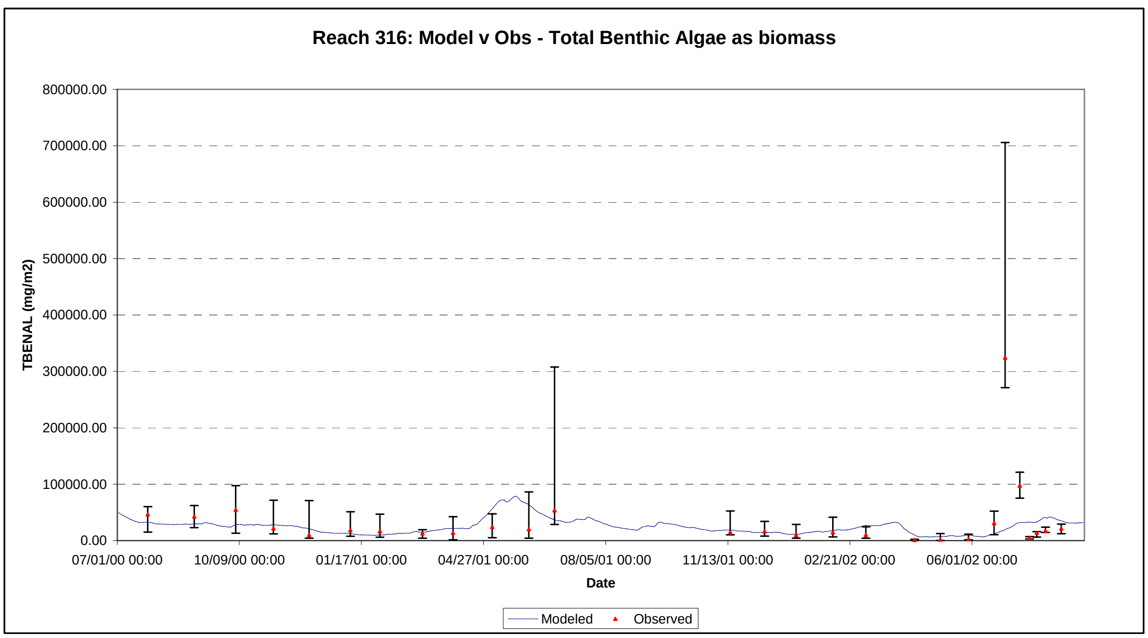

Figure A-88. Comparison of Observed and Modeled Periphtyon Biomass at Tracy (Reach 316) between July 1, 2000 and August 31, 2002.

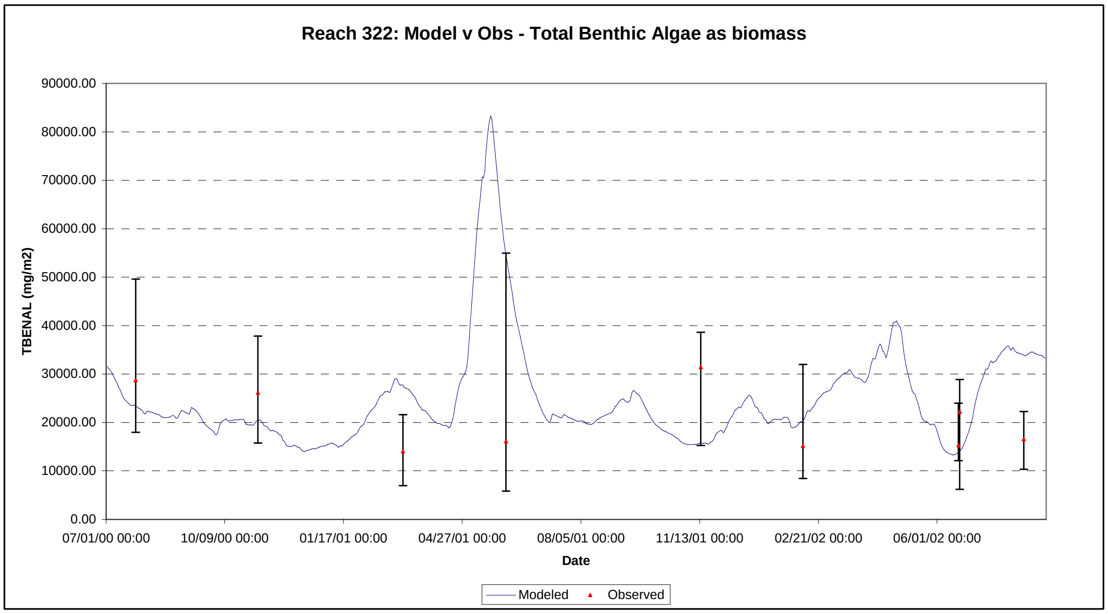

Figure A-89. Comparison of Observed and Modeled Periphtyon Biomass at Painted Rock (Reach 322) between July 1, 2000 and August 31, 2002.

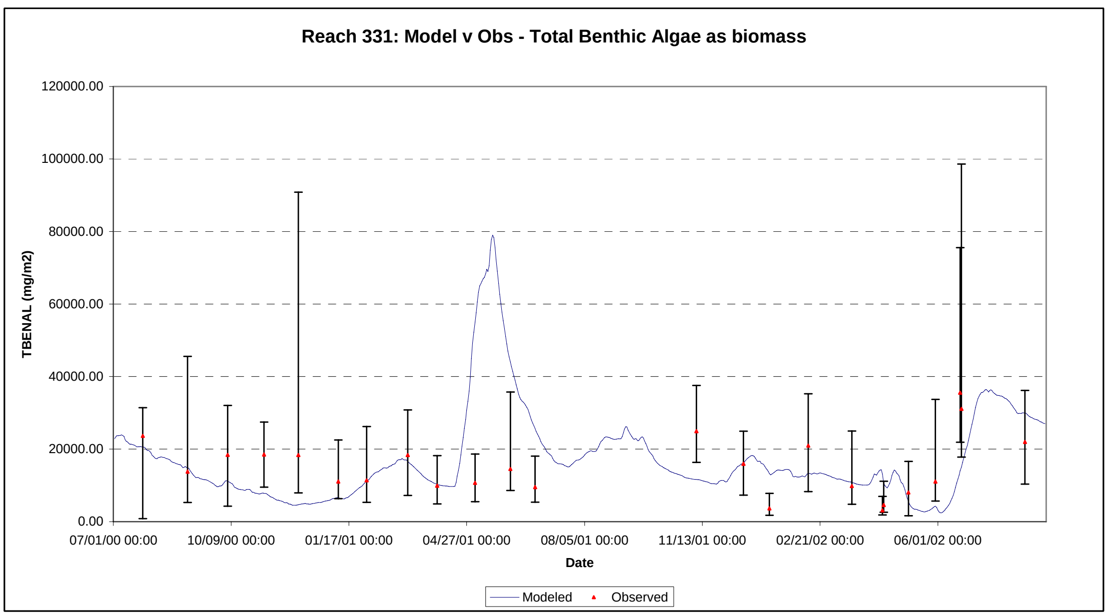

Figure A-90. Comparison of Observed and Modeled Periphtyon Biomass at Johns Ranch (Reach 331) between July 1, 2000 and August 31, 2002.

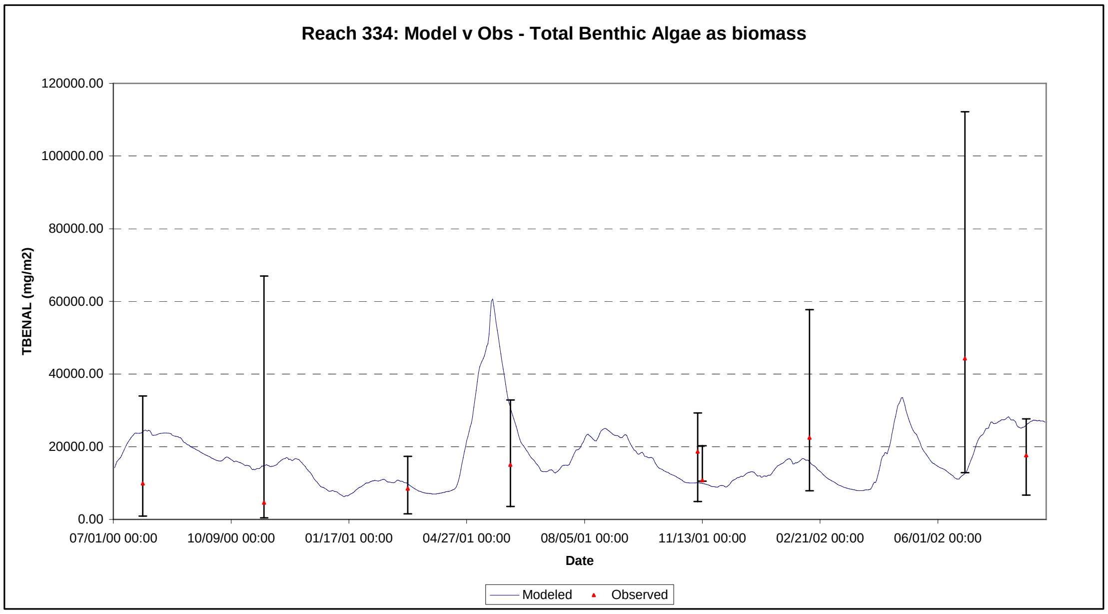

Figure A-91. Comparison of Observed and Modeled Periphtyon Biomass at Dead Ox (Reach 334) between July 1, 2000 and August 31, 2002.

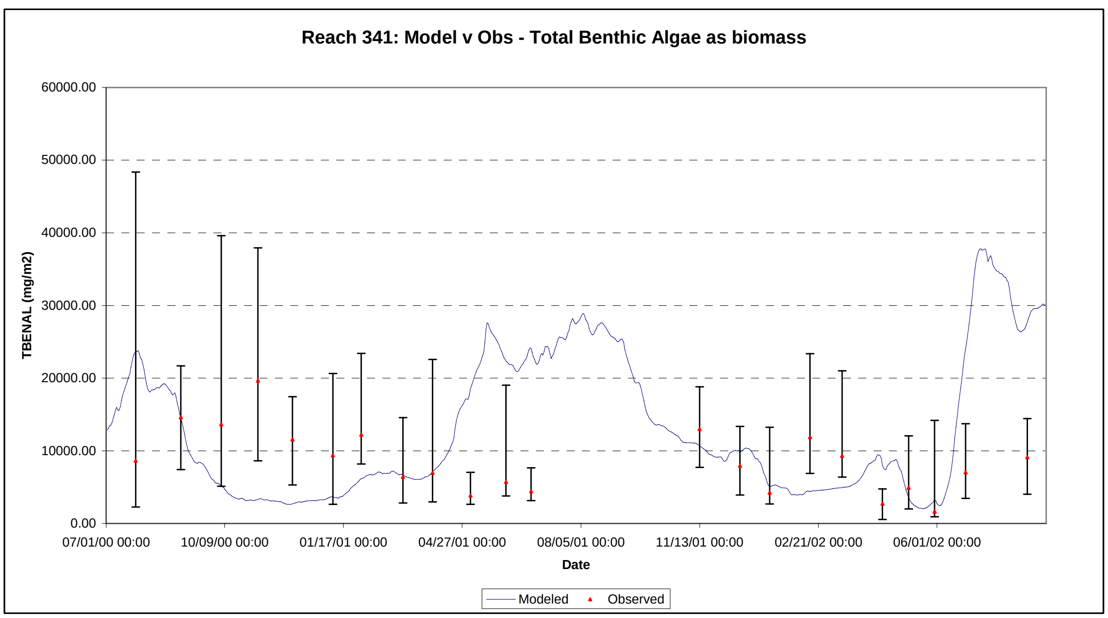

Figure A-92. Comparison of Observed and Modeled Periphtyon Biomass at Little Nixon (Reach 341) between July 1, 2000 and August 31, 2002.

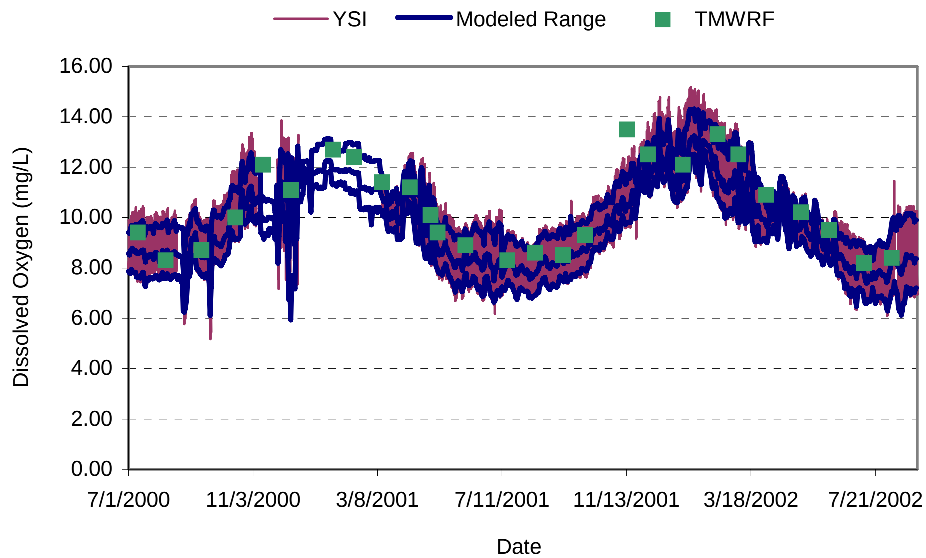

Figure A-93. Comparison of Observed and Modeled Dissolved Oxygen (mg/L) at East McCarran between July 1, 2000 and August 31, 2002.

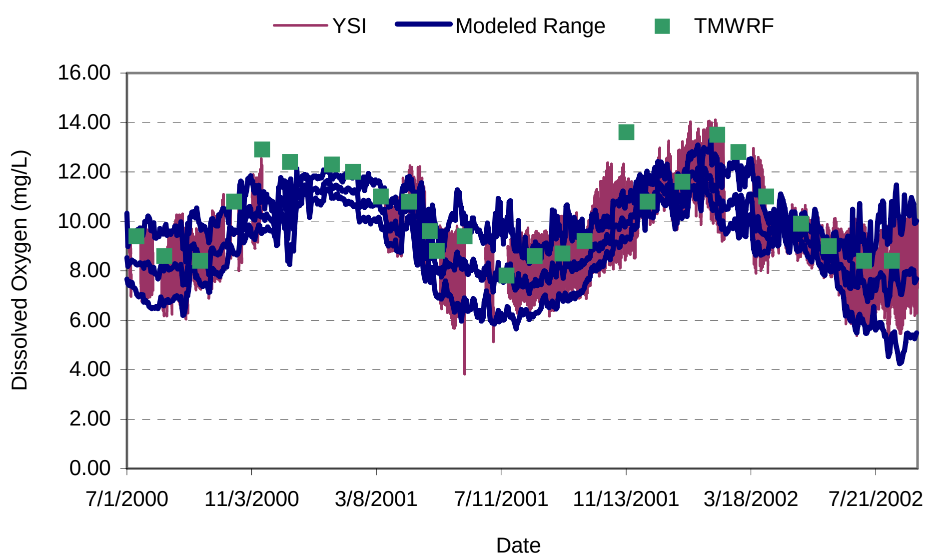

Figure A-94. Comparison of Observed and Modeled Dissolved Oxygen (mg/L) at Lockwood between July 1, 2000 and August 31, 2002.

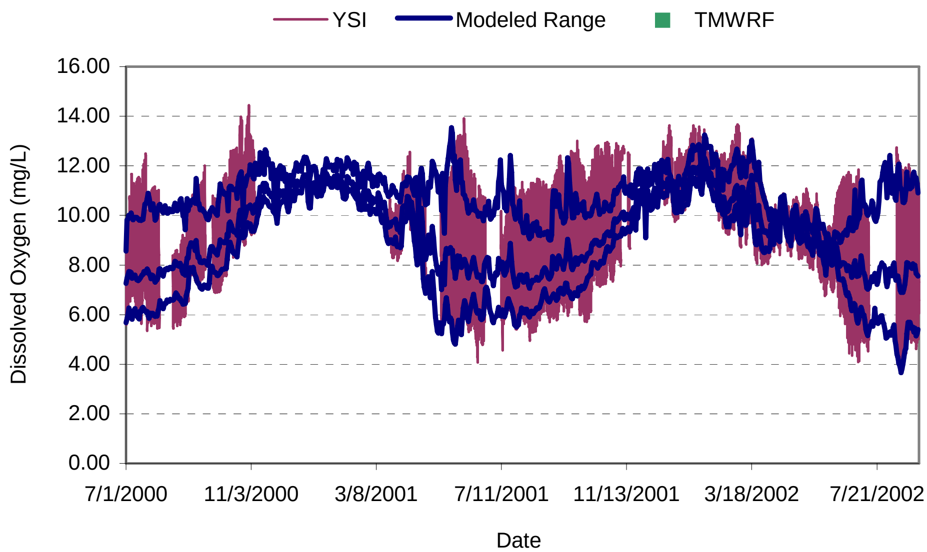

Figure A-95. Comparison of Observed and Modeled Dissolved Oxygen (mg/L) at Tracy between July 1, 2000 and August 31, 2002.

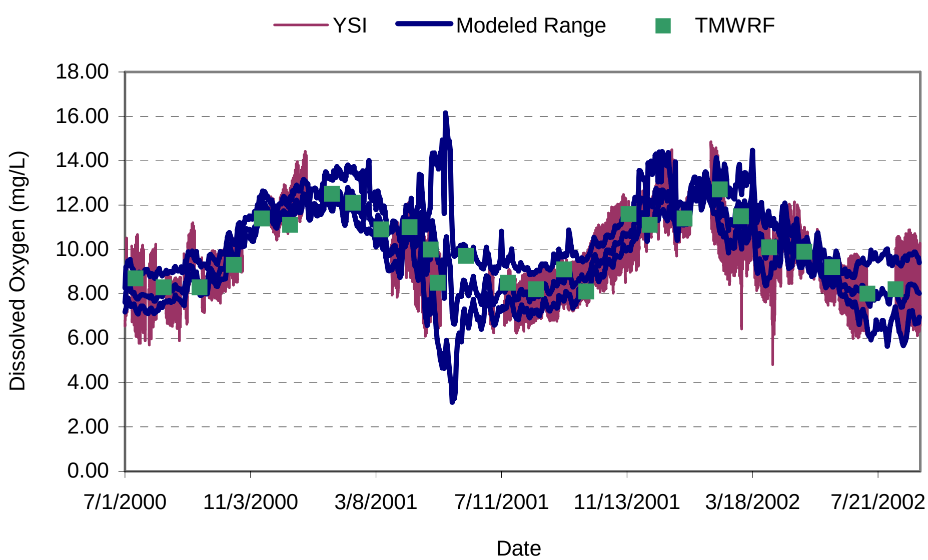

Figure A-96. Comparison of Observed and Modeled Dissolved Oxygen (mg/L) at Painted Rock between July 1, 2000 and August 31, 2002.

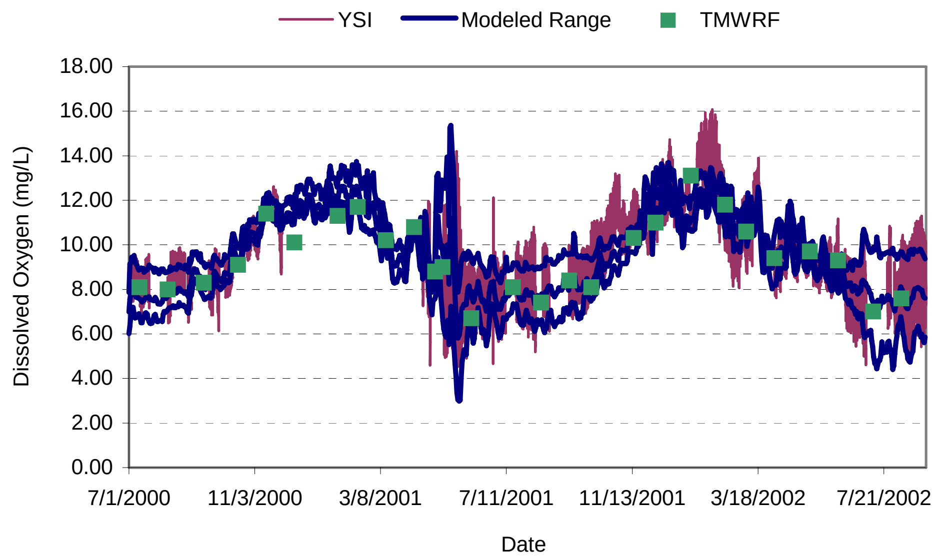

Figure A-97. Comparison of Observed and Modeled Dissolved Oxygen (mg/L) at Wadsworth between July 1, 2000 and August 31, 2002.

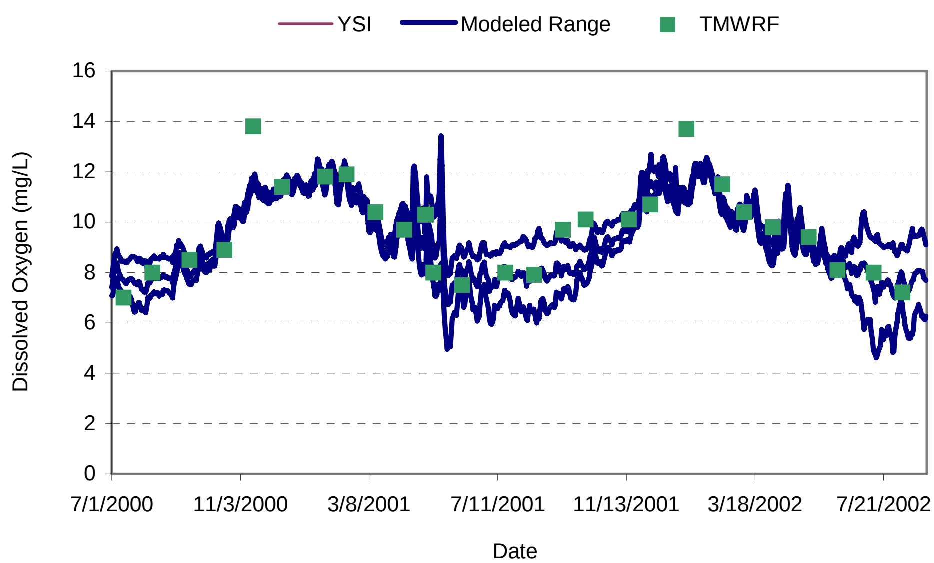

Figure A-98. Comparison of Observed and Modeled Dissolved Oxygen (mg/L) at Little Nixon between July 1, 2000 and August 31, 2002.

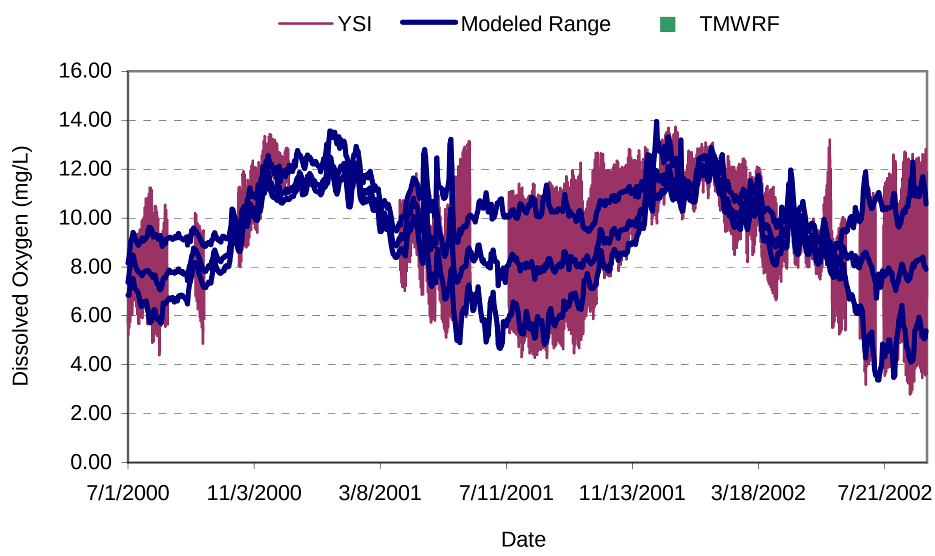

Figure A-99. Comparison of Observed and Modeled Dissolved Oxygen (mg/L) at Marble Bluff Dam between July 1, 2000 and August 31, 2002.

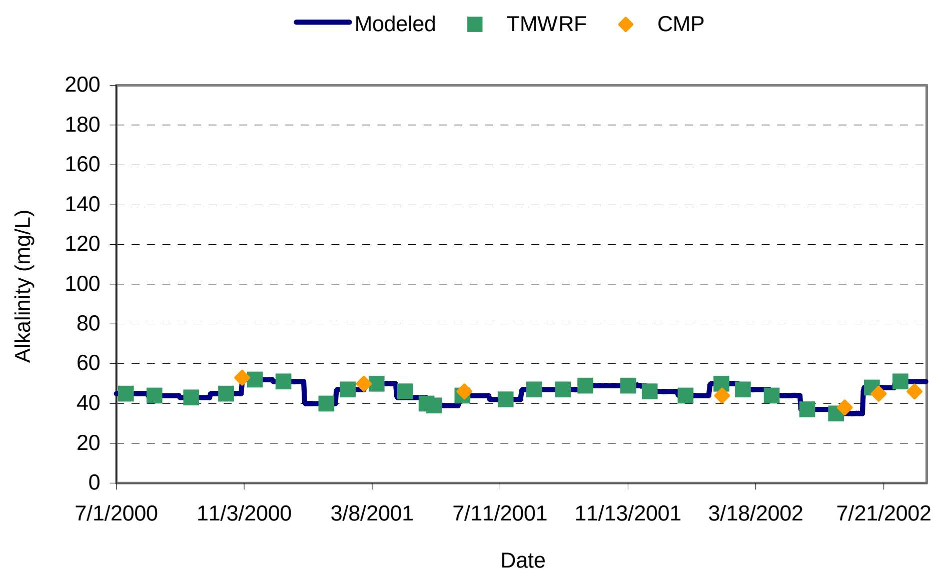

Figure A-100. Comparison of Observed and Modeled Alkalinity as $CaCO_3$ (mg/L) at East McCarran between July 1, 2000 and August 31, 2002.

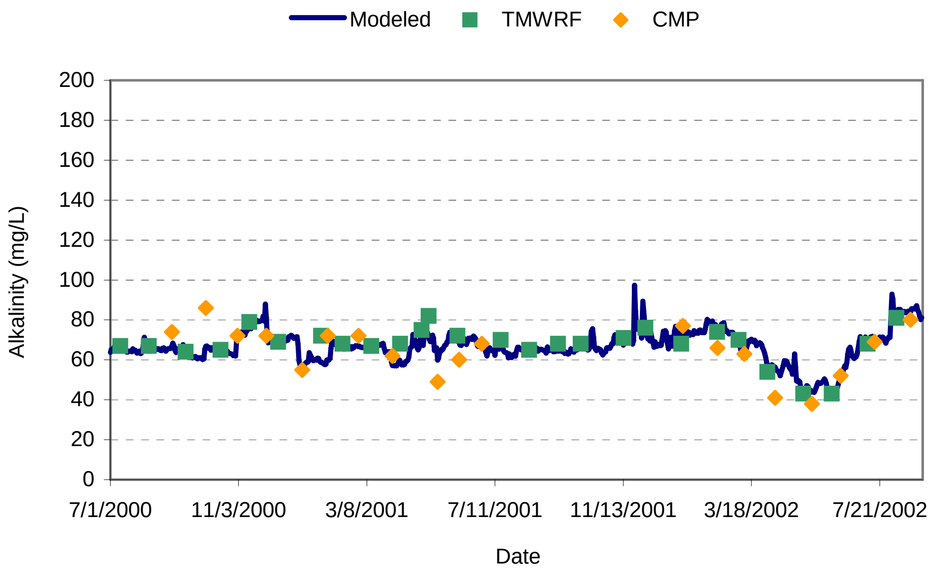

Figure A-101. Comparison of Observed and Modeled Alkalinity as $CaCO_3$ (mg/L) at Lockwood between July 1, 2000 and August 31, 2002.

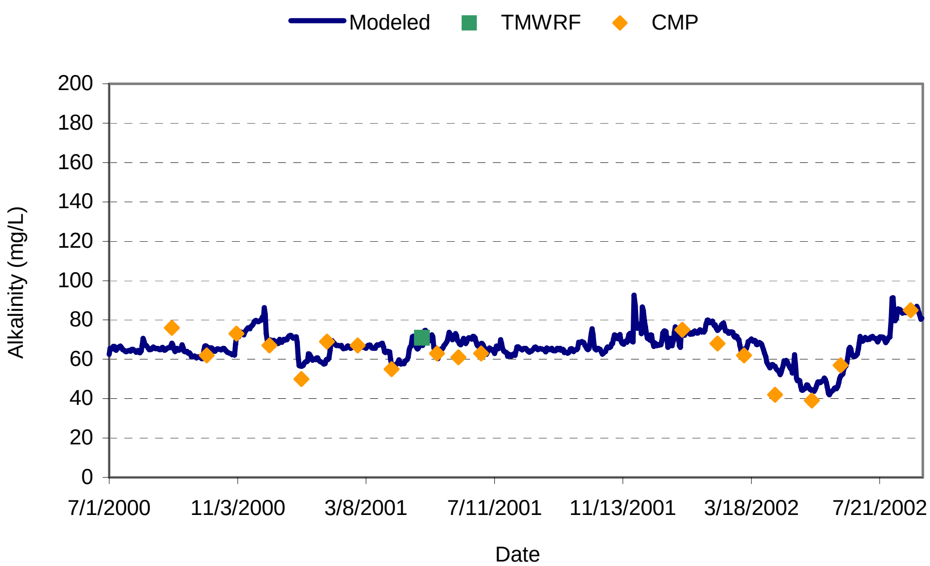

Figure A-102. Comparison of Observed and Modeled Alkalinity as $CaCO_3$ (mg/L) at Patrick between July 1, 2000 and August 31, 2002.

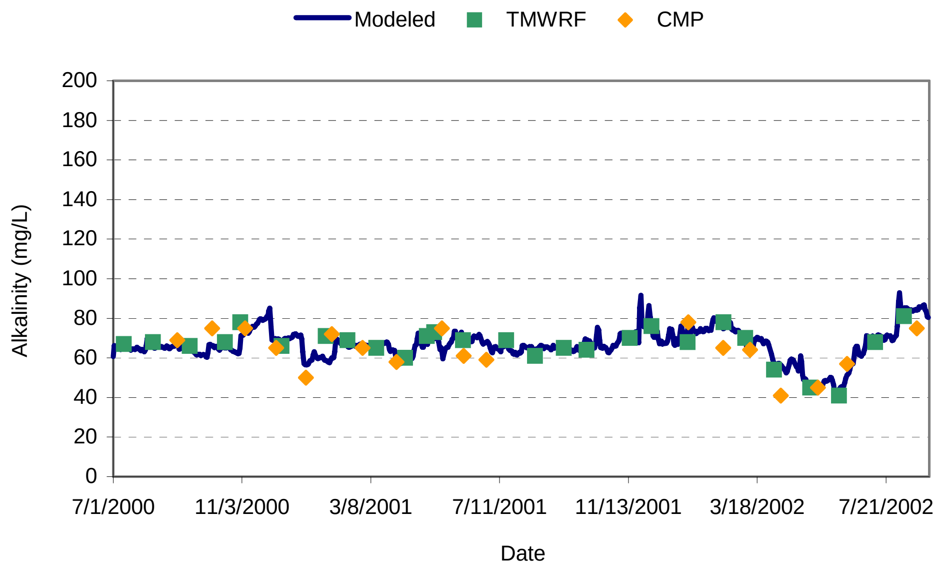

Figure A-103. Comparison of Observed and Modeled Alkalinity as $CaCO_3$ (mg/L) at Tracy-Clark Dam between July 1, 2000 and August 31, 2002.

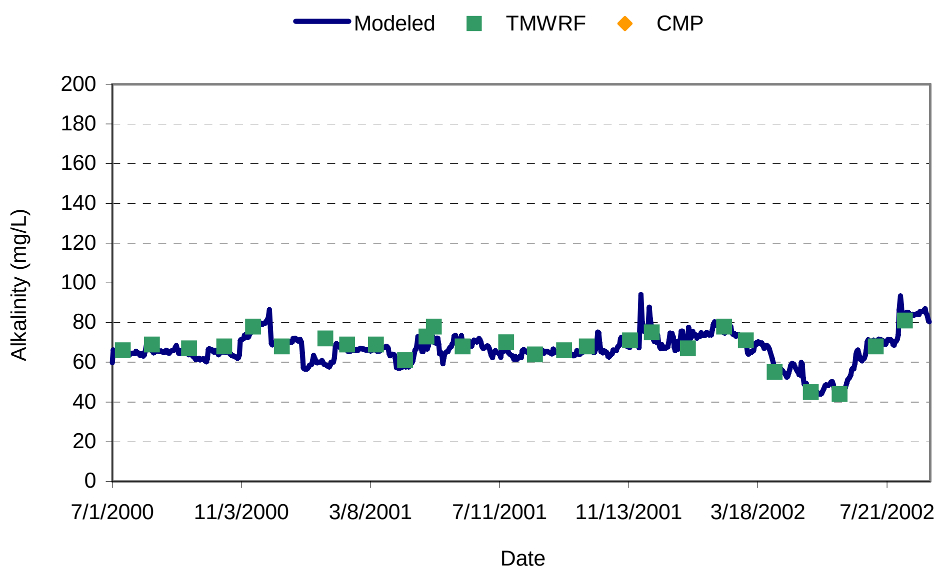

Figure A-104. Comparison of Observed and Modeled Alkalinity as $CaCO_3$ (mg/L) at below Derby Dam between July 1, 2000 and August 31, 2002.

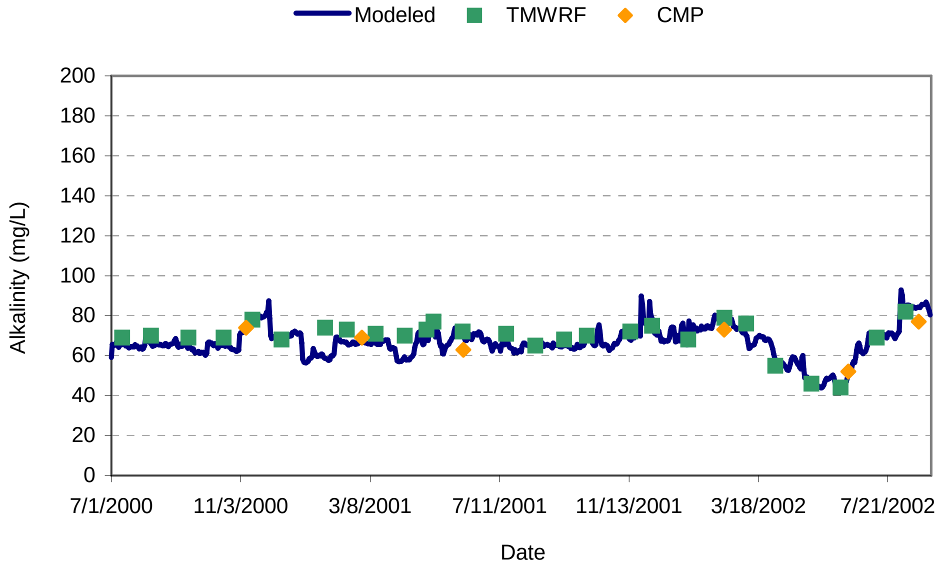

Figure A-105. Comparison of Observed and Modeled Alkalinity as $CaCO_3$ (mg/L) at Painted Rock between July 1, 2000 and August 31, 2002.

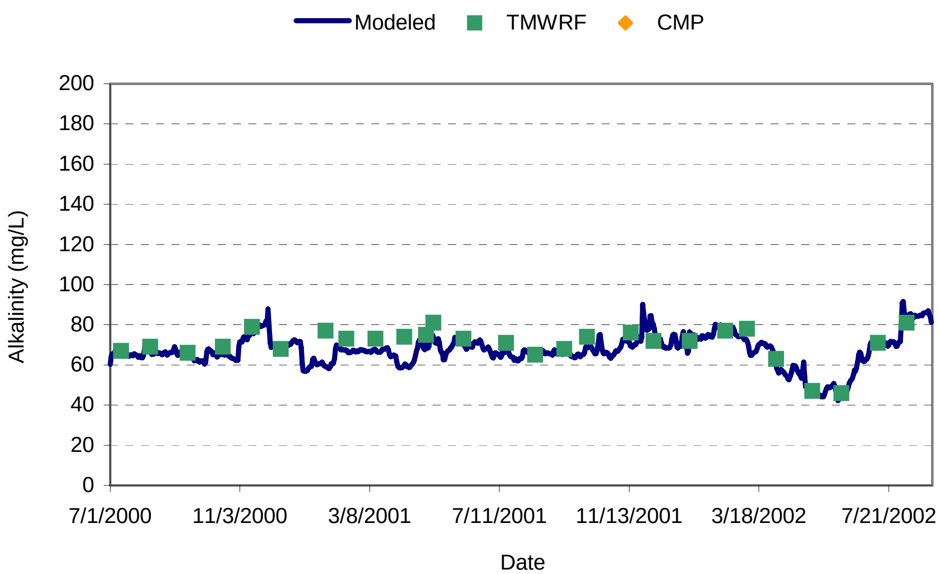

Figure A-106. Comparison of Observed and Modeled Alkalinity as $CaCO_3$ (mg/L) at Wadsworth between July 1, 2000 and August 31, 2002.

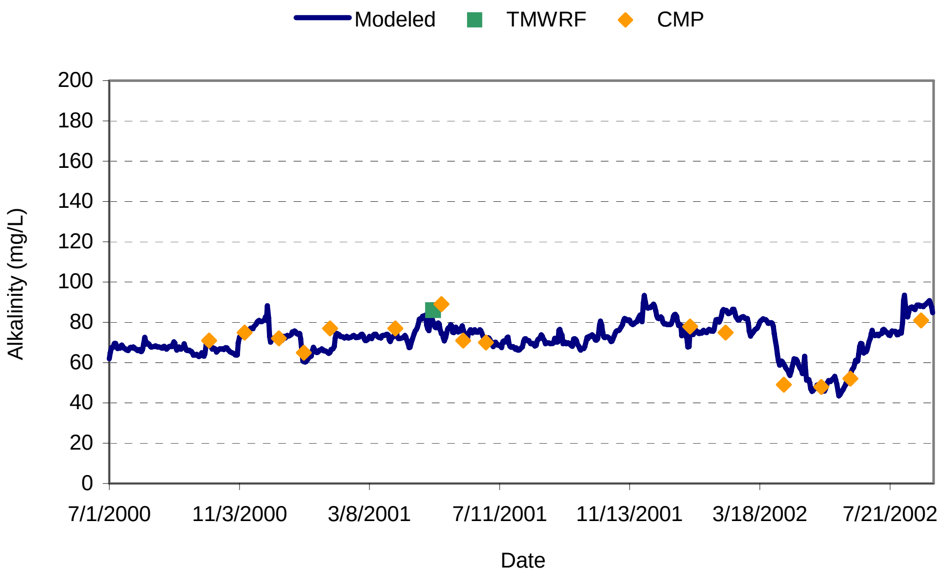

Figure A-107. Comparison of Observed and Modeled Alkalinity as $CaCO_3$ (mg/L) at John's Ranch between July 1, 2000 and August 31, 2002.

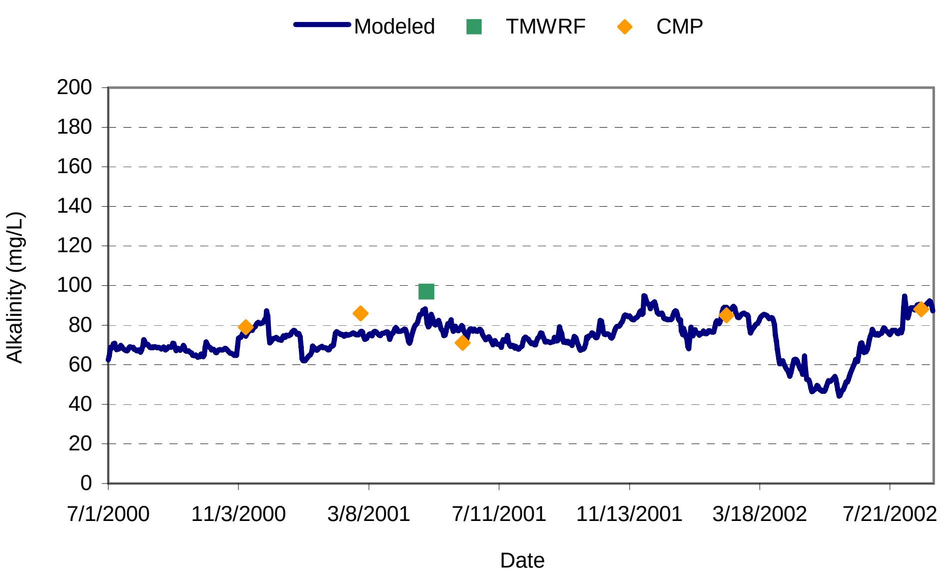

Figure A-108. Comparison of Observed and Modeled Alkalinity as $CaCO_3$ (mg/L) at Dead Ox between July 1, 2000 and August 31, 2002.

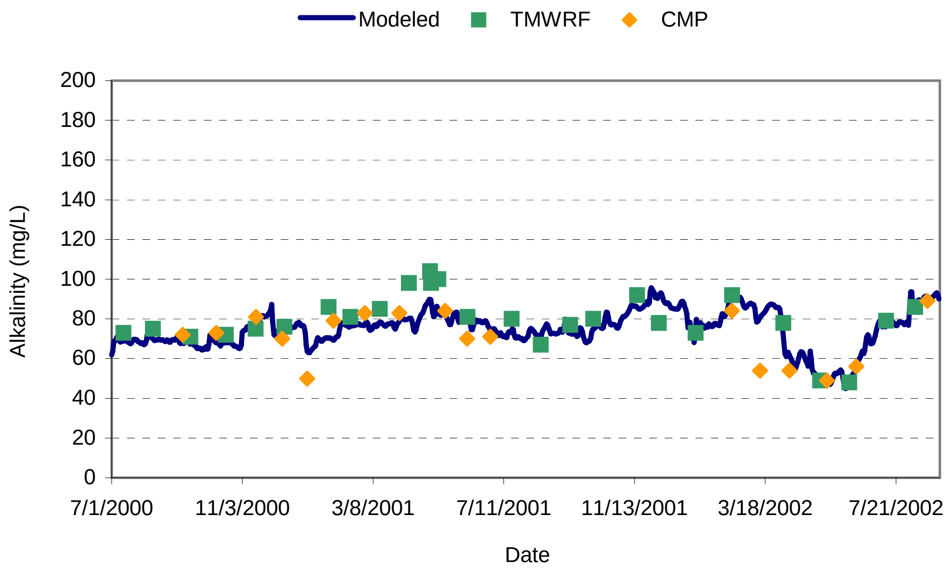

Figure A-109. Comparison of Observed and Modeled Alkalinity as $CaCO_3$ (mg/L) at Little Nixon between July 1, 2000 and August 31, 2002.

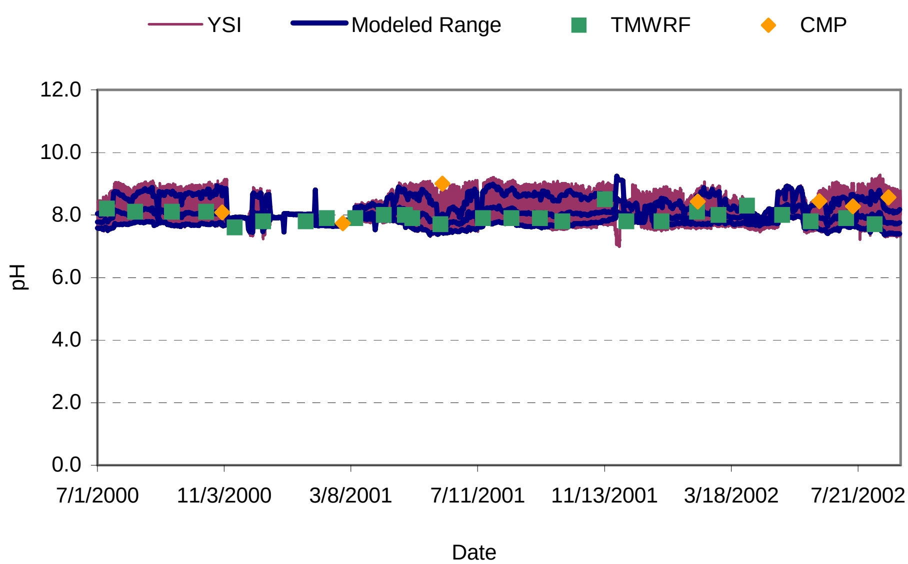

Figure A-110. Comparison of Observed and Modeled pH at East McCarran Bridge between July 1, 2000 and August 31, 2002.

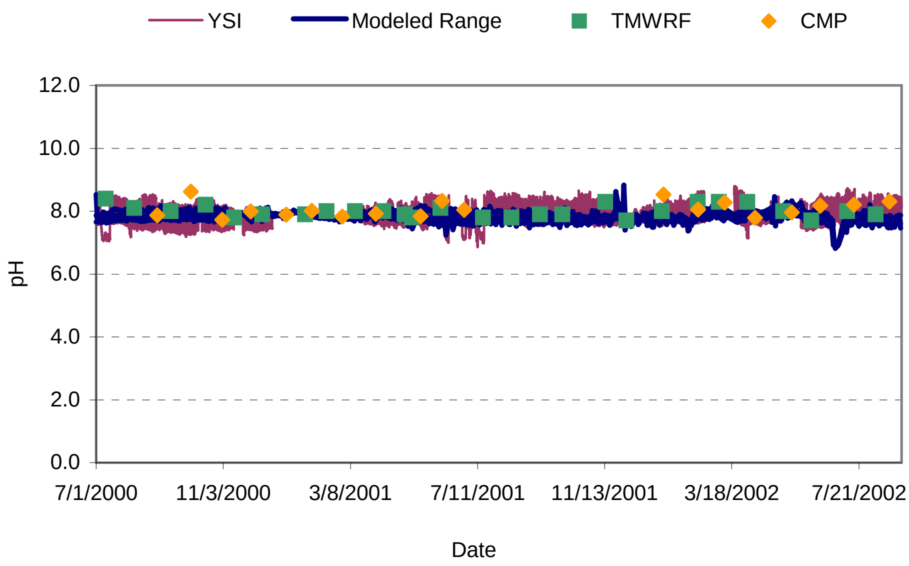

Figure A-111. Comparison of Observed and Modeled pH at Lockwood between July 1, 2000 and August 31, 2002.

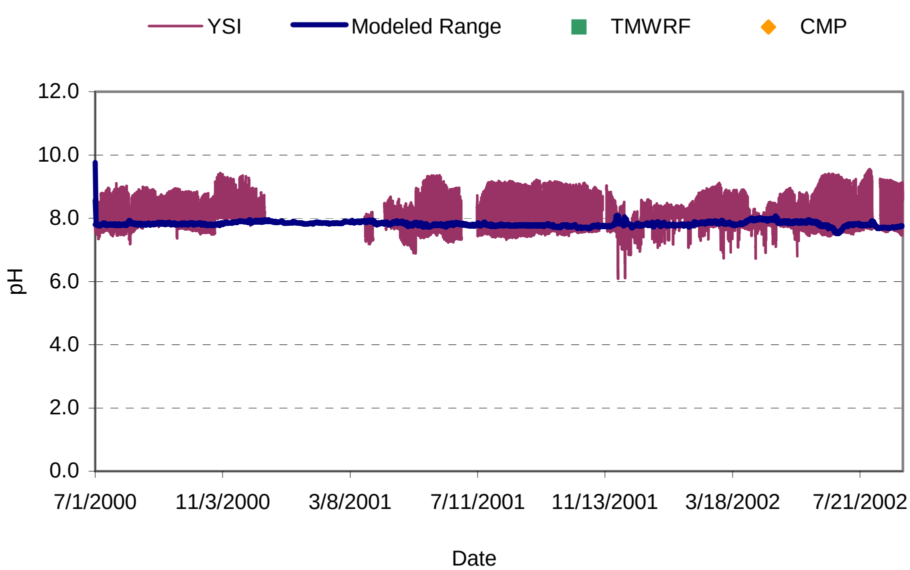

Figure A-112. Comparison of Observed and Modeled pH at Tracy between July 1, 2000 and August 31, 2002.

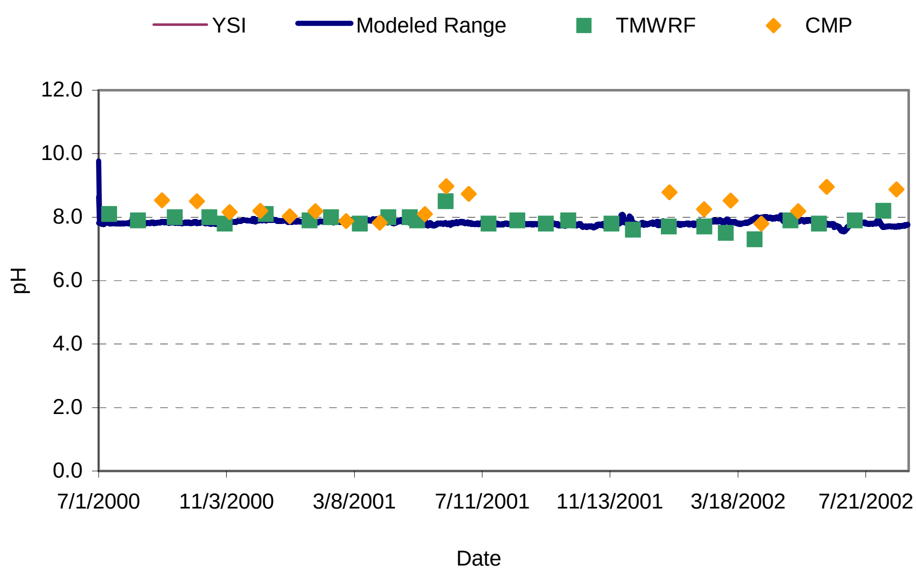

Figure A-113. Comparison of Observed and Modeled pH at Tracy-Clark between July 1, 2000 and August 31, 2002.

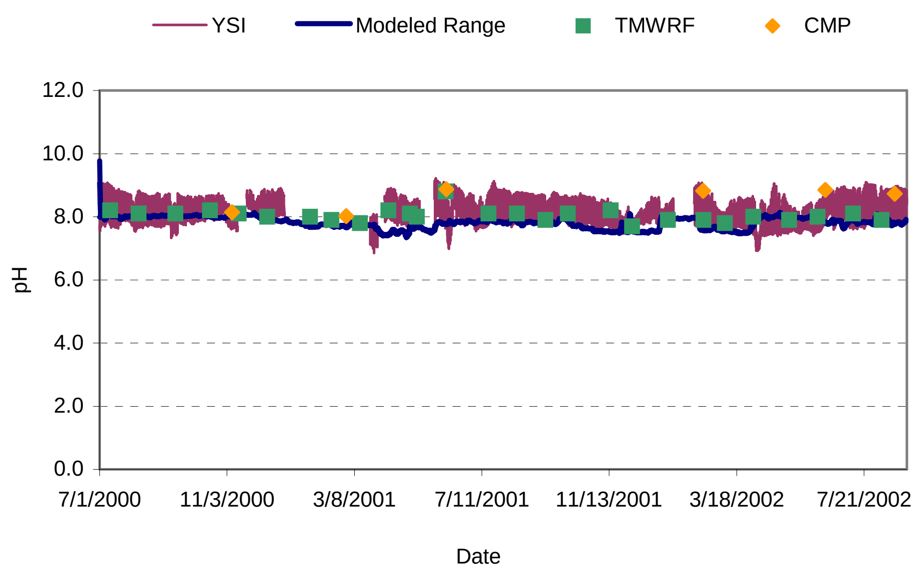

Figure A-114. Comparison of Observed and Modeled pH at Painted Rock between July 1, 2000 and August 31, 2002.

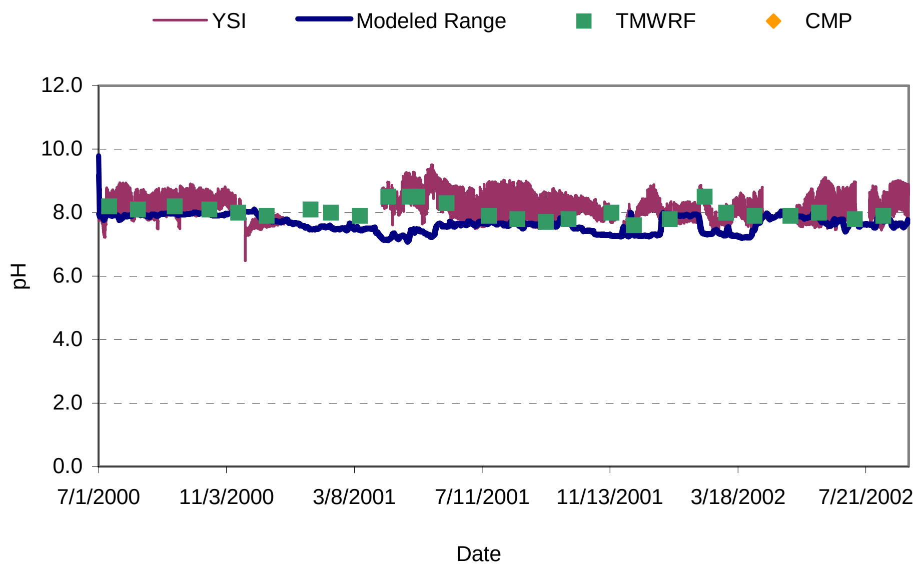

Figure A-115. Comparison of Observed and Modeled pH at Wadsworth between July 1, 2000 and August 31, 2002.

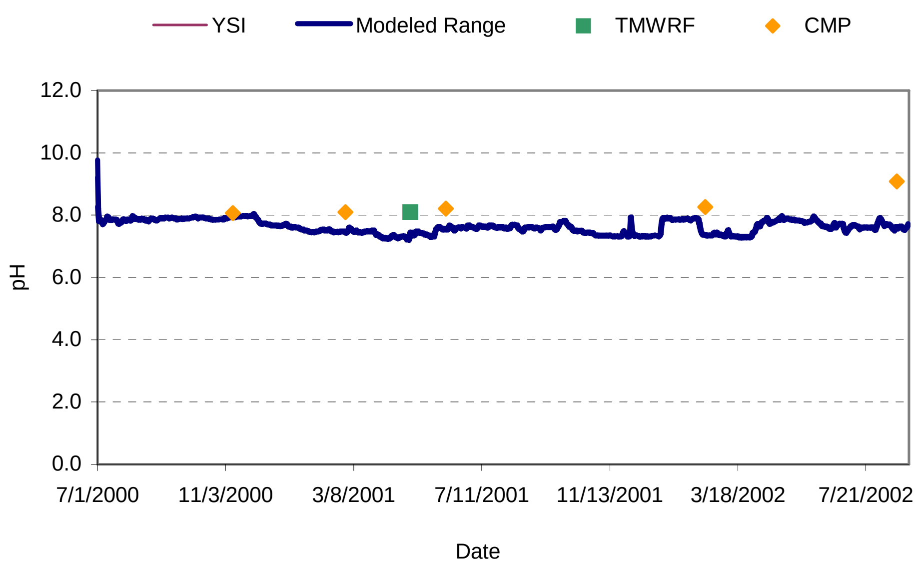

Figure A-116. Comparison of Observed and Modeled pH at Dead Ox between July 1, 2000 and August 31, 2002.

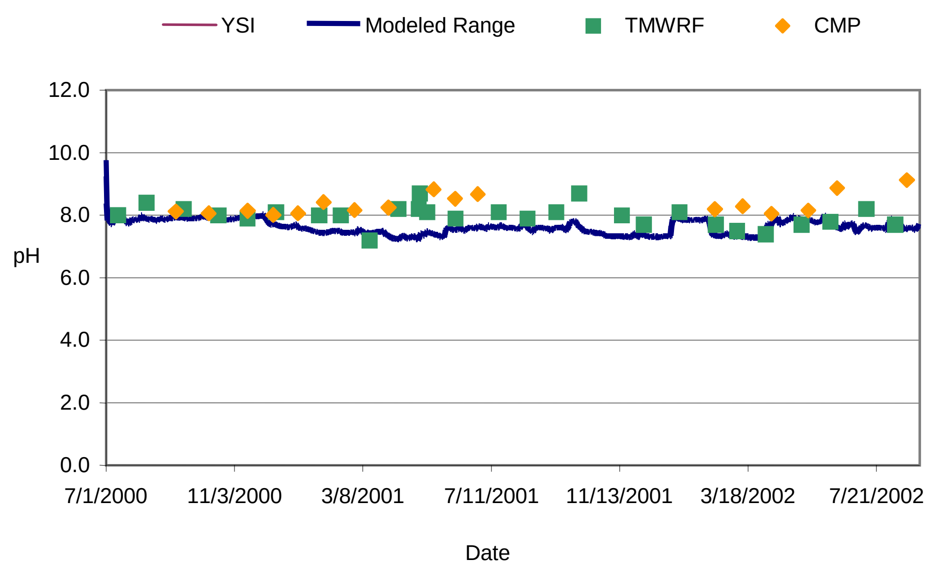

Figure A-117. Comparison of Observed and Modeled pH at Little Nixon between July 1, 2000 and August 31, 2002.

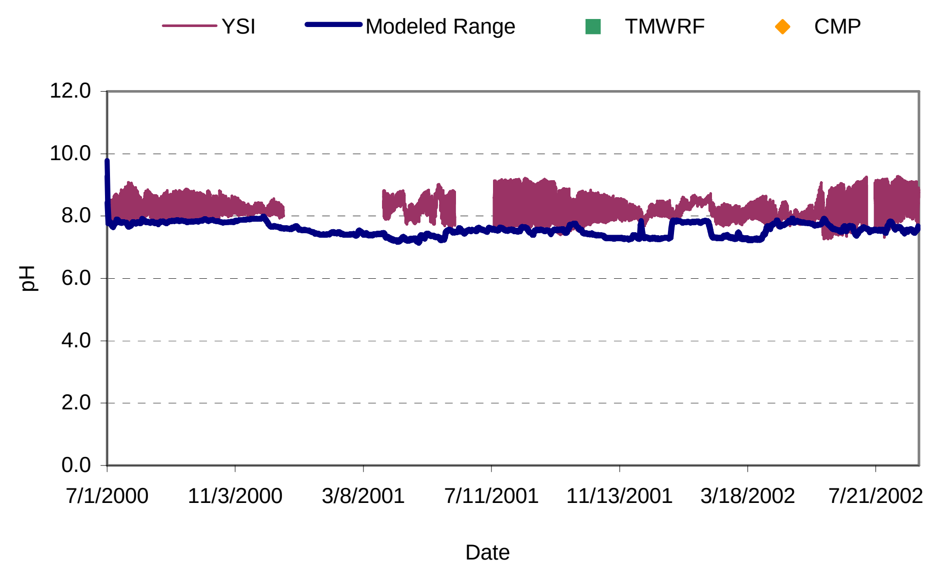

Figure A 118. Comparison of Observed and Modeled pH at Marble Bluff Dam between July 1, 2000 and August 31, 2002.

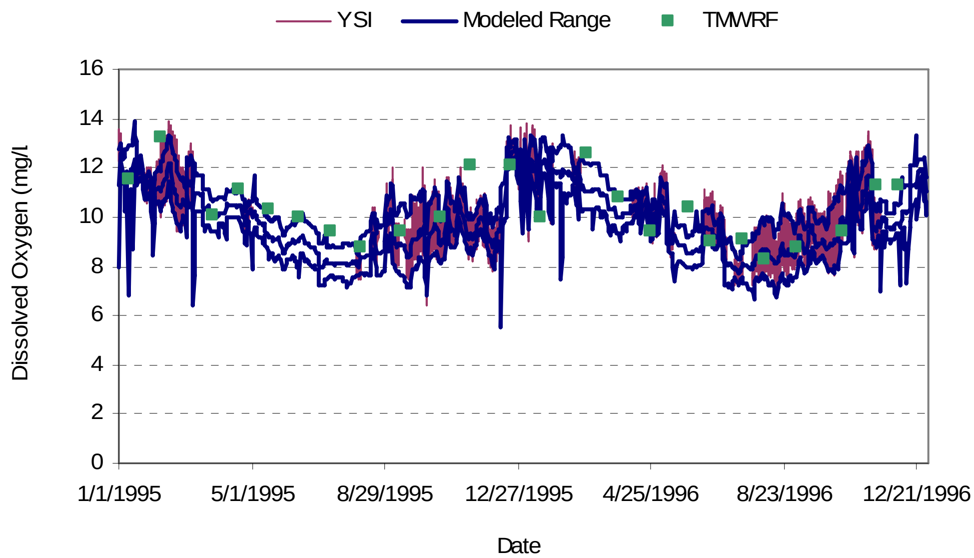

Figure A-119. Comparison of Observed and Modeled Dissolved Oxygen (mg/L) at East McCarran between January 1, 1995 and December 31, 1996.

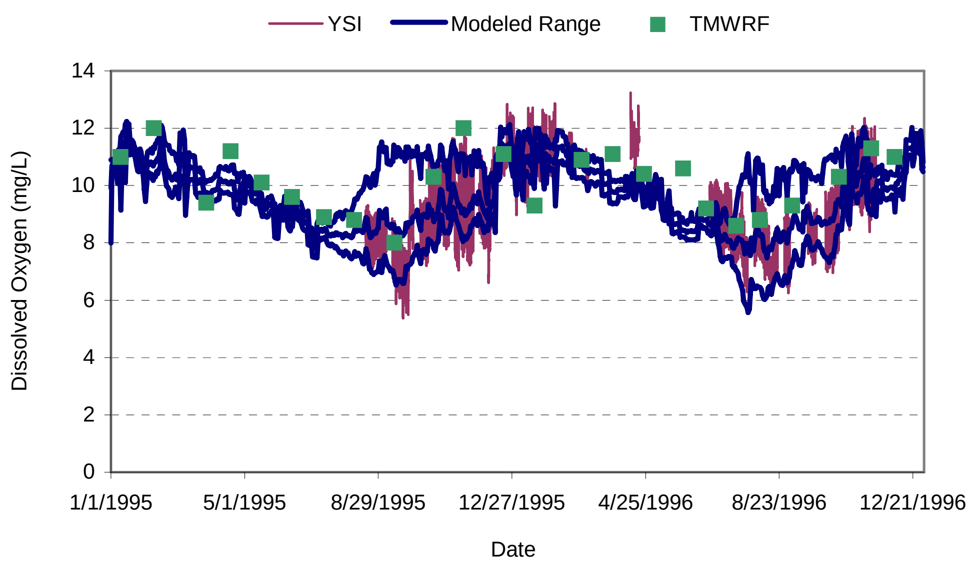

Figure A-120. Comparison of Observed and Modeled Dissolved Oxygen (mg/L) at Lockwood between January 1, 1995 and December 31, 1996

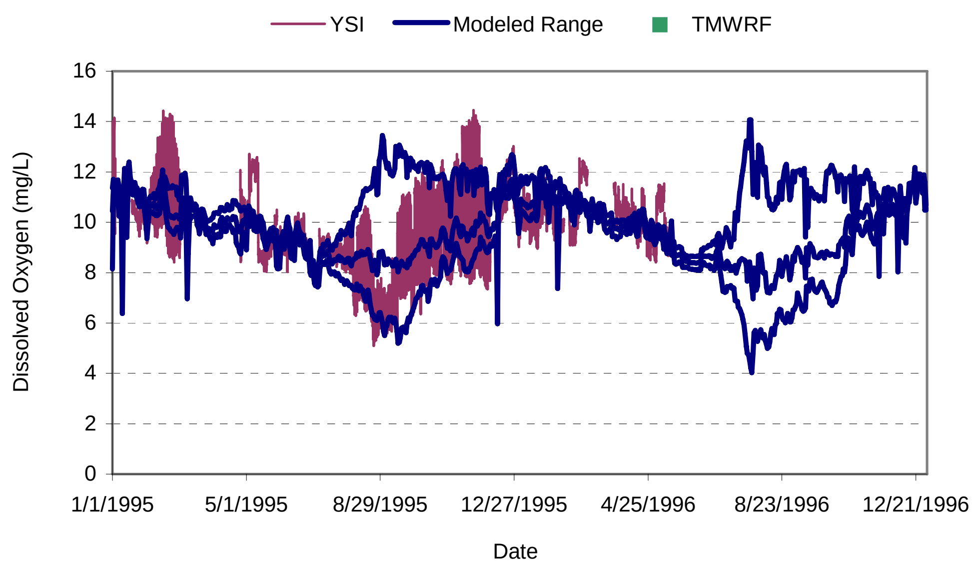

Figure A-121. Comparison of Observed and Modeled Dissolved Oxygen (mg/L) at Tracy between January 1, 1995 and December 31, 1996.

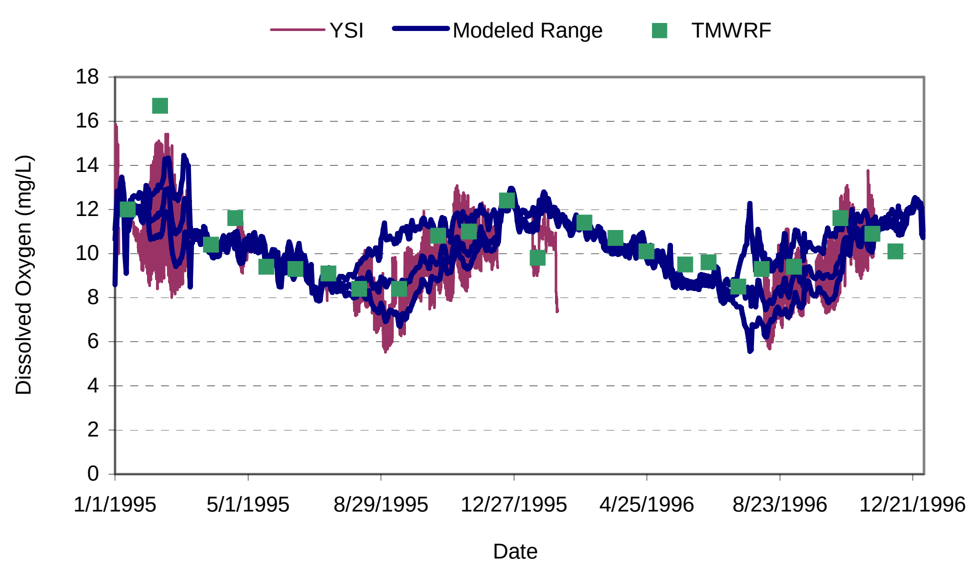

Figure A-122. Comparison of Observed and Modeled Dissolved Oxygen (mg/L) at Painted Rock between January 1, 1995 and December 31, 1996.

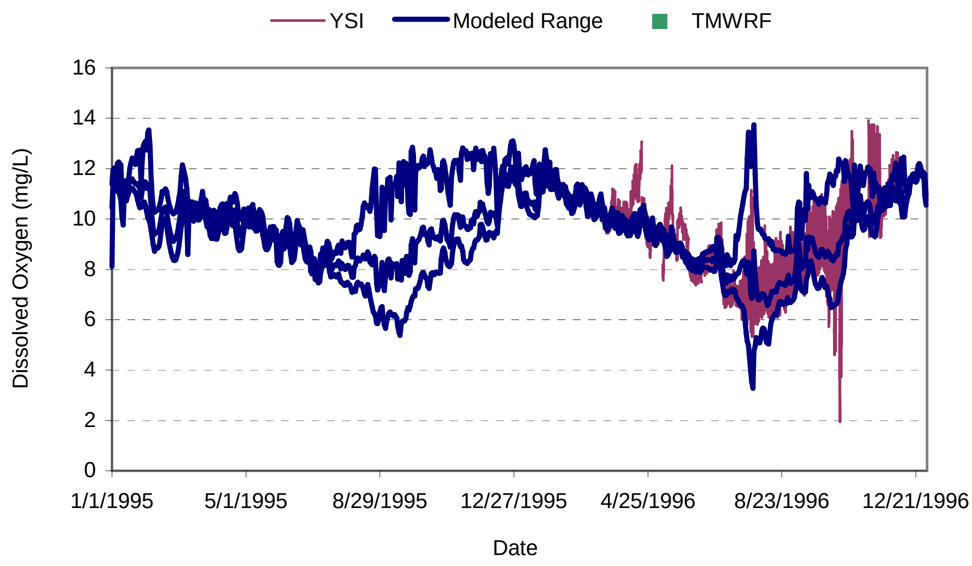

Figure A-123. Comparison of Observed and Modeled Dissolved Oxygen (mg/L) at Marble Bluff Dam between January 1, 1995 and December 31, 1996.

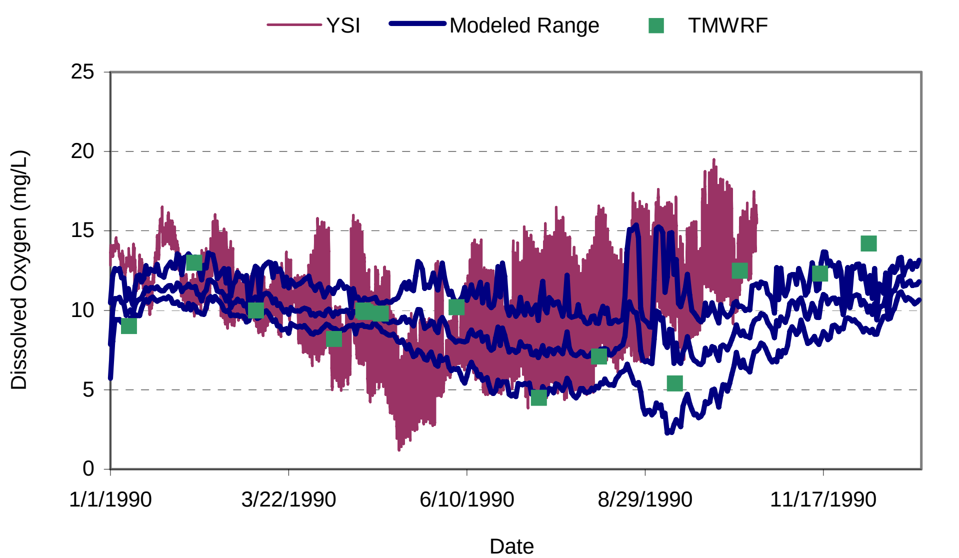

Figure A-124. Comparison of Observed and Modeled Dissolved Oxygen (mg/L) at Tracy between January 1, 1990 and December 31, 1990.

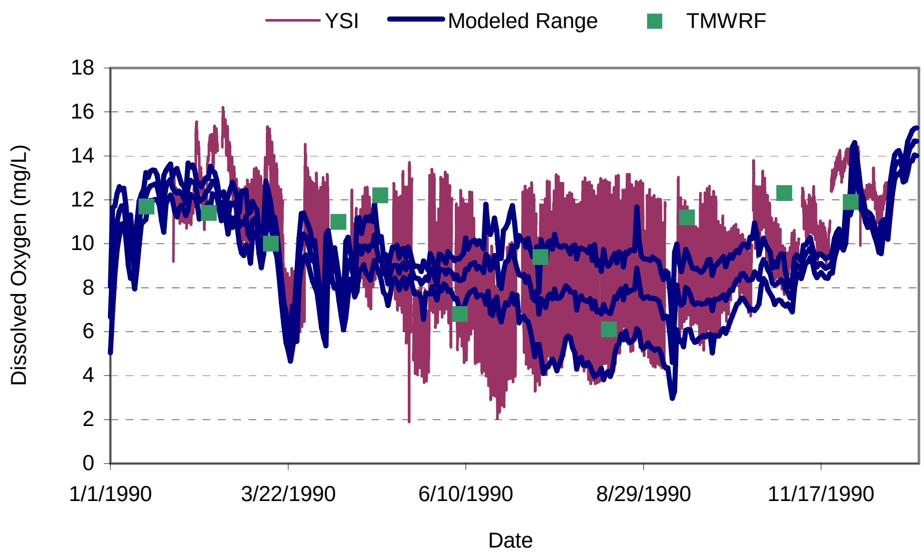

Figure A-125. Comparison of Observed and Modeled Dissolved Oxygen (mg/L) at Wadsworth between January 1, 1990 and December 31, 1990.