Model Confirmation & Database Extension for WARMF & TRHSPF to Support the Third-Party Reviews of Truckee River Nutrient Water Quality Standards & TMDLs

Prepared for:
Truckee River Third-Parties:
City of Reno, City of Sparks,
Washoe County,
and Truckee Meadows Water Authority

FINAL REPORT

Original: November 29, 2011
Updated: September 3, 2013

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1. REPORT UPDATE PREFACE

This report is an update to the draft report dated November 28, 2011 (LimnoTech 2011). The information presented in this report supersedes the previous draft report. The primary objective the most recent update was to extend the model input databases to include the 1/1/2009 to 12/31/2011 time period. The models were run for the 2009 to 2011 time period to extend the confirmation period and to utilize the most recent observed streamflow and water quality datasets to evaluate model performance. Additional modifications and updates made to the models and the updated report are summarized below:

- WARMF software was upgraded to version 6.5b.
- Diversion input data were reviewed to ensure consistency between the watershed and river models, and confirm that the "best available" data were included in the model. Diversion input data were modified, as needed, to incorporate the most robust data available to date.
- The methodology for calculating replacement values for observed data collected below the Practical Quantitation Limit (PQL) was refined and documented.
- In WARMF, minor calibration adjustments were made to soil hydrology coefficients near Lake Tahoe and temperature lapse rates for catchments near Lake Tahoe and Steamboat Creek.
- In TRHSPF, a reduction was made to the "LABSET" coefficient, which represents the rate of organic labile nitrogen and phosphorus settling. The value of the coefficient remains within recommended values noted in literature.

The remaining sections of the report further describe the model modifications listed above for WARMF and TRSHPF. The report also includes updated WARMF and TRHSPF model results for the expanded 2000 to 2011 time period

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2. SUMMARY

The City of Reno, City of Sparks, Washoe County, and Truckee Meadows Water Authority (TMWA) are leading a formal review of the current Nevada water quality standards (WQS) for nutrients (nitrogen and phosphorus) in the Truckee River, focusing on the sections of the river downstream of East McCarran Blvd. As part of the State's WQS Triennial Review process, Nevada Division of Environmental Protection (NDEP) has agreed to consider third-party proposed revisions to the WQS in an effort to ensure that any future Total Maximum Daily Load (TMDL) reviews are based on the most appropriate, site-specific WQS. To support the WQS and TMDL reviews, two water quality modeling tools (WARMF and TRHSPF) were applied to simulate watershed processes, stream hydrology and river water quality for a range of nutrient loads and concentrations. These tools are being applied in a linked approach, along with an external flow management model. The models provide a valuable mechanism for simulating the complex relationship of how various levels of nutrient concentrations, in combination with other factors such as temperature, light, and streamflow, could potentially lead to excessive growth of algae and ultimately a situation of depleted dissolved oxygen in the Truckee River. The use of the models will help ensure that any proposed nutrient WQS reflect the site-specific response of the Truckee River to nutrient loads and provide protection of the beneficial uses. A study published by the Water Environment Research Foundation (WERF, 2013) focused on the proper use of models to set waterbody-specific nutrient goals identified both WARMF and HSPF as appropriate models capable of quantifying the relationship between nutrient loads and their impacts in terms of water quality or ecological response indicators.

Model calibration and confirmation were previously conducted for both models and focused on time periods through 2002 (TRHSPF) and 2004 (WARMF). Detailed descriptions of both models can be found in the original calibration reports (Systech Engineering 2007, LimnoTech 2008). In 2011, an additional model confirmation exercise was undertaken to extend the simulation, for both models, through 2008 (LimnoTech 2011). The most recent effort, documented in this report, was undertaken to conduct further model confirmation to more recent time periods. The simulation time periods of both models were extended through December 31, 2011. The model update process included an extension of databases to include more recent data such as land use/land cover, climate, point source discharge, diversions, observed streamflow, and observed water quality.

Several previous shortcomings identified in 2011 (LimnoTech 2011) were addressed in this model update/confirmation exercise:

- Snowmelt and low flow hydrology simulations were improved in upper watershed.
- The general under-prediction of total nitrogen in the Truckee was reduced.
- Diversion data model inputs were updated and verified for quality control.

The overall model performance of the updated and extended models can be summarized as:

- The updated model results for the 2000-2008 time period compare to observed data "as good as" or "better" than the results obtained during the previous model update and confirmation exercise.
- The model results are within the range of uncertainty of the observed data for the majority of the extended simulation period (2009-2011); however, model simulations did not correlate well with unusually high total nitrogen data observed during 2009.

- Overall, the models slightly under-predict total nutrient concentrations; however, the simulation of inorganic nutrients is within the range of data uncertainty. The deficit of total nutrients is attributed to lower than observed organic nutrient concentrations. Organic nutrients are not bioavailable for uptake by algae and do not directly impact dissolved oxygen concentrations.
- Additional model adjustments to increase the simulated concentration of organic nutrients (and further address the slight under-prediction of total nitrogen and total phosphorus) would not change dissolved oxygen concentrations significantly.
- Overall, the prediction of dissolved oxygen throughout all locations and across the 12-year simulation period is consistent with previous model calibration/confirmation efforts and is considered “good”.

Simulation results indicate that both models satisfactorily predict hydrology and water quality for the entire extended time period (2000 to 2011). Both models are ready for use to support the third-party WQS and TMDL review efforts.

This report provides a brief overview of each model, a summary of previous calibration and confirmation efforts, and a description of recent model update efforts including database extension and results from model simulations. A final section of the report describes the intended use of the models to support the WQS and TMDL review processes.

3. HISTORY OF MODEL DEVELOPMENT AND CALIBRATION

In efforts that began in the late 1990's, two modeling tools were developed to simulate watershed processes, stream hydrology, and water quality to support a proposed third-party TMDL review and possible revision for the Truckee River:

- Watershed Analysis Risk Management Framework (WARMF) – watershed model
- Hydrological Simulation Program FORTRAN (TRHSPF) – river water quality model

The intent is to apply these two models in a linked approach (along with a flow management model such as TROM or RiverWare) to assess the water quality response of the Truckee River to nutrient loading under varied flow conditions (Figure 3-1). The remainder of this section provides a brief overview of the model development and previous calibration efforts for WARMF and TRHSPF.

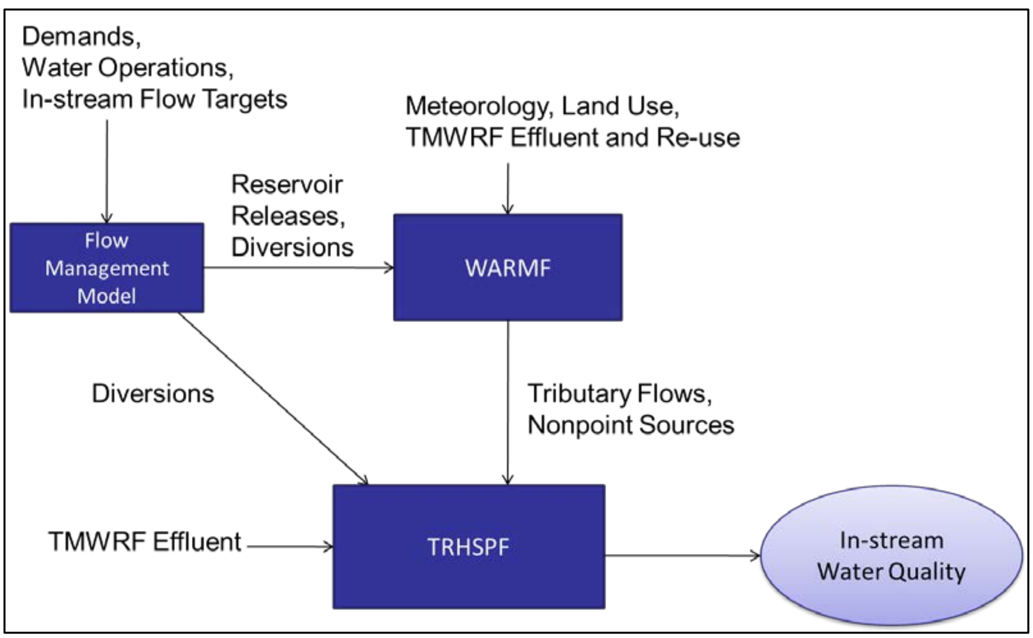

Figure 3-1. Model Linkage for Truckee River TMDL Analysis

3.1 WARMF Development and Previous Calibration

WARMF is a watershed model adapted to the Truckee River basin that provides capabilities to simulate nonpoint source pollution loads under current and/or future land use and management practices. The spatial domain of WARMF encompasses the entire Truckee River basin from the tributaries flowing to Lake Tahoe downstream to Pyramid Lake (Figure 3-2). Within this broader model domain, sub regions of the model are relevant for linkage to the river water quality model (TRHSPF).

WARMF is a physically-based model which represents the watershed as a network of land catchments, stream segments, and (as necessary) lake layers. WARMF is a public domain model available from the United States Environmental

Protection Agency (USEPA) and has been applied to other arid, heavily managed watersheds such as the Santa Clara and San Joaquin basins of California. The model simulates all standard constituents including flow, temperature, nitrogen, phosphorus, organic carbon, suspended sediment, and total dissolved solids. WARMF distinguishes between storm water and non-storm water nonpoint sources when calculating pollution loads and can also simulate potential reductions of nonpoint source loads due to changes in the watershed such as BMPs, conversion of agricultural lands, and removal of septic systems.

The model uses land use and land cover data, topography, and precipitation records to calculate a mass balance of pollutants as transported in snow and soil hydrology, overland flow, and groundwater accretion to river segments. WARMF has capabilities to model the impacts of diversions and irrigation. The model diverts water out of rivers, applies a portion of the diverted water and irrigation to specified land areas, and computes infiltration and runoff. WARMF data inputs include meteorology, land use, and managed flows (which can be based on historic records or projected by a flow management model such as RiverWare or TROM). The model also incorporates point source inputs based on historic flows and loads.

WARMF was originally adapted to the Truckee River Basin during 1998 to 2001. The model adaptation included data compilation, model enhancements (to account for diversions and irrigation, periphyton, and septic systems), model setup, calibration, and confirmation. WARMF uses existing regional data are documented in Section 4 of this report. including land use, water quality and quantity as well as data collected through the Coordinated Monitoring Program. The model accounts for municipal and agricultural diversions, irrigation, periphyton (algae on the riverbed), septic tank loading, fertilizer application to farms and golf courses, and livestock loading to the land as well as rivers. Regional stakeholders participated in the project by providing input data and feedback through a series of workshops. The initial WARMF-Truckee model adaptation and calibration was completed and documented by Systech Engineering (Systech Engineering 2007).

Several additional activities occurred in concert with the WARMF development and calibration effort. A model comparison was conducted to evaluate two models, WARMF and HSPF, which were applied to the Steamboat Creek watershed. The study showed comparable results between the two models (Carollo 2001). In 2003, WARMF was used to predict flow and loading boundary conditions for input to the DSSAMt model as part of the TROA EIS/EIR development (USBR 2008). Truckee River watershed stakeholders participated in WARMF training workshops that were conducted by Systech Engineering and sponsored by the City of Reno and City of Sparks in 2004 and 2006.

In 2011, LimnoTech extended the WARMF databases and conducted model confirmation simulations through the year 2008. In 2012 and 2013, LimnoTech further extended the WARMF database and conducted model confirmation simulations through the year 2011.

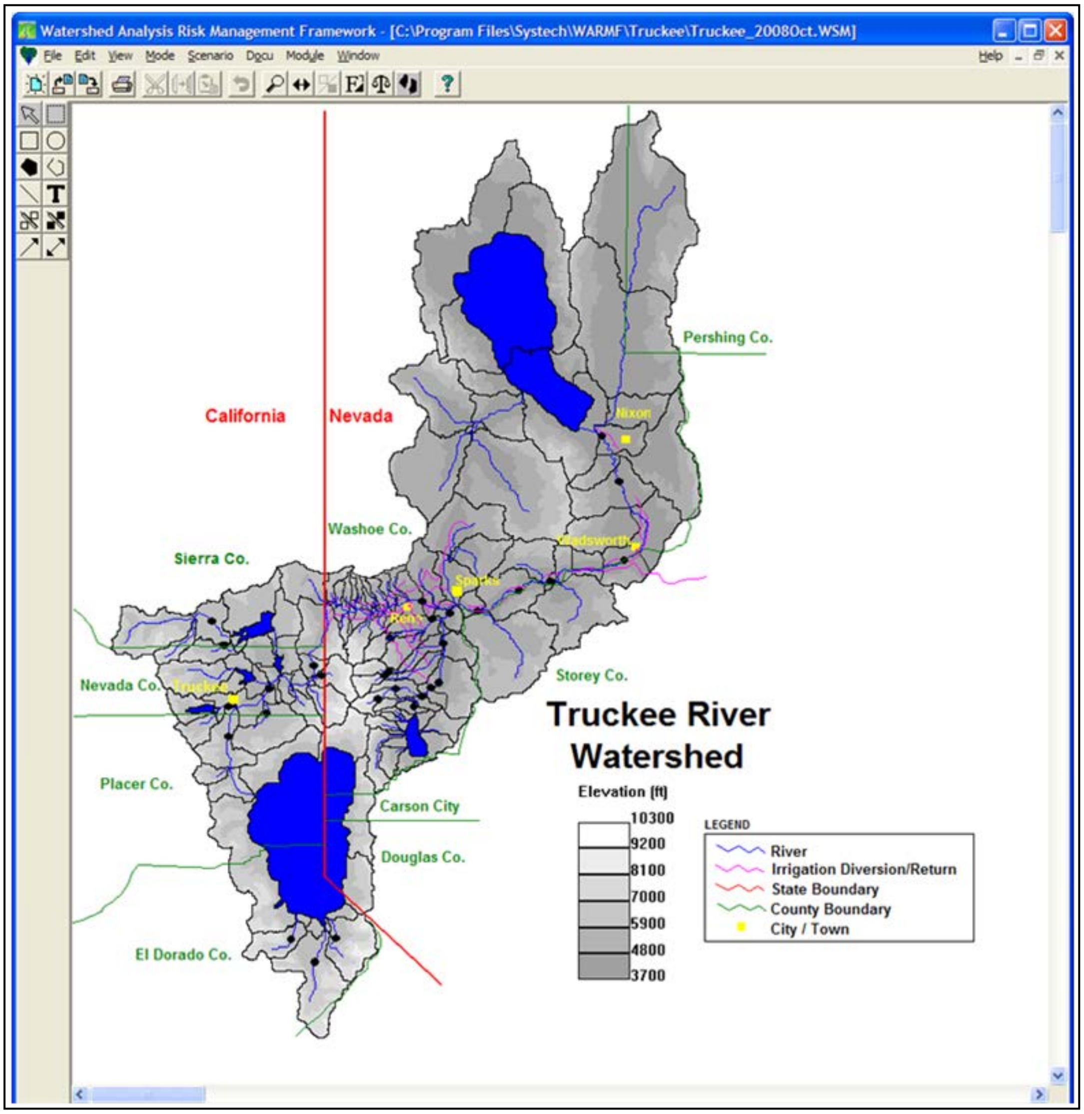

Figure 3-2. Spatial Domain of WARMF Applied to the Truckee River

3.2 TRHSPF Development and Previous Calibration

TRHSPF is an instream water quality model used to predict occurrences of low dissolved oxygen resulting from benthic algae, low flow, and other pollutants. It is an enhanced version of the USEPA supported and publically available Hydrological Simulation Program – FORTRAN (HSPF) model and incorporates peer-reviewed empirical and theoretical equations related to the growth, death, nutrient preferences, and removal of benthic algae based on the DSSAMt model, which is a variation of the DSAMM III model used for the 1994 Truckee River nutrient TMDL.

LimnoTech was contracted to develop TRHSPF as the long-term management tool for river water quality by enhancing the HSPF model with the periphyton routines from DSSAMt, and improving other select routines. TRHSPF is based on the modeling work completed by Lynn Taylor of the United States Geological Survey (USGS) in 1998, which resulted in a calibrated and validated HSPF model for flow, stream temperature, and total dissolved solids (TDS) in the Truckee River (Taylor 1998).

From 2001 to 2004, LimnoTech expanded the HSPF framework to better describe nutrients and benthic algae growth and set up the model to simulate several different time periods including 1990, 1995, 1996, and July 2000 to September 2002. The enhancements made to HSPF included adding additional growth limitation terms, additional loss terms, and increasing the number of benthic algal types that can be simulated. The additional growth terms include a temperature limitation, standard Michaelis-Menton nutrient limitation terms, a stream velocity limitation term on nutrient availability, a light limitation term using the Steele equation, and a density limitation. Loss terms include both basal and photo-respiration, a grazing and disturbance loss, and a scour loss. In addition, other routines were improved in HSPF and included a macroinvertebrate grazing/removal function; insignificant nutrient concentrations were changed from being hardwired into the model to being user selected parameters; total solar radiation was adjusted to better represent photosynthetically active solar radiation (PAR); the hydraulic representation was improved; and the capability to simulate nitrogen-fixing algae and multiple algal groups was incorporated. The selection, development, and enhancements made to HSPF are documented in the January 2008 calibration report (LimnoTech 2008). The improved model, which is now being applied to the Truckee River, is referred to as TRHSPF.

TRHSPF simulates water quality and flow within the Truckee River from McCarran Bridge in Reno, Nevada, to the entrance to Pyramid Lake at the downstream end of the Truckee River (Figure 3-3). The model domain covers a 55 mile section of the Truckee River and the system is divided into 43 linked segments. The model runs with a 0.5 hour time step and provides time series output for the following parameters at each model reach from Reno to Pyramid Lake: flow, temperature, dissolved oxygen, BOD, nitrate, ammonia, phosphate, total nitrogen, total phosphorus, pH, total dissolved solids, alkalinity, and benthic algae biomass. TRHSPF inputs include flows and constituent loads at the upstream boundary (Truckee River at East McCarran Blvd), tributary inputs (e.g., Steamboat Creek and North Truckee Drain), and nonpoint source load contributions along the length of the river. These inputs can be based on either historical data or output from the watershed model, WARMF. TRHSPF also requires inputs to represent diversions and point sources, which can be based on either historical data or output from a flow management model (e.g., TROM, RiverWare).

Calibration and confirmation of the enhanced TRHSPF model was conducted by LimnoTech using data collected by USGS, NDEP, Truckee Meadows Water Reclamation Facility (TMWRF), and the Truckee River Coordinated Monitoring Program (CMP) (LimnoTech 2008). The calibration period focused on July 2000 through September 2002 because monitoring data from this time period included comprehensive benthic algae measurements. A model confirmation was also conducted by comparing model output to observed data for three other years to add additional confidence in the model parameters selected. The additional years for model confirmation were 1990, 1995, and 1996. These years were selected because they represent low, medium, and high flow periods. Truckee River watershed stakeholders participated in TRHSPF training workshops that were conducted by LimnoTech and sponsored by the City of Reno and City of Sparks in 2003, 2006, and 2009.

In 2011, LimnoTech extended the TRHSPF database and conducted model confirmation simulations through the year 2008. In 2012 and 2013, LimnoTech further extended the TRHSPF database and conducted model confirmation simulations through the year 2011. These updates are documented in Section4 of this report.

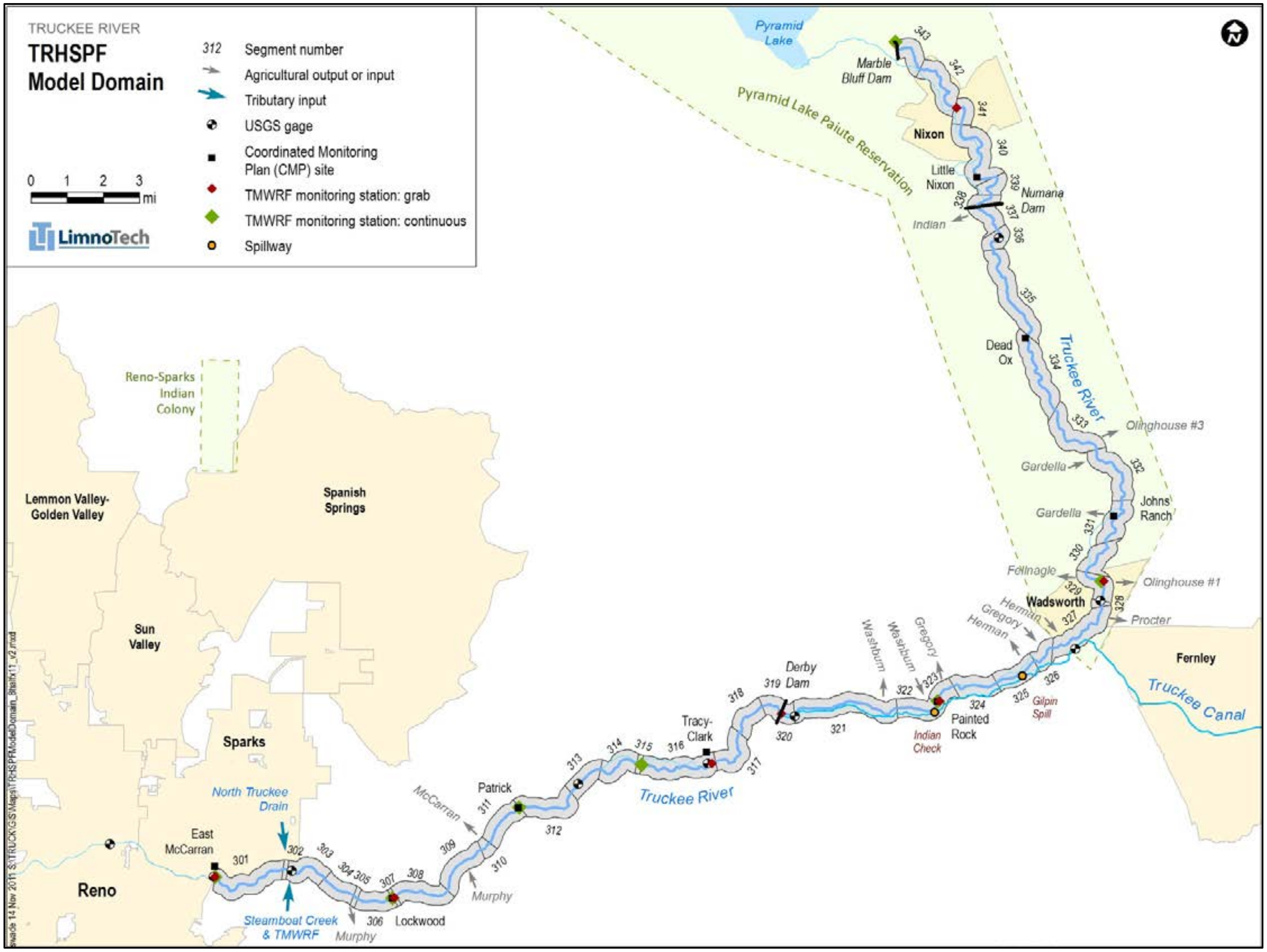

Figure 3-3. TRHSPF Model Domain and Spatial Segmentation

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4. MODEL UPDATES

Several model enhancements have been implemented for both WARMF and TRHSPF since the publication of the latest calibration reports (Systech Engineering 2007, LimnoTech 2008). In addition, the databases of both models were extended through December 2008 (LimnoTech 2011) and then again, through December 2011. The model confirmation simulations were conducted to demonstrate reasonable performance of the models for the newly, extended time periods. This section summarizes the recent model enhancements, database updates, and model confirmation simulation results for both WARMF and TRHSPF.

4.1 WARMF

4.1.1 Recent WARMF Enhancements

Since the publication of the original WARMF calibration report (Systech Engineering 2007), two notable model enhancements were implemented to the model framework.

1. **Model Version Updates:** In October, 2008, Systech Water Resources (formerly Systech Engineering) delivered an updated version of WARMF to the City of Reno which included finer spatial resolution of land catchments along the Truckee River from Verdi to Steamboat Creek / North Truckee Drain. This version of WARMF also included a general update of the model database and some re-calibration of the model in the Chalk Creek region. Since 2009, LimnoTech has conducted all WARMF modeling, and has consulted with Systech Water Resources for technical support on an as-needed basis. In May, 2012, Systech Water Resources provided an additional updated version of the WARMF software (version 6.5b). Simulations using based on the previous WARMF version for the 2000-2009 time period were compared to results from version 6.5b to verify that the updated model framework was performing similarly to the previous model version. While there were some small differences in model results, no significant differences were observed, and WARMF version 6.5b was used to produce the results in this report. The following were some of the changes introduced in the new model version:
    - The algorithm for calculating evapotranspiration was improved to better account for the effects of sun angle;
    - A correction was made in the nutrient calculation on catchments with irrigation; and,
    - Several changes were made to prevent simulation software crashes under a variety of unusual circumstances.
2. **Temperature Improvements:** In 2009, Systech Water Resources improved the formulation of stream temperature calculations in WARMF in an attempt to improve model predictions during the spring snowmelt period. As described by Systech Water Resources (2009) the changes included:

- <u>Bedrock heat transfer</u>: The bottom of the lowest soil layer simulated by WARMF is assumed to be the limit of shallow groundwater, below which groundwater does not readily interact with surface water. In mountainous areas, this coincides with the transition from soil to bedrock. The original

WARMF formulation assumed that no heat crossed between the lower boundary of the lowest soil layer and the bedrock below. The new formulation allows for heat transfer across this boundary. The temperature below the WARMF soil layers is assumed to be constant year round at the average temperature of the catchment.

- River ice formation: The original WARMF algorithms for rivers performed complete heat balance calculations except it made the assumption that ice formation did not occur. This resulted in river temperature dropping below zero degrees C. The new formulation assumes that a lack of heat below zero degrees C goes toward the fusion of liquid water into ice instead of lowering the temperature of the river. The result is that river temperature no longer drops below zero degrees C.
- River friction: A literature search indicated that there is a significant warming effect caused by river flow friction relative to the river bed. This factor increases with velocity and causes a small increase in temperature.

The model changes were tested using 1985-1990 and 1999-2002 simulations. For both time periods, the improvement in simulated temperature was greatest during spring snowmelt when the discrepancies between model predictions and observations had been greatest. Simulation over the rest of the year was largely improved as well.

4.1.2 Database Extension for WARMF

In order to extend WARMF simulations through the year 2011, it was necessary to extend several input data files and incorporate an updated land use / land cover (LULC) spatial layer. The following time series data files were extended in the WARMF database:

- **Climate** – data for eight climate stations were extended through 12/31/2011 with data from the National Climatic Data Center (NCDC) and Natural Resources Conservation Service (NRCS) SNOwpack TELemetry (SNOTEL) databases. Data include daily precipitation, minimum temperature, maximum temperature, cloud cover, dewpoint temperature, air pressure, and wind speed. When necessary, data from nearby stations were applied to fill gaps in data for individual stations.
- **Air Quality** – the single WARMF input file for air quality (NOx, SOx, major cations and anions) was extended through 12/31/2011 using wet deposition data from the National Atmospheric Deposition Program (NADP) database, and dry deposition data from the Clean Air Status and Trends Network (CASTNET) database.
- **Diversions** – historical diversion data for all municipal, industrial, and agricultural diversions along the Truckee River were obtained from both the Federal Water Master's office (Dave Wathen) and http://www.troa.net/ to extend all input files through 12/31/2011. For diversions without complete data records, gaps were filled based on best available information. Diversion input data were reviewed to ensure consistency between the watershed and river model where the model boundaries overlap (i.e., from East McCarran to Marble Bluff Dam). Because the WARMF and TRHSPF models were originally developed independently and at different times, the original diversion datasets used to develop model inputs were not necessarily the same. In addition, diversion data were not necessarily processed in the same manner (e.g., method used to fill data gaps). During the model update process, the diversion input data were modified, as needed, to incorporate the most robust datasets available to date.
- **Point Sources** – flow and concentration data for all permitted point sources to the Truckee River were obtained, and all WARMF input files were extended through 12/31/2011. Data for TMWRF were obtained directly from the facility. Data for four smaller point sources (Vista Canyon Group,

Sparks Marina, Harrah's, and Masonic Temple) were obtained from NDEP. NDEP also confirmed that two point sources (Ranch 102 Sand and Gravel, and Western Energetix) are no longer active and were not discharging during the 2000-20011 time period.

- **Reservoir Release –** flow release records for all reservoirs in the upper watershed (Lake Tahoe, Donner Lake, Boca Reservoir, Prosser Creek Reservoir, and Stampede Reservoir) were obtained from USGS and used to extend WARMF input files through 12/31/20011. Observed elevation records for this time period were also obtained and entered into the WARMF database.
- **Observed Streamflow** – daily flow records were obtained from the USGS to extend all relevant WARMF input files through 12/31/2011. These data are used for comparison with stream flow simulated by WARMF.
- **Observed Water Quality** – instream water quality monitoring data were obtained from TRIG (http://www.truckeeriverinfo.org/) and the Truckee Meadows Regional Stormwater Management Program. The collected data extended all relevant WARMF input files through 12/31/2011.The update of observed water quality data files included a QA/QC process to determine the most appropriate method for reporting values noted to be less than practical quantitation limit (<PQL). For model-to-data comparisons, observed values reported as <PQL were replaced with reasonable alternative values. If a value for a nutrient parameter was reported as <PQL, the value was assumed to be equal to one half of the PQL. The only exception was for ammonia at the "Reno/Sparks" location, where values reported as a <PQL were assumed to be 0.01 mg/L. For non-nutrient parameters, if a value was reported as <PQL, the value was assumed to be equal to the PQL. The basis for this adjustment was data measured upstream at the "Arlington" station which indicate the typical range of ammonia measurements to range from 0.001 to 0.024 mg/L in the river. For total nutrients (total nitrogen and total phosphorus), the selection of how to specify a component species (e.g., nitrate) that was measured as <PQL will influence the "total" constituent value. Setting the values to one half of the PQL had the effect of lowering the total nutrient value, better accounting for the uncertainty in measurement of water quality values below the detection limit.

Where applicable, data processing templates were provided by Systech Water Resources for use in the database extension effort. This allowed for more efficient data processing, and ensured that any necessary data transformations or unit conversions were done consistently with previous WARMF modeling efforts.

A second major element of updating the WARMF database to a more recent time period was the incorporation of a land use / land cover (LULC) data layer. As documented in the WARMF calibration report (Systech Engineering 2007), the original development of the WARMF application for the Truckee River basin used LULC data reflective of the late 1990's. This data layer was based on a combination of parcel level data provided by Washoe County and nationally available GIRAS data contained in USEPA's BASINS tool. The GIRAS data were applied for all watershed areas outside of Washoe County.

A rapid period of growth occurred in the Truckee Meadows region from the late-1990's through approximately 2006. An updated LULC spatial layer was assembled which reflected this growth. The update should result in a more accurate simulation of current load contributions from various land uses within the watershed. Data were obtained from several sources to create this layer:

- **NLCD Data**: 2006 National Land Cover Dataset (NLCD) data were acquired from the Multi-Resolution Land Characteristics Consortium (MRLC), a group of several federal agencies that includes the U.S.

Geological Survey. The data cover the entire Truckee River basin and surrounding areas and was used as a default base layer for the entire modeled area.

- **Washoe County Parcel Data:** In February 2011, Washoe County Technology Services provided the latest parcel-based land use data which were representative of the year 2010. Each parcel has a land use classification that is used for property taxation. In order to make these data more consistent with the NLCD data, several developed categories of Washoe County land use were reclassified and then merged into three broad categories of low-density residential, high-density-residential, and commercial/industrial. In addition, a roads land use was isolated using the parcel data layer from the County. In locations where Washoe County Parcel data were available, the Washoe County parcel data replaced the NLCD data. An exception was Washoe County parcels classified as low-density residential lands which were actually undeveloped or large land tracts with only one small building. To resolve this, low-density residential parcels greater than 5 acres and not classified as a "common area" were declassified, and LULC in these locations was derived solely from the NLCD land cover data.
- **Site-specific Data**: A final layer of information was incorporated in the LULC data layer to represent ski resorts, golf courses, parks, and animal feeding operations. A parks data layer provided by Washoe County (separate from the parcel layer described above) was used to identify parks and golf courses within the county. Additional golf courses – some within Washoe County and most in other parts of the basin – were identified from recent aerial photography supplied by Esri to users of ArcGIS. Information showing approximate locations of ski resorts was used to focus more exploration of aerial photography in order to identify and delineate rough approximations of ski slopes. NDEP confirmed that while some livestock operations are found in the Truckee basin, none of them are large enough to require a state CAFO permit. One cattle operation (Damonte Ranch) was identified and delineated within the LULC data layer. These site-specific classifications, where available, superseded both the NLCD and Washoe County parcel data.

Figure 4-1 shows the updated LULC data for the Truckee River watershed. The updated LULC were compared with the original LULC and it was noted that changes in land use were consistent with expectations (e.g., increased urbanization in the Truckee Meadows region).

The import of the updated LULC layer into WARMF involved the aggregation of several GIS classifications into a single WARMF category. Table 4-1 shows the list of LULC categories represented in WARMF. Developed open-space was combined with grassland, grazing was combined with pasture, quarry/mine was combined with barren, and road was combined with commercial/industrial. The import process also involved the creation of several LULC categories that were not explicitly represented in the previous version of WARMF (Systech Engineering 2007). In the updated model, golf courses and cultivate crops are treated as independent land use categories, and ski areas, parks, and water were added as new land use categories. For each of the new categories, input coefficients in WARMF (e.g., percent impervious, land application rates of nutrients) were set to reflect reasonable values of similar land use categories. A final step of incorporating the updated LULC data involved a rebalancing of the distribution of irrigation water for each relevant diversion and land catchment. As documented in the WARMF calibration report, an external spreadsheet was used to calculate the average rate of irrigation water to each catchment based on the area of irrigated lands (pasture, golf courses, and parks), average diversion flow for each ditch, and percent of diversion applied to catchments (Systech Engineering 2007). With the new LULC data, the percent of each land use classification was different than the previous LULC data, and in some cases diversion data for the 2000-2008 period differed from diversion rates in the late 1990's. Therefore, for some watershed regions it was necessary to redistribute the amount of irrigation water applied to each irrigated land use within in each catchment so that the overall irrigation rate did not far exceed a recommended maximum rate of 4 ft/year (based on the Orr Ditch Decree).

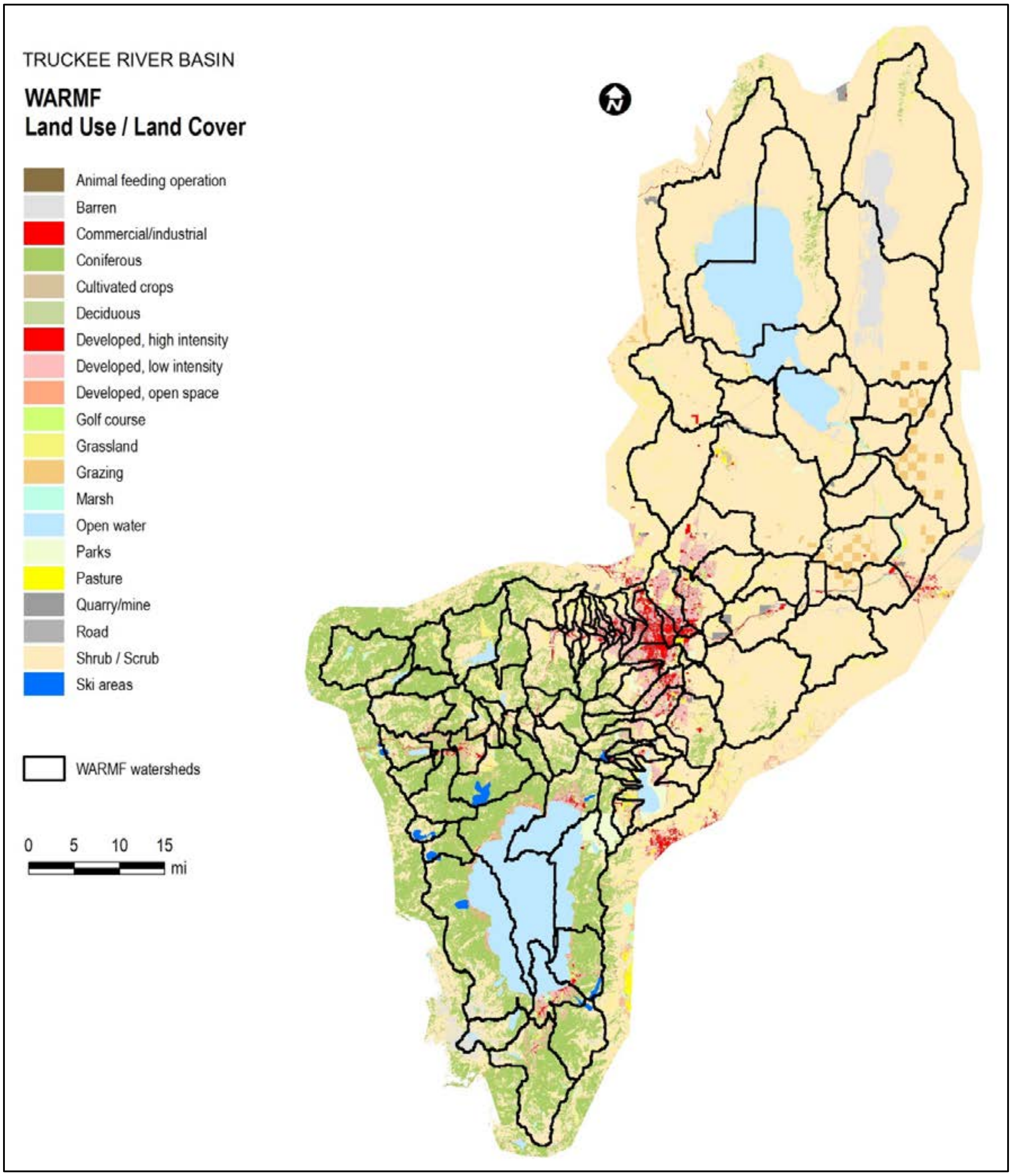


Figure 4-1. Updated Land Use / Land Cover Data for Input to WARMF.

Table 4-1. Land Use / Land Cover Categories in WARMF

Land Use / Land Cover Categories in WARMF	
Deciduous	High Density Residential
Coniferous	Commercial/Industrial
Shrub / Scrub	Animal Feeding Operation
Grassland	Cultivated Crops
Pasture	Golf Course
Marsh	Ski Area
Barren	Parks
Low Density Residential	Water

4.1.3 Limited WARMF Model Changes

After updating all databases described above, WARMF confirmation simulations were set up for 10/31/1999 through 12/31/2011. The simulations were conducted as four discrete time periods rather than one continuous simulation to allow for easier handling of input and output datasets. The objective of the model confirmation was to test model performance with a unique data set for an extended time period while holding model parameters (e.g., reaction rates) equal to values used in the original calibration. During this process, the following minor adjustments were made to the model:

- WARMF was configured to use the previous LULC representation (circa late 1990's) for simulations prior to 2002. For all simulations 2003 and later, the model uses the updated LULC representation which is reflective of approximately 2006 conditions;
- Initial condition values for soil moisture and reservoir elevation were adjusted to represent conditions at the start of each simulation time period;
- For land catchments in the vicinity of Reno/Sparks (downstream of Verdi) as well as the Steamboat Creek and North Truckee Drain subwatersheds, initial soil concentrations of nutrients and organic carbon were increased for the post-2002 simulation periods which use updated LULC data. As described in a study of Chalk Creek (JBR 2010), increased turf fertilization and irrigation in developing watershed areas is likely contributing to an increase in release of nutrients and organic constituents from the shallow soil layers into adjacent streams. LULC changes in the model will directly influence the release of constituents from these developed areas via overland flow; however, it was determined that an adjustment of subsurface soil concentrations, in concert with the new LULC data, was necessary to capture the behavior of increased constituent release from the soils that coincided with additional urbanization;
- WARMF was originally set up to explicitly model the entire upper Truckee River watershed including tributaries to upstream reservoirs and the hydrology (releases, spills, and storage) and water quality of the reservoirs. Due to limitations in available bathymetry data and the dynamic nature of the reservoirs, in particular the smaller reservoirs, WARMF occasionally had difficulty simulating an accurate representation of reservoir releases, and the modeled release was occasionally less than observed. This resulted in incorrect streamflows downstream of the reservoirs. To address this issue, the model was reconfigured to directly use specified release records from reservoirs (USGS data) as direct input to river segments downstream of Donner Lake, Boca Reservoir, and Prosser Creek Reservoir. The associated water quality of these release flows was set to be based on

prior simulations of reservoir water quality within WARMF;

- Minor corrections were made to soil nitrification rates specified for a few catchments in Steamboat Creek area. Previously these rates had inadvertently been set unrealistically high. The rate was adjusted to be similar to surrounding catchments;
- A slight adjustment of soil hydrology coefficients (soil thickness and hydraulic conductivity) was made to catchments in the North Truckee Drain subwatershed to reflect values used in other regions of the watershed. This change resulted in a slight improvement in the prediction of subsurface flow and resulted in a small improvement of the hydrograph shape that was assessed visually;
- A slight adjustment of soil hydrology coefficients was made to catchments in the area of Lake Tahoe and Donner Lake to improve extreme low-flow runoff conditions. During times of extreme low-flow, WARMF was under-predicting runoff to the Truckee River. The adjustment improved the simulation of low-flow runoff and instream flow; and
- A slight adjustment of temperature lapse factor in catchments in the Steamboat Creek area and the area of Lake Tahoe and Donner Lake. This change resulted in a slight improvement in the prediction of snowmelt runoff, especially in high-elevation areas.

4.1.4 WARMF Model Confirmation Results

Model performance evaluations generally use a "weight-of-evidence" approach which includes both statistical and visual comparisons. The following figures (Figures 4-2 through 4-16) show annual average results of the WARMF model confirmation runs from 2000 through 2011. Results are presented for three important locations where WARMF output provides an upstream boundary input to the river water quality model, TRHSPF. Results are presented for flow, total nitrogen, nitrate, total phosphorus, and orthophoshate.

The associated tables (4-2 through 4-6) show summary statistics for modeled and observed data for the 2000-2011 confirmation period. The statistical results provided are consistent with those given in the original calibration report. The coefficient of determination (r^2) is used to evaluate the correlation between predicted and observed values. Residual Error represents the average difference between predicted and observed values, and serves to quantify any consistent bias in predictions. A positive value for the residual error indicates that model predictions are generally greater than observed data, while a negative value indicates that model predictions are generally less than the observed data. The magnitude of the residual error represents the average size of the discrepancy. Average Error represents the average of the absolute values of differences between predicted and observed values. This number is always positive, and indicates the average difference between predictions and results, regardless of sign. Root Mean Square Error represents the square root of the sum of the square of the differences between predictions and observations, and is an alternate way to depict average differences regardless of sign. Appendix A summarizes the equations used to calculate the summary statistics. Full time series results of daily output for all stations as well as for other water quality constituents are provided in Appendix B.

When evaluating model performance, it is important to recognize both the uncertainty and the frequency of the observed data. The uncertainty in the data increases if samples are reported as <PQL. A professional judgment must be made on how to handle data reported as <PQL. For example, values can be assumed to be equal, half, one-fourth, etc. of the PQL value. Alternatively, values can also be specified in terms of a minimum detection limit (MDL) where the PQL is equal to five time (5x) the MDL. The assumptions made in addressing values reported as <PQL can introduce a bias in the model-to-data comparisons. Another important uncertainty to consider is the frequency of the data observations. Streamflow

data are available on a daily basis. Dissolved oxygen and water temperature data are available on an hourly basis when data sondes are deployed. Nutrient data are based on one to two (1-2) samples per month. In contrast, model predictions are based on an hourly or daily basis. These annual total nitrogen and total phosphorus bar charts below provide an illustration of the difference in frequency of data versus model predictions.

Streamflow

Model results for observed and predicted streamflow are presented on an annual average basis in Figures 4-2 through 4-4 for the following locations corresponding to USGS gauges:

- Truckee River near Sparks, NV (10348200)
- Steamboat Creek at Cleanwater Way (10349980)
- North Truckee Drain at Kleppe Lane (10348300)

Model predictions capture the annual variability very well for all stations. Results are consistent with those presented in the original calibration report. Regression statistics corresponding to daily flows are reported in Table 4-2. For the Truckee River station, the r^2 value for daily flows is 0.89 which corresponds to a “very good” (the highest rating) calibration using the metrics provided by Donigian (2002) and Parajuli et al. (2009) for watershed model calibration. The WARMF-predicted flow at this location accounts for approximately 90% of the total flow entering the upstream boundaries of the TRHSPF model. The r^2 values for the two smaller tributary inputs to TRHSPF, Steamboat Creek and North Truckee Drain, were less favorable (0.37 and 0.10, respectively). However, it is noted that WARMF-predicted flows for these two tributaries resulted in very small relative, absolute, and RMS errors. Relative error is reported to range from -8.27 to 1.35 cfs, absolute error is report to be 16 cfs or less, and RMS error is reported to be 39 cfs or less. The small magnitude of these errors, in conjunction with low r^2 values, indicate that:

- Day to day variability in flow is small, especially compared to the Truckee River; and
- While WARMF does not accurately capture this variability, it accurately describes the average flows.

For these reasons, the WARMF calibration to Steamboat Creek and North Truckee Drain is judged fully acceptable.

Nitrogen

Model results for observed and predicted total nitrogen are presented on an annual average basis in Figures 4-5 through 4-7. Similar results for nitrate are presented in Figure 4-8 through 4-10. Error bars are used when representing the observed data (calculated as the 90% confidence interval of the mean), reflecting the fact that significant uncertainty may exist when estimating an annual average based on a limited number of observations. Observed nitrogen data were calculated as the sum of nitrite, nitrate, and total Kjeldahl nitrogen (TKN). The method for calculating total nitrogen as a function of nitrate, nitrite, and TKN results in a high number of observed values that are reported below the PQL. The result of this is that the model is expected to predict less nitrogen than the observed data suggest.

Regression statistics corresponding to discrete observations for total nitrogen and nitrate are reported in Tables 4-3 and 4-4, respectively. For all stations, modeled mean, minimum, and maximum concentrations compare well to observed data. Relative error for nitrogen was generally as good for the 2000-2011 period as the previously reported 2000-2008 period (LimnoTech 2011) and are still considered acceptable.

Model predictions of total nitrogen and nitrate fall within the range of uncertainty of observed data for the large majority of years and locations. Review of the average annual concentration plots and statistics suggest that WARMF is slightly under-predicting total nitrogen at the Reno/Sparks location. The detailed time series plots provided in Appendix B demonstrate that the simulation of inorganic nitrogen (ammonia and nitrate) is within the range of observed data; however, the slight under-prediction of nitrogen can be attributed to the organic components of total nitrogen.

For Truckee River at Reno/Sparks, model-to-data comparisons for 2009 yielded the poorest as compared to other years, with the annual average total nitrogen simulated being less than observed. Review of the time series plot (Figure B-13 in Appendix B) shows a cluster of higher than expected observed total nitrogen measurements over an extended period of time. Further inspection of Figures B-7, A-10, B-13, and B-16 suggest that organic nitrogen is the component of total nitrogen (rather than ammonia or nitrate) that was measured to be higher than predicted. Because it was observed for the Reno/Sparks monitoring location but not at the upstream Arlington/Idlewild monitoring station the condition appears to be isolated to the Truckee Meadows region. It is suspected there may be either a data anomaly or an unusual event that occurred this year and the model was not able to reproduce this condition. Precipitation or weather anomalies were ruled out as sources of the error because the deviation extends for multiple months. Other possibilities include a temporary change in land use practices that the model does not consider, or other land surface change. In 2013, stormwater outfall monitoring data is expected to be available for the Truckee Meadows area. This may provide additional observed data to validate model parameters with regard to storrmwater runoff parameters originating from the land surface.

Phosphorus

Model results for observed and predicted total phosphorus and orthophosphate are presented on an annual average basis in Figures 4-11 through 4-16.

Regression statistics corresponding to discrete observations are reported in Tables 4-5 and 4-6. For all stations, modeled mean, minimum, and maximum concentrations compare well to observed data. Relative error for phosphorus was as good or better for the 2000-2011 model period than previously calculated for the 2000-2008 period. Modeled values for total phosphorus at Reno/Sparks generally fell below the PQL for observed data, which indicates as good of a match as is possible given the observed conditions.

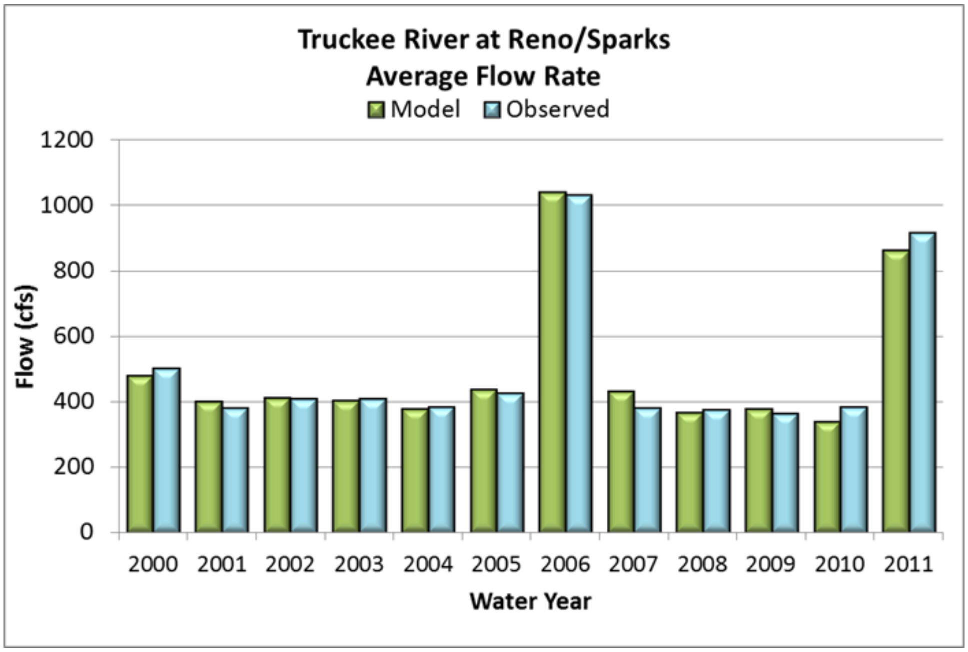
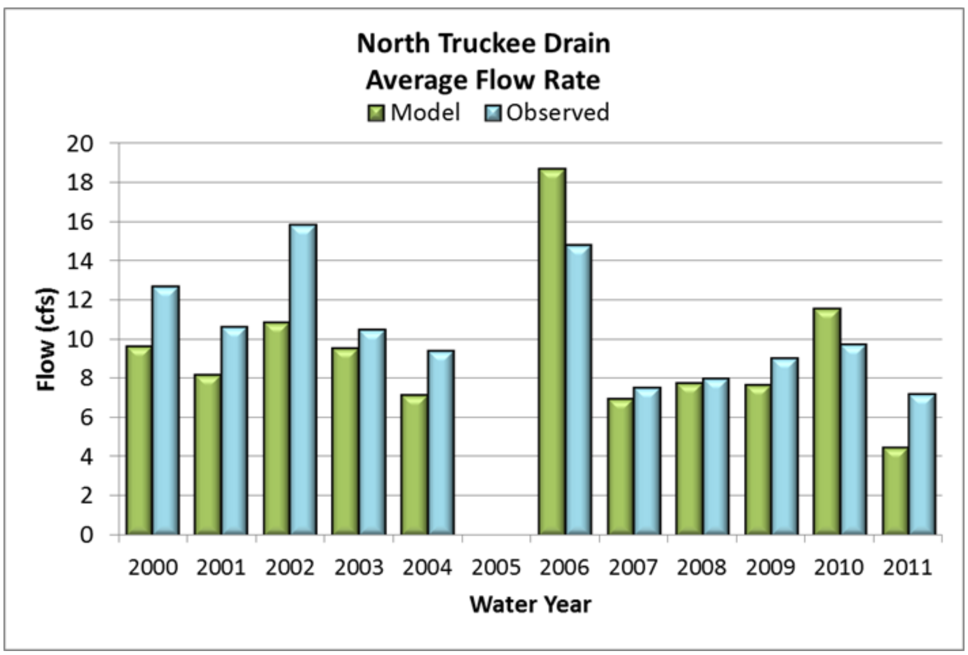


Figure 4-2. Average Annual Modeled and Observed Flow at Reno/Sparks



Note: Observed data for water year 2005 was not available at this station

Figure 4-3. Average Annual Modeled and Observed Flow at North Truckee Drain

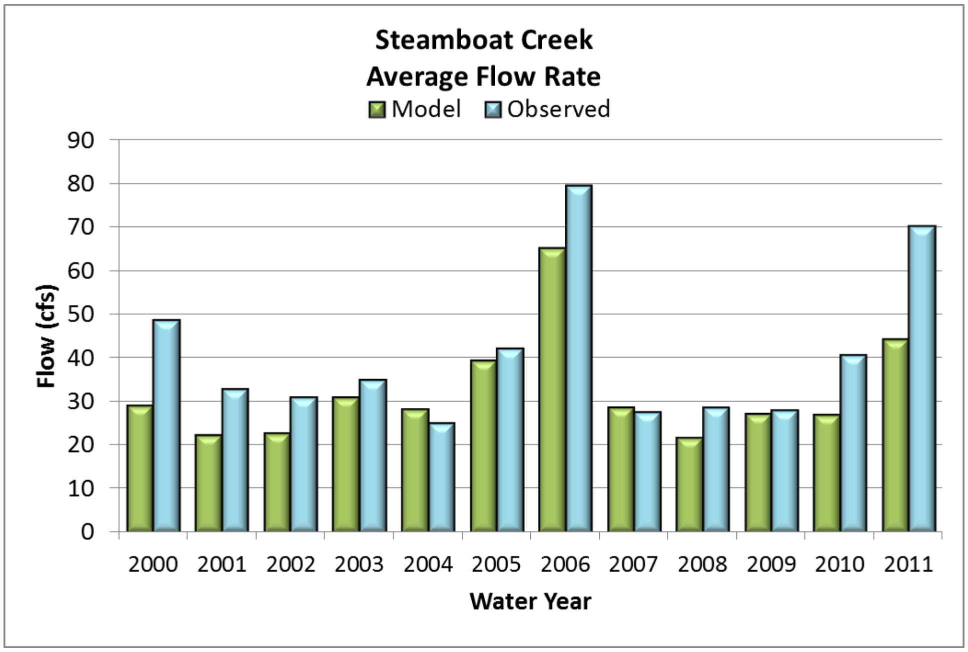


Figure 4-4. Average Annual Modeled and Observed Flow at Steamboat Creek

Table 4-2. Summary Statistics for Flow (cfs) (1/1/2000 – 12/31/2011)

Location	Modeled Mean	Observed Mean	Modeled Minimum	Observed Minimum	Modeled Maximum	Observed Maximum	Number of Observed Points
Reno/Sparks	496.2	498.8	19.6	0.0	9921	12201	4383
North Truckee Drain	9.7	10.8	1.5	1.9	278	240	3508
Steamboat Creek	32.3	40.6	9.7	8.4	537	2000	4383

Location	Residual Error	Average Error	RMS Error	r^2
Reno/Sparks	-2.61	91.32	168.45	0.89
North Truckee Drain	1.35	9.11	15.54	0.10
Steamboat Creek	-8.27	16.31	38.49	0.37

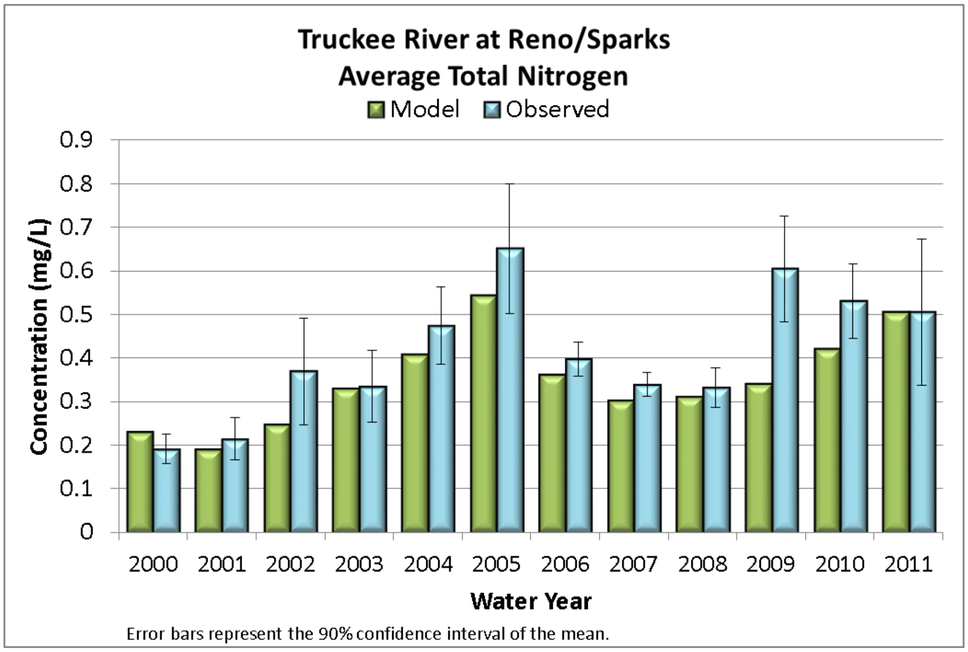


Figure 4-5. Average Annual Modeled and Observed Total Nitrogen at Reno/Sparks

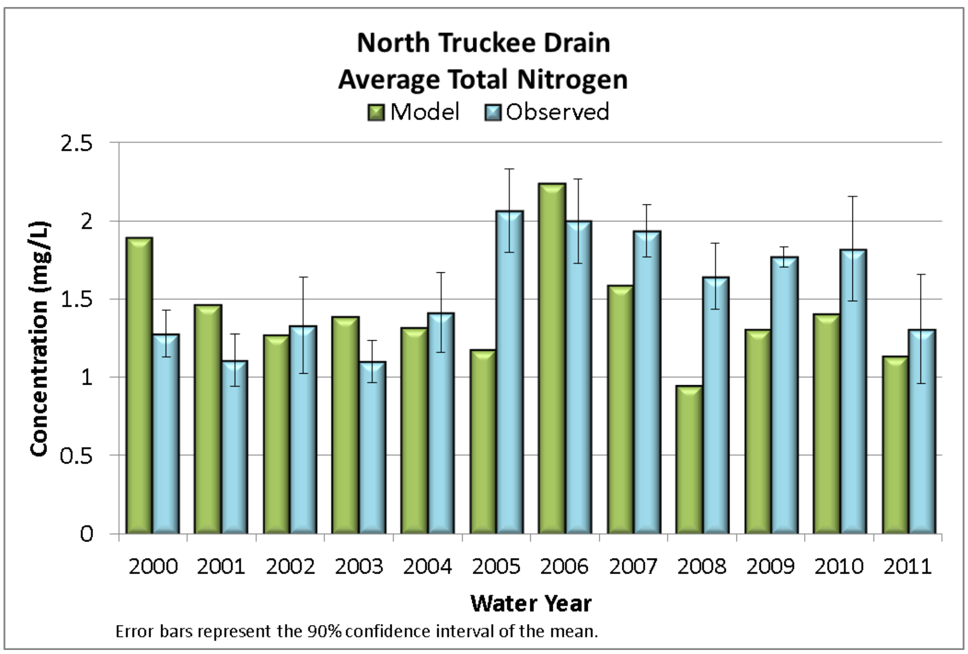


Figure 4-6. Average Annual Modeled and Observed Total Nitrogen at North Truckee Drain

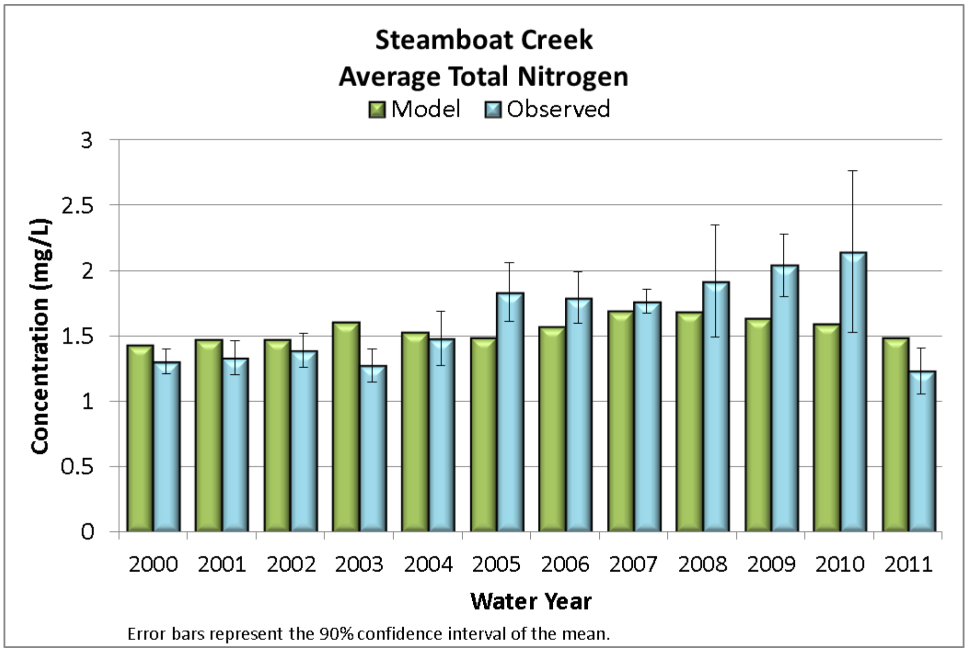


Figure 4-7. Average Annual Modeled and Observed Total Nitrogen at Steamboat Creek

Table 4-3. Summary Statistics for Total Nitrogen (mg/L) (1/1/2000 – 12/31/2011)

Location	Modeled Mean	Observed Mean	Modeled Minimum	Observed Minimum	Modeled Maximum	Observed Maximum	Number of Observed Points
Reno/Sparks[1]	0.35	0.42	0.10	0.13	1.59	1.48	145
North Truckee Drain[2]	1.44	1.57	0.04	0.05	6.10	4.92	175
Steamboat Creek[3]	1.56	1.63	0.15	0.54	5.90	7.02	175

Location	Residual Error	Average Error	RMS Error
Reno/Sparks[1]	-0.07	0.16	0.23
North Truckee Drain[2]	-0.17	0.77	1.00
Steamboat Creek[3]	-0.11	0.48	0.85

[1]For Reno/Sparks, 98% of the calculated nitrogen data points were reported as below the PQL.
[2]For North Truckee Drain, 44% of the calculated nitrogen data points were reported as below the PQL.
[3]For Steamboat Creek, 63% of the calculated nitrogen data points were reported as below the PQL.

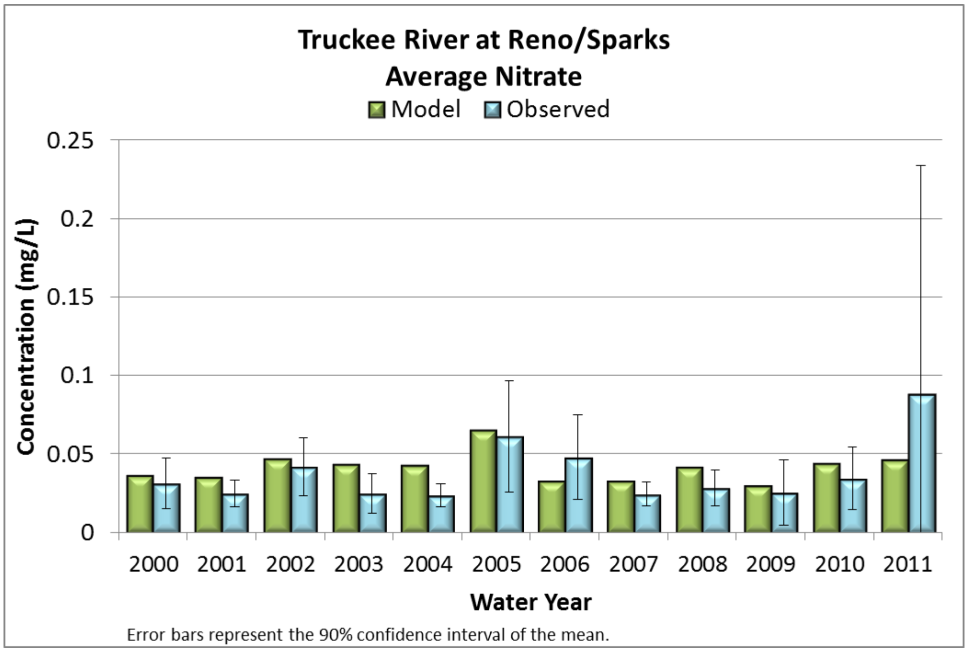


Figure 4-8. Average Annual Modeled and Observed Nitrate at Reno/Sparks

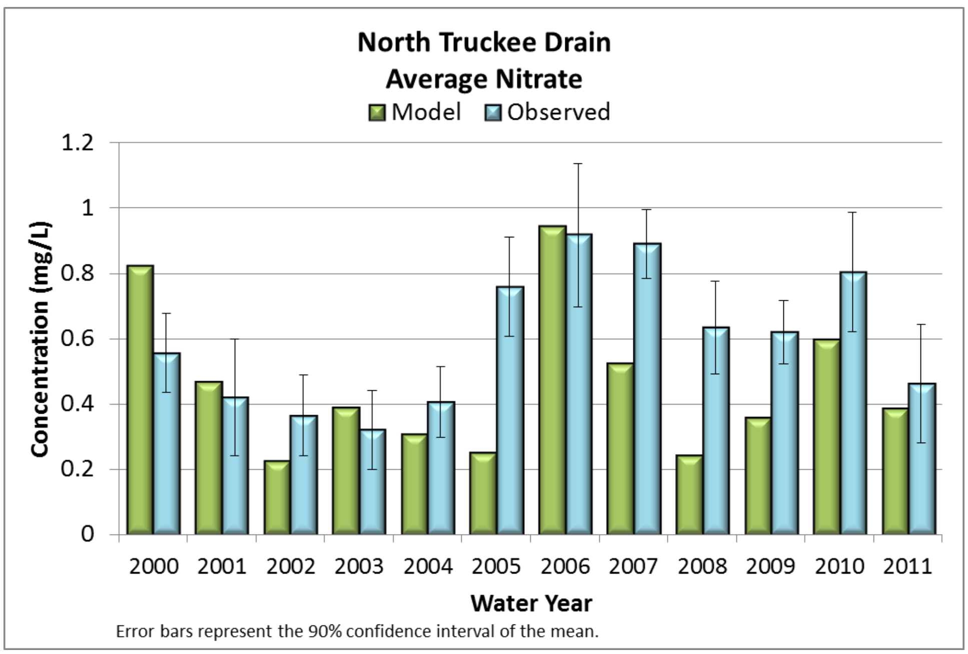


Figure 4-9. Average Annual Modeled and Observed Nitrate at North Truckee Drain

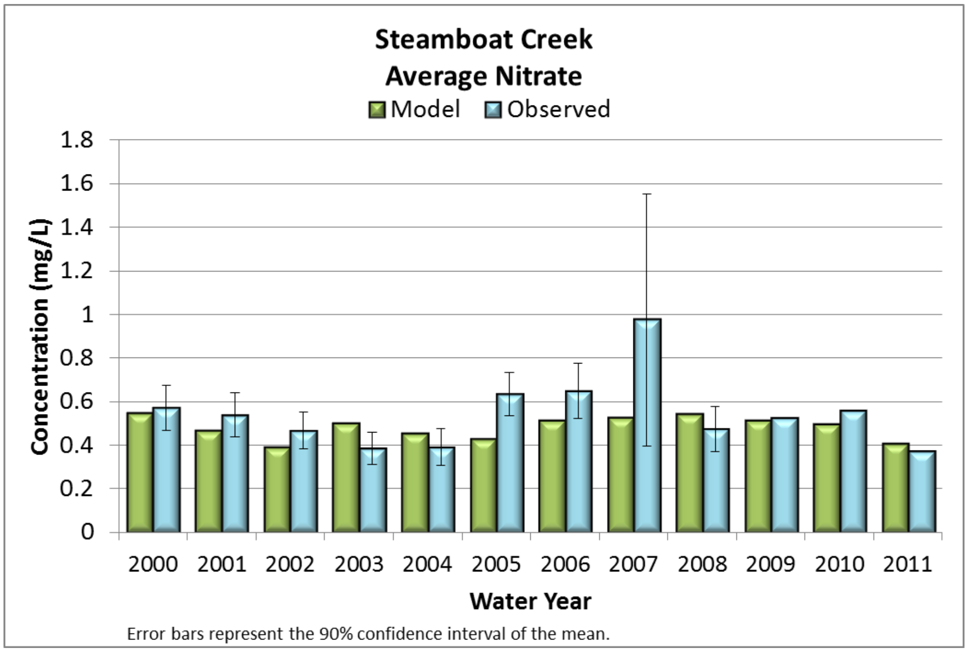


Figure 4-10. Average Annual Modeled and Observed Nitrate at Steamboat Creek

Table 4-4. Summary Statistics for Nitrate (mg/L) (1/1/2000 – 12/31/2000)

Location	Modeled Mean	Observed Mean	Modeled Minimum	Observed Minimum	Modeled Maximum	Observed Maximum	Number of Observed Points
Reno/Sparks[1]	0.04	0.04	0.01	0.01	0.29	0.66	145
North Truckee Drain[2]	0.46	0.61	0.01	0.01	1.79	1.80	171
Steamboat Creek[3]	0.48	0.55	0.05	0.04	1.09	6.17	171

Location	Residual Error	Average Error	RMS Error
Reno/Sparks[1]	0.00	0.03	0.06
North Truckee Drain[2]	-0.16	0.40	0.52
Steamboat Creek[3]	-0.07	0.21	0.48

[1]For Reno/Sparks, 61% of the nitrate data points were reported as below the PQL.
[2]For North Truckee Drain, 5% of the nitrate data points were reported as below the PQL.
[3]For Steamboat Creek, none of the nitrate data points were reported as below the PQL.

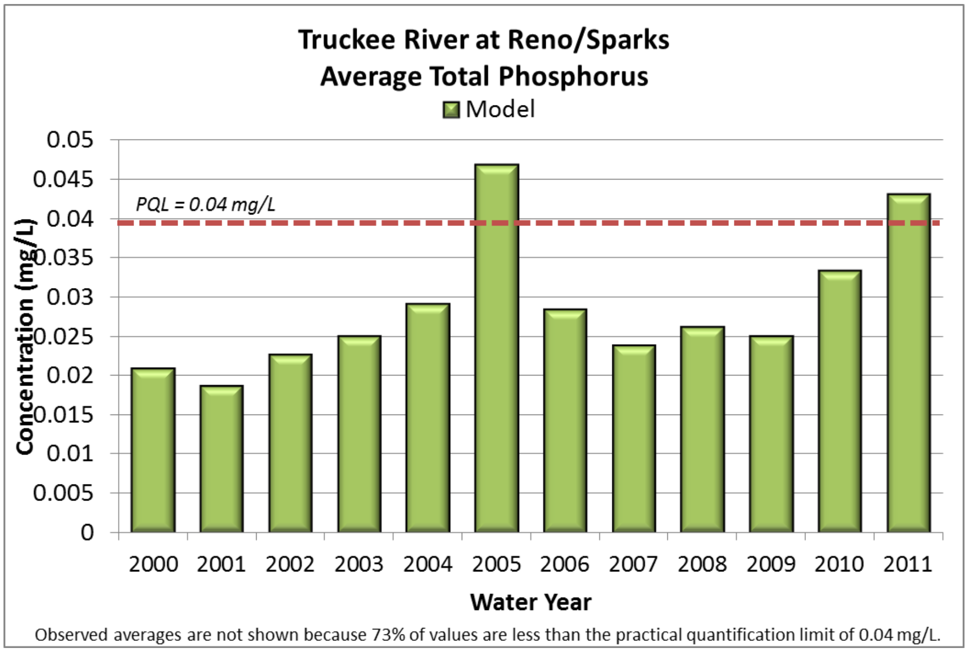


Figure 4-11. Average Annual Modeled Total Phosphorus at Reno/Sparks

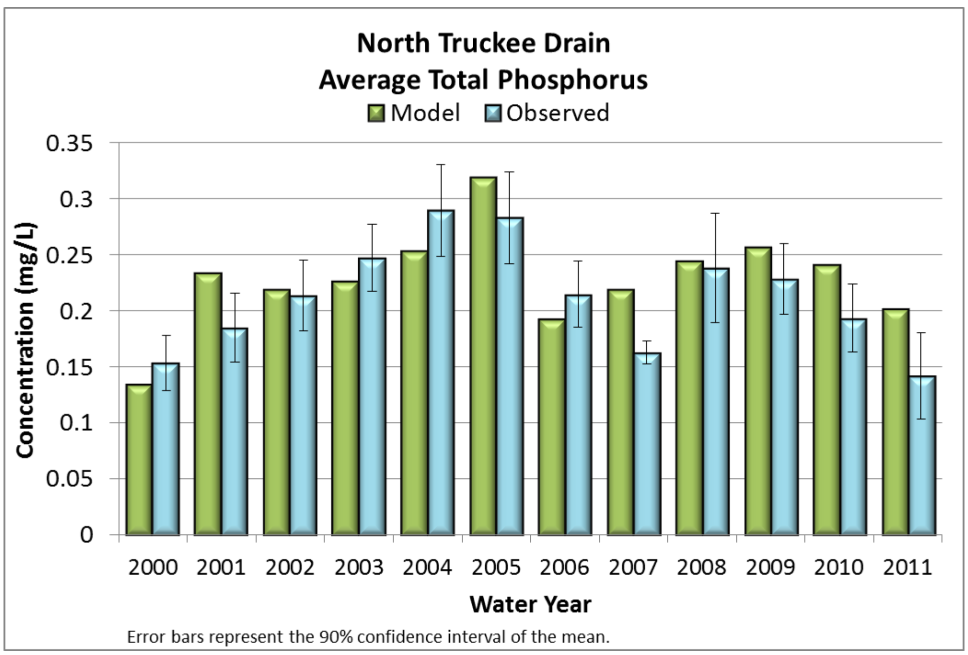


Figure 4-12. Average Annual Modeled and Observed Total Phosphorus at North Truckee Drain

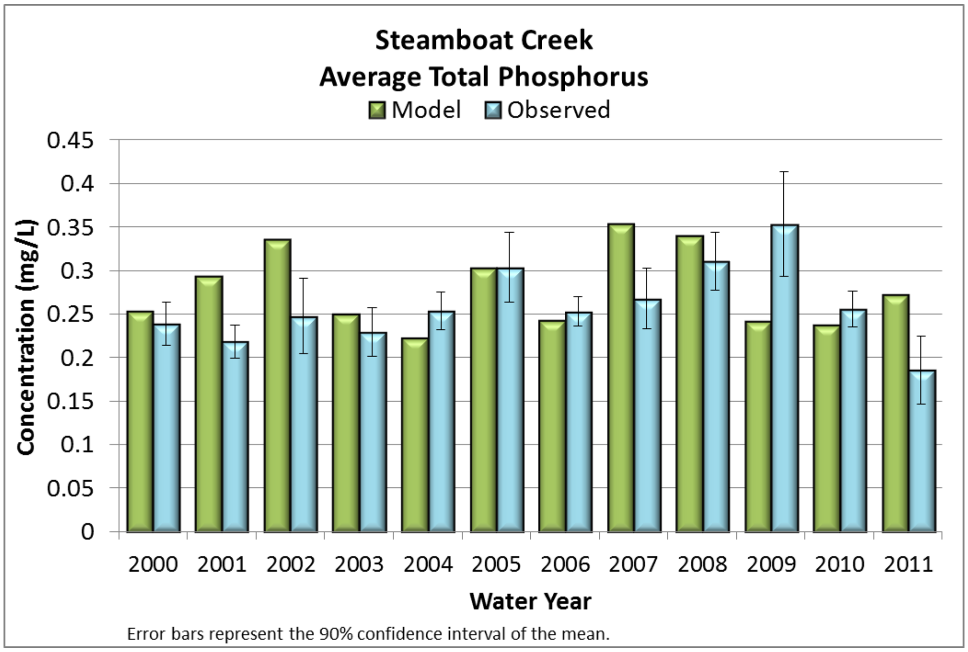


Figure 4-13. Average Annual Modeled and Observed Total Phosphorus at Steamboat Creek

Table 4-5. Summary Statistics for Total Phosphorus (mg/L) (1/1/2000 – 12/31/2011)

Location	Modeled Mean	Observed Mean	Modeled Minimum	Observed Minimum	Modeled Maximum	Observed Maximum	Number of Observed Points
Reno/Sparks[1]	0.03	0.03	0.01	0.02	0.19	0.19	145
North Truckee Drain[2]	0.23	0.23	0.01	0.02	1.15	1.50	172
Steamboat Creek[3]	0.28	0.26	0.02	0.05	1.51	0.66	171

Location	Residual Error	Average Error	RMS Error
Reno/Sparks[1]	0.00	0.01	0.03
North Truckee Drain[2]	0.00	0.10	0.17
Steamboat Creek[3]	0.01	0.10	0.14

[1]For Reno/Sparks, 73% of the total phosphorus data points were reported as below the PQL.
[2]For North Truckee Drain, 1% of the total phosphorus data points were reported as below the PQL.
[3]For Steamboat Creek, none of the total phosphorus data points were reported as below the PQL.

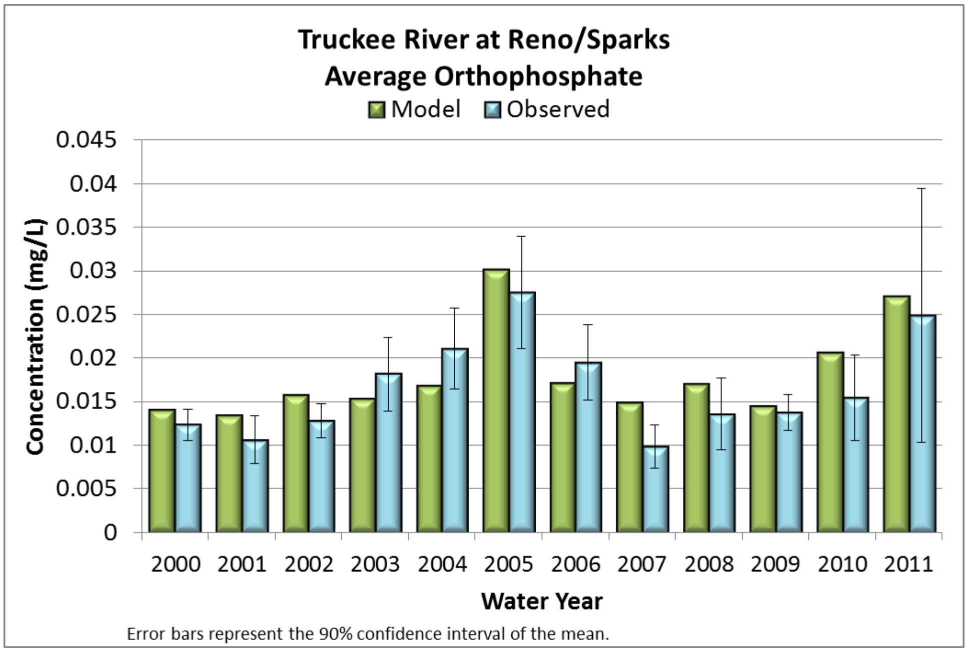


Figure 4-14. Average Annual Modeled and Observed Orthophosphate at Reno/Sparks

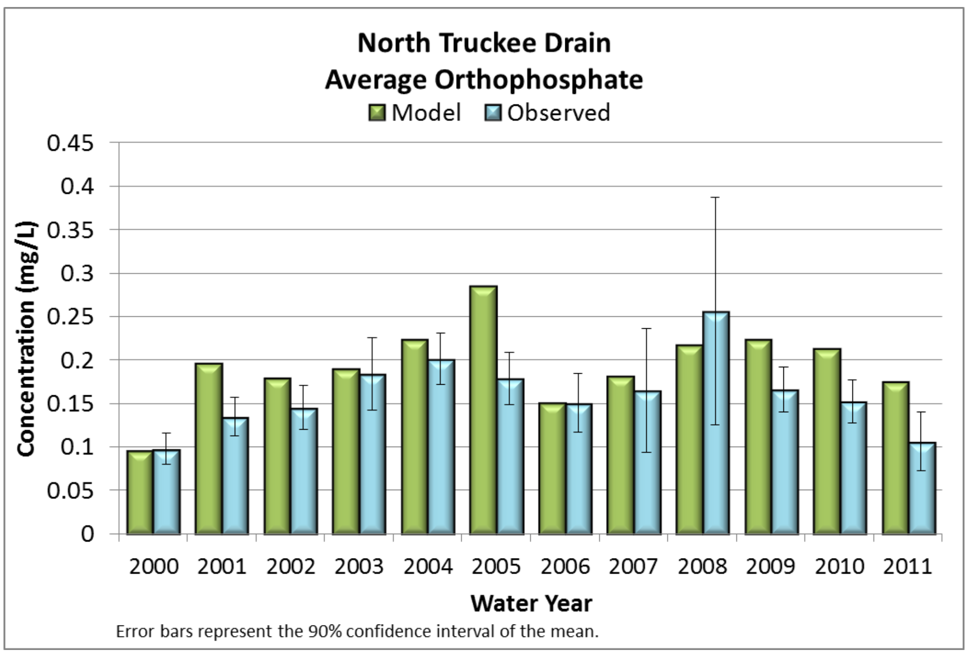


Figure 4-15. Average Annual Modeled and Observed Orthophosphate at North Truckee Drain

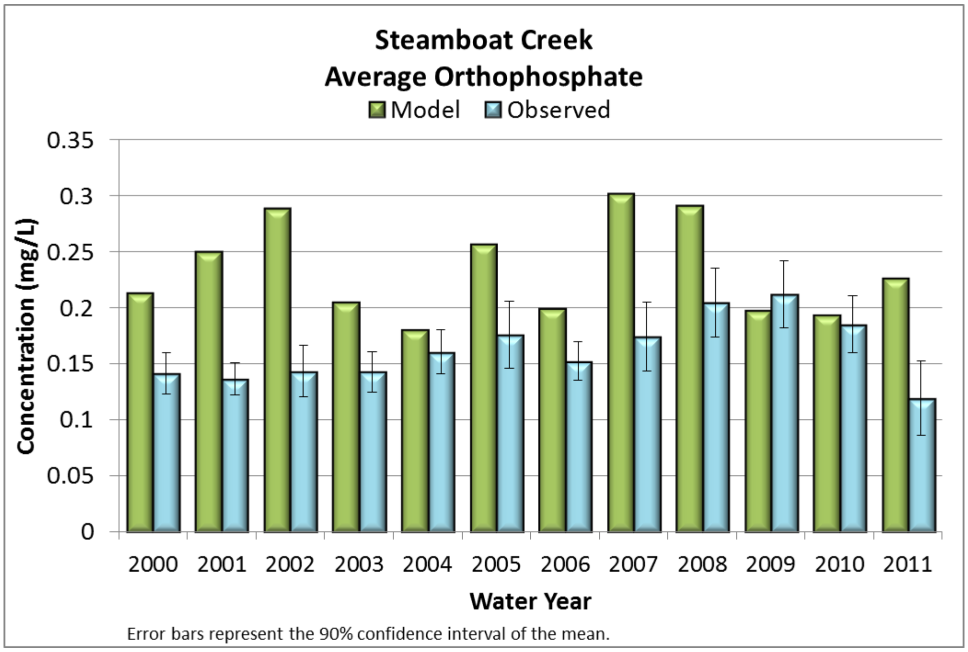


Figure 4-16. Average Annual Modeled and Observed Orthophosphate at Steamboat Creek

Table 4-6. Summary Statistics for Orthophosphate (mg/L) (1/1/2000 – 12/31/2000)

Location	Modeled Mean	Observed Mean	Modeled Minimum	Observed Minimum	Modeled Maximum	Observed Maximum	Number of Observed Points
Reno/Sparks[1]	0.02	0.02	0.01	0.01	0.13	0.12	145
North Truckee Drain[2]	0.20	0.15	0.01	0.02	0.83	0.80	145
Steamboat Creek[3]	0.23	0.15	0.02	0.02	1.29	0.35	145

Location	Residual Error	Average Error	RMS Error
Reno/Sparks[1]	0.00	0.01	0.01
North Truckee Drain[2]	0.05	0.09	0.12
Steamboat Creek[3]	0.07	0.09	0.13

[1]For Reno/Sparks, 19% of the orthophosphate data points were reported as below the PQL.
[2]For North Truckee Drain, none of the orthophosphate data points were reported as below the PQL.
[3]For Steamboat Creek, none of the orthophosphate data points were reported as below the PQL.

4.1.5 Discussion of WARMF Confirmation Results

The results presented above suggest that WARMF is accurately simulating both hydrology and water quality within the Truckee River watershed for an extended time period which reflects an increase in regional growth and development. As mentioned above, it is important to evaluate uncertainty using a "weight-of-evidence" approach which includes evaluation of both statistical and visual comparisons and recognizes both the uncertainty and the frequency of the observed data.

Although the model calibration and confirmation is satisfactory, several minor limitations in model performance were identified during this exercise:

- **Snow melt peaks:** For some years, WARMF has difficulty simulating the full spring snowmelt from the upper watershed, particularly during wetter years with higher snowpack. This under-prediction of snowmelt can result in an occasional under-prediction of streamflow near Farad which then propagates downstream to the point where WARMF flows are transferred into the TRHSPF model. This shortcoming was identified during the first model extension effort (LimnoTech 2011). As part of the most recent model extension through 2011, minor calibration adjustments in the upper watershed (described above) were helpful to improve the hydrology simulation during both extreme low-flow periods and higher snow melt periods. Because the modeling efforts presented here focus mainly on capturing the Truckee River's water quality response (e.g., dissolved oxygen concentrations) to nutrient loads during critical, low flow periods, it was determined that additional calibration refinement efforts to close the remaining gap between simulated and observed snowmelt peaks during wet years is not warranted.
- **Summer irrigation**: The process of updating LULC data in the model and simulating more recent time periods brought to light that WARMF typically under-predicts flow in Steamboat Creek and North Truckee Drain during the summer. Consultation with local experts and review of a study of Chalk Creek (JBR 2010) led to the conclusion that landscape irrigation in developed watershed areas using either potable or reclaimed water was contributing to increased tributary flows in the summer. WARMF currently only simulates watershed hydrology based on natural precipitation and prescribed irrigation from river diversions to cropland, pasture, golf course, and park areas. WARMF is not currently configured to allow for irrigation of potable or reuse water to residential areas. This under-prediction of flow did not cause a significant impact in summer flow in the Truckee River downstream of the confluence with Steamboat Creek and North Truckee Drain.
- **Spring water temperature:** As described above, efforts were made to improve WARMF's prediction of stream temperature during spring periods. Although improvements were made, the model still has some limitations in accuracy. For example, during simulations of 1999-2002, WARMF stream temperature predictions showed a relative error of approximately 3°C during April and May as compared to a relative error of less than 1.5 °C during other months (Systech Engineering 2009). This remaining under-prediction of stream temperature during some months of the year creates the potential for TRHSPF to over-predict dissolved oxygen during the corresponding months; however, a sensitivity analysis determined that small improvements in TRHSPF dissolved oxygen simulations using measured stream temperature instead of WARMF simulated stream temperature only occurred during the non-critical late winter/early spring period.

4.2 TRHSPF

4.2.1 Recent TRHSPF Enhancements

Since the publication of the TRHSPF calibration report (LimnoTech 2008), five notable model enhancements were implemented:

1. **Organic labile nutrient state variables:** Revisions were made to TRHSPF algorithms to improve the representation and simulation of organic labile nutrients. TRHSPF simulates a large number of instream constituents including dissolved oxygen and biochemical oxygen demand (BOD), inorganic and organic forms of nitrogen and phosphorus, and two types of benthic algae. Calibration and application work with the TRHSPF model revealed fundamental limitations in how the standard HSPF framework handles organic labile nitrogen (OLN) and organic labile phosphorus (OLP) mass and associated kinetics:

    a. OLN and OLP concentrations are derived indirectly from BOD concentrations and stoichiometric ratios associated with phytoplankton (i.e., carbon to nitrogen to phosphorus content in plants); and
    b. Implicit decay of OLN and OLP mass does not include recycling to available nitrogen and phosphorus pools (i.e., total ammonia and orthophosphate).

    To overcome the limitations described above, LimnoTech modified the HSPF version 12.2 source code (LimnoTech 2009). New state variables were created to represent OLN and OLP mass in the water column and associated variables were added to track associated mass inflows and outflows. The newly created OLN and OLP variables are independent quantities that have no dependence on either BOD concentration or stoichiometry for phytoplankton biomass. Settling and decay have been added as optional "sink" processes for the new OLN and OLP state variables. Settling is represented in the same manner as settling processes for other suspended constituents in HSPF. The decay of OLN and OLP mass is calculated analogously to the decay of BOD. Recycle of decayed OLN and OLP mass to the available N (total ammonia) and P (orthophosphate) pools is handled in the same manner as decay of other organic material.

2. **Linkage with WARMF model:** One objective of using improved modeling tools to review nutrient WQS and TMDLs in the Truckee River is the use of a linked (coupled) watershed-receiving water model. A linked tool provides the capability to evaluate the Truckee River water quality response to changes in watershed activities (e.g., land development, BMPs) in addition to changes in point source loadings. As described in their respective calibration reports, WARMF and TRHSPF were initially developed and calibrated independently of one another. TRHSPF was originally calibrated using monitoring data to specify flow and water quality at all upstream boundaries, tributary inputs and nonpoint source loading contributions along the length of the river. However, the WQS and TMDL review and revision requires that the modeling tools work in conjunction with each other. To create a linked (coupled) model system, TRHPSF was re-run using WARMF-generated output to specify the upstream flow and load boundary conditions for Truckee River (at East McCarran Blvd.), Steamboat Creek, and North Truckee Drain. WARMF output was also used as the flow and load boundary condition for sub-catchment runoff adjacent to the Truckee River. A tool was developed to convert WARMF output into a format that could

easily be read by TRHSPF. Water quality constituents were converted from the constituents in WARMF to the constituents needed by TRHSPF. All constituents were converted using 1:1 ratios with the exception of total nitrogen (TN) and total phosphorus (TP) which required further delineation of the fraction of organic nutrient in labile and refractory forms. These two constituents were split 50:50 between organic labile and organic refractory components after subtracting off the dissolved inorganic components. The distribution of organic matter between refractory and labile forms is not readily measured, and is known to vary between sources. LimnoTech (2008) reviewed several modeling applications and found that the assumption of the split between refractory and labile forms ranged across models from 75% refractory : 25% labile to 25% refractory : 75% labile. A split of 50% refractory : 50% labile was used for this application as a mid-point between the ranges used in other model applications. For time periods that overlapped with the original TRHSPF calibration, the WARMF-driven linkage scenarios were compared to data-driven scenarios to verify linkage of the simulated parameters.

3. **Gilpin Spill bypass channel:** A discrete reach segment was created in TRHSPF to explicitly represent return flow from Gilpin Spillway. Truckee River operations include the diversion of water at Derby Dam (located approximately 25 miles downstream from Reno) into the Truckee Canal. An ungauged amount of water spills back to the Truckee River from the Truckee Canal upstream via the Gilpin Spillway, which is located approximately 8 miles downstream of Derby Dam. In previous versions of TRHSPF, the return flow from Gilpin Spill was not directly represented in the model. Instead, the Gilpin Spill flow was "lumped in" with the flow over Derby Dam, which meant that the volume of water returned via the spill was simply left in the river and not diverted. Under conditions where Gilpin Spill was operating and flow was returned to the Truckee River, TRSHPF would have simulated higher than actual flows in model segments 320 to 325 (approximately 8 miles). With the creation of a new reach segment for the Gilpin Spill "bypass", flow returned via Gilpin Spill is directly accounted for in the model by sending the "total" Truckee Canal flow down the canal at Derby Dam and then returning the appropriate amount of flow back to the river at segment 325. A model segment was added to represent the portion of the Truckee Canal upstream of where Gilpin Spill returns water to the river. The "total" Truckee Canal flow and Gilpin Spill return flows are based on USGS streamflow gage data and are directly input to the model. However, due to inherent error and uncertainty in the streamflow gage measurements and the fact that, at times, the watershed model (WARMF) may under-predict the upstream flow, model instabilities may arise due to flow imbalances and extremely low modeled flows (i.e., less than 2 cfs). These imbalances and extreme low flows are corrected by making minor adjustments to the amount of flow diverted via the Truckee Canal so that any error or uncertainty is "sent down the canal". The water quality modeled in the new Truckee Canal-Gilpin Spill (TC-GS) reach is simulated with similar kinetics as the Derby Dam model segment with the exception of periphyton biomass. Coefficients were adjusted for initial biomass and minimum and maximum biomass parameters to minimize the impact of periphyton biomass on water quality as it is transported within the Truckee Canal and returned back to the Truckee River. This approach was implemented to prevent predicted periphyton dynamics in the TC-GS reach (which does not provide natural periphyton habitat) from unduly influencing the water quality being returned to the Truckee River.

4. **Organic labile nutrient settling rate:**

A slight adjustment was made to the "LABSET" coefficient, which represents the rate of organic labile nitrogen and phosphorus settling. The coefficient was revised from 0.05 ft/hr to 0.01 ft/hr (literature range: 0.0059-0.47 ft/hr). The change had very little to no effect on dissolved oxygen predictions and resulted in a slight improvement in the prediction of total nitrogen and phosphorus in the downstream reaches of the Truckee River.

4.2.2 Database Extension for TRHSPF

In order to extend TRHSPF simulations through the year 2011, it was necessary to extend several data input files. The following time series data files were extended in the TRHSPF database:

Climate – hourly data for air temperature, dew point temperature, wind speed and cloud cover were available from the National Climatic Data Center (NCDC) for the Reno Airport. Hourly solar radiation data for the North Reno Station were available from the Western Regional Climate Center (WRCC).

Diversions – historical diversion data for all municipal, industrial, and agricultural diversions along the Truckee River were obtained from both the Federal Water Master's office (Dave Wathen) and the TROA - Truckee River Operating Agreement website (http://www.troa.net/) to extend all input files through 12/31/2011. For diversions without complete data records, gaps were filled based on best available information. Diversion input data were reviewed to ensure consistency between the watershed and river model where the model boundaries overlap (i.e., from East McCarran to Marble Bluff Dam). Because the WARMF and TRHSPF models were originally developed independently and at different times, the original diversion datasets used to develop model inputs were not necessarily the same. In addition, diversion data were not necessarily processed in the same manner (e.g., method used to fill data gaps). During the model update process, the diversion input data were modified, as needed, to incorporate the most robust datasets available to date.

Point Sources – flow and concentration data for TMWRF discharge were obtained directly from the facility and entered into the TRHSPF database in order to extend the input file through 12/31/2011. TMWRF is the only permitted point source discharge within the spatial domain of the TRHSPF model.

Observed Streamflow – daily flow records were obtained from the USGS to extend all relevant TRHSPF input files through 12/31/2011. These data are used for comparison with stream flow simulated by TRHSPF. Flow records for the TCID diversion were also obtained and used to specify diversions down Truckee Canal as well as flow that is returned to the Truckee River via Gilpin Spill.

Observed Water Quality – instream water quality monitoring data were obtained from TRIG (http://www.truckeeriverinfo.org/) and used to extend all relevant TRHSPF input files through 12/31/2011. These data are used for comparison with instream concentrations simulated by TRHSPF. The update of these data files included incorporation of data from all available years which had undergone a more thorough QA/QC process to prevent the reporting of quantitative values noted to be less than the practical quantitation limit (<PQL). For model-to-data comparisons, observed values reported as <PQL were replaced with reasonable alternative values. For nutrient parameters, if a value was reported as a <PQL, the value was assumed to be equal to one half of the PQL. For non-nutrient parameters, if a value was reported as <PQL, the value was assumed to be equal to the PQL. For total nutrients (total nitrogen and total phosphorus), the selection of how to specify a component species (e.g., nitrate) that was measured as <PQL will influence the "total" constituent value. Setting the values to one half of the PQL had the effect of lowering the total nutrient value, better accounting for the uncertainty in measurement of water quality values below the detection limit.

Additional TRHSPF inputs were not readily available for the extended time period such as estimates of groundwater and TDS loads into the Lower Truckee River near Fernley and biological data for observed periphyton densities in the Truckee River. Although Desert Research Institute (DRI) may have additional groundwater and biological data, they were not available for use during the time of the model updates. Therefore, groundwater inputs of flow and TDS which were based on previous studies (Nowlin1987, Brock 1992, Pohll 2001) were extended to be consistent with earlier time periods. The TRHSPF simulation of water quality was evaluated by comparing model results to instream concentrations of water temperature, nutrients, and dissolved oxygen, but did not include a comparison with periphyton measurements.

4.2.3 Limited Model Changes

After updating all of the databases described above, TRHSPF confirmation simulations were set up for 01/01/2000 through 12/31/2011. Similar to WARMF, the simulations were set up as runs for four discrete time periods rather than one continuous simulation (i.e., 2000-2002, 2003-2005, 2006-2008, and 2009-2011). Where applicable, boundary conditions inputs were derived from WARMF output rather than observed data. The objective was to test model performance with a unique data set for an extended time period while holding model calibration parameters (e.g., reaction rates) equal to values used in the original calibration. During this process, calibration parameters related to nutrient transformation or periphyton growth were not adjusted with the exception of the organic nutrient labile settling rate as described above. However, a few adjustments were made to the model to improve the flow balance and model stability:

Flow Balance: Development of input files for the Truckee Canal diversion from the Truckee Rivers, as well as return flow to the river via Gilpin Spill, was based on USGS gage data. The total flow diverted to the Truckee Canal was calculated based on the following equation:

> "Total" Truckee Canal Flow Diversion = Flow at Truckee River near Tracy [010350340] – Flow at Truckee River below Derby Dam [010351600]

The flow returned from the Truckee Canal to the river via Gilpin Spill was calculated based on the following equation:

> Gilpin Spill Return Flow = "Total" Truckee Canal Flow Diversion – USGS gage Truckee Canal near Wadsworth [010351300]

Review of the measured flow records revealed an occasional mismatch between flow records, which when used to calculate a flow balance sometimes resulted in negative flows in the Truckee River downstream of Derby Dam. This inconsistency in flow data was determined to be related to error in the gage streamflow measurements. To better understand the possible error in streamflow measurements Steven Berris, Data Chief of the USGS Nevada Water Science Center, was contacted for assistance. In addition, USGS reports and datasets were also reviewed (USGS 2011a, USGS 2011b, and USGS 2011c).

On an annual basis, USGS summarizes gage performance in a report to provide an estimate for the accuracy of streamflow measurements. In addition, comments are made for individual months or days where accuracy may have been compromised for any reason. Yearly accuracy is assigned a value from "Excellent" to "Poor". Excellent indicates that 95% of the daily discharges are within 5 % of the true value, "Good" is 10%, "Fair" is 15%, and "Poor" is greater than 15% from the actual value. The accuracy assignments were compiled and reviewed for the four gages used to estimate the Truckee Canal diversion and the Gilpin Spill return flows (Truckee River near Tracy [10350340], Truckee River below Derby Dam [10351600], Truckee Canal near Wadsworth [10351300], Truckee at Wadsworth [10351650]).

Overall, the accuracy of the gages was listed as "Good", indicating that all flow values are within 10% of the real value. However, the Truckee River near Tracy [10350340] gage was listed as "Fair" for 2002-2004 with three months listed as "Poor" in 2002. This indicates that accuracy was only within 15% of the actual value for these years and was less than 15% of the actual value for a few months. In general, the overall gage accuracy from best to worst for the gages reviewed would be as follows:

1) Truckee at Wadsworth [10351650] and Truckee River below Derby Dam [10351600] (approximately the same accuracy)
2) Truckee Canal near Wadsworth [10351300]
3) Truckee River near Tracy [10350340]

To resolve the situation of negative flow balances, Truckee Canal flow diversions were adjusted to prevent the occurrence of negative flow in the Truckee River for days where there was an obvious mismatch in flow records. In addition, at times, the watershed model (WARMF) may under-predict the upstream flow and flow imbalances may arise when more water is diverted from the river based on data versus what is available to be diverted in the model. These imbalances were also corrected by adjusting the amount of flow diverted to the Truckee Canal so that any error or uncertainty is "sent down the canal". The Gilpin Spill return flow was also adjusted, as needed, along with the Truckee Canal flow in both cases to maintain a flow balance.

Model Stability: Model runs for the extended time period resulted in some days with model instability in the segment directly downstream of Derby Dam. These instabilities related to the simulation of very low flows which have the potential to completely dry the segment during isolated time steps (1/2 hr) over the course of a day within the model. To resolve the issue, the TRHSPF model code was modified to set a minimal "floor" or limit (100 ft^3) which prevents the volume in a reach from ever going to zero within a single ½ hr time step. When this limit is applied during a flow balance calculation under very low flow conditions, the outflow out of the reach will be adjusted by less than 0.05 cfs to ensure that the volume in the reach will always be greater than zero. This slight revision to the model code successfully prevents model instabilities and does not significantly change the model predicted flow rates or volumes.

4.2.4 TRHSPF Model Confirmation Results

Model performance evaluations used the same "weight-of-evidence" approach (statistical and visual comparisons) as described previously for WARMF. The following figures (Figures 4-17 through 4-68) show results of the TRHSPF model confirmation runs from 2000 through 2011. These simulations used WARMF output (presented in Section 3.1.4) to define the upstream boundary conditions for the TRHSPF model. Results are presented for all locations within the TRHSPF model domain where observed data are available for comparison with simulation results.

The associated tables (Tables 7 through 13) show summary statistics for modeled and observed data for the 2000-2011 confirmation period. The statistical results provided are consistent with those given in the original calibration report and the previous model confirmation report (LimnoTech 2011). The coefficient of determination (r^2) is used to evaluate the correlation between predicted and observed values. It is expressed as a value between zero and one. An r^2 value of one (1), with a regression slope near one (1) and an intercept near zero (0), indicates a perfect correlation between model predictions. A value of zero (0) indicates no correlation between model predictions and observations. Residual Error represents the average difference between predicted and observed values, and serves to quantify any consistent bias in predictions. A positive value for the residual error indicates that model predictions are generally greater than observed data, while a negative value indicates that model predictions are generally less than the observed data. Average Error represents the average of the absolute values of differences between predicted and observed values. This number is always positive, and indicates the average difference between predictions and results, regardless of sign. Relative Error is similar to residual error, but divides each difference by the observed concentration to provide the error in terms of "percent of observed value" rather than absolute concentration. Appendix A summarizes the equations used to calculate the summary statistics. Full time series results of daily output for all stations as well as for other water quality constituents are provided in Appendix C.

When evaluating model performance, it is important to recognize the uncertainty in the observed data. The uncertainty in the data increases if samples are reported as <PQL. A professional judgment must be made on how to handle data reported as <PQL. For example, values can be assumed to be equal, half, one-fourth, etc. of the PQL value. Alternatively, values can also be specified in terms of a minimum detection limit (MDL) where the PQL is equal to five times (5x) the MDL. The assumptions made in addressing values reported as <PQL can introduce a bias in the model-to-data comparisons. Another important uncertainty to consider is the frequency of the data observations. Streamflow data are available on a daily basis. Dissolved oxygen and water temperature data are available on a hourly basis when data sondes are deployed. However, nutrient data are based on one to two (1-2) samples per month. In contrast, model predictions are based on an hourly or daily basis. The annual total nitrogen and total phosphorus bar charts below provide an illustration of the difference in frequency of data versus model predictions. The bar charts comparisons are based on annual averages calculated from 12-24 data points versus 365-366 model points.

Streamflow

Model results for observed and predicted streamflow are presented on an annual average basis in Figures 4-17 through 4-20 for the following locations corresponding to USGS gauges:

- Vista, NV (10350000)
- Tracy, NV (10350340)
- Below Derby Dam, NV (10351600)
- Nixon, NV (10351700)

Model predictions capture the annual variability very well for all stations. Regression statistics corresponding to daily flows are reported in Table 4-7. r^2 values for daily flows range between 0.86 and 0.90 for all stations. These statistics correspond to a "very good" (the highest rating) model performance rating. This rating is based on the calibration/confirmation metrics provided by Donigian (2002) for evaluating the agreement between model predictions and observed data in an HSPF application. Overall, streamflow predictions are "better" than the previous model confirmation (LimnoTech 2011).

Temperature

Regression statistics corresponding to temperature observations are reported in Tables 4-8 and 4-9. Error statistics are not as good as those observed during the original calibration report, with the discrepancy due to the limitation of WARMF in providing accurate upstream boundary temperatures to TRHSPF during periods of peak snow melt. Comparisons of predicted and observed temperatures are greatly improved during periods of moderate and low flow, which are the most important periods to accurately simulate. Model-to-data visual and statistical comparisons indicate that the temperature predictions are reasonable and good. Overall, the temperature predictions are "as good as" the previous model confirmation (LimnoTech 2011).

Nitrogen

Model results for observed and predicted total nitrogen are presented on an annual average basis in Figures 4-21 through 4-26. Corresponding results for nitrate are presented in Figures 4-27-4-32. Error bars are used when representing the observed data (calculated as the

90% confidence interval of the mean), reflecting the fact that significant uncertainty may exist when estimating an annual average based on a limited number of observations. Model predictions fall within the range of uncertainty of observed data for the large majority of years and locations.

Regression statistics corresponding to discrete observations are reported in Table 4-10. Observed error statistics are almost as good as the previous model confirmation (LimnoTech 2011). The 2000 to 2008 model predictions are "as good as" or "better" than the previous model confirmation (LimnoTech 2011). The 2009 and 2010 model predictions have the greatest discrepancy with the observed data. The 2011 model predictions compare very well to the observed data.

The model predicted total nitrogen is slightly low compared to the observed data. Ammonia and nitrogen model predictions are within the range of uncertainty. Organic nitrogen model predictions are slightly low, especially at the downstream locations. The missing nitrogen is likely attributed to the organic component, which doesn't have a significant impact on dissolved oxygen. Overall, annual model-to-data comparisons indicate that the model predictions of total nitrogen are good.

Phosphorus

Model results for observed and predicted total phosphorus are presented on an annual average basis in Figures 4-33 through 4-38. Model results for orthophosphate are presented in Figures 4-39 through 4-44. Similar to nitrogen, model predictions fall within the range of uncertainty of observed data for the large majority of years and locations.

Regression statistics corresponding to discrete observations are reported in Table 4-11. Observed error statistics are "as good as" or "better" than the previous model confirmation (LimnoTech 2011). The model predicted total phosphorus is slightly low compared to the observed data. Orthophosphorus predictions are slightly high. The missing phosphorus is likely attributed to the organic component, which doesn't have a significant impact on dissolved oxygen. Overall, annual model-to-data comparisons indicate that the model predictions of total phosphorus are good.

Dissolved Oxygen

Model results for observed and predicted dissolved oxygen are presented on a daily basis in Figures 4-45 through 4-68. These figures show three lines representing simulated daily maximum, daily average, and daily minimum dissolved oxygen concentrations. The measured data are displayed as a solid band that covers the range of values observed each day. Regression statistics corresponding to dissolved oxygen observations are reported in Tables 4-12 and 4-13. Both time series plot comparisons and observed error statistics are consistent with the previous model confirmation (LimnoTech 2011). Dissolved oxygen model predictions can be considered "as good as" before for the 2000-2008 time period. Observed data are more limited for the 2009-2011 time period. However, visual and statistical model-to-data comparisons indicate model predictions of dissolved oxygen are good.

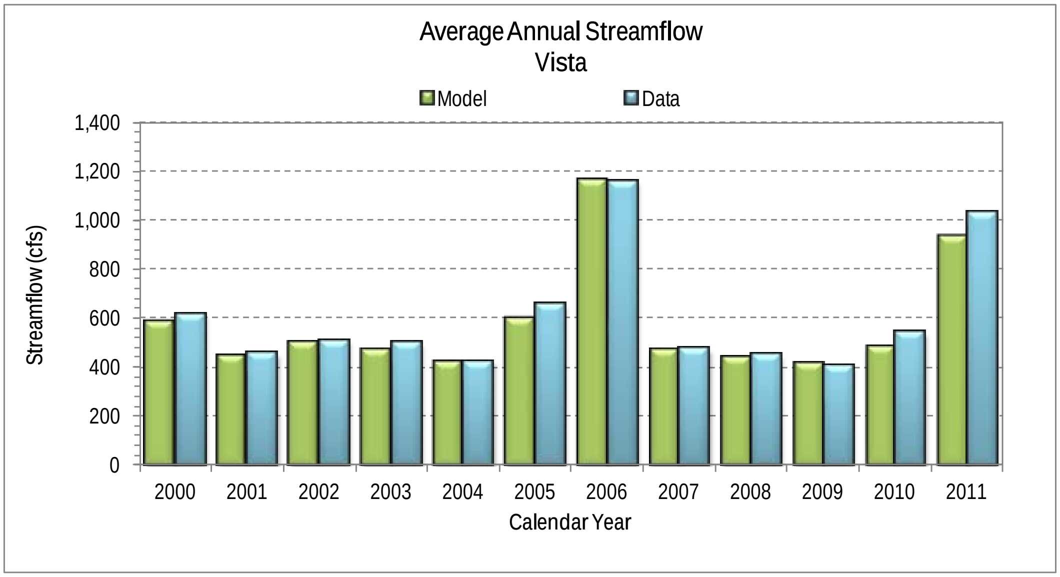


Figure 4-17. Comparison of Average Annual Modeled and Observed Flow at Vista between 2000 and 2011.

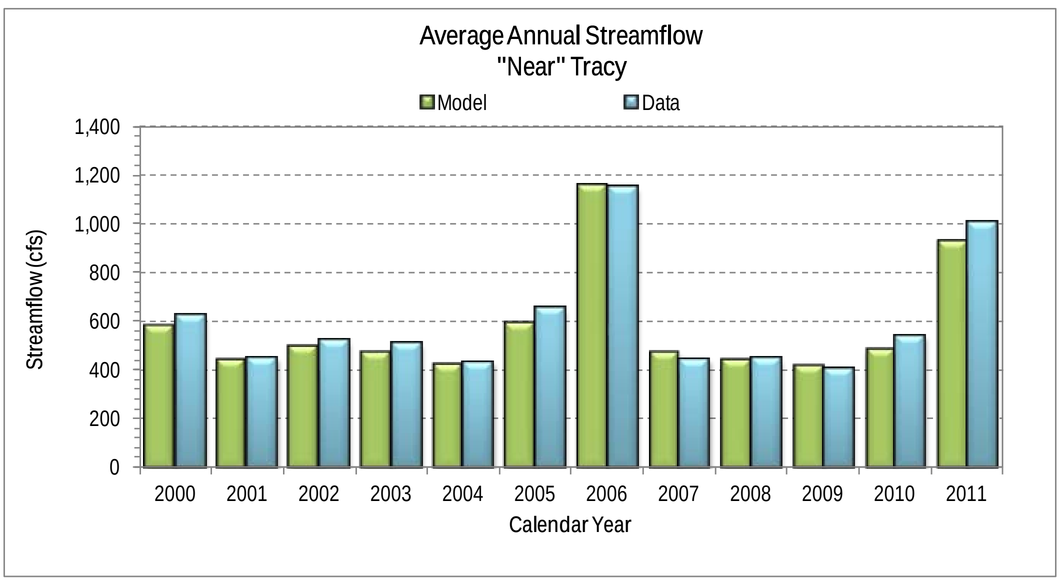


Figure 4-18. Comparison of Average Annual Modeled and Observed Flow near Tracy between 2000 and 2011.

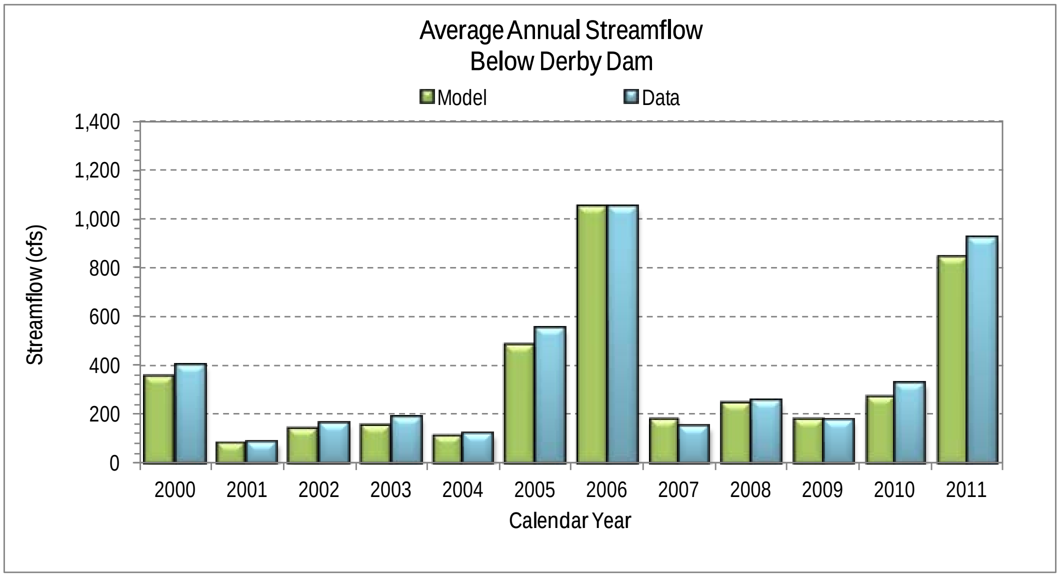


Figure 4-19. Comparison of Average Annual Modeled and Observed Flow below Derby Dam between 2000 and 2011.

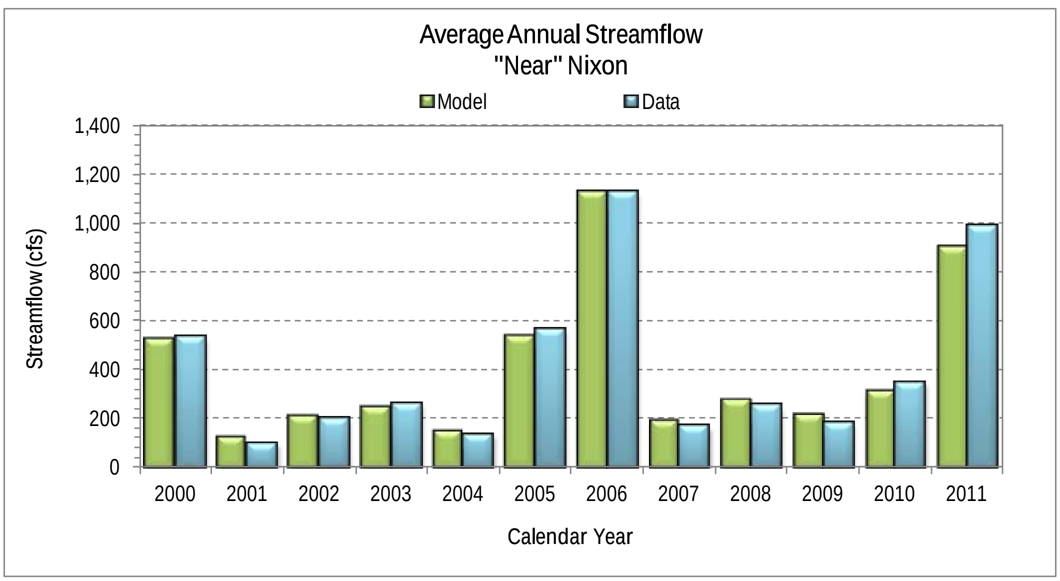


Figure 4-20. Comparison of Average Annual Modeled and Observed Flow near Nixon between 2000 and 2011.

Table 4-7. Summary of Regression Statistics for Daily Streamflow (1/1/2000 – 12/31/2011)

Location	R^2	N
Vista	0.88	4,383
Near Tracy	0.89	4,383
Below Derby Dam	0.90	4,383
Wadsworth	0.88	4,383
Near Nixon	0.86	4,383

Table 4-8. Regression Statistics between Hourly Observed and Predicted Temperature Values (1/1/2000 – 12/31/2011)

Location	r^2	Slope	Intercept	N
Lockwood	0.92	1.06	-5.25	3,177
Patrick	0.93	1.04	-4.11	2,102
Tracy/Clark	0.94	1.05	-4.46	3,617
Painted Rock	0.94	1.05	-4.25	2,907
Wadsworth	0.93	1.04	-3.35	1,999
Marble Bluff Dam	0.91	0.98	1.67	3,409

Table 4-9. Average and Residual Error between Daily Observed and Predicted Maximum, Mean, and Minimum Temperature Values (1/1/2000 – 12/31/2011)

Location	Average Error			Residual Error			N
	Max	Mean	Min	Max	Mean	Min	
Lockwood	3.14	2.97	2.79	-2.28	-2.27	-1.74	3,177
Patrick	2.67	2.68	2.73	-1.49	-1.77	-1.79	2,102
Tracy/Clark	2.83	2.52	2.58	-2.06	-1.55	-1.21	3,617
Painted Rock	2.71	2.49	2.48	-1.58	-1.63	-1.29	2,907
Wadsworth	2.56	2.42	2.45	-0.93	-1.32	-1.23	1,999
Marble Bluff Dam	2.76	2.29	2.38	0.89	0.62	0.72	3,409

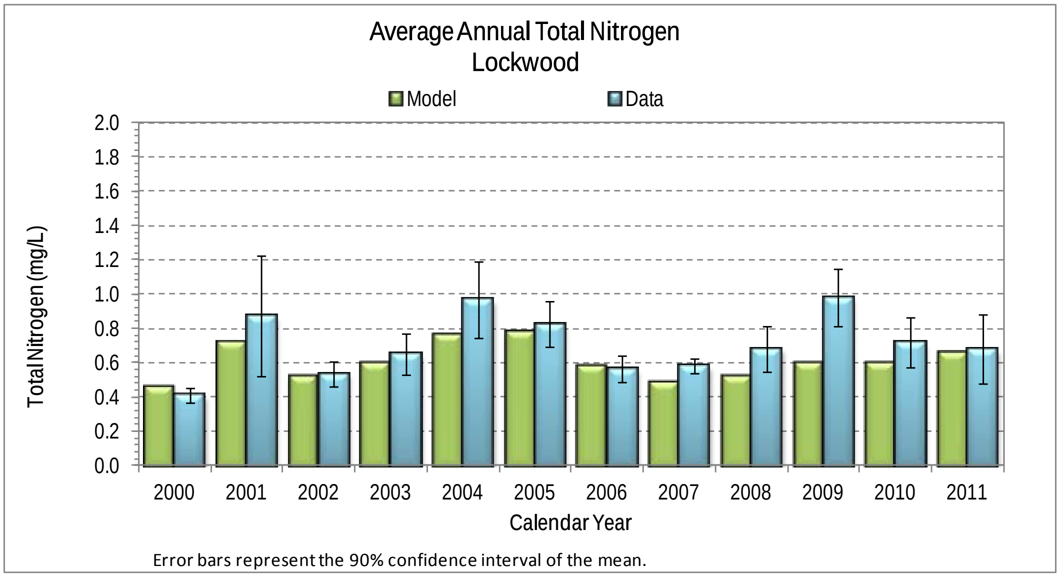


Figure 4-21. Comparison of Average Annual Modeled and Observed Total Nitrogen at Lockwood between 2000 and 2011.

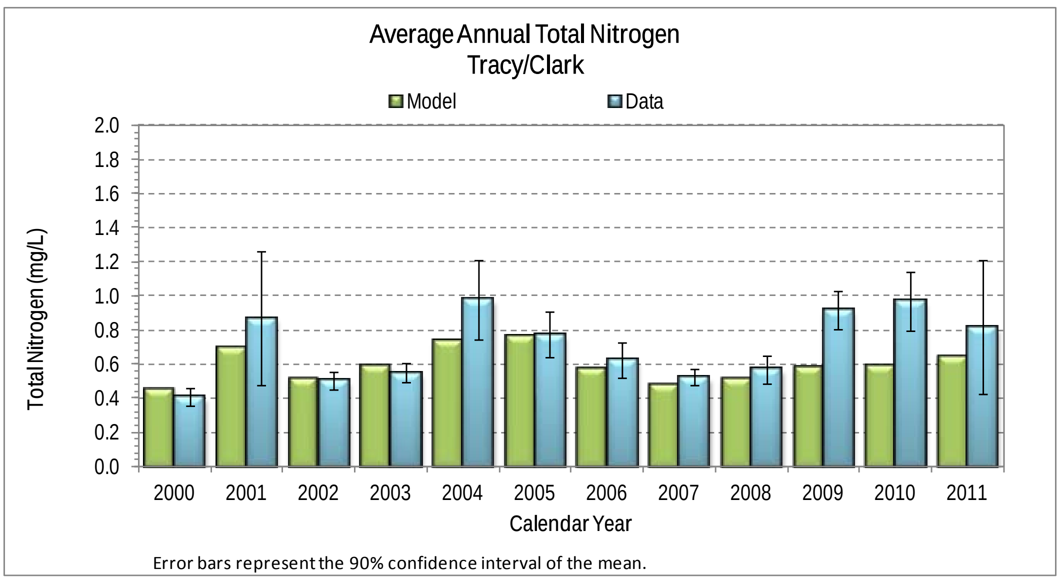


Figure 4-22. Comparison of Average Annual Modeled and Observed Total Nitrogen at Tracy/Clark between 2000 and 2011.

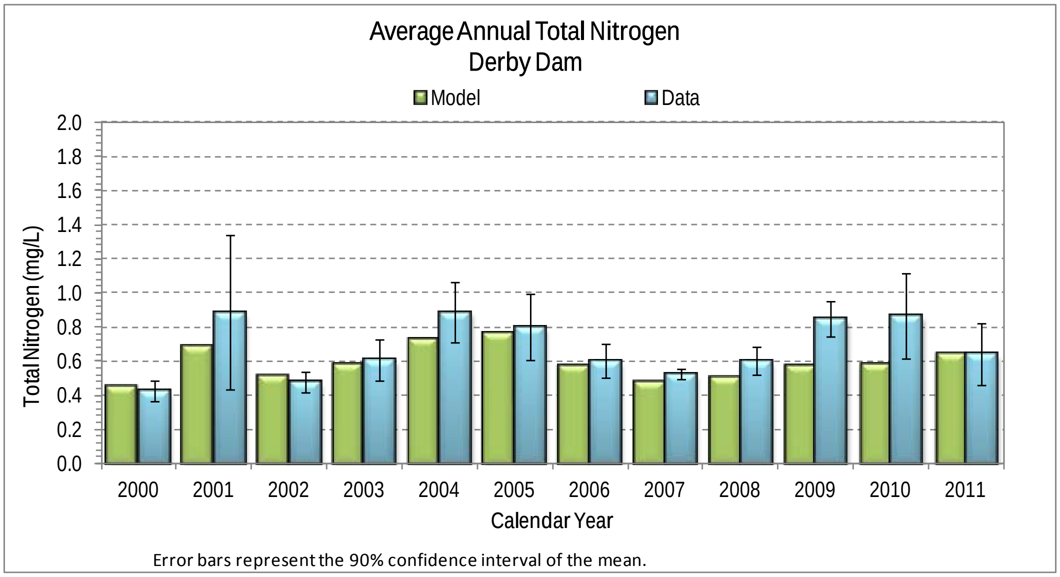


Figure 4-23. Comparison of Average Annual Modeled and Observed Total Nitrogen at Derby Dam between 2000 and 2011.

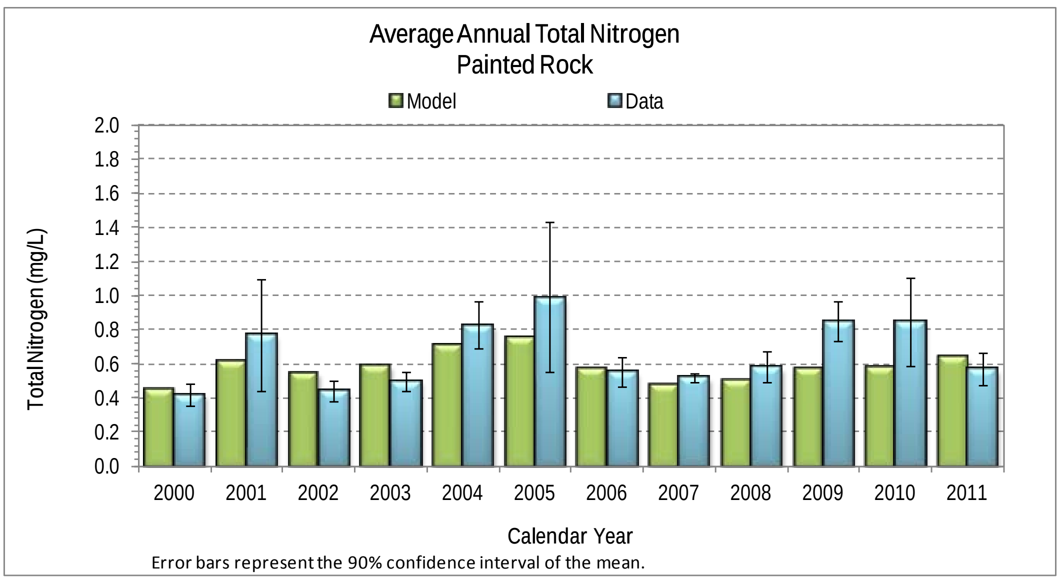


Figure 4-24. Comparison of Average Annual Modeled and Observed Total Nitrogen at Painted Rock between 2000 and 2011.

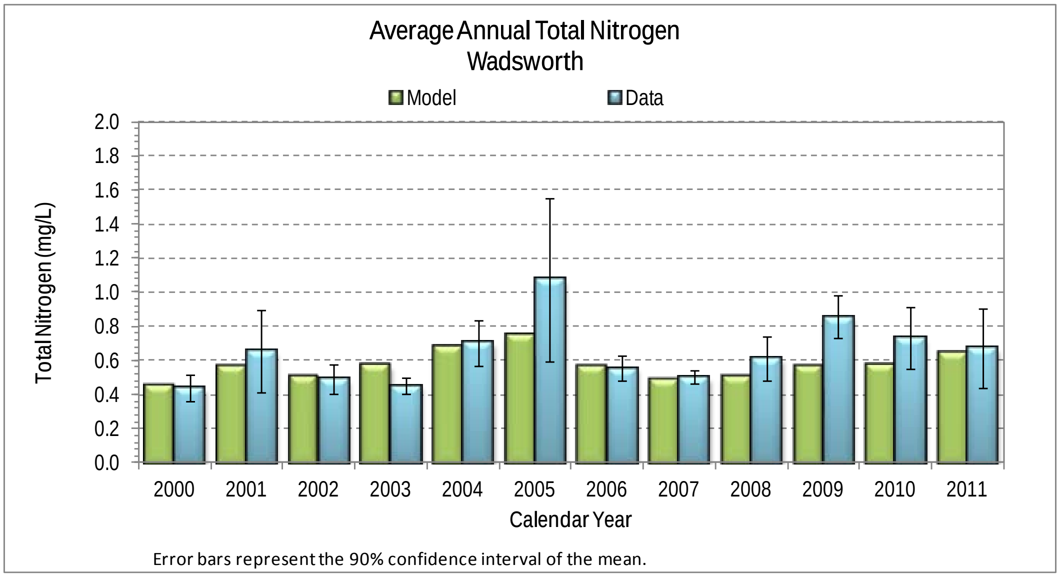


Figure 4-25. Comparison of Average Annual Modeled and Observed Total Nitrogen at Wadsworth between 2000 and 2011.

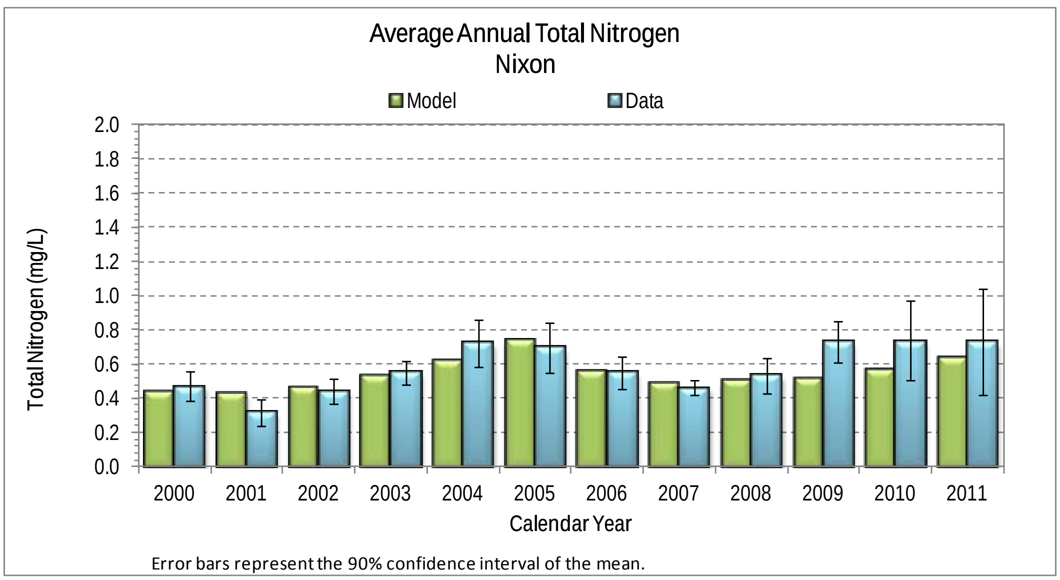


Figure 4-26. Comparison of Average Annual Modeled and Observed Total Nitrogen at Nixon between 2000 and 2011.

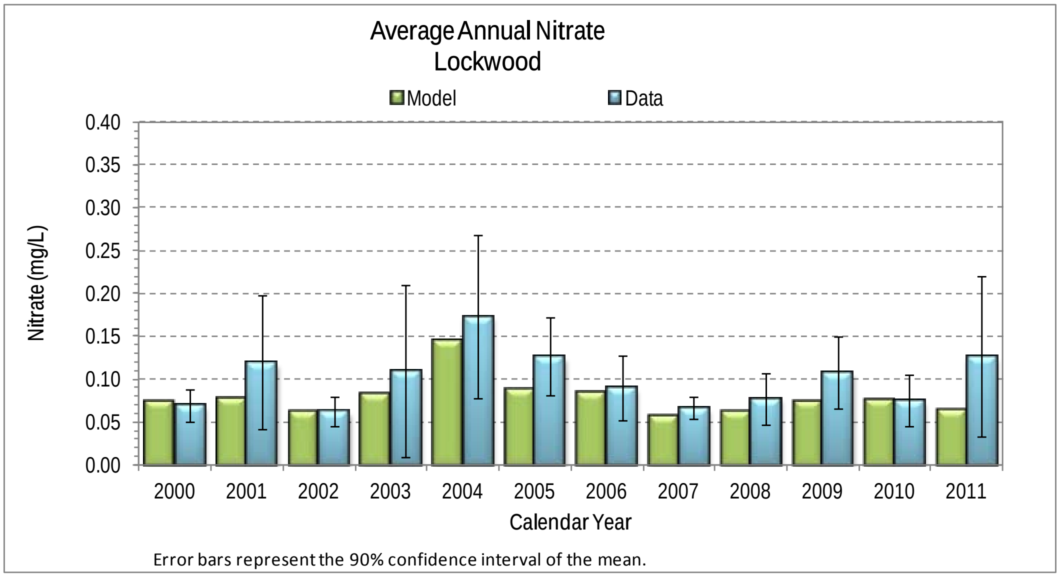


Figure 4-27. . Comparison of Average Annual Modeled and Observed Nitrate/Nitrite at Lockwood between 2000 and 2011.

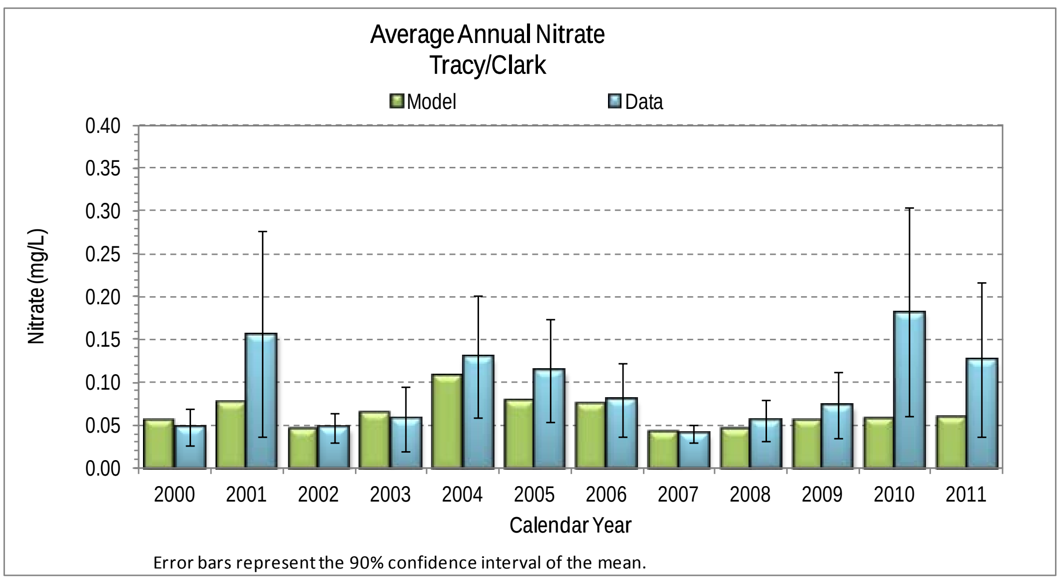


Figure 4-28. Comparison of Average Annual Modeled and Observed Nitrate/Nitrite at Tracy/Clark between 2000 and 2011.

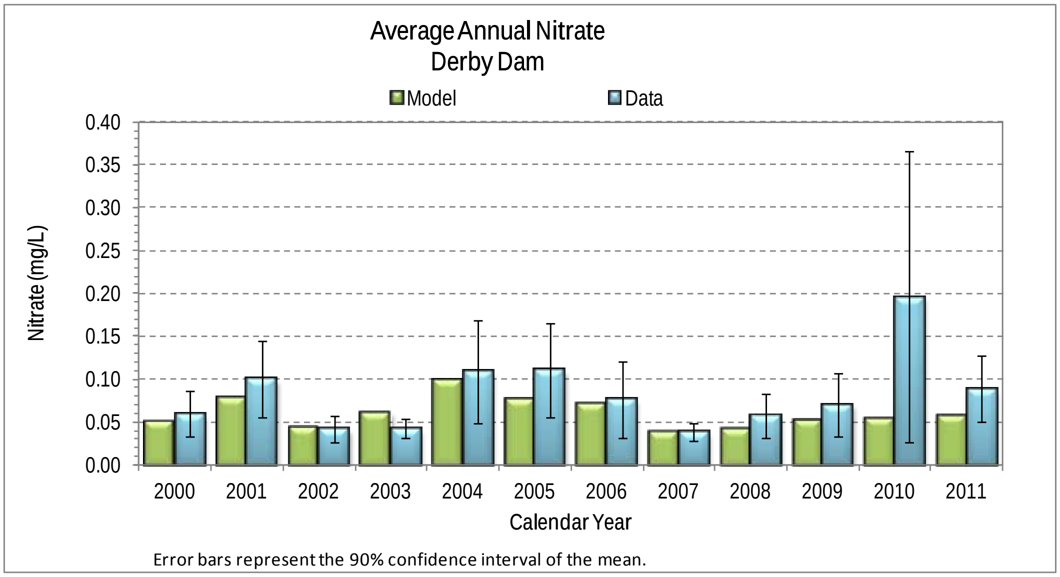


Figure 4-29. Comparison of Average Annual Modeled and Observed Nitrate/Nitrite at Derby Dam between 2000 and 2011.

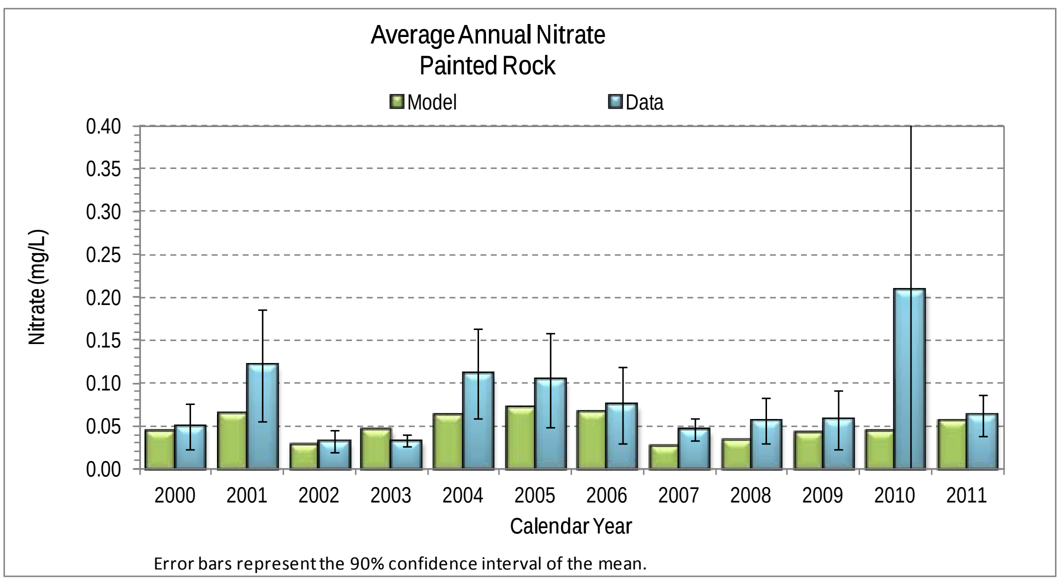


Figure 4-30. Comparison of Average Annual Modeled and Observed Nitrate/Nitrite at Painted Rock between 2000 and 2011.

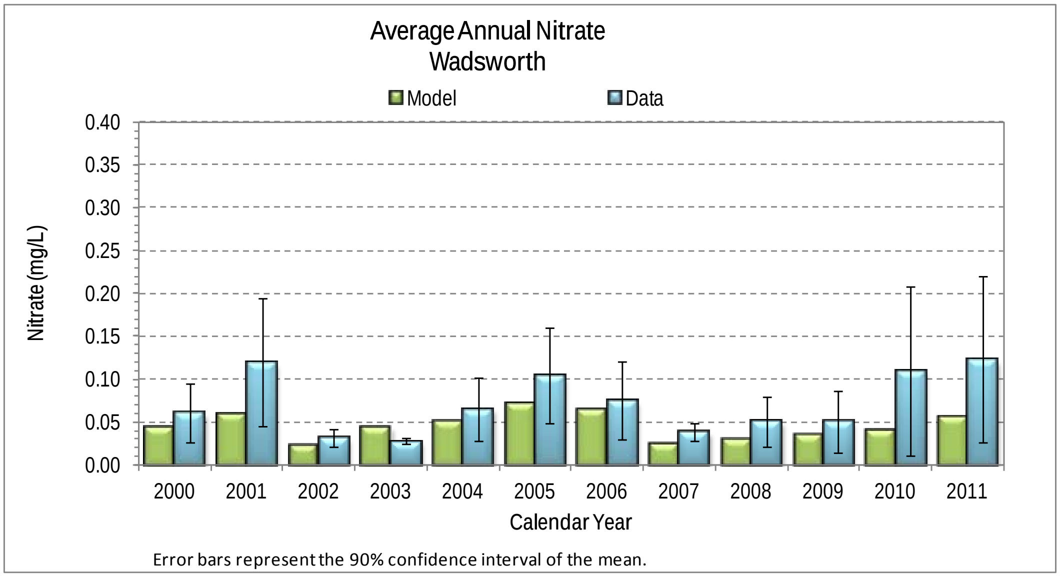


Figure 4-31. Comparison of Average Annual Modeled and Observed Nitrate/Nitrite at Wadsworth between 2000 and 2011.

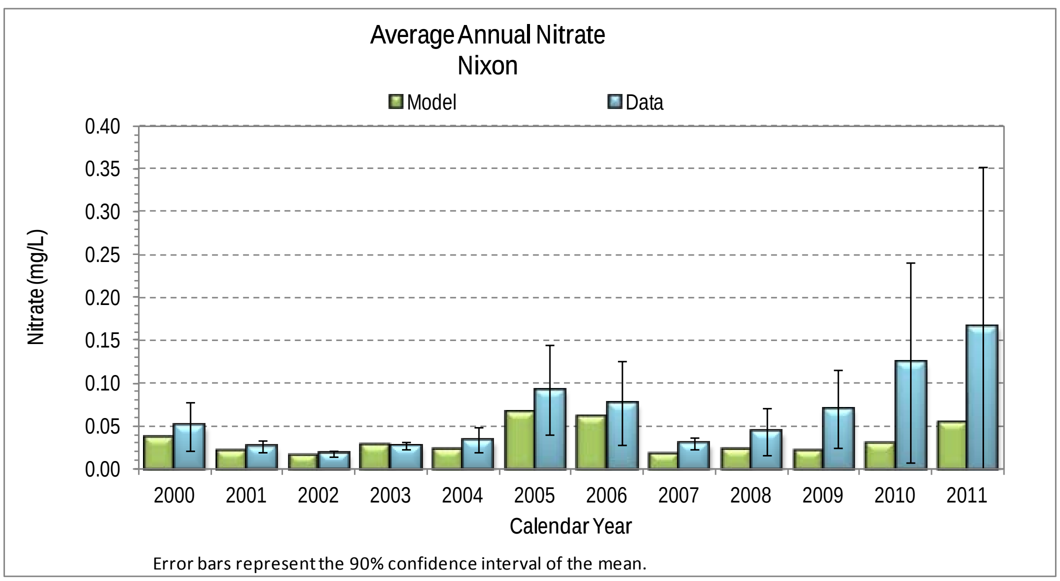


Figure 4-32. Comparison of Average Annual Modeled and Observed Nitrate/Nitrite at Nixon between 2000 and 2011.

Table 4-10. Summary Error Statistics for Nitrogen (mg/L) (1/1/2000 – 12/31/2011)

Location	Total Nitrogen				Nitrate-Nitrogen			
	Average Error	Relative Error	Residual Error	N	Average Error	Relative Error	Residual Error	N
Lockwood[1]	0.21	27%	-0.06	158	0.05	96%	-0.01	159
Patrick	0.23	26%	0.00	19	0.07	192%	-0.03	20
Tracy/Clark[1]	0.22	29%	-0.08	157	0.05	112%	-0.02	158
Derby Dam[2]	0.22	28%	-0.06	140	0.05	103%	-0.01	140
Painted Rock[2]	0.21	32%	-0.06	147	0.05	108%	-0.02	147
Wadsworth[3]	0.22	33%	-0.07	140	0.04	106%	-0.01	140
Near Nixon[3]	0.20	38%	-0.03	146	0.04	109%	-0.01	156

Location	Total Ammonia				Dissolved Organic Nitrogen			
	Average Error	Relative Error	Residual Error	N	Average Error	Relative Error	Residual Error	N
Lockwood[4]	0.05	70%	-0.01	158	0.14	64%	-0.07	146
Patrick	0.05	55%	0.04	19	0.11	49%	-0.05	6
Tracy/Clark[4]	0.04	64%	-0.03	158	0.15	53%	-0.10	146
Derby Dam[5]	0.04	67%	-0.03	139	0.14	61%	-0.09	138
Painted Rock[5]	0.04	66%	-0.04	148	0.15	63%	-0.10	142
Wadsworth[5]	0.04	79%	-0.03	140	0.15	64%	-0.10	139
Near Nixon[4]	0.04	74%	-0.04	157	0.15	66%	-0.11	145

Notes:
1 - Greater than 20% of the Nitrate data points were reported as <PQL.
2 - Greater than 40% of the Nitrate data points were reported as <PQL.
3 - Greater than 60% of the Nitrate data points were reported as <PQL.
4 - Greater than 80% of the Ammonia data points were reported as <PQL.
5 - Greater than 90% of the Ammonia data points were reported as <PQL.

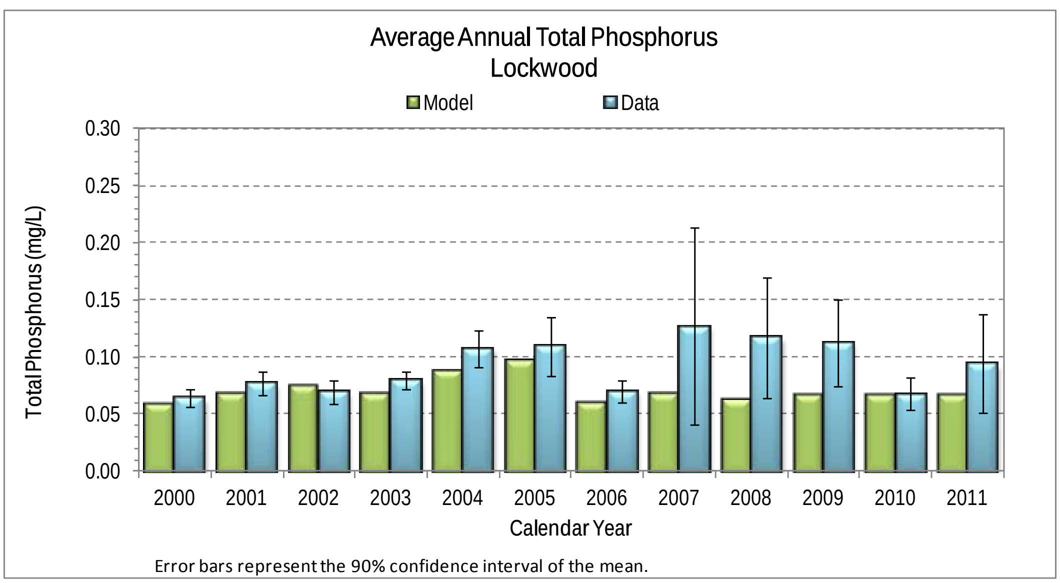


Figure 4-33. Comparison of Average Annual Modeled and Observed Total Phosphorus at Lockwood between 2000 and 2011.

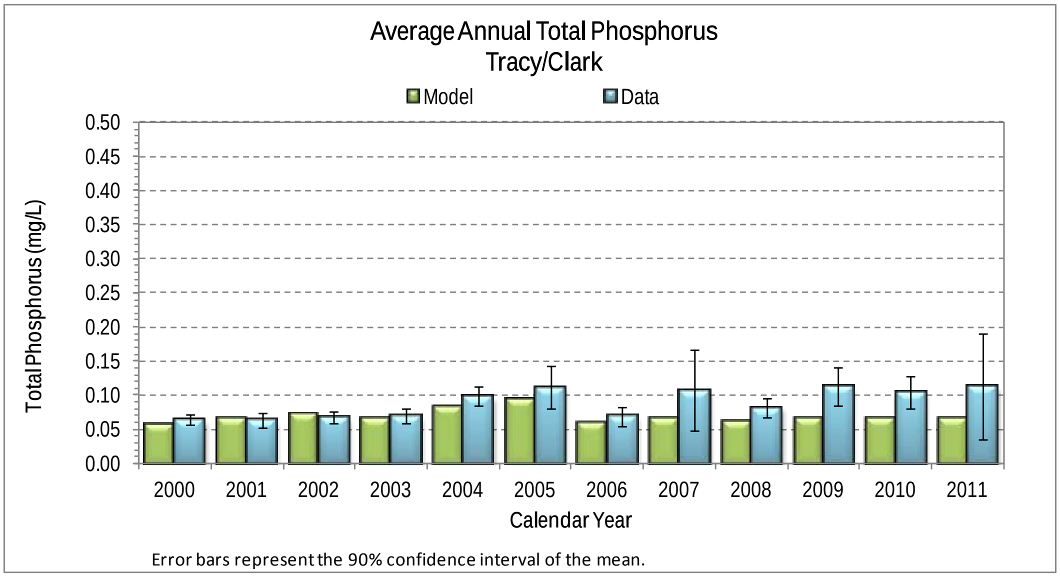


Figure 4-34. Comparison of Average Annual Modeled and Observed Total Phosphorus at Tracy/Clark between 2000 and 2011.

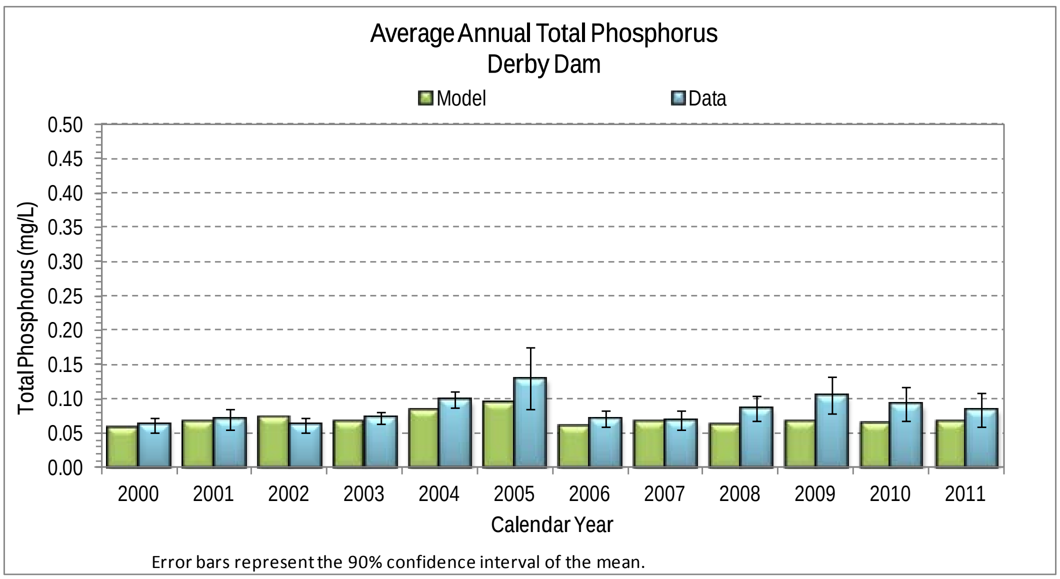


Figure 4-35. Comparison of Average Annual Modeled and Observed Total Phosphorus at Derby Dam between 2000 and 2011.

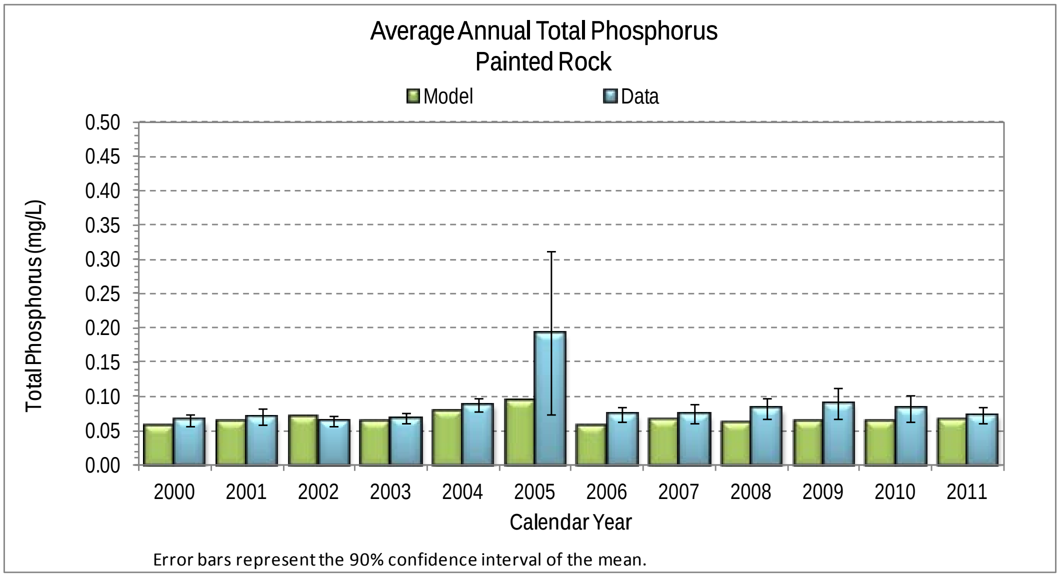


Figure 4-36. Comparison of Average Annual Modeled and Observed Total Phosphorus at Painted Rock between 2000 and 2011.

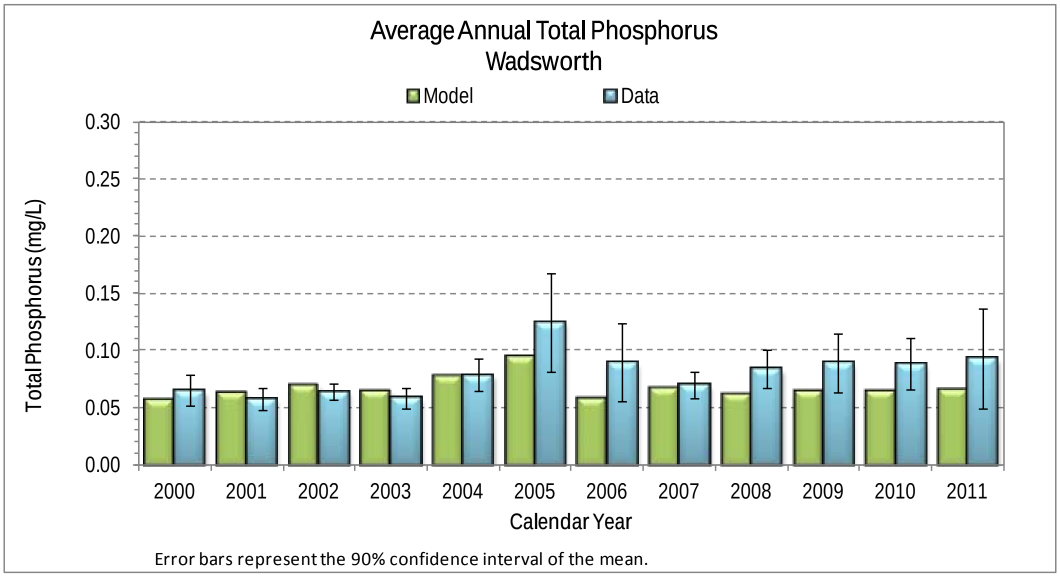


Figure 4-37. Comparison of Average Annual Modeled and Observed Total Phosphorus at Wadsworth between 2000 and 2011.

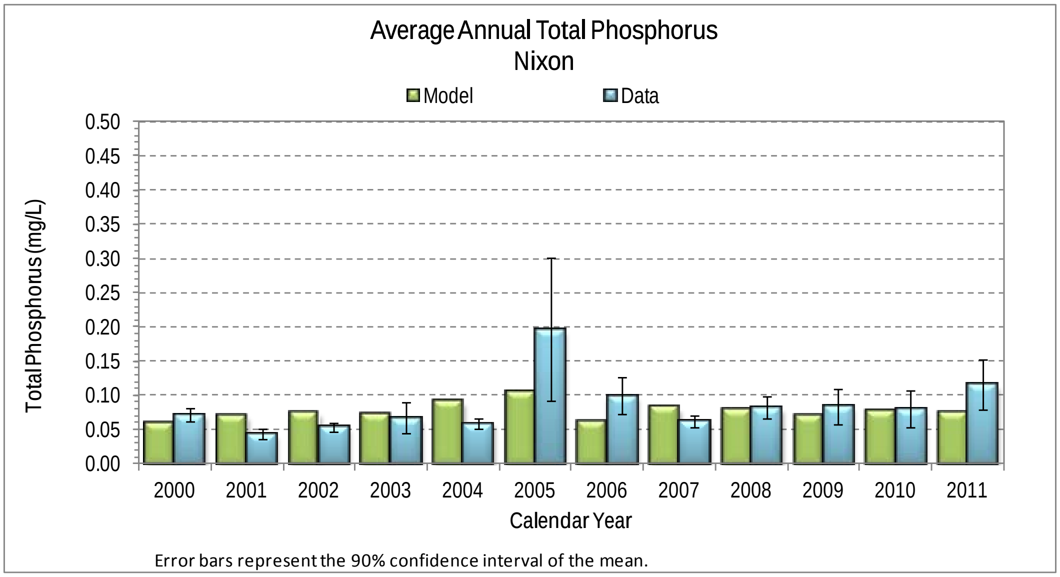


Figure 4-38. Comparison of Average Annual Modeled and Observed Total Phosphorus at Nixon between 2000 and 2011.

8% of the Total Phosphorus data points were reported as <PQL. The PQL for Total Phosphorus is 0.04 mg/L.

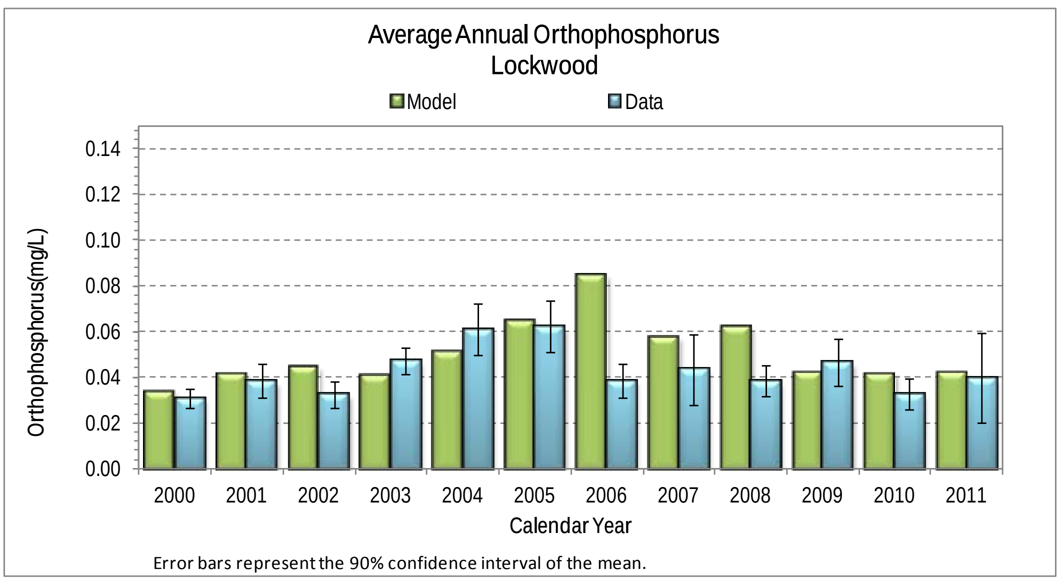


Figure 4-39. Comparison of Average Annual Modeled and Observed Ortho P at Lockwood between 2000 and 2011.

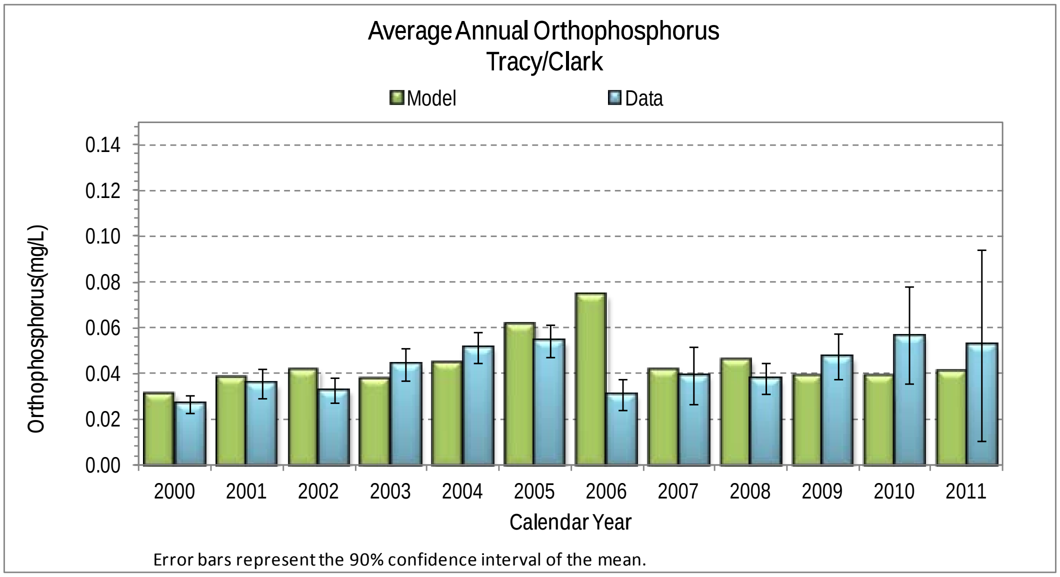


Figure 4-40. Comparison of Average Annual Modeled and Observed Ortho P at Tracy/Clark between 2000 and 2011.

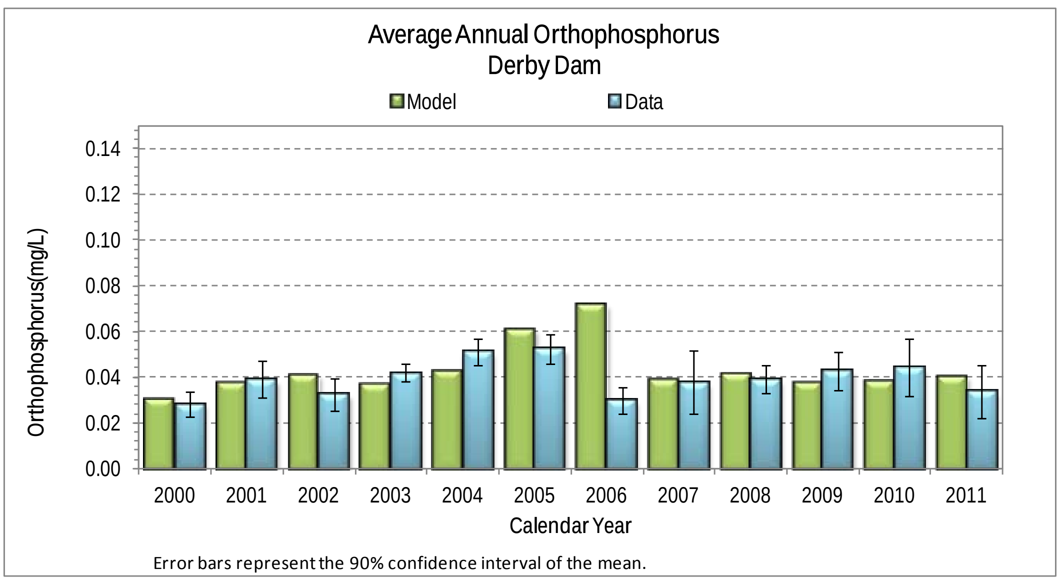


Figure 4-41. Comparison of Average Annual Modeled and Observed Ortho P at Derby Dam between 2000 and 2011.

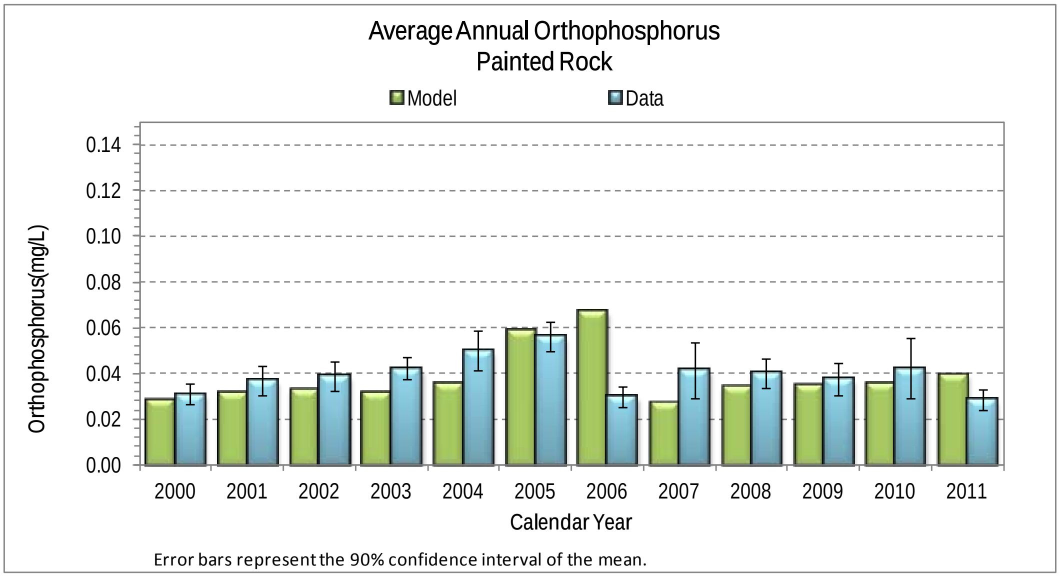


Figure 4-42. Comparison of Average Annual Modeled and Observed Ortho P at Painted Rock between 2000 and 2011.

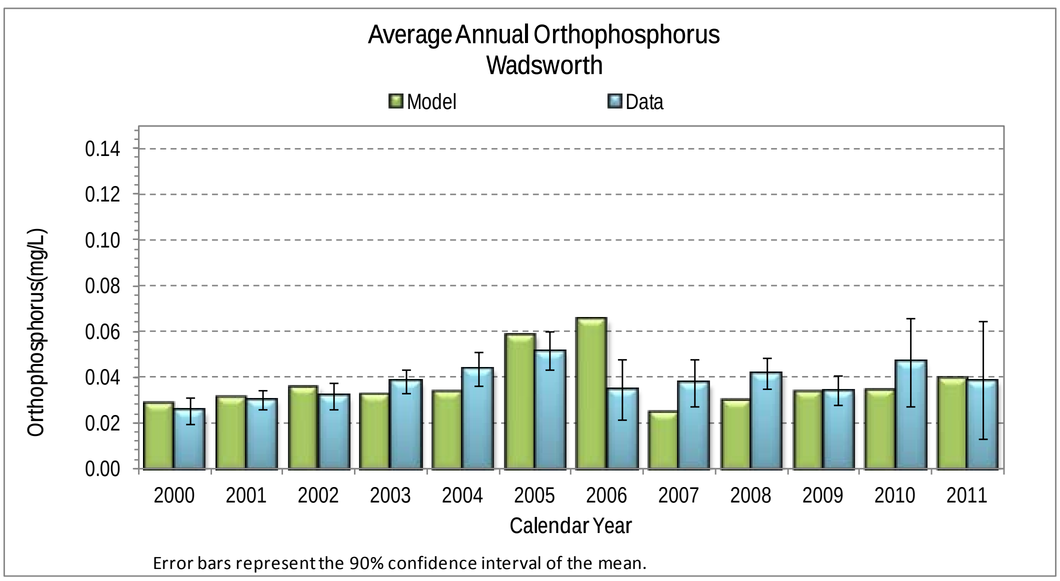


Figure 4-43. Comparison of Average Annual Modeled and Observed Ortho P at Wadsworth between 2000 and 2011.

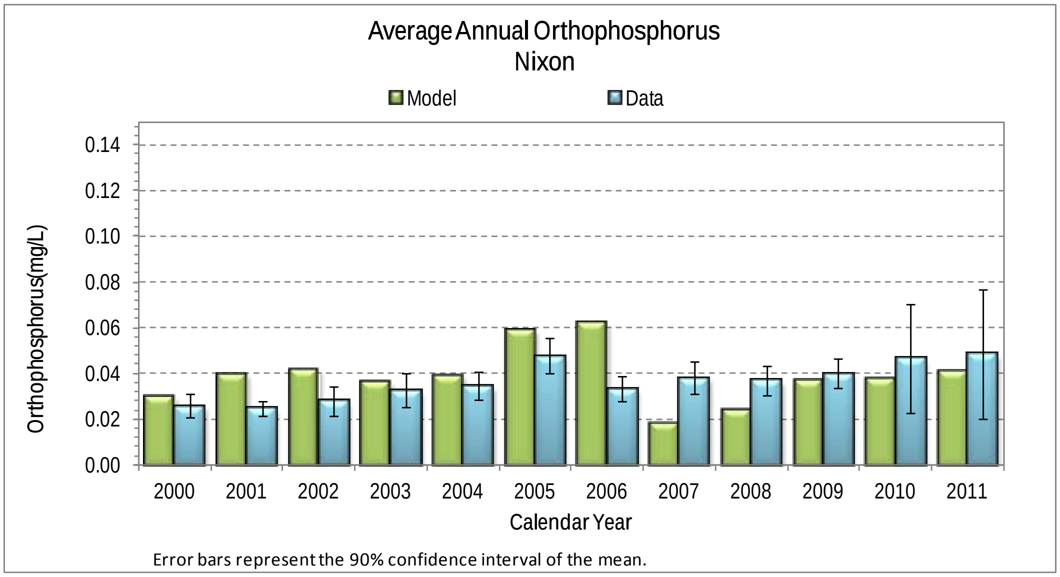


Figure 4-44. Comparison of Average Annual Modeled and Observed Ortho P at Nixon between 2000 and 2011.

Table 4-11. Summary Error Statistics for Phosphorus (mg/L) (1/1/2000 – 12/31/2011)

Location	Total Phosphorus				Orthophosphorus			
	Average Error	Relative Error	Residual Error	N	Average Error	Relative Error	Residual Error	N
Lockwood	0.03	34%	-0.02	160	0.02	57%	0.01	159
Patrick	0.02	26%	0.00	18	0.01	30%	0.01	18
Tracy/Clark	0.03	38%	-0.01	159	0.02	70%	0.00	158
Derby Dam	0.03	42%	-0.01	140	0.02	79%	0.00	140
Painted Rock	0.04	41%	-0.01	148	0.02	66%	0.00	148
Wadsworth	0.04	49%	-0.01	139	0.02	84%	0.00	139
Near Nixon[1]	0.04	66%	0.00	154	0.02	104%	0.00	154

Notes:
1 - 8% of the Total Phosphorus data points were reported as <PQL.

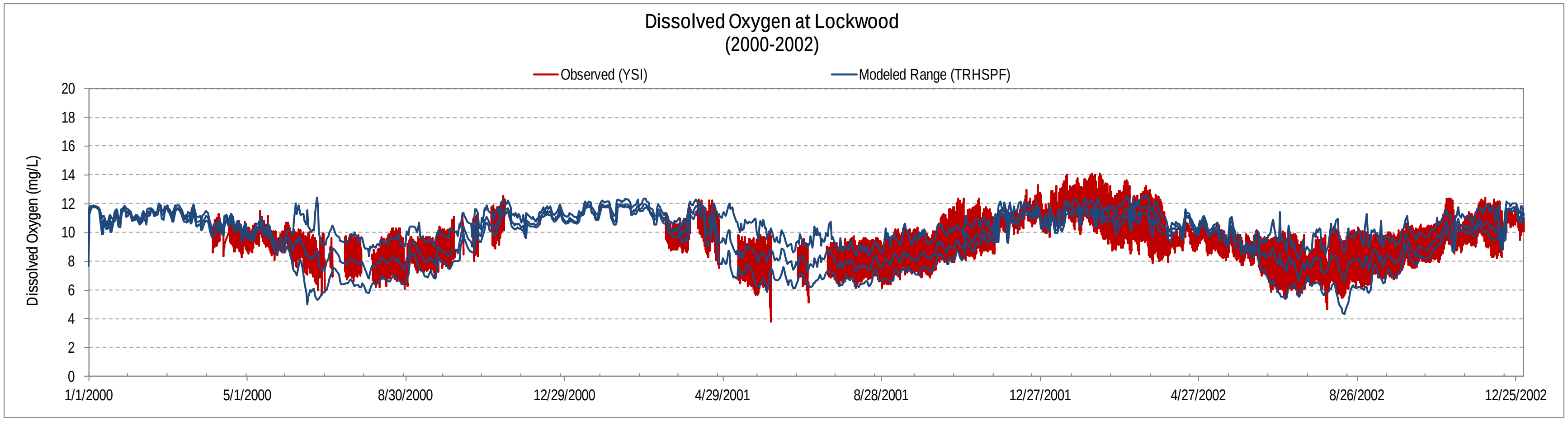


Figure 4-45. Comparison of Modeled and Observed Dissolved Oxygen at Lockwood between 2000 and 2002.

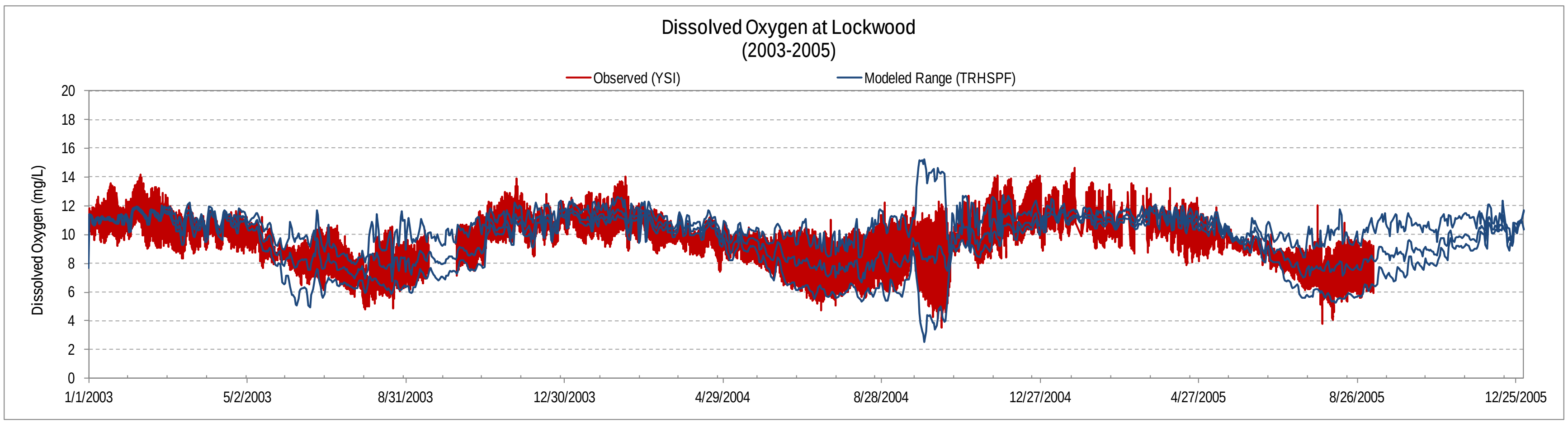


Figure 4-46. Comparison of Modeled and Observed Dissolved Oxygen at Lockwood between 2003 and 2005.

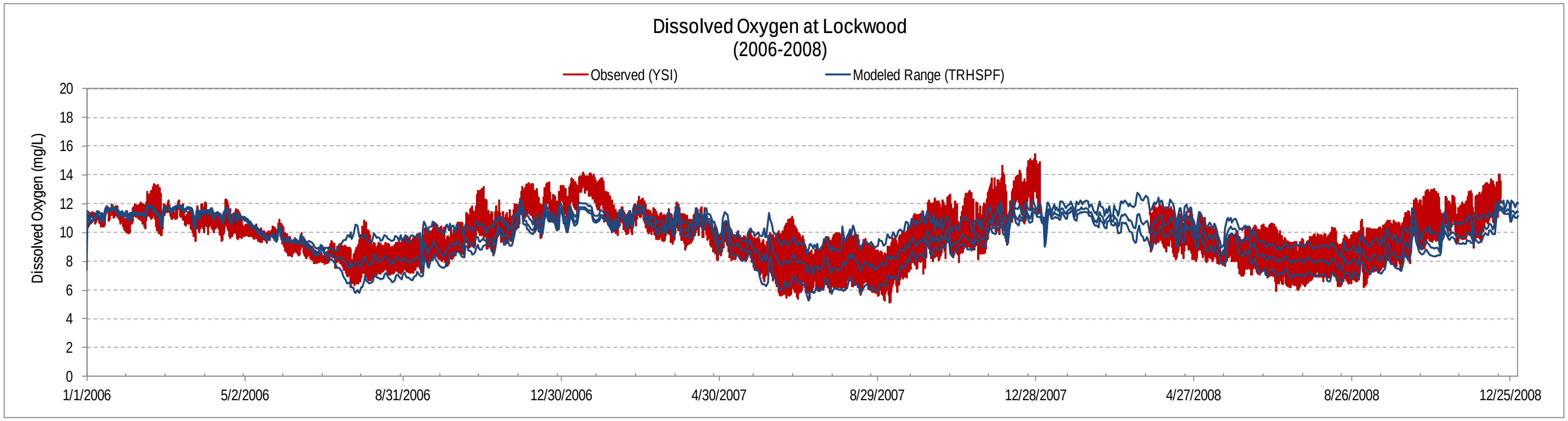


Figure 4-47. Comparison of Modeled and Observed Dissolved Oxygen at Lockwood between 2006 and 2008.

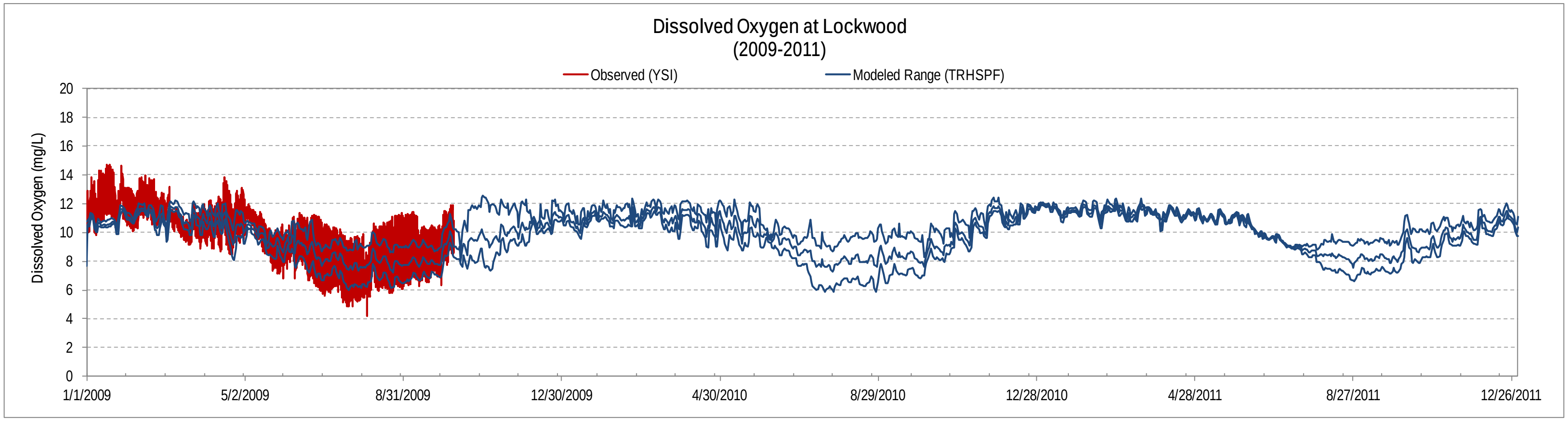


Figure 4-48. Comparison of Modeled and Observed Dissolved Oxygen at Lockwood between 2009 and 2011.

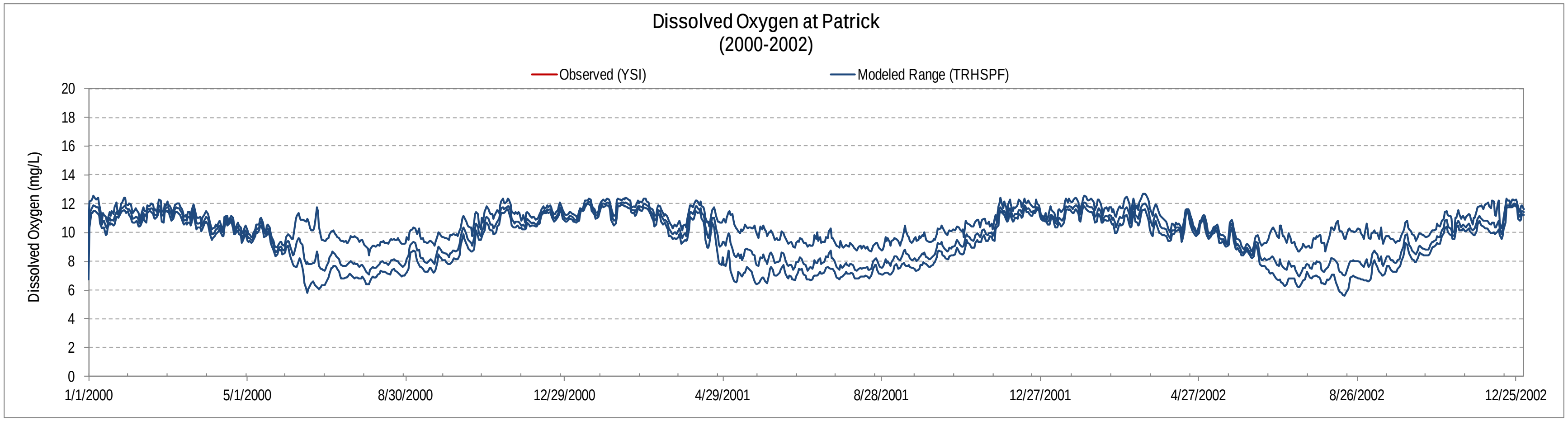


Figure 4-49. Comparison of Modeled and Observed Dissolved Oxygen at Patrick between 2000 and 2002.

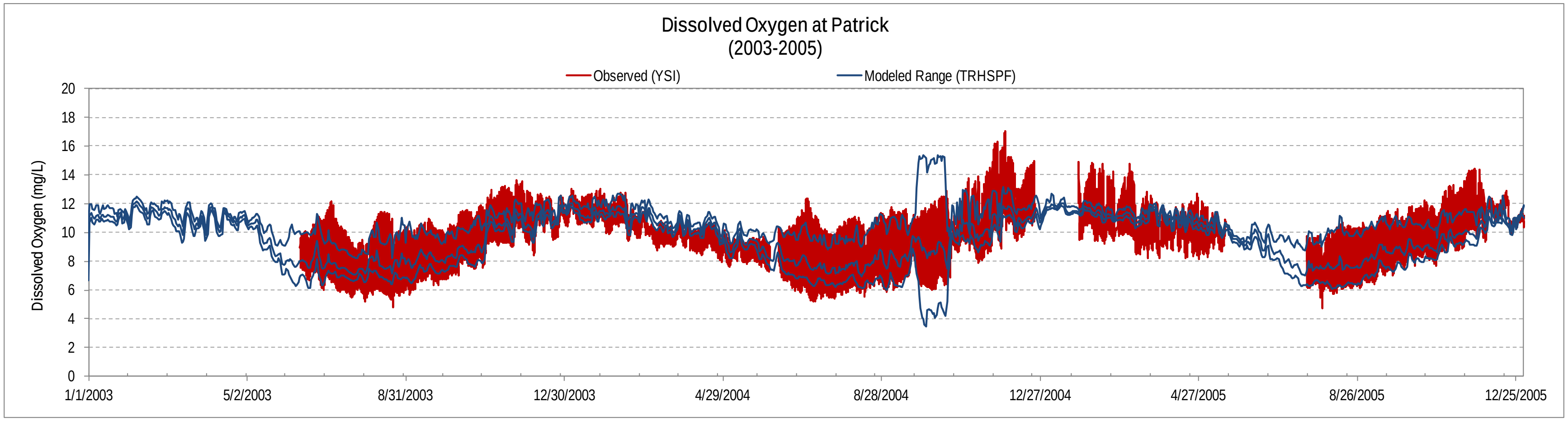


Figure 4-50. Comparison of Modeled and Observed Dissolved Oxygen at Patrick between 2003 and 2005.

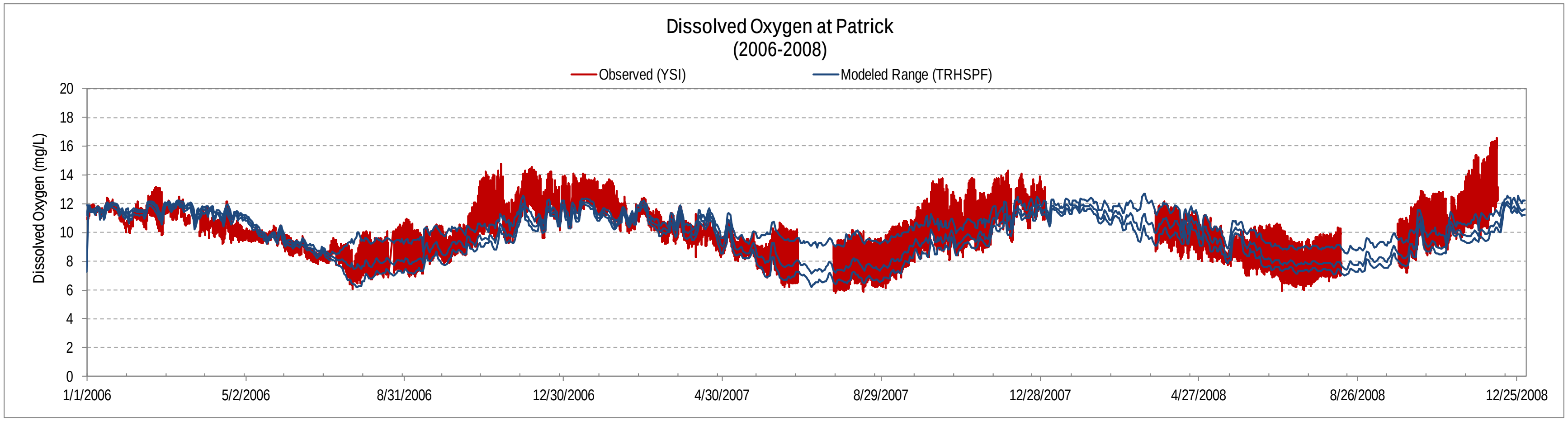


Figure 4-51. Comparison of Modeled and Observed Dissolved Oxygen at Patrick between 2006 and 2008.

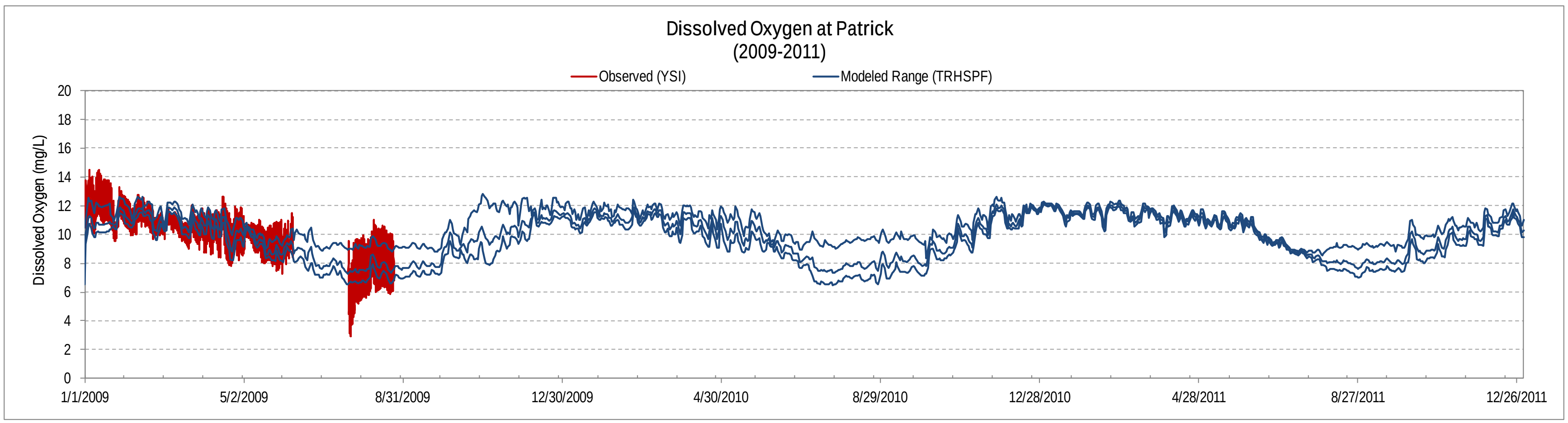


Figure 4-52. Comparison of Modeled and Observed Dissolved Oxygen at Patrick between 2009 and 2011.

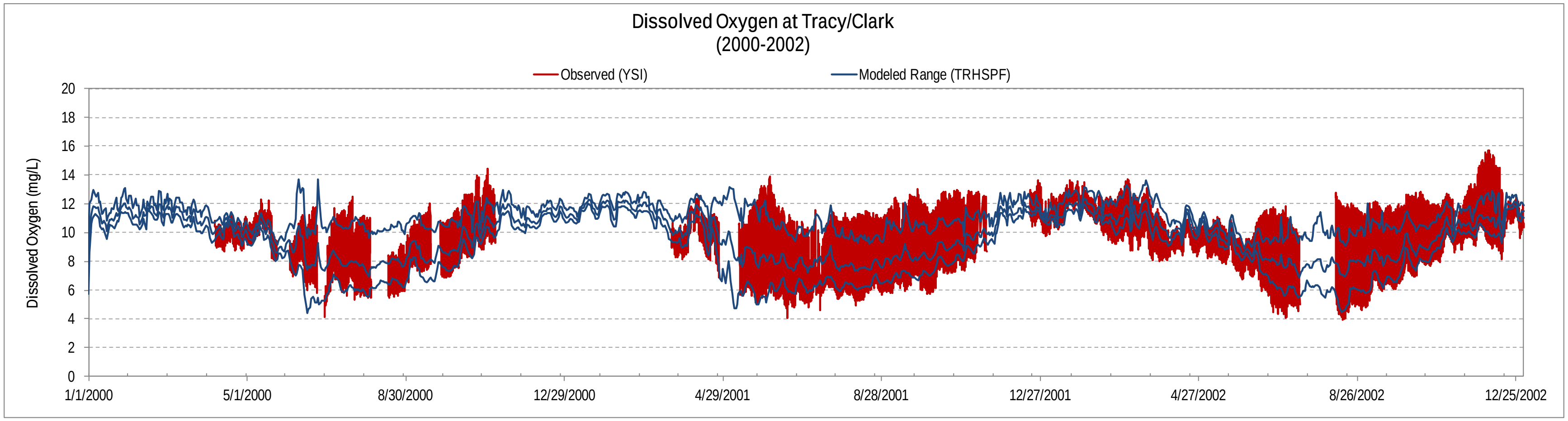


Figure 4-53. Comparison of Modeled and Observed Dissolved Oxygen at Tracy/Clark between 2000 and 2002.

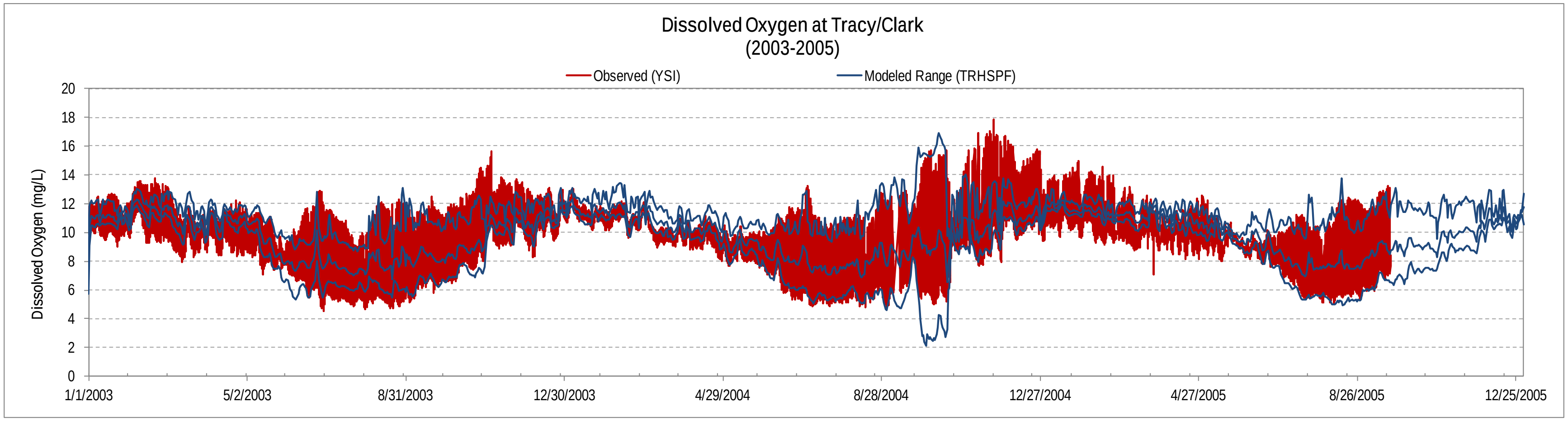


Figure 4-54. Comparison of Modeled and Observed Dissolved Oxygen at Tracy/Clark between 2003 and 2005.

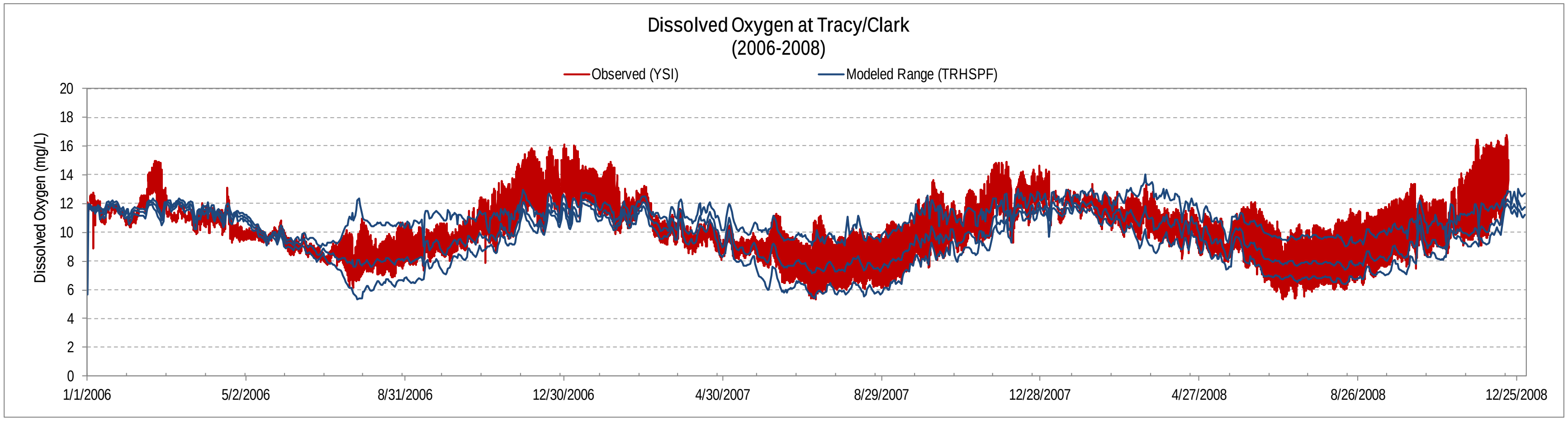


Figure 4-55. Comparison of Modeled and Observed Dissolved Oxygen at Tracy/Clark between 2006 and 2008.

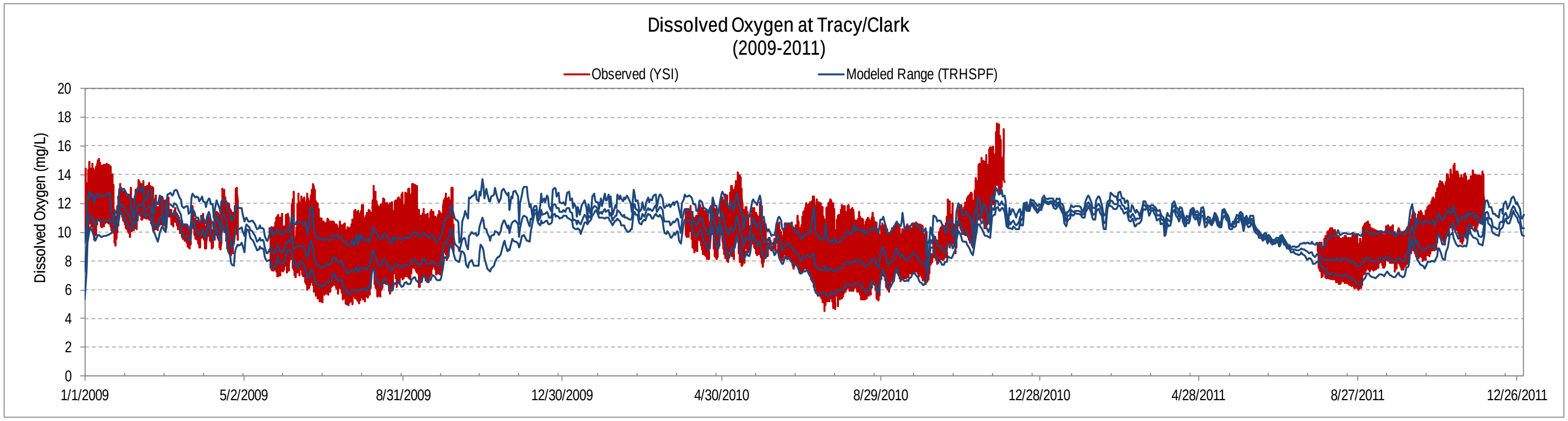


Figure 4-56. Comparison of Modeled and Observed Dissolved Oxygen at Tracy/Clark between 2009 and 2011.

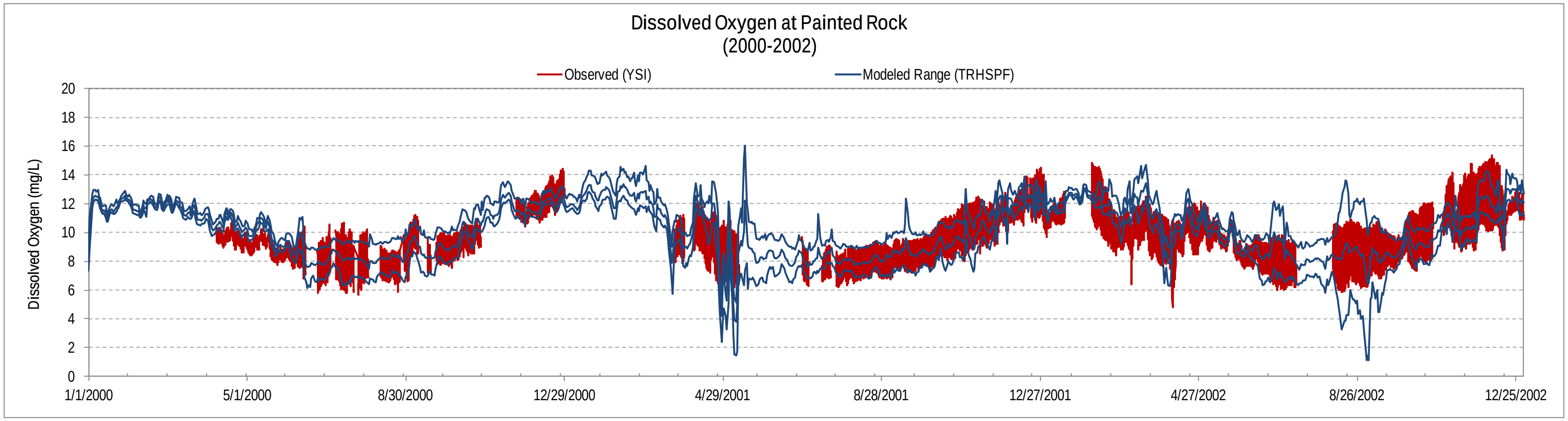


Figure 4-57. Comparison of Modeled and Observed Dissolved Oxygen at Painted Rock between 2000 and 2002.

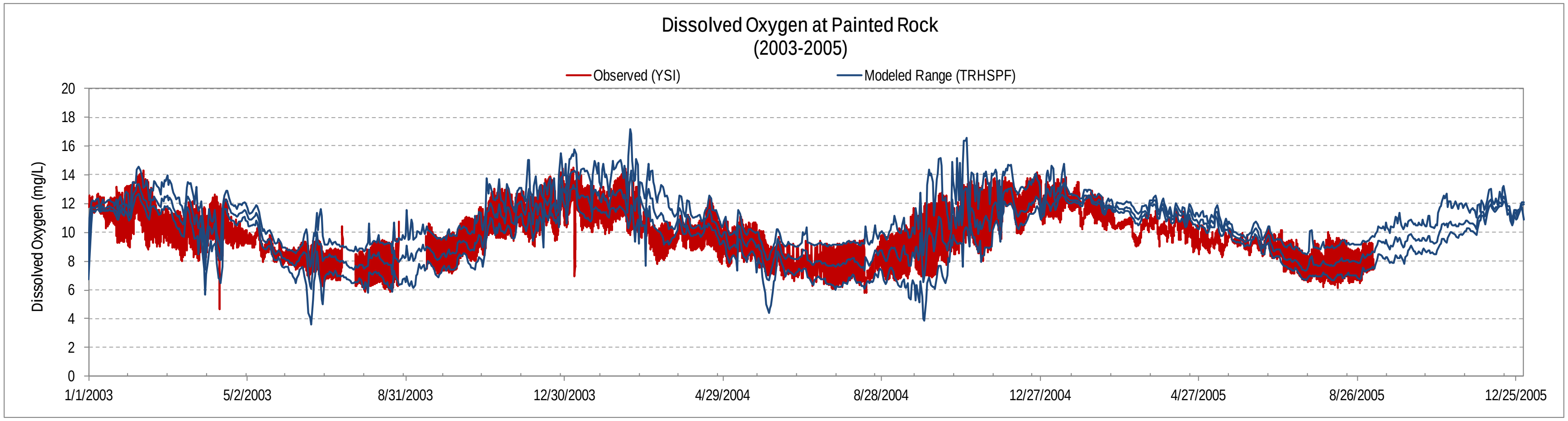


Figure 4-58. Comparison of Modeled and Observed Dissolved Oxygen at Painted Rock between 2003 and 2005.

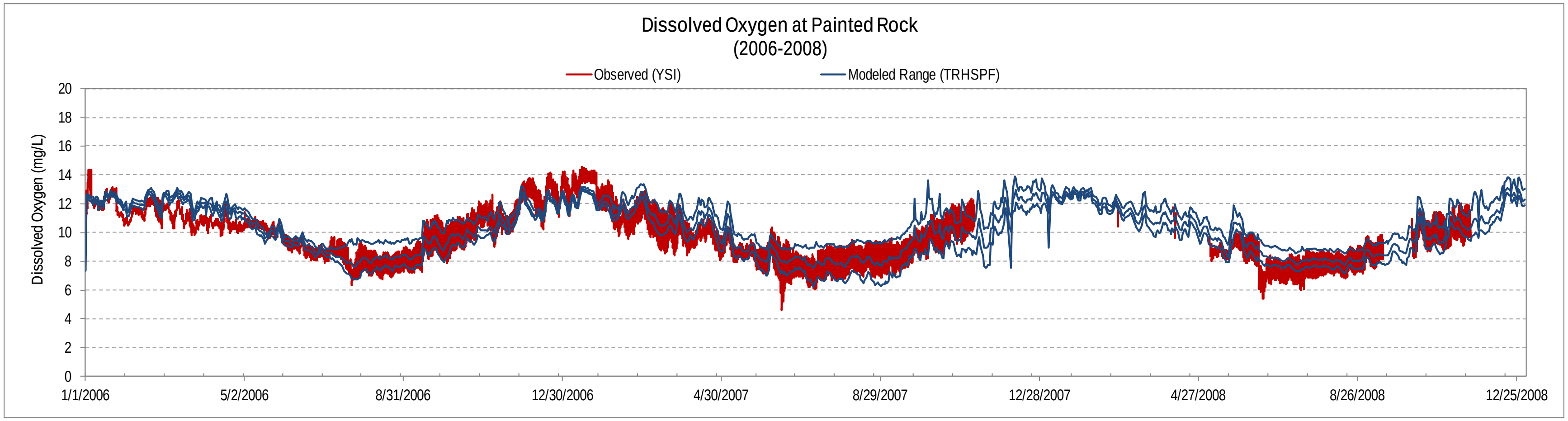


Figure 4-59. Comparison of Modeled and Observed Dissolved Oxygen at Painted Rock between 2006 and 2008.

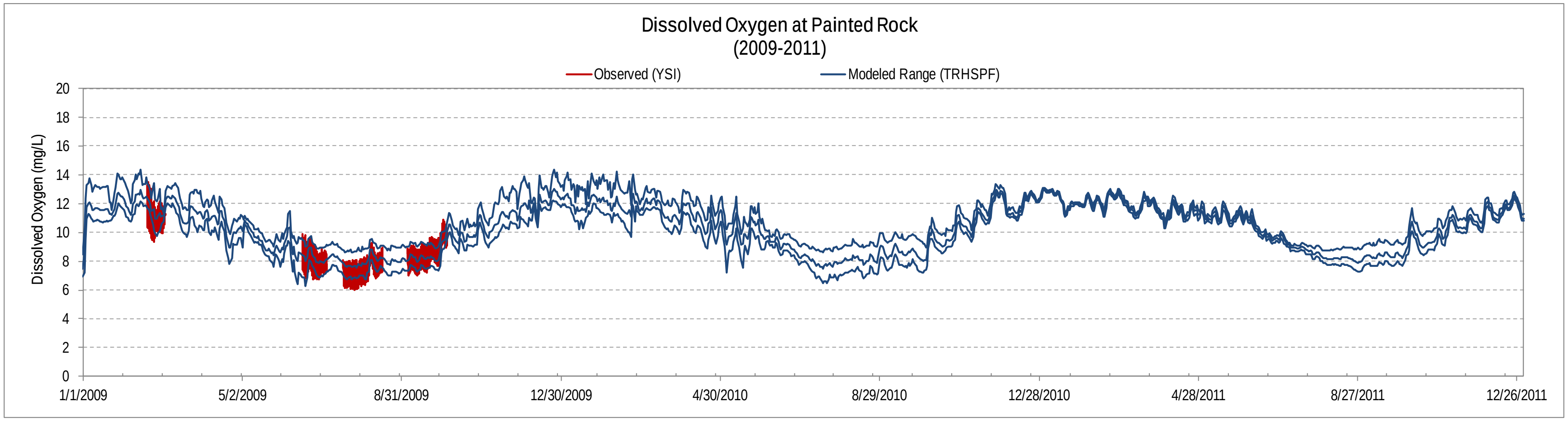


Figure 4-60. Comparison of Modeled and Observed Dissolved Oxygen at Painted Rock between 2009 and 2011.

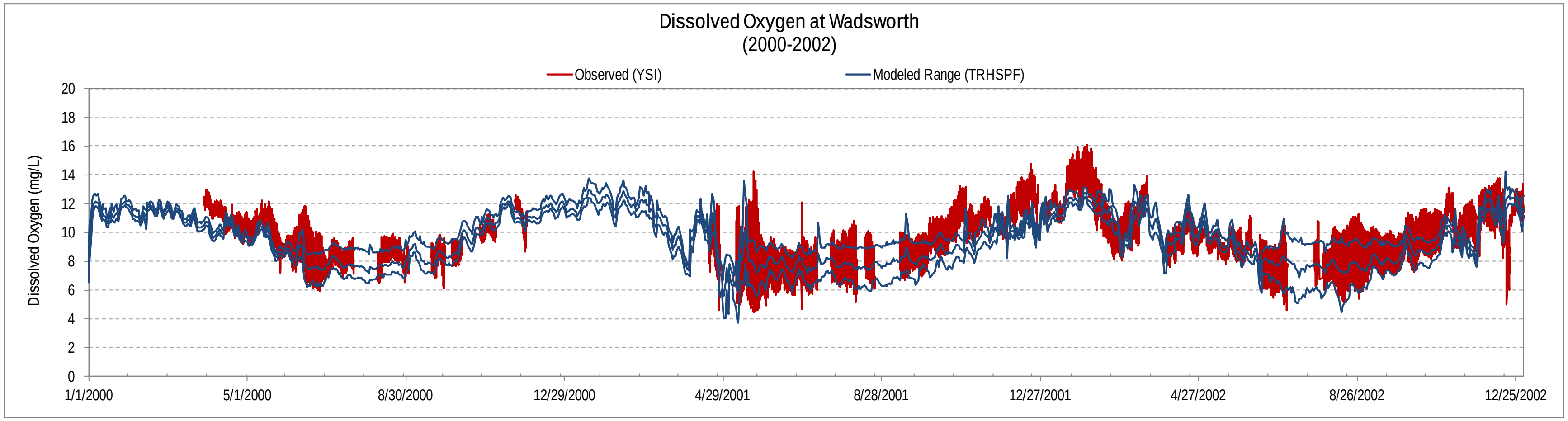


Figure 4-61. Comparison of Modeled and Observed Dissolved Oxygen at Wadsworth between 2000 and 2002.

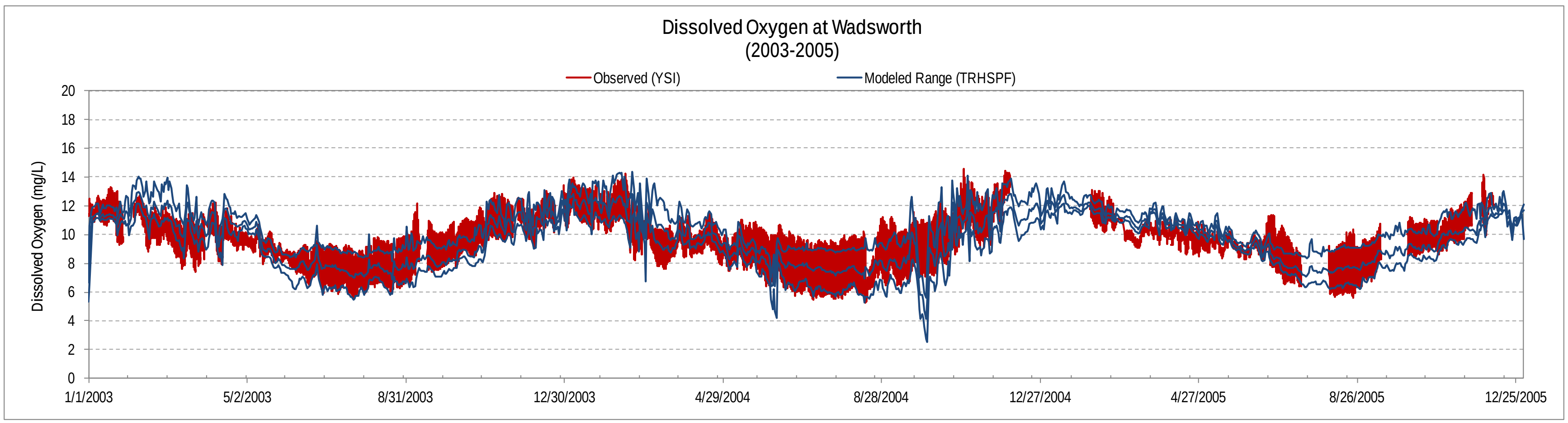


Figure 4-62. Comparison of Modeled and Observed Dissolved Oxygen at Wadsworth between 2003 and 2005.

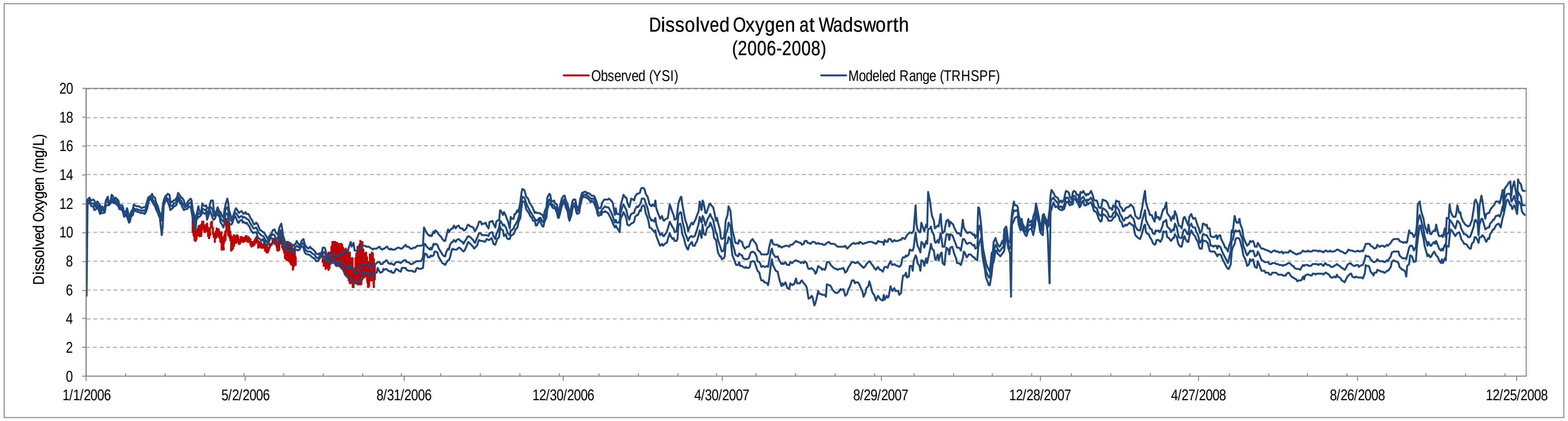


Figure 4-63. Comparison of Modeled and Observed Dissolved Oxygen at Wadsworth between 2006 and 2008.

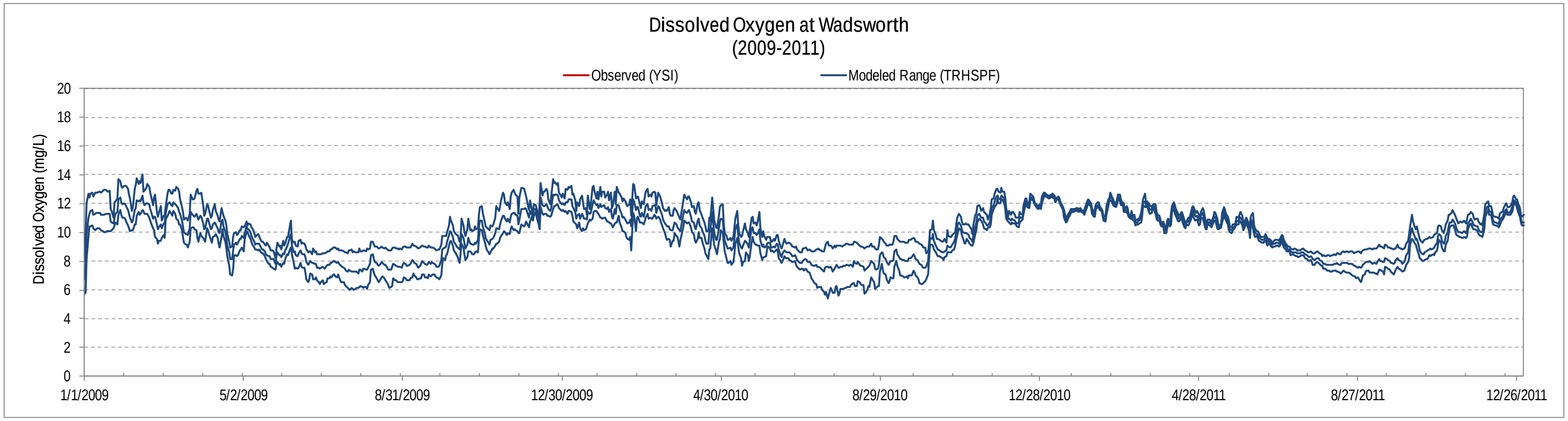


Figure 4-64. Comparison of Modeled and Observed Dissolved Oxygen at Wadsworth between 2009 and 2011.

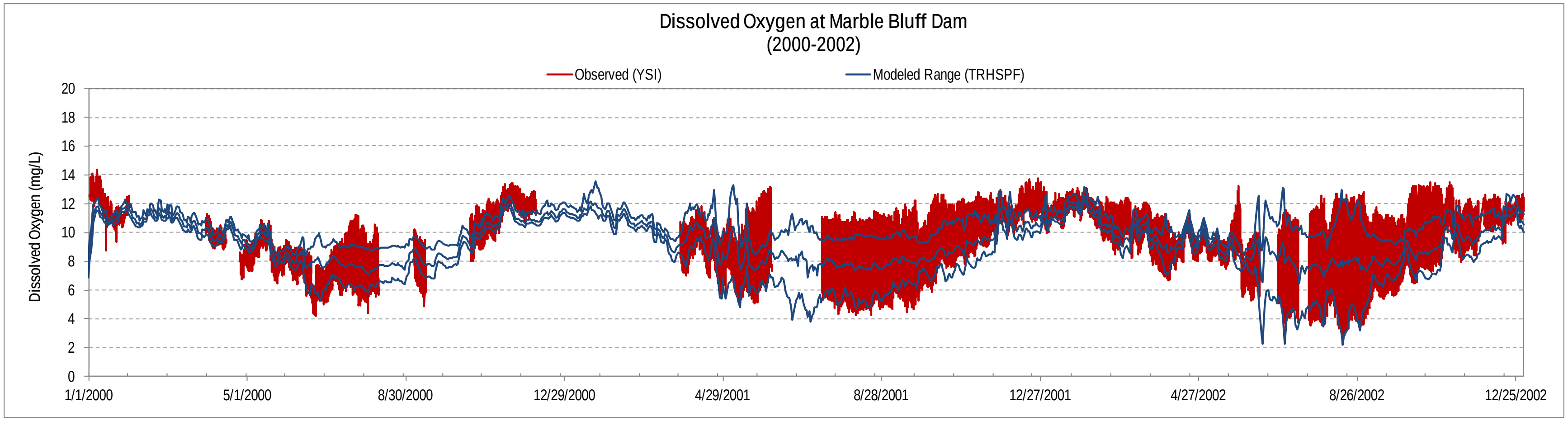


Figure 4-65. Comparison of Modeled and Observed Dissolved Oxygen at Marble Bluff Dam between 2000 and 2002.

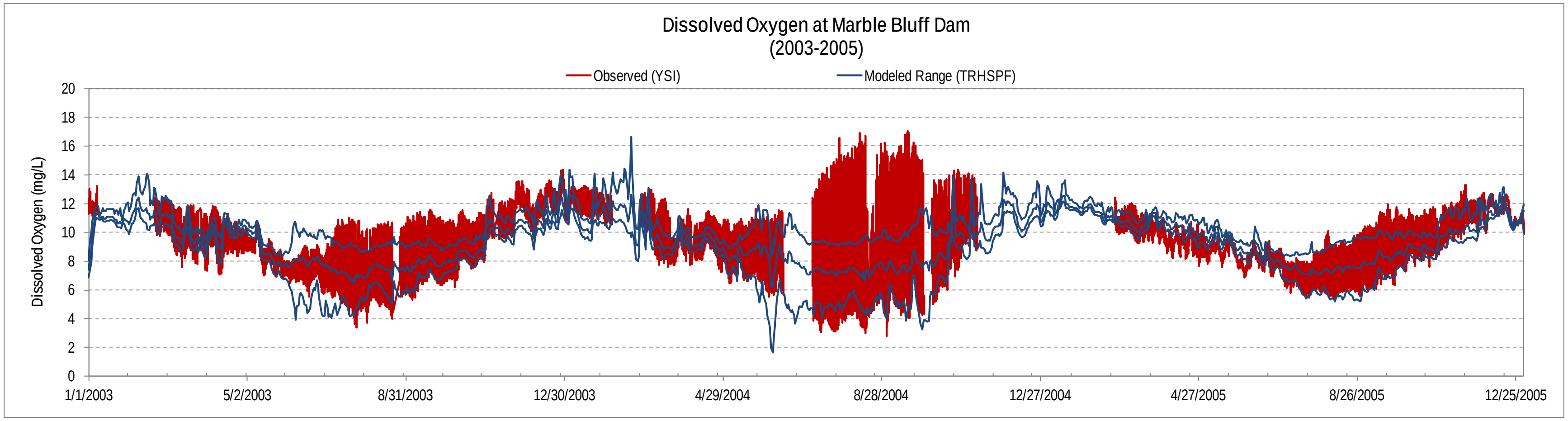


Figure 4-66. Comparison of Modeled and Observed Dissolved Oxygen at Marble Bluff Dam between 2003 and 2005.

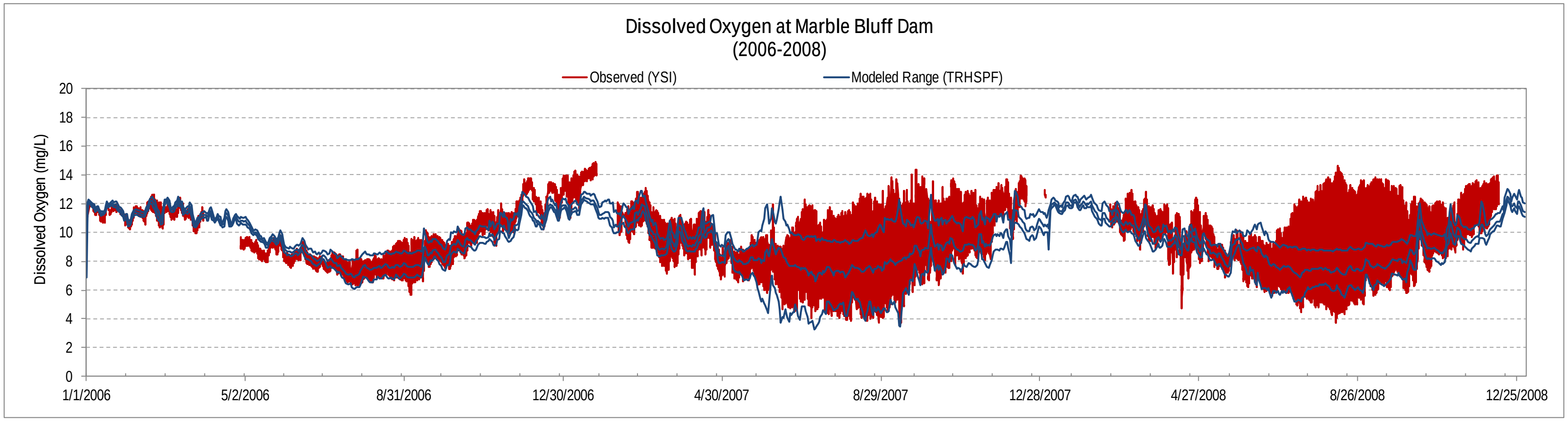


Figure 4-67. Comparison of Modeled and Observed Dissolved Oxygen at Marble Bluff Dam between 2006 and 2008.

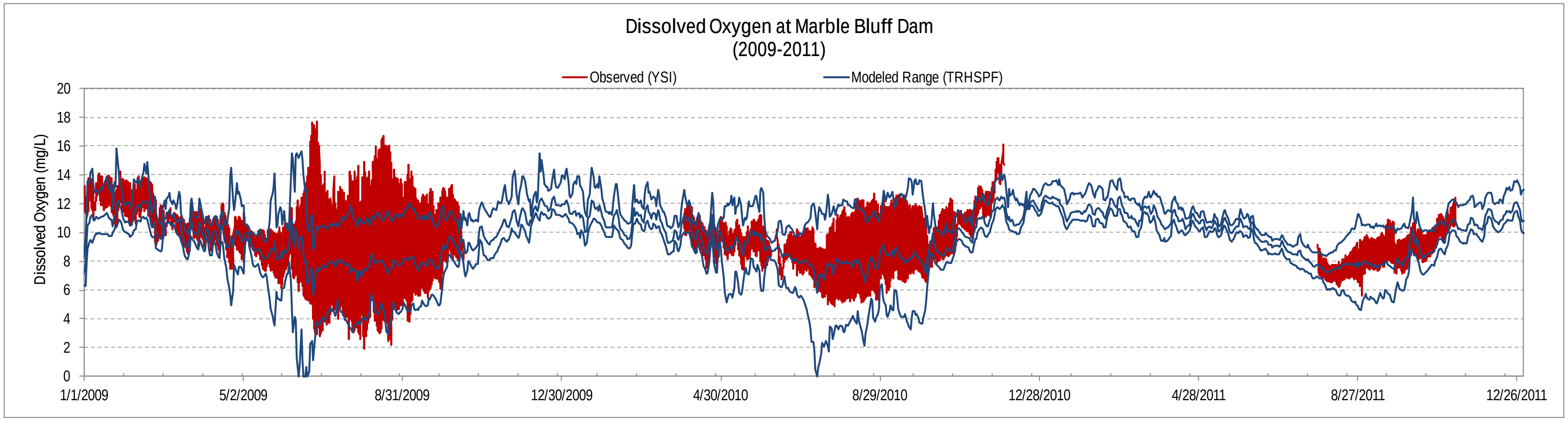


Figure 4-68. Comparison of Modeled and Observed Dissolved Oxygen at Marble Bluff Dam between 2009 and 2011.

Table 4-12. Error and Regression Statistics between Hourly Observed and Predicted Dissolved Oxygen Measurements (1/1/2000 – 12/31/2011)

Location	R^2	Slope	Intercept	Average Error	Relative Error	Residual Error	N
Lockwood	0.75	0.80	2.05	0.69	7%	0.11	71,224
Patrick	0.62	0.69	2.97	0.86	9%	-0.03	46,463
Tracy/Clark	0.66	0.73	2.49	0.92	10%	-0.09	81,996
Painted Rock	0.77	0.93	1.18	0.78	8%	0.48	62,089
Wadsworth	0.63	0.78	2.10	0.87	9%	-0.01	41,481
Marble Bluff Dam	0.46	0.59	3.59	1.21	14%	-0.24	78,559

Table 4-13. Average, Relative, and Residual Error For Daily and Predicted Maximum, Mean, and Minimum Dissolved Oxygen Values (1/1/2000 – 12/31/2011)

Location	Average Error			Relative Error			Residual Error			N
	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	
Lockwood	0.77	0.50	0.66	7%	5%	8%	-0.34	0.13	0.38	3,009
Patrick	0.93	0.52	0.65	8%	5%	8%	-0.58	-0.04	0.42	1,946
Tracy/Clark	1.07	0.60	0.63	9%	6%	8%	-0.49	-0.10	0.20	3,465
Painted Rock	0.74	0.67	0.73	7%	7%	9%	0.27	0.48	0.41	2,647
Wadsworth	0.92	0.65	0.66	8%	7%	8%	-0.33	-0.01	0.13	1,770
Marble Bluff Dam	1.26	0.62	0.77	11%	7%	11%	-0.75	-0.23	-0.10	3,303

4.2.5 Discussion of TRHSPF Confirmation Results

The results presented above indicate that TRHSPF is accurately simulating both hydrology and water quality within the Truckee River for an extended time period which reflects an increase in regional growth and development.

As mentioned above, it is important to recognize uncertainty using a "weight-of-evidence" approach which includes evaluation of both statistical and visual comparisons and recognizes both the uncertainty and the frequency of the observed data. Based on both visual and statistical model-to-data comparisons, model predictions of streamflow is "very good". Overall, the model predictions of water temperature is "good".

The model predictions for nutrients fall within the range of uncertainty of the observed data for a large majority of years. The model is slightly under-predicting total nitrogen and total phosphorus. The inorganic components (ammonia, nitrate, orthophosphorus) of the total nutrients are reasonable overall where the inorganic nitrogen is within the range of uncertainty and orthophosphorus is slighty over-predicted. Organic nitrogen and phosphorus are slightly under-predicted by the model, which likely explains the overall slight under-prediction of the total nutrients. Dissolved oxygen model predictions are within the range of the data and the overall model performance is "good".

Given the known limitations in WARMF predictions of streamflow and water temperature that were noted in Section 3.1.5, a sensitivity analysis was conducted for the 2000-20o8 time period to evaluate whether or not water quality simulations by TRHSPF would be improved if historical data for flow and temperature were used in place of WARMF output. Overall, dissolved oxygen simulated by TRHSPF using WARMF predicted flows are not drastically different than results using USGS data for upstream boundary flows. Also, small improvements in dissolved oxygen simulations using measured stream temperature instead of WARMF simulated stream temperature only occurred during the non-critical late winter/early spring period. The results of this sensitivity analysis confirm that the use of WARMF simulated flows and temperatures is adequate and is a preferred approach because it maintains a consistent link between flow and nutrient loads generated by WARMF.

4.3 Summary of Model Confirmation

Several previous shortcomings identified in 2011 (LimnoTech 2011) were addressed in this model update/confirmation exercise:

- Snowmelt and low flow hydrology simulations were improved in upper watershed.
- The general under-prediction of total nitrogen in the Truckee was reduced.
- Diversion data model inputs were updated and verified for quality control.

The overall model performance of the updated and extended WARMF and TRHSPF models can be summarized as:

- The updated model results for the 2000-2008 time period compare to observed data "as good as" or "better" than the results obtained during the previous model update and confirmation exercise.
- The model results are within the range of uncertainty of the observed data for the majority of the extended simulation period (2009-2011); however, model simulations did not correlate well with unusually high total nitrogen data observed during 2009.
- Overall, the models slightly under-predict total nutrient concentrations; however, the simulation of inorganic nutrients is within the range of data uncertainty. The deficit of total nutrients is attributed to lower than observed organic nutrient concentrations. Organic nutrients are not bioavailable for uptake by algae and do not directly impact dissolved oxygen concentrations.
- Additional model adjustments to increase the simulated concentration of organic nutrients (and further address the slight under-prediction of total nitrogen and total phosphorus) would not change dissolved oxygen concentrations significantly.
- Overall, the prediction of dissolved oxygen throughout all locations and across the 12-year simulation period is consistent with previous

model calibration/confirmation efforts and is considered "good".

The results of the model update and confirmation described above for both WARMF and TRHSPF indicate that both models have successfully been extended to simulation conditions in the Truckee River watershed for a more recent time period. LimnoTech recommends that both models have been adequately calibrated and confirmed and are ready for use to support the third-party effort to review Truckee River nutrient WQS and TMDLs.

5. INTENDED USE OF MODELS

The review and potential revision of the Truckee River nutrient WQS and/or TMDL is a complex process that will benefit from the coupled watershed and river water quality models described above. Truckee River flows are highly managed through competing water rights. Flows are regulated through releases from several California reservoirs and then reduced by sizable municipal, industrial, and agricultural diversions in Nevada. The relationship between flow, nutrients, benthic algae, and the resulting water quality (e.g., dissolved oxygen concentrations) is highly complex and can best be characterized through water quality modeling. A study published by the Water Environment Research Foundation (WERF, 2013) focused on the proper use of models to set waterbody-specific nutrient goals identified both WARMF and HSPF as appropriate models capable of quantifying the relationship between nutrient loads and their impacts in terms of water quality or ecological response indicators.

Both WARMF and TRHSPF will allow for calculation of the Truckee River's response to nutrient loading under low flow conditions, assuming current operational strategies. For scenario analysis, the flow in the river can be based on a combination of reservoir releases and diversions, and will be best characterized using a flow management model such as the Truckee River Operations Model (TROM) or RiverWare:

TROM: The Truckee River Operations Model (TROM) is a river operations model that projects regulatory flows (reservoir releases, diversions) under various flow management conditions. One of the main uses of TROM has been to support the development and approval process of TROA (USBR 2008). Inputs to TROM include historic hydrologic data for rivers tributary to reservoirs and local runoff; reservoir operation rules; historic and/or projected demands for municipal, industrial, and agricultural uses; and instream flow targets (e.g., Floriston Rates). For a given flow management condition, TROM simulates preferred operating conditions and calculates resulting reservoir releases and stream flows on a monthly or bi-weekly basis. The database for TROM scenarios includes 100 years of records from 1901 to 2000. TROM simulations include multiple scenarios for each of the 100 years under either a current (2002) or future (2033) time horizon for water demands.

RiverWare: The United States Bureau of Reclamation (USBR) has developed a set of closely related models that can be used to improve water management efficiency in the Truckee River Basin. The RiverWare modeling system is ideal for modeling complex river and reservoir operations (Zagona et al., 2001). The RiverWare water accounting system is one of a set of linked models to be used under current reservoir operating policy and is being developed for use in the future under a proposed river and reservoir operating agreement. The Reclamation Carson City Area Office has decided to use RiverWare as the scheduling and operational model for future implementation of the Truckee River Operating Agreement (TROA). The version of RiverWare which incorporates TROA is still under development. A "pre-TROA" version of RiverWare which represents current Truckee River operations has been developed and was used to support a recent Newlands Project Planning Study (USBR, 2013). This version of RiverWare would likely be most applicable for the WQS and TMDL review; however, it is still under refinement.

A next step in the WQS review process will be to select the flow management model most suitable for use along with the linked WARMF-TRHSPF framework. Then, representative flow conditions will be established that can serve as the basis for the WQS review process.

A review of the Truckee River nutrient WQS is justified because NDEP supports the effort as part of their triennial review process, acknowledges that the existing WQS were based on limited information, and recommends that a WQS review process precede the proposed TMDL review. Both WARMF and TRHSPF simulate the complex relationship of how various levels of nutrient concentrations, in combination with other factors such as flow, temperature and light, can lead to excessive growth of algae and ultimately a situation of depleted dissolved oxygen. Under representative low flow conditions, these modeling tools will be used to determine the maximum acceptable nitrogen and phosphorus (TP and/or orthophosphate) concentrations for a given region of the Truckee River that will still allow for meeting dissolved oxygen criteria and associated beneficial uses. Currently, both Nevada and the Pyramid Lake Paiute Tribe (PLPT) express a nitrogen standard in terms of TN; however, for phosphorus, PLPT uses a dissolved reactive phosphorus standard whereas Nevada uses a TP standard (from Lockwood to the PLPT boundary). Additional discussion with NDEP and USEPA will be needed to develop a preferred approach for selecting an appropriate form of phosphorus for any proposed revisions to the phosphorus WQS. The models will help ensure that any proposed nutrient WQS reflect the site-specific response of the Truckee River to nutrient loads and provide protection of the beneficial uses.

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Appendix A
Equations for Statistics Used in 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*	$\sum_{i=1}^{n} \frac{\lvert Simulated\ Value - Observed\ Value \rvert}{n_{obs}}$
Relative Error	$\sum_{i=1}^{n} \frac{\left(Absolute\ Average\ Error \middle/ Observed\ Value \right)}{n_{obs}}$
Residual Error**	$\sum_{i=1}^{n} \frac{(Simulated\ Value - Observed\ Value)}{n_{obs}}$
Root Mean Square Error	$\sqrt{\frac{\sum_{i=1}^{n}(Simulated\ Value - Observed\ Value)^2}{n_{obs}}}$

* Referred to as Absolute Error in original WARMF calibration report

** Referred to as Relative Error in original WARMF calibration report

Appendix B
Additional Model Confirmation Results for WARMF

Appendix B: Additional Model Confirmation Results for WARMF

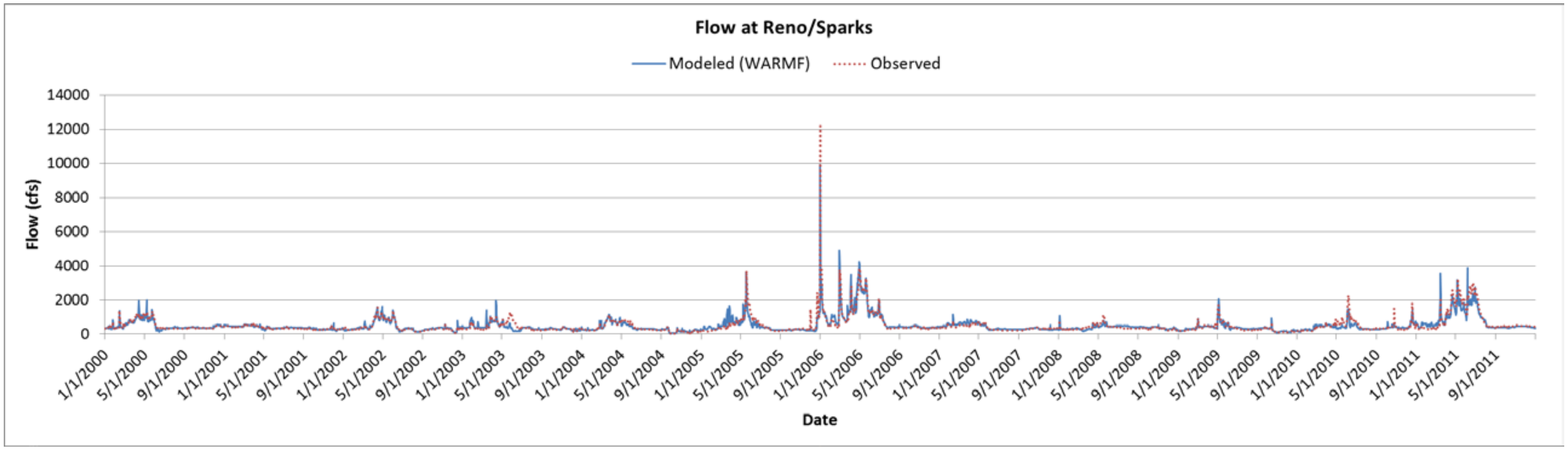


Figure B-1. Modeled and Observed Flow at Reno/Sparks

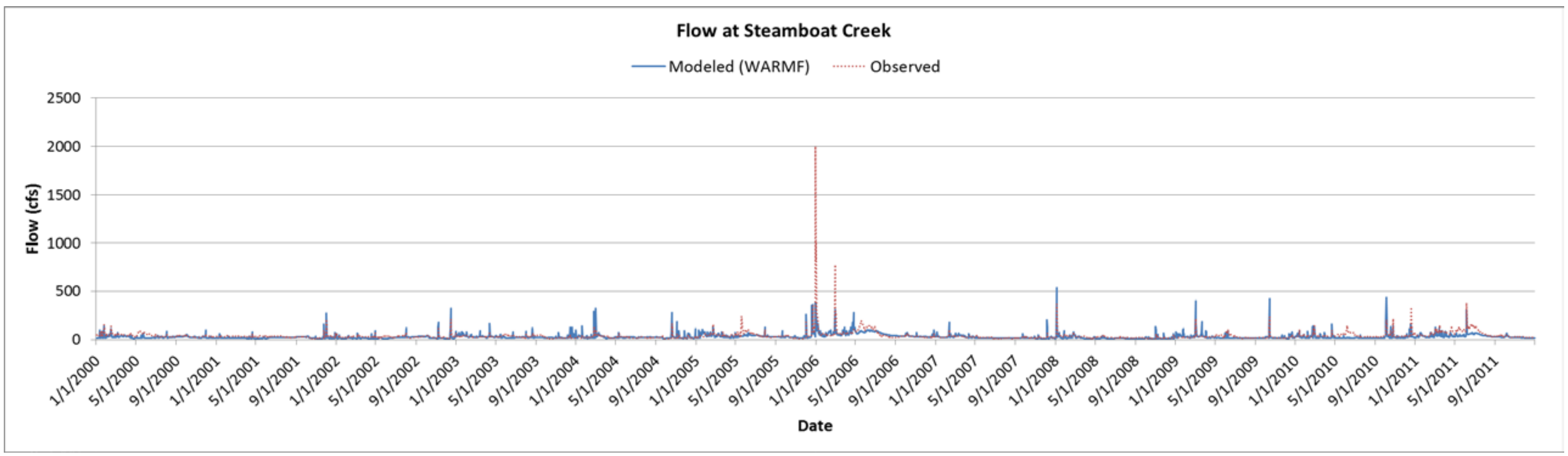


Figure B-2. Modeled and Observed Flow at Steamboat Creek

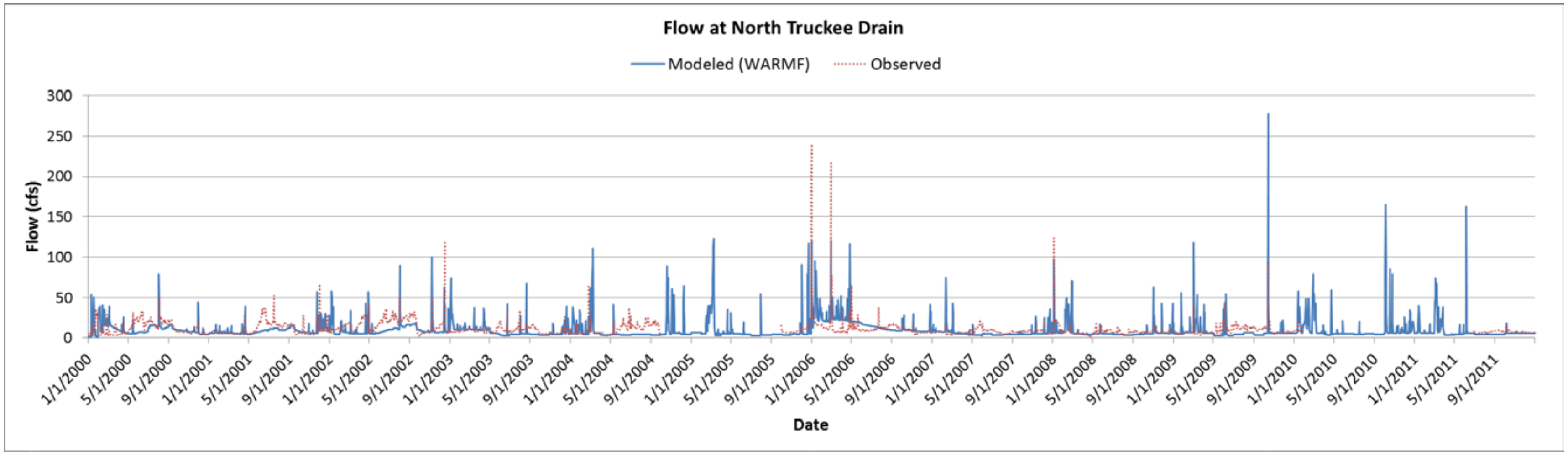


Figure B-3.Modeled and Observed Flow at North Truckee Drain

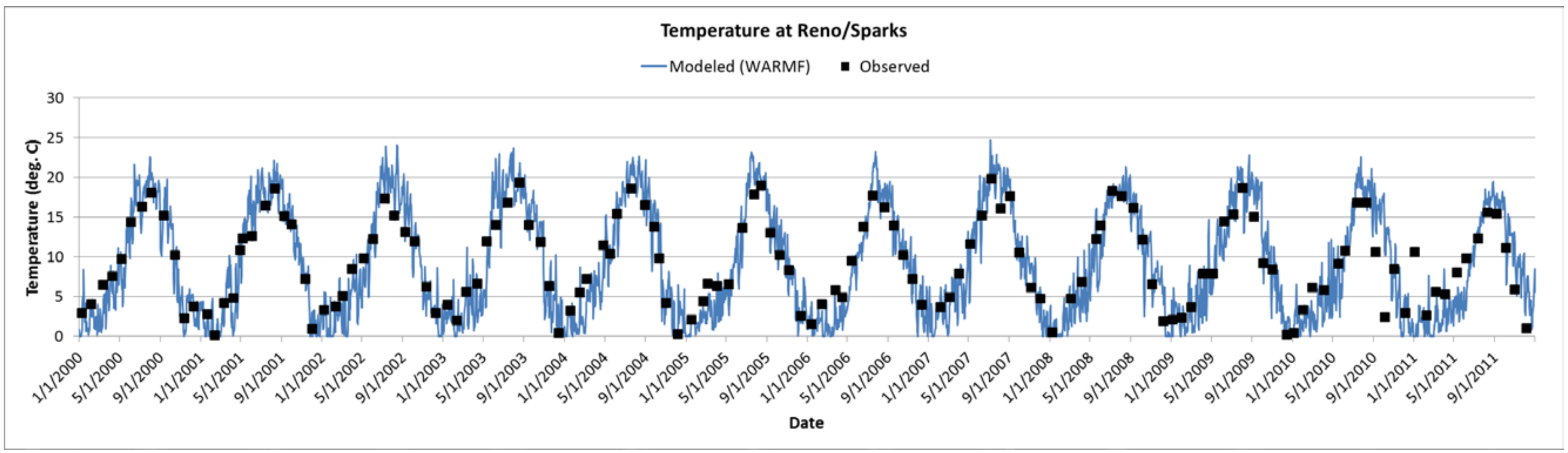


Figure B-4. Modeled and Observed Temperature at Reno/Sparks

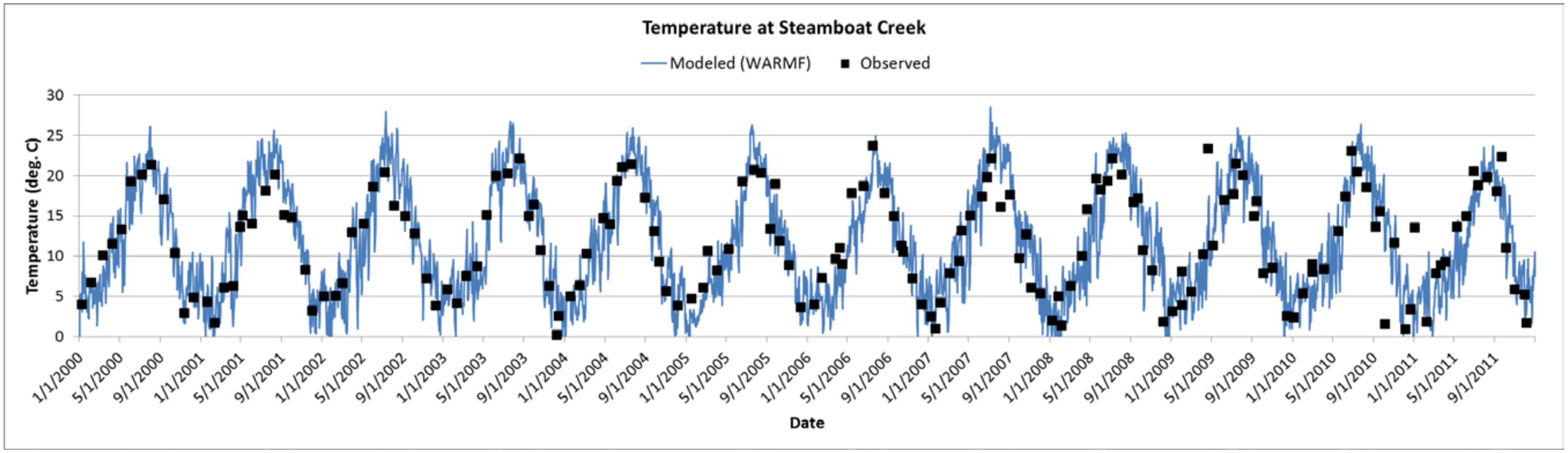


Figure B-5. Modeled and Observed Temperature at Steamboat Creek

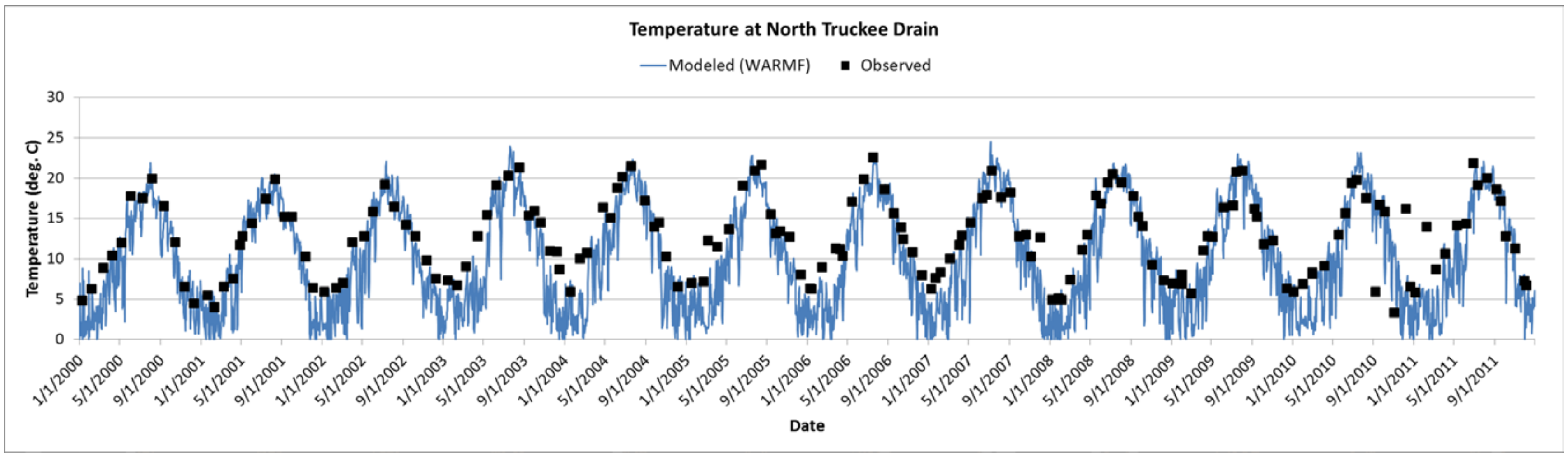


Figure B-6. Modeled and Observed Temperature at North Truckee Drain

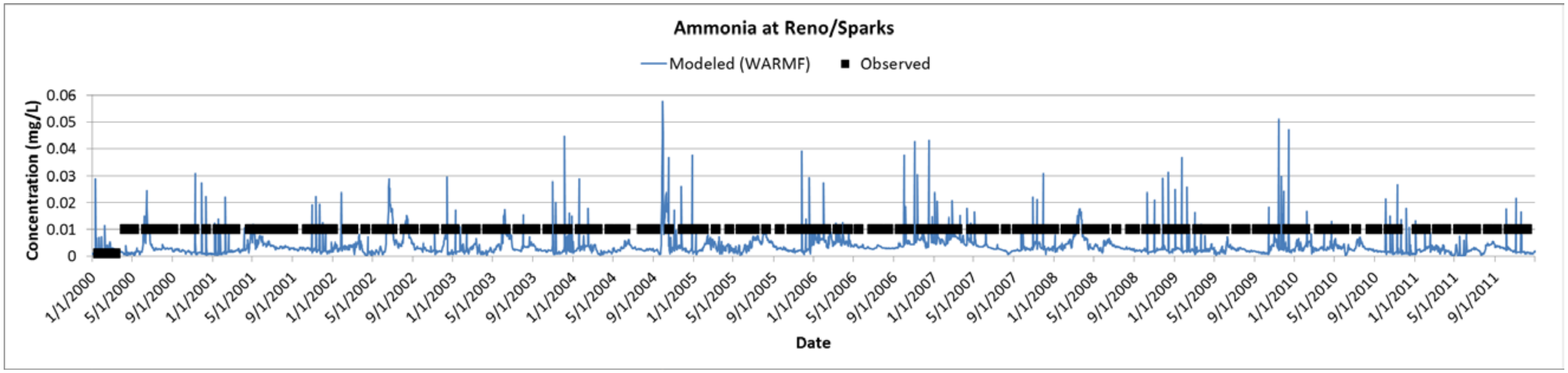


Figure B-7. Modeled and Observed Ammonia at Reno/Sparks. 99% of the Ammonia data points were reported as <PQL. The PQL for Ammonia is 0.1 mg/L. One outlier observed sample not shown on plot: 0.11 on 12/9/2010

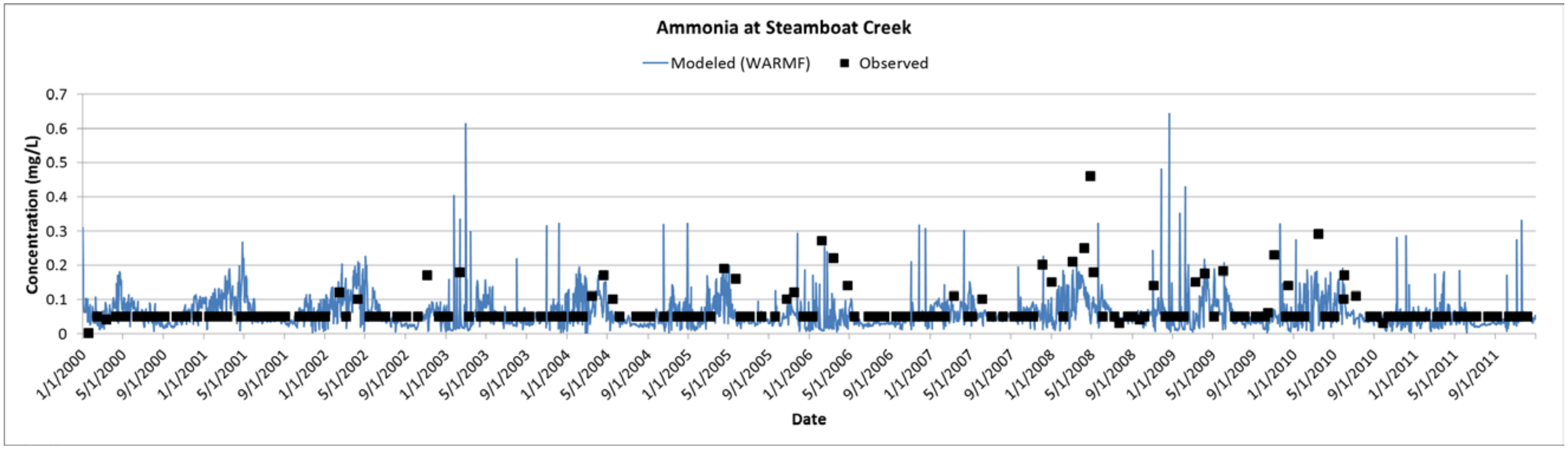


Figure B-8. Modeled and Observed Ammonia at Steamboat Creek. 80% of the Ammonia data points were reported as <PQL. The PQL for Ammonia is 0.1 mg/L. One outlier observed sample not shown on plot: 1.27 mg/L on 3/24/2011

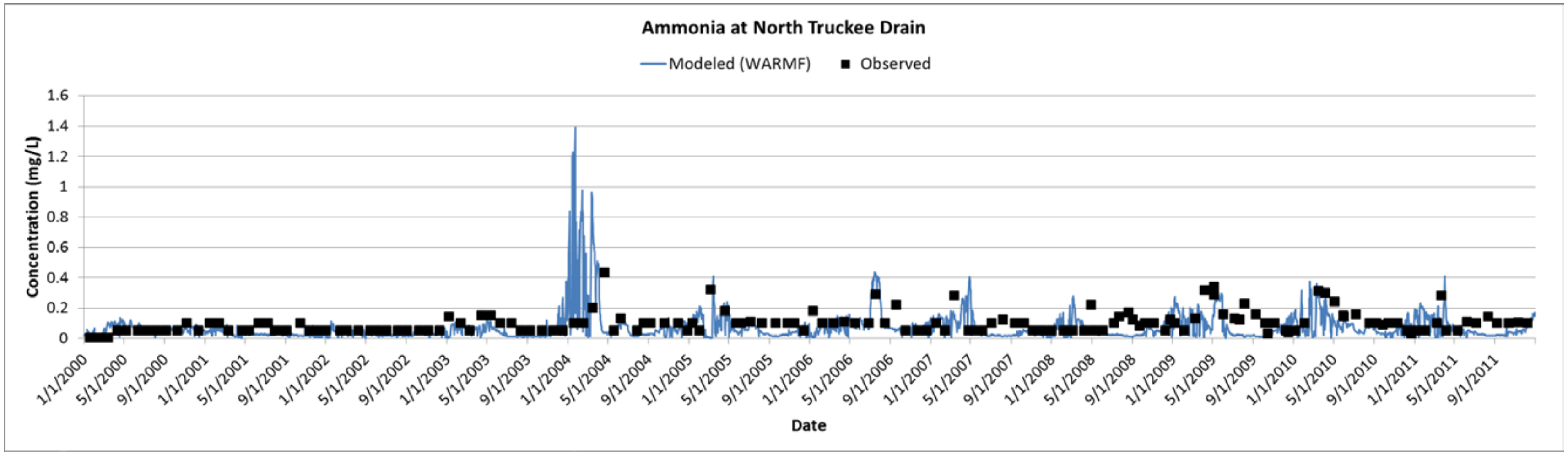


Figure B-9. Modeled and Observed Ammonia at North Truckee Drain. 68% of the Ammonia data points were reported as <PQL. The PQL for Ammonia is 0.1 mg/L.

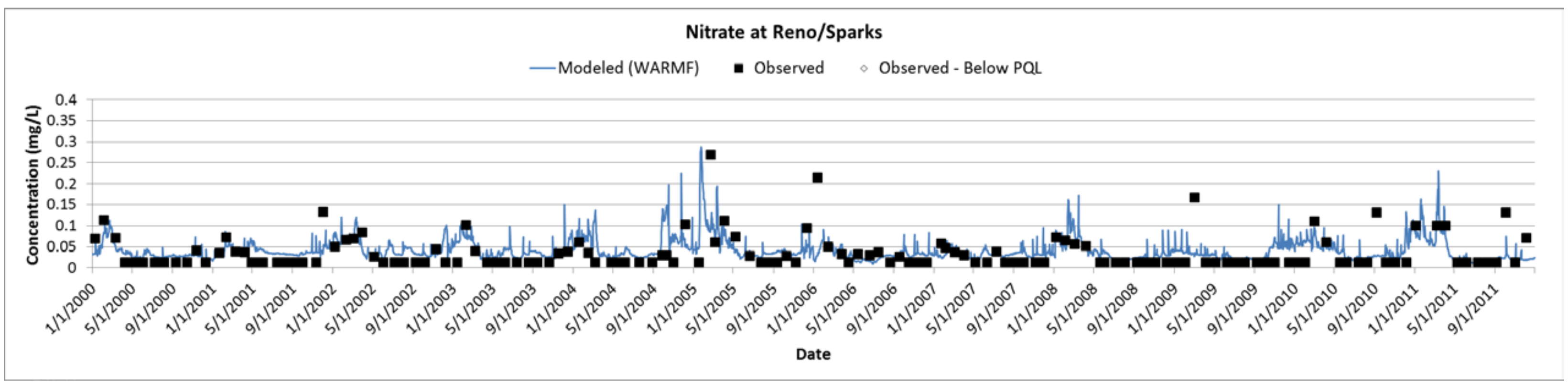


Figure B-10. Modeled and Observed Nitrate at Reno/Sparks. 61% of the Nitrate data points were reported as <PQL. The PQL for Nitrate is 0.025 mg/L. One outlier observed sample not shown on plot: 0.662 mg/L on 2/9/2011

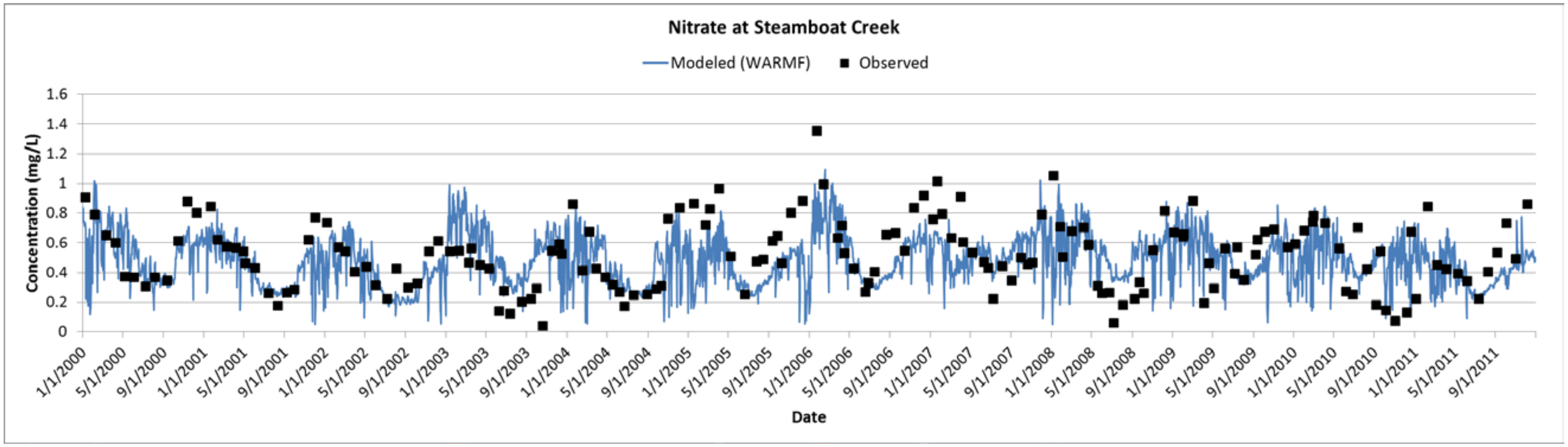


Figure B-11. Modeled and Observed Nitrate at Steamboat Creek. 0% of the Nitrate data points were reported as <PQL. The PQL for Nitrate is 0.025 mg/L. One outlier observed sample not shown on plot: 6.17 mg/L on 10/11/2006

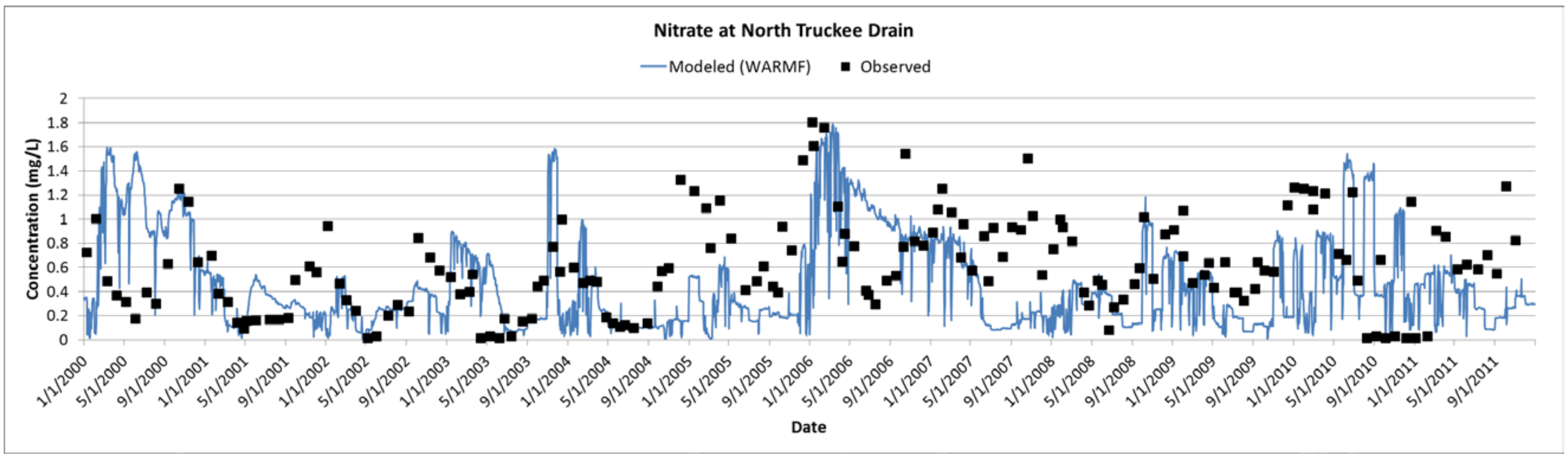


Figure B-12. Modeled and Observed Nitrate at North Truckee Drain. 5% of the Nitrate data points were reported as <PQL. The PQL for Nitrate is 0.025 mg/L.

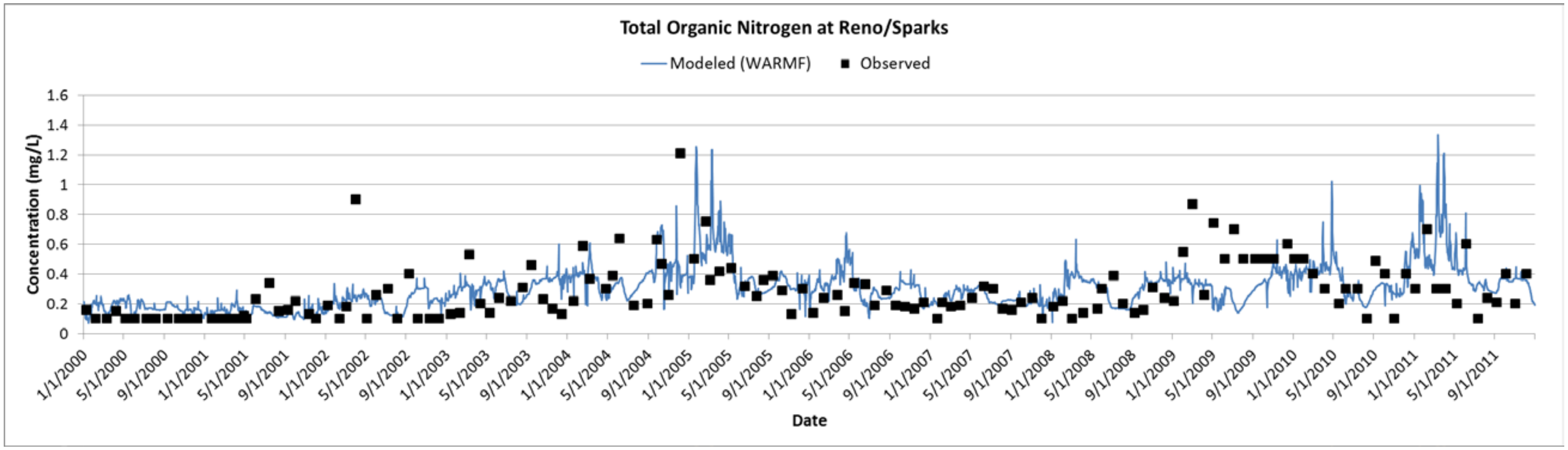


Figure B-13. Modeled and Observed Total Organic Nitrogen at Reno/Sparks. 99% of the TON data points were reported as <PQL for either TKN or Ammonia, which were used to calculate TON.

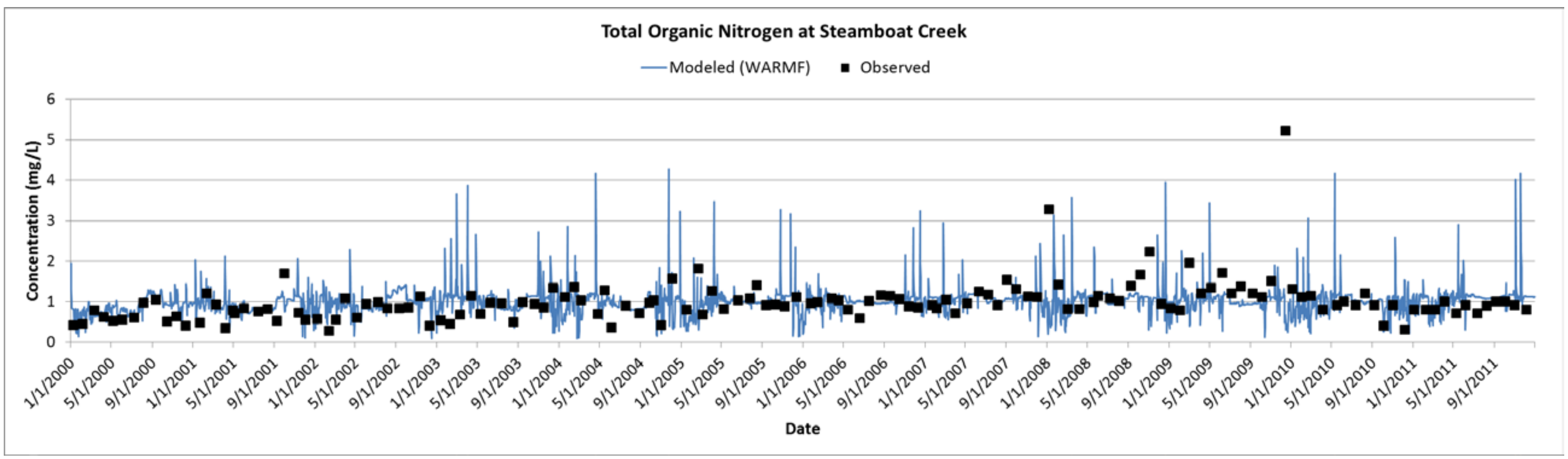


Figure B-14. Modeled and Observed Total Organic Nitrogen at Steamboat Creek. 80% of the TON data points were reported as <PQL for either TKN or Ammonia, which were used to calculate TON.

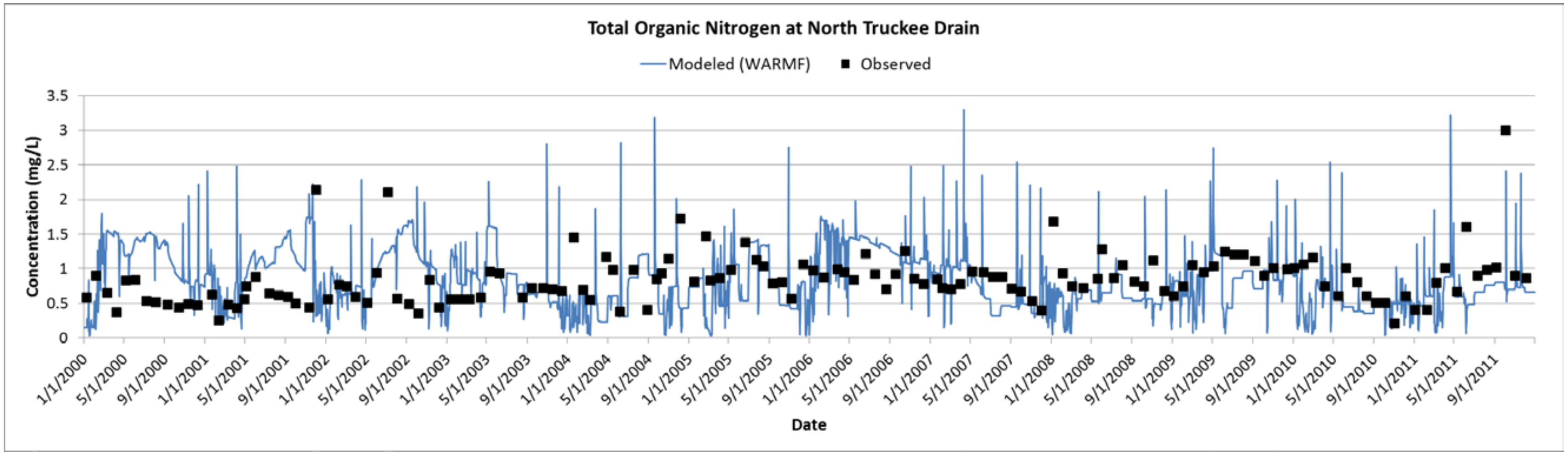


Figure B-15. Modeled and Observed Total Organic Nitrogen at North Truckee Drain. 68% of the TON data points were reported as <PQL for either TKN or Ammonia, which were used to calculate TON.

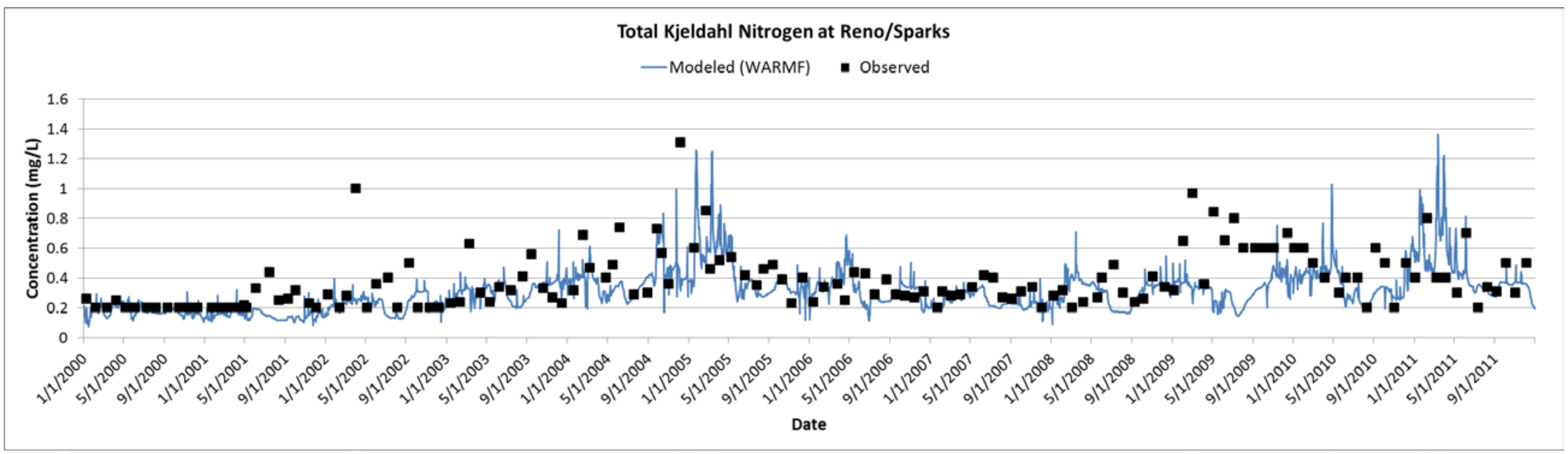


Figure B-16. Modeled and Observed Total Kjeldahl Nitrogen at Reno/Sparks. 17% of the TKN data points were reported as <PQL. The PQL for TKN is 0.2 mg/L.

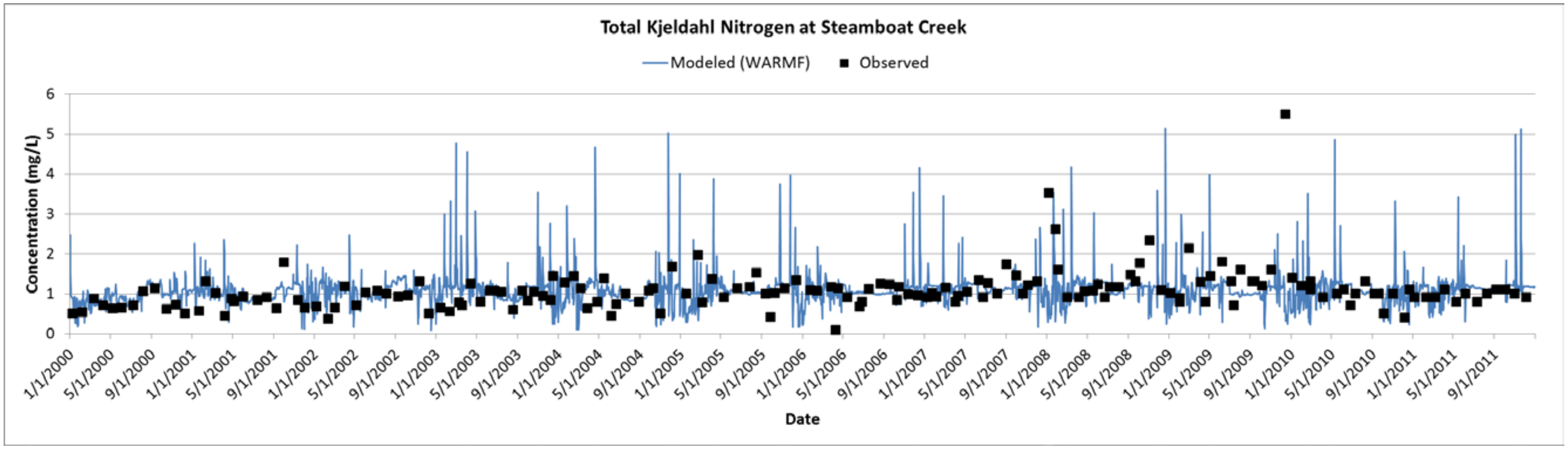


Figure B-17. Modeled and Observed Total Kjeldahl Nitrogen at Steamboat Creek. 0% of the TKN data points were reported as <PQL. The PQL for TKN is 0.2 mg/L.

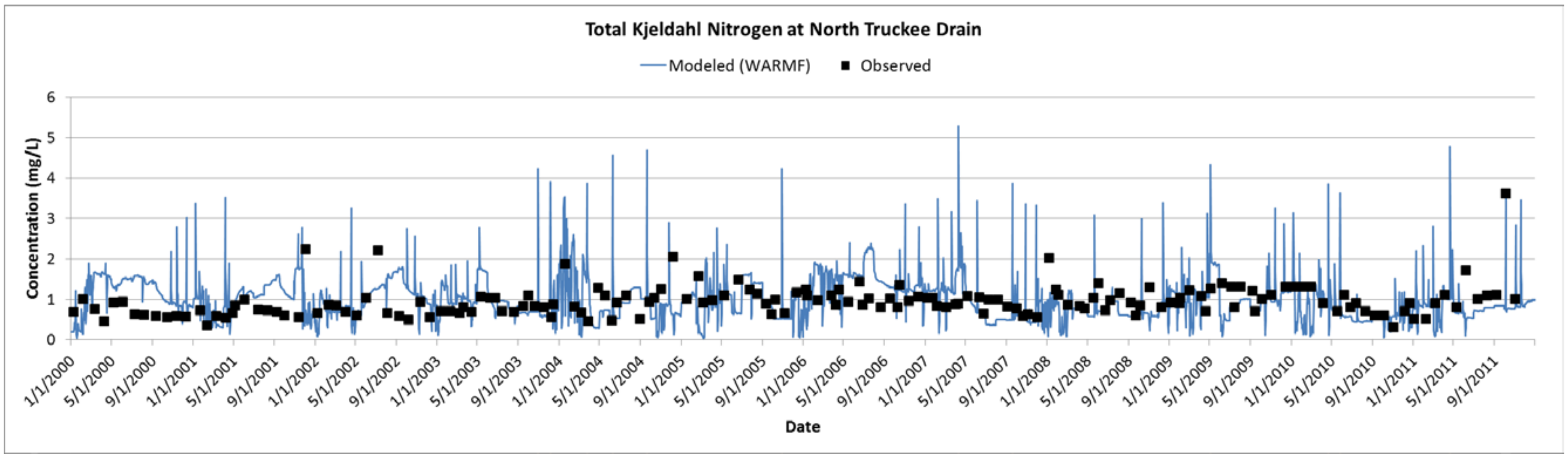


Figure B-18. Modeled and Observed Total Kjeldahl Nitrogen at North Truckee Drain. 0% of the TKN data points were reported as <PQL. The PQL for TKN is 0.2 mg/L.

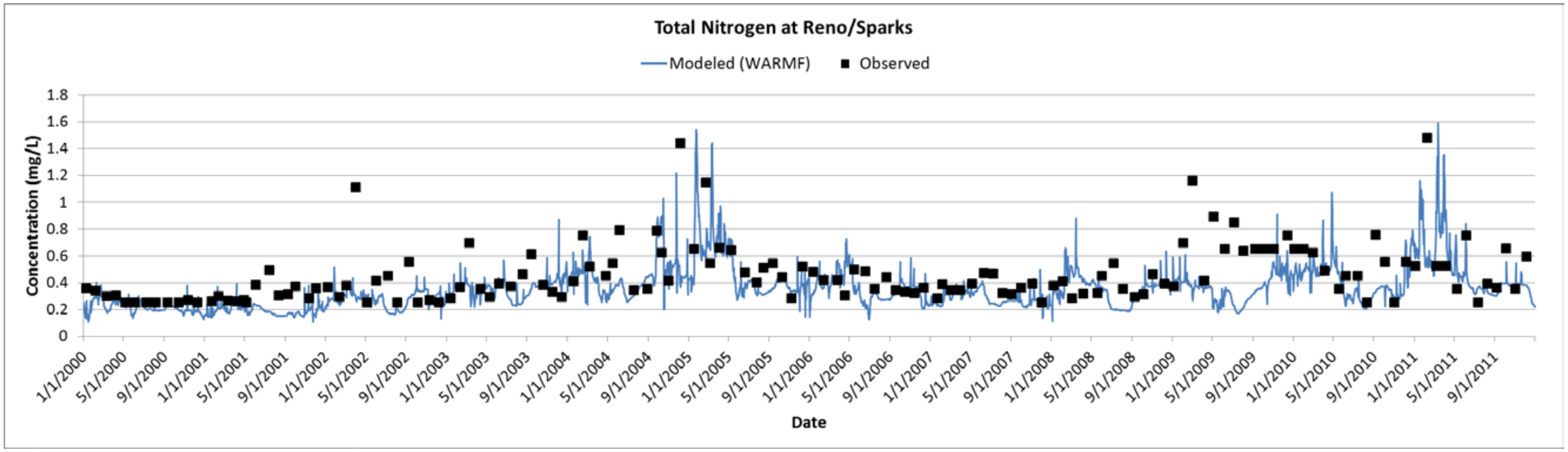


Figure B-19. Modeled and Observed Total Nitrogen at Reno/Sparks. 99% of the Total Nitrogen data points were reported as <PQL for TKN, Nitrate, or Nitrite, which were used to calculate Total Nitrogen.

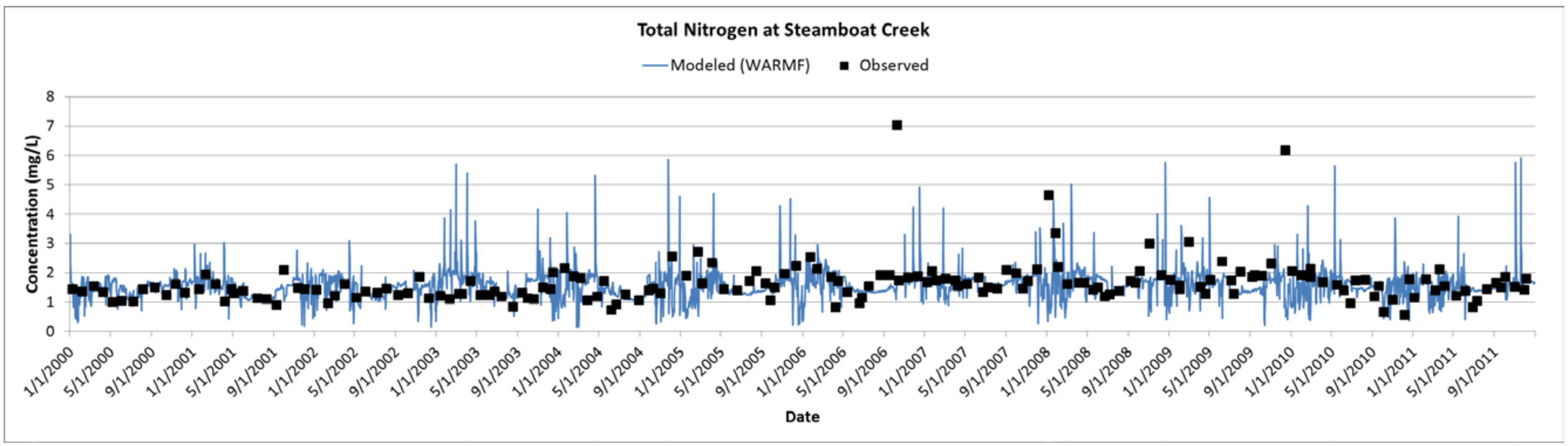


Figure B-20. Modeled and Observed Total Nitrogen at Steamboat Creek. 67% of the Total Nitrogen data points were reported as <PQL for TKN, Nitrate, or Nitrite, which were used to calculate Total Nitrogen.

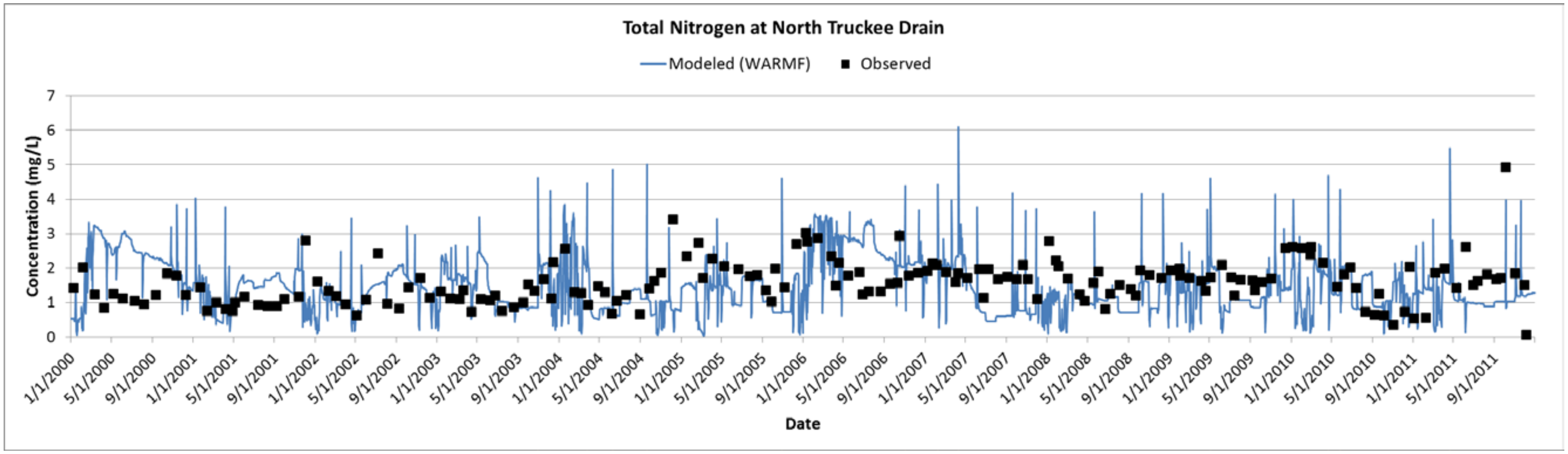


Figure B-21. Modeled and Observed Total Nitrogen at North Truckee Drain. 43% of the Total Nitrogen data points were reported as <PQL for TKN, Nitrate, or Nitrite, which were used to calculate Total Nitrogen.

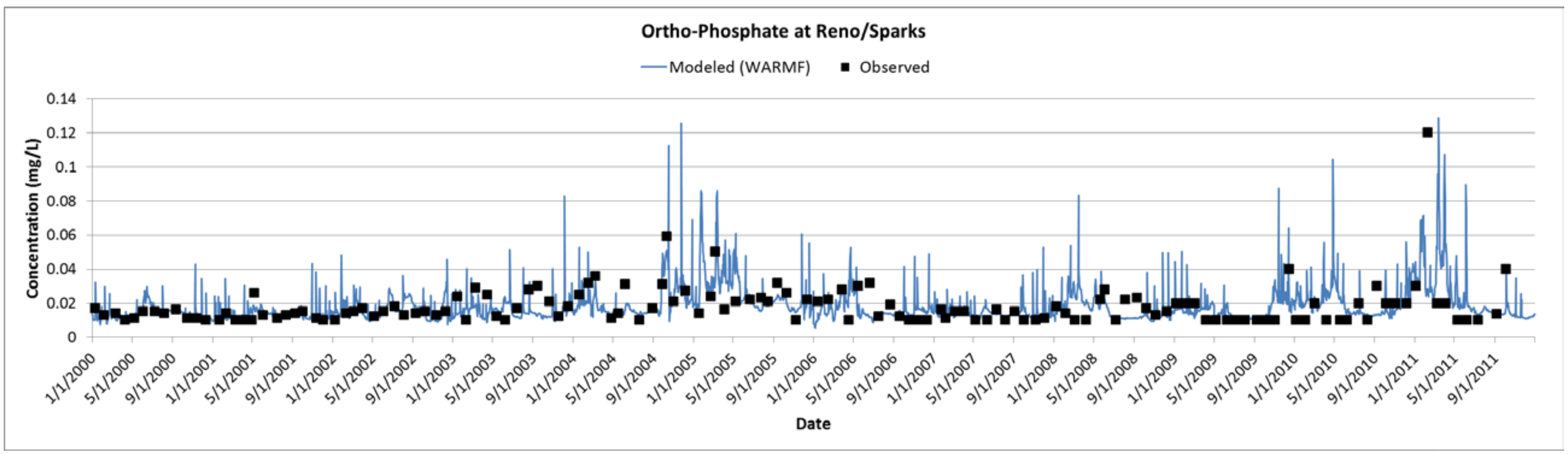


Figure B-22. Modeled and Observed Orthophosphate at Reno/Sparks. 19% of the Orthophosphate data points were reported as <PQL. The PQL for Orthophosphate is 0.01 mg/L.

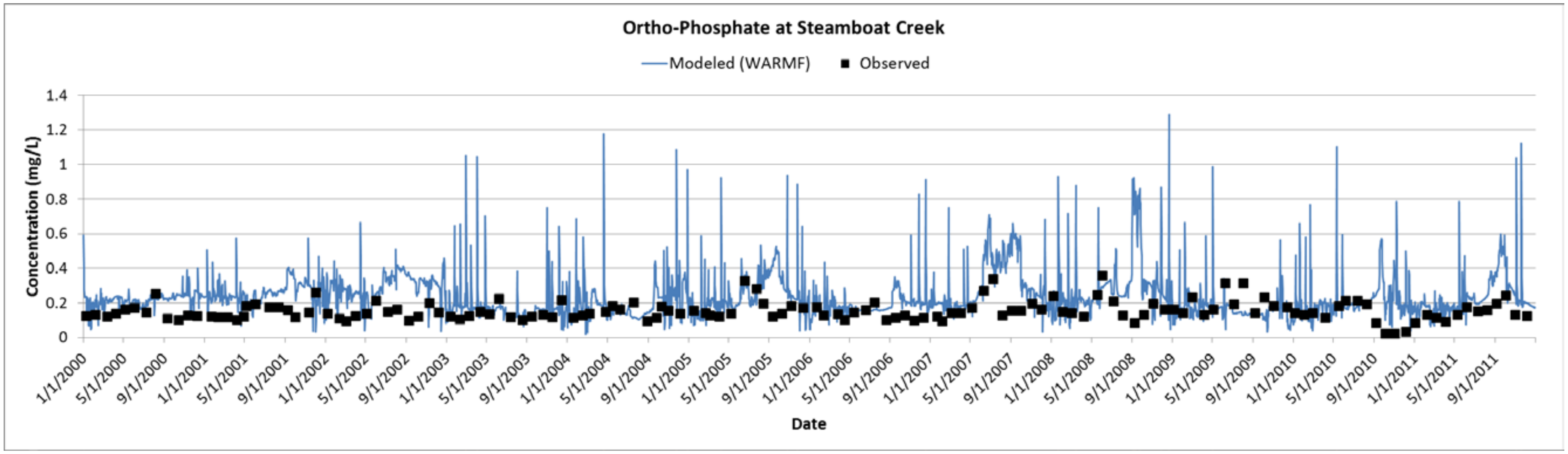


Figure B-23. Modeled and Observed Orthophosphate at Steamboat Creek. 0% of the Orthophosphate data points were reported as <PQL. The PQL for Orthophosphate is 0.01 mg/L.

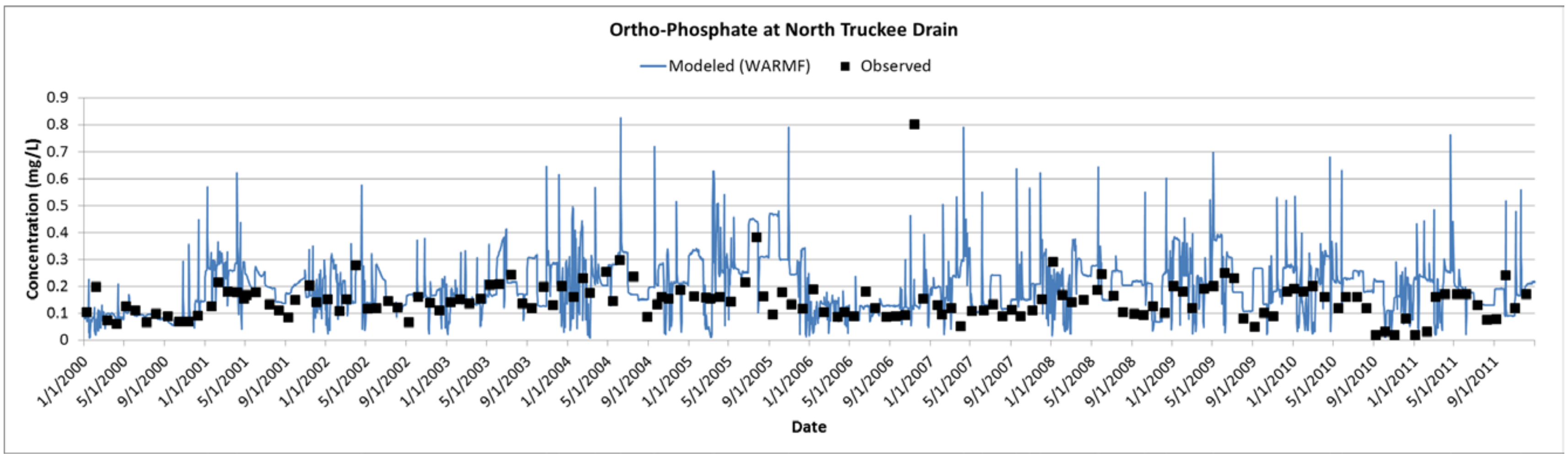


Figure B-24. Modeled and Observed Orthophosphate at North Truckee Drain. 0% of the Orthophosphate data points were reported as <PQL. The PQL for Orthophosphate is 0.01 mg/L.

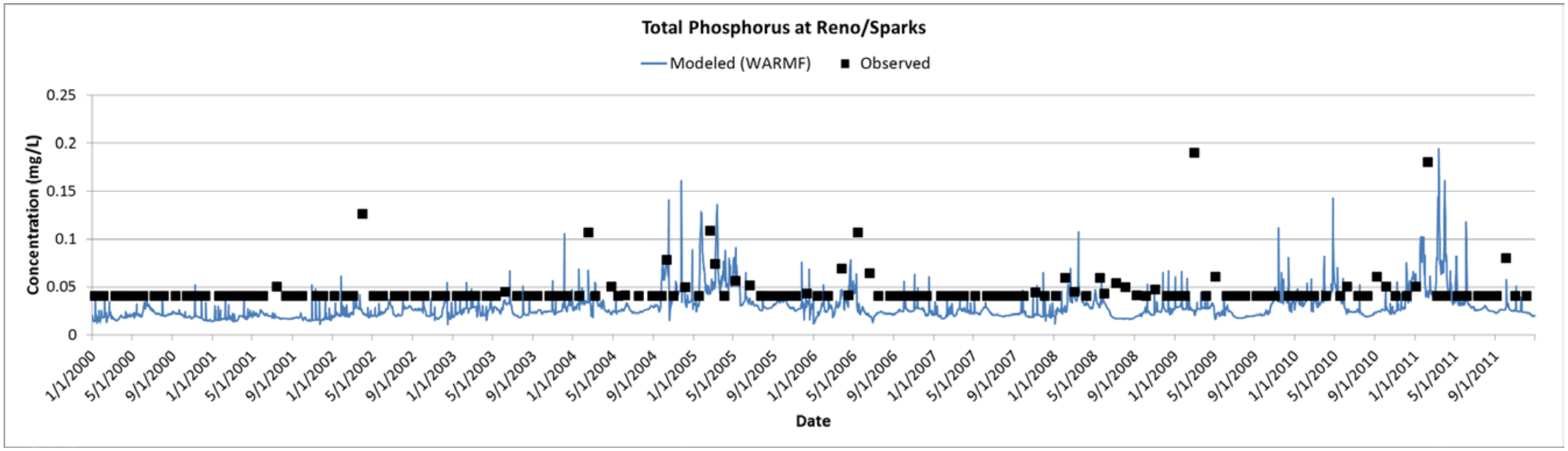


Figure B-25. Modeled and Observed Total Phosphorus at Reno/Sparks. 73% of the Total Phosphorus data points were reported as <PQL. The PQL for Total Phosphorus is 0.04 mg/L.

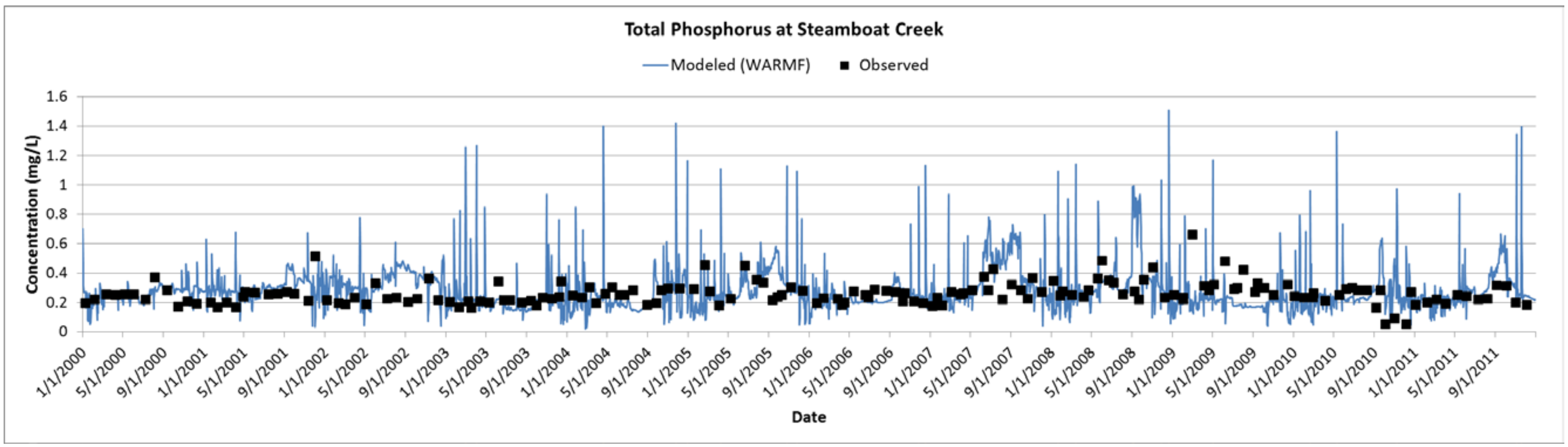


Figure B-26. Modeled **and Observed Total Phosphorus at Steamboat Creek. 0% of the Total Phosphorus data points were reported as <PQL. The PQL for Total Phosphorus is 0.04 mg/L.**

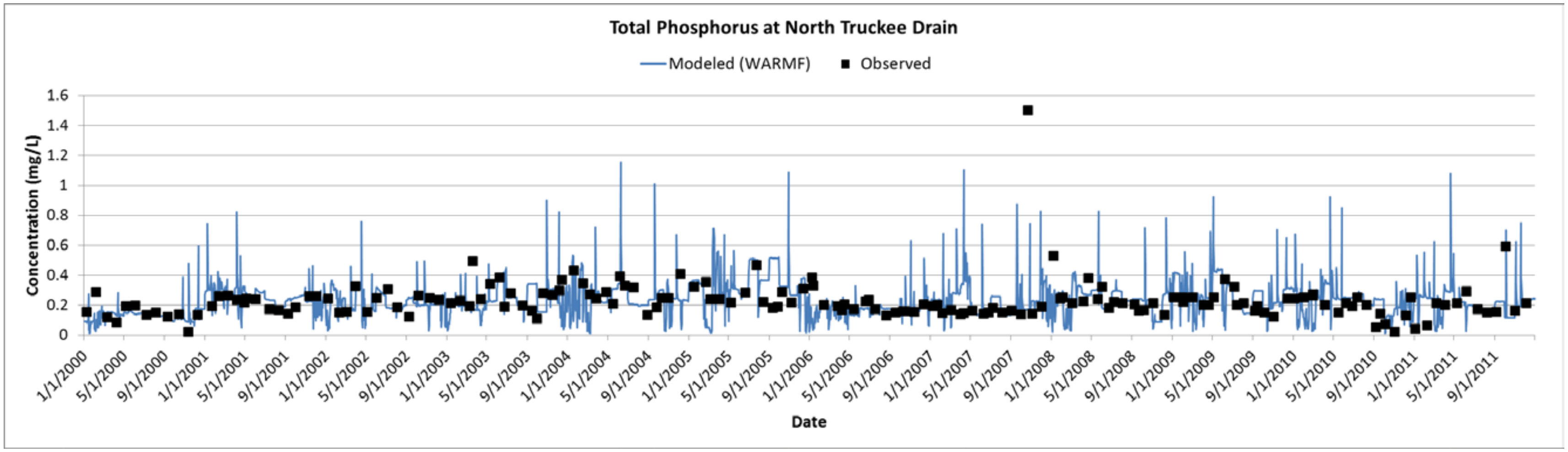
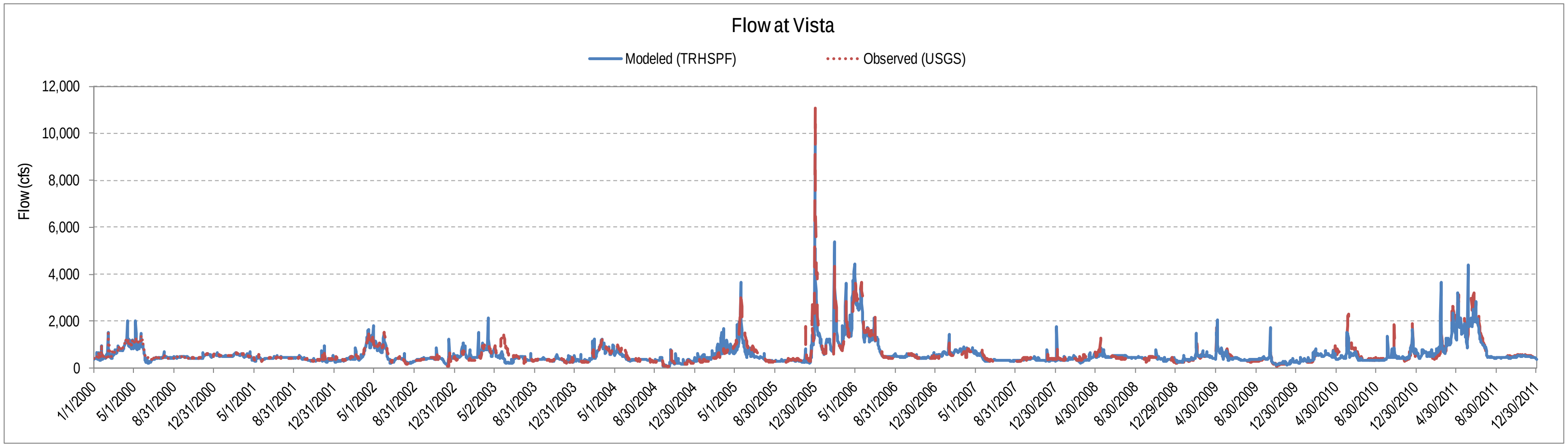


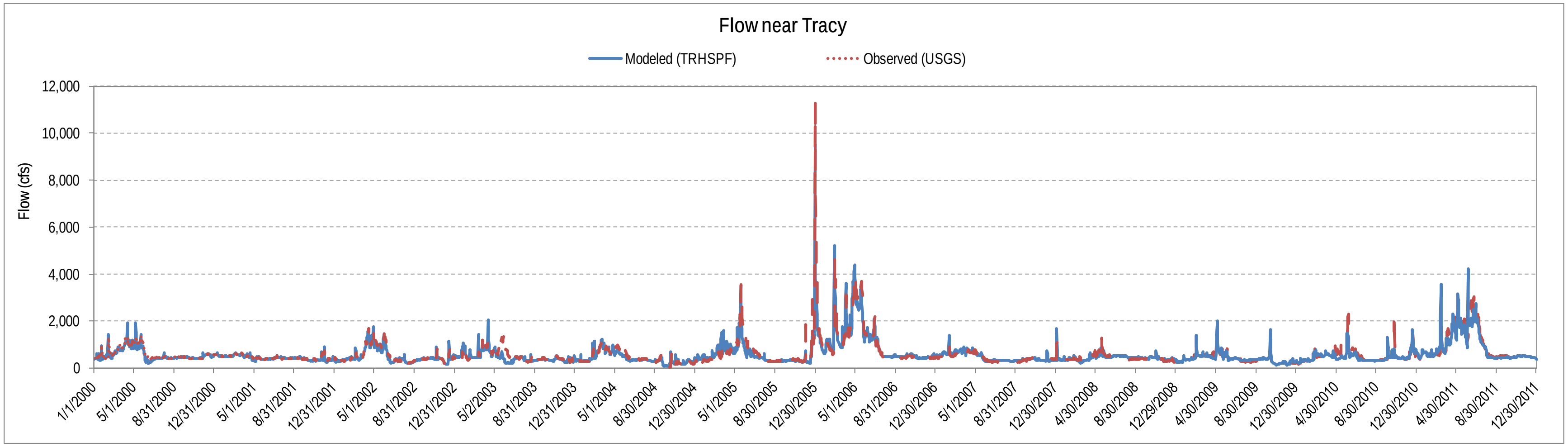
Figure B-27. Modeled and Observed Total Phosphorus at North Truckee Drain. 1% of the Total Phosphorus data points were reported as <PQL. The PQL for Total Phosphorus is 0.04 mg/L.

Appendix C
Additional Model Confirmation Results for TRHSPF

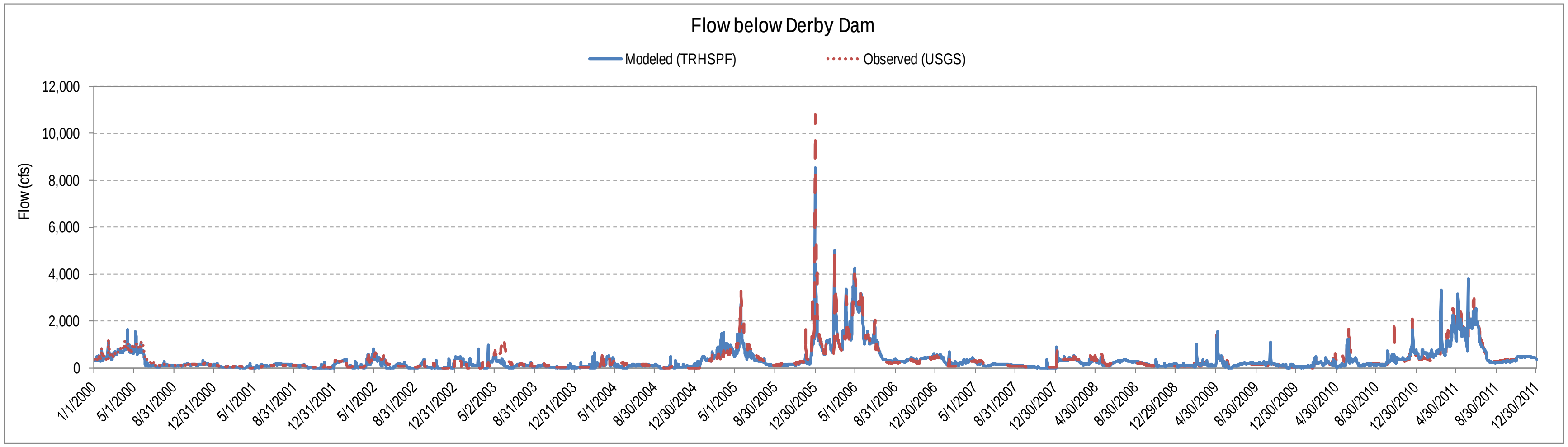
Appendix C: Additional Model Confirmation Results for TRHSPF



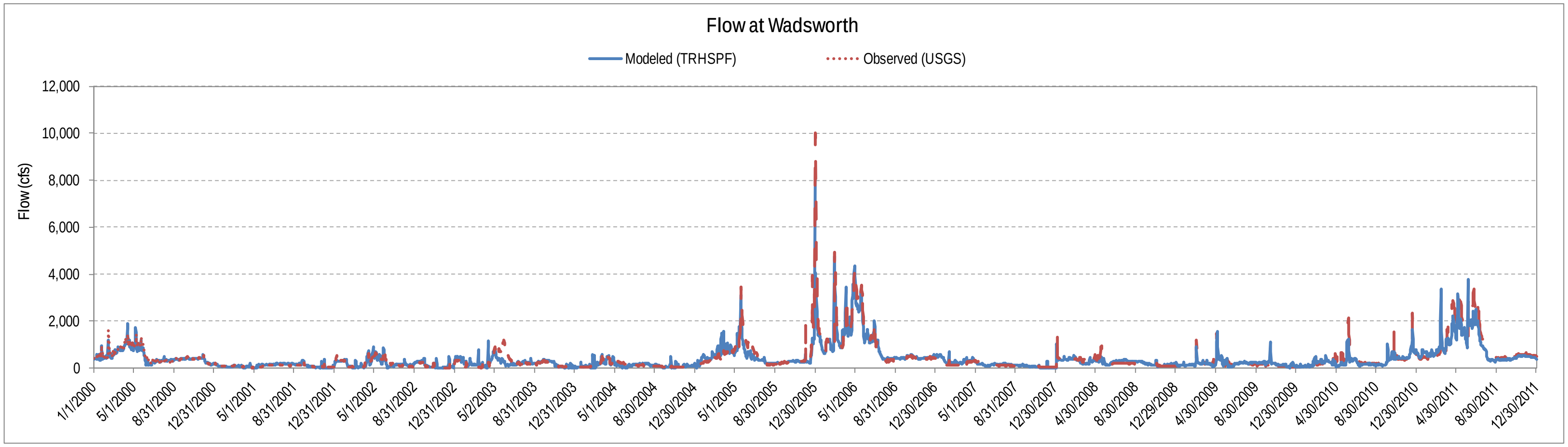
C-1. Comparison of Modeled and Observed Flow at Vista between 2000 and 2011.



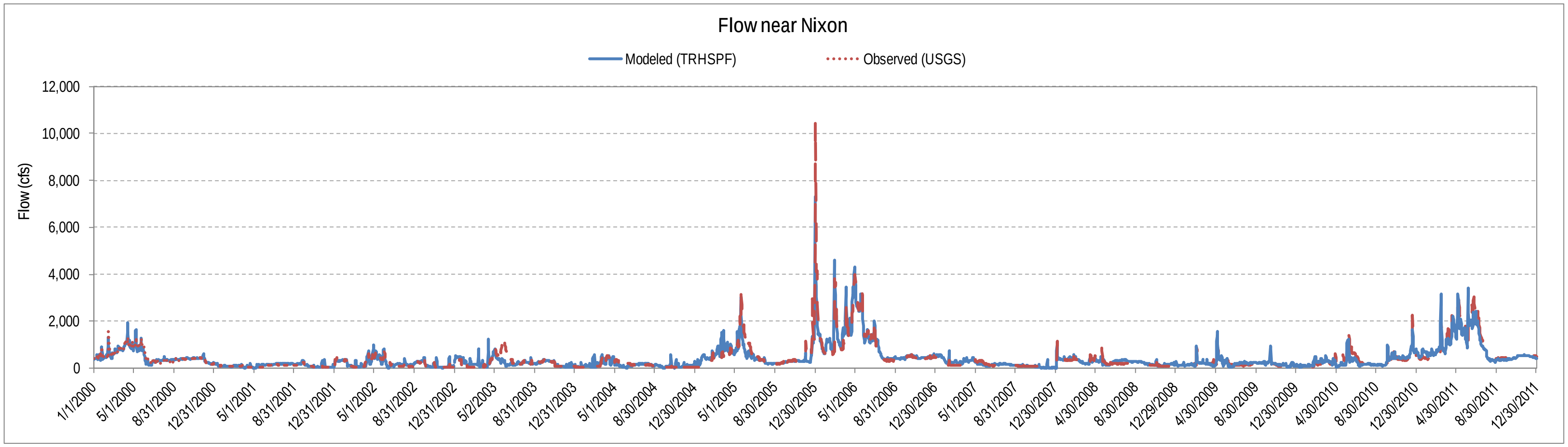
C-2. Comparison of Modeled and Observed Flow near Tracy between 2000 and 2011.



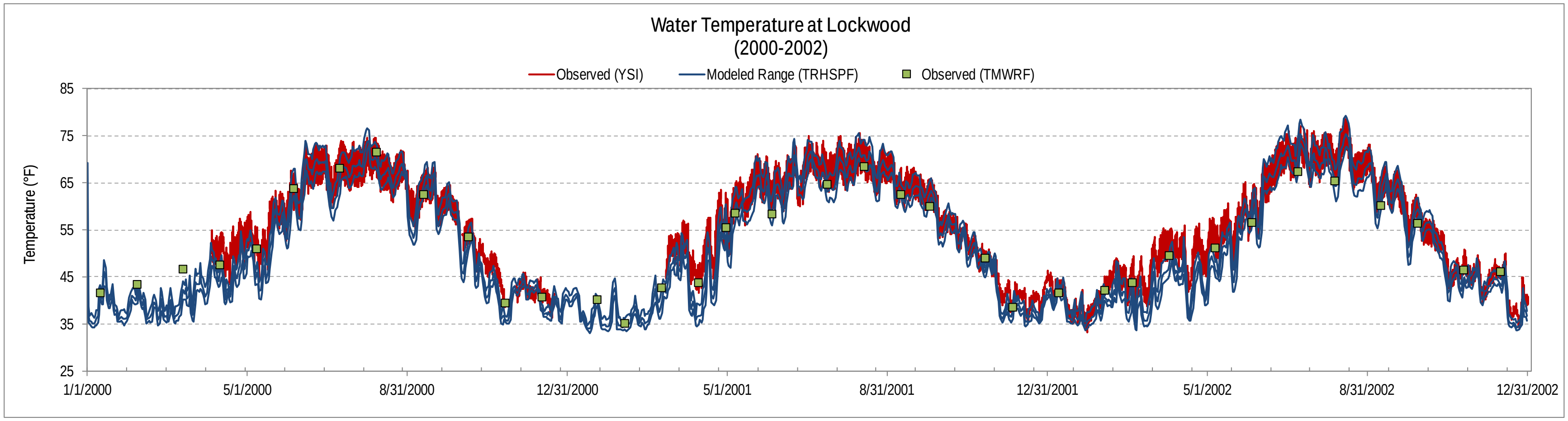
C-3. Comparison of Modeled and Observed Flow below Derby Dam between 2000 and 2011.



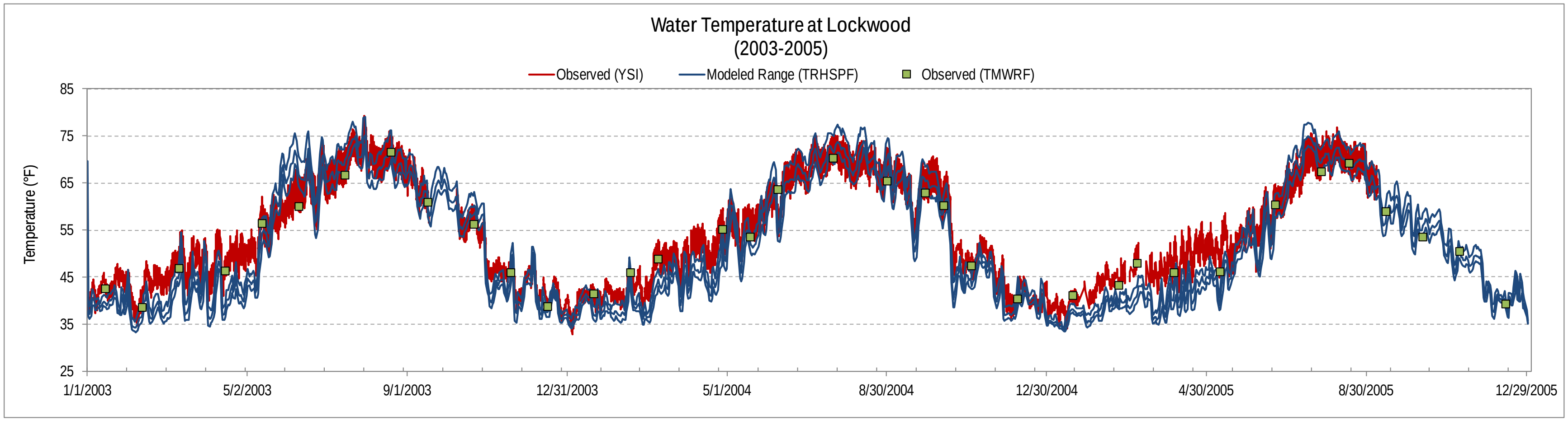
C-4. Comparison of Modeled and Observed Flow at Wadsworth between 2000 and 2011.



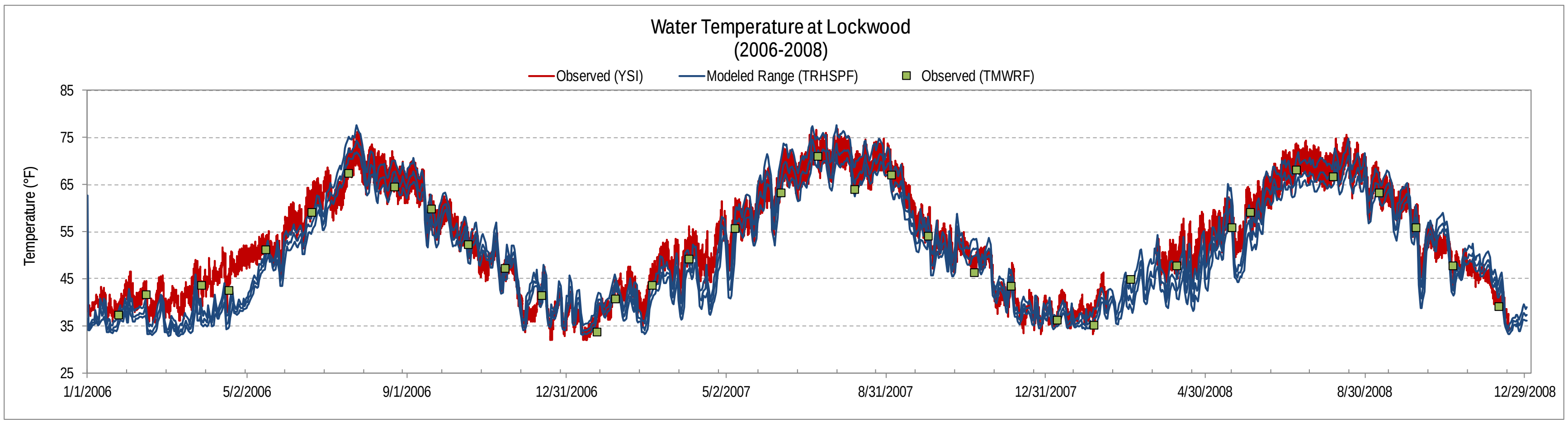
C-5. Comparison of Modeled and Observed Flow near Nixon between 2000 and 2011.



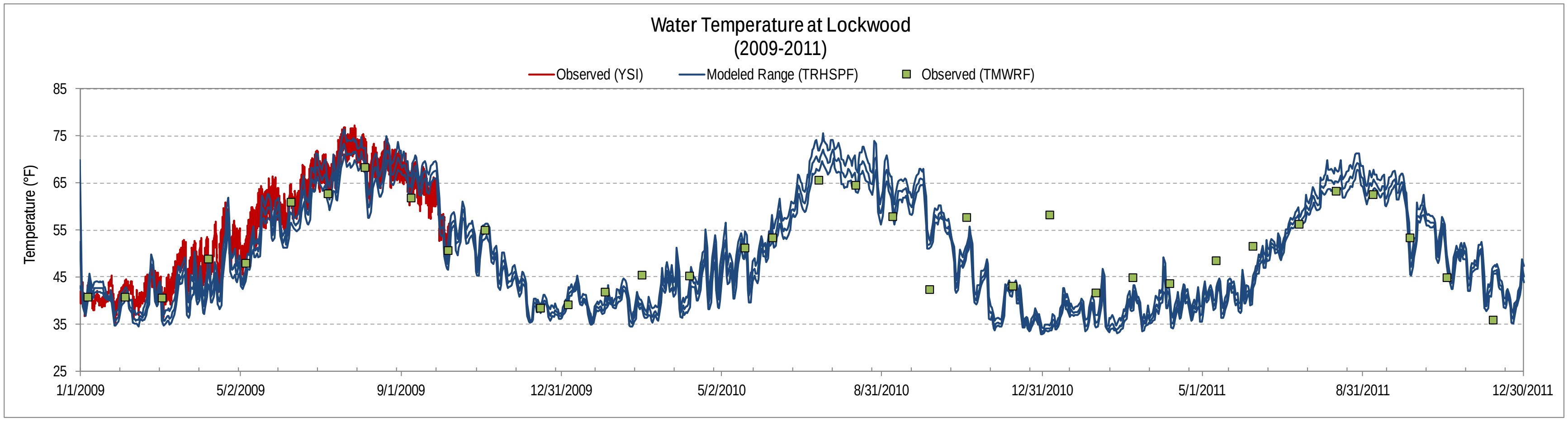
C-6. Comparison of Modeled and Observed Water Temperature at Lockwood between 2000 and 2002.



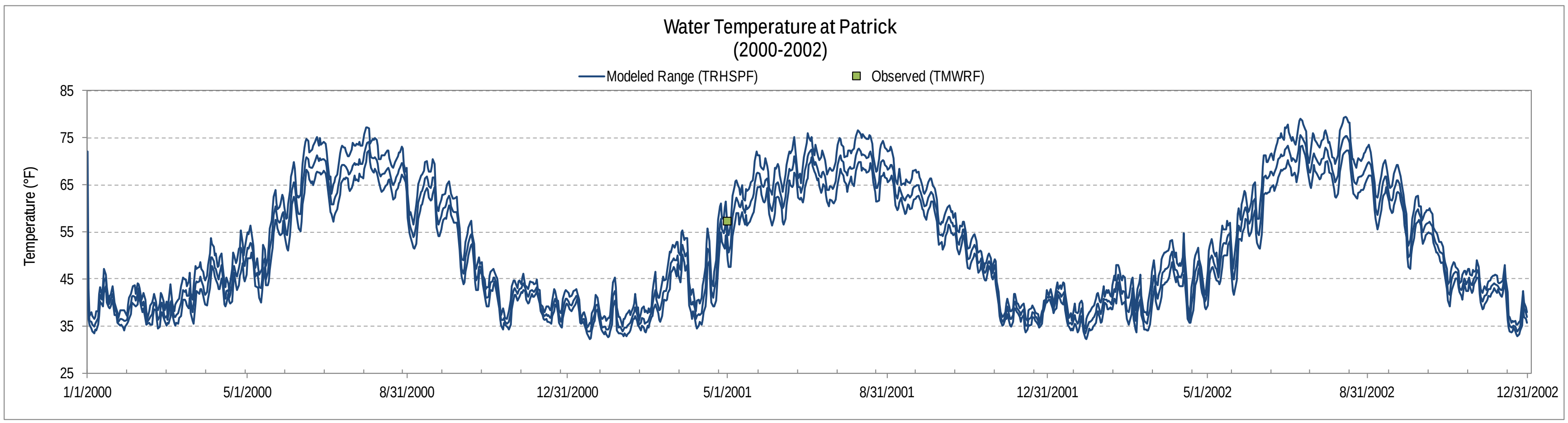
C-7. Comparison of Modeled and Observed Water Temperature at Lockwood between 2003 and 2005.



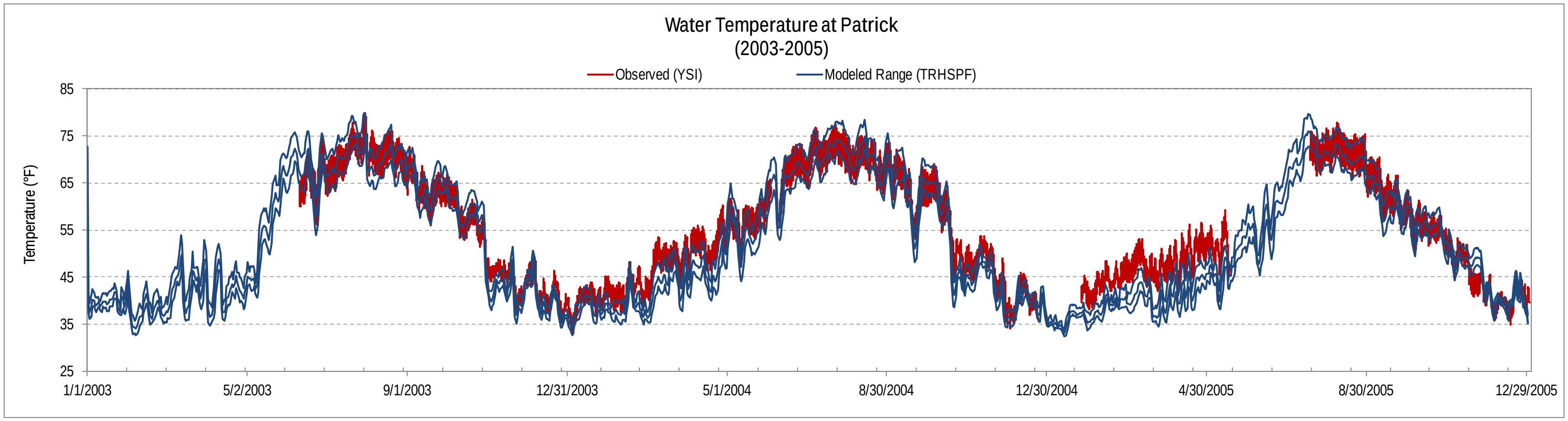
C-8. Comparison of Modeled and Observed Water Temperature at Lockwood between 2006 and 2008.



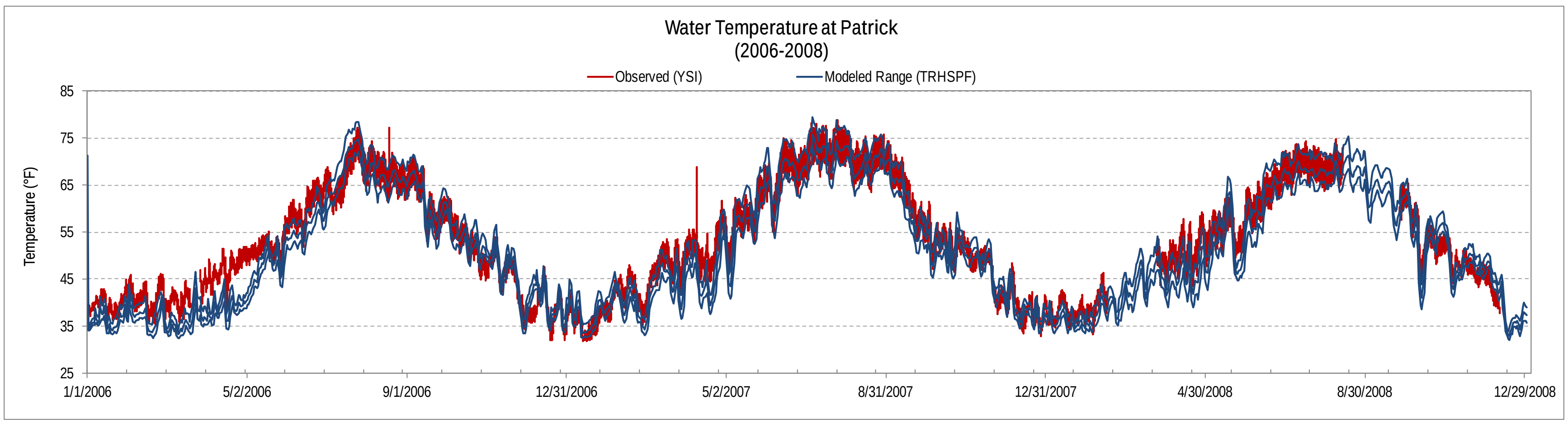
C-9. Comparison of Modeled and Observed Water Temperature at Lockwood between 2009 and 2011.



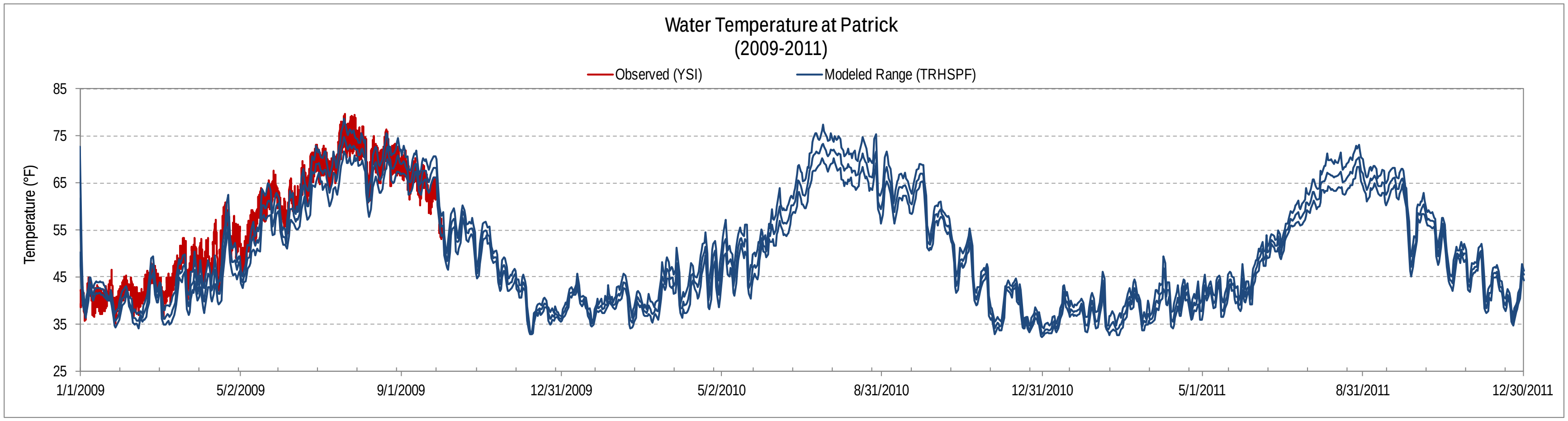
C-10. Comparison of Modeled and Observed Water Temperature at Patrick between 2000 and 2002.



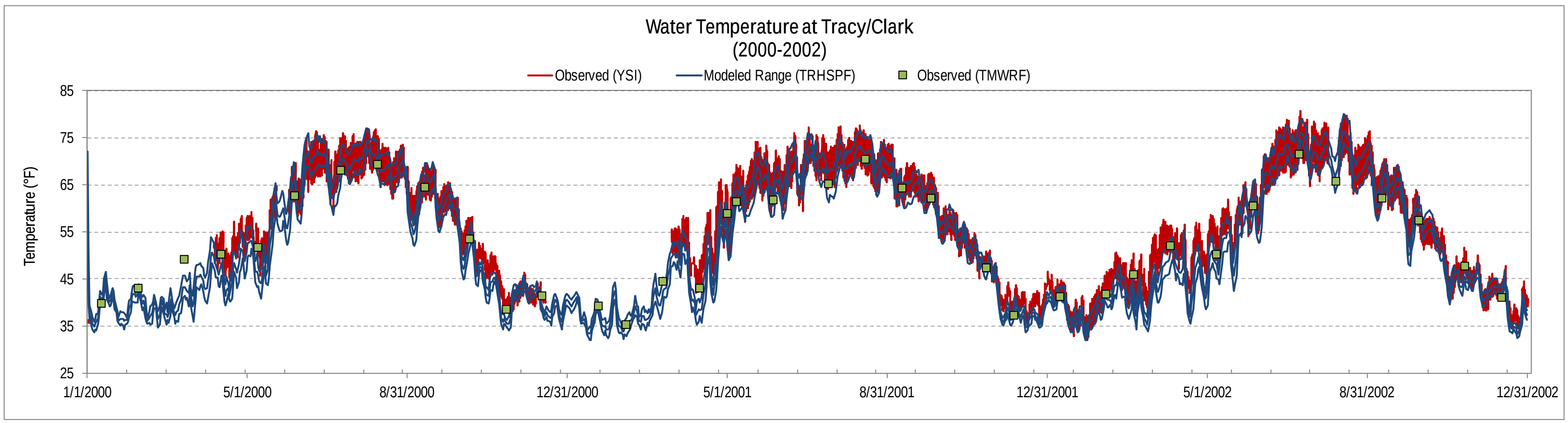
C-11. Comparison of Modeled and Observed Water Temperature at Patrick between 2003 and 2005.



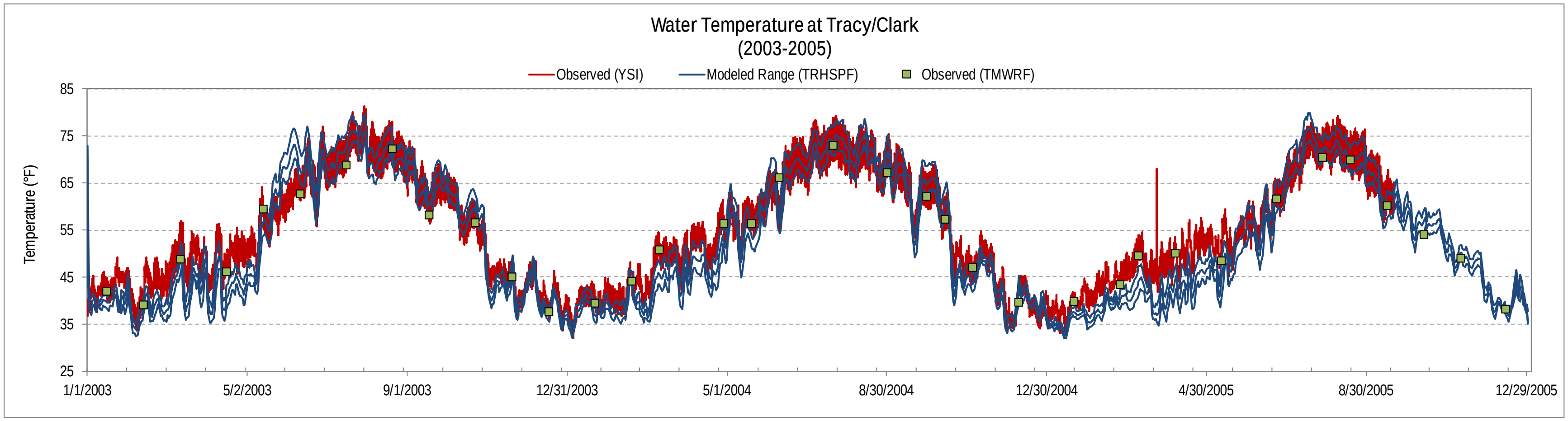
C-12. Comparison of Modeled and Observed Water Temperature at Patrick between 2006 and 2008.



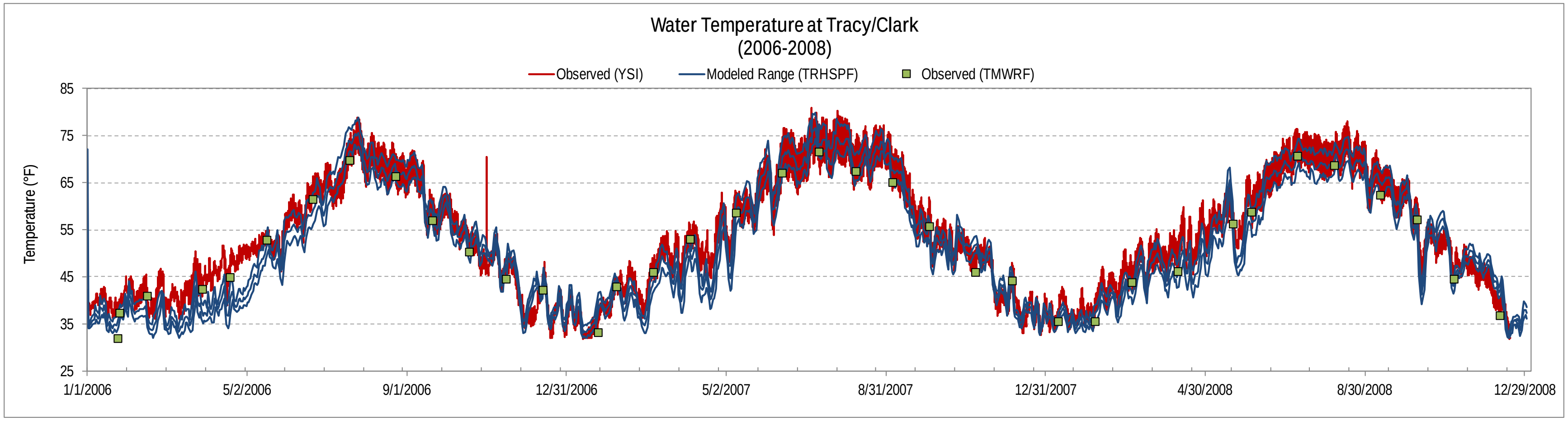
C-13 Comparison of Modeled and Observed Water Temperature at Patrick between 2009 and 2011.



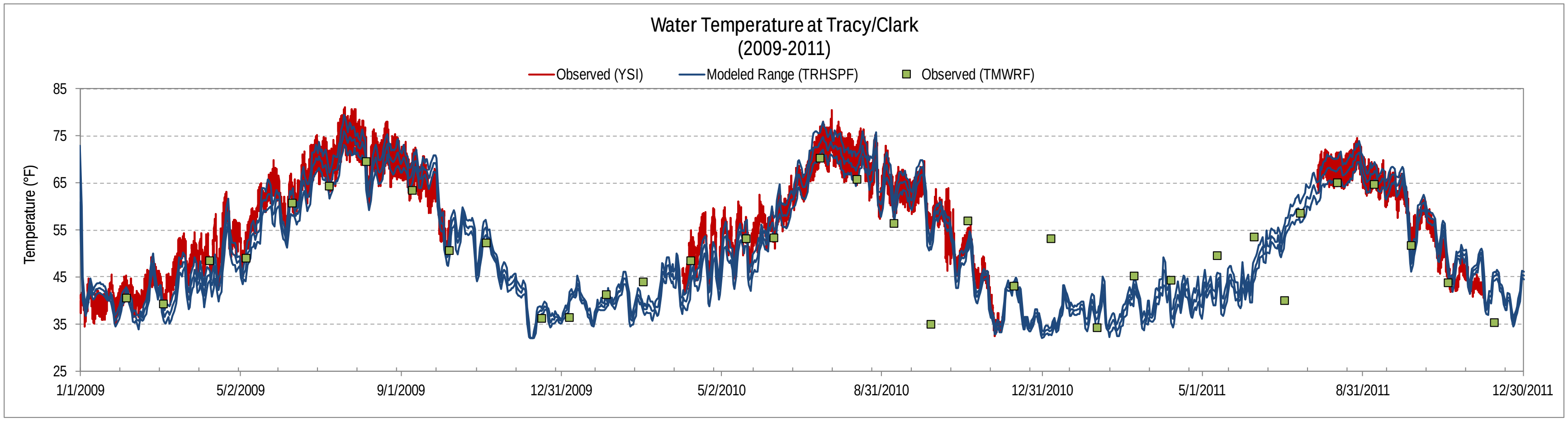
C-14. Comparison of Modeled and Observed Water Temperature at Tracy/Clark between 2000 and 2002.



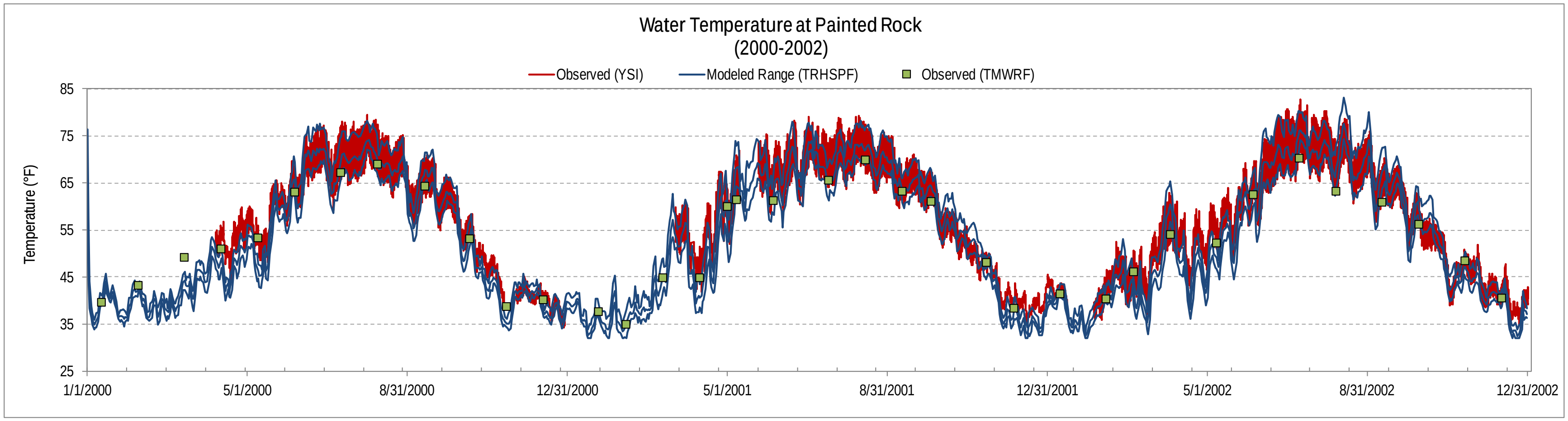
C-15. Comparison of Modeled and Observed Water Temperature at Tracy/Clark between 2003 and 2005.



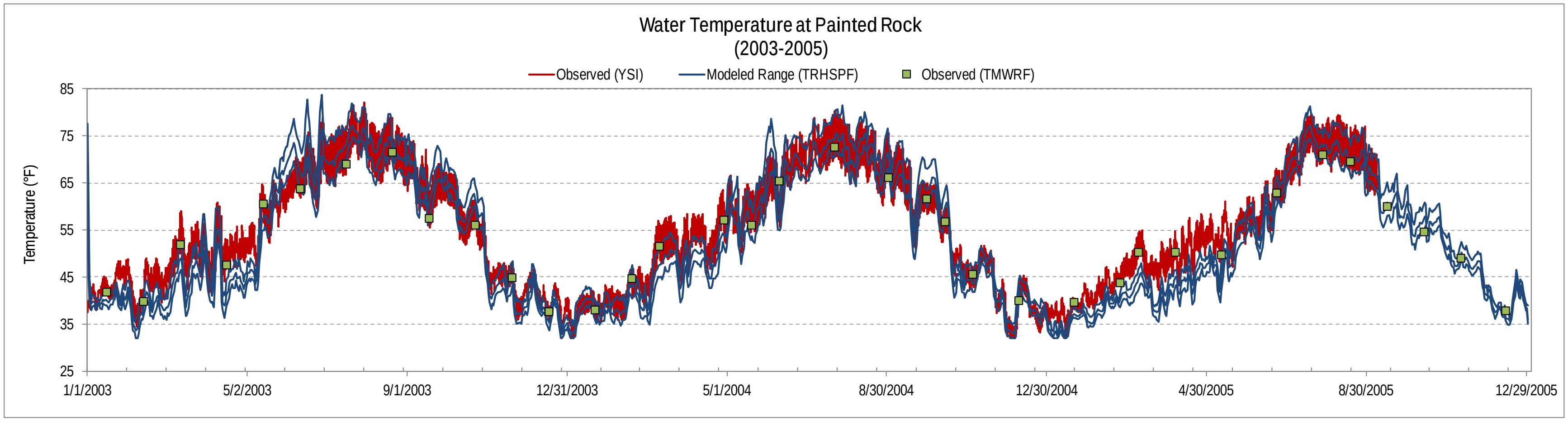
C-16. Comparison of Modeled and Observed Water Temperature at Tracy/Clark between 2006 and 2008.



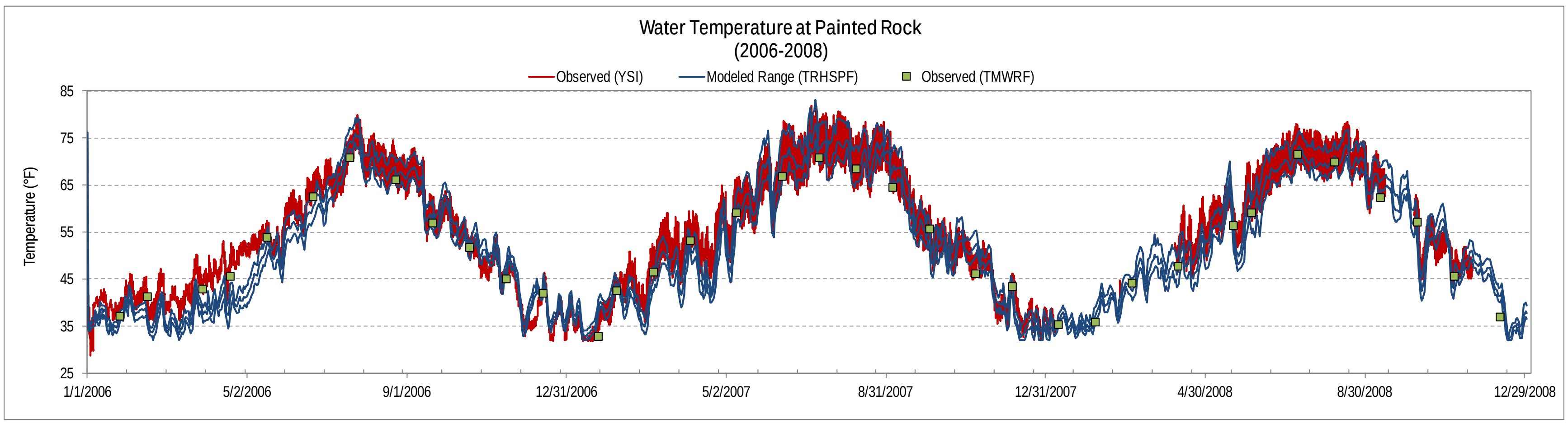
C-17. Comparison of Modeled and Observed Water Temperature at Tracy/Clark between 2009 and 2011.



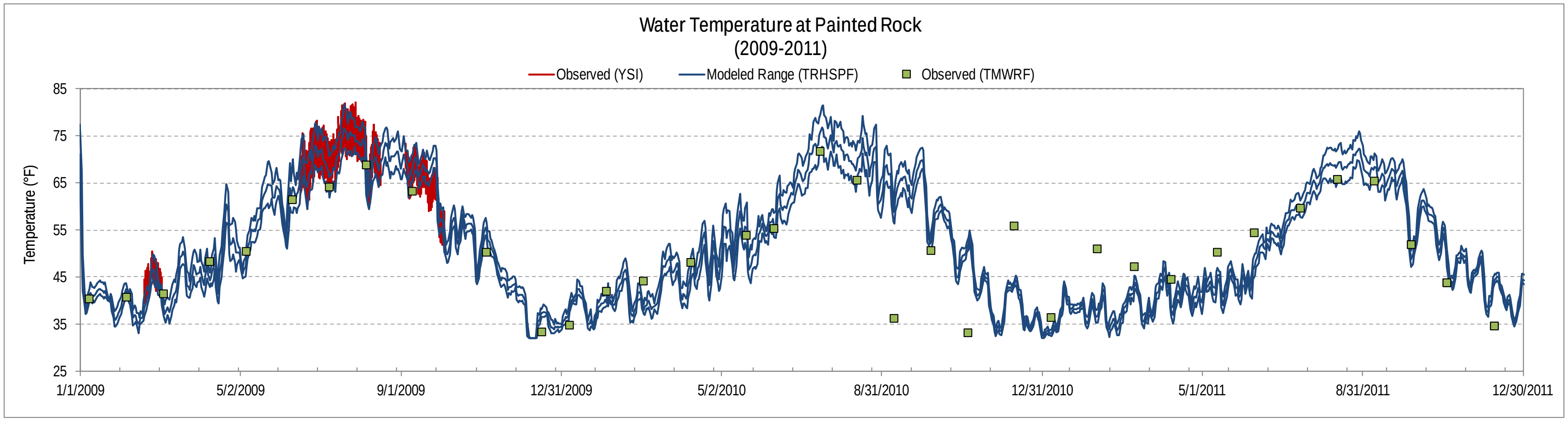
C-18. Comparison of Modeled and Observed Water Temperature at Painted Rock between 2000 and 2002.



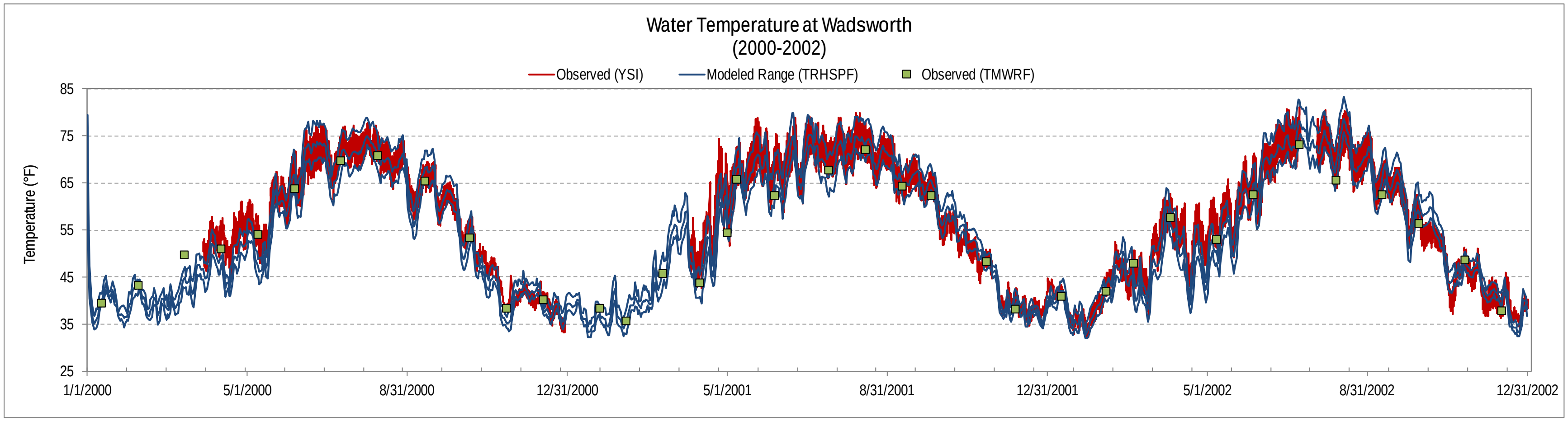
C-19. Comparison of Modeled and Observed Water Temperature at Painted Rock between 2003 and 2005.



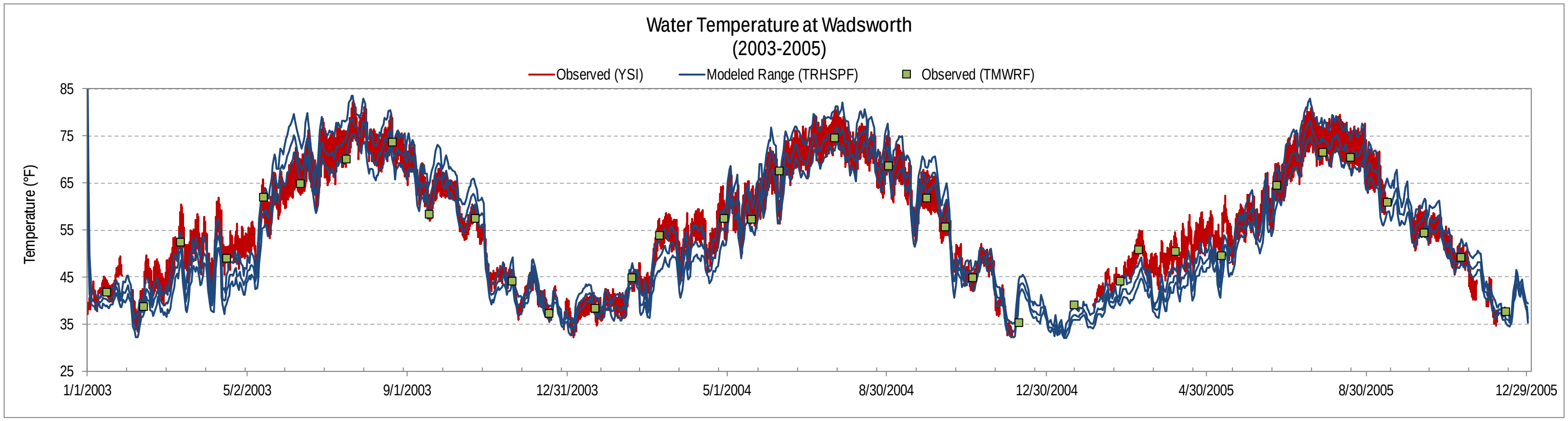
C-20. Comparison of Modeled and Observed Water Temperature at Painted Rock between 2006 and 2008.



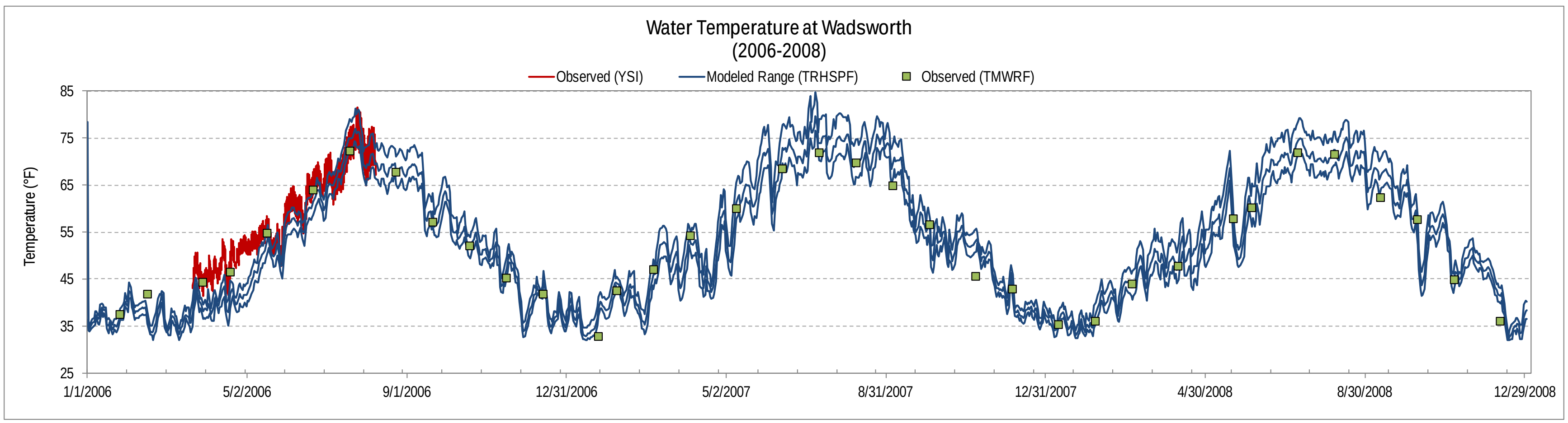
C-21. Comparison of Modeled and Observed Water Temperature at Painted Rock between 2009 and 2011.



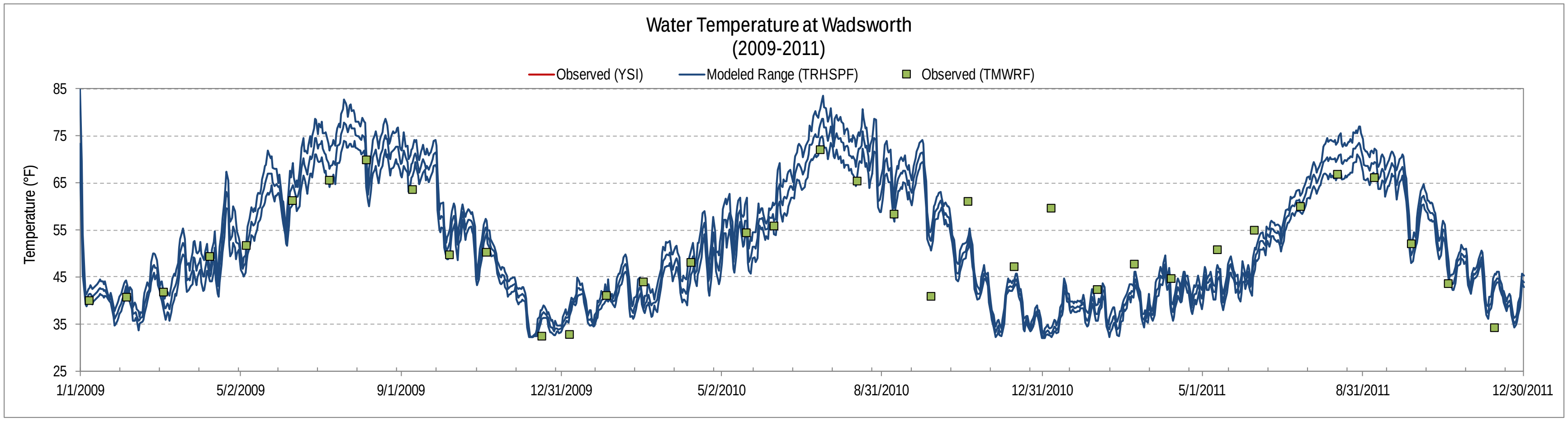
C-22. Comparison of Modeled and Observed Water Temperature at Wadsworth between 2000 and 2002.



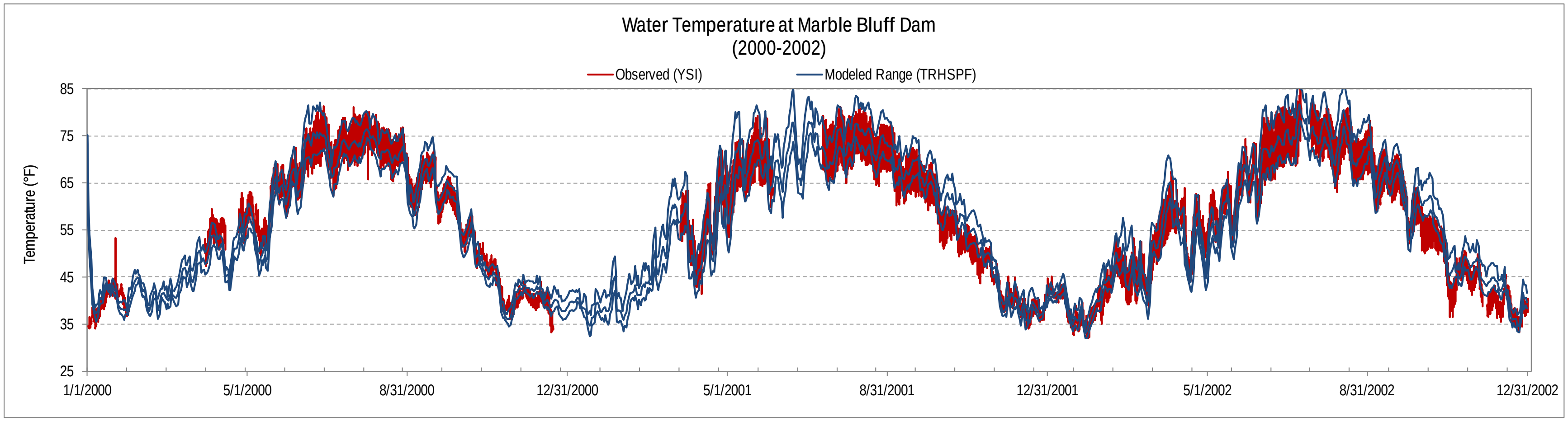
C-23. Comparison of Modeled and Observed Water Temperature at Wadsworth between 2003 and 2005.



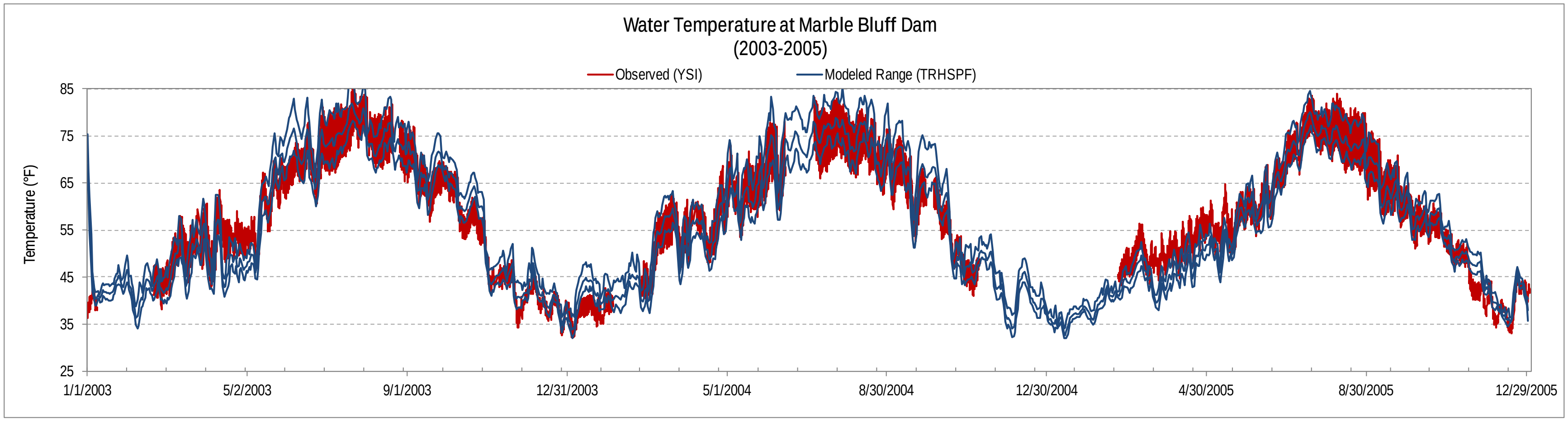
C-24. Comparison of Modeled and Observed Water Temperature at Wadsworth between 2006 and 2008.



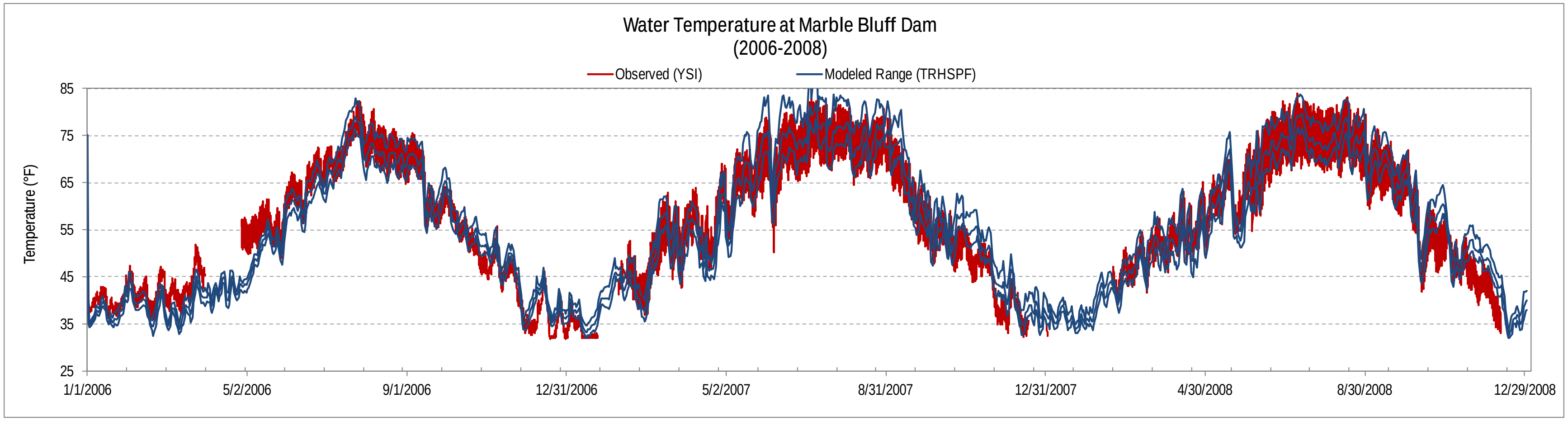
C-25. Comparison of Modeled and Observed Water Temperature at Wadsworth between 2009 and 2011.



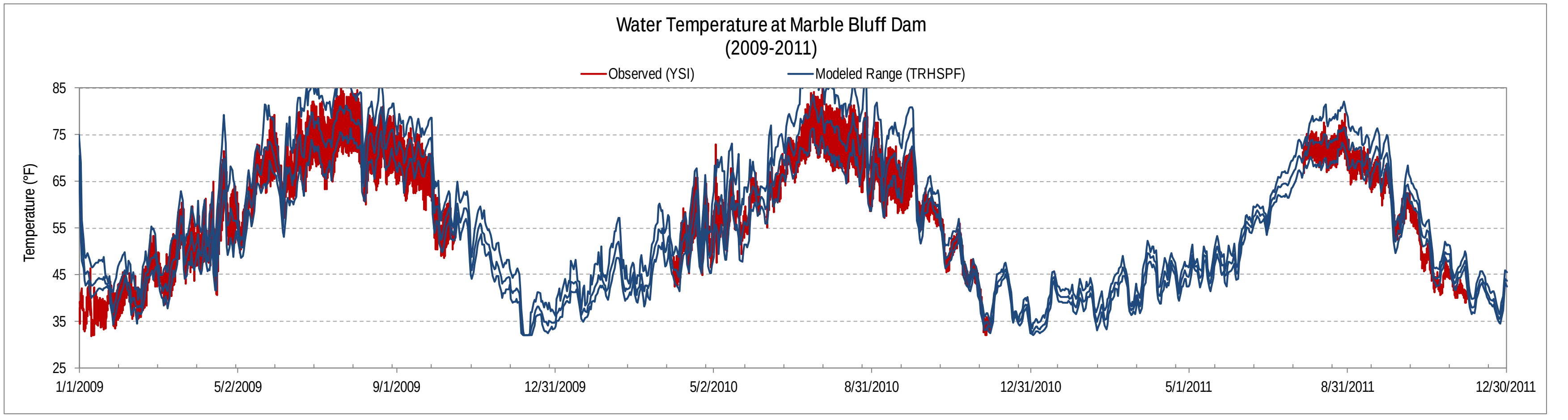
C-26. Comparison of Modeled and Observed Water Temperature at Marble Bluff Dam between 2000 and 2002.



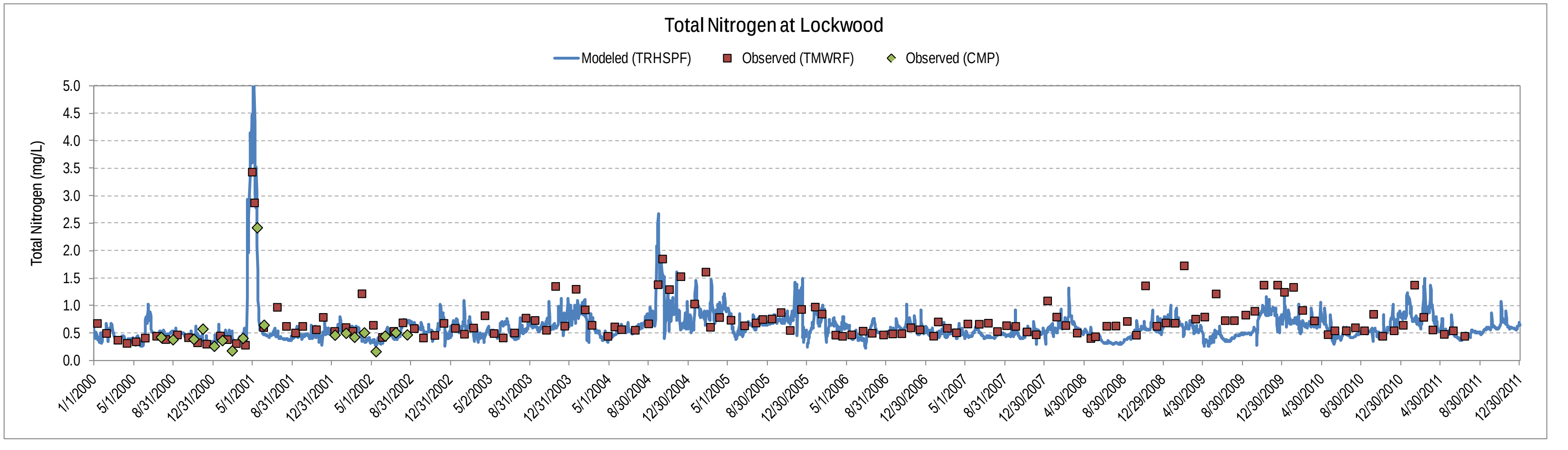
C-27. Comparison of Modeled and Observed Water Temperature at Marble Bluff Dam between 2003 and 2005.



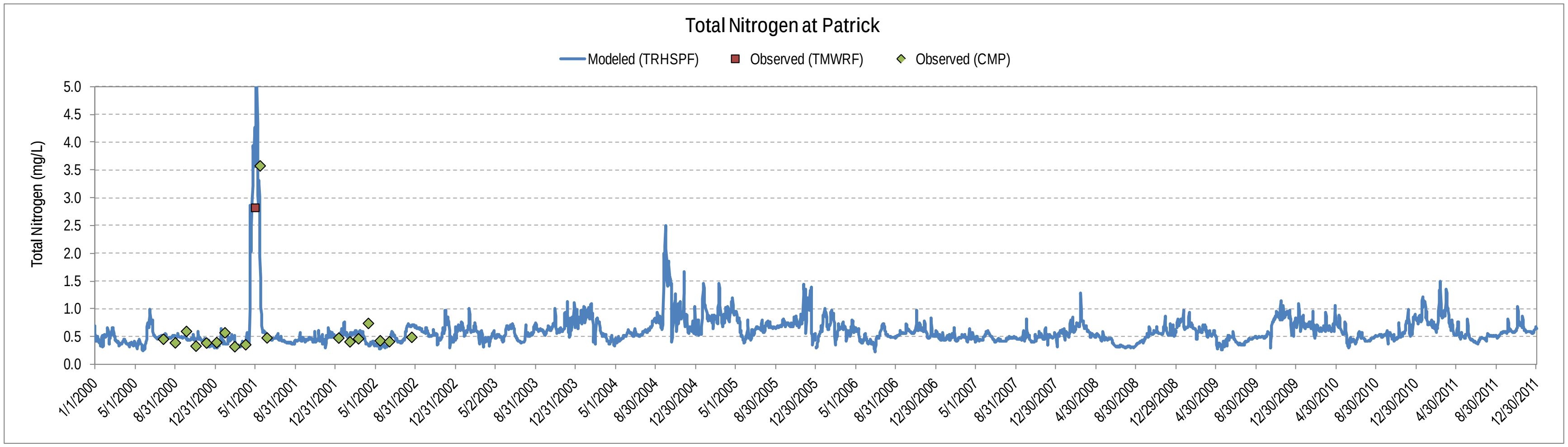
C-28. Comparison of Modeled and Observed Water Temperature at Marble Bluff Dam between 2006 and 2008.



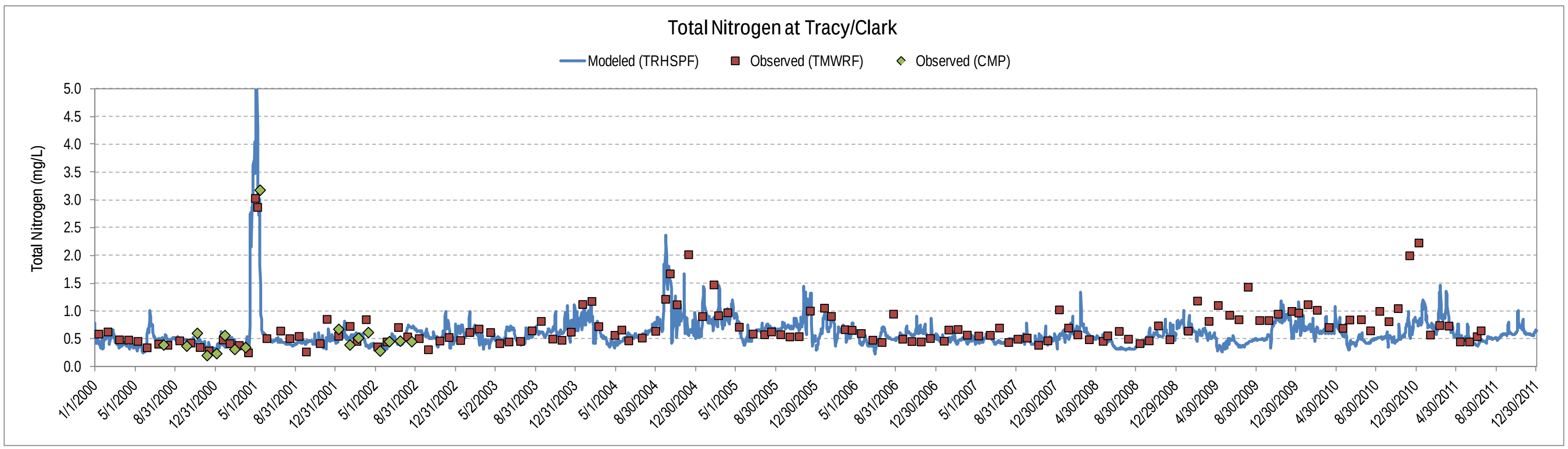
C-29. Comparison of Modeled and Observed Water Temperature at Marble Bluff Dam between 2009 and 2011.



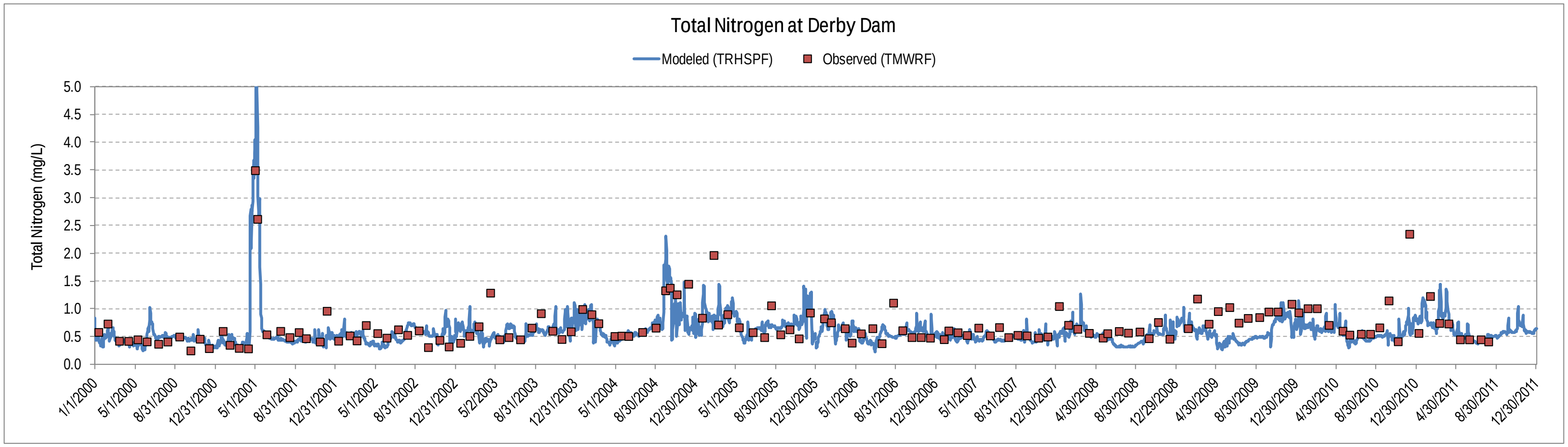
C-30. Comparison of Modeled and Observed Total Nitrogen at Lockwood between 2000 and 2011.



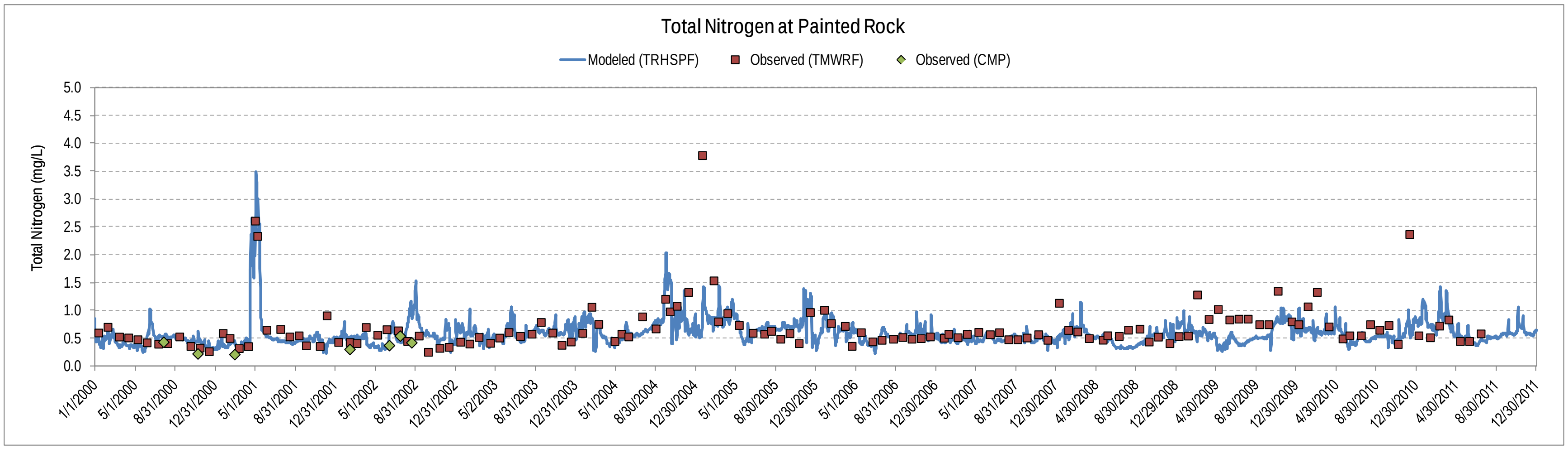
C-31. Comparison of Modeled and Observed Total Nitrogen at Patrick between 2000 and 2011.



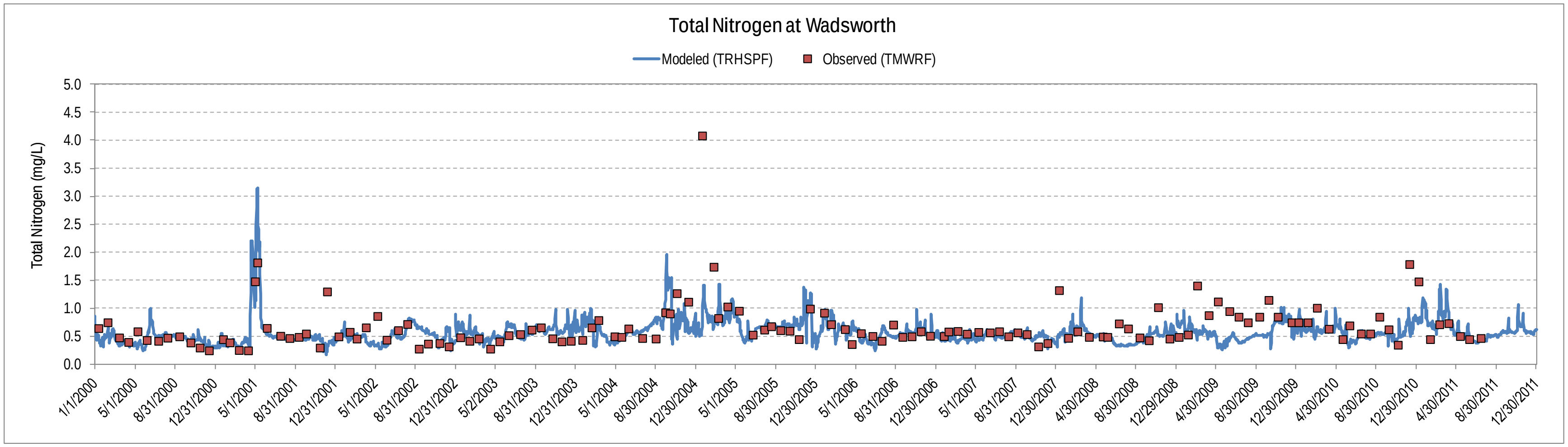
C-32. Comparison of Modeled and Observed Total Nitrogen at Tracy/Clark between 2000 and 2011.



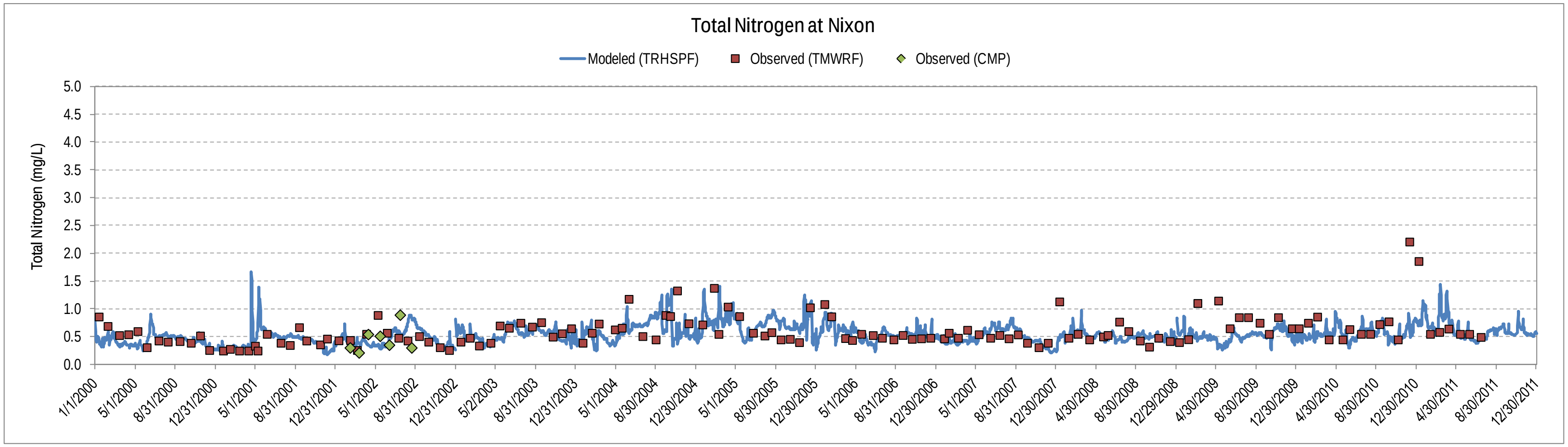
C-33. Comparison of Modeled and Observed Total Nitrogen at Derby Dam between 2000 and 2011.



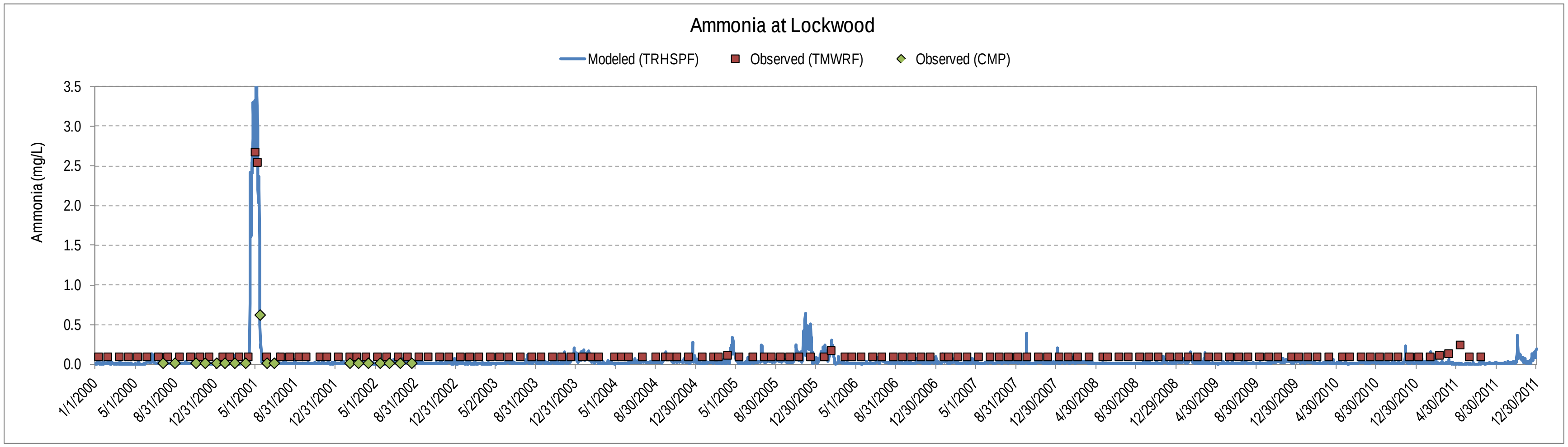
C-34. Comparison of Modeled and Observed Total Nitrogen at Painted Rock between 2000 and 2011.



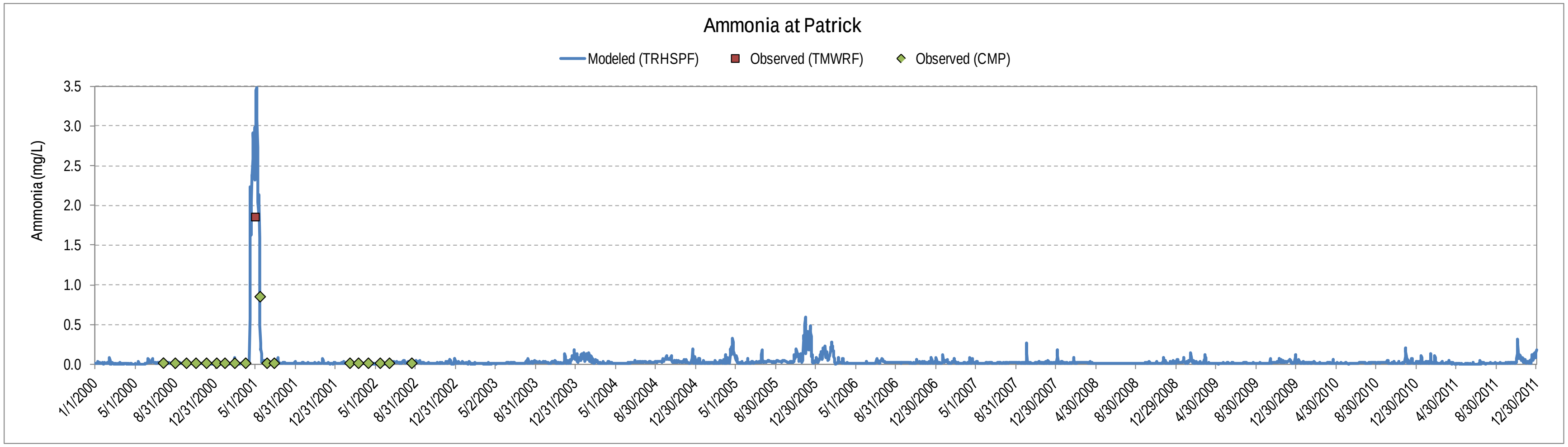
C-35. Comparison of Modeled and Observed Total Nitrogen at Wadsworth between 2000 and 2011.



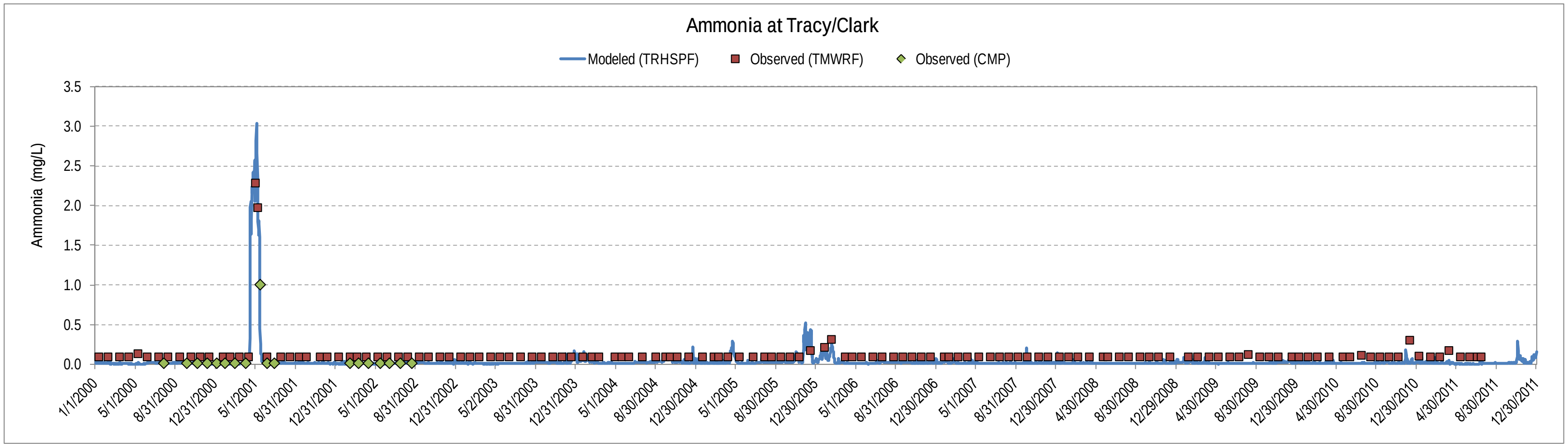
C-36. Comparison of Modeled and Observed Total Nitrogen at Nixon between 2000 and 2011.



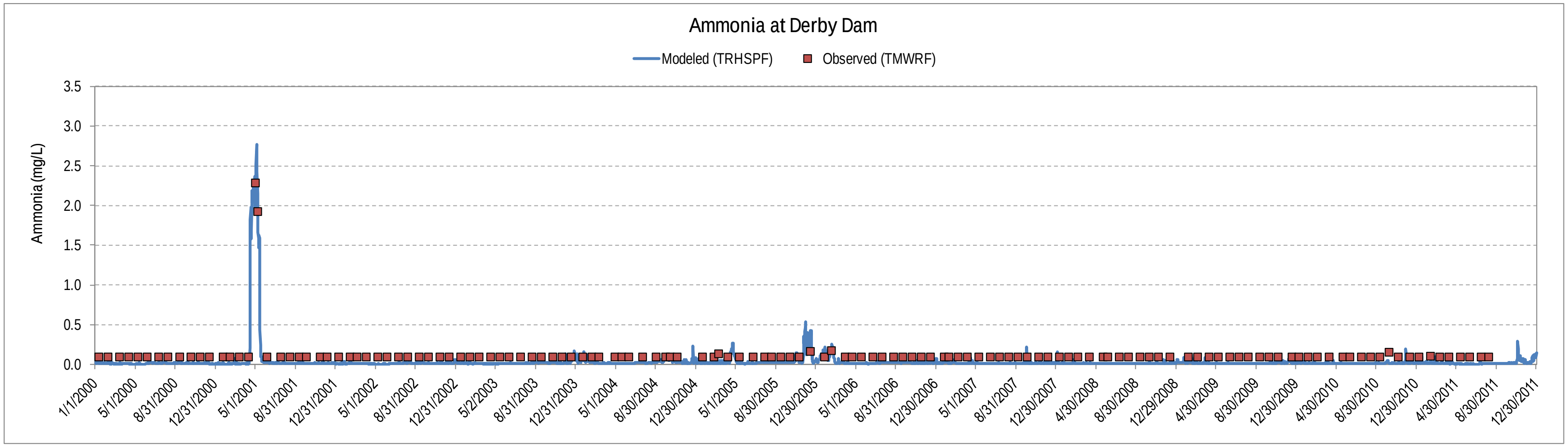
C-37. Comparison of Modeled and Observed Ammonia at Lockwood between 2000 and 2011. 84% of the Ammonia data points were reported as <PQL. The PQL for Ammonia is 0.1 mg/L.



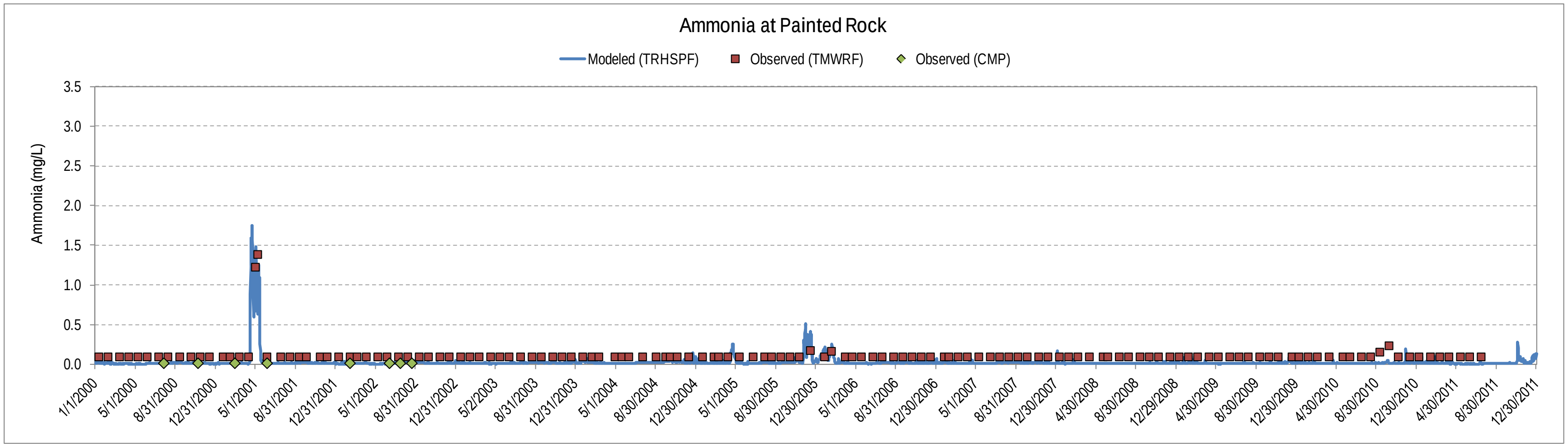
C-38. Comparison of Modeled and Observed Ammonia at Patrick between 2000 and 2011.



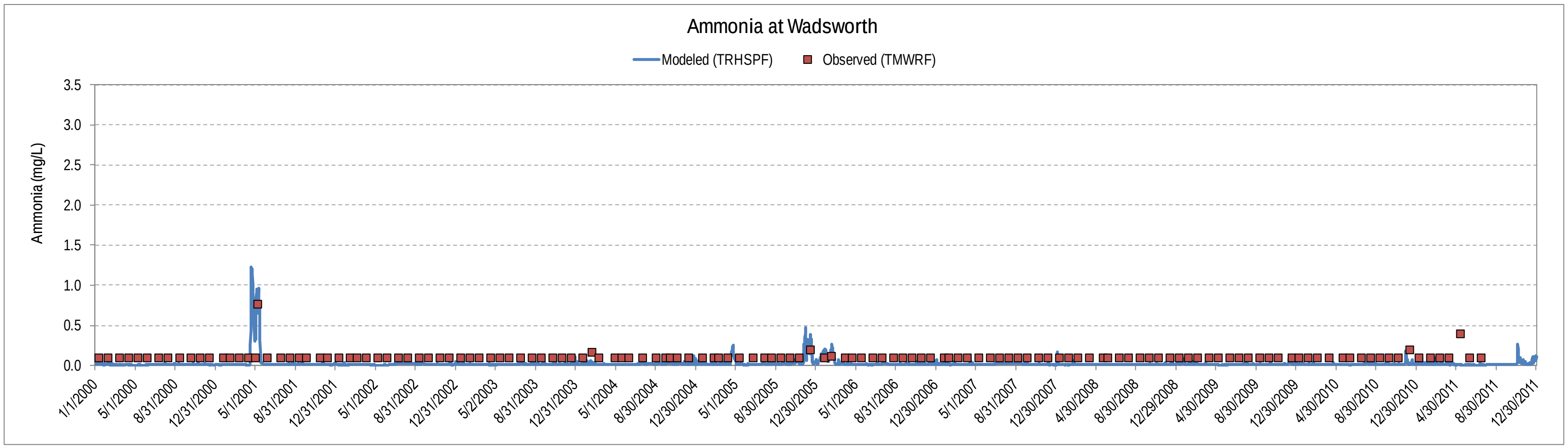
C-39. Comparison of Modeled and Observed Ammonia at Tracy/Clark between 2000 and 2011. 81% of the Ammonia data points were reported as <PQL. The PQL for Ammonia is 0.1 mg/L.



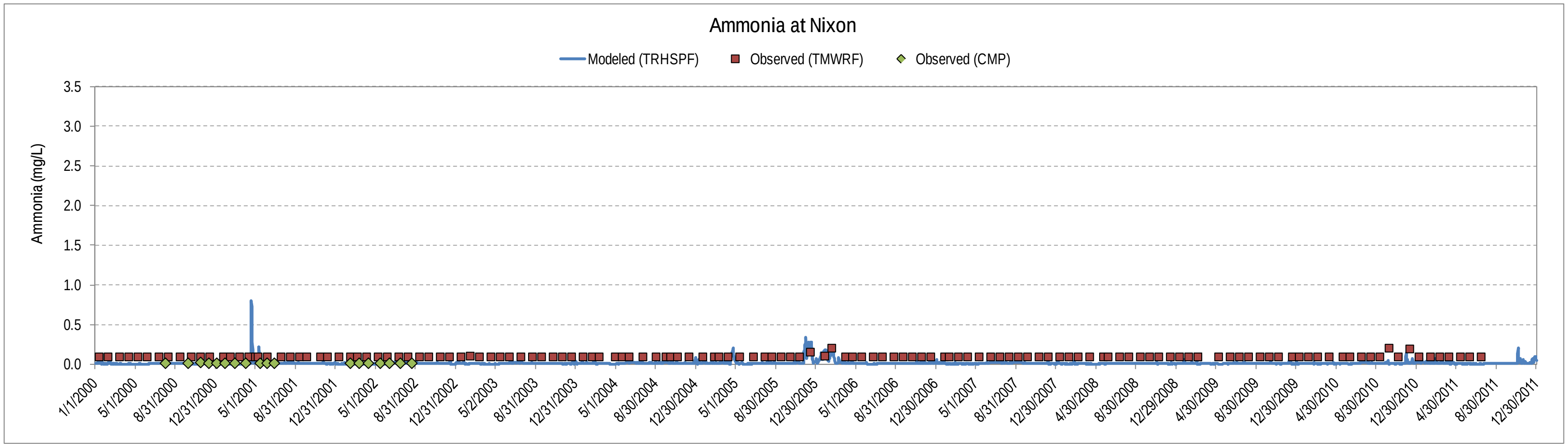
C-40. Comparison of Modeled and Observed Ammonia at Derby Dam between 2000 and 2011. 94% of the Ammonia data points were reported as <PQL. The PQL for Ammonia is 0.1 mg/L.



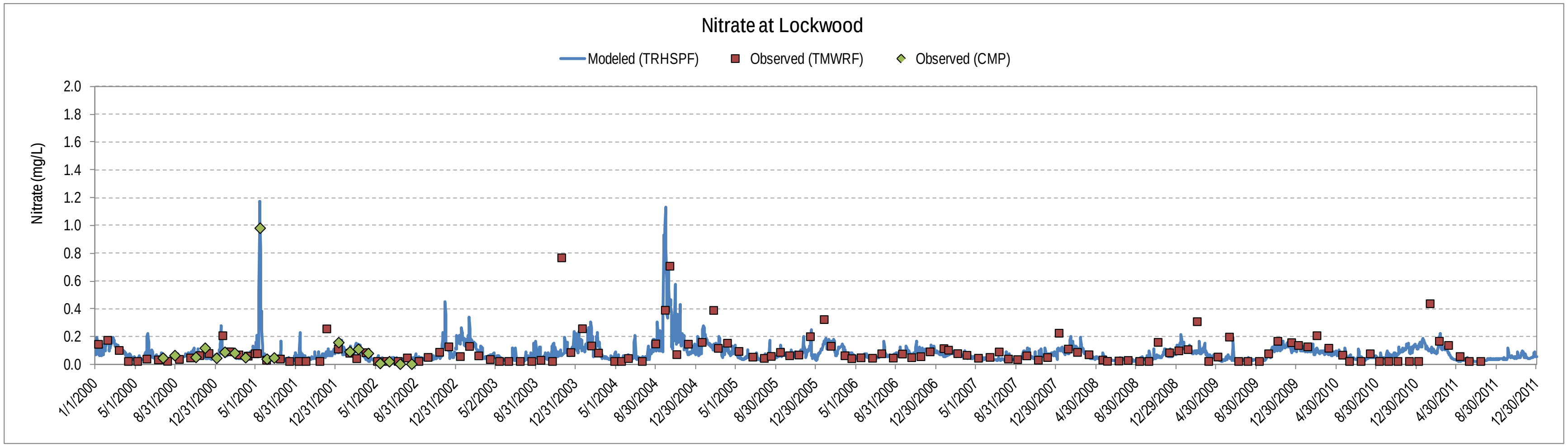
C-41. Comparison of Modeled and Observed Ammonia at Painted Rock between 2000 and 2011. 91% of the Ammonia data points were reported as <PQL. The PQL for Ammonia is 0.1 mg/L.



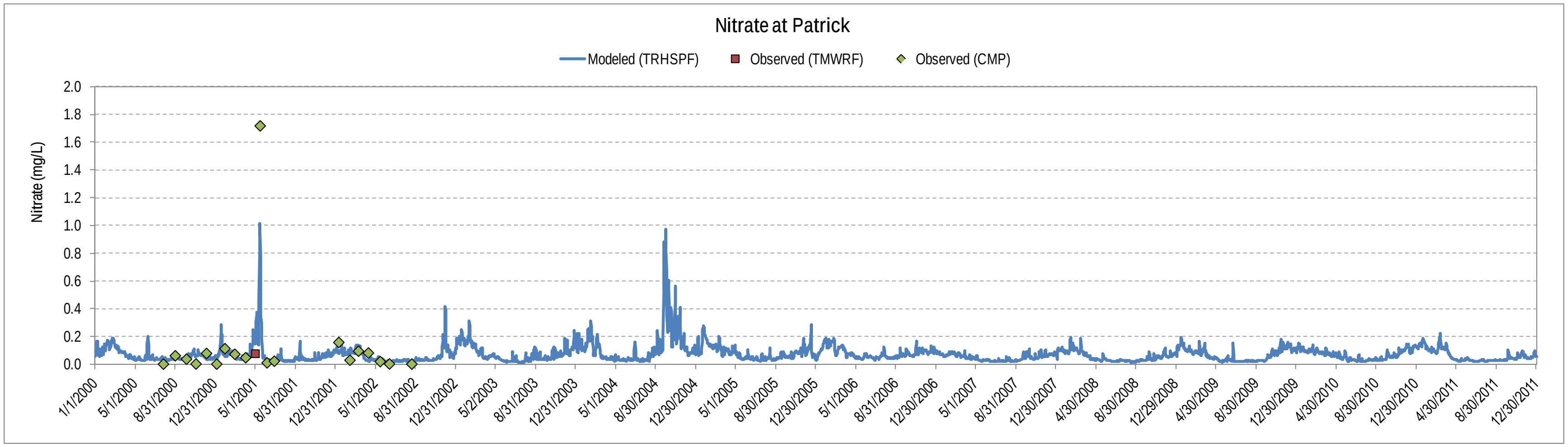
C-42. Comparison of Modeled and Observed Ammonia at Wadsworth between 2000 and 2011. 95% of the Ammonia data points were reported as <PQL. The PQL for Ammonia is 0.1 mg/L.



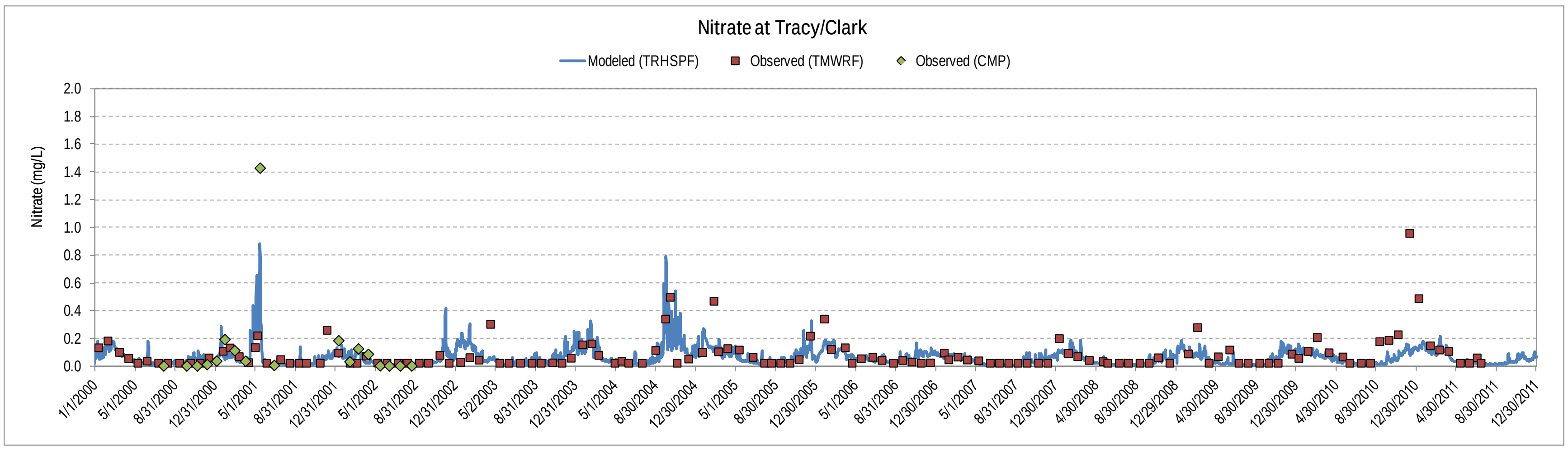
C-43. Comparison of Modeled and Observed Ammonia at Nixon between 2000 and 2011. 85% of the Ammonia data points were reported as <PQL. The PQL for Ammonia is 0.1 mg/L.



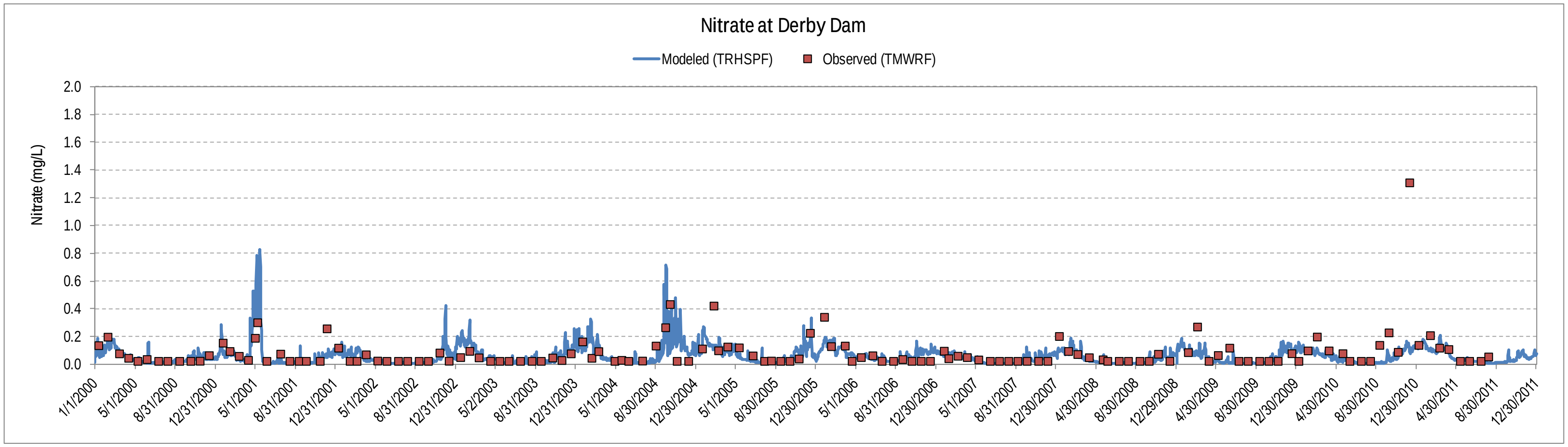
C-44. Comparison of Modeled and Observed Nitrate at Lockwood between 2000 and 2011. 21% of the Nitrate data points were reported as <PQL. The PQL for Nitrate is 0.025 mg/L.



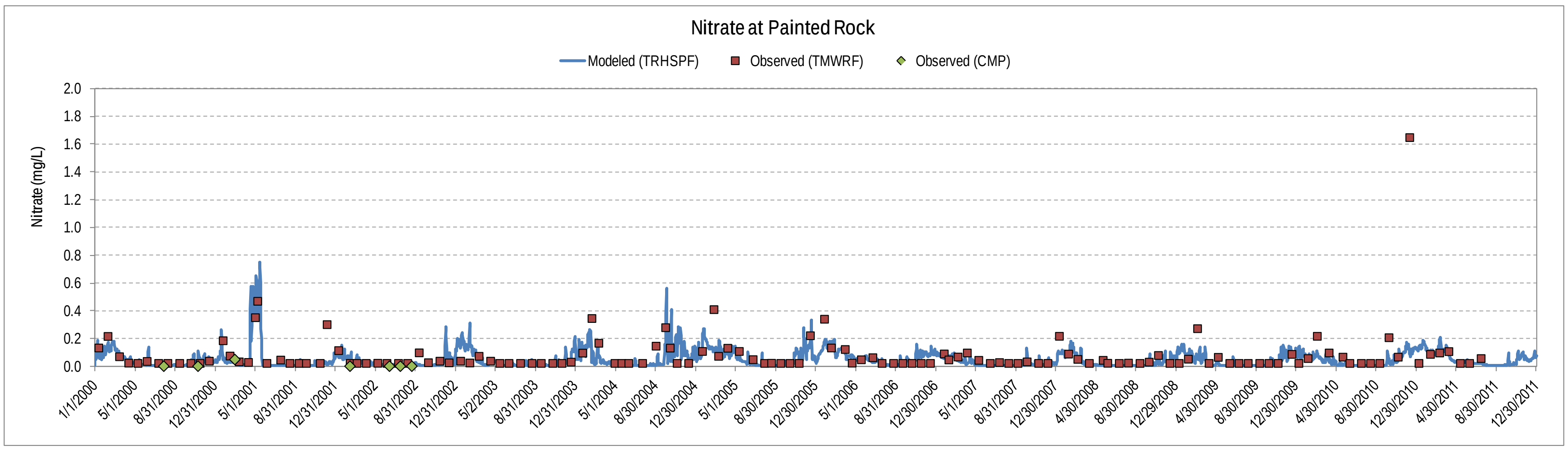
C-45. Comparison of Modeled and Observed Nitrate at Patrick between 2000 and 2011.



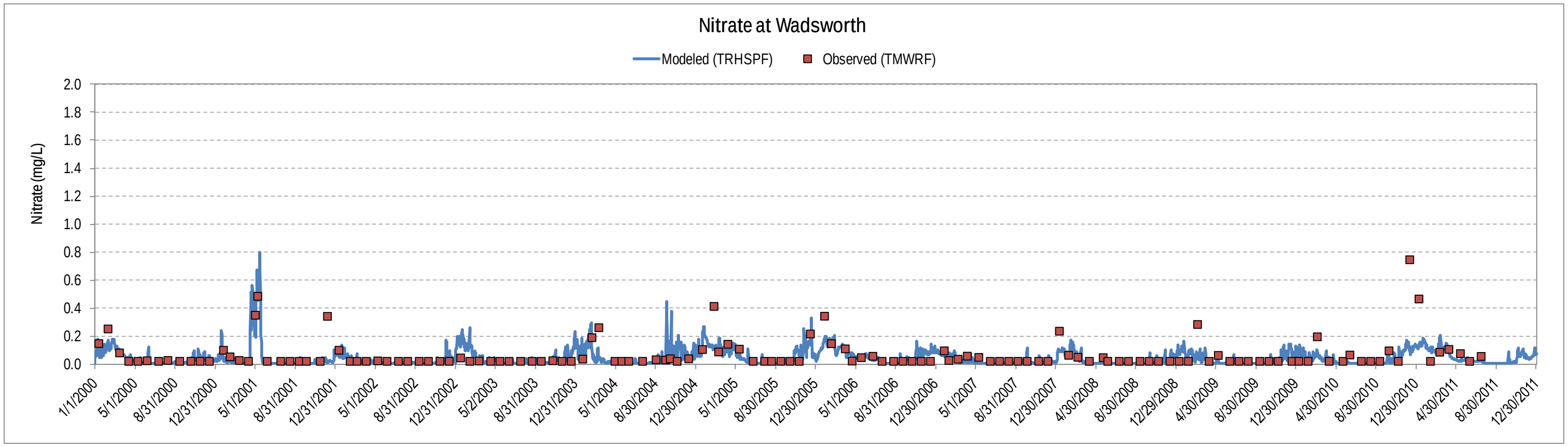
C-46. Comparison of Modeled and Observed Nitrate at Tracy/Clark between 2000 and 2011. 38% of the Nitrate data points were reported as <PQL. The PQL for Nitrate is 0.025 mg/L.



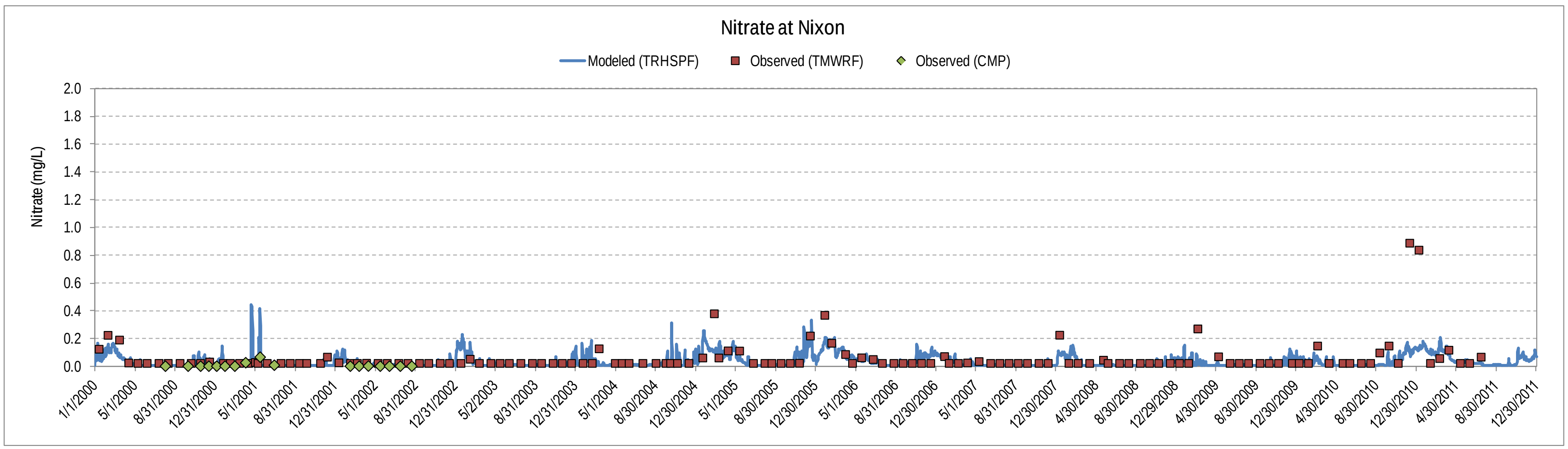
C-47. Comparison of Modeled and Observed Nitrate at Derby Dam between 2000 and 2011. 41% of the Nitrate data points were reported as <PQL. The PQL for Nitrate is 0.025 mg/L.



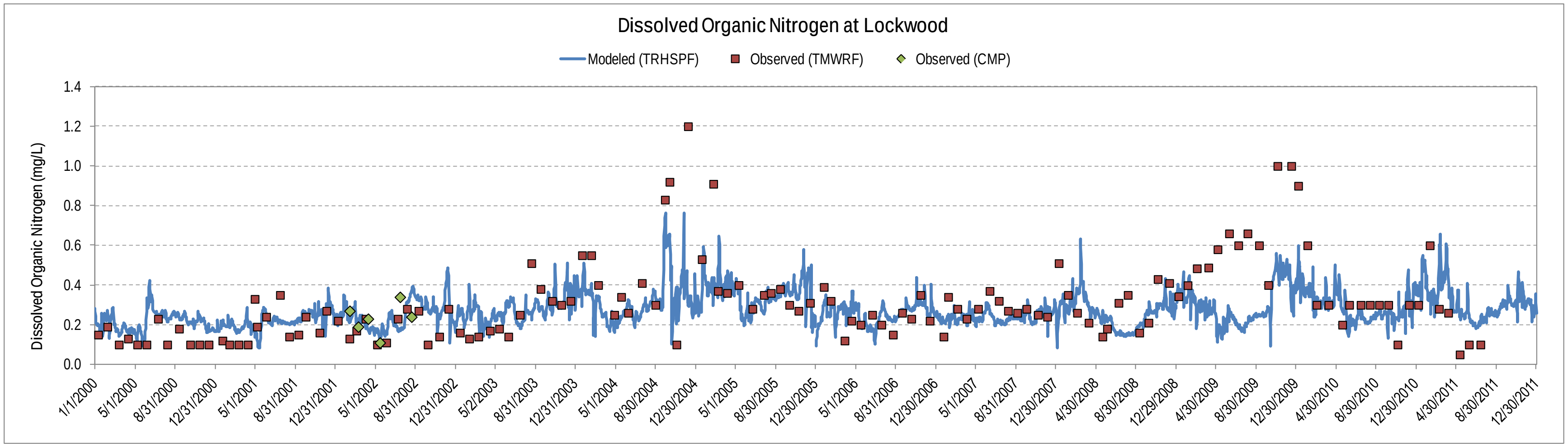
C-48. Comparison of Modeled and Observed Nitrate at Painted Rock between 2000 and 2011. 43% of the Nitrate data points were reported as <PQL. The PQL for Nitrate is 0.025 mg/L.



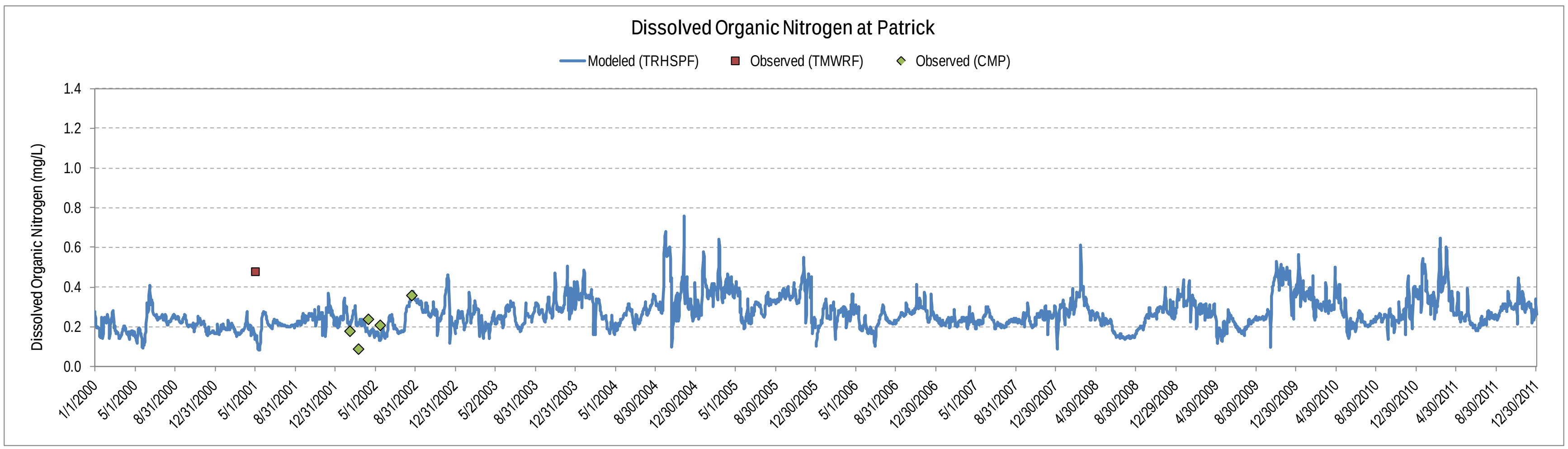
C-49. Comparison of Modeled and Observed Nitrate at Wadsworth between 2000 and 2011. 60% of the Nitrate data points were reported as <PQL. The PQL for Nitrate is 0.025 mg/L.



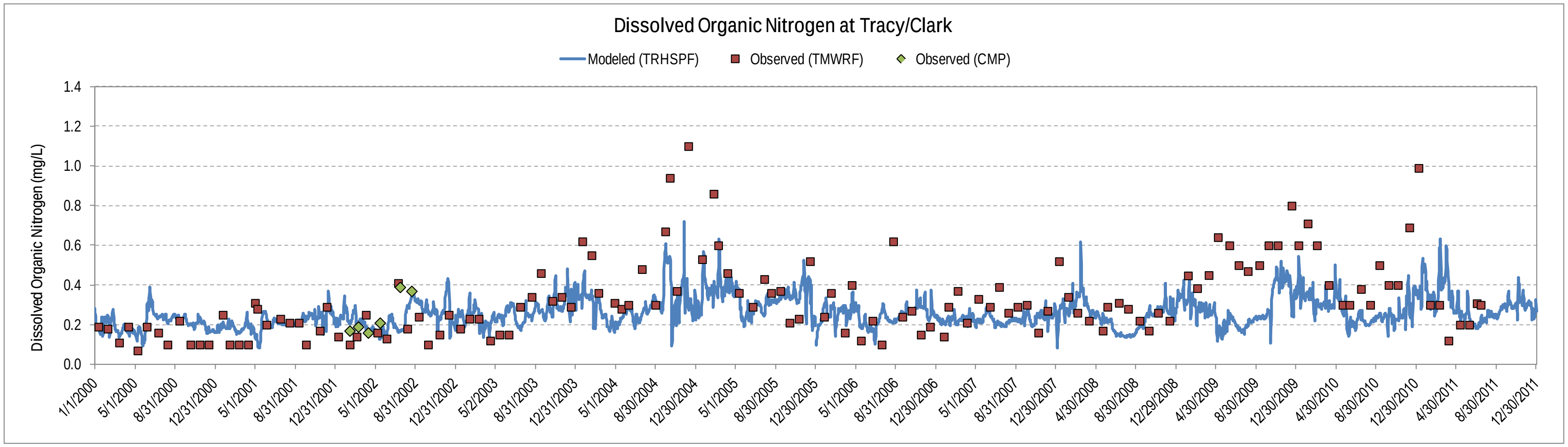
C-50. Comparison of Modeled and Observed Nitrate at Nixon between 2000 and 2011. 64% of the Nitrate data points were reported as <PQL. The PQL for Nitrate is 0.025 mg/L.



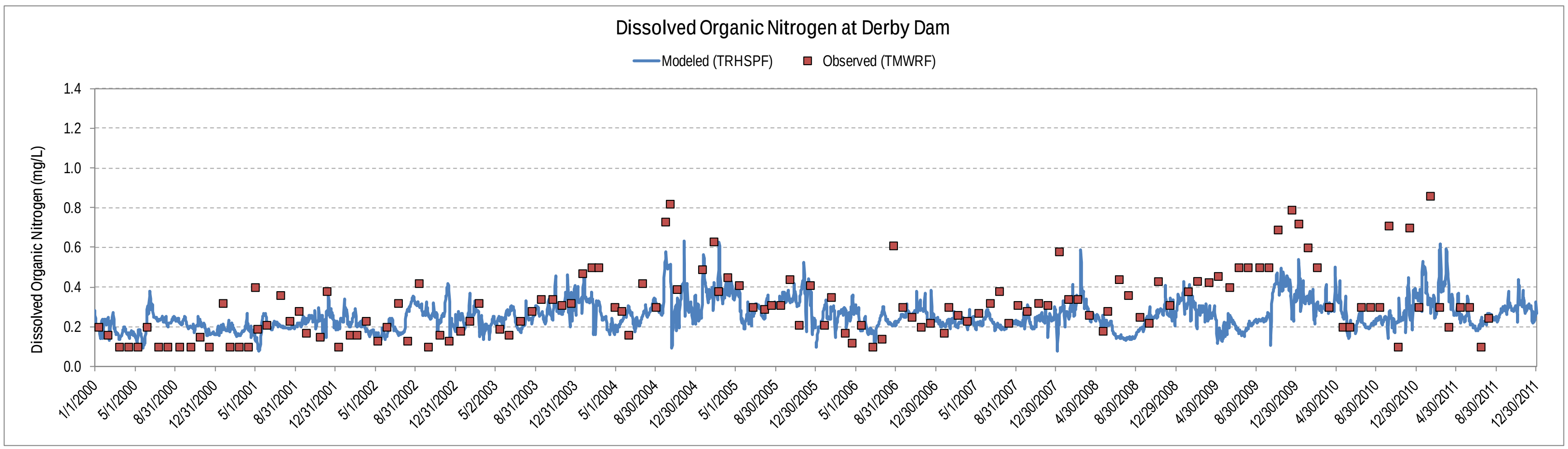
C-51. Comparison of Modeled and Observed Dissolved Organic Nitrogen at Lockwood between 2000 and 2011.



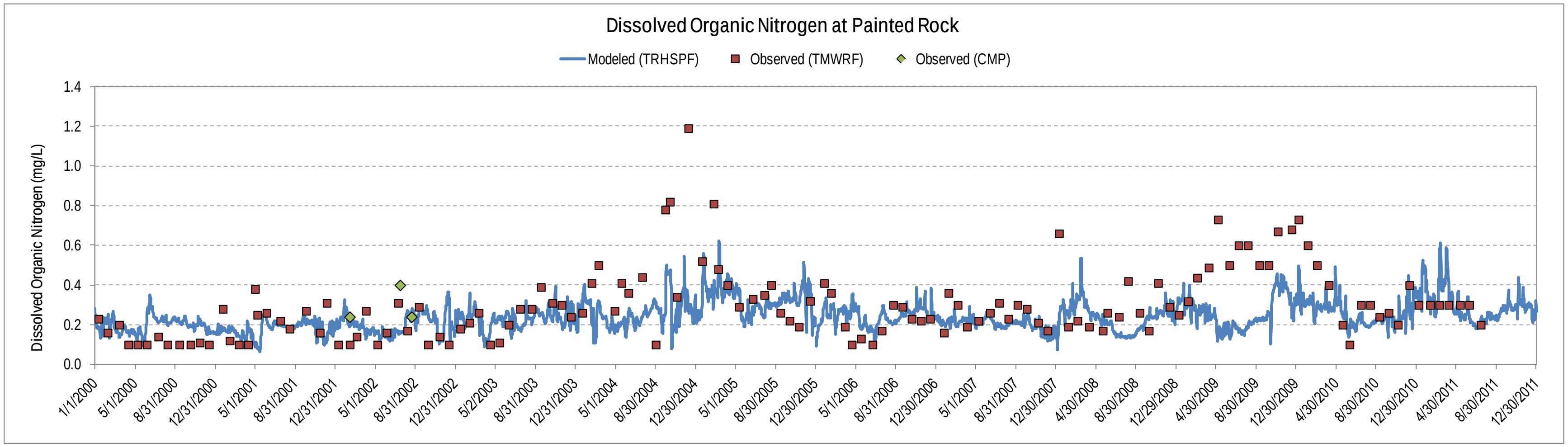
C-52. Comparison of Modeled and Observed Dissolved Organic Nitrogen at Patrick between 2000 and 2011.



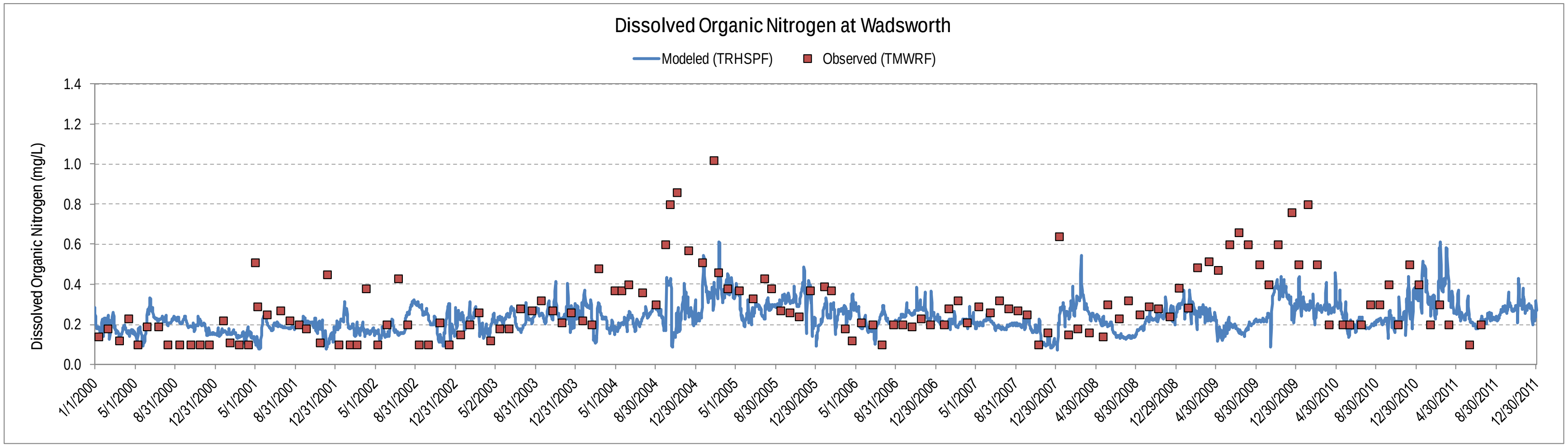
C-53. Comparison of Modeled and Observed Dissolved Organic Nitrogen at Tracy/Clark between 2000 and 2011.



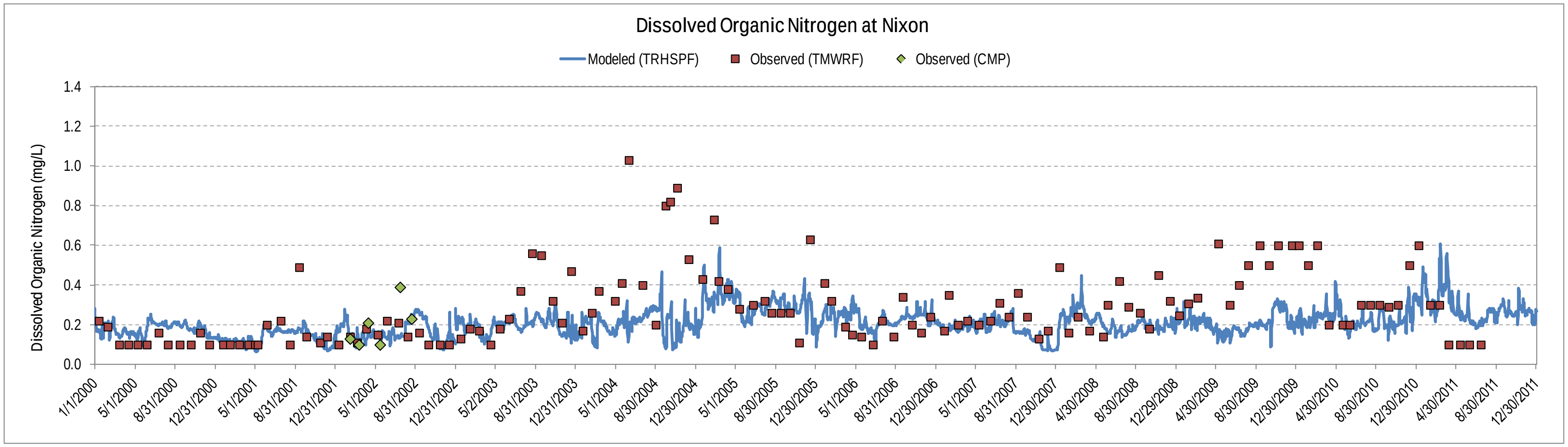
C-54. Comparison of Modeled and Observed Dissolved Organic Nitrogen at Derby Dam between 2000 and 2011.



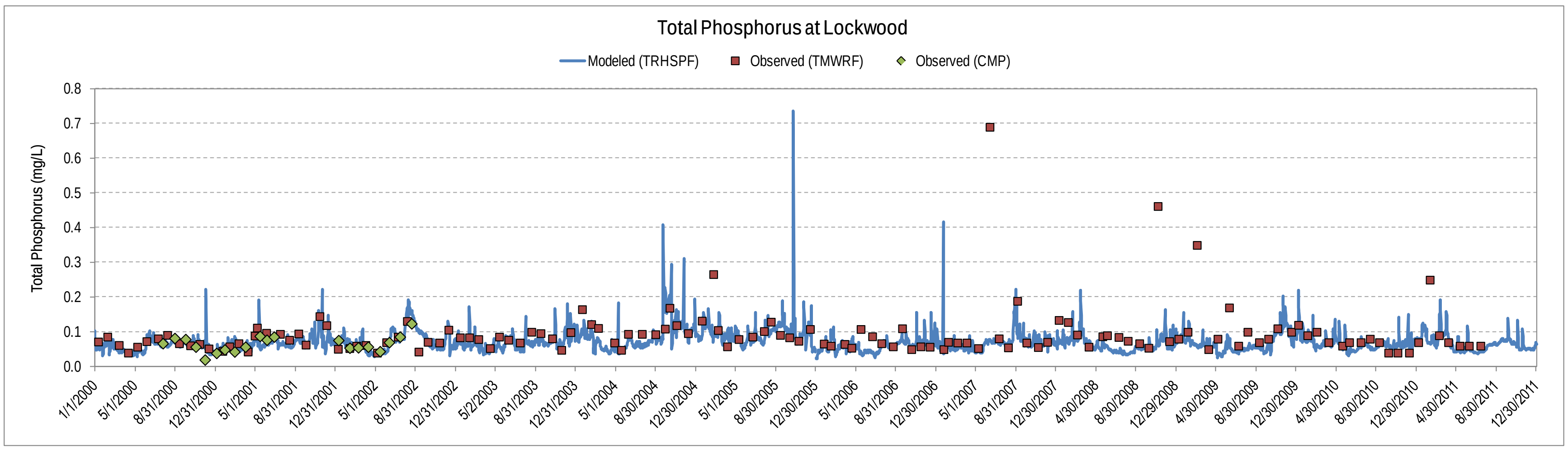
C-55. Comparison of Modeled and Observed Dissolved Organic Nitrogen at Painted Rock between 2000 and 2011.



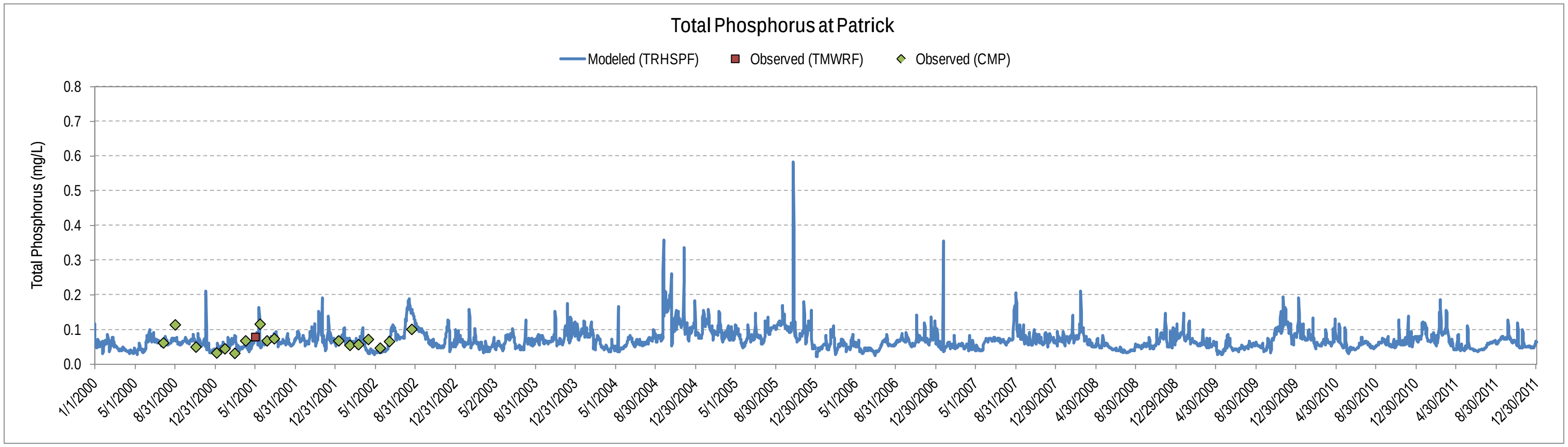
C-56. Comparison of Modeled and Observed Dissolved Organic Nitrogen at Wadsworth between 2000 and 2011.



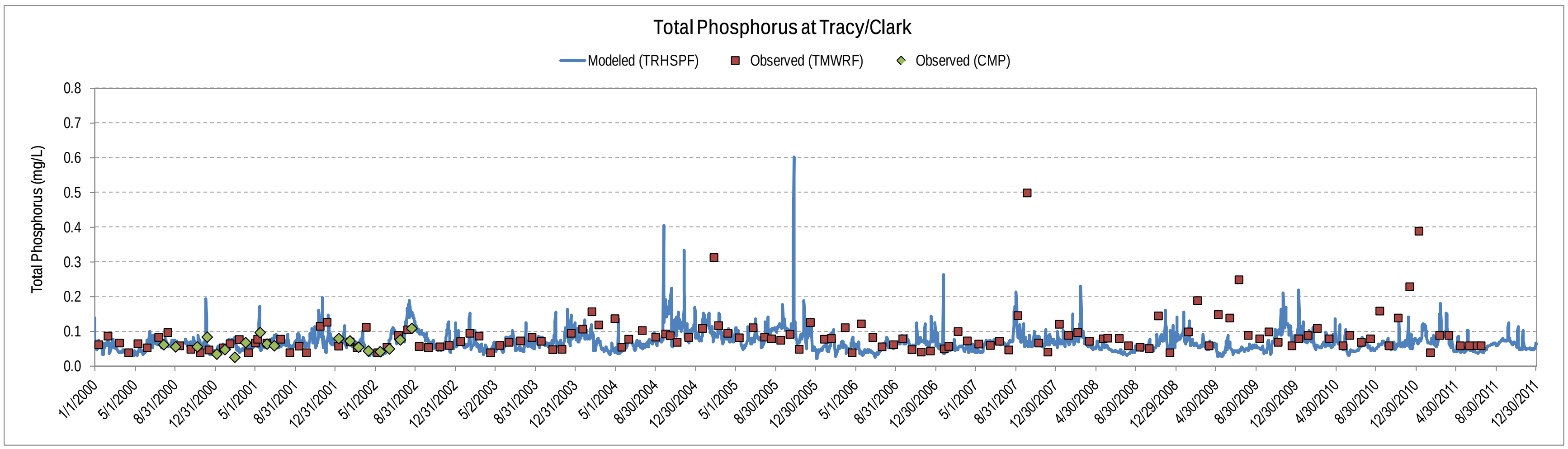
C-57. Comparison of Modeled and Observed Dissolved Organic Nitrogen at Nixon between 2000 and 2011.



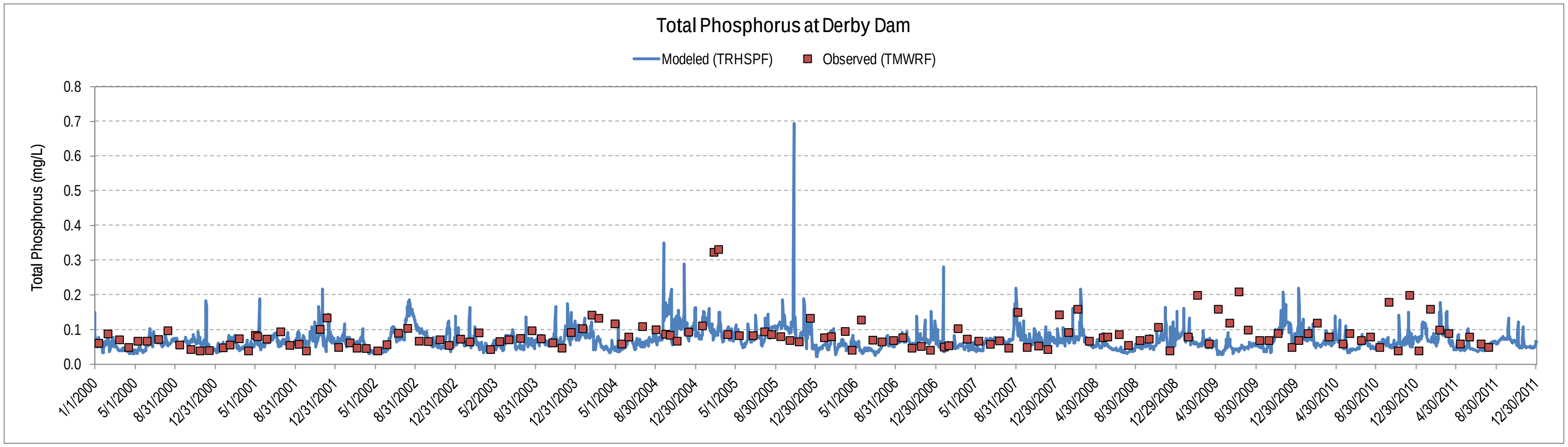
C-58. Comparison of Modeled and Observed Total Phosphorus at Lockwood between 2000 and 2011.



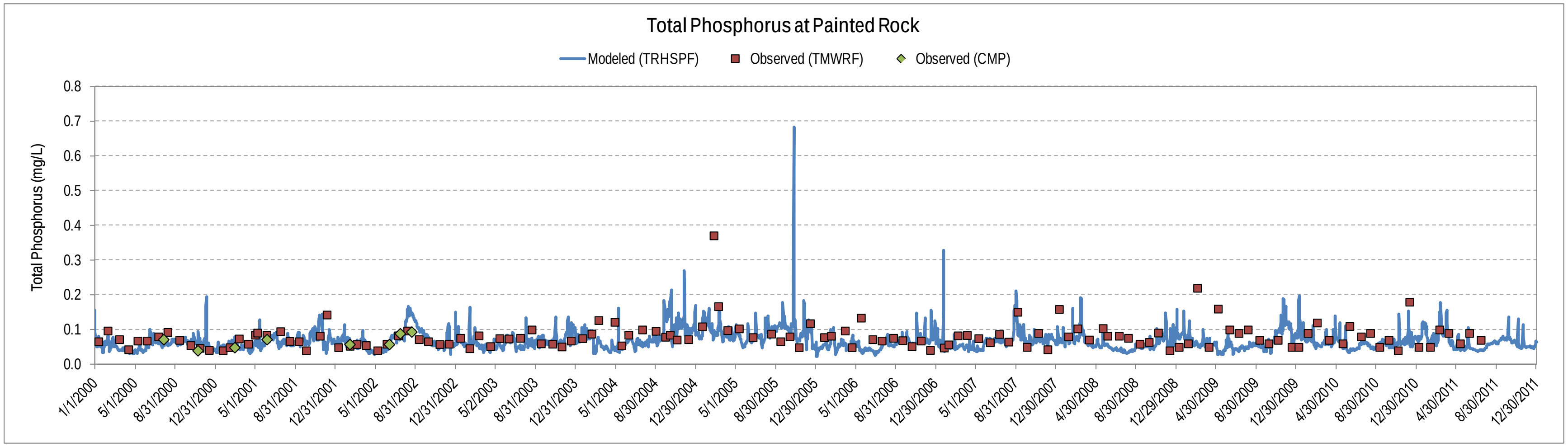
C-59. Comparison of Modeled and Observed Total Phosphorus at Patrick between 2000 and 2011.



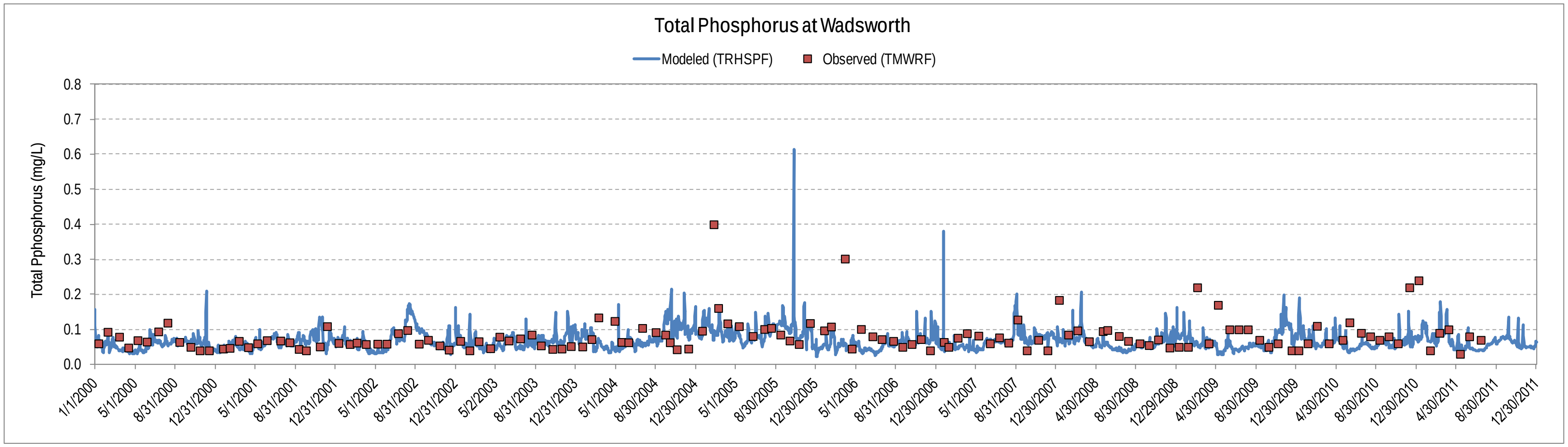
C-60. Comparison of Modeled and Observed Total Phosphorus at Tracy/Clark between 2000 and 2011.



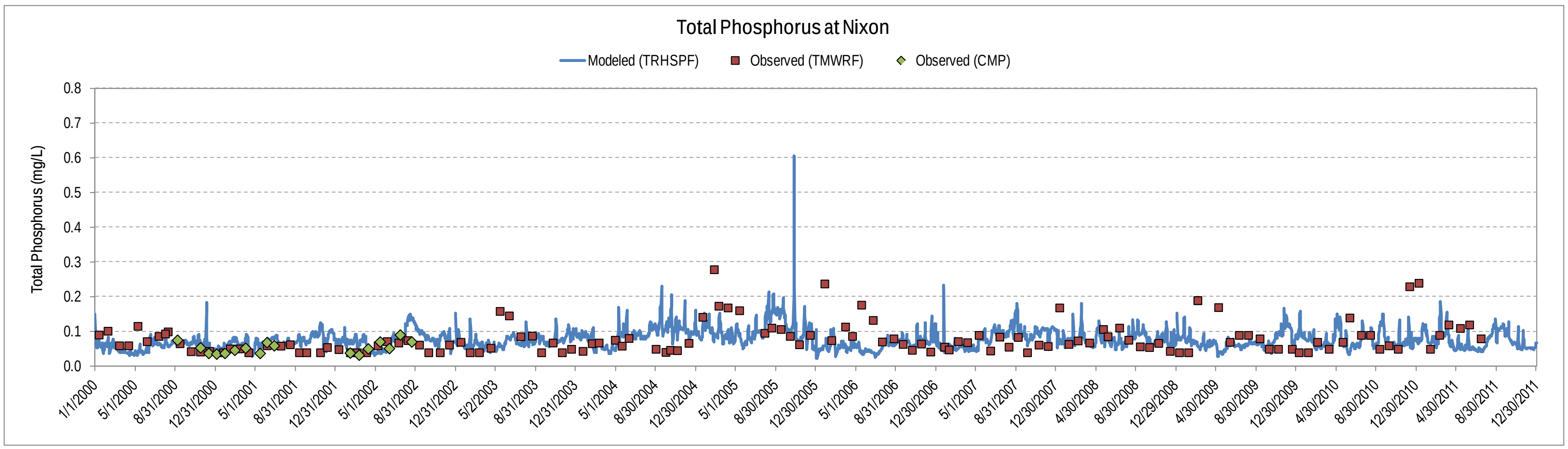
C-61. Comparison of Modeled and Observed Total Phosphorus at Derby Dam between 2000 and 2011.



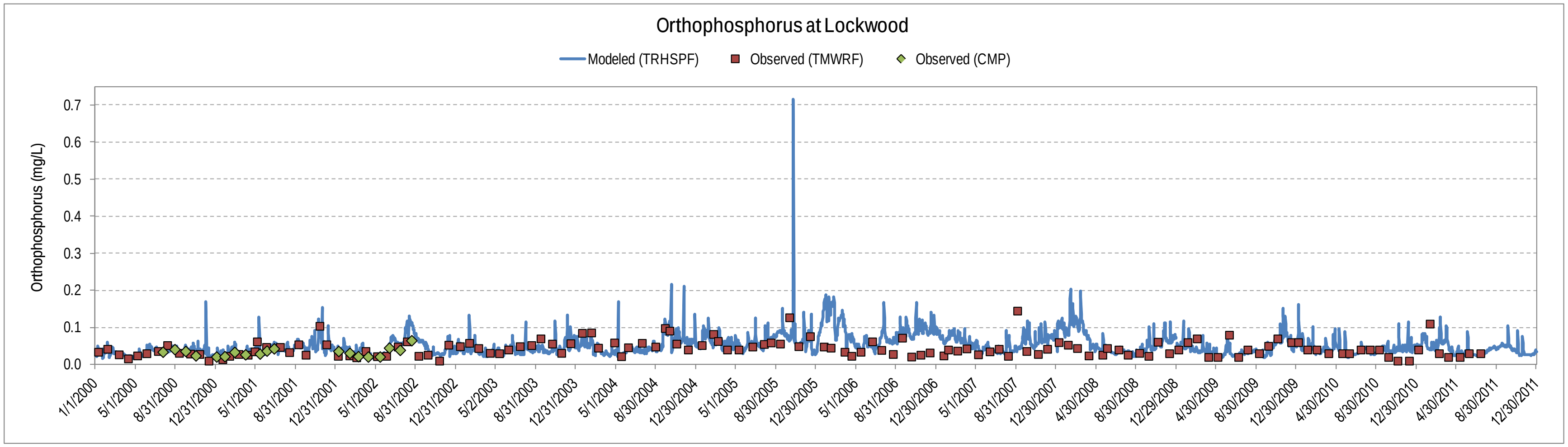
C-62. Comparison of Modeled and Observed Total Phosphorus at Painted Rock between 2000 and 2011.



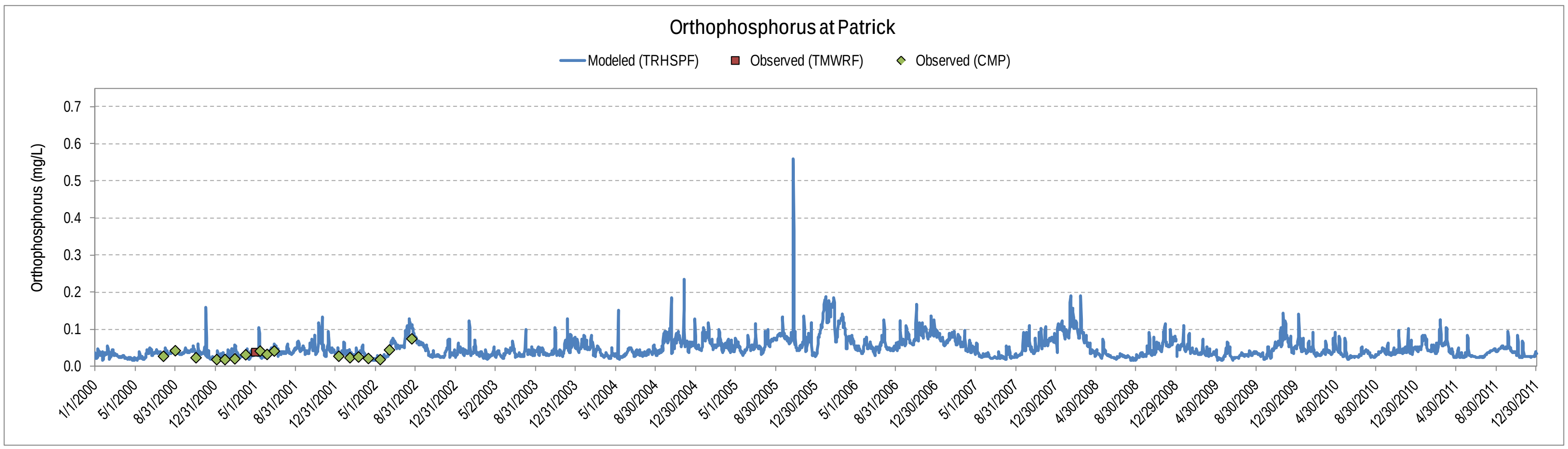
C-63. Comparison of Modeled and Observed Total Phosphorus at Wadsworth between 2000 and 2011.



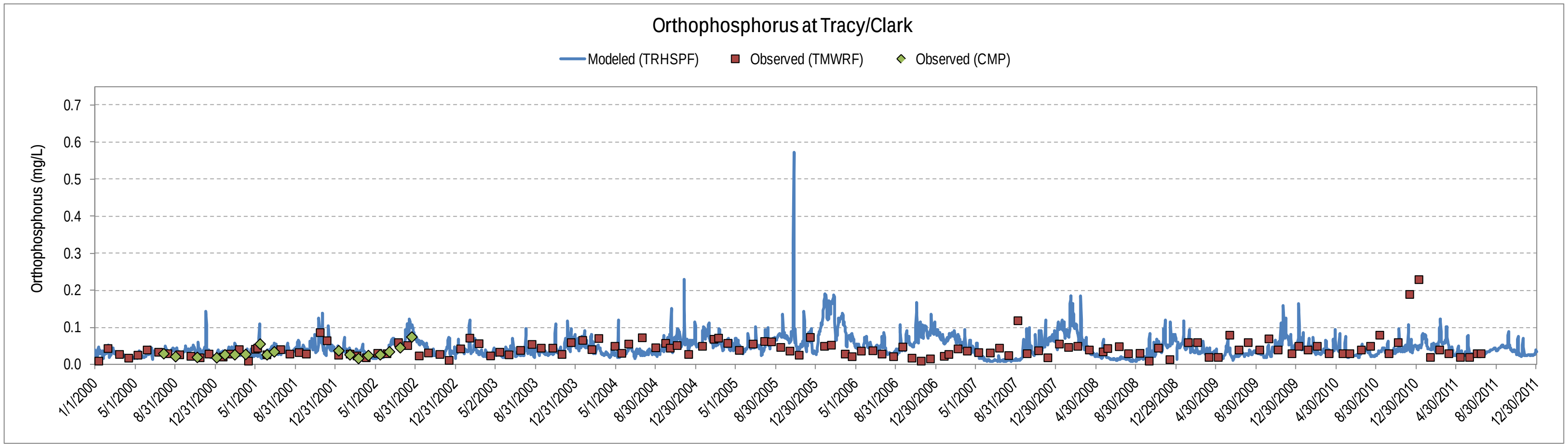
C-64. Comparison of Modeled and Observed Total Phosphorus at Nixon between 2000 and 2011. 8% of the Total Phosphorus data points were reported as <PQL. The PQL for Total Phosphorus is 0.04 mg/L.



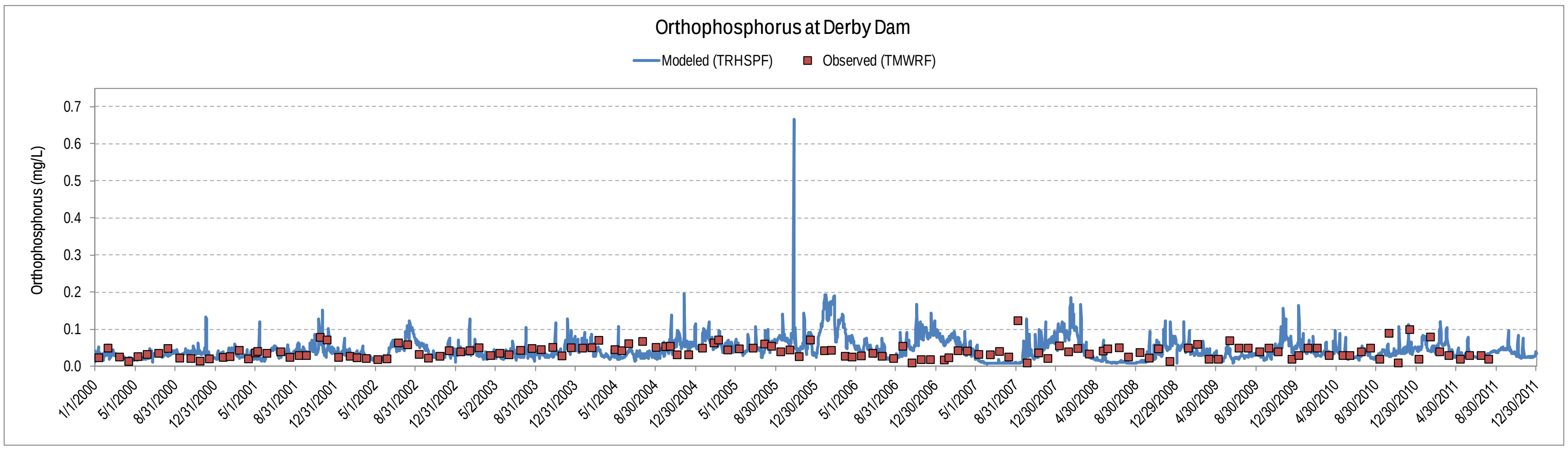
C-65. Comparison of Modeled and Observed Orthophosphorus at Lockwood between 2000 and 2011.



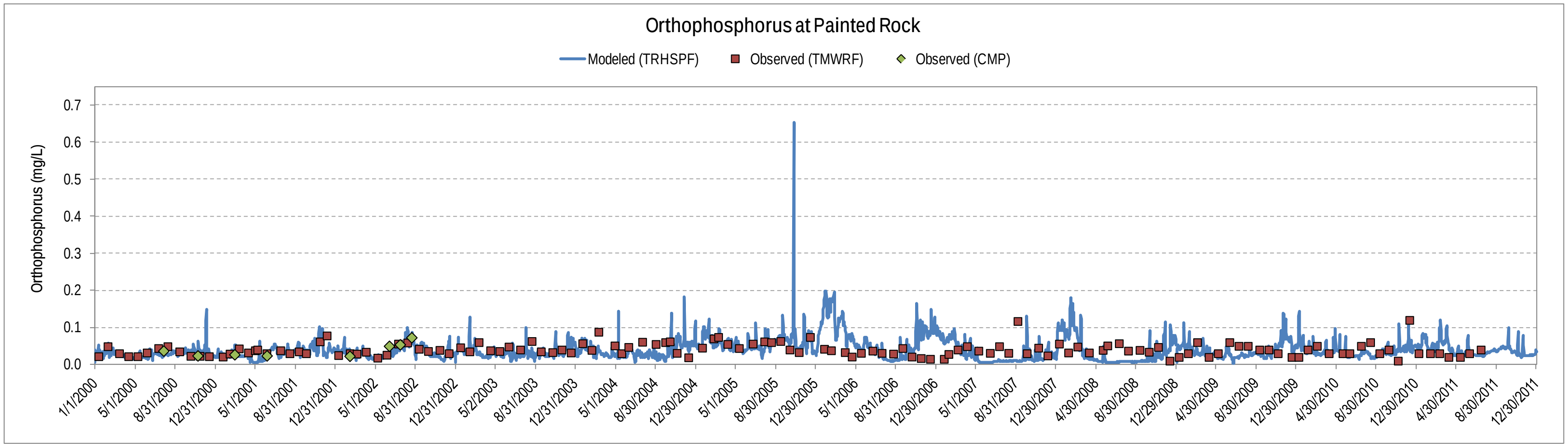
C-66. Comparison of Modeled and Observed Orthophosphorus at Patrick between 2000 and 2011.



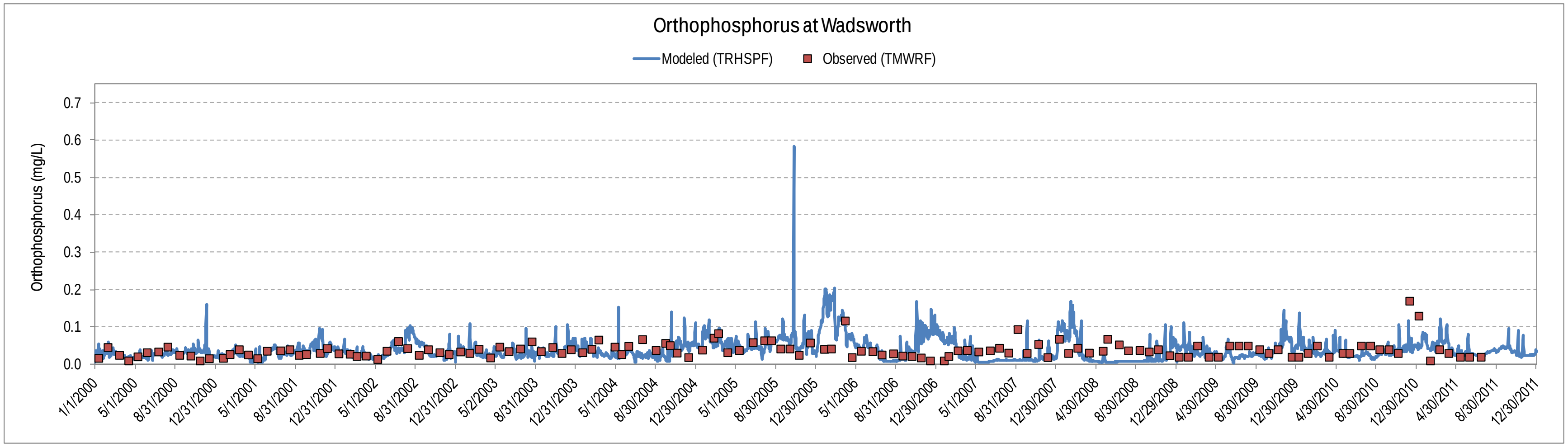
C-67. Comparison of Modeled and Observed Orthophosphorus at Tracy/Clark between 2000 and 2011.



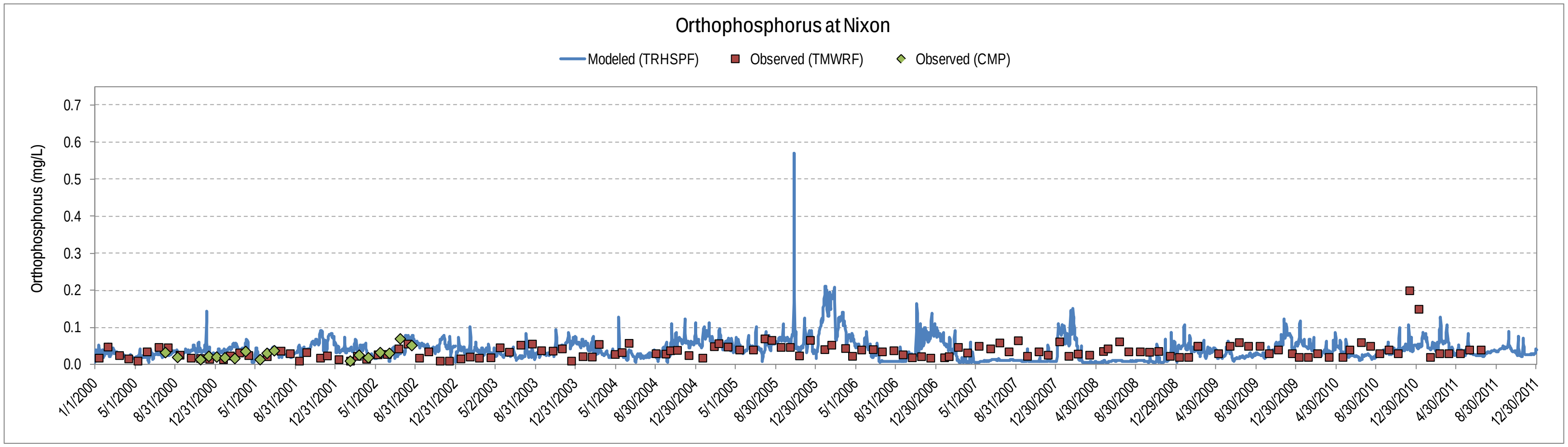
C-68. Comparison of Modeled and Observed Orthophosphorus at Derby Dam between 2000 and 2011.



C-69. Comparison of Modeled and Observed Orthophosphorus at Painted Rock between 2000 and 2011.



C-70. Comparison of Modeled and Observed Orthophosphorus at Wadsworth between 2000 and 2011.



C-71. Comparison of Modeled and Observed Orthophosphorus at Nixon between 2000 and 2011.