Santa Margarita River Watershed Model – San Diego County Update (FINAL)

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EXECUTIVE SUMMARY

This report presents an update to the Santa Margarita River watershed model for the portion of the watershed lying within San Diego County, including parts of USMC Camp Pendleton. Several important modifications are designed to provide better support to forthcoming Water Quality Improvement Plans. First, the model land use has been updated to the most recent available (2015) coverage and auxiliary information has been used to identify and delineate the area in nurseries, which appear to be significant contributors to nutrient loads in Rainbow Creek. Second, the model simulation, which previously ended in 2010, has been extended through September of 2016. Thirdly, the issue of sparse rain gauge information over the full time period of the model has been addressed through the use of gridded precipitation data that combines rain gauge calibration, Doppler radar information, and regressions across topography to provide a more accurate spatial representation of rainfall distribution. Finally, the watershed model has been integrated with a groundwater model of the aquifers on Camp Pendleton that is developed through 2016 and greatly improves the representation of flows between Camp Pendleton and the Santa Margarita Estuary.

In addition to bringing the model up through last year, these enhancements allow significant improvements in the model representation of hydrology, covering both wet and extremely dry periods. Improvements in the hydrologic simulation will in turn lead to more accurate estimation of load delivery to the Estuary as well as better representation of low flow conditions within the stream network.

Most of the water quality monitoring data collected in recent years has focused on dry weather samples in the Rainbow Creek watershed. This allows improvement in the representation of dry weather conditions and sources in Rainbow Creek that will aid in implementing the Total Maximum Daily Load requirements. Only rather limited sampling has occurred in recent years for wet weather conditions or for locations outside Rainbow Creek, so opportunities to improve the representation of wet weather nutrient loads are limited. Nonetheless, the improved representation of land use, precipitation, runoff, and ground water – surface water interactions should result in more accurate estimates of the sources of nutrient loads within San Diego County and their delivery to the Estuary.

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1.0 INTRODUCTION

1.1 PREVIOUS WATERSHED MODELING

A watershed simulation model has been developed for the Santa Margarita watershed as a tool to estimate sources of nutrient loads within the watershed and the timing and amounts of nutrient loads delivered to the Santa Margarita Estuary. The model is implemented using the USEPA-supported Hydrologic Simulation Program-FORTRAN (HSPF) model (Bicknell et al., 2005).

HSPF is a comprehensive, EPA-supported and widely applied watershed modeling package that can simulate water quantity and quality for a wide range of pollutants. HSPF was selected for this study because of its capability to assess the impact of point and nonpoint sources in a large watershed with varying land cover and management conditions. The HSPF model has been applied throughout the US and has a long history of application for nutrient management, Total Maximum Daily Load, and water supply protection studies.

HSPF divides the larger watershed into smaller sub-basins, each of which is conceptualized as a group of various land uses routed to a representative stream reach. The sub-basins are linked together by the stream reach network to represent the larger watershed drainage. A variety of instream modules describe flow, sediment transport, and water quality kinetics for nutrients, dissolved oxygen, algae, and other components, including exchanges with the sediment bed and kinetic transformations simulated at an hourly time step.

Upland land processes are simulated in HSPF on a unit area basis and multiplied by area to provide input to the stream reach simulation, with separate modules for pervious and directly connected impervious areas. These include routines to dynamically simulate the water budget, sediment erosion and transport, and water quality constituents. Hydrology is modeled as a water balance in multiple surface and soil layer storage compartments. Interception, infiltration, evapotranspiration, interflow, groundwater loss, and overland flow processes are considered. Sediment production is based on detachment and/or scour from a soil matrix and transport by overland flow in pervious areas, whereas solids buildup and washoff is simulated for impervious areas. Nutrient loads from the land surface are represented either by buildup/washoff processes or as a function of sediment transport, while the pervious land simulation also incorporates transport via interflow and shallow groundwater.

The Santa Margarita River watershed HSPF model was developed in 2013 (hydrology) and updated in 2014 (Phase 2, water quality calibration) based on then available data (Tetra Tech, 2013; 2014), with further updates in 2016 to integrate output from the USMC Camp Pendleton groundwater model into the surface water simulation (Sutula et al., 2016).

The existing HSPF model provided a reasonable representation of flow, sediment, and nutrient concentrations in the Santa Margarita River and loading and transport from the river to the Santa Margarita estuary; however, as with any model, there was a degree of uncertainty in the representation of watershed processes that could potentially be reduced. The wet weather simulation was primarily limited by a lack of detail in the spatial representation of precipitation in the watershed, where areas of significant topographic relief are represented by a limited number of individual rain gauges. The dry weather simulation was primarily limited by a lack of detail on the complex interactions between surface water and groundwater in the basin. Minor updates were carried out in conjunction with the 2016 load allocation estimates, including work to integrate groundwater exchanges in the lower Santa Margarita mainstem with the Camp Pendleton groundwater model (Sutula et al., 2016).

1.2 SCOPE OF CURRENT EFFORT

The existing HSPF watershed model of the Santa Margarita watershed (Tetra Tech, 2013, 2014; Sutula et al., 2016) was developed to support the Santa Margarita Estuary nutrient investigation and Total Maximum Daily Load (TMDL) alternative. This model ran through the end of water year 2010 and used older land use information from 2005 and 2009.

San Diego County authorized an update of the watershed model for areas that affect the calculation of Municipal Separate Storm Sewer System (MS4) loads from San Diego County, United States Marine Corps (USMC) Camp Pendleton, and other MS4 permittees in the watershed downstream of the Riverside – San Diego County border. Model drainage areas and hydrography have been refined and updated for San Diego County and recent (2015) land use information has been incorporated. The representation of the watershed within Riverside County has not been updated, except for the headwaters of tributaries (e.g., De Luz, Sandia, and Rainbow Creeks) that originate in Riverside County and flow to the Santa Margarita River within San Diego County. The revised watershed model incorporates an improved representation of precipitation (using gridded estimates incorporating radar data), and the model has been recalibrated for flow and pollutant fate and transport within the downstream portion of the watershed in San Diego County. Many other refinements have also been made to improve the model. These are described in detail in Section 2.0 (for spatial data) and Section 3.0 (for temporal data).

In sum, this effort updates the HSPF watershed model for the Santa Margarita River mainstem below U.S. Geological Survey (USGS) gage 11044000 at the head of the Gorge (situated below the confluence of Murrieta and Temecula Creeks and below the Comprehensive Water Rights Management Agreement [CWRMA] discharge), as well as all tributaries discharging into the mainstem below this point. The model time period has been extended through September of 2016 and the quality of the model calibration has been improved. The work described herein results in a documented and tested tool that is applicable to estimating nutrient loads from San Diego County and USMC Camp Pendleton MS4s, supporting the development of the Water Quality Improvement Plan (WQIP), providing time series of nutrient loads delivered to the Santa Margarita Estuary, and supporting the analysis of management strategies to address requirements of the Rainbow Creek TMDL for total nitrogen and total phosphorus.

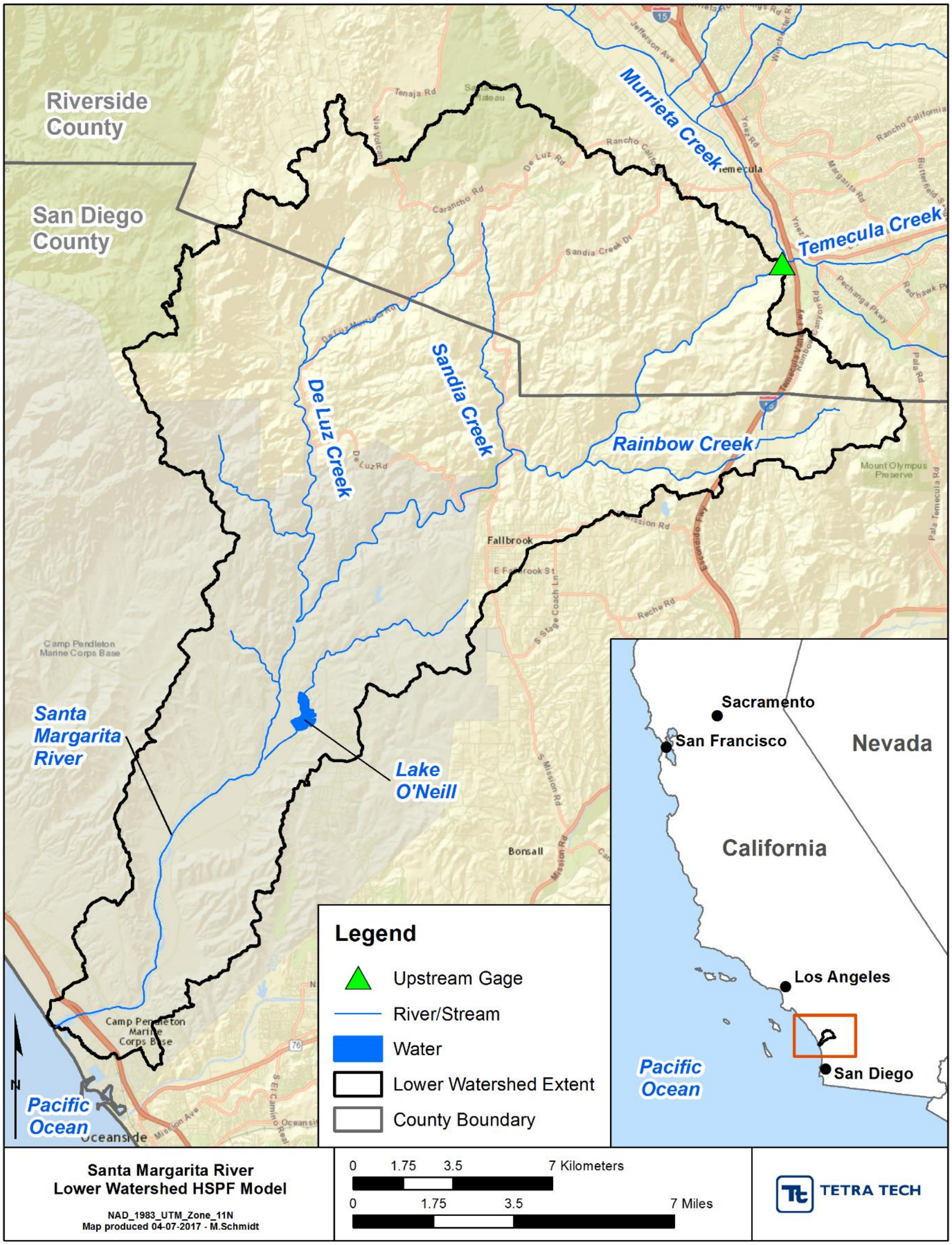

Figure 1-1. Area Represented in the Updated Santa Margarita River Watershed Model

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2.0 MODEL DEVELOPMENT – SPATIAL DATA

2.1 UPLAND HYDROLOGIC RESPONSE UNITS

The watershed model requires a basis for distributing hydrologic and pollutant loading parameters. This is necessary to appropriately represent hydrologic variability throughout the basin, which is influenced by land surface and subsurface characteristics. It is also necessary to represent variability in pollutant loading, which is highly correlated to land practices and geology and will be used to allocate allowable loadings to nonpoint sources. The basis for this distribution is provided by the overlaying land use, soils characteristics, and impervious surfaces to form hydrologic response units (HRU).

Land use within the San Diego County portion of the study area was updated using the latest GIS coverages from several sources, described below. Land use within the Riverside County portion of the study area was left unchanged from that described in Tetra Tech (2013), which was based on the 2005 Southern California Association of Governments (SCAG) coverage with rural areas refined using LANDFIRE.

2.1.1 SANDAG 2015 Land Use

The SANDAG land use GIS data layer, covering the San Diego County portion of the watershed, is based on the interpretation of current and historic aerial imagery, San Diego Geographic Information Source (SanGIS) land base (i.e., parcels) and miscellaneous ancillary data sources. SANDAG's land layers are created for use in the Regional Growth Forecast to distribute projected growth for the San Diego region to suitable subareas in the region. These land layers include existing land use, planned land use, land ownership, land available for development, and lands available for redevelopment and infill. The land layers inventory is updated when new information is available.

Many of these data sets are built from the SanGIS land base. The land use information has been updated continuously since 2000 using aerial photography, the San Diego County Assessor Master Property Records file, and other ancillary information. The land use information was reviewed by each of the local jurisdictions and San Diego County to ensure its accuracy. For the current model application, we have updated the SANDAG land use coverage to use the most recent (2015) available information. The previous model was built using SANDAG 2009 data.

The California Department of Transportation (Caltrans) maintains a GIS coverage of the roads and areas under their responsibility. This coverage was used to provide a better representation of these lands in the study area. The polygons from SANDAG, which already lined up with the Caltrans highway network, were re-assigned as Caltrans because Caltrans holds a separate MS4 permit.

Although agricultural lands are included in the inventory, they have not been systematically maintained or updated since the middle 1990s. The land use inventory only has agricultural land use change when the land becomes developed or urbanized. New agricultural lands have not been systematically added to the inventory, and must be obtained from other sources.

2.1.2 LANDFIRE

The Landscape Fire and Resource Management Planning Tools (LANDFIRE) is an interagency vegetation, fire, and fuel characteristics mapping program, sponsored by the United States Department of the Interior (DOI) and the United States Department of Agriculture, Forest Service (http://www.landfire.gov/index.php). LANDFIRE produces a land use coverage that was used to supplement the SCAG and SANDAG coverages.

LANDFIRE is a coverage of vegetation types, with focus on native vegetation, developed primarily for fire potential analysis. It is the best source for discriminating different types of rural undeveloped land cover present in the SANDAG and SCAG coverages. It can be used to distinguish chaparral from scrub forest, for example.

2.1.3 Agricultural Lands

The land use layer was further refined to incorporate detailed spatial information on agricultural land use provided by San Diego County in the geodatabase feature class AG_TYPES_LOWER_SMR_2014. The revised agricultural land use information (which does not cover Riverside County portions of this watershed) represents a best estimate of agricultural land uses (excluding incorporated cities and military reservations) and has been used to refine the model land use coverage. The San Diego County effort used a 4 category classification system, and is based on review of interpretation of 2012 aerial photos updated with 2014 aerial photos and selected other GIS layers. The attribute known as “TYPE” in the San Diego County GIS coverage was employed for agricultural land use revisions in the watershed model, which includes a separate category for “nursery/greenhouses” in addition to “tree crops” (considered orchard/vineyards as in SANDAG’s classification system), “row crops,” and “other agricultural.”

2.1.4 Combined Land Use Coverage

After processing, there are 18 model land use categories, shown in Table 2-1. The undeveloped land categories in SANDAG were further defined by the LANDFIRE coverage. The resulting model land use areas are summarized in Table 2-2 and shown in Figure 2-1. The land use categories are the same as those used in earlier versions of the model, except that nurseries have been separated from the orchard/vineyard class. Chaparral, grassland, and low density residential land uses occupy 74 percent of the study area.

Table 2-1. Model Land Use Categories

Model Land Use Description	Model Land Use Abbreviation
Low Density Residential	Low_Den_Res
High Density Residential	High_Den_Res
Commercial, Institutional	Commercial_Institutional
Industrial	Industrial
Road, freeway	Road/freeway
Parks and recreation	Parks_Rec
Open and recreation	Open_Rec
Irrigated agriculture	Irrigated_Ag
Non-irrigated agriculture	Non_Irrigated_Ag
Orchard, vineyard	Orchard_Vineyard
Dairy, livestock	Dairy_livestock
Horse ranches	Horse_ranches
Forest	Forest
Chaparral, scrub	Chaparral/scrub
Grassland, herbaceous	Grassland/herbaceous
Water	Water
Transitional	Transitional
Caltrans	Caltrans
Nurseries	Nurseries

Note: Categories are the same as those used in Tetra Tech (2013), except that the combined category of “Orchard, vineyard, nurseries” has been split to separate categories for “Orchard, vineyard” and “Nurseries.”

Table 2-2. Model Land Use Acreage and Percentage Distribution in the Study Area

Model Lane Use Description	Area (ac)	Percent of Study Area
Low Density Residential	11,015	11%
High Density Residential	395	0%
Commercial, Institutional	786	1%
Industrial	1,082	1%
Road, freeway	2,654	3%
Parks and recreation	215	0%
Open and recreation	27	0%
Irrigated agriculture	2,046	2%
Non-irrigated agriculture	401	0%
Orchard, vineyard	14,954	15%
Dairy, livestock	0	0%
Horse ranches	31	0%
Forest	2,486	2%
Chaparral, scrub	45,001	45%
Grassland, herbaceous	17,553	18%
Water	295	0%
Transitional	176	0%
Caltrans	302	0%
Nurseries	590	1%
TOTAL	100,006	100%

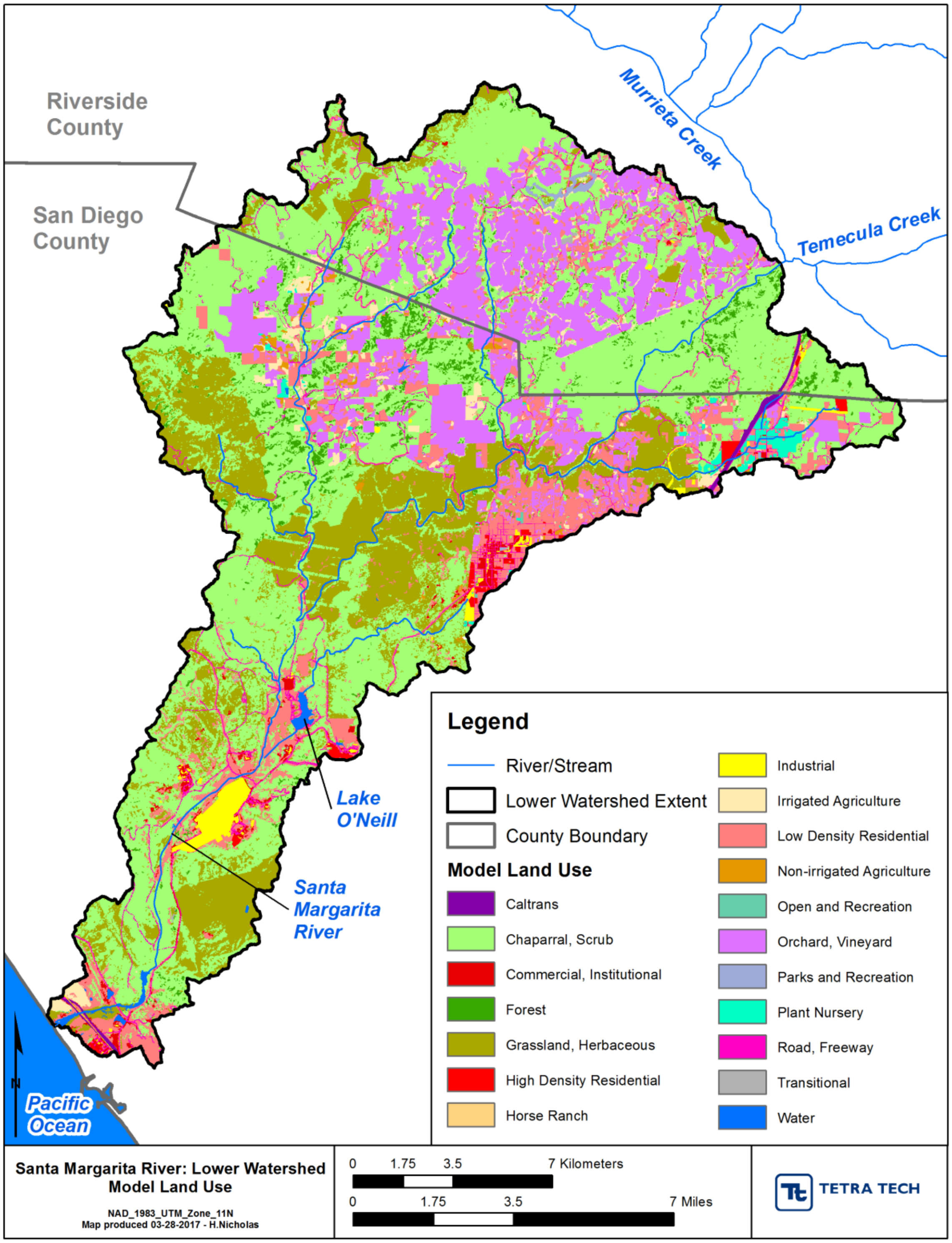


Figure 2-1. Model Land Uses within the Study Area

2.1.5 Hydrologic Soil Groups

The USDA SSURGO soil polygons were used to assess the hydrologic soil groups (HSGs) in the Santa Margarita River watershed, as was done previously. The general descriptions of the HSG categories, which reflect infiltration capacity and drainage, are shown in Table 2-3.

Table 2-3. Description of Hydrologic Soil Groups (USDA, 1986)

Hydrologic Soil Group	Description	Soil Texture
A	Low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well- to excessively-drained sand or gravel and have a high rate of water transmission (greater than 0.30 in/hr).	Sand, loamy sand, or sandy loam
B	Moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well-drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (0.15-0.30 in/hr).	Silt loam or loam
C	Low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture. These soils have a low rate of water transmission (0.05-0.15 in/hr).	Sandy clay loam
D	High runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very low rate of water transmission (0-0.05 in/hr)	Clay loam, silty clay loam, sandy clay, silty clay, or clay

HSG D is the dominant category in the study area (Table 2-4) accounting for 70 percent of the area (Figure 2-2). Note that the SSURGO coverage for the watershed has been updated since the 2013 modeling effort, with substantial portions of the watershed (e.g., De Luz Creek) reclassified from HSG C to HSG D.

Table 2-4. Hydrologic Soil Group Distribution in Study Area

Hydrologic Soil Group	Area (ac)	Percent of Study Area
B (including some A)	10,322	10%
C	19,817	20%
D	69,867	70%

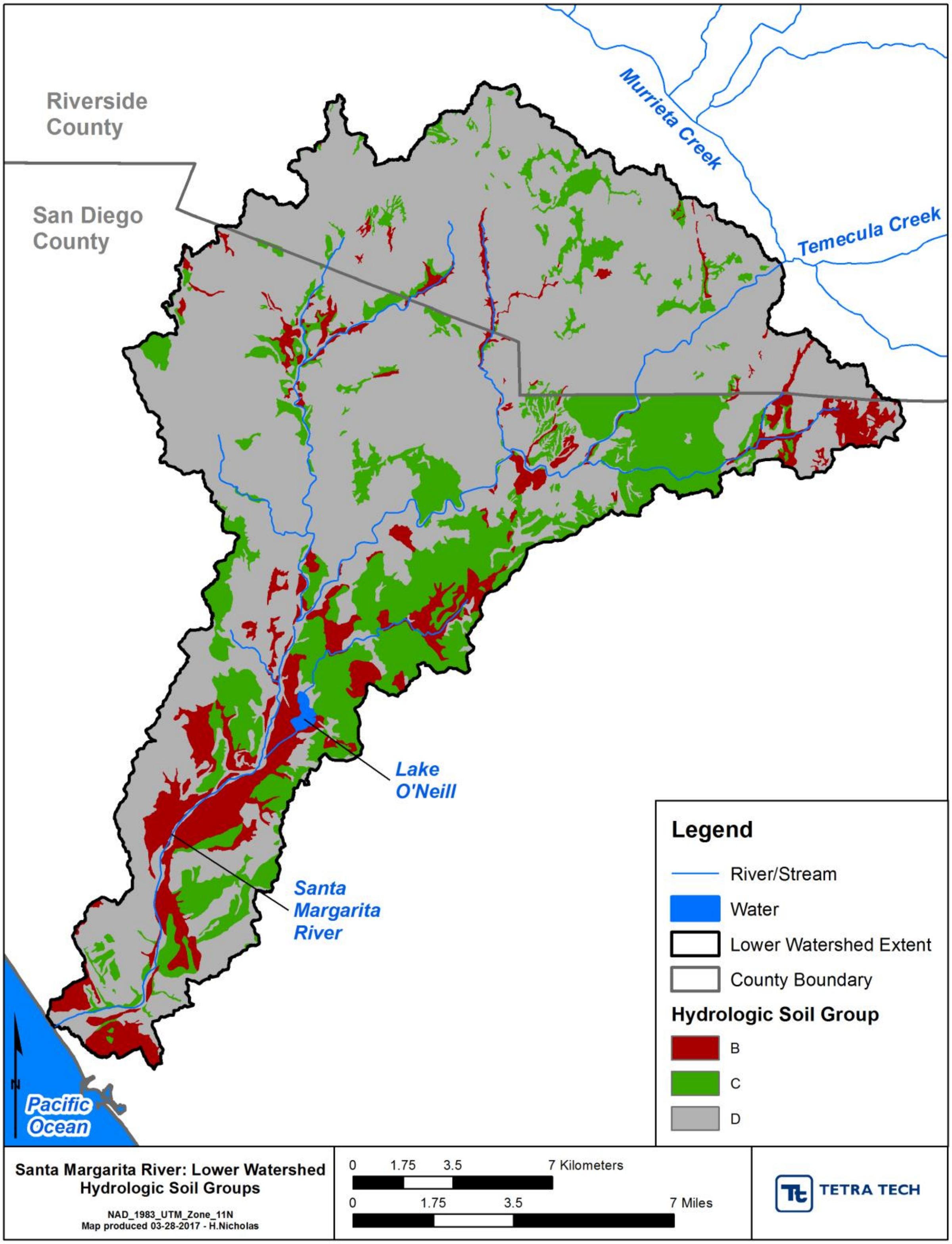


Figure 2-2. Hydrologic Soil Groups within the Study Area

2.1.6 Impervious Surfaces

HSPF algorithms require that land use categories be divided into separate pervious and impervious land units for modeling. This division has been made for the appropriate land use classes.

The impervious cover of a watershed has many impacts. It eliminates or significantly reduces the ability of water to be absorbed in the ground, which creates flashier stream responses to rainfall events. Impervious surfaces generally provide a more expedient means for pollutants to be swept from the surface into a defined drainage such as an open channel. The National Land Cover Database (NLCD) 2011 impervious cover (https://www.mrlc.gov/) was used to determine total impervious areas in the watershed.

Particularly in less densely developed areas, substantial fractions of impervious surfaces (such as roof drains) are not directly connected to the stream network. The impervious area that is hydraulically connected to the stream or surface drainage network over an entirely impervious pathway is referred to as effective impervious area or EIA, which is a fraction of the total impervious area (TIA). Land areas simulated in the watershed model as impervious surfaces should represent only the EIA, rather than the total impervious area. Impervious areas that are not hydraulically connected are either isolated depressions or flow onto adjacent pervious areas (where they may infiltrate or, during larger events, contribute to overland flow) and flows originating from such surfaces are best represented as having the characteristics of the receiving pervious area. Given the low total imperviousness in the basin, the EIA fraction was estimated using the Sutherland's (1995) equation 1, applicable to average basins, in which

$$EIA = 0.1\ TIA^{1.5}.$$

EIA accounts for 2,260 acres or 2.26% of the study area.

2.2 MODEL SEGMENTATION

HSPF divides the model area into smaller subbasins for simulation. This section first describes the refinement of model subbasins. It then discusses the representation of diversions and impoundments within the study area.

2.2.1 Subbasin Delineation

Initial subbasin boundaries are as described in Tetra Tech (2013). These were modified to provide additional resolution and align with internal drainage divides provided by San Diego County (personal communication from Steven Di Donna, March 30, 2017) to be as consistent as possible with the County's most recent delineations of MS4 watershed areas. San Diego County's MS4 watershed areas do not extend into Riverside County and boundaries of subbasins in Riverside County and within USMC Camp Pendleton were not updated from the previous version. Additional subwatersheds were created to match up with impaired stream segments, as well as to define water quality monitoring locations for the revised model calibration. Major refinements were made to better define the Rainbow Creek TMDL study area. The 200 series subbasins in the final delineation represent added segments (Figure 2-3).

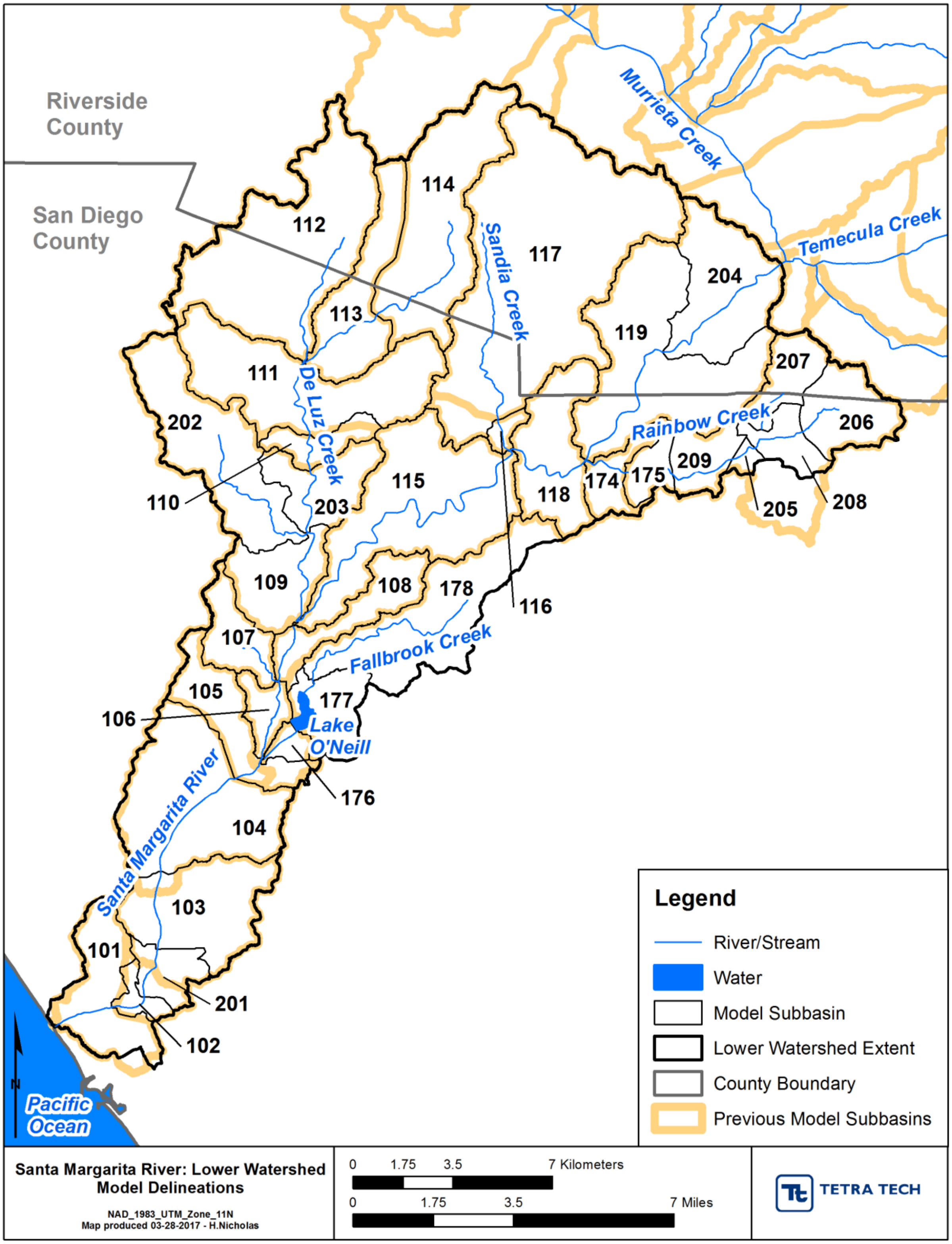


Figure 2-3. Subbasin Delineations in the Revised Lower Santa Margarita River Watershed Model

2.2.2 Camp Pendleton Diversion

A major diversion is present on the mainstem of the Santa Margarita River at USMC Camp Pendleton (model reach 106). This diversion has a significant effect on flow in the lower portion of the river, and also diverts a portion of the pollutant load present upstream in to Lake O'Neill. The diversion is represented in the model as a second outlet from reach 106 with a demand series based on monitored diversion amounts.

2.2.3 Fallbrook Creek and Lake O'Neill

Lake O'Neill, an impoundment of Fallbrook Creek on USMC Camp Pendleton, has a capacity of 1,400 acre-feet. In addition to direct flow from Fallbrook Creek, USMC Camp Pendleton exercises an appropriative water right to divert water from the mainstem of the Santa Margarita River via O'Neill Ditch through use of a low head diversion dam. A larger portion of the diverted water is used for groundwater recharge purposes through spreading structures adjacent to the river channel. In an average year, groundwater pumping is about twice the amount of water infiltrated from recharge ponds, indicating that there is a net loss from the river to groundwater in this portion of the river (see Section 3.6). Spillage from Lake O'Neill returns to the river via lower Fallbrook Creek.

2.3 CHANNEL HYDRAULICS

HSPF is a one-dimensional model that balances hydrology, but does not perform detailed hydraulic calculations. Instead, the hydraulic response is represented through Functional Tables (FTables) that summarize stage-storage-discharge relationships in each stream reach.

Where information on channel geometry is available, the hydraulic relationships can be developed through use of external hydraulic models or Manning's equation. Where detailed channel geometry is not available, HSPF develops approximate FTables based on a trapezoidal channel assumption and regional relationships of channel geometry to drainage area.

For the Santa Margarita River watershed, HEC-RAS flood profile models are available for the mainstem, and have been used to further refine the representation of channel dimensions and the functional relationships between volume, stage, and discharge for each reach. In 2000, West Consultants, Inc. developed a HEC-RAS model of the Santa Margarita River from the confluence of Murrieta and Temecula creeks to its outlet at the Pacific Ocean. WEST Consultants used both new and existing cross section geometries (from previous models developed by Simons, Li and Associates [SLA] and Northwest Hydraulic Consultants [NHC]) to analyze the 5-, 10-, 50-, and 100-year flood events. The sources of the topographic data used to create the cross-section geometries are included in Table 2-5.

Table 2-5. Cross Section Data Sources (from Santa Margarita River – Final Report, WEST, 2000)

Cross-Sections (ft)	Creator	Method
0 – 20,620	Simons, Li & Associates	5-ft contour map
20,646 – 48,145	Northwest Hydraulic Consultants	Laser topography
49,580 – 54,830	Simons, Li & Associates	5-ft contour map
55,583 – 93,227	WEST Consultants, Inc.	5-ft digital contour map
94,068 – 128,383	WEST Consultants, Inc.	5-ft digital contour map
128,883 – 154,453	WEST Consultants, Inc.	5-ft digital contour map

2.3.1 Creating FTables from HEC-RAS

HEC-RAS applications provide an excellent basis for creating the FTables at selected points within a stream network. The accuracy of the generated FTable is dependent upon the spacing and number of HEC-RAS cross sections throughout a stream network, as well as the accuracy of the measured flows used to correlate river stage to discharge. HEC-RAS can interpolate between cross sections if the gaps are relatively small, but large gaps can eliminate the usefulness of disconnected upstream sections for FTable generation. If several measured flows are provided with a HEC-RAS model (e.g., flows from the 10-, 50-, 100-, 500-year return periods), the HSPF modeler can interpolate additional flows using percent differences in order to complete enough points in an FTable.

To use HEC-RAS to generate FTables, additional flow profiles were created for every flow change point along a modeled reach in order to account for lower flows and improve FTable accuracy. The existing HEC-RAS model already contained estimated flow profiles for four flood return periods (e.g., 5-, 10-, 50-, 100-yr storms); however, more flow profiles were needed to create an FTable. As a result, Tetra Tech calculated the mean percent change between every flow change point along the reach from the provided flow profiles. Tetra Tech subsequently assigned nine flow profiles (ranging between base flow and the 500-yr event peak flow) to the most upstream cross section. Finally, downstream flows were calculated for each flow change point and flow profile using the mean percent flow change values.

For each flow profile, HEC-RAS models provide the following water surface profile outputs for FTable generation:

- Q Total – total flow in cross section (cfs)
- Length Wt – weighted cross section reach length based on flow distribution (ft)
- Max Chl Dpth – maximum main channel depth (ft)
- SA Total – cumulative surface area for entire cross section from the bottom of the reach (acres)
- Volume – cumulative volume of water in the direction of computation (acre-ft)

Each point (or flow profile) representing the discharge-storage-surface area relationship by computed FTable is thus a weighted average of channel stage and discharge that is based on the weighted cross section reach length within the entire modeled reach. Also included for each flow profile in the FTable are the cumulative surface area and water volume between the reaches' upstream and downstream cross sections.

2.3.2 Regional Hydraulic Geometry Equations

For reaches that lack detailed hydraulic models such as HEC-RAS, FTables are generated using regional hydraulic geometry equations and the trapezoidal channel approximation method recommended in USEPA (2007). Regional hydraulic geometry relationships are those of the Pacific Mountain System region provided in Bieger et al. (2015). Specifically, we use the equations for bankfull width and cross-sectional area and recalculate average bankfull depth. These equations, based on drainage area (DA) in km^2, are bankfull width (m) = 2.76 $DA^{0.399}$ and bankfull cross-sectional area (m^2) = 0.87 $DA^{0.652}$. We modified the default approach in USEPA (2007) to use separate Manning's roughness coefficients (n) for the channel and floodplain, and assume no friction loss between these segments. The current models assume n = 0.03 for the channel and n = 0.06 for the floodplain, but can be modified if site-specific information is available.

3.0 MODEL DEVELOPMENT – TEMPORAL DATA

3.1 WEATHER DATA

Runoff response time series in a watershed model are a result of the interaction of weather time series with the characteristics of the land surface – most notably the interaction of precipitation and evaporation. The accuracy of the watershed model is limited by the accuracy of the weather time series, so these must be carefully specified, as described below.

3.1.1 Precipitation

Precipitation monitoring in the watershed is sparse. The original Santa Margarita watershed model (Tetra Tech, 2013) relied on precipitation data from six long-term rainfall gauge stations, only one of which was in San Diego County (Oceanside Marina). This was believed to be an important source of uncertainty in the model.

Point-in-space monitoring rainfall records are often not representative of integrated weather over a surrounding model area. This is clearly the case for the Santa Margarita River Watershed where annual precipitation totals vary significantly across the landscape, and precipitation gauging is sparse. Gridded weather products can be used to better represent climatic variations across a diverse landscape. These products also directly provide hourly air temperature, wind, and solar radiation data as well as parameters for computing cloud cover, dew point temperature, and potential evapotranspiration, all of which are required for a watershed model. Another benefit of gridded meteorological products is that these sources provide continuous data without gaps. This is not the case for point-in-space stations. Significant QA work is required to process station-based records and, for earlier modeling efforts, this included patching missing records and developing proximity-based composite time series. Gridded products also simplify and streamline the process of extending the spatial domain of the model and/or lengthening the simulation period. The revised Santa Margarita River watershed model therefore relies on gridded precipitation time series rather than sparse rain gauge measurements.

PRISM (Parameter-elevation Relationships on Independent Slopes Model) provides annual, monthly, and daily gridded precipitation data for the conterminous United States (Daly et al., 2008, 2015; daily output was added to PRISM in 2015). PRISM calculates a climate-elevation regression function for each grid cell and the regression is used to distribute station-based precipitation data to the grid cell. Approximately 13,000 precipitation stations are used in the analysis. For each grid cell, precipitation stations are assigned weights based on location, elevation, coastal proximity, topographic facet orientation, vertical atmospheric layer, topographic position, and orographic effectiveness of the terrain; the stations are then entered into the regression function to establish the gridded precipitation product.

Another gridded product is the North American Land Data Assimilation System (NLDAS-2) meteorological time-series (Mitchell et al., 2004). NLDAS-2 (http://ldas.gsfc.nasa.gov/nldas/NLDAS2forcing.php) provides continuous hourly data from 1979 to present on a 1/8 degree grid. It is thus available at a finer temporal scale but a coarser spatial scale than daily PRISM.

PRISM has been shown to better represent precipitation than WorldClim and Daymet, which are other publicly available gridded meteorological products (Daly et al., 2008). This is especially true for regions similar to the Santa Margarita River Watershed where coastal effects and large elevation gradients affect precipitation patterns (Daly et al., 2008). Because of this, PRISM was used to generate precipitation

(PREC) series for the model. A total of 98 PRISM grid cells span the model study area. These are shown in Figure 3-1. Daily precipitation data for these grid cells were retrieved from the PRISM database using Python scripts created by Tetra Tech. Daily precipitation records for each PRISM grid cell were then disaggregated to an hourly time step. To do this, sub-daily rainfall distributions were generated from NLDAS hourly precipitation records. Each PRISM grid cell was then spatially mapped to an NLDAS grid cell and the PRISM data were disaggregated to an hourly time step according to the sub-daily precipitation patterns of the overlapping NLDAS grid cell.

On a small fraction of days, a PRISM cell reports precipitation but the larger NLDAS grid cell does not. This generally occurs when the total precipitation amount reported by PRISM was very low, averaging less than 0.01 in/day and often at the beginning or end of a multi-day event. In such cases, an NRCS Type 1 24-hour rainfall distribution pattern was used to disaggregate the non-zero PRISM precipitation. A spatial analysis was completed to assign input precipitation time series to model subbasins and reaches.

The PRISM precipitation data were aggregated to four weather zones with similar characteristics (based on 30-year normal precipitation) and separate model HRUs were created for each zone (last digit of HRU identifier). During calibration it became evident that hydrologic responses in the Rainbow Creek area were quite different from those in Fallbrook Creek (both within weather zone 2). As a result, Fallbrook Creek was designated as a separate weather zone 5, using the same meteorological series as weather zone 2. This allows for specification of separate parameters for the two areas.

3.1.2 Potential Evapotranspiration

Potential evapotranspiration time series are based on California Irrigation Management Information System (CIMIS) measured data. CIMIS provides direct time series estimates of reference crop evapotranspiration under unlimited water supply (ETo) by zone CIMIS zones 4 and 6 cover the area of the watershed within San Diego County with the exception of a small strip along the coast. Missing periods were estimated by using the ratio of long-term averages of a neighbor station to scale the value.

3.1.3 Other Meteorological Inputs

Simulation of dissolved oxygen and algal growth requires several other input variables. Note that water temperature is not being dynamically simulated (see Section 3.3), so dew point, wind, and cloud cover series are not required.

NLDAS directly provides hourly air temperature (TMP) at 2 meters above the surface. NLDAS reports temperatures in Kelvin and data retrieved for model were converted to degrees Fahrenheit.

NLDAS also directly provides estimation of hourly shortwave solar radiation (DSWRF) at 2 meters above the surface (W/m^2) corrected for atmospheric conditions. The solar radiation data were converted to HSPF compatible units (Langleys).

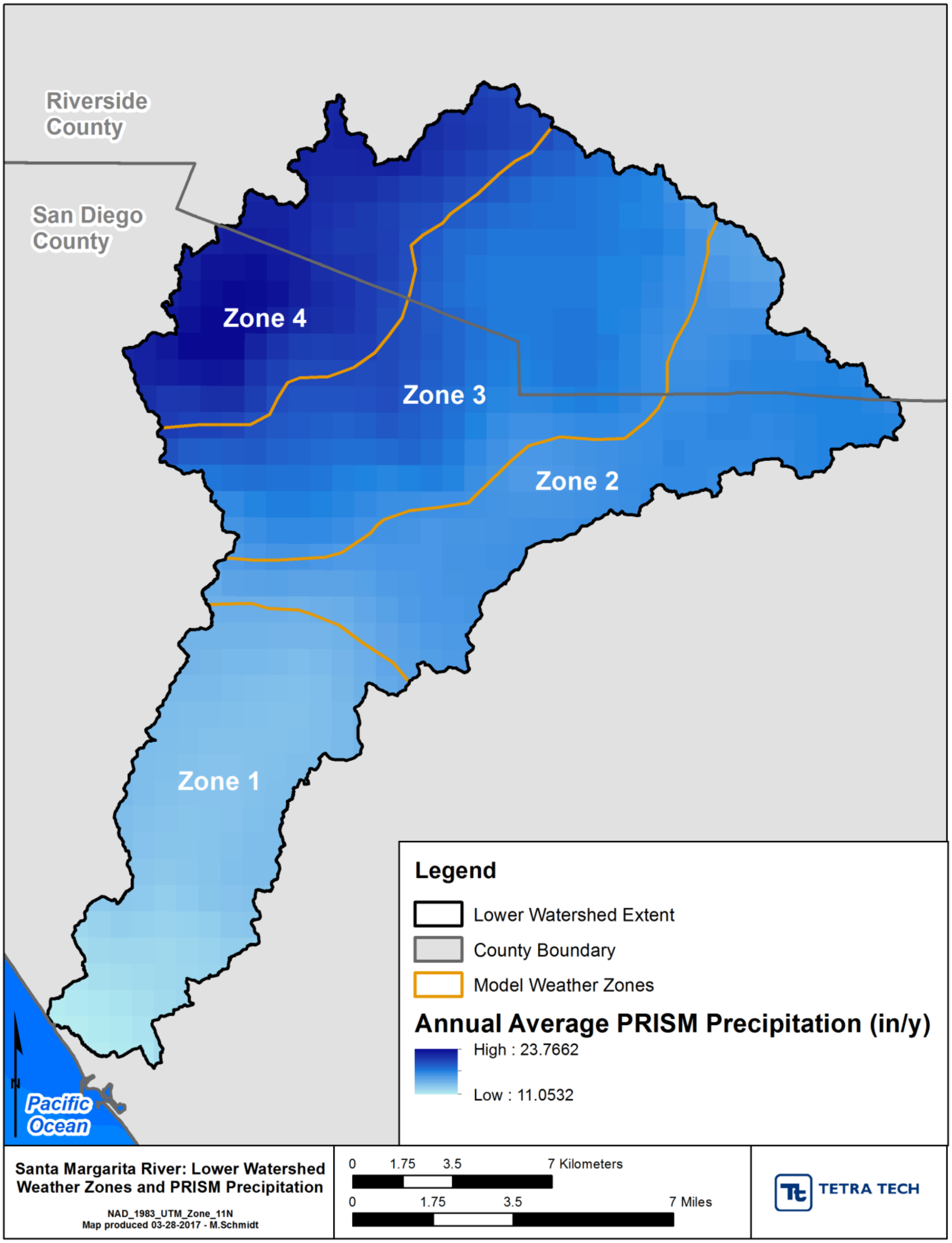


Figure 3-1. PRISM Precipitation and Aggregation for the San Diego County Portion of the Santa Margarita River Watershed Model

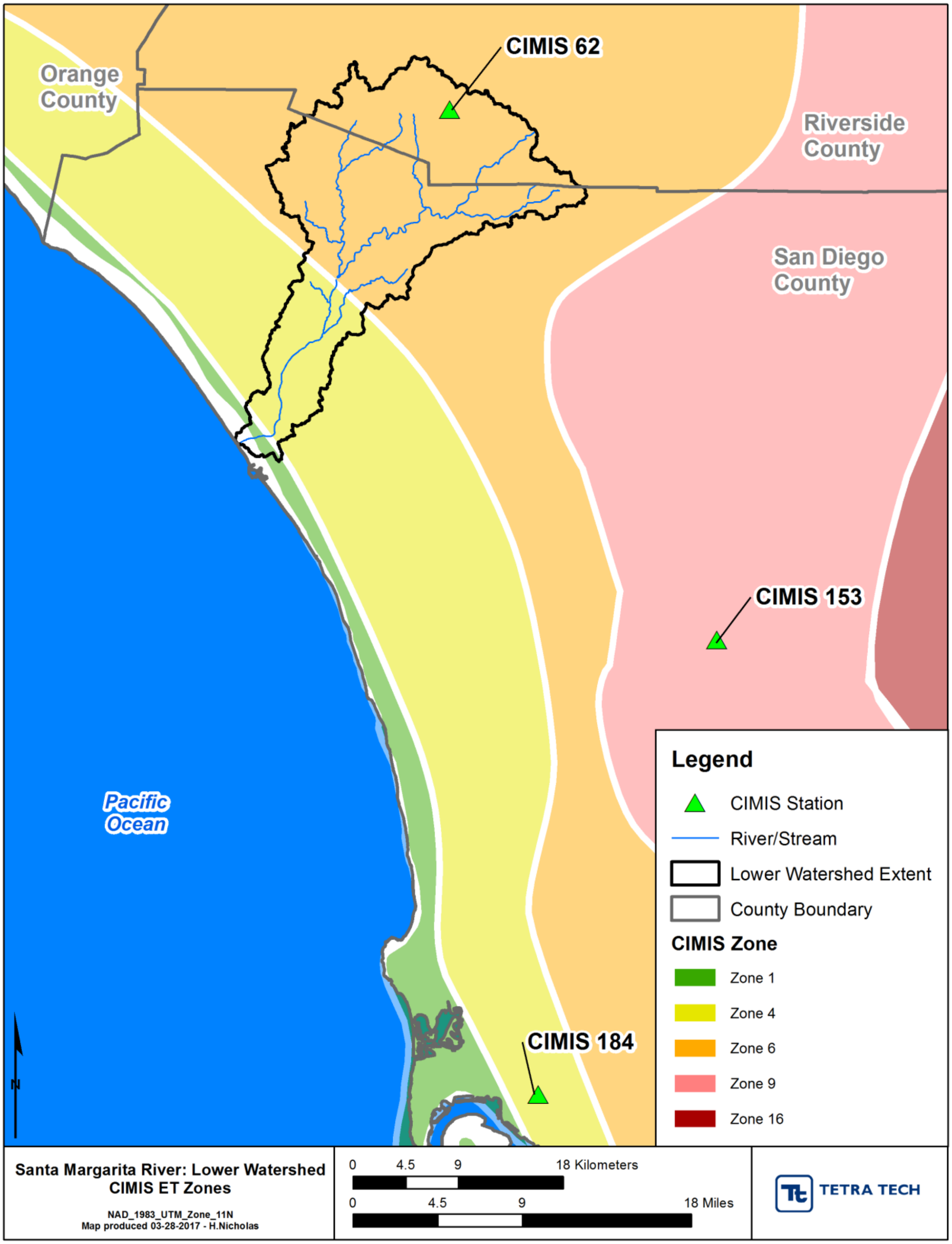


Figure 3-2. CIMIS Evapotranspiration Zones

3.2 IRRIGATION

In the climate of Southern California, irrigation of lawns and agricultural crops is necessary to sustain viable plants. To accurately simulate low flow hydrology, this additional supply of water must be considered. Since application rates are not exactly known across the watershed, estimates of irrigation demand are required.

The irrigation demand for the Santa Margarita model was calculated based on information presented in "A Guide to Estimating Irrigation Water Needs of Landscape Plantings in California" (UCCE, 2000). This guide recommends comparing daily precipitation to water demand to determine the amount of irrigation water needed. In California, reference evapotranspiration rates are measured and, in combination with daily rainfall data, can be used estimate daily irrigation demand. Irrigation demand is adjusted with crop or grass coefficients specific to each land use, and external water is applied to model pervious land uses receiving irrigation. Applying this method typically results in simulation of base flows during the summer. Without accounting for irrigation and its effect on groundwater and baseflow, the simulated summer flows would be grossly underestimated.

In the Santa Margarita River watershed, most irrigation is for orchard, nursery, or lawn irrigation. Irrigation water for lawns is derived primarily from municipal systems, while irrigation of crops often combines external water with groundwater sources.

The approach for simulation of irrigation applications consists of two components: calculation of potential irrigation demand based on cropping data, cover coefficients, reference ET, and irrigation efficiency; and calculation of irrigation applications after accounting for rainfall contributions.

3.2.1 Irrigation Demand

Daily irrigation demands were calculated from precipitation data and reference crop and lawn ET demands determined by CIMIS from either measured daily data (when available) or long-term monthly average ET demand values. Tetra Tech utilized the landscape coefficient method described in the WUCOLS III (Water Use Classifications of Landscape Species) manual (UCCE, 2000) to calculate the ET demands within the Ventura River Watershed. The equation to calculate ET Demand is:

$$\text{ET Demand} = \text{ETo} \cdot \text{Kc},$$

where ET Demand = Crop/lawn evapotranspiration demand (in.), ETo = Reference crop evapotranspiration (in.), and Kc = crop/lawn coefficient (dimensionless).

Reference ETo was calculated from CIMIS data, as described in Section 3.1.2. Irrigation demands were calculated separately for the major crop/lawn types in the watershed, crop coefficient values, which are measured in the field for specific crop types, represent the fraction of water lost from a crop relative to its reference evapotranspiration (ETo). The Kc values are taken as a constant fraction of ETo, although in fact the ratio is likely to vary with growth stage.

The majority of the irrigated agriculture land within the watershed includes citrus, avocado and fruit orchards, vineyards, row/truck crops, and plant nurseries. The WUCOLS III manual provides crop coefficients for various crop and turf grasses. Where a high and low seasonal range was provided, the average value was used to calculate irrigation demand. Table 3-1 shows the selected Kc values used for the major crop groups in the watershed.

Table 3-1. Crop Irrigation Coefficients (Kc)

Land Use	Crop Type	Kc
Agriculture	Row/truck crops	0.75
	Orchards, vineyards	0.70
Urban	Warm season turfgrass	0.6

3.2.2 Irrigation Application

Irrigation application rates were estimated external to the model and saved to the meteorology WDM. The fraction of land of a given class that is actually irrigated is specified in the External Sources block of the model input file and can be used as a calibration parameter.

Irrigation application is influenced by soil moisture storage from precipitation events, and it is not appropriate to calculate application rates based only on the irrigation demand. Instead, the application rate (or actual irrigation demand) should be calculated as the difference between the theoretical irrigation demand and the cumulated effective precipitation (P_e), where P_e is the fraction of precipitation that is stored in the soil and available to plants. USDA (1993) provides a method for estimating P_e (inches) on a monthly basis:

$$P_e = SF \cdot \left(0.70917\, P_t^{0.82416} - 0.11556\right) \cdot \left(10^{0.02426 ET_c}\right)$$, with

$$SF = \left(0.531747 + 0.295164\, D - 0.057697\, D^2 + 0.003804\, D^3\right)$$

Here, P_t is the monthly total precipitation (in.), D is equal to 50 percent of the available water capacity of the soil (in.), and ET_c is the monthly crop evapotranspiration demand. The use of D helps account for the variability among different soil types. Following USDA (1993), the resulting value of P_e is then limited to the smaller of the value calculated above, monthly total precipitation, and monthly crop evapotranspiration demand.

The monthly corrected irrigation application rate was divided among all days in the month on which there was not more than 0.2 inches precipitation on that day or the preceding day. The daily irrigation application amount was then disaggregated to hourly values under the assumption that most irrigation occurs between 6 and 9 AM.

3.2.3 Irrigation Efficiency and Extent

Because irrigation systems never perform 100 percent efficiently, additional water must be applied to satisfy crop requirements. Irrigation efficiency largely depends on the type of system (e.g., microjet, drip, sprinkler, and furrow), which is selected depending on intended crop/landscape type, soil and slope conditions, water source, and growth conditions. Well-designed and operated systems have an efficiency range of 80 percent to 90 percent while poorly performing systems can have irrigation efficiencies less than 50 percent. The value of water in Southern California has encouraged adoption of more high efficiency systems in recent years.

It is, however, also the case that not all land potentially subject to irrigation is actually irrigated in a given year. Only a fraction of residential pervious surfaces is maintained in turfgrass, and xeriscaping has become increasingly popular. For some parcels, irrigation may be used, but at a lesser rate than the ideal demand. The ratio of the fraction of a landuse type that is irrigated over the irrigation efficiency is applied as a multiplier on the irrigation demand time series to estimate the water applied.

Changes in irrigation practices over time introduce uncertainty into the watershed model. The San Diego County Department of Agriculture, Weights, and Measures (personal communication from Craig Lawson via Jo Ann Weber, March 14, 2017) reports that many nurseries switched from spray irrigation to drip irrigation during the drought, which would have increased efficiency, but also stated that close to 100 percent of land identified as irrigated agriculture is actually planted and irrigated in any given year. Orchards (primarily avocados) and row crops (primarily strawberries and cut flowers) use drip irrigation. Information was not available from the County on irrigation of residential parcels.

Quantitative estimates of the ratio of the fraction of a land type irrigated to irrigation efficiency are not available at this time; however, the model assumes a ratio of 0.25 for developed land (reflecting a relatively low fraction of residential lots in turfgrass). In contrast, a ratio of 1.0 is assumed for agricultural land uses, implying that slightly less than 100 percent of the areal irrigation demand is satisfied at any given time (because efficiency is less than 100 percent).

3.3 UPSTREAM BOUNDARY CONDITION

The current update of the model does not include revision of the simulation of the watershed above the confluence of Murrieta and Temecula Creeks in Riverside County. Accordingly, measured flows and estimated constituent loads at the upstream end of the Santa Margarita River gorge within Riverside County are taken as boundary conditions for the current model update. In contrast, the previous model simulated flows above this gage, but suffered from uncertainties due to the lack of detailed information on surface-ground water exchanges in the Murrieta – Temecula aquifer area.

3.3.1 Flow

The upstream extent of the San Diego model is USGS gage 11044000 – Santa Margarita River near Temecula. This gage, at the head of the Santa Margarita Gorge, is located just downstream of the Colorado River project water discharges from Rancho California Water District (RCWD) to satisfy water rights claims under CWRMA. It is also downstream of earlier discharges of reclaimed water by RCWD that occurred in the Murrieta area ending in 2002.

3.3.2 Water Quality

The upstream model boundary is located just downstream of the confluence of Temecula and Murrieta Creeks (USGS 11044000) in Riverside County and water quality conditions at this location were established using simulated loads from the previous (Tetra Tech, 2014) Santa Margarita River HSPF model as the Riverside County portion of the upstream watershed model has not been updated.

The previous HSPF model represented hydrologic and pollutant fate and transport processes across the entire Santa Margarita River watershed, which spans both San Diego and Riverside Counties. Daily pollutant loads for the boundary condition specification were calculated from observed flows at the USGS gage and simulated pollutant concentrations at this location (total suspended solids [TSS], ammonia/ammonium-nitrogen [NH_3+NH_4–N], nitrite plus nitrate-nitrogen [NO_2+NO_3–N], organic N, ortho-phosphate [PO_4–P]], and organic P). Monthly average wet and dry weather nutrient concentrations were used to establish loads on days after the previous HSPF model end date (9/30/2009). Following the approach used for pollutant loading assessments in the watershed, wet periods were identified as days with ≥ 0.1 inch rainfall on that day or on any of the three prior days. This approach was also used to define daily TSS loads when observed flows were less than 80 cubic feet per second (cfs). During high flow periods scour of the channel bed can effectively spike instream TSS concentrations. Therefore, monthly averages do not provide a proper representation of TSS concentrations during high flow periods. To establish representative TSS concentrations for observed high flows (> 80 cfs), the concentration was assumed to equal that of a flow of similar magnitude simulated by the previous model.

This procedure for establishing the upstream boundary condition is likely to result in considerable uncertainty in the representation of upstream loads after September 2010. Prior to September 2010, the uncertainty in the boundary condition specification is that inherent in the un-updated HSPF model of the upstream watershed.

3.3.3 Water Temperature

The current implementation of the model does not undertake dynamic simulation of water temperature; however, water temperature affects many instream processes and a reasonable approximation is required for the model. The approximate water temperature series was therefore created based on monitored temperature in Santa Margarita River near Temecula for WY 1995 – WY 2016.

There is a distinct difference in the hydrograph around the beginning of Water Year 2003 associated with the start of the CWRMA discharge. For WY 2003- 2016 missing data were filled in with the mean value for that week of year over this period and disaggregated to an hourly time step using WDMUtil. For earlier periods, missing data were filled with the mean value for that week of year in WY 1995-1999.

3.4 POINT SOURCE DISCHARGES

No permitted point source discharges (other than MS4 discharges) occur in the model study area under current conditions. During the 1990s, USMC Camp Pendleton had several wastewater treatment plant lagoon discharges to the lower Santa Margarita (model reaches 104 and 105). The last of these was discontinued in 2003 and are of limited relevance to current conditions except for model:data comparisons for the earlier period of monitoring. Monthly flow data are available for these discharges and are included in the model. During their period of operation, the discharges are assigned their monthly average permit limits (1 mg/L total N and 0.1 mg/L total P) for use in the simulation.

3.5 CAMP PENDLETON SURFACE WATER MANAGEMENT

The Camp Pendleton appropriative diversion from the mainstem Santa Margarita River (reach 106) is input as a demand outflow series based on daily records provided by Camp Pendleton. The Camp makes controlled releases from Lake O'Neill, and there are occasional wet season spillage discharges. These two outflows are both monitored by USGS (gages 11045600 and 11045700) and are incorporated as demand series. Because Lake O'Neill represents a combination of water from different sources (Santa Margarita River and Fallbrook Creek) and substantial nutrient processing and retention is believed to occur in the lake, nutrient concentrations associated with releases are based on average concentrations reported in monitoring for Fallbrook Creek near Fallbrook (11045300). These amount to 0.21 mg/L PO_4-P, 0.09 mg/L Organic P, 0.81 mg/L NO_3-N, 0.11 mg/L NH_4-N, and 0.33 mg/L Organic N.

3.6 GROUNDWATER EXCHANGES

The Santa Margarita River flows through an area of alluvial aquifers on Camp Pendleton. Depending on conditions, the river both loses water to and gains water from the aquifers, and these exchanges play a major role in determining the flow and associated nutrient loads that reach the Santa Margarita Estuary. In the earlier phases of the model (Tetra Tech, 2013), these exchanges were represented by a rough approximation. Stetson Engineers subsequently developed a groundwater model of the aquifers and preliminary results for 2008 – 2010 were incorporated into the HSPF model (Sutula et al., 2016). The groundwater model has now been recalibrated and extended through 2016, allowing an improved representation of interactions with surface flows.

3.6.1 Integration with Lower Santa Margarita Groundwater Model

The hydrogeology of the Santa Margarita River basin near Marine Corps Camp Pendleton is complex and has significant consequences for the transport of water, sediment, and nutrients from the upper river to the Estuary. Water from the river is diverted to groundwater recharge ponds as well as to Lake O’Neill on Camp Pendleton. The recharge ponds are designed to supply water to the alluvial groundwater basin, which is pumped for water supply and irrigation. Streambed recharge contributes water to the groundwater aquifer, and the groundwater aquifer recharges the river as baseflow, depending on the height of the seasonal water table relative to the river surface.

The major components of the water balance in the Lower Santa Margarita River Basin are summarized in Figure 3-3 (from Brown and Caldwell, 2012). Appendix E in the Salt and Nutrient Management Plan (Brown and Caldwell, 2012) provides a detailed summary of the water budget for water years (WY) 2008-2009. During this period, the upstream inflow in the Santa Margarita River amounted to 32,800 AF/yr. Of this inflow, 7,330 AF/yr was diverted to recharge ponds on Camp Pendleton and 2,260 AF/yr was diverted to Lake O’Neill, together constituting 29% of the river flow in WY 2008-2009; however, releases from Lake O’Neill returned 2,160 AF/yr to the river (including all upstream flow from Fallbrook Creek; 570 AF/yr on average). Groundwater pumping from the Lower Santa Margarita River groundwater basin amounted to 6,640 AF/yr. There are multiple other fluxes, such as evapotranspiration, channel underflow, and local tributary discharges. The balance between these fluxes has a strong seasonal component, with most diversions occurring during the winter wet period and the highest pumping demand during the summer. Describing these complex interactions is best accomplished through use of a groundwater model.

3.6.1.1 Camp Pendleton MODFLOW Model

Stetson Engineers extended Camp Pendleton’s existing water supply MODFLOW model of the alluvial aquifer on for the Salt and Nutrient Management Plan (SNMP), as documented in Brown and Caldwell (2012). The alluvial aquifer in the vicinity of Camp Pendleton consists of three sub-basins (Upper Ysidora, Chappo, and Lower Ysidora; see Figure 3-4), which correspond closely (although not exactly) to HSPF river reaches 106 (Upper Ysidora from above Camp Pendleton diversion to Fallbrook Creek), 105 (Upper Ysidora from Fallbrook Creek to Ysidora Gage), 104 (Chappo), and 103 (Lower Ysidora). The three groundwater sub-basins are separated by narrows with shallow bedrock that can cause subsurface water to resurface.

The CP MODFLOW model was initially calibrated to groundwater conditions on Camp Pendleton for water years 2008 and 2009 (Stetson, 2015), and was recently extended through the end of water year

2016. The MODFLOW application successfully represents the water balance on Camp Pendleton and in the adjacent segments of the river.

An important part of the MODFLOW model is simulation of exchanges between the aquifer and surface water cells. The MODFLOW model operates at a monthly time interval (referred to as a “stress period”) and for each month estimates streambed recharge and streambed discharge, which is sufficient for developing an aquifer water budget but does not provide a detailed prediction of streamflow or exchanges between the river and aquifer at the hourly time step required by the watershed model. Stetson Engineers provided monthly time series of external forcing, streamflow exchange rate results, and simulated monthly surface flows by groundwater sub-basin from the MODFLOW model.

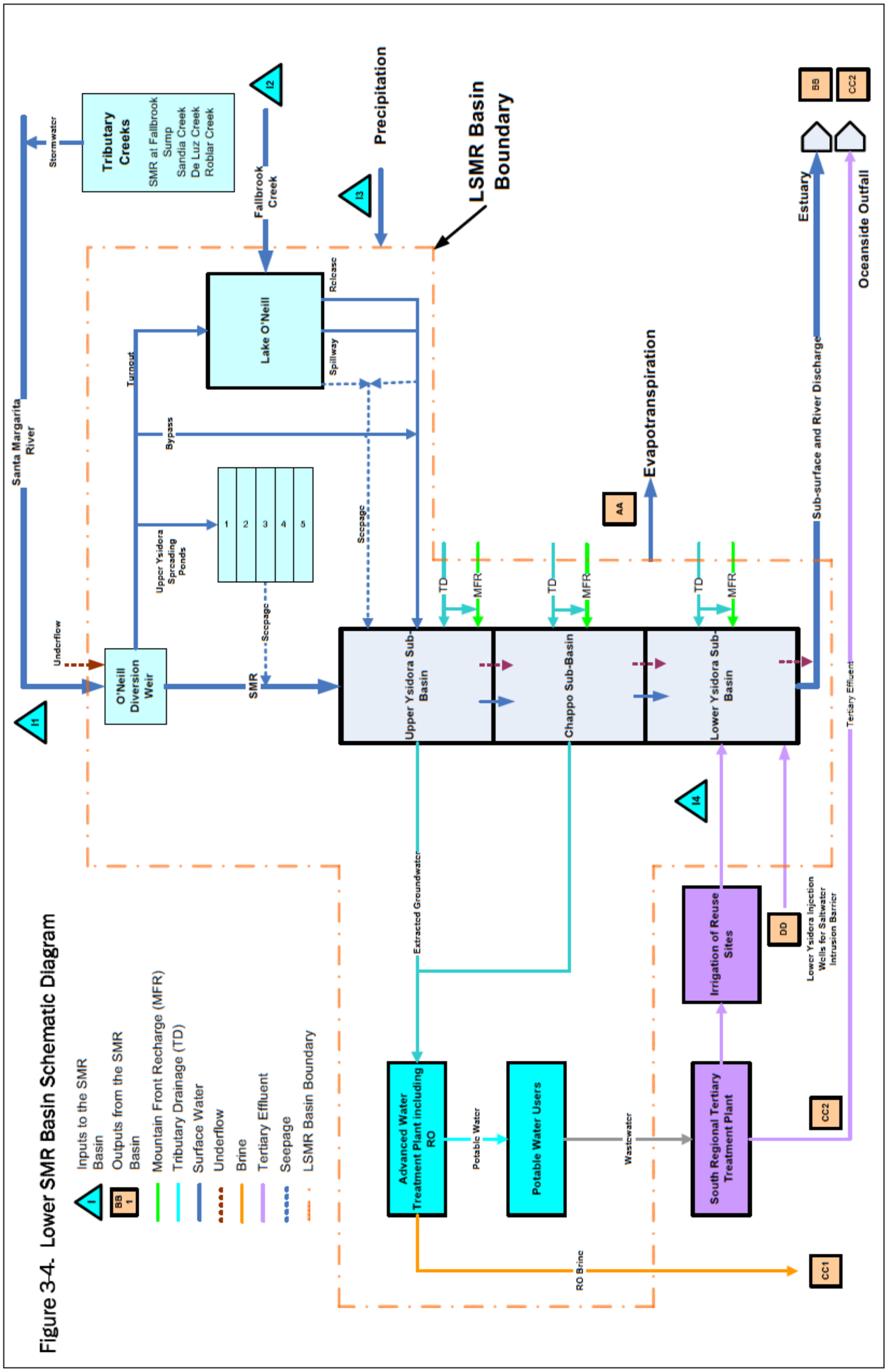


Figure 3-3. Water Balance Components of the Lower SMR Basin (from Brown and Caldwell, 2012)

Note: Input from Tributary Creeks should be indicated as containing both surface and subsurface flows.

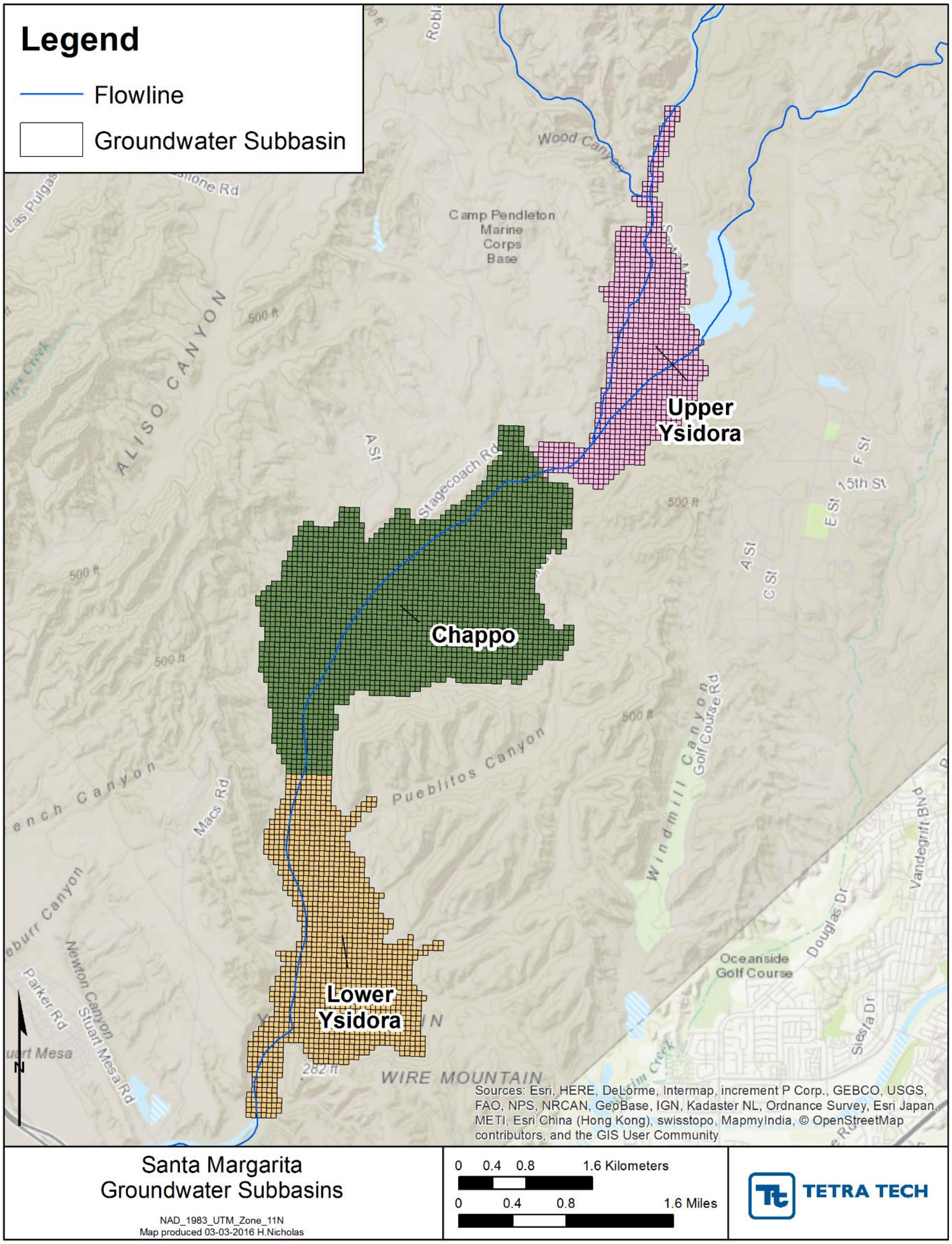


Figure 3-4. Lower Santa Margarita Groundwater Sub-basins in the MODFLOW Model

3.6.1.2 Integration with the HSPF Model

The MODFLOW model successfully achieves its intended purpose of evaluating the surface and subsurface water balance in the area of Camp Pendleton. The MODFLOW application was not developed for direct integration with a surface flow model like HSPF that operates at a sub-daily time step. Nonetheless, the MODFLOW application provides important information that can help constrain the HSPF watershed model representation of channel processes and exchanges in the vicinity of Camp Pendleton. Integration of the two models is not, however, straightforward or easy. This occurs for a number of reasons:

1. The HSPF model operates on an hourly time step whereas the MODFLOW model represents a mass balance on a monthly time step.
2. The MODFLOW model uses gaged flow as a model input, including flows at the Santa Margarita River at FPUD sump (USGS 11044300) and De Luz Creek (11044800), plus an estimated incremental gain or loss between those two gages and the MODFLOW model boundary. In contrast, the HSPF model simulates flows upstream of the MODFLOW domain based on precipitation inputs and runoff calibration at the USGS gage locations in the watershed. As a result, the HSPF model simulation approximates, but does not exactly match, the MODFLOW model input flows.
3. There is overlap in mass balance accounting between the two models as HSPF simulates a local shallow groundwater cycle driven by percolation from the overlying soil, but does not simulate the water balance of the regional aquifer. The MODFLOW model was developed as a water supply model and simulates water leaving the aquifer (below the groundwater table) due to evapotranspiration from phreatophytes. It does not simulate the moisture in the soil zone or water use from non-phreatophyte vegetation. Because of the overlap in the accounting of shallow ground water, it is difficult to prevent double counting of moisture stores between the two models.
4. MODFLOW output for stream exchanges cover both the main stem of the Santa Margarita and numerous ephemeral tributaries. The streambed recharge and streambed discharge used for the SNMP groundwater aquifer budget are based on the stream leakance term from the MODFLOW volumetric budget terms. Stream leakance represents the exchange of water between the main stem and tributary stream cells and the groundwater table. This is not the same as additions to or losses from surface flow as a portion of the “streambed” discharge simulated by MODFLOW goes to evapotranspiration from the riparian zones of the Santa Margarita River and tributaries without becoming surface flow. The MODFLOW “streambed discharge” term should thus not be interpreted as being equivalent to a direct inflow to the river.
5. The MODFLOW calibration is focused on the aquifer water and dissolved solids mass balance. It is calibrated to surface flows in the sense that the model attempts to reproduce monthly streamflow observed at the USGS gage for the Santa Margarita River at Ysidora (11046000, corresponding to the outflow from the Upper Ysidora groundwater sub-basin), based on gaged upstream flows in the Santa Margarita River at FPUD sump (11045300) and measured diversions to the Camp Pendleton recharge ponds and Lake O’Neill. Surface flows leaving the Chappo and Lower Ysidora sub-basins are not gaged and thus are not truly calibrated.

Based on discussions with Jean Moran of Stetson Engineers (personal communication, February 3, 2016), the Santa Margarita River streambed discharge and recharge terms cannot be directly exported from the MODFLOW volumetric budget of the aquifer. The bulk budget term can be misleading because of the multiple network of stream segments representing ditches and side tributary flow. The recommendation from Stetson was that it would be better to work starting with the simulated streamflow at the exit of each of the three groundwater sub-basins as a measure of the net changes in surface flow across each sub-basin.

The surface flow inputs to the MODFLOW model at the upstream end are calculated as the sum of flows at the FPUD sump (11044300) and De Luz Creek (11044800), plus an estimated incremental gain or loss between those two gages and the MODFLOW model boundary. Diversions from the river to the recharge ponds are simulated in a reservoir operations model (ROM), and monthly diversions and recharge are incorporated on a monthly basis into the MODFLOW model as inputs. This direct forcing means that the MODFLOW model should provide a very close match to wet weather flows at the Ysidora gage. However, it is important to note that the MODFLOW model is not a perfect predictor of the surface water balance at the Ysidora gage, and indeed tends to over-estimate dry weather flows while closely matching peak flows (due to assimilation of the upstream gage data; Figure 3.4).

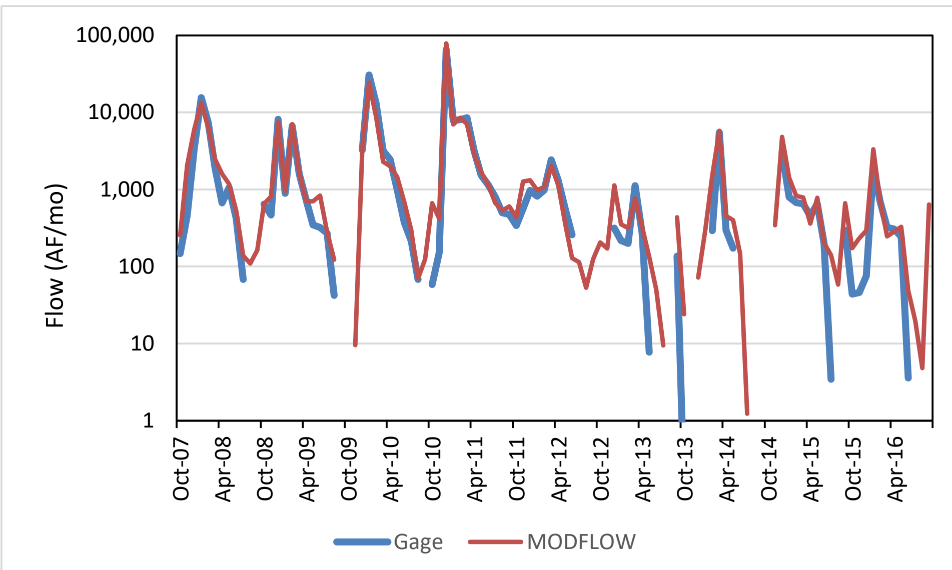


Figure 3-5. Comparison of MODFLOW and Gaged Flow Volumes, Santa Margarita River at Ysidora

As the HSPF model reaches correspond to the surface projection of the MODFLOW groundwater sub-basins in this area, the final approach adopted was to calculate the net residual surface flow balance (in MODFLOW) for each sub-basin as the outflow at the downstream point minus the net sum of inflows, which quantifies the net monthly exchanges with groundwater (as predicted by the MODFLOW application). The calculation is adjusted to use the HSPF simulation of local inflows and reach evaporation. The local inflows consist of HSPF-simulated surface runoff and interflow. Local groundwater discharge predicted by HSPF is disconnected and is assumed to be represented by the MODFLOW exchanges. This provides the basis for estimating the hourly average exchanges needed for the HSPF model. A schematic illustration of the process is shown in Figure 3-6.

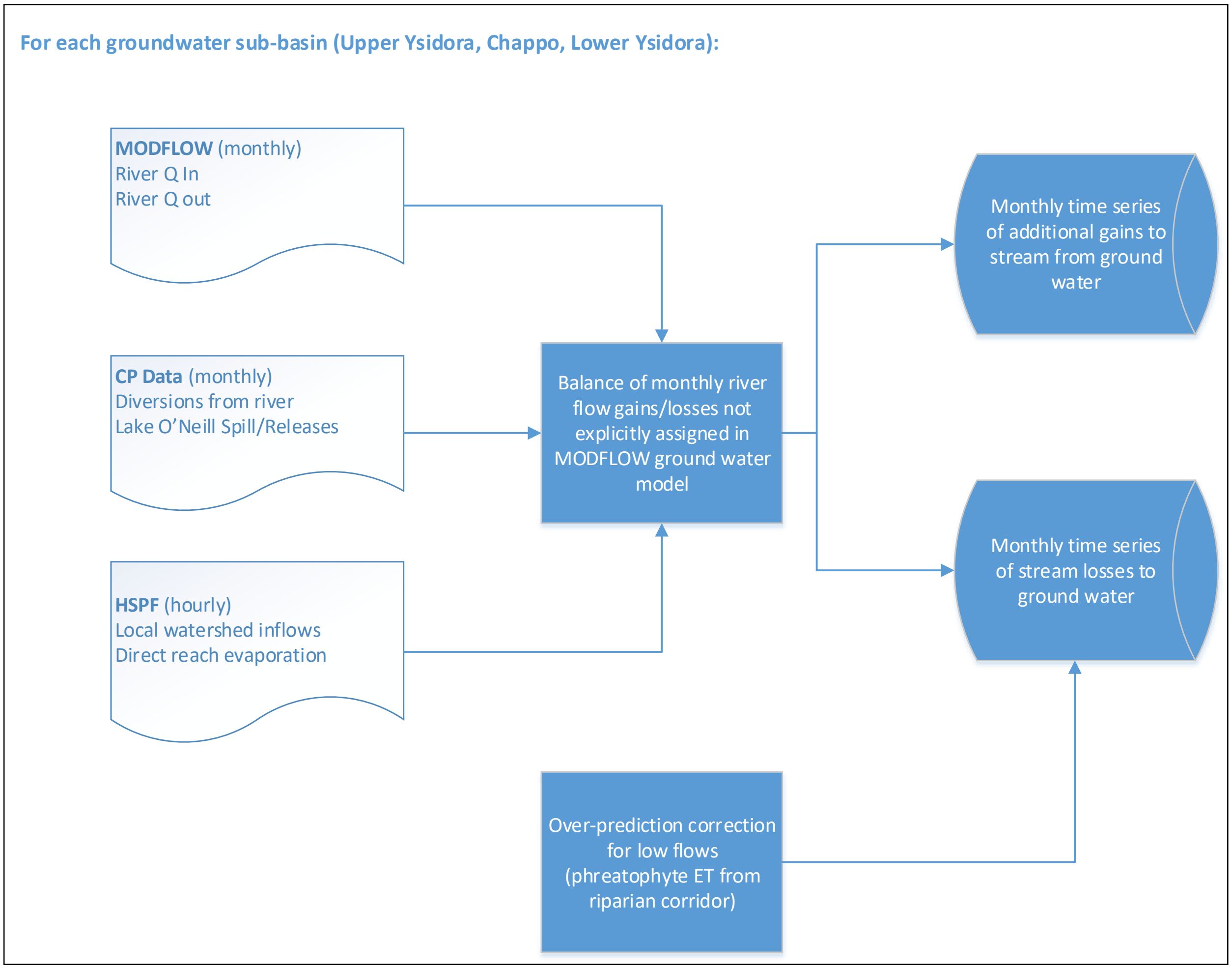


Figure 3-6. Schematic for Reconciliation of MODFLOW and HSPF Simulations

For the Upper Ysidora groundwater sub basin downstream of the Camp Pendleton diversions, corresponding to HSPF reach 105 (see Figure 3.1 above), this residual balance is given by: (MODFLOW simulated flow at Ysidora) – Sum {(gaged flow into model at FPUD sump) + (Lake O'Neill spill/release series) + (local inflow direct to this sub basin simulated by HSPF) – (gaged diversion to recharge) – (HSPF simulated evaporation from reach)}. The residual balance is applied to HSPF reach 105, rather than 106 plus 105, because the HSPF model simulates the Camp Pendleton diversion within reach 106 (as a fully mixed segment) and the corrections must be applied after accounting for this diversion.

For the Chappo and Lower Ysidora sub basins, corresponding to HSPF reaches 104 and 103, the balance is given by: (MODFLOW simulated surface outflow) – Sum {(MODFLOW simulated inflow from upstream) + (local inflow simulated by HSPF) – (HSPF simulated evaporation from reach)}.

If the resulting monthly term is negative, indicating a loss to ground water, this term is assigned as a demand-based outflow on the HSPF reach that goes to ground water rather than being transmitted downstream. If the resulting monthly term is positive, indicating a gain from ground water, this term is assigned as an external inflow to the surface water model. In both cases, the monthly result is assumed to be evenly distributed over that month for the hourly HSPF model to create hourly inflow or reach loss time series. Note that the use of monthly averages for channel losses in HSPF may introduce some inaccuracies into the simulation of the surface flow hydrograph on a sub-monthly scale (i.e., the daily or hourly hydrograph), especially for a runoff event that occurs after an extended period of dry conditions; however, the monthly average estimates of fluxes between the surface water model and groundwater are the best information that is currently available.

The initial application to the 2008 – 2016 MODFLOW calibration period showed that the HSPF model (like the MODFLOW model) tended to over-predict dry weather flows in the river. The over-prediction suggests that somewhat more water from the river is likely being taken up and diverted to evapotranspiration by phreatophytes. Assigning additional losses from the river of 1.2 cfs for the summer (July through September) in the Upper Ysidora sub-basin brought predictions at the Ysidora gage into much closer agreement. This value was pro-rated to the Chappo and Lower Ysidora sub-basins using the ratio of MODFLOW annual evapotranspiration for these basins shown in Appendix E of Brown and Caldwell (2012).

The HSPF model with these exchanges included provides a good fit to the observed volumetric flows at the Ysidora gage (Figure 3-7), although there are still discrepancies present.

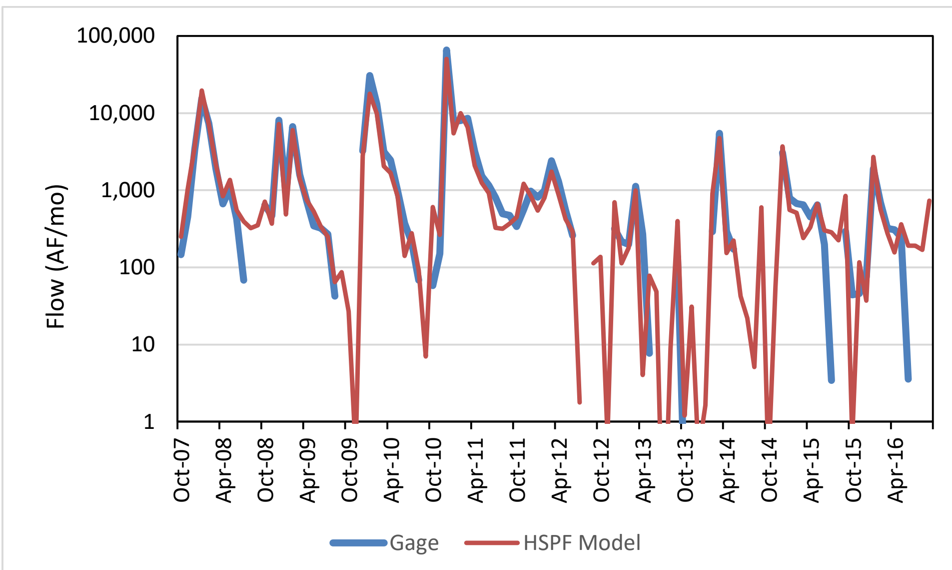


Figure 3-7. Comparison of Corrected HSPF and Gaged Flow Volumes, Santa Margarita River at Ysidora

3.6.1.3 Extension beyond MODFLOW Calibration Period

The MODFLOW model is only developed for water years 2008-2016. In contrast, the HSPF model is run from January 1995 on.

Lacking a groundwater model application for earlier years will decrease the accuracy of simulation, but does not make it impossible. To accomplish this we first developed surrogate models that predict the MODFLOW results (specifically, the residual surface flow balances for each sub-basin) from other variables that are available for the entire period.

For the Upper Ysidora basin, the residual surface flow balance (ΔS) for the MODFLOW simulation follows a seasonal pattern that is roughly sinusoidal. It also implicitly depends on the recent water input, which can be linked to the lagged flow volume gaged in the Santa Margarita at FPUD sump.

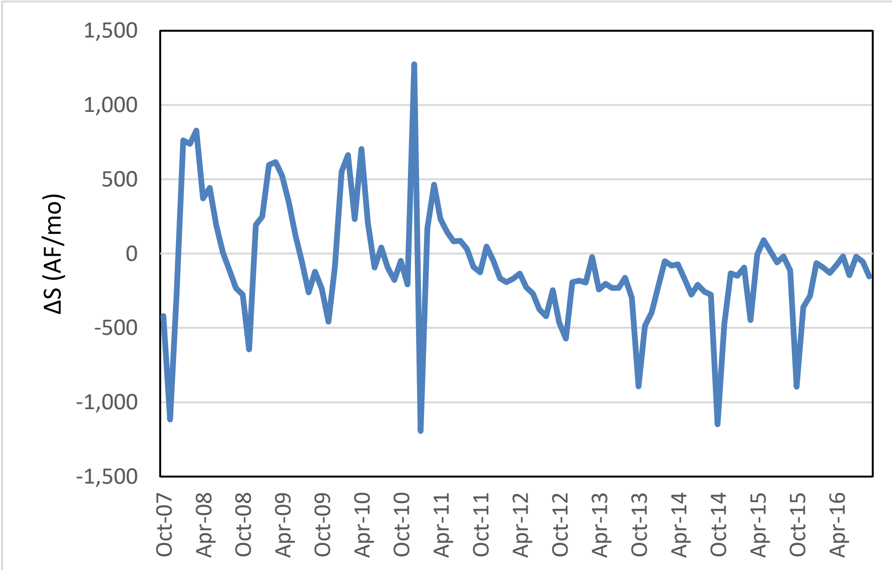


Figure 3-8. Residual Surface Flow Balance Pattern, Upper Ysidora

The following surrogate model was fit to describe the Stetson model results:

$$\Delta S_{i,t} = [\propto + \beta_1 \cdot FPUD_t + \beta_2 \cdot FPUD_{t-1}] \cdot M_i$$

Here $\Delta S_{i,t}$ is the residual in the surface flow balance (AF) in calendar month *i* and sequential month *t*, $FPUD_t$ and $FPUD_{t-1}$ are the current and one month lagged flow volumes at FPUD sump, and M_i is an adjustment applicable to month *i*. Parameters were fit by minimizing sum of squared differences, resulting in the following parameter set:

α = 1,478, β_1 = 0.669, β_2 = -2.44, and M = {0.010,-0.021,-0.057,-0.007,-0.012,-0.172,-0.172,-0.167, -0.182,-0.460,-0.399, 0.038}

This provides a reasonable fit to the MODFLOW output, explaining about 60% of the observed variability in ΔS, as is shown in Figure 3-9.

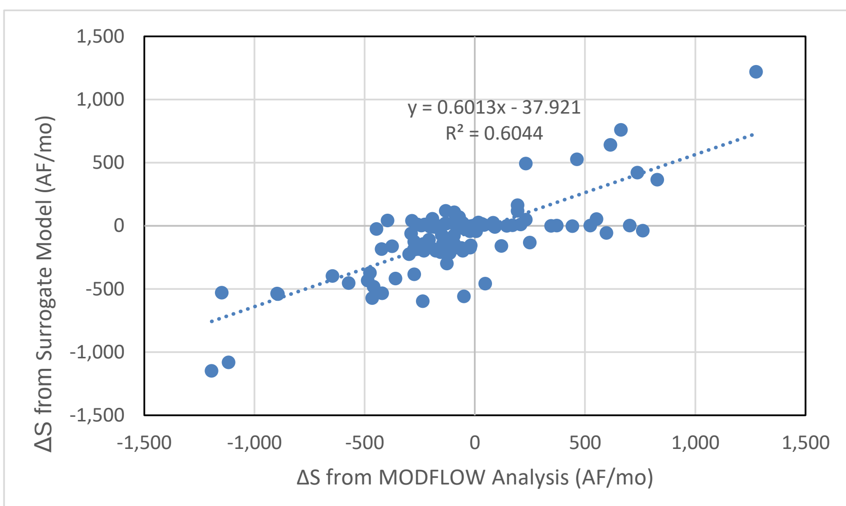


Figure 3-9. Surrogate Model for ΔS, Upper Ysidora Sub-Basin

Results for the Chappo and Lower Ysidora Basins are more difficult to fit with a surrogate model, but the exchanges are also of smaller magnitude than those in the Upper Ysidora Basin. Reasonable surrogate model results are obtained for both using a current and lagged regression on the simulated ΔS for Upper Ysidora:

$$\Delta S_{i,t} = [\propto + \beta_1 \cdot YSD_t + \beta_2 \cdot YSD_{t-1}] \cdot M_i$$

Chappo: α = -10, β_1 = -0.035, β_2 = -0.871, and
M = {0.142,-0.034,0.648,0.492,5.701,7.729,-0.138,0.019,-3.113,-1.548,-0.663,-0.922}, R^2=0.356.

Lower Ysidora: α = -1,146, β_1 = 4.507, β_2 = 2.141, and
M = {0.006, 0.002,0.000,-0.003,-0.017,-0.028,-0.010,0.000,-0.014,-0.018,-0.028,0.006}., R^2=0.548.

The surrogate models depend only upon the month and gaged flows at FPUD Sump, which are complete for the model simulation period. They can therefore be used to create reasonable time series of groundwater exchanges for months prior to WY 2008 (Figure 3-10) – although the results will of course be less certain than if a full groundwater model simulation was available for those years.

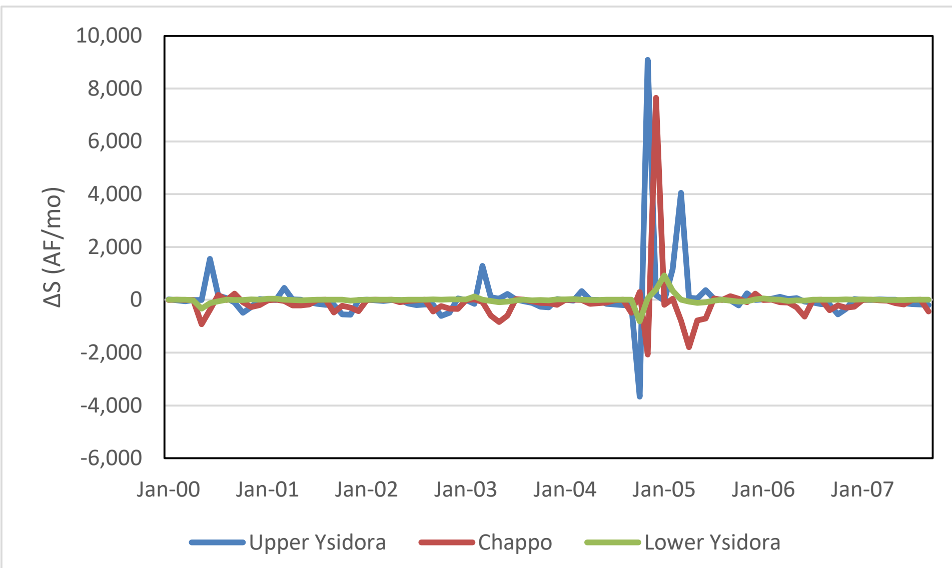


Figure 3-10. Surrogate Model Results, January 2000 – September 2008

For application in the HSPF model, the results from the direct analysis of MODFLOW are used for water years 2008 – 2016, combined with the surrogate model results for January 2000 to September 2007, allowing exploration of a broader range of climate conditions. Groundwater exchanges prior to 2000 are not incorporated. As with the direct analysis of MODFLOW, the surrogate model results are split into additions to and subtractions from the simulated reach flow and small additional reach losses are added for January through September. While the surrogate model provides a reasonable statistical approximation, results are more reliable for the period for which the actual MODFLOW model is available. Note that because the streambed losses are specified to the model as an outflow demand, any periods in which the projected losses exceed available flow will simply result in zero simulated flows in the model.

3.6.1.4 Water Quality Associated with Groundwater Discharges

Nitrogen contained in water discharging from the aquifer to the river is considered to be predominantly in the form of nitrate in this coarse-grained, highly transmissive aquifer. We represent these in HSPF as constant average concentrations in discharging seepage.

Nitrate was addressed in the SNMP and aquifer concentrations were monitored (Brown and Caldwell, 2012, Table 3-12). Stetson provided calibrated flow-weighted concentration estimates of nitrate in MODFLOW discharges to the river, which are 3.012 mg/L NO_3-N for UY and 0.225 mg/L for LY. These are reasonably close to the average groundwater concentrations of 2.74 mg/L for UY and 0.14 mg/L for LY reported by Brown and Caldwell. The current MODFLOW runs do not show any months in which there is a net predicted discharge from groundwater to the river in the CH basin; however, the difference approach described in Section 3.6.1.2 does produce a few months with net discharge. For these scattered months, we use the LY estimate of 0.225 mg/L, which is similar to the concentration of 0.2 mg/L reported for CH by Brown and Caldwell.

Stetson also provided flow-weighted concentrations of PO4-P in water discharging from the aquifer to surface water of 0.137 mg/L for UY and 0.092 mg/L for LY. As with NO_3-N, the LY estimate is also used for CH.

3.6.2 Other Groundwater Exchanges

The Rainbow Valley associated with Rainbow Creek constitutes a small alluvial aquifer and is documented to have a high water table due to a combination of extensive use of imported water for irrigation and constrictions on groundwater discharge. This situation is most evident in the area dominated by plant nurseries to the east of I-15. Baseflow conditions in Rainbow Creek are well monitored at multiple sequential stations. During water quality calibration (Section 5.0), it became evident that upstream concentrations are diluted in the downstream portions of Rainbow Creek. The concentrations were brought into agreement with observations by assuming a constant discharge from groundwater of 0.2 cfs in model reach 175, which also improved the low flow hydrology fit.

For Sandia Creek, flow gaging shows nearly persistent baseflow of 1 – 2 cfs that does not appear to be explained by the extent of irrigated agriculture in the drainage area. Tetra Tech (2013) interpreted this to be due to longer-range groundwater inputs, possibly derived from the adjacent Murrieta-Temecula groundwater basin. This assumption is maintained in the current model, with assignment of a discharge of 2 cfs to reach 117.

There also appears to be a small gain from groundwater within the Santa Margarita River Gorge that is not accounted for by the gage at the head of the gorge. Again, this may be derived from underflow from the adjacent Murrieta-Temecula groundwater basin. This is represented by assignment of a discharge of 0.5 cfs to the head of reach 119.

In contrast, De Luz Creek appears to lose channel flow to groundwater, resulting in long periods of no flow at the gage. This is represented by assigning seepage losses (about 0.4 cfs) during low flow conditions to the FTable for reach 111.

These minor groundwater exchanges are largely speculative without development of additional groundwater models; however, they do appear to be consistent with observations. These minor gains from groundwater are assigned an NO_3-N concentration of 5 mg/L.

3.7 ATMOSPHERIC DEPOSITION OF NUTRIENTS

Atmospheric deposition of N is explicitly included in the model. Gridded annual data from the National Atmospheric Deposition Program (NADP) for dry and total deposition mass of NOx and NH_4 is available for the years 2000-2015 (http://nadp.sws.uiuc.edu/committees/tdep/tdepmaps/). These data were aggregated over the four weather zones. For dry deposition of NOx and NH_4 the raw data as kg-N/ha/yr and was converted to lb-N/ac/yr. To calculate wet deposition concentrations for NOx and NH_4 for each weather station area, the difference between total and dry deposition was calculated to estimate wet deposition mass in kg-N/ha/yr. These values were converted to a concentration basis by dividing by the total precipitation for the year. The annual datasets were then converted to monthly values for input to the HSPF model.

Atmospheric deposition of phosphorus is not regularly monitored by USEPA or other agencies and is not included in the model at this time.

4.0 HYDROLOGY RECALIBRATION

Calibration consists of the process of adjusting model parameters to provide a match to observed conditions. Calibration is necessary because of the semi-empirical nature of water quality models. Although these models are formulated from mass balance principles, most of the kinetic descriptions in the models are empirically derived. These empirical derivations contain a number of coefficients that are usually determined by calibration to data collected in the waterbody of interest.

4.1 HYDROLOGIC CALIBRATION APPROACH

The revised model was recalibrated, starting with parameters from the previous model. Hydrologic calibration for the Santa Margarita River watershed used the standard operating procedures for the HSPF model described in Donigian et al. (1984), Lumb et al. (1994), and Duda et al. (2012). The general approach begins with replicating the total water balance, followed by adjustments to represent the division between high flows (due mostly to surface runoff) and low flows (due mostly to subsurface flow). Fine-tuning is then used to adjust the seasonal balance. Calibration performance was tracked using Tetra Tech's HydroCal spreadsheet tool, which automatically retrieves model output and generates relevant statistics and graphical comparisons.

Current model simulations covered the period from October 1994 to December 2016, whereas the earlier models were calibrated only through the end of Water Year 2010. In most cases, water years 2001 through 2016 were used for calibration. This avoids the period in the 1990s for which estimates of groundwater exchange in the Lower Santa Margarita are not available and when land use may have differed from current conditions. It also allows for model spin up time to stabilize soil moisture stores. Because the current effort is an update to an existing calibrated model, no separate validation period is specified.

As in the previous iteration (Tetra Tech, 2013), values of hydrologic parameters were generally consistent with the ranges recommended in USEPA (2000) and adjusted during calibration. Key hydrologic parameters included the following:

LZSN: The LZSN parameter in HSPF is an index of the lower zone nominal soil moisture storage (inches), where the lower zone is operationally defined as the depth of the soil profile subject to evapotranspiration losses. LZSN is related, but not equivalent to the available water capacity (AWC) of a soil. It also reflects precipitation characteristics. USEPA (2000) recommends setting initial values at one-quarter of annual mean rainfall plus 4 inches in arid and semi-arid regions, but also notes that these estimates need to be revised through calibration. We found that the response in Rainbow Creek watershed was best simulated with a low LZSN value of 3 inches. For the remainder of the watershed, the calibrated estimates ranged from 6 – 11 inches.

INFILT: INFILT is an index to mean soil infiltration rate (in/hr), which controls the overall division of the available moisture from precipitation (after interception) into surface and subsurface flows. INFILT is not a maximum infiltration rate, nor an infiltration capacity term. As a result, values of INFILT used in the model are expected to be much less than published infiltration rates or permeability rates shown in the soil survey (often approximately 1 to 10 percent of soil survey values). USEPA (2000) shows acceptable ranges of INFILT for soil hydrologic groups, ranging from a minimum of 0.01 in/hr for group D soils to a maximum of 1.0 in/hr for group A soils. The Santa Margarita watershed has a mix of predominantly B, C, and D soils. Final calibrated values of INFILT are 0.03 in/hr for D soils, 0.073 in/hr for C soils, and 0.2625 in/hr for B soils, consistent with recommended ranges. Nurseries were calibrated separately, with an INFILT value of 0.04 in/hr.

AGWRC: The active groundwater recession coefficient was initially estimated based on baseflow separation and analysis of recession rates – which are, however, difficult to interpret in highly managed systems. Adjustments during calibration resulted in final values that ranged from 0.93 to 0.999, with higher values in the weather zone 3. AGWRC was combined with KVARY values from 1 to 7, with higher values allowing for faster groundwater recession rates during wet periods and slower groundwater recession rates during dry periods.

LZETP: The LZETP parameter is a coefficient to define the evapotranspiration opportunity from the soil lower zone and is a function of cover type. Monthly coefficients (MON-LZETP) were specified for all land uses, with a strong seasonal component for crops and forest cover and a weaker seasonal component for herbaceous cover.

The full set of parameters may be examined in the model user control input (*.UCI) file, provided electronically.

4.2 HYDROLOGIC CALIBRATION CRITERIA

For HSPF simulation of hydrology, a variety of performance targets have been specified, including Donigian et al. (1984), Lumb et al. (1994), and Duda et al. (2012). Based on these references and previous experience with similar models, hydrology performance targets are summarized in Table 4-1.

Table 4-1. Performance Targets for HSPF Hydrologic Simulation (Magnitude of Annual and Seasonal Relative Mean Error (RE); Daily NSE)

Model Component	Very Good	Good	Fair	Poor
1. Error in total volume	≤ 5%	5 - 10%	10 - 15%	> 15%
2. Error in 50% lowest flow volumes	≤ 10%	10 - 15%	15 - 25%	> 25%
3. Error in 10% highest flow volumes	≤ 10%	10 - 15%	15 - 25%	> 25%
4. Error in storm volume	≤ 10%	10 - 15%	15 - 25%	> 25%
5. Winter volume error	≤ 15%	15 - 30%	30 - 50%	> 50%
6. Spring volume error	≤ 15%	15 - 30%	30 - 50%	> 50%
7. Summer volume error	≤ 15%	15 - 30%	30 - 50%	> 50%
8. Fall volume error	≤ 15%	15 - 30%	30 - 50%	> 50%
9. Nash-Sutcliffe coefficient of model fit efficiency (NSE)	> 0.80	> 0.70	> 0.40	≤ 0.40

It is important to clarify that the RE performance target ranges are intended to be applied to average values, and that individual events or observations may show larger differences and still be acceptable

(Donigian, 2000). They are also obviously not applicable to situations where the observed flow is zero – for instance, the percentage "error in 50% lowest flow volumes" is not applicable at gages where measurable flow occurs less than 50 percent of the time.

Adequacy of daily flow predictions was also evaluated using the Nash-Sutcliffe coefficient of model fit efficiency (NSE). NSE is a commonly used model performance measure and extensive information is available on reported values from various studies. It is recommended for use by ASCE (1993), Legates and McCabe (1999), and Moriasi et al. (2007). The NSE statistic ranges from minus infinity to one and is given by the following formula:

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{sim} \right)^2}{\sum_{i=1}^{n} \left(Y_i^{obs} - Y^{mean} \right)^2} \right],$$

where Y_i^{obs} is the ith observation, Y_i^{sim} is the paired simulated value, Y^{mean} is the mean of the observed values, and n is the number of observations. The NSE is thus a normalized statistic that determines the relative magnitude of the residual variance ("noise") compared to the measured data variance ("information").

An NSE value of 1 indicates perfect prediction, while a value of zero indicates that the model does no better than the long-term average in explaining variability among individual observations. An NSE value of 0.7 or better is generally accepted as a measure of excellent model fit; however, the ability to obtain high NSE values is limited by the accuracy and representativeness of precipitation data. Moriasi et al. (2007) recommend an NSE of 0.50 or better (applied to monthly sums) as an indicator of adequate hydrologic calibration when accompanied by a relative error of 25 percent or less.

4.3 HYDROLOGY CALIBRATION RESULTS

Three long-term stream gages are present on the Santa Margarita mainstem: Santa Margarita River near Temecula (USGS 11044000), just below the confluence of Murrieta and Temecula Creeks; at the FPUD sump (USGS 11044300), above the Camp Pendleton diversions; and at Ysidora (11046000), downstream of Camp Pendleton and above the estuary (Figure 4-1). The first of these stations forms the boundary condition for the updated watershed model, and so is not a calibration target. In addition, calibration was pursued at four tributary stations: De Luz Creek near De Luz (11044800), Rainbow Creek near Fallbrook (11044250), Sandia Creek near Fallbrook (11044350), and Fallbrook Creek near Fallbrook (11045300).

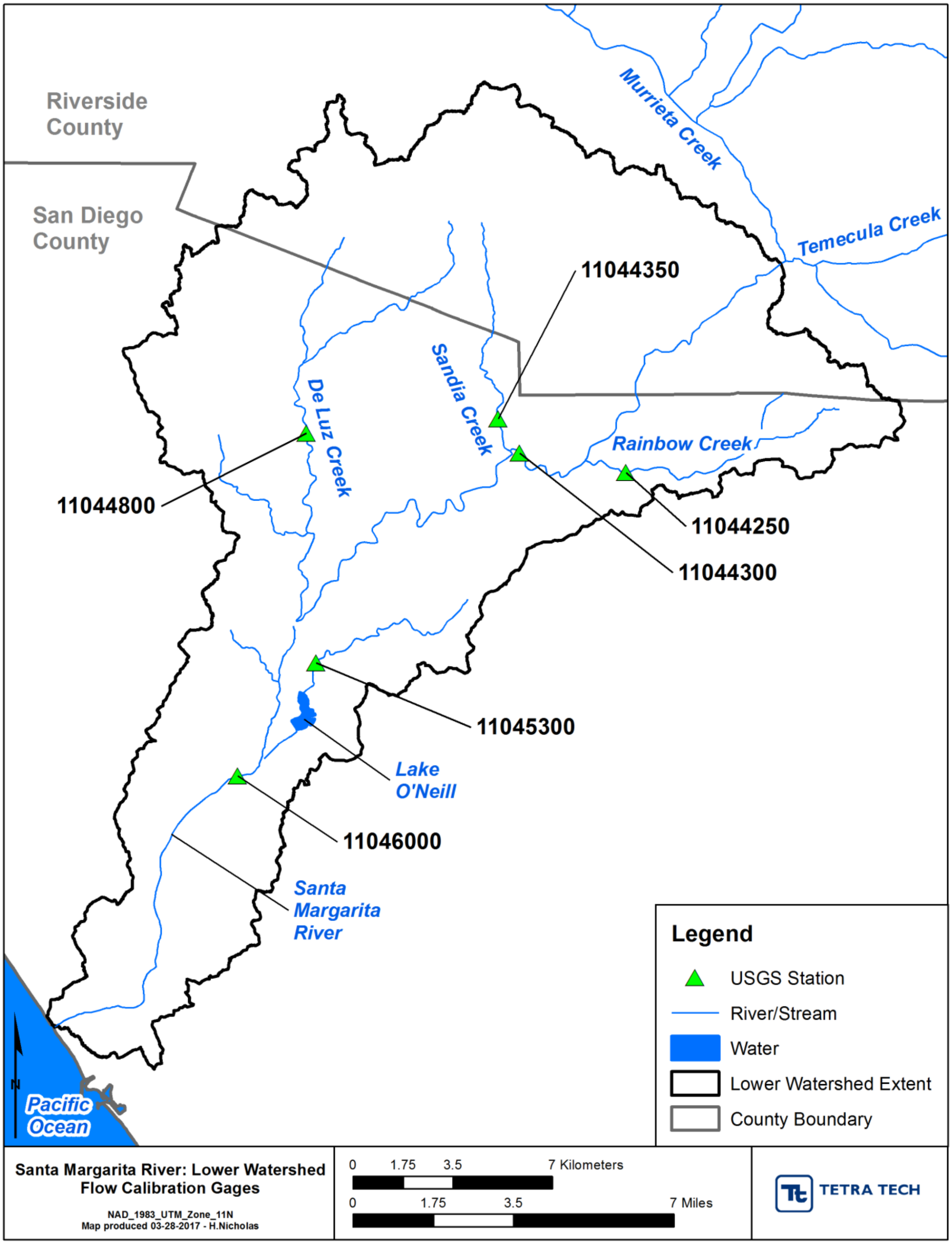


Figure 4-1. Flow Gage Locations

For each of these stations a consistent series of plots and tables is presented below, first for the calibration and then for the validation period. These include, in order, plots of daily flow, monthly flow, regression of modeled on observed monthly flow, water balance comparison of simulated and observed flows, regression of modeled on observed annual flows, comparison of average monthly flows, comparison of median and ranges of monthly flows, table of observed and modeled monthly flows, flow duration curves, flow accumulation curves, and a table of summary statistics.

In general, the recalibration was successful, resulting in improvements in Nash-Sutcliffe coefficients and relative error compared to Tetra Tech (2013). Caution should, however, be exercised in interpreting some of the relative error statistics. At most stations, summer storm volume and total summer flow volume are near zero, as are the 50% low flows at most tributary stations. For those measures, a large percentage error may represent a trivial absolute error. For example, a 50% relative error on an average flow of 0.2 cfs is only ±0.1 cfs.

Table 4-2. Summary of Hydrologic Calibration (2000-2016)

Flow Gage	Error in Total Volume	NSE, Daily Flow	NSE, Monthly Flow
11044300, Santa Margarita River at FPUD Sump	3.41%	0.780	0.871
11046000, Santa Margarita River at Ysidora	-2.20%	0.865	0.890
11044800, De Luz Creek near De Luz	7.06%	0.695	0.777
11044250, Rainbow Creek near Fallbrook	-3.93%	0.637	0.910
11044350, Sandia Creek near Fallbrook	-9.40%	0.694	0.869
11045300, Fallbrook Creek near Fallbrook	2.13%	0.725	0.927

Five of these flow gages (all except Fallbrook Creek) were also evaluated with the prior version of the model (see updated results in Tetra Tech, 2014). A direct comparison is not appropriate because the revised model covers a different time period; however, model performance does appear to be improved. Errors in total volumes are similar (and in all cases for these gages less than ±10%); however, the NSE coefficients improve in every case and in many cases by large amounts. For Rainbow Creek near Fallbrook, the daily NSE increased from 0.525 to 0.637 and the monthly NSE from 0.730 to 0.910, while for Santa Margarita River at Ysidora, the daily NSE increased from 0.691 to 0.865 and the monthly NSE increased from 0.786 to 0.890, indicating a better representation of the patterns of runoff time series. These improvements are largely due to the incorporation of PRISM precipitation, which better accounts for spatial variability in rainfall across the watershed.

4.3.1 Santa Margarita River at FPUD Sump

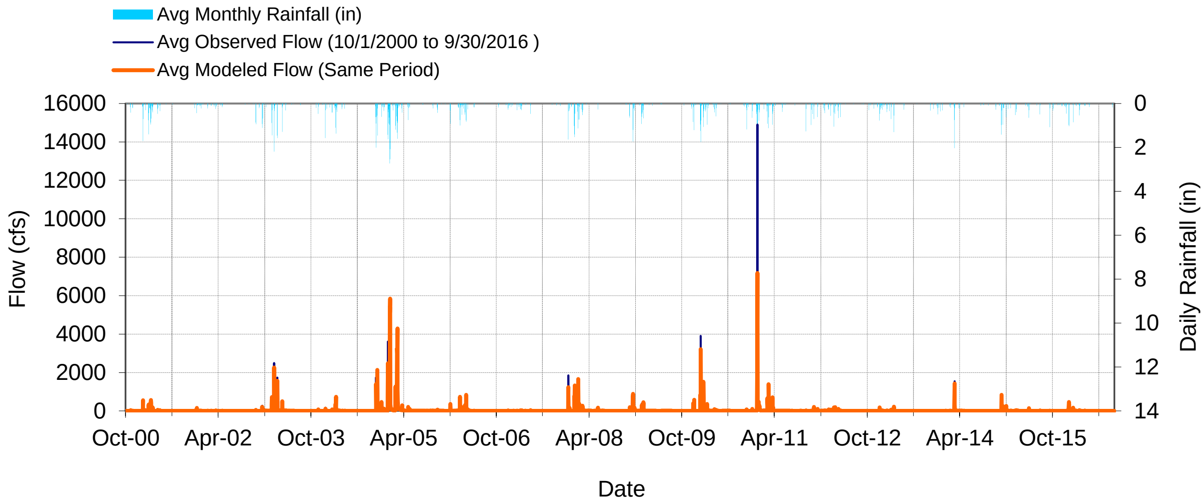


Figure 4-2. Mean daily flow: Model DSN 4118 vs. USGS 11044300 Santa Margarita R at FPUD Sump nr Fallbrook, CA

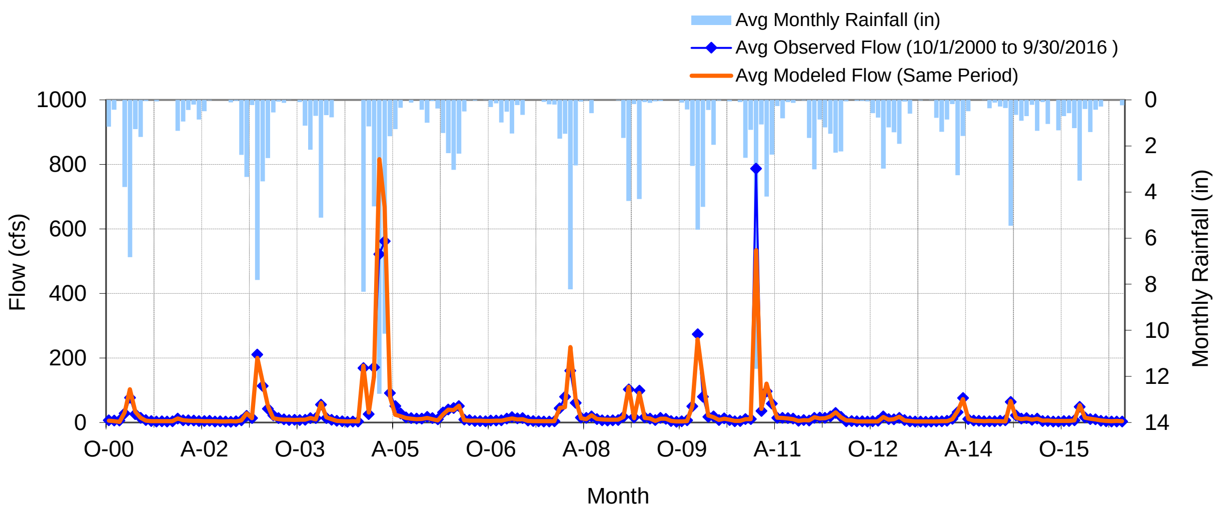


Figure 4-3. Mean monthly flow: Model DSN 4118 vs. USGS 11044300 Santa Margarita R at FPUD Sump nr Fallbrook, CA

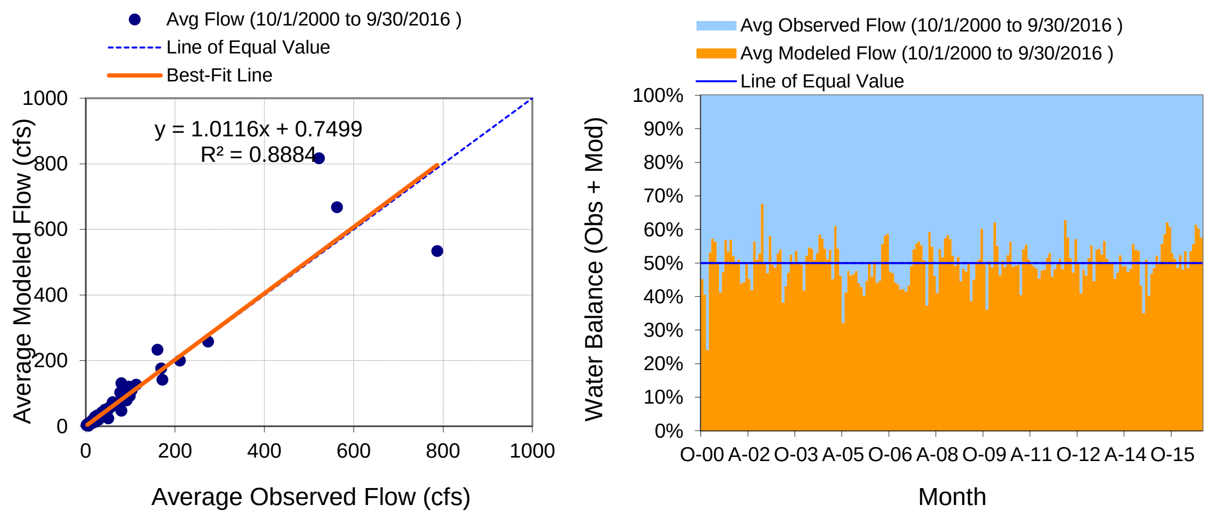


Figure 4-4. Monthly flow regression and temporal variation: Model DSN 4118 vs. USGS 11044300 Santa Margarita R at FPUD Sump nr Fallbrook, CA

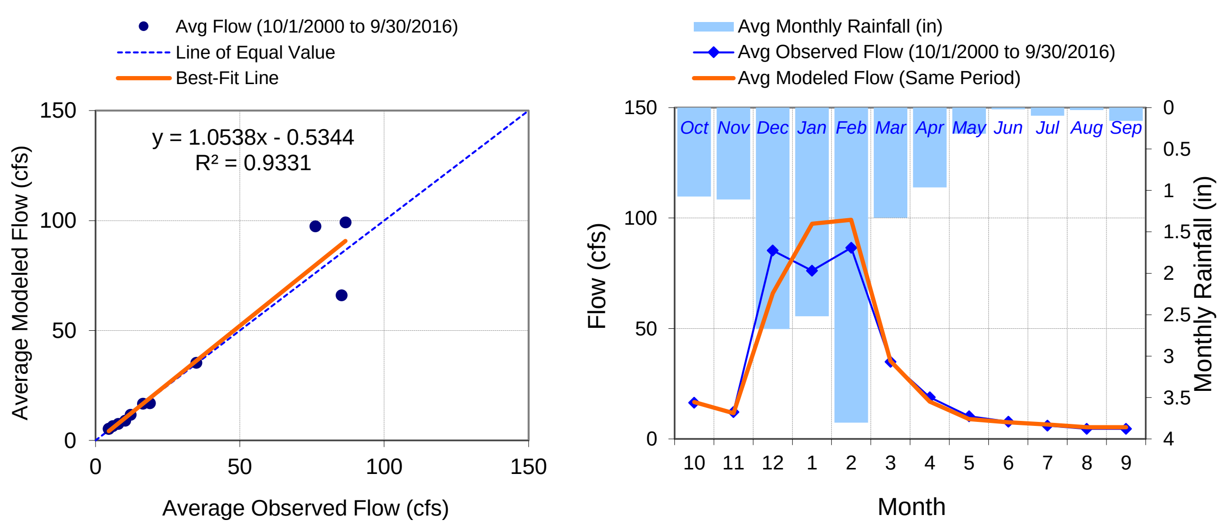


Figure 4-5. Seasonal regression and temporal aggregate: Model DSN 4118 vs. USGS 11044300 Santa Margarita R at FPUD Sump nr Fallbrook, CA

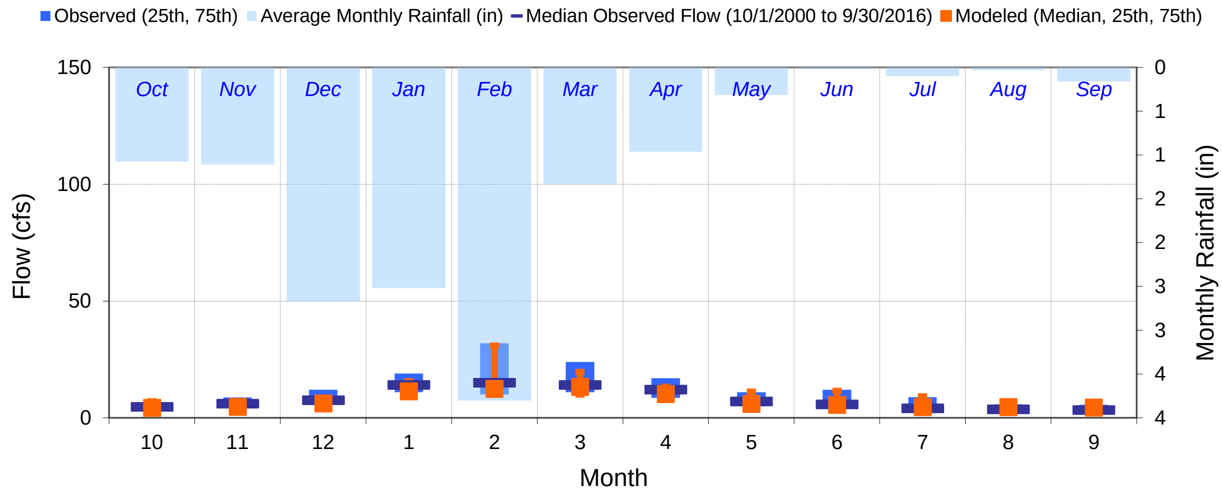


Figure 4-6. Seasonal medians and ranges: Model DSN 4118 vs. USGS 11044300 Santa Margarita R at FPUD Sump nr Fallbrook, CA

Table 4-3. Seasonal summary: Model DSN 4118 vs. USGS 11044300 Santa Margarita R at FPUD Sump nr Fallbrook, CA

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	16.43	4.70	3.40	6.70	16.68	4.39	3.65	7.11
Nov	12.17	6.00	4.60	8.83	11.71	4.83	3.56	6.75
Dec	85.28	7.55	5.50	12.00	66.00	6.29	4.58	8.61
Jan	76.20	14.00	11.00	19.00	97.42	11.45	9.28	15.73
Feb	86.60	15.00	10.00	32.00	99.20	12.51	9.91	31.01
Mar	34.89	14.00	11.00	24.00	35.28	13.34	10.04	19.69
Apr	18.86	12.00	8.60	17.00	16.89	10.28	8.57	13.34
May	10.26	6.95	5.00	11.00	9.01	6.07	4.94	11.24
Jun	7.85	5.70	3.80	12.00	7.55	5.58	4.33	11.62
Jul	6.04	4.00	3.00	8.93	6.50	4.71	3.98	9.29
Aug	4.62	3.60	2.90	5.80	5.34	4.64	3.80	5.64
Sep	4.56	3.30	2.78	5.63	5.33	4.43	3.71	5.50

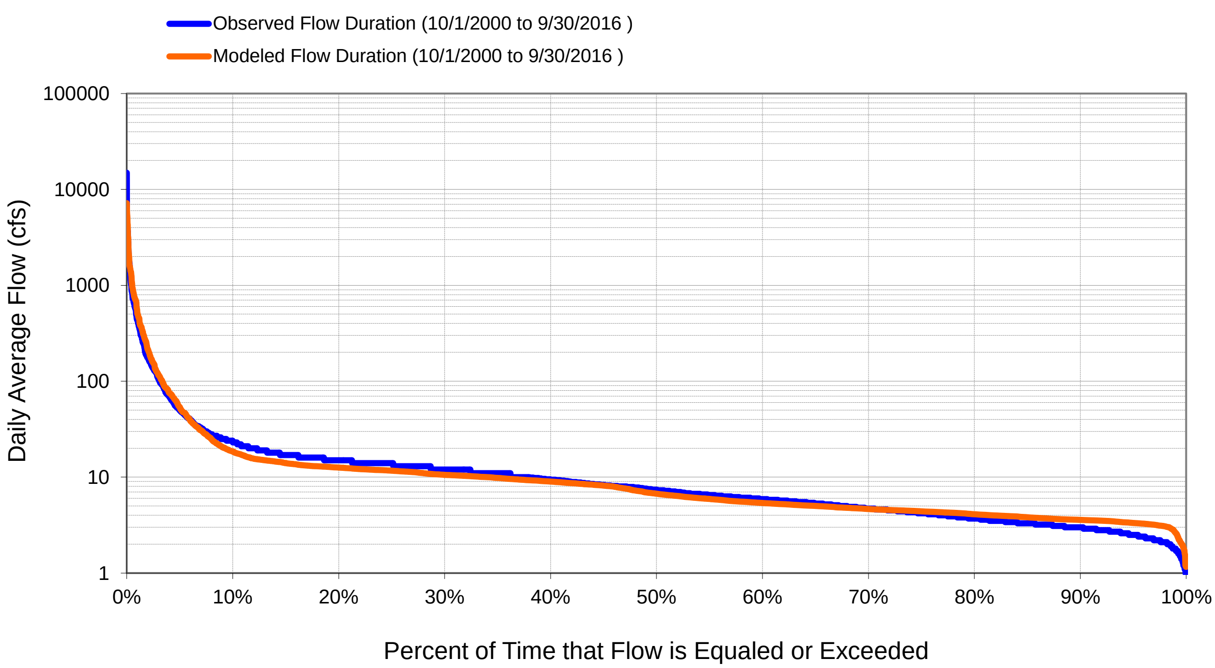


Figure 4-7. Flow exceedence: Model DSN 4118 vs. USGS 11044300 Santa Margarita R at FPUD Sump nr Fallbrook, CA

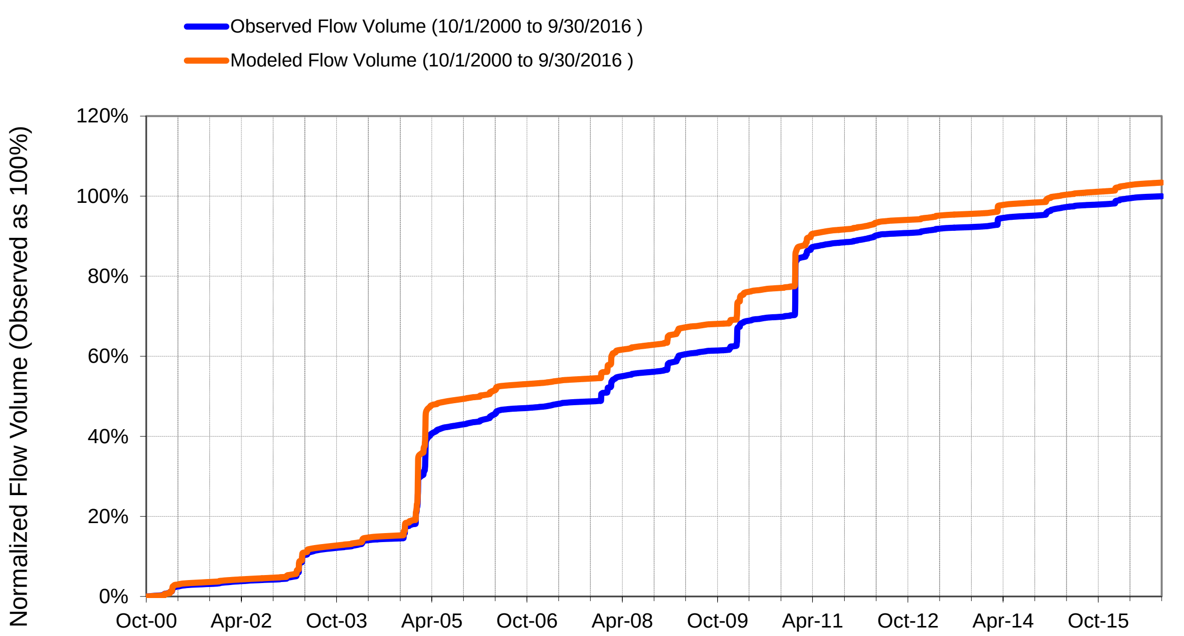


Figure 4-8. Flow accumulation: Model DSN 4118 vs. USGS 11044300 Santa Margarita R at FPUD Sump nr Fallbrook, CA

Table 4-4. Summary statistics: Model DSN 4118 vs. USGS 11044300 Santa Margarita R at FPUD Sump nr Fallbrook, CA

HSPF Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM DSN 4118 16-Year Analysis Period: 10/1/2000 - 9/30/2016 Flow volumes are (inches/year) for upstream drainage area		USGS 11044300 SANTA MARGARITA R A FPUD SUMP NR FALLBROOK CA Hydrologic Unit Code: 18070302 Latitude: 33.41364059 Longitude: -117.2411462 Drainage Area (sq-mi): 620	
Total Simulated In-stream Flow:	**0.68**	Total Observed In-stream Flow:	**0.66**
Total of simulated highest 10% flows:	**0.54**	Total of Observed highest 10% flows:	**0.50**
Total of Simulated lowest 50% flows:	**0.05**	Total of Observed Lowest 50% flows:	**0.05**
Simulated Summer Flow Volume (months 7-9):	**0.03**	Observed Summer Flow Volume (7-9):	**0.03**
Simulated Fall Flow Volume (months 10-12):	**0.17**	Observed Fall Flow Volume (10-12):	**0.21**
Simulated Winter Flow Volume (months 1-3):	**0.41**	Observed Winter Flow Volume (1-3):	**0.35**
Simulated Spring Flow Volume (months 4-6):	**0.06**	Observed Spring Flow Volume (4-6):	**0.07**
Total Simulated Storm Volume:	**0.49**	Total Observed Storm Volume:	**0.46**
Simulated Summer Storm Volume (7-9):	**0.00**	Observed Summer Storm Volume (7-9):	**0.00**

Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*		
Error in total volume:	3.41	10		
Error in 50% lowest flows:	2.64	10		
Error in 10% highest flows:	7.11	15		
Seasonal volume error - Summer:	12.78	30		
Seasonal volume error - Fall:	-17.16 >>	30		Clear
Seasonal volume error - Winter:	17.41	30		
Seasonal volume error - Spring:	-9.52	30		
Error in storm volumes:	5.55	20		
Error in summer storm volumes:	**-60.99**	**50**		
Nash-Sutcliffe Coefficient of Efficiency, E:	0.780	Model accuracy increases		
Baseline adjusted coefficient (Garrick), E':	0.768	as E or E' approaches 1.0		
Monthly NSE	0.871			

4.3.2 Santa Margarita River at Ysidora

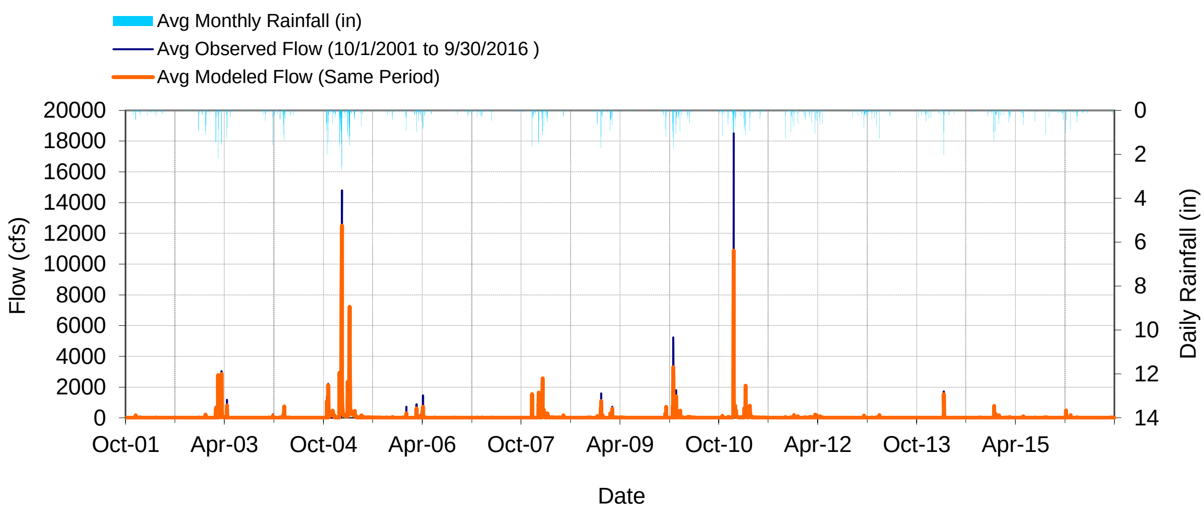


Figure 4-9. Mean daily flow: Model DSN 4105 vs. USGS 11046000 Santa Margarita R at Ysidora, CA

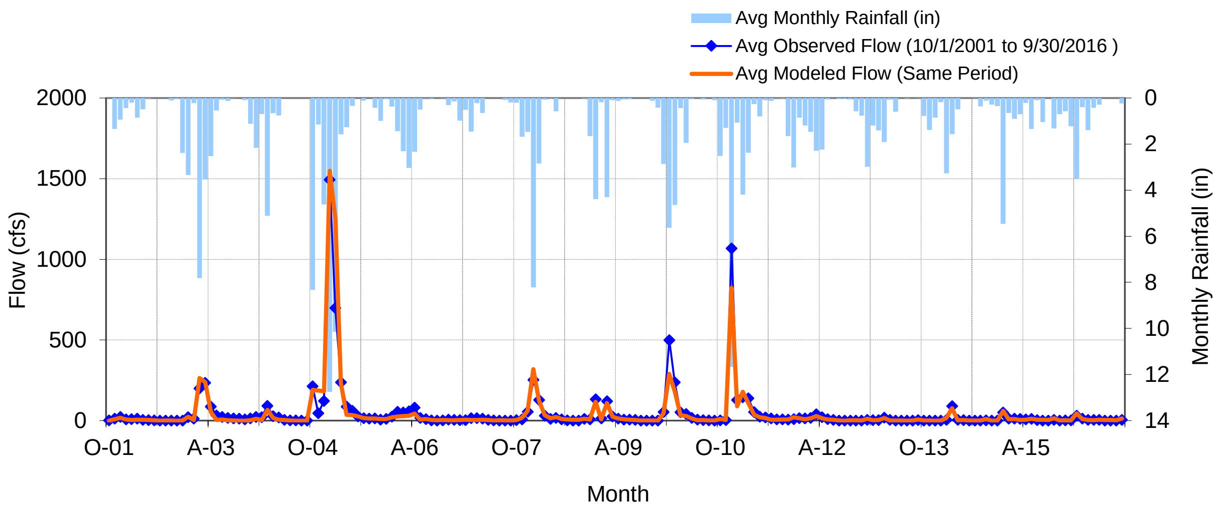


Figure 4-10. Mean monthly flow: Model DSN 4105 vs. USGS 11046000 Santa Margarita R at Ysidora, CA

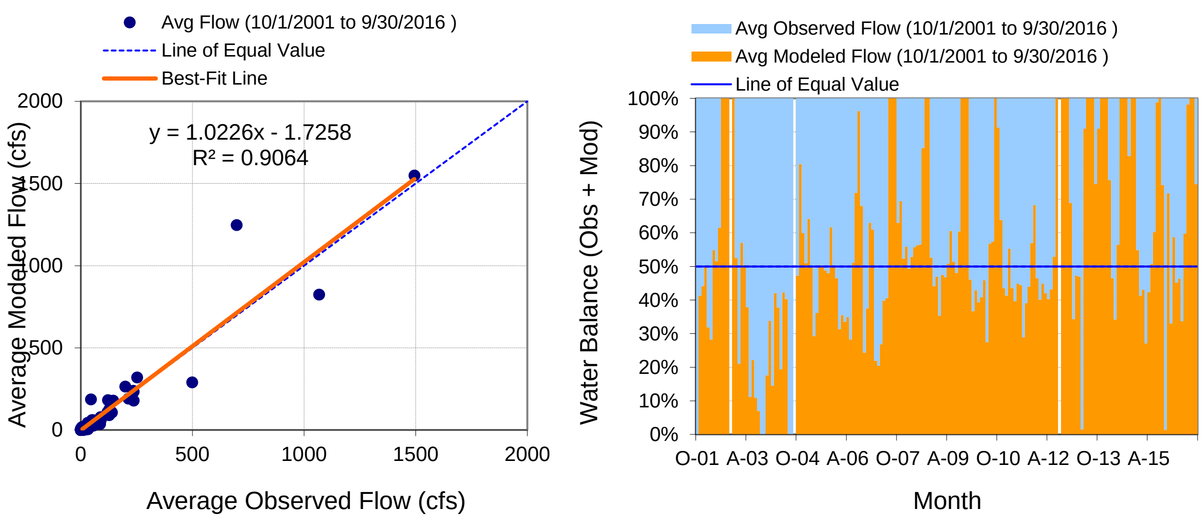


Figure 4-11. Monthly flow regression and temporal variation: Model DSN 4105 vs. USGS 11046000 Santa Margarita R at Ysidora, CA

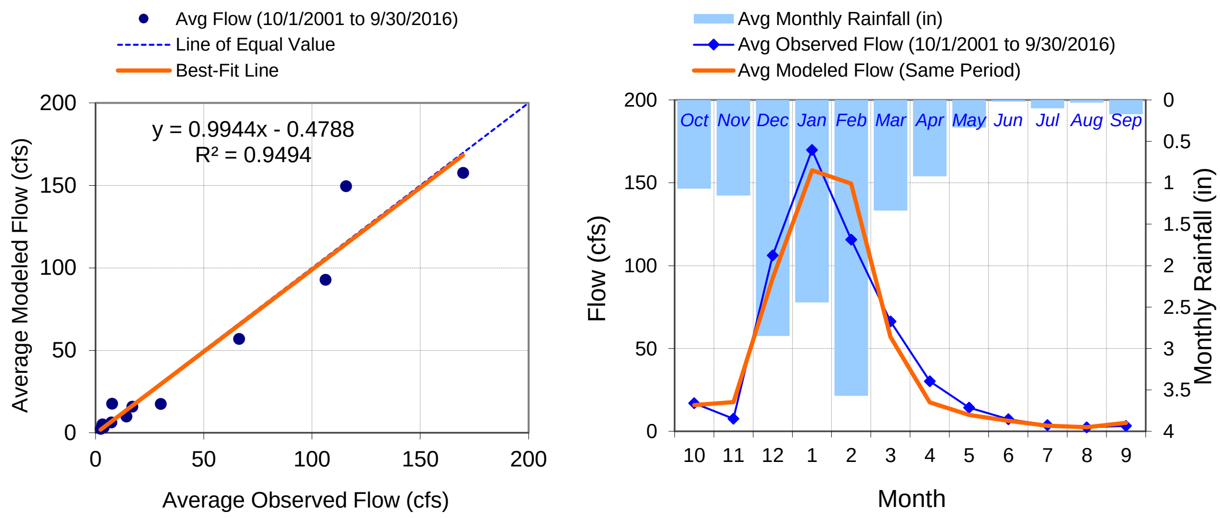


Figure 4-12. Seasonal regression and temporal aggregate: Model DSN 4105 vs. USGS 11046000 Santa Margarita R at Ysidora, CA

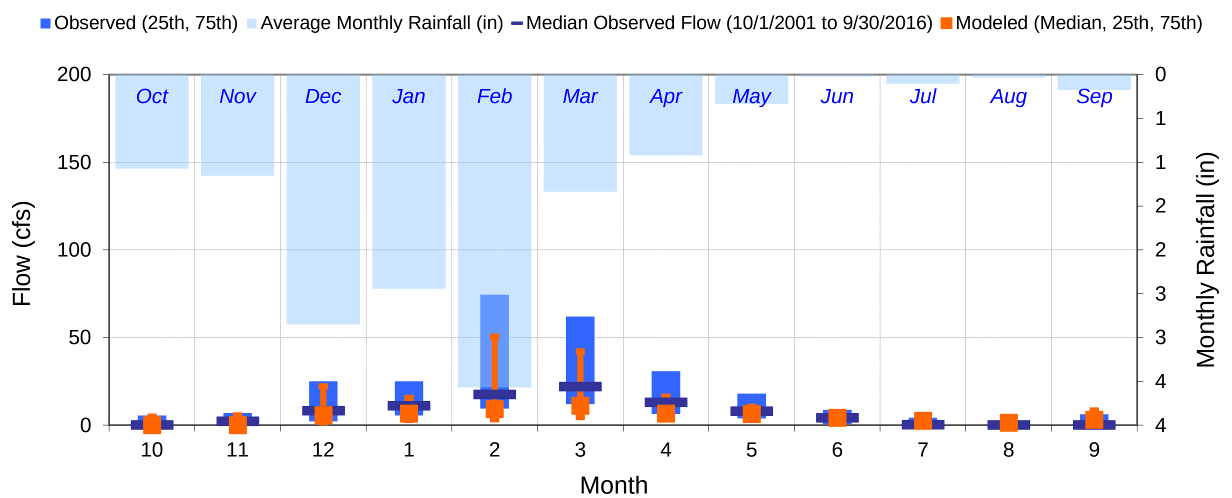


Figure 4-13. Seasonal medians and ranges: Model DSN 4105 vs. USGS 11046000 Santa Margarita R at Ysidora, CA

Table 4-5. Seasonal summary: Model DSN 4105 vs. USGS 11046000 Santa Margarita R at Ysidora, CA

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	17.06	0.05	0.00	5.50	15.92	0.00	0.00	4.93
Nov	7.64	2.10	0.00	6.98	17.61	0.01	0.00	5.63
Dec	106.26	8.20	2.10	25.00	92.80	5.76	1.65	22.19
Jan	169.76	11.00	5.50	25.00	157.59	6.60	2.97	15.61
Feb	115.75	17.50	9.40	74.50	149.52	9.17	3.35	50.52
Mar	66.28	22.00	12.00	62.00	57.01	11.15	4.66	42.13
Apr	30.19	13.00	6.33	30.75	17.47	6.61	3.63	16.25
May	14.30	7.90	3.80	18.00	9.98	6.35	3.72	10.59
Jun	7.34	4.10	0.52	8.75	6.35	4.28	1.42	7.45
Jul	3.80	0.17	0.00	4.30	3.38	2.55	0.03	4.67
Aug	2.41	0.00	0.00	0.93	2.46	1.40	0.03	3.58
Sep	3.24	0.00	0.00	6.20	5.14	3.20	0.11	8.43

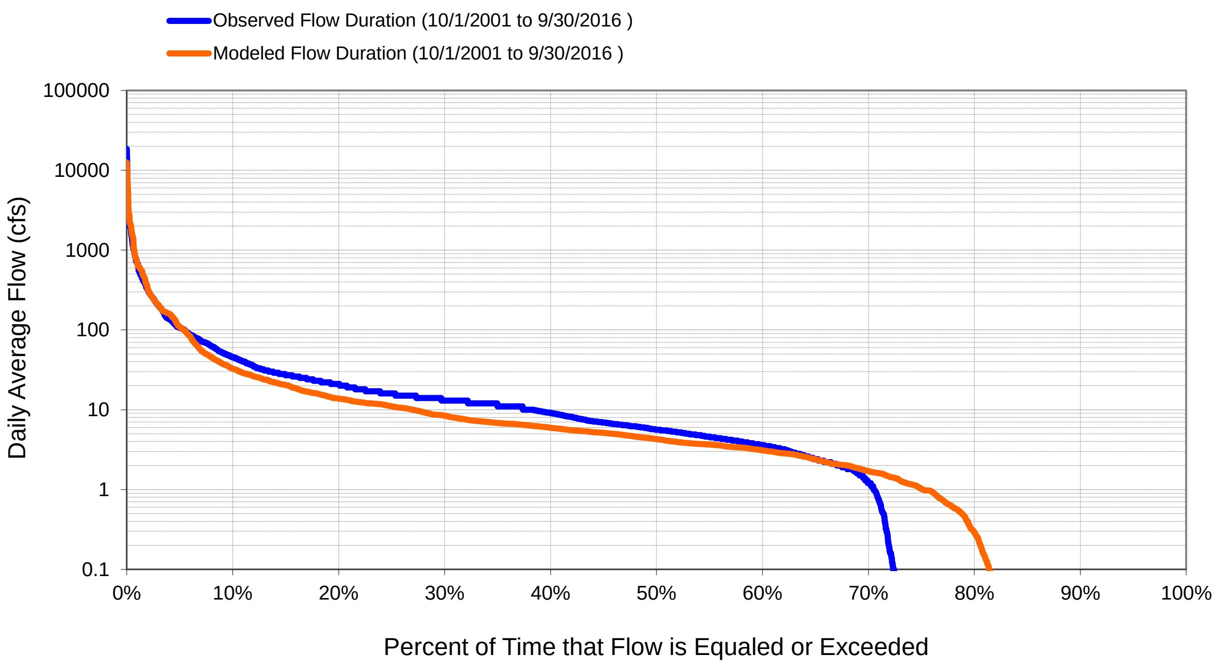


Figure 4-14. Flow exceedence: Model DSN 4105 vs. USGS 11046000 Santa Margarita R at Ysidora, CA

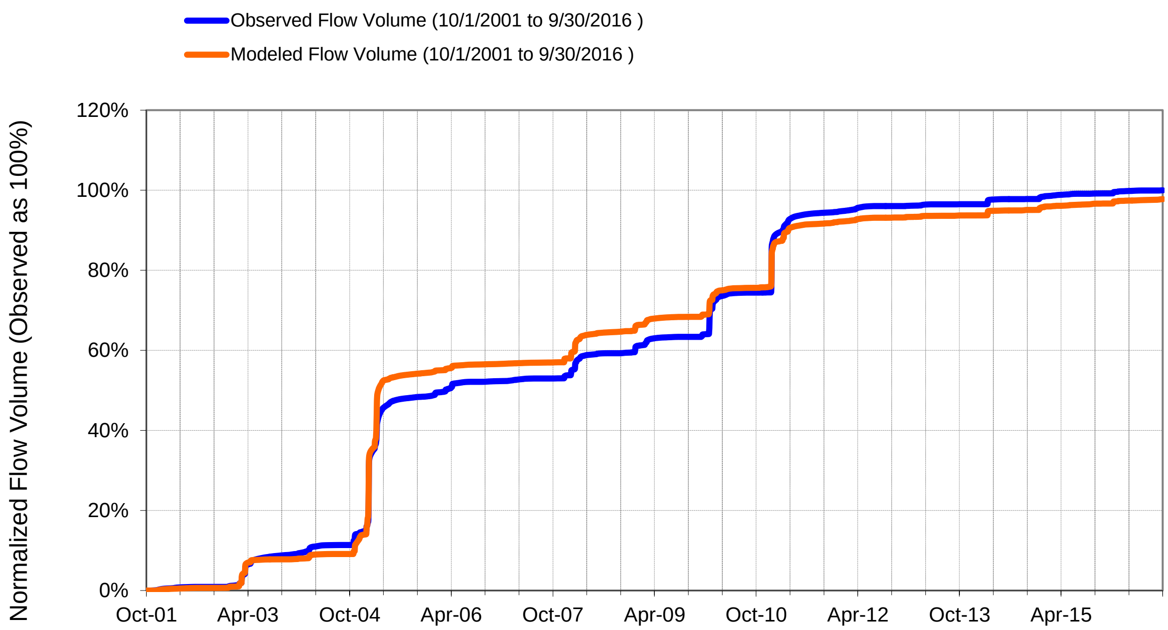


Figure 4-15. Flow accumulation: Model DSN 4105 vs. USGS 11046000 Santa Margarita R at Ysidora

Table 4-6. Summary statistics: Model DSN 4105 vs. USGS 11046000 Santa Margarita R at Ysidora, CA

HSPF Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM DSN 4105 15-Year Analysis Period: 10/1/2001 - 9/30/2016 Flow volumes are (inches/year) for upstream drainage area REVISED FOR PENDLETON GW EXCHANGES BASED ON STETSON MODEL		USGS 11046000 SANTA MARGARITA R A YSIDORA CA Hydrologic Unit Code: 18070302 Latitude: 33.3111436 Longitude: -117.3472604 Drainage Area (sq-mi): 723	
Total Simulated In-stream Flow:	**0.83**	Total Observed In-stream Flow:	**0.85**
Total of simulated highest 10% flows:	**0.73**	Total of Observed highest 10% flows:	**0.72**
Total of Simulated lowest 50% flows:	**0.01**	Total of Observed Lowest 50% flows:	**0.01**
Simulated Summer Flow Volume (months 7-9):	**0.02**	Observed Summer Flow Volume (7-9):	**0.01**
Simulated Fall Flow Volume (months 10-12):	**0.20**	Observed Fall Flow Volume (10-12):	**0.21**
Simulated Winter Flow Volume (months 1-3):	**0.56**	Observed Winter Flow Volume (1-3):	**0.54**
Simulated Spring Flow Volume (months 4-6):	**0.05**	Observed Spring Flow Volume (4-6):	**0.08**
Total Simulated Storm Volume:	**0.61**	Total Observed Storm Volume:	**0.58**
Simulated Summer Storm Volume (7-9):	**0.00**	Observed Summer Storm Volume (7-9):	**0.00**

Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*		
Error in total volume:	-2.20	10		
Error in 50% lowest flows:	-1.42	10		
Error in 10% highest flows:	2.57	15		
Seasonal volume error - Summer:	15.65	30		
Seasonal volume error - Fall:	-3.78	>> 30		Clear
Seasonal volume error - Winter:	2.74	30		
Seasonal volume error - Spring:	**-34.74**	**30**		
Error in storm volumes:	6.36	20		
Error in summer storm volumes:	33.43	50		
Nash-Sutcliffe Coefficient of Efficiency, E:	0.865	Model accuracy increases		
Baseline adjusted coefficient (Garrick), E':	0.715	as E or E' approaches 1.0		
Monthly NSE	0.890			

4.3.3 De Luz Creek near De Luz

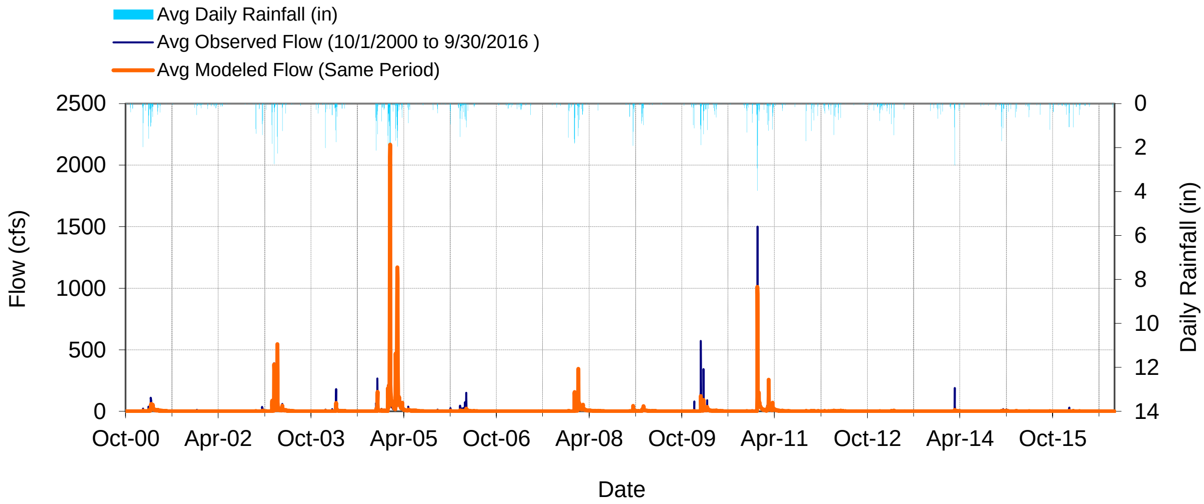


Figure 4-16. Mean daily flow: Model DSN 4111 vs. USGS 11044800 De Luz Cr nr De Luz, CA

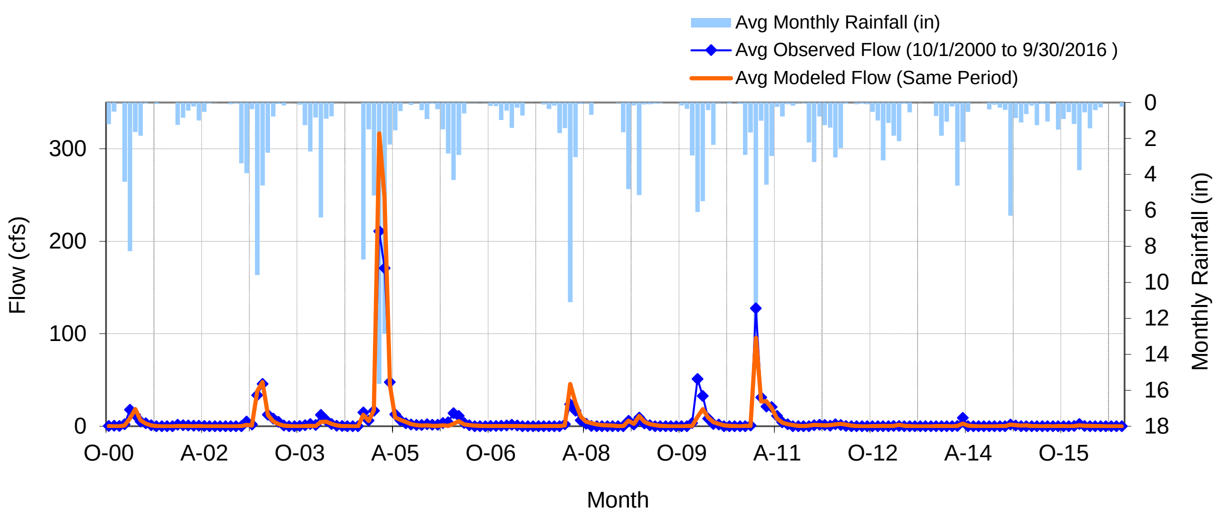


Figure 4-17. Mean monthly flow: Model DSN 4111 vs. USGS 11044800 De Luz Cr nr De Luz, CA

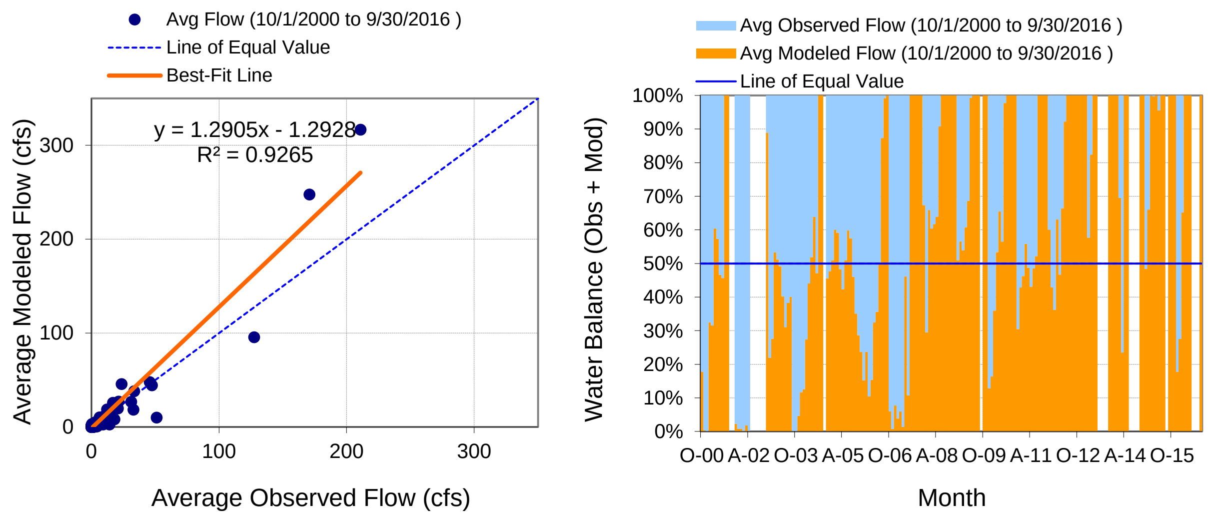


Figure 4-18. Monthly flow regression and temporal variation: Model DSN 4111 vs. USGS 11044800 De Luz Cr nr De Luz, CA

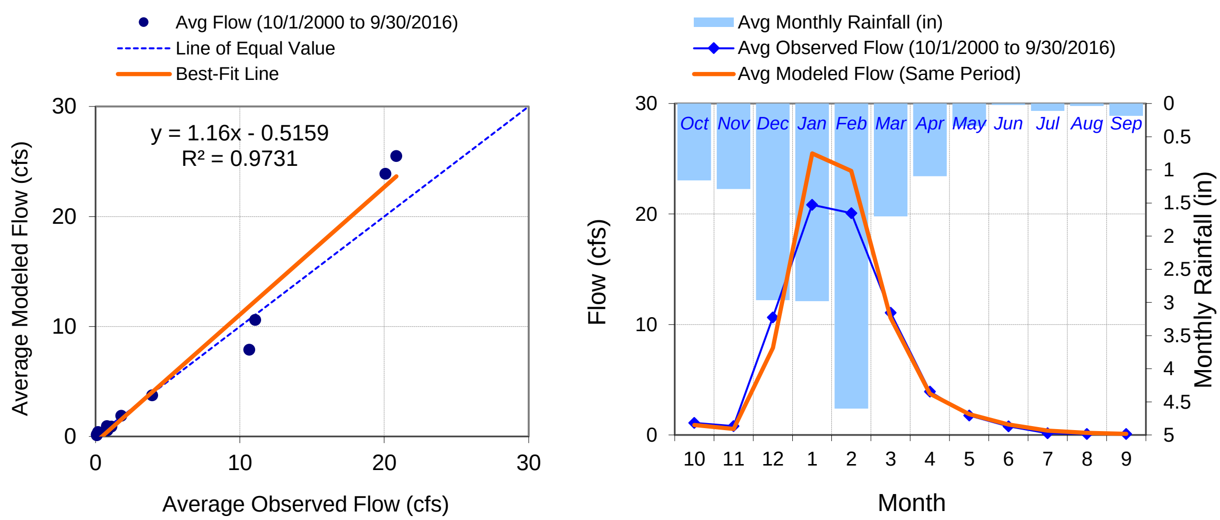


Figure 4-19. Seasonal regression and temporal aggregate: Model DSN 4111 vs. USGS 11044800 De Luz Cr nr De Luz, CA

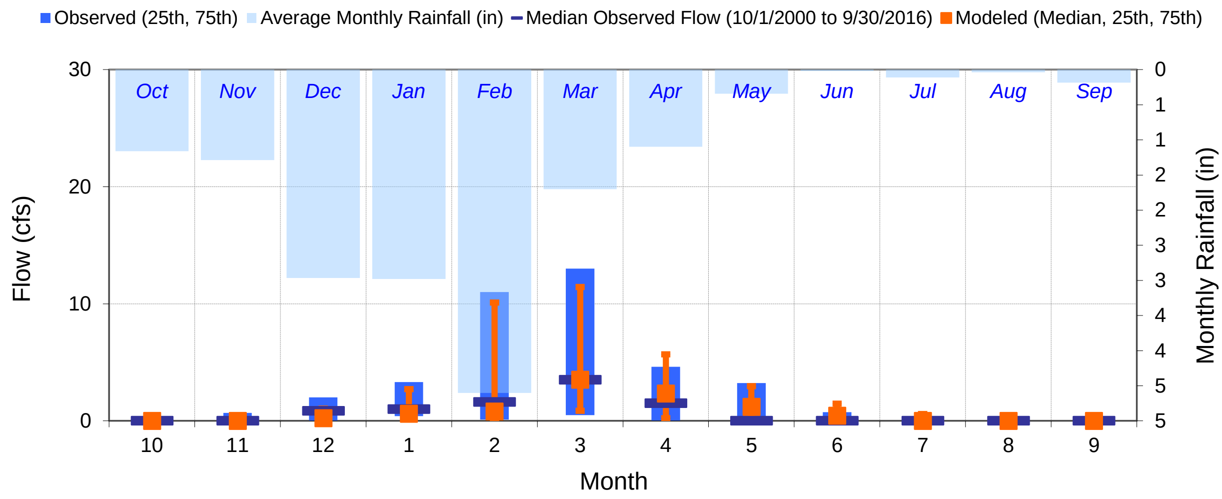


Figure 4-20. Seasonal medians and ranges: Model DSN 4111 vs. USGS 11044800 De Luz Cr nr De Luz, CA

Table 4-7. Seasonal summary: Model DSN 4111 vs. USGS 11044800 De Luz Cr nr De Luz, CA

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	1.10	0.00	0.00	0.00	0.91	0.00	0.00	0.08
Nov	0.82	0.00	0.00	0.69	0.56	0.00	0.00	0.15
Dec	10.65	0.85	0.00	2.00	7.88	0.25	0.00	1.05
Jan	20.84	1.00	0.42	3.33	25.49	0.62	0.00	2.71
Feb	20.07	1.60	0.12	11.00	23.89	0.81	0.15	10.12
Mar	11.07	3.50	0.50	13.00	10.60	3.53	0.86	11.45
Apr	3.92	1.50	0.00	4.63	3.74	2.34	0.23	5.69
May	1.78	0.00	0.00	3.23	1.90	1.22	0.00	2.98
Jun	0.79	0.00	0.00	0.74	0.95	0.46	0.00	1.46
Jul	0.17	0.00	0.00	0.00	0.40	0.01	0.00	0.59
Aug	0.09	0.00	0.00	0.00	0.19	0.00	0.00	0.17
Sep	0.10	0.00	0.00	0.00	0.11	0.00	0.00	0.00

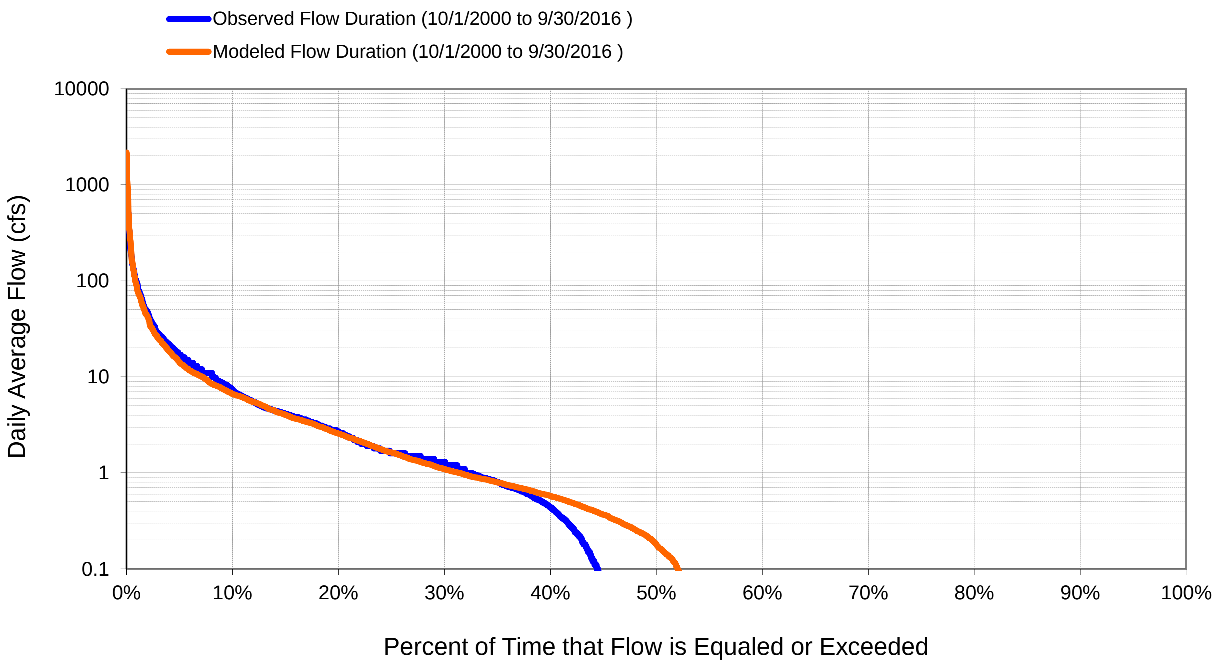


Figure 4-21. Flow exceedence: Model DSN 4111 vs. USGS 11044800 De Luz Cr nr De Luz, CA

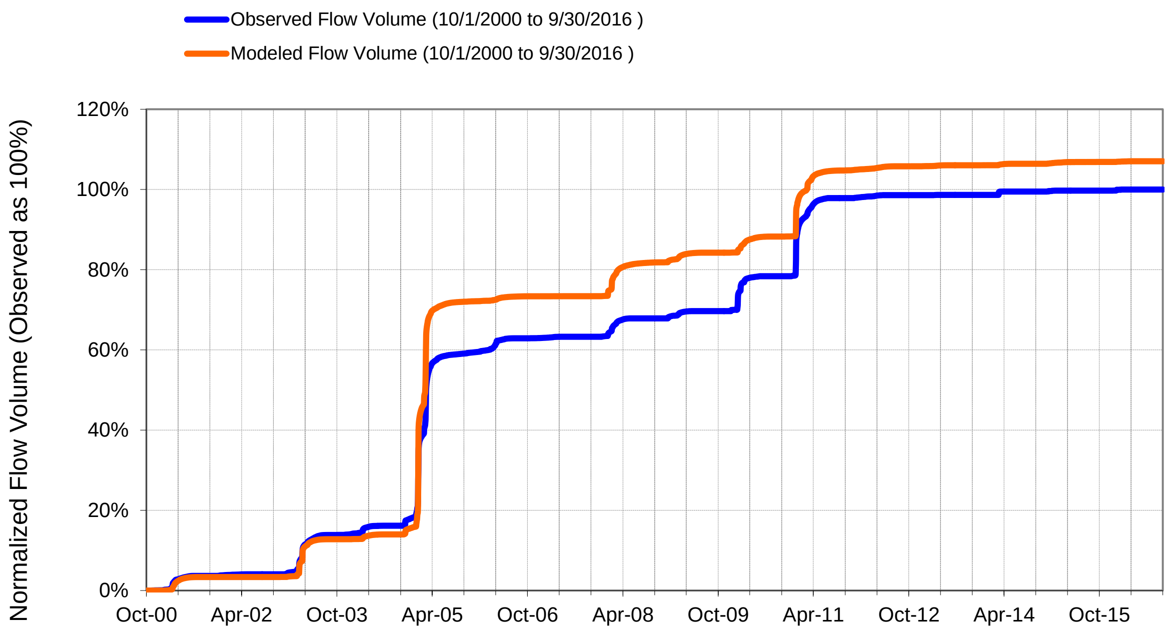


Figure 4-22. Flow accumulation: Model DSN 4111 vs. USGS 11044800 De Luz Cr nr De Luz, CA

Table 4-8. Summary statistics: Model DSN 4111 vs. USGS 11044800 De Luz Cr nr De Luz, CA

HSPF Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM DSN 4111 16-Year Analysis Period: 10/1/2000 - 9/30/2016 Flow volumes are (inches/year) for upstream drainage area 3/31/17 8:07		USGS 11044800 DE LUZ C NR DE LUZ CA Hydrologic Unit Code: 18070302 Latitude: 33.4197511 Longitude: -117.3217044 Drainage Area (sq-mi): 33	
Total Simulated In-stream Flow:	**2.60**	Total Observed In-stream Flow:	**2.43**
Total of simulated highest 10% flows:	**2.30**	Total of Observed highest 10% flows:	**2.14**
Total of Simulated lowest 50% flows:	**0.00**	Total of Observed Lowest 50% flows:	**0.00**
Simulated Summer Flow Volume (months 7-9):	**0.02**	Observed Summer Flow Volume (7-9):	**0.01**
Simulated Fall Flow Volume (months 10-12):	**0.33**	Observed Fall Flow Volume (10-12):	**0.44**
Simulated Winter Flow Volume (months 1-3):	**2.02**	Observed Winter Flow Volume (1-3):	**1.75**
Simulated Spring Flow Volume (months 4-6):	**0.22**	Observed Spring Flow Volume (4-6):	**0.22**
Total Simulated Storm Volume:	**1.52**	Total Observed Storm Volume:	**1.37**
Simulated Summer Storm Volume (7-9):	**0.00**	Observed Summer Storm Volume (7-9):	**0.00**

Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*		
Error in total volume:	7.06	10		
Error in 50% lowest flows:	**199691.25**	**10**		
Error in 10% highest flows:	7.74	15		
Seasonal volume error - Summer:	**98.41**	**30**		
Seasonal volume error - Fall:	-25.62	>> 30		Clear
Seasonal volume error - Winter:	15.27	30		
Seasonal volume error - Spring:	1.60	30		
Error in storm volumes:	11.31	20		
Error in summer storm volumes:	12.26	50		
Nash-Sutcliffe Coefficient of Efficiency, E:	0.695	Model accuracy increases		
Baseline adjusted coefficient (Garrick), E':	0.666	as E or E' approaches 1.0		
Monthly NSE	0.777			

4.3.4 Rainbow Creek near Fallbrook

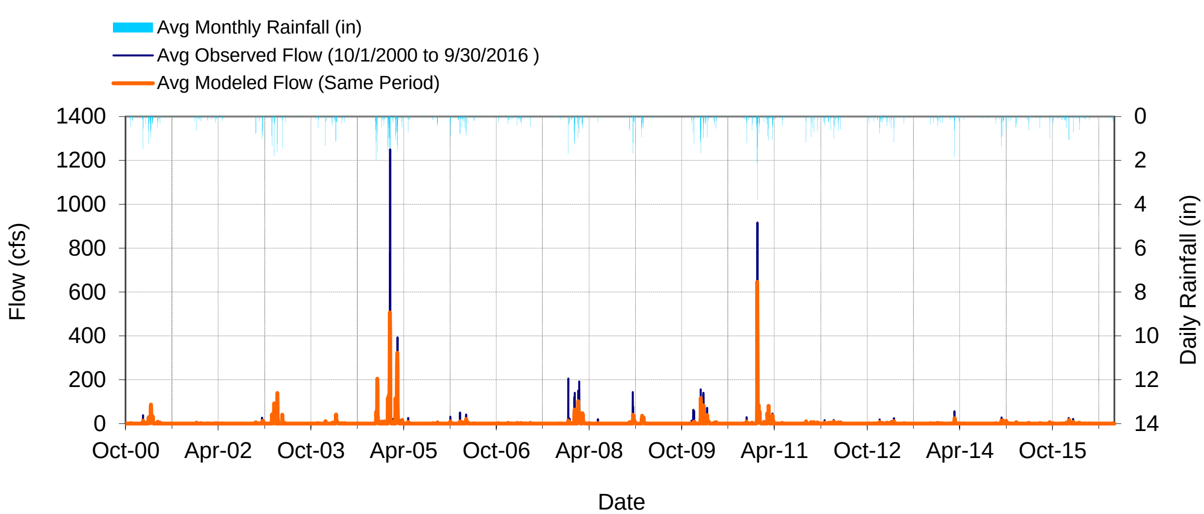


Figure 4-23. Mean daily flow: Model DSN 4175 vs. USGS 11044250 Rainbow Cr nr Fallbrook, CA

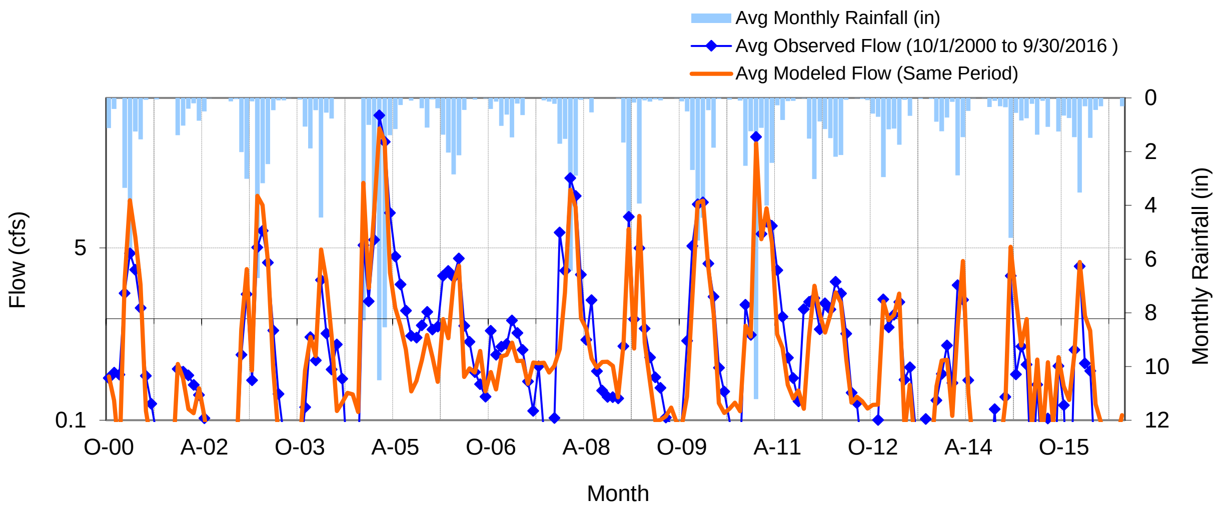


Figure 4-24. Mean monthly flow: Model DSN 4175 vs. USGS 11044250 Rainbow Cr nr Fallbrook, CA

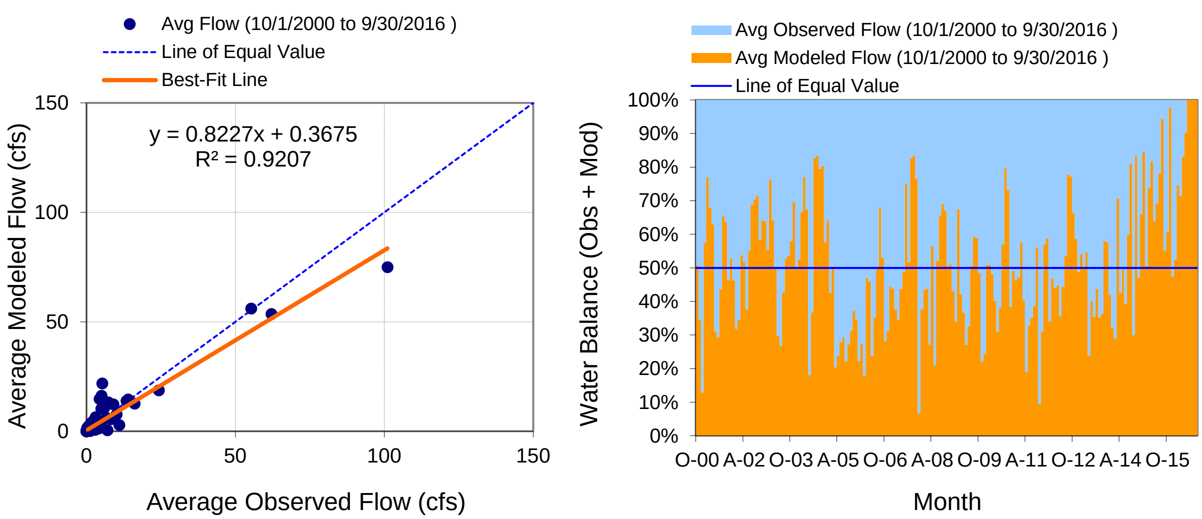


Figure 4-25. Monthly flow regression and temporal variation: Model DSN 4175 vs. USGS 11044250 Rainbow Cr nr Fallbrook, CA

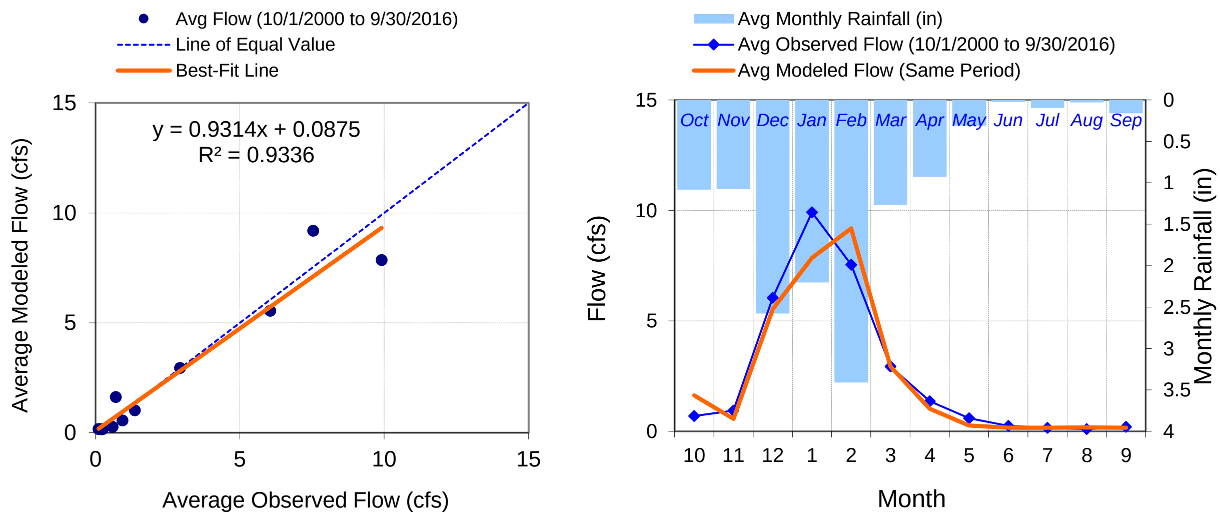


Figure 4-26. Seasonal regression and temporal aggregate: Model DSN 4175 vs. USGS 11044250 Rainbow Cr nr Fallbrook, CA

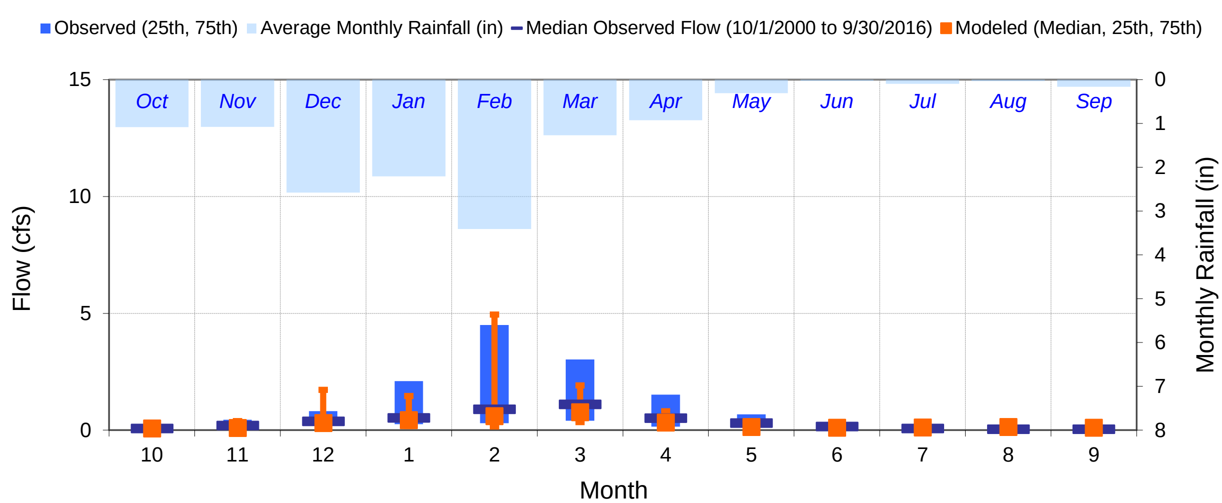


Figure 4-27. Seasonal medians and ranges: Model DSN 4175 vs. USGS 11044250 Rainbow Cr nr Fallbrook, CA

Table 4-9. Seasonal summary: Model DSN 4175 vs. USGS 11044250 Rainbow Cr nr Fallbrook, CA

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	0.70	0.07	0.04	0.19	1.62	0.07	0.04	0.24
Nov	0.94	0.19	0.07	0.44	0.57	0.10	0.04	0.39
Dec	6.05	0.37	0.23	0.81	5.54	0.31	0.12	1.72
Jan	9.91	0.52	0.26	2.10	7.86	0.44	0.18	1.47
Feb	7.54	0.89	0.30	4.50	9.19	0.60	0.15	4.95
Mar	2.93	1.10	0.40	3.03	2.95	0.77	0.35	1.92
Apr	1.36	0.51	0.15	1.53	1.02	0.33	0.10	0.81
May	0.59	0.30	0.12	0.68	0.27	0.14	0.07	0.26
Jun	0.25	0.15	0.05	0.30	0.17	0.11	0.05	0.27
Jul	0.16	0.07	0.04	0.19	0.17	0.12	0.06	0.20
Aug	0.11	0.04	0.03	0.12	0.17	0.14	0.06	0.21
Sep	0.21	0.04	0.03	0.13	0.16	0.11	0.05	0.18

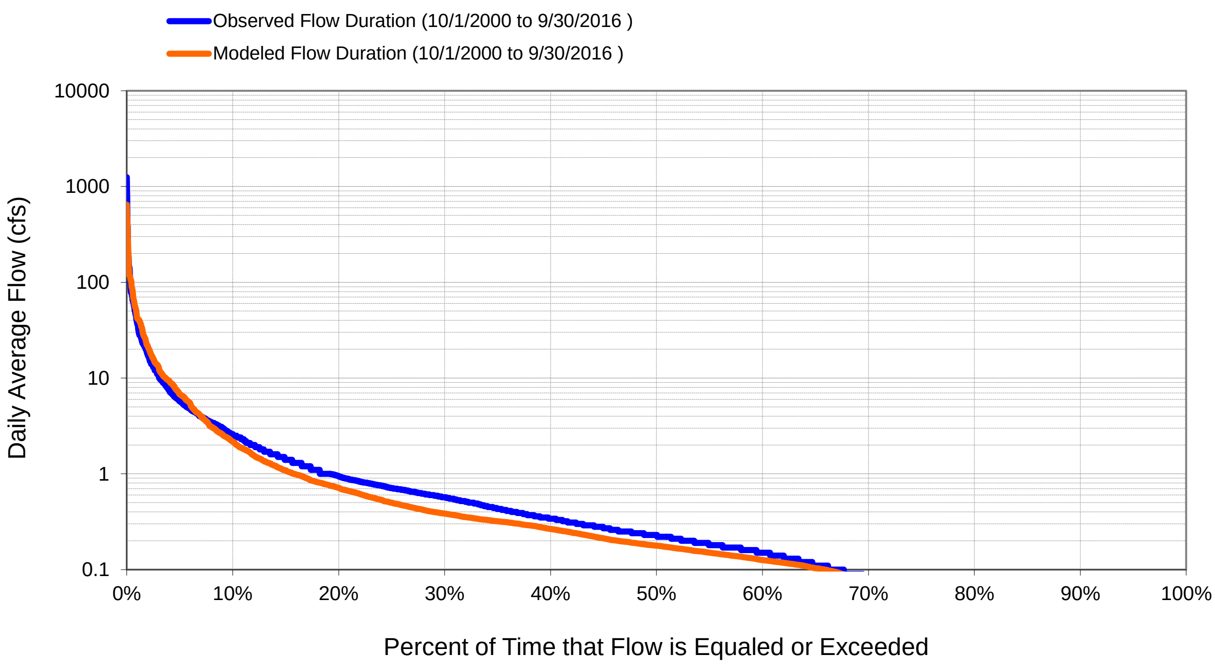


Figure 4-28. Flow exceedence: Model DSN 4175 vs. USGS 11044250 Rainbow Cr nr Fallbrook, CA

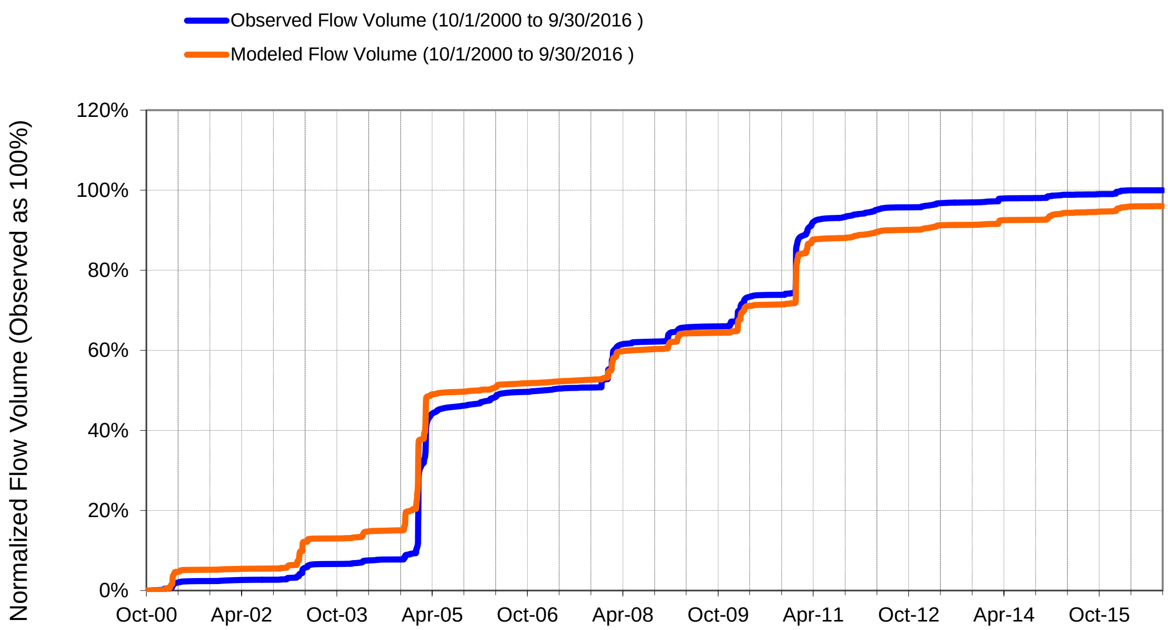


Figure 4-29. Flow accumulation: Model DSN 4175 vs. USGS 11044250 Rainbow Cr nr Fallbrook, CA

Table 4-10. Summary statistics: Model DSN 4175 vs. USGS 11044250 Rainbow Cr nr Fallbrook, CA

HSPF Simulated Flow		**Observed Flow Gage**	
REACH OUTFLOW FROM DSN 4175 16-Year Analysis Period: 10/1/2000 - 9/30/2016 Flow volumes are (inches/year) for upstream drainage area 3/31/17 8:04		USGS 11044250 RAINBOW C NR FALLBROOK CA Hydrologic Unit Code: 18070302 Latitude: 33.40753006 Longitude: -117.200867 Drainage Area (sq-mi): 10.3	
Total Simulated In-stream Flow:	**3.22**	Total Observed In-stream Flow:	**3.36**
Total of simulated highest 10% flows:	**2.88**	Total of Observed highest 10% flows:	**2.91**
Total of Simulated lowest 50% flows:	**0.05**	Total of Observed Lowest 50% flows:	**0.05**
Simulated Summer Flow Volume (months 7-9):	**0.06**	Observed Summer Flow Volume (7-9):	**0.05**
Simulated Fall Flow Volume (months 10-12):	**0.86**	Observed Fall Flow Volume (10-12):	**0.86**
Simulated Winter Flow Volume (months 1-3):	**2.15**	Observed Winter Flow Volume (1-3):	**2.21**
Simulated Spring Flow Volume (months 4-6):	**0.16**	Observed Spring Flow Volume (4-6):	**0.24**
Total Simulated Storm Volume:	**1.63**	Total Observed Storm Volume:	**1.95**
Simulated Summer Storm Volume (7-9):	**0.01**	Observed Summer Storm Volume (7-9):	**0.01**

Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*		
Error in total volume:	-3.93	10		
Error in 50% lowest flows:	-1.42	10		
Error in 10% highest flows:	-1.21	15		
Seasonal volume error - Summer:	6.68	30		
Seasonal volume error - Fall:	0.81 >>	30		Clear
Seasonal volume error - Winter:	-2.71	30		
Seasonal volume error - Spring:	**-34.27**	**30**		
Error in storm volumes:	-16.48	20		
Error in summer storm volumes:	-24.97	50		
Nash-Sutcliffe Coefficient of Efficiency, E:	0.637	Model accuracy increases		
Baseline adjusted coefficient (Garrick), E':	0.524	as E or E' approaches 1.0		
Monthly NSE	0.910			

4.3.5 Sandia Creek near Fallbrook

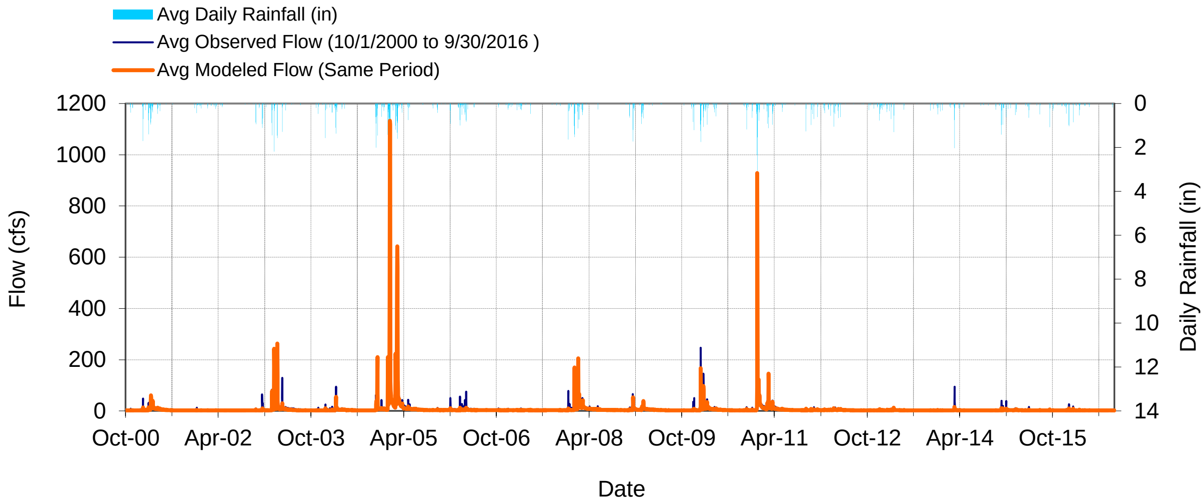


Figure 4-30. Mean daily flow: Model DSN 4117 vs. USGS 11044350 Sandia Cr nr Fallbrook, CA

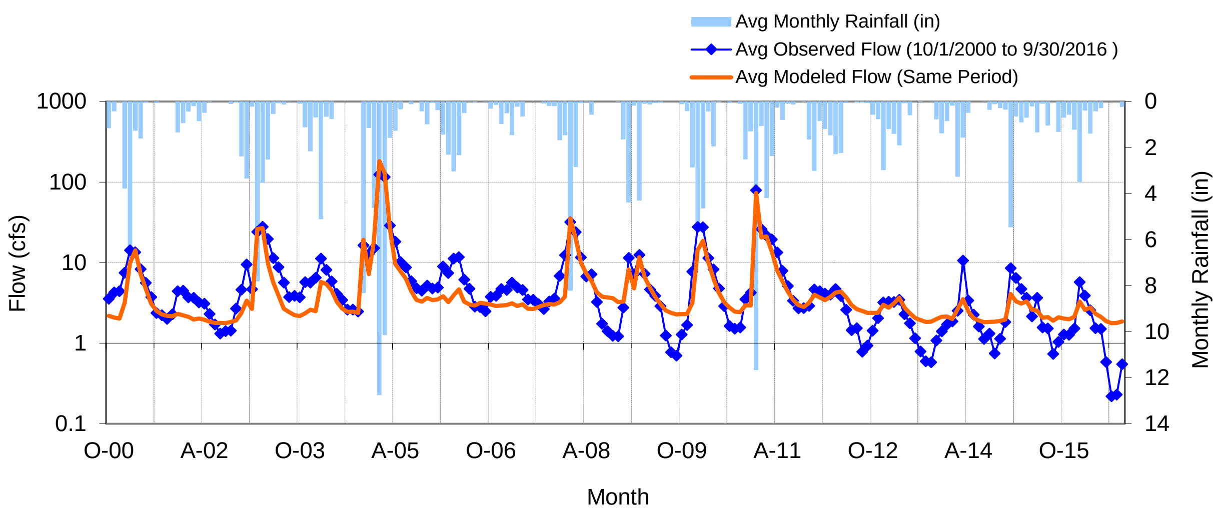


Figure 4-31. Mean monthly flow: Model DSN 4117 vs. USGS 11044350 Sandia Cr nr Fallbrook, CA

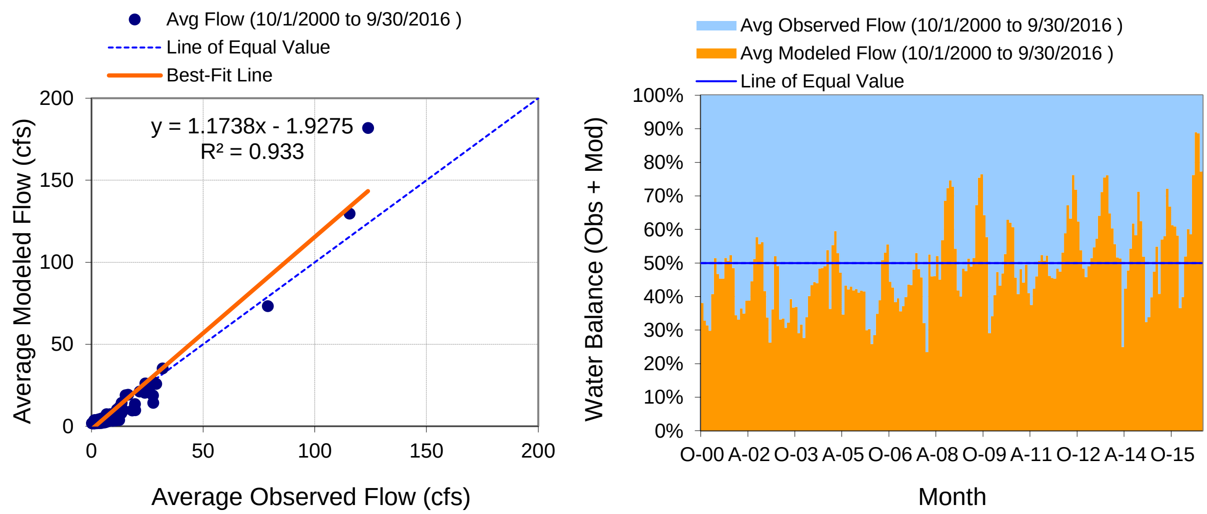


Figure 4-32. Monthly flow regression and temporal variation: Model DSN 4117 vs. USGS 11044350 Sandia Cr nr Fallbrook, CA

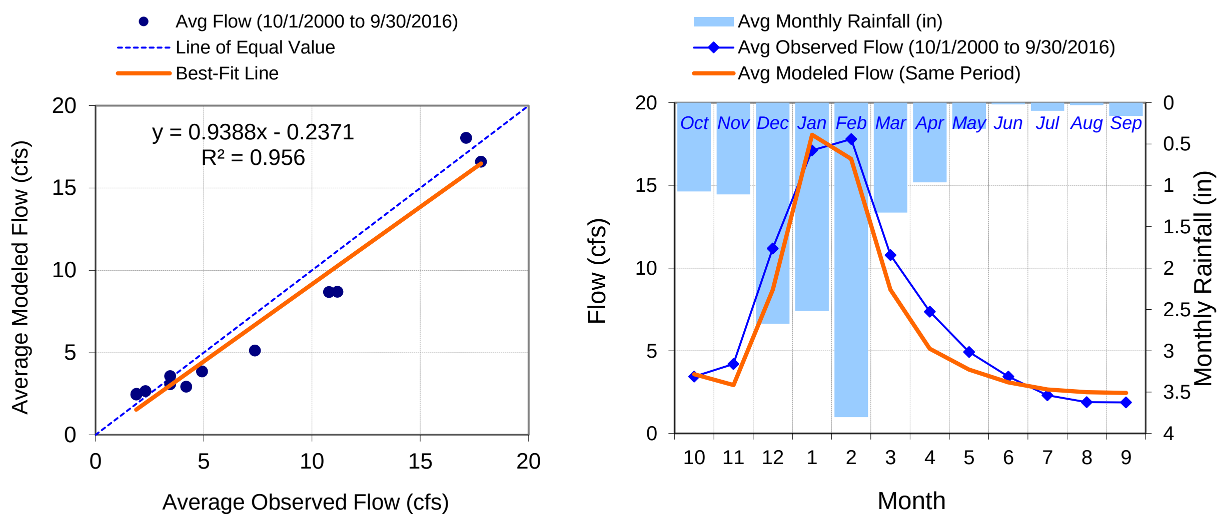


Figure 4-33. Seasonal regression and temporal aggregate: Model DSN 4117 vs. USGS 11044350 Sandia Cr nr Fallbrook, CA

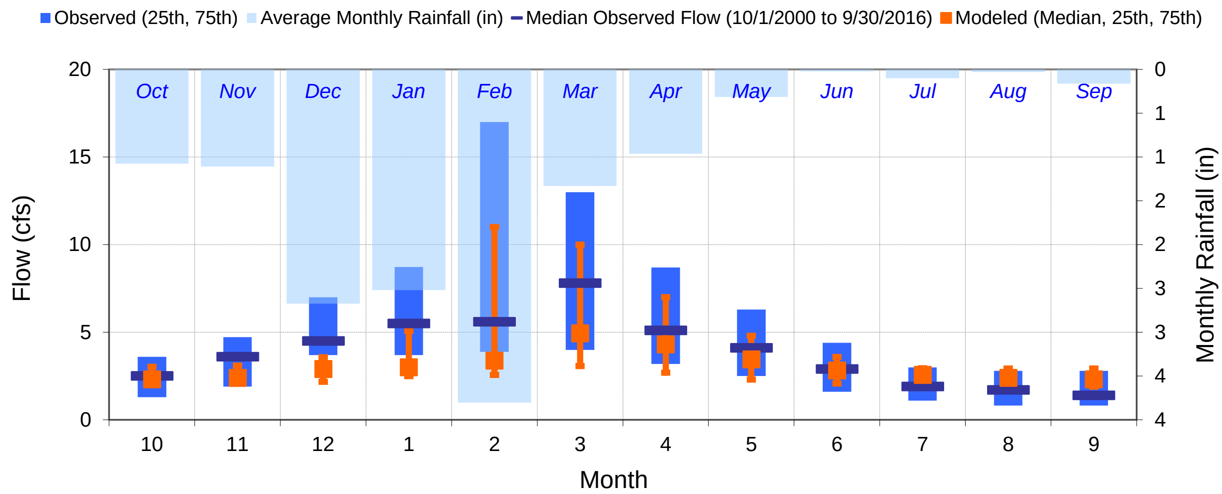


Figure 4-34. Seasonal medians and ranges: Model DSN 4117 vs. USGS 11044350 Sandia Cr nr Fallbrook, CA

Table 4-11. Seasonal summary: Model DSN 4117 vs. USGS 11044350 Sandia Cr nr Fallbrook, CA

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	3.44	2.50	1.30	3.60	3.57	2.33	2.01	3.03
Nov	4.19	3.60	1.90	4.73	2.93	2.40	2.08	3.10
Dec	11.18	4.50	3.70	7.00	8.69	2.91	2.18	3.58
Jan	17.12	5.50	3.70	8.73	18.05	3.02	2.49	5.08
Feb	17.80	5.60	3.88	17.00	16.60	3.38	2.57	11.01
Mar	10.78	7.80	4.00	13.00	8.69	4.95	3.07	10.00
Apr	7.36	5.10	3.20	8.70	5.12	4.31	2.69	7.00
May	4.92	4.10	2.50	6.30	3.86	3.47	2.30	4.80
Jun	3.44	2.90	1.60	4.40	3.08	2.82	2.08	3.59
Jul	2.31	1.90	1.10	3.00	2.66	2.57	1.95	2.94
Aug	1.90	1.70	0.82	2.80	2.50	2.41	1.88	2.94
Sep	1.88	1.40	0.82	2.80	2.45	2.33	1.90	2.93

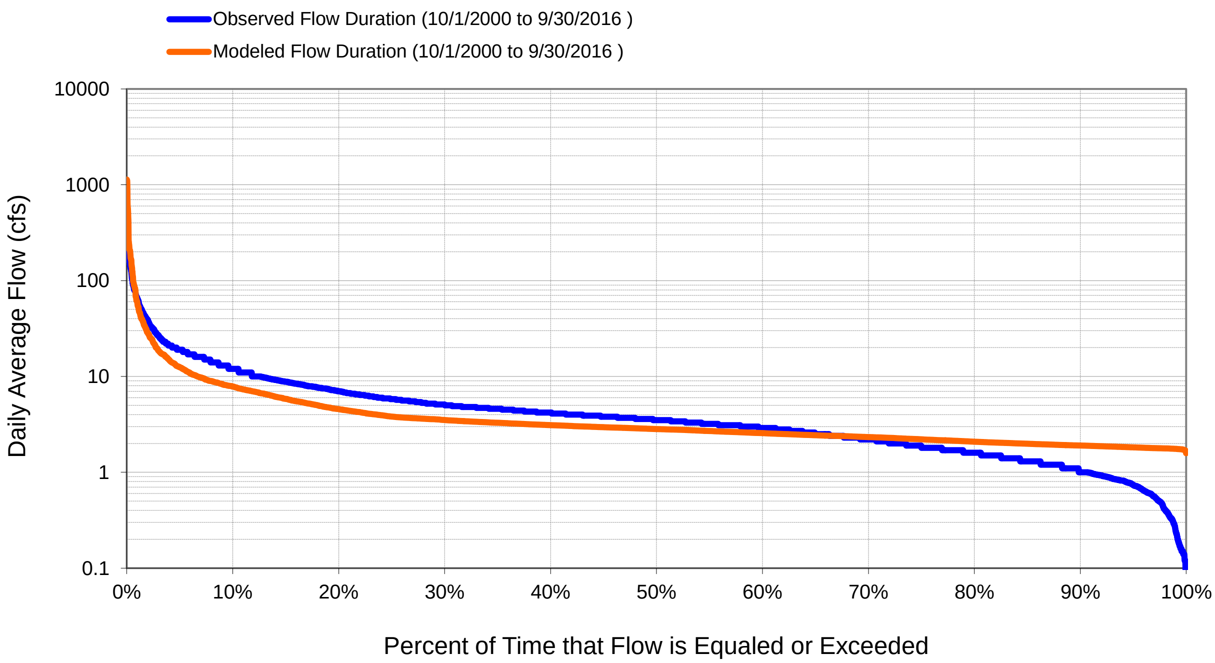


Figure 4-35. Flow exceedence: Model DSN 4117 vs. USGS 11044350 Sandia Cr nr Fallbrook, CA

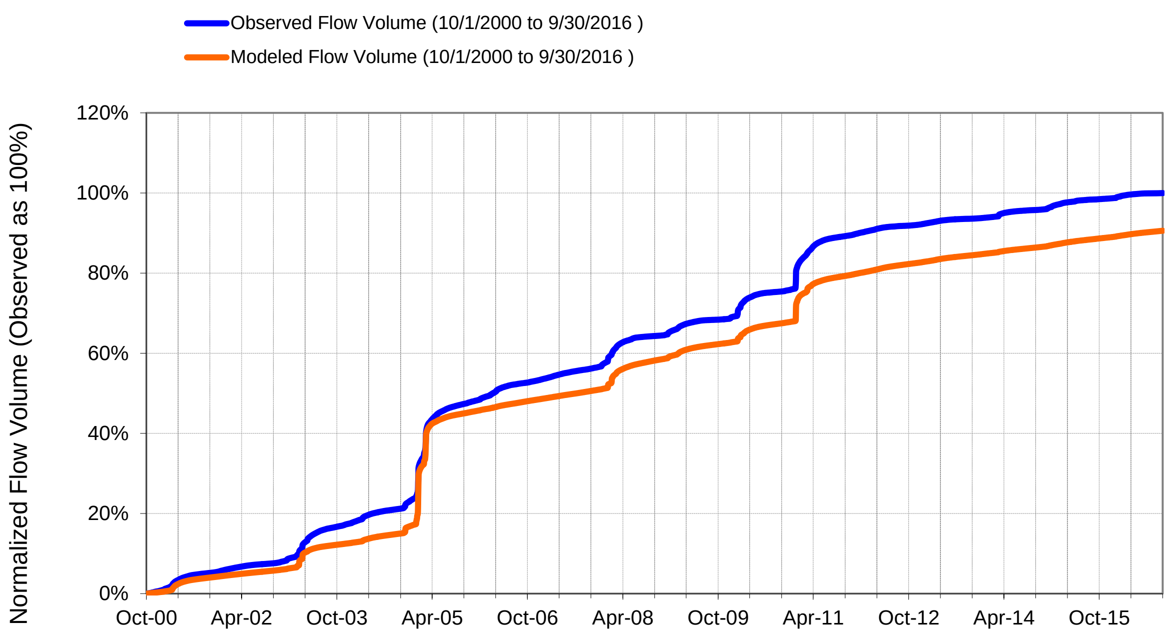


Figure 4-36. Flow accumulation: Model DSN 4117 vs. USGS 11044350 Sandia Cr nr Fallbrook, CA

Table 4-12. Summary statistics: Model DSN 4117 vs. USGS 11044350 Sandia Cr nr Fallbrook, CA

HSPF Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM DSN 4117		USGS 11044350 SANDIA C NR FALLBROOK CA	
16-Year Analysis Period: 10/1/2000 - 9/30/2016 Flow volumes are (inches/year) for upstream drainage area 3/31/17 8:05		Hydrologic Unit Code: 18070302 Latitude: 33.42447348 Longitude: -117.249202 Drainage Area (sq-mi): 21.1	
Total Simulated In-stream Flow:	**4.17**	Total Observed In-stream Flow:	**4.60**
Total of simulated highest 10% flows:	**2.41**	Total of Observed highest 10% flows:	**2.48**
Total of Simulated lowest 50% flows:	**0.72**	Total of Observed Lowest 50% flows:	**0.62**
Simulated Summer Flow Volume (months 7-9):	**0.41**	Observed Summer Flow Volume (7-9):	**0.33**
Simulated Fall Flow Volume (months 10-12):	**0.82**	Observed Fall Flow Volume (10-12):	**1.02**
Simulated Winter Flow Volume (months 1-3):	**2.29**	Observed Winter Flow Volume (1-3):	**2.41**
Simulated Spring Flow Volume (months 4-6):	**0.64**	Observed Spring Flow Volume (4-6):	**0.84**
Total Simulated Storm Volume:	**1.15**	Total Observed Storm Volume:	**1.13**
Simulated Summer Storm Volume (7-9):	**0.01**	Observed Summer Storm Volume (7-9):	**0.04**

Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*
Error in total volume:	-9.40	10
Error in 50% lowest flows:	**15.68**	**10**
Error in 10% highest flows:	-2.71	15
Seasonal volume error - Summer:	24.96	30
Seasonal volume error - Fall:	-19.17	30
Seasonal volume error - Winter:	-5.12	30
Seasonal volume error - Spring:	-23.27	30
Error in storm volumes:	1.95	20
Error in summer storm volumes:	**-69.40**	**50**
Nash-Sutcliffe Coefficient of Efficiency, E:	0.694	Model accuracy increases
Baseline adjusted coefficient (Garrick), E':	0.556	as E or E' approaches 1.0
Monthly NSE	0.869	

>> Clear

4.3.6 Fallbrook Creek near Fallbrook

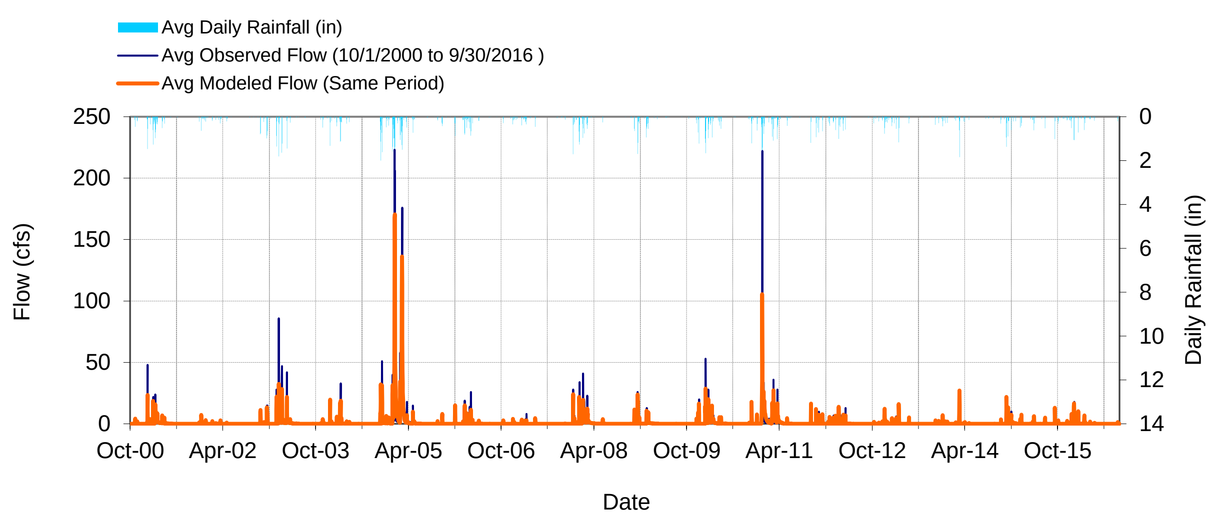


Figure 4-37. Mean daily flow: Model DSN 4178 vs. USGS 11045300 Fallbrook Cr nr Fallbrook, CA

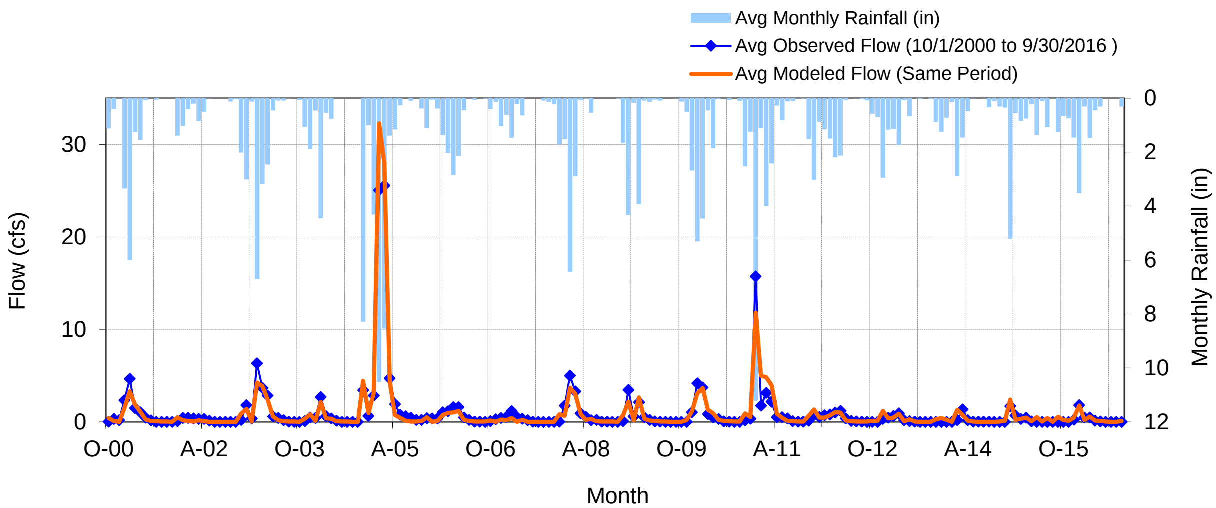


Figure 4-38. Mean monthly flow: Model DSN 4178 vs. USGS 11045300 Fallbrook Cr nr Fallbrook, CA

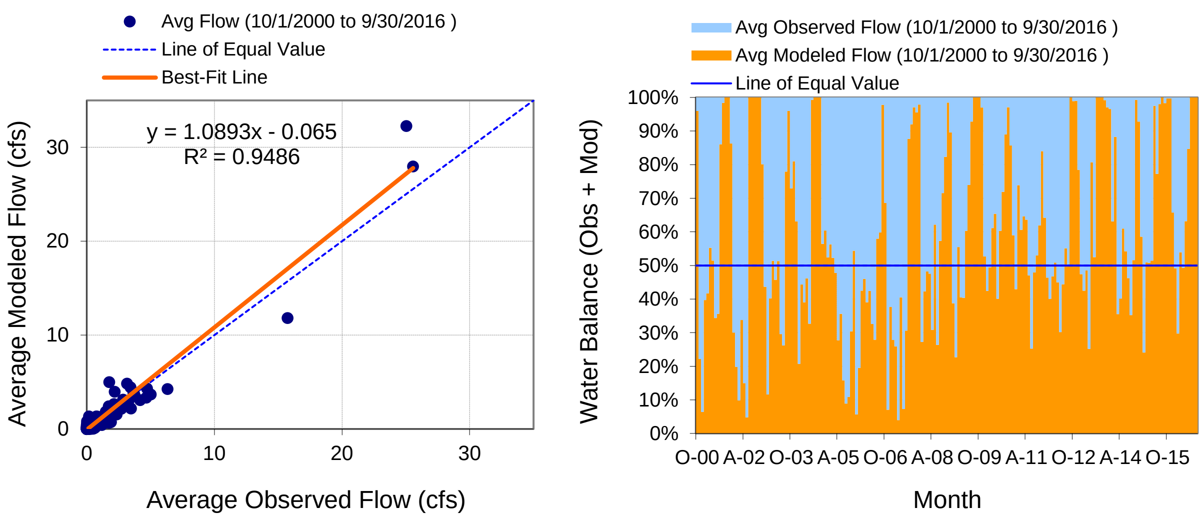


Figure 4-39. Monthly flow regression and temporal variation: Model DSN 4178 vs. USGS 11045300 Fallbrook Cr nr Fallbrook, CA

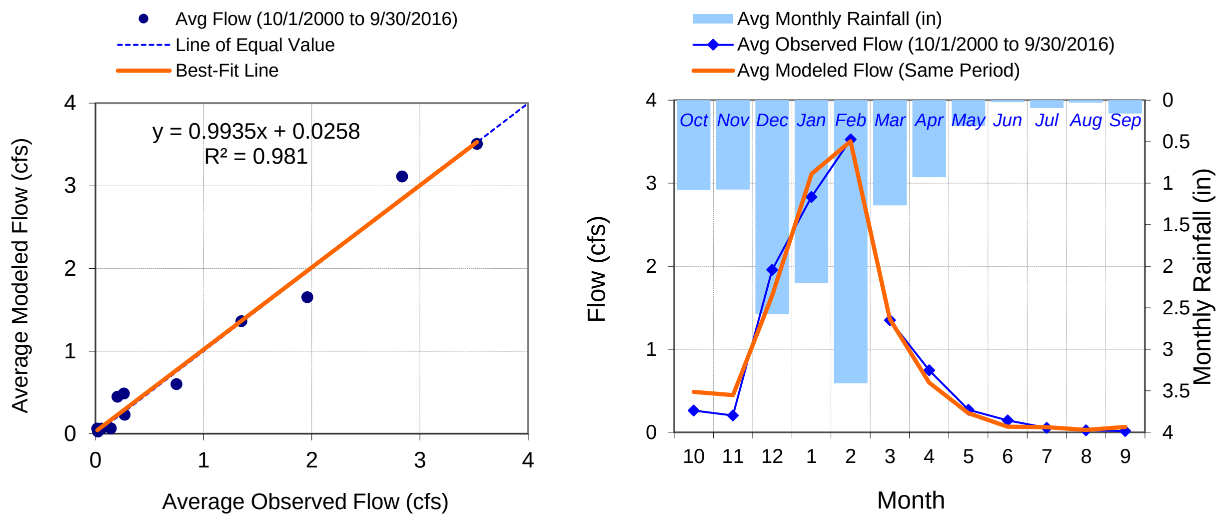


Figure 4-40. Seasonal regression and temporal aggregate: Model DSN 4178 vs. USGS 11045300 Fallbrook Cr nr Fallbrook, CA

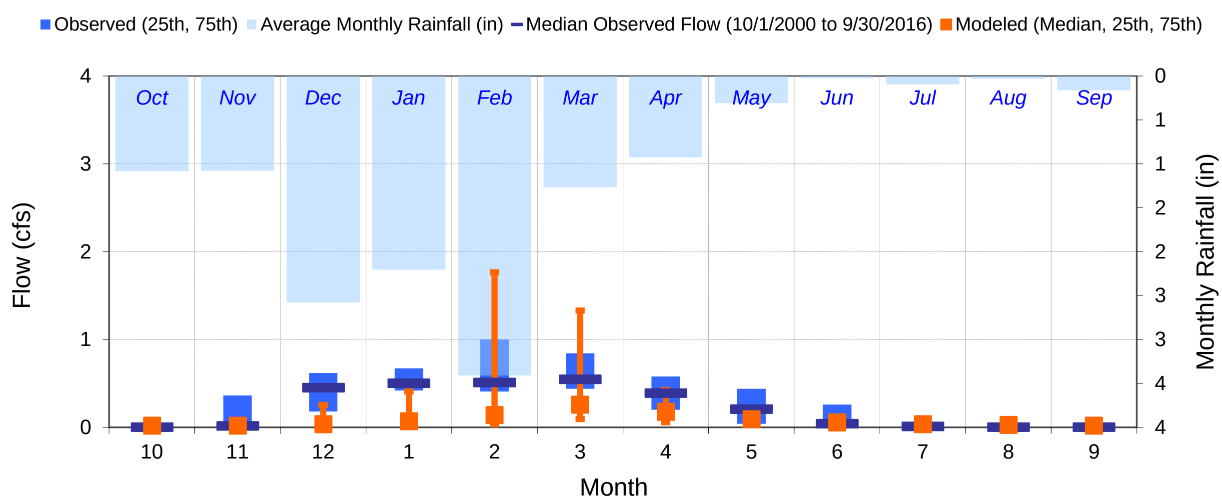


Figure 4-41. Seasonal medians and ranges: Model DSN 4178 vs. USGS 11045300 Fallbrook Cr nr Fallbrook, CA

Table 4-13. Seasonal summary: Model DSN 4178 vs. USGS 11045300 Fallbrook Cr nr Fallbrook, CA

MONTH	OBSERVED FLOW (CFS)				MODELED FLOW (CFS)			
	MEAN	MEDIAN	25TH	75TH	MEAN	MEDIAN	25TH	75TH
Oct	0.26	0.00	0.00	0.01	0.49	0.02	0.01	0.03
Nov	0.20	0.02	0.00	0.36	0.45	0.02	0.01	0.05
Dec	1.96	0.45	0.18	0.62	1.65	0.04	0.02	0.25
Jan	2.84	0.50	0.42	0.67	3.11	0.07	0.03	0.41
Feb	3.53	0.51	0.41	1.00	3.51	0.14	0.04	1.77
Mar	1.35	0.55	0.44	0.84	1.36	0.26	0.09	1.33
Apr	0.75	0.39	0.20	0.58	0.60	0.18	0.06	0.43
May	0.27	0.21	0.04	0.44	0.23	0.09	0.04	0.22
Jun	0.14	0.04	0.01	0.26	0.07	0.06	0.03	0.09
Jul	0.06	0.01	0.00	0.04	0.06	0.04	0.02	0.05
Aug	0.02	0.00	0.00	0.02	0.03	0.03	0.02	0.04
Sep	0.02	0.00	0.00	0.00	0.06	0.02	0.01	0.03

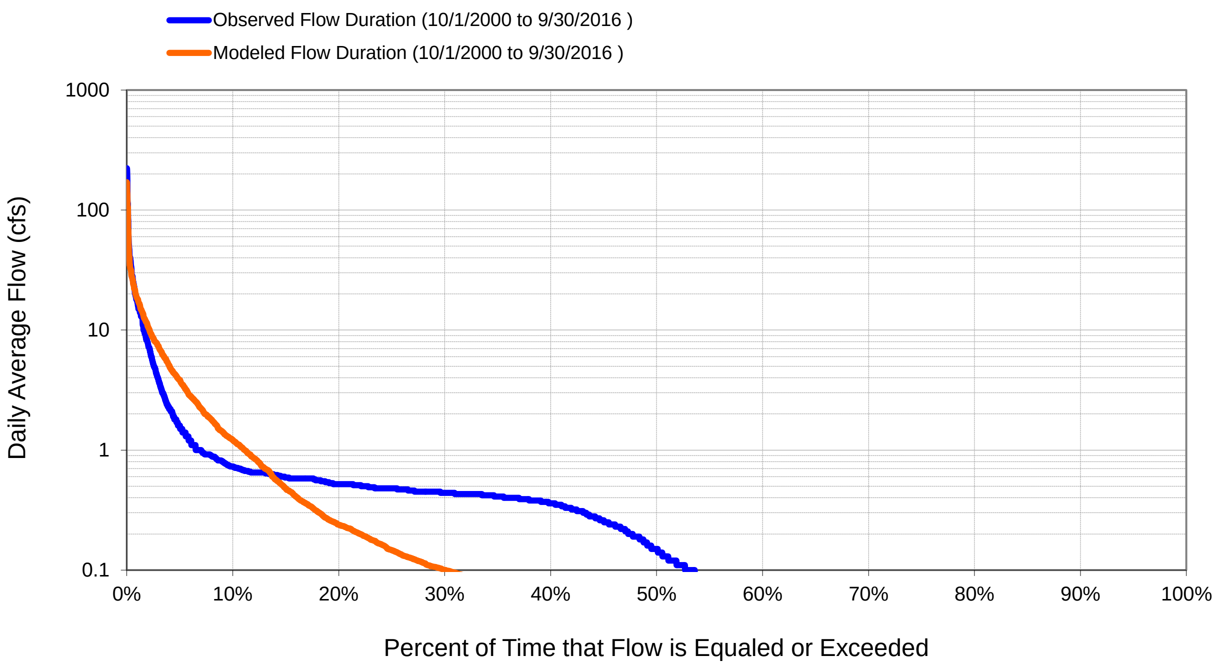


Figure 4-42. Flow exceedence: Model DSN 4178 vs. USGS 11045300 Fallbrook Cr nr Fallbrook, CA

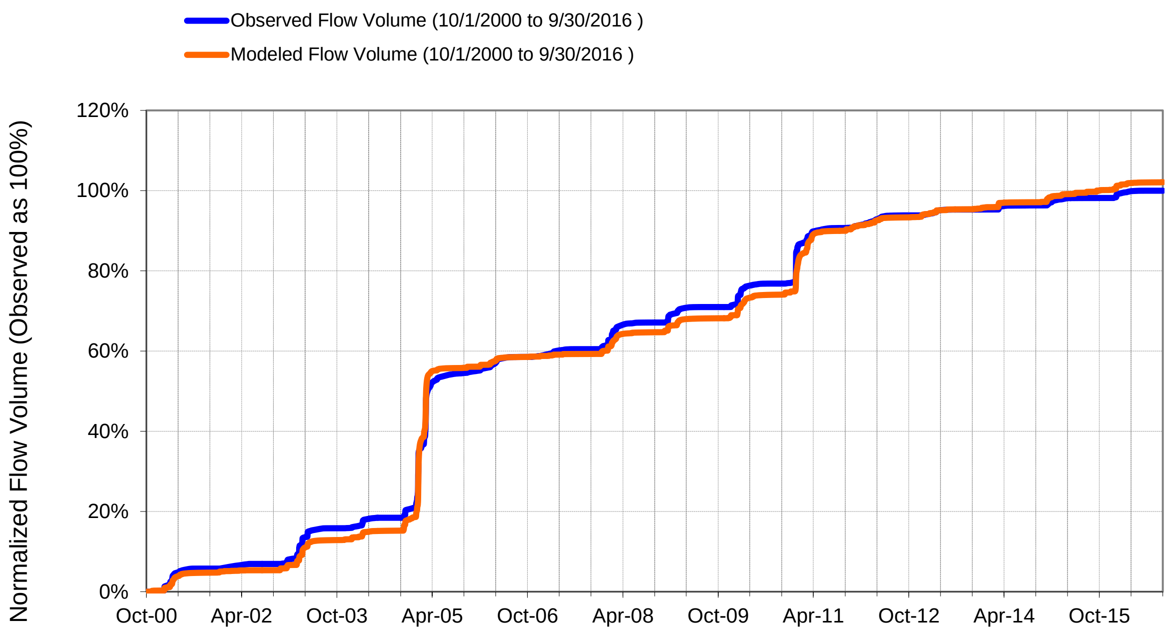


Figure 4-43. Flow accumulation: Model DSN 4178 vs. USGS 11045300 Fallbrook Cr nr Fallbrook, CA

Table 4-14. Summary statistics: Model DSN 4178 vs. USGS 11045300 Fallbrook Cr nr Fallbrook, CA

HSPF Simulated Flow		Observed Flow Gage	
REACH OUTFLOW FROM DSN 4178 16-Year Analysis Period: 10/1/2000 - 9/30/2016 Flow volumes are (inches/year) for upstream drainage area 3/29/17 9:27		USGS 11045300 FALLBROOK C NR FALLBROOK CA Hydrologic Unit Code: 18070302 Latitude: 33.34697584 Longitude: -117.3178152 Drainage Area (sq-mi): 6.97	
Total Simulated In-stream Flow:	**1.87**	Total Observed In-stream Flow:	**1.83**
Total of simulated highest 10% flows:	**1.68**	Total of Observed highest 10% flows:	**1.47**
Total of Simulated lowest 50% flows:	**0.02**	Total of Observed Lowest 50% flows:	**0.02**
Simulated Summer Flow Volume (months 7-9):	**0.03**	Observed Summer Flow Volume (7-9):	**0.02**
Simulated Fall Flow Volume (months 10-12):	**0.43**	Observed Fall Flow Volume (10-12):	**0.40**
Simulated Winter Flow Volume (months 1-3):	**1.27**	Observed Winter Flow Volume (1-3):	**1.22**
Simulated Spring Flow Volume (months 4-6):	**0.15**	Observed Spring Flow Volume (4-6):	**0.19**
Total Simulated Storm Volume:	**0.96**	Total Observed Storm Volume:	**1.02**
Simulated Summer Storm Volume (7-9):	**0.01**	Observed Summer Storm Volume (7-9):	**0.00**

Errors (Simulated-Observed)	*Error Statistics*	*Recommended Criteria*		
Error in total volume:	2.13	10		
Error in 50% lowest flows:	1.27	10		
Error in 10% highest flows:	14.55	15		
Seasonal volume error - Summer:	**59.37**	**30**		
Seasonal volume error - Fall:	6.55	>> 30		Clear
Seasonal volume error - Winter:	3.71	30		
Seasonal volume error - Spring:	-22.42	30		
Error in storm volumes:	-6.21	20		
Error in summer storm volumes:	**567.97**	**50**		
Nash-Sutcliffe Coefficient of Efficiency, E:	0.725	Model accuracy increases		
Baseline adjusted coefficient (Garrick), E':	0.489	as E or E' approaches 1.0		
Monthly NSE	0.927			

5.0 WATER QUALITY RECALIBRATION

Tetra Tech (2014) describes detailed calibration of the Santa Margarita River watershed model for sediment and nutrients, using monitoring data collected through 2010. The current effort provides an adjustment and recalibration of the model using data collected through the end of Water Year 2016 and incorporating the refinements to the hydrology calibration described above.

5.1 WATER QUALITY DATA

Water quality data have been collected at many locations and under many different programs in the Santa Margarita River watershed. Section 3 in Tetra Tech (2014) provides a summary of the data that are available for 1990 – 2013. Stations most useful for watershed model calibration are those that have a relatively large number of samples and cover a range of flow conditions. The number of stations that meet these criteria is limited. Individual or small sets of observations are less useful because there is typically a large component of random variability in water quality measurements.

Tetra Tech (2014) identified the primary quantitative calibration stations as those stations that had at least 30 nutrient observations (relative to the prior model application period of 1990 - 2010) and were located on a stream segment explicitly represented in the model. Tetra Tech (2014) also identified "qualitative" calibration stations that had between 10 and 29 nutrient observations for 1990 – 2010. The previously identified quantitative and qualitative calibration stations that are in the portions of the watershed that drain downstream of the Santa Margarita near Temecula are recapitulated in Table 5-1 and Table 5-2.

Table 5-1. Quantitative Water Quality Calibration Stations Identified in Tetra Tech (2014), Count of Samples for 1990 - 2013

Station IDs	Station Name	TSS	NO_2+NO_3-N	TKN	NH_3+NH_4-N	TP	PO_4-P
RC-WGR	Rainbow Creek near Fallbrook	0	190	1	1	7	142
902SMRNB4, SMG06	Rainbow Creek Fallbrook PUC Trail, Rainbow Creek 4, Rainbow Creek Stage Coach Lane	7	214	91	147	122	189
11043500, SC-SCR, SMG07	Sandia Creek near Fallbrook, Sandia Creek at Sandia Creek Drive	8	67	35	50	41	54
Tt21	Santa Margarita River at confluence with Rainbow Creek	0	208	0	0	89	0
X2137660, 11044300, MS4-SMG-045	Santa Margarita River at FPUD Sump near Fallbrook	10	190	39	38	33	195
SMR-WGR	Santa Margarita River at Willow Glen	0	38	30	17	25	43

Notes: Tetra Tech (2014) provided sample counts through 2013, although the modelling for that effort extended only through 2010. TKN = Total Kjeldahl N, the sum of NH3+NH4-N and organic N. TP = Total P.

Table 5-2. Qualitative Water Quality Calibration Stations Identified in Tetra Tech (2014), Count of Samples for 1990 – 2013

Station IDs	Station Name	TSS	NO_2+NO_3-N	TKN	NH_3+NH_4-N	TP	PO_4-P
11044800	De Luz Creek near De Luz	0	28	14	12	19	14
11045300	Fallbrook Creek near Fallbrook	0	17	6	6	11	12
Tt25	Santa Margarita River downstream of confluence Rainbow Creek	0	12	12	12	3	21
Tt31	Santa Margarita River upstream of confluence De Luz Creek	0	14	13	13	0	26
RBC01	Rainbow Creek @ Jubilee Way	1	40	23	41	26	35
RBC02	Rainbow Creek @ Huffstatler Street	1	116	84	131	98	108
RBC04	Rainbow Creek @ Old Highway 395	0	106	87	123	99	100
RBC06	Rainbow Creek @ 2219 Willow Glen Road	0	110	77	118	97	107
RBC10	Rainbow Creek @ MWD Road Crossing	0	102	80	115	97	99
SMG05	Rainbow Creek @ Willow Glen Road	1	117	71	120	99	113
Tt28	Santa Margarita River downstream confluence of Sandia Cr	0	18	16	14	0	36
X2114040, 11046000	Santa Margarita River at Ysidora	0	31	22	22	16	37

Notes: Tetra Tech (2014) provided sample counts through 2013, although the modelling for that effort extended only through 2010. TKN = Total Kjeldahl N, the sum of NH3+NH4-N and organic N. TP = Total P.

Much of the data summarized above was collected during intensive sampling campaigns in the 1990s. For the current recalibration effort, we focus on more recent data for two reasons: (1) the updated model is built with 2015 land use, which likely becomes progressively less appropriate for older observations, and (2) the parameters calibrated in the previous water quality effort, which used 2005 – 2009 land use, provide a reasonable representation of the earlier data. We therefore updated the previous calibration based on the more recent data and updated parameters only where the need is clearly indicated by the data.

Additional data collection has proceeded since 2013, conducted by San Diego County, USMC Camp Pendleton, and SCCWRP. The Rainbow Creek TMDL monitoring (which includes the “RBC” stations listed in Table 5-2) continued, but many other sampling efforts were reorganized in conjunction with the 2013 MS4 permit reissuance that set forth transitional monitoring requirements until the WQIPs are completed (Weston, 2016, 2017). The following sampling programs are covered under the transitional monitoring requirements:

1. NPDES Receiving Water Monitoring. This element covers the long-term mass loading station (MLS) monitoring. The 2013 permit resulted in the establishment of sampling at MLS-2 (upstream boundary of Camp Pendleton). This is also designated as the long-term monitoring station for the Santa Margarita WMA, and is in addition to the MLS-1 station maintained by Camp Pendleton downstream near Basilone Road. Current requirements are to obtain three dry

weather and three wet weather samples per year – but only during those years in which the Santa Margarita WMA is in rotation. Because of the low frequency of sample collection and movement of the MLS station from its earlier location there is only a limited sample record established at MLS-2.

2. Transitional Dry Weather MS4 Outfall Discharge Monitoring. This element is designed to identify non-storm water and illicit discharges. Those outfalls with persistent discharges were subject to further investigation and sampling.
3. Transitional Wet Weather MS4 Outfall Discharge Monitoring. Two MS4 outfall discharge locations were monitored, both in the Fallbrook Creek drainage, at a frequency of once per year.

The transitional monitoring has few sites and low frequency of collection, and so has not added much in the way of new data. The Rainbow Creek TMDL monitoring has been more extensive. The update to the sampling plan in 2011 identifies 14 sampling locations on the Rainbow Creek mainstem and various tributaries (including many sites previously monitored by the Regional Board for development of the TMDL). These samples are collected once per month. It is important to note, however, that the current monitoring effort is intended to collect dry weather samples only, as the focus is on identifying anthropogenic discharges: "Monitoring is not to be conducted during any rain event >0.1 inch until the water level returns to within approximately 10% of the pre-rain creek level" (County of San Diego, 2011). The recent sampling thus is informative as to baseflow conditions, but does not provide new information on wet weather responses.

Additional water quality samples available for 2014 – 2016 are summarized in Table 5-3.

Table 5-3. Water Quality Sampling, 2014-2016

Station ID	Location	Sampling Program	Sample Count
HST01	Brow Ditch to Rainbow Creek at Huffstatler Street. 33.41526 -117.15204	RBC TMDL	9
HST02	Pipe from a nursery along Huffstatler Street. 33.41174 -117.15196	RBC TMDL	9
RBC02	Rainbow Creek @ Huffstatler Street. 33.41544 -117.15199	RBC TMDL	33
RBC04	Rainbow Creek @ Old Highway 395. 33.41272 -117.15853	RBC TMDL	33
RBC06	Rainbow Creek @ 2219 Willow Glen Road. 33.40859 -117.20523	RBC TMDL	33
RBC10	Rainbow Creek @ MWD Road Crossing. 33.40696 -117.18344	RBC TMDL	15
RVT02	Chica tributary @ 1st Street. 33.42126 -117.14983	RBC TMDL	8
SMG05, RC-WGR, 11044250	Rainbow Creek @ Willow Glen Road. 33.40757 -117.20253	RBC TMDL, SMRWQ Stetson	36

Station ID	Location	Sampling Program	Sample Count
SMG06, 902SMRNB4, and RBC	Rainbow Creek @ Stage Coach Lane. 33.41056 -117.21477	RBC TMDL, SMRWQ Stetson, SCCWRP	43
WGT01	Pinckney Tributary @ Willow Glen Road. 33.40784 -117.20309	RBC TMDL	34
MLS-1, SMR0, SMR1	MLS-1. 33.284 -117.374	MCBCP_2015-2016_MWSWWQMR, SCCWRP	8
SMR-MLS-2	De Luz Road Bridge over Santa Margarita Bridge. 33.398142 -117.26273	San Diego County long term and transitional monitoring	6
MLS-3	33.353333, -117.326389	MCBCP_2015-2016_MWSWWQMR	3
SME-1	Inlet of the embayment 33.23512, -117.40929	MCBCP_2015-2016_MWSWWQMR	3
SME-2	Mid-point of estuary 33.23436, -117.41127	MCBCP_2015-2016_MWSWWQMR	3
SME-3	Near the outlet of the embayment 33.23378, -117.41329	MCBCP_2015-2016_MWSWWQMR	3
SMR-U	Reach upstream of De Luz Road Arizona crossing. 33.363064, -117.320461	MCBCP_2015-2016_MWSWWQMR	3
DC	Devils Creek. 33.464055 -117.170571	SCCWRP	12
FB	Unknown	SCCWRP	8
FB1	Fallbrook Reach 1. 33.403861 -117.251214	SCCWRP	5
FB2	Fallbrook reach 2. 33.404209 -117.250867	SCCWRP	4
G	Unknown	SCCWRP	3
G1	Gorge Reach 1. 33.472561 -117.144391	SCCWRP	4
G2	Gorge Reach 2. 33.473825 -117.142828	SCCWRP	4
GG	Unknown	SCCWRP	4
MWD	Unknown	SCCWRP	8
MWD1	The Crossing Reach 1. 33.455589 -117.171385	SCCWRP	4
MWD2	The Crossing Reach 2. 33.456564 -117.169596	SCCWRP	4

Station ID	Location	Sampling Program	Sample Count
RB	Unknown	SCCWRP	9
RB1	Rainbow Above Confluence. 33.406051 -117.219396	SCCWRP	4
RB2	Rainbow Below confluence. 33.409774 -117.21788	SCCWRP	4
SC	Sandia Creek. 33.4145 -117.245403	SCCWRP	10
SMR2	33.31141 -117.34799	SCCWRP	12
SMR3	33.31162 -117.34567	SCCWRP	19
SMR4	33.31156 -117.34359	SCCWRP	16
SMR5	33.34253 -117.33185	SCCWRP	17
SMR6	33.34401 -117.33095	SCCWRP	21

As in the previous work, the focus for model recalibration is on sites with relatively large numbers of samples. Sites were generally excluded from use in the recalibration effort if they had fewer than 30 observations, or had few observations after 2000. One exception to these rules is made for the Santa Margarita River at Ysidora, where there were multiple analytes with 15-25 observations. Based on the importance of this site it was retained for model calibration. Several of the small tributary sites in the Rainbow Creek watershed had frequent samples but represent drainage areas at a smaller spatial scale than the model segmentation. The final set of stations used in the recalibration effort is shown in Figure 5-1 and Table 5-4. Only four of these 13 stations were used in the prior calibration effort (Tetra Tech, 2014) reflecting the large changes in monitoring programs and locations that have occurred since 2000. Many of the sites that had intensive data collection in the 1990s have few later data and are of less certain applicability for comparison to model results obtained with 2015 land use.

Table 5-4. Water Quality Stations used in Recalibration

Station ID	Location	Prior Quantitative Station
RBC01	Rainbow Creek at Jubilee Way	No
RBC02	Rainbow Creek @ Huffstatler Street	No
RBC04	Rainbow Creek @ Old Highway 395	No
RBC06	Rainbow Creek @ 2219 Willow Glen Road	No
RBC10	Rainbow Creek @ MWD Road Crossing	No
RGT01	Rainbow Glen Tributary to Rainbow Creek	No
RVT02	Chica tributary @ 1st Street	No
SMG05	Rainbow Creek @ Willow Glen Road	No
SMG06	Rainbow Creek @ Stage Coach Lane	Yes
MLS-1	Santa Margarita River at Macs Road	No
11044300	Santa Margarita River at FPUD Sump	Yes
11044350	Sandia Creek at Sandia Drive	Yes
11046000	Santa Margarita River at Ysidora	Yes

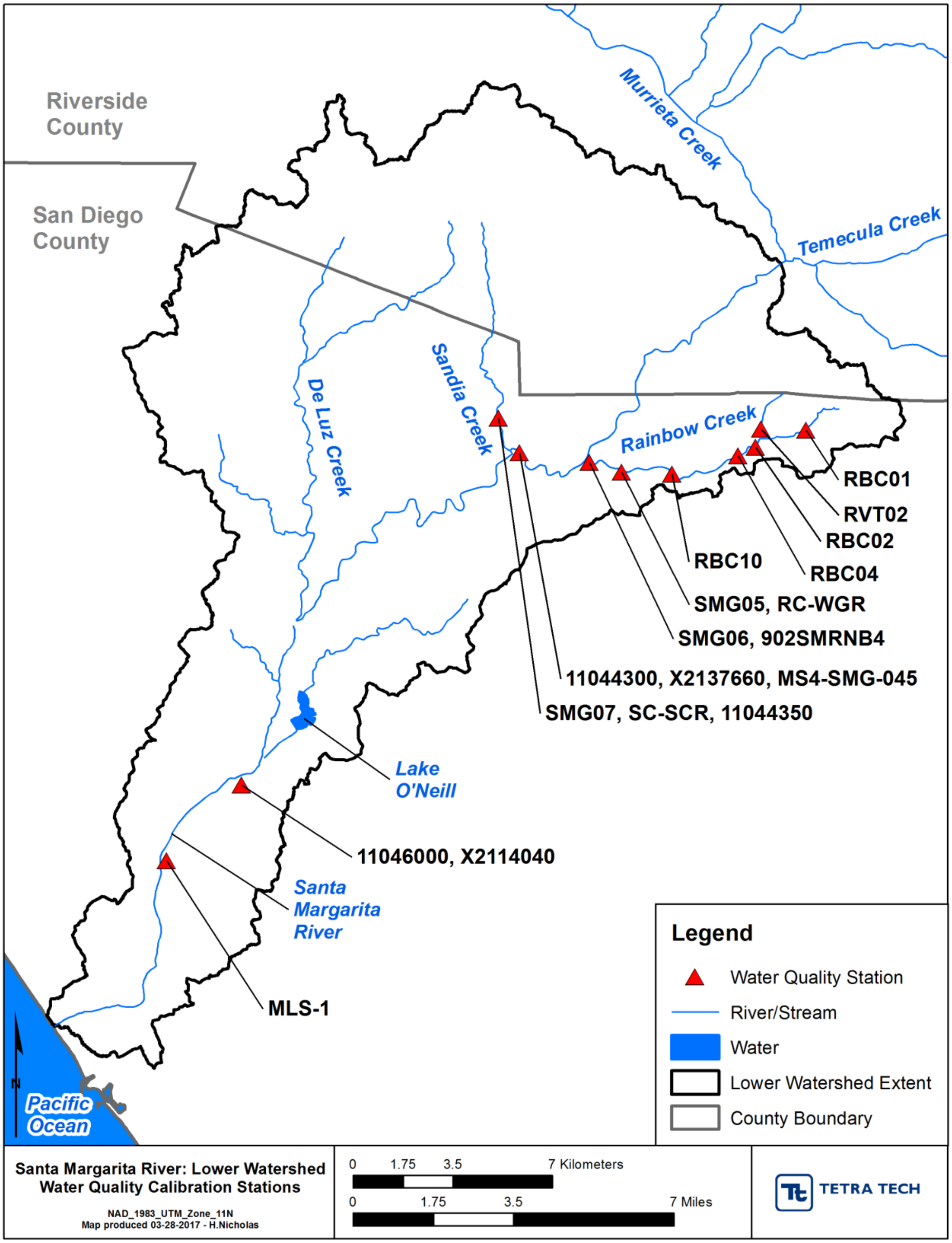


Figure 5-1. Water Quality Monitoring Stations used for Model Recalibration

5.2 WATER QUALITY CALIBRATION APPROACH

The Santa Margarita watershed model is calibrated for suspended sediment, total phosphorus, and total nitrogen. Sediment is calibrated first, as nutrient transport (particularly phosphorus transport) is strongly influenced by sediment transport. The HSPF watershed model represents land-based and channel-based sediment. Three classes of sediment are simulated in HSPF: sand, silt, and clay. Silt and clay are simulated as cohesive sediment classes.

The approach for sediment calibration generally follows the guidance of USEPA (2006), with some enhancements. Suspended sediment concentrations observed in-stream are the result of both upland and channel processes, so there are multiple sets of parameters that control results. The general strategy for sediment calibration consists of the following steps:

- Specify initial upland parameter values based on external information (e.g., soils data).
- Adjust upland sediment erosion to reproduce calibration targets available from other studies or literature.
- Adjust instream/channel parameters to approximate available observations of TSS concentration.
- Check long-term channel evolution predictions against the mainstem sedimentation study (WEST Consultants, 2000)

In rural watersheds, much of the nutrient load can move as a constituent of organic matter (including leaf litter, other debris, and dissolved organic compounds, such as humic acids), while stream concentrations of inorganic nutrients remain low in these watersheds. In contrast, agriculture and fertilized lawns may export significant amounts of nutrients in inorganic forms.

The approach taken for the Santa Margarita model is to simulate loading of total N and total P from the land surface as general quality constituents (GQUALs). The total nutrient loads are then partitioned at the point of entry into the stream network into inorganic nitrogen (nitrate, nitrite, and ammonia), organic nitrogen, inorganic phosphorus), and organic phosphorus. Total phosphorus loading is assumed to be 70 percent PO_4 - P and 30 percent organic phosphorus. Total nitrogen from the land surface is assumed to be 40 percent NO_3-N, 10 percent NH_4-N, 10 percent NO_2-N, and 40 percent organic N; total nitrogen loading from ground water is assumed to be 90 percent NO_3-N and 10 percent NH_4-N. Individual nutrient species are not simulated on the land surface because most of the regional concentration and loading data refers to total nutrient concentrations.

Both nitrogen and phosphorus may be loaded through either surface flow or subsurface flow (interflow and groundwater discharge). The HSPF GQUAL algorithms do not maintain a full mass balance of subsurface constituents (which would require a groundwater quality model); rather, the user specifies concentration values, which may vary monthly, for interflow and groundwater. Surface washoff loading is considered from both pervious and impervious surfaces.

Phosphorus loading from pervious surfaces is often simulated as a sediment-associated process because of the strong affinity of orthophosphate for soil particles. In this approach, loading of phosphorus is represented by a potency factor applied to the simulated sediment load. This approach presents problems for the Santa Margarita model due to the small amount of data and associated relatively high uncertainty in the sediment simulation. To prevent the sediment simulation uncertainty from overwhelming the phosphorus simulation, we adopt a hybrid approach in which phosphorus loading from both pervious and impervious surfaces is first represented via a buildup-washoff process, with the total load supplemented by assigning a small potency factor to eroded sediment.

In contrast to phosphorus, inorganic nitrogen is highly soluble, and loading in surface runoff is less dependent on sediment movement (particularly where fertilizer is applied). Nitrogen loading from the land surface is also represented via a buildup-washoff process. Subsurface pathways are more significant for nitrogen than for phosphorus, and instream concentrations at lower flows depend largely on the specification of interflow and groundwater nitrogen concentrations.

For nutrients, it is unreasonable to expect that the model will predict all temporal variations in concentration and load. The model should, however, provide an accurate representation of long-term and seasonal trends in concentration and load, and correctly represent the relationship between flow and load. To ensure this, it is important to use statistical tests of equivalence between observed and simulated concentrations, rather than relying on a pre-specified model tolerance on difference in concentrations.

Ideally, average errors and average absolute errors should both be low, reflecting a lack of bias and high degree of precision, respectively. In many cases, the average error statistics will be inflated by a few highly discrepant outliers. It is therefore also useful to compare the median error statistics.

General performance targets for nutrient water quality simulation with HSPF are also provided by Duda et al. (2012) and are shown in Table 5-5. These are calculated from observed and simulated daily concentrations, and should only be applied in cases where there are a minimum of 20 observations.

Table 5-5. Performance Targets for HSPF Water Quality Simulation (Magnitude of Annual and Seasonal Relative Average Error (*RE*) on Daily Values)

Model Component	Very Good	Good	Fair	Poor
Nutrients	≤ 15%	15 - 25%	25 - 35%	> 35%

Evaluation of water quality simulations presents a number of challenges because, unlike flow, water quality is generally not monitored continuously. Grab samples at a point in space and time may not be representative of average conditions in a model reach on a given day due to either spatial or temporal uncertainty (i.e., an instantaneous measurement in time may deviate from the daily average, especially during storm events, while a point in space may not be representative of average conditions across an entire model reach). Where constituent concentrations are near reporting levels, relative uncertainty in reported results is naturally high. Accurate information on daily variability in point source loads is also rarely available.

Evaluation of relative average error is recommended, but averages are prone to biasing by one or a few extreme outliers. Therefore, it is also useful to examine median relative errors, which are less influenced by outliers.

5.3 SEDIMENT MODEL PARAMETERIZATION

Upland sediment loading is determined by a combination of soil characteristics (e.g., erodibility, slope), hydrologic characteristics (rainfall energy, depth of overland flow), and land management practices. Because of the strong dependence on soil characteristics, parameters for sediment loading are not directly transferable between watersheds. In addition, observed suspended sediment in streams during runoff events is often determined primarily by channel scour and deposition processes. Further, much of the sediment delivered from the watershed may move as bedload and can thus be missed during monitoring.

The HSPF model does not use the Universal Soil Loss Equation (USLE) for sediment simulation. However, some of the parameters used in HSPF are similar to those in the USLE. The SSURGO and STATSGO soils databases provide a number of USLE parameter estimates by soil type, and these can be used to set initial parameter values – ensuring relative consistency between the HSPF and USLE approaches.

HSPF calculates the detachment rate of sediment by rainfall (in tons/acre) as

$$DET = (1 - COVER) \cdot SMPF \cdot KRER \cdot P^{JRER}$$

where *DET* is the detachment rate (tons/acre), *COVER* is the dimensionless factor accounting for the effects of cover on the detachment of soil particles, *SMPF* is the dimensionless management practice factor, *KRER* is the coefficient in the soil detachment equation, *JRER* is the exponent in the soil detachment equation, and P is precipitation in inches. Actual sediment storage available for transport (*DETS*) is a function of accumulation over time and the reincorporation rate, *AFFIX*. The equation for *DET* is formally similar to the USLE equation (Wischmeier and Smith, 1978),

$$RE \cdot K \cdot LS \cdot C \cdot P,$$

where *RE* is the rainfall erosivity, K is the soil erodibility factor, LS is the length-slope factor, C is the cover factor, and P is the practice factor.

USLE predicts sediment loss from one or a series of events at the field scale, and thus incorporates local transport as well as sediment detachment. For a large event with a significant antecedent dry period, it is reasonable to assume that *DET≈DETS* if *AFFIX* is greater than zero and the transport capacity of the previous large rainfall event was sufficient to remove most of the detached sediment. That is, storm sediment yield is primarily a result of the current event. Further, during a large event, sediment yield at the field scale is assumed to be limited by supply, rather than transport capacity. Under those conditions, the USLE yield from an event should approximate *DET* in HSPF.

With these assumptions, the HSPF variable *SMPF* may be taken as fully analogous to the USLE *P* factor. The complement of *COVER* is equivalent to the USLE *C* factor (i.e., (1 - *COVER*) = C). This leaves the following equivalence:

$$KRER \cdot P^{JRER} = RE \cdot K \cdot LS\ .$$

The empirical equation of Richardson et al. (1983) as further tested by Haith and Merrill (1987) gives an expression for RE (in SI units of MJ-mm/ha-h) in terms of precipitation:

$$RE = 64.6 \cdot a_t \cdot R^{1.81},$$

where R is precipitation in cm and a_t is an empirical factor that varies by location and season. This suggests that the exponent *JRER* on *P* should be 1.81, yielding

$$KRER = {RE \cdot K \cdot LS}/{P^{1.81}}\ .$$

This further implies a linear relationship of *KRER* to *K* and *LS*, as rainfall raised to the 1.81 power appears in both the top and bottom of the equation:

$$KRER = G \cdot K \cdot LS\ ,$$

where *G* is a parameter that accounts for unit conversion and also includes the a_t factors from the Richardson model.

For areas in which the a_t parameters of the Richardson model have been developed (a laborious process), the value of *G* can be evaluated explicitly, yielding a quantitative theoretical relationship between *KRER* and the USLE *K* and *LS* parameters.

The a_t parameters do not appear to have been derived for the Los Angeles region. Isoerodent maps of *RE* have been developed for California (Renard et al., 1996). Values of RE vary across short differences in this area (Figure 5-2). However, *RE* is a function of both α_t and precipitation amount. In the Los Angeles region, the variability in *RE* appears to be primarily a result of storm volume, suggesting that the a_t factor may have limited variability in this region. If so, the isoerodent map is driven primarily by rainfall amount and yields little information on the value of *KRER*.

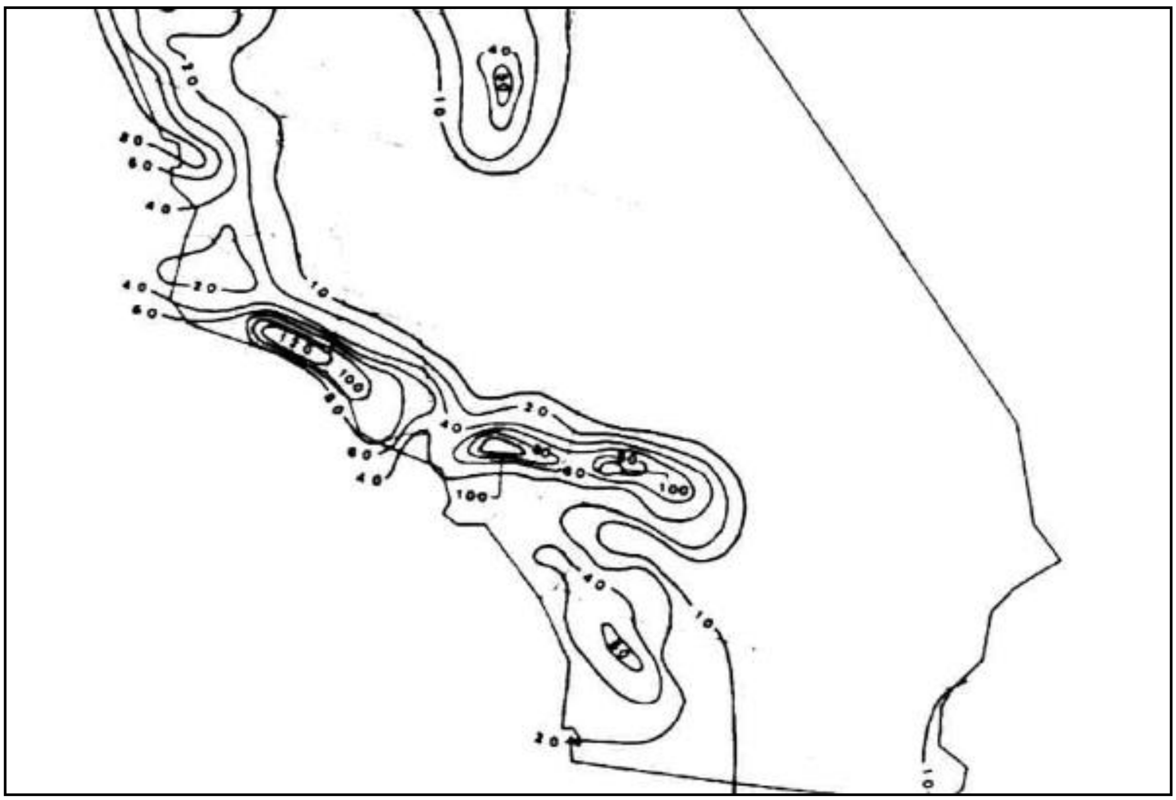


Figure 5-2. Isoerodent Map of Southern California (ft-tonf/(ac-hr-yr); Renard et al., 1996)

The approximate expected magnitude of *KRER* can be obtained with an assumption of the value of α_t. *RE* is converted from the SI units of MJ-mm/ha-h-yr to English units of 100s of ft-ton-in/ac-hr-yr (used in the development of USLE *K* factors and consistent with the English units in HSPF) by a factor of 0.05875. In addition, the ratio of precipitation factors (in cm and in) must be converted to a common basis by multiplying by $2.54^{1.81}$. This suggests that the value of *G* should be about 20.51 a_t. Values of a_t are typically on the order of 0.15 – 0.20. A value of α_t of 0.15 would suggest that *KRER* should be about

3.07 *K LS*, while α_t of 0.2 yields 4.1 *K LS*. For lower slope (1-5 percent) sites with slope lengths around 15 to 30 m, *LS* often evaluates to around 0.3, in which case *KRER* ≈ *K*. This is consistent with the recommendations on sediment parameter setup for HSPF (USEPA, 2006) that a starting point for calibration is to set *KRER* equal to the USLE *K* value. However, it is obvious from the discussions above that higher values will be needed on higher slopes.

Tetra Tech extracted soil and slope parameters from both the STATSGO and SSURGO soils coverage. The USLE *K* factor is available directly from soil surveys, while the *LS* factor can be estimated from slope, using the expression of Wischmeier and Smith (1978):

$$LS = (0.045\,L)^{b} \cdot \left(65.41 \sin^{2}\theta_{k} + 4.56 \sin\theta_{k} + 0.065\right), \text{ where}$$

$\theta_k = \tan^{-1}(S/100)$, *S* is the slope in percent, *L* is the slope length (m), and *b* takes the following values: 0.5 for $S \geq 5$, 0.4 for $3.5 \leq S < 5$, 0.3 for $1 \leq S < 3$, and 0.2 for $S < 1$. Slopes were taken as the representative value from the soil unit. Finally, interpolated values of *RE* (in hundreds of ft-ton-in $(\text{ac-h-yr})^{-1}$ were obtained by superimposing the California isoerodent map figure on the site location map.

SSURGO soil data for San Diego and Riverside counties were used to calculate weighted KRER values for each land use and soil hydrologic group (HSG) within the watershed. A weighted average of soil slope (*S*) and soil erodibility factors (*K*, Figure 5-3) was calculated for each soil map unit in ArcGIS using the NRCS Soil Data Viewer. Areas where SSURGO K factors are not available were filled from STATSGO data, as described in Tetra Tech (2014). The land use classification layer (which contained HSG values for each parcel) was subsequently intersected with both slope and K factor layers. Slope and K factor values were subtotaled and area weighted for each HRU. Length-slope (*LS*) factors were calculated according to the Wischmeier and Smith (1978) equation. A slope length (L) value of 15 meters was used for all *LS* calculations, but *LS* values were not allowed to exceed 5. This correction adjusts for the resolution of the DEM, as soils in very steep areas are primarily on small segments of lesser slope.

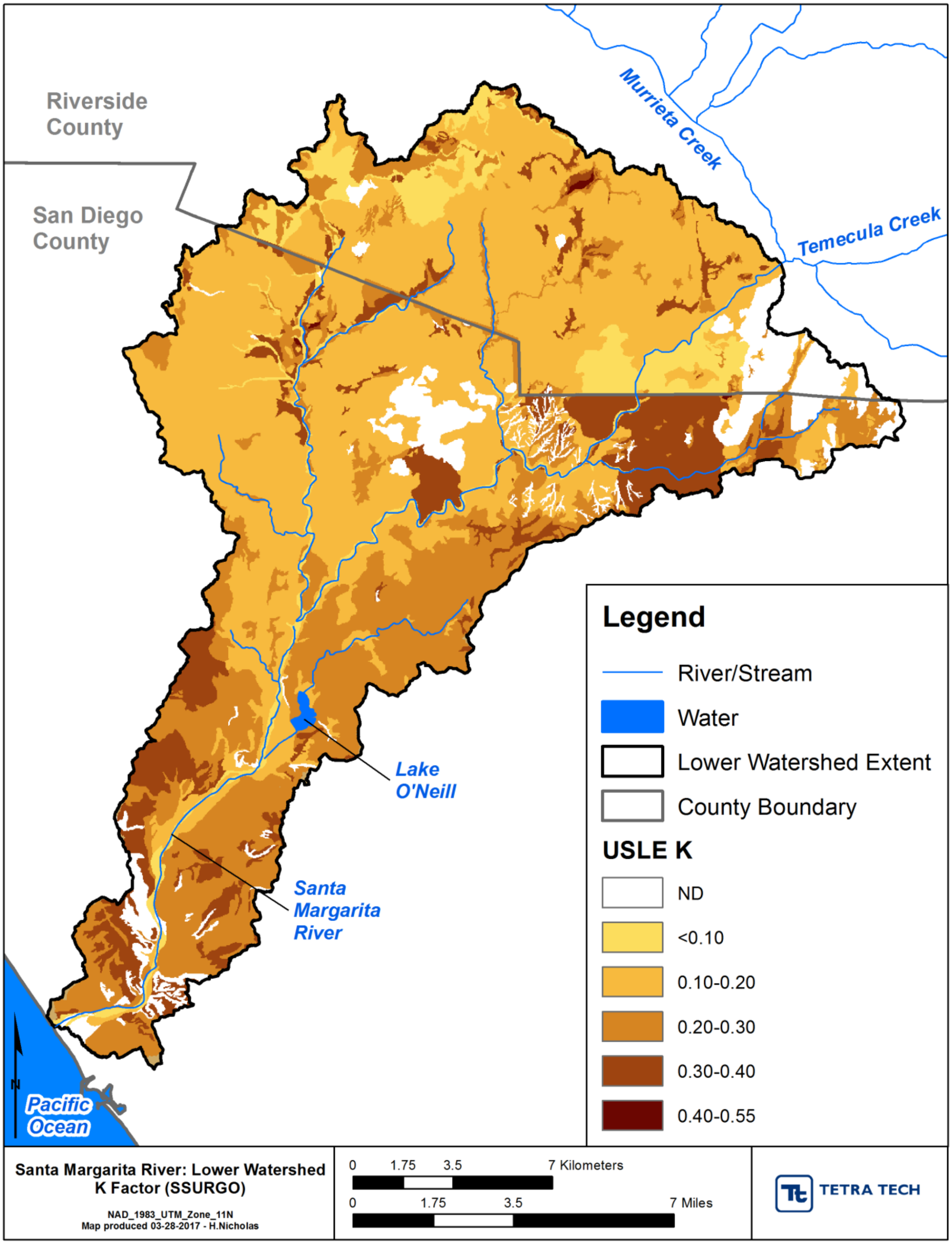


Figure 5-3. SSURGO Erosion Factor (K factor)

5.4 SEDIMENT RECALIBRATION

In contrast to nutrients, instream monitoring for suspended sediment is extremely limited for the Santa Margarita watershed and is primarily available for Murrieta and Temecula Creeks in Riverside County (outside the domain for this recalibration effort). There are some detailed sedimentation studies for the mainstem Santa Margarita have been conducted for Camp Pendleton (e.g., WEST, 2000), including HEC-6T scour and deposition modeling and estimates of total sediment yield by a variety of methods. Those studies and the available suspended sediment monitoring data were used to establish the baseline sediment calibration described in Tetra Tech (2014).

For this recalibration update, the only monitoring station with a data set useful for sediment recalibration is the MLS-1 station on Camp Pendleton (19 observations from 2009 – 2016, primarily for winter conditions when flow is present). Model predictions appear reasonable for this station; although a majority of the model results are higher than concurrent observations. Investigation of the behavior of the model show that sediment concentrations in the mainstem during winter are strongly controlled by the concentrations present at the head of the Santa Margarita Gorge. As described in Section 3.3.2, the boundary concentrations at this location after September 2010 are specified based on typical values for the month and flow conditions (as the upstream model has not been developed past the end of WY 2010). As sediment concentrations vary rapidly in time during winter wet weather, it is not surprising that model predictions at MLS-1 are highly uncertain.

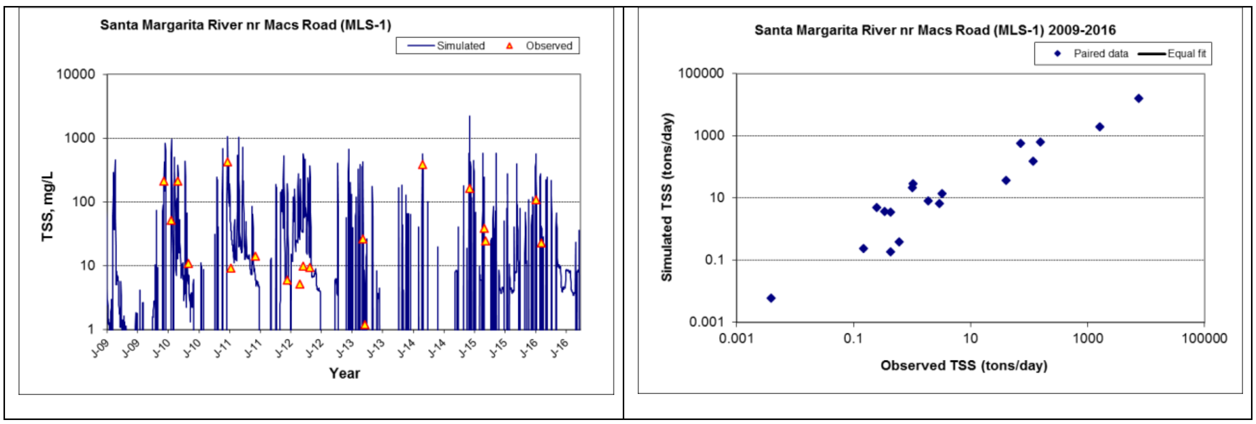


Figure 5-4. Sediment Model Performance at MLS-1

5.5 NUTRIENT MODEL PARAMETERIZATION

The initial nutrient parameterization for the lower watershed model was derived from the previously calibrated Santa Margarita River watershed HSPF Model (Tetra Tech, 2014). The 2014 model was calibrated to available instream data through 2010 and that model provided an appropriate initial parameter set for the recalibration effort – especially as only limited wet weather sampling is available after 2010.

In the 2014 model, orchards, vineyards, and nurseries were grouped into a single land use class. Nurseries are separated from orchards and vineyards in the revised San Diego model due to differences in fertilizer application and irrigation practices. Nurseries in the watershed are concentrated in the Rainbow Creek drainage, especially reaches 207 and 208 (see Figure 2-1 and Figure 2-3 above).

Intensive inspections of nurseries and monitoring of nursery outfalls establishes that they are a major source of nitrogen load to Rainbow Creek (Weston, 2010; 2016; 2017).

Nutrient parameters were reassessed during the recalibration effort, but few changes in the upland loading characteristics were required. In addition to adjusting parameters to match instream nutrient concentrations and associated estimates of loads, the recalibration effort considered land use specific event mean concentrations and annual nutrient yield studies.

Land use-based nutrient yields are estimated in the Rainbow Creek TMDL (CRWQCB-SDR, 2006), based primarily on literature values deemed appropriate to Southern California. As shown in Table 5-6, annual TN export is cited as highest for urban, nurseries, and row crops. The highest TP yields are attributed to urban land and residential land. Weston (2010) re-evaluated these loading estimates and found that they significantly under-estimated apparent actual loading rates in Rainbow Creek.

Table 5-6. TN and TP Export Rates used in the Rainbow Creek TMDL (CRWQCB-SDR, 2006)

Land Use/Cover	Total Nitrogen (kg/ha/yr)	Total Phosphorus (kg/ha/yr)
Nurseries	3.7	0.2
Row crops	3.7	0.2
Orchards	2.5	0.2
Park land	3.4	0.1
Residential	2.6	0.5
Urban	3.8	0.8

San Diego County, in accordance with the transitional MS4 permit, summarized wet weather Event Mean Concentrations (EMCs) for the dominant land uses in the San Diego County portion of the Santa Margarita River watershed (Weston, 2017, Appendix H). EMCs in Weston (2017) were primarily estimated from samples collected at MS4 monitored sites within the watershed management area during 2013-2016 and representative wet weather EMCs reported for rural and urban land uses are summarized in Table 5-7**.** For comparison, the table also shows EMCs estimated for the neighboring San Luis Rey River Watershed Management Area (LWA, 2016), which are about one-half of those estimated by Weston (2017) but maintain a similar relative rank order. These EMC estimates are presented only as a general indication of the magnitude of wet weather concentrations expected for different land uses. They are not used as model inputs for the HSPF simulation.

Table 5-7. Representative Event Mean Concentrations (mg/L) for Land Uses in the Santa Margarita River Watershed (Weston, 2017, Appendix H)

Land Use/Cover	Nitrite-N + Nitrate-N	Total Kjeldahl Nitrogen	Total Phosphorus
Agriculture	55.5/34.4	15.6/7.3	7.52/3.34
Commercial	0.88/0.55	7.28/3.44	0.74/0.32
Educational	0.950.61	3.48/1.71	0.93/0.46
Industrial	1.40/0.87	6.11/2.87	0.99/0.45
Mixed Use	1.66/ND	5.56/ND	0.63/ND
Multi-Family Residential	2.44/1.51	3.84/1.80	0.52/0.21
Open Space	1.88/1.17	2.04/0.96	0.27/0.12
Orchard	ND/26.11	ND/2.31	ND/0.36
Rural-Residential	2.16/1.50	5.34/2.68	3.07/1.59
Single-Family Residential	2.14/1.58	5.51/2.51	1.06/0.49
Transportation	1.19/0.74	3.87/1.84	1.51/0.68

Note: First value is from Weston (2017, Appendix H) as estimated for the Santa Margarita watershed; second value is from LWA (2016, Appendix C3) as estimated for the San Luis Rey watershed. ND = No Data.

EMCs and export coefficients characterize different aspects of nutrient contributions in the watershed; the former provides information on wet weather flow-weighted concentrations and the latter identifies long-term dry and wet weather nutrient loads. There are clear discrepancies between the information provided in Table 5-6 and Table 5-7, likely because the former relied on literature values while the latter is based on local monitoring, albeit of limited extent. The agricultural EMCs are significantly higher than other land uses, but this is not the case for the estimated nutrient export rates used in the TMDL. Furthermore, estimated agricultural TP loads (nurseries, row crops, and orchards) are low compared to urban and residential TP loads, but agricultural TP EMCs are much higher than all other reported land uses. Nonetheless, these studies provide approximate range-finding values that can be used in conjunction with instream water quality samples to support model calibration.

Recent water quality sampling efforts have primarily been conducted during dry weather, especially on Rainbow Creek. During low flow dry weather periods, nutrient loads are dominated by baseflow, irrigation runoff, dry atmospheric deposition, and instream biological processes. Earlier data provide more wet weather samples and were used to develop the calibrated surface loading parameters reported in Tetra Tech (2014). More recent data appear consistent with those estimates of wet weather loading by surface runoff pathways, so upland parameter modifications were minor.

In contrast, there is extensive new information on dry weather nutrient concentrations. The model was therefore adjusted to better match the additional baseflow information by adjusting the concentrations in interflow and groundwater discharge (which were considered to have the same concentrations). The calibrated concentrations are summarized in Table 5-8.

Table 5-8. Interflow and Groundwater Concentrations for Land Uses in the Revised Santa Margarita River Watershed HSPF Model

Land Use/Cover	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)
Low and high density residential	4.0	0.25
Commercial, institutional, and industrial	4.0	0.20
Road and freeway	4.0	0.40
Parks and recreation, open and recreation	4.0	0.03
Irrigated agriculture	10.0	0.26
Non-irrigated agriculture	0.33	0.16
Orchards and vineyards	5.0	0.12
Dairy and livestock, horse ranches	5.0	0.07
Forest	0.33	0.04
Chaparral and scrub	2.0	0.12
Grassland and herbaceous	0.33	0.001
Transitional	4.0	0.20
Nurseries	10.0	0.66

Operations of individual nurseries is highly diverse and includes a mix of container, greenhouse, and field practices. Most nurseries add nitrate to their irrigation water, which is often applied by overhead spray systems. Typically, there are collection systems for excess irrigation runoff (such as spray that lands on hard surfaces between containers), but these often are not fully functional and can result in direct discharges (Mellano, 2009). In examining water quality at the many closely spaced monitoring sites in the Rainbow Creek watershed it appeared evident that nurseries were contributing direct loads of nitrate independent of the subsurface water balance, presumably via irrigation water. This is represented in the model by assigning an NO_3-N load to nurseries in Rainbow Creek reaches 207 and 208 that is equivalent to 10 mg/L in 20 percent of the applied irrigation water (implemented through a link in the EXTERNAL SOURCES block).

Instream biogeochemical processes simulated by the HSPF model include nutrient uptake and release by dynamic plankton and benthic algae populations, decay of organic matter, biochemical oxygen demand and dissolved oxygen fluxes, nitrification/denitrification, absorption/desorption of nutrients on suspended sediment, and deposition and scour of sediment-stored nutrients. Instream parameters from the 2014 HSPF model appeared appropriate and modifications for the lower watershed model were minor.

5.6 NUTRIENT RECALIBRATION RESULTS

Water samples collected between WY 1996 – WY 2016 were used to parameterize the model and to evaluate model performance. The model calibration was adjusted using samples collected after the beginning of WY 2008. Earlier samples from WY 1996 – WY 2007 were used for validation checks, although they are less likely to be accurately matched to 2015 land use.

Results from the nutrient calibration of the revised HSPF model are presented and discussed in the following sections. In Section 5.6.1 simulated TN and TP loading rates are provided for land uses in the watershed. In Section 5.6.2 instream nutrient calibration results are summarized. Graphical representations and tabular statistics are presented for stream calibration locations. In general, quantitative statistics are only presented when the sample count equals or exceeds 30, as discussed in Section 5.2. Exceptions were made for sites on the lower Santa Margarita River and for Sandia Creek where monitoring data is sparse but important to review.

5.6.1 Upland Nutrient Loads

Upland nutrient loading rates for land uses in the study area are presented in Table 5-9. These represent nutrient loads combined from surface and subsurface flow pathways. For most land uses, simulated yields are of similar magnitude to rates specified in the Rainbow Creek TMDL, which range from 0.2 - 0.8 kg/ha/yr for TP and 2.5 – 3.8 kg/ha/yr for TN (Table 5-6). This is not the case for nurseries, for which simulated loads are much higher. Review of observations collected in the vicinity of nurseries warranted these higher rates.

Table 5-9. Simulated TN and TP Loading Rates for Revised HSPF Model

Land Use/Cover	Total Nitrogen Yield (kg/ha/yr)	Total Phosphorus Yield (kg/ha/yr)
Low and high density residential	2.23	0.32
Commercial and institutional	1.54	0.12
Industrial	2.34	0.18
Road and freeway	2.25	0.40
Parks and recreation	2.34	0.28
Open and recreation	2.05	0.23
Irrigated agriculture	6.38	0.83
Non-irrigated agriculture	0.78	0.39
Orchards and vineyards	5.30	0.51
Dairy and livestock	0.00	0.00
Horse ranches	3.10	0.52
Forest	0.51	0.15
Chaparral and scrub	1.11	0.22
Grassland and herbaceous	0.46	0.18
Transitional	2.31	0.90
Nurseries	18.9	1.83
Impervious	1.65	0.44

Note: Nutrient yields for daily and livestock are zero because there are no daily and livestock operations in the lower watershed.

5.6.2 Stream Nutrient Recalibration Results

Nutrient parameters are varied by land use, but are held constant across all weather zones due to the relative shortage of monitoring data in locations other than the Rainbow Creek drainage. Results are variable, but generally reasonable for TN and TP given the relative lack of storm event sampling in recent years. Strong spatial and temporal shifts are evident at many of the Rainbow Creek stations, likely representing differences in operation of individual nurseries and orchards combined with changes in management practices over time. Many samples are from extreme low flow conditions, where highly variable results can be expected from water that is near stagnant conditions and likely experiencing transient algal blooms. In most cases, ammonia N concentrations were over-estimated and total Kjeldahl nitrogen (TKN) concentrations under-estimated, likely reflecting the impact of attached algae and macrophytes.

It should be noted that some of the concentration data are of suspect quality. Rainbow Creek monitoring during 2005-2007 was obtained using field colorometric strips rather than via laboratory analyses, likely resulting in poor precision (Weston, 2017). Some of the concentration data obtained during the 1990s is also either suspect or influenced by unknown external factors, as noted in Tetra Tech (2014). For example the station on the Santa Margarita River at Fallbrook PUD shows nitrate N concentrations consistently in the range of 10 mg/L in 1995-1996, followed by an abrupt downward shift to the 2 mg/L range in 1997 and thereafter. Results at the downstream stations on the mainstem (Ysidora and MLS-1) appear credible, suggesting the model is appropriate for use in evaluating loads to the estuary.

Because of the nature of most recent water quality monitoring, the revisions to the nutrient calibration primarily apply to low flow, dry weather conditions. Under these conditions, observed water quality primarily reflects groundwater discharge and irrigation return flows. Nutrient loads associated with wet weather events must primarily be inferred from monitoring prior to 2000, so there was not a firm basis to alter those aspects of the calibration from the prior effort. Overall statistics comparing observed and simulated concentrations and loads for nutrients are thus generally of similar quality to those presented previously in Tetra Tech (2014), although using a somewhat different selection of monitoring sites.

The majority of the newer data are for Rainbow Creek, and the revised model provides considerably more detail in that subwatershed. The a high degree of variability in observed concentrations is a consequence of the focus of monitoring on low flow conditions under which variations in nursery operations likely play a key role in observed concentrations. Variability in the model fit during dry weather conditions provides an indication of the extent of influence of operations at these sites and other dry weather sources, including irrigated orchards and residential parcels.

Little recent monitoring has occurred on De Luz and Sandia Creeks. For the Santa Margarita mainstem, concentrations simulated by the model are strongly influenced by the upstream boundary condition below the confluence of Murrieta and Temecula Creeks, which is subject to a high degree of uncertainty as described in Section 3.3.2.

Further refinements and improvements to the water quality model would require collection of more data at multiple sites and other both wet and dry weather conditions. For modeling support purposes, it is particularly important to collect large sets of data over time at consistent monitoring locations. Finally, simulations of nutrients in the mainstem and their delivery to the estuary could likely be improved by the creation of an updated unified model that simulates the loads delivered from Murrieta and Temecula Creeks in Riverside County, rather than relying on older model results (through 2010) and estimated approximate boundary conditions for more recent years.

The following sections present detailed results by station, arranged in approximate upstream to downstream order.

5.6.2.1 Chica Tributary of Rainbow Creek at 1st Street (RVT02)

Chica Creek is a small tributary stream to upper Rainbow Creek. During periods of extended dry weather Chica Creek ponds, retaining flow and nutrients that would otherwise be discharged to Rainbow Creek. Water quality sampling near the mouth of Chica Creek began in the mid-2000s and samples were collected a few times each year through 2016. Accompanying flow records confirm that sampling was primarily conducted during dry weather and, at times, the creek was at a standstill. Observed TN and TP concentrations were steadily high, averaging 24.7 mg/L and 0.60 mg/L, respectively, despite the largely rural characteristics of the drainage area.

Table 5-10. Water Quality Calibration Statistics for Chica Tributary at 1st Street (RVT02)

Metric	Validation (WY 1996 – WY 2007)							Calibration (WY 2008 – WY 2016)						
	NH_3+ NH_4-N	OrgN	TKN	NO_2+ NO_3-N	TN	SRP	TP	NH_3+ NH_4-N	OrgN	TKN	NO_2+ NO_3-N	TN	SRP	TP
Count	36	24	30	39	31	38	30	61	46	61	63	63	63	63
Concentration Average Error	113.86%		-10.04%	-42.42%	-43.09%	-29.02%	-13.63%	171.29%	-95.99%	-30.35%	-66.68%	-65.06%	-38.30%	-20.95%
Concentration Median Error	213.30%		13.88%	-29.90%	-26.76%	-14.95%	-8.02%	206.97%	-54.97%	6.74%	-57.51%	-53.44%	-31.62%	-11.03%
Load Average Error	2.16%		-79.06%	-81.06%	-73.82%	-71.39%	-50.52%	20.26%	-96.65%	-86.75%	-79.69%	-80.71%	-70.03%	-62.62%
Load Median Error	41.48%		6.41%	-36.47%	4.63%	-18.31%	12.62%	33.94%	-7.46%	-3.35%	-43.01%	-35.99%	-19.22%	-19.74%

Note: NH_3+ NH_4-N = ammonium plus ammonia as nitrogen. OrgN = organic nitrogen, TKN = total Kjeldahl nitrogen (organic N plus NH_3+ NH_4-N), NO_2+NO_3-N = nitrite plus nitrate as nitrogen, TN = total nitrogen, SRP = soluble reactive phosphorus, TP = total phosphorus.

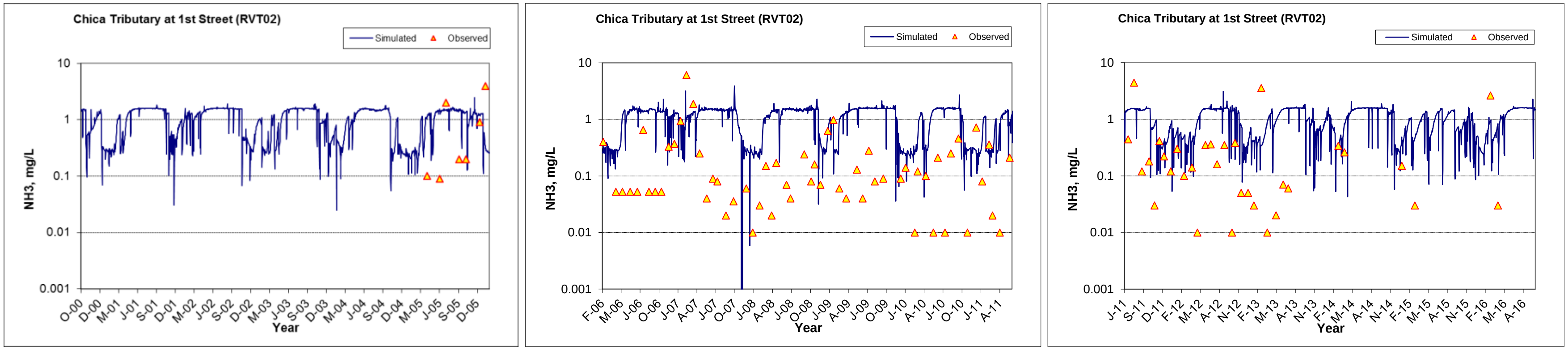


Figure 5-5. Time Series of Observed and Simulated Ammonia Nitrogen (NH_3+ NH_4-N) Concentration at Chica Tributary at 1st Street (RVT02)

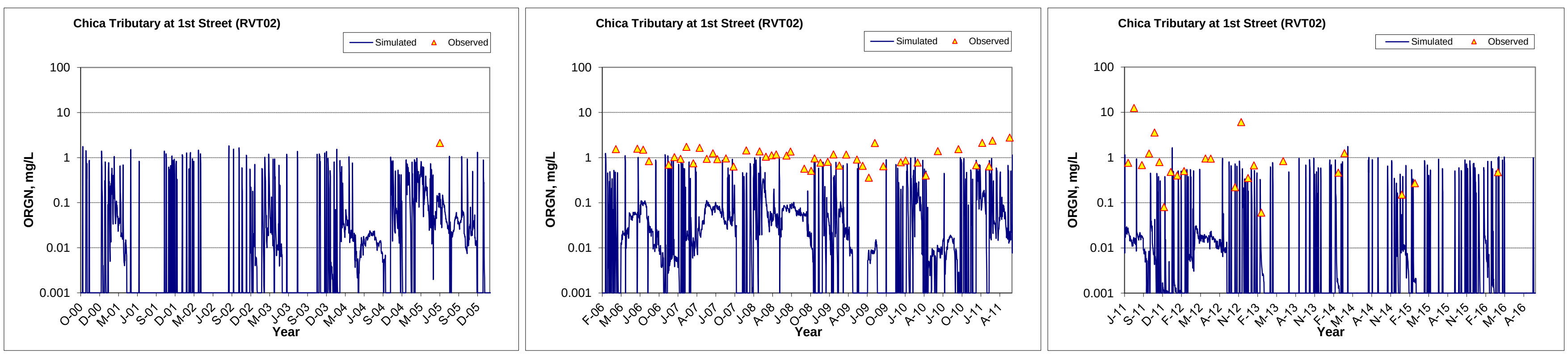


Figure 5-6. Time Series of Observed and Simulated Organic Nitrogen (OrgN) Concentration at Chica Tributary at 1st Street (RVT02)

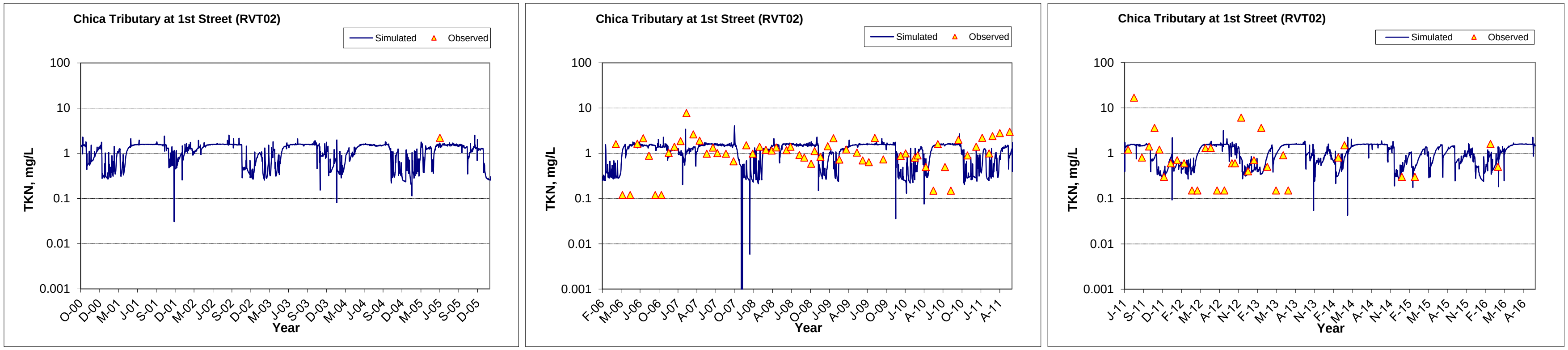


Figure 5-7. Time Series of Observed and Simulated Total Kjeldahl Nitrogen (TKN) Concentration at Chica Tributary at 1st Street (RVT02)

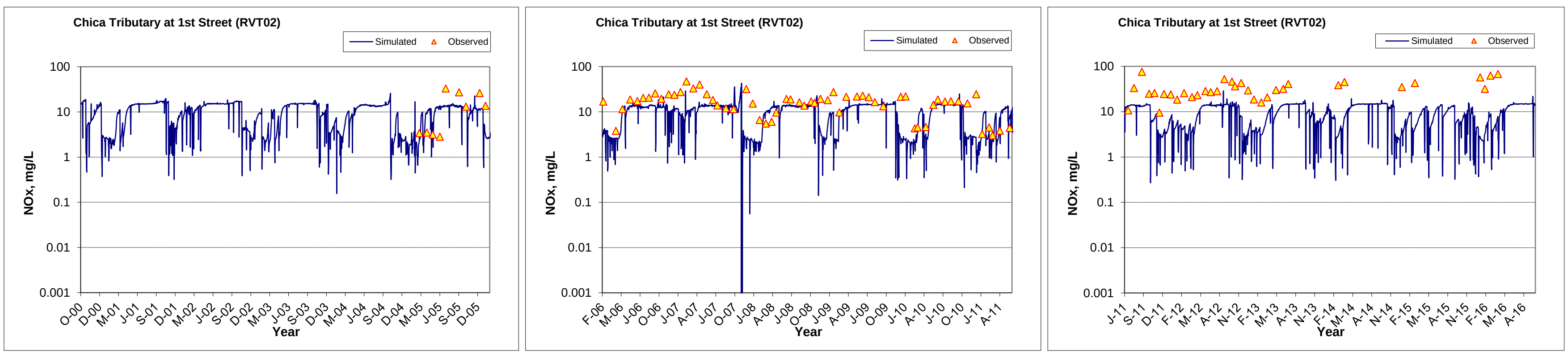


Figure 5-8. Time Series of Observed and Simulated Nitrite+ Nitrate Nitrogen (NOx) Concentration at Chica Tributary at 1st Street (RVT02)

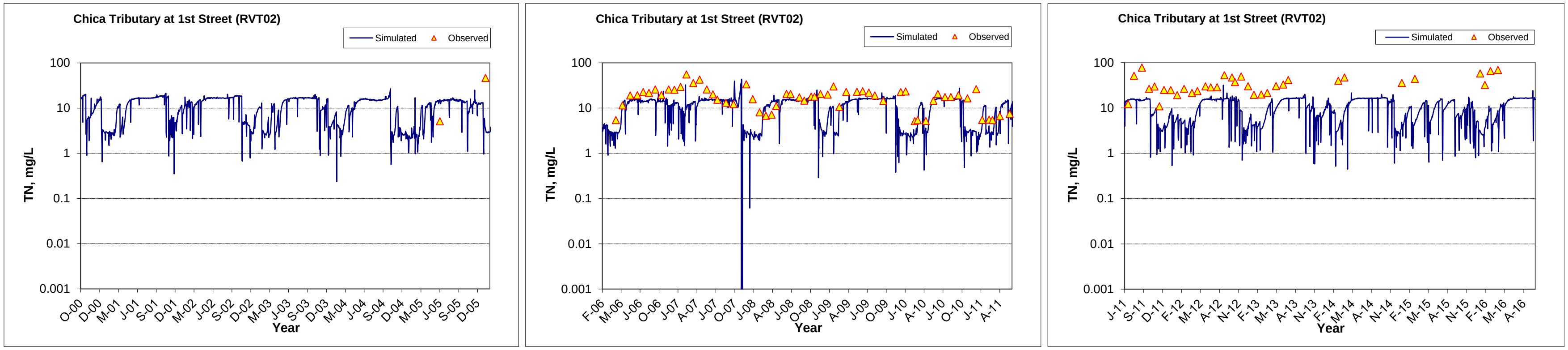


Figure 5-9. Time Series of Observed and Simulated Total Nitrogen (TN) Concentration at Chica Tributary at 1st Street (RVT02)

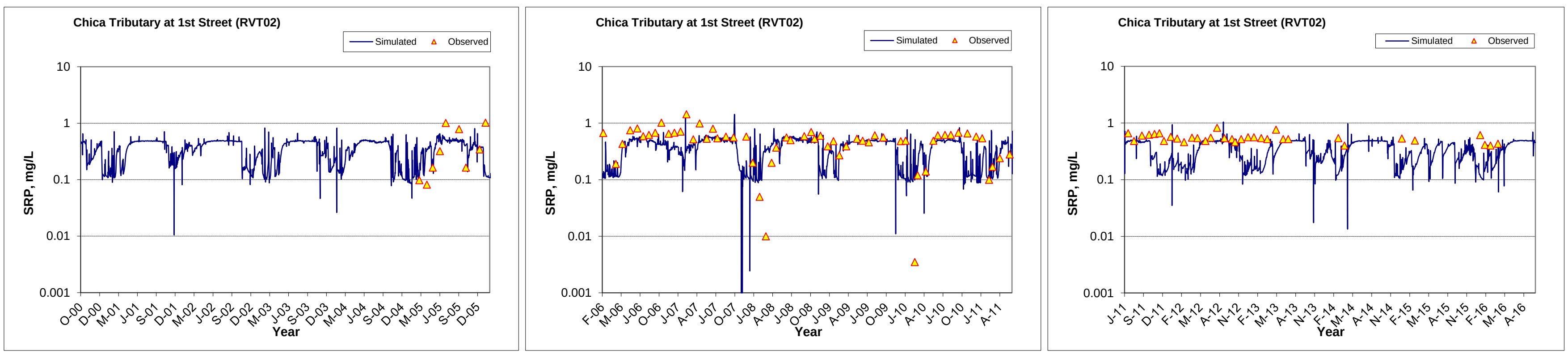


Figure 5-10. Time Series of Observed and Simulated Soluble Reactive Phosphorus (SRP) Concentration at Chica Tributary at 1st Street (RVT02)

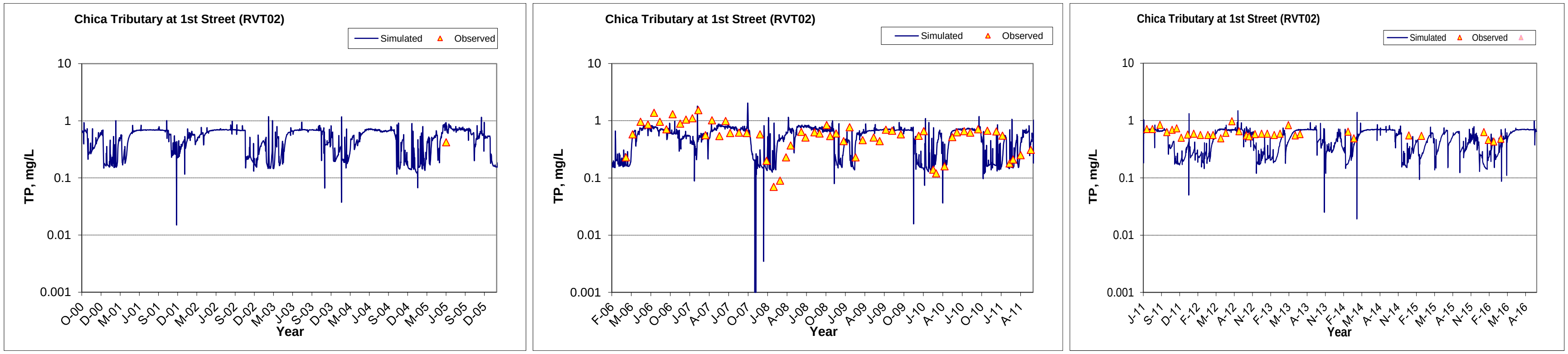


Figure 5-11. Time Series of Observed and Simulated Total Phosphorus (TP) Concentration at Chica Tributary at 1st Street (RVT02)

5.6.2.2 Rainbow Creek at Jubilee Way (RBC01)

Jubilee Way is the most upstream sampling site on Rainbow Creek. Nutrient data was collected at this location from the mid-2000s to 2011. Nitrogen and phosphorus concentrations vary widely in the headwaters of Rainbow Creek. Recorded soluble reactive P concentrations, for example, range from as low as 0.002 mg/L to as high as 0.32 mg-P/L. Sample counts for all nutrient species are less than 30, so formal statistics are not presented. Nonetheless, this sampling site was useful for characterizing water quality conditions in the headwaters of Rainbow Creek.

Table 5-11. Water Quality Calibration Statistics at Rainbow Creek at Jubilee Way (RBC01)

Metric	Validation (WY 1996 – WY 2007)							Calibration (WY 2008 – WY 2016)						
	NH_3+ NH_4-N	OrgN	TKN	NO_2+ NO_3-N	TN	SRP	TP	NH_3+ NH_4-N	OrgN	TKN	NO_2+ NO_3-N	TN	SRP	TP
Count	21	8	14	23	14	23	17	14	10	14	14	14	14	14

Note: NH_3+ NH_4-N = ammonium plus ammonia as nitrogen. OrgN = organic nitrogen, TKN = total Kjeldahl nitrogen (organic N plus NH_3+ NH_4-N), NO_2+NO_3-N = nitrite plus nitrate as nitrogen, TN = total nitrogen, SRP = soluble reactive phosphorus, TP = total phosphorus.

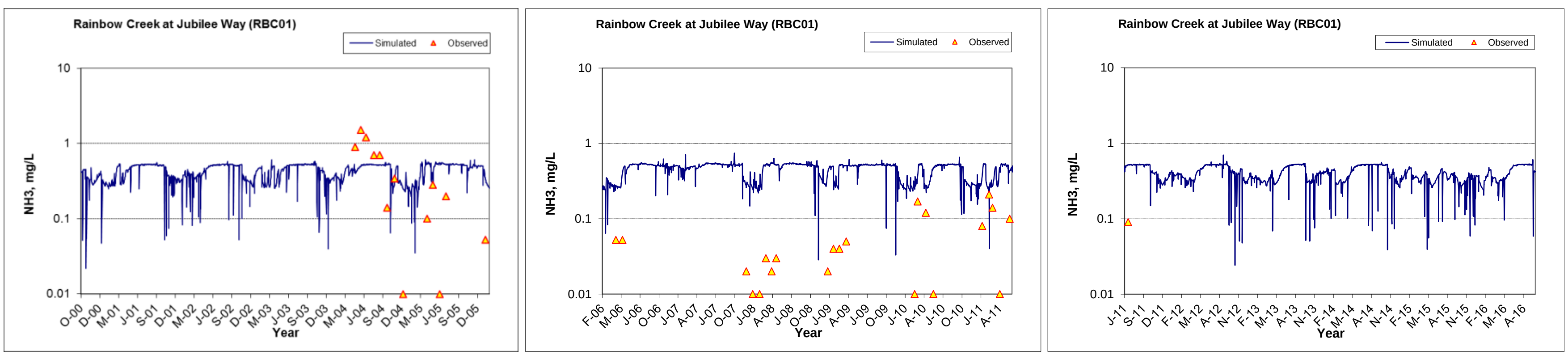


Figure 5-12. Time Series of Observed and Simulated Ammonia Nitrogen (NH_3+ NH_4-N) Concentration at Rainbow Creek at Jubilee Way (RBC01)

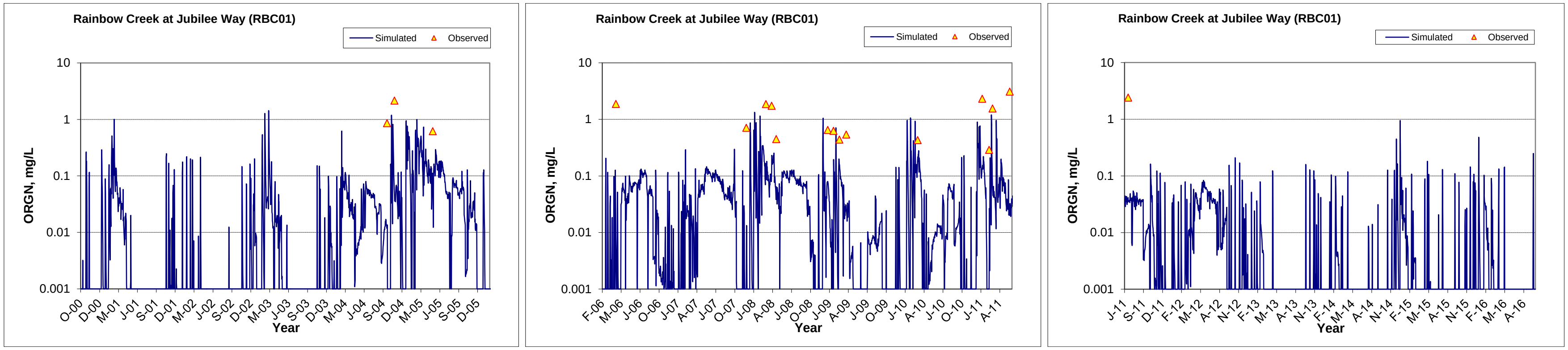


Figure 5-13. Time Series of Observed and Simulated Organic Nitrogen (OrgN) Concentration at Rainbow Creek at Jubilee Way (RBC01)

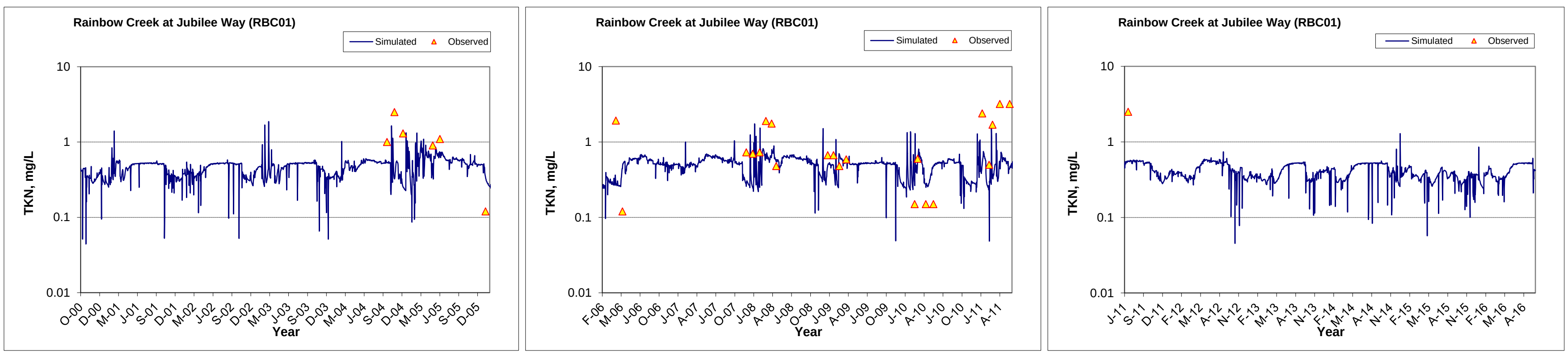


Figure 5-14. Time Series of Observed and Simulated Total Kjeldahl Nitrogen (TKN) Concentration at Rainbow Creek at Jubilee Way (RBC01)

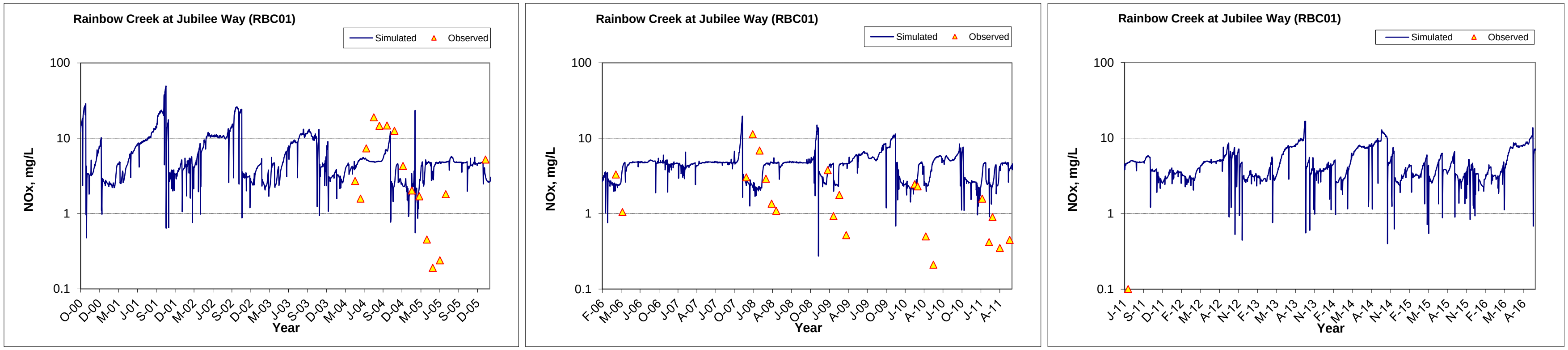


Figure 5-15. Time Series of Observed and Simulated Nitrite+ Nitrate Nitrogen (NOx) Concentration at Rainbow Creek at Jubilee Way (RBC01)

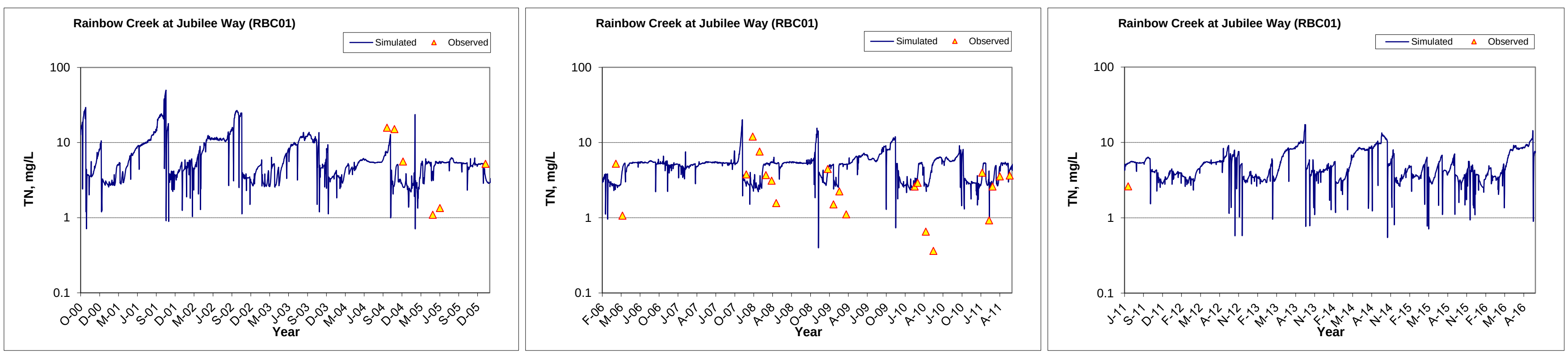


Figure 5-16. Time Series of Observed and Simulated Total Nitrogen (TN) Concentration at Rainbow Creek at Jubilee Way (RBC01)

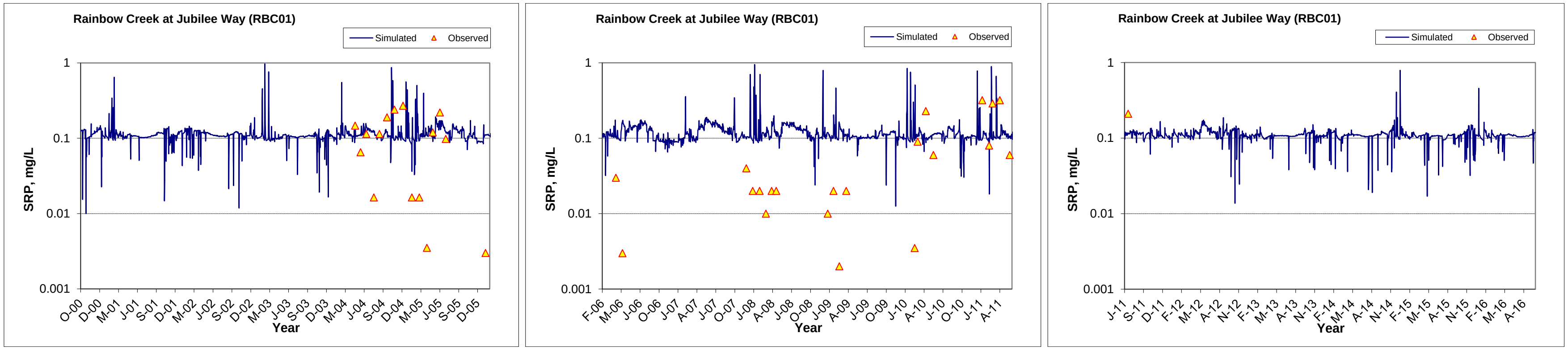


Figure 5-17. Time Series of Observed and Simulated Soluble Reactive Phosphorus (SRP) Concentration at Rainbow Creek at Jubilee Way (RBC01)

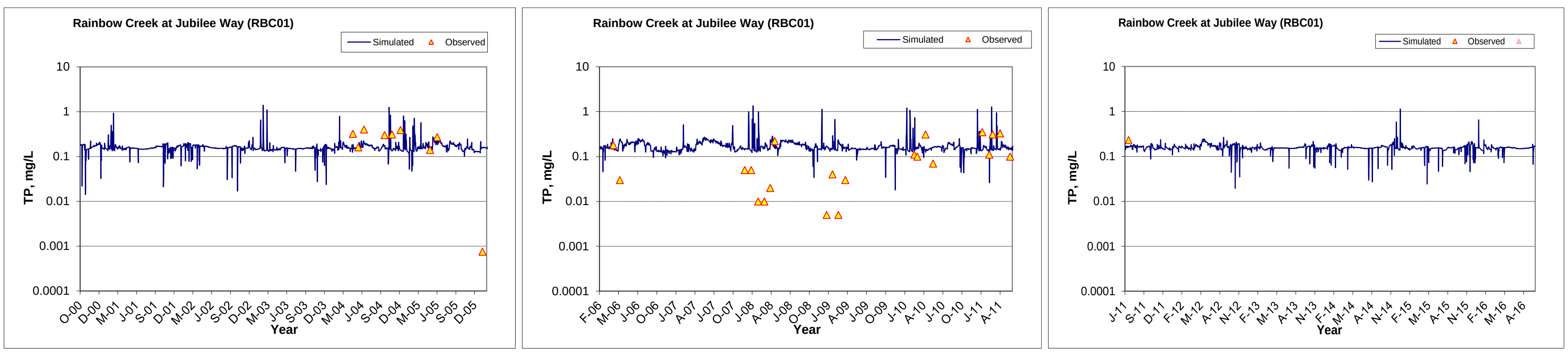


Figure 5-18. Time Series of Observed and Simulated Total Phosphorus (TP) Concentration at Rainbow Creek at Jubilee Way (RBC01)

5.6.2.3 Rainbow Creek at Huffstatler Street (RBC02)

The Huffstatler Street location is the second most upstream water quality sampling site for Rainbow Creek, but is located in an area of intensive nursery development. Samples were retrieved more frequently during recent years. Time series plots of observed concentrations show temporal dynamics in nutrient concentrations at this location. Soluble reactive P concentrations were consistently marked as high during 2005-2007; low precision field test strips were used to measure concentrations during this time so samples collected during the validation period are subject to inaccuracies. Nitrite-N + nitrate-N concentrations spike in 2011 and remain elevated through 2016. This trend is possibly due to changes in fertilizer application, malfunctioning irrigation water recovery systems, or other practice changes by nurseries in the area.

Table 5-12. Water Quality Calibration Statistics at Rainbow Creek at Huffstatler Street (RBC02)

Metric	Validation (WY 1996 – WY 2007)							Calibration (WY 2008 – WY 2016)						
	NH_3+ NH_4-N	OrgN	TKN	NO_2+ NO_3-N	TN	SRP	TP	NH_3+ NH_4-N	OrgN	TKN	NO_2+ NO_3-N	TN	SRP	TP
Count	44	32	39	48	39	46	39	88	66	88	92	91	91	91
Concentration Average Error	9.27%	-95.56%	-42.26%	-40.03%	-50.44%	-47.89%	-41.13%	185.33%	-97.03%	-9.71%	-68.47%	-67.07%	8.84%	32.30%
Concentration Median Error	79.17%	-89.68%	-17.24%	-36.68%	-50.36%	-45.53%	-39.27%	256.98%	-65.19%	16.12%	-65.52%	-62.81%	12.23%	38.21%
Load Average Error	-84.64%	-96.58%	-84.46%	-85.19%	-80.93%	-78.72%	-65.85%	-27.72%	-98.19%	-83.44%	-84.30%	-84.36%	-64.82%	-57.92%
Load Median Error	7.23%	-13.75%	-0.32%	-6.97%	-8.60%	-1.23%	2.43%	21.53%	-5.49%	-0.97%	-53.91%	-50.77%	-7.22%	-4.31%

Note: NH_3+ NH_4-N = ammonium plus ammonia as nitrogen. OrgN = organic nitrogen, TKN = total Kjeldahl nitrogen (organic N plus NH_3+ NH_4-N), NO_2+NO_3-N = nitrite plus nitrate as nitrogen, TN = total nitrogen, SRP = soluble reactive phosphorus, TP = total phosphorus.

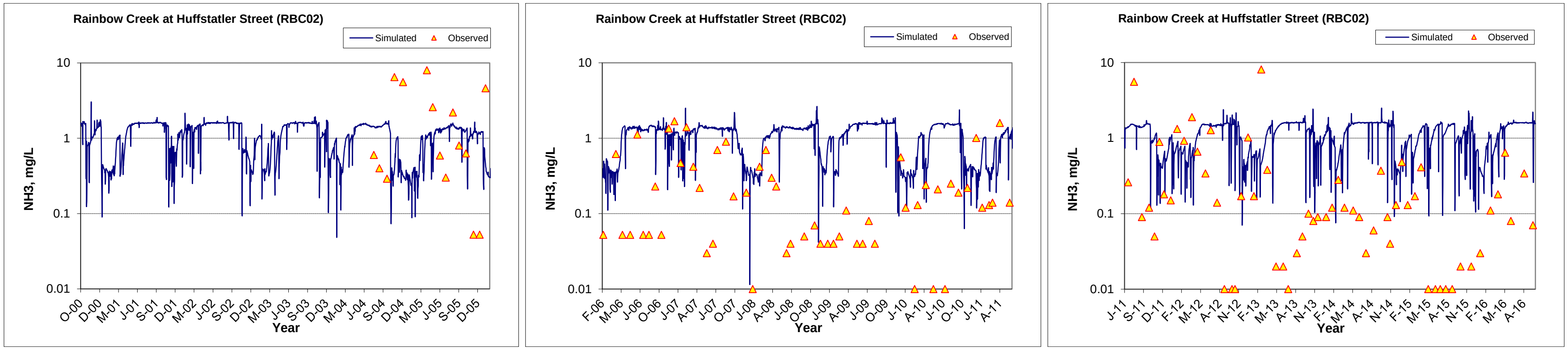


Figure 5-19. Time Series of Observed and Simulated Ammonia Nitrogen (NH_3+ NH_4-N) Concentration at Rainbow Creek at Huffstatler Street (RBC02)

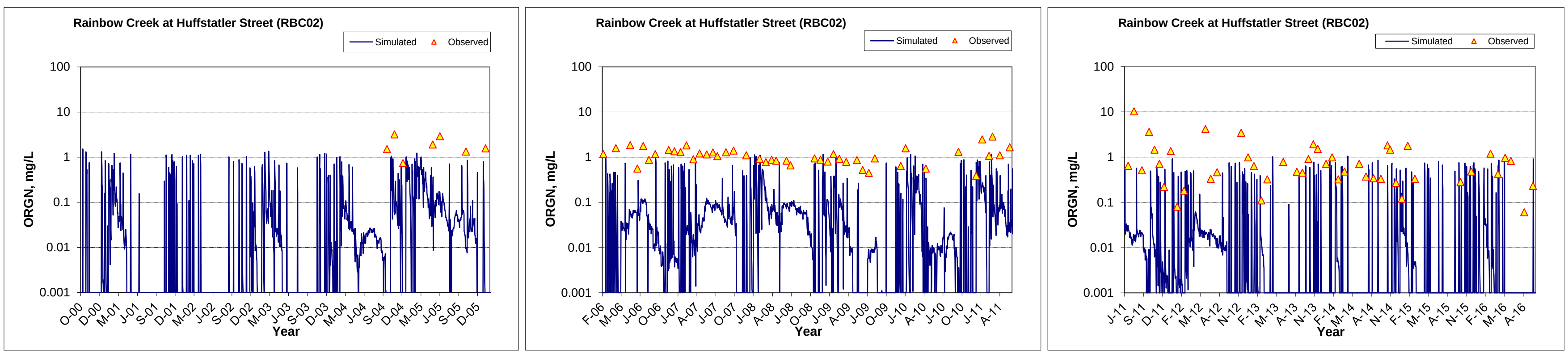


Figure 5-20. Time Series of Observed and Simulated Organic Nitrogen (OrgN) Concentration at Rainbow Creek at Huffstatler Street (RBC02)

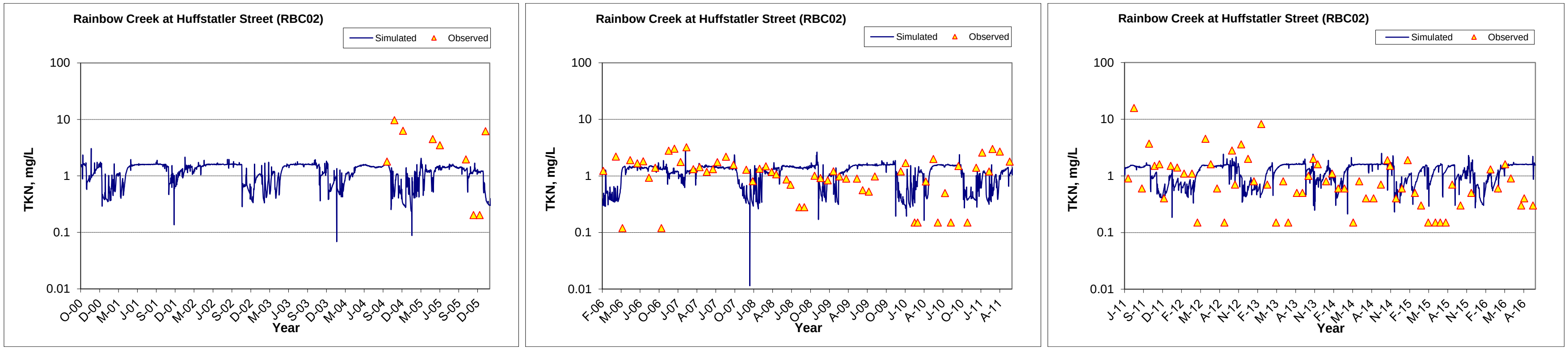


Figure 5-21. Time Series of Observed and Simulated Total Kjeldahl Nitrogen (TKN) Concentration at Rainbow Creek at Huffstatler Street (RBC02)

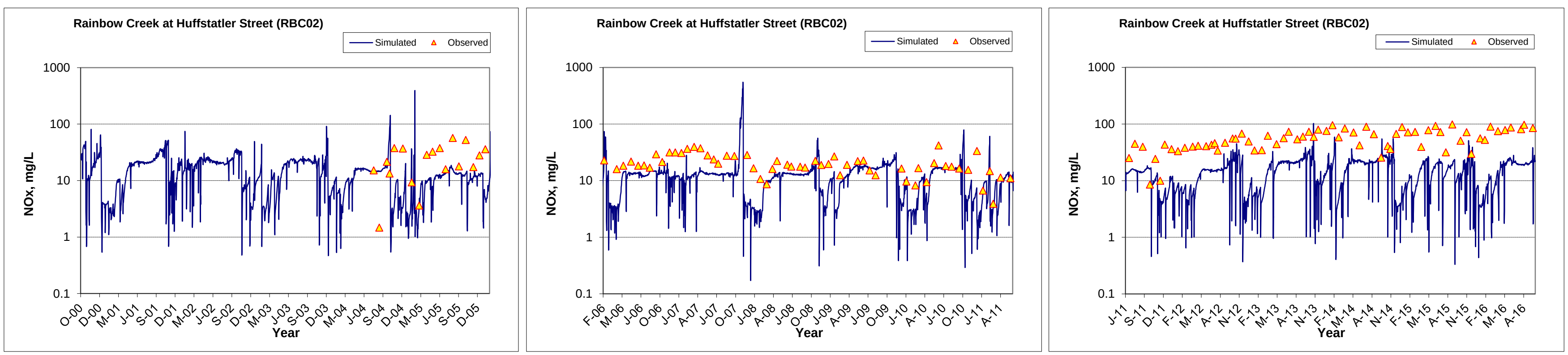


Figure 5-22. Time Series of Observed and Simulated Nitrite+ Nitrate Nitrogen (NOx) Concentration at Rainbow Creek at Huffstatler Street (RBC02)

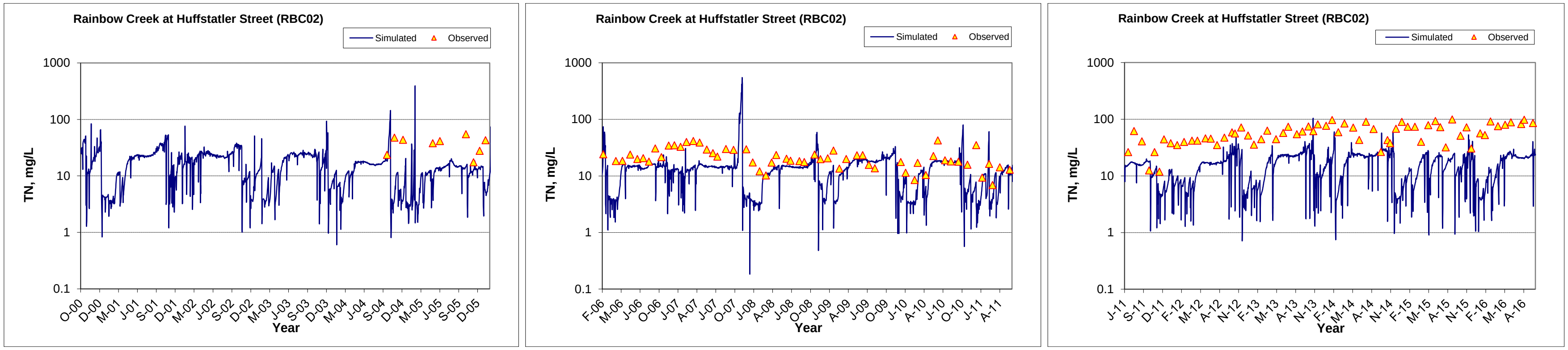


Figure 5-23. Time Series of Observed and Simulated Total Nitrogen (TN) Concentration at Rainbow Creek at Huffstatler Street (RBC02)

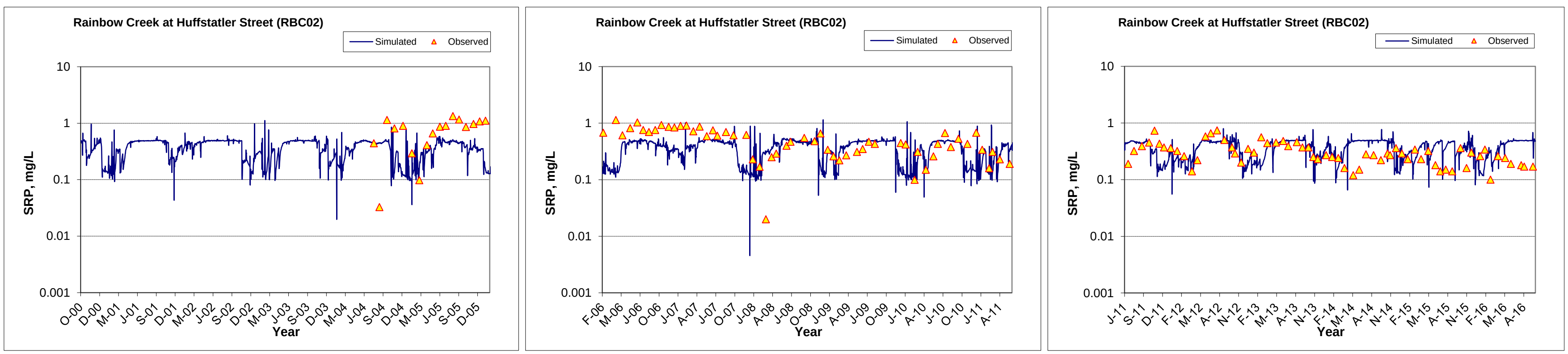


Figure 5-24. Time Series of Observed and Simulated Soluble Reactive Phosphorus (SRP) Concentration at Rainbow Creek at Huffstatler Street (RBC02)

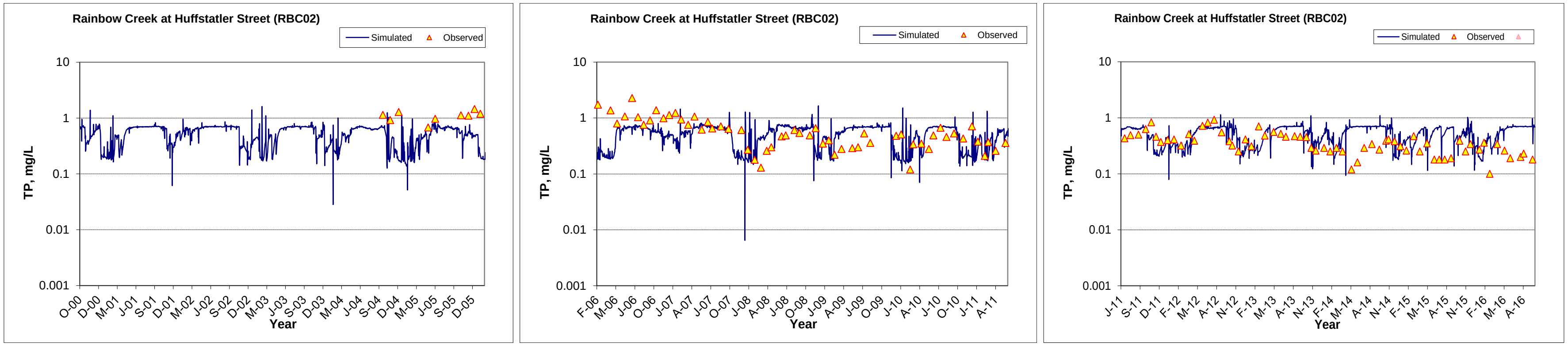


Figure 5-25. Time Series of Observed and Simulated Total Phosphorus (TP) Concentration at Rainbow Creek at Huffstatler Street (RBC02)

5.6.2.4 Rainbow Creek at Old Hwy 395 (RBC04)

The sampling location at Old Highway 395 is situated downstream of Huffstatler (RBC02). Similar to the Huffstatler site, soluble reactive P concentrations are consistently higher for the validation period compared to the calibration period at Old Highway 395. Also, observed nitrite-N + nitrate-N concentrations have been trending upward in recent years, consistent with the trend analysis in .Appendix A to Weston (2017). Model fit for soluble reactive P is better for the calibration period while simulated nitrite-N + nitrate-N concentrations match more closely to observed concentrations prior to 2011.

Table 5-13. Water Quality Calibration Statistics at Rainbow Creek at Old Hwy 395 (RBC04)

Metric	Validation (WY 1996 – WY 2007)							Calibration (WY 2008 – WY 2016)						
	NH_3+ NH_4-N	OrgN	TKN	NO_2+ NO_3-N	TN	SRP	TP	NH_3+ NH_4-N	OrgN	TKN	NO_2+ NO_3-N	TN	SRP	TP
Count	36	25	34	38	34	36	34	89	66	88	95	94	94	94
Concentration Average Error	475.99%	-94.44%	-10.11%	-15.76%	-27.14%	-23.79%	-17.96%	289.82%	-97.97%	-38.19%	-55.87%	-54.99%	7.35%	33.39%
Concentration Median Error	579.75%	-73.44%	18.12%	-17.65%	-10.10%	-27.14%	-2.62%	394.73%	-42.26%	1.89%	-46.69%	-44.09%	14.62%	48.00%
Load Average Error	3.67%	-94.82%	-76.64%	-70.41%	-72.24%	-55.59%	-57.33%	-8.72%	-97.41%	-84.91%	-84.85%	-85.01%	-66.92%	-59.68%
Load Median Error	64.87%	-15.95%	5.72%	-0.08%	-2.42%	-2.72%	-2.60%	33.88%	-9.18%	-2.08%	-30.19%	-31.89%	-7.32%	-1.90%

Note: NH_3+ NH_4-N = ammonium plus ammonia as nitrogen. OrgN = organic nitrogen, TKN = total Kjeldahl nitrogen (organic N plus NH_3+ NH_4-N), NO_2+NO_3-N = nitrite plus nitrate as nitrogen, TN = total nitrogen, SRP = soluble reactive phosphorus, TP = total phosphorus.

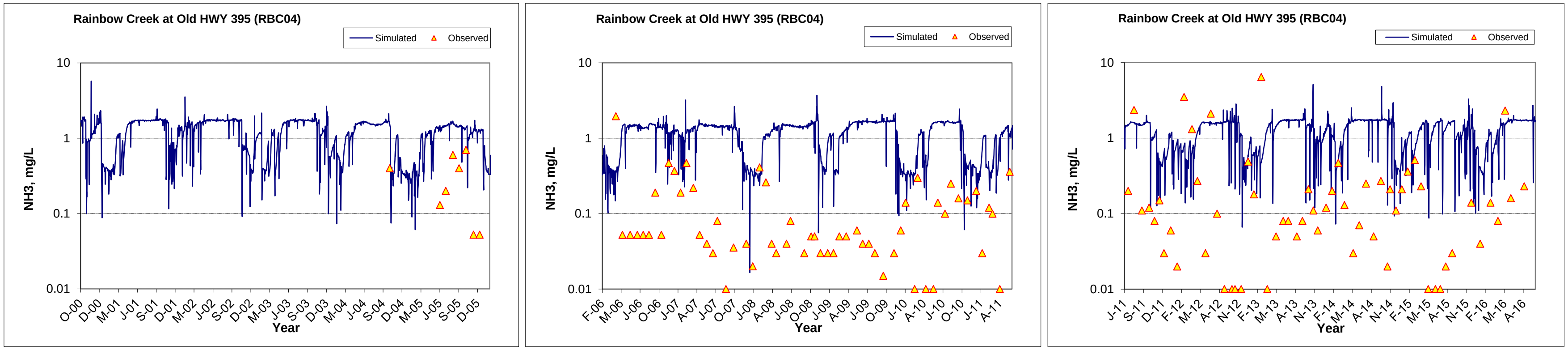


Figure 5-26. Time Series of Observed and Simulated Ammonia Nitrogen (NH_3+ NH_4-N) Concentration at Rainbow Creek at Old Hwy 395 (RBC04)

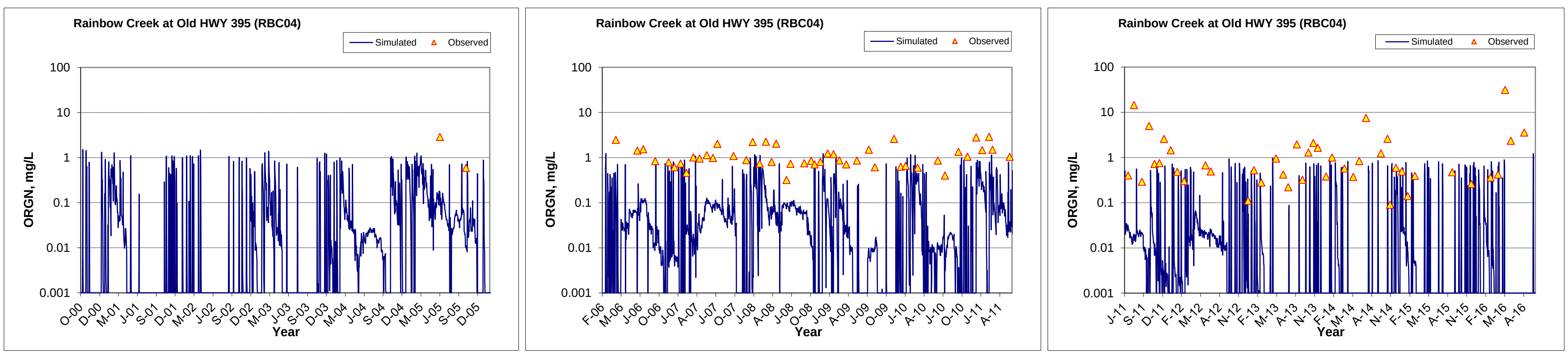


Figure 5-27. Time Series of Observed and Simulated Organic Nitrogen (OrgN) Concentration at Rainbow Creek at Old Hwy 395 (RBC04)

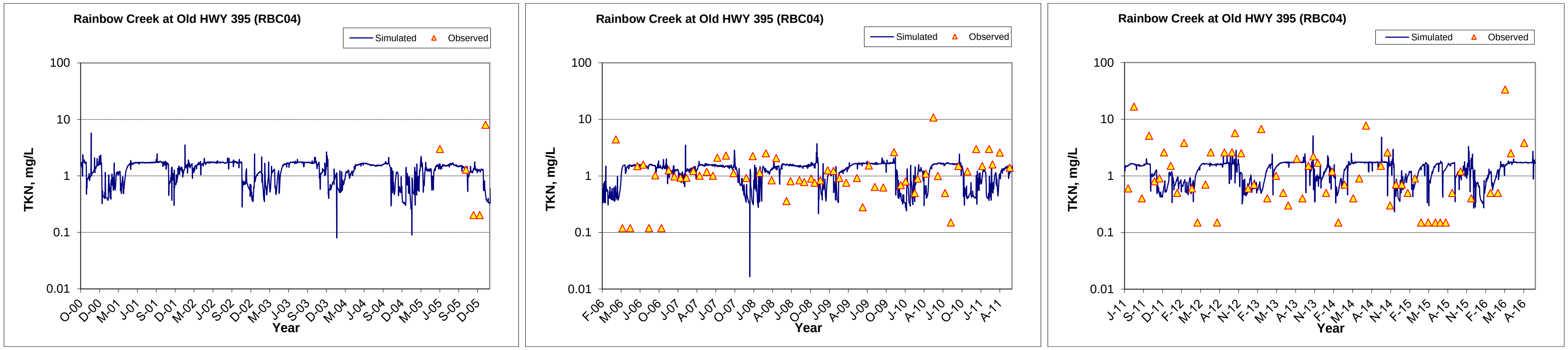


Figure 5-28. Time Series of Observed and Simulated Total Kjeldahl Nitrogen (TKN) Concentration at Rainbow Creek at Old Hwy 395 (RBC04)

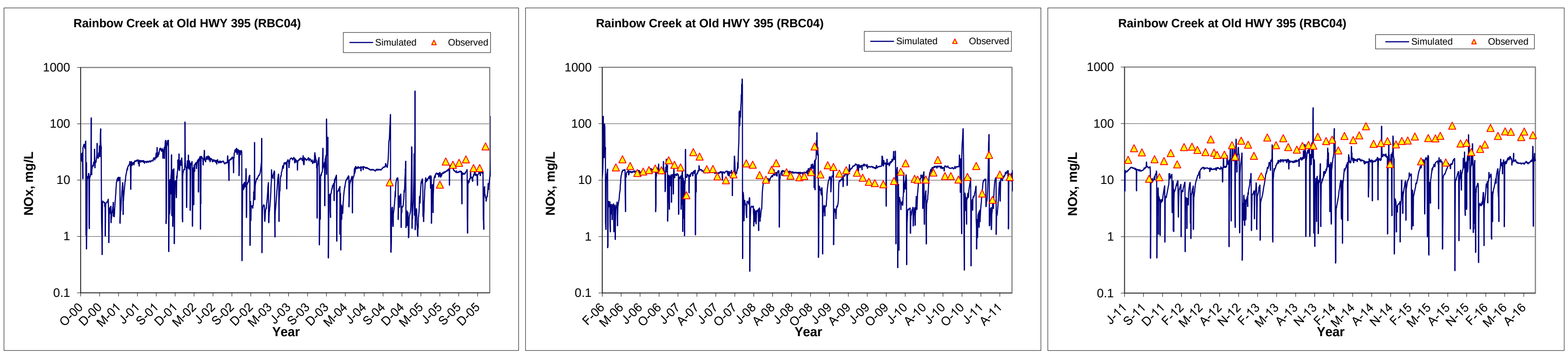


Figure 5-29. Time Series of Observed and Simulated Nitrite+ Nitrate Nitrogen (NOx) Concentration at Rainbow Creek at Old Hwy 395 (RBC04)

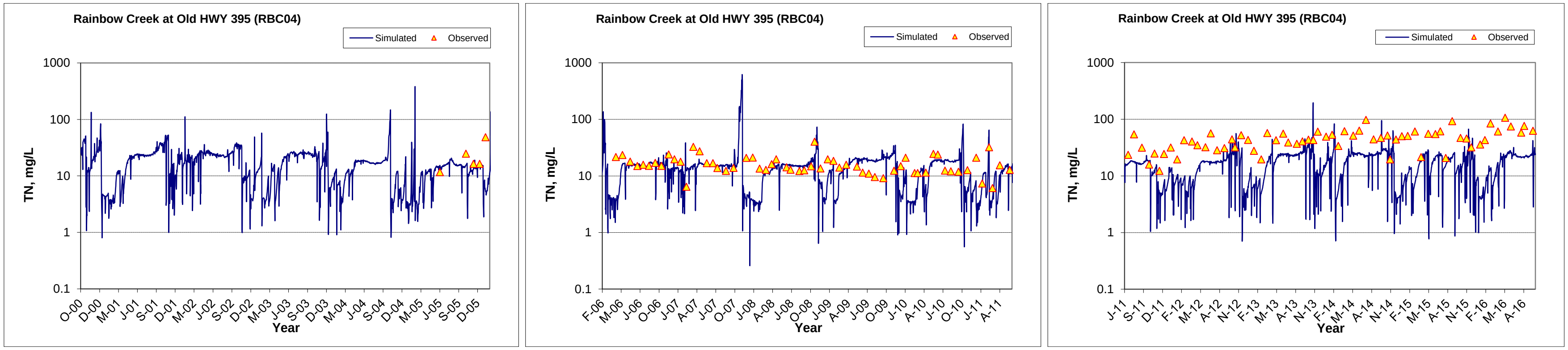


Figure 5-30. Time Series of Observed and Simulated Total Nitrogen (TN) Concentration at Rainbow Creek at Old Hwy 395 (RBC04)

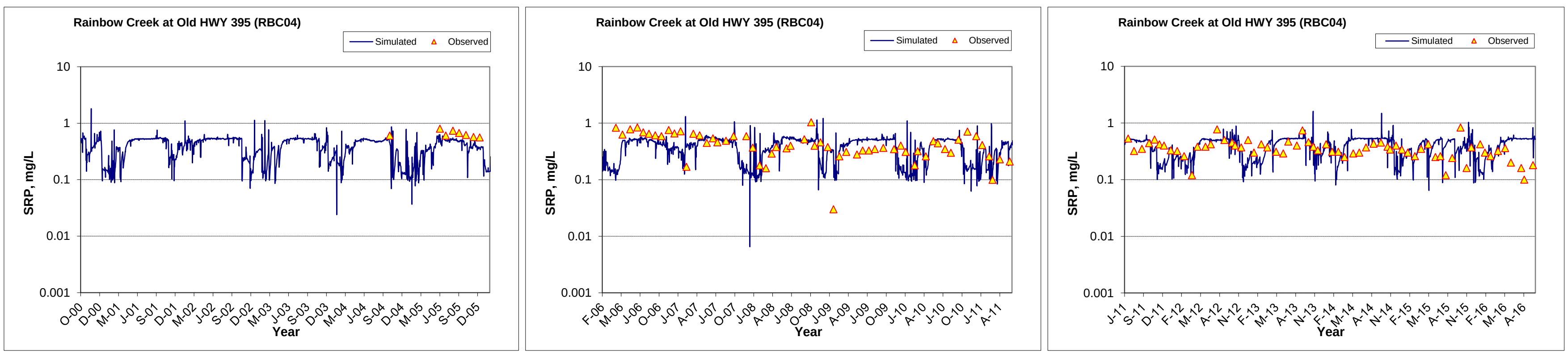
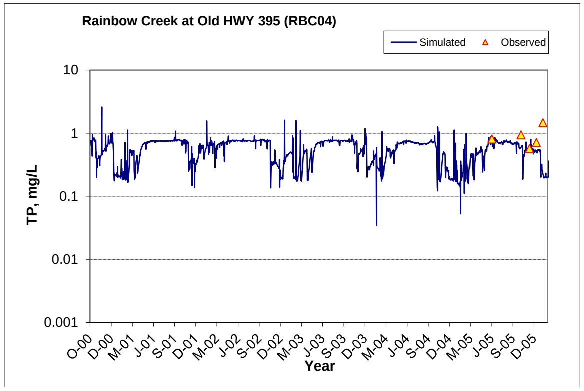
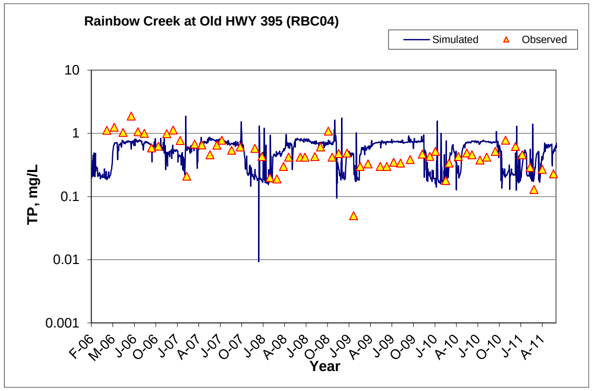


Figure 5-31. Time Series of Observed and Simulated Soluble Reactive Phosphorus (SRP) Concentration at Rainbow Creek at Old Hwy 395 (RBC04)





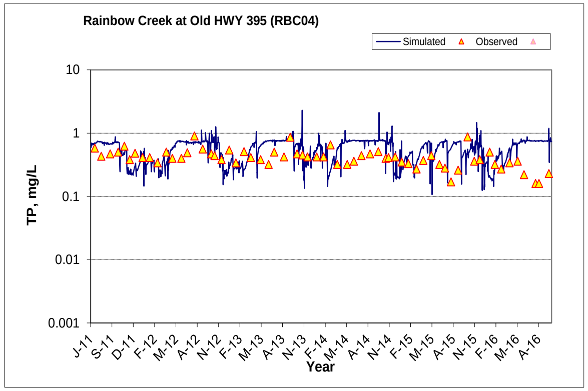


Figure 5-32. Time Series of Observed and Simulated Total Phosphorus (TP) Concentration at Rainbow Creek at Old Hwy 395 (RBC04)

5.6.2.5 Rainbow Creek at MWD Road Crossing (RBC10)

Simulated ammonia-N + ammonium-N are significantly higher than observed concentrations under dry weather conditions at Rainbow Creek at MWD Road Crossing and may reflect contributions for onsite wastewater disposal systems. Simulated TKN concentrations are representative of instream TKN concentrations, especially in recent years. Instream soluble reactive P and TP concentrations are more diluted at MDW Road Crossing compared to upstream. The average soluble reactive P concentrations upstream at Huffstatler is 0.45 mg-P/L and at MDW Road Crossing the average concentration drops to 0.28 mg-P/L.

Table 5-14. Water Quality Calibration Statistics at Rainbow Creek at MWD Road Crossing (RBC10)

Metric	Validation (WY 1996 – WY 2007)							Calibration (WY 2008 – WY 2016)						
	NH_3+ NH_4-N	OrgN	TKN	NO_2+ NO_3-N	TN	SRP	TP	NH_3+ NH_4-N	OrgN	TKN	NO_2+ NO_3-N	TN	SRP	TP
Count	36	24	35	37	35	36	35	72	55	73	75	75	75	75
Concentration Average Error	1072%		58.06%	140.71%	129.35%	57.55%	64.25%	944.70%	-97.38%	-3.28%	1.91%	1.15%	37.70%	63.22%
Concentration Median Error	1214%		77.12%	163.53%	161.23%	88.09%	74.47%	1039%	-61.76%	26.14%	4.90%	-3.07%	40.83%	66.24%
Load Average Error	852.67%		46.11%	-11.44%	-10.15%	-20.31%	-21.76%	454.68%	-93.94%	-55.15%	-58.17%	-57.75%	-17.32%	3.13%
Load Median Error	652.79%		43.04%	36.57%	34.18%	20.68%	18.64%	318.70%	-20.90%	4.33%	1.33%	-1.14%	7.42%	14.74%

Note: NH_3+ NH_4-N = ammonium plus ammonia as nitrogen. OrgN = organic nitrogen, TKN = total Kjeldahl nitrogen (organic N plus NH_3+ NH_4-N), NO_2+NO_3-N = nitrite plus nitrate as nitrogen, TN = total nitrogen, SRP = soluble reactive phosphorus, TP = total phosphorus.

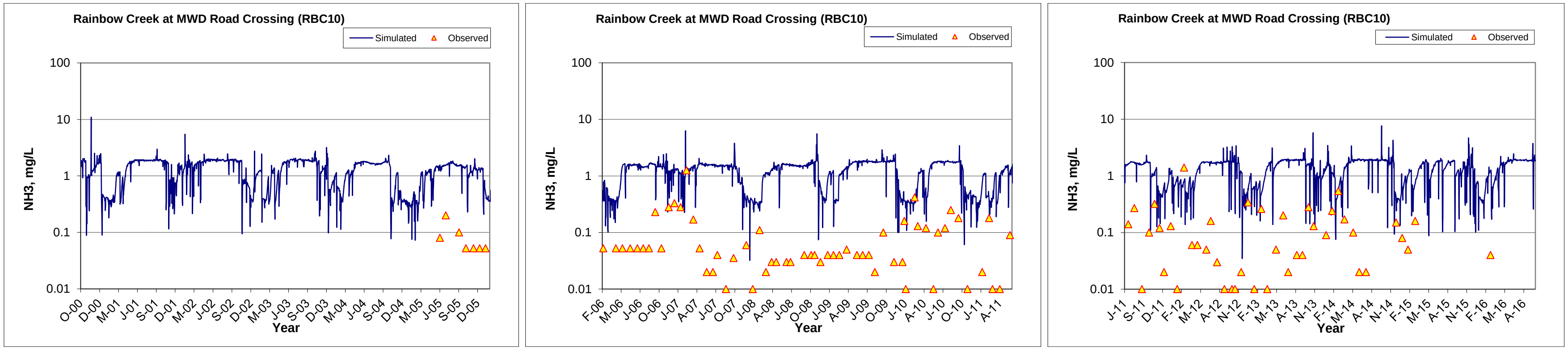


Figure 5-33. Time Series of Observed and Simulated Ammonia Nitrogen (NH_3+ NH_4-N) Concentration at Rainbow Creek at MWD Road Crossing (RBC10)

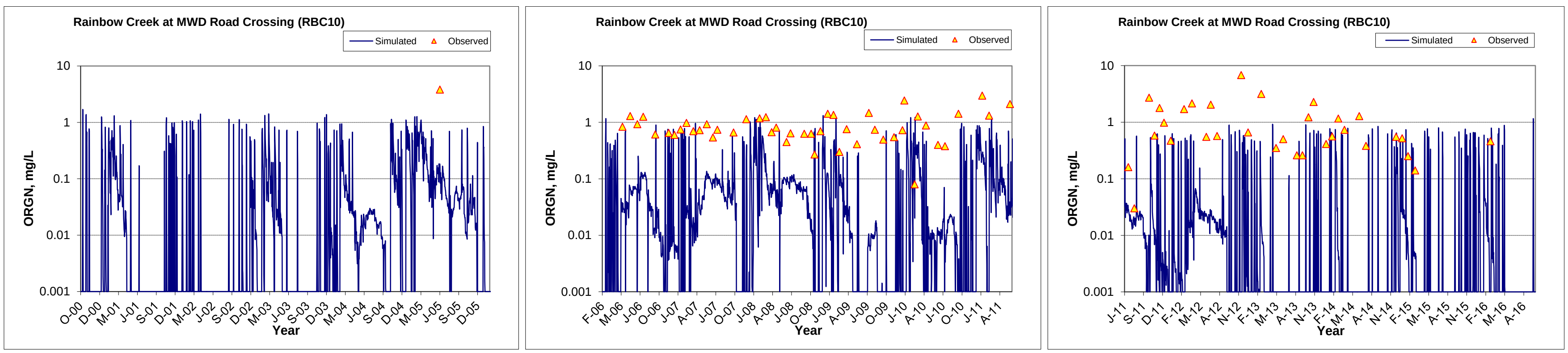


Figure 5-34. Time Series of Observed and Simulated Organic Nitrogen (OrgN) Concentration at Rainbow Creek at MWD Road Crossing (RBC10)

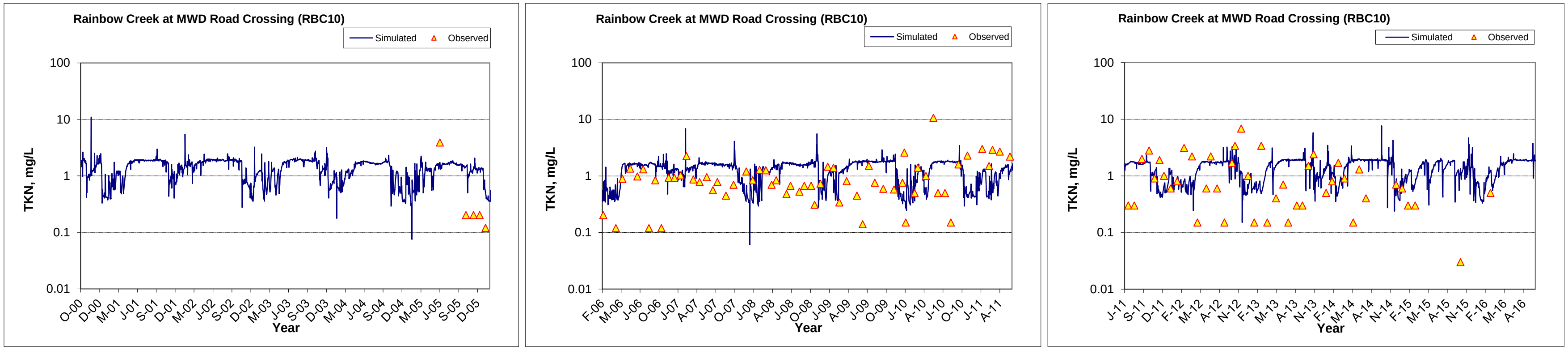


Figure 5-35. Time Series of Observed and Simulated Total Kjeldahl Nitrogen (TKN) Concentration at Rainbow Creek at MWD Road Crossing (RBC10)

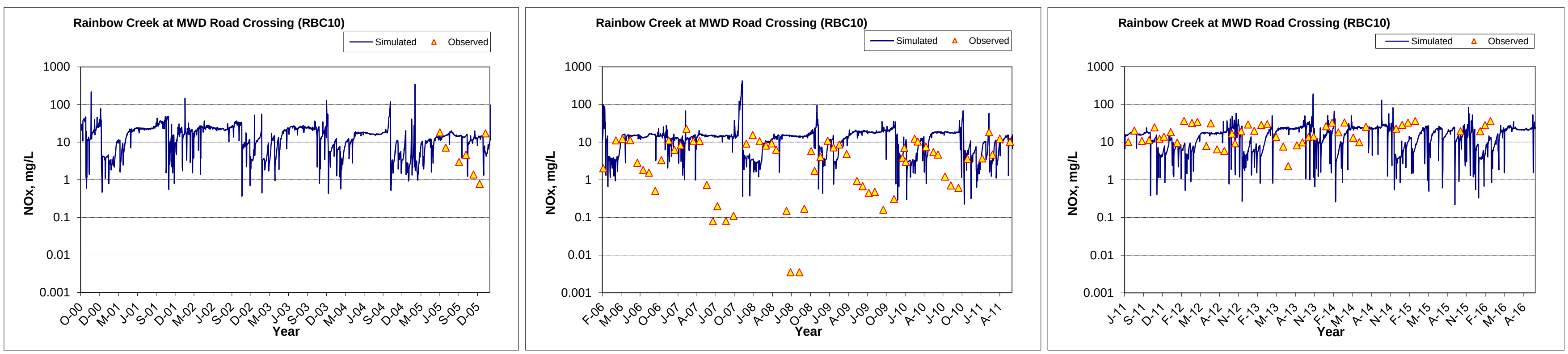


Figure 5-36. Time Series of Observed and Simulated Nitrite+ Nitrate Nitrogen (NOx) Concentration at Rainbow Creek at MWD Road Crossing (RBC10)

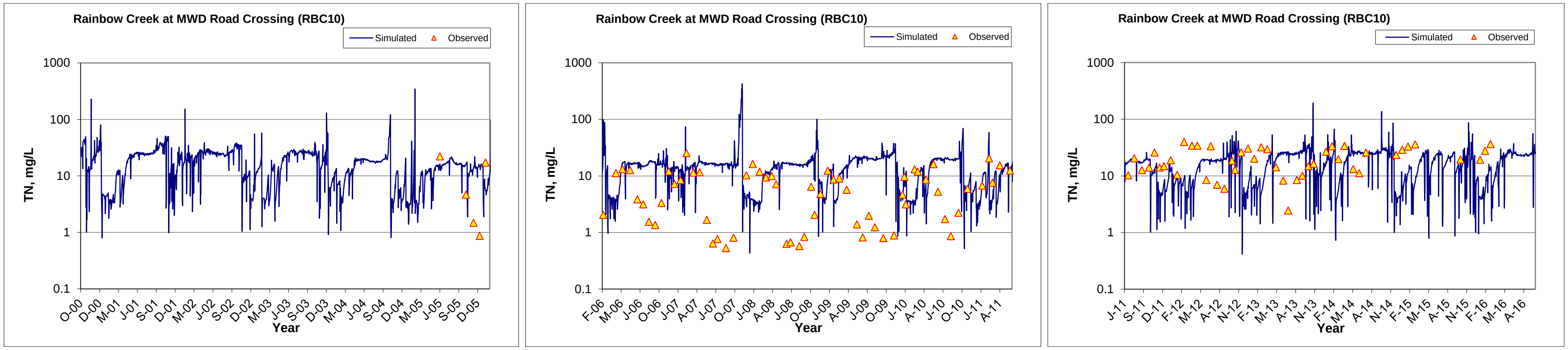


Figure 5-37. Time Series of Observed and Simulated Total Nitrogen (TN) Concentration at Rainbow Creek at MWD Road Crossing (RBC10)

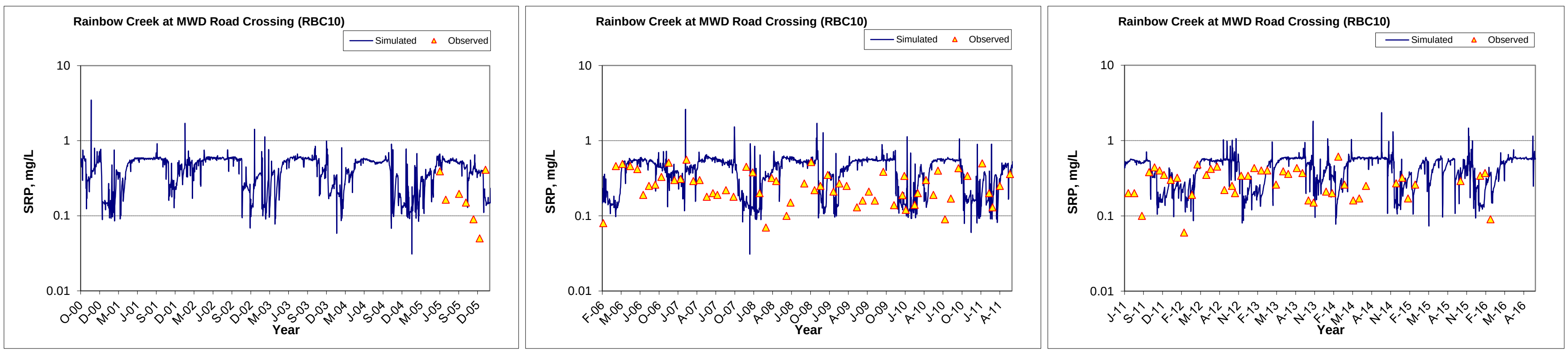


Figure 5-38. Time Series of Observed and Simulated Soluble Reactive Phosphorus (SRP) Concentration at Rainbow Creek at MWD Road Crossing (RBC10)

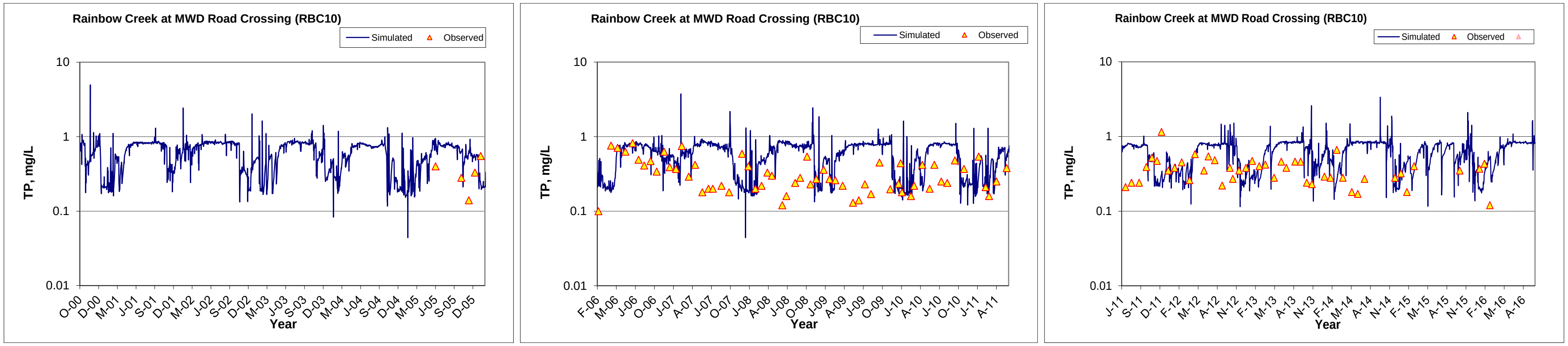


Figure 5-39. Time Series of Observed and Simulated Total Phosphorus (TP) Concentration at Rainbow Creek at MWD Road Crossing (RBC10)

5.6.2.6 Rainbow Creek at Willow Glen Road (SMG05)

The Willow Glen Road sampling location is situated near the mouth of Rainbow Creek. The model tends to overestimate TN and TP concentrations during dry weather; however, simulated loads are comparable to observed loads. Similar to upstream sites, temporal variations, which may be due to changes in analytical methods and/or changing nutrient management practices, are evident.

Table 5-15. Water Quality Calibration Statistics at Rainbow Creek at Willow Glen Road (SMG05)

Metric	Validation (WY 1996 – WY 2007)							Calibration (WY 2008 – WY 2016)						
	NH_3+ NH_4-N	OrgN	TKN	NO_2+ NO_3-N	TN	SRP	TP	NH_3+ NH_4-N	OrgN	TKN	NO_2+ NO_3-N	TN	SRP	TP
Count	48	20	38	169	38	182	48	87	51	88	97	95	97	97
Concentration Average Error	1242%		103.81%	135.19%	28.18%	-21.49%	65.86%	1077%	-96.87%	22.69%	25.54%	22.80%	134.50%	181.34%
Concentration Median Error	1434%		149.55%	147.25%	56.11%	-22.46%	85.36%	1311%	-53.74%	50.50%	25.52%	20.48%	150.39%	214.42%
Load Average Error	730.31%		-4.11%	-31.09%	-45.37%	-65.46%	-48.04%	139.70%	-97.91%	-68.22%	-50.28%	-53.20%	-21.61%	-10.75%
Load Median Error	503.43%		31.50%	4.63%	10.87%	-18.20%	4.29%	104.49%	-8.36%	6.72%	6.98%	5.19%	12.55%	18.53%

Note: NH_3+ NH_4-N = ammonium plus ammonia as nitrogen. OrgN = organic nitrogen, TKN = total Kjeldahl nitrogen (organic N plus NH_3+ NH_4-N), NO_2+NO_3-N = nitrite plus nitrate as nitrogen, TN = total nitrogen, SRP = soluble reactive phosphorus, TP = total phosphorus.

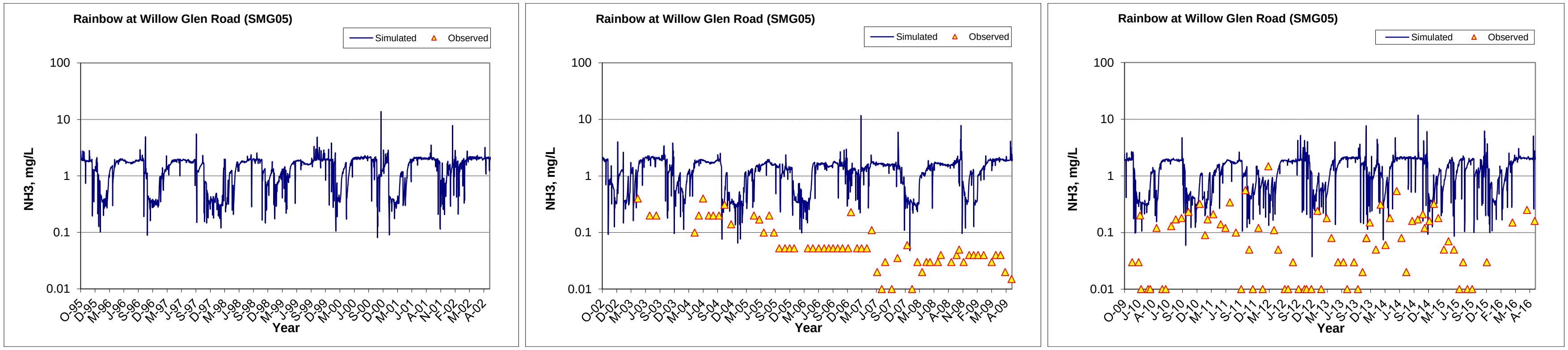


Figure 5-40. Time Series of Observed and Simulated Ammonia Nitrogen (NH_3+ NH_4-N) Concentration at Rainbow at Willow Glen Road (SMG05)

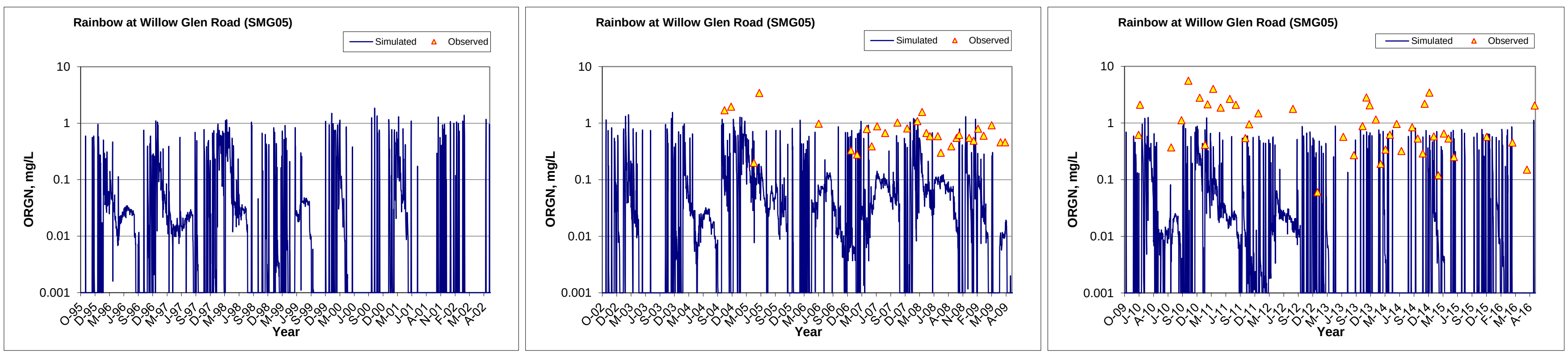


Figure 5-41. Time Series of Observed and Simulated Organic Nitrogen (OrgN) Concentration at Rainbow at Willow Glen Road (SMG05)

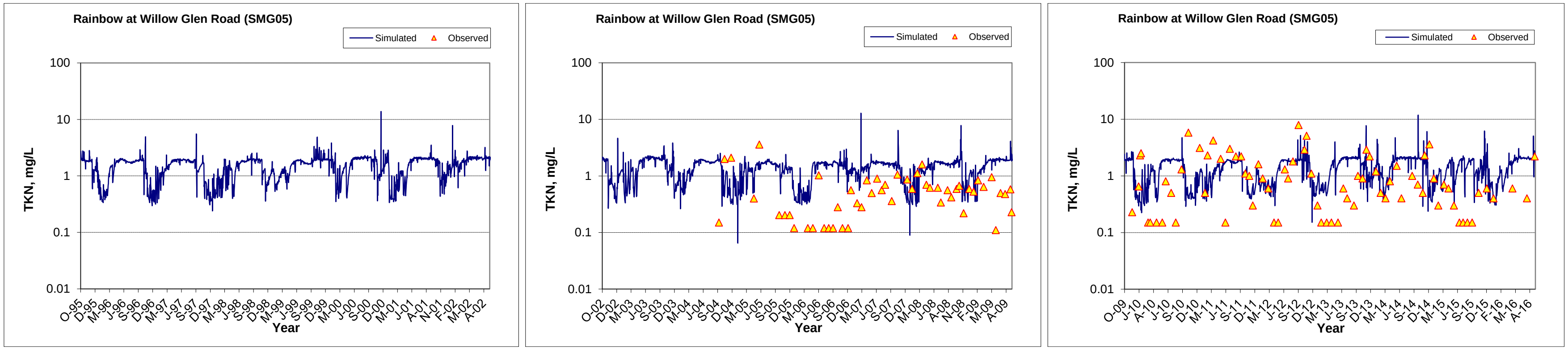


Figure 5-42. Time Series of Observed and Simulated Total Kjeldahl Nitrogen (TKN) Concentration at Rainbow at Willow Glen Road (SMG05)

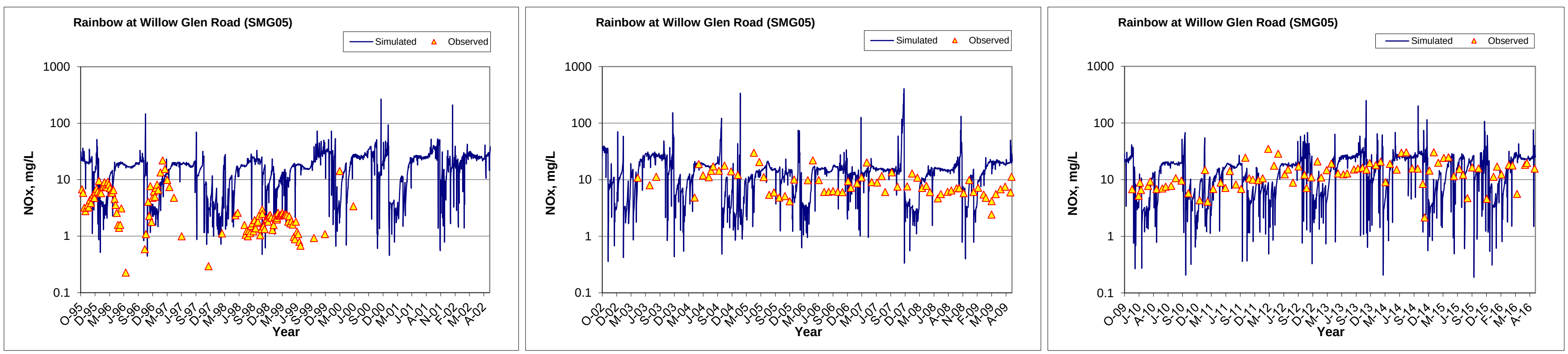


Figure 5-43. Time Series of Observed and Simulated Nitrite+ Nitrate Nitrogen (NOx) Concentration at Rainbow at Willow Glen Road (SMG05)

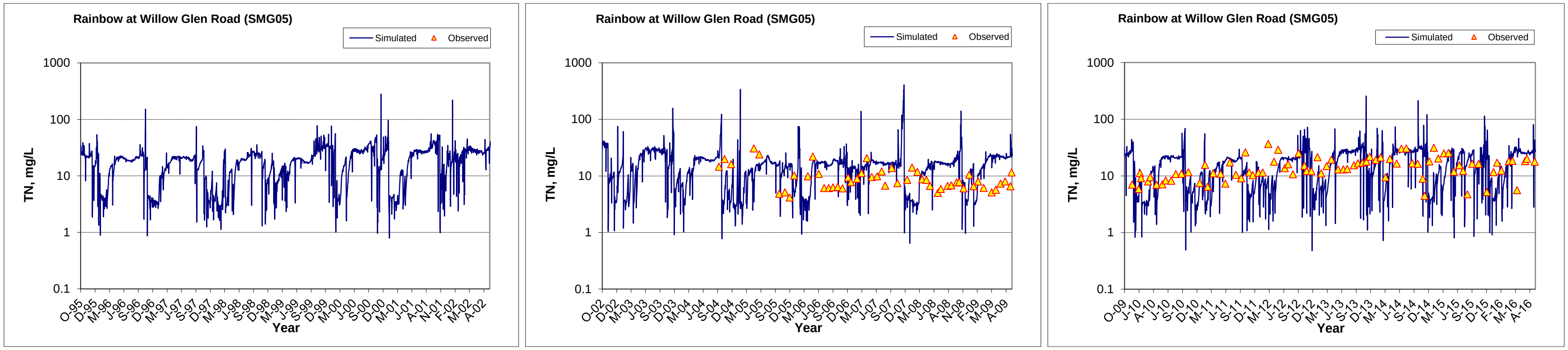


Figure 5-44. Time Series of Observed and Simulated Total Nitrogen (TN) Concentration at Rainbow at Willow Glen Road (SMG05)

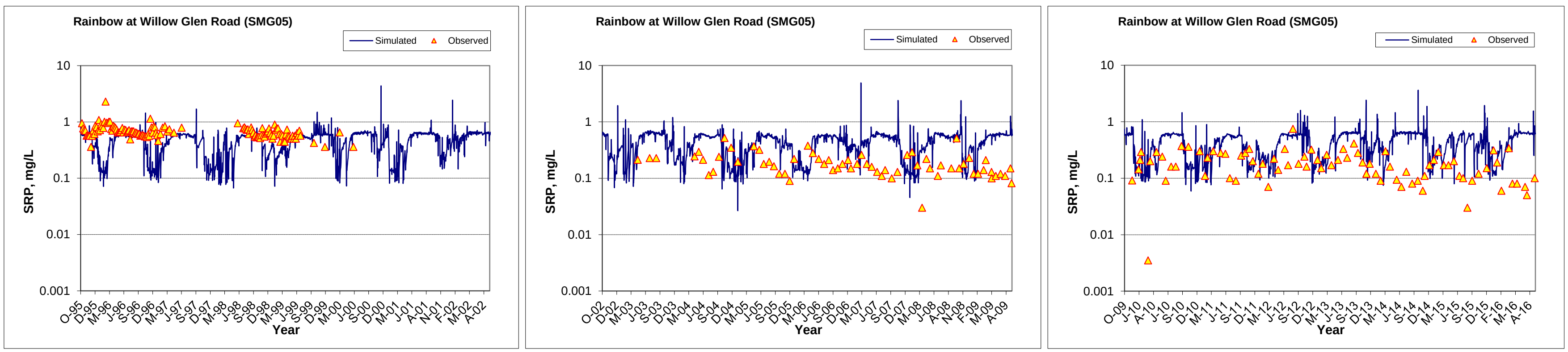


Figure 5-45. Time Series of Observed and Simulated Soluble Reactive Phosphorus (SRP) Concentration at Rainbow at Willow Glen Road (SMG05)

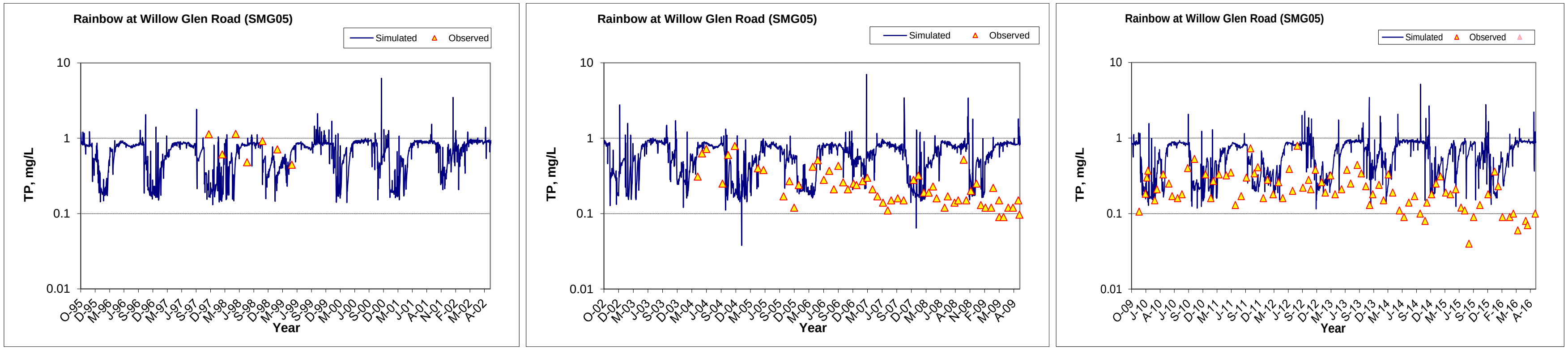


Figure 5-46. Time Series of Observed and Simulated Total Phosphorus (TP) Concentration at Rainbow at Willow Glen Road (SMG05)

5.6.2.7 Rainbow Creek at Stage Coach Lane (SMG06)

Frequent nitrite-N + nitrate-N samples were taken at Rainbow Creek at Stage Coach Lane and the model provides a good representation of nitrite-N + nitrate-N concentrations during the calibration period. Simulated phosphorus concentrations are higher than observed concentrations although modeled loads are lower than estimates from the monitoring – although a shortage of wet weather samples makes conclusions about load unclear. This station is also referred to as Rainbow Creek at Fallbrook PUC Trail.

Table 5-16. Water Quality Calibration Statistics at Rainbow Creek at Stage Coach Lane (SMG06)

Metric	Validation (WY 1996 – WY 2007)							Calibration (WY 2008 – WY 2016)						
	NH_3+ NH_4-N	OrgN	TKN	NO_2+ NO_3-N	TN	SRP	TP	NH_3+ NH_4-N	OrgN	TKN	NO_2+ NO_3-N	TN	SRP	TP
Count	65	10	43	142	43	122	56	91	39	84	103	96	93	103
Concentration Average Error	-67.99%		97.91%	58.28%	14.32%	42.55%	18.36%	76.74%	-96.34%	4.80%	20.86%	17.57%	165.49%	237.29%
Concentration Median Error	-83.63%		119.97%	45.00%	10.47%	64.35%	73.06%	158.30%	-70.64%	31.24%	15.13%	7.05%	186.87%	263.46%
Load Average Error	-92.78%		-33.08%	-63.77%	-59.07%	-53.24%	-53.48%	-67.80%	-95.46%	-70.23%	-74.86%	-74.88%	-47.08%	-30.04%
Load Median Error	-27.19%		0.02%	2.42%	-30.71%	0.78%	-3.75%	7.25%	-35.96%	-23.39%	-46.54%	-40.52%	-17.85%	-9.21%

Note: NH_3+ NH_4-N = ammonium plus ammonia as nitrogen. OrgN = organic nitrogen, TKN = total Kjeldahl nitrogen (organic N plus NH_3+ NH_4-N), NO_2+NO_3-N = nitrite plus nitrate as nitrogen, TN = total nitrogen, SRP = soluble reactive phosphorus, TP = total phosphorus.

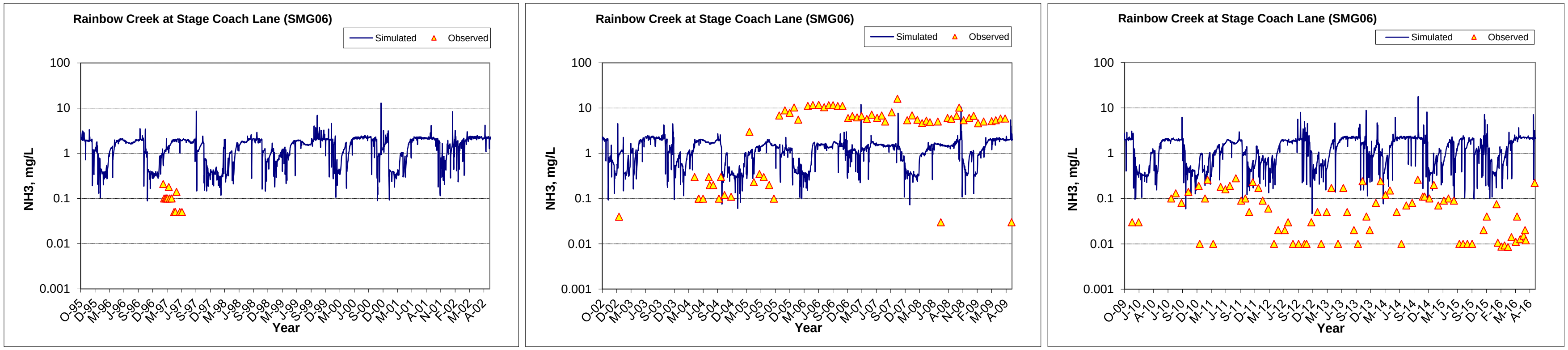


Figure 5-47. Time Series of Observed and Simulated Ammonia Nitrogen (NH_3+ NH_4-N) Concentration at Rainbow Creek at Stage Coach Lane (SMG06)

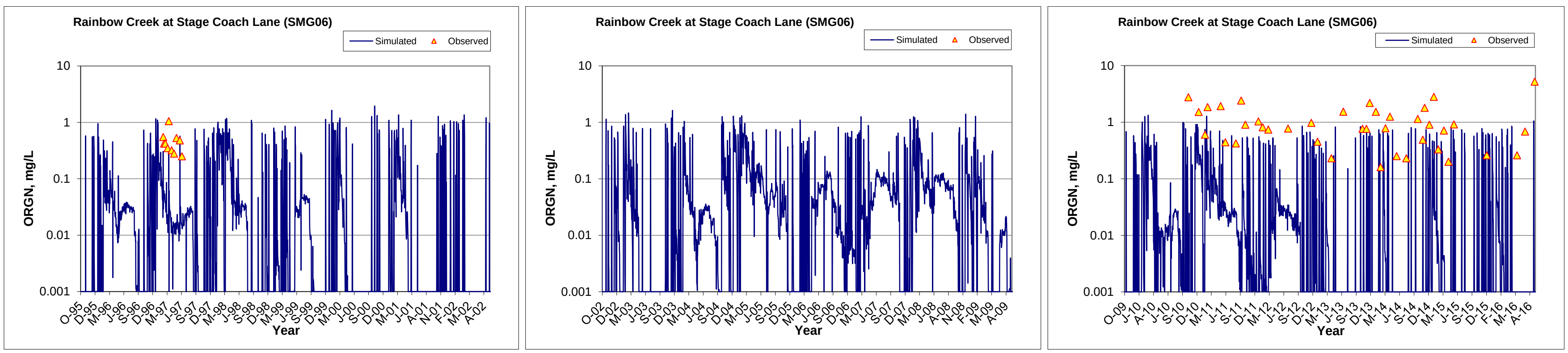


Figure 5-48. Time Series of Observed and Simulated Organic Nitrogen (OrgN) Concentration at Rainbow Creek at Stage Coach Lane (SMG06)

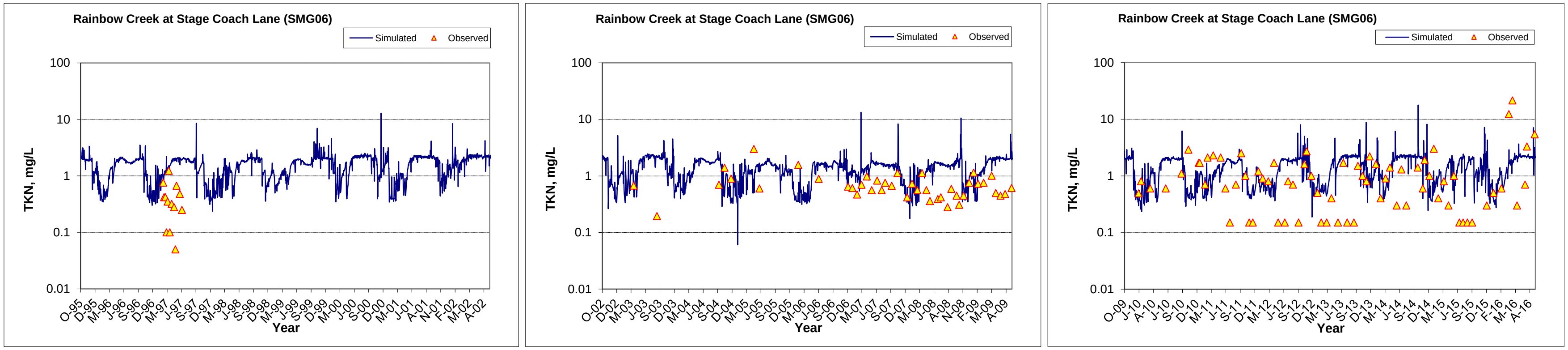


Figure 5-49. Time Series of Observed and Simulated Total Kjeldahl Nitrogen (TKN) Concentration at Rainbow Creek at Stage Coach Lane (SMG06)

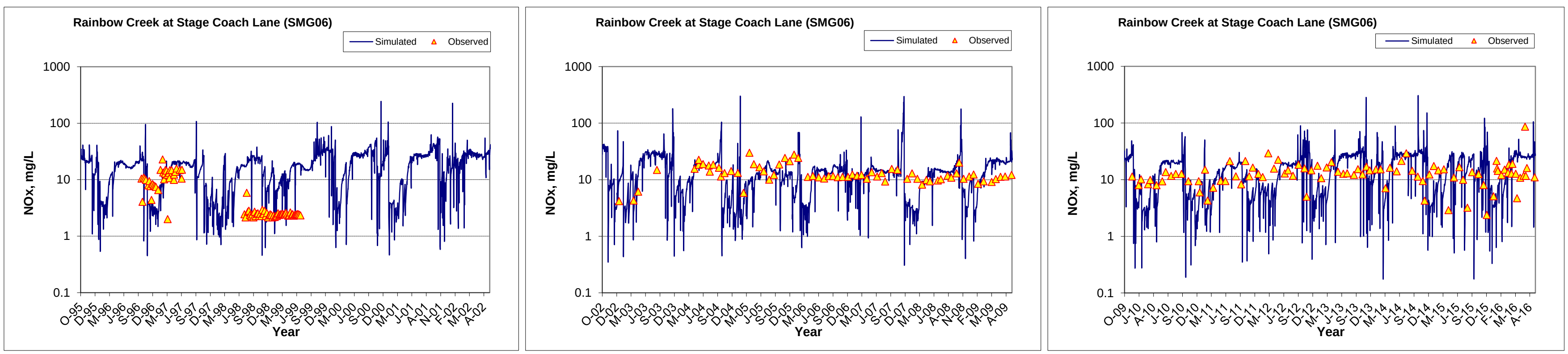


Figure 5-50. Time Series of Observed and Simulated Nitrite+ Nitrate Nitrogen (NOx) Concentration at Rainbow Creek at Stage Coach Lane (SMG06)

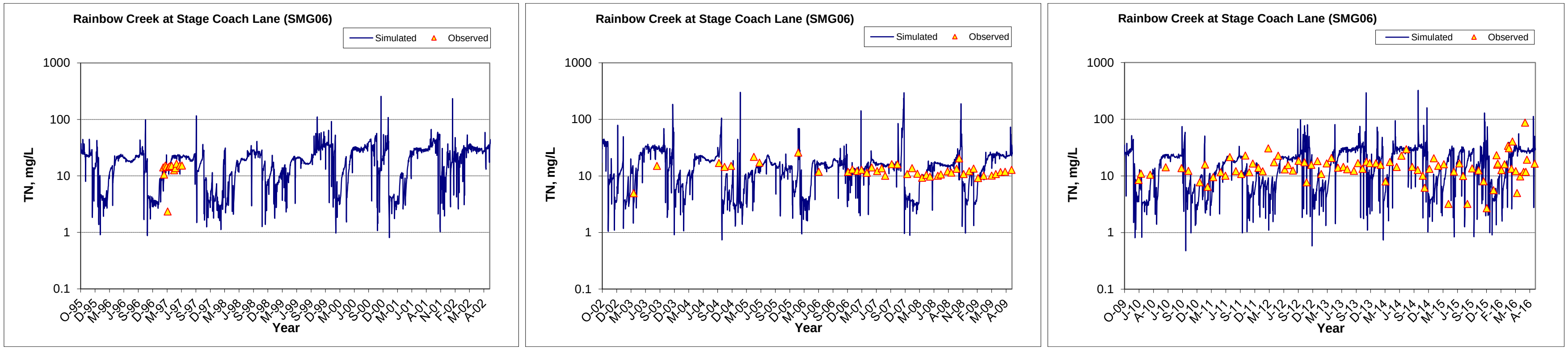


Figure 5-51. Time Series of Observed and Simulated Total Nitrogen (TN) Concentration at Rainbow Creek at Stage Coach Lane (SMG06)

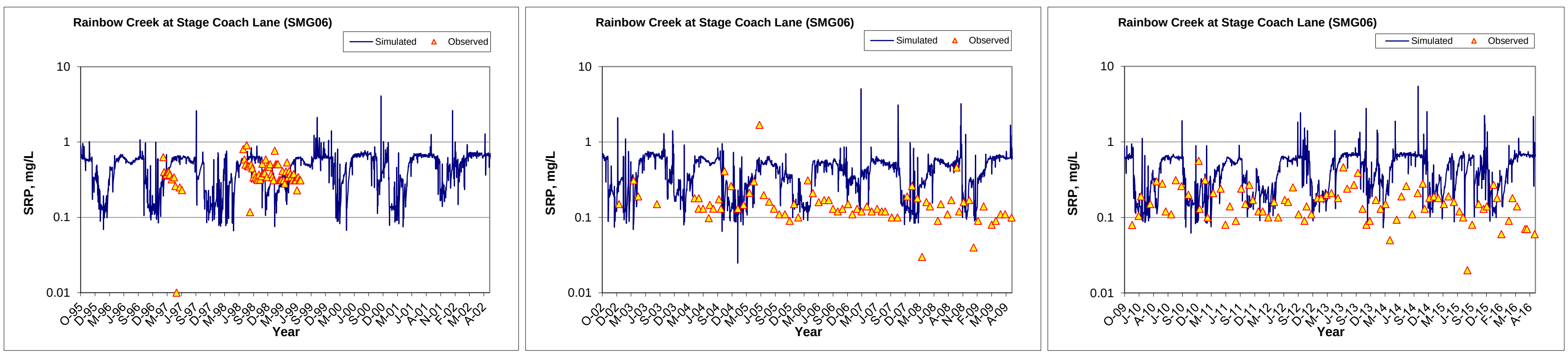


Figure 5-52. Time Series of Observed and Simulated Soluble Reactive Phosphorus (SRP) Concentration at Rainbow Creek at Stage Coach Lane (SMG06)

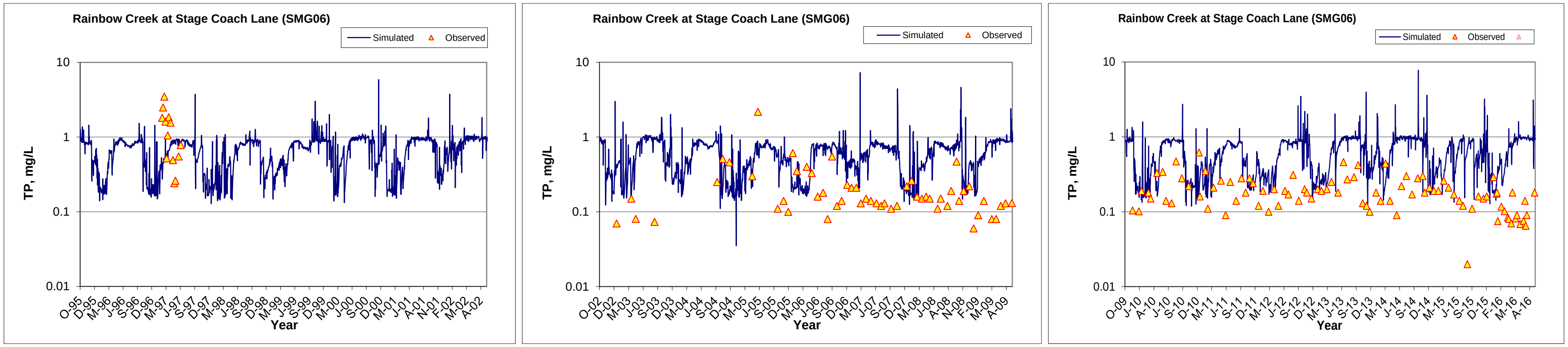


Figure 5-53. Time Series of Observed and Simulated Total Phosphorus (TP) Concentration at Rainbow Creek at Stage Coach Lane (SMG06)

5.6.2.8 Santa Margarita River at FPUD Sump nr Fallbrook (11044300)

There are very few water quality samples at Santa Margarita River near Fallbrook in recent years. As evidenced by the time series plots, the model does a fair job of characterizing water quality conditions at this site.

Table 5-17. Water Quality Calibration Statistics at Santa Margarita River at FPUD Sump near Fallbrook (11044300)

Metric	Validation (WY 1996 – WY 2007)							Calibration (WY 2008 – WY 2016)						
	NH_3+ NH_4-N	OrgN	TKN	NO_2+ NO_3-N	TN	SRP	TP	NH_3+ NH_4-N	OrgN	TKN	NO_2+ NO_3-N	TN	SRP	TP
Count	18	11	25	162	25	149	19	10	1	13	14	11	11	13
Concentration Average Error				-78.71%		-54.82%								
Concentration Median Error				-52.50%		-47.40%								
Load Average Error				-81.64%		-62.29%								
Load Median Error				-34.89%		-27.57%								

Note: NH_3+ NH_4-N = ammonium plus ammonia as nitrogen. OrgN = organic nitrogen, TKN = total Kjeldahl nitrogen (organic N plus NH_3+ NH_4-N), NO_2+NO_3-N = nitrite plus nitrate as nitrogen, TN = total nitrogen, SRP = soluble reactive phosphorus, TP = total phosphorus.

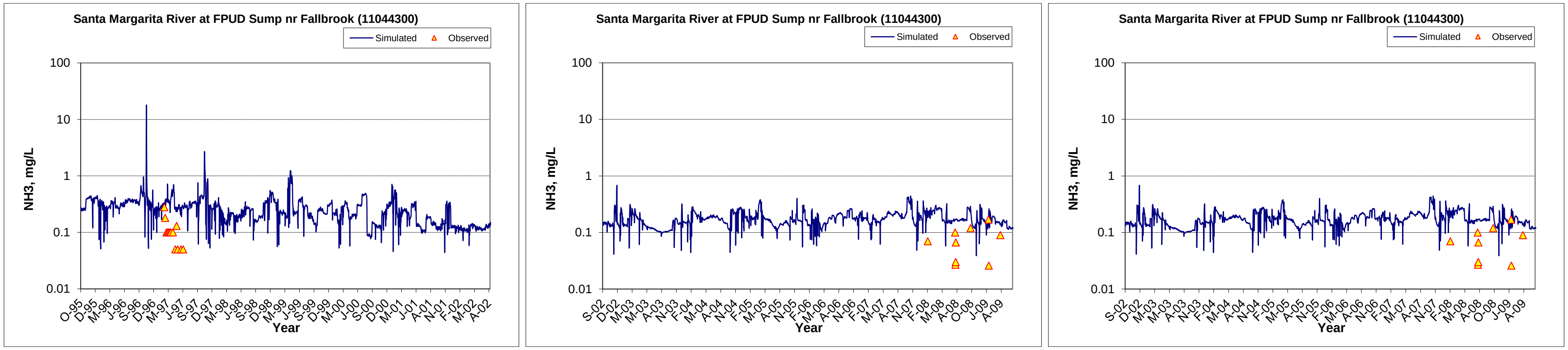


Figure 5-54. Time Series of Observed and Simulated Ammonia Nitrogen (NH_3+ NH_4-N) Concentration at Santa Margarita River at FPUD Sump nr Fallbrook (11044300)

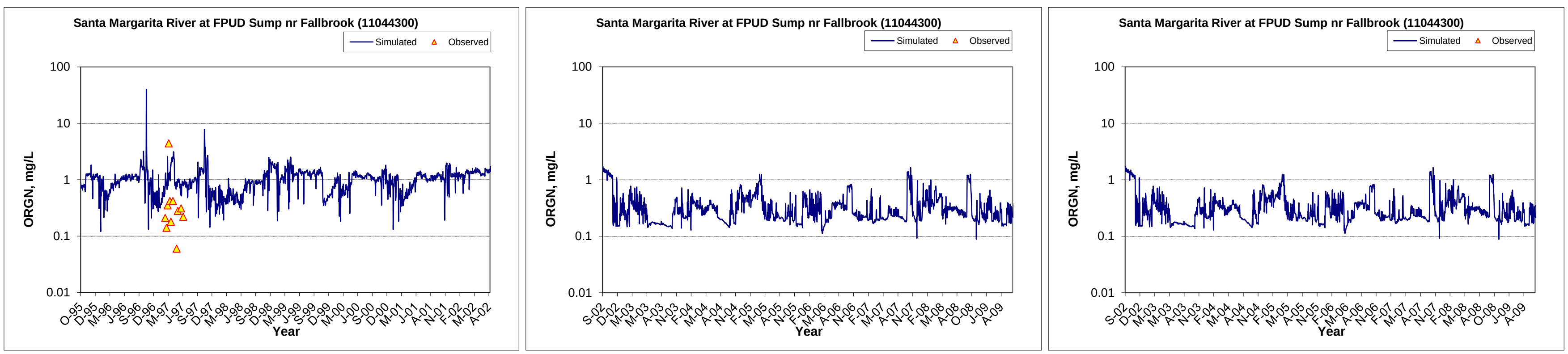


Figure 5-55. Time Series of Observed and Simulated Organic Nitrogen (OrgN) Concentration at Santa Margarita River at FPUD Sump nr Fallbrook (11044300)

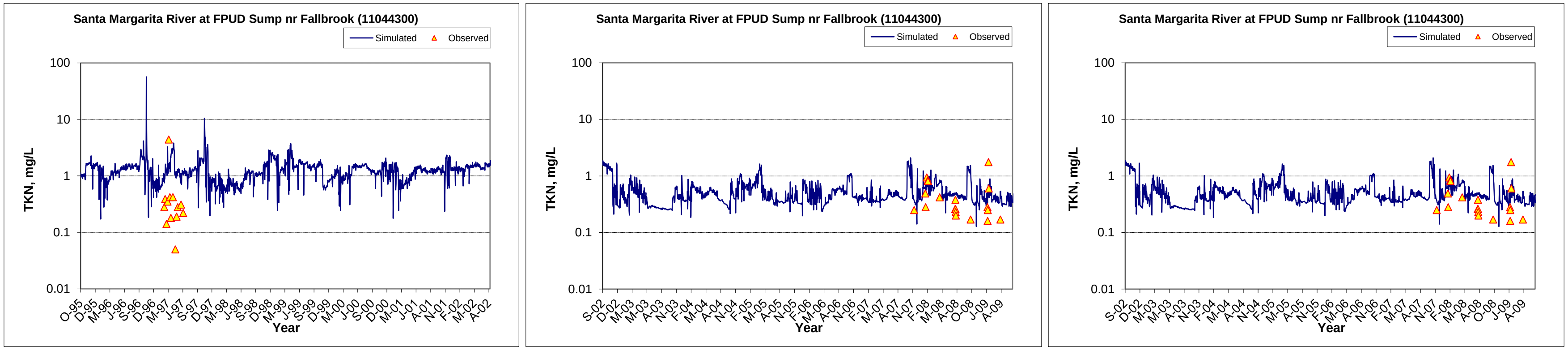


Figure 5-56. Time Series of Observed and Simulated Total Kjeldahl Nitrogen (TKN) Concentration at Santa Margarita River at FPUD Sump nr Fallbrook (11044300)

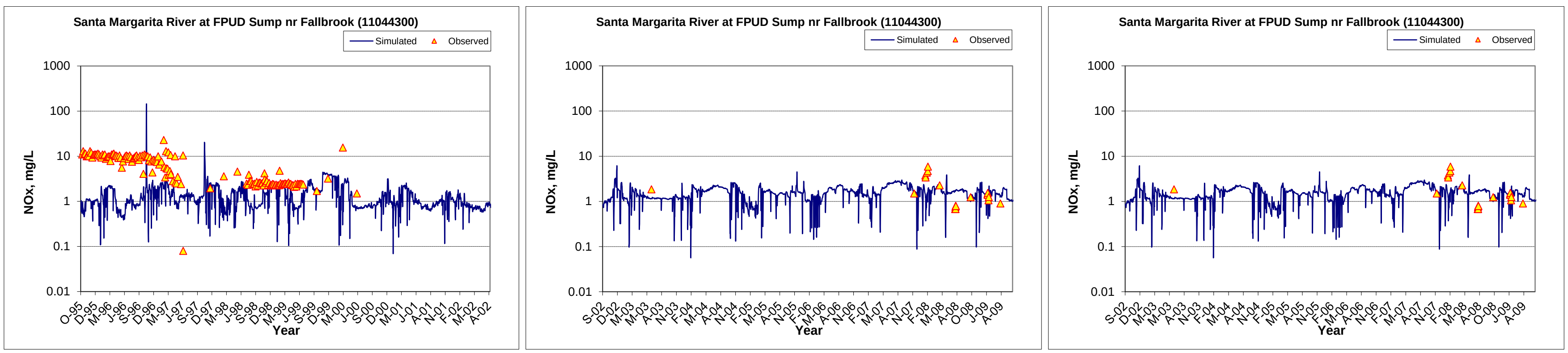


Figure 5-57. Time Series of Observed and Simulated Nitrite+ Nitrate Nitrogen (NOx) Concentration at Santa Margarita River at FPUD Sump nr Fallbrook (11044300)

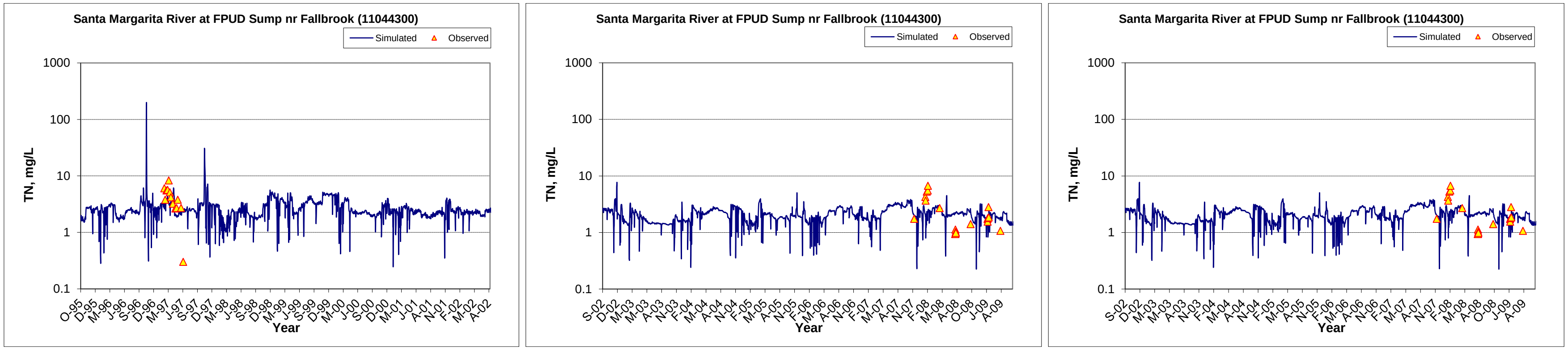


Figure 5-58. Time Series of Observed and Simulated Total Nitrogen (TN) Concentration at Santa Margarita River at FPUD Sump nr Fallbrook (11044300)

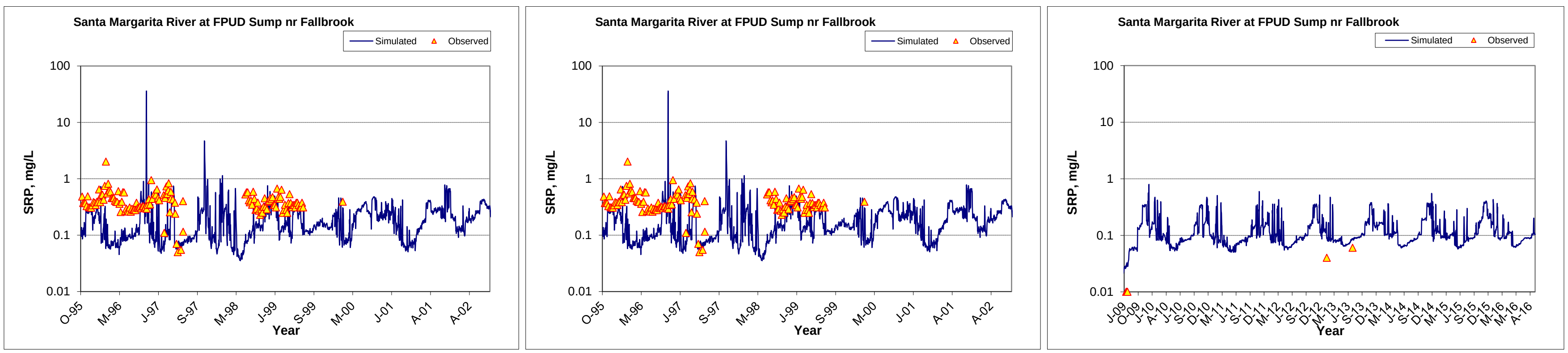


Figure 5-59. Time Series of Observed and Simulated Soluble Reactive Phosphorus (SRP) Concentration at Santa Margarita River at FPUD Sump nr Fallbrook (11044300)

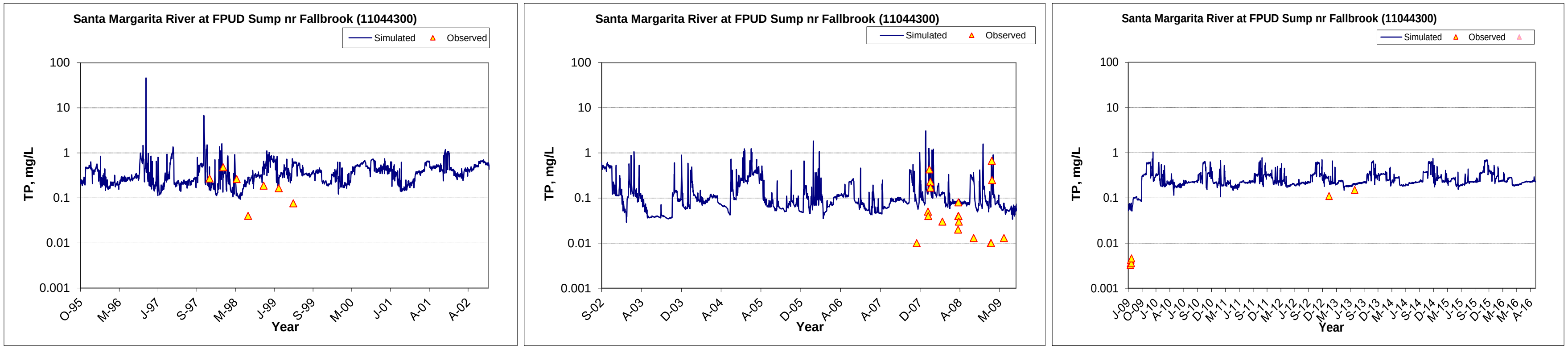


Figure 5-60. Time Series of Observed and Simulated Total Phosphorus (TP) Concentration at Santa Margarita River at FPUD Sump nr Fallbrook (11044300)

5.6.2.9 Sandia Creek at Sandia Creek Drive (11044350)

There are only limited sampling records at Sandia Creek but this site was included in the water quality calibration to better characterize conditions in Sandia Creek, a small tributary stream to Santa Margarita River.

Table 5-18. Water Quality Calibration Statistics at Sandia Creek at Sandia Creek Drive (11044350)

Metric	Validation (WY 1996 – WY 2007)							Calibration (WY 2008 – WY 2016)						
	NH_3+ NH_4-N	OrgN	TKN	NO_2+ NO_3-N	TN	SRP	TP	NH_3+ NH_4-N	OrgN	TKN	NO_2+ NO_3-N	TN	SRP	TP
Count	16	2	13	34	2	24	18	11	2	15	20	2	18	16
Concentration Average Error				-39.05%										
Concentration Median Error				-30.36%										
Load Average Error				-60.36%										
Load Median Error				-11.09%										

Note: NH_3+ NH_4-N = ammonium plus ammonia as nitrogen. OrgN = organic nitrogen, TKN = total Kjeldahl nitrogen (organic N plus NH_3+ NH_4-N), NO_2+NO_3-N = nitrite plus nitrate as nitrogen, TN = total nitrogen, SRP = soluble reactive phosphorus, TP = total phosphorus.

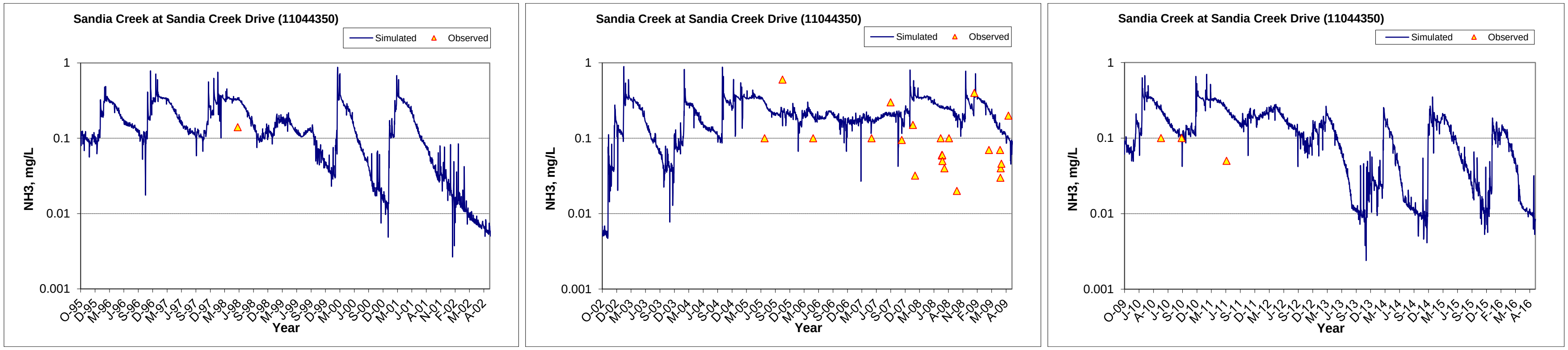


Figure 5-61. Time Series of Observed and Simulated Ammonia Nitrogen (NH_3+ NH_4-N) Concentration at Sandia Creek at Sandia Creek Drive (11044350)

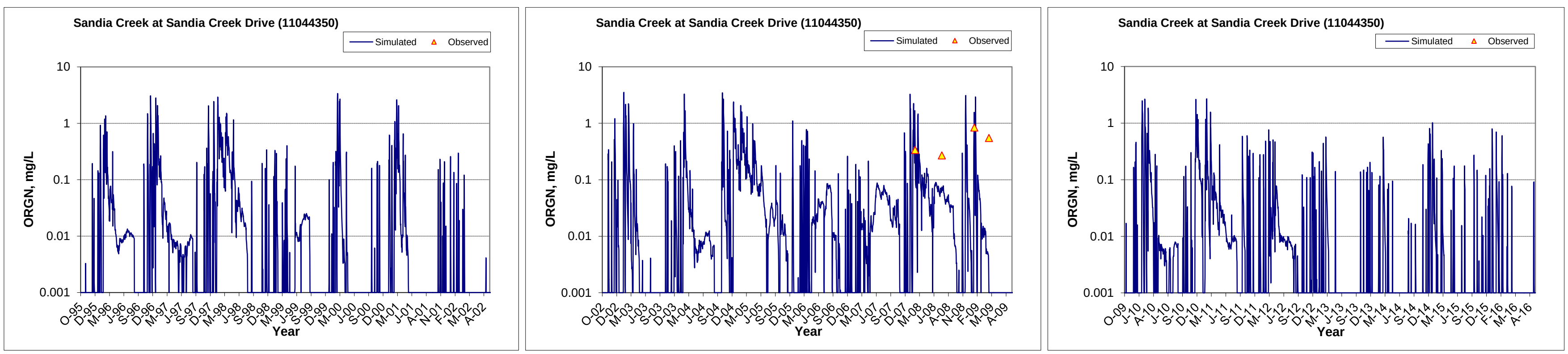


Figure 5-62. Time Series of Observed and Simulated Organic Nitrogen (OrgN) Concentration at Sandia Creek at Sandia Creek Drive (11044350)

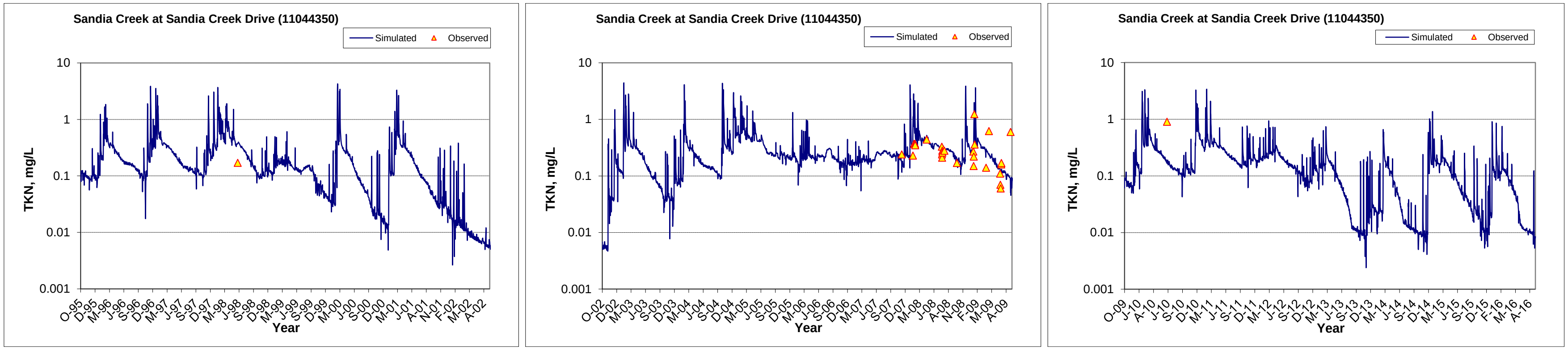


Figure 5-63. Time Series of Observed and Simulated Total Kjeldahl Nitrogen (TKN) Concentration at Sandia Creek at Sandia Creek Drive (11044350)

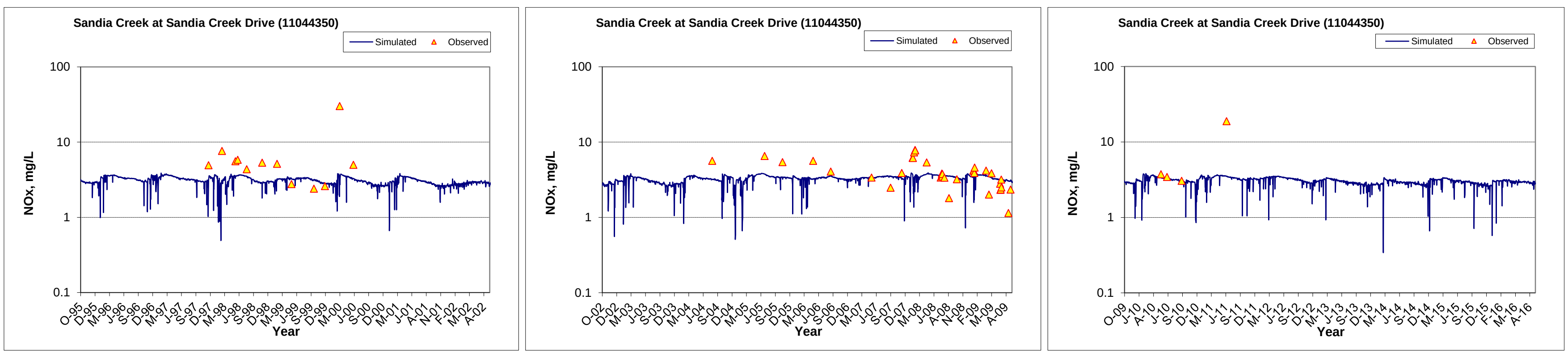


Figure 5-64. Time Series of Observed and Simulated Nitrite+ Nitrate Nitrogen (NOx) Concentration at Sandia Creek at Sandia Creek Drive (11044350)

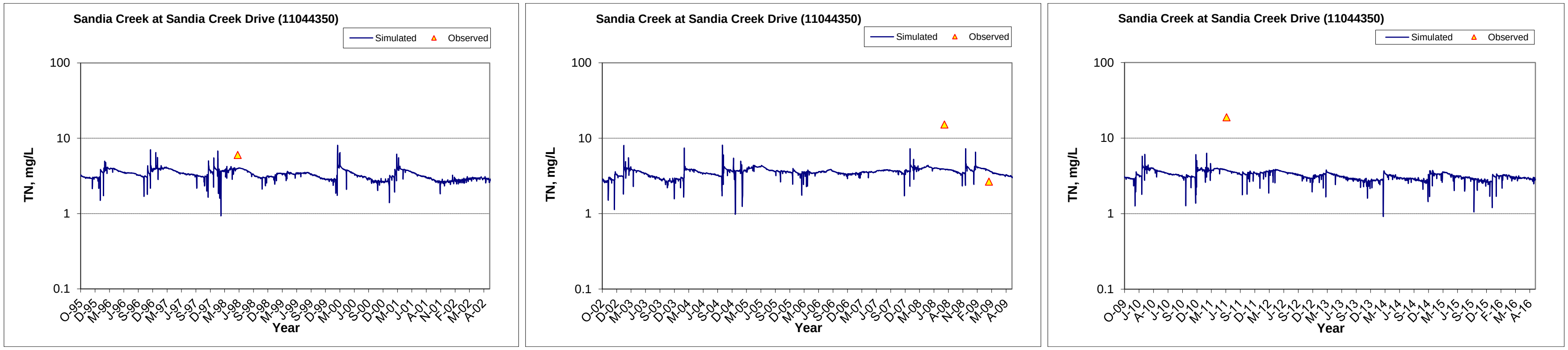


Figure 5-65. Time Series of Observed and Simulated Total Nitrogen (TN) Concentration at Sandia Creek at Sandia Creek Drive (11044350)

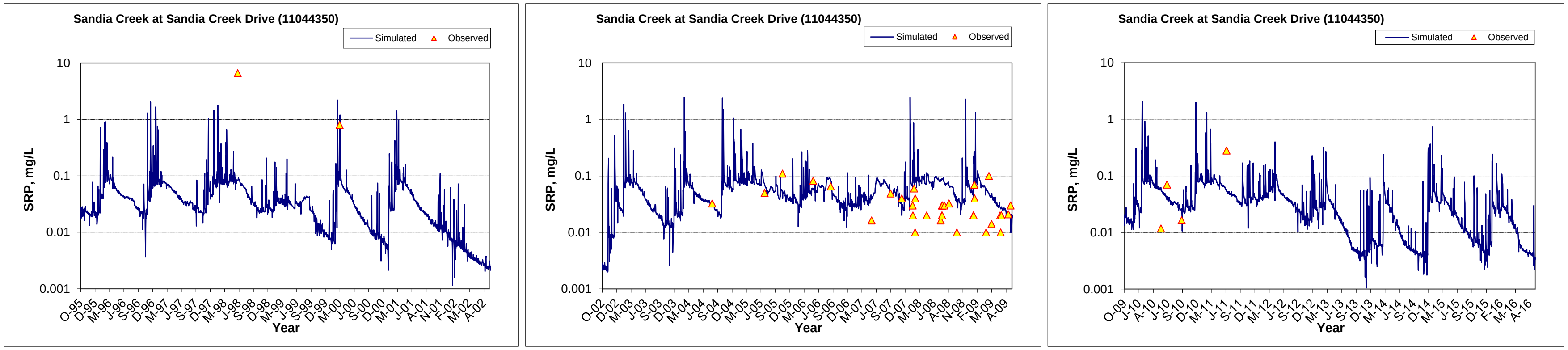


Figure 5-66. Time Series of Observed and Simulated Soluble Reactive Phosphorus (SRP) Concentration at Sandia Creek at Sandia Creek Drive (11044350)

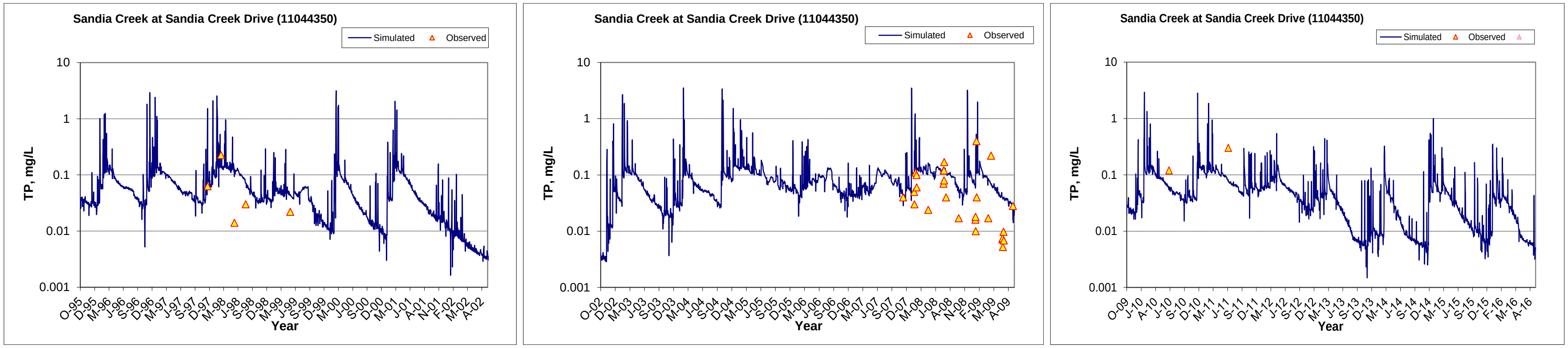


Figure 5-67. Time Series of Observed and Simulated Total Phosphorus (TP) Concentration at Sandia Creek at Sandia Creek Drive (11044350)

5.6.2.10 Santa Margarita River at Ysidora (11046000)

The Santa Margarita River at Ysidora station was used for model calibration although sample counts were low for all constituents. The Ysidora site was included because it provides information about nutrient concentrations and loads in the lower portion of the drainage area where sampling has been infrequent. Quantitative statistics are not supplied due to the small sample size.

Table 5-19. Water Quality Calibration Statistics at Santa Margarita River at Ysidora (11046000)

Metric	Validation (WY 1996 – WY 2007)							Calibration (WY 2008 – WY 2016)						
	NH_3+ NH_4-N	OrgN	TKN	NO_2+ NO_3-N	TN	SRP	TP	NH_3+ NH_4-N	OrgN	TKN	NO_2+ NO_3-N	TN	SRP	TP
Count	12	10	12	20	12	13	7	7	1	8	8	8	10	5

Note: NH_3+ NH_4-N = ammonium plus ammonia as nitrogen. OrgN = organic nitrogen, TKN = total Kjeldahl nitrogen (organic N plus NH_3+ NH_4-N), NO_2+NO_3-N = nitrite plus nitrate as nitrogen, TN = total nitrogen, SRP = soluble reactive phosphorus, TP = total phosphorus.

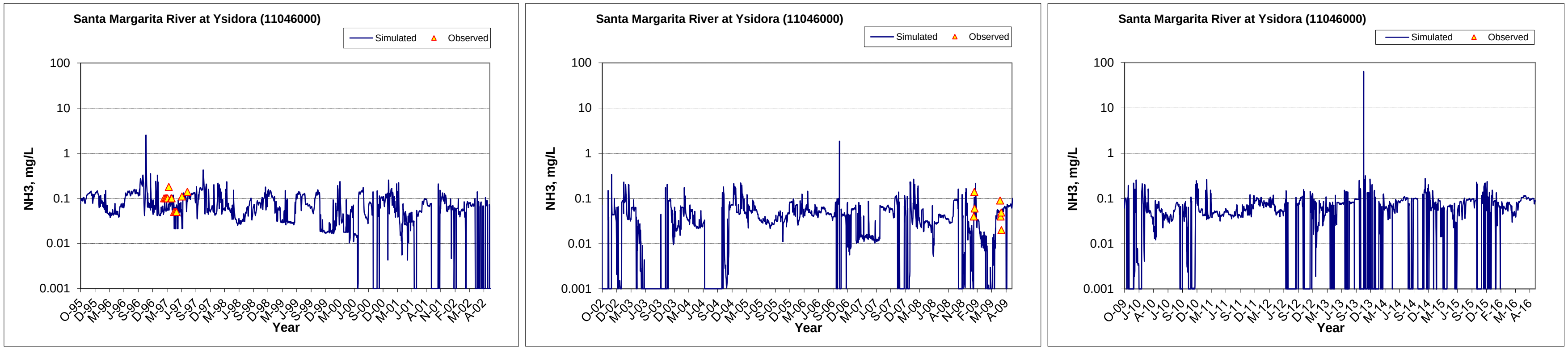


Figure 5-68. Time Series of Observed and Simulated Ammonia Nitrogen (NH_3+ NH_4-N) Concentration at Santa Margarita River at Ysidora (11046000)

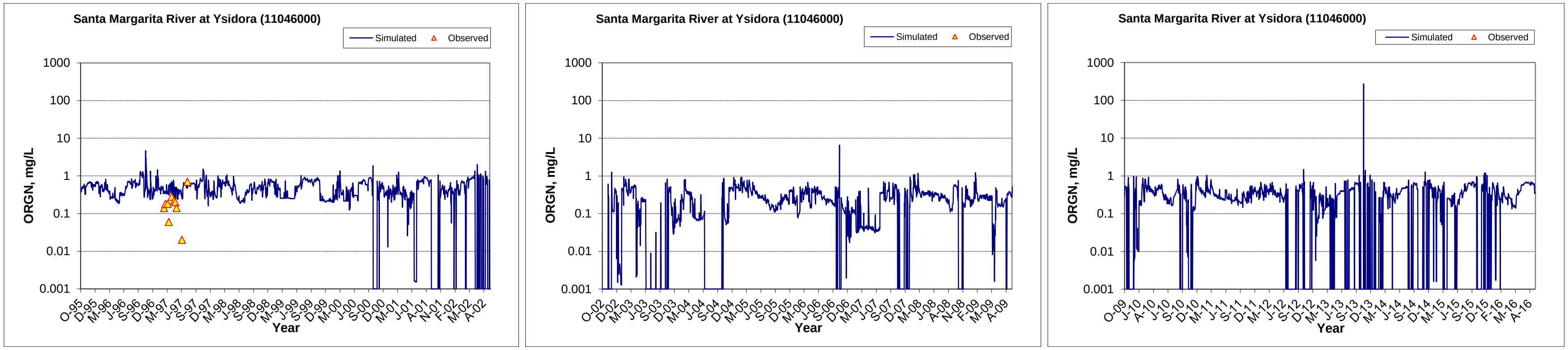


Figure 5-69. Time Series of Observed and Simulated Organic Nitrogen (OrgN) Concentration at Santa Margarita River at Ysidora (11046000)

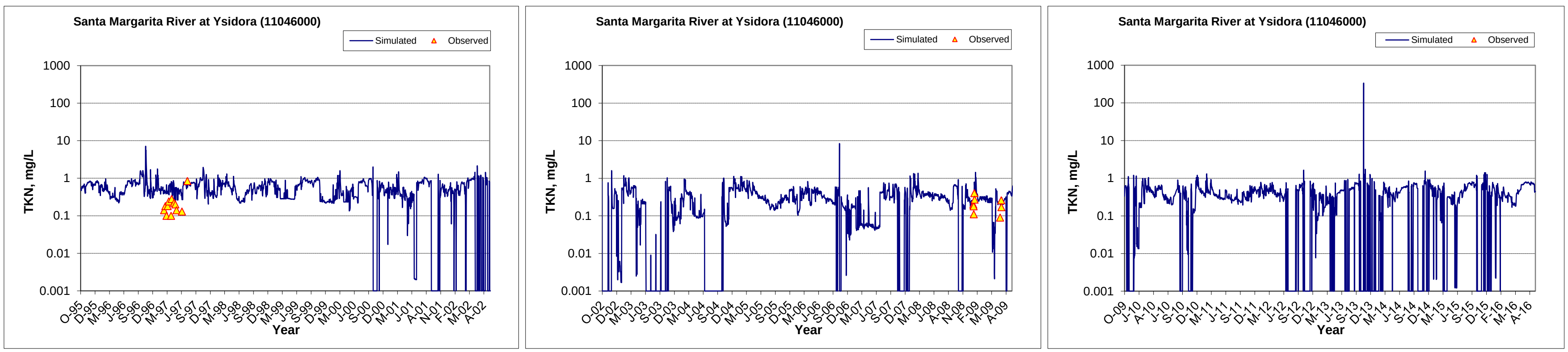


Figure 5-70. Time Series of Observed and Simulated Total Kjeldahl Nitrogen (TKN) Concentration at Santa Margarita River at Ysidora (11046000)

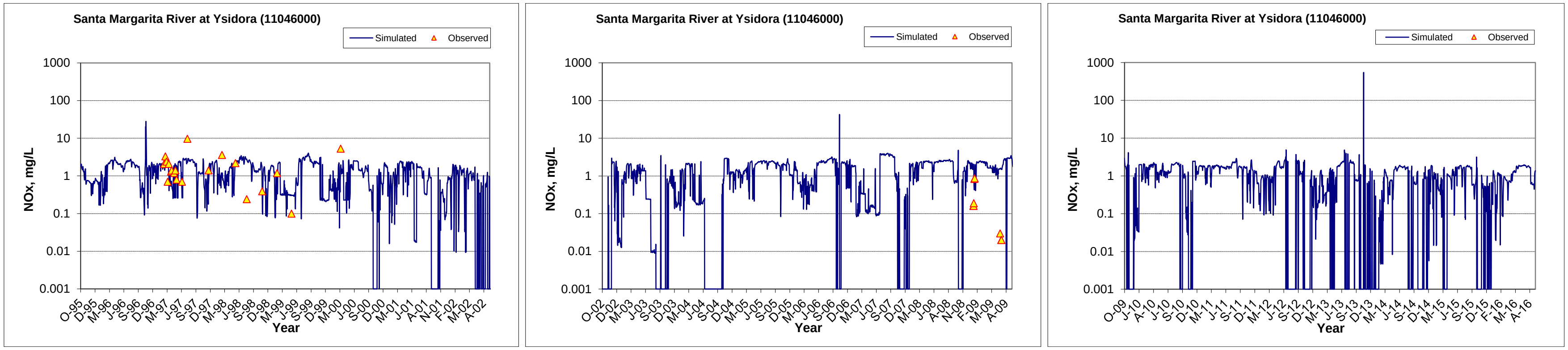


Figure 5-71. Time Series of Observed and Simulated Nitrite+ Nitrate Nitrogen (NOx) Concentration at Santa Margarita River at Ysidora (11046000)

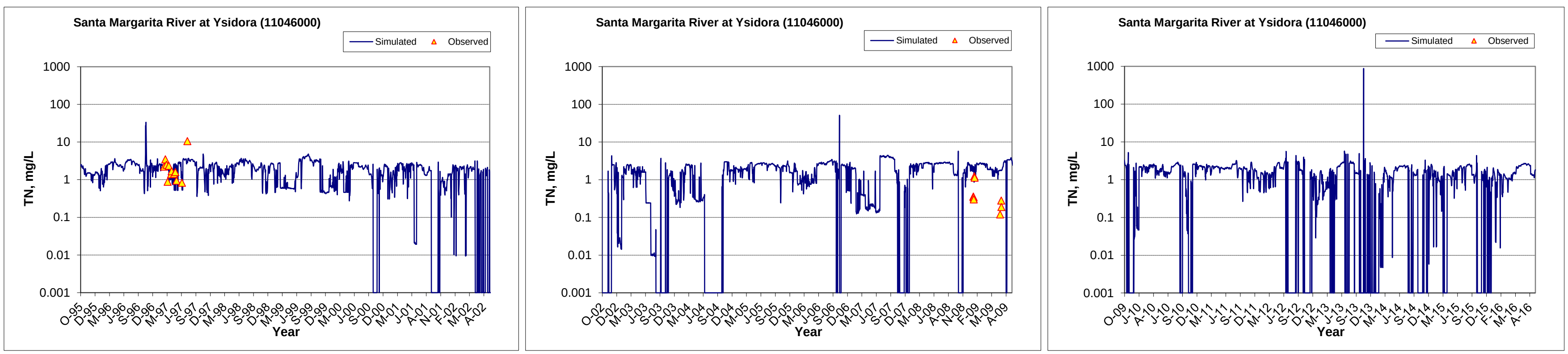


Figure 5-72. Time Series of Observed and Simulated Total Nitrogen (TN) Concentration at Santa Margarita River at Ysidora (11046000)

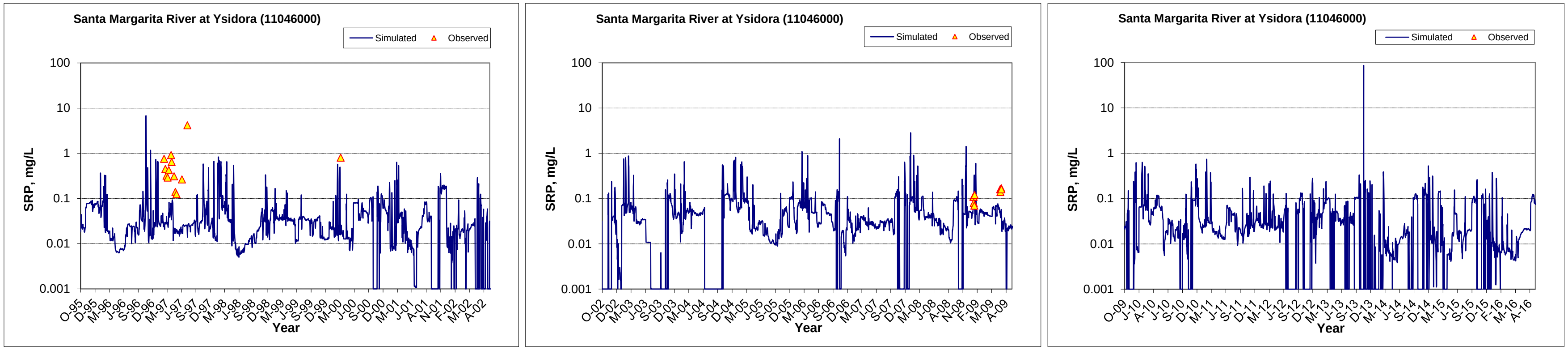


Figure 5-73. Time Series of Observed and Simulated Soluble Reactive Phosphorus (SRP) Concentration at Santa Margarita River at Ysidora (11046000)

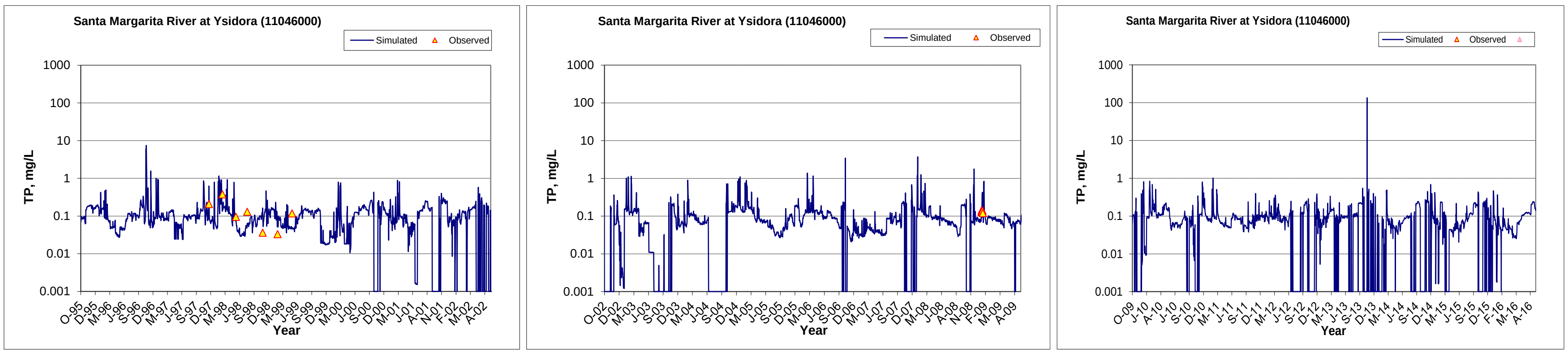


Figure 5-74. Time Series of Observed and Simulated Total Phosphorus (TP) Concentration at Santa Margarita River at Ysidora (11046000)

5.6.2.11 Santa Margarita River nr Macs Road (MLS-1)

Sample records are limited at MLS-1, the most downstream sampling site used for the model nutrient calibration. Unlike most upstream sampling locations, nutrient concentrations were frequently measured during wet weather conditions.

Table 5-20. Water Quality Calibration Statistics at Santa Margarita River near Macs Road (MLS-1)

Metric	Validation (WY 1996 – WY 2007)							Calibration (WY 2008 – WY 2016)						
	NH_3+ NH_4-N	OrgN	TKN	NO_2+ NO_3-N	TN	SRP	TP	NH_3+ NH_4-N	OrgN	TKN	NO_2+ NO_3-N	TN	SRP	TP
Count	1	1	3	4	3	0	1	13	7	18	20	15	0	22

Note: NH_3+ NH_4-N = ammonium plus ammonia as nitrogen. OrgN = organic nitrogen, TKN = total Kjeldahl nitrogen (organic N plus NH_3+ NH_4-N), NO_2+NO_3-N = nitrite plus nitrate as nitrogen, TN = total nitrogen, SRP = soluble reactive phosphorus, TP = total phosphorus.

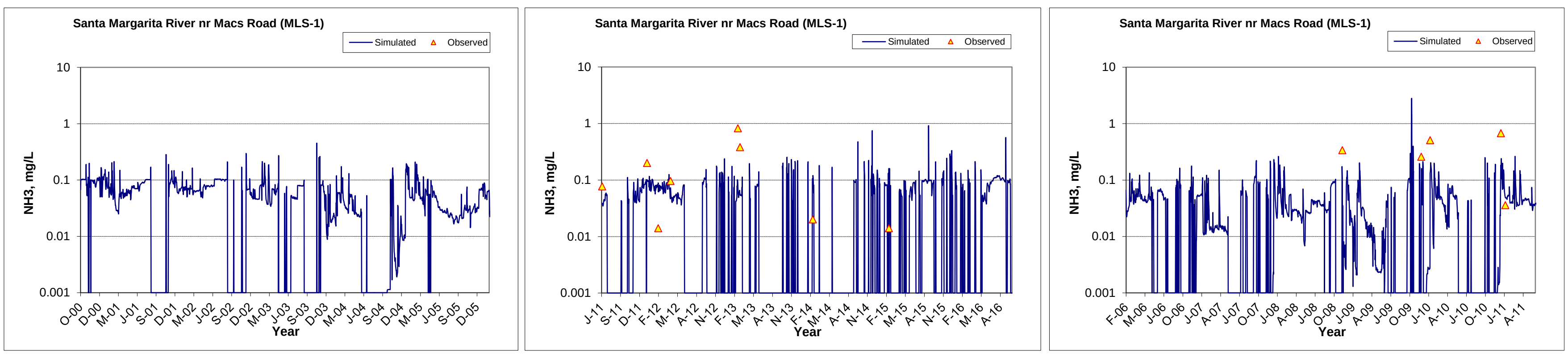


Figure 5-75. Time Series of Observed and Simulated Ammonia Nitrogen (NH_3+ NH_4-N) Concentration at Santa Margarita River nr Macs Road (MLS-1)

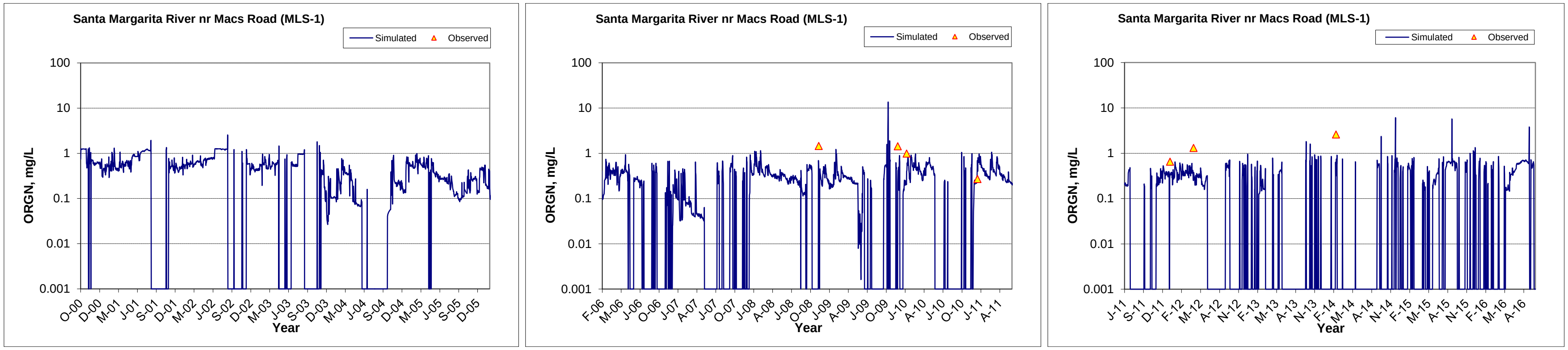


Figure 5-76. Time Series of Observed and Simulated Organic Nitrogen (OrgN) Concentration at Santa Margarita River nr Macs Road (MLS-1)

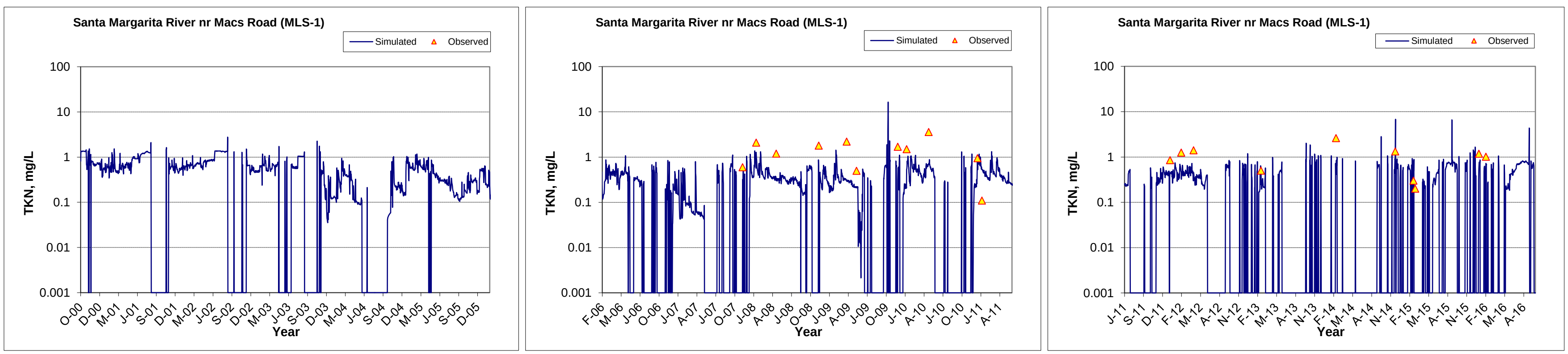


Figure 5-77. Time Series of Observed and Simulated Total Kjeldahl Nitrogen (TKN) Concentration at Santa Margarita River nr Macs Road (MLS-1)

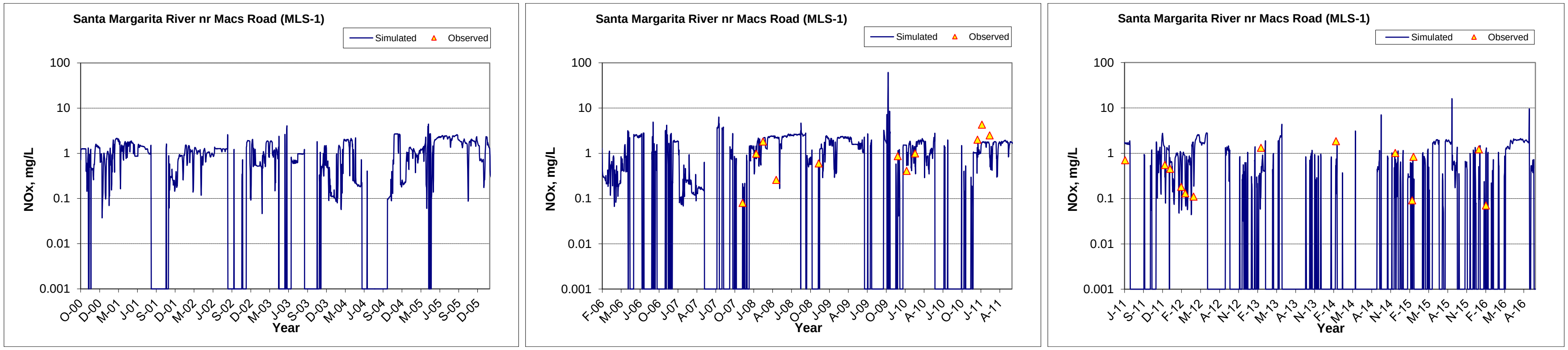


Figure 5-78. Time Series of Observed and Simulated Nitrite+ Nitrate Nitrogen (NOx) Concentration at Santa Margarita River nr Macs Road (MLS-1)

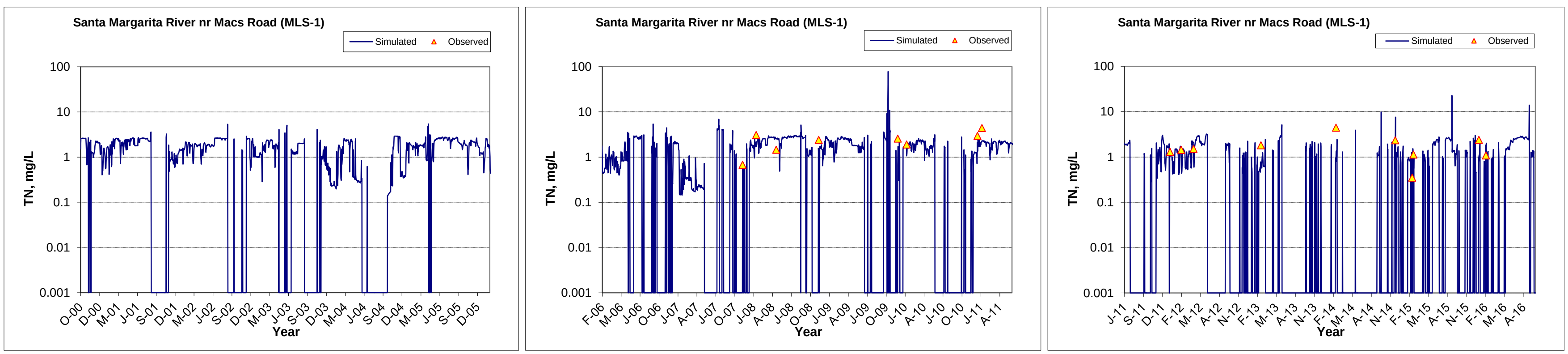


Figure 5-79. Time Series of Observed and Simulated Total Nitrogen (TN) Concentration at Santa Margarita River nr Macs Road (MLS-1)

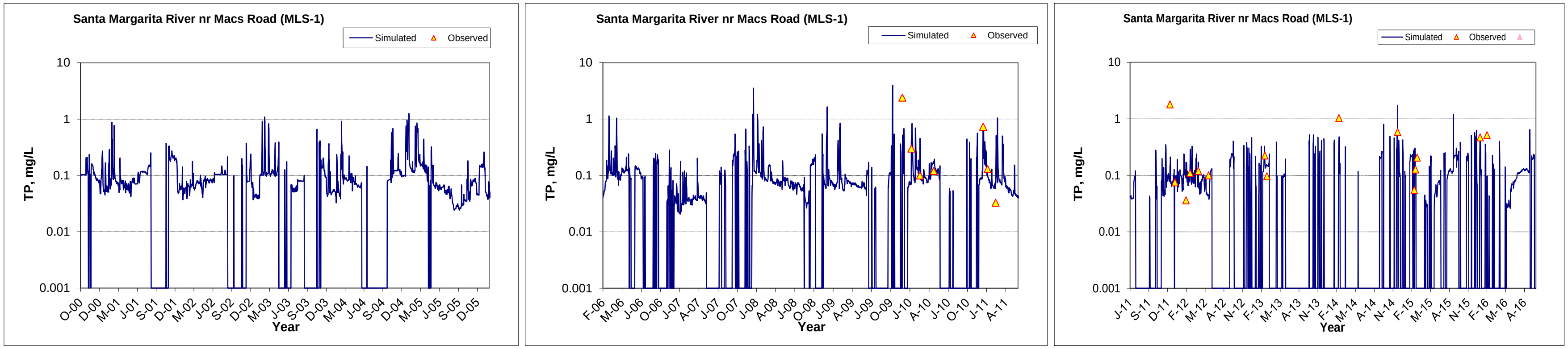


Figure 5-80. Time Series of Observed and Simulated Total Phosphorus (TP) Concentration at Santa Margarita River nr Macs Road (MLS-1)

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