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The Demonstration and Validation of a Linked Watershed Riverine Modeling System for DOD Installations-Calleguas, California

Resource Conservation and Climate Change Projects, RC-201302, Version 2.00

Billy E. Johnson, Mark George, and Zhonglong Zhang

July 2018

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The Demonstration and Validation of a Linked Watershed-Riverine Modeling System for DOD Installations-Calleguas, California

Resource Conservation and Climate Change Projects, RC-201302, Version 2.00

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Under Project Number RC-201302, Demonstration and Validation of a Linked Watershed-Riverine Modeling System for DOD Installations

Abstract

The objective of this project is to demonstrate and validate a linked watershed and riverine modeling system for the Calleguas Creek Watershed. The system helps land managers assess outcomes resulting from military activities; the system also supports installation sustainability through informed watershed management of water, water quality, contaminants, and land-use impacts.

The modeling system was developed and enhanced from existing watershed and riverine models. Hydrological Simulation Program-Fortran (HSPF) was used to compute water flow, soil erosion/sedimentation, nutrients, and contaminant loadings, whereas the Hydrologic Engineering Centers-River Analysis System (HEC-RAS) was used to evaluate instream water quality and aquatic ecosystem responses from watersheds both within and outside an installation.

HSPF simulates, for extended periods of time, the hydrologic and associated water quality processes on pervious and impervious land surfaces and in streams and well-mixed impoundments. Benefits can be derived from the ability of the linked modeling system to determine contaminant loads entering and leaving the installation. In certain locations, this information can be used to identify to what extent the installation is responsible for the impaired waters. In cases where mitigation is necessary, the system will help land managers better assess which scenarios will provide the most environmental benefits for the least financial cost.

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Preface

This study was conducted for the Environmental Security Technology Certification Program (ESTCP) under Project Number RC-201302, "Demonstration and Validation of a Linked Watershed-Riverine Modeling System for DOD Installations." Dr. Kurt Preston served as the ESTCP Program Manager with Mr. Lee Mulkey, Mulkey Consultants, serving as lead technical reviewer.

The work was performed by the Water Quality and Contaminant Modeling Branch (CEERD-EPW) of the Environmental Processing and Engineering Division (CEERD-EP), U.S. Army Engineer Research and Development Center, Environmental Laboratory (ERDC-EL). At the time of publication, Mr. Mark Noel was Chief, CEERD-EPW; Mr. Warren Lorentz was Chief, CEERD-EP; and Dr. Elizabeth Ferguson, CEERD-EZT, was the Senior Science Technical Manager and Lead Technical Manager for Environmental Quality and Installations. The Deputy Director of ERDC-EL was Dr. Jack Davis and the Director of ERDC-EL was Dr. Ilker Adiguzel.

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At the time of publication, COL Bryan S. Green was the Commander of ERDC, and Dr. David W. Pittman was the Director.

Summary

Objectives of the Demonstration

The objective of this project was to evaluate a linked watershed and riverine modeling system for Calleguas Creek Watershed, California, against observed field data and against output from the watershed model/Hydrologic Simulation Program-Fortran only (HSPF-only). HSPF was simulated from WY1998 to WY2009. The model evaluation consisted of calibrating the models for the period of record from WY2005-WY2009 (HSPF-only) and October 2007 to September 2009 (linked models), validating the models for water year (WY)1998-WY2004 (HSPF-only) and January 2003 to September 2005 (linked models). The Hydrologic Engineer Center-River Analysis System (HEC-RAS) model validation period was extended to 2001-2005, if additional sediment and water quality data were available. The management scenarios were performed for HSPF-only and linked models for WY2005-WY2009. In some cases, the linked model simulation period is shorter than HSPF-only because observed water quality data were limited for the mainstem Calleguas Creek, and the current HEC-RAS is not stable for dry periods where base flows may not exist in the stream. This is a shortcoming that will need to be addressed in the model if it is to be used on intermittent streams. Where applicable, the performance objectives (Nash-Sutcliffe Efficiency (NSE), percent bias (PBIAS), and RSR) were computed for streamflow, sediment, hardness, chloride, copper, nickel, mercury, selenium, total phosphorus, orthophosphorus, total nitrogen, and nitrate using both daily and monthly average model predictions and measured data.

Technology Description

HSPF was used to compute runoff, sediment, contaminant and nutrient loadings, whereas HEC-RAS was used to evaluate in-stream flow, channel sedimentation, and the fate/transport of contaminants and nutrients.

HSPF simulates the hydrologic and associated water quality processes on pervious and impervious land surfaces and in streams and well-mixed impoundments for extended periods of time, thus providing a valuable tool to land managers. Since HSPF is more comprehensive than most watershed systems, it permits effective planning.

The HEC-RAS system contains four one-dimensional river analysis components for (1) steady-flow water surface profile computations; (2) unsteady-flow simulation; (3) movable boundary sediment transport computations; and (4) water quality analysis (via the Nutrient Simulation Module (NSM) and the Contaminant Simulation Module (CSM)). A key element is that all four components use a common geometric data representation and common geometric and hydraulic computation routines.

Demonstration Results

The watershed only and linked modeling system performance was evaluated using both quantitative and qualitative measures. The quantitative measures used were performance evaluation statistics, and the qualitative measures used were visual comparisons of simulated and observed time series. There were sufficient daily streamflow records to compute the required statistics for the three time periods mentioned above. For sediment, contaminants, and nutrients, the availability of samples was sparse relative to the time period over which sampling was completed (approximately one sample per month for most parameters); thus, in some cases, only qualitative measures were evaluated.

The following is a summary of model performance as related to the performance objectives discussed in more detail within Chapter 3.

Performance Objective 1 – Linked model accurately simulates major components of hydrologic cycle and stream flow

Sections 5.4.1 and 6.1.1 describe the performance of the HSPF-only and the linked model for the calibration and validation of daily average and monthly flows. Based on the performance ratings, the HSPF-only model was not able to produce acceptable daily streamflow results for the model calibration period, but produced “very good” monthly streamflow results for nearly all statistics and locations. In general, shorter time steps produce poorer model simulations than longer time steps (e.g., daily versus monthly or yearly) (Engel et al. 2007). When visually comparing daily flow results, the HSPF-only model appeared to overpredict flows at Revolon Slough and underpredict peak flows at California State University Channel Islands (CSUCI) and Conejo Creek, but on the whole represented the overall hydrograph shape and timing within reasonable limits. Based on the performance ratings and visual comparison of modeled and

observed hydrographs, the linked model was able to produce satisfactory daily and monthly flow results for its calibration period.

Based on the performance statistics and visual comparisons of hydrographs, the HSPF-only model was able to produce satisfactory flow results during the validation period for both daily and monthly streamflow simulation. The linked model was also able to produce satisfactory monthly flow results when compared to the performance statistics and hydrograph plots, but failed to meet the NSE criteria for simulation of daily streamflow for the validation period, although the computed NSE was near the threshold.

In conclusion, the HSPF-only model performed better during the validation than during calibration for daily streamflow simulation, but it performed equally well for both the calibration and validation periods for monthly streamflow simulation. Increases in model performance for the validation period could be attributed to a number of factors; however, one of the main reasons was likely the longer simulation timeframe for the validation period. The linked model performed equally well in simulating monthly streamflow volumes for both the calibration and validation periods, but it performed slightly better at simulating daily streamflow for the calibration period relative to the validation period.

Performance Objective 2 – Linked model accurately simulates soil erosion and sediment transport

Sections 5.4.2 and 6.1.2 describe the performance of the HSPF-only and the linked model for the calibration and validation of daily average and monthly sediment simulation. The statistical performance evaluations were based on observed concentrations, not loads. The HSPF-only model produced satisfactory daily average results for all three metrics for both the calibration and validation periods for simulation of TSS concentrations. The HSPF-only model met the monthly percent bias (PBIAS) threshold for both the calibration and validation period, but did not meet NSE and RSR thresholds for monthly average results. This may be due to the relatively low number of samples used to compute observed monthly averages (often just one sample per month) and not necessarily an indication of the model's failure to represent monthly average conditions. Visual inspection of simulated concentration time series

indicates the HSPF-only model accurately simulates baseflow and storm flow total suspended sediment (TSS) concentrations.

Based on review of the daily calibration performance statistics for the linked model, the model was not able to produce satisfactory NSE or RSR statistics based on daily results for TSS. The visual plots indicate that the linked model was able to capture the temporal variation of observed TSS at the CSUCI location. From reviewing the daily validation performance statistics for the linked model, the model was able to produce satisfactory daily results with NSE, RSR, and PBIAS for TSS during this period. The visual plots indicate that the linked model was able to capture the temporal variation of observed TSS at the CSUCI location. Due to the inadequacy of the sampling data, monthly calibration and validation performance statistics were not computed for the linked model.

In summary, the HSPF-only and linked model was judged to successfully simulate sediment in the watershed and riverine environments.

Performance Objective 3 – Linked model accurately simulates contaminant fate and transport

Sections 5.4.2 and 6.1.2 describe the performance of the HSPF-only and the linked model for the calibration and validation of daily average and monthly contaminants. The HSPF-only model met all three statistical targets for daily average results for chloride, copper, and nickel for the calibration period and for chloride and mercury for the validation period. The other contaminants simulated met at least one statistical threshold. All contaminants simulated met PBIAS targets for the calibration and validation periods for both daily and monthly average results. The only contaminants to meet statistical thresholds for simulation of monthly average concentrations were nickel for the calibration period and copper and mercury for the validation period. This may be due to the relatively low number of samples used to compute observed monthly averages (often just one sample per month) and not necessarily an indication of the model's failure to represent monthly average conditions. Visual inspection of simulated concentration time series indicates the HSPF-only model generally matched high-flow and low-flow variability in observed contaminant concentrations, but it tended to overpredict low-flow hardness, copper, and selenium concentrations.

Based on review of the daily calibration performance statistics for the linked model, the model was not able to produce satisfactory daily results for copper. PBIAS indicated very good results with dissolved copper in streamflow; however, copper had unsatisfactory daily NSE and RSR statistics. The visual plots indicate that the linked model was able to capture the temporal variation of observed copper at the CSUCI location. Based on review of the daily validation performance statistics for the linked model, the model was able to produce satisfactory daily results with PBIAS for copper. Dissolved copper had unsatisfactory daily NSE and RSR. The visual plots indicate that the linked model was able to capture the temporal variation of observed copper at the CSUCI location. Due to the inadequacy of sampling data, monthly calibration and validation performance statistics were not computed for the linked model.

In summary, the HSPF-only model was judged to successfully simulate daily observed contaminant concentrations for some constituents and time periods, but was unsuccessful for other constituents and time periods, as described above. Therefore, the calibration results for the linked model were not fully satisfactory; however, the validation results indicate that the model was able to satisfactorily simulate contaminants when compared to field observations.

Performance Objective 4 – Linked model accurately simulates nutrient fate and transport

Sections 5.4.3 and 6.1.3 describe the performance of the HSPF-only and the linked model for the calibration and validation of daily average and monthly nutrient simulation. The statistical performance evaluations were based on observed concentrations, not loads. The HSPF-only model met PBIAS targets for all nutrient species evaluated (total phosphorus, orthophosphate, total nitrogen, and nitrate) for simulation of both daily and monthly averages for both the calibration and validation periods. The HSPF-only model did not meet NSE and RSR thresholds for either daily or monthly averages for both the calibration and validation periods, with the exception of the daily nitrate RSR value for the calibration period. Visual inspection of time series plots indicates the HSPF-only model tends to underpredict peak phosphorus concentrations and overpredict total nitrogen and nitrate concentrations.

Based on review of the daily calibration performance statistics for the linked model, the model was not able to produce satisfactory daily results for TP, TN, NH_4 and NO_3. PBIAS indicated very good results for these constituents in streamflow; however, these constituents had unsatisfactory results for daily NSE and RSR. The visual plots shown indicate that the linked model was able to capture the temporal variation of observed data at the CSUCI location. Based on review of the daily validation performance statistics for the linked model, the model was not able to produce satisfactory daily results for TP, TN, NH_4, and NO_3. PBIAS indicated overall satisfactory results for these constituents in streamflow; however, these constituents had unsatisfactory results for daily NSE and RSR. The visual plots indicate that the linked model was able to capture the temporal variation of observed data at the CSUCI location. Given the flashy nature of streamflow in the Calleguas Creek system, a field sample taken during a single instance is unlikely to be representative of monthly average conditions, and therefore, while performance statistics were computed, it may be inappropriate to compare monthly average model results against these point-in-time measurements.

In summary, the HSPF-only and linked models were judged unsuccessful in their ability to simulate observed nutrient concentrations. In order to improve the models and the evaluation of their performance, more nutrient samples need to be collected and analyzed, including storm event samples to characterize nutrient concentrations and loads during high-flow conditions.

Performance Objective 5 – Management Scenarios

Section 6.2 describes the performance of the HSPF-only and the linked model relative to simulating the effect of management scenarios. The scenario simulated was a hypothetical land use conversion scenario, in which 50% of open space land use was converted to agricultural land use in the Arroyo Las Posas area and 50% of open space land use was converted to developed land uses (residential and commercial/industrial) in the Arroyo Simi headwaters area. Both models appeared to simulate reasonable flow conditions based on the management scenarios implemented within the models. Sediment and contaminant simulations differed slightly between the HSPF-only and linked models, but that is to be expected given the differences in sediment and contaminant formulations found within the in-stream portions of the models.

Differences in nutrient simulation between the two models seemed to be the most pronounced. One challenge with comparing HSPF-only and linked (HSPF/HEC-RAS) model results is that the in-stream portions of the models compute nutrient kinetics differently. In addition, overland water quality state variables do not directly match up with water quality variables in HEC-RAS, a circumstance that requires the modeler to estimate boundary condition input for some in-stream state variables within HEC-RAS and causes differences in nutrient concentrations between the HSPF-only and HSPF/HEC-RAS models.

In summary, more work needs to be done to improve the linkage of HSPF output to HEC-RAS and to evaluate the relative benefits of the linked modeling approach with respect to simulating management scenarios. In particular, robust observed water quality data sets need to be identified, in order to more accurately represent and calibrate the fate and transport of nutrients within HEC-RAS. In order to better evaluate how the modeling systems are able to simulate sediment, contaminant, and nutrient effects due to land use changes, management scenarios need to be carried out in conjunction with field data collection.

Performance Objective 6 – Data Availability

Ventura County personnel served as local resources to assist in the data gathering and model conceptualization. There were sufficient national and local datasets available to develop the needed model inputs for both HSPF and HEC-RAS.

In regard to field data collection, there were sufficient streamflow data to perform model calibration and validation and generate the required statistics for storm event periods; however, HEC-RAS model instability issues encountered during simulation of low- or zero-flow conditions necessitated the use of a different (shorter) simulation period for HEC-RAS than for the HSPF-only model. There were sufficient observed water quality data to perform statistical evaluations at one location in the watershed for simulation of daily average concentrations. The sampling frequency for the various water quality parameters was approximately once per month; therefore, most “monthly average” observations represented only a single sample. Given the flashy nature of streamflow in the Calleguas Creek system, a field sample taken during a single instance is very unlikely to be representative of monthly average conditions;

consequently, it may be inappropriate to compare monthly average model results against these point-in-time measurements. All visual and statistical performance evaluations were based on observed sediment, contaminant, and nutrient concentrations, not loads. Comparison of model-simulated loads against data-based estimates of loads would require more extensive monitoring to adequately characterize constituent loading during both high- and low-flow conditions.

Therefore, for Performance Objectives 6.1 to 6.3 respectively, the team judges the demonstration to be adequate but not fully successful.

Performance Objective 7 – Ease of Use

Summarizing ease of use, both models had mature graphical user interfaces that facilitated the set up and simulation of the models. Two professional engineers with master's degrees and more than five years of work experience developed the watershed and riverine models. One of these engineers performed calibration and validation of the models with a senior-level engineer (a PhD with more than 20 years of experience), performing technical peer review of the work. Thus, there were sufficient resources and personnel to run the HSPF-only and linked models. The initial set up of the models took a total of two weeks for the HSPF watershed model and two weeks for the HEC-RAS riverine model. The calibration phase took approximately five months; the validation phase took approximately one month; and the management scenario evaluations required approximately one month. Based on experience in performing these types of studies in the past, the goals the team set in Performance Objectives 7.1 to 7.4 were successfully met.

Implementation Issues

A number of challenges were encountered at this demonstration site, including unique hydrologic characteristics of the Calleguas Creek Watershed that led to model instabilities, a relatively large number of model segments, a relatively long simulation period, observed data limitations, and a relatively high number of constituents modeled. These challenges presented opportunities for applying lessons learned when using the linked watershed-riverine models in the future.

Several hydrologic characteristics of the Calleguas Creek Watershed presented challenges for the water quality calibration. Streamflow

throughout the system is relatively flashy, with the majority of discharge occurring during winter months, followed by extended low-flow periods where the only sources of streamflow are groundwater inflow, municipal point source discharges, and pumping from groundwater dewatering wells. A large fraction of the HSPF reach/reservoir segments (RCHRES) have zero outflow for greater than 90% of the simulation period. Simulated reach outflows of zero or nearly zero often occurred in RCHRES with no groundwater inflow routed to them (e.g., in the Arroyo Simi headwaters) or no contributing area (e.g., several RCHRES representing debris basins). Additionally, several RCHRES along the main river channel were characterized with a subsurface loss pathway that often exceeded the downstream flow pathway during low-water depth conditions. HSPF simulates unrealistically large in-stream water quality constituent concentrations or returns erroneous values (-1.0E+30) when simulated outflows are at or near zero. While this model behavior has been documented by LimnoTech (LimnoTech 2014) and others (Benham et al. 2006, Seong et al. 2013) in past HSPF applications, the frequency of zero-reach outflow conditions in the Calleguas Creek model was extreme.

The low-flow and zero-flow occurrences also caused model stability challenges for HEC-RAS, especially near abrupt vertical transitions and near the bridges, which led to fatal model instability. Several HEC-RAS model refinements were required to stabilize the model, including setting a minimum upstream boundary condition flow rate of 100 cfs, decreasing the computational timestep, and increasing cross-section resolution.

Although streamflow data were sufficient for calibration and validation to daily and monthly average conditions, sediment, contaminant, and nutrient data were relatively sparse. The sampling frequency for the various water quality parameters was approximately once per month and therefore most “monthly average” observations represented just a single sample. Given the flashy nature of streamflow in the Calleguas Creek system, a field sample taken during a single instance is very unlikely to be representative of monthly average conditions. Therefore, it may be inappropriate to compare monthly average model results against these point-in-time measurements. Additionally, all statistical evaluations of model performance were made using measured and model-predicted concentrations, not loads. However, all watershed model studies cited by Moriasi et al. (2007), which was used to derive the recommended model performance evaluation thresholds presented in this report, used

measured and model-predicted loads when completing statistical evaluations. Therefore, future demonstration sites should either emphasize computation of observed loads from available datasets, or employ alternative performance evaluation metrics and/or relaxed thresholds that have a precedence for use in comparing simulated and observed concentrations.

As noted in the above discussion related to the various performance objectives, available monitoring data were relatively limited for all water quality constituents, including suspended sediment, nutrients, and contaminants. Point-in-time samples collected at a monthly frequency are generally insufficient to characterize either a monthly average concentration or the monthly average load (i.e., when paired with measured streamflow for the same point in time). This is particularly true for an extremely flashy system like Calleguas Creek, which experiences flows that range from near zero to thousands of cubic feet per second in the span of hours to days. For riverine systems such as Calleguas Creek, characterization of constituent transport and fate over monthly to annual timescales requires the development of data-based estimates of loading for key water quality constituents. It follows that the performance of an integrated or linked streamflow / water quality model should be evaluated against data-based loading estimates (e.g., on a monthly scale) in addition to evaluating the capability of the model to reproduce individual, point-in-time observations (which will generally represent low-flow conditions). Because the vast majority of constituent loading in Calleguas Creek occurs during episodic runoff / high-flow events, developing appropriate loading estimates for this system would require a monitoring program that intentionally conducts sampling during high-flow events in addition to periodic sampling during low-flow conditions. A minimum of four to six high-flow events of varying intensity should be monitored for water quality over a one-to-two-year period to capture the range of concentrations and loadings occurring during these events. Ideally, high-flow monitoring events would include the collection of multiple samples during various points in the event hydrograph and/or continuous monitoring (or compositing of samples) via automated sampling equipment, as these approaches would support the most accurate estimates of event-specific loads to support model calibration and validation efforts.

Although the model calibration achieved is as good as can be expected given the measured data limitations and resource constraints of this

project, the Calleguas Creek Watershed linked model water quality calibration could be further evaluated and enhanced to improve the model's predictive capabilities if the following actions are performed: (1) the model simulation period would need to be extended beyond water year 2009 to allow for comparisons against more recently collected water quality measurements, and/or (2) model-predicted loads would need to be compared against the alternate load estimates if estimations of annual, monthly, and/or daily loads become available.

Abbreviations

BASINS	Better Assessment Science Integrating point and Non-point Sources
BMP	Best Management Practice
CASTNET	Clean Air Status and Trends Network
CBOD	Carbonaceous biochemical oxygen demand
CEQ	Council on Environmental Quality
CERL	Construction Engineer Research Laboratory
CSM	Contaminant Simulation Module
CSUCI	California State University Channel Islands
CTT&F	Contaminant Transport, Transformation, and Fate
CWA	Clean Water Act
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DOD	Department of Defense
DSS	Data Storage System
ERDC	U.S. Army Engineer Research and Development Center
ESTCP	Environmental Security Technology Certification Program
EXWC	Expeditionary Warfare Center
FTABLE	Hydraulic Function Table
HEC-DSS	Hydrologic Engineer Center-Data Storage System
HEC-RAS	Hydrologic Engineer Center-River Analysis System
HSPF	Hydrological Simulation Program Fortran
IMPLND	Impervious Land Segment
LIDAR	Light Detection and Ranging
LOADEST	Load Estimator
MDNN	Mercury Deposition Network

MV	Modeled Value
NADP	National Atmospheric Deposition Program
NAVFC	Naval Facilities Engineering Command
NEPA	National Environmental Policy Act
NH4	Ammonium
NO3	Nitrate
NPDES	National Pollutant Discharge Elimination System
NSE	Nash-Sutcliffe Efficiency
NSM	Nutrient Simulation Module
OV	Observed Value
PBIAS	Percent Bias
PCS	Permit Compliance System
PERLND	Pervious Land Segment
PO4	Phosphate
RMSE	Root Mean Square Error
RSR	RMSE-observations standard deviation ratio
SERDP	Strategic Environmental Research and Development Program
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Sediment
UCI	User Control Input
UNET	Unsteady Network
U.S.	United States
USEPA	U.S. Environmental Protection Agency
UG	User's Guidance Report
USGS	United States Geological Survey

WWTP	Wastewater Treatment Plant
WDM	Water Data Management
WY	Water Year

1 Introduction

Background

A linked watershed-river modeling system for the Calleguas Creek Watershed was developed for using existing watershed and riverine models where applicable. The Hydrological Simulation Program (HSPF) was used to compute watershed processes and the Hydrologic Engineering Centers River Analysis System (HEC-RAS) was used to compute river processes. Information was fed from HSPF to HEC-RAS as time series data using the better assessment science integrating point and non-point sources (BASINS) Water Data Management (WDM) database and the HEC Data Storage System (HEC-DSS). A tool was created that allows easy transfer of time series data between the two data storage systems.

HSPF simulates the hydrologic and associated water quality processes on pervious and impervious land surfaces and in streams and well-mixed impoundments for extended periods of time. More comprehensive than most watershed modeling systems, HSPF is a valuable tool for land managers.

The HEC-RAS model contains four one-dimensional river analysis components for (1) steady-flow water surface profile computations; (2) unsteady-flow simulation; (3) movable boundary sediment transport computations; and (4) water quality analysis (via the Nutrient Simulation Module (NSM) and (Contaminant Simulation Module (CSM)). A key element is that all four components use a common geometric data representation and common geometric and hydraulic computation routines. NSM is a set of nutrient kinetic libraries developed within HEC-RAS. NSM computes riverine multiple algal biomass, nitrogen, phosphorus, and carbon cycling, as well as dissolved oxygen (DO), chemical oxygen demand, alkalinity, pH, and pathogens. CSM enables a user to assess the impacts of contaminated areas on military installations and ranges as well as superfund sites. The HEC-RAS/CSM model addresses transport and fate of multi-species and multi-phase contaminants; as a result, it is able to handle military contaminants, such as explosives and heavy metals.

The HSPF and HEC-RAS models were linked via time series data to create a comprehensive watershed modeling tool required to address flow, sediment, contaminant, and nutrient land use impacts at Calleguas Creek Watershed, Ventura County, California. Benefits were derived from the ability of the linked modeling system being able to determine sediment, contaminant, and nutrient loads entering the stream network. The linked modeling system was used to assess the impacts of a hypothetical land use conversion scenario, which demonstrated the usefulness of the system for assessing implementation of future management actions.

Objective of the demonstration

The overall objective of this project is to demonstrate and validate a linked watershed and riverine modeling system, HSPF/HEC-RAS, for DOD installations across varying climatic and hydrologic regions. The linked model is used to assess outcomes resulting from military activities and support installation sustainability through informed watershed management of water, water quality, contaminant, and land-use impacts (where applicable) at all demonstration sites. Simulation results from the linked HSPF/HEC-RAS model are compared against observed field data as well as results from the HSPF-only model using standards for assessing modeling efficacy.

Regulatory drivers

The two major national regulatory drivers at military installations are (1) the National Environmental Policy Act (NEPA); and (2) the Clean Water Act (CWA).

National Environmental Policy Act (NEPA)

NEPA was signed into law by President Richard Nixon on January 1, 1970. Acknowledging the decades of environmental neglect that had significantly degraded the nation's landscape and damaged the human environment, the law was established to foster and promote the general welfare, to create and maintain conditions under which man and nature can exist in productive harmony, and fulfill the social, economic, and other requirements of present and future generations of Americans.

NEPA advanced an interdisciplinary approach to federal project planning and decision-making through environmental impact assessment. This

approach requires federal officials to consider environmental values alongside the technical and economic considerations that are inherent factors in federal decision-making. Environmental impact assessment also calls for the evaluation of reasonable alternatives to a proposed federal action; solicitation of input from organizations and individuals that could potentially be affected; and the unbiased presentation of direct, indirect, and cumulative environmental impacts. This information is used by a federal official before a decision is made. Doing so results in informed—and ultimately, improved—federal decision-making.

Council on Environmental Quality (CEQ) regulations (40 C.F.R. Parts 1500-1508) set the standard for NEPA compliance. They also require agencies to create their own NEPA-implementing procedures. These procedures must meet the CEQ standard while reflecting each agency's unique mandate and mission.

Clean Water Act (CWA)

The CWA establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters. The basis of the CWA was enacted in 1948 and was called the Federal Water Pollution Control Act, but the Act was significantly reorganized and expanded in 1972. "Clean Water Act" became the Act's common name with the 1972 amendments.

Under the CWA, the United States Environmental Protection Agency (USEPA) has implemented pollution control programs such as setting wastewater standards for industry. USEPA also sets water quality standards for all contaminants in surface waters. The CWA made it unlawful to discharge any pollutant from a point source into navigable waters, unless a permit was obtained. USEPA's National Pollutant Discharge Elimination System (NPDES) permit program controls discharges.

Approach

The NEPA requires all federal agencies to evaluate the environmental implications of their plans, policies, programs, and projects. In addition, the CWA regulations concerning water quality and effluent standards have grown exponentially in the past 20 years, and Section 438 of the Energy Independence and Security Act requires restoration of predevelopment hydrology for certain federal development and redevelopment projects.

Military impacts on training lands are well documented and understood (Milchunas et al. 1999). These impacts include soil compaction, complete loss of vegetative cover, increased erosion rates, and shifts from native vegetation communities. Consequently, since streams and rivers are functionally linked to the watershed, training can degrade water quality in the form of sediment, nutrient, and contaminant loading and general decline in aquatic ecosystem health (Quist et al. 2003).

In addition to impacts from military training, deficient land use management practices outside of military installations can also pose a threat to the installation's natural resources and mission readiness. The Department of Defense (DOD) installation missions and assets are increasingly threatened by encroachment, which can include watersheds traversing both public/private and DOD property. Encroachment is often caused by a lack of upstream land management practices that contribute to sediment loading, erosion, trash disposal, invasive plant species, and other environmental and biological stressors that ultimately impact the watershed at the DOD installation and the training mission. Erosion and sediment loading is exacerbated when there is an absence of flood control measures, and the river system at the installation is located within a floodplain. In some cases, DOD installations are located within a Tsunami inundation zone, and installation contained rivers are listed on the 303(d) list of impaired waters. These conditions coupled with a lack of land management practices create an unbalanced system that threatens installation assets, resources, and operational capabilities.

Quantitative assessments of past, current, and future mission impacts on wetland and surface water ecosystems is often a difficult task requiring expensive monitoring efforts. Changing and/or extreme weather events and improper loading of a river with a variety of contaminants creates a high level of variability and uncertainty to preserving installation habitat(s), operation and maintenance of facilities, and conducting night/day military training exercises. As such, watershed modeling systems are becoming increasingly critical in assessing mission impact and managing military training lands. In order to demonstrate the linked modeling system's ability to assess past, current, and future mission impacts, the project team will coordinate with local land managers to identify appropriate land use coverage to account for temporal changes in cover type. In addition, the project team will contact the Integrated

Training Area Management program to see whether these data sets exist and can be made available for the various demonstration sites.

Installation decision makers require a system that enables proactive decision-making and strategic investments that support erosion and flood-control measures, pollutant-loading prevention, and critical-habitat preservation. The system should also support mission readiness as a result of unhindered military training exercises and it should promote buy-in from a variety of stakeholders. The linked HSPF-HEC-RAS (HSPF/HEC-RAS) model will provide predictions so that managers can determine optimum times for training, in addition to being used to evaluate mitigation scenarios supporting issues with flow, sediment, and/or constituent runoff. The chosen models are mechanistic models with a track record of performing military as well as non-military analyses. They are all capable of using available national databases and cover all climatic regions, hence making them transferrable to all military installations. A demonstration and validation project is required to assess and quantify the overall performance of the linked modeling system. Specifically, the demonstration project aimed to quantify the accuracy of the linked system compared with the HSPF-only model performance and documented the added information provided by the linked system that the HSPF-only model does not provide.

2 Technology/Methodology Description

This section provides an overview of the linked modeling system and its components, as well as a brief discussion of the technology's advantages and limitations.

Technology/methodology overview

The linked modeling system provides predictions so that training range managers can determine optimum times for training in addition to being used to evaluate mitigation scenarios supporting issues with flow, sediment, and/or constituent runoff.

For each demonstration site, the modeling system was developed from existing watershed and riverine models, if possible. Otherwise, new models were developed using existing national, regional, and local data sets. The chosen modeling systems were composed of mechanistic models with a track record of performing military as well as non-military analyses. They are all able to use available national databases and cover all climatic regions, thereby making them transferrable to all military installations. Where local data exists, the models were able to incorporate them into the model construct. Typically local data such as land use/land cover, channel cross sections, installation facilities, stream flows, constituent flows, precipitation, and meteorological data were locally available and required by the models.

The modeling systems are available for download along with detailed documentation describing the model theory and users' manuals to help in training people on their use. These modeling systems have been used across broad spatial (acres to many square miles) and temporal scales (seconds to years), which allows the flexibility to solve a host of environmental modeling problems associated with military installations. These modeling systems require the user to have a working knowledge of hydraulics, hydrology, erosion and sedimentation, and water quality. Typically a person with a Bachelor of Science degree in the Water Resources and Land Management technical areas, along with two to five years of work experience, will be able to set up, use, and interpret model results.

Computationally, both of the models (HSPF and HEC-RAS) are able to simulate years to decades in a matter of minutes to a few hours of

computer time. These models are mature systems that have excellent documentation and training opportunities. For each system, a user should be able to take a one-to-two-week training session, per model, and be able to set up, parameterize, and run the respective model.

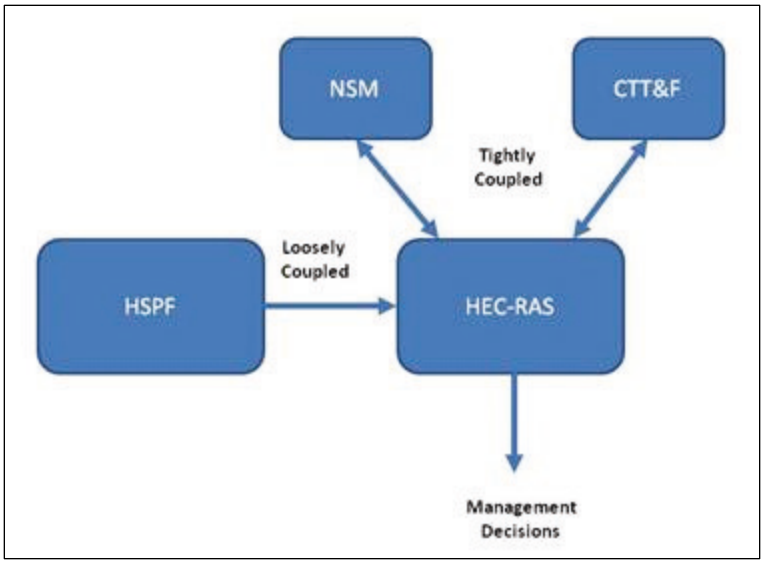
As with any numerical model, these models do need to be calibrated and validated for each new application site. If these models are used over a long period of time, then it may be necessary to recalibrate them as more data becomes available. In calibrating either model, a sufficiently long data set needs to be gathered so that model results can be compared with field observations. One portion of the data set is used for the calibration phase and the remainder of the period of record is used to validate the model parameters. In the calibration phase, those parameters that are deemed most sensitive to the simulations are allowed to vary within acceptable ranges until the model results best fit the field observations. Once this has been accomplished, then the remainder of the period of record is used to simulate model results with the parameters unadjusted. If the model results are able to reproduce the field observations within acceptable error criteria then the model is said to be validated and useful for making predictions. This process, while not difficult, can be time-consuming due to having to make many model runs and parameter adjustments.

For Calleguas Creek Watershed, HSPF was used to compute watershed processes, while HEC-RAS was used for the riverine environment. HSPF simulates the hydrologic and associated water quality processes on pervious and impervious land surfaces and in streams and well-mixed impoundments for extended periods of time. HSPF is a valuable tool for land managers. Because it is more comprehensive than most systems, HSPF enables effective planning. The benefits to the user include

- Flexibility in solving a wide range of water quantity and quality problems using a single model
- Convenient data management features that save time and money
- Modular program structure, which facilitates program changes and additions for special applications

While HSPF encompasses flow, sediment, nutrients, and contaminants within its model formulations, HEC-RAS has been integrated with NSM and CSM (formerly Contaminant Transport, Transformation and Fate (CTT&F), thus providing flow, sediment, nutrient, and contaminant fate and transport within the riverine environment, Figure 2.1.

Figure 2.1. Model integration strategy.



HSPF (Hydrological Simulation Program—Fortran)

HSPF simulates for extended periods of time the hydrologic—and associated water quality—processes on pervious and impervious land surfaces and in streams and well-mixed impoundments. The model uses continuous rainfall and other meteorological records to compute streamflow hydrographs and pollutographs (Bicknell et al. 2005). HSPF simulates interception soil moisture, surface runoff, interflow, base flow, snowpack depth and water content, snowmelt, evapotranspiration, ground-water recharge, dissolved oxygen, biochemical oxygen demand, temperature, pesticides, conservatives, fecal coliforms, sediment detachment and transport, sediment routing by particle size, channel routing, reservoir routing, constituent routing, pH, ammonia, nitrite-nitrate, organic nitrogen, orthophosphate, organic phosphorus, phytoplankton, and zooplankton. The program can simulate one or many pervious or impervious unit areas discharging to one or many river reaches or reservoirs. Frequency-duration analysis can be done for any time series. Any time step from one minute to one day that divides equally into one day can be used. Any period from a few minutes to hundreds of years may be simulated. HSPF is generally used to assess the effects of land-use change, reservoir operations, point or nonpoint source treatment alternatives, flow diversions, etc. Programs, available separately, support data pre-processing and post-processing for statistical and graphical analysis of data saved to the Water Data Management (WDM) file.

Pervious land segments

A land segment (polygon) is a subdivision of the simulated watershed. The boundaries are established according to the user's needs, but generally, a segment is defined as an area with similar hydrologic characteristics. For modeling purposes, water, sediment, and water quality constituents leaving the watershed move laterally to a downslope segment or to a reach/reservoir. A segment of land that has the capacity to allow enough infiltration to influence the water budget is considered pervious. In HSPF, pervious land segment (PERLND) is the module that simulates the water quality and quantity processes that occur on a pervious land segment.

The primary module sections in PERLND simulate snow accumulation and melt, the water budget, sediment produced by land surface erosion, and water quality constituents by various methods. Other sections perform the auxiliary functions of correcting air temperature for use in snowmelt and soil temperature calculations, producing soil temperatures for estimating the outflow temperatures and influencing reaction rates in the agri-chemical sections, and determining outflow temperatures, which influence the solubility of oxygen and carbon dioxide.

Impervious land segments

In an impervious land segment (polygon), little or no infiltration occurs; however, land surface processes do occur. Snow may accumulate and melt, and water may be stored or may evaporate. Various water quality constituents accumulate and are removed. Water, solids, and various pollutants flow from the segments by moving laterally to a downslope segment or to a reach/reservoir.

The HSPF impervious land segment (IMPLND) module simulates a number of processes, with many of them similar to the corresponding sections in the PERLND module. In fact, since sections with snow and air temperature components perform functions that can be applied to pervious or impervious segments, they are shared by both modules.

Streams and reservoirs

This module simulates the processes that occur in a single reach of an open or closed channel or a completely mixed lake. For convenience, such a processing unit is referred to as a RCHRES. In keeping with the

assumption of complete mixing, the RCHRES consists of a single zone situated between two nodes, which are the extremities of the RCHRES.

Flow through a RCHRES is assumed to be unidirectional. Water and other constituents that arrive from other RCHRESs and local sources enter the RCHRES through a single gate. Outflows may leave the RCHRES through one of several gates or exits. A RCHRES can have up to five outflow exits. Precipitation, evaporation, and other fluxes also influence the processes that occur in the RCHRES, but do not pass through the exits.

HEC-RAS (Hydrologic Engineering Center - River Analysis System)

The HEC-RAS system contains four one-dimensional river analysis components for (1) steady-flow water surface profile computations; (2) unsteady-flow simulation; (3) movable boundary sediment transport computations; and (4) water quality analysis (via NSM and CSM). A key element is that all four components use a common geometric data representation and common geometric and hydraulic computation routines. In addition to the four river analysis components, the system contains several hydraulic design features that can be invoked once the basic water surface profiles are computed.

Steady-Flow Water Surface Profiles

This component of the modeling system is intended for calculating water surface profiles for steady gradually varied flow. The system can handle a full network of channels, a dendritic system, or a single river reach. The steady-flow component is capable of modeling subcritical, supercritical, and mixed-flow regimes water surface profiles.

The basic computational procedure is based on the solution of the one-dimensional energy equation. Energy losses are evaluated by friction (Manning's equation) and contraction/expansion (coefficient multiplied by the change in velocity head). The momentum equation may be used in situations where the water surface profile is rapidly varied. These situations include mixed-flow regime calculations (i.e., hydraulic jumps), hydraulics of bridges, and evaluating profiles at river confluences (stream junctions).

The effects of various obstructions, such as bridges, culverts, weirs, and structures in the floodplain may be considered in the computations. The steady-flow system is designed for application in floodplain management

and flood insurance studies to evaluate floodway encroachments. Also, capabilities are available for assessing the change in water surface profiles due to channel improvements and levees.

Special features of the steady-flow component include multiple plan analyses; multiple profile computations; multiple bridge and/or culvert opening analyses; and split-flow optimization.

Unsteady-Flow Simulation

This component of the HEC-RAS modeling system is capable of simulating one-dimensional unsteady-flow through a full network of open channels. The unsteady-flow equation solver was adapted from the unsteady-network (UNET) model (Barkau 1992; and HEC 1997). The unsteady-flow component was developed primarily for subcritical flow regime calculations. However, with the latest release of HEC-RAS, the model can now perform mixed-flow regime (subcritical, supercritical, hydraulic jumps, and drawdowns) calculations in the unsteady-flow computations module.

HEC-RAS solves the complete one-dimensional Saint-Venant equations of unsteady flow. The model is able to simulate backwater flow effects and a variety of hydraulic structures, thus allowing one to model tidally influenced streams and rivers. As an example, the National Weather Service used HEC-RAS to model the Potomac River under tidal influence (Mashriqui et al. 2010) using observed time series as the tidal boundary conditions.

The hydraulic calculations for cross sections, bridges, culverts, and other hydraulic structures that were developed for the steady-flow component were incorporated into the unsteady-flow module. Special features of the unsteady-flow module include dam break analysis; levee breaching and overtopping; Pumping stations; navigation dam operations; and pressurized pipe systems.

Sediment Transport/Movable Boundary Computations

This component of the modeling system is intended for the simulation of one-dimensional sediment transport/movable boundary calculations resulting from scour and deposition over moderate time periods (typically years, although applications to single flood events are possible).

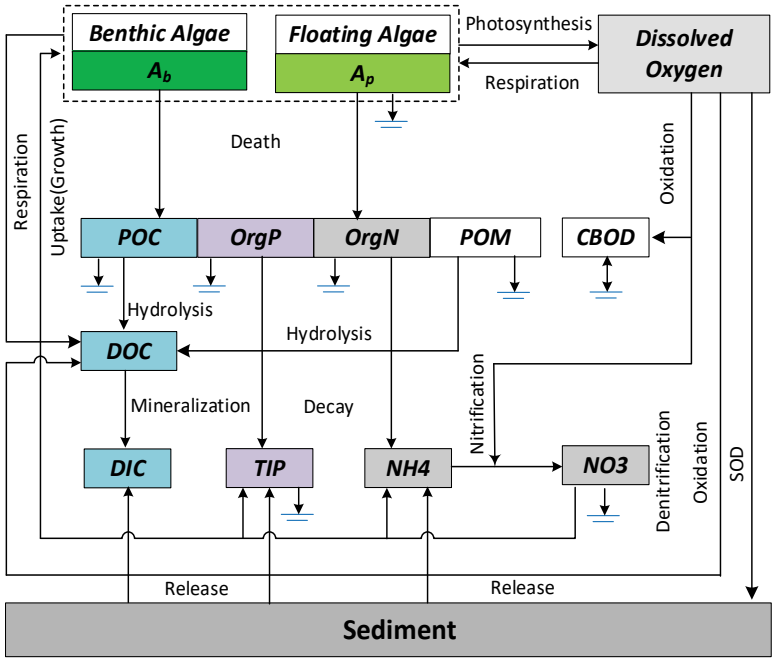
The sediment transport potential is computed by grain-size fraction, thereby allowing the simulation of hydraulic sorting and armoring. Major features include the ability to model a full network of streams, channel dredging, various levee and encroachment alternatives, and the use of several different equations for the computation of sediment transport.

The model is designed to simulate long-term trends of scour and deposition in a stream channel that might result from modifying the frequency and duration of the water discharge and stage, or modifying the channel geometry. This system can be used to evaluate deposition in reservoirs, design channel contractions required to maintain navigation depths, predict the influence of dredging on the rate of deposition, estimate maximum possible scour during large flood events, and evaluate sedimentation in fixed channels.

NSM (Nutrient Simulation Module)

The NSM includes two kinetics: NSMI and NSMII. The levels of NSM are determined by the number of interacting state variables involved in water quality simulation and the degree of their interactions. NSMI simulates nutrients and eutrophication processes using 16 state variables. Water quality state variables may be individually activated or deactivated. Using 24 state variables, NSMII simulates nutrients and eutrophication processes in the water column. Sediment oxygen demand and nutrient release can be simulated using zero-order approach or a sediment diagenesis module. Figure 2.2 provides an overview of the NSMI representation of water quality state variables and major processes involved in the water column. Carbon, nitrogen, and phosphorus have complex cycles that are mediated by physical, chemical, and biotic processes in the water and in the bed sediment. The NSMI consists of three nitrogen species, two phosphorus species, three carbon species (particulate organic carbon, dissolved organic carbon (DOC), and dissolved inorganic carbon). Algae, benthic algae, DO, carbonaceous biochemical oxygen demand (CBOD), pathogen, and alkalinity are also simulated in NSMI.

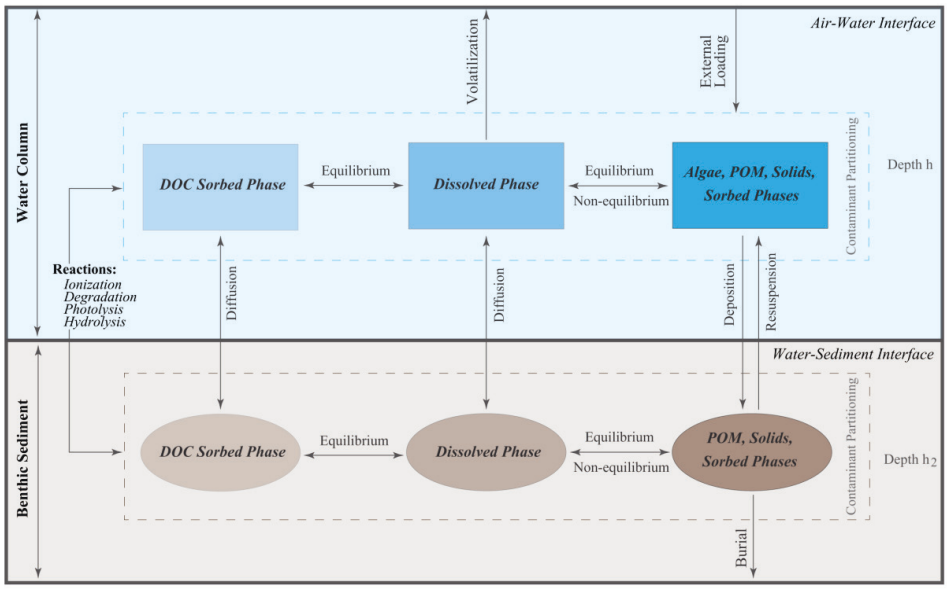
Figure 2.2. Water quality state variables and major processes simulated in NSMI.



CSM (Contaminant Simulation Module)

The CTT&F sub-model was renamed as the Contaminant Simulation Module (CSM) in HEC-RAS. The CSM is capable of modeling contaminants in an aquatic system as influenced by the following processes: ionization, multi-phase partitioning, degradation, photolysis, hydrolysis, volatilization, generalized second-order reaction, and transformations where one chemical undergoes a reaction and is transformed to a daughter product. Any process in CSM can be ignored by the use of switches where such processes are not applicable. Each contaminant in the water column is subject to adsorption and desorption with DOC and solids. The dissolved phase in the bulk water (aqueous phase), the adsorbed phase to DOC in the bulk water, and the adsorbed phases to organic and inorganic solids are simulated in CSM. Two types of contaminant partitioning options are included for algae and solid particulates: equilibrium and non-equilibrium, in which adsorption/desorption can be affected by rate-limiting processes. The water column exchange with underlying sediments and exchange with the atmosphere are also simulated in CSM. The CSM can model multiple contaminants in one simulation. The contaminants themselves are arbitrary, in that the specific contaminant to be simulated is defined through the specification of processes and kinetic rates. The conceptual representation of a water column and sediment contaminant interactions and processes simulated in CSM is depicted in Figure 2.3.

Figure 2.3. Conceptual representation of contaminant processes simulated in CSM.



Advantages and limitations of the technology/methodology

HSPF simulates the hydraulics in the river channel network by using a simplified hydraulic function table (FTABLE) of water depth, surface area, water volume, and outflow of a reach. The FTABLE in the HSPF model is the essential component for flow routing in reaches. It describes a fixed functional relationship between water depth, surface area, water volume, and outflow in the river reach. Under the assumption of a fixed depth, area, volume, and outflow relationship, the HSPF model cannot account for reverse flow and backwater effects to the upstream reaches in a time-dependent way. It is very important to perform the flow-routing process accurately because routed results affect sediment routing and the in-stream contaminant process, both of which are strongly tied to water routing. The limitations of a stand-alone HSPF model (HSPF-only) and the demands of assessing the attainability of contaminant standards derived from the model-based results require additional capabilities not available within HSPF. These needed capabilities will be accomplished through the linked HSPF/HEC-RAS system. For the HEC-RAS boundary requirements, HSPF will provide discharge, sediment, and contaminant loads from the major streams and drainages tributary to the HEC-RAS model segments. HSPF is used to estimate flow, sediment, and water quality loadings based on watershed characteristics and land use practices for all demonstration sites. HEC-RAS is used to estimate in-stream aquatic sediment and contaminant concentrations and to relate these concentrations to the contaminant criteria. Therefore, a linked modeling system,

HSPF/HEC-RAS, should better address regulatory compliance and the range of environmental migration pathways and potential exposures. In order to demonstrate the improvements HSPF/HEC-RAS may have over HSPF-only, the performance objectives (PO 1 through PO 5) discussed in Chapter 3 were assessed for HSPF-only and HSPF/HEC-RAS. In cases where no improvement was observed between HSPF-only and HSPF/HEC-RAS, the factors that contribute to no improvement were discussed and recommendations were made for the cases where a linked modeling system may not be advantageous to an installation.

Given that HSPF/HEC-RAS computes more state variables than HSPF-only, one limitation may be the availability of field data sufficient to calibrate and validate the system for all the required model state variables. The existing data being collected at the various installations were assessed to see whether sufficient data are being collected—and if not, recommendations were made for additional sampling efforts that could improve the models.

Model linkage procedures must consider spatial and temporal characteristics of the systems being linked, correspondence and transference of the state variables between the models, and file format specifics for proper communications between two models. All of these issues were adequately investigated and analyzed to ensure proper representation of the watershed and riverine system.

3 Performance Objectives

Linked modeling system performance objectives are provided in Table 3.1. Performance metrics include qualitative and quantitative parameters. Quantitative parameter threshold values were based on the recommended model performance evaluation statistics from a literature review (ASCE 1993; Moriasi et al. 2007). Qualitative parameters were based on visual comparison of modeled and observed data and previous modeling experience. According to Legates and McCabe (1999), graphical techniques are essential to appropriate model evaluation. A graph is defined as a time series plot of modeled results and observed data throughout the calibration and validation periods. Time series graphs help identify model bias and can identify differences in timing and magnitude of peak flows.

The performance metrics found in Table 3.1 are organized by demonstration/validation study component and methodology component.

As mentioned in Table 3.1, three statistical measures were computed to assess how well the linked modeling system performs when compared to observed data: (1) Nash-Sutcliffe Efficiency (NSE); (2) Percent Bias (PBIAS); and (3) RMSE-observations standard deviation ratio (RSR). Table 3.2 indicates the general performance ratings for recommended statistics for a monthly time step.

Table 3.1. Demonstration validation performance objectives and thresholds.

Performance Objective	Metric	Data Requirements	Success Criteria
Quantitative and Qualitative Performance Objectives			
1. Linked model (HSPF+HEC-RAS) accurately simulates major components of hydrologic cycle and stream flow	1.1. Linked model improves accuracy in simulating monthly observed stream flow at watershed outlet when compared to field observations.	Climate data Stream flow over time at a minimum of one site for each watershed Soil survey Land use/Land cover data Channel cross sections Observed daily flow discharge data	At each site, linked model performance will be evaluated as "successful" if NSE>0.5, RSR<0.7, PBIAS<25% of monthly observed stream flow volume at the watershed outlet. Visual comparison of modeled monthly time series stream flow and observed data is acceptable.
	1.2. Linked model improves accuracy in simulating daily average observed stream flow at watershed outlet when compared to field observations.	Climate data Stream flow over time at a minimum of one site for each watershed Soil survey Land use/cover data Channel cross sections Observed daily flow discharge data	At each site, linked model performance will be evaluated as "successful" if NSE>0.5, RSR<0.7, PBIAS<25% of daily observed stream flow volume at the watershed outlet. Visual comparison of modeled daily time series stream flow and observed data is acceptable.
2. Linked model accurately simulates soil erosion and sediment transport	2.1. Linked model improves accuracy in simulating monthly sediment load discharging from watershed when compared to field observations.	Mass of sediment that discharges from watershed Physical characteristics of riverine sediments Observed suspended sediment concentration data	Linked model performance will be evaluated as "successful" if NSE>0.5, RSR<0.7, PBIAS<55% of monthly sediment load discharging from watershed. Visual comparison of modeled monthly time series stream sediment load and observed data is acceptable.
	2.2. Linked model improves accuracy in simulating daily average sediment load discharging from watershed when compared to field observations.	Mass of sediment that discharges from watershed Physical characteristics of riverine sediments Observed suspended sediment concentration data	Linked model performance will be evaluated as "successful" if NSE>0.5, RSR<0.7, PBIAS<70% of daily sediment load discharging from watershed. Visual comparison of modeled daily time series stream sediment load and observed data is acceptable.

Performance Objective	Metric	Data Requirements	Success Criteria
3. Linked model accurately simulates selected contaminant fate and transport	3.1. Linked model improves accuracy in simulating monthly contaminant load discharging from watershed when compared to field observations.	Mass of contaminant that discharges from watershed Observed contaminant concentration data	Linked model performance will be evaluated as "successful" if NSE>0.5, RSR<0.7, PBIAS <70% of monthly contaminant load discharging from watershed. Visual comparison of modeled monthly time series stream contaminant load and observed data is acceptable.
	3.2. Linked model improves accuracy in simulating daily average contaminant load discharging from watershed compared to field observations.	Mass of contaminant that discharges from watershed Observed contaminant concentration data	Linked model performance will be evaluated as "successful" if NSE>0.5, RSR<0.7, PBIAS<70% of daily contaminant load discharging from watershed. Visual comparison of modeled daily time series stream contaminant load and observed data is acceptable.
4. Linked model accurately simulates nutrient (nitrogen and phosphorus) fate and transport	4.1. Linked model improves accuracy in simulating monthly nutrient load discharging from watershed compared to field observations.	Mass of nutrients that discharge from watershed Observed nutrient concentration data	Linked model performance will be evaluated as "successful" if NSE>0.5, RSR<0.7, PBIAS <70% of monthly nutrient load discharging from watershed. Visual comparison of modeled monthly time series stream nutrient load and observed data is acceptable.
	4.2. Linked model improves accuracy in simulating daily average nutrient load discharging from watershed compared to the field observations.	Mass of nutrients that discharge from watershed Observed nutrient concentration data	Linked models performance will be evaluated as "successful" if NSE>0.5, RSR<0.7, PBIAS <70% of daily nutrient load discharging from watershed. Visual comparison of modeled daily time series stream nutrient load and observed data is acceptable.

Performance Objective	Metric	Data Requirements	Success Criteria
5. Ability of Linked Model to Simulate Management Scenarios	5.1 Linked model is able to simulate the effect of management scenarios on monthly flows, sediment, nutrients, and contaminants	Management Scenarios Same data as stated in Project Objectives (PO) 1.1, 2.1, 3.1, and 4.1.	If no observed data are available, then a visual comparison between base conditions and management scenarios. If observed data are available, then same criteria as stated in POs 1.1, 2.1, 3.1, and 4.1
	5.2 Linked model is able to simulate the effect of management scenarios on daily average flows, sediment, nutrients, and contaminants	Management Scenarios Same data as stated in POs 1.2, 2.2, 3.2, and 4.2.	If no observed data are available, then a visual comparison between base conditions and management scenarios. If observed data are available, then same criteria as stated in POs 1.1, 2.1, 3.1, and 4.1
Qualitative Performance Objectives			
6. Data Availability	6.1. Degree model is capable of using readily available national data sets versus installation specific data to run the model.	All data model required to obtain “successful” results	Most data required for model is readily available in national datasets.
	6.2. If local data are required or useful, degree which it is typically available.	Local data model required to obtain “successful” results	Local data required for model is readily available at installation or able to be obtained with minimal resource requirements
	6.3. Resource requirements to collect local data (if necessary) are acceptable.	Local data model required to obtain “successful” results	Resources required to obtain necessary local data are reasonable in time and cost
7. Ease of use	7.1. Resources and expertise required to run linked model	Interviews with range of personnel and contractors	Resources and expertise to run linked model are reasonable.
	7.2. Time requirement to obtain output variables is reasonable.	Interviews with range of personnel and contractors Time required to run model and summarize results	Engineer with 1 to 5 years of experience in modeling, hydrology, and water quality can run the model in a matter of minutes to hours

Performance Objective	Metric	Data Requirements	Success Criteria
	7.3. Expertise required to setup, parameterize, run, and interpret the results of the model is reasonable.	Interviews with range of personnel and contractors Time required to train on system use	Engineer with 1 to 5 years of experience in modeling, hydrology, and water quality can be trained on model use and results interpretation in 2 weeks. (Based on previous modeling experience)
	7.4. Degree and ease of which the model needs to be calibrated and validated to set the model up at new application site	Interviews with range of personnel and contractors Time required to calibrate and validate model at a new site	Linked model can be set up for one watershed within 2 months. (Based on previous modeling experience) Linked model can be calibrated and validated for one watershed within 4 months. (Based on previous modeling experience)

Table 3.2. General performance ratings for recommended statistics.

Stream Flow			
Statistical Modeling Metrics	Performance Rating	Daily Average	Monthly Average
Nash-Sutcliffe (NSE)	Very Good Good Satisfactory Unsatisfactory	NSE>=0.5	0.75<=NSE<=1.0 0.65<NSE<=0.75 0.5<=NSE<=0.65 NSE<0.5
RMSE-observation standard deviation ratio (RSR)	Very Good Good Satisfactory Unsatisfactory	RSR<0.8	0.0<=RSR<=0.5 0.5<RSR<=0.6 0.6<RSR<=0.7 RSR>0.7
Percent Bias (PBAIS %)	Very Good Good Satisfactory Unsatisfactory	PBIAS<=|35|	PBIAS<|10| |10|<=PBIAS<|15| |15|<=PBIAS<|25| PBIAS<=|25|
Sediment load discharging			
Statistical Modeling Metrics	Performance Rating	Daily Average	Monthly Average
Nash-Sutcliffe (NSE)	Very Good Good Satisfactory Unsatisfactory	NSE>=0.25	NSE>0.4
RMSE-observation standard deviation ratio (RSR)	Very Good Good Satisfactory Unsatisfactory	RSR<0.9	RSR<0.75
Percent Bias (PBAIS %)	Very Good Good Satisfactory Unsatisfactory	PBIAS<=|75|	PBIAS<|15| |15|<=PBIAS<|30| |30|<=PBIAS<|55| PBIAS<=|55|
Water Quality/Nutrients			
Statistical Modeling Metrics	Performance Rating	Daily Average	Monthly Average
Nash-Sutcliffe (NSE)	Very Good Good Satisfactory Unsatisfactory	NSE>=0.35	NSE>0.5
RMSE-observation standard deviation ratio (RSR)	Very Good Good Satisfactory Unsatisfactory	RSR<0.85	RSR<0.7
Percent Bias (PBAIS %)	Very Good Good Satisfactory Unsatisfactory	PBIAS<=|85|	PBIAS<|25| |25|<=PBIAS<|40| |40|<=PBIAS<|70| PBIAS<=|70|

Nash-Sutcliffe efficiency (NSE)

NSE is a normalized statistic that determines the relative magnitude of the residual variance ("noise") compared to the observed data variance ("information"). NSE indicates how well the plot of observed versus modeled data fits the 1:1 line. NSE ranges between -∞ and 1.0 (1 inclusive), with NSE = 1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values <0.0 indicates that the mean observed value is a better predictor than the modeled value, which indicates unacceptable performance.

$$NSE = 1.0 - \frac{\sum_i (OV_i - MV_i)^2}{\sum_i (OV_i - \overline{OV})^2} \tag{3.1}$$

Based on Moriasi et al. (2007), a "successful" NSE for flow, sediment, contaminants, and nutrients will be greater than 0.5.

NSE is the best objective function for reflecting the overall fit of a hydrograph (shape, peak, timing, etc.).

Percent bias (PBIAS)

PBIAS measures the average tendency of the modeled data to be larger or smaller than their observed counterparts. The optimal value of PBIAS is 0.0, with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias. PBIAS has the ability to clearly indicate poor model performance.

$$PBIAS = \frac{\sum_i (OV_i - MV_i)}{\sum_i OV_i} * 100 \tag{3.2}$$

Based on Moriasi et al. (2007), a "successful" PBIAS for monthly and peak flows will be less than 25 percent; for monthly sediment, less than 55 percent; for peak sediment, less than 70 percent; and for monthly and peak contaminants and nutrients, a "successful" PBIAS for monthly and peak flows will be less than 70 percent.

PBIAS is commonly used to quantify water balance (streamflow volume) errors and can be easily extended to evaluate load (mass load) errors.

RMSE-observations standard deviation ratio (RSR)

RSR standardizes root mean square error (RMSE) using the observations standard deviation. RSR incorporates the benefits of error index statistics and includes a scaling/normalization factor so that resulting statistics and reported values can apply to various constituents. RSR varies from the optimal value of 0—which indicates zero RMSE or residual variation and therefore perfect model simulation—to a large positive value. The lower the RSR, the lower the RMSE, and the better the model simulation performance will be.

$$RSR = \frac{RMSE}{OV_{STDEV}} = \frac{\sqrt{\frac{1}{n}\sum_i (OV_i - MV_i)^2}}{\sqrt{\frac{1}{n}\sum_i (OV_i - \overline{OV})^2}} \tag{3.3}$$

where n is the number of observations during the simulation period, OV_i = observed value, $\overline{OV}$ = mean observed value, MV_i = modeled value, $\overline{MV}$ = mean modeled value.

Performance Objective 1 – Linked model (HSPF/HEC-RAS) accurately simulates major components of the hydrologic cycle and stream flow. This objective evaluated the linked model (HSPF/HEC-RAS) performance to simulate watershed hydrology during the model calibration and validation periods. Two metrics were considered: monthly stream flow and daily peak flow. The evaluation of monthly flows ascertained whether or not the model was able to accurately simulate runoff volumes while daily peak flows determined how well the model simulated flow magnitude and timing. The metrics were evaluated using both quantitative and qualitative performance criteria. Model results were compared with observed flow data collected at monitoring gauges for two-to-five-year periods of record, depending upon availability of data. Besides visual comparison of modeled results and observed data, Nash-Sutcliffe (NSE), Percent Bias (PBIAS), and RMSE Observations Standard Deviation Ratio (RSR) statistic indices were calculated to determine whether or not the success criteria had been achieved (ASCE 1993; Moriasi et al. 2007). In addition, cumulative frequency curves were computed in order to evaluate the flow duration of the linked model as compared to field observations. Finally, the linked

model output was compared to model output from HSPF-only in order to determine how much increased accuracy, if any, was gained by developing a linked model versus HSPF-only.

Performance Objective 2 – Linked model accurately simulates soil erosion and sediment transport. This objective evaluated linked model (HSPF/HEC-RAS) performance to simulate soil erosion and sediment transport during the model calibration and validation periods. Two metrics were considered: monthly stream sediment load and daily peak sediment load. The metric was evaluated using the same quantitative and qualitative performance criteria as described in Performance Objective 1. In addition, cumulative frequency curves and comparisons with HSPF-only were done in order to determine how well the linked model simulated sediment transport over a wide range of flows and to ascertain the increased accuracy, if any, of the linked system as compared to HSPF-only.

Performance Objective 3 – Linked model accurately simulates selected contaminant fate and transport. This objective evaluated linked model (HSPF/HEC-RAS) performance to simulate contaminant transport and fate during the model calibration and validation periods. Target contaminants of interest depended upon the individual installation. Usually, continuous time series data were not available for contaminant runoff. In an effort to overcome this, continuous time series data was synthetically developed for this performance objective. If that was not achievable, then visual evaluations were performed between disparate observed data and modeled data as a means to evaluate model performance.

Performance Objective 4 – Linked model accurately simulates nutrient (nitrogen and phosphorus) fate and transport. This objective evaluated linked model (HSPF/HEC-RAS) performance to simulate nutrient transport and fate during the model calibration and validation periods. Target nutrients of interest depended upon the individual installation. As is the case with contaminants, nutrient runoff continuous time series data were usually not available for long time periods. In an effort to overcome this, continuous time series data was synthetically developed for this performance objective. If that was not achievable, visual evaluations were performed between disparate observed data and modeled data as a means to evaluate model performance.

Performance Objective 5 – Management Scenarios suitable for each demonstration site were simulated in order to demonstrate the utility of the linked modeling system to evaluate the effects of management scenarios on flows, sediment, nutrients, and contaminants as they relate to base conditions. If no observed data existed that encompassed the time period when management scenarios had been implemented, then a visual comparison of management scenario results as compared to base condition results was done in order to see whether the management scenario results were reasonable. In cases where observed data did exist, the performance objective statistics (NSE, PBIAS, and RSR) were computed to assess how well the linked model performed with the implementation of management scenarios.

Performance Objective 6 – Data Availability. As the data for each site was gathered and evaluated, where comparable national data sets and installation specific data existed, the temporal and spatial scales of each data set were evaluated for usefulness in the linked model and the HSPF-only model.

In the process of gathering and evaluating data for the model demonstration, the local data were evaluated for usefulness and to determine whether or not local data was required for a successful model study. For those local data sets that were required, it was determined whether those data were currently being collected as part of a typical data collection effort at installations or whether those data were not currently being gathered but need to be considered for collection at more installations.

For necessary local data collection efforts, the resources (hardware/software costs, technical expertise, and time expenditure) required to collect the data at the demonstration sites were documented, and general data collection methods were discussed.

Success was judged by how many data were readily available at the installations, whether or not additional required data can be collected within normal data collection activities at a minimal cost, or if model data necessary for successful applications need a separate data collection activity above and beyond what installations are currently doing. For those sites that require no additional data collection activities, then the chances of success would be rated as high. For those sites that require additional data to be collected within the normal data collection activities, the

chances of success would be rated as moderate. For those sites that require additional data to be collected outside of normal data collection activities, the chances of success would be rated as low.

Performance Objective 7 – Ease of use. ERDC documented the effort required to setup, calibrate, and simulate management scenarios for HSPF-only first, followed by the linked modeling system, in order to evaluate the effort and expertise required for the increased modeling requirements.

For all the demonstration sites, the model computational time was compared to watershed size, and variable output was documented so as to allow those interested in this approach to be able to ascertain the amount of time it will take to run a simulation at another installation.

Statistics were computed based on field observations and model results such that interpretation of the results was straight forward and did not require a high level of hydrologic, hydraulic, or water quality understanding.

All models need to be calibrated and validated to some degree. The ease of doing so for the demonstration sites was documented, and the pitfalls that one may encounter at a new installation were discussed. The documentation accounted for data availability, time for model setup, and model simulation times for the calibration and validation phases.

For installations with "trained staff" available to collaborate, the model calibration and validation was coordinated with them in order to document the ease-of-use criteria between an experienced modeler (ERDC) and a moderate modeler (Installation).

Additional Performance Objective Comments: In previous Strategic Environmental and Research Development Program (SERDP) projects, military Best Management Practices (BMPs) have been developed for HSPF. The HSPF Military BMP version of the model was used where applicable, in order to explicitly account for on-ground military and other land use activities—including grazing—in order to facilitate useful interactions between the modeling team and installation staff.

4 Site Description

This section provides a concise description of the second demonstration site, The Naval Facilities Engineering Command (NAVFAC) site in Ventura County, California (Calleguas Creek Watershed). The overall project calls for a sequential demonstration at Fort Hood, NAVFAC site, and the Patuxent Watershed, located in Maryland. The sequential plan design is developed with the intent of applying the lessons learned at each previous demonstration site to the next demonstration location.

Site selection

The NAVFAC Expeditionary Warfare Center (EXWC) in Port Hueneme, Ventura County, California, was selected as the second demonstration location due to the relatively high abundance of available datasets to support model input development and model calibration activities in the nearby Calleguas Creek Watershed. Figures 4.1 and 4.2 and Tables 4.1 to 4.3 show streamflow and water quality sampling station locations and inventories for sites in the Calleguas Creek Watershed. In addition, this site was selected due to it being in a different climate region of the country from the first demonstration site, as well as being linked to the Pacific Ocean. This site allowed us to demonstrate the utility of the models for the Western U.S. in addition to demonstrating that the models could handle tidal influences.

Figure 4.1. Primary streamflow stations in the Calleguas Creek watershed.

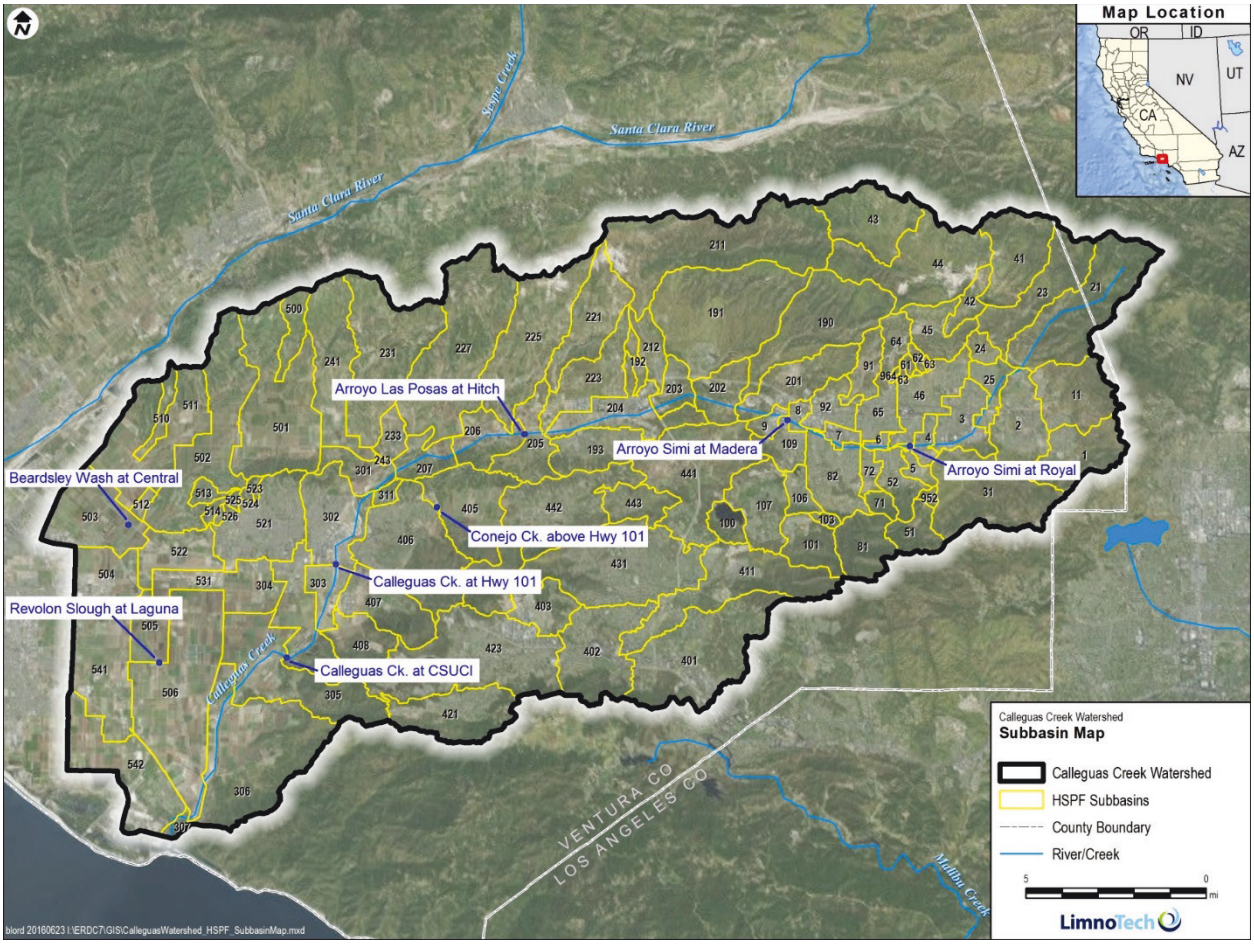


Figure 4.2. Primary water quality sampling stations in the Calleguas Creek watershed.

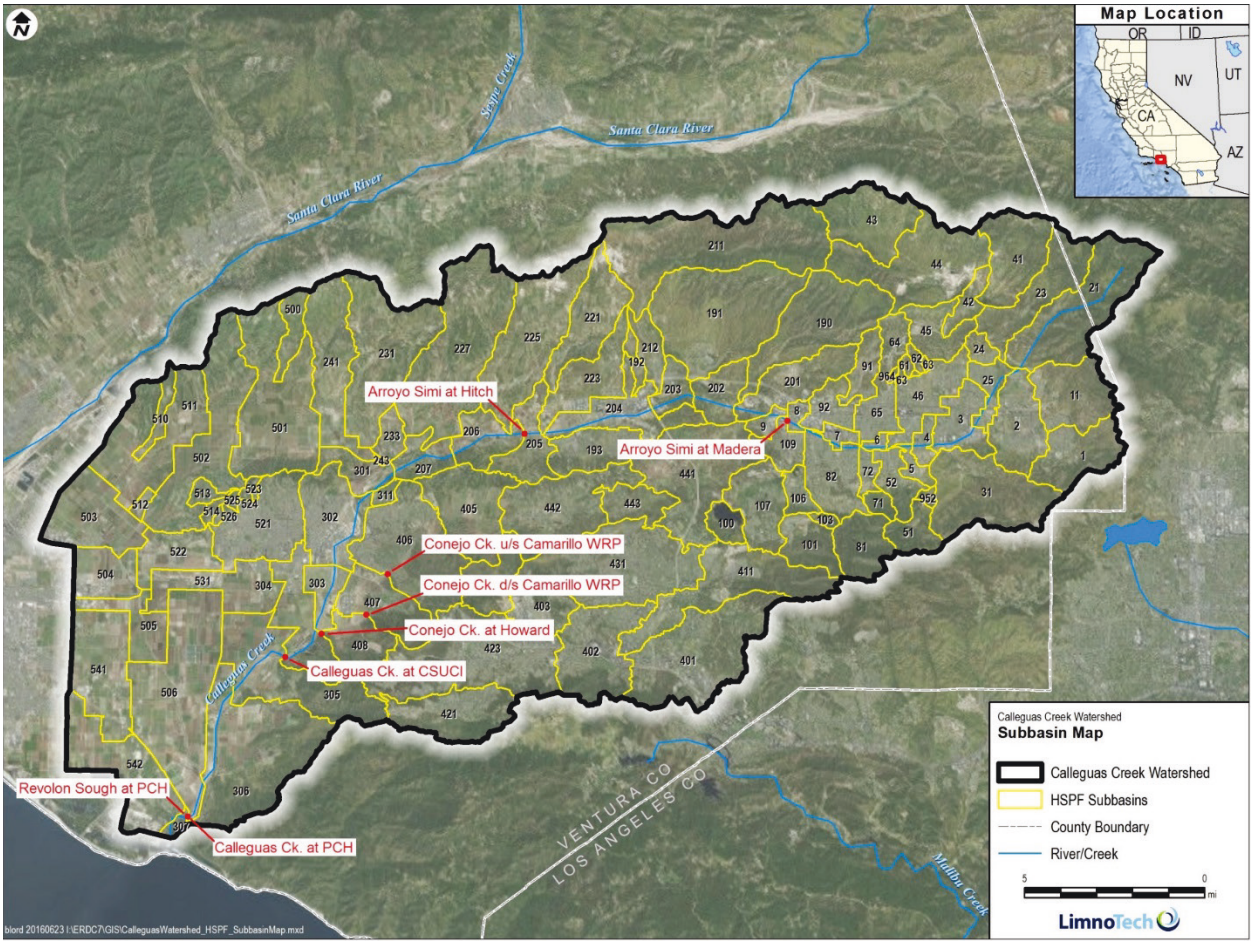


Table 4.1. Inventory of daily average streamflow observations for sampling stations in the Calleguas Creek watershed.

Station Description	RCHRES#	Count	Start	End
Calleguas Creek at CSUCI	304	8309	1/1/1987	9/30/2009
Calleguas Creek at Hwy 101	302	7577	1/1/1987	9/29/2007
Arroyo Las Posas at Hitch Rd	205	6482	10/1/1990	9/30/2009
Arroyo Simi at Madera Rd	8	7944	10/1/1987	9/30/2009
Arroyo Simi at Royal Ave	904	6482	10/1/1987	9/29/2005
Conejo Creek above Hwy 101	405	8217	1/1/1987	9/30/2009
Revolon Slough at Laguna Rd	505	8217	1/1/1987	9/30/2009
Beardsley Wash at Central Ave	503	5641	1/20/1994	9/30/2009
Santa Clara Drain	511	4210	12/20/1995	9/29/2007
Las Posas Estates Drain	514	774	8/18/2000	9/30/2002

Table 4.2. Inventory (count and start/end years) of sediment, hardness, chloride, copper, nickel, mercury, and selenium concentration observations for sampling stations in the Calleguas Creek watershed.

Station Description	RCHRES#	TSS	Hardness	Chloride	Cu	Ni	Hg	Se
Mugu Lagoon @ Ronald Reagan St. Bridge	307	10 2008-2009	2 2008-2009	-	10 2008-2009	10 2008-2009	3 2008-2009	9 2008-2009
Calleguas Creek at PCH	306	42 1998-2009	38 1987-2008	53 1987-1999	17 1998-2008	22 1998-2008	16 1998-2008	15 1998-2008
Calleguas Creek at CSUCI	304	96 2001-2009	142 1987-2009	119 1987-2009	80 2001-2009	79 2001-2009	76 2001-2009	80 2001-2009
Calleguas Creek at Hwy. 101	302	16 2001-2005	10 2001-2004	3 2001-2001	1 2001-2001	1 2001-2001	-	1 2001-2001
Arroyo Las Posas off Somis Rd.	207	7 2008-2009	-	-	-	-	-	-
Arroyo Simi at Hitch	205	89 1993-2009	72 1990-2005	101 1996-2005	20 1996-2005	20 1996-2005	7 1998-2005	27 1998-2005
Arroyo Simi at Madera	8	68 1993-2009	50 1993-2005	94 1996-2005	11 1996-2005	13 1996-2005	8 1998-2005	27 1996-2005
Arroyo Simi at Royal Ave.	904	5 1993-2004	-	94 1996-2005	-	-	-	-
Conejo Creek at Howard	408	67 1997-2009	148 1987-2005	133 1992-2005	6 1998-2004	6 1998-2004	4 1998-1999	1 2004-2004
Conejo Creek d/s Camarillo WRP	407	45 2006-2009	181 2006-2009	45 2006-2009	-	-	-	-
Conejo Creek u/s Camarillo WRP	406	45 2006-2009	182 2006-2009	45 2006-2009	-	-	-	-
Conejo Creek at CCDP	406	54 1997-2009	227 1987-2005	265 1987-2005	-	10 1998-2001	-	7 1999-2001
Conejo Creek at Hwy. 101	405	-	-	-	10 1998-2001	-	8 1998-2001	-
Conejo Creek at Hill Canyon	404	50 1996-2009	227 1987-2005	202 1987-2005	22 1998-2004	11 1998-2004	12 1998-2004	1 2003-2003
Arroyo Conejo S. Branch	403	17 1998-2009	170 1990-2005	199 1987-2005	4 1998-1999	4 1998-1999	4 1998-1999	4 1998-1999
Arroyo Conejo N. Branch	431	11 1996-2003	243 1990-2005	231 1987-2005	2 2001-2003	2 2001-2003	-	-
Arroyo Conejo N. Branch (u/s Hill Canyon)	431	28 2003-2009	-	-	16 2003-2004	4 2003-2004	8 2003-2004	4 2003-2004
Arroyo Santa Rosa	442	6 1998-2005	1 2004-2004	62 1996-2004	3 1998-1999	3 1998-1999	4 1998-1999	2 1998-1999
Revolon Slough at PCH	506	50 1998-2005	49 1990-2004	24 1998-2004	29 1998-2004	31 1998-2005	23 1998-2004	30 1998-2004
Revolon Slough E. Side of Wood Rd.	505	10 2008-2009	10 2008-2009	-	10 2008-2009	10 2008-2009	3 2008-2009	10 2008-2009
Beardsley Wash	503	23 2003-2009	13 1991-2004	1 2004-2004	-	-	-	-

Table 4.3. Inventory (count and start/end years) of nutrient, BOD, and DO concentration observations for sampling stations in the Calleguas Creek watershed.

Station Description	RCHRES#	TP	PO4	TN	NH3	NO3	BOD	DO
Mugu Lagoon @ Ronald Reagan St. Bridge	307	5 2008-2009	7 2008-2009	6 2008-2009	7 2008-2009	7 2008-2009	-	-
Calleguas Creek at PCH	306	5 2008-2009	5 2008-2009	5 2008-2009	5 2008-2009	5 2008-2009	-	-
Calleguas Creek at CSUCI	304	60 2001-2009	60 2001-2009	59 2001-2009	61 2001-2009	60 2001-2009	52 2001-2009	-
Calleguas Creek at Hwy. 101	302	-	-	-	-	-	-	-
Arroyo Las Posas off Somis Rd.	207	7 2008-2009	7 2008-2009	7 2008-2009	5 2008-2009	7 2008-2009	-	-
Arroyo Simi at Hitch	205	7 2008-2009	7 2008-2009	6 2008-2009	7 2008-2009	7 2008-2009	-	-
Arroyo Simi at Madera	8	4 2008-2009	3 2008-2009	7 2008-2009	7 2008-2009	7 2008-2009	-	-
Arroyo Simi at Royal Ave.	904	-	-	-	-	-	-	-
Conejo Creek at Howard	408	5 2008-2009	5 2008-2009	5 2008-2009	5 2008-2009	5 2008-2009	-	-
Conejo Creek d/s Camarillo WRP	407	45 2006-2009	45 2006-2009	45 2006-2009	45 2006-2009	45 2006-2009	26 2006-2009	183 2006-2009
Conejo Creek u/s Camarillo WRP	406	45 2006-2009	45 2006-2009	45 2006-2009	35 2006-2009	45 2006-2009	4 2006-2008	184 2006-2009
Conejo Creek at CCDP	406	7 2008-2009	7 2008-2009	7 2008-2009	7 2008-2009	7 2008-2009	-	-
Conejo Creek at Hwy. 101	405	-	-	-	-	-	-	-
Conejo Creek at Hill Canyon	404	7 2008-2009	7 2008-2009	7 2008-2009	7 2008-2009	7 2008-2009	-	-
Arroyo Conejo S. Branch	403	5 2008-2009	4 2008-2009	5 2008-2009	1 2009-2009	5 2008-2009	-	-
Arroyo Conejo N. Branch	431	-	-	-	-	-	-	-
Arroyo Conejo N. Branch (u/s Hill Canyon)	431	3 2008-2009	4 2008-2009	5 2008-2009	3 2008-2009	5 2008-2009	-	-
Arroyo Santa Rosa	442	-	-	-	-	-	-	-
Revolon Slough at PCH	506	-	-	-	-	-	-	-
Revolon Slough E. Side of Wood Rd.	505	7 2008-2009	4 2008-2009	5 2008-2009	6 2008-2009	7 2008-2009	-	-
Beardsley Wash	503	7 2008-2009	4 2008-2009	7 2008-2009	6 2008-2009	7 2008-2009	-	-

Site location and history

This section provides a short description of the location, mission, and relevant physical characteristics for Ventura County, California.

Ventura County, California

Ventura County, California (Figure 4.3), is home to the NAVFAC EXWC office in Port Hueneme, which is located in the south central area of the county. The county is dominated by undeveloped land uses (forest and shrub/scrub), with several mountain ranges and the Los Padres National Forest in the northern portions. Developed and agricultural areas lie within the various river valleys and are more concentrated in southern portions of the county. Pastureland is the most dominant agricultural use by land area, followed by production of vegetables, lemons, and avocados.

Site characteristics

Calleguas Creek Watershed in Ventura County, California

The Calleguas Creek Watershed is located northwest of Los Angeles in Ventura County, California (Figure 4.4). The dominant land use is undeveloped open space, followed by agricultural and developed urban areas, including the communities of Simi Valley, Thousand Oaks, Moorpark, and Camarillo. Undeveloped open spaces tend to be on the higher sloped/mountainous areas of the watershed, while urban and agricultural areas are located in the relatively flatter valley areas. The most dominant crops are row-crop vegetables, citrus, avocados, and strawberries.

Figure 4.3. Map depicting Ventura County location, land cover, and stream network (figure source: wikiwatershed.org).

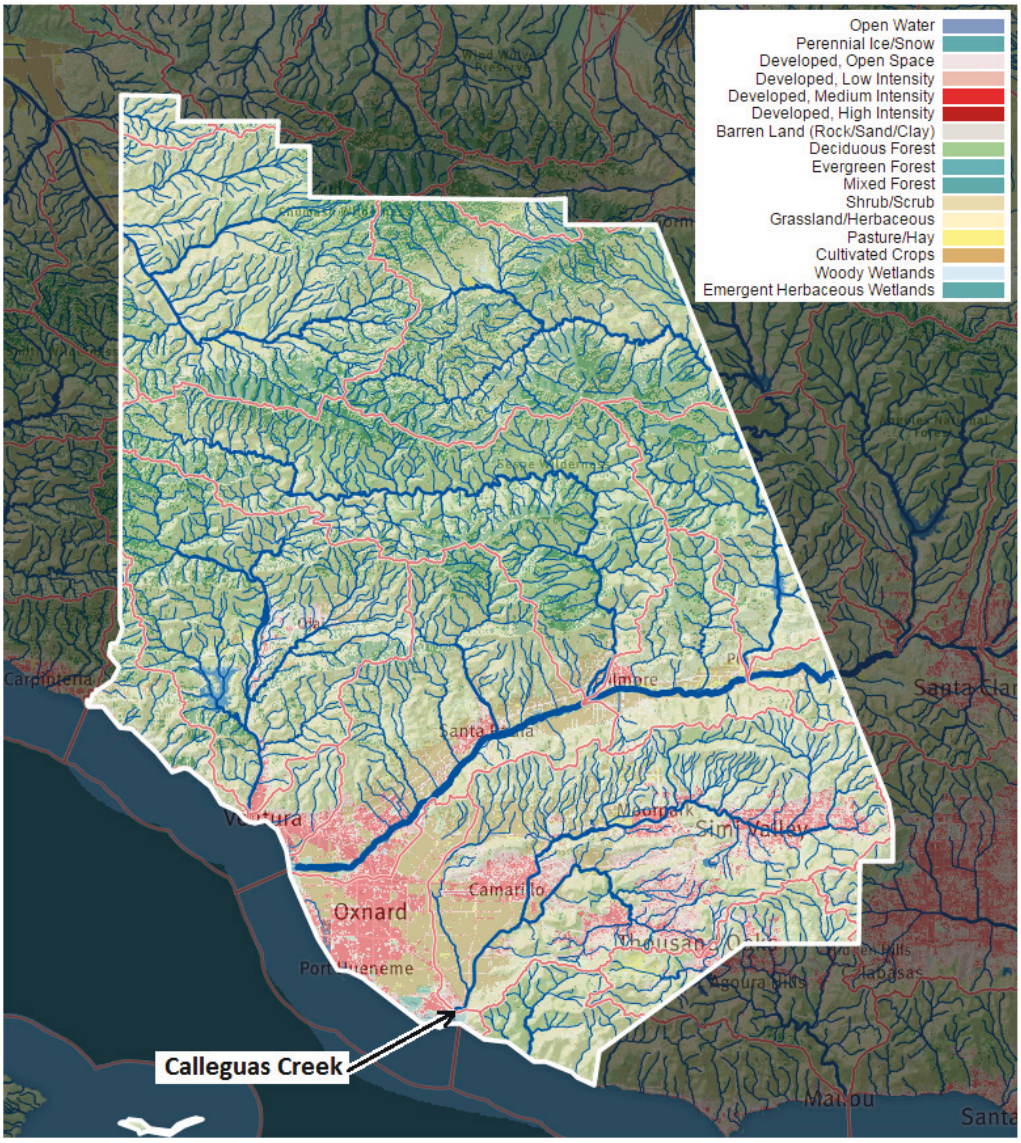
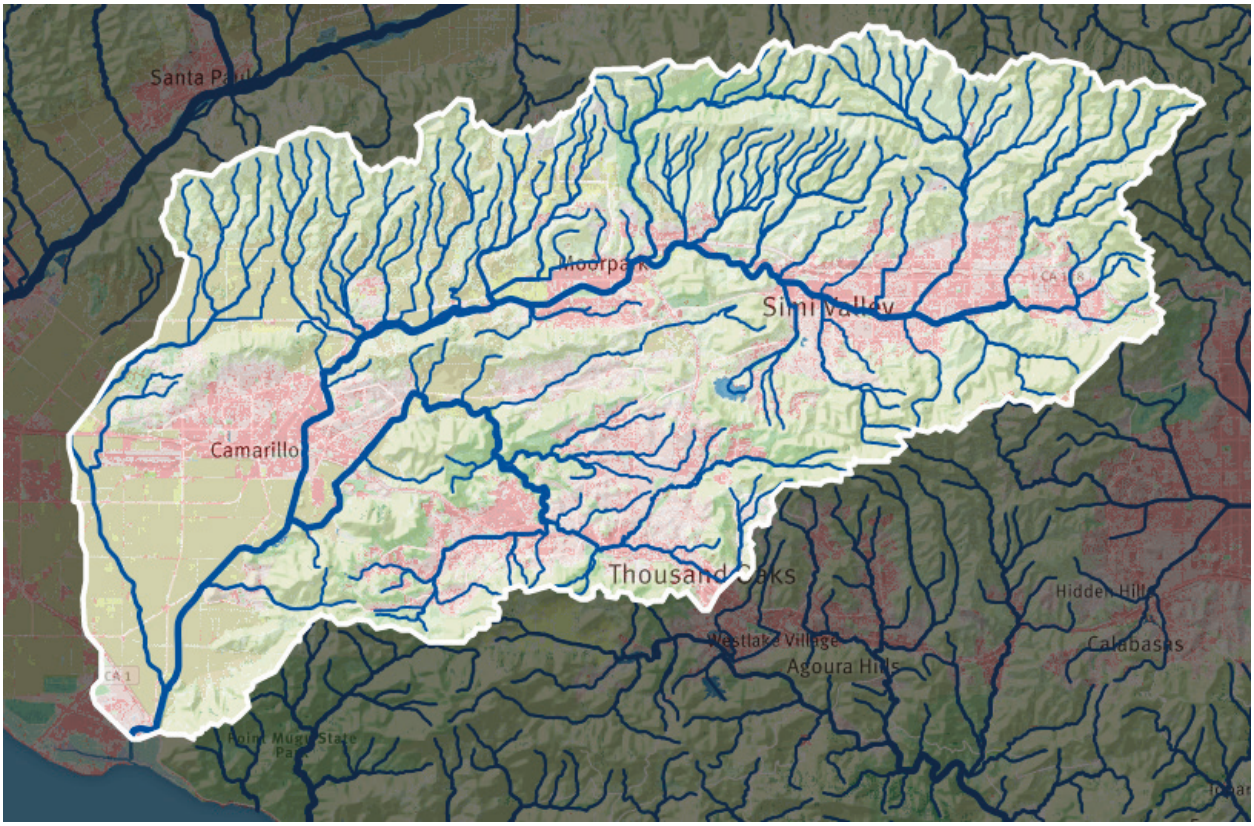


Figure 4.4. Map depicting the Calleguas Creek Watershed (source: wikiwatershed.org).



Site-related permits and regulations

The scope of this project did not require environmental permits in order for the demonstration to proceed. Conversely, this project quantifies the functional link of streams and rivers to the watershed in order to better assess sediment, nutrient, and contaminant loading to water systems as a result of landscape activities. The major environmental drivers for Calleguas Creek Watershed is upland erosion, and nutrient and contaminant fate and transport due to a broad range of military, agricultural, and municipal activities. Consequently, this demonstration focused on soil erosion, channel sedimentation, and nutrient and contaminant fate and transport.

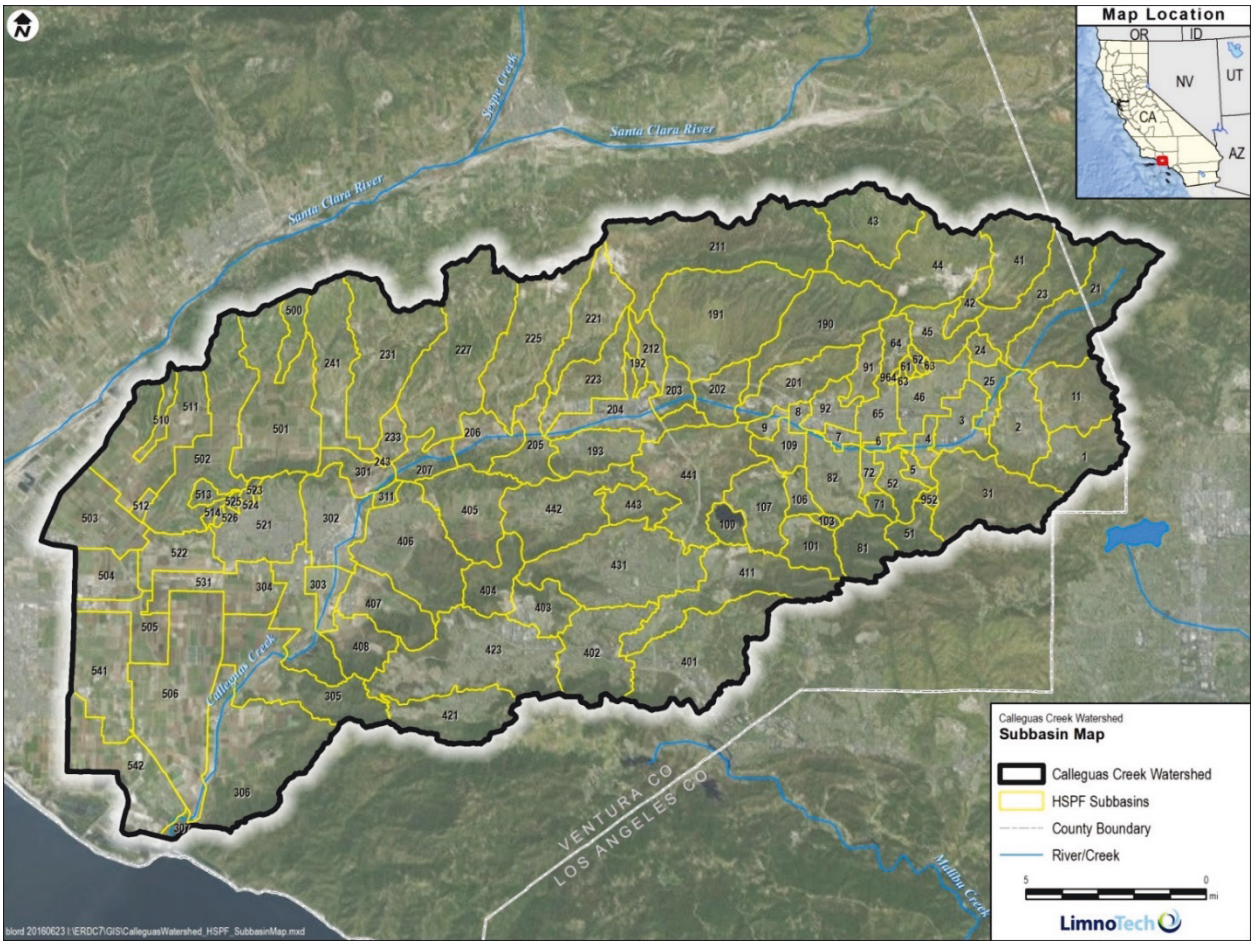
5 Test Design

The following section will discuss model conceptualization, data preparation, model setup, model calibration, sampling protocols, and calibration and data quality issues.

Watershed and river model conceptualization

A map of the Calleguas Creek Watershed HSPF delineation is provided below (Figure 5.1). The model consists of 123 reach segments (RCHRES), 213 pervious land segments (PERLND), and 36 IMPLND.

Figure 5.1. Map of the Calleguas Creek Watershed HSPF model delineation, Ventura County, California.



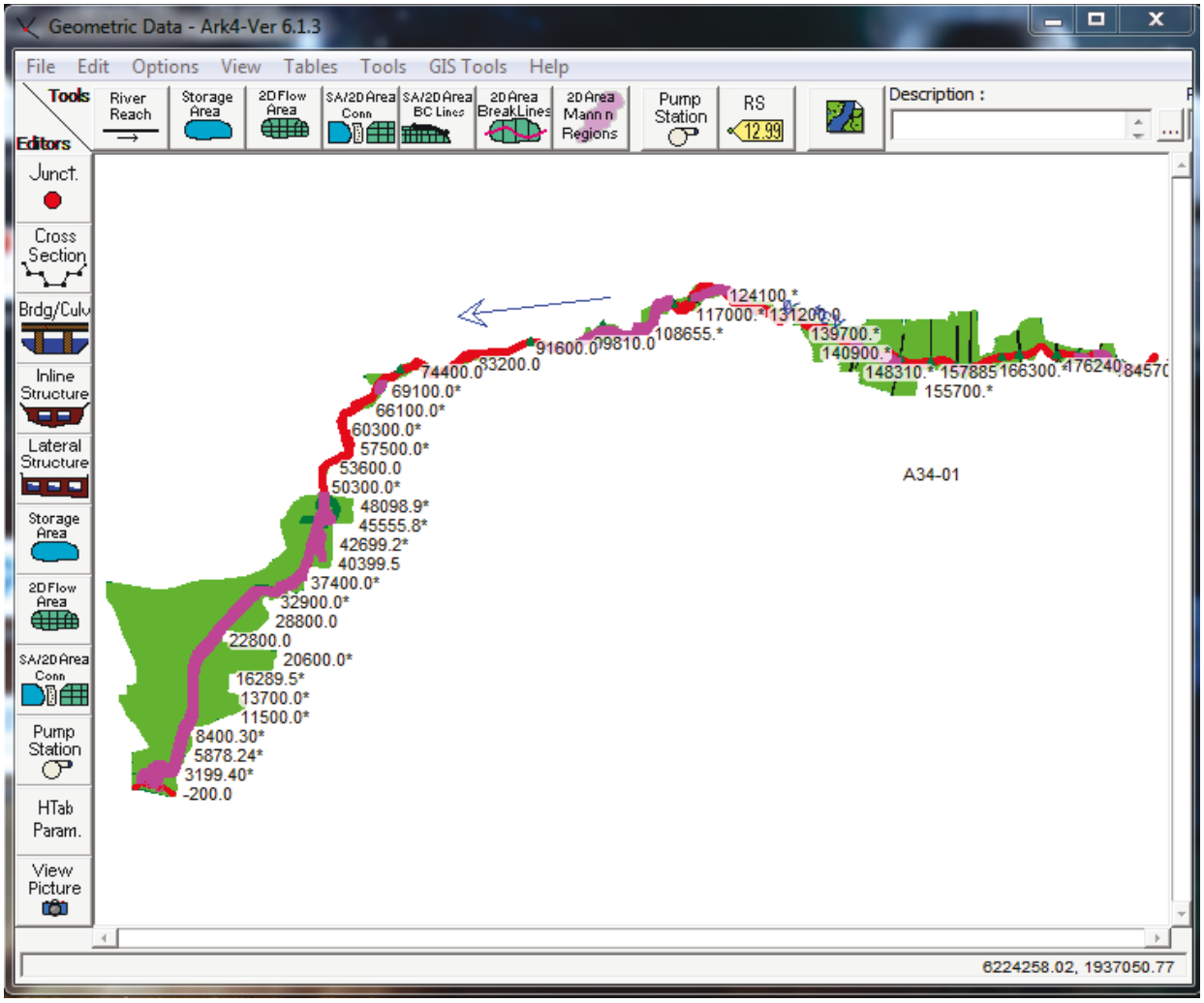
The HEC-RAS model (Figure 5.2) was developed from 34 separate steady-state HEC-RAS models prepared by Ventura County for individual reaches and bridges throughout the model domain. The cross-section geometry for these models was collected through topographic survey. Schematic data retrieved from these models includes

- cross-section locations,
- cross-section geometry,
- downstream reach lengths,
- bank stations,
- ineffective areas,
- bridges (hydraulic structures), and
- roughness coefficients.

The bank stations, levee locations, roughness coefficients, minimum baseflow, and pilot channel were adjusted as deemed appropriate to the morphology and hydraulics of the system.

In addition to geometric data, both of these GUI allow for the input of job control, model parameters, meteorological, flow, sediment, and constituent data in support of model simulations.

Figure 5.2. Example HEC-RAS graphical user interface.



Data collection and preparation

The input data needed to run the HSPF model include topography, soil, land use, weather, management conditions, stream network, and watershed configuration data. Subwatershed boundaries used by the Ventura County Watershed Protection District supported model land segmentation (AQUA TERRA 2005). Geospatial cropping data for 1997 and 2002 and annual crop reports from the Ventura County Agricultural Commissioner's Office were used in developing model land use inputs (AQUA TERRA 2005). Historical precipitation data from a network of stations maintained by the Ventura County Watershed Protection District were used for locations both in and around the watershed (AQUA TERRA 2005). Pan evaporation data from several locations in or around the watershed were used to generate potential evapotranspiration input time series (AQUA TERRA 2005).

The cross-section geometry data from the individual steady-state models was of sufficient quality to support unsteady-model development; however, the cross-section spacing was insufficient to support unsteady-model development. In refining the HEC-RAS model, additional cross-section longitudinal resolution was achieved through cross-section interpolation. Cross-section interpolation provided sufficient resolution to achieve unsteady-model stability.

Measured streamflow and water quality data were provided by the Ventura County Watershed Protection District. Data inventories are provided in Tables 4.1 to 4.3. The primary streamflow calibration stations were Calleguas Creek at California State University Channel Islands (CSUCI), Conejo Creek above Highway 101, and Revolon Slough at Laguna Road. The primary water quality calibration station was Calleguas Creek at CSUCI, which overall had the most complete set of samples for the water quality constituents considered.

Watershed and river model setup

The following section discusses the data used and discretization to set up the HSPF (Watershed Model) and HEC-RAS (River Model) models.

HSPF

The Calleguas Creek Watershed is located northwest of Los Angeles in Ventura County, California. The dominant land use is undeveloped open space, followed by agricultural and developed urban areas, including the communities of Simi Valley, Thousand Oaks, Moorpark, and Camarillo. The Calleguas Creek Watershed HSPF model was originally developed during a pilot application of HSPF to the Arroyo Simi Watershed and was later extended to cover the entire Calleguas Creek Watershed (AQUA TERRA Consultants 2005). The AQUA TERRA (2005) version of the model used a one-hour time step and covered water years 1988-2002. Additional enhancements were made to the model, including use of a 15-minute time step, extension through water year 2009, representation of additional debris basins, and resegmentation of the reach network. The study team obtained and modified the HSPF model, beginning with the user control input (UCI) file “CallegGW15min2012.uci” and watershed data management (WDM) file “ch1r.wdm.” The model obtained by the study team was configured and calibrated for simulation of hydrology only. In addition to conducting a detailed review and evaluation of the

model to ensure that the model configuration and hydrology calibration were acceptable and appropriate for use as a foundation for the water quality components, enhancements made over the course of this project included reconfiguring the model to simulate sediment, nutrients, and contaminants. Changes were not made to the land use/land cover distribution, reach segmentation, simulation period (10/1/1987-9/29/2009), or the hydrology parameterization/calibration.

Sediment was simulated using the SEDMNT module for pervious land areas, the SOLIDS module for impervious land areas, and the SEDTRN module for reaches. The SEDMNT module in the Calleguas Creek Watershed HSPF model was implemented with sediment removal via both wash off of detached sediment and scour of soil. The SEDTRN module simulates inorganic sediment via three particle-size classes (sand, silt, and clay) and includes both erosion/scour and deposition processes.

The general quality constituent approach was taken to simulate nutrient and contaminant loading from the landside via the PQUAL (for pervious land areas) and IQUAL (for impervious land areas) modules. These modules simulate water quality constituents in the outflows using simple relationships with water and/or sediment yield (Bicknell et al. 2005). Any constituent can be simulated by this module section where the user supplies the name, units, and parameter values appropriate to each of the constituents that are needed in the simulation (Bicknell et al. 2005). The general quality constituents represented in the Calleguas Creek Watershed HSPF model include the following:

- PQUAL\IQUAL 1 = Hardness
- PQUAL\IQUAL 2 = Chloride
- PQUAL\IQUAL 3 = Copper
- PQUAL\IQUAL 4 = Nickel
- PQUAL\IQUAL 5 = Mercury
- PQUAL\IQUAL 6 = Selenium
- PQUAL\IQUAL 7 = NH3
- PQUAL\IQUAL 8 = NO3+NO2
- PQUAL\IQUAL 9 = PO4
- PQUAL\IQUAL 10 = “Organic N&P”

Each of the simulated general quality constituents is then partitioned or divided during the transfer of loads from the landside to the reach segment. The partitioning represented in the HSPF model is described below:

- Hardness is transferred to the reach as a conservative constituent (#1)
- Chloride is transferred to the reach as a conservative constituent (#2)
- Copper is transferred to the reach as a dissolved general quality constituent (#1)
- Nickel is transferred to the reach as a dissolved general quality constituent (#2)
- Mercury is transferred to the reach as a dissolved general quality constituent (#3)
- Selenium is transferred to the reach as a dissolved general quality constituent (#4)
- NH3 is transferred to the reach as dissolved ammonia
- NO3+NO2 is transferred to the reach as dissolved nitrate
- PO4 is transferred to the reach as dissolved orthophosphate
- "Organic N&P" divided into various fractions and is transferred to the reach as organic refractory nitrogen (ORN), organic refractory phosphorus (ORP), organic refractory carbon (ORC), and as BOD

The model represents individual nutrient species (i.e., orthophosphate, organic phosphorus, ammonia, nitrate, nitrite, and organic nitrogen) within the reach segments. The RCHRES module in the Calleguas Creek Watershed HSPF model was implemented with the full nutrient simulation, which includes the uptake and release of nutrients by phytoplankton and benthic algae, decay of organic matter, oxidation of ammonium to nitrite and nitrite to nitrate nitrogen, and bed exchanges of dissolved and sorbed nutrients. Inorganic, labile, and organic refractory components of nitrogen and phosphorus are summed for total nitrogen (TN) and total phosphorus (TP).

Precipitation, potential evaporation, air temperature, dew point temperature, wind speed, solar radiation, and cloud cover time series were provided with the HSPF modeling files for the full simulation period. Multiple precipitation and potential evaporation time series were provided. One time series from the Camarillo Airport was provided for each of the following forcing functions: air temperature, dew point temperature, wind speed, solar radiation, and cloud cover. LimnoTech developed and added an air temperature time series from the Van Nuys Airport (CA722886) to the

model to better represent the gradient in air temperatures moving from the coastal to the inland areas of the watershed.

Atmospheric deposition of NH_4-N, NO_3-N, copper, nickel, mercury, and selenium was included in the HSPF model. Dry and wet atmospheric deposition data were downloaded from the USEPA Clean Air Status and Trends Network (CASTNET) for NH_4-N and NO_3-N. Data were available at the Converse (CON186) station, located in San Bernardino County, for the 2004-2010 time period for dry deposition and for the 1989-2013 time period for wet deposition. Wet deposition data were downloaded from the National Atmospheric Deposition Program (NADP) Mercury Deposition Network (MDNN) for mercury. Data were available at the Converse Flats (CA94) station, located in San Bernardino County, for the 2007-2014 time period. Additional dry deposition (copper, nickel, mercury, and selenium) and wet deposition (copper, nickel, and selenium) estimates were obtained from Larry Walker Associates (2006).

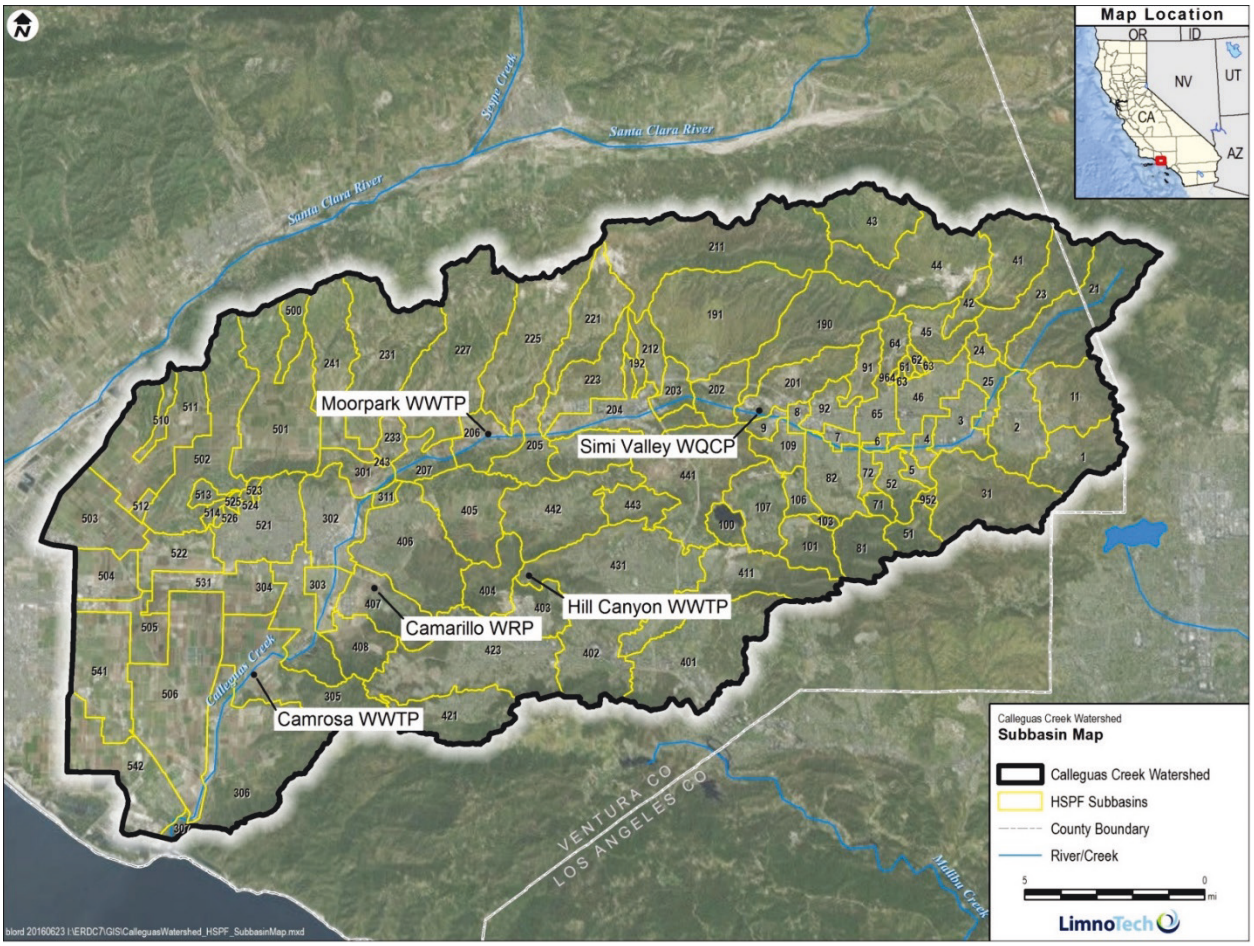
The HSPF modeling files provided to the study team included point source flow time series for six municipal wastewater treatment plants (WWTPs) and five groundwater dewatering wells in the Simi Valley area. Point source load time series were developed or assumed to be constant concentrations for all water quality constituents simulated (see Table 5.1). Point source effluent data were downloaded from the USEPA Permit Compliance System (PCS) database for the Hill Canyon, Simi Valley, and Camarillo WWTPs and generally covered the 1998-2008 time period. If sufficient data were available, a temporally variable load time series was developed using the PCS effluent concentration data and baseline flow time series. If sufficient data were not available, a constant concentration was assumed and multiplied by the baseline flow time series within the EXT SOURCES block of the UCI file to serve as the load time series. Figure 5.3 shows the locations of municipal wastewater treatment point sources represented in the model.

Table 5.1. Assumed water quality constituent concentrations for point sources represented in the Calleguas Creek Watershed HSPF model.

Constituent	Municipal Wastewater Treatment Plants								Simi Valley Dewatering Wells				
	Hill Canyon	Simi Valley	Camarillo	Moorpark	Moorpark Ponds	Camrosa	Camrosa Ponds	Olsen Rd	1st St.	Chain Dr.	Madera	Sinaloa	Ward St.
TSS, mg/L	*variable*	*variable*	*variable*	2.5	2.5	2.5	2.5	2.5	15	15	15	15	15
Hardness, mg/L	*variable*	*variable*	*variable*	180	180	180	180	180	1000	1000	1000	1000	1000
Chloride, mg/L	*variable*	*variable*	*variable*	150	150	150	150	150	150	150	150	150	150
Cu, ug/L	*variable*	5	8	5	5	5	5	5	4	4	4	4	4
Ni, ug/L	*variable*	*variable*	6	4	4	4	4	4	6	6	6	6	6
Hg, ng/L	15	5	3	1	1	1	1	1	1	1	1	1	1
Se, ug/L	1	*variable*	1	1	1	1	1	1	15	15	15	15	15
TAM, mg/L	*variable*	*variable*	*variable*	27.6	27.6	3.4	3.4	3.4	0.1	0.1	0.1	0.1	0.1
NO3, mg/L	*variable*	*variable*	*variable*	0.18	0.18	2.5	2.5	2.5	10	10	10	10	10
NO2, mg/L	*variable*	*variable*	*variable*	0.045	0.045	0.045	0.045	0.045	2	2	2	2	2
ORN, mg/L	*variable*	*variable*	*variable*	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
PO4, mg/L	*variable*	*variable*	*variable*	0.7	0.7	0.7	0.7	0.7	0.01	0.01	0.01	0.01	0.01
ORP, mg/L	*variable*	*variable*	*variable*	0.3	0.3	0.3	0.3	0.3	0.1	0.1	0.1	0.1	0.1
ORC, mg/L	1	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5
DO, mg/L	*variable*	*variable*	*variable*	8	8	8	8	8	8	8	8	8	8
BOD, mg/L	*variable*	*variable*	*variable*	5	5	5	5	5	0.5	0.5	0.5	0.5	0.5

Sources for assumed water quality constituent concentrations: USEPA PCS Database, Larry Walker Associates (2001).

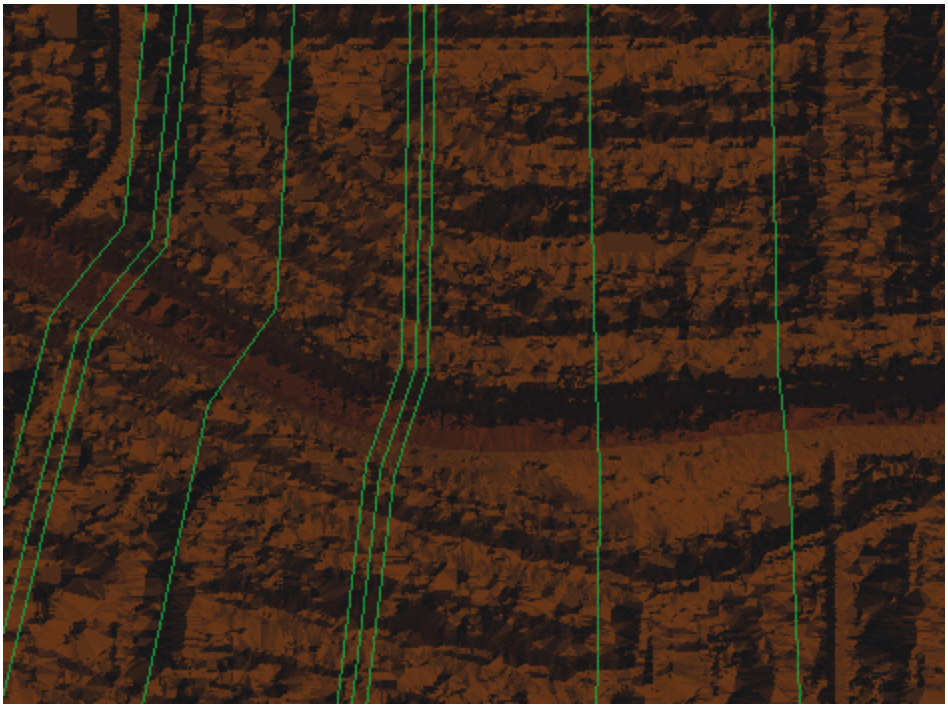
Figure 5.3. Map of point sources represented in the Calleguas Creek Watershed HSPF model.



HEC-RAS

The geometry information from the source steady-state models was collected from topographic survey, a light detection and ranging (LIDAR)-based TIN, and construction plan drawings provide by Ventura County (Figure 5.4). A cursory comparison was made between the triangulated irregular network (TIN) surface and the steady-state model data. It was determined that the steady-state model data were sufficient for this study.

Figure 5.4. Sample TIN dataset with cross-section cut-lines.



The final HEC-RAS model configuration consisted of a single reach (Figure 5.5), with interpolated cross sections between the surveyed cross sections. The baseline model had stability challenges near abrupt vertical transitions and near the bridges—both lead to fatal model instability. Below is a list of the types of model refinements that were required to stabilize the model.

- Set the minimum upstream boundary condition flow to 100 cfs.
- Decrease the computational time step to 0.5 sec
- Increase the cross-section resolution to 20 to 100 ft
- Add a pilot channel
- Add levees in areas where the overbank elevation is below the channel bank elevation

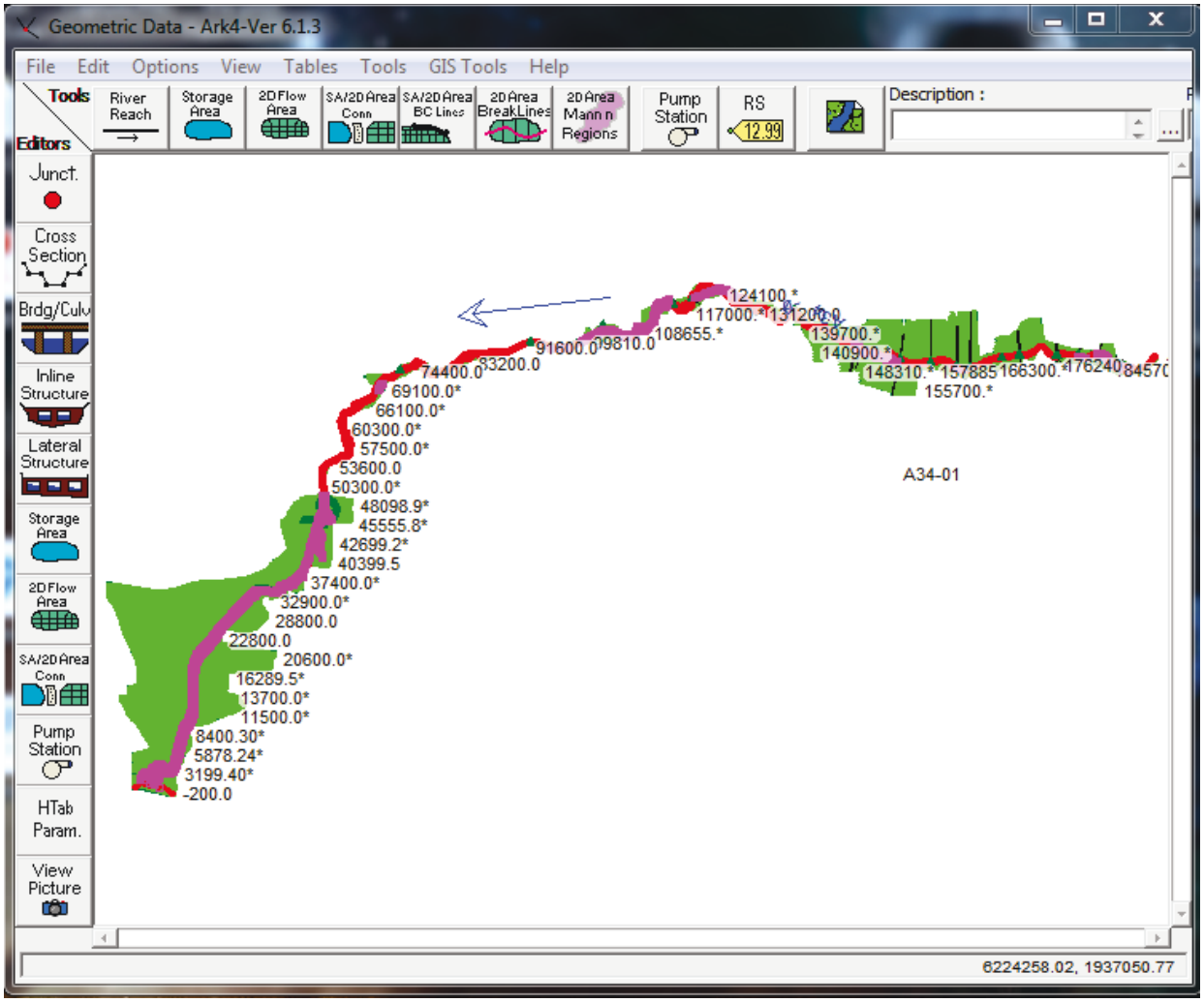
- Correct the orientation of select cross-section cutlines
- Increase Manning's n values in areas with steep gradients
- Increase the overbank of Manning's n throughout the entire domain
- Add ineffective flow areas near bridges
- Smooth the transitions into and out of the bridges by moving the internal bridge cross-sections to replace the bridge bounding cross sections for select bridges
- Add expansion and contraction coefficients to the bridge bounding cross sections
- Adjust HTAB parameters
- Change bridge modeling approach to select bridges
- Smooth abrupt longitudinal transitions by shifting cross-section elevations

With these refinements, the model was able to run a simulation of the winter of 1995-1996 without fatal errors; however, the 0.5-second time step made the runtimes excessive.

In order to reduce the computational time, the time step was increased to 5 min. This change necessitated removing some of the bridges in order to increase model stability. For all of the bridges that were removed, the internal bridge cross sections had previously been used to replace the bridge bounding cross-section geometries. This helped to minimize the impact of the bridge removal on the river hydraulics.

With the bridge removal, the model was able to use a five-minute time step to run a two-year simulation in about 30 minutes.

Figure 5.5. HEC-RAS model reach representation of Calleguas Creek.



Watershed and River Model Calibration

In evaluating performance for model calibration, average daily and average monthly performance for flow, sediment, contaminants, and nutrients was evaluated for Calleguas Creek watershed. Three statistics, Nash-Sutcliffe Efficiency (NSE), Percent Bias (PBIAS), and RMSE-observations standard deviation ratio (RSR), were computed for sites within the watershed for both average daily and average monthly simulations. The model calibration period used for this project was water year (WY) 2005-WY2009 for the HSPF model. This period had the most complete set of samples for sediment, contaminants, and nutrients. The remainder of the simulation period served as a validation period (WY1988-WY2004). Table 5.2 lists the various HSPF calibration parameters, description, and final values.

Table 5.2. Calibrated parameter values for streamflow, sediment, contaminants, and nutrients.

Parameter Description	Symbol	Units	Final Value(s)
PERLND - Hydrology			
Fraction forest cover	FOREST	-	0
Lower zone nominal soil moisture storage	LZSN	in	3.0-14.5
Index to infiltration capacity	INFILT	in/hr	0.02-0.25
Base groundwater recession	AGWRC	/day	0.75-0.999
Interflow inflow parameter	INTFW	-	0.3-1.9
Interflow recession parameter	IRC	/day	0.15-0.70
Monthly values of interception storage	INTERCEP	in	0.08-0.20
Monthly values of the upper zone nominal soil moisture storage	UZSN	in	0.3-1.2
Monthly values of the lower zone evapotranspiration parameter	LZETPARM	-	0.3-0.8
PERLND - Sediment	**Symbol**	**Units**	**Final Value(s)**
Management practice factor	SMPF	-	1
Coefficient in soil detachment equation	KRER	*complex*	0.42-0.56
Exponent in soil detachment equation	JRER	-	2
Daily reduction in attached sediment	AFFIX	/day	0.005-0.020
Fraction of land surface which is shielded from rainfall erosion	COVER	-	0.4-0.8
Atmospheric additions to storage	NVSI	lb/ac/day	20
Coefficient in soil detachment equation	KSER	*complex*	3.0-9.7
Exponent in soil detachment equation	JSER	-	2.0-2.5
Coefficient in soil detachment equation	KGER	*complex*	0.5-9.9
Exponent in soil detachment equation	JGER	-	1.5

PERLND - Contaminants	Symbol	Units	Hardness	Chloride	Copper	Nickel	Mercury	Selenium
Initial storage of qual	SQO	lb/acre	2.5E-1 to 5.0E-1	5.0E-1	1.0E-4	1.0E-4	2.5E-7	5.0E-5
Washoff potency factor	POTFW	lb/ton	-	-	3.0E-2 to 6.0E-2	4.0E-2 to 8.0E-2	1.0E-4	6.0E-3
Scour potency factor	POTFS	lb/ton	-	-	1.5E-2 to 3.0E-2	2.0E-2 to 4.0E-2	5.0E-5	3.0E-3
Accumulation rate	ACQOP	lb/ac/day	1.0E-2 to 2.0E-2	1.0E-2	3.5E-5 to 7.0E-5	1.8E-5	1.0E-7	1.0E-6
Maximum storage limit	SQOLIM	lb/ac	5.0E-1 to 1.0E+0	1.0E+0	5.3E-4 to 1.1E-3	2.7E-4 to 5.4E-4	1.0E-6	1.0E-4
Rate of surface runoff to remove 90%	WSQOP	in/hr	1.0E+0	1.0E+0	1.0E+0	1.0E+0	1.0E+0	1.0E+0
Concentration in interflow outflow	IOQC	lb/ft3	2.2E-2 to 7.5E-2	6.2E-3 to 1.1E-2	2.8E-7 to 5.6E-7	3.8E-7 to 9.4E-7	1.4E-10	3.8E-7 to 7.5E-7
Concentration in groundwater outflow	AOQC	lb/ft3	2.2E-2 to 7.5E-2	6.2E-3 to 1.1E-2	1.9E-7 to 3.8E-7	3.8E-7 to 9.4E-7	9.4E-11	2.5E-7 to 5.0E-7
Dry atmospheric deposition	PQADFX	lb/ac/mo	-	-	7.4E-4	4.2E-4	4.8E-4	1.5E-5
Wet atmospheric deposition	PQADCN	lb/ft3	-	-	5.4E-8	2.1E-8	6.2E-10	4.3E-8

PERLND - Nutrients	Symbol	Units	Ammonia	Nitrate	Phosphate	Organic
Initial storage of qual	SQO	lb/acre	1.0E-2 to 2.0E-2	2.5E-1 to 2.5E+0	1.0E-2 to 2.0E-2	2.5E+0 to 5.0E+0
Washoff potency factor	POTFW	lb/ton	-	-	6.0E-1 to 1.5E+0	5.0E+1
Scour potency factor	POTFS	lb/ton	-	-	3.0E-1 to 8.0E-1	5.0E+1
Accumulation rate	ACQOP	lb/ac/day	2.0E-3 to 4.0E-3	5.0E-2 to 5.0E-1	2.0E-3 to 4.0E-3	5.0E-1 to 1.0E+0
Maximum storage limit	SQOLIM	lb/ac	2.0E-2 to 4.0E-2	5.0E-1 to 5.0E+0	2.0E-2 to 4.0E-2	5.0E+0 to 1.0E+1
Rate of surface runoff to remove 90%	WSQOP	in/hr	1.0E+0	1.0E+0	1.0E+0	1.0E+0
Concentration in interflow outflow	IOQC	lb/ft3	6.2E-6 to 3.1E-5	5.0E-4 to 1.3E-3	3.1E-6 to 6.2E-6	1.3E-3
Concentration in groundwater outflow	AOQC	lb/ft3	3.1E-6	3.8E-4	6.2E-7	1.3E-3
Dry atmospheric deposition	PQADFX	lb/ac/mo	1.4E-2	1.1E-2	-	-
Wet atmospheric deposition	PQADCN	lb/ft3	1.1E-5	1.1E-5	-	-

Note: For those final parameter values that reflect a range rather than a single value, the values may have varied (1) by land use category, (2) by month, and/or (3) by sub-area.

The HSPF model for the Calleguas Creek watershed was run from 10/1/1987 to 9/30/2009 on a 15-minute basis. HSPF parameters were adjusted during the model calibration. Predictions made by HSPF were compared with observed data at monitoring gages in the watershed to evaluate the model's performance discussed in the next sections. The monitoring gage stations were screened for observed data availability, length, and coverage of the data record. Data inventories are provided in Tables 4.1, 4.2, and 4.3. The primary HSPF water quality calibration stations were Calleguas Creek at California State University Channel Islands (CSUCI), Conejo Creek downstream of the Camarillo WRP, and Revolon Slough at Wood Road. The Calleguas Creek at CSUCI sampling station had the most sediment, hardness, chloride, copper, nickel, mercury, and selenium samples. The sampling station on Conejo Creek downstream of the Camarillo WRP station had the most nutrient samples and therefore served as the primary calibration location for nitrogen and phosphorus.

The study team did not make changes to the hydrology parameterization/calibration as part of this project. Further details on the hydrology calibration process can be found in the report documenting development and calibration of the full Calleguas Creek Watershed HSPF model (AQUA TERRA Consultants 2005). The performance analyses in this document serve to confirm that the hydrology simulation performance was maintained after the model enhancements described above were performed (e.g., extension of the simulation period, resegmentation, etc.) and to evaluate model performance for the following constituents added to the model over the course of this project: sediment, hardness, chloride, copper, nickel, mercury, selenium, nitrogen (total and nitrate), and phosphorus (total and orthophosphate).

Flow

The HSPF-only calibration was performed for stream gages Calleguas Creek at CSUCI (near the watershed outlet), Conejo Creek above Highway 101 (near the Conejo Creek outlet), and Revolon Slough at Laguna Road (near the Revolon Slough outlet), Figure 4.1. Because the tributary reaches Conejo Creek above Hwy 101 and Revolon Slough at Laguna Rd were not modeled in HEC-RAS, Calleguas Creek at CSUCI was used to evaluate how well the linked system performed. The performance objectives for the linked model were evaluated for a different time period than the HSPF-only modeling calibration period. This was necessary because of

differences in the overall simulation periods between the HSPF-only and the linked model.

Based on comparisons between daily HSPF-only model results and daily observed values, Table 5.3 and Figures C.1 to C.3, the HSPF-only model produced unsatisfactory results for the calibration period. Although PBIAS indicated very good results at all gages, NSE and RSR indicated unsatisfactory results for the calibration period at all gages. From visual inspection of the simulated and observed hydrographs, the model appeared to capture the flow pattern and over predict flows at Revolon Slough and under predict peak flows at CSUCI and Conejo Creek.

From reviewing the performance statistics for the linked model, Table 5.3, and Figure C.7, the linked model produced "very good" results with respect to estimation of daily streamflow volumes (as indicated by PBIAS), peak flows, time to peak (indicated by NSE), and minimizing residual errors (indicated by RSR) for Calleguas Creek at CSUCI.

Table 5.3. Calibration performance objectives for flow – daily average.

Framework	Performance Objective	Calleguas Creek at CSUCI	Conejo Creek above Hwy 101	Revolon Slough at Laguna Rd
HSPF-only	NSE	0.16	-0.16	0.11
	RSR	0.92	1.08	0.94
	PBIAS	9.7	1.7	2.6
HSPF / HEC-RAS	NSE	0.41	N/A	N/A
	RSR	0.77	N/A	N/A
	PBIAS	-18	N/A	N/A

See Table 3.2 for General Performance Ratings

Note, different time periods were used for the HSPF-only (10/1/2004-9/30/2009) and linked model (10/1/2007-9/30/2009) calibration evaluation

Based on comparisons between monthly model results and monthly observed values, Table 5.4 and Figures C.4 to C.6, the HSPF-only model produced satisfactory performance. PBIAS indicated very good results at all gages for streamflow volume. NSE indicated good to very good results for all gages with regard to matching peak flows and time to peak. From visual inspection of the simulated and observed hydrographs, the model slightly over predicted the peak flows in Jan-Feb 2005, but otherwise matched monthly flow volumes well. RSR values indicate satisfactory correlation between modeled and observed values, provided residual error is minimized between modeled and observed values.

Table 5.4. Calibration performance objectives for flow – monthly average.

Framework	Performance Objective	Calleguas Creek at CSUCI	Conejo Creek above Hwy 101	Revolon Slough at Laguna Rd
HSPF-only	NSE	0.94	0.70	0.92
	RSR	0.25	0.54	0.29
	PBIAS	9.7	1.7	2.6
HSPF / HEC-RAS	NSE	0.81	N/A	N/A
	RSR	0.44	N/A	N/A
	PBIAS	-18	N/A	N/A

See Table 3.2 for General Performance Ratings

Note, different time periods were used for the HSPF-only (10/1/2004-9/30/2009) and linked model (10/1/2007-9/30/2009) calibration evaluation

From reviewing the performance statistics for the linked model, Table 5.4, and Figure C.8, the linked model was able to produce satisfactory monthly results overall. PBIAS indicated very good results with a slight overestimation of streamflow volumes. The NSE, RSR, and visual plots indicate that the linked model performed very similar to the HSPF-only model.

Sediment and contaminants

In order to evaluate HSPF-only and linked model performance for sediment, measured total suspended solids (TSS) concentrations from field sampling efforts were used. As summarized in Table 4.2, the availability of TSS samples was sparse relative to the time period over which sampling was completed. Additionally, only the Calleguas Creek at CSUCI location had sufficient data available for computing performance statistics. The flashy nature of the Calleguas Creek system produced a wide range of observed TSS concentrations, ranging from <1 mg/l to >10,000 mg/l in various reaches of the watershed. This made model calibration difficult, and therefore in discussing model results the authors will reference the statistics, but a better indication of model performance will be the visual comparison between model results and observed data.

In addition to TSS comparisons, performance measures were computed for several contaminants, including hardness, chloride, copper, nickel, mercury, and selenium. As shown in Table 4.2, the Calleguas Creek at CSUCI location had the overall most abundant dataset for these parameters and therefore was chosen to evaluate model performance for the HSPF-only model. The linked model only simulates copper due to data limitation. Like

TSS, observed concentrations from discrete samples were used for these parameters.

Based on Table 5.5, the statistics indicate the HSPF-only model performed satisfactorily for all parameters except selenium, which had a "good" PBIAS rating, but NSE and RSR values were well outside acceptable ranges. All other parameters, when evaluated on a daily time scale, performed within acceptable ranges for NSE and RSR, indicating good timing of peak concentrations and minimization of residual errors. PBIAS ratings were "very good" for all parameters except selenium. Figures C.9 to C.15 show daily time series comparisons of HSPF-only model predicted concentrations and discrete field samples for these parameters.

From reviewing the performance statistics for the linked model, Table 5.5, and Figure C.20 and C.21, the linked model was not able to produce satisfactory daily results for TSS and Copper. PBIAS indicated very good results with dissolved copper in streamflow. Both TSS and copper had unsatisfactory daily NSE and RSR, The visual plots shown in Figure C.20 and C.21 indicate that the linked model was able to capture the temporal variation of observed TSS and copper at CSUCI location.

Table 5.5. Calibration performance objectives for sediment, hardness, chloride, copper, nickel, mercury, and selenium concentrations at Calleguas Creek at CSUCI – Daily Average.

Framework	Performance Objective	TSS	Hardness	Chloride	Cu	Ni	Hg	Se
HSPF-only	NSE	0.43	0.26	0.36	0.48	0.72	0.29	-3.71
	RSR	0.76	0.86	0.80	0.72	0.53	0.84	2.17
	PBIAS	7.5	-16.6	-2.9	0.8	14.6	-5.6	-41.0
HSPF / HEC-RAS	NSE	-0.17	N/A	N/A	-2.61	N/A	N/A	N/A
	RSR	1.08	N/A	N/A	1.90	N/A	N/A	N/A
	PBIAS	306	N/A	N/A	-23.48	N/A	N/A	N/A

See Table 3.2 for General Performance Ratings

Note, different time periods were used for the HSPF-only (10/1/2004-9/30/2009) and linked model (10/1/2007-9/30/2009) calibration evaluation

Based on Table 5.6, the statistics indicate the HSPF-only model when compared to monthly average observed concentrations, minimized PBIAS for all parameters, but only produced satisfactory performance for nickel when evaluating NSE and RSR. All parameters but copper had unsatisfactory monthly NSE and RSR, suggesting the timing and residual errors were not optimized, though several parameters evaluated had statistics *nearly* meeting the thresholds (NSE>0.50 and RSR<0.70).

Table 5.6. Calibration performance objectives for sediment, hardness, chloride, copper, nickel, mercury, and selenium concentrations at Calleguas Creek at CSUCI – Monthly.

Framework	Performance Objective	TSS	Hardness	Chloride	Cu	Ni	Hg	Se
	NSE	0.32	0.36	0.36	0.38	0.72	0.30	-3.73
HSPF-only	RSR	0.83	0.80	0.80	0.79	0.52	0.84	2.17
	PBIAS	23.6	-16.8	-2.7	-3.3	12.5	3.7	-38.4

See Table 3.2 for General Performance Ratings

An important caveat to these evaluations is the inadequacy of sampling data to support monthly average computation for observed data. Therefore, the performance objectives were only computed for the HSPF-only model. The sampling frequency for the calibration for these parameters was approximately one per month and therefore most "monthly average" observations represented just a single sample. Given the flashy nature of streamflow in the Calleguas Creek system, a field sample taken during a single instance is unlikely to be representative of monthly average conditions, and therefore it may be inappropriate to compare monthly average model results against these point-in-time measurements.

Nutrients

In order to evaluate HSPF-only and linked model performance for nitrogen (total and nitrate) and phosphorus (total and orthophosphate), measured nutrient concentrations rather than load estimates, were used. As summarized in Table 4.3, the availability of nutrient samples was sparse relative to the time period over which sampling was completed. Additionally, the only location within the modeling domain for both HSPF and HEC-RAS with more than ten nutrient samples was Calleguas Creek at CSUCI.

Based on Table 5.7, the statistics indicate the HSPF-only model performed "good" to "very good" relative to the PBIAS ratings, but failed to meet NSE and RSR thresholds for all but nitrate RSR, indicating poor timing of peak concentrations and relatively high residual errors. Figures C.16 to C.19 show daily time series comparisons of HSPF-only model-predicted concentrations and discrete field samples for these parameters.

From reviewing the performance statistics for the linked model, Table 5.7, and Figure C.22 to C.25, the linked model was not able to produce satisfactory daily results for TP, TN, NH4 and NO3. PBIAS indicated very good results with these constituents in streamflow. These constituents had unsatisfactory daily NSE and RSR; the visual plots shown in Figure C.22 to C.25 indicate that the linked model was able to capture the temporal variation of observed data at CSUCI location.

Table 5.7. Calibration performance objectives for phosphorus and nitrogen concentrations at Calleguas Creek at CSUCI – daily average.

Framework	Performance Objective	TP	PO4	TN	NO3	NH4
	NSE	-0.88	0.18	-0.07	0.30	N/A
HSPF-only	RSR	1.37	0.90	1.03	0.84	N/A
	PBIAS	5.6	6.9	-28.6	-7.9	N/A
HSPF / HEC-RAS	NSE	-2.89	N/A	-2.77	-0.78	0.09
	RSR	1.99	N/A	1.94	1.33	0.95
	PBIAS	29.03	N/A	-7.88	44.01	33.95

See Table 3.2 for General Performance Ratings

Note, different time periods were used for the HSPF-only (10/1/2004-9/30/2009) and linked model (10/1/2006-9/30/2009) calibration evaluation

Based on Table 5.8, the statistics indicate the HSPF-only model when compared to monthly average observed concentrations, minimized PBIAS for all parameters within acceptable thresholds, but did not meet the performance thresholds for NSE and RSR, suggesting the timing and residual errors were not optimized.

Like described above for TSS and contaminants, an important caveat to these monthly nutrient evaluations is the inadequacy of sampling data to support monthly average computation for observed data. The sampling frequency for the calibration for these parameters was approximately one per month and therefore most “monthly average” observations represented just a single sample. Given the flashy nature of streamflow in the Calleguas Creek system, a field sample taken during a single instance is unlikely to be representative of monthly average conditions, and therefore it may be inappropriate to compare monthly average model results against these point-in-time measurements.

Table 5.8. Calibration performance objectives for phosphorus and nitrogen concentrations at Calleguas Creek at CSUCI – monthly.

Framework	Performance Objective	TP	PO4	TN	NO3
	NSE	-0.95	0.12	-0.10	0.29
HSPF-only	RSR	1.40	0.94	1.05	0.84
	PBIAS	4.2	4.0	-31.3	-8.0

See Table 3.2 for General Performance Ratings

Sampling protocol

There were no field samples collected as a part of this demonstration study.

Equipment calibration and data quality issues

There were no field samples collected as a part of this demonstration study.

6 Performance Assessment

In evaluating performance for model validation, average daily and average monthly performance for streamflow, sediment, contaminants, and nutrients were evaluated for Calleguas Creek Watershed. Three statistics, Nash-Sutcliffe Efficiency (NSE), Percent Bias (PBIAS), and RMSE-observations standard deviation ratio (RSR), were computed for sites within the watershed for both average daily and average monthly simulations. Due to limited observed sediment, contaminant, and nutrient samples, a continuous time series of observed/estimated constituent loading could not be developed (e.g., using the U.S. Geological Survey (USGS) load estimator computer program or other methods), and therefore computation of the required statistics to evaluate model performance relied on comparisons of discrete samples against corresponding model-predicted daily or monthly averages.

Watershed and river model validation

The validation is used to evaluate the reliability of a calibrated model. The HSPF model for the Calleguas Creek watershed was run for an additional seventeen-year period without adjusting calibrated parameters. The period of record for validating streamflow, sediment, contaminants, and nutrients for HSPF-only was set from WY1988-WY2004. The HEC-RAS model validation period was 2003-2005; the validation period was extended to 2001-2005 if additional sediment and water quality data was available.

Flow

Validation for the HSPF-only calibration was performed for stream gages Calleguas Creek at CSUCI, Conejo Creek above Hwy 101, and Revolon Slough at Laguna Rd, Figure 4.1. Because the tributary reaches Conejo Creek above Hwy 101 and Revolon Slough at Laguna Rd were not modeled in HEC-RAS, Calleguas Creek at CSUCI was used to evaluate how well the linked system performed. The performance objectives for the linked model were evaluated a different time period than the HSPF-only modeling validation period. This was necessary because of differences in the overall simulation periods between the HSPF-only and linked model.

Based on comparisons between daily HSPF-only model predictions and daily observed values, Table 6.1 and Figures D.1 to D.3, the HSPF-only model produced satisfactory results. PBIAS indicated very good performance in replicating daily streamflow volumes at all three gages. NSE indicated very good performance in matching peak flows and time to peak at all three gages. This was confirmed from visual inspection of the simulated and observed hydrographs. RSR values indicate satisfactory correlation between measured and observed values, provided residual error is minimized with all three gages.

Based on the daily performance statistics in Table 6.1 and visual inspection of the hydrographs in Figure D.7, the linked model performed acceptably. It produced satisfactory results for both PBIAS, with a slight overestimation of flow volumes, and for RSR in relation to minimizing residual errors. The unsatisfactory NSE statistic for Calleguas Creek at CSUCI is believed to be due to the fact that the model consistently predicts a higher baseflow than the gage observes. Note the NSE value was near the satisfactory threshold of 0.50.

Table 6.1. Validation performance objectives for flow – daily average.

Framework	Performance Objective	Calleguas Creek at CSUCI	Conejo Creek above Hwy 101	Revolon Slough at Laguna Rd
	NSE	0.83	0.81	0.75
HSPF-only	RSR	0.41	0.43	0.50
	PBIAS	0.4	8.2	7.2
HSPF / HEC-RAS	NSE	0.83	N/A	N/A
	RSR	0.41	N/A	N/A
	PBIAS	-8.0	N/A	N/A

See Table 3.2 for General Performance Ratings

Note, different time periods were used for the HSPF-only (10/1/1987-9/30/2004) and linked model (1/1/2003-5/31/2005) calibration evaluation

Based on comparisons between monthly HSPF-only model predictions and average monthly observed values, Table 6.2 and Figures D.4 to D.6, the HSPF-only model produced “very good” results. PBIAS indicated very good performance in replicating monthly streamflow volumes at all three gages. NSE indicated very good performance in matching peak monthly flows at all three gages. This was confirmed from visual inspection of the simulated and observed hydrographs (Figures D.4 to D.6). RSR values

indicate very good correlation between measured and observed values, provided residual error is minimized at all three gages.

Based on the monthly performance statistics in Table 6.2, and visual inspection of Figure D.8, the linked model was able to produce satisfactory results. PBIAS indicated satisfactory results when estimating streamflow volumes. The NSE, RSR, and visual plots indicate that the linked model performed satisfactorily in regard to estimating magnitude and timing of monthly flow volumes as well as minimizing residual errors.

Table 6.2. Validation performance objectives for flow – monthly average.

Framework	Performance Objective	Calleguas Creek at CSUCI	Conejo Creek above Hwy 101	Revolon Slough at Laguna Rd
	NSE	0.94	0.92	0.94
HSPF-only	RSR	0.24	0.29	0.24
	PBIAS	0.4	8.2	7.2
HSPF / HEC-RAS	NSE	0.90	N/A	N/A
	RSR	0.31	N/A	N/A
	PBIAS	-15.0	N/A	N/A

See Table 3.2 for General Performance Ratings

Note, different time periods were used for the HSPF-only (10/1/1987-9/30/2004) and linked model (1/1/2003-5/31/2005) calibration evaluation

Sediment and contaminants

Based on Table 6.3, the statistics indicate the HSPF-only model, when compared to daily observed concentrations, produced satisfactory performance for TSS, chloride, and mercury for all three objectives. PBIAS was in acceptable ranges for all parameters shown, but hardness, copper, nickel, and selenium did not meet the performance thresholds for NSE and RSR. The performance metrics for copper were nearly within acceptable thresholds. Figures D.9 to D.15 show daily time series comparisons of HSPF-only model predicted concentrations and discrete field samples for these parameters.

From reviewing the performance statistics for the linked model, Table 6.3, and Figure D.20 and D.21, the linked model was able to produce satisfactory daily results with NSE; RSR and PBIS for TSS; and PBIAS for Copper. Dissolved copper had unsatisfactory daily NSE and RSR; the visual plots shown in Figure D.20 and D.21 indicate that the linked model was able to capture the temporal variation of observed TSS and copper at CSUCI location.

Table 6.3. Validation performance objectives for sediment, hardness, chloride, copper, nickel, mercury, and selenium concentrations at Calleguas Creek at CSUCI – daily average.

Framework	Performance Objective	TSS	Hardness	Chloride	Cu	Ni	Hg	Se
	NSE	0.37	-0.13	0.39	0.20	0.01	0.55	-0.02
HSPF-only	RSR	0.79	1.06	0.78	0.90	0.99	0.67	1.01
	PBIAS	38.9	14.1	2.9	37.5	59.7	35.4	3.2
HSPF / HEC-RAS	NSE	0.41	N/A	N/A	-0.24	N/A	N/A	N/A
	RSR	0.77	N/A	N/A	1.11	N/A	N/A	N/A
	PBIAS	48.51	N/A	N/A	-6.45	N/A	N/A	N/A

See Table 3.2 for General Performance Ratings

Note, different time periods were used for the HSPF-only (10/1/1987-9/30/2004) and linked model (2001-2005) calibration evaluation

Based on Table 6.4, the statistics indicate the HSPF-only model when compared to monthly average observed concentrations, minimized PBIAS for all parameters, but only produced satisfactory performance for TSS, copper, and mercury when evaluating NSE and RSR. All other parameters had unsatisfactory monthly NSE and RSR, suggesting the timing and residual errors were not optimized.

As described above in the calibration section, an important caveat to these monthly evaluations is the inadequacy of sampling data to support monthly average computation for observed data. The sampling frequency of approximately one per month unlikely results in samples representative of monthly average conditions; therefore, it may be inappropriate to compare monthly average model results against these point-in-time measurements.

Table 6.4. Validation performance objectives for sediment, hardness, chloride, copper, nickel, mercury, and selenium concentrations at Calleguas Creek at CSUCI – monthly.

Framework	Performance Objective	TSS	Hardness	Chloride	Cu	Ni	Hg	Se
	NSE	0.43	-0.43	0.30	0.52	0.18	0.70	-0.39
HSPF-only	RSR	0.76	1.20	0.84	0.69	0.91	0.54	1.18
	PBIAS	17.4	20.0	4.9	23.6	46.4	21.8	-9.9

See Table 3.2 for General Performance Ratings

Nutrients

Based on Table 6.5, the statistics indicate the HSPF-only model, when compared to daily observed concentrations, produced satisfactory performance with respect to PBIAS but did not meet the performance thresholds for NSE and RSR. Figures D.16 to D.19 show daily time series comparisons of HSPF-only model-predicted concentrations and discrete field samples for these parameters. Visual inspection of the time series plots suggest the HSPF-only model tends to underpredict peak phosphorus concentrations and overpredict total nitrogen and nitrate concentrations.

From reviewing the performance statistics for the linked model, Table 6.5, and Figure D.22 to D.25, the linked model was not able to produce satisfactory daily results for TP, TN, NH4 and NO3. PBIAS indicated overall satisfactory results with these constituents in streamflow. These constituents had unsatisfactory daily NSE and RSR; the visual plots shown in Figure D.22 to D.25 indicate that the linked model was able to capture the temporal variation of observed data at CSUCI location.

Table 6.5. Validation performance objectives for phosphorus and nitrogen concentrations at Calleguas Creek at CSUCI – daily average.

Framework	Performance Objective	TP	PO4	TN	NO3	NH4
	NSE	-0.48	0.10	-0.69	-0.09	N/A
HSPF-only	RSR	1.22	0.95	1.30	1.05	N/A
	PBIAS	23.0	4.8	-29.3	-35.8	N/A
HSPF / HEC-RAS	NSE	-1.75	N/A	-2.13	-0.61	-1.30
	RSR	1.66	N/A	1.77	1.27	1.52
	PBIAS	24.49	N/A	15.02	55.02	-5.19

See Table 3.2 for General Performance Ratings

Note, different time periods were used for the HSPF-only (10/1/1987-9/30/2004) and linked model (2001-2005) calibration evaluation

Based on Table 6.6, the statistics indicate the HSPF-only model when compared to monthly average observed concentrations minimized PBIAS for all parameters within acceptable thresholds, but did not meet the performance thresholds for NSE and RSR, suggesting the timing and residual errors were not optimized.

As described above in the calibration section, an important caveat to these monthly nutrient evaluations is the inadequacy of sampling data to support monthly average computation for observed data. The sampling frequency of approximately one per month unlikely results in samples representative of monthly average conditions; therefore, it may be inappropriate to compare monthly average model results against these point-in-time measurements.

Table 6.6. Validation performance objectives for phosphorus and nitrogen concentrations at Calleguas Creek at CSUCI – monthly

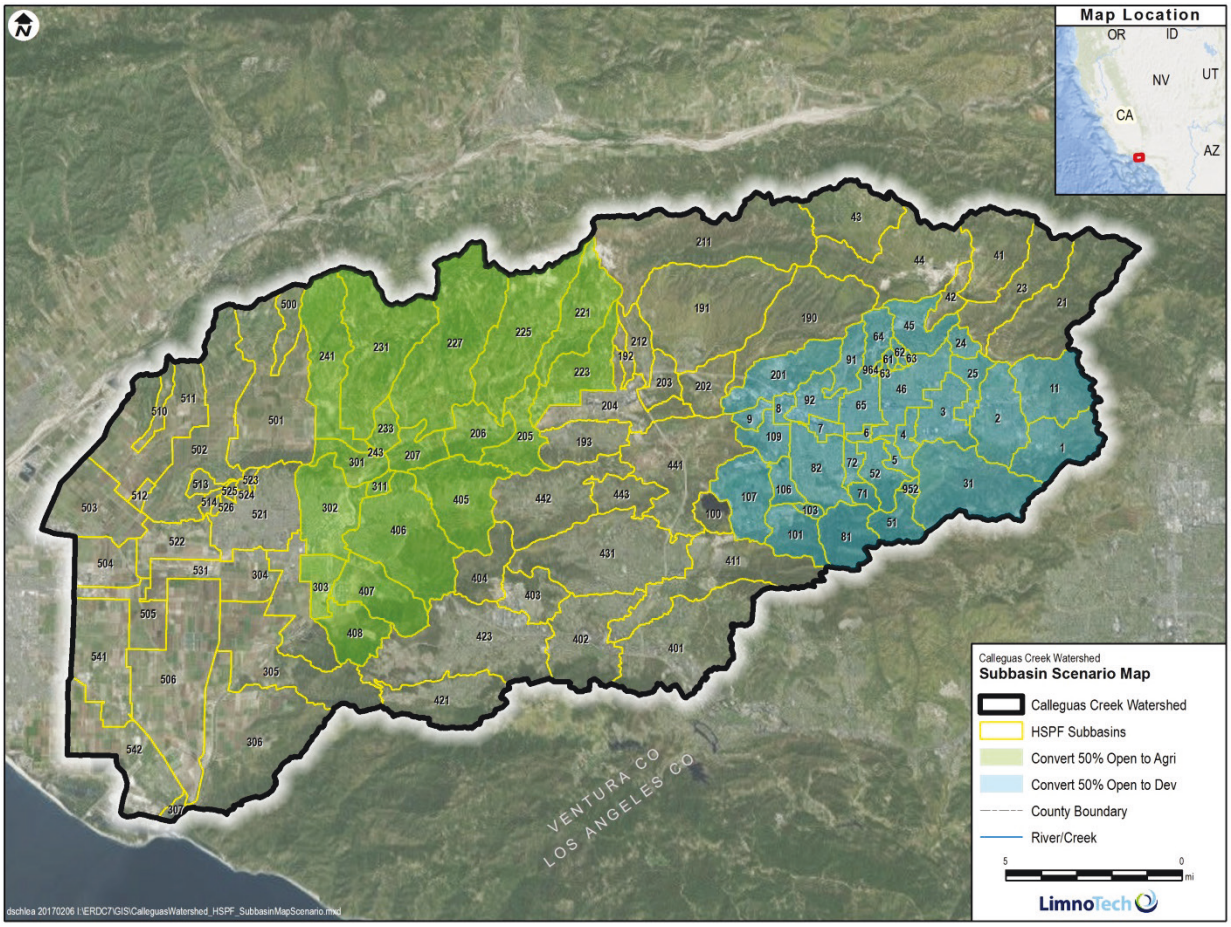
Framework	Performance Objective	TP	PO4	TN	NO3
	NSE	-0.19	0.11	-0.91	-0.29
HSPF-only	RSR	1.09	0.94	1.38	1.14
	PBIAS	22.2	1.5	-40.6	-37.4

See Table 3.2 for General Performance Ratings

Modeling best management practices (management scenarios)

The simulation period for evaluating watershed response to a land use change scenario was the same as the calibration period, WY2005-2009. The land use changes represented in this scenario were conversion of 50% of open space land use to agricultural land use in the Arroyo Las Posas area and conversion of 50% of open space land use to developed land uses (residential and commercial/industrial) in the Arroyo Simi headwaters area (Figure 6.1). These changes are hypothetical changes performed to show the utility of the modeling system to simulate changes in flow, sediment, nutrients, and contaminants based on changes in the landscape. Through conversations with the watershed stakeholders, there were no management scenarios implemented; thus, the authors were not able to model actual management scenarios and compare them to field data.

Figure 6.1. Areas of assumed land use change within the watershed.



Flow

Management Scenario analysis for the HSPF-only model was performed for stream gages Calleguas Creek at CSUCI, Conejo Creek above Hwy 101, and Revolon Slough at Laguna Rd, Figure 4.1. Because the tributary reaches Conejo Creek above Hwy 101 and Revolon Slough at Laguna Rd were not modeled in HEC-RAS, Calleguas Creek at CSUCI was used to evaluate how well the linked system performed.

Figures E.1 to E.6, show the HSPF-only model flow simulations for daily and monthly values respectively. Figures E.7 and E.8 show the HSPF/HEC-RAS flow simulations for daily and monthly values, respectively. Both modeling systems seemed to produce reasonable flow results based on the management scenarios implemented.

Sediment and Contaminants

Figures E.9 to E.15 show HSPF-only daily model results for total suspended solids and contaminants. Figures E.20 and E.21 show HSPF/HEC-RAS daily model results for total suspended solids and dissolved copper, respectively. HSPF and HEC-RAS have different algorithms for sediment transport and contaminant fate and transport; hence, there are differences in the model response to the management scenarios. In order to better evaluate how the modeling systems are able to simulate effects due to land use changes, management scenarios need to be carried out in conjunction with field data collection.

Nutrients

Figures E.16 to E.19 show HSPF-only daily model results for nutrients. Figures E.22 and E.25 show HSPF/HEC-RAS daily model results for nutrients. Differences in nutrient simulation between the two models seem to be the most pronounced. One of the challenges with comparing HSPF-only and HSPF/HEC-RAS model results is the in-stream portions of the models computing nutrient kinetics differently. In addition, overland water quality state variables do not directly sync with water quality variables in HEC-RAS, thus causing the modeler to estimate boundary condition input for some in-stream state variables within HEC-RAS and causing differences in nutrient concentrations between HSPF-only and HSPF/HEC-RAS. More work needs to be done to better link HSPF output to HEC-RAS, or observed water quality data sets need to be identified, in order to more accurately model the fate and transport of nutrients within HEC-RAS. In order to better evaluate how the modeling systems are able to simulate nutrient effects due to land use changes, management scenarios need to be carried out in conjunction with field data collection.

Summary and conclusions

The objective of this project was to evaluate a linked watershed and riverine modeling system for Calleguas Creek Watershed, California, against observed field data as well as against model output from only the watershed model (HSPF-only). The model evaluation consisted of calibrating the models for the period of record from WY2005 to WY2009 (HSPF-only) or from Jan 2003 to May 2005 (linked models); validating the models for WY1998-WY2004 or Oct 2007-Sep 2009 (linked models), and performing management scenarios for WY2005-WY2009 for HSPF-

only and linked models. The performance objectives (NSE, PBIAS, and RSR) were computed for streamflow, sediment, hardness, chloride, copper, nickel, mercury, selenium, total phosphorus, orthophosphorus, total nitrogen, and nitrate using both daily and monthly average model predictions and measured data.

There were sufficient daily streamflow records to compute the required statistics for the three time periods mentioned above. For sediment and the various other water quality constituents, the availability of samples was sparse relative to the time period over which sampling was completed. Although performance statistics were computed for the water quality parameters, the sampling frequency (approximately one sample per month for most parameters) must be considered when evaluating model performance against prescribed thresholds. Given the flashy nature of streamflow in the Calleguas Creek system, a field sample taken during a single instance may not be representative of daily or monthly average conditions; therefore, it may be inappropriate to compare model results against these infrequent, point-in-time measurements.

The following is a discussion of model performance as it relates to performance objectives.

Performance Objective 1 – Linked model accurately simulates major components of hydrologic cycle and stream flow

Sections 5.4.1 and 6.1.1 describe the performance of HSPF-only and the linked model for the calibration and validation of daily average and monthly flows. Based on the performance ratings, the HSPF-only model was not able to produce acceptable daily streamflow results for the model calibration period, but produced “very good” monthly streamflow results for nearly all statistics and locations. In general, shorter temporal scales produce poorer model simulations than longer temporal scales (e.g., daily versus monthly or yearly) (Engel et al. 2007). When visually comparing daily flow results the HSPF-only model appeared to overpredict flows at Revolon Slough and underpredict peak flows at CSUCI and Conejo Creek, but generally represented the overall hydrograph shape and timing within reasonable limits. Based on the performance ratings and visual comparison of modeled and observed hydrographs, the linked model was able to produce satisfactory daily and monthly flow results for its calibration period.

Based on the performance statistics and visual comparisons of hydrographs, the HSPF-only model was able to produce satisfactory flow results during the validation period for both daily and monthly streamflow simulation. The linked model was also able to produce satisfactory monthly flow results when compared to the performance statistics and hydrograph plots but failed to meet the NSE criteria for simulation of daily streamflow for the validation period, though it was near the threshold.

In conclusion, the HSPF-only model performed better during the validation than during calibration for daily streamflow simulation, but it performed equally well for both the calibration and validation periods for monthly streamflow simulation. Increases in model performance for the validation period could be attributed to a number of factors; however, one of the main reasons for this was likely the longer simulation period for the validation period. The linked model performed equally well in simulating monthly streamflow volumes for both the calibration and validation periods, but it performed slightly better at simulating daily streamflow for the calibration period as opposed to the validation period.

Performance Objective 2 – Linked model accurately simulates soil erosion and sediment transport

Sections 5.4.2 and 6.1.2 describe the performance of HSPF-only and the linked model for the calibration and validation of daily average and monthly sediment simulation. The statistical performance evaluations were based on observed concentrations, not loads. The HSPF-only model produced satisfactory daily average results for all three metrics for both the calibration and validation periods for simulation of TSS concentrations. The HSPF-only model met monthly PBIAS threshold for both the calibration and validation period, but did not meet NSE and RSR thresholds for monthly average results. This may be due to the relatively low number of samples used to compute observed monthly averages (often just one sample per month) and not necessarily an indication of the model's failure to represent monthly average conditions. Visual inspection of simulated concentration time series indicates the HSPF-only model accurately simulates baseflow and storm flow TSS concentrations.

A review of the daily calibration performance statistics for the linked model indicated it was not able to produce satisfactory daily results for TSS. TSS had unsatisfactory daily NSE and RSR; the visual plots indicated

that the linked model was able to capture the temporal variation of observed TSS at CSUCI location. A review of the daily validation performance statistics for the linked model indicated it was able to produce satisfactory daily results with NSE, RSR, and PBIS for TSS. The visual plots indicate that the linked model was able to capture the temporal variation of observed TSS at CSUCI location. Due to the inadequacy of sampling data, monthly calibration and validation performance statistics were not computed for the linked model.

In summary, the HSPF-only and linked model were judged to successfully simulate sediment in the watershed and riverine environments.

Performance Objective 3 – Linked model accurately simulates contaminant fate and transport

Sections 5.4.2 and 6.1.2 describe the performance of the HSPF-only and the linked model for the calibration and validation of daily average and monthly contaminants. The HSPF-only model met all three statistical targets for daily average results for chloride, copper, and nickel for the calibration period and for chloride and mercury for the validation period. The other simulated contaminants met at least one statistical threshold. All simulated contaminants met PBIAS targets for both the calibration and validation periods for both daily and monthly average results. The only contaminants to meet statistical thresholds for simulation of monthly average concentrations were nickel for the calibration period and copper and mercury for the validation period. This may be due to the relatively low number of samples used to compute observed monthly averages (often just one sample per month) and not necessarily an indication of the model's failure to represent monthly average conditions. Visual inspection of simulated concentration time series indicates the HSPF-only model generally matched high-flow and low-flow variability in observed contaminant concentrations, but it tended to overpredict low-flow hardness, copper, and selenium concentrations.

A review of the daily calibration performance statistics for the linked model indicated it was not able to produce satisfactory daily results for Copper. PBIAS indicated very good results with dissolved copper in streamflow; however, copper had unsatisfactory daily NSE and RSR. The visual plots indicate that the linked model was able to capture the temporal variation of observed copper at CSUCI location. The daily

validation performance statistics for the linked model indicated it was able to produce satisfactory daily results with PBIAS for Copper. Dissolved copper had unsatisfactory daily NSE and RSR. The visual plots indicate that the linked model was able to capture the temporal variation of observed copper at CSUCI location. Due to the inadequacy of sampling data, monthly calibration and validation performance statistics were not computed for the linked model.

In summary, the HSPF-only model was judged to successfully simulate daily observed contaminant concentrations for some constituents and time periods. However, it was unsuccessful for other constituents and time periods, as described above. The calibration results for the linked model were not fully satisfactory; however, the validation results indicate that the model was able to satisfactorily simulate contaminants when compared to field observations.

Performance Objective 4 – Linked model accurately simulates nutrient fate and transport

Sections 5.4.3 and 6.1.3 describe the performance of HSPF-only and the linked model for the calibration and validation of daily average and monthly nutrient simulation. The statistical performance evaluations were based on observed concentrations, not loads. The HSPF-only model met PBIAS targets for all nutrient species evaluated (total phosphorus, orthophosphate, total nitrogen, and nitrate) for simulation of both daily and monthly averages for both the calibration and validation periods. The HSPF-only model did not meet NSE and RSR thresholds for simulation of both daily and monthly averages for both the calibration and validation periods, with the exception of daily nitrate RSR value for the calibration period. Visual inspection of time series plots indicates the HSPF-only model tends to underpredict peak phosphorus concentrations and overpredict total nitrogen and nitrate concentrations.

A review of the daily calibration performance statistics for the linked model indicated it was not able to produce satisfactory daily results for TP, TN, NH4, and NO3. PBIAS indicated very good results with these constituents in streamflow. These constituents had unsatisfactory daily NSE and RSR; the visual plots shown indicate that the linked model was able to capture the temporal variation of observed data at the CSUCI location. The daily validation performance statistics for the linked model

demonstrated that it was not able to produce satisfactory daily results for TP, TN, NH4 and NO3. PBIAS indicated overall satisfactory results with these constituents in streamflow. These constituents had unsatisfactory daily NSE and RSR. The visual plots indicate that the linked model was able to capture the temporal variation of observed data at CSUCI location. Given the flashy nature of streamflow in the Calleguas Creek system, a field sample taken during a single instance is unlikely to be representative of monthly average conditions. Consequently, while the authors did compute performance statistics, it may be inappropriate to compare monthly average model results against these point-in-time measurements.

In summary, the HSPF-only and linked models were judged unsuccessful in their ability to simulate observed nutrient concentrations. In order to improve the models and the evaluation of their performance, more nutrient samples need to be taken. In addition to monthly samples, storm event samples need to be taken.

Performance Objective 5 – Management Scenarios

Section 6.2 describes the performance of HSPF-only and the linked model in being able to simulate the effect of management scenarios. The scenario simulated was a hypothetical land use conversion scenario, in which 50% of open space land use was converted to agricultural land use in the Arroyo Las Posas area, and 50% of open space land use was converted to developed land uses (residential and commercial or industrial) in the Arroyo Simi headwaters area. Both models appeared to simulate flows based on the management scenarios implemented within the models. Sediment and contaminant simulations differed slightly, but that is to be expected given the differences in sediment and contaminant formulations found within the in-stream portions of the models. Differences in nutrient simulation between the two models seem to be the most pronounced. Part of the issue in comparing HSPF-only and HSPF/HEC-RAS model results is due to the in-stream portions of the models computing nutrient kinetics differently. In addition, overland water quality state variables do not directly sync with water quality variables in HEC-RAS, thus causing the modeler to estimate boundary condition input for some in-stream state variables within HEC-RAS and causing differences in nutrient concentrations between HSPF-only and HSPF/HEC-RAS.

In summary, more work needs to be done to better link HSPF output to HEC-RAS, or observed water quality data sets need to be identified in order to more accurately model the fate and transport of nutrients within HEC-RAS. In order to better evaluate how the modeling systems are able to simulate sediment, contaminant, and nutrient effects due to land use changes, management scenarios need to be carried out in conjunction with field data collection.

Performance Objective 6 – Data Availability

Ventura County personnel served as local resources to assist in the data gathering and model conceptualization. There were sufficient national and local datasets available to develop the needed model inputs for both HSPF and HEC-RAS.

In regard to field data collection, there were sufficient streamflow data to perform model calibration and validation and generate the required statistics for storm event periods; however, HEC-RAS model instability issues encountered during simulation of low- or zero-flow conditions necessitated it to have a different (shorter) simulation period than the HSPF-only model. There were sufficient observed water quality data to perform statistical evaluations at one location in the watershed for simulation of daily average concentrations. The sampling frequency for the various water quality parameters was approximately one per month, however, and therefore most "monthly average" observations represented just a single sample. Given the flashy nature of streamflow in the Calleguas Creek system, a field sample taken during a single instance is unlikely to be representative of monthly average conditions; therefore, it may be inappropriate to compare monthly average model results against these point-in-time measurements. All visual and statistical performance evaluations were based on observed sediment, contaminant, and nutrient concentrations, not loads.

Therefore for Performance Objectives 6.1 to 6.3 respectively, the authors judge the demonstration to be adequate but not fully successful.

Performance Objective 7 – Ease of Use

Summarizing ease of use, both models had mature graphical user interfaces, thus facilitating the set up and simulation of the models. Two

professional engineers with master's degrees and over five years of work experience developed the watershed and riverine models. One of these engineers was accustomed to performing calibration and validation of the models with a senior-level engineer with a PhD and over 20 years of experience, who performed technical peer review of the work. Thus, there were sufficient resources and personnel to run the HSPF-only and linked models. The initial set up of the models took a total of two weeks for the HSPF watershed model and two weeks for the HEC-RAS riverine model. The calibration phase took approximately five months; the validation phase took approximately one month, and the management scenario evaluations took approximately one month. Based on experience in performing these types of studies in the past, the goals the team set in Performance Objectives 7.1 to 7.4 were met and thus successful.

Lessons Learned

A number of challenges were encountered at this demonstration site, including unique hydrologic characteristics of the Calleguas Creek Watershed that led to model instabilities, a relatively large number of model segments, a relatively long simulation period, observed data limitations, and a relatively high number of constituents modeled. These challenges presented opportunities for lessons learned when applying the linked watershed-riverine models in the future.

Several hydrologic characteristics of the Calleguas Creek Watershed presented challenges for the water quality calibration. Streamflow throughout the system is relatively flashy, with the majority of discharge occurring during winter months followed by extended low-flow periods where the only sources of streamflow are groundwater inflow, municipal point source discharges, and pumping from groundwater dewatering wells. A large portion of the HSPF RCHRES have zero outflow over 90% of the simulation period. Simulated reach outflows of zero or nearly zero often occurred in RCHRES with no groundwater inflow routed to them (e.g., in the Arroyo Simi headwaters) or no contributing area (e.g., several RCHRES representing debris basins). Additionally, several RCHRES along the main river channel were characterized with a subsurface loss pathway that often exceeded the downstream flow pathway during low depths. HSPF simulates unrealistically large in-stream water quality constituent concentrations or return erroneous values (-1.0E+30) when simulated outflows are at or near zero. While this model behavior has been documented by LimnoTech (LimnoTech 2014) and others (Benham et al.

2006, Seong et al. 2013) in past HSPF applications, the frequency of zero-reach outflow conditions in the Calleguas Creek model was extreme.

The low-flow and zero-flow occurrences also caused model stability challenges for HEC-RAS, especially near abrupt vertical transitions and near the bridges, which lead to fatal model instability. Several HEC-RAS model refinements were required to stabilize the model, including setting a minimum upstream boundary condition flow rate of 100 cfs, decreasing the computational timestep, and increasing cross-section resolution.

Although streamflow data were sufficient for calibration and validation to daily and monthly average conditions, sediment, contaminant, and nutrient data were relatively sparse. The sampling frequency for the various water quality parameters was approximately one per month and therefore most "monthly average" observations represented just a single sample. Given the flashy nature of streamflow in the Calleguas Creek system, a field sample taken during a single instance is unlikely to be representative of monthly average conditions. It may be inappropriate to compare monthly average model results against these point-in-time measurements. Additionally, all statistical evaluations of model performance were made using measured and model-predicted concentrations, not loads, but all watershed model studies cited by Moriasi et al. (2007), which was used to derive the recommended model performance evaluation thresholds presented in this report, used measured and model-predicted loads when completing statistical evaluations. Therefore, future demonstration sites should either emphasize computation of observed loads from available datasets, or employ alternative performance evaluation metrics and/or relaxed thresholds that have a precedence for use in comparing simulated and observed concentrations.

Although the model calibration achieved is as good as can be expected given the measured data limitations and resource constraints of this project, the Calleguas Creek Watershed linked model water quality calibration could be further evaluated and enhanced, if necessary, to improve the model's predictive capabilities, if the following actions are performed: (1) the model simulation period could be extended beyond water year 2009 to allow for comparisons against more recently collected water quality measurements; and/or (2) if estimations of annual, monthly, and/or daily loads become available, model-predicted loads could be compared against the alternate load estimates.

References

AQUA TERRA Consultants. 2005. *Hydrologic Modeling of the Calleguas Creek Watershed with the U.S. EPA Hydrologic Simulation Program* – FORTRAN (HSPF). Final Report. March 10, 2005.

ASCE (American Society of Civil Engineers). 1993. Criteria for evaluation of watershed models. *J. Irrigation Drainage Eng*. 119(3): 429-442.

Barkau, R. L. 1992. UNET, One-Dimensional Unsteady Flow through a Full Network of Open Channels, Computer Program, St. Louis, MO.

Benham, B. L., C. Baffaut, R. W. Zeckoski, K. R. Mankin, Y. A. Pachepsky, A. M. Sadeghi, K. M. Brannan, M. L. Soupir, M. J. Habersack. 2006. Modeling Bacteria Fate and Transport in Watersheds to Support TMDLs. *Transactions of the ASABE* 49(4): 987-1002.

Bicknell, Brian R., J. C. Imhoff, J. L. Kittle Jr., T. H. Jobes, A. S. Donigian, Jr. 2005.*HSPF Version 12.2 User's Manual*. Mountain View, CA: AQUA TERRA Consultants..

Engel, B., D. Storm, M. White, J. Arnold, and M. Arabi. 2007. A hydrologic/water quality model application protocol. *Journal of the American Water Resources Association* 43(5):1223-1236.

Hydrologic Engineering Center (HEC), 1997. *UNET, One-Dimensional Unsteady Flow through a Full Network Open Channels, User's Manual*. Davis, CA: U.S. Army Corps of Engineers.

Krause, P., D. P Boyle., F. Base. 2005. Comparison of different efficiency criteria for hydrological model assessment. *Advances in Geosciences* 5: 89–97.

Larry Walker Associates. 2001. Calleguas Creek Nutrient TMDLs. Final Report.

Larry Walker Associates. 2006. Calleguas Creek Watershed Metals and Selenium TMDL. Draft Final Technical Report. March 29, 2006.

Legates, D. R., and G. J. McCabe Jr. 1999. Evaluating the use of "goodness-of-fit" measures in hydrologic and hydroclimatic model validation. *Water Resour. Res.* 35(1): 233–241.

LimnoTech. 2014. *Zumbro River Watershed HSPF Model Development Project*. Final report prepared for Minnesota Pollution Control Agency (MPCA). May 12, 2014.

Mashriqui, H., S. Reed, and C. Aschwanden. 2010. Toward modeling of river-estuary-ocean interactions to enhance operational river forecasting in the NOAA national weather service, 2nd Joint Federal Interagency Conference. Las Vegas, NV.

Milchunas, D. G., K. A. Schultz, and R. B. Shaw. 1999. Plant community response to disturbance by mechanized military maneuvers. *Journal of Environmental Quality* 28:1533–1547.

Moriasi, D. N., J. G.Arnold, M. W. Van Liew, R. L. Bingner, R. D. Harmel, T. L. Veith. 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations *Transactions of the ASABE* 50(3): 885-900.

Quist M. C., P. A. Fay, C. S. Guy, A. K. Knapp, and B. N. Rubenstein. 2003. Military Training Effects on Terrestrial and Aquatic Communities on a Grassland Military Installation. *Ecological Applications* 13(2): 432-442.

Runkel, R. L., C. G. Crawford, and T. A. Cohn. 2004. *Load Estimator (LOADEST): A FORTRAN Program for Estimating Constituent Loads in Streams and Rivers: U.S. Geological Survey Techniques and Methods* Book 4, Chapter A5.

Seong, C. H., B. L. Benham, K. M. Hall, and K. Kline. 2013. Comparison of alternative methods to simulate bacteria concentrations with HSPF under low-flow conditions. *Applied Engineering in Agriculture* 29(6): 917-931.

Appendix A: Health and Safety Plan (HASP)

HASP applies to exposure to chemical and hazardous materials. This ESTCP project does not require exposure to chemical and hazardous materials. We are currently working with the ERDC Safety Office in developing a plan and will submit a signed copy once it has been approved.

POSITION HAZARD ANALYSIS

JOB TITLE: Research Civil Engineer	**PRINCIPAL GEOGRAPHIC LOCATION:** Fort Hood, Texas
LABORATORY/CSD OFFICE: Environmental Laboratory	**DIVISION/BRANCH/OFFICE:** Water Quality and Contaminant Modeling Branch

HAZARDOUS ACTIVITIES	HAZARDS	REQUIRED CONTROLS: PROTECTIVE CLOTHING AND EQUIPMENT	REQUIRED CONTROLS: TRAINING AND OTHER CONTROLS
Field work in remote locations. Field work involves collecting channel cross-sections and general watershed reconnaissance. Field work is in natural areas that have open to dense grass, shrub, and forest vegetation. Employees are in the field the full day. Field location is CONUS. This analysis is group analysis for multiple personnel conducting similar data collection activities.	Employee exposed to sun for long periods of time. Employees risk sunburn. Vegetation is common habitat for biting insects, ticks, chigars. Insects carry diseases like lime's disease. Vegetation often contains noxious vegetation like poison ivy. Poison ivy causes rashes and potential skin scarring. Thick vegetation puts employee at risk for eye injury. Rough terrain risks ankle injury.	Protective measures are: 1) Sun exposure: sunscreen to prevent sunburn. 2) Biting insects, ticks, chigars: Natrapel to repel ticks. Deet to repel biting insects and chigars. 3) Thick vegetation: Protective eye gear to prevent injury to eyes. Hard hat for head protection. Thick gloves for hand protection. 4) Rough terrain: High topped boots to prevent ankle injury.	Complete required installation field security training.

Reviewed by: Billy E. Johnson **Employee (type or print name)**	Billy E. Johnson **Signature**	9/20/13 **Date**
Prepared by: Dorothy H. Tillman **Supervisor (type or print name)**	Dorothy H. Tillman **Signature**	9/20/13 **Date**

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Appendix B: Points of Contact

POINT OF CONTACT Name	ORGANIZATION Name Address	Phone Fax E-mail	Role in Project
Billy Johnson	ERDC-EL, 3909 Halls Ferry Road, Vicksburg, MS, 39180	Phone: 601-634-3714 Fax: 601-634-3129 Email: billy.e.johnson@usace.army.mil	Project Coordinator, ERDC Demonstration Lead
Heidi Howard	ERDC-CERL, 2902 Newmark Dr. Champaign IL, 61822-1076	Phone: 217-373-5865 Fax: 217-373-7266 Email: heidi.r.howard@usace.army.mil	Installation Coordinator
Zhonglong Zhang	LimnoTech, 3909 Halls Ferry Road, Vicksburg, MS, 39180	Phone: 601-634-3337 Fax: 601-634-3129 Email: zhonglong.zhang@usace.army.mil	Model application and development
Jeffrey Gerald	ERDC-EL, 3909 Halls Ferry Road, Vicksburg, MS, 39180	Phone: 601-634-3590 Fax: 601-634-3129 Email: jeff.gerald@usace.army.mil	Model Linkage
Mark George	Environmental Department (EV14) Naval Facilities Engineering Service Center 1100 23rd Avenue, Port Hueneme, CA 93043	Phone: (805)982-3110; Fax: (805)982-4832 Email: mark.s.george@navy.mil	Data Collector and Installation Coordinator
Kurt Preston	ESTCP, 901 N. Stuart St., Suite 303, Arlington, VA, 22203-1853	Phone - 703-697-0487 Email: Kurt.T.Preston@usace.army.mil	Resource Conservation Program Manager
Cassandra Bergstedt	ESTCP/Noblis; 16414 San Pedro Avenue, Suite 400, San Antonio, TX 78232	Phone – 210-403-5409 Email: Cassandra.A.Bergstedt@noblis.org	Project reporting
Stephanie Lawless	ESTCP/Noblis; 3150 Fairview Park Drive, Falls Church, VA 2204	Phone – 703-610-2817 Email: Stephanie.Lawless@noblis.org	Project reporting

Appendix C: Calibration Model Results

Figure C.1. Daily average observed versus HSPF modeled streamflow for Calleguas Creek at CSUCI for the calibration period (WY2005-WY2009).

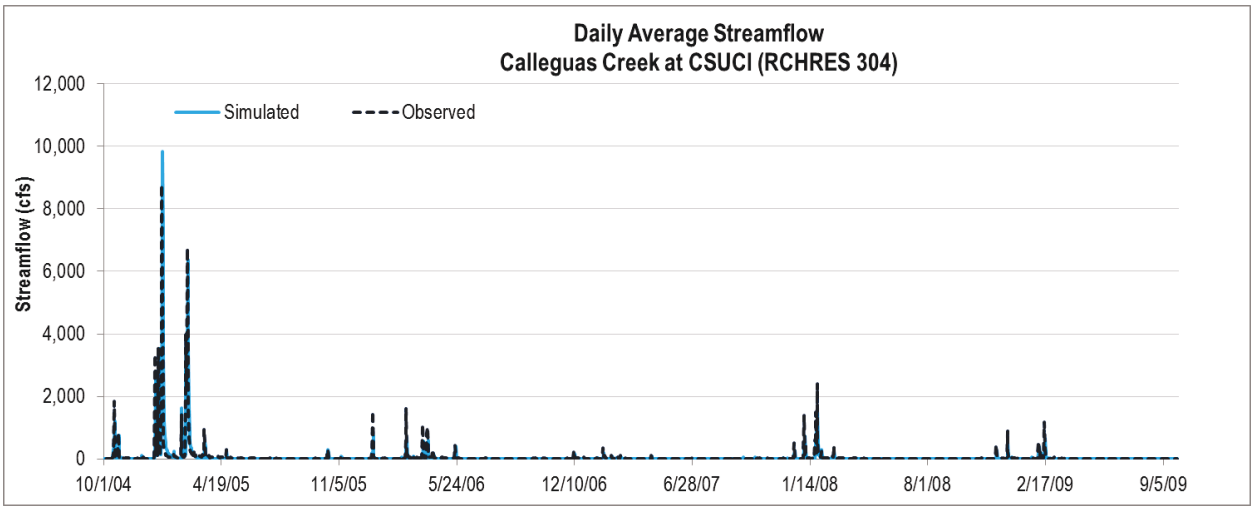


Figure C.2. Daily average observed versus HSPF modeled streamflow for Conejo Creek above Hwy. 101 for the calibration period (WY2005-WY2009).

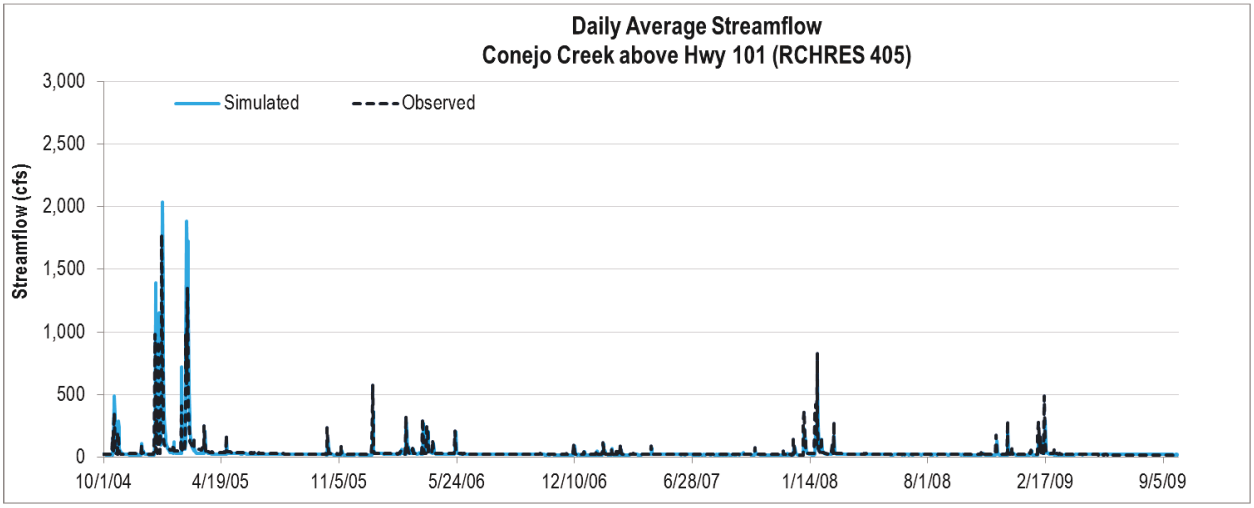


Figure C.3. Daily average observed versus HSPF modeled streamflow for Revolon Slough at Laguna Rd. for the calibration period (WY2005-WY2009).

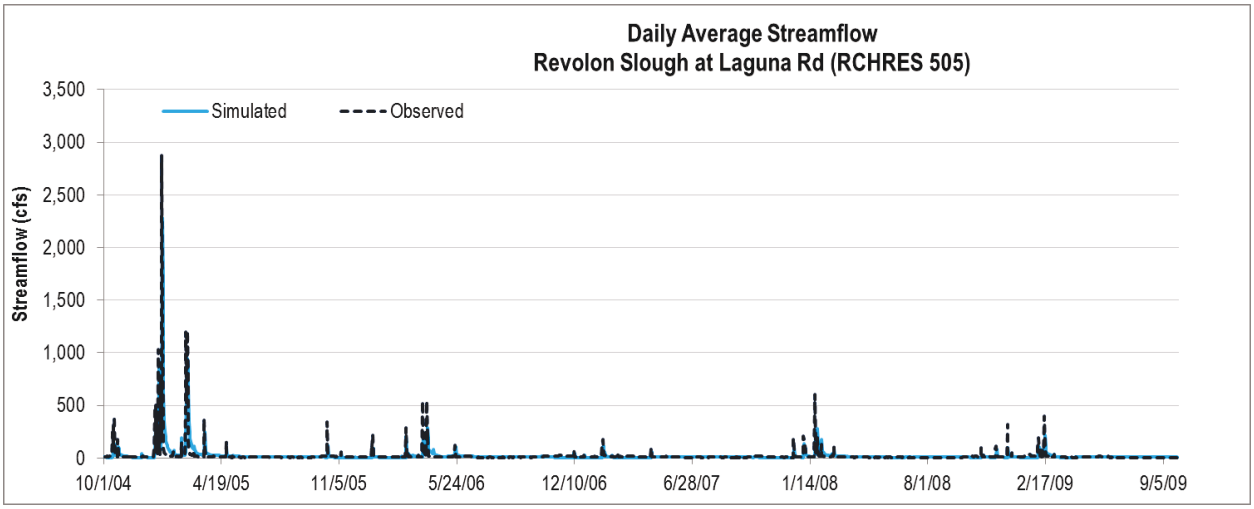


Figure C.4. Monthly observed versus HSPF modeled streamflow for Calleguas Creek at CSUCI for the calibration period (WY2005-WY2009).

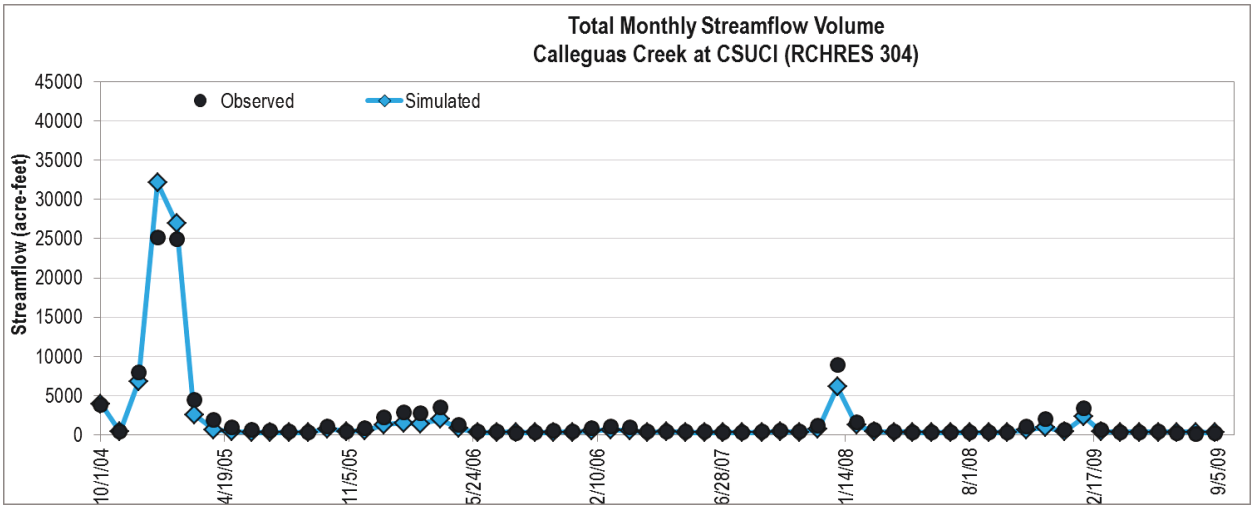


Figure C.5. Monthly observed versus HSPF modeled streamflow for Conejo Creek above Hwy. 101 for the calibration period (WY2005-WY2009).

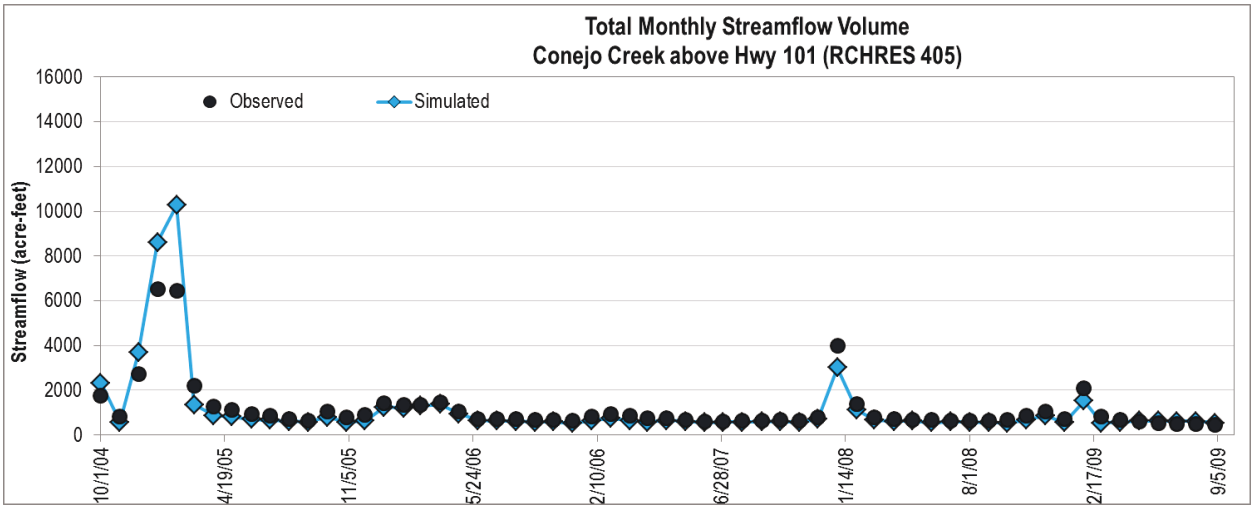


Figure C.6. Monthly observed versus HSPF modeled streamflow for Revolon Slough at Laguna Rd. for the calibration period (WY2005-WY2009).

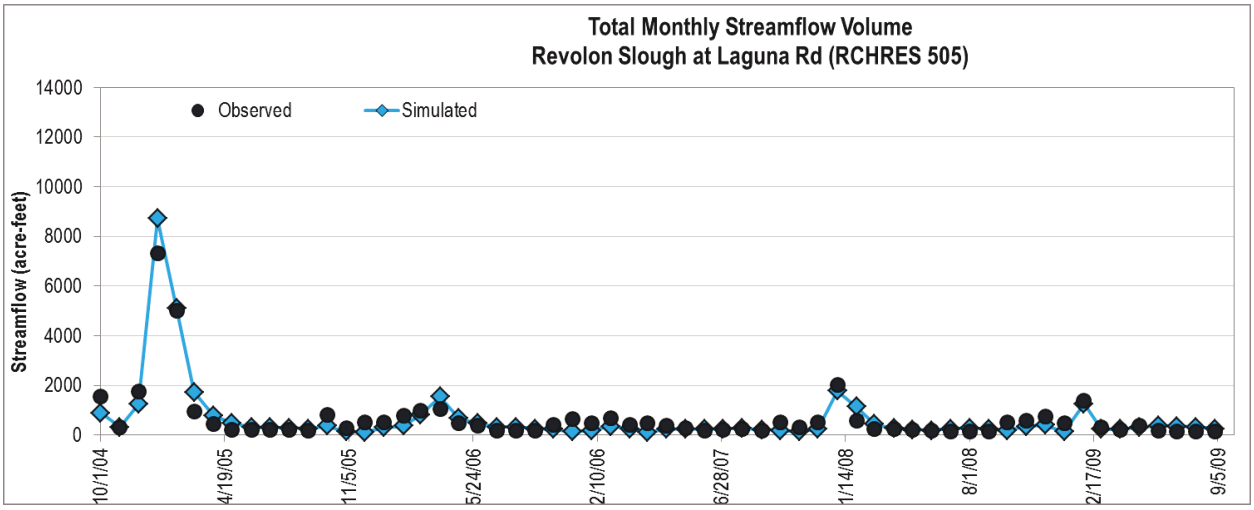


Figure C.7. Daily average observed versus linked HSPF/HEC-RAS modeled streamflow at Calleguas Creek at CSUCI (Gage 805) for the calibration period (2007–2009).

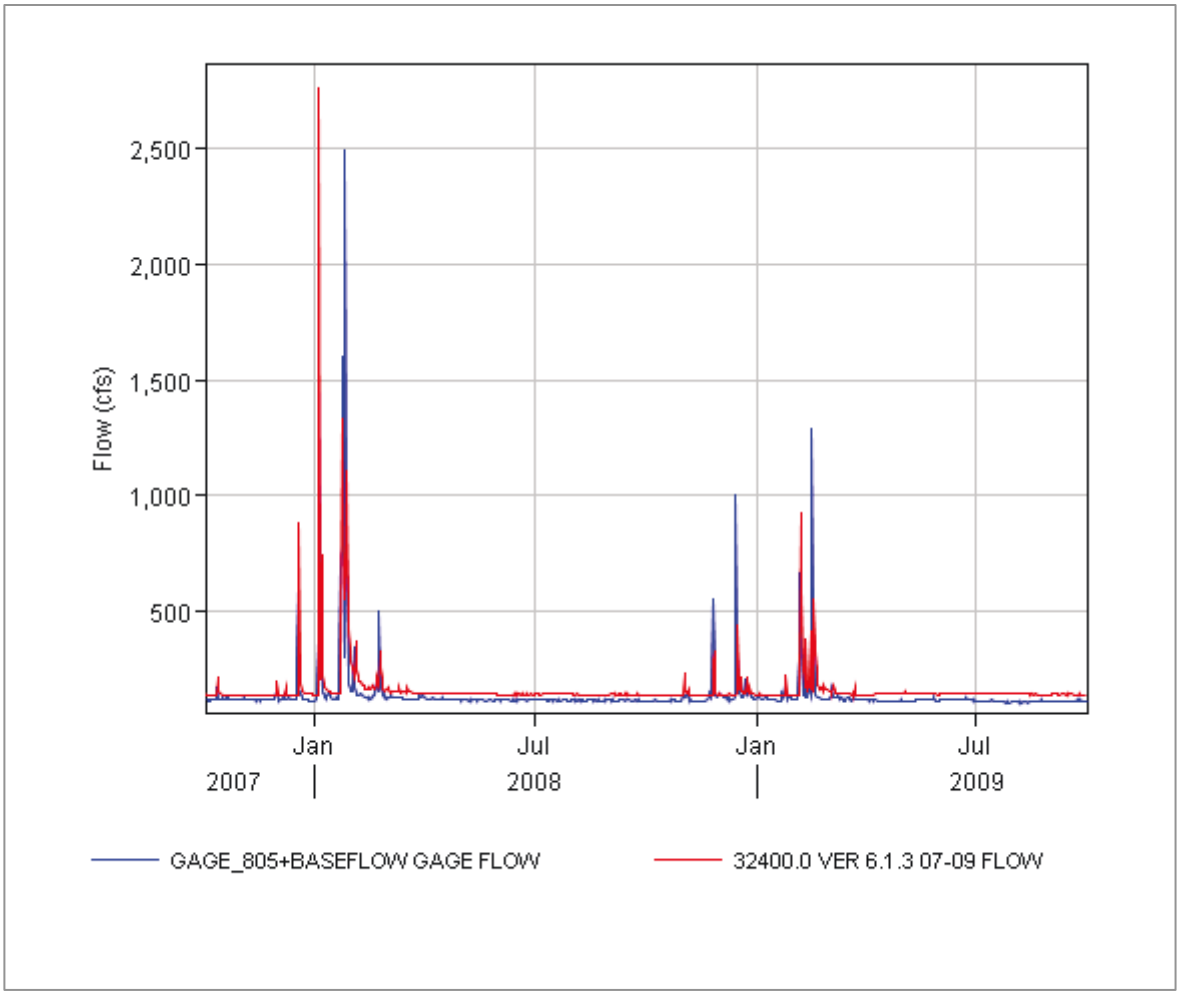


Figure C.8. Monthly average observed versus linked HSPF/HEC-RAS modeled streamflow at Calleguas Creek at CSUCI (Gage 805) for the calibration period (2007–2009).

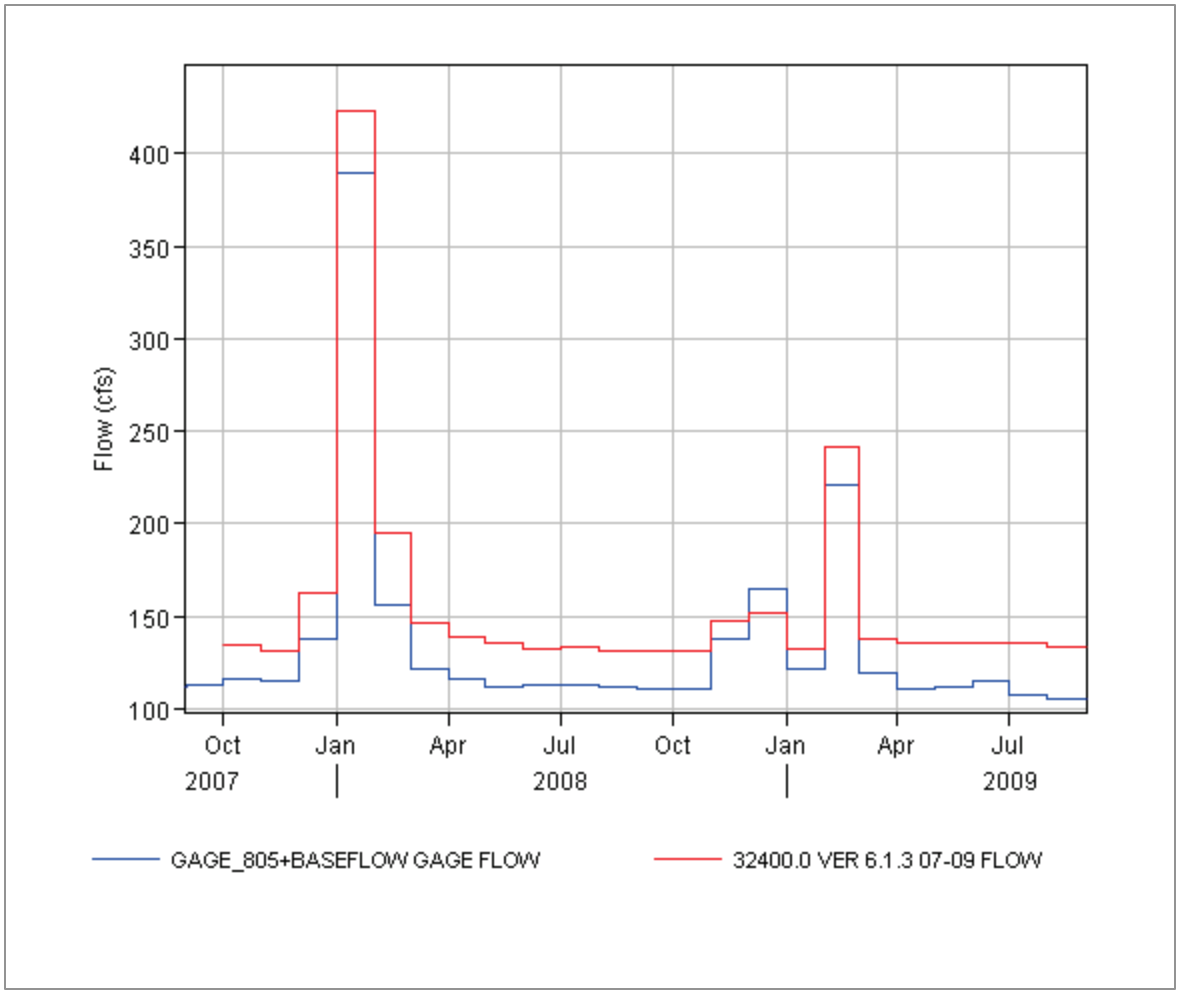


Figure C.9. Daily average observed versus HSPF modeled TSS concentrations for Calleguas Creek at CSUCI for the calibration period (WY2005-WY2009).

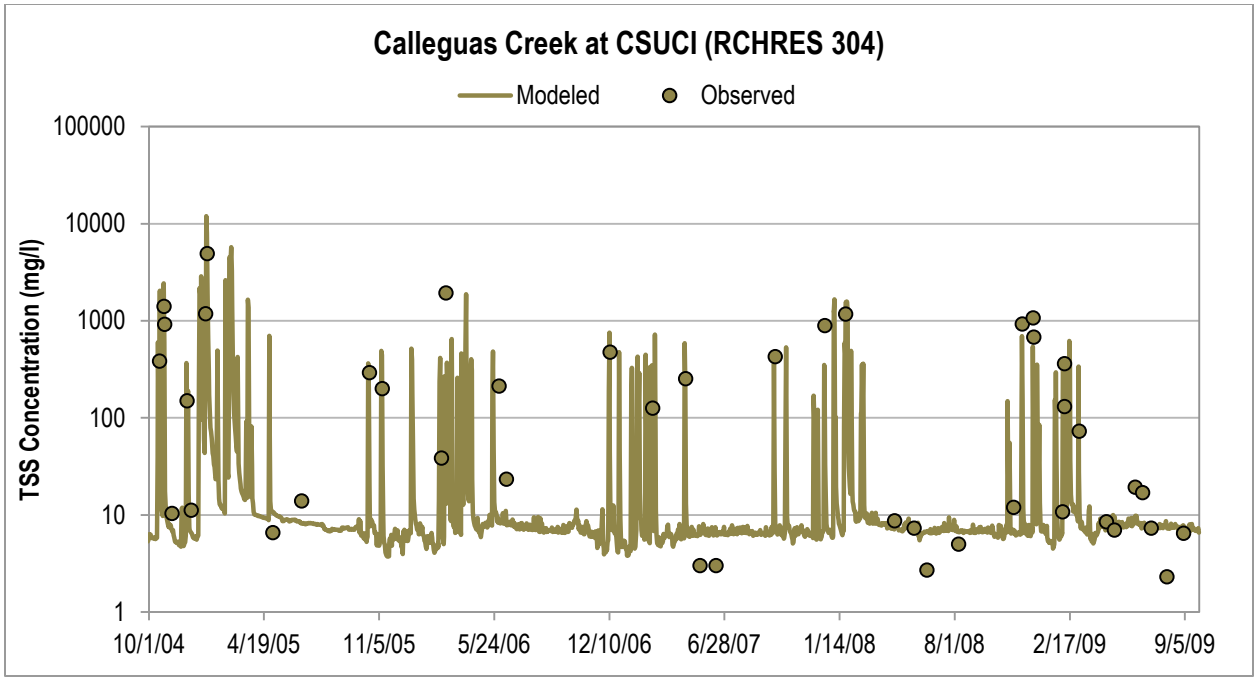


Figure C.10. Daily average observed versus HSPF modeled hardness concentrations for Calleguas Creek at CSUCI for the calibration period (WY2005-WY2009).

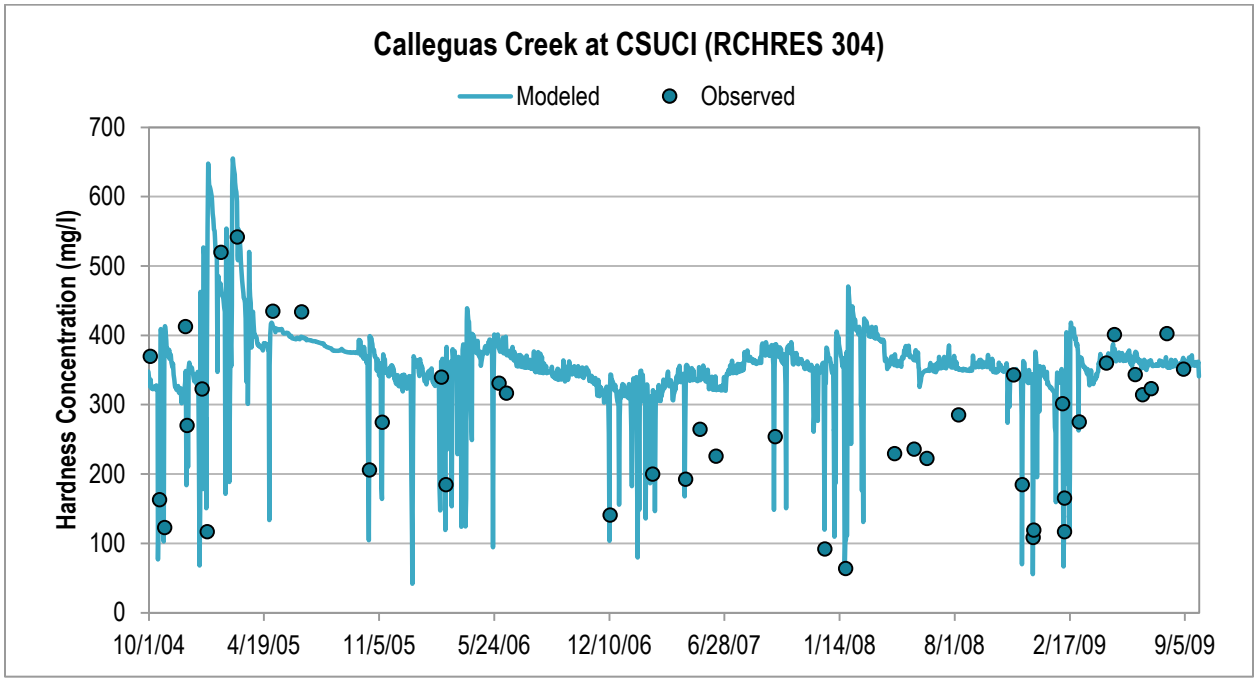


Figure C.11. Daily average observed versus HSPF modeled chloride concentrations for Calleguas Creek at CSUCI for the calibration period (WY2005-WY2009).

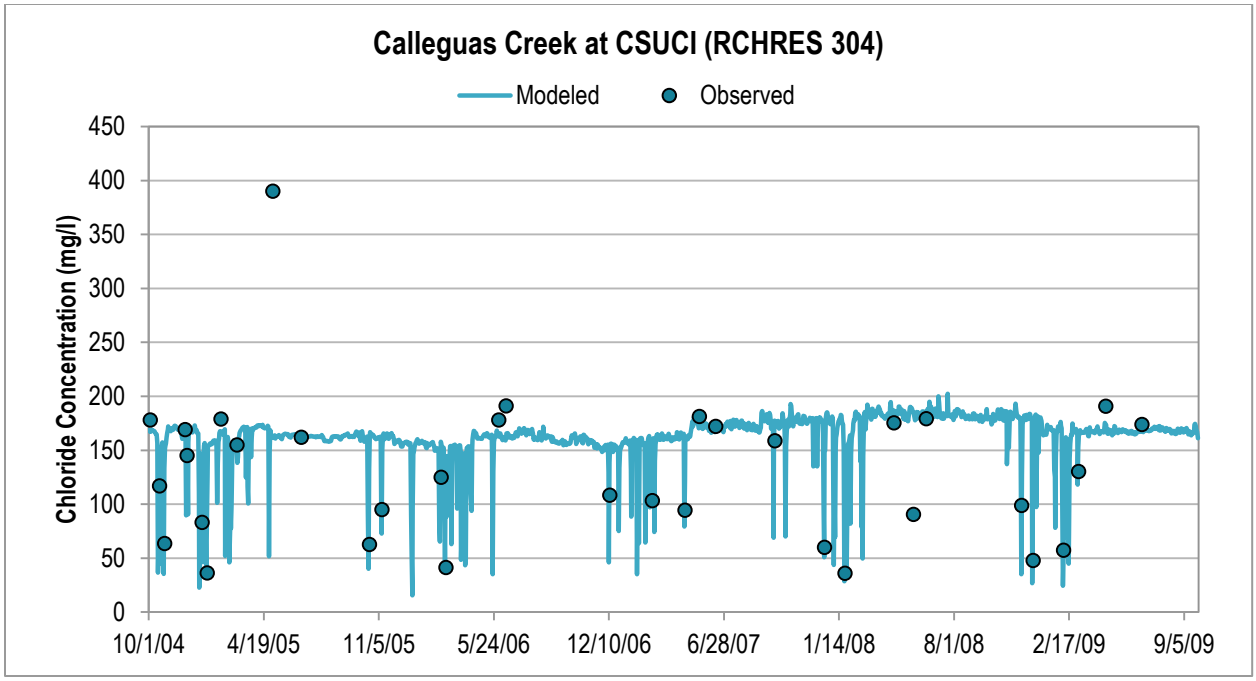


Figure C.12. Daily average observed versus HSPF modeled total copper concentrations for Calleguas Creek at CSUCI for the calibration period (WY2005-WY2009).

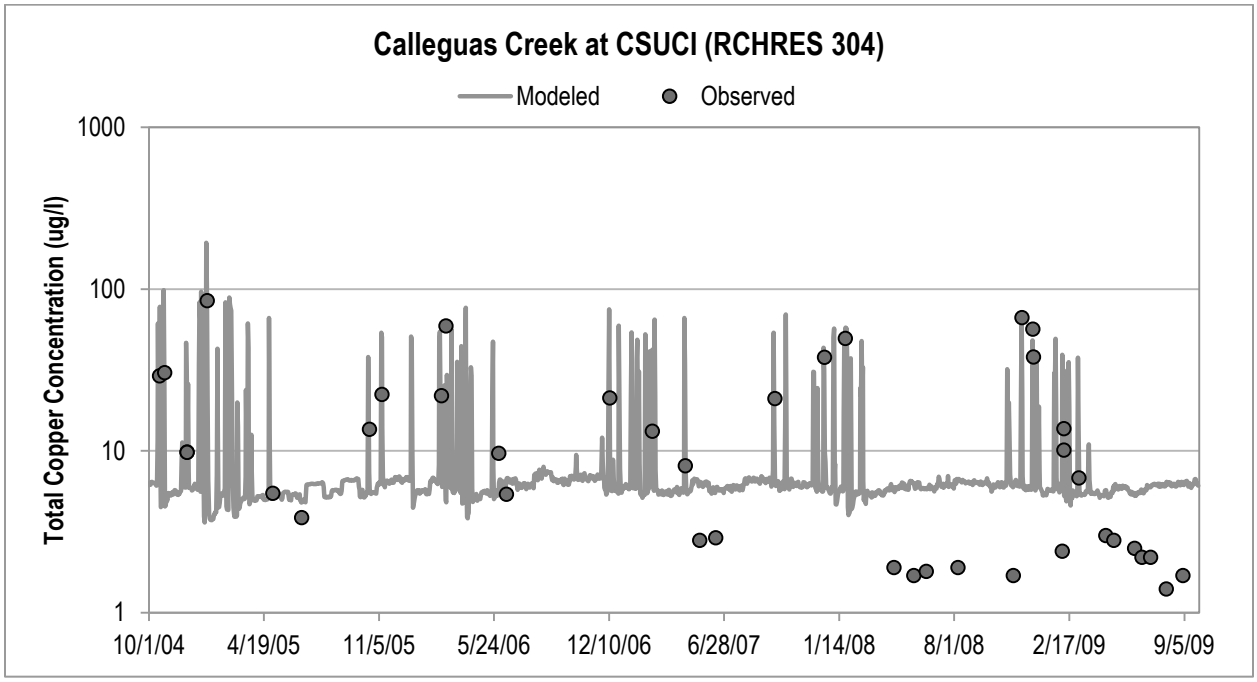


Figure C.13. Daily average observed versus HSPF modeled total nickel concentrations for Calleguas Creek at CSUCI for the calibration period (WY2005-WY2009).

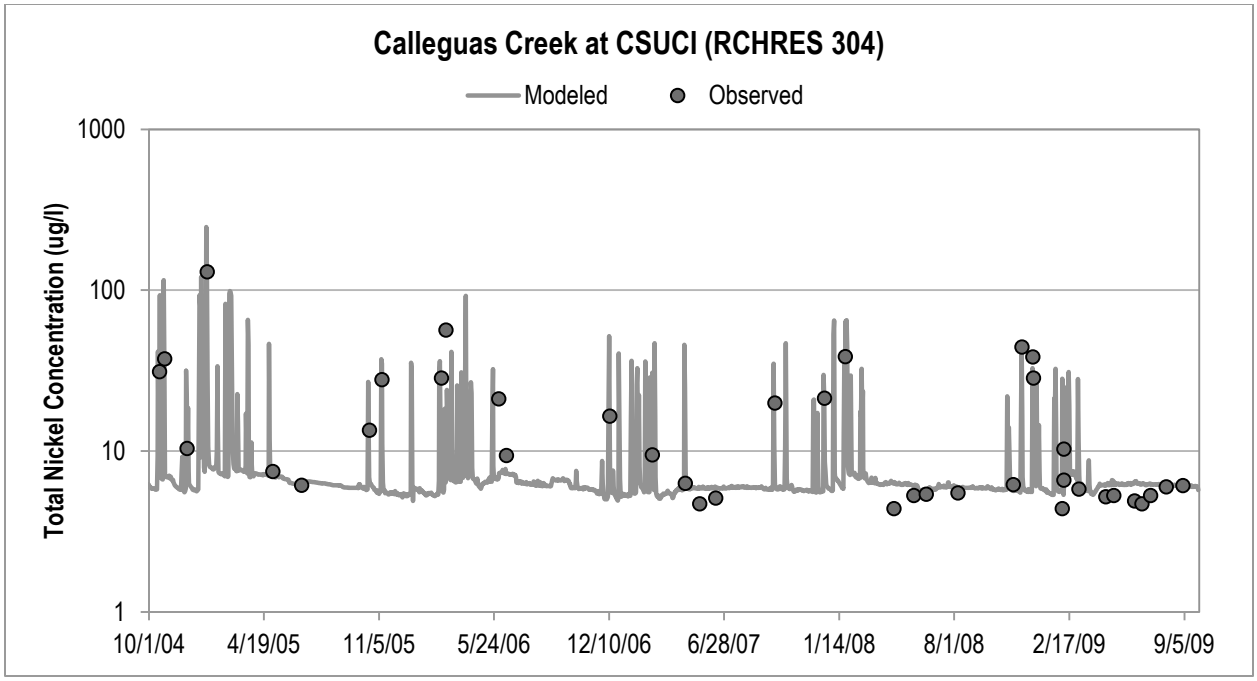


Figure C.14. Daily average observed versus HSPF modeled total mercury concentrations for Calleguas Creek at CSUCI for the calibration period (WY2005-WY2009).

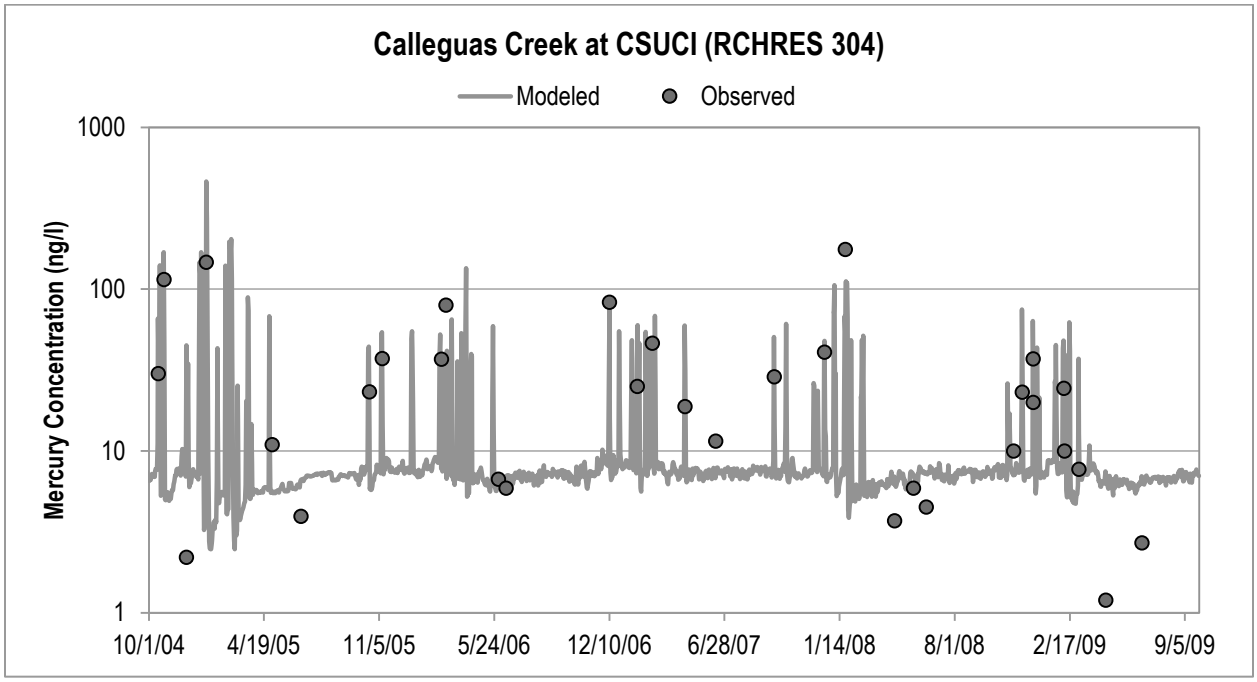


Figure C.15. Daily average observed versus HSPF modeled total selenium concentrations for Calleguas Creek at CSUCI for the calibration period (WY2005-WY2009).

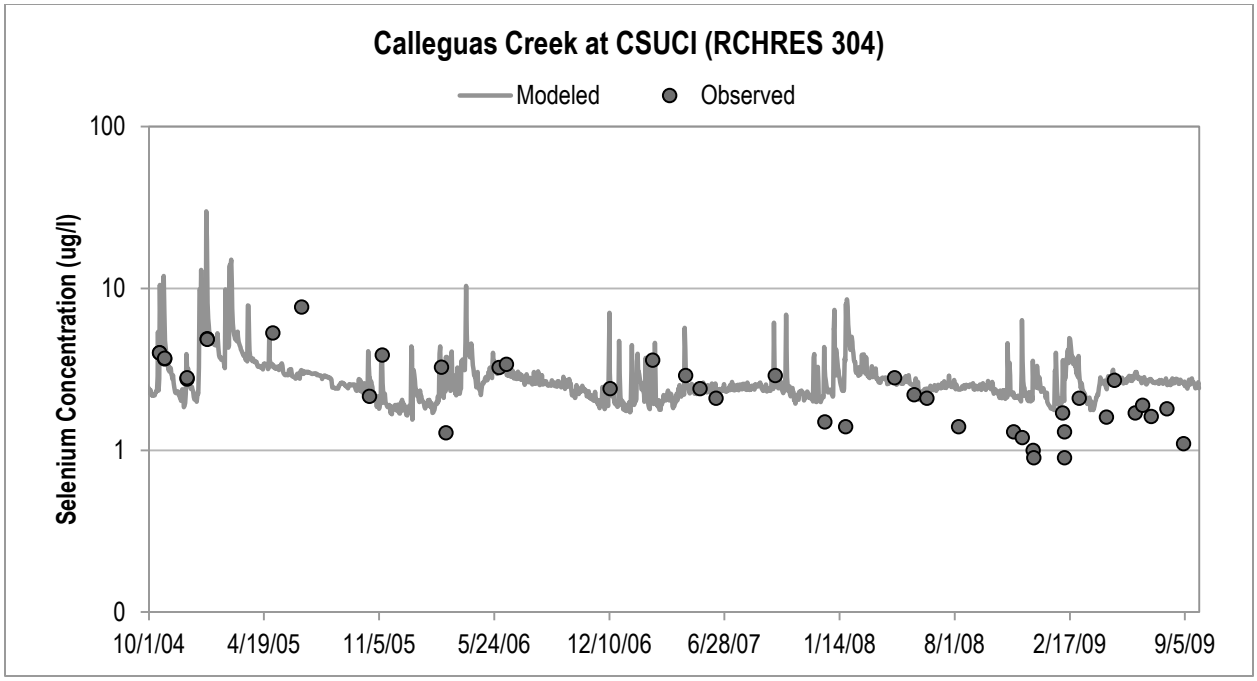


Figure C.16. Daily average observed versus HSPF modeled total phosphorus concentrations for Calleguas Creek at CSUCI for the calibration period (WY2005-WY2009).

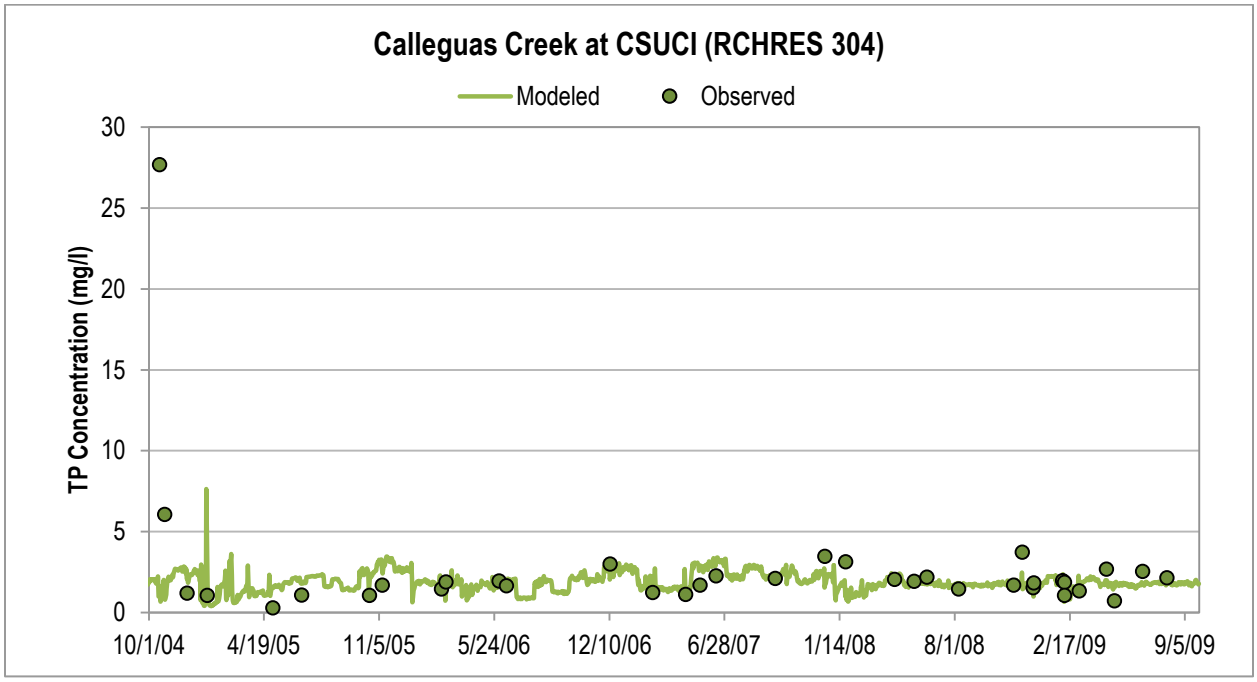


Figure C.17. Daily average observed versus HSPF modeled orthophosphate concentrations for Calleguas Creek at CSUCI for the calibration period (WY2005-WY2009).

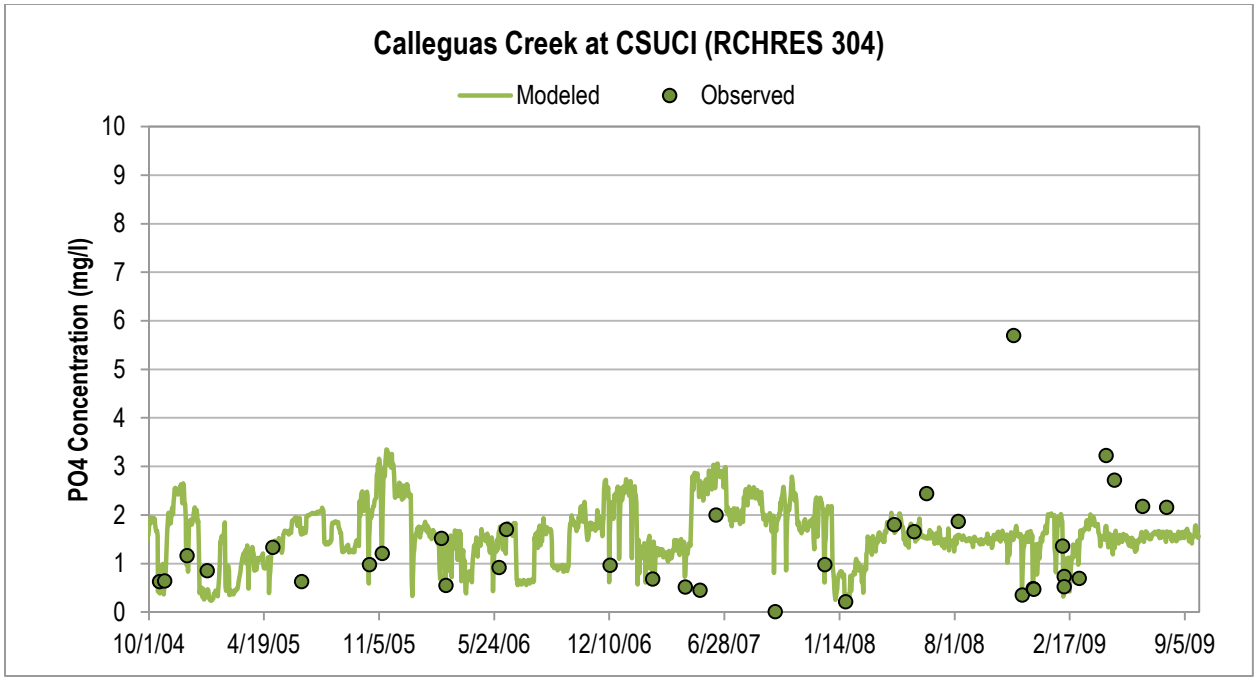


Figure C.18. Daily average observed versus HSPF modeled total nitrogen concentrations for Calleguas Creek at CSUCI for the calibration period (WY2005-WY2009).

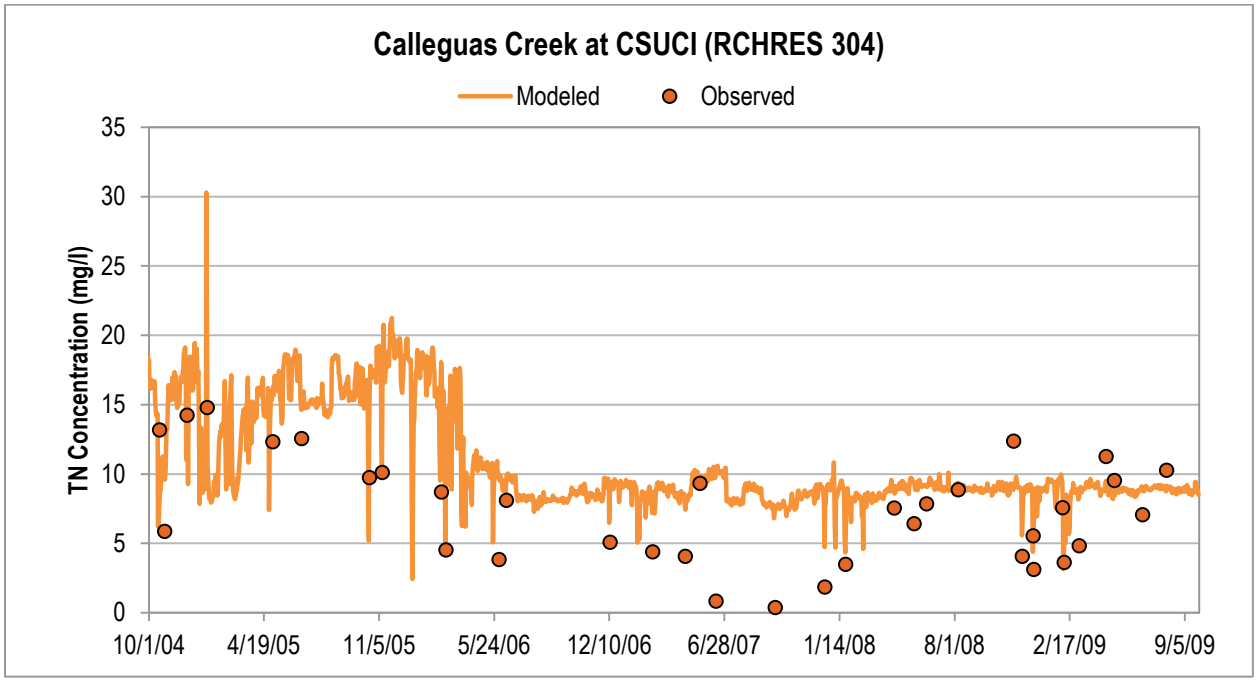


Figure C.19. Daily average observed versus HSPF modeled nitrate concentrations for Calleguas Creek at CSUCI for the calibration period (WY2005-WY2009).

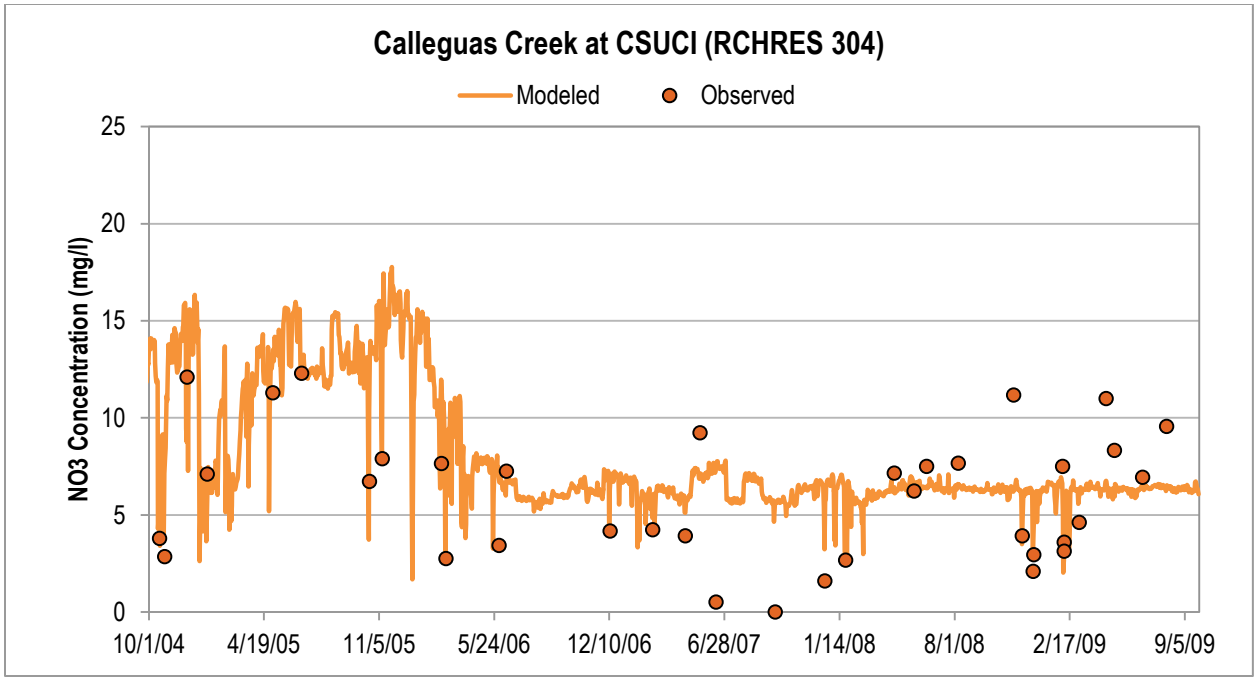


Figure C.20. Daily average observed versus linked HSPF/HEC-RAS modeled dissolved TSS concentrations for Calleguas Creek at CSUCI for the calibration period (2006-2009).

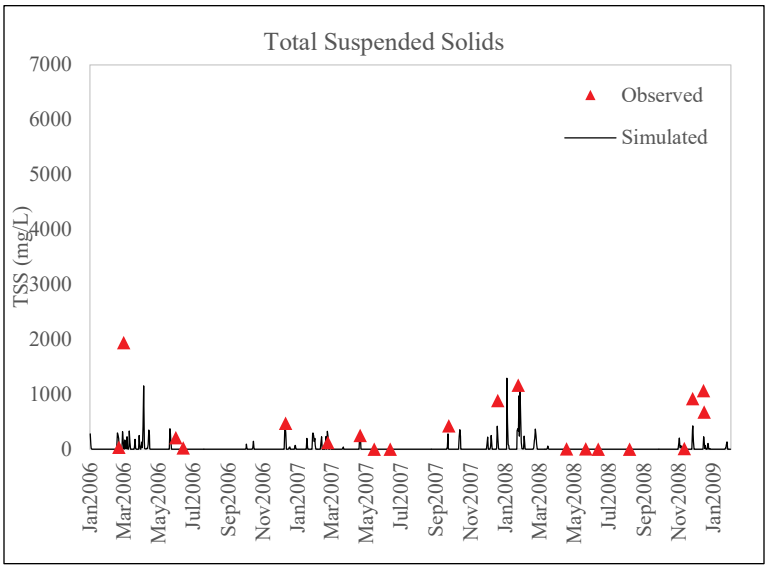


Figure C.21. Daily average observed versus linked HSPF/HEC-RAS modeled dissolved copper concentrations for Calleguas Creek at CSUCI for the calibration period (2006-2009).

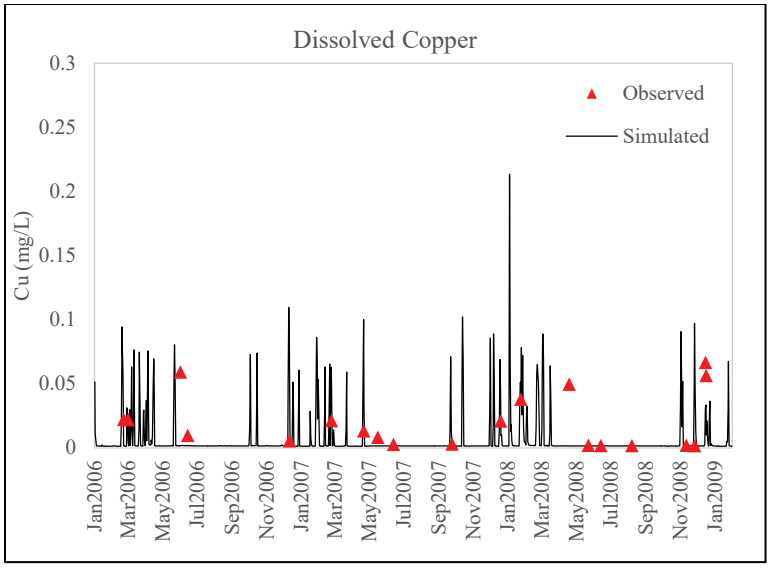


Figure C.22. Daily average observed versus linked HSPF/HEC-RAS modeled total phosphorous concentrations for Calleguas Creek at CSUCI for the calibration period (2006-2009).

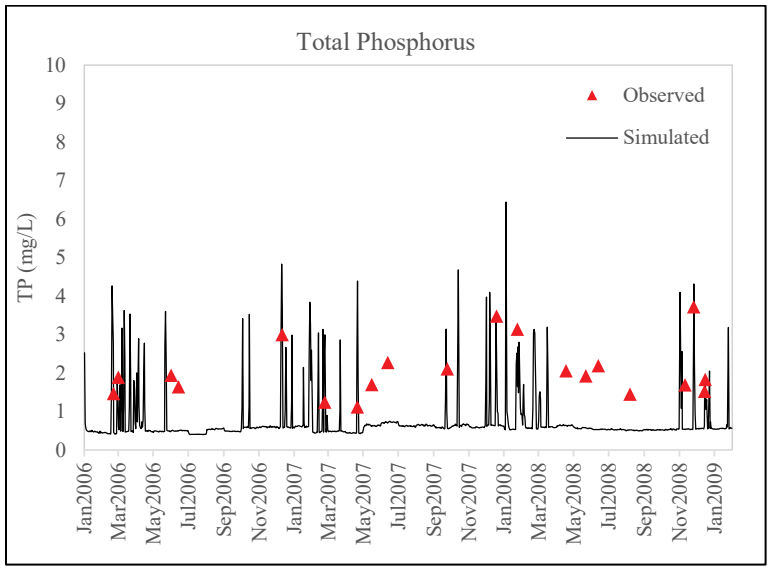


Figure C.23. Daily average observed versus linked HSPF/HEC-RAS modeled total nitrogen concentrations for Calleguas Creek at CSUCI for the calibration period (2006-2009).

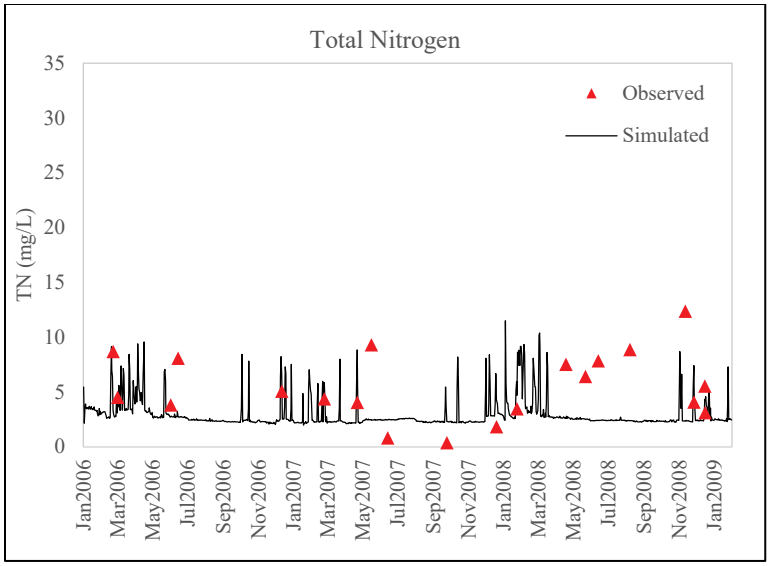


Figure C.24. Daily average observed versus linked HSPF/HEC-RAS modeled ammonium concentrations for Calleguas Creek at CSUCI for the calibration period (2006-2009).

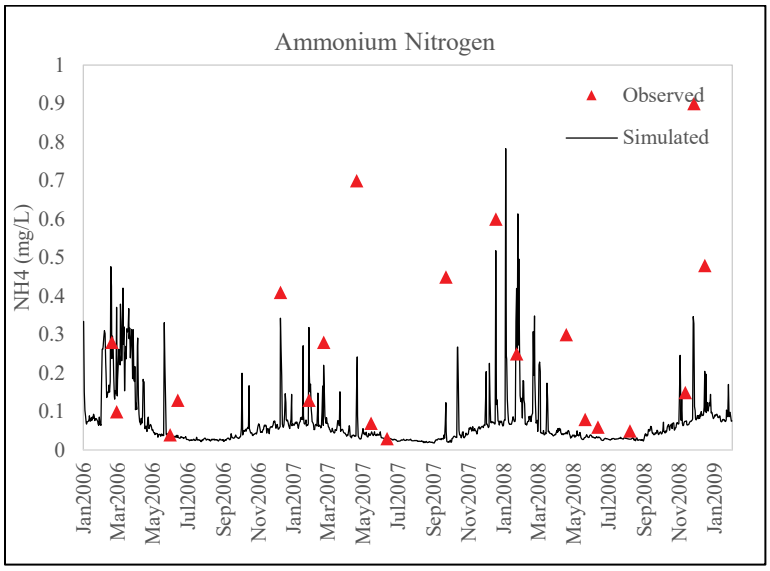
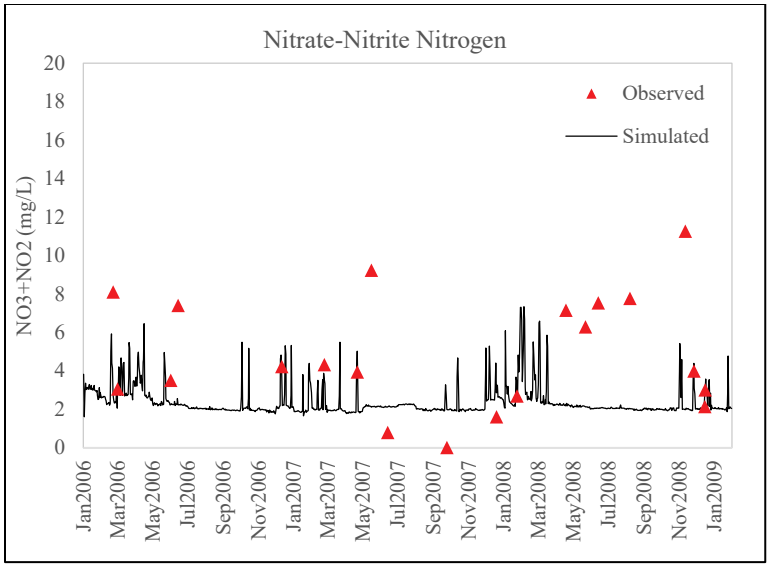


Figure C.25. Daily average observed versus linked HSPF/HEC-RAS modeled nitrate concentrations for Calleguas Creek at CSUCI for the calibration period (2006-2009).



Appendix D: Validation Model Results

Figure D.1. Daily average observed versus HSPF modeled streamflow for Calleguas Creek at CSUCI for the validation period (WY1988-WY2004).

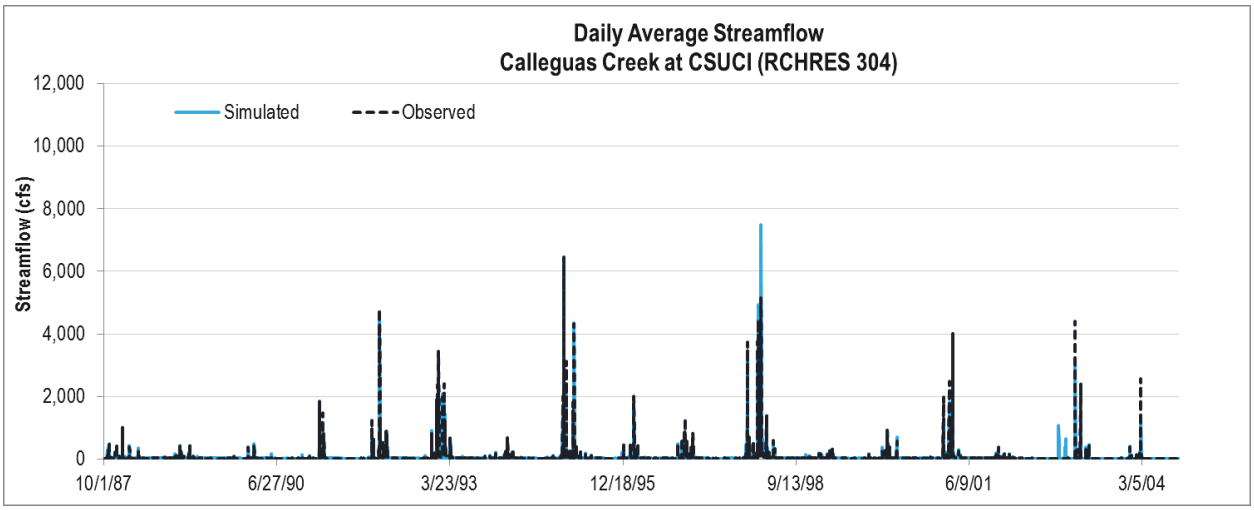


Figure D.2. Daily average observed versus HSPF modeled streamflow for Conejo Creek above Hwy. 101 for the validation period (WY1988-WY2004).

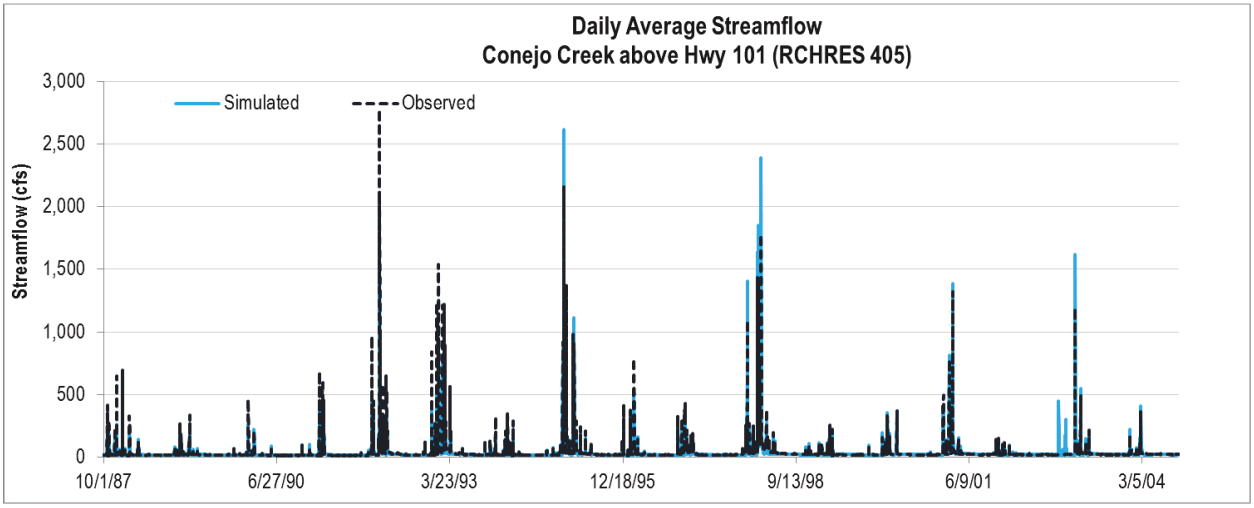


Figure D.3. Daily average observed versus HSPF modeled streamflow for Revolon Slough at Laguna Rd. for the validation period (WY1988-WY2004).

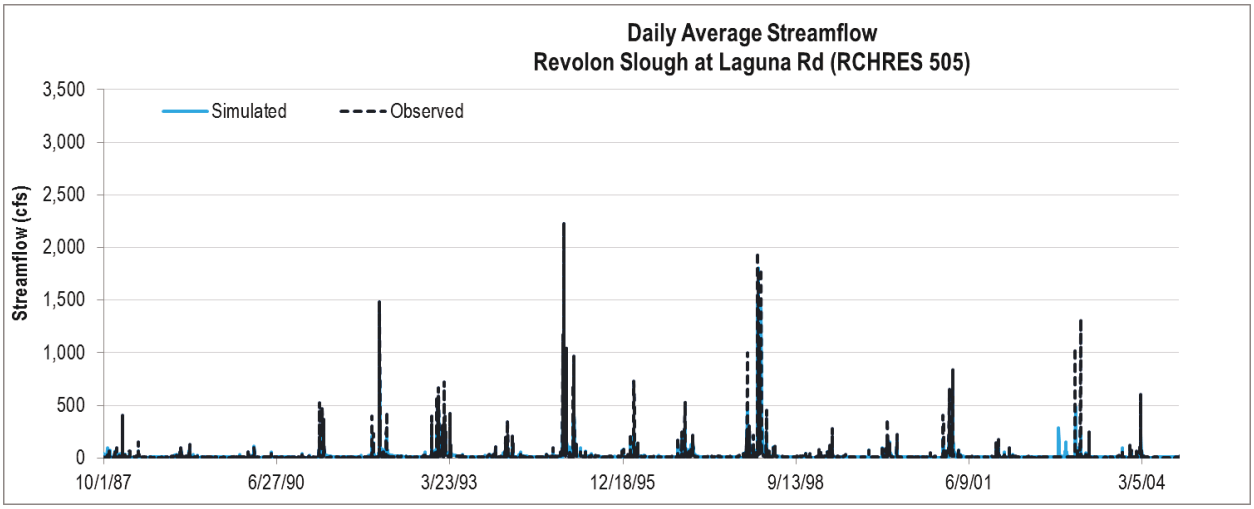


Figure D.4. Monthly observed versus HSPF modeled streamflow for Calleguas Creek at CSUCI for the validation period (WY1988-WY2004).

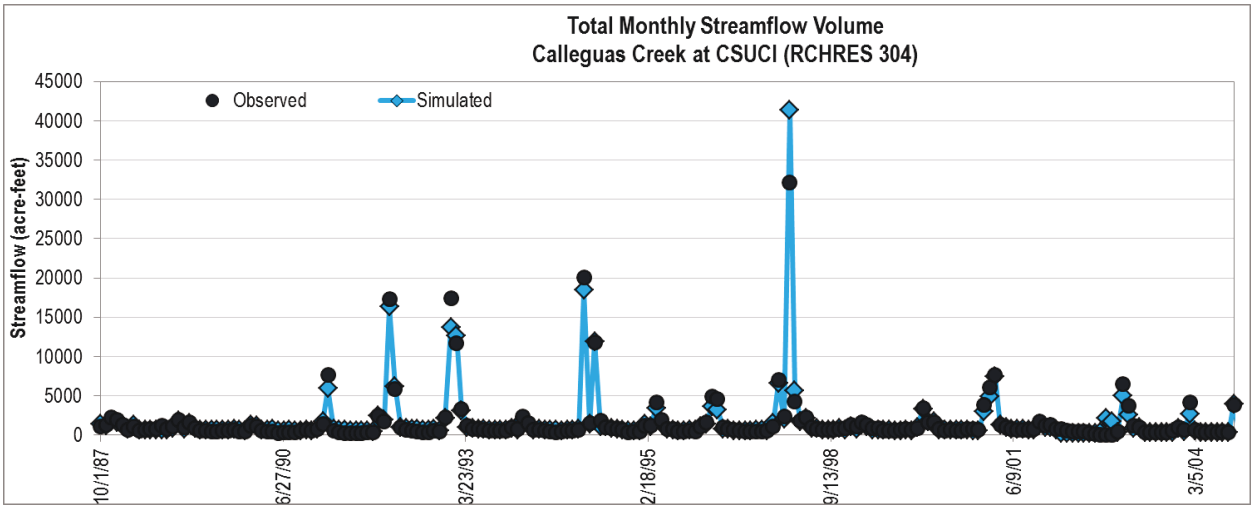


Figure D.5. Monthly observed versus HSPF modeled streamflow for Conejo Creek above Hwy. 101 for the validation period (WY1988-WY2004).

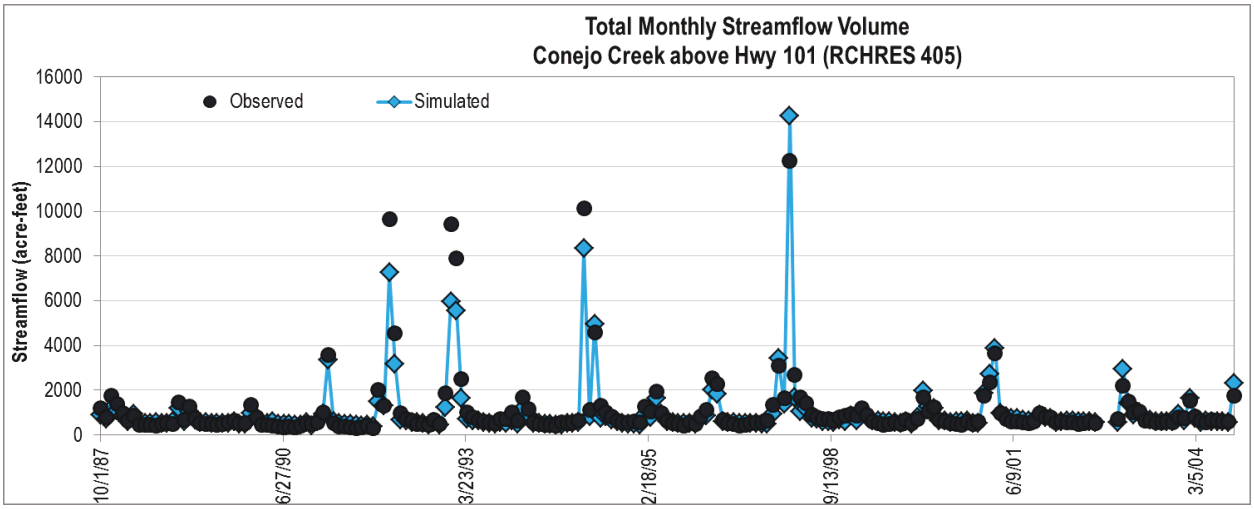


Figure D.6. Monthly observed versus HSPF modeled streamflow for Revolon Slough at Laguna Rd. for the validation period (WY1988-WY2004).

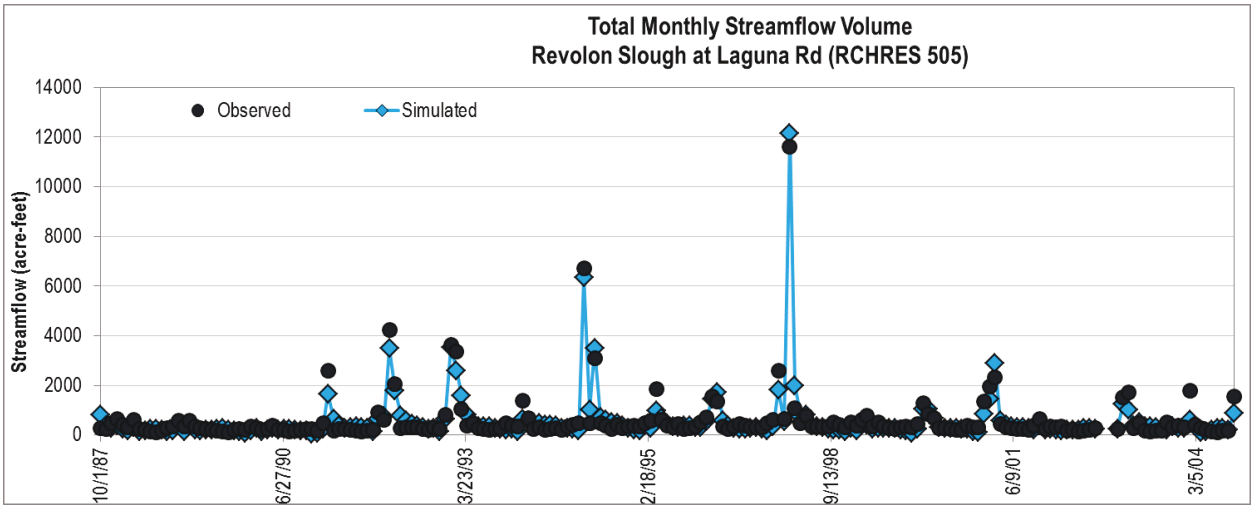


Figure D.7. Daily average observed versus linked HSPF/HEC-RAS modeled streamflow at Calleguas Creek at CSUCI (Gage 805) for the validation period (2003-2005).

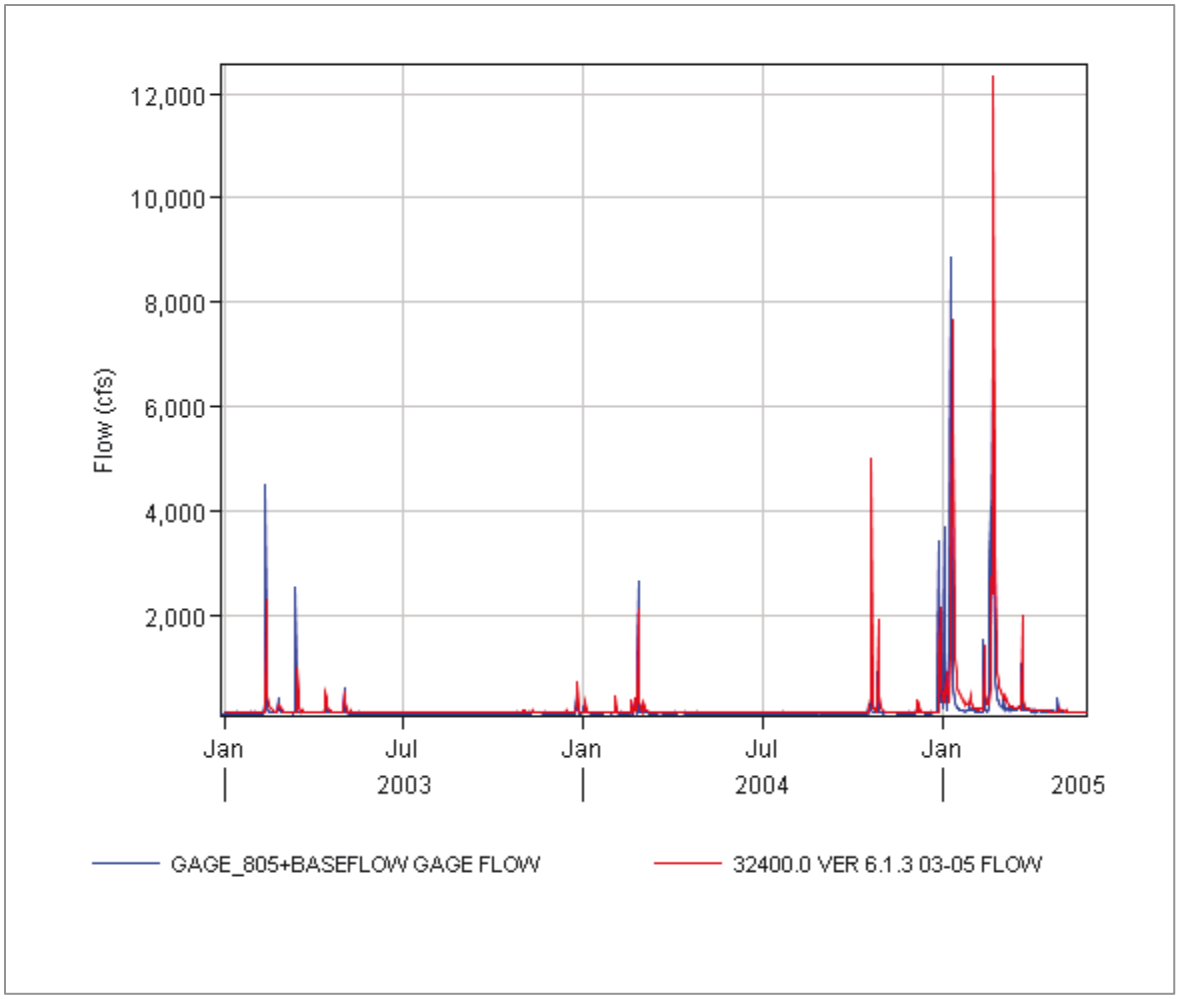


Figure D.8. Monthly average observed versus linked HSPF/HEC-RAS modeled streamflow at Calleguas Creek at CSUCI (Gage 805) for the validation period (2003-2005).

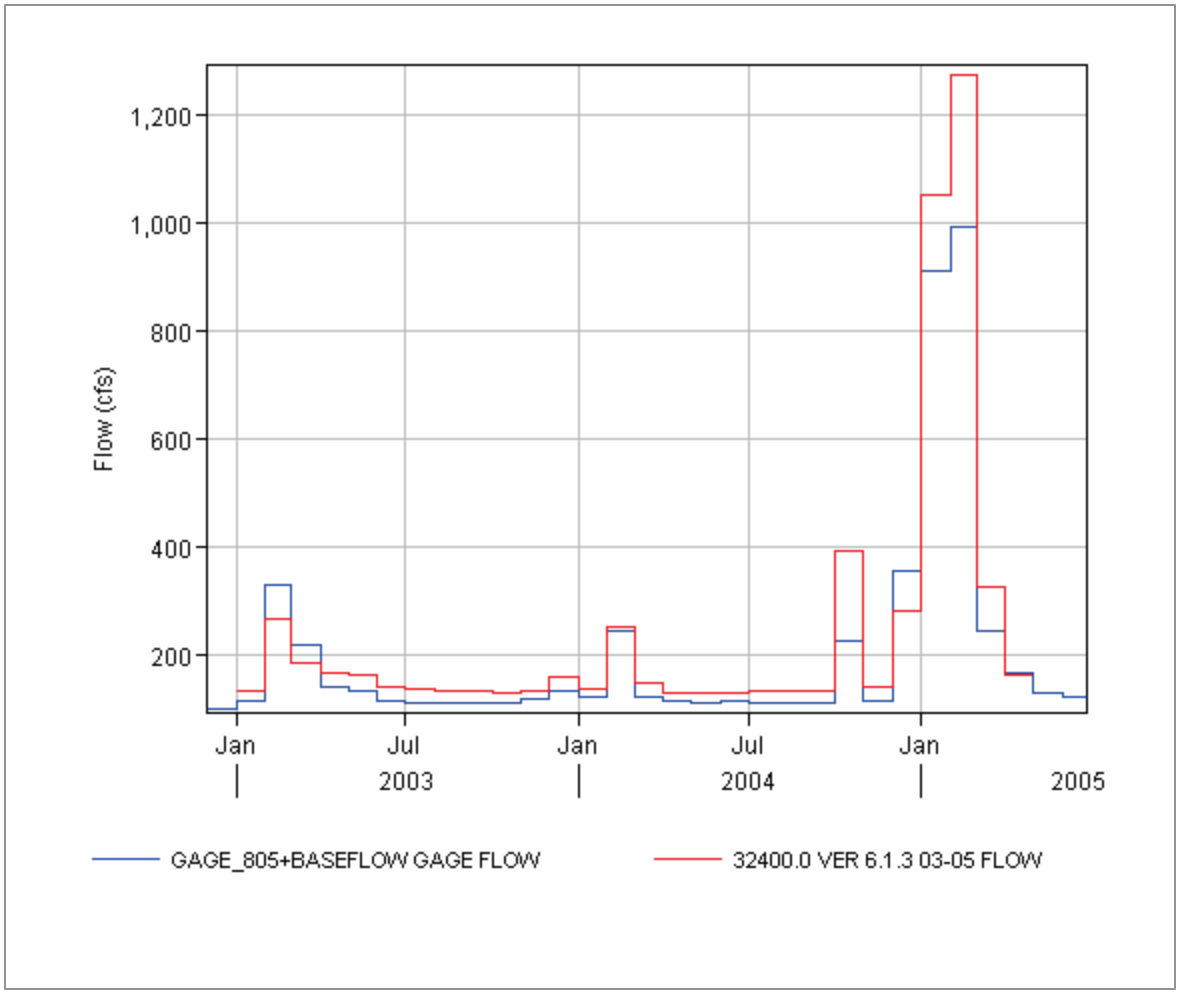


Figure D.9. Daily average observed versus HSPF modeled TSS concentrations for Calleguas Creek at CSUCI for the validation period (WY1988-WY2004).

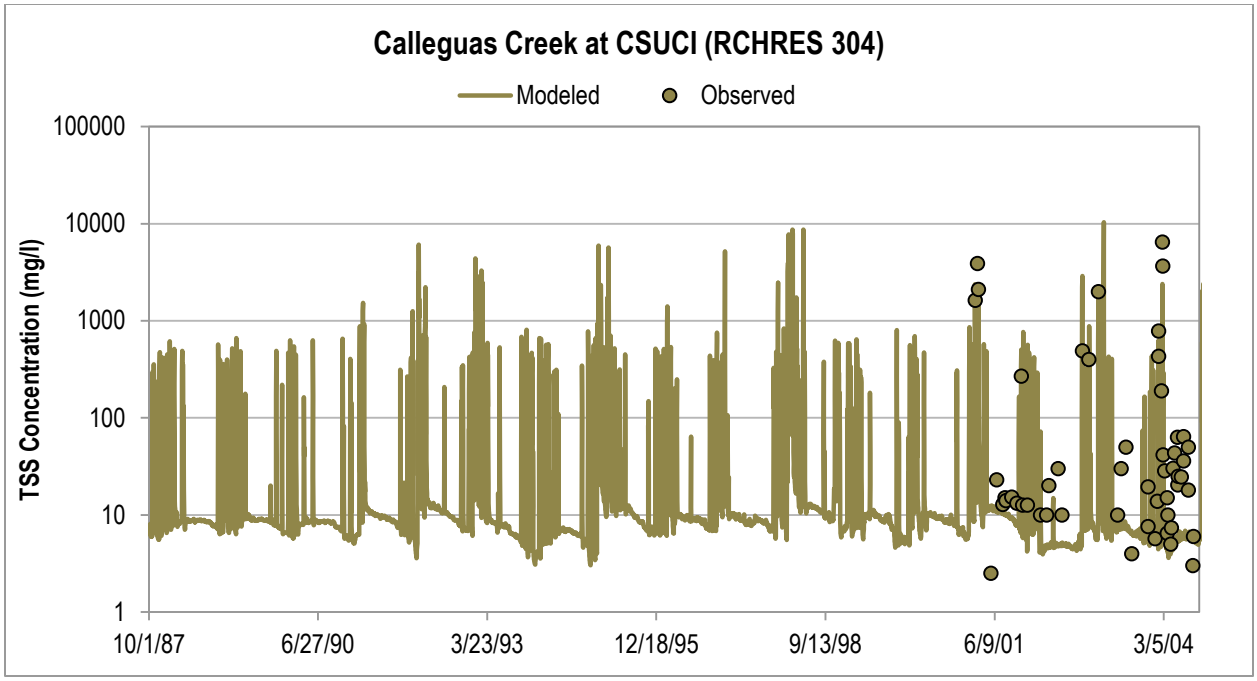


Figure D.10. Daily average observed versus HSPF modeled hardness concentrations for Calleguas Creek at CSUCI for the validation period (WY1988-WY2004).

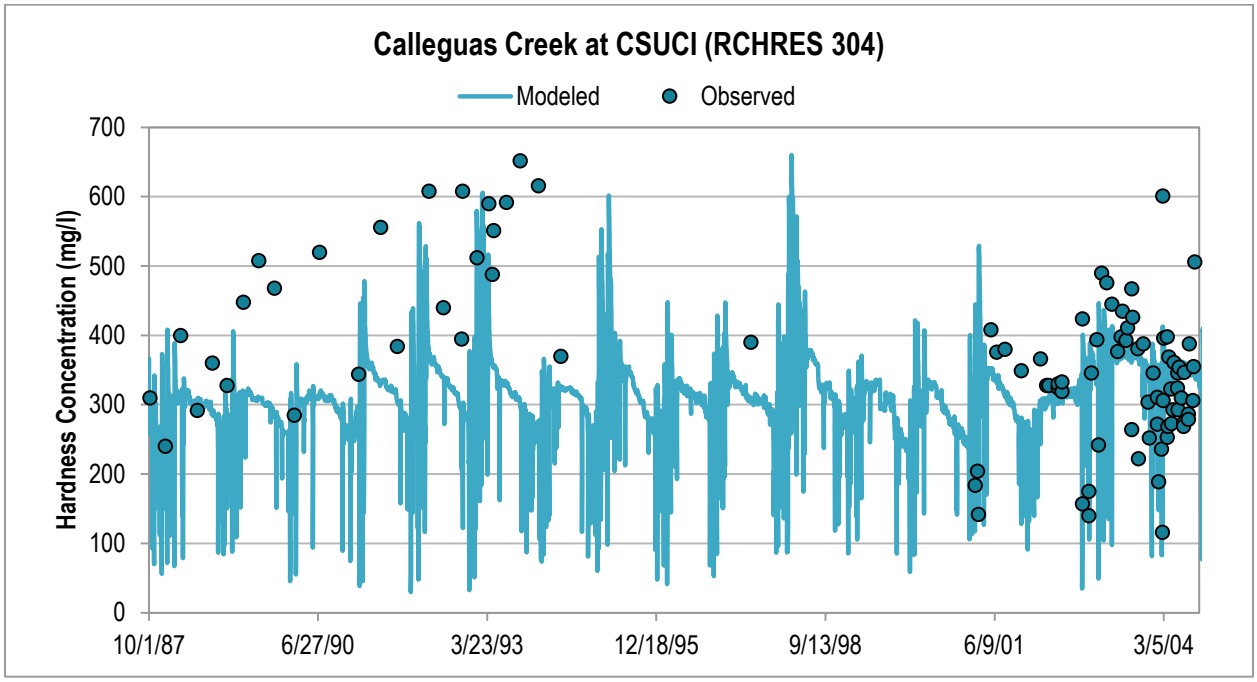


Figure D.11. Daily average observed versus HSPF modeled chloride concentrations for Calleguas Creek at CSUCI for the validation period (WY1988-WY2004).

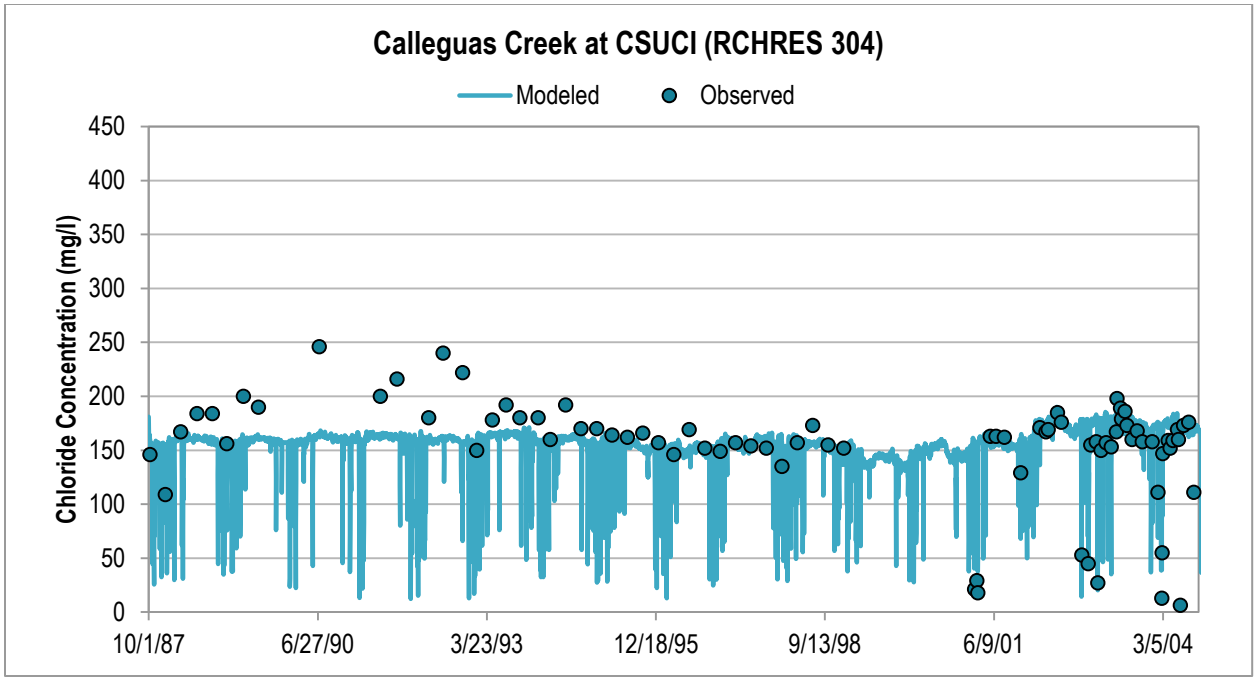


Figure D.12. Daily average observed versus HSPF modeled total copper concentrations for Calleguas Creek at CSUCI for the validation period (WY1988-WY2004).

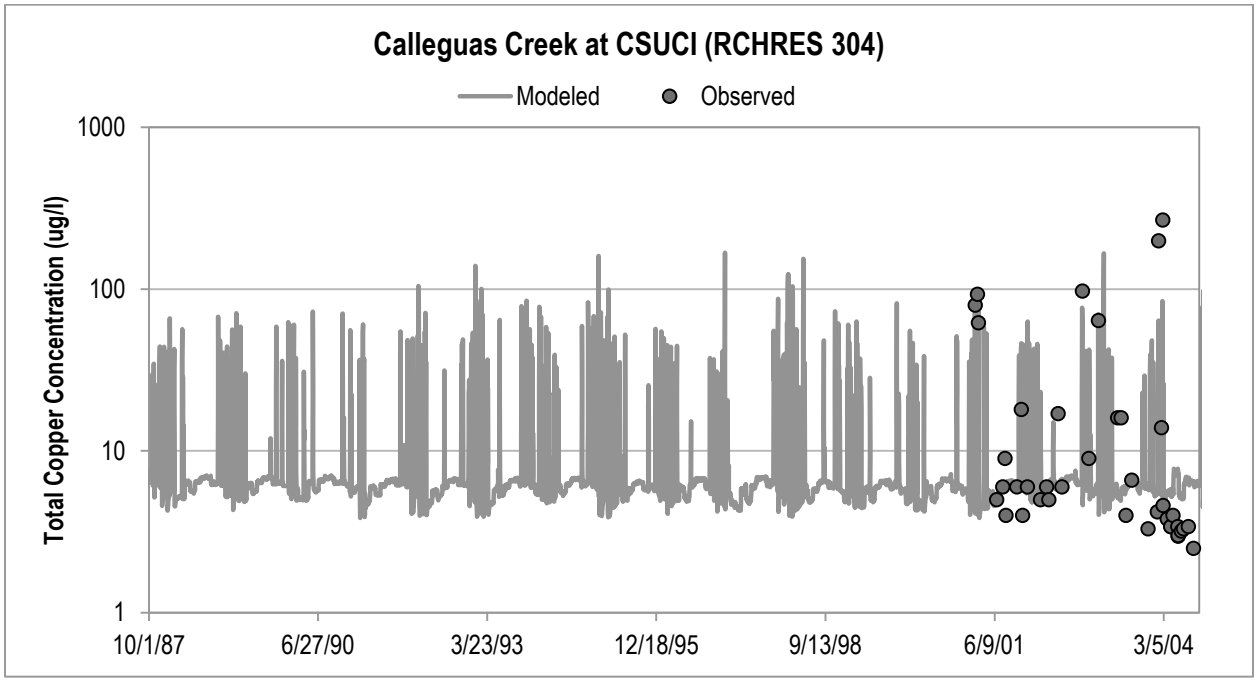


Figure D.13. Daily average observed versus HSPF modeled total nickel concentrations for Calleguas Creek at CSUCI for the validation period (WY1988-WY2004).

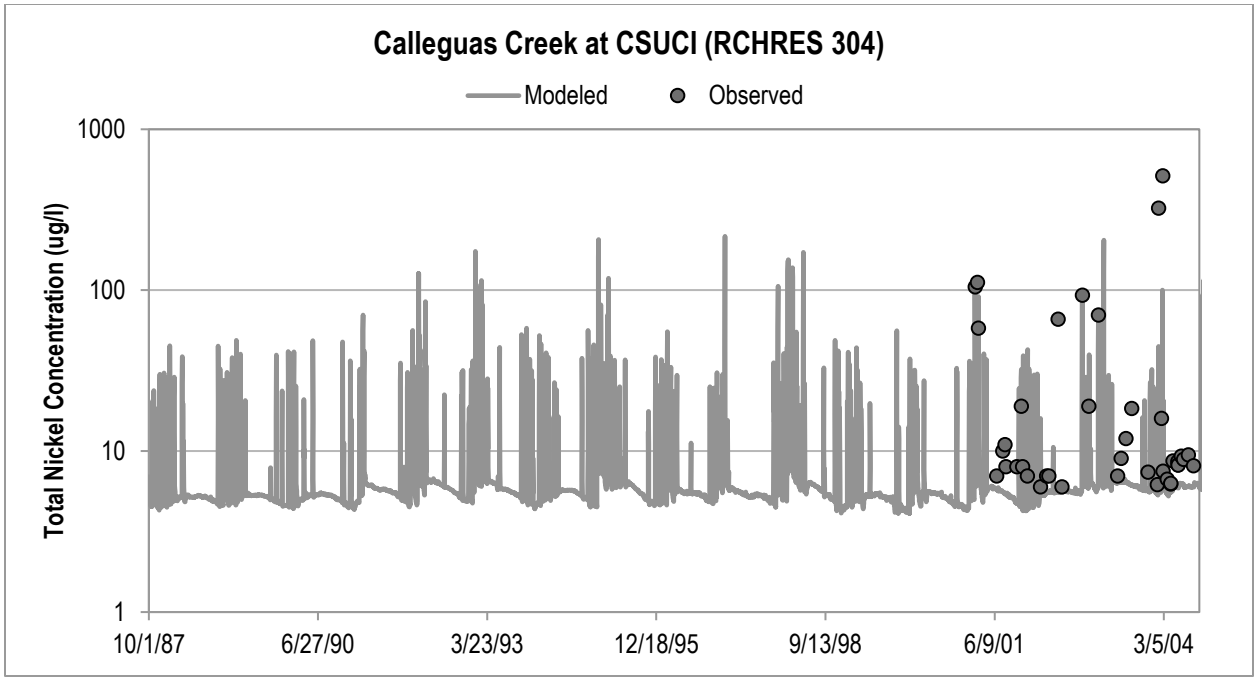


Figure D.14. Daily average observed versus HSPF modeled total mercury concentrations for Calleguas Creek at CSUCI for the validation period (WY1988-WY2004).

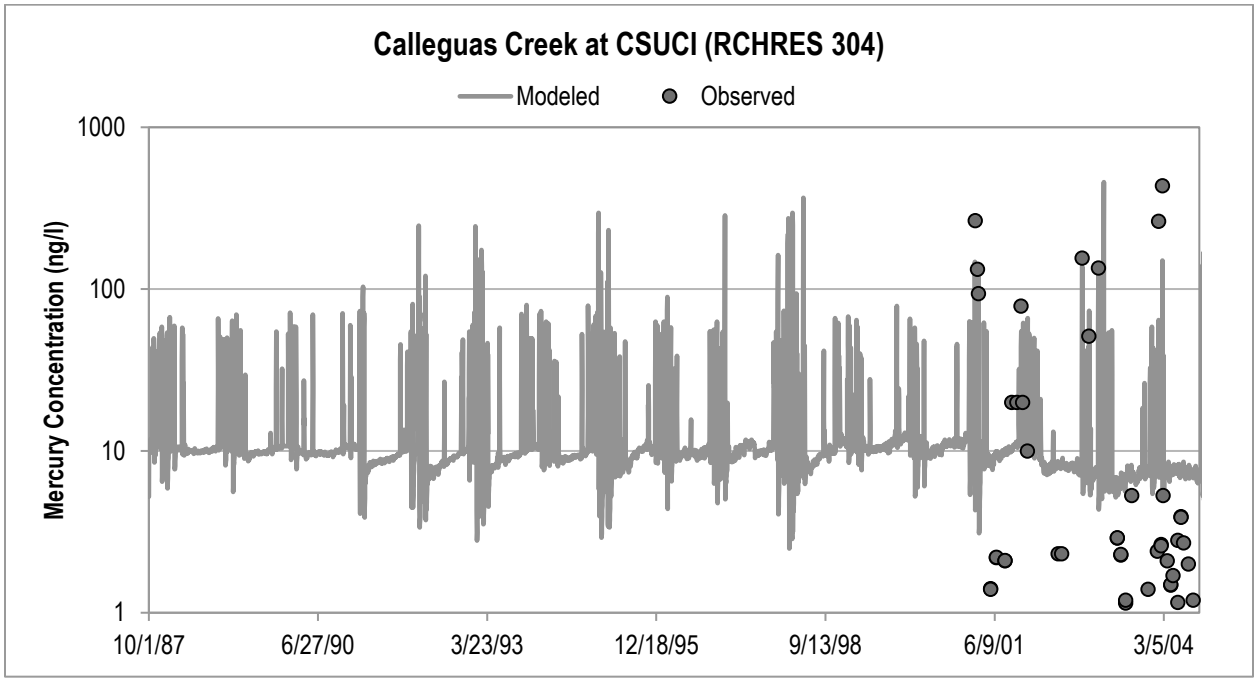


Figure D.15. Daily average observed versus HSPF modeled total selenium concentrations for Calleguas Creek at CSUCI for the validation period (WY1988-WY2004).

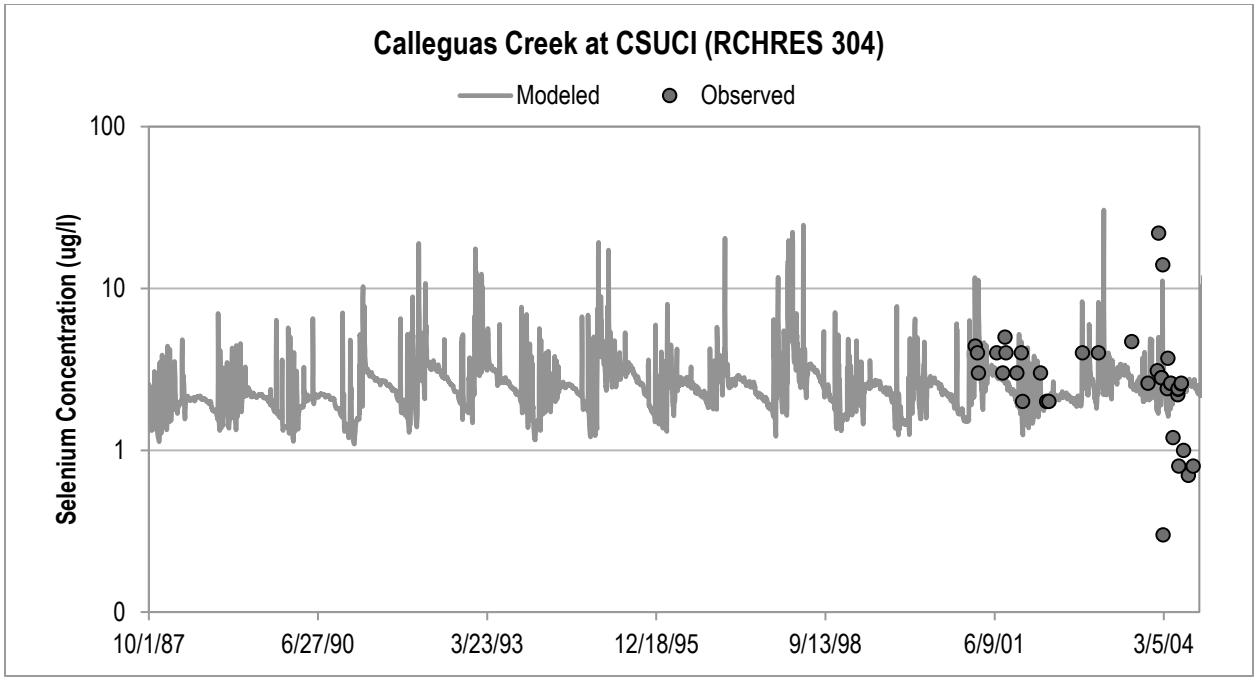


Figure D.16. Daily average observed versus HSPF modeled total phosphorus concentrations for Calleguas Creek at CSUCI for the validation period (WY1988-WY2004).

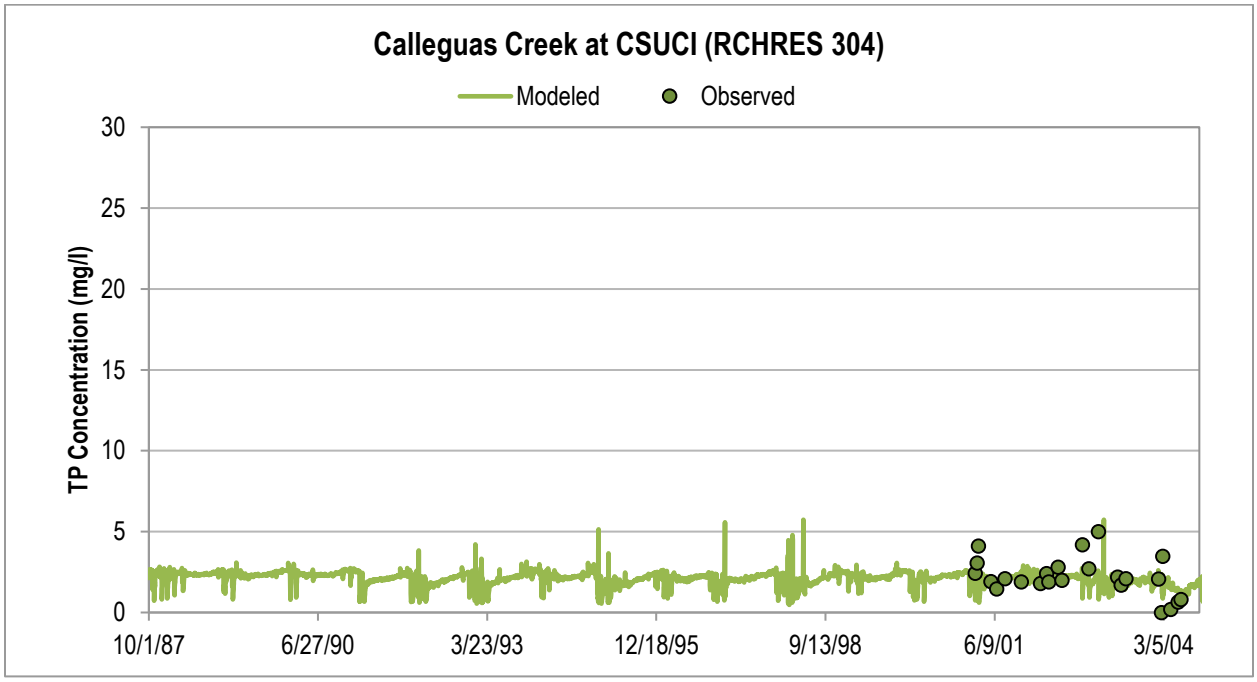


Figure D.17. Daily average observed versus HSPF modeled orthophosphate concentrations for Calleguas Creek at CSUCI for the validation period (WY1988-WY2004).

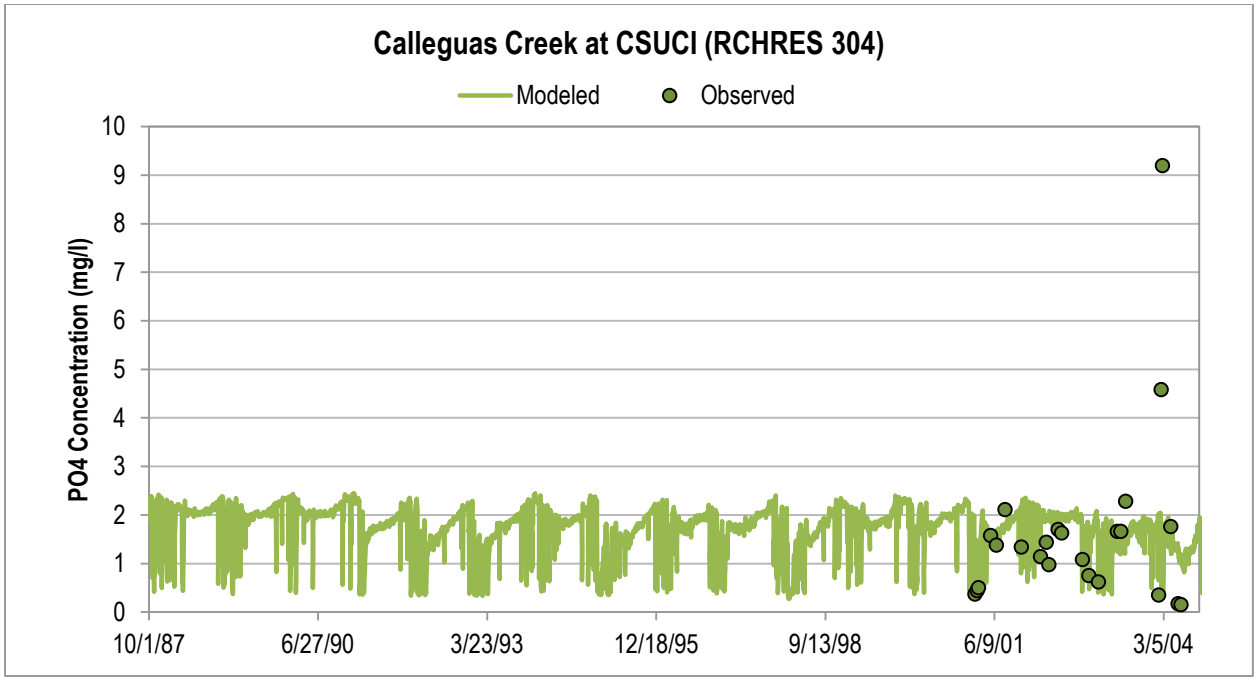


Figure D.18. Daily average observed versus HSPF modeled total nitrogen concentrations for Calleguas Creek at CSUCI for the validation period (WY1988-WY2004).

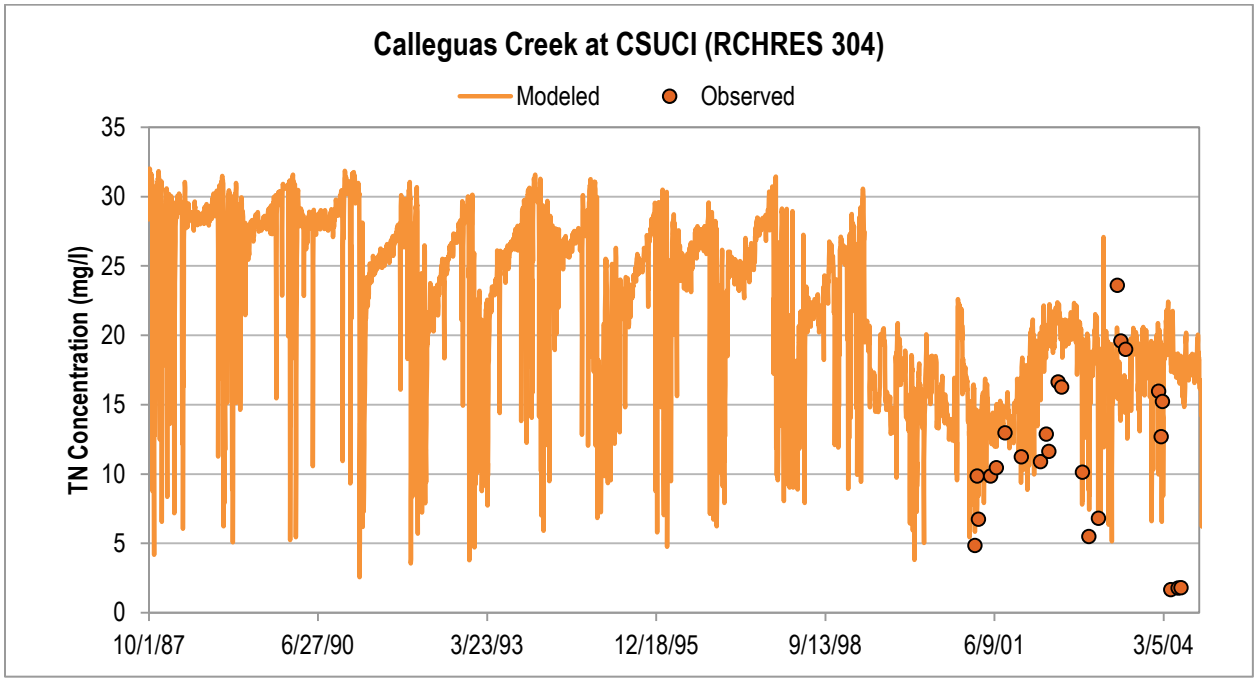


Figure D.19. Daily average observed versus HSPF modeled nitrate concentrations for Calleguas Creek at CSUCI for the validation period (WY1988-WY2004).

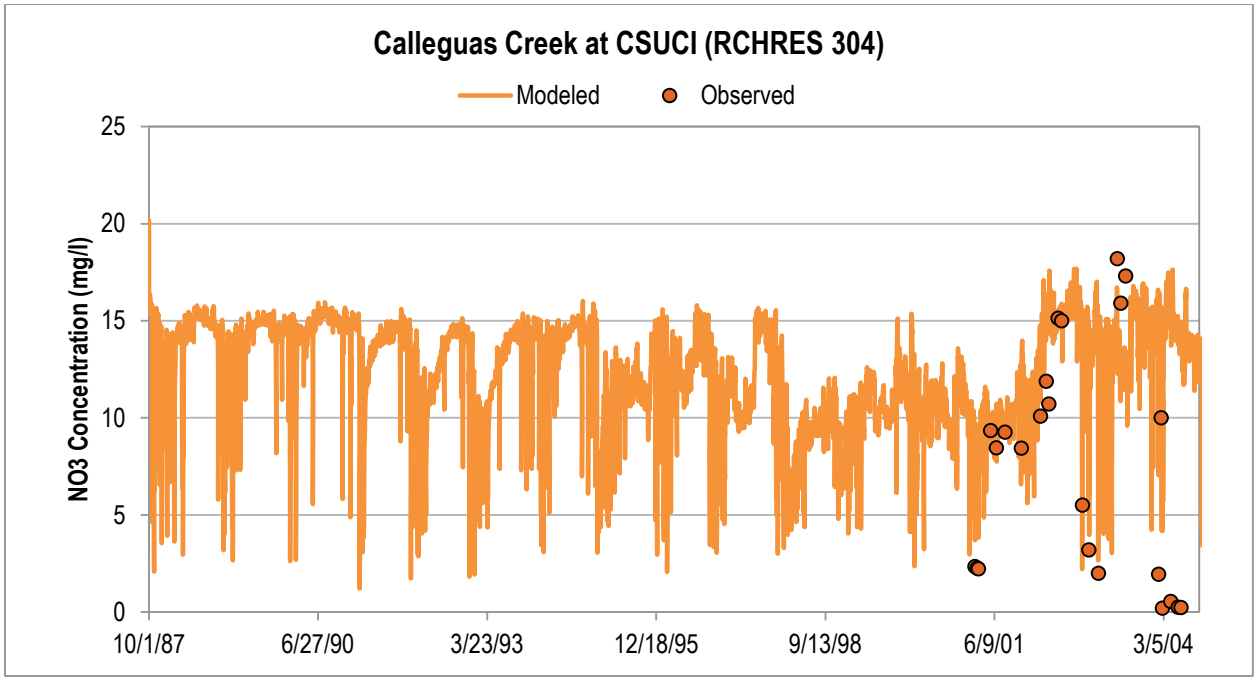


Figure D.20. Daily average observed versus linked HSPF/HEC-RAS modeled TSS concentrations for Calleguas Creek at CSUCI for the validation period (2001-2005).

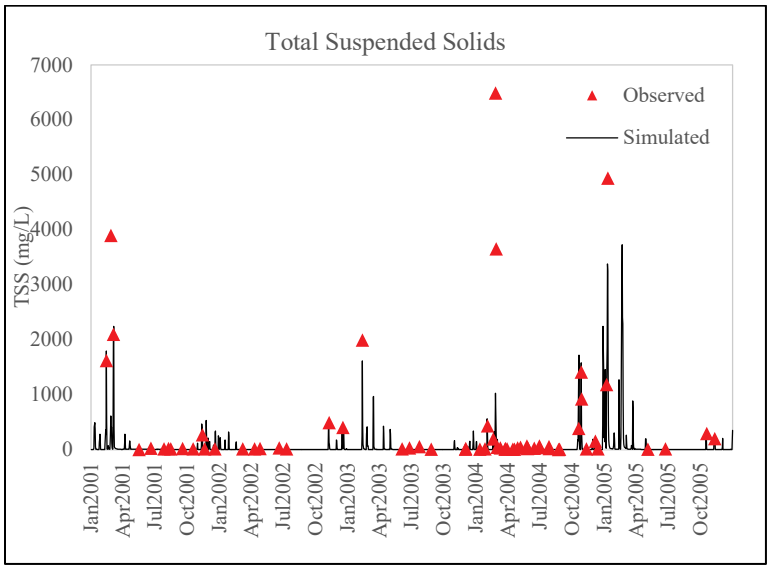


Figure D.21. Daily average observed versus linked HSPF/HEC-RAS modeled dissolved copper concentrations for Calleguas Creek at CSUCI for the validation period (2001-2005).

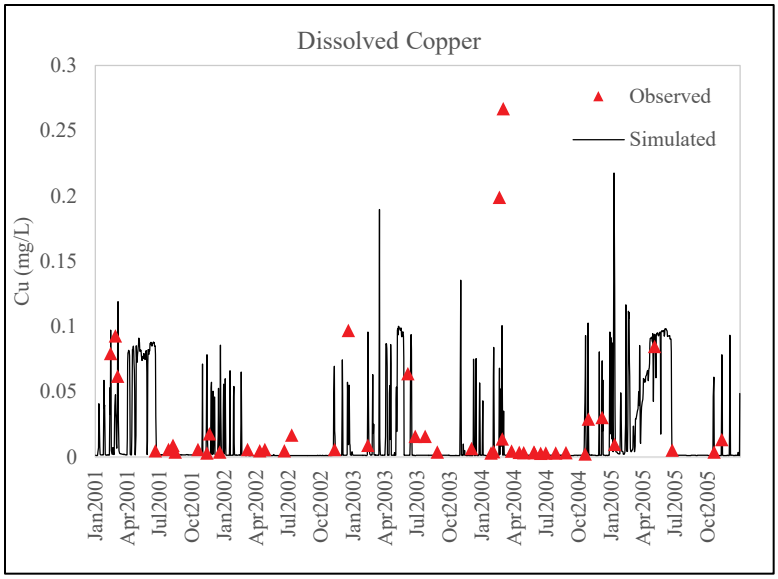


Figure D.22. Daily average observed versus linked HSPF/HEC-RAS modeled total phosphorous concentrations for Calleguas Creek at CSUCI for the validation period (2001-2005).

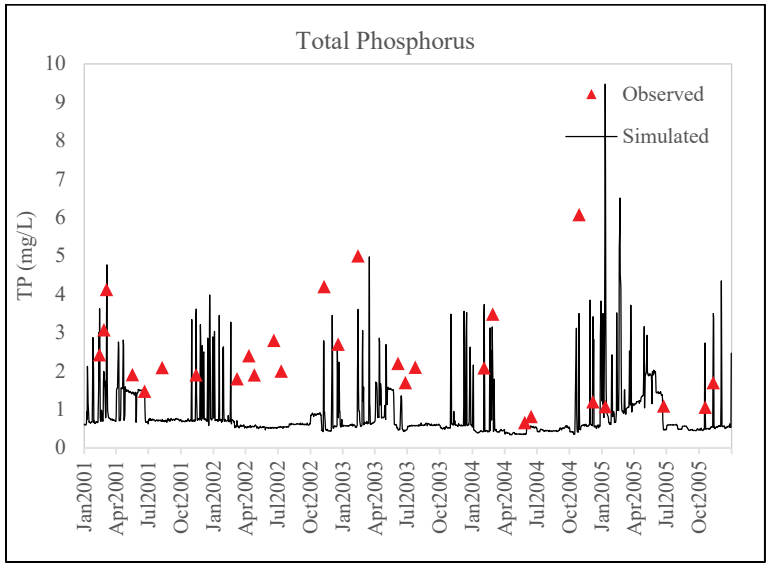


Figure D.23. Daily average observed versus linked HSPF/HEC-RAS modeled total nitrogen concentrations for Calleguas Creek at CSUCI for the validation period (2003-2005).

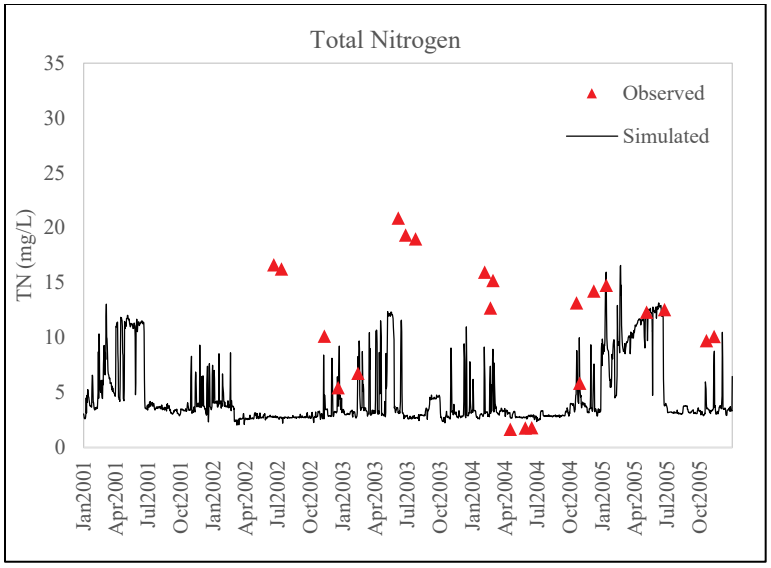


Figure D.24. Daily average observed versus linked HSPF/HEC-RAS modeled ammonium concentrations for Calleguas Creek at CSUCI for the validation period (2001-2005).

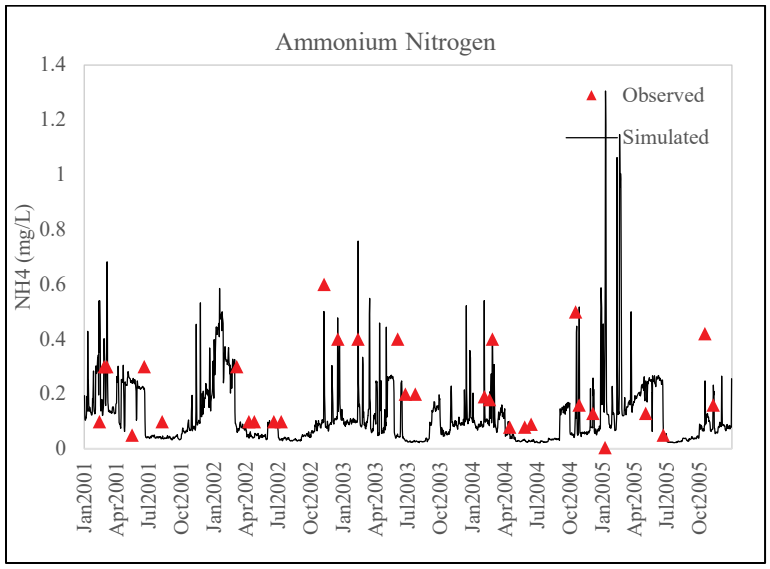
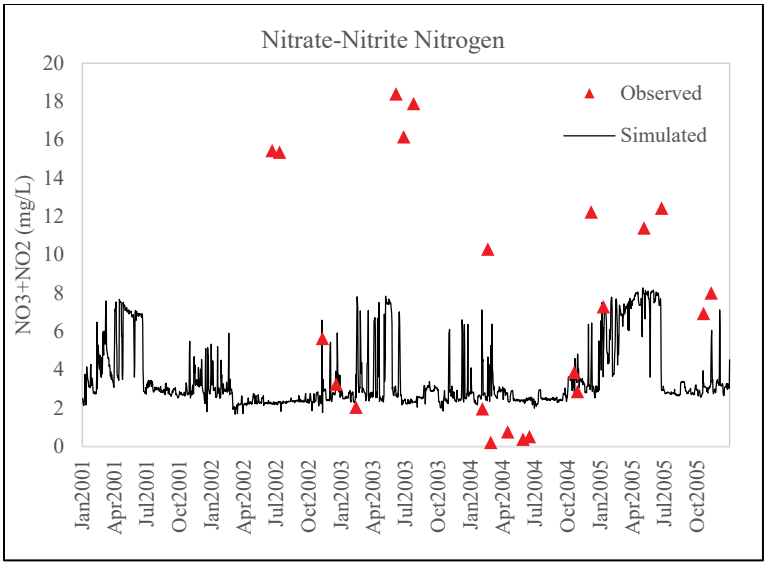


Figure D.25. Daily average observed versus linked HSPF/HEC-RAS modeled nitrate concentrations for Calleguas Creek at CSUCI for the validation period (2003-2005).



Appendix E: Management Scenario Model Results

Figure E.1. Daily average observed versus HSPF modeled streamflow for Calleguas Creek at CSUCI for the management scenario.

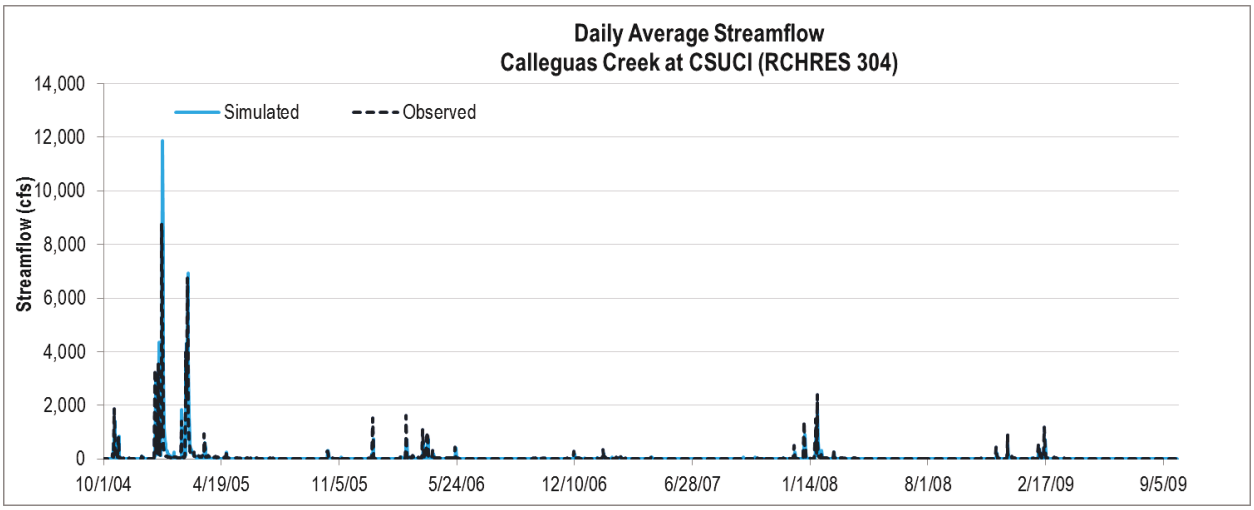


Figure E.2. Daily average observed versus HSPF modeled streamflow for Conejo Creek above Hwy. 101 for the management scenario.

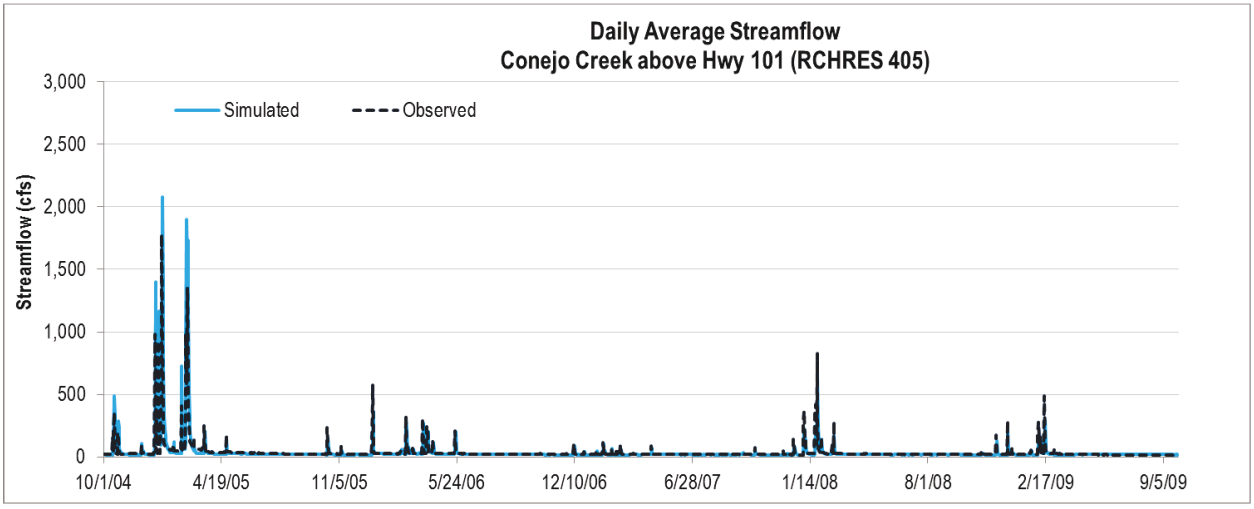


Figure E.3. Daily average observed versus HSPF modeled streamflow for Revolon Slough at Laguna Rd. for the management scenario.

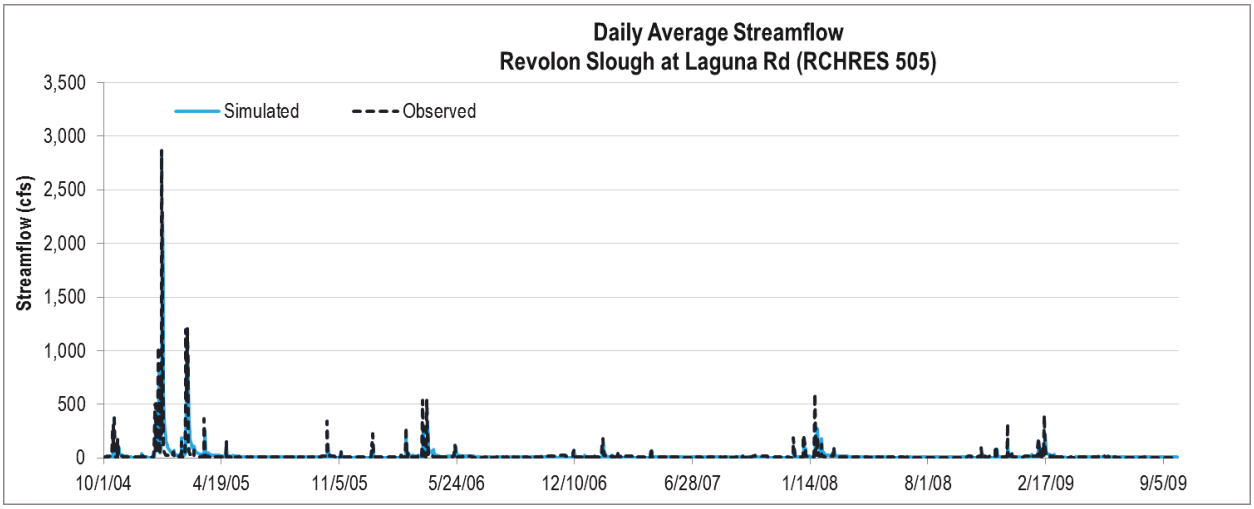


Figure E.4. Monthly observed versus HSPF modeled streamflow for Calleguas Creek at CSUCI for the management scenario.

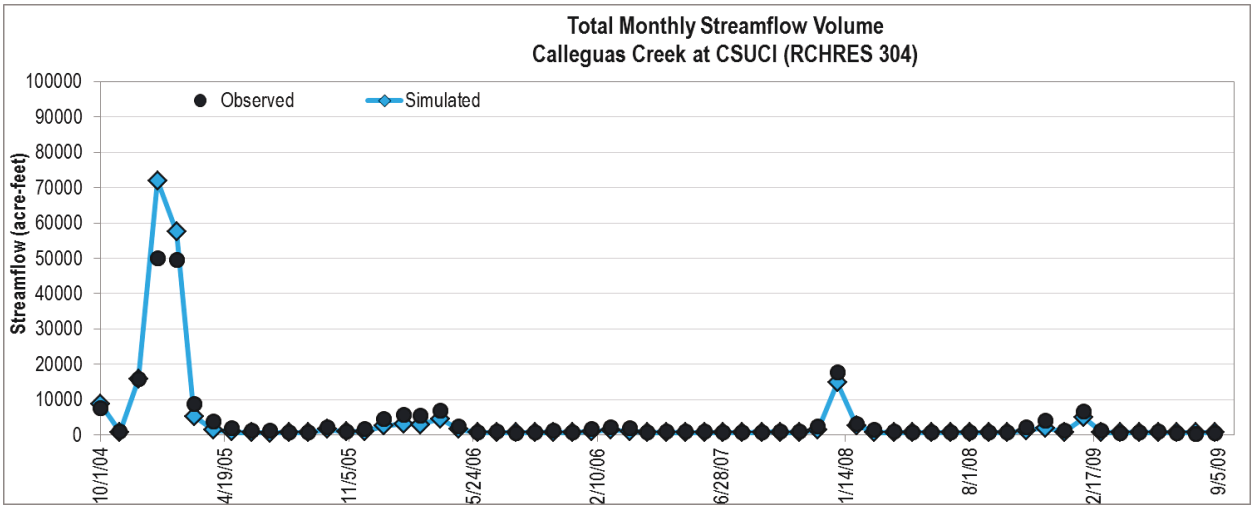


Figure E.5. Monthly observed versus HSPF modeled streamflow for Conejo Creek above Hwy. 101 for the management scenario.

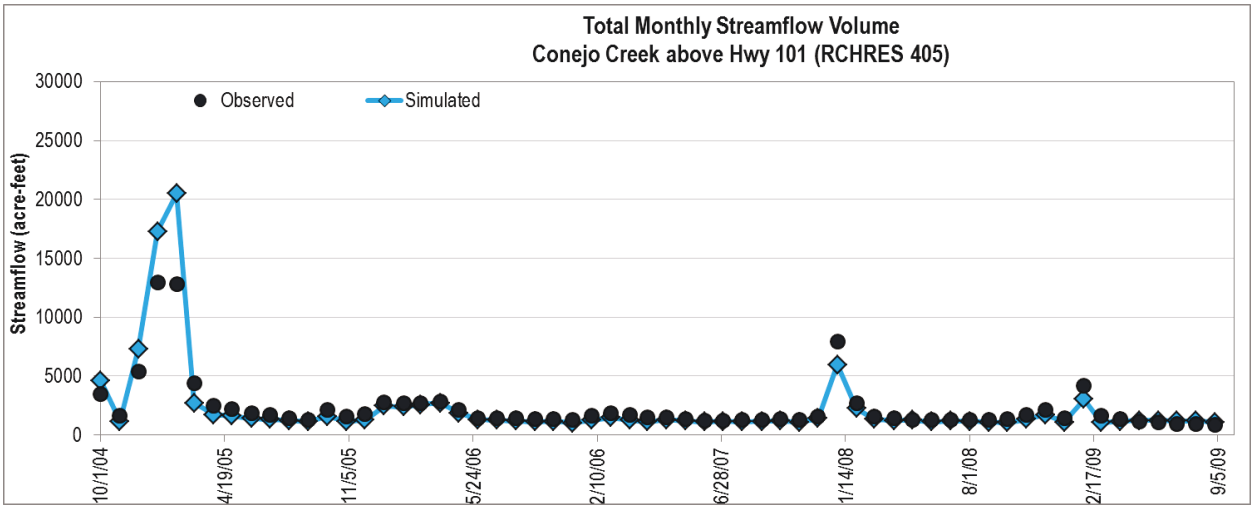


Figure E.6. Monthly observed versus HSPF modeled streamflow for Revolon Slough at Laguna Rd. for the management scenario.

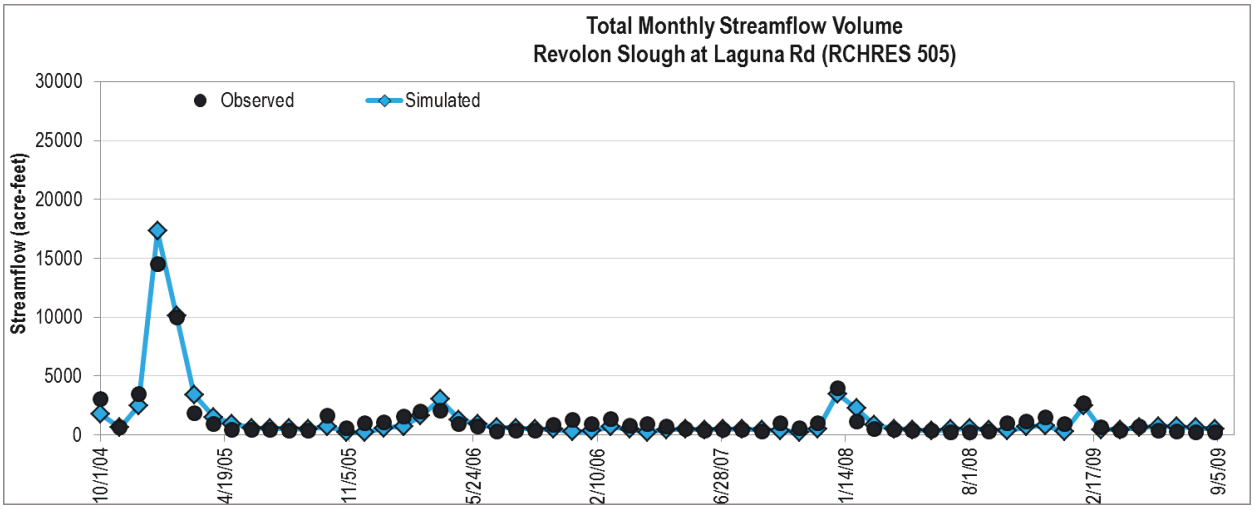


Figure E.7. Daily average observed versus linked HSPF/HEC-RAS modeled streamflow at Calleguas Creek at CSUCI (Gage 805) for the management scenario.

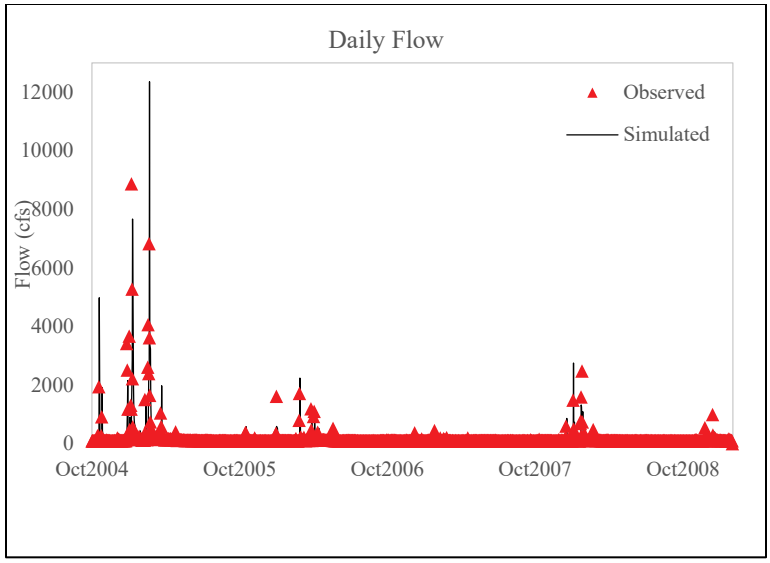


Figure E.8. Monthly average observed versus linked HSPF/HEC-RAS modeled streamflow at Calleguas Creek at CSUCI (Gage 805) for the management scenario.

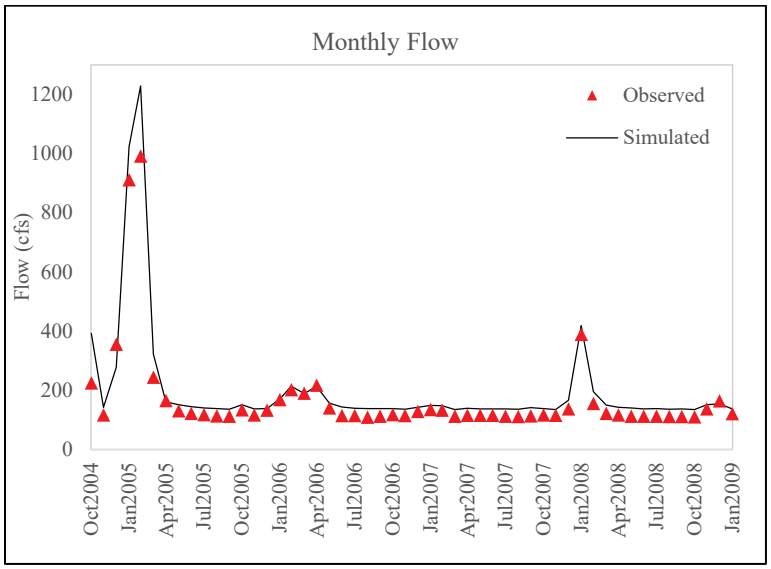


Figure E.9. Daily average observed versus HSPF modeled TSS concentrations for Calleguas Creek at CSUCI for the management scenario.

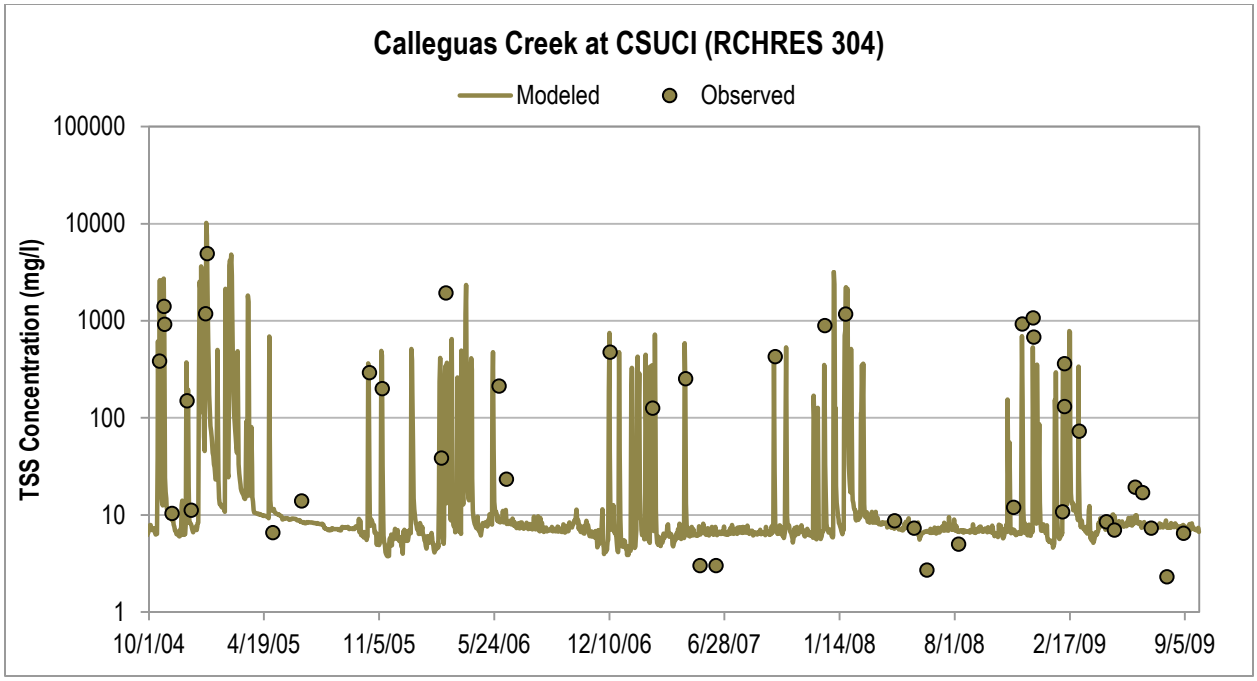


Figure E.10. Daily average observed versus HSPF modeled hardness concentrations for Calleguas Creek at CSUCI for the management scenario.

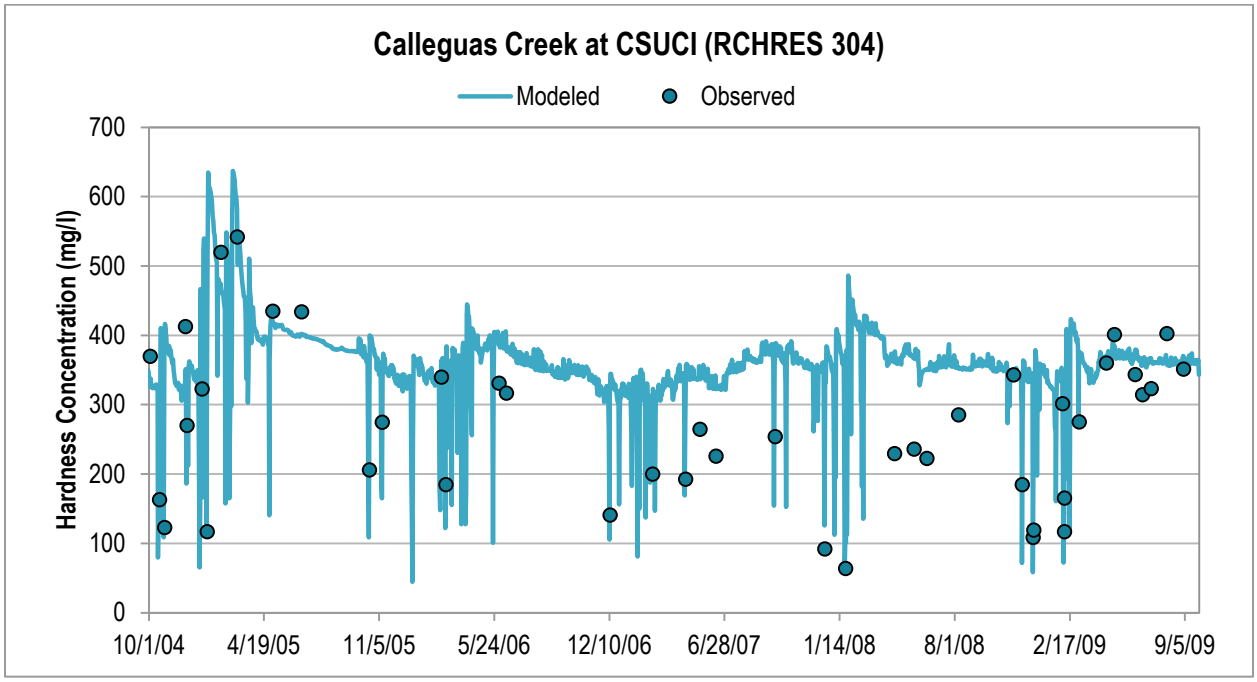


Figure E.11. Daily average observed versus HSPF modeled chloride concentrations for Calleguas Creek at CSUCI for the management scenario.

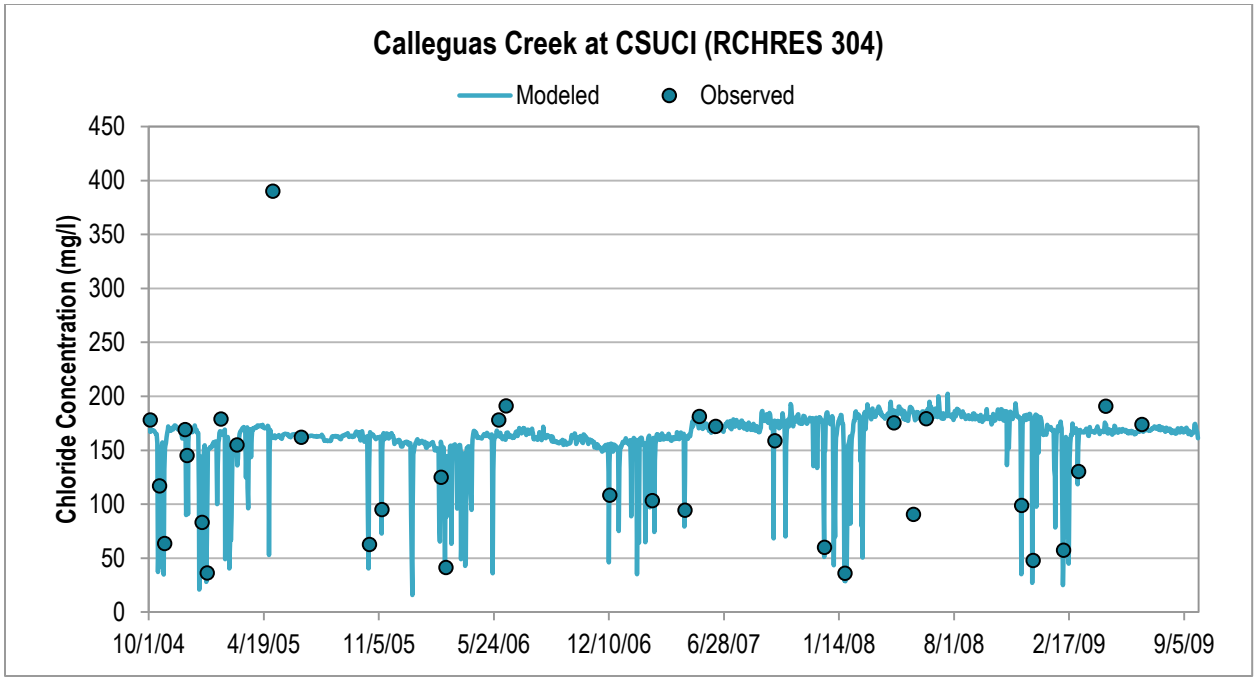


Figure E.12. Daily average observed versus HSPF modeled total copper concentrations for Calleguas Creek at CSUCI for the management scenario.

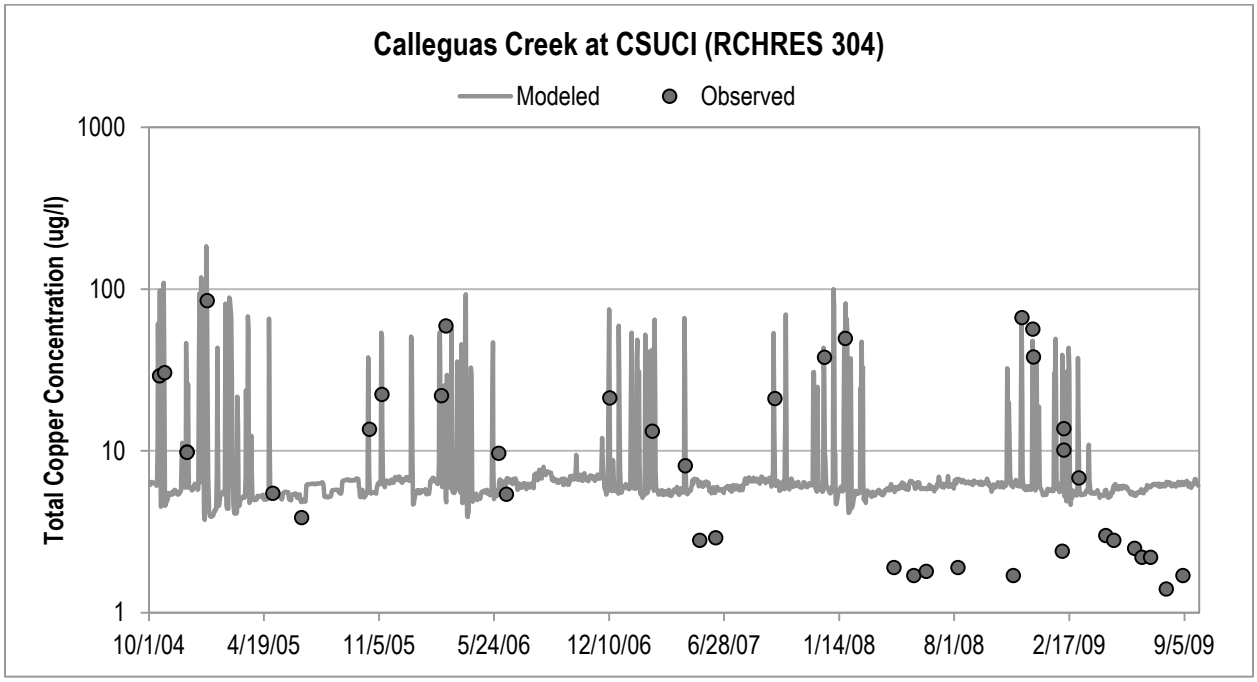


Figure E.13. Daily average observed versus HSPF modeled total nickel concentrations for Calleguas Creek at CSUCI for the management scenario.

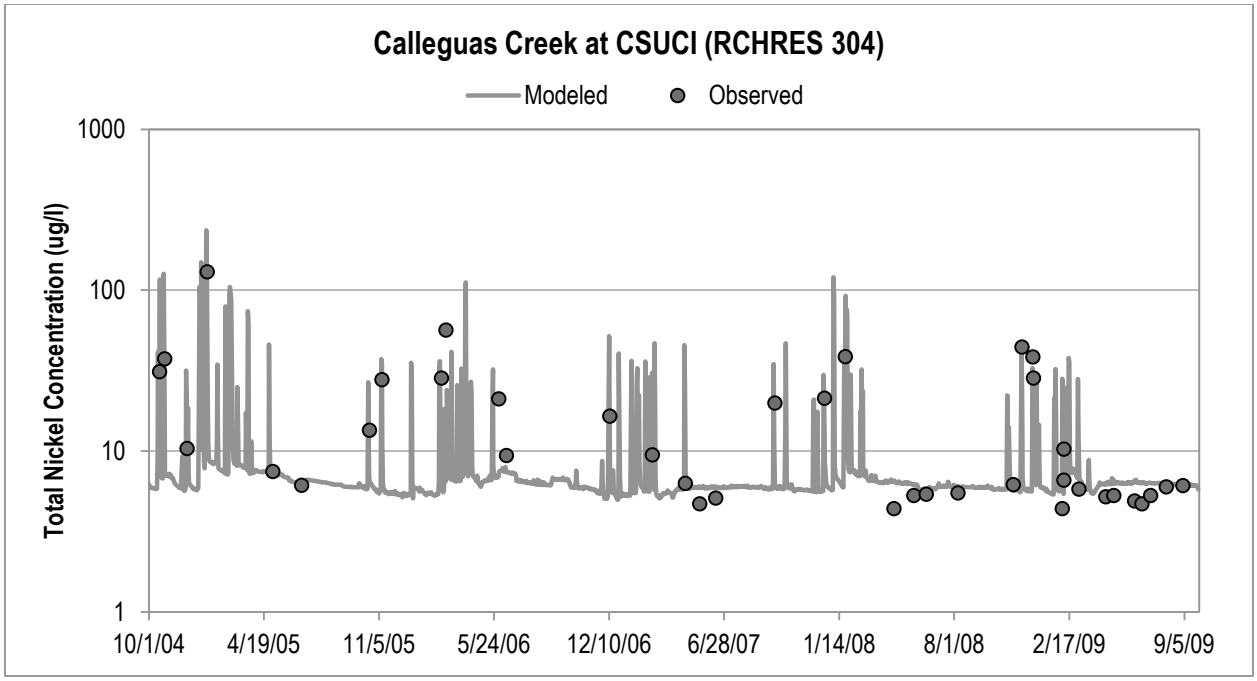


Figure E.14. Daily average observed versus HSPF modeled total mercury concentrations for Calleguas Creek at CSUCI for the management scenario.

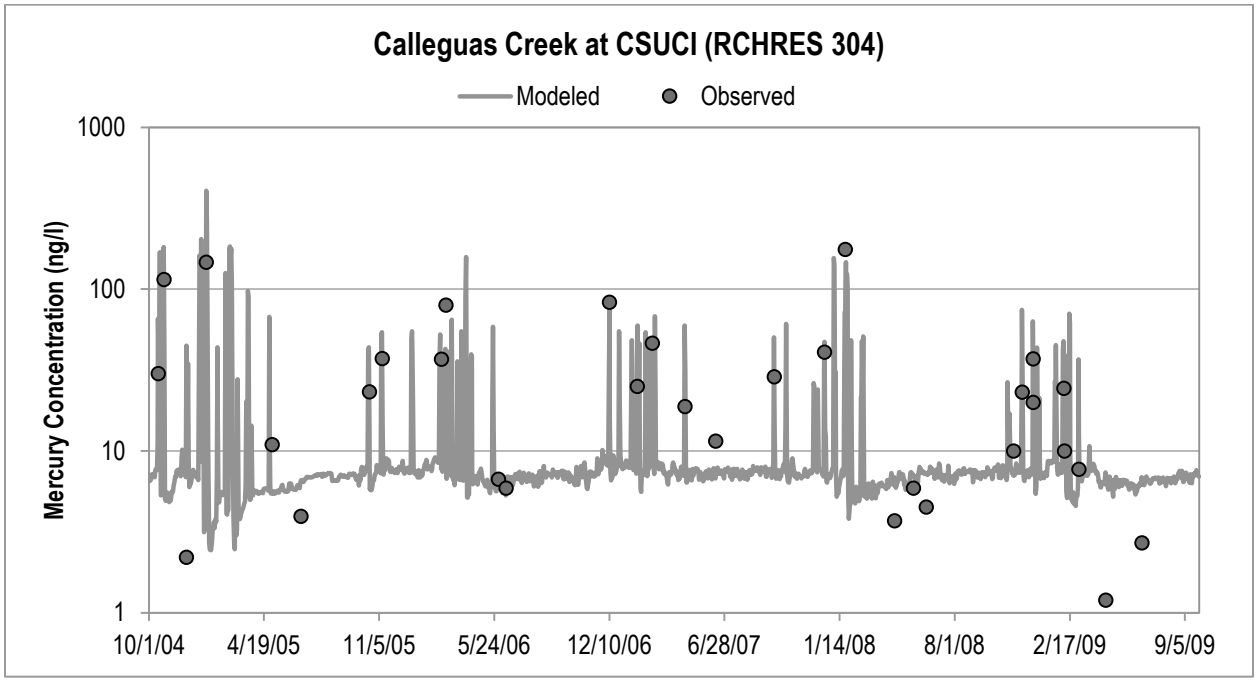


Figure E.15. Daily average observed versus HSPF modeled total selenium concentrations for Calleguas Creek at CSUCI for the management scenario.

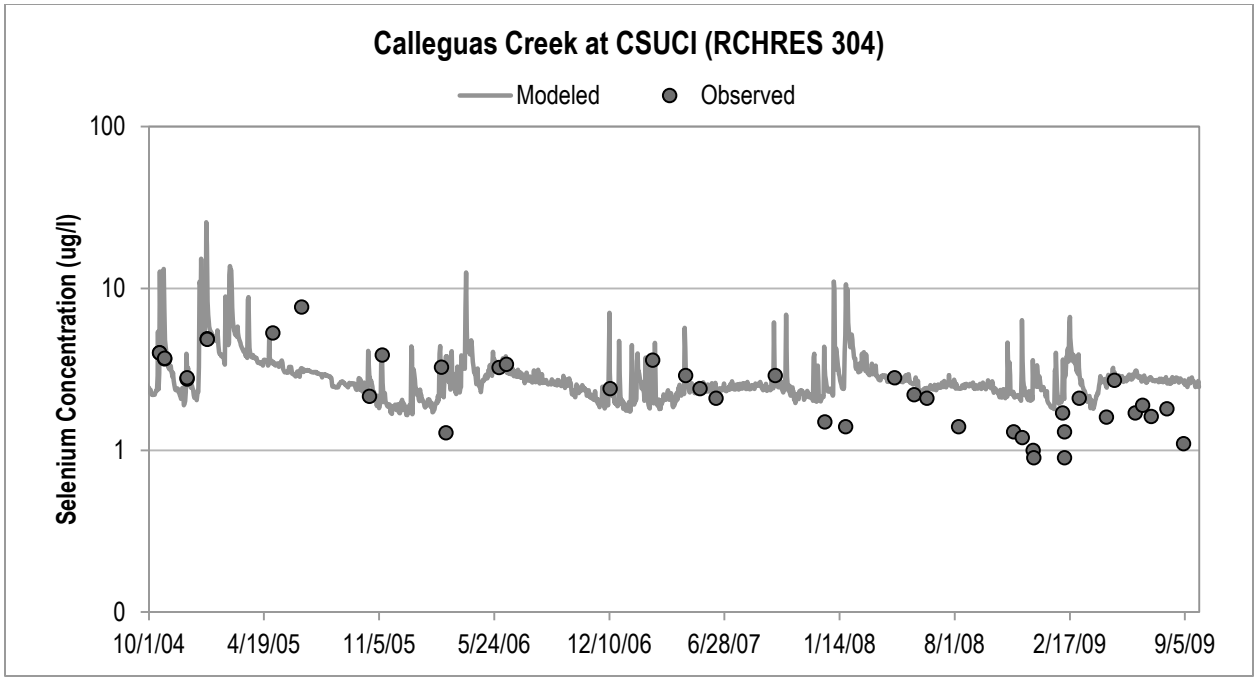


Figure E.16. Daily average observed versus HSPF modeled total phosphorus concentrations for Calleguas Creek at CSUCI for the management scenario.

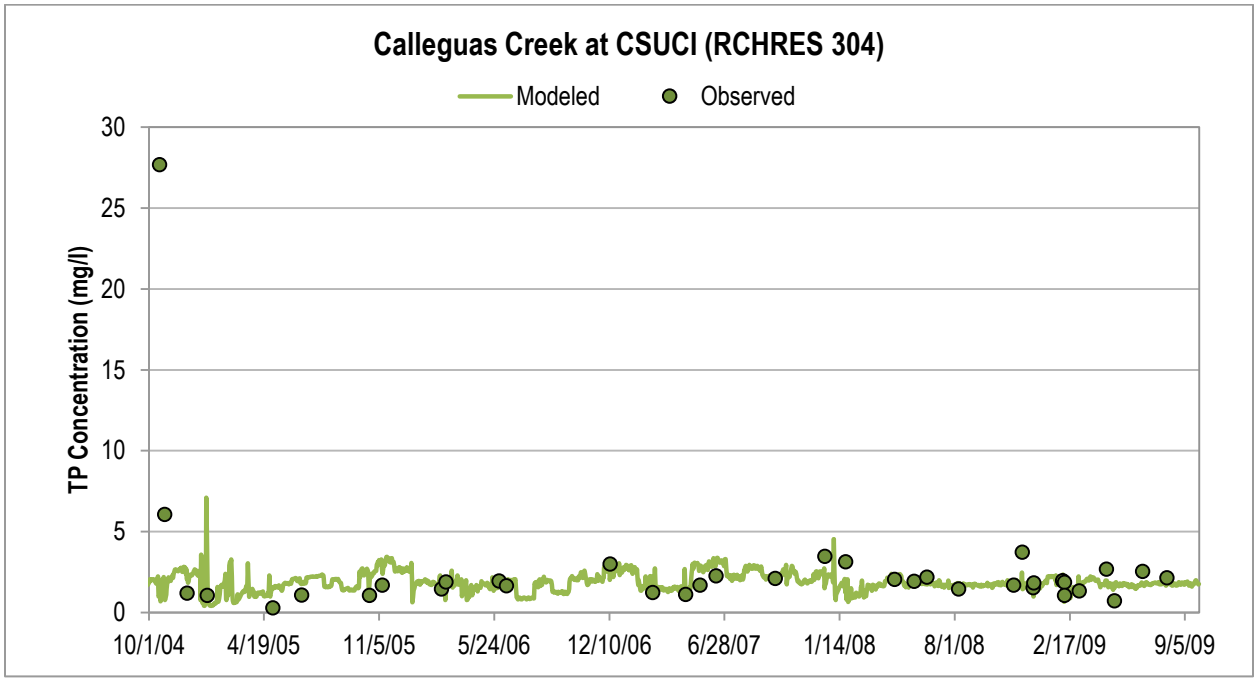


Figure E.17. Daily average observed versus HSPF modeled orthophosphate concentrations for Calleguas Creek at CSUCI for the management scenario.

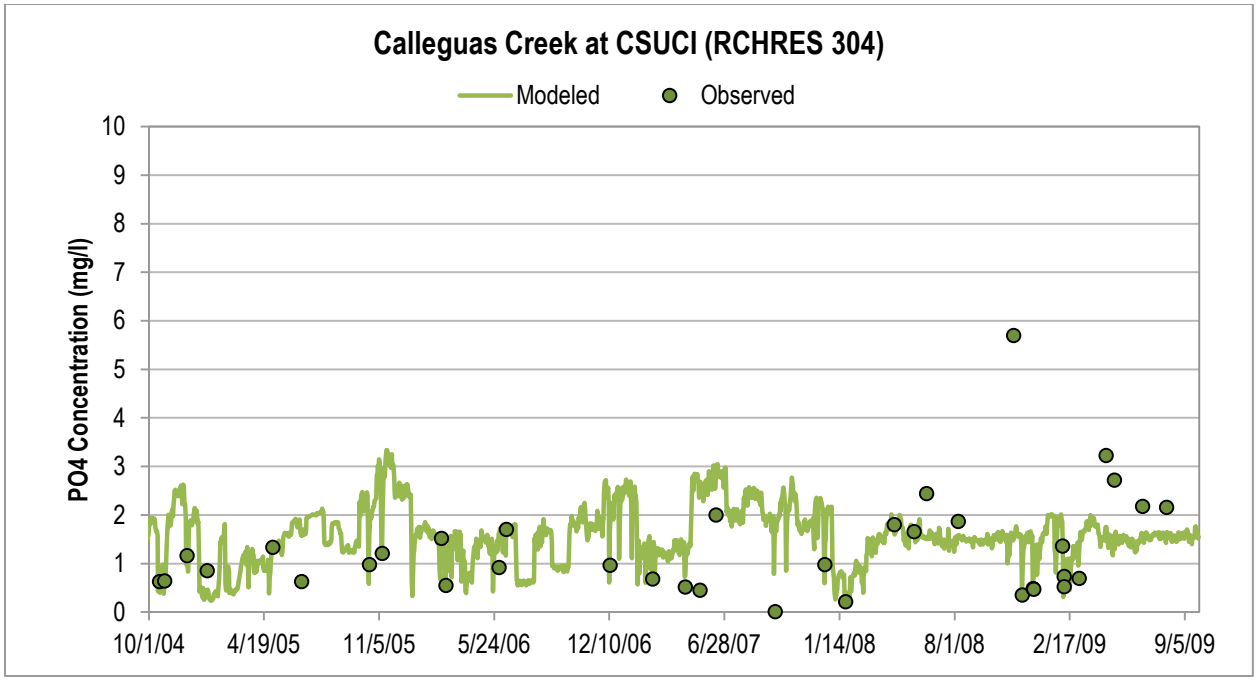


Figure E.18. Daily average observed versus HSPF modeled total nitrogen concentrations for Calleguas Creek at CSUCI for the management scenario.

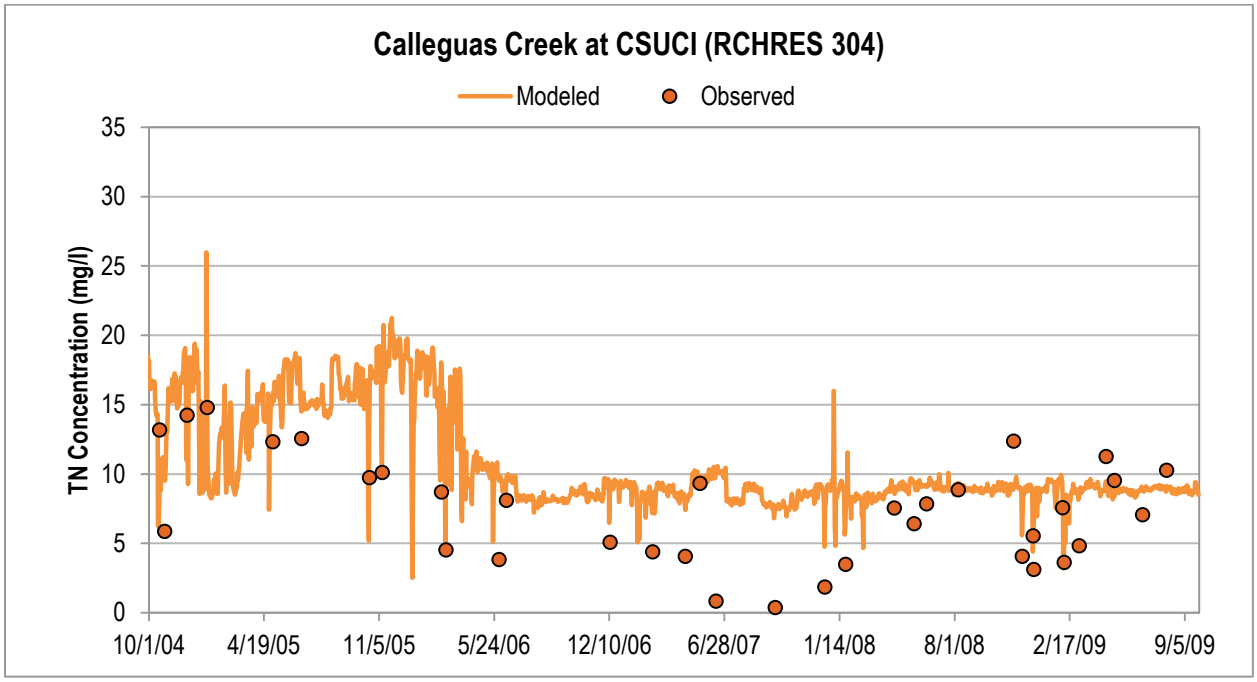


Figure E.19. Daily average observed versus HSPF modeled nitrate concentrations for Calleguas Creek at CSUCI for the management scenario.

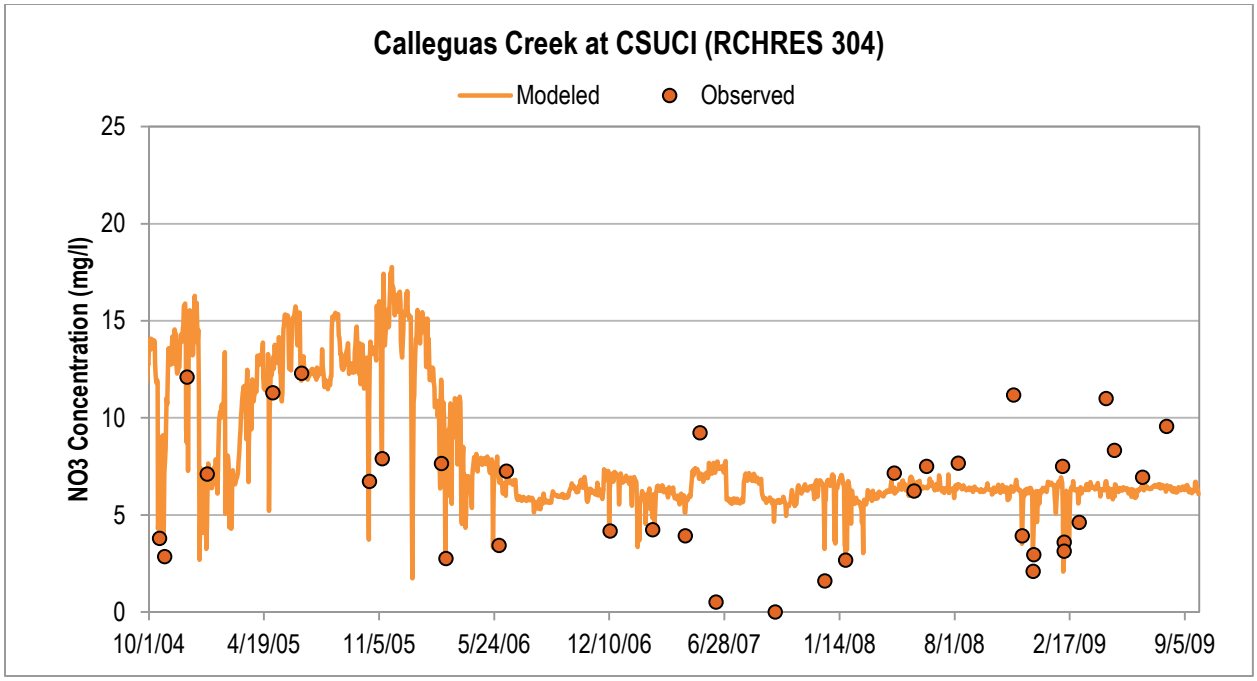


Figure E.20. Daily average observed versus linked HSPF/HEC-RAS modeled TSS concentrations for Calleguas Creek at CSUCI for the management scenario.

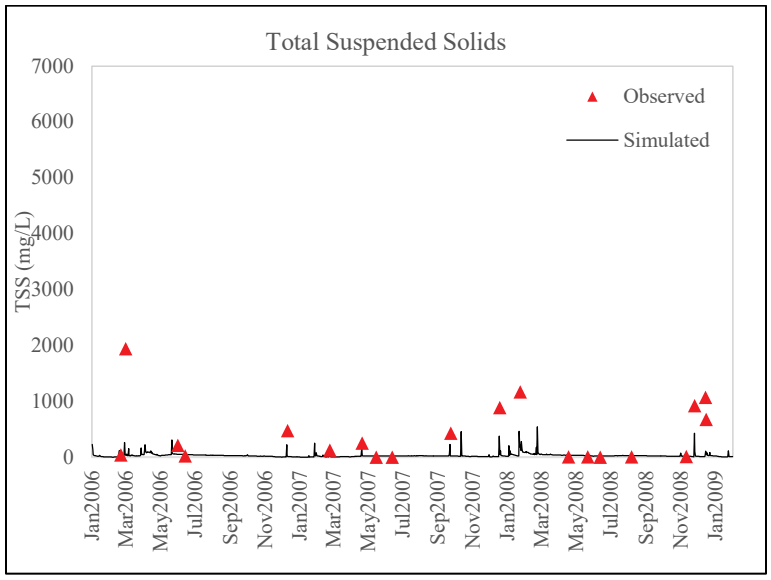


Figure E.21. Daily average observed versus linked HSPF/HEC-RAS modeled dissolved copper concentrations for Calleguas Creek at CSUCI for the management scenario.

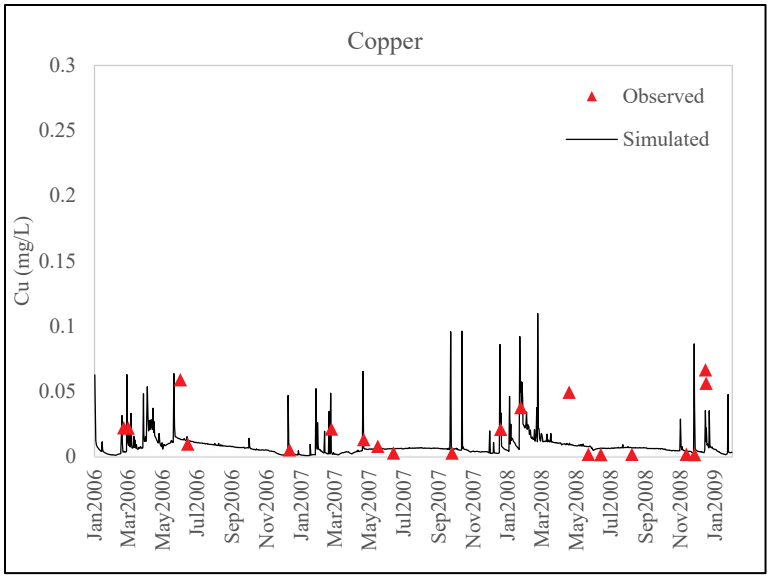


Figure E.22. Daily average observed versus linked HSPF/HEC-RAS modeled total phosphorous concentrations for Calleguas Creek at CSUCI for the management scenario.

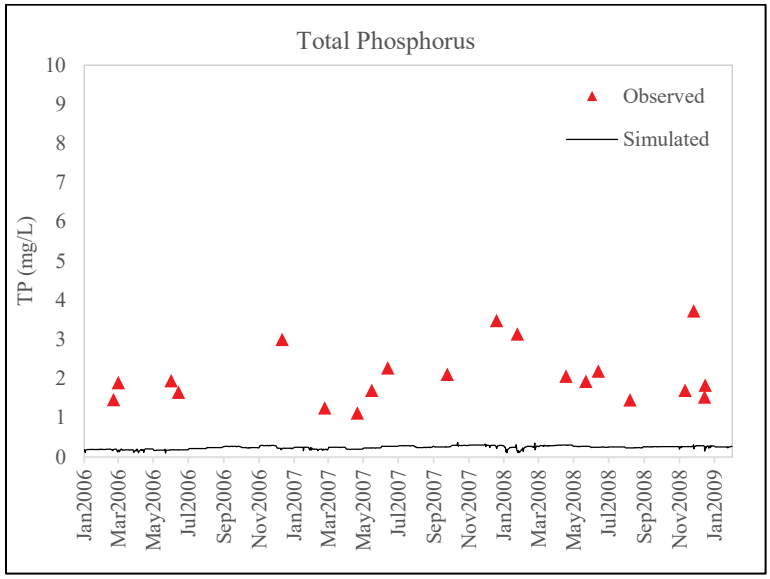


Figure E.23. Daily average observed versus linked HSPF/HEC-RAS modeled total nitrogen concentrations for Calleguas Creek at CSUCI for the management scenario.

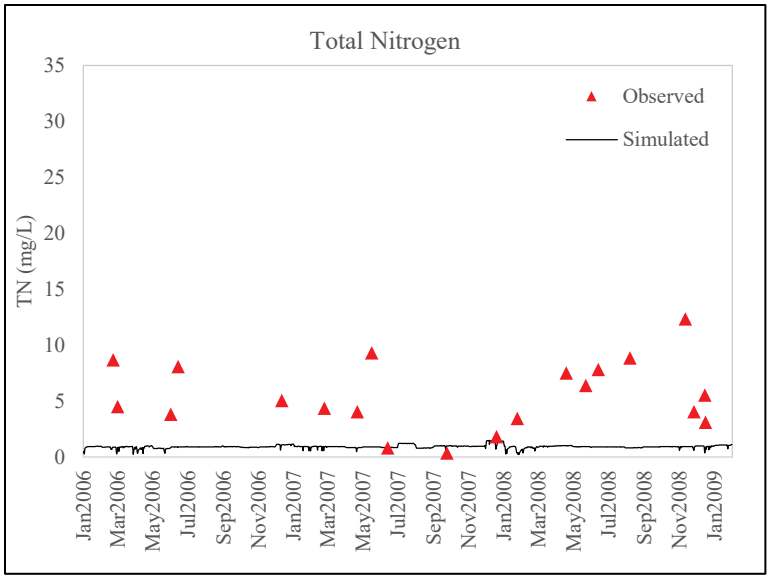


Figure E.24. Daily average observed versus linked HSPF/HEC-RAS modeled ammonium concentrations for Calleguas Creek at CSUCI for the management scenario.

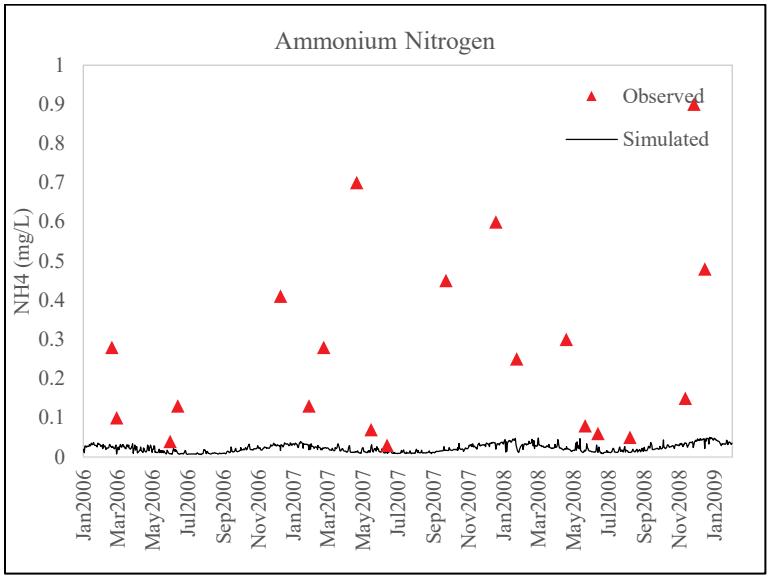
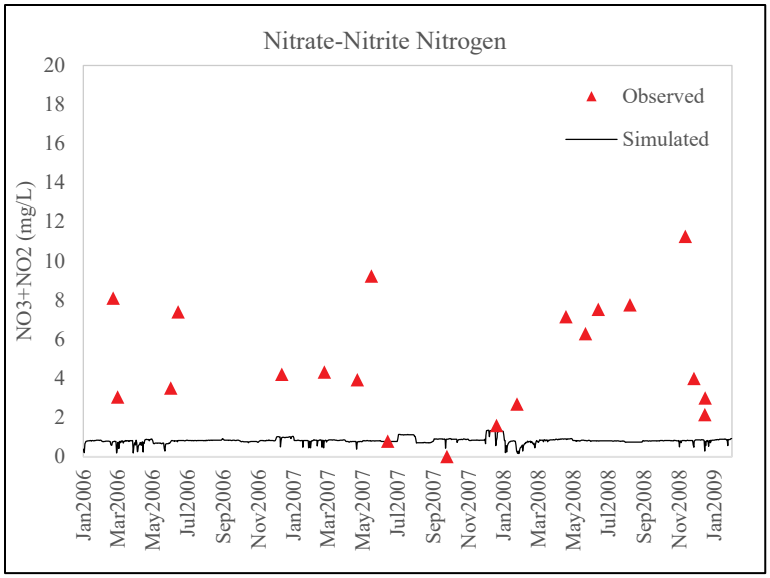


Figure E.25. Daily average observed versus linked HSPF/HEC-RAS modeled nitrate concentrations for Calleguas Creek at CSUCI for the validation period (2003-2005).



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14. ABSTRACT

The objective of this project is to demonstrate and validate a linked watershed and riverine modeling system for the Calleguas Creek Watershed. The system helps land managers assess outcomes resulting from military activities; the system also supports installation sustainability through informed watershed management of water, water quality, contaminants, and land-use impacts.

The modeling system was developed and enhanced from existing watershed and riverine models. Hydrological Simulation Program-Fortran (HSPF) was used to compute water flow, soil erosion/sedimentation, nutrients, and contaminant loadings, whereas the Hydrologic Engineering Centers-River Analysis System (HEC-RAS) was used to evaluate instream water quality and aquatic ecosystem responses from watersheds both within and outside an installation.

HSPF simulates, for extended periods of time, the hydrologic, and associated water quality, processes on pervious and impervious land surfaces and in streams and well-mixed impoundments. Benefits can be derived from the ability of the linked modeling system to determine contaminant loads entering and leaving the installation. In certain locations, this information can be used to identify to what extent the installation is responsible for the impaired waters. In cases where mitigation is necessary, the system will help land managers better assess which scenarios will provide the most environmental benefits for the least financial cost.

15. SUBJECT TERMS

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