# Simulating Wetland Assimilation Capacity in the Lower Santa Rosa Creek Watershed Pilot Demonstration Area Using the HSPF Model

## 1. INTRODUCTION

The modeling component of this project is to demonstrate a framework and process for identifying and assessing alternative options for wetland creation and restoration placement in the Santa Rosa Plain to help reduce nutrient and sediment loads, the targeted pollutants of concern to the Laguna de Santa Rosa. This demonstration involved testing the efficacy of the Hydrological Simulation Program-FORTRAN (HSPF), a commonly available hydrological model, for comparing alternative wetland placement scenarios.

HSPF was selected as the watershed model for this study because of its comprehensive nature and wetland simulation capacity (Bicknell et al., 1997; 2005). HSPF is a comprehensive hydrology and water quality model that predicts loadings and instream water quality in mixed land use watersheds for a range of pollutants. It is the primary watershed model in the U.S. EPA (EPA) BASINS modeling system (U.S. EPA. 2001) and is widely used across the United States for comprehensive watershed assessments. As a public domain model jointly supported and maintained by EPA and the U.S. Geological Survey (USGS), HSPF has enjoyed the continued availability and development of the model code. A recent addition to the model is its advanced wetlands setup capability, which provides a way to represent and simulate wetlands in HSPF for water quality improvements. This new capability of HSPF is a primary reason for its use in this study.

This report documents the modeling effort of using HSPF to estimate sediment and nutrient load reductions from wetlands for the Santa Rosa Creek watershed. Section 2 describes the model setup process and the input data used to both characterize the watershed conditions and drive the model simulation. Section 3 discusses model calibration and results. Section 4 describes the development and simulation of three wetland restoration/creation scenarios and resulting flow and load reductions.

## 2. MODEL SETUP

Watershed modeling with HSPF requires delineating the study area into smaller subbasins (model segments) and collecting and compiling both spatial and meteorologic data to develop the

model and perform model simulations. This section describes the model setup process and each of the data types and the specific data used in the model.

## 2.1 Study Area

Lower Santa Rosa Creek watershed, one of tributary basins that drains to the Laguna, was chosen for the demonstration of the modeling approach (Figure 1). The watershed has a drainage area of 20,700 acres, with mixed urban and agricultural land uses. This watershed was chosen primarily because: 1) it has the data to support model development; and 2) there are potential locations for wetland restoration or creation.
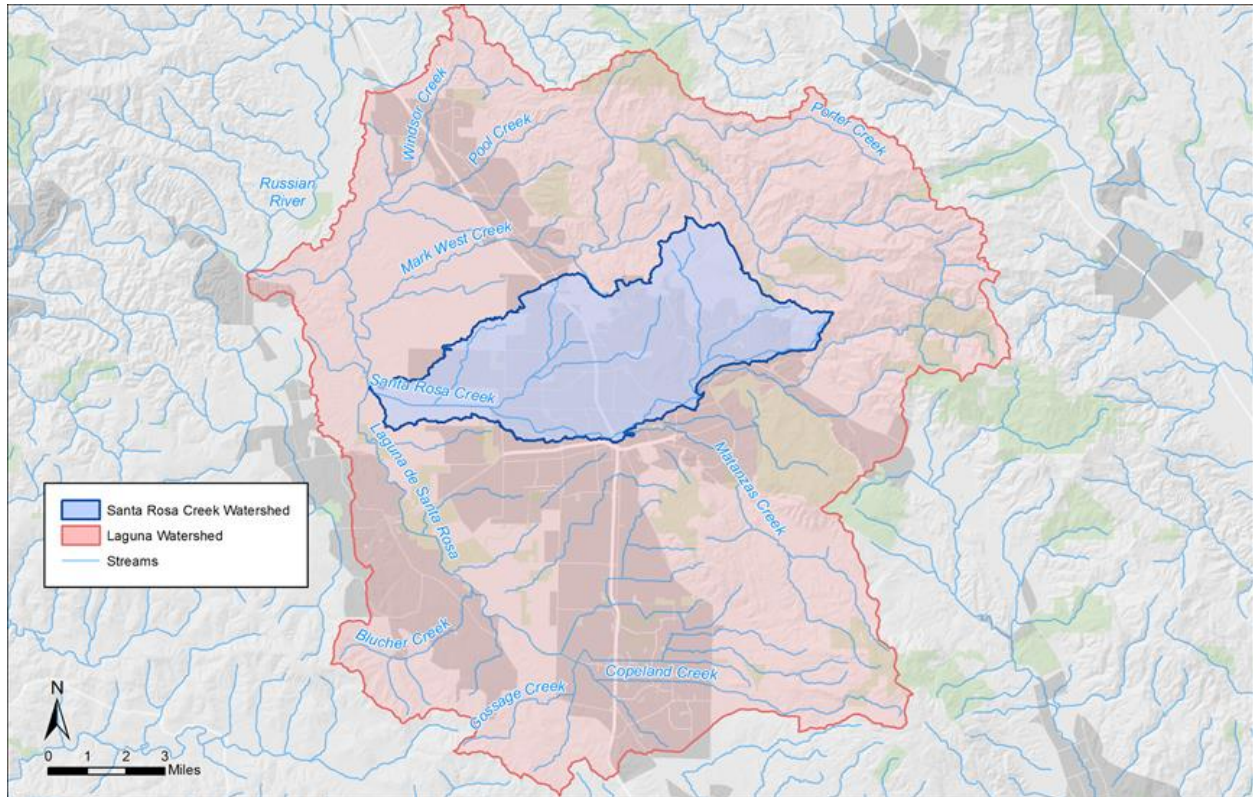


Figure 1. Study area - Lower Santa Rosa Creek watershed

## 2.2 Watershed Delineation

The Lower Santa Rosa Creek watershed was delineated into 35 sub-basins using topographical data. Each sub-basin was treated as a homogeneous segment for parameterization and analysis of local (sub-basin scale) conditions (Figure 2). GIS coverages used for watershed delineation were obtained from multiple sources. 10-meter DEM was from USGS National Elevation Dataset (NED) (https://lta.cr.usgs.gov/NED). Stream network data were a combination of a high resolution layer created by Tetra Tech (Jon Butcher, personal communication) and a stream layer derived from the NED 10m DEM.
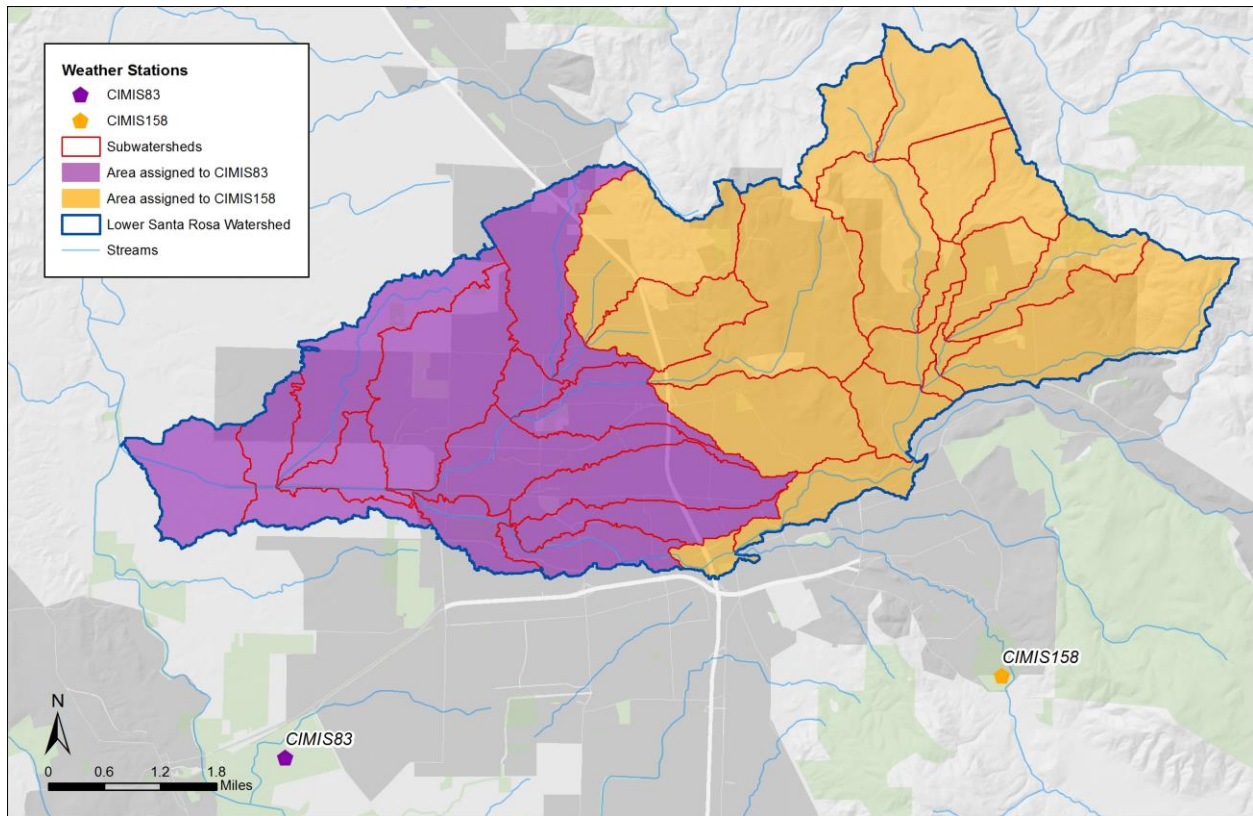
Figure 2. Delineated sub-watersheds, weather stations, and calibration stations

## 2.3 Model Inputs

**Meteorologic data**

HSPF requires meteorologic inputs of precipitation, potential Evapotranspiration (ET), air temperature, wind speed, solar radiation, dewpoint temperature, and cloud cover to drive the model simulation. Hourly meteorologic data for all parameters except cloud cover were obtained for two climate stations of the California Irrigation Management Information System (CIMIS) (http://wwwcimis.water.ca.gov/cimis/data.jsp). Both stations are outside of the watershed but within the larger watershed of the Laguna (Figure 2). Cloud cover data were obtained from a nearby station at Sonoma County Airport. The Thiessen analysis, a standard hydrologic technique to define the watershed area that will receive the rainfall recorded at a gage, was used to assign the appropriate rain gages to each sub-watershed. Figure 2 shows the sub-watersheds and the corresponding weather stations assigned to each sub-watershed.

**Land use**

land use acreage for each sub-basin was required to define hydrology and pollutant loads. Land use data were customarily created from National Land Cover Database (NLCD) 2011 land cover and Crop Data Layer (CDL) 2015 coverage. The CDL coverage contains 32 different land use classifications, which were than aggregated down to six model categories. The aggregated land use groups for the HSPF model and their distribution are listed in Table 1.

Table 1. Land use categories and distributions in Lower Santa Rosa Creek watershed

| Land use | Area (acre) | % area |
|---|---|---|
| Rangeland | 3566 | 17 |
| Forest | 1446 | 7 |
| Cropland & Pasture | 1015 | 5 |
| Orchard & Vineyards | 1176 | 6 |
| Urban | 13178 | 64 |
| Other Land Use | 319 | 2 |
| **Total** | **20700** | **100** |

**Impervious area**

The urban category was represented in the model as both pervious and impervious areas because of the importance of impervious surfaces in contributing to both stormwater volumes and pollutants. The percent of imperviousness from National Land Cover Dataset (NLCD) 2011 was used to estimate the impervious area of the watershed. From the analysis, an average 38.7% of imperviousness was used to calculate the acreage of impervious area for each model segment.

**Soil data**

Soils properties affect the watershed response for both hydrology and water quality and required by the HSPF model to characterize the varying behaviors of the sub-watersheds. For soils information, SSURGO soils data was obtained from the USDA Soil Data Mart (http://soildatamart.nrcs.usda.gov/) for the Lower Santa Rosa Creek watershed, and processed to identify soil textural classifications and correlate those classes with four hydrologic soils groups (A, B, C and D) as classified by the Natural Resource Conservation Service based on the soil's runoff potential. Group A has generally the smallest runoff potential and Group D has the greatest. The Lower Santa Rosa Creek watershed has mostly soil types C and D. The distribution of soil groups across the watershed provided the basis for assigning model parameters to each sub-watershed and each land use category.

## 3. MODEL CALIBRATION

Model calibration is an iterative process of adjusting key model parameters to match model predictions with observed data. The model calibration is necessary to ensure that the model will accurately represent important aspects of the actual system and therefore can be used to establish a representative baseline condition as a basis for comparative assessment of various wetland

restoration/creation scenarios. Typical calibration and validation procedures for HSPF involve a 'weight-of-evidence' approach to assess model performance through multiple graphical and statistical comparisons of observed and simulated flow and water quality constituents, which requires extensive observed data and calibration efforts.

The model calibration focused on ensuring that the model is sufficiently realistic for the demonstration purposes of this study. The observed data are sufficient for those purposes. However, the results of model simulation should not be interpreted as an accurate representation of the actual flow and loads from the watershed. The model was calibrated first for hydrology, and then for sediment and nutrients. The calibration period was from 2008 to 2010. Most of the observed water quality data pertain to this period.

**3.1 Hydrologic Calibration**

The hydrologic calibration was to adjust key model parameters governing the hydrologic processes to match model predicted flow with observed data. The hydrologic calibration was performed for a USGS station (11466320) near the mouth of the watershed (Figure 3,) where long-term flow data are available. Since Lower Santa Rosa Creek is hydrologically connected with other tributaries within larger Laguna de Santa Rosa watershed, this station receives water not only from the study area but also from upstream basins, including Matanzas Creek and upper Santa Rosa Creek. The observed flow from another USGS station (11466200) at the confluence of Matanzas Creek and upper portion of Santa Rosa Creek was used to account for upstream inflow into the study area. This confluence site, however, also receives water from part of Lower Santa Rosa watershed. To avoid double-counting flow, this portion of the watershed was removed from model calibration. The resulting calibration area is shown in Figure 3. It covers 20 of the 35 sub-basins. Once the model is calibrated, the model parameters were then assigned to the other 15 uncalibrated sub-basins.
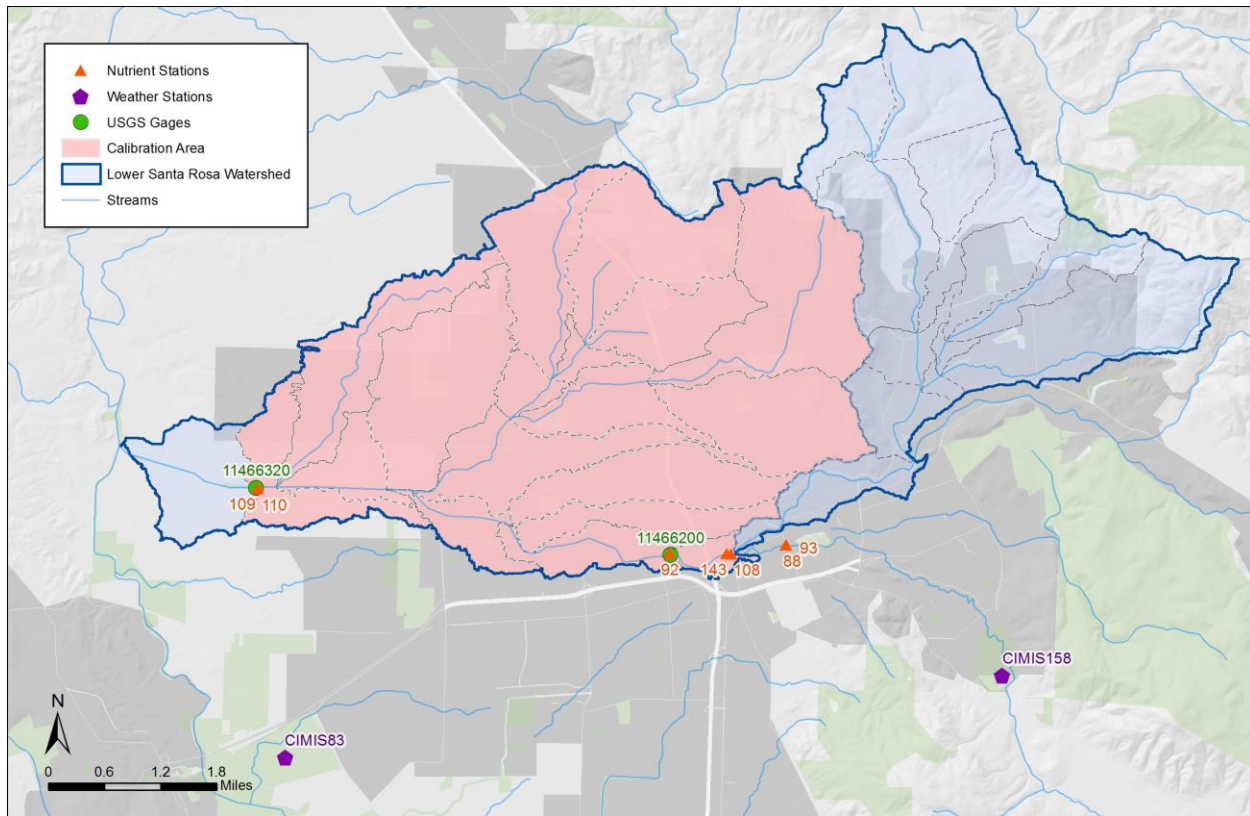
Figure 3. Model calibration area and flow and water quality stations

The hydrologic calibration was assessed through both graphical and statistical comparisons of observed and simulated flow. As shown in Figure 4 and Figure 5, modeled daily flow matched the volume and timing of observed data very well, with an $R^2$ of 0.94. The peak flows, however, were consistently under-estimated. Several factors could contribute to this. The model uses precipitation data from two weather stations and assigns representative stations to sub-basins based on Thiessen polygon method. , Localized rainfall events may not be captured and could contribute to the discrepancy between modeled and observed peak flows. Given the distance between the climate stations and the study area, the actual evaporation may also be different than assumed. In addition, uncertainty in some key input data, such as the percent of imperviousness, local soil conditions, and the degree of connectivity between impervious areas and streams or channels could also affected peak flow results. The model calibration was also assessed based on the calculated mean error for the modeled and observed runoff volume and Nash–Sutcliffe model efficiency (Nash and Sutcliffe, 1970). The statistical assessment indicated an overall very good hydrologic calibration according to the criteria established for HSPF (Duda, et. al.2012), with error for runoff volume of 5% and model efficiency of 0.94. The good calibration of hydrology suggests that the model captured underlying hydrologic processes well, thus providing a reasonable foundation for subsequent water quality calibration and wetland scenario simulations.
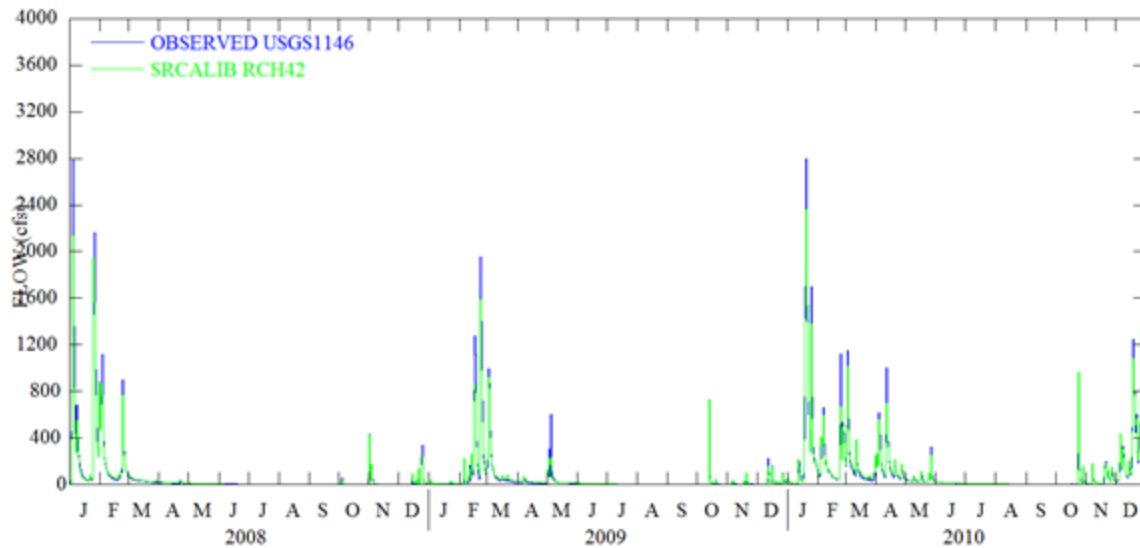
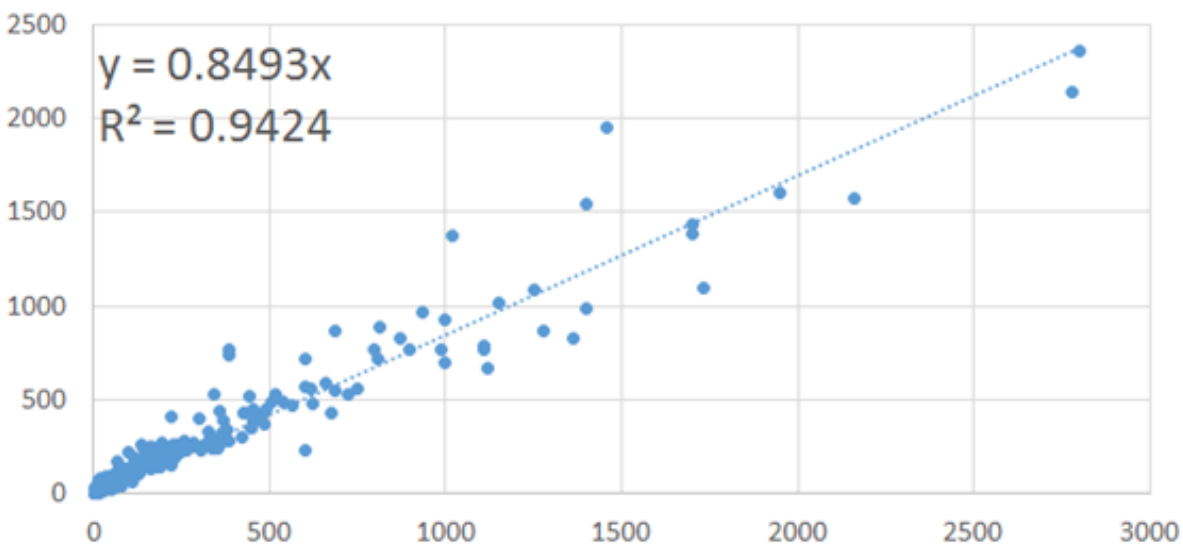Figure 4. Modeled and observed daily flow at the calibration station



Figure 5. Scatter plot of modeled and observed daily flow at the calibration station

## 3.2 Water Quality Calibration

Water quality calibration was to adjust model parameters to match modeled sediment and nutrient concentrations with observed data. These are the targeted pollutants for this project. The monitoring data collected by North Coast Regional Board at two attainment points (109 and 110)) were downloaded from California Environmental Data Exchange Network (CEDEN) ( http://www.ceden.org) and used for calibration (Figure 3). Since only very sparse water quality data are available, and in keeping with the purpose of this project, a fuller calibration, as conducted for hydrology, could not be conducted for water quality. Water quality calibration was thus focused on making sure the modeled concentrations are within the range of observed

data. However, as with flow, the sediment and pollutant loads from upstream needed to be quantified. These loads were estimated by multiplying average concentrations from the four sites sampled by the Regional Water Board (CEDEN) near the USGS confluent station (Figure 3) by flow at that station.

Figures 6-9 show calibration results for total suspended sediment (TSS), Ammonia, NO3, and PO4. Overall, the modeled concentrations are within the range of observed data, which is deemed acceptable for this demonstration project.
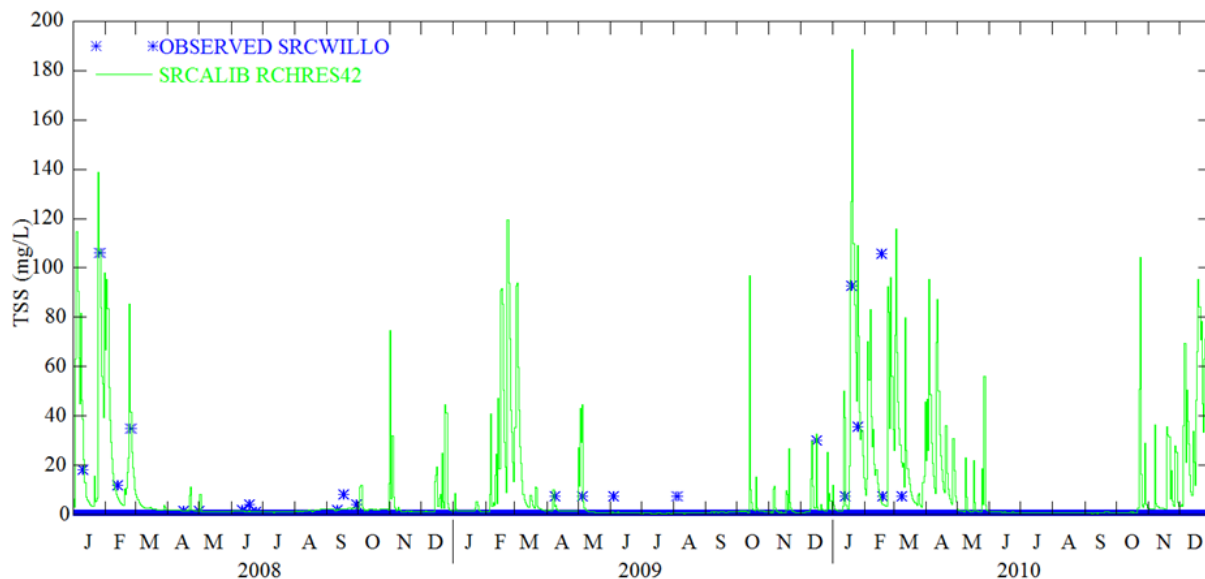


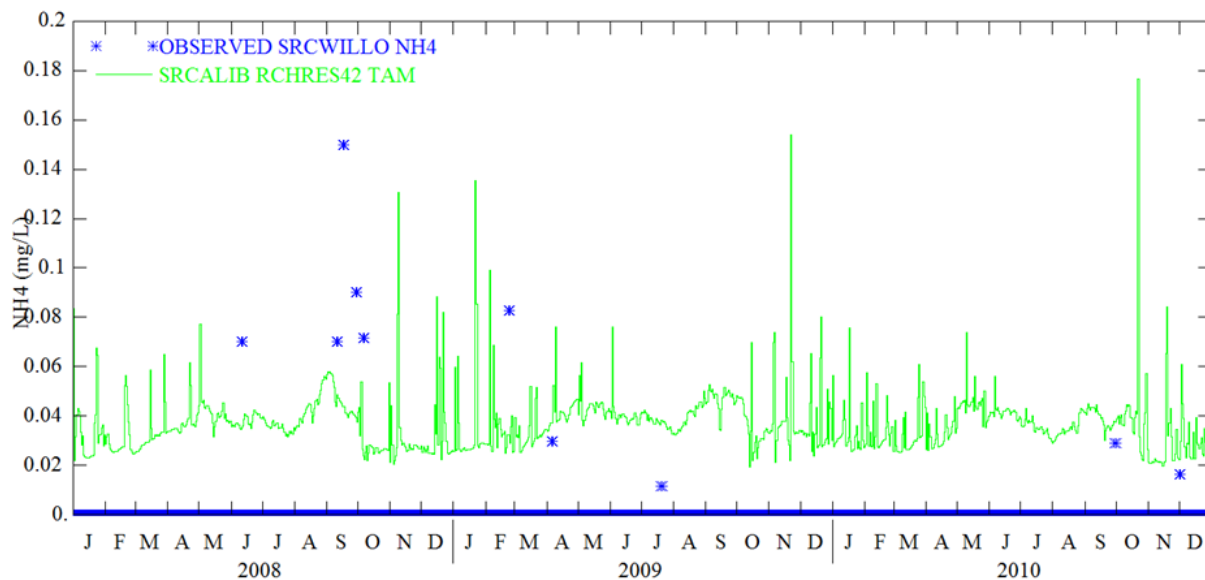Figure 6. Modeled and observed TSS concentrations at calibration sites



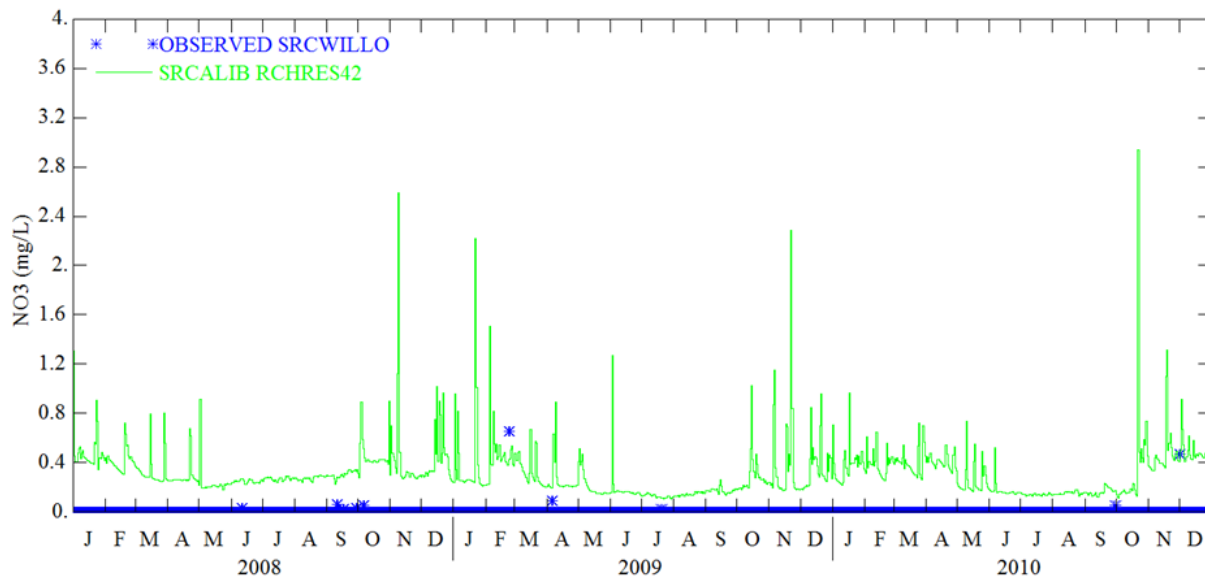Figure 7. Modeled and observed ammonia concentrations at calibration sites

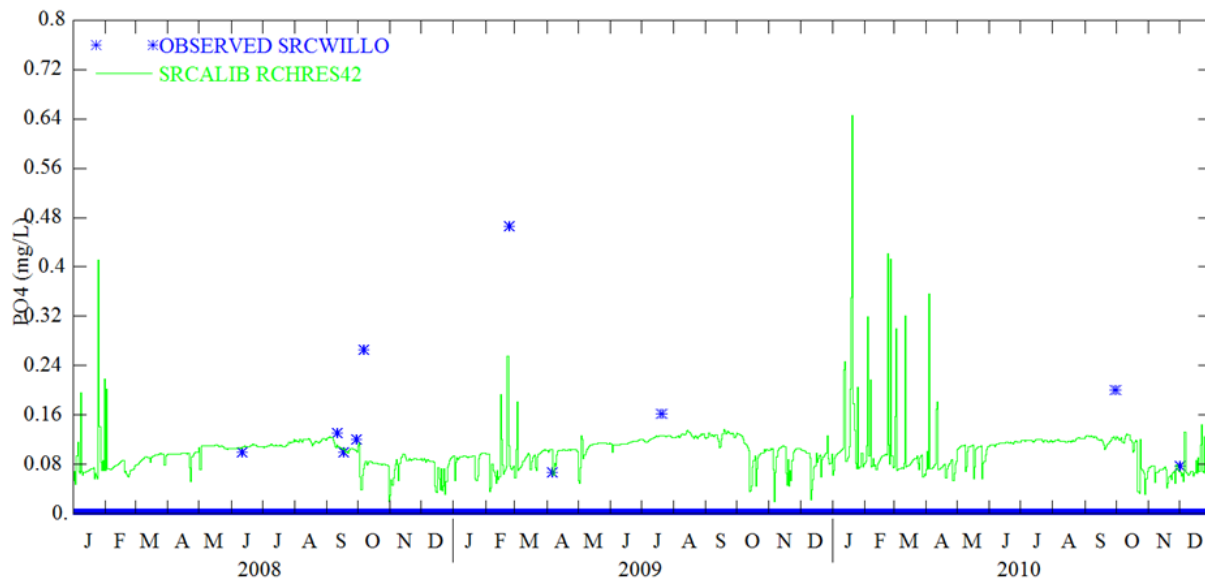Figure 8. Modeled and observed NO3 concentrations at calibration sites



Figure 9. Modeled and observed PO4 concentrations at calibration sites

**3.3 Establish Baseline Condition**

After model calibration was completed, the calibrated model parameters were then assigned to the 15 sub-basins that were excluded from the calibration (Figure 3). The resulting baseline condition pertains to the existing landscape. It serves to compare and contrast the different wetland creation/restoration scenarios. Since the portion of the Lower Santa Rosa Creek watershed that drains to the confluent site was now included into the model simulation, an area ratio was used to estimate the portion of flow and loads entering the study area from upstream of its boundary.

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## 4. SIMULATION OF WETLAND SCENARIOS

The calibration model was used to simulate flow and pollutant loads to the Laguna under three different levels of potential wetland restoration/creation scenarios. The results of the simulation are intended to demonstrate how the scenarios can be compared using a common modeling tool.

### 4.1 Development of Wetland Scenarios

Three wetland placement scenarios were developed that differed in terms of the number and total area of additional wetlands. The scenarios are termed existing (i.e., baseline), moderate, and extreme. For the existing scenario, the distribution and abundance of wetlands and streams was based on CARI (California Aquatic Resources Inventory), which was recently updated in the Santa Rosa Plain region for a separate WRAMP pilot demonstration project funded by the USEPA. This scenario served as a reference point from which the other two scenarios were assessed with regard to flow and load reductions. The two hypothetical, future scenarios were based on many considerations, especially land use, proximity to stream channels, proximity to impervious areas, and topographic slope. For the moderate scenario, the objective was to locate new potential wetland restoration areas in undeveloped locations close to existing wetlands and/or existing channels. The intent was to have as little economic impact as possible, while taking advantage of the most logistically feasible locations that would provide significant benefits. For the extreme scenario, the objective was to effectively capture all or close to all of the stormwater runoff draining through or from the study area into the Laguna. This scenario added new wetlands to the moderate scenario.

Future wetlands were hand-drawn at a scale of 1:3,000 or greater for each of the two future scenarios. A separate shape-file was created in a GIS for all the wetlands for each scenario. These shape-files were then brought together with the DEM and stream network into the BASINS HSPF setup tool (USEPA 2013) to determine the amount of land area draining to a wetland before reaching any stream reach. With the advanced wetland setup, the HSPF model contains both a "wetlands reach" and a "stream reach" within each sub-basin, where the wetlands reach is a local tributary to the stream reach. This feature makes it possible to explicitly model a wetland as well as the normal stream channel within each sub-basin. Figures 10-12 show the three wetland scenarios and corresponding drainage areas. The total drainage area for wetlands increases about 1000 acres between the existing and extreme scenarios, but majority of the watershed drains to streams for each scenario (Table 2).
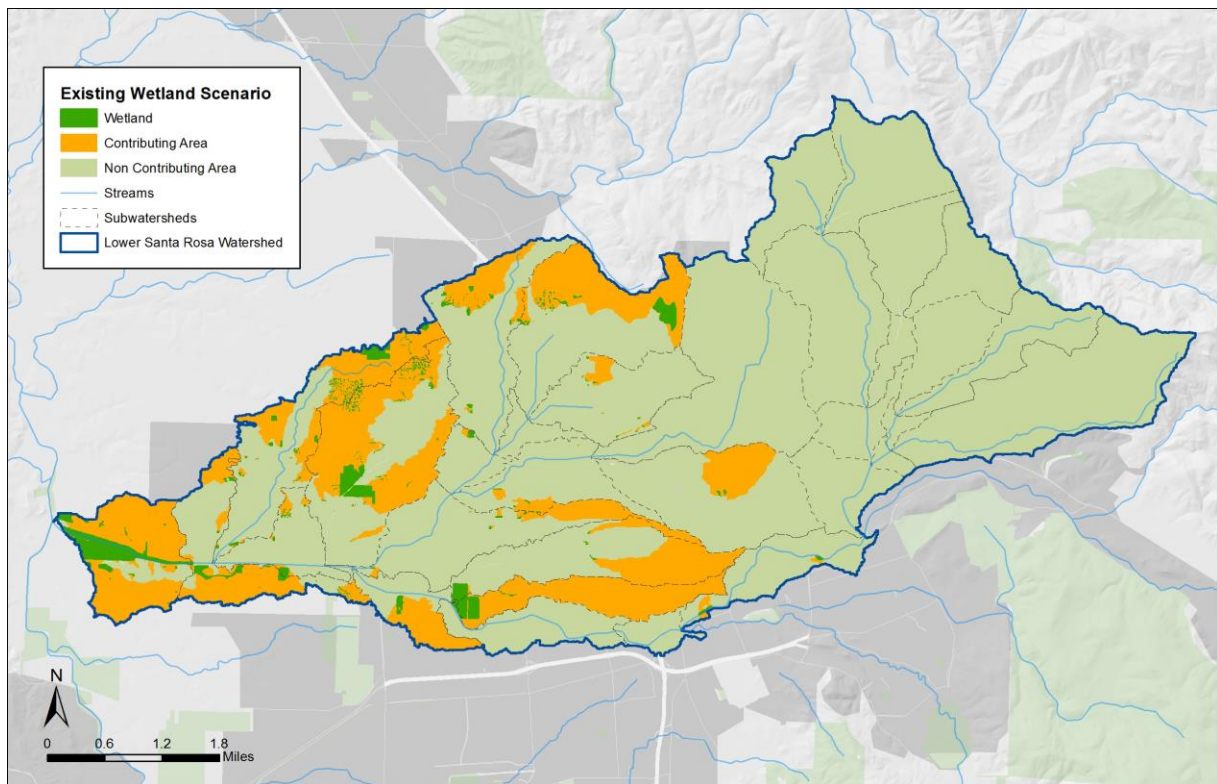
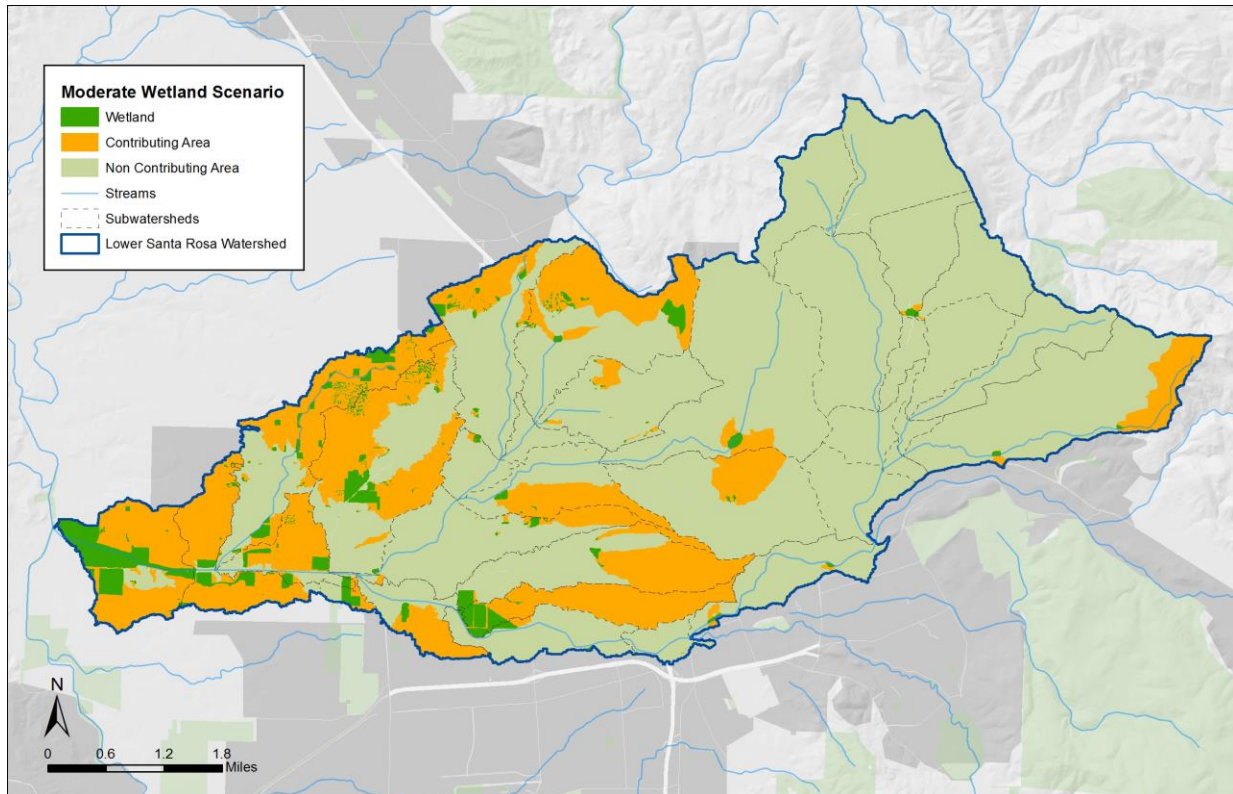Figure 10. Existing wetland area extents based on CARI


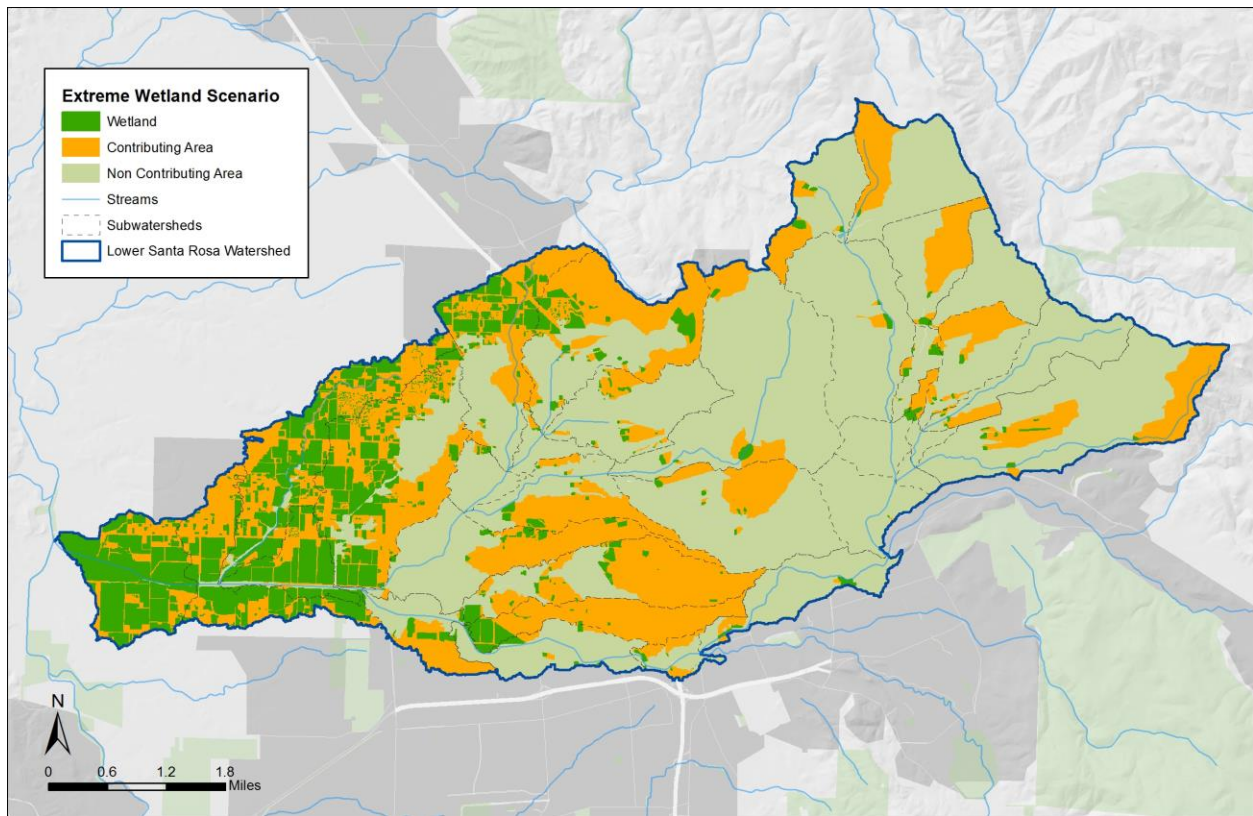Figure 11. Moderate wetland placement scenario

Figure 12. Extreme wetland placement scenario

Table 2 Drainage areas to wetlands and streams for three scenarios

| Scenario | Total Wetland Area (acre) | Drainage to Wetland (acre) | Drainage to Stream (acre) |
|---|---|---|---|
| Existing | 380 | 4142 | 16558 |
| Moderate | 838 | 5303 | 15091 |
| Extreme | 2914 | 6333 | 11987 |

## 4.2 Simulation of Wetland Scenarios

Within HSPF, wetlands are represented and simulated through an "F-table". The F-table in the HSPF is a hydraulic function table that defines the functional relationship between water depth, surface area, water volume, and outflow in the segment (Table 3). HSPF requires an F-table for each wetland. Adequate F-tables are essential for accurate simulations. For this modeling effort,

a number of assumptions were made to develop F-tables for each existing and proposed wetland: 1) every wetland is treated as a reservoir, with an assumed depth of 2 feet; 2) wetland area is well-estimated from the GIS; and 3) a full wetland will drain downstream.

Table 3. Example F-table for wetlands

```
FTABLE    35
rows cols                        ***
  8   4
  depth      area   volume  outflow1 ***
   0.0       1.76       0       0
   0.07       1.8     0.12    0.08
   0.68       2.1     1.31    3.47
   0.85      2.18     1.67    5.04
   1.06      6.59     3.04    6.76
   1.27      6.80     4.46    12.5
  21.78     27.15   352.72  6964.52
  42.3       47.5  1118.53 32650.75
END FTABLE 35
```

Based on these assumptions and using a simple weir equation, the outflow from a full wetland can be calculated as follows:

$$Q = 2.5H^{(5/2)},$$

Where Q is discharge in cfs, and H is backwater height (ft) in the wetland above the weir.

The calculated outflow, together with wetland surface area, volume, and depth, as estimated from the GIS, were then used to form the F-table for each wetland under each scenario. Once the F-tables were developed and put into the model, the model was run for each scenario for the same time period (2008 to 2010), to generate estimates of downstream flow and sediment and nutrient loads.

### 4.3 Simulation Results
The simulated flow and pollutant loads were summarized for the wet season only (September 15 to April 15) for the three-year simulation period (Table 4). There were only traces of precipitation during dry season, during which most streams had little or no flow. The wet season reductions in flow and pollutant loads were calculated as the percent difference between the existing scenario and each of the other alternative future scenarios (Table 4). Model results show

reasonable reductions for flow volume and pollutants, except for TSS, for both the moderate and extreme scenarios. This is consistent with the well-documented wetland capacity for assimilating nutrients.

Unlike flow and nutrients, TSS loads were estimated to increase under moderate and extreme scenarios, which is counterintuitive and contradicts many field studies on effectiveness of wetlands in trapping sediment.  The TSS results are the consequence of an existing problem with how HSPF addresses extreme low flow or zero flow. Pollutant concentrations from the first storm after a prolonged dry period spike artificially and erratically due to numerical instability caused by initial flow values approaching zero. This problem becomes especially serious for this study area,  where most streams naturally experience a long dry period prior to first wet season flows, or the low flow condition is caused by a future scenario with wetlands that capture precipitation and runoff. The problem affected the  estimated sediment loads because of their suspension. To a much lesser degree, the problem also affected the estimates of nutrient loads. The model generated large sediment concentrations in individual wetland, even though pertinent model parameters were adjusted to make the wetlands function like reservoirs. This suggests that the wetland simulation module in HSPF is not very robust and its further development is needed.

Table 4. Simulated flow and loads for existing, moderate, and extreme scenarios and % reductions

| Flow/Loads | Existing | Moderate | % Reduction | Extreme | % Reduction |
|---|---|---|---|---|---|
| FLOW (ac.ft) | 6588 | 6453 | 2 | 5972 | 9 |
| TSS (ton) | 1313 | 1521 | -16 | 1362 | -4 |
| NO3 (lbs) | 6304 | 4776 | 24 | 4798 | 24 |
| TAM (lbs) | 559 | 298 | 47 | 344 | 38 |
| PO4 (lbs) | 5488 | 1176 | 79 | 1125 | 80 |

In terms of the nutrient load reduction, the moderate scenario appeared as effective as the extreme scenario. In each case the reductions were estimated to be 24% for NO3, 47% for total ammonia, and 80% for PO4.  The similarity between the two future scenarios is probably due to the fact that the extreme scenario was developed by adding numerous small wetlands in the upstream reaches of the study area, above the densest land uses,  where they are likely to have little impact on downstream water quality.  Even though wetland acreage increased by over 2000 acres from the  moderate to extreme scenarios, the drainage area to wetlands increased only about 1000 acres (Table 2), indicating inefficient positioning and utilization of wetlands in the extreme scenario. In addition, although not as severe, the above-mentioned low flow problem

also affected nutrient concentrations. The effect of this modeling problem is bigger for the extreme scenario because it increased the extent of desiccated streams.

**4.4 Summary of Wetland Simulation**
Simulation of the three wetland scenarios using the HSPF wetland function provided some useful insights for developing a watershed approach to wetland planning. Below is a summary of findings from this modeling effort.

- Wetlands can reduce stormwater runoff and nutrient loads, and this benefit can be quantified with a modeling tool.

- Wetland size and location matter, and larger downstream wetlands appear more effective than smaller upstream wetlands  in reducing stormwater runoff and pollutant loads.

- A modeling tool is useful for coarse, landscape scale comparisons of wetland restoration/creation scenarios.

- HSPF shows promise with its comprehensive capacities to simulate hydrology and water quality processes as well as wetland hydrological functions, but has problems simulating TSS for low flows and seasonal wetlands, which significantly complicates model simulation and the interpretation of model results.

- In the areas with semi-arid or arid climate, adding wetlands helps reduce nutrient loads but may decrease the amount of perennial stream habitat,, and this should be taken into account when designing and implementing wetlands in a semi-arid or arid watershed.

## 5. REFERENCES

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