Famosa Slough
Nutrients / Eutrophication Total Maximum Daily Loads

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Abbreviations

BMP	Best management practice
CA NNE	California numeric endpoint
CBOD	Biological oxygen demand
CIMIS	California Irrigation Management Information System
CWA	Clean Water Act
DO	Dissolved oxygen
EFDC	Environmental Fluid Dynamics Code
FoFS	Friends of Famosa Slough
HSPF	Hydrologic Simulation Program Fortran
JRMP	Jurisdictional Runoff Management Program
LA	Load allocation
LID	Low impact development
LRS	Load reduction strategy
LSPC	Load Simulation Program C++
MEP	Maximum extent practical
MES	Mass emission site
MOS	Margin of safety
MS4	Municipal separate storm sewer system
NADP	National Atmospheric Deposition Program
NCDC	National Climatic Data Center
NHD	National Hydrography Dataset
NOAA	National Oceanic and Atmospheric Administration
NOI	Notice of Intent
NPDES	National Pollutant Discharge Elimination System
NPS	Nonpoint source
OAL	Office of Administrative Law
SANDAG	San Diego Association of Governments
SAV	Submerged aquatic vegetation
SCCWRP	Southern California Coastal Water Research Project
SSURGO	Soil Survey Geographic
SWMP	Storm Water Management Program
SWRCB	State Water Resources Control Board
TBELs	Technology Based Effluent Limitations
TMDL	Total Maximum Daily Load
TN	Total nitrogen
TP	Total phosphorus
USDOI	United States Department of the Interior
USEPA	United States Environmental Protection Agency
WDRs	Waste Discharge Requirements
WLA	Wasteload allocation
WQBELs	Water Quality Based Effluent Limitations
WQIP	Water Quality Improvement Plan
WQOs	Water quality objectives

Executive Summary

The purpose of this technical report is to summarize the development of Total Maximum Daily Loads (TMDLs) to address eutrophication in Famosa Slough. Eutrophic conditions within Famosa Slough can affect water quality conditions, aquatic habitat, and designated beneficial uses. As required by Section 303(d) of the Clean Water Act (CWA), TMDLs were developed to address these conditions.

TMDLs are developed to ensure attainment of the water quality objectives (WQOs) that support beneficial uses in the waterbody. A TMDL is defined as the sum of the waste load allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources, and natural background [40 CFR 130.2] such that the capacity of the waterbody to assimilate pollutant loading (i.e., the loading capacity) is not exceeded. Therefore, a TMDL represents the maximum amount of the pollutant of concern that the waterbody can receive and still attain water quality standards. Additionally, a TMDL represents a strategy for meeting WQOs by allocating quantitative limits for point and nonpoint pollution sources. Once this maximum pollutant amount has been calculated, it is divided up and allocated among all of the contributing sources in the watershed.

Based on historical and current accounts of nutrient-associated impacts to Famosa Slough, the San Diego Regional Water Quality Control Board (San Diego Water Board) placed it on the CWA Section 303(d) List of Water Quality Limited Segments as being impaired (i.e., does not meet applicable water quality standards) for eutrophic conditions, or excessive nutrient enrichment. The Water Quality Control Plan for the San Diego Basin (Basin Plan) contains dissolved oxygen (DO) and biostimulatory targets that are narrative in nature and ensure that nutrient enrichment does not promote aquatic growth or adversely affect beneficial uses. Eutrophic conditions within Famosa Slough threaten critical habitat areas and beneficial uses such as, Estuarine (EST), Marine Life Habitat (MAR), and Wildlife Habitat (WILD). Eutrophic conditions can promote algal growth, thereby creating nuisance conditions that also may negatively affect Contact and Non-Contact Water Recreation (REC-1 and REC-2). Additional information on the beneficial uses potentially affected is discussed in Section 2.4.1. Note that Famosa Slough includes two main sections which exhibit very different characteristics due to several factors including the degree of tidal and freshwater influence, flushing ability, and physical configuration. For this document, the entire system is referenced as Famosa Slough. The open water portion south of Point Loma Boulevard is referenced as the Slough, whereas, the reach that connects the Slough with the San Diego River is referenced as the Channel.

Numeric targets must be identified to calculate TMDLs for eutrophic conditions. Due to the narrative nature of the biostimulatory substances WQO, this WQO must be interpreted through the development of a numeric target. For the purpose of these TMDLs, a DO level of 5.0 mg/L and a macroalgae biomass of less than 60 g dry weight (dw)/m^2 in the Slough was used to establish the corresponding nitrogen and phosphorus loading rates (Section 3). The near-term plan for the Channel is to focus on monitoring and adaptive management on the basis that current conditions in the Channel appear to show that beneficial uses are being met.

Available data were used to develop and calibrate a customized modeling framework to support nutrient TMDL development and evaluate potential management strategies. The modeling framework consists of a watershed model (Loading Simulation Program in C++ [LSPC]) and a receiving water model (Environmental Fluid Dynamics Code [EFDC]). The watershed model was used to calculate existing nutrient loading to Famosa Slough from the surrounding watershed, while the receiving water model was used to simulate hydrodynamics and nutrient transport characteristics for this tidally-influenced waterbody.

A source analysis was performed to identify and quantify the sources of nutrients to Famosa Slough. The most significant sources identified were urban runoff delivered by the storm drain system from the surrounding watershed and internal nutrient cycling. In particular, storm water outfalls in the residential portions of the watershed and discharges from the California Department of Transportation (Caltrans; state highways) were identified as sources. Additional nonpoint sources include sheet flow from developed areas directly adjacent to Famosa Slough, benthic nitrogen flux, and tidal exchange.

A margin of safety (MOS) must also be included in a TMDL to account for the uncertainty in the relationship between pollutant loads and the predicted water quality response of the receiving water. An implicit MOS was included through the application of a number of conservative assumptions, including establishing the TMDLs based on the critical summer period, and consideration of the overall predictive capability of the modeling framework that was developed for this study.

TMDLs are divided into WLAs for point sources, LAs for nonpoint sources, and the MOS. Loading requirements are assigned to point and nonpoint sources. Identified point sources include the City of San Diego Phase I municipal separate storm sewer system (MS4) and Caltrans. Nutrient loading to Famosa Slough was estimated based on modeling of watershed runoff and nutrient transport. WLAs were assigned to the City of San Diego, which is included as a regulated municipality under the San Diego Region Phase I MS4 permit (Order No. R9-2013-0001, as amended in February 2015 and in November 2015; Regional MS4 Phase I Permit), and Caltrans, which is regulated under a separate state permit (Order No. 2012-0011-DWQ).

The San Diego Water Board has legal authority to require dischargers to implement and monitor compliance with the requirements set forth in this TMDL. As previously noted, nutrients are transported through runoff generated from urbanization, land use practices, and other processes. A significant amount of the nutrient load originates from controllable water quality factors which are defined as those actions, conditions, or circumstances that result from anthropogenic activities that may influence the quality of the waters of the State and that could be reasonably controlled.

The regulatory framework for point sources differs from the regulatory framework for nonpoint sources. CWA section 402 establishes the National Pollutant Discharge Elimination System (NPDES) program to regulate the ‘‘discharge of a pollutant,’’ other than dredged or fill materials, from a ‘‘point source’’ into ‘‘waters of the U.S.” Under section 402, discharges of pollutants to waters of the U.S. are authorized by obtaining and complying with NPDES permits. These permits commonly contain effluent limitations consisting of either Technology Based Effluent Limitations (TBELs) or Water Quality Based Effluent Limitations (WQBELs).

In California, State Waste Discharge Requirements (WDRs) for discharges of pollutants from point sources to navigable waters of the United States that implement federal NPDES requirements and CWA requirements (NPDES requirements) serve in lieu of federal NPDES permits. Such requirements are issued by the State pursuant to the authority that is described in California's Porter Cologne Water Quality Control Act. As described above, point source discharges of nutrients to Famosa Slough include City of San Diego MS4 and Caltrans responsible areas within the watershed.

For TMDLs where nonpoint sources are determined to be significant, a LA is calculated which is the maximum amount of a pollutant that may be contributed to a waterbody by "nonpoint source" discharges to attain WQOs. The Porter-Cologne Water Quality Control Act applies to both point and nonpoint sources of pollution and serves as the principle legal authority in California for the application and enforcement of TMDL LAs for nonpoint sources. The State plan and policy for control and regulation of nonpoint source pollution is contained in the Plan for California's Nonpoint Source Pollution Control Program (NPS Program Plan) and the Policy for the Implementation and Enforcement of the Nonpoint Source Pollution Control Program (NPS Implementation and Enforcement Policy). Nonpoint source discharges from natural sources are considered largely uncontrollable, and therefore should not be regulated. Nutrients discharged via tidal exchange is an example of an uncontrollable nonpoint nutrient source that is not governed by a MS4 permit; however, hydromodification and accelerated erosion via storm water runoff are controllable sources of nutrients.

The modeling results indicate a 37 percent reduction in nutrient loading from the watershed (with a focus on reducing dry weather contributions), along with twice-a-year harvesting of algae in the Slough (as necessary), would result in acceptable macroalgae biomass and DO conditions within the Slough. Actions for the Channel will focus on monitoring and adaptive management given that current conditions show beneficial uses are being met. The TMDL results are summarized in Table ES-0-1. The WLAs represent watershed contributions while the LA includes loads from internal cycling, atmospheric deposition, and tidal flows (Table ES-0-1).

Table ES-0-1. TMDLs for Net Annual Watershed Nutrient Loads to Famosa Slough.

Input Location	Annual Net Total Nitrogen (kg/yr)	Annual Net Total Phosphorus (kg/yr)	Daily Net Total Nitrogen (kg/day)	Daily Net Total Phosphorus (kg/day)
TMDL	1,187.90	583.76	3.25	1.60
WLA (City of San Diego MS4)	1,152.26	566.25	3.16	1.55
WLA (Caltrans MS4)	35.64	17.51	0.10	0.05
LA	Not calculated due to minor impacts on eutrophic conditions			
MOS	Implicit	Implicit	Implicit	Implicit

During the TMDL development process, it was determined that the combination of necessary nutrient reductions and algal harvesting could be achieved with actions taken in compliance with the existing Regional Phase I MS4 Permit via consultation between the San Diego Water Board and the City of San Diego. As a result, the San Diego Water Board intends to postpone the TMDL adoption process in favor of relying on, and verifying the success of actions taken by the City of San Diego in accordance with the existing Regional Phase I MS4 Permit; and to reinitiate the TMDL process or initiate compliance actions if monitoring does not show progress.

To help meet these TMDLs, an Implementation Plan is included (Section 8). Fundamental to the Implementation Plan is that the City of San Diego, as a copermittee to the Regional Phase I MS4 Permit, will take reasonable and appropriate actions to comply with the receiving water limitations (Provisions A.2 and A.4) and elimination of illicit non-stormwater discharges (Provision II. A.1.b). In addition, the San Diego River Water Quality Improvement Plan (WQIP; Provision II.B) priorities will be updated in the future to support attainment of the numeric goals and restoration of the beneficial uses of Famosa Slough. These actions include updating the Jurisdictional Runoff Management Plan (JRMP) and other elements of the WQIP, properly implementing an illicit discharge detection and elimination program in compliance with existing requirements of the Regional MS4 Permit, and conducting monitoring to assess the effectiveness of specific implementation measures toward meeting the reductions needed to achieve these TMDLs.

The expected timeframe to achieve the required reduction in pollutant loading is 10 years following adoption of Resolution No. R9-2017-0017 (Resolution of Commitment to an Alternative Process for Achieving Water Quality Objectives for Nitrogen and Phosphorus in Famosa Slough) and the necessary JRMP/WQIP updates. Compliance with the TMDL, WLAs, and LAs will be assessed primarily by 1) comparing the water quality results from monitoring stations in Famosa Slough with the numeric targets established by these TMDLs, and 2) comparing the calculated total mass load (and reductions) for nutrients contributed by the watershed (considering tidal influences) with the total allowable loads. If the receiving water limitations (based on the numeric targets established by these TMDLs) are met in the receiving waters, the permitted dischargers will be assumed to have met their WLAs. If, however, the receiving water limitations are not being met, the dischargers will be responsible for reducing their nutrient loads and/or demonstrating that controllable discharges are not causing the exceedances.

In the event that additional NPDES permits (e.g., Phase II MS4s, industrial or construction permits) are granted to dischargers within the watershed in the future, tidal contributions are considered to have a more significant influence on water quality conditions, or other sources are identified, further requirements may be needed. The San Diego Water Board will initiate additional actions, as appropriate, to address existing or potential future impacts to water quality and beneficial uses within Famosa Slough.

1. Introduction

The purpose of this technical report is to summarize the development of Total Maximum Daily Loads (TMDLs) to address eutrophication in Famosa Slough. Famosa Slough was first listed on the Clean Water Act (CWA) Section 303(d) List of Water Quality Limited Segments due to eutrophic conditions in 1996. Eutrophication represents actual or threatened water quality degradation affecting aquatic habitat and recreational beneficial uses. For this reason, TMDLs are needed to define the conditions necessary to achieve water quality objectives (WQOs) and restore beneficial uses. Note that Famosa Slough includes two main sections which exhibit very different characteristics due to several factors including the degree of tidal and freshwater influence, flushing ability, and physical configuration. For this document, the entire system is referenced as Famosa Slough. The open water portion south of Point Loma Boulevard is referenced as the Slough, whereas, the reach that connects the Slough with the San Diego River is referenced as the Channel.

Section 303(d) of the CWA requires that each state identify waterbodies within its boundaries for which effluent limitations are not stringent enough to meet applicable water quality standards, which consist of beneficial uses, WQOs, and an antidegradation policy. The CWA also requires states to establish a priority ranking for these impaired waters, known as the CWA Section 303(d) List, and to establish TMDLs for the identified waterbodies.

A TMDL is defined as the sum of the individual wasteload allocations (WLAs) for point sources, and load allocations (LAs) for nonpoint sources and natural background, such that the waterbody's capacity to assimilate pollutant loading (i.e., the loading capacity) is not exceeded (40 CFR 130.2). A TMDL, therefore, represents the maximum amount of pollutant of concern a waterbody can receive and still attain water quality standards. Additionally, a TMDL represents a strategy for meeting WQOs by allocating quantitative limits for point and nonpoint pollution sources. Once the total maximum pollutant load (the TMDL) has been calculated, it is divided up and allocated among all of the contributing sources in the watershed. This technical report details the process that was used to develop TMDLs to address eutrophic conditions and the calculated TMDLs and load allocations. The seven key TMDL components presented in this technical report include:

1. **Problem Statement** – generally describes the waterbody impairment (Section 2)
2. **Numeric Targets** – identifies the numeric target(s) which will result in attainment of the WQOs and protection of beneficial uses (Section 3)
3. **Source Assessment** – identifies all of the known point and nonpoint sources of the impairing pollutant(s) in the watershed (Section 4)
4. **Linkage Analysis** – establishes the relationship between pollutant sources and receiving water conditions and calculates the loading capacity of the waterbody, which is the maximum load of the pollutant that may be discharged to the waterbody without causing exceedances of WQOs and impairment of beneficial uses (Section 5)
5. **Margin of Safety (MOS)** – accounts for uncertainties in the analysis (Section 6.7)
6. **Seasonal Variation and Critical Conditions** – describes how these factors are accounted for in the TMDL determination (Section 6.8)

7. **Allocation of the TMDL** – division of the TMDL among each of the contributing sources in the watershed; WLAs for point sources and LAs for nonpoint and background sources (Section 7)

This document also includes an implementation plan that describes ongoing activities, proposed actions, and a schedule of compliance for the TMDL (Section 8). The TMDL technical analysis relied on the development and application of computer models specific to Famosa Slough, its associated watershed, and tidal influences. Specifically, the Loading Simulation Program C++ (LSPC) (Shen et al., 2004; USEPA, 2003b) was applied to simulate watershed hydrology and pollutant loading. The Environmental Fluid Dynamics Code (EFDC) (Hamrick, 1992 and 1996; USEPA, 2003a) was used to simulate the complex hydrologic and pollutant transport relationships within Famosa Slough. These models were used to quantify the connection between pollutant sources and waterbody conditions, as described in the Linkage Analysis (Section 5).

The TMDL provisions will be implemented through development and approval of an alternative process resolution by the San Diego Water Board. The City of San Diego and Caltrans represent the responsible agencies that contribute nutrient loads to Famosa Slough via storm water runoff. An alternative process is appropriate because the nutrient reductions that were identified during development of the TMDL can be achieved with actions taken in compliance with the existing Regional Phase I MS4 Permit. The San Diego Water Board can reasonably rely upon the existing permit, particularly the prohibitions and requirements regarding control of non-storm water flows into and from the MS4, as the regulatory tool to achieve the necessary reductions in total nitrogen and total phosphorus loading.

This TMDL was developed through close collaboration between the City of San Diego, the Friends of Famosa Slough (FoFS), and representatives from the San Diego Water Board. This third party TMDL effort was led by the City of San Diego and included detailed monitoring and modeling of Famosa Slough and its contributing watershed.

2. Problem Statement

Under Section 303(d) of the CWA, states are required to identify waters whose beneficial uses have been impaired for specific constituents. Famosa Slough was placed on the Section 303(d) List due to eutrophic conditions in 1996. As part of the 303(d) listing process, Famosa Slough is subject to the development of a TMDL. This TMDL was developed to attain the WQOs prescribed in the Basin Plan for bays and estuaries and, ultimately protect aquatic life and other beneficial uses of Famosa Slough from the negative impacts of eutrophication.

Eutrophication is the process by which an increase in nutrients (generally phosphorus and/or nitrogen) leads to an overabundance of nuisance algae and ultimately, a reduction in DO levels. Eutrophication can negatively affect a waterbody's designated beneficial uses for both habitat and recreation. Aquatic life can be affected by low DO concentrations leading to fish kills and reduced light penetration due to the presence of nuisance plants and algae (USEPA, 2000). Additionally, recreational uses can be affected through increased turbidity interfering with recreation, odors, and the presence of algal mats (USEPA, 2000). The process and effects of eutrophication are discussed in further detail in Section 2.1.

The problem statement consists of an overview of the eutrophication process, a description of Famosa Slough and its watershed, a description of the impairment, and identification of the applicable water quality standards and beneficial uses. The impairment description is further supported by the source assessment and conceptual model linking sources to impairments as discussed in Sections 4 and 5, respectively.

2.1 Nutrients and Eutrophication

Eutrophication is a process in which a waterbody experiences an increase in nutrient loading, primarily phosphorus and nitrogen, leading to nuisance algal growth and ultimately, reduced levels of DO and degraded water quality. The Basin Plan refers to phosphorus and nitrogen as "biostimulatory substances" that stimulate algal production, create nuisance conditions for beneficial uses of a waterbody, and deplete the water of oxygen. Phosphorus and nitrogen are naturally occurring in the environment and coastal waterbodies receive these nutrients through tidal flows, inputs from the local watershed, and in-situ cycling through various aquatic processes. Human activities, such as certain agricultural practices, wastewater treatment plant effluent, and the use of fertilizers have greatly accelerated nutrient loading to waterbodies, and in some cases, these activities lead to an imbalanced nutrient cycle. The process in which anthropogenic activities accelerate eutrophication of a waterbody is often referred to as cultural eutrophication Figure 2-1 provides a conceptual model of nutrient loading.

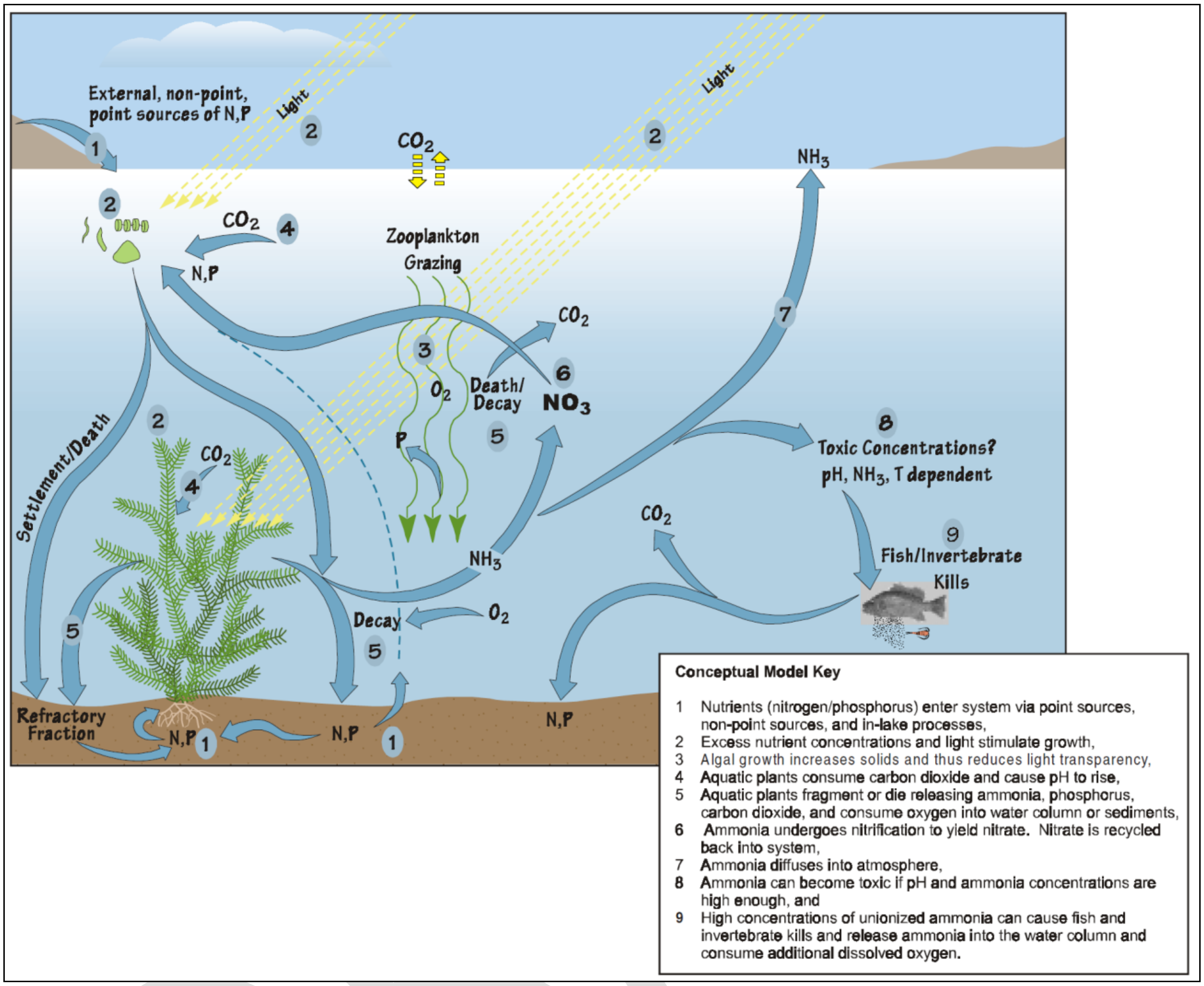


Figure 2-1. Nutrient loading and internal cycling (USEPA, 2000).

Small, coastal lagoons are often subject to eutrophic conditions due to tidal muting and nutrient loading from urban storm water runoff (SCCWRP, 2010). Eutrophication disrupts the natural cycling of nutrients in the water column that can lead to an overabundance of algal growth and low DO concentrations. For example, dense algal growth degrades the local ecosystem by blocking the penetration of sunlight into the water column and preventing submerged aquatic species from receiving light, thereby reducing aquatic plant production of oxygen. Additionally, the decomposition of nuisance algae increases the oxygen demand within the water column and consumes oxygen that would have been available to other aquatic species. Due to these disturbances, eutrophic conditions can lead to fish kills, reduction of biodiversity, and increased turbidity, odors, and unpleasant aesthetic conditions (Regional Board, 1994). Lower levels of oxygen (a condition called hypoxia) can often result in fish kills, affecting native and sport fish that require higher levels of DO, and the pervasiveness of fish, such as carp, that are tolerable of low DO levels. A similar species shift is also seen in benthic communities with species tolerant of low DO becoming more dominant. This change in aquatic species and reduction in biodiversity has ramifications for the entire ecosystem, including impacts to recreational uses.

2.2 Project Area Description

The Famosa Slough watershed is a small, 358-acre coastal watershed located within the City of San Diego, between the neighborhoods of Ocean Beach and Loma Portal (Figure 2-2). The watershed is roughly bordered to the west by Nimitz Boulevard, to the north by the San Diego River, to the south by Chatsworth Boulevard, and to the east by Midway Drive. The watershed encompasses the 32-acre Slough and a 10-acre Channel, which connects the Slough with the tidal portion of the San Diego River via tide gates. The Channel is connected to the Slough by two pairs of culverts that flow under Sports Arena Boulevard. Approximately half of the watershed drains directly into the Slough while the remaining area drains into the Channel.

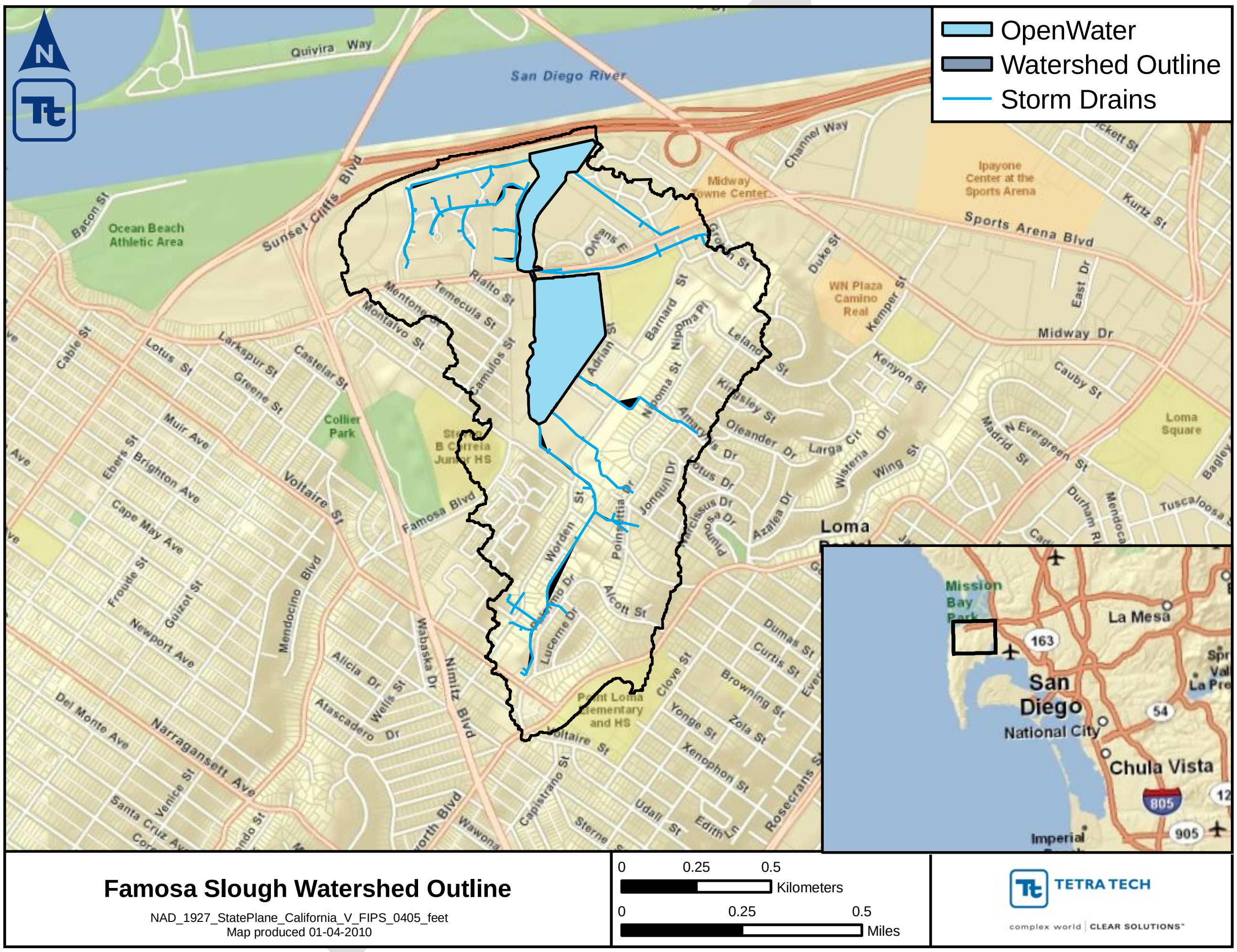


Figure 2-2. Location of the Famosa Slough watershed.

Prior to the 1930s, Famosa Slough was part of the Mission Bay wetlands (False Bay), and was directly connected to the San Diego River. Due to construction of Interstate 8 and channelization of the San Diego River, Famosa Slough gradually became an isolated wetland and is now the only portion of False Bay that remains connected to the San Diego River. However, the current connection between the Channel and the San Diego River is limited to hydraulic structures on the northern side of the highway. Flow occurs through three 5-foot diameter flag gates (and concrete pipes under Interstate 8). The gates were constructed in the 1950s and originally only allowed water to flow out of the Channel. Between 1991 and 1995, the flap gates were replaced and are now open to allow water to enter the Channel during high tides and storm events, however, the gates are usually closed during storm events to prevent water from the river from entering the Channel (Weston Solutions, 2009). Visual observations and discussions with City officials confirmed that the flap gates were not closed during the 2007–2008 monitoring period (Weston Solutions, 2009). The hydraulic structures restrict tidal exchange between the San Diego River and Famosa Slough, resulting in muted tidal flows.

Tidal flow is the main source of water and biodiversity in Famosa Slough. The oceanic tide cycle allows seawater to mix with the San Diego River, which then flows into the Channel during high tide. During low tide, the water flow is reversed and the Channel water that has mixed with urban runoff from the watershed flows out of the Channel and into the San Diego River.

The tidal cycle of a coastal waterbody contributes to the balance of nutrient-rich water, oxygen, plant material, and aquatic species. Additionally, it improves the water quality by reducing the impacts of chemical buildups and excessive algal growth. However, muted tidal flows experienced in Famosa Slough increase the amount of time the water resides in the waterbody, thereby increasing the potential for algal growth (SCCWRP, 2010).

In 1993, the California Coastal Conservancy supported the development of an Enhancement Plan that included treatment ponds and improvement of tidal flows. During dry weather, the water treatment ponds collect urban runoff, trash, and sediment, and treat approximately 130 acres prior to discharging into Famosa Slough (Weston Solutions, 2009). In 2008, a concrete pipe was constructed between Famosa Slough and the channel to increase tidal flow (SCCWRP, 2010). Other watershed improvements are summarized in Section 8.

Urban runoff from land uses in the watershed provides a secondary source of water to Famosa Slough through 19 storm drains (Weston Solutions, 2006). Data detailing land use in the Famosa Slough watershed, presented in Figure 2-3, are available through the San Diego Association of Governments (SANDAG, 2009). The most significant land use is multi-family residential (125.6 acres), followed by single-family residential (91.7 acres), and roads (69.2 acres). Additionally, open space, open recreational areas, schools, and parks account for nearly 28 acres. This local watershed provides a small but continuous flow of urban runoff, including runoff from over-irrigation and storm water. Residential and road runoff washes fertilizers and sediment-bound nutrients from surfaces and is, therefore, a potentially significant source of nutrient loading. Ultimately, urban runoff from the watershed is collected and conveyed to Famosa Slough through 19 different storm drains. Caltrans and the City of San Diego have been identified as the main dischargers to Famosa Slough (Weston Solutions, 2009). Additional key watershed characteristics that are important for model configuration are described in later sections and within the modeling report (Appendix A).

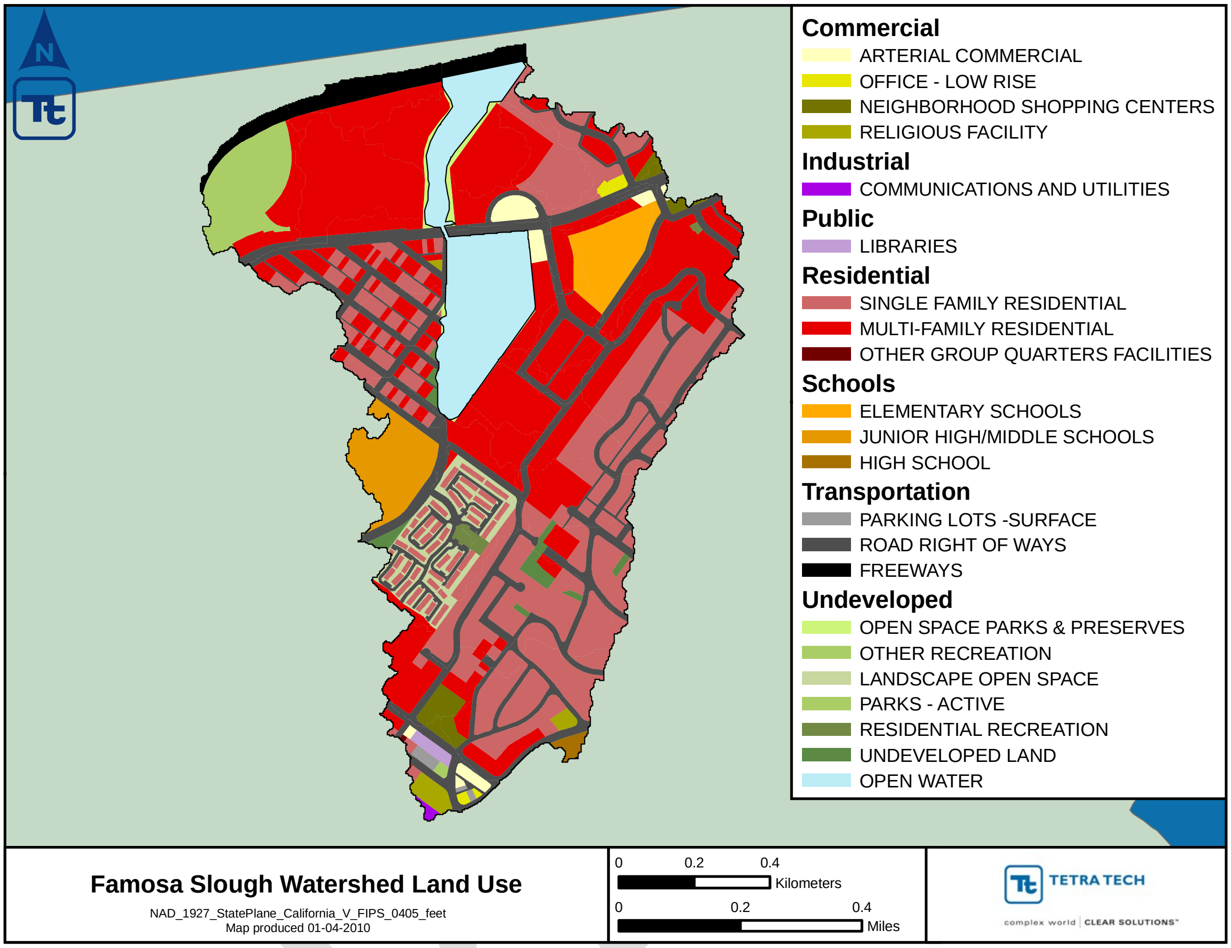


Figure 2-3. Famosa Slough watershed land use.

Famosa Slough is ecologically diverse, supporting a variety of plant species, and providing habitat for numerous birds, fish, and small mammal populations. Currently, the San Diego Park and Recreation Department, with help from the Friends of Famosa Slough (FoFS), manage the Slough as a wetland preserve. Famosa Slough also serves as a nesting area for birds and provides habitat for both coastal marine and salt marsh species. More than 180 species of birds have been observed at Famosa Slough, of which 48 species are regularly observed. Bird species include grebes and heron, ducks, waterfowl, gulls and terns, doves, hummingbirds, and perching birds. Numerous species of fish, crustaceans, mollusks, amphibians, mammals, and insects are found in Famosa Slough. A number of special status species have been identified at the Slough and Mission Bay Wetlands, including the American white pelican, light-footed clapper rail, peregrine falcon, California least tern, and Belding’s Savannah sparrow (CERES, 1996). Famosa Slough also contains native wetland plants including salt marsh plants, coastal sage scrub, trees, and freshwater marsh plants. In 1990, biologists identified more than 80 non-native plant species including, pampas grass, palms, and Bermuda grass. A volunteer program has eradicated a number of non-native plants and continues to replace non-native species with native vegetation.

The climate in the region is generally mild with annual temperatures averaging around 65°F near the coastal areas. Average annual rainfall ranges from 9 to 11 inches along the coast. Three distinct types of seasonal weather conditions occur in the region. Summer dry weather occurs from May 1 to September 30, while the winter season occurs from October 1 to April 30 and has two types of weather; 1) winter dry weather when rain has not fallen for the preceding 72 hours, and 2) wet weather consisting of storms of 0.1 inches of rainfall (or greater) and the 72 hour period after the storm. Most of the annual rainfall (85 to 90 percent) occurs during the winter season.

2.3 Impairment Overview

Famosa Slough is listed as impaired on the 303(d) list for eutrophic conditions. This impairment may affect aquatic life and degrade beneficial uses. As discussed above, impacts associated with nutrient enrichment include excessive algal growth, reduced DO levels, and loss of biodiversity. Potential nutrient sources identified in Famosa Slough and its watershed include urban runoff, tidal inflow, atmospheric deposition, sediment accumulation, and benthic nitrogen flux. Some of these processes are exacerbated by anthropogenic disturbances such as urban development, including the tidal restrictions that resulted from channelization of the San Diego River. The Basin Plan and CWA Section 303(d) highlight eutrophic conditions as having a significant impact that is associated with urban development and human activities because such development transforms the natural landscape and results in increased runoff due to hydromodification. With increased runoff, nutrient loads are transported to Famosa Slough during storm events causing sediment accumulation and nutrient enrichment.

To help determine the sources of impairment and aid in assigning numeric targets for TMDL development, water quality monitoring was conducted by FoFS, Weston Solutions, and the Southern California Coastal Water Research Project (SCCWRP). Data collected by FoFS indicate low levels of DO before dawn, with the site at the most southern end of the Slough having the lowest mean DO concentrations. Key findings of the Weston Solutions and SCCWRP data identified eutrophic conditions including high biomass coverage, low DO levels, an imbalance of nutrient cycling and high organic matter content in sediment.

Spatial and temporal trends were identified by the monitoring efforts (Weston Solutions, 2009; SCCWRP, 2010). For example, samples taken at three locations in Famosa Slough (shown in Figure 2-4) suggest that nutrient loading was greatest at the mass emission site (MES), in the southern portion of the Slough and farthest from the river. Under both wet weather and dry weather conditions, samples from the MES indicated elevated mean concentrations of total phosphorus (TP), and an imbalance of total nitrogen (TN) to TP relative to the WQOs for biostimulatory substances. Additionally, DO concentrations below the WQO (5 mg/L) at the Ocean Inlet site were most frequently observed during September and October and, at the segment site, from June through October (Weston Solutions, 2009).

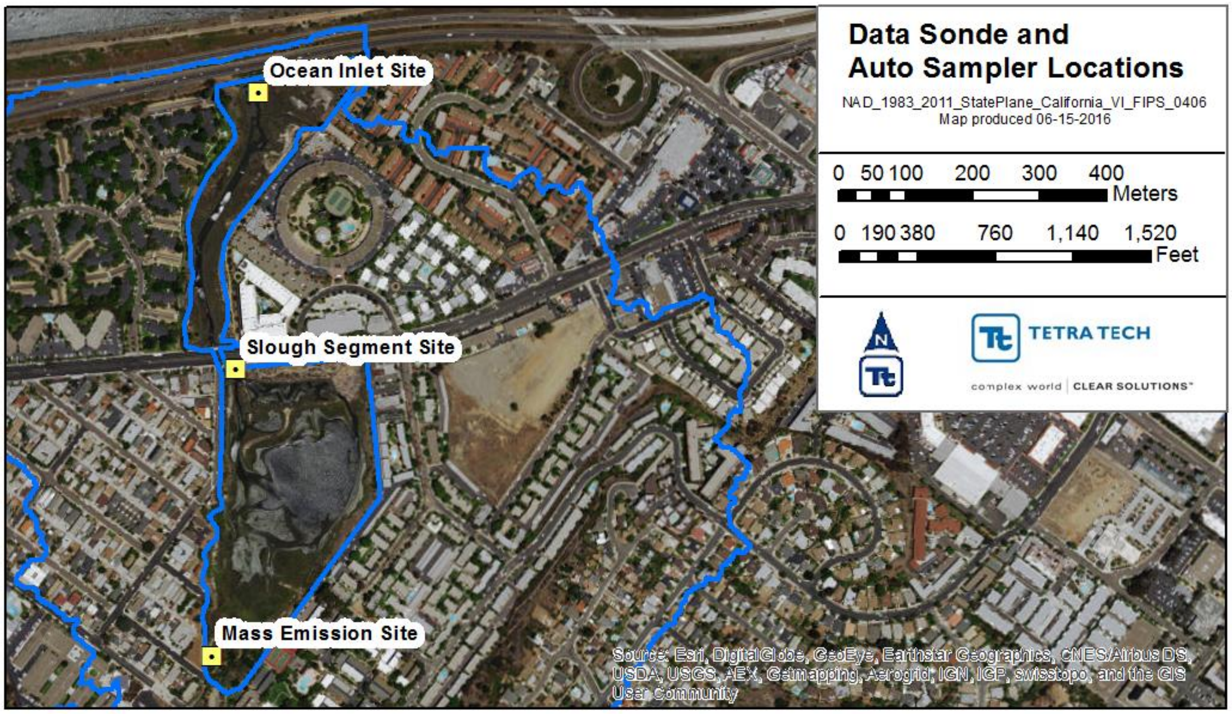


Figure 2-4. Continuous monitoring site locations.

The study conducted by SCCWRP (2010), analyzed the nutrient budget and balance within the watershed. The study identified Famosa Slough as being limited by nitrogen as opposed to phosphorus and the most significant source of phosphorus loading was attributed to urban runoff. Additionally, data suggested that benthic nitrogen flux contributed more nitrogen to Famosa Slough than either urban runoff or tidal inflow from the San Diego River. Annual TN and TP budgets suggest that Famosa Slough generally has losses (of both TN and TP) throughout most of the year, except for spring when monitoring data indicated a net gain of nitrogen and phosphorus to Famosa Slough (SCCWRP, 2010).

Specific to DO trends, Weston Solutions monitoring data suggested that DO levels were highest during flood tides for each index period. Sampling conducted at the MES showed a greater indication of eutrophic conditions, with a yearly average DO concentration lower than WQOs. Moreover, although both the ocean inlet and slough segment monitoring locations had yearly averages above the WQOs, low DO concentrations at these locations were documented during the summer and fall monitoring periods (Weston Solutions, 2009; SCCWRP, 2010).

High biomass coverage during the summer months was also linked in the SCCWRP report to the presence of low DO levels and peak TN and TP concentrations (2010). Data from the study identified high levels of organic matter present in the sediment, which the decomposition of, likely contributes to hypoxic and anoxic conditions. For instance, the study indicated that hypoxia was likely due to respiration of biomass during the nighttime and accumulation and decomposition of biomass on and within sediment throughout the day and evening (SCCWRP, 2010).

Wet weather data were collected during three sampled storms in the 2007–2008 storm season by Weston Solutions (2009). Under wet weather conditions, the MES samples indicate higher mean concentrations of TP than specified by the WQO for biostimulatory substances and the ratio of TN to TP did not meet the WQO of a 10:1 ratio, indicating an imbalance between TN and TP (Weston Solutions, 2009).

The wet weather conditions at the slough segment site and ocean inlet site were taken during high and low tides for the three storm events. The mean samples for the slough segment site showed no exceedance of TN or TP during either high or low tide; however, the ratio of TN to TP did not comply with the 10:1 ratio for the WQO. Monitoring data from the ocean inlet site showed exceedances of the mean concentrations of TP during low tide; additionally, the ratio of TN to TP did not meet the 10:1 ratio for the WQO for biostimulatory substances (Weston Solutions, 2009).

Seasonal dry weather samples were also collected by Weston Solutions during the same monitoring period at the three sites over four two-week intervals. Throughout this monitoring, the MES samples showed a higher indication of eutrophic conditions with TN to TP ratios consistently showing an imbalance of TN:TP when compared to the WQO of 10:1. The slough segment site mean concentration ratio of TN to TP showed greatest indication of nutrient imbalance during the winter, summer and fall months. The ocean inlet site mean concentration ratio of TN to TP indicated greater imbalance during winter and summer. At each site monitored, TN and TP were highest during the summer months (Weston Solutions, 2009).

In summary, monitoring data indicate minimal evidence of elevated nutrient concentrations or low DO levels at the slough segment and ocean inlet sites, but the MES data were indicative of eutrophic conditions, with more frequent imbalance of nutrient cycling in the water column and low DO levels. Therefore, this TMDL focuses largely on the Slough, although conditions in the Channel are also discussed. The near-term plan for the Channel is to focus on monitoring and adaptive management as current conditions in the Channel appear to show that beneficial uses are being met. Eutrophication impacts are of greatest concern during the summer and fall periods. Lastly, the results showed little evidence that the San Diego River inflow contributes to eutrophic conditions. Urban runoff from the local watershed and nutrient flux were identified as the most significant sources.

2.4 Applicable Water Quality Standards

Water quality standards consist of beneficial uses, WQOs, and an antidegradation policy. WQOs are defined under Water Code section 13050(h) as “limits or levels of water quality constituents or characteristics which are established for the reasonable protection of beneficial uses of water.” Under section 304(a)(1) of the CWA, the USEPA is required to publish water quality criteria that incorporate ecological and human health assessments based on current scientific information. WQOs must be based on scientifically sound water quality criteria, and be at least as stringent as those criteria.

The San Diego Basin Plan (Regional Board, 1994) specifies water quality standards for all waters in the San Diego region, including Famosa Slough. Water quality standards that apply to

Famosa Slough include beneficial uses that could be adversely affected by excessive nutrients (defined as biostimulatory substances) resulting in degraded water quality conditions including low DO. Beneficial uses, WQOs and the antidegradation policy, as they apply to Famosa Slough, are discussed in the following sections.

2.4.1 Beneficial Uses

Beneficial uses are defined by the Basin Plan as, "[T]he uses of water necessary for the survival or wellbeing of man, plants and wildlife. These uses serve to promote the tangible and intangible economic, social and environmental goals of mankind." WQOs in the Basin Plan are designated to protect the most sensitive beneficial uses of a waterbody. As shown in Table 2-1, the Basin Plan identifies ten beneficial uses for Famosa Slough (Regional Board, 1994). Compliance with WQOs must be assessed and maintained throughout the waterbody to protect all beneficial uses.

Table 2-1. Beneficial uses in Famosa Slough.

Beneficial Use	Beneficial Use Description
REC 1	Includes uses of water for recreation activities involving body contact with water, where ingestion of water is reasonably possible. These uses include, but are not limited to, swimming, wading, water skiing, skin and SCUBA diving, surfing, white water activities, fishing, or use of natural hot springs.
REC 2	Includes the use of water for recreational activities involving proximity to water, but not normally involving body contact with water, where ingestion of water is reasonably possible. These uses include, but are not limited to, picnicking, sunbathing, hiking, beachcombing, camping, boating, tide pool and marine life study, hunting, sightseeing, or aesthetic enjoyment in conjunction with the above activities.
COMM	Includes the uses of water for commercial or recreational collection of fish, shellfish, or other organisms including, but not limited to, uses involving organisms intended for human consumption or bait purposes.
EST	Includes uses of water that support estuarine ecosystems including, but not limited to, preservation or enhancement of estuarine habitats, vegetation, fish, shellfish, or wildlife (e.g., estuarine mammals, waterfowl, shorebirds).
WILD	Includes uses of water that support terrestrial ecosystems including, but not limited to, preservation and enhancement of terrestrial habitats, vegetation, wildlife (e.g., mammals, birds, reptiles, amphibians, invertebrates), or wildlife water and food sources.
RARE	Includes uses of water that support habitats necessary, at least in part, for the survival and successful maintenance of plant or animal species established under state or federal law as rare, threatened or endangered.
MAR	Includes uses of water that support marine ecosystems including, but not limited to, preservation or enhancement of marine habitats, vegetation such as kelp, fish, shellfish, or wildlife (e.g., marine mammals, shorebirds).
MIGR	Includes uses of water that support habitats necessary for migration, acclimatization, between fresh and salt water, or other temporary activities by aquatic organisms, such as anadromous fish.

Beneficial Use	Beneficial Use Description
SPWN	Includes uses of water that support high quality aquatic habitats suitable for reproduction and early development of fish. This use is applicable only for the protection of anadromous fish.
SHELL	Includes uses of water that support habitats suitable for the collection of filter-feeding shellfish (e.g., clams, oysters and mussels) for human consumption, commercial, or sport purposes.

2.4.2 WQOs for Enclosed Bays and Estuaries

The California Water Code defines WQOs as “the limits or levels of water quality constituents or characteristics which are established for the reasonable protection of beneficial uses of water or the prevention of nuisance within a specific area.” WQOs most applicable to eutrophic conditions include biostimulatory substances (phosphorus and nitrogen) and DO. The WQO for biostimulatory substances is both numeric and narrative in nature, while numeric limits for DO are also available. These are presented below and are summarized in Table 2-2 (Regional Board, 1994). Note that macroalgae (and the targeted level identified) was selected to interpret the narrative biostimulatory substances WQO for the purpose of this TMDL, but does not represent a regulatory requirement that has been through the formal rulemaking process WQOs are subject to. This information was used to identify numeric targets to quantify the allowable nutrient load to Famosa Slough. Section 3 presents the detailed information that was used to develop the numeric targets.

Table 2-2. Applicable WQOs for the Slough.

Water Quality Objective	Constituent	Targeted Level (mg/l)
Biostimulatory substances	Macroalgae (see discussion above)	60 g dw/m^2
DO		5.0 instantaneous minimum
		Annual average >7.0

2.4.2.1 Biostimulatory Substances

The WQO for biostimulatory substances is narrative and sets tolerance levels for aquatic growth. Additionally, the Basin Plan states threshold levels for nitrogen and phosphorus. The WQO for biostimulatory substances (phosphorus and nitrogen) is as follows:

> *Inland surface waters, bays and estuaries and coastal lagoon waters shall not contain biostimulatory substances in concentrations that promote aquatic growth to the extent that such growths cause nuisance or adversely affect beneficial uses.*
>
> *Concentrations of nitrogen and phosphorus, by themselves or in combination with other nutrients, shall be maintained at levels below those which stimulate algae and emergent*

plant growth. Threshold total phosphorus (P) concentrations shall not exceed 0.05 mg/l in any stream at the point where it enters any standing body of water, nor 0.025 mg/l in any standing body of water. A desired goal in order to prevent plant nuisance in streams and other flowing water appears to be 0.1 mg/l total P. These values are not to be exceeded more than 10 percent of the time unless studies of the specific waterbody in question clearly show that water quality objective changes are permissible and changes are approved by the Regional Board. Analogous threshold values have not been set for nitrogen compounds; however, natural ratios of nitrogen to phosphorus are to be determined by surveillance and monitoring and upheld. If data are lacking, a ratio of N:P = 10:1, on a weight to weight basis shall be used (Regional Board, 1994).

2.4.2.2 DO

DO criteria consist of both daily average and daily minimum levels and are applicable throughout the year. Time-variable modeling permits evaluation of both criteria. The WQO for DO is set as follows:

Dissolved oxygen levels shall not be less than 5.0 mg/L in inland surface waters with designated MAR or WARM beneficial uses or less than 6.0 mg/L in waters with designated COLD beneficial uses. The annual mean dissolved oxygen concentration shall not be less than 7.0 mg/L more than 10 percent of the time (Regional Board, 1994).

2.4.3 Antidegradation

State Water Resource Control Board (SWRCB) Resolution No. 68-16, “Statement of Policy with Respect to Maintaining High Quality Water” in California, known as the “Antidegradation Policy,” protects surface and ground waters from degradation (SWRCB, 1968). Any actions that can adversely affect water quality in all surface and ground waters must be consistent with the maximum benefit to the people of the state, must not unreasonably affect present and anticipated beneficial use of such water, and must not result in water quality less than that prescribed in water quality plans and policies. Furthermore, any actions that can adversely affect surface waters are subject to the federal Anti-degradation Policy (40 CFR 131.12).

3. Numeric Targets

When calculating TMDLs, numeric targets are selected to meet the WQOs for a waterbody and subsequently establish measurable targets for the restoration and/or protection of beneficial uses. Due to the narrative nature of the biostimulatory substances WQO, this WQO must be interpreted through the development of a numeric target. The selected numeric targets for the Slough are DO and macroalgae biomass. For this TMDL, nutrient concentration targets were not identified; however, nutrient load reductions and other management measures were evaluated to meet the targets (Appendix A). The Basin Plan states "[c]oncentrations of nitrogen and phosphorus, by themselves or in combination with other nutrients, shall be maintained at levels below those which stimulate algae and emergent plant growth". Nutrient loadings are important indicators of eutrophication; however, nutrient monitoring results can be influenced by where the sample is collected, and various biological, chemical, and physical factors. DO and macroalgae biomass are considered to be better indicators of beneficial use support, rather than nutrient concentrations that can vary significantly due to natural and anthropogenic impacts. Additional information to support the selection of the numeric targets is provided below.

3.1 DO

The DO WQO, as set forth in the Basin Plan (Regional Board, 1994), states:

> *Dissolved oxygen levels shall not be less than 5.0 mg/L in inland surface waters with designated MAR or WARM beneficial uses or less than 6.0 mg/L in waters with designated COLD beneficial uses. The annual mean dissolved oxygen concentration shall not be less than 7 mg/L more than 10 percent of the time.*

This WQO focuses on inland waters, specifically streams and rivers that have continuous flow during most periods. The Basin Plan does not include specific DO criteria for receiving waters, such as lakes, lagoons, or bays. These systems do not act in the same manner as streams and rivers. For instance, lakes and bays can exhibit stratification and limited water circulation/flushing, while lagoons (such as Famosa Slough) can be relatively stagnant for extended periods if there is not constant flow to flush out the system.

The SWRCB policy for developing the 303(d) list describes the conditions that may result in a waterbody being placed on the 303(d) list (SWRCB, 2015). For DO, the policy states that,

> *For depressed dissolved oxygen, if measurements of dissolved oxygen taken over the day (diel) show low concentrations in the morning and sufficient concentrations in the afternoon, then it shall be assumed that nutrients are responsible for the observed dissolved oxygen concentrations if riparian cover, substrate composition or other pertinent factors can be ruled out as controlling dissolved oxygen fluctuations. When continuous monitoring data are available, the seven-day average of daily minimum measurements shall be assessed.*

Based on this policy, waters are placed on the 303(d) list if the number of measured exceedances supports the rejection of the null hypothesis from the binomial distribution. The policy also allows for the removal of waters from the 303(d) list if conditions are met.

Based on this information, a TMDL for Famosa Slough was developed considering a 10 percent allowable exceedance as part of the numeric target for DO. Several factors were used in this determination.

1. The Basin Plan 5.0 mg/L WQO is more applicable to inland waters that have continuous flow during most periods.
2. The annual mean WQO allows for a 10 percent exceedance.
3. The WQO considers discreet grab samples and the 303(d) listing guidance considers a seven-day running average. This TMDL analysis incorporates continuous modeling results.

For the purpose of this TMDL, models were developed and run for Famosa Slough and its associated watershed. These models simulate nutrients, water temperature, salinity, macroalgae biomass, DO, and other parameters to evaluate pollutant loading from the watershed and the receiving water response. The results of these models were used to develop numeric targets and are presented in detail in Appendix A. For the reasons stated above, the preferred management scenario analysis (Section 4 of Appendix A) used a 10 percent allowable exceedance of the 5.0 mg/L daily minimum DO value.

3.2 Macroalgae Biomass

Macroalgae biomass is a measurable biological symptom of eutrophication that can be interpreted as an appropriate numeric target of the Basin Plan's WQOs for biostimulatory substances. The Basin Plan states "[e]xcessive growth of algae and/or other aquatic plants can degrade water quality. Algal blooms sometimes occur naturally; however, they are often the result of waste discharges or nonpoint source pollutants. Algal blooms depress the DO content of water and can result in fish kills."

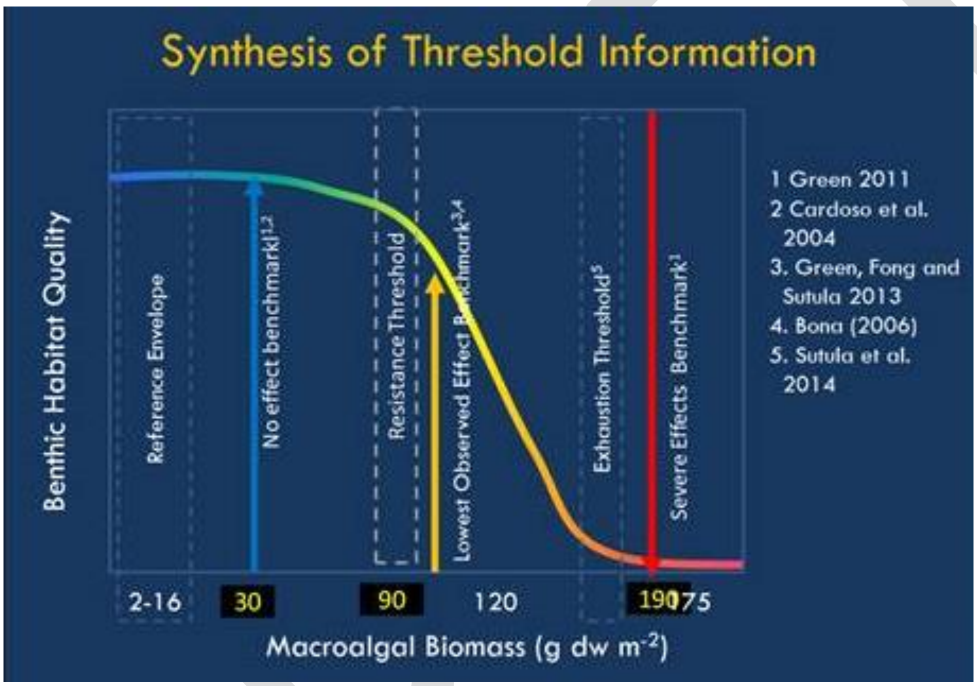
Macroalgae biomass is an ecological-based numeric target suitable for coastal sloughs (Creager et al., 2006). Macroalgae biomass was used as the target for the Loma Alta Slough TMDL (Regional Board, 2014). While this TMDL does not set a specific numeric target for the Slough and Channel, biomass estimates based on the modeling results indicate acceptable levels after considering the selected management action (watershed nutrient load reduction and periodic algal harvesting). The management scenario analysis (Section 4 of Appendix A) evaluated different combinations of watershed nutrient load reduction (over different climatological conditions) and harvesting. The scenarios identified the required reduction in year-round watershed nutrient loads and concluded that a twice-a-year harvest (if necessary, depending on sufficient algal growth), would be the best option. Note that the harvest dates may vary depending on the anticipated timing for peak algal growth each year.

The selected management scenario (twice-a-year harvesting in the Slough and a 37 percent reduction in overall year-round watershed nutrient inflow) would result in a total macroalgae biomass (floating and benthic) of 58 grams dry weight (dw) per square meter (g dw/m^2) in the Slough. This amount is the midpoint of the acceptable range of 50-70 g dw/m^2 (Figure 3-1 and

Figure 3-2) based on literature; therefore the numeric target for macroalgae biomass is 60 g dw/m^2 (Sutula et al., 2016).

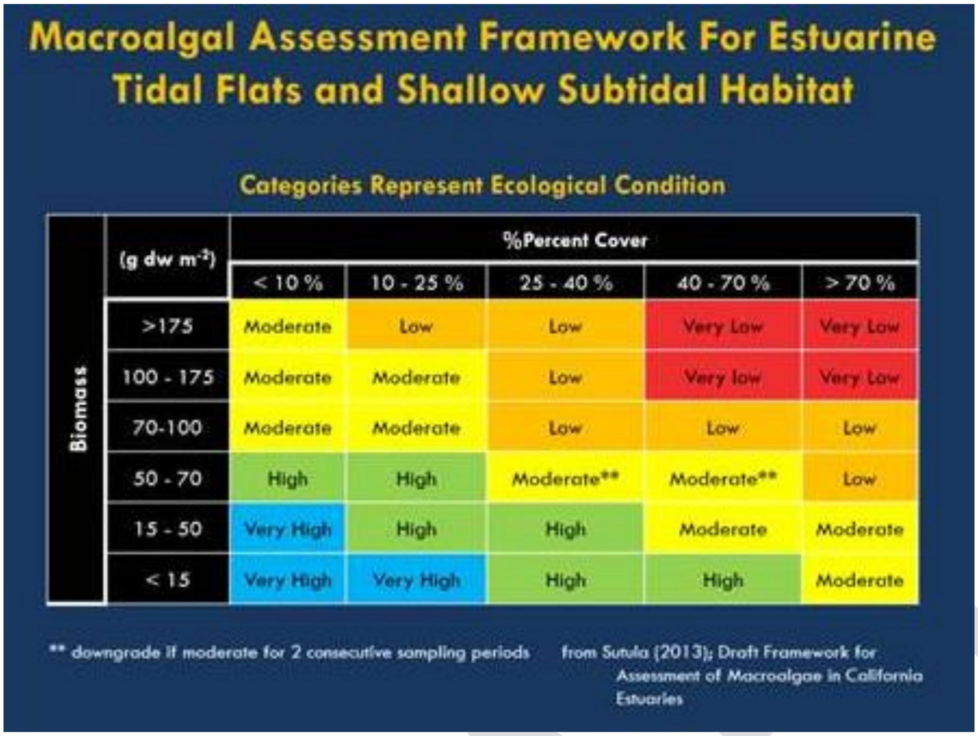
Figure 3-1 shows that benthic habitat quality starts to degrade at a biomass amount of 90 g dw/m^2, while Figure 3-2 shows that a decreasing biomass and percent areal cover corresponds to increasing ecological conditions.

Table 3-1 presents the results of the preferred management scenarios (detailed in Section 4 of Appendix A) for the Slough. There is a strong negative correlation between the total macroalgae biomass and the daily minimum DO, indicating that a high macroalgae biomass often accompanies low DO levels, and vice versa. This figure shows that watershed nutrient load reductions decrease macroalgae biomass, which results in higher DO for the Slough. As described in Appendix A, the selected management scenario achieves the DO target (5 mg/L) and results in macroalgae biomass within an acceptable level (below 60 g dw/m^2) in the Slough. This scenario also results in markedly improved conditions within the Channel.



Source: Sutula et al., 2016

Figure 3-1. Benthic habitat quality versus macroalgal biomass.


Macroalgal Assessment Framework For Estuarine Tidal Flats and Shallow Subtidal Habitat

Categories Represent Ecological Condition

Biomass (g dw m^{-2})	%Percent Cover				
	< 10 %	10 - 25 %	25 - 40 %	40 - 70 %	> 70 %
>175	Moderate	Low	Low	Very Low	Very Low
100 - 175	Moderate	Moderate	Low	Very low	Very Low
70-100	Moderate	Moderate	Low	Low	Low
50 - 70	High	High	Moderate**	Moderate**	Low
15 - 50	Very High	High	High	Moderate	Moderate
< 15	Very High	Very High	High	High	Moderate

** downgrade if moderate for 2 consecutive sampling periods

from Sutula (2013); Draft Framework for Assessment of Macroalgae in California Estuaries

Source: Sutula et al., 2016

Figure 3-2. Ecological condition based on macroalgal biomass and percent cover.

Table 3-1. Management scenario results for the Slough comparing macroalgae biomass and DO.

Percent Nutrient Reduction	Harvesting 2x/yr?	Reduction Applied To	DOmin (mg/L)	Macroalgae Biomass (g dw/m2)
0%	No	Wet and Dry Weather	3.47	135
28%	No	Wet and Dry Weather	4.66	98
28%	Yes	Wet and Dry Weather	**5.07**	69
35%	Yes	Wet and Dry Weather	**5.22**	62
37%	Yes	Wet and Dry Weather	**5.27**	**58**
40%	Yes	Wet and Dry Weather	**5.32**	**55**
50%	Yes	Dry Weather	**5.20**	**54**
60%	Yes	Dry Weather	**5.35**	**46**
70%	Yes	Dry Weather	**5.49**	**40**
70%	Yes	Wet Weather	4.99	82

Note: Bold text indicates target(s) were met.

Multiple sources of data were used to characterize water quality conditions in the Slough, identify sources of nutrient loading, and support calculation of the TMDL. The analysis of data provided an understanding of the conditions that resulted in eutrophic conditions.

Two categories of data used to develop this TMDL were (1) physiographic data to describe the physical conditions of the watershed, and (2) environmental monitoring data to identify past and current conditions and support the identification of potential pollutant sources. Data sources used in this TMDL are shown in Table 3-2 and key data sets are summarized below. Appendix A contains additional details regarding data used for model configuration and calibration.

Table 3-2. Inventory of data and information on source assessment of pollutants.

Data Set	Type of Information	Data Source(s)
Environmental monitoring data	Water Quality and Storm water Monitoring Data	SCCWRP (2010); City of San Diego (2009); FoFS (2002–2009)
	Meteorological Data: for Model Input	National Oceanic and Atmospheric Administration - National Climatic Data Center (NOAA-NCDC) for San Diego International Airport; MES rainfall monitoring; California Irrigation Management Information System (CIMIS) station 184 evapotranspiration data
Watershed physiographic data	Stream network	USEPA BASINS (Reach File, Versions 1 and 3); USGS National Hydrography Dataset (NHD) reach file
	Land use	San Diego Regional Planning Agency – 2009 land use coverage for San Diego County (SANDAG)
	Counties	USEPA BASINS
	Cities/populated places	USEPA BASINS, U.S. Census Bureau's Tiger Data
	Soils	Soil Survey Geographic (SSURGO) Database
	Watershed boundaries	USEPA BASINS (8-digit hydrologic cataloging unit); CALWTR 2.2 (1995)
	Topographic (3-meter elevation data)	Natural Resources Conservation Service (2010)
	Storm drains	SanGIS 2010

3.3 Water Quality Monitoring Data

Water quality data within the Famosa Slough watershed were collected by the FoFS, Weston Solutions, and SCCWRP. Data from the three entities were used to confirm and evaluate the extent of impairment and calibrate water quality models.

- Samples were collected before dawn twice a month at five locations by the FoFS from 2002 to 2009. Parameters included temperature, DO, pH, salinity, turbidity, nitrate, nitrite, and phosphate.
- In compliance with San Diego Water Board Investigation Order R9-2006-0076, monitoring of Famosa Slough was also conducted by Weston Solutions from October 2007 through October 2008. Sampling included continuous DO monitoring at three sites in Famosa Slough: the MES, located at the southern portion of the Slough; the slough segment site, located just below West Point Loma Boulevard; and, the ocean inlet site, located at the north end of the channel (Figure 2-4). Wet weather monitoring was also conducted at the slough segment site and ocean inlet site during high and low tides for the three storm events and seasonal dry weather samples were collected during the monitoring period at the three sites over four two-week intervals. Additional monitoring parameters included: temperature, conductivity, turbidity, pH, total suspended solids, DO, TN, TP, total dissolved nitrogen, total dissolved phosphorus, nitrate, nitrite, ammonia as N, soluble reactive phosphorus, chlorophyll-*a*, carbonaceous biological oxygen demand (CBOD), percent fines or percent sand/silt/clay, percent organic carbon, percent TN, and percent TP.
- In 2008, SCCWRP conducted monitoring during four index periods: Storm season (January), post-storm/pre-algal bloom (March), high algal bloom (July), and post-algal bloom/pre-storm (September) (SCCWRP, 2010). Index period monitoring included a benthic chamber study as well as analysis of porewater and sediment cores. Sampling also included percent cover and tissue nutrient content as well as analysis of seasonal variation in sediment bulk characteristics. Data collected by SCCWRP as well as Weston Solutions, University of California – Los Angeles, and Louisiana State University were considered and presented within the recent SCCWRP Report (SCCWRP, 2010).

3.4 Flow Monitoring Data

Available streamflow data collected within the watershed were compiled for model calibration and validation. Data continuously collected at the storm drain at the MES monitoring location were used. Flows at the MES were estimated every 15 minutes from October 2007 to October 2008 based on a conversion of water depth to flow using Manning's equation (Weston Solutions, 2009). See the Modeling Report (Appendix A) for further detail on streamflow and irrigation data.

3.5 Meteorological Data

Meteorological data are a critical component of the watershed model. LSPC and EFDC both require appropriate representations of precipitation and potential evapotranspiration. Rainfall-runoff processes for each catchment were driven by precipitation data from the closest representative station. In general, hourly precipitation data are recommended for nonpoint source modeling. Therefore, only weather stations with hourly-recorded data were considered in the climate data selection process. National Climatic Data Center (NCDC) precipitation data were reviewed based on geographic location, period of record, and missing data to determine the most appropriate meteorological stations to represent the watersheds. Lindbergh Field station at the San Diego Airport (COOP ID # 047740), was selected as the most representative weather station for the project watersheds with hourly data. The station also has long-term hourly data; and so, hourly measurements of atmospheric pressure, dry and wet bulb atmospheric temperatures, rainfall rate, wind speed and direction, and fractional cloud cover were obtained. Evapotranspiration data were obtained from the California Irrigation Management Information System (CIMIS) station 184, which is in a nearby watershed near Balboa Park.

Rainfall was also monitored at the mass emission station but was not used in the modeling of the watershed. Analysis of the MES rainfall data showed that several runoff events in February had no measurable rainfall recorded at the MES but were measured at the airport. Due to the inconsistencies between the monitored rainfall at the MES and the flow at the MES, the rainfall record at the airport was used to characterize the rainfall throughout the watershed.

3.6 Land Characteristic Data

The watershed model requires a basis for distributing hydrologic and pollutant loading parameters. This is necessary to appropriately represent hydrologic variability and variability in pollutant loading, which is highly correlated to land practices and geology and was used to allocate allowable loadings to nonpoint sources.

This study was supported by available land use data from the San Diego Association of Governments (SANDAG) 2009 land use dataset covering San Diego County. SANDAG land use data provide the most complete and up-to-date land use representation of the project area. The SANDAG land data includes existing land use, planned land use, land ownership, land available for development, and lands available for redevelopment and infill. Residential land uses (e.g. multi- and single family residential) represent the majority of land uses within the Famosa Slough watershed.

Soils data for the Famosa Slough watershed were used to classify the soil types throughout the watershed based on differing infiltration rates. The Soil Survey Geographic (SSURGO) Database (http://soils.usda.gov/survey/geography/ssurgo/) was used to characterize the soils. Sixty percent of the watershed was not classified by the SSURGO data; however, the majority of the watershed that was characterized (32 percent of entire watershed) was classified as hydrologic type B soils. The unclassified soils were likely modified urban soils that have a high degree of development and impervious development. Within the model, soils of like characteristics are grouped into hydrological soils groups (HSGs).

4. Source Assessment

Sources of nutrients are generally the same under both wet weather and dry weather conditions; however, storm events can cause significant erosion and transport of sediment and adsorbed nutrients downstream. Dry weather loading is dominated by excess flows from urban land use activities such as car washing and lawn over-irrigation, which transport nutrients into receiving waters. Wet weather loading is dominated by episodic storm flows that wash off nutrients (often adsorbed to sediment) that have built up on land surfaces during dry periods. The purpose of the source assessment is to identify and quantify the sources of nutrients that may contribute to eutrophic conditions in Famosa Slough.

4.1 Drainage Area Outflow Characterization

Storm water runoff from the surrounding drainage area has been identified as a likely source of pollutants to the impaired drainage area (SCCWRP, 2010). During wet weather events, storm water dischargers from various land uses provide a significant mechanism for transport of nutrients to surface waterbodies. Given the fact that pollutants from various land uses wash from surfaces during rainfall events, the amount of runoff and associated pollutant concentrations are highly dependent on the nearby land management practices. For example, residential and commercial area runoff can contribute significant loadings of nutrients to waterbodies due to sources that include fertilizer application, yard debris, phosphorus in car wash detergents, and domestic animal waste. Many of these pollutants build up over time, especially on impervious surfaces, and are transported to waterways through storm water runoff. Often, these loads are highest when major storm events occur after long dry periods. During dry periods, activities such as car washing and overwatering of lawns can contribute to nutrient loading through dry weather runoff or shallow groundwater flows.

All land uses within the watershed can be classified as generating point source loads because, although the nutrient sources on these land use types may be diffuse in origin, the pollutant loading is collected, conveyed and discharged to receiving waters through the municipal separate storm sewer systems (MS4). To determine land use based loadings, the TP and TN load contributed by each land use type within the watershed was calculated using LSPC modeling (Section 5). Modeling results indicate that, of all land uses modeled, residential areas accounted for the greatest fraction of both water and nutrient loads. Specifically, multi-family and single family residential areas contributed nearly 50 percent of the volumetric inputs to Famosa Slough (Figure 4-1). The distribution of nutrients inputs to Famosa Slough followed the same pattern as the volumetric inputs where residential areas contributed the largest portion of TN and TP (60 and 65 percent, respectively) (Figure 4-2 and Figure 4-3). Runoff from open lands also contributed significant nitrogen and phosphorus loadings (Figure 4-2 and Figure 4-3) and runoff from highways and roadways contain pollutants from vehicles such as oils/grease, metals and sediment. Because storm water discharges from open space and I-8 are collected and directed through storm water conveyance systems, it considered a point source of pollution.

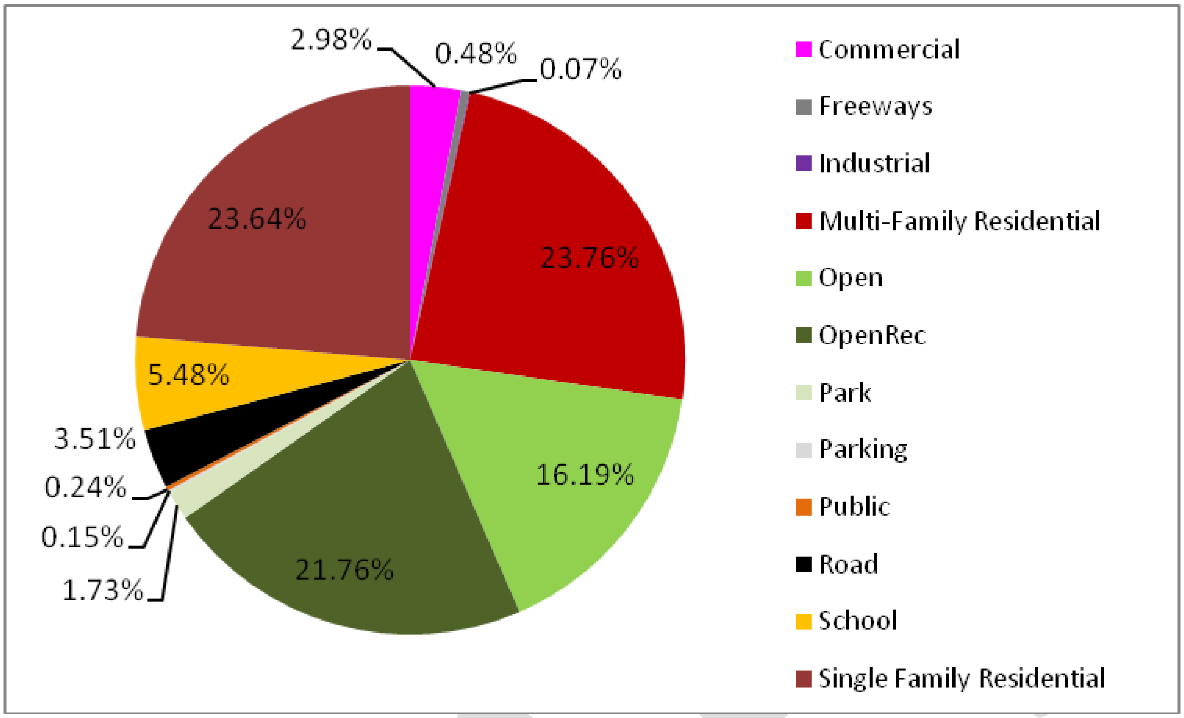


Figure 4-1. Land use volumetric loads to the Famosa Slough.

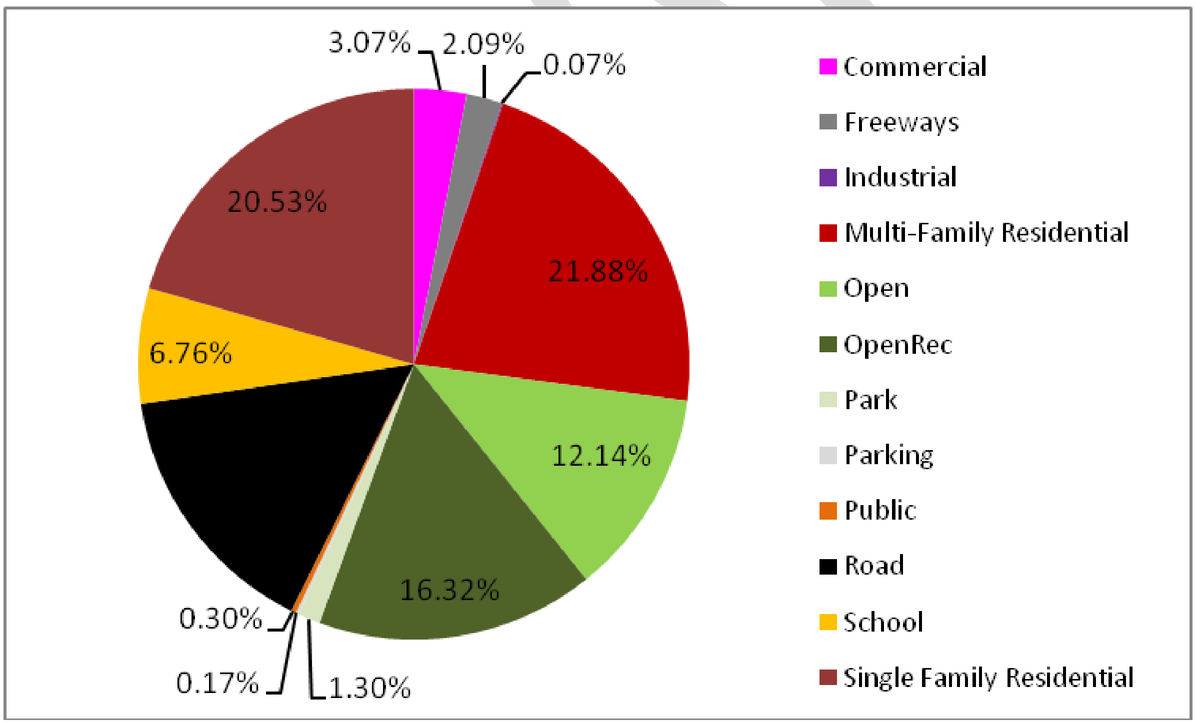


Figure 4-2. Land use total nitrogen loads to the Famosa Slough.

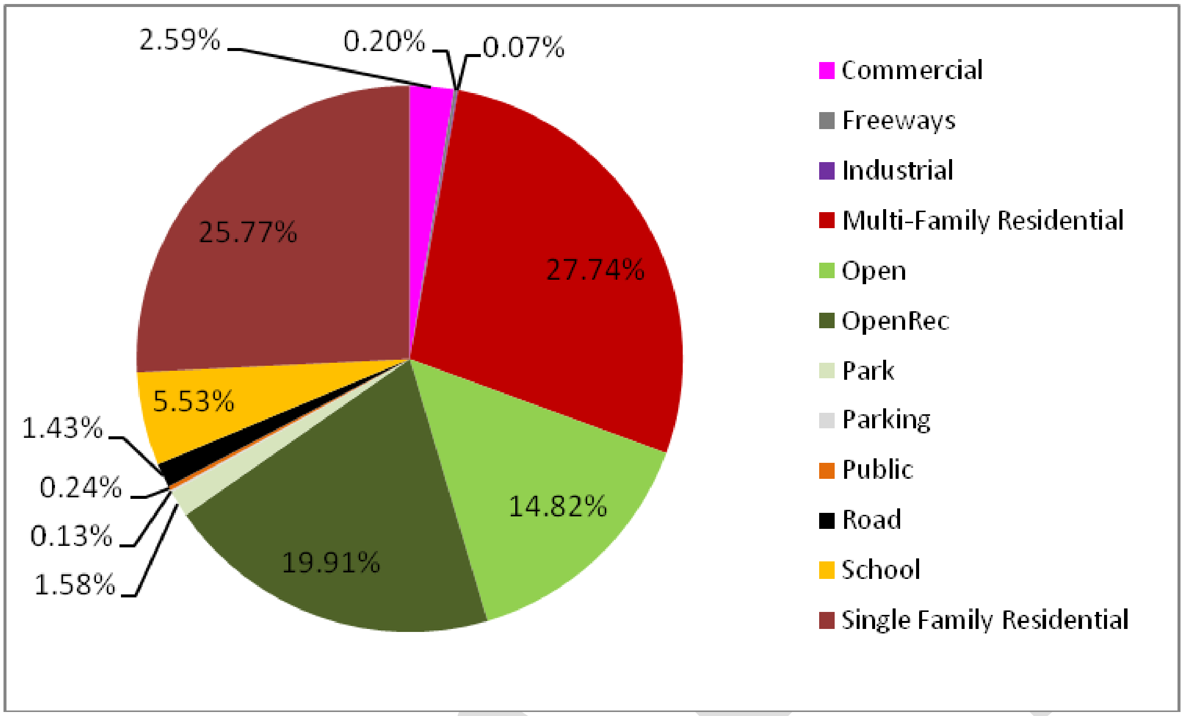


Figure 4-3. Land use total phosphorus loads to the Famosa Slough.

4.2 Identification of Sources

Nutrients can enter surface waters from both point and nonpoint sources. Point sources typically discharge at a specific location from pipes, outfalls, and conveyance channels from, for example, municipal wastewater treatment plants or MS4s. In California, these discharges are regulated through WDRs that implement federal NPDES regulations issued by the SWRCB or the San Diego Water Board through various orders. Nonpoint sources are diffuse and have multiple routes of entry into surface waters. Some nonpoint sources, such as agricultural and livestock operations, are regulated under the Basin Plan's waste discharge requirement waiver policy (Waiver Policy). The source assessment quantification is measured as an annual or daily load, which is then used to separate the LA or WLA for the TMDL. The following sections discuss the nutrient sources that contribute to Famosa Slough.

As discussed below, specific point sources potentially affecting Famosa Slough include the City of San Diego (Phase I MS4) and Caltrans. NPDES permits may be granted to dischargers within the watershed in the future that may have impacts on conditions in Famosa Slough. These permittees may include Phase II MS4s, industrial facilities, and construction sites. These point source categories are also discussed for completeness. Additionally, nonpoint sources may include atmospheric deposition, nutrient flux and sediment resuspension, and tidal influence.

4.2.1 Point Sources

Point source pollution is defined by the Federal CWA § 502(14) as: "any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged.”

Within the Famosa Slough watershed, storm water runoff is regulated through NPDES permits, including the Phase I Regional MS4 permit and the statewide storm water permit issued to Caltrans. The permitting process defines these discharges as point sources because storm water is typically discharged from the end of a storm water conveyance system, as described below. NPDES permits are also issued for construction and industrial sites that are enrolled in the statewide general storm water permit program. Existing and potential future point sources within the Famosa Slough watershed are discussed in this section.

4.2.1.1 Phase I MS4s

In 1990, the USEPA developed rules establishing Phase I of the NPDES storm water program, designed to prevent harmful pollutants from being washed by urban runoff into MS4s or from being discharged directly into MS4s, and then local receiving waters. Phase I of the program required operators of medium and large MS4s (those generally serving populations of 100,000 or more) to implement an urban runoff management program as a means to control polluted discharges from MS4s.

Approved urban runoff management programs for medium and large MS4s are required to address a variety of water quality-related issues, including roadway runoff management, municipally owned operations and hazardous waste treatment. More specifically, large and medium operators are required to develop and implement Urban Runoff Management Plans that address, at a minimum, the following elements:

- Structural control maintenance;
- Areas of significant development or redevelopment;
- Roadway runoff management;
- Flood control related to water quality issues;
- Municipally owned operations such as landfills, wastewater treatment plants, etc.;
- Hazardous waste treatment, storage, or disposal sites, etc.;
- Application of pesticides, herbicides and fertilizers;
- Illicit discharge detection and elimination;
- Regulation of sites classified as associated with industrial activity;
- Construction site and post-construction site runoff control; and
- Public education and outreach.

San Diego Water Board Order R9-2013-0001, as amended by Orders R9-2015-0001 and R9-2015-0100 (NPDES No. CAS0109266) identified municipalities that are responsible for addressing water quality concerns under the Regional Phase I MS4 permit (Regional Board, 2013; Regional Board, February 2015; Regional Board, November 2015); however, responsible Phase I municipal dischargers within the Famosa Slough watershed are limited to the City of San Diego.

4.2.1.2 Phase II MS4s

In 1999, the USEPA developed rules establishing Phase II of the NPDES storm water program, extending the regulations to storm water discharges from small MS4s located in “urbanized areas” and construction activities that disturb 1 to 5 acres of land. Small MS4 systems are not permitted under the municipal Phase I regulations, and are owned or operated by the United States, a State, city, town, borough, county, parish, district, association, or other public body (created by or pursuant to State law) having jurisdiction over disposal of sewage, industrial wastes, storm water, or other wastes, including special districts under State law such as a sewer district, flood control district or drainage district, or similar entity.

The General Permit for the Discharge of Storm Water from Small MS4s, Water Quality Order No. 2013-0001-DWQ (Small MS4 General Permit) regulates discharges of storm water from “regulated Small MS4s.” A “regulated Small MS4” is defined as a Small MS4 that discharges to a water of the United States or to another MS4 regulated by an NPDES permit. The General Permit requires that Small MS4 Dischargers develop and implement a Storm Water Management Program (SWMP) that reduces the discharge of pollutants through their MS4s to the Maximum Extent Practicable (MEP). The SWMP must describe the best management practices (BMPs), measurable goals, include time schedules of implementation, and assign responsibility of each task.

Non-traditional Small MS4s may also require coverage by the permit. The nontraditional Small MS4s include those located within or discharge to a permitted MS4, and that pose significant water quality threats. In general, these are storm water systems serving public campuses (including universities, community colleges, primary schools, and other publicly owned learning institutions with campuses), military bases, and prison and hospital complexes within or adjacent to other regulated MS4s, or which pose significant water quality threats. The State Water Board considered designating non-traditional small MS4s when adopting this General Permit.

Entities that enroll in Order No. 2013-0001-DWQ are responsible for addressing water quality concerns from their small MS4s. In the San Diego Region, non-traditional small MS4s that are subject to the Order may include the San Diego Unified School District (SDUSD) and others, as applicable, in the watershed.

As with Phase I MS4s, pollutants build up on land surfaces and then are washed off during rainfall events. The amount of runoff and associated concentrations are highly dependent on the nearby land uses and management practices. There are currently no Phase II MS4s located within the Famosa Slough watershed.

4.2.1.3 Caltrans

Caltrans is regulated by a statewide storm water discharge permit that covers all municipal storm water activities and construction activities (State Board Order No. 2012-0011-DWQ;

CAS000003, amendments in Orders WQ 2014-0006-EXEC, WQ 2014-0077-DWQ, and WQ 2015-0036-EXEC). The Caltrans storm water permit authorizes storm water discharges from Caltrans properties such as the state highway system, park and ride facilities, and maintenance yards. The storm water discharges from most of these Caltrans properties and facilities eventually ends up in either a city or county storm drain system or discharges directly to surface waters.

Roadway and pavement runoff from Caltrans' highways and facilities contains organic and inorganic pollutants that can impair receiving water quality and disrupt aquatic and benthic ecosystems. Storm water discharges from roadways could contain pollutants, including suspended solids, heavy metals, hydrocarbons, indicator bacteria and pathogens, nutrients, herbicides, and deicing salts (Caltrans, 2003; Grant et al., 2003; Cerco and Cole, 1994). The principal sources of pollutants from roadways are atmospheric deposition (precipitation and dust fall), automobiles, and the road surfaces themselves (Grant et al., 2003).

4.2.1.4 Statewide General Industrial and Construction Storm Water

The SWRCB issued a statewide general NPDES permit for Discharges of Storm Water Associated with Industrial Activities (Order No. 2014-0057-DWQ), effective July 1, 2015. This Order regulates storm water discharges and authorized non-storm water discharges from nine specific categories of industrial facilities, including but not limited to manufacturing facilities, oil and gas mining facilities, landfills, hazardous waste facilities, power generation facilities, sewage or wastewater treatment facilities, and transportation facilities. Potential pollutants from an industrial site will depend on the type of facility and operations that take place at that facility.

Wet weather runoff from industrial sites has the potential to convey pollutant loads to Famosa Slough. Under the statewide Industrial General Permit (Order No. 2014-0057- DWQ), non-storm water discharges are authorized only when they do not contain "pollutants that cause or threaten to cause pollution, contamination, or nuisance," where BMPs are in place to minimize contact with materials and equipment that are potential pollutant sources and reduce flow, discharges to not contain pollutants at a quantity sufficient to cause or contribute to an exceedance of water quality standards and when the discharges are in compliance with San Diego Water Board and local agency requirements.

The SWRCB also adopted a statewide NPDES General Permit for Storm Water Discharges Associated with Construction and Land Disturbance Activities (Order No. 2012-0006-DWQ) in July 2012. The statewide permit went into effect on July 17, 2012 and amends the original SWRCB construction storm water permit Order No. 2009-0009-DWQ. The statewide permit covers new construction and redevelopment of existing properties which are the most likely types of eligible construction projects that would be located within the impaired drainage areas. Wet weather runoff from construction sites has the potential to discharge into Famosa Slough. Under the Statewide Construction Storm Water permit, discharges of non-storm water are authorized only where they do not cause or contribute to an exceedance of any water quality standard, do not exceed sediment effluent limitations specified in the permit, and are controlled through implementation of appropriate BMPs for elimination or reduction of pollutants. Potential pollutants from construction and redevelopment projects in highly urbanized watersheds include sediment that may contain residual concentrations of pesticides and nutrients. There are currently no dischargers enrolled under the General Construction Permit in the Famosa Slough watershed (based on a query of an excel file from the SWRCB website as of November 2016; however, note that additional facilities may exist that did not show up in the query or new facilities could be permitted in the future).

4.2.2 Nonpoint Sources

The term nonpoint source pollution is defined to mean any source of pollution that does not meet the legal definition of point sources (as discussed in Section 4.2.1). Within the watershed, monitoring data indicate that tidal flow provides both a sink and source of nutrients to Famosa Slough and for this reason, ocean tides can be a source of nutrients to the Slough and Channel. Other nonpoint sources of nutrient loading to Famosa Slough include nutrient flux, internal cycling, and atmospheric deposition. Each potential nonpoint source is summarized below.

4.2.2.1 Resuspension and Internal Cycling

The burial and sequestration of nutrients are important mechanisms that can reduce the mass of bioavailable nutrients within the water column. Alternatively, sediment stores of nutrients can be released into the water column through multiple mechanisms. As discussed below, resuspension and internal nutrient cycling can be considered continuous nonpoint sources of nutrients to the water column.

Resuspension

Under certain conditions, sediments can behave as significant sinks, removing pollutants from the water column by allowing for deep burial and sequestration. Sedimentation rates depend on the specific waterbody characteristics as well as the size and settling velocity of the particulate matter to which the phosphorus is bound (Welch and Jacoby, 2004). In general, deep burial depends on the net sedimentation rate, which is the external sediment supply less resuspension. Rates of burial loss of specific compounds depend on the extent to which the compound is adsorbed to sediment and the waterbody characteristics (e.g., internal mixing, depth) that determine rates of recycling of deposited material. Burial rates are often higher in arid climates due to the sparse vegetative ground cover compared to areas receiving higher amounts of rainfall.

Resuspension of sediment (and adsorbed nutrients) could occur by wind mixing and/or bioturbation. These processes can result in additional cycling from sediment to the water column. For example, wind mixing has the potential to increase resuspension of bed sediments and associated pollutants, especially in shallow waters. Bioturbation is the mixing and resuspension of sediment and benthic material (including nutrients) by fish, birds, and macroinvertebrates. This disturbance of sediments can have an impact on nutrient cycling and availability of sediment-associated pollutants.

Internal Cycling

Internal cycling (specifically, nitrogen flux) has been identified as a potentially significant source of nutrients to Famosa Slough (SCCWRP, 2010). The SCCWRP study indicates that summer concentrations of TN due to benthic flux were twice as much as urban runoff and much greater than the San Diego River contributions (223kg, 110kg, and 70 kg TN, respectively) (SCCWRP, 2010). Furthermore, phosphorus monitoring indicated urban runoff is the main contributor to phosphorus loading. Monitoring data show that inflow from the San Diego River and urban runoff provided 90 kg of TP as compared to benthic flux, which only provided 16 kg of TP (SCCWRP, 2010). DO concentrations at the sediment-water interface play an important role in the internal loading of various ionic compounds. The decomposition associated with eutrophication (and nuisance algae) requires oxygen, thus decreasing the available oxygen within the water column, particularly near the sediment-water interface where decaying organic matter tends to settle. The oxidation-reduction potential of an aquatic system is used to describe the process or degree to which ions are exchanged within a system. Compounds gaining electrons are said to be reduced, while those losing electrons are oxidized. The most energetically favorable reaction occurs with the oxidation of organic matter. However, in the absence of oxygen, bacterial processes shift to denitrification or the reduction of other compounds (releasing compounds such as NH_3/NH_4^+). This process can dramatically increase the concentration of reduced species (e.g. NH_3/NH_4^+). In addition, nutrient flux during anoxic conditions tends to increase phosphorus concentrations, adding to the available nutrient pool and continuing the cycle of eutrophication.

4.2.2.2 Atmospheric Deposition

Atmospheric deposition can also contribute to nutrient loading both during wet and dry weather, but generally only a small portion of this is deposited directly to the surface of the waterbody. Direct atmospheric deposition is considered a nonpoint source of pollution; however, due to the size of the watershed, it is unlikely to be a significant source of nutrients to Famosa Slough. Alternatively, deposition to surfaces across the watershed (a process referred to as indirect atmospheric deposition) ultimately washes into storm water conveyance systems, which is considered a point source.

The National Atmospheric Deposition Program (NADP) measures atmospheric nitrate and ammonium in nearly 240 regionally representative locations in 48 states (NADP, 2000). Much of the earth's atmosphere (78 percent) is comprised of molecular nitrogen (N_2), additionally trace concentrations of nitrogen oxides, nitric acid vapor, gaseous ammonia, particulate nitrate and ammonium compounds and organic nitrogen circulate through the atmosphere (NADP, 2000). Human activities have increased the atmospheric concentration of certain nitrogen species. For example, more than 90 percent of nitrogen oxide emissions can be attributed to human combustion processes associated with vehicles, utilities, or industrial practices. Additionally, the USEPA estimated that a half a million metric tons of ammonia were released into the atmosphere from the application of fertilizers and more than three times this was released from livestock waste (NADP, 2000). Such nitrogen compounds circle from the atmosphere to the land through atmospheric deposition where wet weather deposits predominately nitrate and ammonia while dry deposition involves the complex interactions between airborne nitrogen compounds and plant, water, soil, rock or building surfaces (NADP, 2000). The SCCWRP study conducted in the Famosa Slough watershed found atmospheric deposition to be negligible (SCCWRP, 2010).

Given the likelihood that direct deposition of phosphorus to a waterbody is insignificant relative to other sources of loading, the nutrient TMDL assumes zero phosphorus loading from direct atmospheric deposition. This is supported by a SCCWRP study that found direct atmospheric deposition of phosphorus to Famosa Slough was negligible (SCCWRP, 2010). SCCWRP is conducting a deposition monitoring study that will measure phosphorus; however, results have yet to be released. If this study indicates that atmospheric deposition of phosphorus is a significant source of phosphorus to waterbodies in the region, this TMDL may be amended to reflect these data.

4.2.2.3 Tidal Influence

Tidal flow has been identified as a significant source of volume to Famosa Slough. The tidal cycle allows seawater to mix with the San Diego River, which then flows into the Channel during high tide; however, during low tide, the water flow is reversed and the Channel water, mixed with urban runoff, flows out of the Channel and into the San Diego River. The tidal cycle of a costal waterbody contributes to the balance of nutrient-rich water, oxygen, plant material, and aquatic species. Nitrogen exchange with the San Diego River was estimated to be 70 kg of TN and 20 kg of dissolved inorganic nitrogen during the May-July period, providing a minor source of nitrogen (SCCWRP, 2010). Additionally, high tides improve the water quality by diluting the impacts of chemical buildups and excessive algal growth. However, muted tidal flows experienced in Famosa Slough, increase the amount of time the water resides in the waterbody, thereby increasing potential for algal growth (SCCWRP, 2010).

5. Linkage Analysis

The technical analysis of the relationship between pollutant loading from identified sources and the response of the waterbody to this loading is referred to as the linkage analysis. The purpose of the linkage analysis is to quantify the maximum allowable nutrient loading that can be received by an impaired waterbody and still attain the WQOs of the applicable beneficial uses. This numeric value is represented by the TMDL.

The linkage analysis for this TMDL uses computer models that simulate the physical processes within the impaired receiving water (Famosa Slough) and its watershed. The models provide an estimation of nutrient loading from the watersheds based on rainfall events, and simulation of the response of the receiving water to this loading. The following sections provide a detailed discussion regarding model selection and linkage analyses.

5.1 Consideration Factors for Model Selection

Technical and regulatory criteria were considered in selecting an appropriate approach for TMDL calculation. Technical criteria include the physical system, including watershed or receiving water characteristics and processes and the constituents of interest. Regulatory criteria include WQOs or procedural protocol. The following discussion details the considerations in each of these categories. Based on these considerations, appropriate models were chosen to simulate watershed and receiving water conditions.

5.1.1 Technical Criteria

Technical criteria were divided into four main topics: physical domain, source contributions, critical conditions, and constituents. As discussed below, consideration of each topic was critical in selecting the most appropriate modeling system to address the types of sources and the numeric target associated with the impaired waterbody.

5.1.1.1 Physical Domain

Representation of the physical domain is perhaps the most important consideration in model selection. The physical domain is the focus of the modeling effort—typically, either the receiving water itself or a combination of the contributing watershed and the receiving water. Selection of the appropriate modeling domain depends on the constituents and the conditions under which the waterbody exhibits impairment. A steady-state approach is typically used for a waterbody dominated by point source inputs that exhibits impairments under only low-flow conditions. If the system includes tidal influences, a quasi-steady-state simulation is typically performed that assumes steady-state inputs, but includes diurnal variability in hydrodynamics associated with tidal effects. The steady-state and quasi-steady-state modeling approaches primarily focus on receiving water processes during a user-specified condition.

A dynamic approach is recommended for waterbodies affected additionally or solely by nonpoint sources or primarily rainfall-driven flow and pollutant contributions. Dynamic models consider time-variable nonpoint source contributions from a watershed surface or subsurface, as well as a hydrodynamic response of the receiving water. Some models consider monthly or seasonal variability, while others enable assessment of conditions immediately before, during, and after individual rainfall events. Dynamic models require a substantial amount of information regarding input parameters and data for calibration purposes.

5.1.1.2 Source Contributions

Primary pollutant sources must be considered in the model selection process. Accurately representing contributions from nonpoint sources and point sources is critical in properly representing the system and ultimately evaluating potential load reduction scenarios.

Water quality monitoring data were not sufficient to fully characterize all sources of nutrients to Famosa Slough; however, available data indicate that the main controllable source is watershed runoff. As a result, the models selected to develop a nutrient TMDL for Famosa Slough must address the major source categories during conditions considered controllable for TMDL implementation purposes.

5.1.1.3 Critical Conditions

The goal of the TMDL analysis is to determine the assimilative capacity of the waterbody and to identify potential allocation scenarios that will enable that waterbody to achieve WQOs. The critical condition is the set of environmental conditions for which controls designed to protect water quality will ensure attainment of objectives for all other conditions. This is typically the period in which the waterbody exhibits the most vulnerability. There is a high degree of temporal variability as to when nutrients are contributed to Famosa Slough. This variability is due to the nature of wet weather events that represent the critical condition for nutrient deposition.

5.1.1.4 Constituents

Another important consideration in model selection and application is the constituent(s) to be assessed. Choice of state variables is a critical part of model implementation. The more state variables included, the more difficult the model will be to apply and calibrate. However, if key state variables are omitted from the simulation, the model may not simulate all necessary aspects of the system and may produce unrealistic results. A delicate balance must be met between minimal constituent simulation and maximum applicability.

5.1.2 Regulatory Criteria

A properly designed and applied model provides the source-response linkage component of the TMDL and enables accurate assessment of assimilative capacity and allocation distribution. The receiving water's assimilative capacity is determined by assuming adherence to WQOs. For all waters in the San Diego Region, the Basin Plan establishes the beneficial uses for each waterbody to be protected and the WQOs that protect those uses. In the case of narrative objectives, interpretation is required to develop a numeric target for TMDL development (refer to Section 3). The modeling framework must enable direct comparison of model results to the selected numeric target and allow for the analysis of the duration of those conditions. For the watershed loading analysis and implementation of required reductions, it is also important that the modeling framework allow for the examination of gross land use loading.

5.2 Model Selection and Overview

Establishing the relationship between the receiving water quality target and source loading is a critical component of TMDL development. This allows for the evaluation of management options that will help achieve the desired source load reductions. This can be established through a number of techniques, ranging from qualitative assumptions based on sound scientific principles to sophisticated modeling techniques. Ideally, the linkage will be supported by monitoring data that allow the TMDL developer to associate certain waterbody responses to flow and loading conditions. The objective of this section is to present the approach taken to develop the linkage between sources and receiving water responses for TMDL development in Famosa Slough.

In addition, the models can be used to simulate various scenarios to assist in TMDL development and to provide decision support for watershed management. To do so, the models may require future modifications to address specific management and environmental factors. Such scenarios may result from the augmentation of input data to be collected in ensuing monitoring efforts, future implementation of various management strategies or BMPs, or adaptation and linkage to additional models developed in subsequent projects. Therefore, model flexibility is a key attribute for model selection.

The modeling system was divided into two components representative of the processes essential for accurately modeling hydrology, hydrodynamics, and water quality. The first component of the modeling system is a watershed model that predicts runoff and external pollutant loading as a result of rainfall events. The second component is a hydrodynamic and water quality model that simulates the complex water circulation and pollutant transport patterns in Famosa Slough.

The models selected for Famosa Slough nutrient TMDL are components of USEPA's TMDL Modeling Toolbox (Toolbox), which was developed through a joint effort between USEPA and Tetra Tech, Inc. (USEPA, 2015). The Toolbox is a collection of models, modeling tools, and databases that have been used over the past decade to assist with TMDL development and other environmental studies. LSPC is the primary watershed hydrology and pollutant loading model and EFDC is the receiving water hydrodynamic and water quality model in the Toolbox modeling package. Both the LSPC and EFDC models are summarized below and described in detail in the Modeling Report (Appendix A).

5.2.1 Watershed Model: Loading Simulation Program in C++

LSPC was selected for simulation of land-use based sources of nutrients and the hydrologic and hydraulic processes that affect delivery (Shen et al., 2004; Tetra Tech, 2002; USEPA, 2003b). LSPC was specifically used to simulate watershed hydrology and transport of nutrients flowing to the impaired Slough. LSPC is a watershed modeling system that includes streamlined Hydrologic Simulation Program Fortran (HSPF) algorithms for simulating hydrology, sediment, and general water quality on land, as well as a simplified stream fate and transport model (Bicknell et al., 1997). Since its original public release, the LSPC model has been expanded to include additional GQUAL components for sorption/desorption of selected water quality constituents with sediment, enhanced temperature simulation, and the HSPF RQUAL module for simulating DO, nutrients, and algae. LSPC has also been customized to address simulation of other pollutants such as nutrients and fecal coliform bacteria.

The hydrologic (water budget) process is complex and interconnected within LSPC. Rain falls and lands on various constructed landscapes, vegetation, and bare soil areas within a watershed. Varying soil types allow the water to infiltrate at different rates while evaporation and plant matter exert a demand on this rainfall. Water flows overland and through the soil matrix. The land representation in the LSPC model environment considers three flowpaths; surface, interflow, and groundwater outflow. LSPC can simulate flow, sediment, metals, nutrients, pesticides, and other conventional pollutants for pervious and impervious lands and waterbodies.

The model can simulate nutrient loadings from specific source areas (i.e., subwatershed or land use areas). This is important in terms of TMDL development and allocation analysis. For this TMDL, the LSPC model was used to calculate existing conditions within the watershed to establish the TMDL numeric target and required load reductions. The LSPC model output was incorporated as an input to the receiving water model for Famosa Slough, as described below.

5.2.2 Receiving Water Model: Environmental Fluid Dynamics Code

An EFDC receiving water model of Famosa Slough was developed to simulate the assimilative capacity, the transport and fate of suspended sediment loading, and dynamic effects of tidal flushing. The LSPC watershed model was linked to EFDC and provided all freshwater flows and loadings as model input. EFDC is a public domain, general purpose modeling package for simulating one-dimensional (1-D), two-dimensional (2-D), and three-dimensional (3-D) flow, nutrient transport, and biogeochemical processes in surface water systems including rivers, lakes, estuaries, reservoirs, wetlands, and coastal regions. The EFDC model was originally developed at the Virginia Institute of Marine Science for estuarine and coastal applications (Hamrick, 1992). This model is now being supported by the USEPA and has been used extensively to support TMDL development throughout the country. In addition to hydrodynamic, salinity, and temperature transport simulation capabilities, EFDC is capable of simulating cohesive and noncohesive sediment transport, near-field and far-field discharge dilution from multiple sources, eutrophication processes, the transport and fate of toxic contaminants in the water and sediment phases, and the transport and fate of various life stages of finfish and shellfish. The EFDC model has been extensively tested, documented, and applied to environmental studies worldwide by universities, governmental agencies, and other entities.

The EFDC model includes four primary modules: (1) a hydrodynamic model, (2) a water quality model, (3) a sediment transport model, and (4) a toxics model. The hydrodynamic model predicts water depth, velocities, and water temperature. The water quality portion of the model uses the results from the hydrodynamic model to compute the transport of the water quality variables. The water quality model then computes the fate of up to 22 water quality parameters including DO, phytoplankton (three groups), benthic algae, various components of carbon, nitrogen, phosphorus and silica cycles, and fecal coliform bacteria (Cerco and Cole, 1994). The sediment transport and toxics modules use the hydrodynamic model results to calculate the settling of suspended sediment and toxics, resuspension of bottom sediments and toxics, and bed load movement of noncohesive sediments and associated toxics. For this project, the hydrodynamics and water quality models were used. The hydrodynamics model simulated the circulation, water temperature, and depth in Famosa Slough driven by ocean tides and watershed inflows. The water quality model simulated nutrients, DO, and algal biomass. Details of the EFDC model's hydrodynamic and eutrophication components are provided in Hamrick (1992) and Tetra Tech (2002, 2006a, 2006b, 2006c, 2006d).

The EFDC model was configured to simulate hydrodynamics and water quality in Famosa Slough for existing conditions. Specifically, water temperature and depth were both modeled for hydrodynamics. Several water quality parameters, including their interactions, were modeled using the water quality model in EFDC.

5.2.3 Model Application

A complete discussion, including model configuration, hydrologic and hydrodynamic calibration and validation, and water quality calibration and validation, of the LSPC and EFDC models is provided in the Modeling Report (Appendix A). These models are an important tool and provide the technical analysis framework that will be used to make regulatory and management decisions for Famosa Slough and its watershed. They provide a linkage between pollutant loading from the watershed and receiving waterbody responses such as internal Slough and Channel mechanics, algal growth, and DO depletion.

The models were initially calibrated to observed hydrologic and water quality data to characterize existing conditions in the watershed and Famosa Slough. The required load reductions were developed using these existing loads. Through multiple scenarios, the models were used to evaluate compliance with the TMDL numeric target for DO and establish the corresponding macroalgae biomass numeric target. The resulting watershed nutrient loads that are capable of attaining the DO WQO were identified and represent the loading (assimilative) capacity for Famosa Slough (i.e. the TMDL). Percent reductions were calculated based on the difference between the TMDL load and the nutrient load that corresponds with existing conditions.

6. Identification of Load Allocations and Reductions

Computer simulation models were developed to understand water quality conditions within Famosa Slough and associated internal/external influences. The computer models provided the foundation from which numeric targets were evaluated and the corresponding TMDL and load reductions were established. Point sources were assigned WLAs, while nonpoint sources were assigned LAs. This section discusses the methodology used for TMDL development and the TMDL results in terms of loading capacity and the required watershed load reduction. Other TMDL components are also discussed including the margin of safety (MOS), seasonality, critical conditions, and the daily load expression.

6.1 Loading Analysis

The calibrated LSPC model was used to estimate existing nutrient loads from the watershed and San Diego River, with the receiving water (Famosa Slough) simulated using EFDC (Appendix A). Using the EFDC model, the assimilative capacity of Famosa Slough was assessed and compared to numeric targets for evaluation of eutrophic conditions (macroalgae biomass and DO levels). The selected management scenario includes reduced nutrient loads from the watershed along with periodic macroalgae harvesting (if necessary) to achieve acceptable conditions (based on the modeling analysis).

6.2 Identification of Critical Conditions

The EFDC model was run for January 1 – December 31, 2008 to compare the modeling results with observed data that were collected during the same time period. Annual precipitation for this year was within the 70th percentile between calendar years 1994 and 2014. In addition, the model was run for the 10th percentile (2009), median (2001), and 90th percentile (2005) years to test the sensitivity of the model predictions based on different annual precipitation amounts. In each of the sensitivity runs, the watershed flow, loading, and atmospheric boundary conditions of the corresponding years were used to drive the model, while the other parameters were kept the same as in the 2008 baseline model. Sensitivity of the water quality conditions to different years was evaluated by comparing time/area-weighted average total nitrogen, total phosphorus, and macroalgae concentrations between the critical summer period for the 4 years (2001, 2005, 2008, and 2009). Table 6-1 presents the coefficient of variation and the standard deviation for this analysis. The results showed that it is reasonable to use the critical summer period during 2008 for TMDL development. There are relatively small changes in water quality response patterns due to the simulated nutrient and macroalgae conditions from different hydrological years. Therefore, using 2008 as the TMDL baseline year was considered appropriate.

Table 6-1. Results of Selection Year Sensitivity Analysis.

Analyte	Coefficient of Variation		Standard Deviation	
	Channel	Slough	Channel	Slough
Total nitrogen	5.20%	7.80%	0.022 mg/L	0.056 mg/L
Total phosphorus	1.70%	3.00%	0.002 mg/L	0.005 mg/L
Total biomass	6.40%	11.80%	1.72 g C/m^2	11.75 g C/m^2

Notes:
Biomass in Slough = floating/benthic macroalgae; Biomass in Channel = benthic macroalgae/macrophyte
Floating macroalgae dominates in the Slough, while macrophytes dominate in the Channel.

6.3 Critical Locations for TMDL Calculation

For TMDL calculation, the water quality at a *critical location* in an impaired waterbody is compared to numeric targets for assessment of required reductions of pollutant loads to meet WQOs. This critical location is considered conservative for the assessment of water quality conditions. Although, this critical location for water quality assessment is used for TMDL analysis, compliance with WQOs must be assessed and maintained throughout a waterbody to protect beneficial uses. The critical location for this TMDL is the Slough, primarily because the Slough is a more complex system than the Channel, supports a variety of beneficial uses, and has historical macroalgae biomass and DO problems.

6.4 Application of Numeric Targets

The narrative WQO for biostimulatory substances was interpreted using the WQO for DO and the modeled macroalgae biomass. A complete discussion of numeric targets and associated WQOs is provided in Section 3.

These numeric targets represent alternative numeric targets to the Basin Plan WQOs. The USEPA supports the use of alternative numeric targets (Creager et al., 2006). Macroalgae blooms are well documented as primary indicators of eutrophic conditions (Valiela et al., 1997). These blooms decrease DO concentrations in the Slough. The Basin Plan acknowledges that even though algal blooms occur naturally, they are often the result of pollution, such as excess nutrients (Regional Board, 1994). Macroalgae biomass was also used as the primary target in the Loma Alta Slough TMDL (Regional Board, 2014).

The EFDC model is able to use nutrient and flow output from the LSPC watershed model to simulate algal growth and DO depletion in the Slough and Channel. EFDC was run for different management scenarios (Appendix A) to determine the best management strategies. The results from the scenarios were compared to the identified the numeric targets to determine if acceptable conditions were met.

6.5 Load Estimation

Estimation of current watershed loading to Famosa Slough required the use of the LSPC model to predict flows and pollutant concentrations from the watershed. The dynamic model-simulated watershed processes, based on observed rainfall data as model input, provided temporally variable load estimates for the critical period. These load estimates were simulated using calibrated, land use-specific processes associated with hydrology (see Appendix A). Table 6-2 presents the baseline loads from the watershed inflows into the EFDC model, while Figure 6-1 presents the contributing watershed areas for the inflows. The San Diego River loads are included for comparison. Note that under baseline conditions, only a small amount of the loading from the San Diego River would enter the Channel.

Table 6-2. Baseline 2008 Watershed Load Inputs into the Slough and Channel.

Input Location	Total Nitrogen (kg/yr)	Total Phosphorus (kg/yr)
Watershed Inflow 1	850.84	412.48
Watershed Inflow 2	23.21	13.94
Watershed Inflow 3	72.35	34.42
Watershed Inflow 4	12.70	7.59
Watershed Inflow 5	322.37	130.76
Watershed Inflow 6	34.72	15.93
Watershed Inflow 7	34.82	21.75
Watershed Inflow 8	85.85	40.58
Watershed Inflow 9	90.97	56.18
Watershed Inflow 10	38.31	17.50
Watershed Inflow 11	319.42	175.48
Total Watershed	1,885.55	926.61

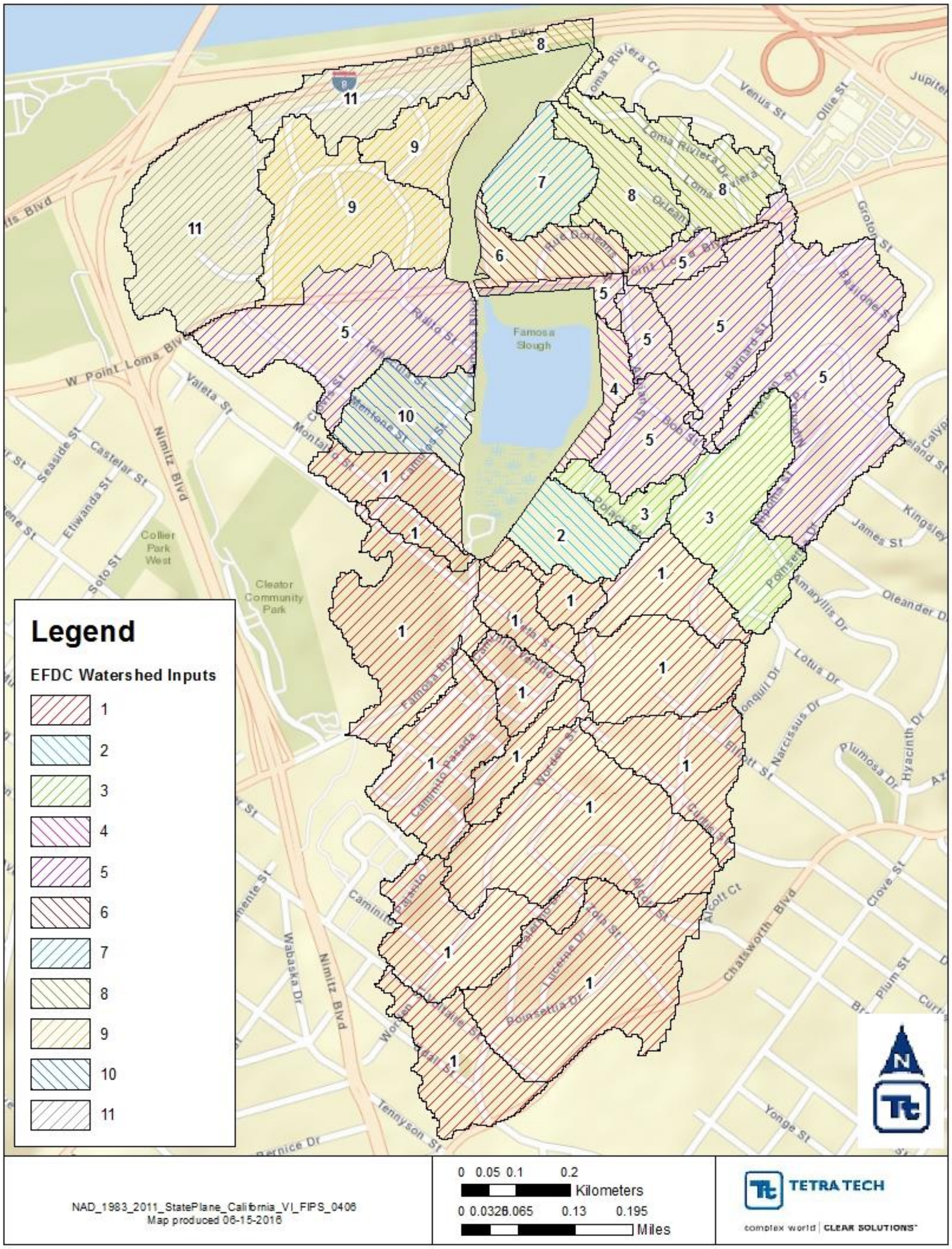


Figure 6-1. Contributing areas for watershed inflows into Famosa Slough.

6.6 Calculation of TMDLs and Allocation of Loads

Load calculations for nutrients were developed using land use-based generation rates and meteorological conditions from 2008. Federal regulations require TMDLs to include individual WLAs for each point source. For this reason, the TMDL was divided among point sources as WLAs and nonpoint sources as LAs. Point sources identified in the Famosa Slough watershed include the City of San Diego (Phase I MS4), Caltrans, and potential future permittees covered under the statewide Phase II MS4 permit, General Construction Storm Water Permit, or the Industrial General Storm Water Permit. Additional point sources of nutrients may exist and if identified shall be given a WLA.

TMDLs must also include LAs for each nonpoint source. Nonpoint sources identified within the Famosa Slough watershed include internal cycling, sediment flux, and atmospheric deposition. These sources were not given load estimations as they are considered part of the overall load from point sources. Loading from the San Diego River (which includes point and nonpoint loading contributions) were not assigned a LA, with the assumption that load reductions are not needed to meet the TMDL based on the current modeling analysis. In the future, if nutrient loads from the San Diego River are considered to impact Famosa Slough (and the Channel, in particular due to its connection with the river), input from the San Diego River may be reevaluated.

The management scenario analysis (Section 4 of Appendix A) included reductions to watershed nutrient loading to determine the best management scenario to demonstrate achievement of the Slough numeric targets. A 37 percent reduction in year-round watershed nitrogen and phosphorus loads (for both the Slough and Channel) was needed, along with twice-a-year macroalgae harvesting (if necessary) in the Slough. The loading from the San Diego River was not reduced as part of the analysis, as mentioned above. The near-term plan for the Channel is to focus on monitoring and adaptive management on the basis of current conditions in the Channel that appear to show that beneficial uses are being met. Adaptive management and continued monitoring in the Channel and Slough are further discussed in Section 9. Based on observations and water quality trends, the Channel appears to currently support beneficial uses (e.g., evidence of diverse biota, lack of floating macroalgae biomass, healthy tidal wetland floodplain).

6.7 Margin of Safety

A MOS is incorporated into a TMDL to account for uncertainty in developing the relationship between pollutant discharges and water quality impacts (USEPA, 1991). The MOS can be incorporated in the TMDL either explicitly or implicitly (USEPA, 2000). Reserving a portion of the loading capacity provides an explicit MOS. In addition, conservative assumptions and use of a detailed modeling analysis to develop the TMDL provides an implicit MOS. In either case, the purpose of the MOS is the same: to ensure that the beneficial uses currently impaired are restored, given the uncertainties in developing the TMDL.

An implicit MOS was incorporated in the model analysis, which included the following conservative assumptions and other aspects:

1. The model assumes that historical parameter values are constant (rather than having them fluctuate or change with tides, storms, seasons, or time),
2. The model assumes that nutrients from tidal fluctuations from the San Diego River will not decrease due to Water Quality Improvement Plan (WQIP) implementation activities that may reduce nutrient loading.
3. An integrated modeling framework that incorporates explicit representation of all key watershed and receiving water processes was used to develop these TMDLs and evaluate various management scenarios. Model development and calibration utilized all data available and incorporated conservative assumptions.
4. TMDLs were developed based on meeting the numeric target (DO) in the Slough (critical location) during the critical time period (summer, dry weather conditions).

6.8 Seasonality

Federal regulations (40 CFR 130.)7 require that TMDLs consider seasonal variation. Sources of sediment are similar for both dry and wet weather seasons. Despite the similarity of wet/dry sources, transport mechanisms can vary between the two seasons. Throughout the TMDL monitoring period, the greatest transport of nutrients, associated with the highest loadings, occurred during rainfall events. It is recognized that dry weather will contribute some nutrients; however, model calibration focused on wet weather conditions as transport potential is dramatically increased during wet weather. Model simulation was completed for a full year to account for seasonal variations in rainfall, evaporation, and associated impacts on runoff and transport of nutrient loads to receiving waters. Although large storms in the wet season of the critical year were associated with large volumes of runoff that transported elevated nutrient loads, smaller storms during the dry season (April to October) also provided nutrient loads resulting from wash-off of sediment that had accumulated on the surface during the preceding extended dry period. Moreover, critical conditions associated with the process of eutrophication tend to align with dry weather, when temperatures are higher and primary productivity is increased. To account for this variability, model simulations were performed for complete water years (not just during wet conditions) and this TMDL was calculated considering all flows rather than at a single critical flow; therefore, seasonality is taken into account.

6.9 Daily Load Expression

TMDLs are presented in Section 8. Allocations are expressed in terms of net nutrient load (kg). Loads were also divided by the number of days in the year (365) to derive daily loading rates (kg/day) (USEPA, 2003a).

7. TMDLs and Allocations

A TMDL is the total amount of pollutant that can be assimilated by the receiving waterbody while still achieving the numeric targets (based on WQOs). In TMDL development, allowable loadings from pollutant sources that cumulatively amount to no more than the TMDL must be established; this provides the basis for establishing water quality-based controls. TMDLs can be expressed on a mass loading basis (e.g., net nutrient amount per year) or as a concentration in accordance with 40 CFR 130.2(l).

A TMDL for a given pollutant and waterbody is comprised of the sum of individual WLAs for point sources and LAs for both nonpoint sources and natural background levels. In addition, the TMDL must include a MOS, either implicitly or explicitly, to account for the uncertainty in the relationship between pollutant loads and the quality in the receiving waterbody. Conceptually, this definition is represented by the equation:

$$\text{TMDL} = \sum \text{WLAs} + \sum \text{LAs} + \text{MOS}$$

TMDLs were established for Famosa Slough (impairments are identified in Section 2) using the methodology described in Section 6. The WLA portion of this equation represents the total loading assigned to point sources. The LA portion represents the loading assigned to nonpoint sources and the San Diego River. The MOS is the portion of loading reserved to account for any uncertainty in the data and computational methodology, as described in Section 6. An implicit MOS (discussed in Section 6.7) was used for this TMDL.

7.1 WLAs

Federal regulations (40 CFR 130.7) require TMDLs to include individual WLAs for each point source discharge regulated under a discharge permit. The City of San Diego is the only municipal MS4 discharger within the local Famosa Slough watershed. Nutrient loads generated from land use activities within the City of San Diego's MS4 area were assigned a WLA. Caltrans was also assigned a WLA for nutrient loads generated from highway infrastructure. The WLA for Caltrans was area-weighted from the total load. Because the area that Caltrans is responsible for (Interstate 8 and its right-of-way) is approximately 3 percent of the total area, it was given 3 percent of the total allowable load. The loading from the San Diego River was assigned a LA, as discussed in Section 6.

Additionally, permittees (existing or future) associated with the Phase II MS4 permit, or Statewide General Construction and Industrial Storm Water Permits shall be assigned WLAs based on areas of disturbance within the watershed. Currently no other permittees are located in the watershed.

7.2 LAs

According to federal regulations (40 CFR 130.2(g)), load allocations are best estimates of the nonpoint source or background loading. For Famosa Slough, nonpoint sources include resuspension and internal cycling, direct atmospheric deposition, and tidal influence from the San Diego River. Atmospheric deposition to the land surface is inherently included in the land use loads, but can be estimated in the future depending on available information and the need to estimate the loading contributed by this source. Atmospheric deposition directly to the Slough and Channel was considered negligible. Nutrients from tidal activity originate from the San Diego River. These loads were not reduced as part of the management scenarios or this TMDL. The WQIP for the San Diego River watershed includes implementation activities that may reduce nutrient loading as a secondary benefit, thus reducing nutrient inflow to the Channel and Slough through tidal activity. None of these nonpoint sources were specifically included in this TMDL as LAs in Table 7-1.

7.3 MOS

The MOS for this TMDL is implicit based on conservative modeling assumptions and other aspects as discussed in Section 6.7.

7.4 Summary of TMDL Results

The TMDL and its three components, the sum of WLAs, LAs, and an implicit MOS are presented in Table 7-1. All land use activities contributing to the MS4s are included in the WLA column, as described above (Section 6.6). Daily loads were estimated by dividing the net annual load by 365 days.

The TMDL values are based on watershed nutrient load reduction and macroalgae harvesting in the Slough that attains the macroalgae biomass and DO numeric targets, as discussed in Section 3. Therefore, the modeled nutrient watershed loads (during the identified critical condition) that comply with these targets, represent the allowable load. Required load reductions represent the difference between calculated existing loads, based on 2008 data and analysis, and these allowable loads.

Table 7-1. TMDL for Net Annual Watershed Nutrient Loads to Famosa Slough.

Input Location	Annual Net Total Nitrogen (kg/yr)	Annual Net Total Phosphorus (kg/yr)	Daily Net Total Nitrogen (kg/day)	Daily Net Total Phosphorus (kg/day)
TMDL	1,187.90	583.76	3.25	1.60
WLA (City of San Diego MS4)	1,152.26	566.25	3.16	1.55
WLA (Caltrans MS4)	35.64	17.51	0.10	0.05
MOS	Implicit	Implicit	Implicit	Implicit

8. Implementation Plan

8.1 Alternative Process - Regional MS4 Permit Approach

Famosa Slough is listed as impaired due to eutrophic conditions, which requires the development of a TMDL (as presented above) and an implementation plan. During the TMDL development process, it was determined that the combination of necessary nutrient reductions and algal harvesting could be achieved with actions taken in compliance with the existing Regional Phase I MS4 Permit via consultation between the San Diego Water Board and the City of San Diego. As a result, the San Diego Water Board intends to postpone the TMDL adoption process in favor of relying on, and verifying the success of actions taken by the City of San Diego in accordance with the existing Regional Phase I MS4 Permit (alternative process to the TMDL adoption); and to reinitiate the TMDL adoption process or initiate compliance actions if monitoring does not show progress.

The goal of the implementation plan is to ensure WQOs for biostimulatory substances and DO are met in the Slough and that the waterbody attains its beneficial uses. The City of San Diego and Caltrans represent the responsible agencies that contribute nutrient loads to Famosa Slough via storm water runoff. Elimination of unauthorized non-storm water discharges to the MS4 is necessary to attain the macroalgae numeric targets in Famosa Slough. In addition, algae harvesting may be necessary to preempt eutrophic conditions while watershed loadings are being reduced. Modeling suggests that all point source reductions necessary to meet the TMDL targets can be done entirely within the City of San Diego's jurisdiction. Further, the WLA assigned to Caltrans is only 3 percent of the total allowable load. At this time, the actions required under Order No. 2012-0011-DWQ (Caltrans statewide permit) are considered adequate to address nutrient load contributions from Interstate 8 into Famosa Slough. Therefore, no additional actions by Caltrans are currently included in the Implementation Plan.

Adoption of the alternative process via the San Diego Water Board Resolution (No. R9-2017-0017) will result in future updates to the Jurisdictional Runoff Management Plan (JRMP) and the San Diego River WQIP. As part of its JRMP, it is recommended that the City prioritize and determine when to perform follow-up investigations in response to visual observations and/or water quality monitoring data collected during an investigation of a detected non-storm water or illicit discharge to or from the MS4. Famosa Slough could be identified as a priority for the City-specific JRMP because the water quality impairment is caused by illicit discharges into and from the MS4.

Provision II.B.2 of the Regional MS4 Permit requires copermittees to identify the water quality priorities within each Watershed Management Area that will be addressed by the WQIP. Watershed Management Areas may be separated into sub-watersheds to focus water quality prioritization and jurisdictional runoff management program implementation efforts by receiving water. The WQIP includes descriptions of the highest priority conditions, goals and strategies to address them, and a schedule to meet the goals. Famosa Slough is included in the San Diego River Watershed Management Area WQIP, which was approved in February 2016 (County of San Diego, 2016). Famosa Slough meets four of the criteria to be used to identify priority water quality impacts:

a. Famosa Slough is listed as an impaired water body on the CWA section 303(d) List (Provision II.B.2.a.1).

b. A TMDL for Famosa Slough is under development by the San Diego Water Board (Provision II.B.2.a.2).

c. Receiving water monitoring data indicates an impairment in Famosa Slough (Provision II.B.2.a.6).

d. There is evidence of adverse impacts to the chemical, physical, and biological integrity of the water in Famosa Slough (Provision II.B.2.a.8).

Famosa Slough was considered, but rejected, by the San Diego River Watershed Management Area copermitees as a designated high priority water quality conditions in their current WQIP (County of San Diego 2016). The rejection was based upon a 2010 SCCWRP study that showed sediments were the major contributor responsible for algal growth in Famosa Slough. However, as noted above, the more recent TMDL Report determined nutrients entering the Slough via the storm drains are the primary source of the seasonal impairment. Thus the City will update the WQIP to achieve the WQOs and associated numeric targets in Famosa Slough.

The San Diego Water Board can reasonably rely upon the existing Regional Phase I MS4 Permit, particularly the prohibitions and requirements regarding control of non-storm water flows into and from the MS4 (Provisions II.A.1.b, II.E.2, and II.B) as the regulatory tool to achieve the necessary reductions in total nitrogen and total phosphorus loading. If necessary to verify progress toward attainment, the San Diego Water Board can issue Order(s) for monitoring and assessment of conditions and regulatory program effectiveness pursuant to Water Code sections 13225 and/or 13267. The Water Code also provides the San Diego Water Board with various enforcement authorities to use if necessary to compel timely compliance with the Regional Phase I MS4 Permit.

In the event that additional NPDES permits (e.g., Phase II MS4s, industrial or construction permits) are granted to dischargers within the watershed in the future, tidal contributions are considered to have a more significant influence on water quality conditions, or other sources are identified, further requirements may be needed. The San Diego Water Board will initiate additional actions, as appropriate, to address existing or potential future impacts to water quality and beneficial uses within Famosa Slough.

8.2 Monitoring

Water quality control plans or Basin Plans are required to include a program of implementation for achieving WQOs (CWC § 13050(j)). Such implementation planning is to include a description of actions necessary to meet WQOs, a timeline in which actions will be implemented, and a description of *surveillance* (or monitoring) to measure the implementation success (CWC § 13242).

Specific to point dischargers, CWC Section 13267(b)(1) states that “the Regional Board may require that any person who has discharged, discharges, or is suspected of having discharged or is discharging, or who proposes to discharge waste within its region … shall furnish, under penalty of perjury, technical or monitoring program reports which the Regional Board requires." Section 13383 of the CWC furthers defines monitoring requirements including an annual reporting requirement.

Monitoring of Famosa Slough is required to insure the TMDL numeric targets are met and beneficial uses are restored. Long term monitoring will allow for documentation of DO and macroalgal response to reduced nutrient loads to Famosa Slough. Monitoring may be modified if data indicates that the implementation efforts taken have resulted in the TMDL targets being met.

Compliance with this TMDL and associated WLAs and LAs will be assessed primarily by comparing the calculated total mass load (and reductions) for nutrients entering Famosa Slough, with the allowable total load (TMDL and required reductions are shown in Section 7.4).

Monitoring for compliance will initially be conducted by the City of San Diego and Caltrans (as necessary). Additionally, a coordinated monitoring program is needed to measure the success of implementation actions. Monitoring provides the foundation from which future management decisions can be more confidently made; as new information is gathered and implementation effectiveness assessed, planned implementation actions can be modified as needed. Future monitoring efforts to measure BMP effectiveness and implementation success will be outlined by the updated WQIP, which will detail a monitoring program for Famosa Slough. Any monitoring program that will be used to evaluate progress toward attainment of the TMDLs should:

- Clearly identify monitoring stations representative of conditions within Famosa Slough and its watershed.
- Cleary identify monitoring periods (e.g. samples should be collected during storm events occurring in the rainy season, October 1 through April 30).
- Record observations of macroalgae biomass and percent coverage, as well as collect samples as needed for quantitative measurements. Identify a macroalgae biomass threshold that will be used to help guide when harvesting should be performed. This threshold may be updated in the future through adaptive management.
- Sample the water quality column for, at a minimum, nitrate, nitrite, ammonia-nitrogen, total Kjeldahl nitrogen, ortho-phosphorus, total phosphorus and chlorophyll *a* using EPA-approved methods.
- Measure flow associated with water quality samples.

Monitoring of physiochemical parameters and qualitative algal coverage/biomass should be performed to document ongoing conditions, as well as to document potential uncharacteristic dry weather inputs to Famosa Slough. Field events should be scheduled to coincide with low tide in order to better discern any dry weather inputs to Famosa Slough. During monitoring, any dry weather inputs that are detected should be documented (e.g., photographs, location). Measurement of flow of these inputs will be attempted if sufficient flow is present.

There is additional monitoring that should be considered in part of an ongoing monitoring process to gage water quality improvements in Famosa Slough.

- A representative sample of each major type of macroalgae observed in Famosa Slough will be collected and brought back to the AFW lab for course taxonomic identification.
- Two in-situ data sonde loggers should be used at appropriate locations for several weeks to document diurnal water quality (i.e., temperature, DO, conductivity, pH), and water depth. As DO is a critical component of the eutrophication impairment, monitoring is required to determine how DO responds to load reduction and macroalgal target achievement.
- Algal biomass (water column phytoplankton and surficial macroalgae density) should be monitored. Algal biomass should be collected according to methods outlined in the Southern California 2008 Bight Regional Marine Monitoring Survey (Bight '08) Estuarine Eutrophication Assessment Field Operations Manual. Briefly, water column phytoplankton density should be estimated through chlorophyll-*a* concentration, and surficial macroalgae density will be estimated through percent cover measured within a $0.5m^2$ quadrat at 10 points along a 30-meter transect.

8.3 TMDL Compliance Schedule and Implementation Milestones

Over the course of the alternative process implementation, the TMDL may be reconsidered to incorporate information acquired through special studies completed by the watershed stakeholders. TMDL reconsideration may refine the numeric targets, the WLAs, and the LAs. The refined allocations and consequential implementation efforts will be defined within an updated WQIP within one year of reconsideration.

The City of San Diego, as a copermittee to the Regional Phase I MS4 Permit, could take reasonable and appropriate actions to comply with Receiving Water Limitations (Provisions A.2 and A.4) of the Regional MS4 Permit that would address the impairment of Famosa Slough including, and not limited to, the following for developing, committing to, and implementing actions that would attain the numeric goals and restoration of the beneficial uses of Famosa Slough by the end of 2027:

a. Identify nutrients in the Famosa Slough watershed as one of the highest priority projects in its JRMP.

b. Use the numeric targets, developed through the stakeholder process and identified in the TMDL Report, as numeric goals in the WQIP.

c. Incorporate a Famosa Slough monitoring and assessment program, as identified in the TMDL Report, into its JRMP or WQIP that includes at least DO and macroalgae biomass and is designed to detect attainment or non-attainment of the interim and final numeric targets of the TMDL Report.

d. Properly implement an illicit discharge detection and elimination program in compliance with existing requirements of the Regional MS4 Permit to effectively prohibit the City's non-storm water discharges into the MS4 system that discharges into Famosa Slough.

e. Develop, commit to, and implement actions to attain the numeric goals and restoration of the beneficial uses of Famosa Slough by the end of 2027 according to the schedule in Table 8-1.

Table 8-1. Implementation compliance schedule.

Year	Schedule to Address the Eutrophication Impairment in Famosa Slough	
	Activity	**Month/Year**
0	Properly implement an illicit discharge detection and elimination program in compliance with existing requirements of the Regional MS4 Permit to effectively prohibit the City's non-storm water discharges into the MS4 system that discharge into Famosa Slough. Implementation includes illicit discharge detection and elimination, and the assessment of accomplishments / progress.[1]	Ongoing
0	City prepares a Jurisdictional Runoff Management Program (JRMP) Compliance Monitoring Plan and QAPP for Famosa Slough. City submits draft plan and QAPP to San Diego Water Board for review.	Dec 2017
0	City updates its JRMP to include this schedule committing to develop, update and implement WQIP strategies (e.g., patrols and monitoring) for the Famosa Slough project.	Jan 2018
0	City initiates the updates to the WQIP Goals, Strategies and Schedules that align with the Famosa Slough TMDL and Staff Reports.	Jan 2018
0	San Diego Water Board approves Monitoring Work Plan and Quality Assurance Project Plan associated with the Famosa Slough Project.	Mar 2018
0	Begin compliance monitoring program for the Slough.	May 2018
0	Begin algae harvesting in response to excessive algal blooms, as needed.	May 2018
0	City submits for review to the San Diego Water Board, the draft WQIP goals, strategies and schedules associated with Famosa Slough project.	July 2018
0	San Diego Water Board approves draft WQIP goals, strategies and schedules associated with the Famosa Slough Project.	Sep 2018
0	City submits final proposed WQIP goals, strategies, monitoring plan, QAPP, and schedules associated with Famosa Slough project with the WQIP Annual Report.	Jan 2019
0	San Diego Water Board approves WQIP update for Famosa Slough as part of the FY19 WQIP Annual Report, compliance schedule begins.	Apr 2019
1	City submits WQIP Annual Report (including annual Monitoring Report) for the Slough.	Jan 2020
2	City submits WQIP Annual Report and (including annual Monitoring Report) for the Slough.	Jan 2021

Year	Schedule to Address the Eutrophication Impairment in Famosa Slough	
	Activity	**Month/Year**
3	City submits WQIP Annual Report and (including annual Monitoring Report) for the Slough.	Jan 2022
4	City submits WQIP Annual Report and (including annual Monitoring Report) for the Slough.	Jan 2023
5	City submits WQIP Report and annual Monitoring Report for the Slough demonstrating 40% attainment with required reduction in WLAs or showing marked progress toward attaining the macroalgae and DO targets.	Jan 2024
6	City submits WQIP Report and (including annual Monitoring Report) for the Slough demonstrating 40% attainment with required reduction in WLAs or showing marked progress toward attaining the macroalgae and DO targets.	Jan 2025
7	City submits WQIP Annual Report and (including annual Monitoring Report) for the Slough demonstrating 40% attainment with required reduction in WLAs or showing marked progress toward attaining the macroalgae and DO targets.	Jan 2026
8	City submits WQIP Annual Report and (including annual Monitoring Report) for the Slough demonstrating 60% attainment with required reduction in WLAs or showing marked progress toward attaining the macroalgae and DO targets.	Jan 2027
9	City submits WQIP Annual Report and (including annual Monitoring Report) for the Slough demonstrating 60% attainment with required reduction in WLAs or showing marked progress toward attaining the macroalgae and DO targets.	Jan 2028
10	City demonstrates 100% attainment of waste load reduction goals or achievement of macroalgae and DO targets.	Jan 2029

[1] The City is currently implementing weekly enforcement patrols of one of three drainage areas to prohibit unauthorized discharges. The drainage area is divided into three quadrants that are patrolled by a Code Enforcement Officer weekly. Weekly patrols will not occur during wet weather conditions (pavement dry after storm event) because of the inability to differentiate between storm flows and unauthorized discharges.

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Appendix A

Famosa Slough Watershed and Receiving Water Modeling Report

Contents

Tables

Figures

1. Introduction

Water quality modeling can be used to establish the quantitative understanding necessary to develop scientifically justifiable Total Maximum Daily Loads (TMDLs) for a waterbody. A water quality model that is customized for a specific waterbody can simulate the major physical, chemical, and biological processes that occur in the system, and thus provide quantitative relationships between the water quality response and external forcing functions. A customized modeling framework was developed to support development of an eutrophication TMDL for Famosa Slough. For this document, the entire system is referenced as Famosa Slough. The open water portion south of Point Loma Boulevard is referenced as the Slough, whereas, the reach that connects the Slough with the San Diego River is referenced as the Channel.

The modeling framework used in this study can be divided into two major components, which represent the processes essential for accurately modeling hydrology, hydrodynamics, and water quality in Famosa Slough and its watershed. The first component of the modeling system is a watershed model developed to predict pollutant loadings for the watershed that drains to Famosa Slough. The second component is a receiving water model of Famosa Slough itself to simulate water circulation and pollutant transport in the tidally-influenced receiving waterbody. The Loading System Program in C++ (LSPC) was selected to simulate the watershed loadings (Shen et al., 2005; USEPA, 2003a), and Famosa Slough was represented by the Environmental Fluid Dynamics Code (EFDC) (Hamrick, 1992).

Both models selected are components of the United States Environmental Protection Agency's (USEPA) TMDL Modeling Toolbox (Toolbox), which has been developed through a joint effort between USEPA and Tetra Tech, Inc. (USEPA, 2003b). The Toolbox is a collection of models, modeling tools, and databases that have been utilized over the past decade in the determination of TMDLs for impaired waters. It takes these proven technologies and provides the capability to more readily apply the models, analyze the results, and integrate watershed and detailed hydrodynamic and water quality receiving water applications. The Toolbox provides exchange of information between the models through common databases; therefore, the results from the LSPC model were easily incorporated into the EFDC water quality model.

The Famosa Slough watershed is a small, 358-acre, coastal watershed that was represented by the LSPC watershed model. It is entirely within the City of San Diego and between Ocean Beach and Loma Portal. The watershed encompasses the 22-acre Famosa Slough and a 10-acre channel, which connects the Slough with the tidal portion of the San Diego River via tide gates (Figure 1). For the purpose of this report, the Slough is considered as the ponded open water area south of Point Loma Boulevard and the Channel as the area connecting the San Diego River estuary to the Slough.

The Channel is connected to the Slough by two pairs of culverts under Sports Arena/Point Loma Boulevard. Approximately half of the watershed drains into the Slough and half into the Channel. The Slough and the Channel were simulated using the EFDC receiving water model. The EFDC receiving water model was linked to the LSPC model to incorporate watershed loads from the subwatersheds draining to Famosa Slough.

This modeling report is intended to accompany a TMDL report and provides a more detailed discussion on the models used for the TMDL analyses, including model configuration, calibration and validation, and assumptions. Specifically, Section 2 describes the watershed model (LSPC), Section 3 discusses the receiving water model (EFDC), Section 4 presents the management scenario results, and Section 5 lists the references that are cited.

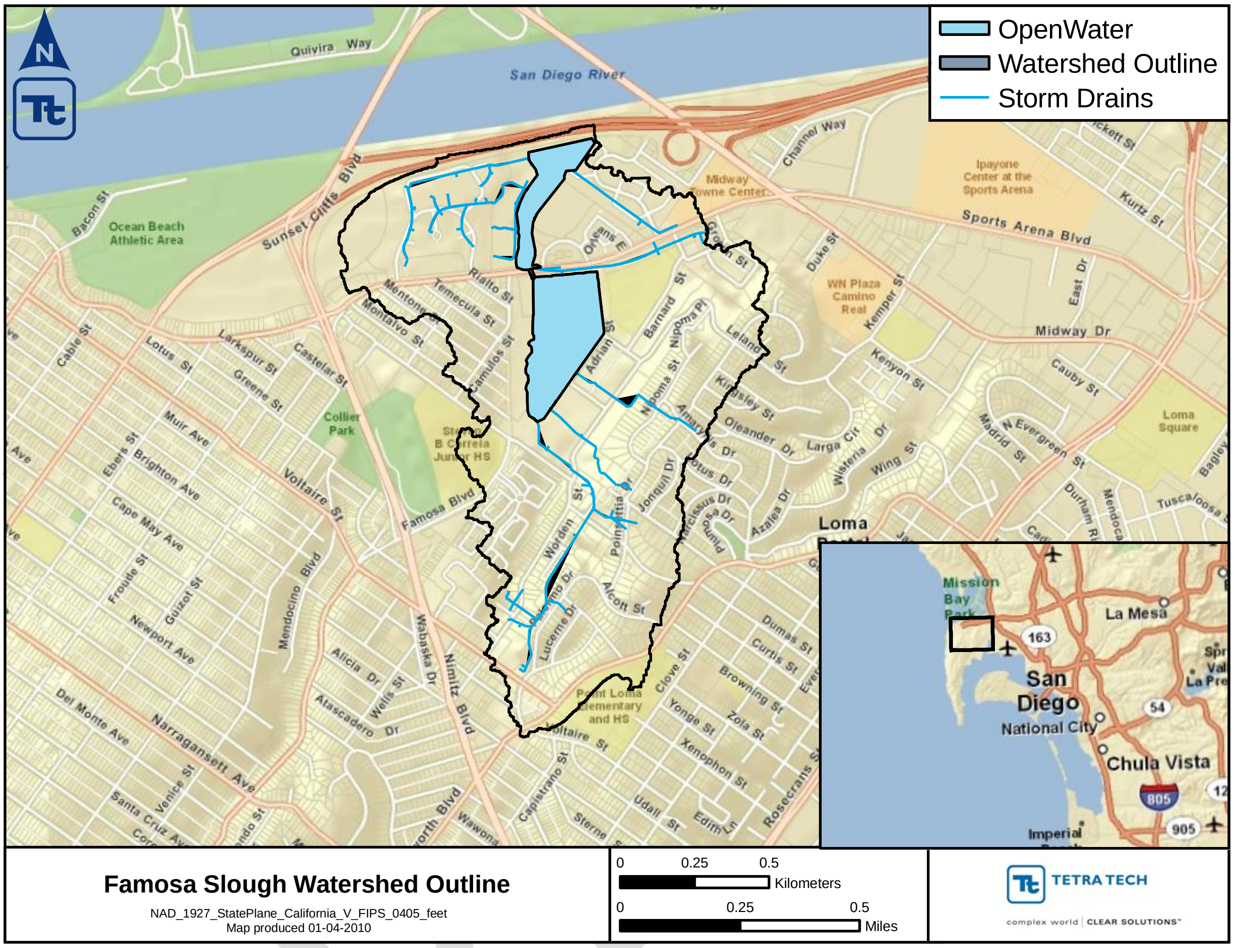


Figure 1. Location of the Famosa Slough Watershed

2. Watershed Loading Model —LSPC

LSPC (Shen et al., 2005; USEPA, 2003a) is a watershed modeling system that contains streamlined Hydrologic Simulation Program Fortran (HSPF) (Bicknell et al., 2001) algorithms to simulate hydrology, sediment, and general water quality on land, as well as a simplified stream fate and transport model. Since its original public release, the LSPC model has been expanded to include additional GQUAL components for sorption/desorption of select water quality constituents with sediment, enhanced temperature simulation, and the HSPF RQUAL module for dissolved oxygen, nutrients, and algae simulation. LSPC has also been customized to address simulation of other pollutants such as nutrients and fecal coliform bacteria.

The hydrologic (water budget) process is complex and interconnected within LSPC (Figure 2). Precipitation falls on various land covers within a watershed including impervious cover, constructed landscapes, vegetation, and bare soil areas. Varying soil types allow the water to infiltrate at different rates while evaporation and plant matter exert a demand on this rainfall. Water flows overland and through the soil matrix. The land representation in the LSPC model environment considers three flowpaths: surface, interflow, and groundwater outflow. LSPC can simulate flow, sediment, metals, nutrients, pesticides, and other conventional pollutants for pervious and impervious lands as well as in water bodies. The model has been successfully applied and calibrated in Southern California for the Los Angeles River, the San Gabriel River, the San Jacinto River, Lake Mathews watershed, the Chollas/Paleta/Switzer Creek watersheds, the B Street/Downtown Anchorage watersheds, and multiple watersheds draining to impaired beaches of the San Diego Region.

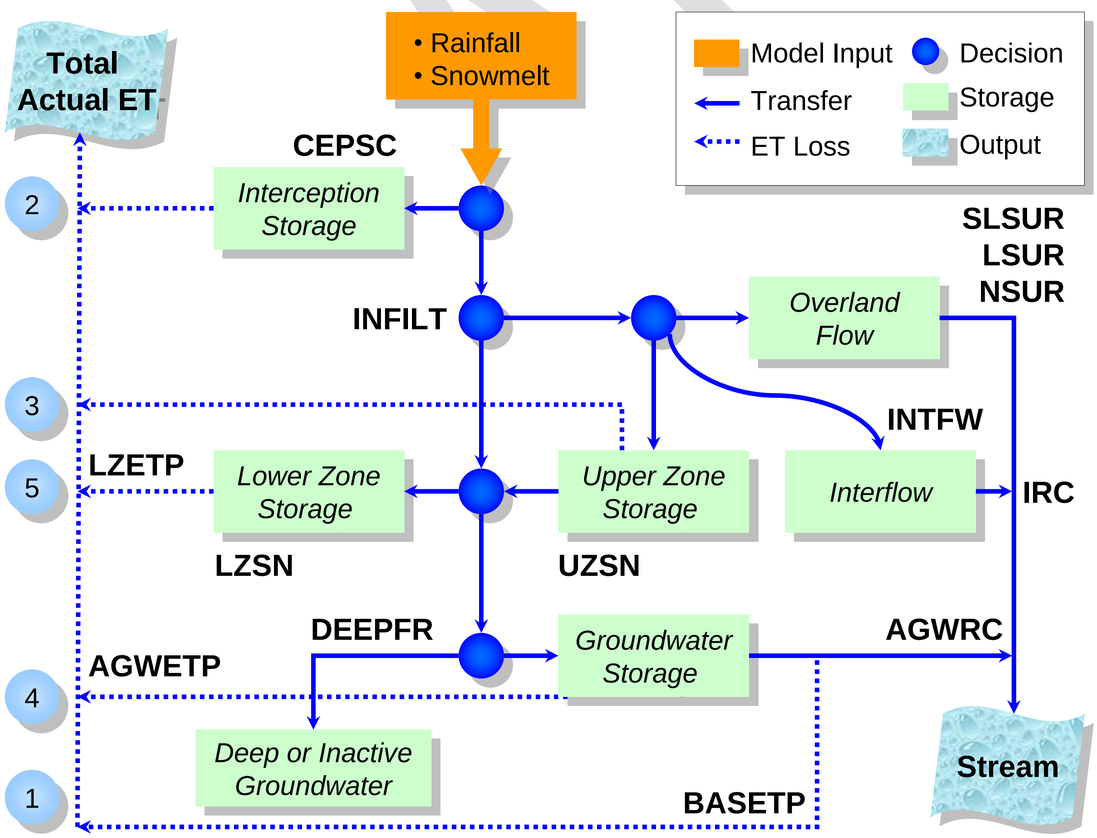


Figure 2. Schematic of LSPC Hydrology Components

2.1. Watershed Data Inventory and Analysis

Multiple data sources were used to characterize the water quality and flows from the watershed into Famosa Slough. The majority of this information was recently collected to assist with model development. Data describing the watershed's topography, land use, and soil characteristics were compiled and used to develop the watershed model. Stream flows and nutrient concentrations were used to validate the watershed model components.

2.1.1. Land Use

The watershed model requires a basis for distributing hydrologic and pollutant loading parameters. This is necessary to appropriately represent hydrologic variability throughout the basin, which is influenced by land surface and subsurface characteristics. It is also necessary to represent variability in pollutant loading, which is highly influenced by land practices. The basis for this distribution was provided by a land use coverage of the entire modeled area. The source of land use data was the San Diego Association of Governments (SANDAG) 2009 land use dataset that covers San Diego County. Land use distribution within the watershed is shown in Figure 3.

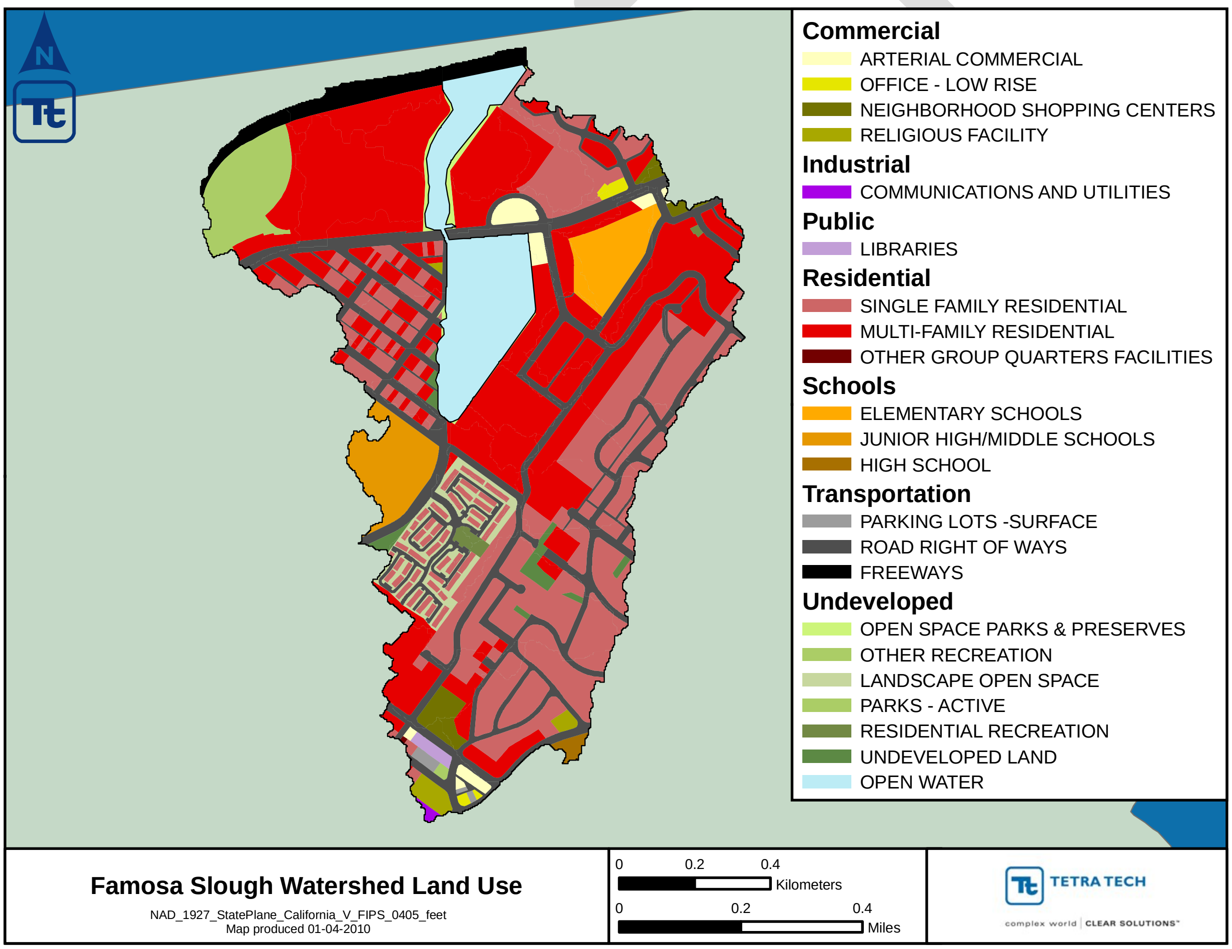


Figure 3. Famosa Slough Watershed Land Use

2.1.2. Storm Drains

Stormwater runoff in the watershed is conveyed to the Famosa Slough via a storm drain network and overland flow (Figure 1 and Figure 4). There are 3.8 linear miles of storm drains in the watershed. Information detailing the storm drains within the Famosa Slough watershed was obtained from SanGIS (SanGIS, 2010).

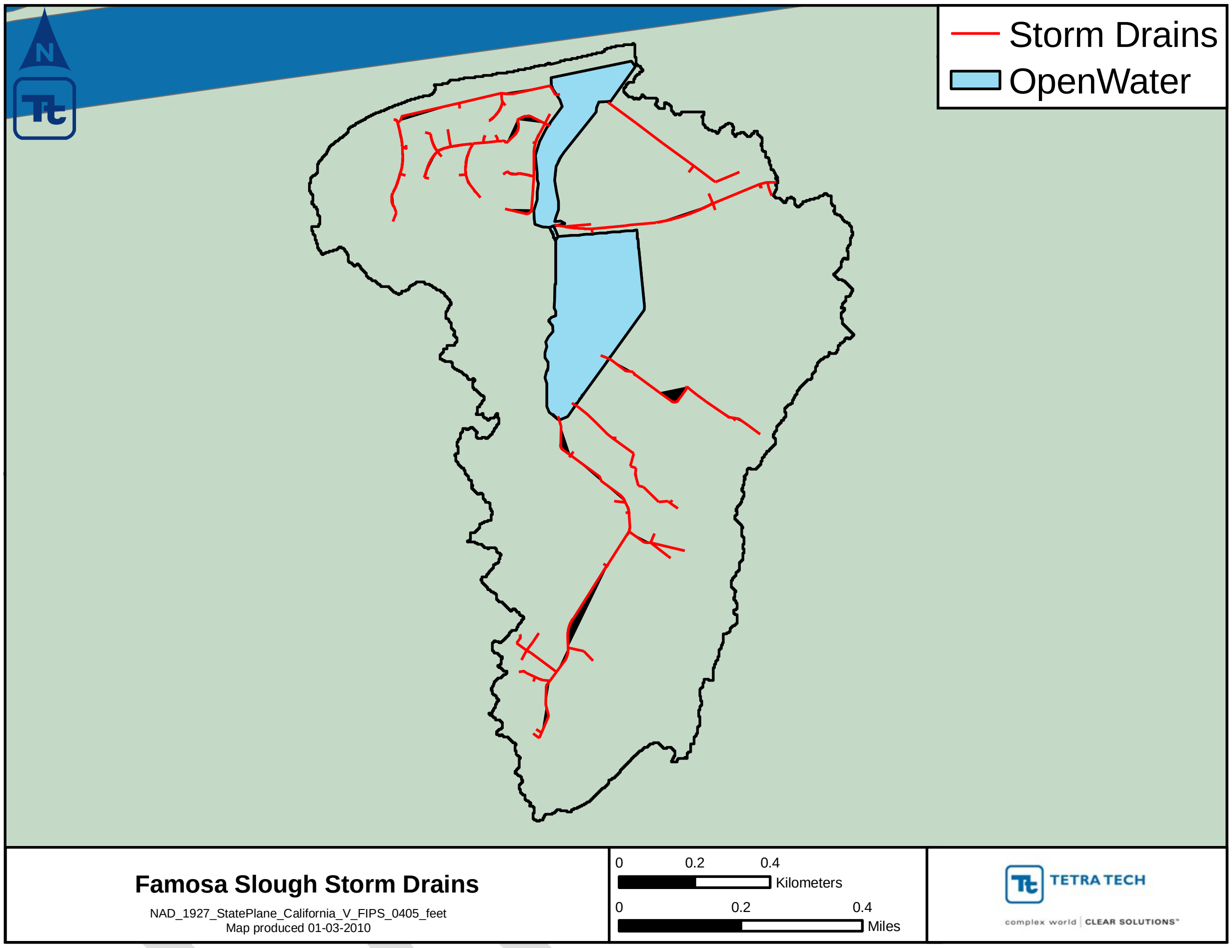


Figure 4. Famosa Slough Storm Drains

2.1.3. Topography

Topographical information was primarily used to describe the slope of the catchment reaches within the watershed. Three-meter elevation data was downloaded from the Natural Resources Conservation Service (NRCS, 2010). Elevation in the watershed ranges from 1.8 to 61 meters (North American Vertical Datum of 1988) (Figure 5). The highest elevations are in the southeastern side of the watersheds and the lowest elevations are near the channel.

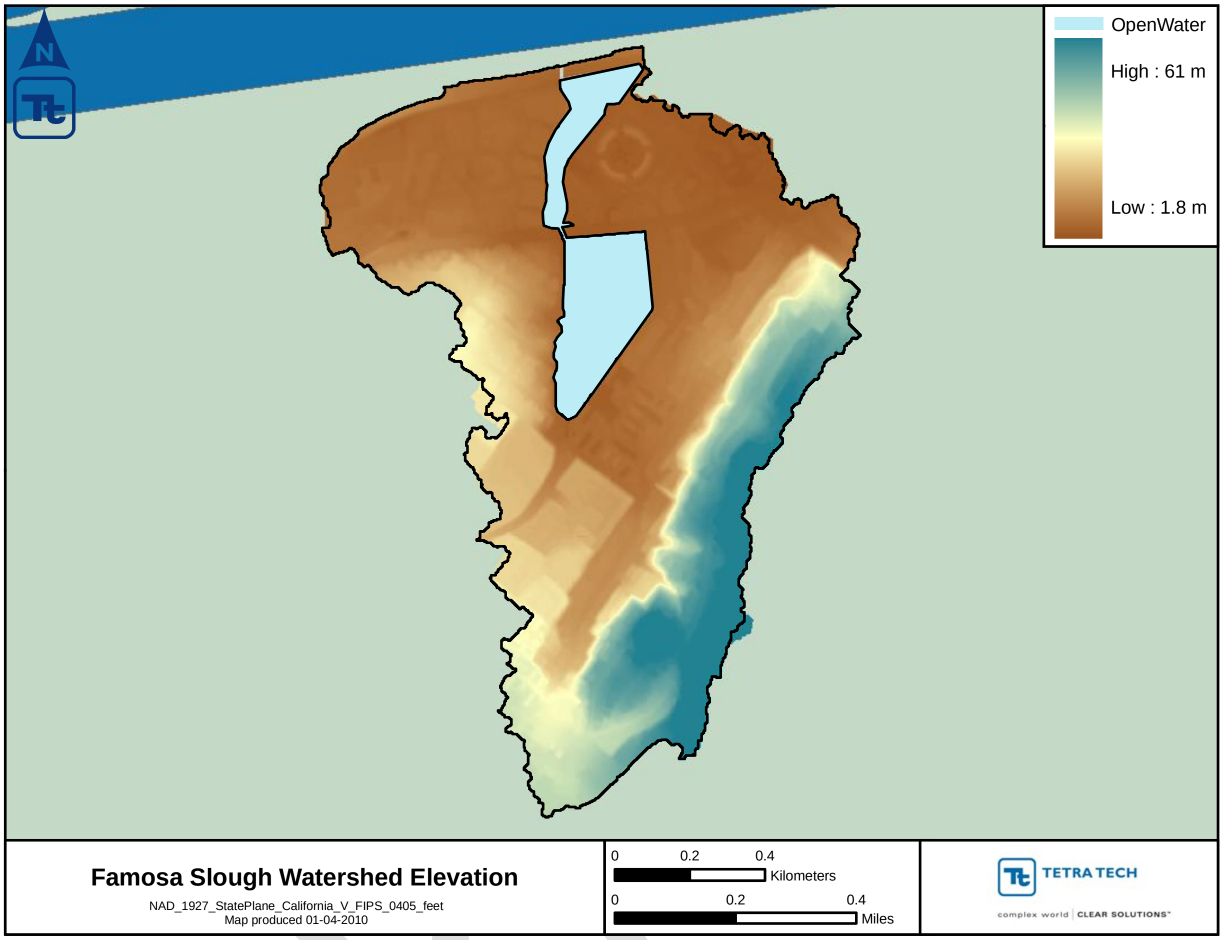


Figure 5. Famosa Slough Watershed Elevation

2.1.4. Soil Characteristics

Soils data for the Famosa Slough watershed were used to classify the soil types throughout the watershed based on infiltration rates. The Soil Survey Geographic (SSURGO) Database was used to characterize the soils.[1] Sixty percent of the watershed was not classified by the SSURGO data; however, the majority of the watershed that was characterized (32 percent of entire watershed) was classified as hydrologic type B soils (Figure 6). The unclassified soils were likely modified urban soils that have a high degree of development and impervious cover. In the model, soils of like characteristics are grouped into hydrological soils groups (HSGs).

[1] http://soils.usda.gov/survey/geography/ssurgo/

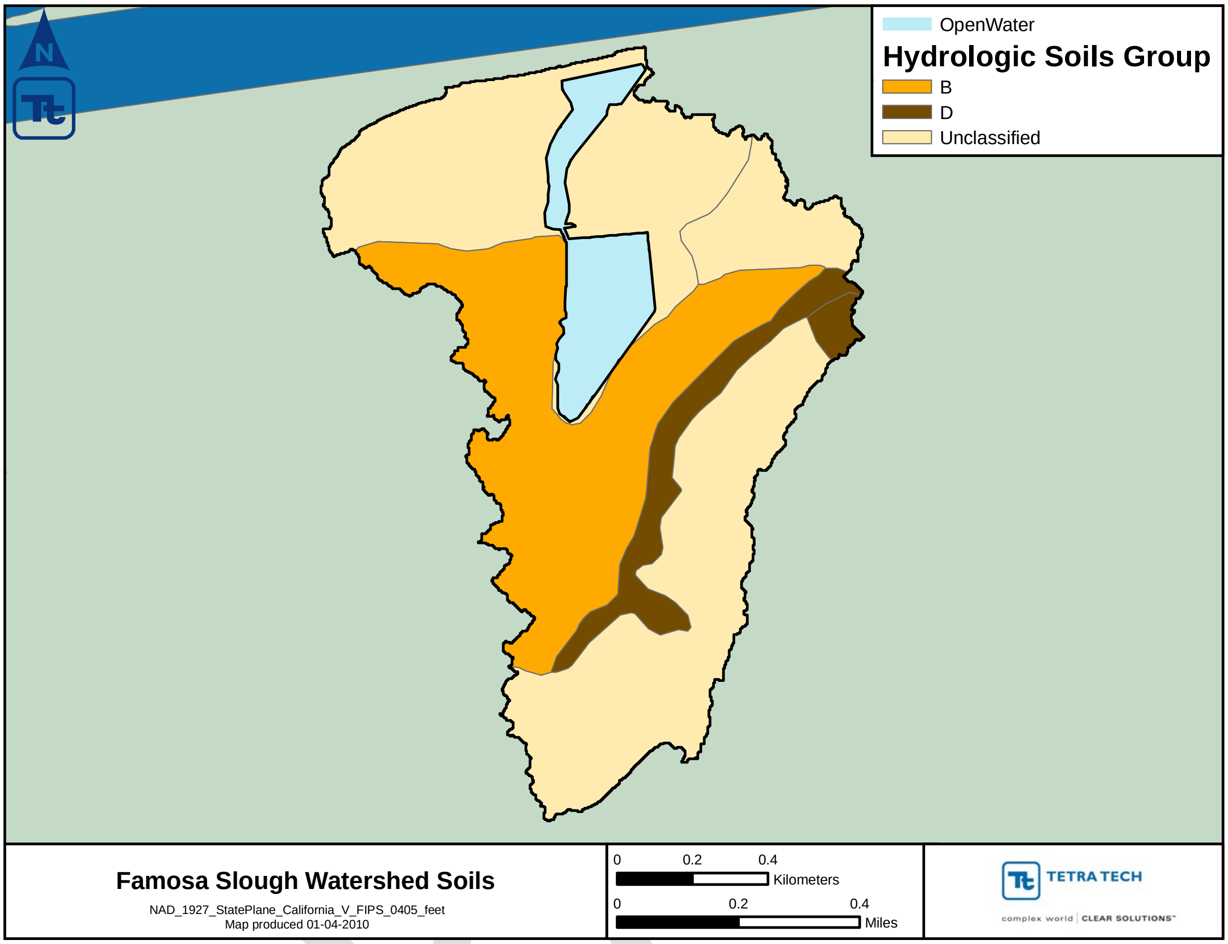


Figure 6. Famosa Slough Watershed Soils

2.1.5. Meteorological Data

Meteorological data are a critical component of the watershed model. LSPC requires appropriate representations of precipitation and potential evapotranspiration. Rainfall-runoff processes for each catchment were driven by precipitation data from the closest representative station. In general, hourly precipitation data are recommended for nonpoint source modeling. Therefore, only weather stations with hourly-recorded data were considered in the climate data selection process. National Climatic Data Center (NCDC) precipitation data were reviewed on the basis of geographic location, period of record, and missing data to determine the most appropriate meteorological stations to represent the watersheds. Lindbergh Field station at the San Diego Airport (COOP ID # 047740) was selected as the most representative weather station for the Famosa Slough watershed (Figure 7). In addition to hourly precipitation data, the station has long-term hourly wind speed, cloud cover, temperature, and dew point data. Evapotranspiration data were obtained from the California Irrigation Management Information System (CIMIS) station 184 (Figure 7).

Rainfall was also monitored at the mass emission station (MES), located at the southern end of Famosa Slough, but was not used in the modeling of the watershed. Analysis of the MES rainfall data showed that several runoff events in February 2008 had no measurable rainfall recorded at the MES but were measured at the Airport (Figure 8)[2]. Because of the inconsistencies between the monitored rainfall at the MES and

[2] Weston Solutions (2009) indicated that there was a rain gauge malfunction for the February 3, 2008 rain event.

the flow at the MES, the rainfall record at the airport was used to characterize rainfall throughout the watershed.

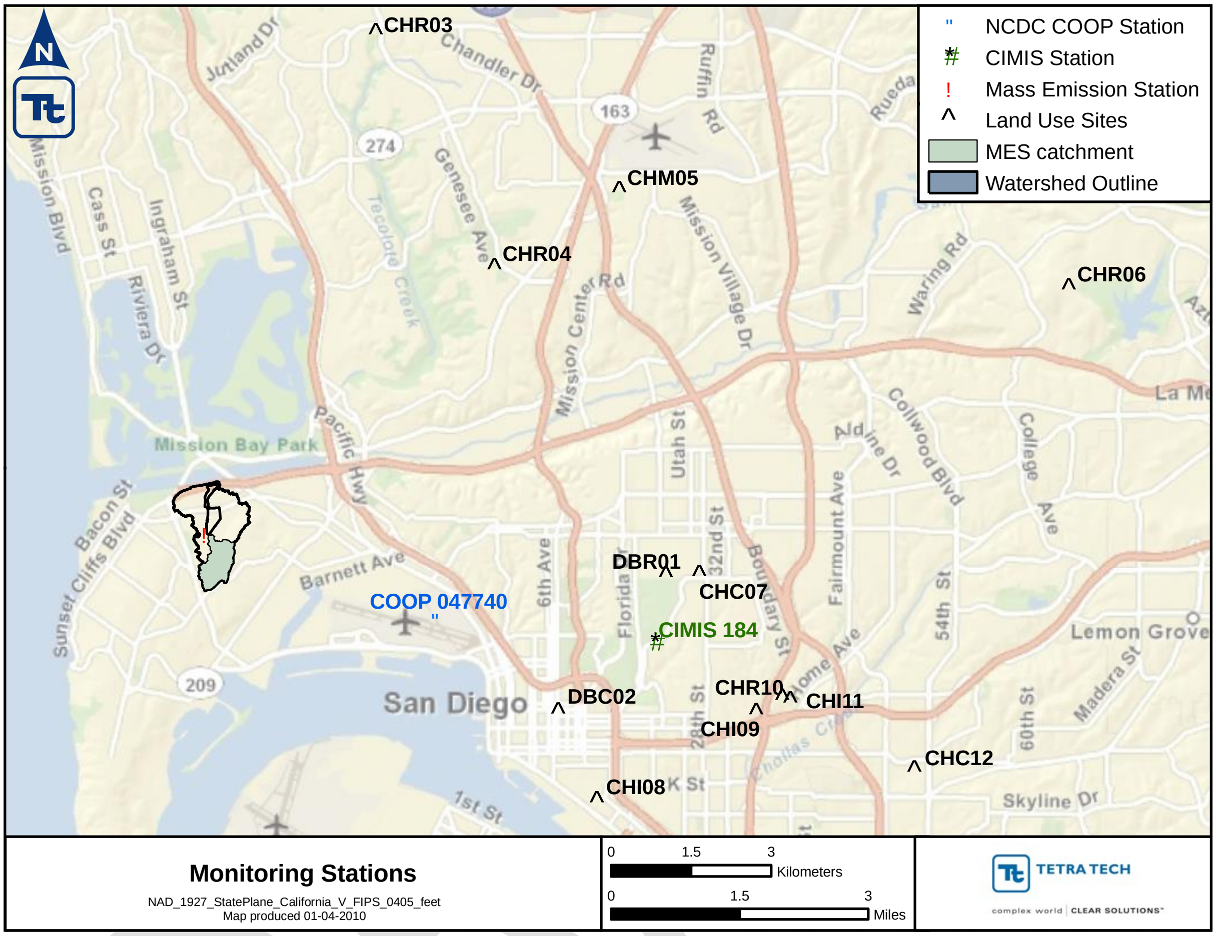


Figure 7. Monitoring Stations near and within the Famosa Slough Watershed

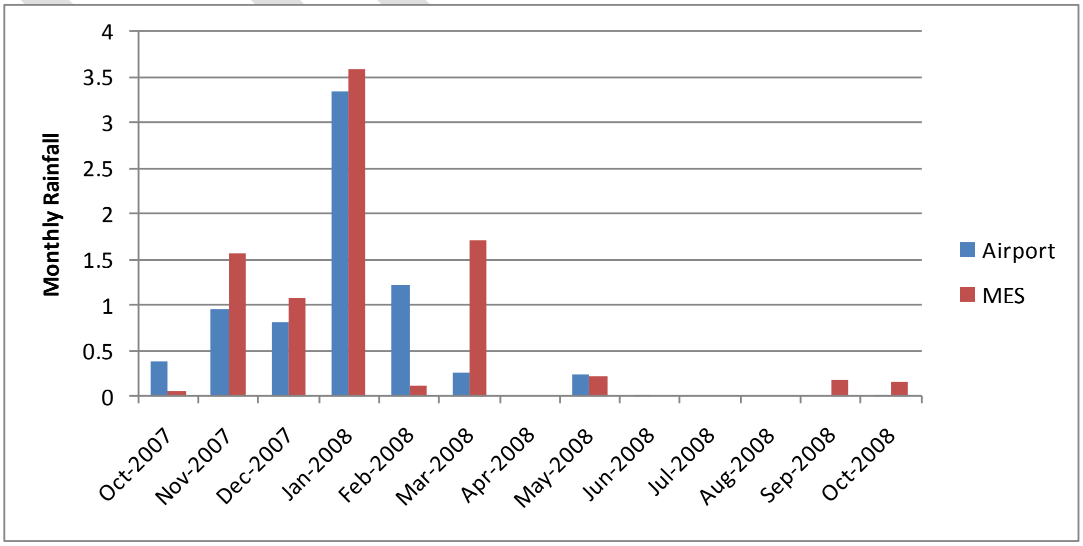


Figure 8. Monthly Rainfall at San Diego International Airport and the MES

2.1.6. Streamflow Data

A continuous record of flows is available from the storm drain at the MES location (Figure 7), which has a catchment area of 106 acres. Flows at the MES were estimated at 15-minute intervals from October 2007 to October 2008 using Manning's equation to convert water depth to flow (Weston Solutions, 2009) (Figure 9). The estimated flow at the MES was never zero. Median flows were 0.35 cubic feet per second (cfs) throughout the monitoring period with only four percent of the monitored flows more than double the median (Figure 10). This is because a small pipe downstream of the monitoring location was raised and slightly pooled the water (Gretel Roberts, personal communication). Figure 11 presents the detailed hydrographs for the three monitored events at the MES.

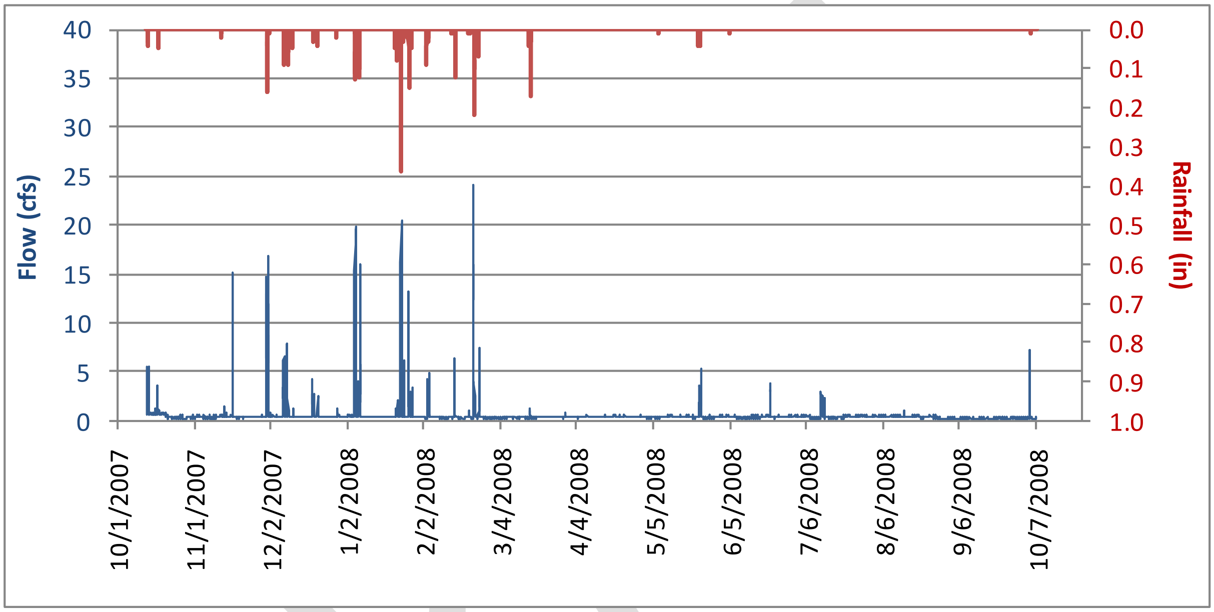


Figure 9. Average Hourly MES Flow and Rainfall

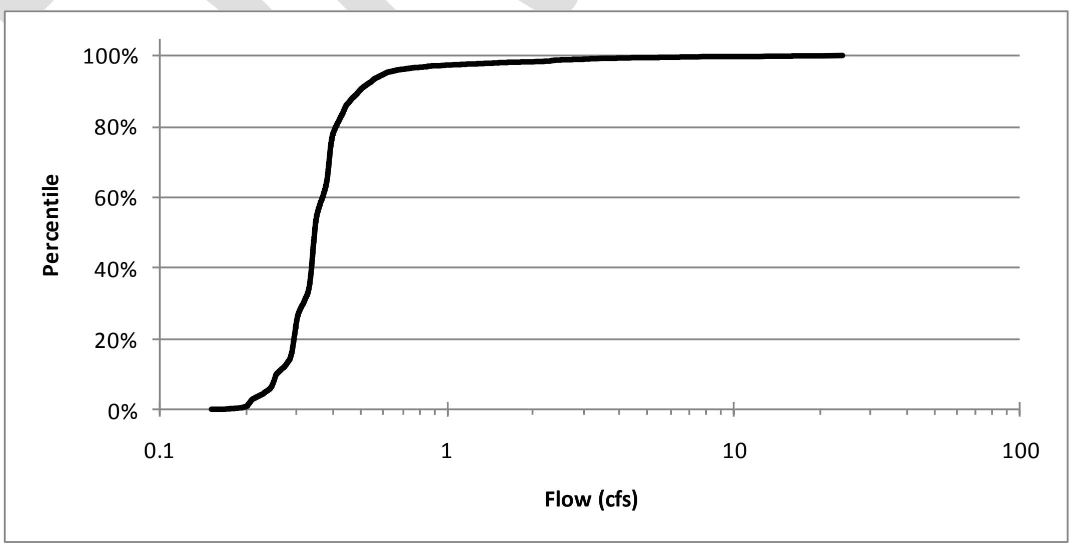


Figure 10. Distribution of Flows at the MES

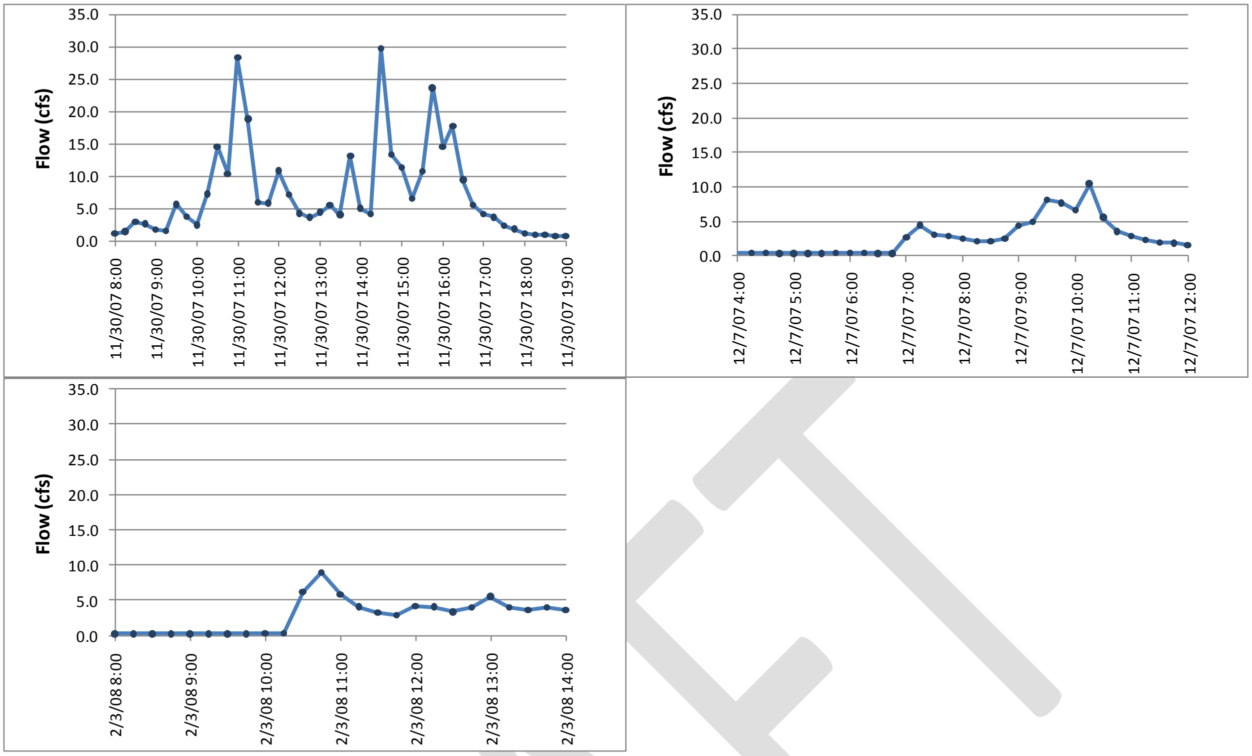


Figure 11. Sampled Storm Hydrographs at MES

2.1.7. Water Quality Data

2.1.7.1. Stormwater Runoff

Stormwater nutrient data were also collected at the MES in Famosa Slough for three events during the October 2007 to October 2008 sampling period. These data were used for validation tests (Section 2.4.2) to ensure the amalgamated runoff from the various land uses was correctly modeled in LSPC.

Flows from the watershed discharge from a 36-in reinforced concrete pipe to a concrete trapezoidal channel and then to the Slough (Figure 12). Within the trapezoidal channel, there is a plant community of *Typha* (cattail) and *Cyperus* (sedge) (Gretel Roberts, Weston Solutions, personal communication) (Figure 13). This plant community reduces the nutrient concentrations flowing into the Slough from the watershed. Because the plants removed nutrients before the sampling point, a rigorous validation of the water quality from the watershed was not possible.

Details of the sampling methodology and results are provided in Weston Solutions (2009). The total nitrogen and total phosphorous pollutographs during the three events, along with the resulting event mean concentrations (EMCs) for each, are presented in Figure 14 and Figure 15, respectively. When comparing the three storms, the December 7, 2007 storm had higher peak concentrations of both total nitrogen and total phosphorous.

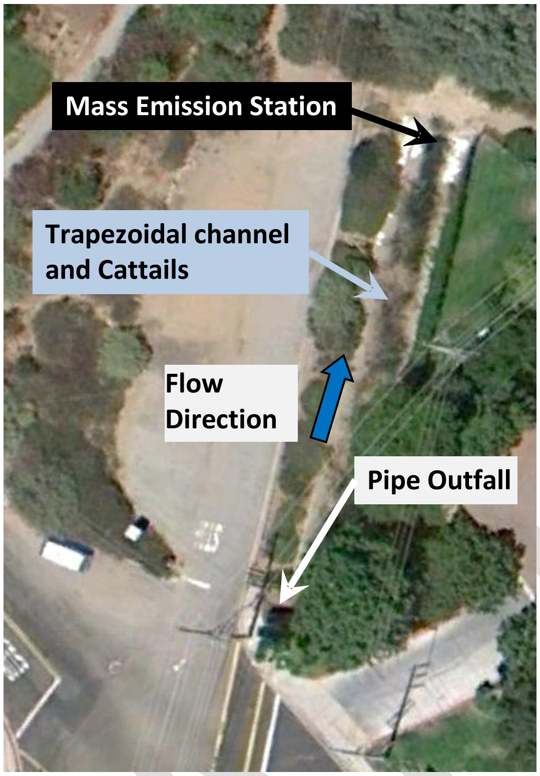


Figure 12. MES Aerial View

Figure 13. Plant Community in the Trapezoidal Channel Upstream of the MES

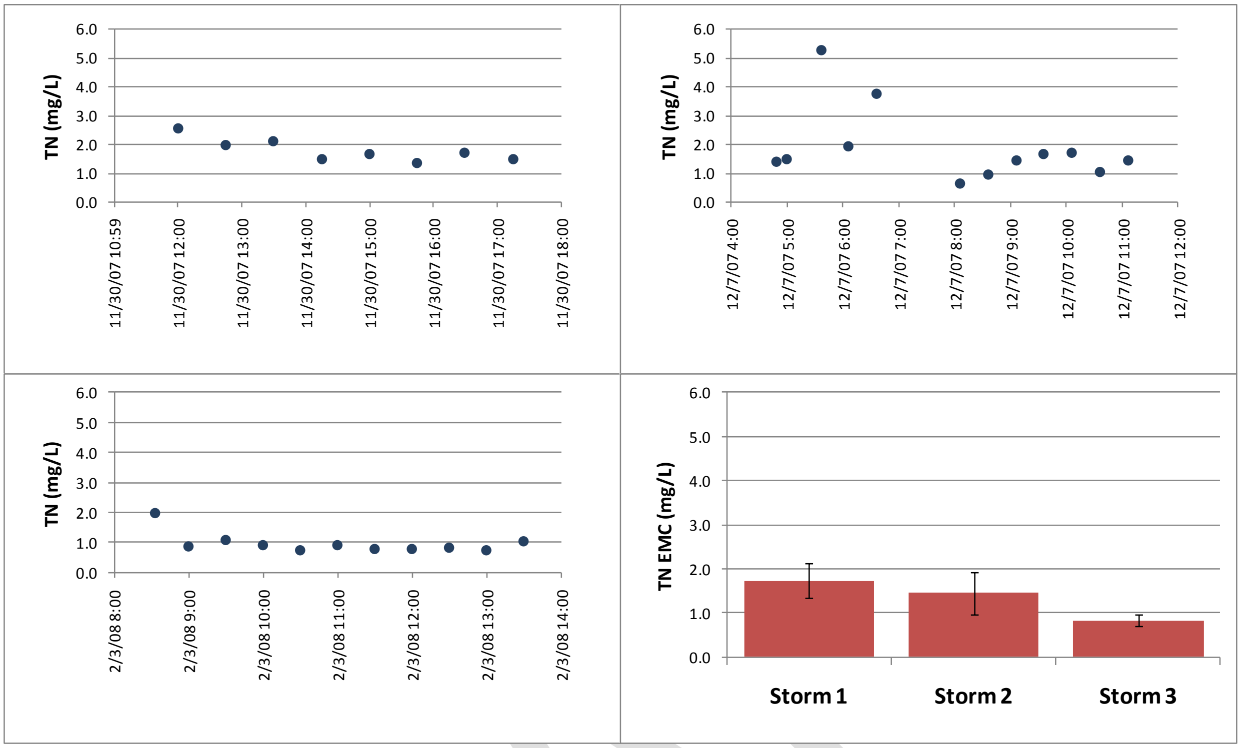


Figure 14. Sampled Storm Total Nitrogen Pollutographs and EMCs

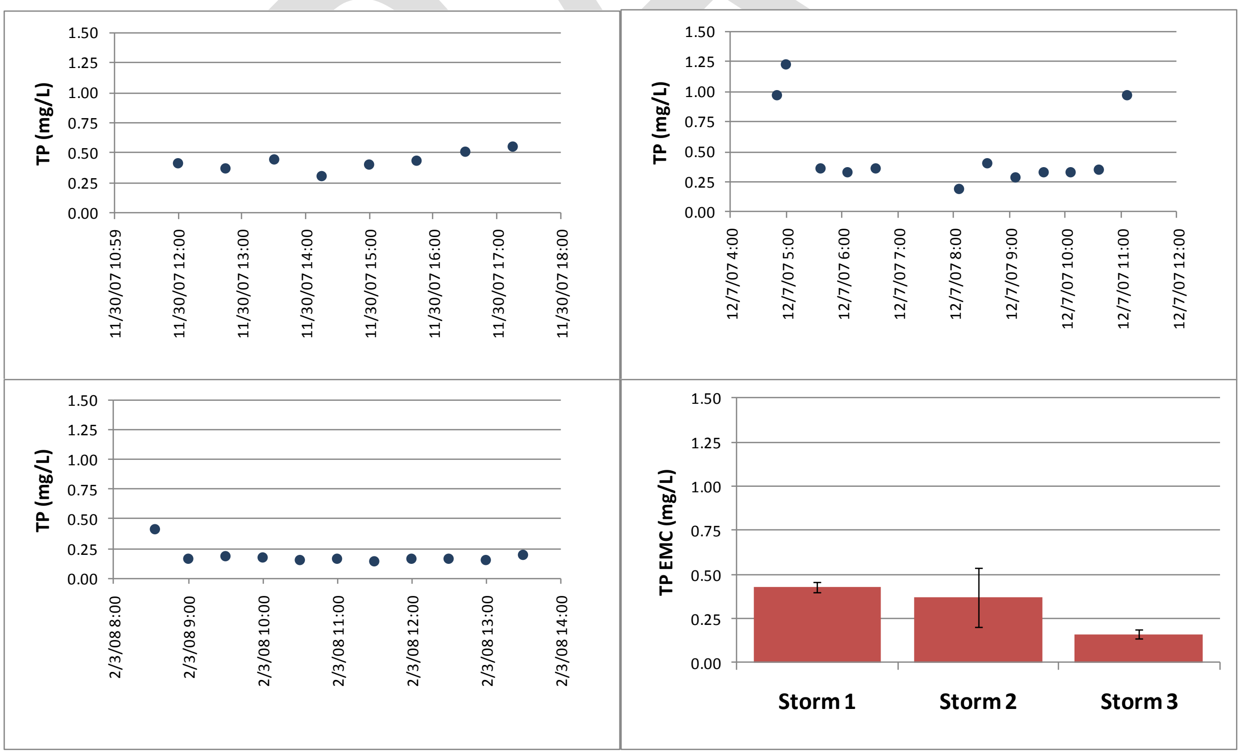


Figure 15. Sampled Storm Total Phosphorous Pollutographs and EMCs

Nutrient levels in the watershed model were calibrated to EMC data collected during a sampling effort in 2009–2010 in the Chollas Creek watershed. The Chollas Creek watershed is 6 miles east of the Famosa Slough watershed and has similar land use characteristics.

Twelve small land use sites (Figure 7) of predominantly a single land use type (Figure 16 and Figure 17) were sampled during two storms (12/07/2009 and 01/18/2010). A detailed description of the sampling methods and resultant nutrient concentrations is provided in other reports (City of San Diego, 2010a and City of San Diego, 2010b). The land use distribution of those 12 sites is shown in Figure 16 and Figure 17.

Figure 16. Land Use Composition of 2009–2010 Chollas Creek Watershed Monitoring Sites (Set 1 of 2)

Figure 17. Land Use Composition of 2009–2010 Chollas Creek Watershed Monitoring Sites (Set 2 of 2)

The total nitrogen and total phosphorous EMCs and 95th percentile flow-weighted confidence interval (Equation 1) were calculated for each site-event (Figure 18 and Figure 19). Overall, stations representing the roads land use demonstrated the highest EMC for total nitrogen, but industrial sites exhibited the highest total phosphorous EMC. When evaluating the total nitrogen EMC results, the first storm had higher EMCs than the second storm at nine of the twelve stations. This trend is less pronounced for total phosphorous, where the EMCs for the first storm exceeded those for the second storm at seven of the twelve sites. The Chollas data were used because it was the best available data. This provides a conservative assumption because of the higher total nitrogen and total phosphorous values in the Chollas watershed monitoring stations compared to the Famosa Slough storm events.

$$95\% \text{ confidence interval} = 1.96\sqrt{\frac{\sum[(c_i - c_{avg})v_i]^2}{(\sum v_i)^2}} \qquad \text{Equation 1}$$

Where:

c_i = concentration at time i

c_{avg} = average concentration

v_i = volume at time i.

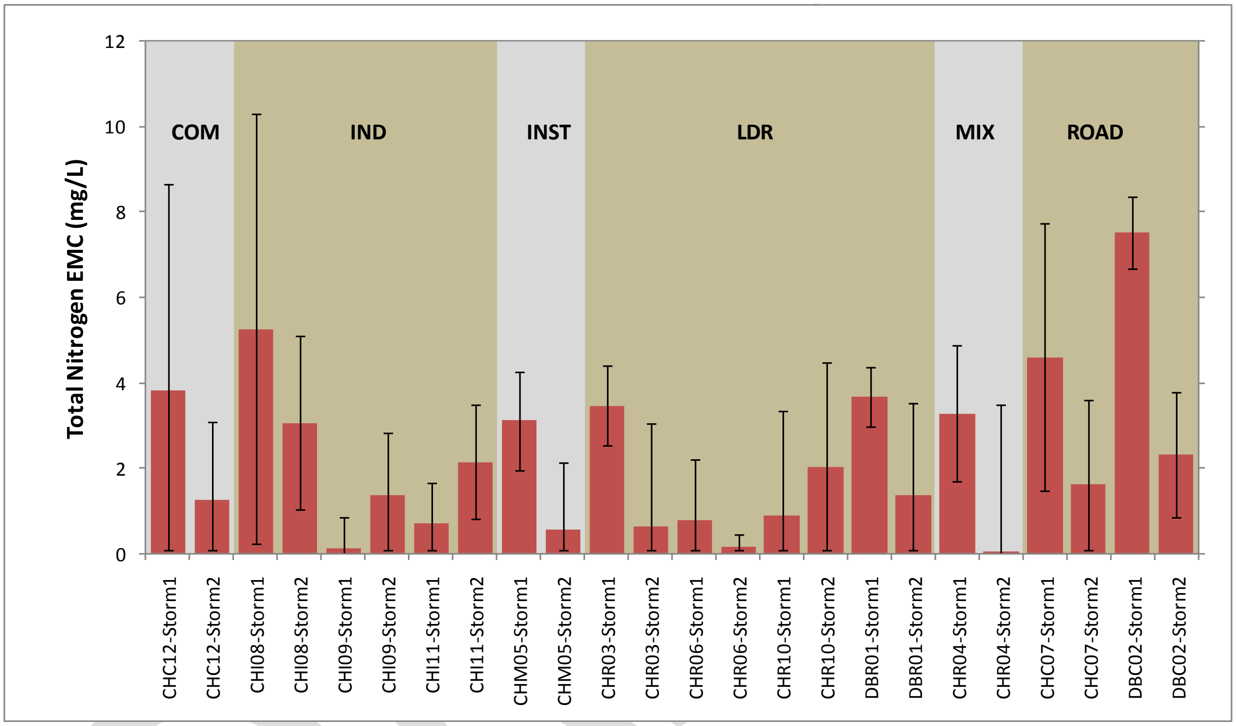


Figure 18. Land Use Total Nitrogen EMCs (Chollas Creek Watershed Monitoring Sites)

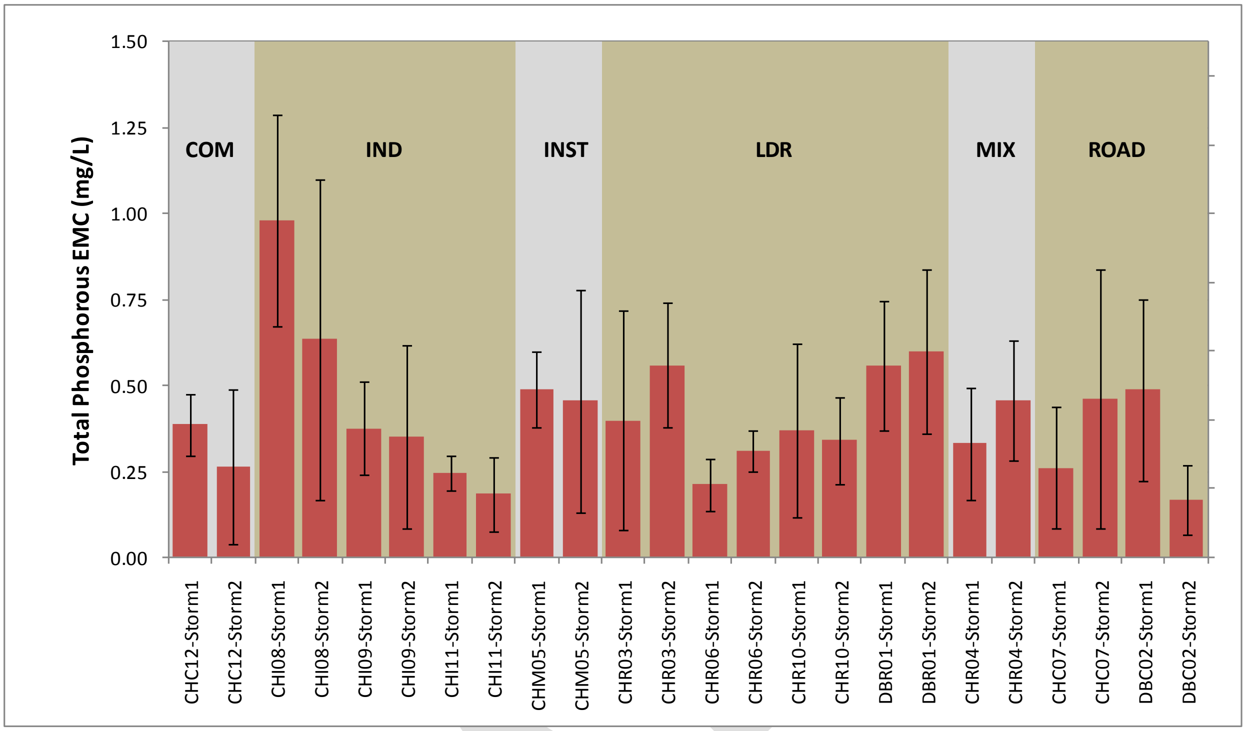


Figure 19. Land Use Total Phosphorous EMCs (Chollas Creek Watershed Monitoring Sites)

2.1.7.2. Dry Weather Runoff

Dry weather water quality concentrations at the MES were measured during samplings in January, March, July, and September of 2008 (Table 1) as part of Index Period monitoring to provide data for calibration and validation of the hydrodynamic and water quality models (Weston Solutions, 2009).

Six daily samples (30-minute composite sampling) were collected during each sampling period (Weston Solutions, 2009). The median concentrations of total nitrogen and total phosphorous were calculated for each monitoring period and was assumed to be representative of the groundwater water quality (see Section 2.2.6 for additional discussion on the baseline water quality).

Table 1. MES 2008 Dry Weather Water Quality Results

Date	Total Nitrogen (mg/L)	Total Phosphorous (mg/L)
01/14/08	0.73	0.38
01/15/08	0.66	0.19
01/16/08	0.46	0.27
01/21/08	0.89	0.59
01/22/08	0.58	0.39
01/23/08	0.65	0.70
03/18/08	1.40	0.82
03/19/08	1.82	0.82
03/20/08	0.73	0.47
03/24/08	1.03	0.27
03/25/08	0.84	0.40
03/26/08	0.85	0.21

Date	Total Nitrogen (mg/L)	Total Phosphorous (mg/L)
07/14/08	0.73	0.48
07/15/08	1.25	0.74
07/16/08	1.07	0.66
07/21/08	1.00	0.68
07/22/08	1.40	0.73
07/23/08	1.13	0.68
09/15/08	0.86	0.65
09/16/08	0.89	0.69
09/17/08	0.81	0.66
09/22/08	0.61	0.56
09/23/08	0.73	0.62
09/24/08	0.58	0.52

2.2. Watershed Model Setup

The watershed model primarily uses information that details soil characteristics, land use distribution, topography, weather data, and the stream network to simulate hydrology and sediment contributions to Famosa Slough. Key data sources were compiled to support development of the watershed model (as described in previous sections).

2.2.1. Catchment Delineation

The modeled watershed is entirely within the City of San Diego and discharges to the Famosa Slough. The contributing drainage area was represented in LSPC by a series of catchments (subwatersheds) to better evaluate sources contributing to the water bodies and to represent the spatial variability of these sources (Figure 20). These subdivisions were based on Digital Elevation Model (DEM) data and GIS defining the storm water conveyance system. The catchments draining to the MES, used to quantify the models' performance, encompass 106 acres, or 30 percent of the 358 acres that drain to the Famosa Slough.

2.2.2. Streams

Streams in each catchment were defined using existing storm drain information where available (Figure 20). Within LSPC, a water conveyance is needed to route water from each catchment. In those catchments where a storm drain was not identified, a reach was delineated using the DEM using ArcGIS processing (Figure 20).

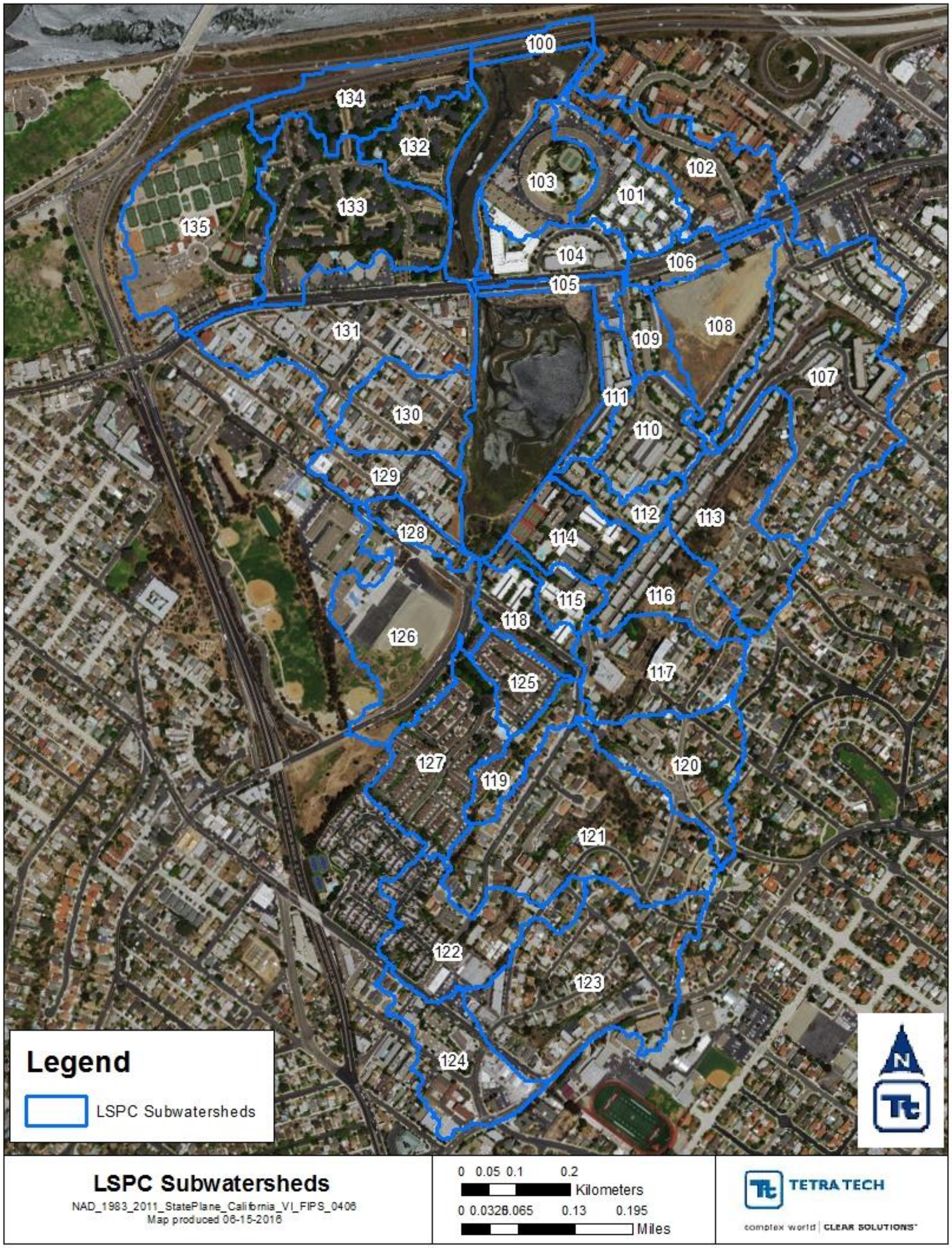


Figure 20. Famosa Slough Watershed Delineation

2.2.3. Land Use

LSPC algorithms require land use in each catchment to be divided into land use types and pervious and impervious categories (Table 2). The land use types with the greatest area in the Famosa Slough watershed are residential lands (multi- and single family residential), followed by roads.

Table 2. Land Use Distribution and Percent Imperviousness

Land Use	Famosa Slough Area (acres)	Percent Imperviousness	MES Drainage Area (acres)
Commercial	11.5	85%	6.5
Freeways	9.4	100%	0.0
Industrial	0.4	75%	0.4
Multi-Family Residential (MFR)	125.6	89%	19.5
Open	11.3	0%	5.5
Open Recreational	15.1	0%	0.0
Park	1.4	15%	0.8
Parking	0.8	90%	0.8
Public	0.9	85%	0.9
Road	69.2	100%	22.8
School	21.2	85%	1.0
Single Family Residential (SFR)	91.6	85%	42.8

2.2.4. Soils

The largest identified HSG within the watershed is hydrologic group B. Type B soils have moderate infiltration rates when thoroughly wetted, and consist of moderately fine to moderately course textures. However, because Famosa Slough has a highly developed (93 percent) watershed, the overall watershed hydrology is influenced more by the impervious surfaces than the soil characteristics.

2.2.5. Dry Weather Flows

In southern California, persistent flow exists during periods between storms that were observed in the flow records (see Figure 9). These anthropogenic flows originate from waters imported into the watershed from activities such as overwatering lawns, washing sidewalks, and washing cars. Dry weather flows need to be included in the model differently than rainfall runoff events. There are 19 storm drains that contribute continuous flow from the watershed to Famosa Slough (Weston Solutions, 2009).

Dry weather flows were simulated in the model by using irrigation algorithms. The irrigation demand for the watershed model was calculated based on information presented in *A Guide to Estimating Irrigation Water Needs of Landscape Plantings in California* (California Department of Water Resources, 2000). The approach described in this document uses the potential evapotranspiration (PET) method and compares daily precipitation to water demand to determine the amount of irrigation water.

The PET method for irrigation application requires seven parameters to be defined for each land use type. The irrigation module in LSPC is flexible in that it can simulate many different types of irrigation based on the model compartment where the irrigation water volume is added (Table 3). For example, sprinklers can be simulated through fraction 1, which applies irrigation in the same manner as rainfall. Drip irrigation can be applied directly to the soil surface through fraction 2. Buried irrigation systems can be simulated by inserting irrigation water into one of three subsurface layers, represented by fractions 3, 4, or 5. For the purposes of this modeling application, it was assumed that waters were applied onto the canopy (fraction 1).

Table 3. Irrigation Parameters in LSPC

Parameter	Definition
fraction1	fraction of irrigation requirement applied over the canopy
fraction2	fraction of irrigation water applied directly to the soil surface
fraction3	fraction of irrigation water applied to the upper soil zone via buried systems
fraction4	fraction of irrigation water likewise applied to the lower soil zone
fraction5	fraction of irrigation water entering directly into the local groundwater, such as seepage irrigation
ETcoeff	coefficient to calculate actual ET, based on PET
ETdays	number of threshold days to calculate irrigation

Estimated hourly PET values were based on data collected at the nearby CIMIS station—CIMIS 184 (Figure 7). Hourly values were summed over each day to determine the daily PET depth in inches.

The difference between daily water demand and daily precipitation was calculated for each day. If precipitation exceeded water demand, then the irrigation demand was set to zero. Precipitation was used to offset water demand from the following days until all of the precipitation was lost from the system. To estimate the amount of irrigation water applied, the California Department of Water Resources (2000) suggests dividing the irrigation demand by the efficiency of the irrigation system. An efficiency factor of 0.77 was used for both lawn and agricultural irrigation systems to estimate the depth of irrigation water applied. Finally, the irrigation water applied to all pervious areas was added to the water balance in the LSPC simulation. The daily amount applied was assumed to be distributed evenly over time.

2.2.6. Water Quality

During dry weather periods, nutrient water quality was monitored at the Slough Segment and Ocean Inlet sites during ebb and flood tides as part of the larger sampling program in the Famosa Slough. Because the MES was not tidally influenced, monitored MES water quality concentrations could be used to characterize the annual variability of dry weather inputs to the Famosa Slough (Table 1). The median monthly nutrient concentrations were calculated and linearly interpolated between sampling periods to characterize the base flow water quality throughout the year (Figure 21 and Table 4).

Table 4. Interpolated Monthly Dry Weather Nutrient Water Quality at MES

Month	Total Nitrogen (mg/L)	Total Phosphorous (mg/L)
January[a]	0.65	0.39
February	0.80	0.41
March[a]	0.94	0.44
April	0.99	0.50
May	1.03	0.56
June	1.08	0.62
July[a]	1.13	0.68
August	0.95	0.66
September[a]	0.77	0.64
October	0.74	0.57

Month	Total Nitrogen (mg/L)	Total Phosphorous (mg/L)
November	0.71	0.51
December	0.68	0.45

[a] Six samples collected during month. Concentrations is median for the month.

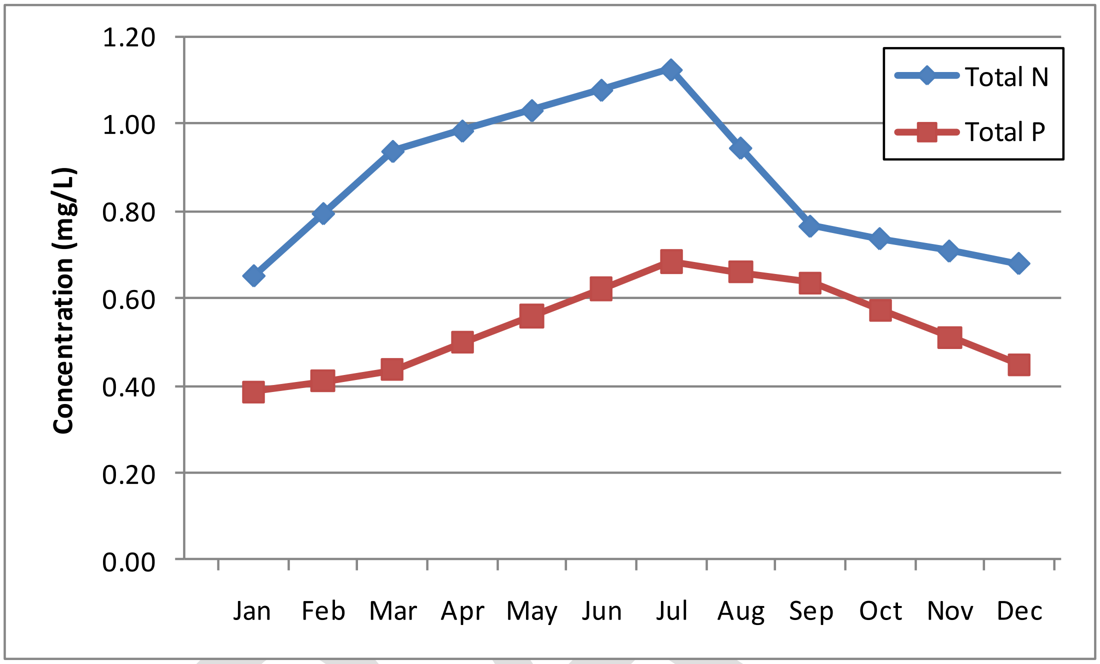


Figure 21. Monthly Dry Weather Nutrient Concentrations

2.3. Watershed Model Calibration

The Famosa Slough watershed model builds upon other watershed modeling work in the City of San Diego. Watershed models have been developed for North and South Chollas creeks, Paleta Creek, Switzer Creek (City of San Diego, 2010a), and the B Street and Downtown Anchorage (City of San Diego, 2010b) watersheds. Those models were calibrated and validated against measured flows and water quality and served as a starting point for model development for Famosa Slough.

The Famosa Slough watershed model used data collected between October 2007 and October 2008. A year's worth of flow monitoring at the MES was used to calibrate the watershed hydrology. Nutrient concentrations were calibrated at small land use sites outside of the watershed in the Downtown San Diego area, typically less than 7 miles away.

2.3.1. Dry Weather Baseflow

Dry weather baseflows were driven by non-storm anthropogenic inputs (e.g., car washing, irrigation). The relatively small baseflow measured at the MES was simulated as resulting from irrigation on pervious areas (Section 2.2.5). The volume irrigated on all pervious areas within the model was controlled by multiplying the PET by a coefficient. A monthly variable coefficient was used within the model to accurately characterize the monitored baseflows throughout the year (Figure 22). Because the anthropogenic inputs to the Famosa Slough are represented by a relationship with PET (which is less in the cooler months), the increase in the coefficient in the winter months reflects a needed modification to achieve a relatively constant baseflow at the MES.

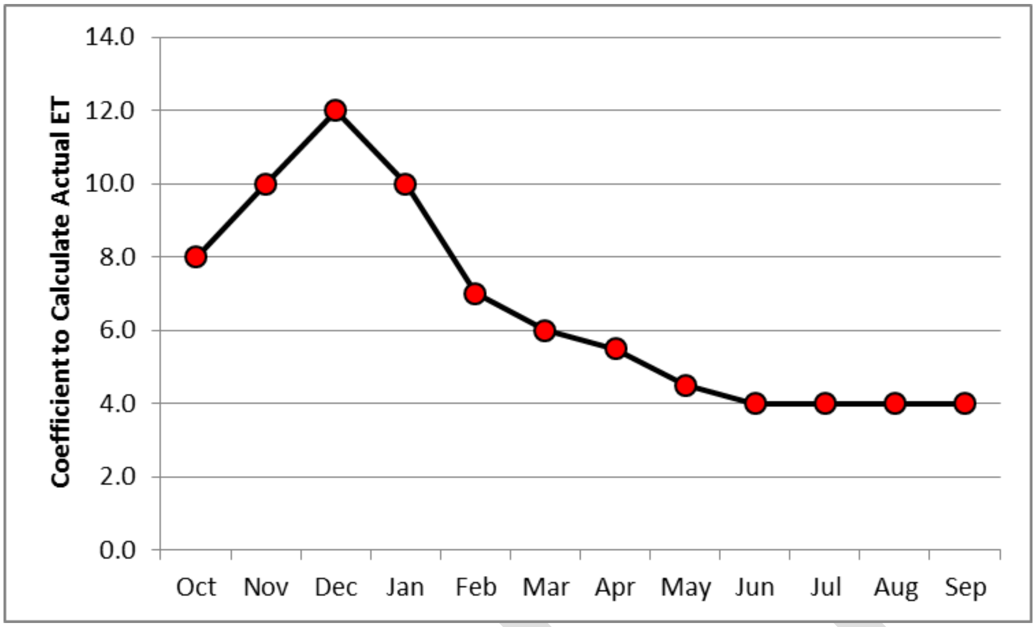


Figure 22. Monthly Variable Coefficient to Calculate Actual ET

2.3.2. Hydrology

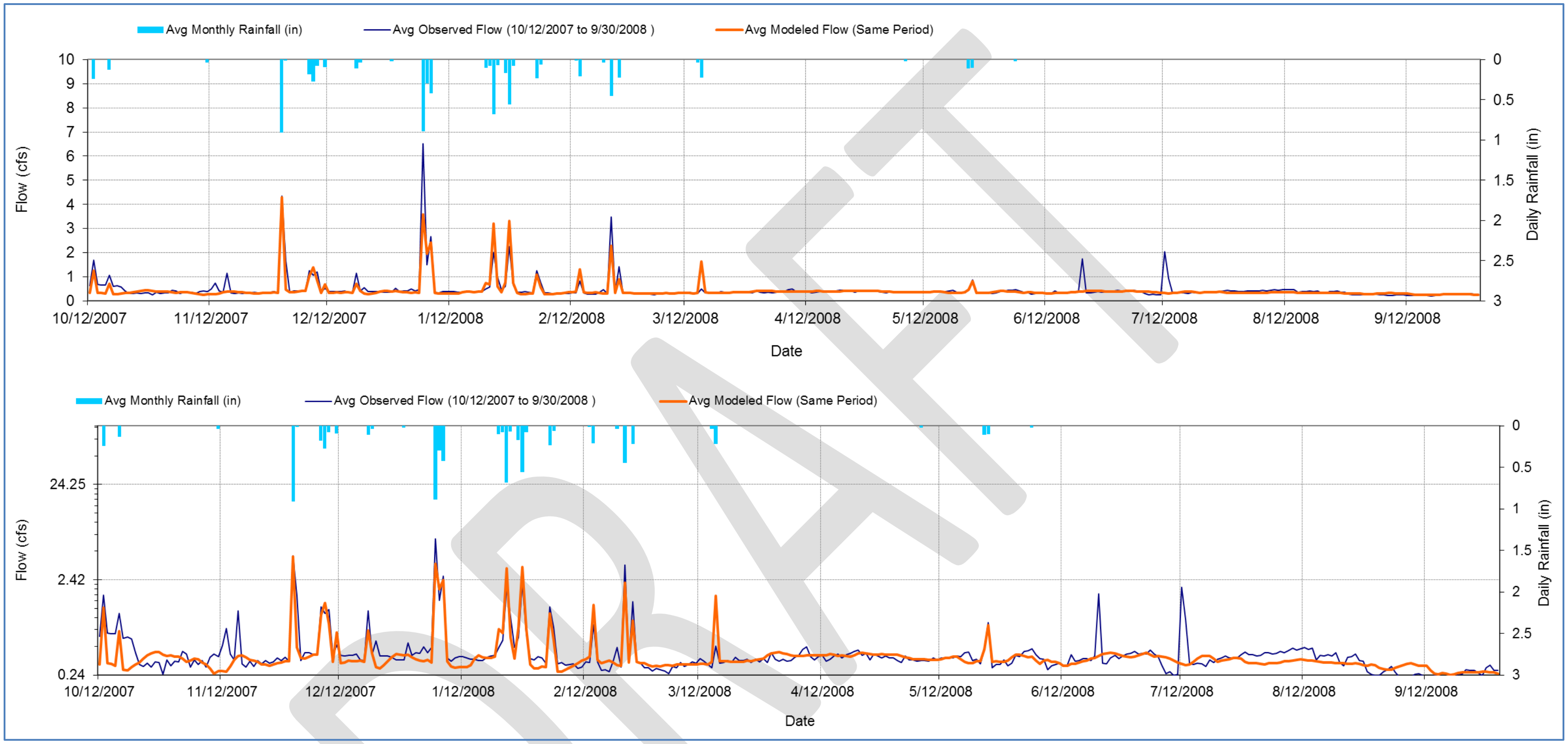
Model hydrology was calibrated against 2007–2008 monitored flows at the MES (Section 2.1.6). Daily average flows compared well throughout the monitoring period matching the timing and magnitude of flows (Figure 23). The overall distribution of measured flows was mimicked by the model well with only a slight divergence at very low flows (~0.02 cfs) which translated into a depth of 0.25 inches (Figure 24). Observed and modeled cumulative volumes normalized to the total volume during the simulation period also compared well to one other (Figure 25).

On a monthly time scale, the model also performed well. The model was able to predict 90 percent of the average monthly flows (Figure 26). The pattern of average monthly flows was similar. The only significant difference between the two was observed in July 2008. The reason for this is that there was an increase in the measured flows in the absence of recorded rainfall.

The predictive ability of the model was typically within the recommended ranges (Donigian, 2002) (Table 5). The model's performance fell outside of those ranges when predicting the summer storm volumes. There were two monitored increases in flow that the processing algorithm defined as summer storms—June and July flow increases (Figure 23)—that were unaccompanied by a rainfall event, and thus likely from an anthropogenic source not included as an input to the model.

Model performance was also outside of the recommended ranges for the highest 10 percent of flows and storm volumes. The model was calibrated to only one year of data, which makes rigorous calibration and validation difficult. This is especially true in southern California where storms are focused during the winter season and only 14 storms more than 0.1 inch were observed during the sample year, which had a total rainfall of 7.2 inches.

The model's performance with regard to seasonal volumes, flow duration curves and monthly volumes compares well with the measured. Because of the model's predictive ability across seasons and a wide range of flows, applying the model to the unmonitored catchments and across unmonitored years should result in reasonable estimates of the terrestrial inputs to the Famosa Slough.



Note: flow results in the figure above are presented on a linear scale in the graph on top and a log scale in the graph on the bottom.

Figure 23. Comparison of Observed and Modeled Average Daily Flows at the MES

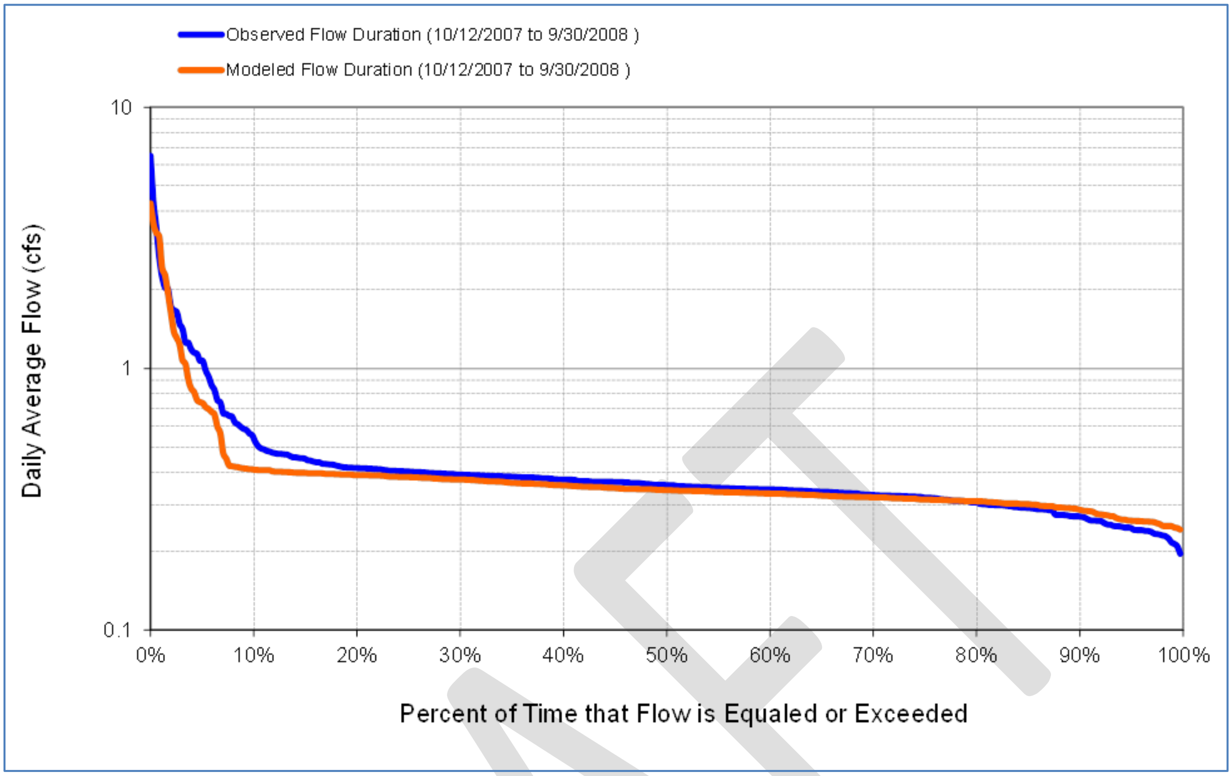


Figure 24. Comparison of Flow Duration Curves at the MES

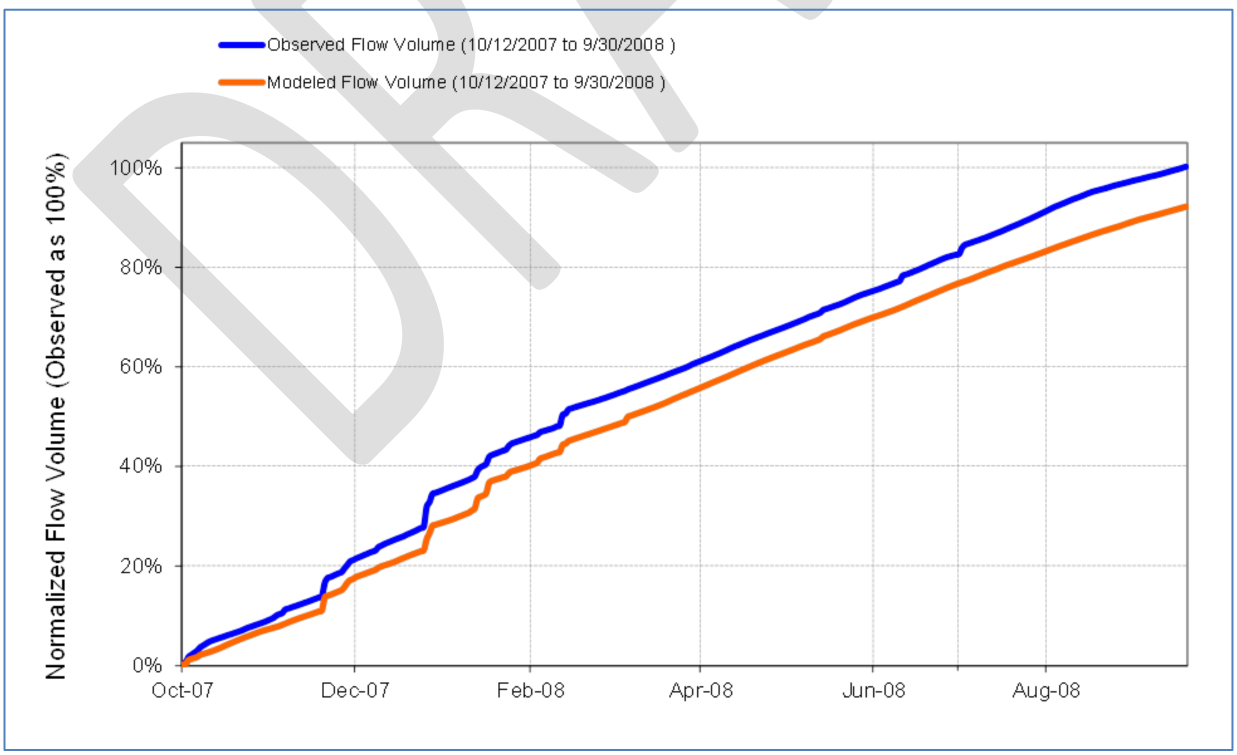


Figure 25. Comparison of Normalized Cumulative Volume at the MES

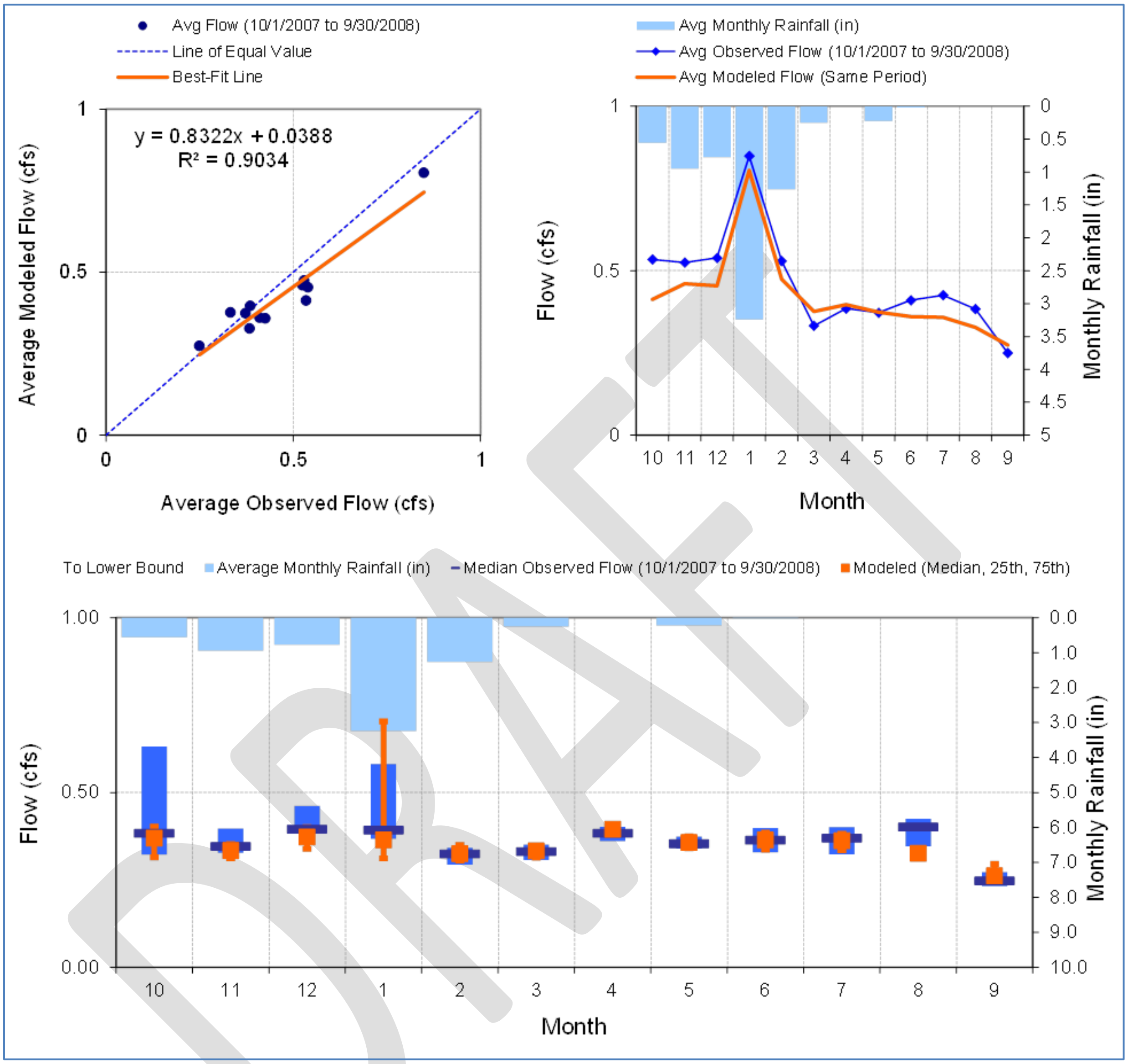


Figure 26. Comparison of Average Monthly Flow at the MES

Table 5. Summary Statistics of the Predicted Hydrology at the MES

Errors (Simulated-Observed)	Error Statistics	Recommended Range[a]
Error in total volume:	-7.87	±10
Error in 50% lowest flows:	0.27	±10
Error in 10% highest flows:	-17.82	±15
Seasonal volume error - Summer:	-9.55	±30
Seasonal volume error - Fall:	-16.26	±30
Seasonal volume error - Winter:	-3.11	±30
Seasonal volume error - Spring:	-3.09	±30
Error in storm volumes:	-26.02	±20
Error in summer storm volumes:	-73.56	±50
Nash-Sutcliffe Coefficient of Efficiency, E:	0.723	--
Baseline adjusted coefficient (Garrick), E':	0.500	--

[a] Donigian, 2002.

2.3.3. Nutrients

Model parameters describing nutrient dynamics were developed using land use monitoring data at the 12 San Diego land use sites (Figure 7). Nutrients were simulated using build-off and wash-off functions in LSPC. Land use-specific parameters were calibrated by comparing to the nutrients data from the 12 land use sites in the nearby Chollas Creek watershed. The resulting build-off and wash-off parameters were then applied in the Famosa Slough watershed LPSC model and confirmed by comparing to MES data (Section 2.4.2). Modeled storm EMCs with the 95th percent confidence intervals were calculated and compared to those measured for the two site-events at each of the 12 monitoring sites in the Chollas Creek watershed. There was no significant difference between the measured and modeled total nitrogen EMCs at the 95th percent confidence interval for any of the measured storm events (Figure 27). The cumulative distribution of total nitrogen concentrations during the sampling period matched well (Figure 28). Total phosphorous model performance was significantly different at the 95th percent confidence interval for only two of the 24 site events (Figure 29). The cumulative distribution of total phosphorous concentrations during the sampling period had a slightly better agreement than the total nitrogen samples (Figure 30).

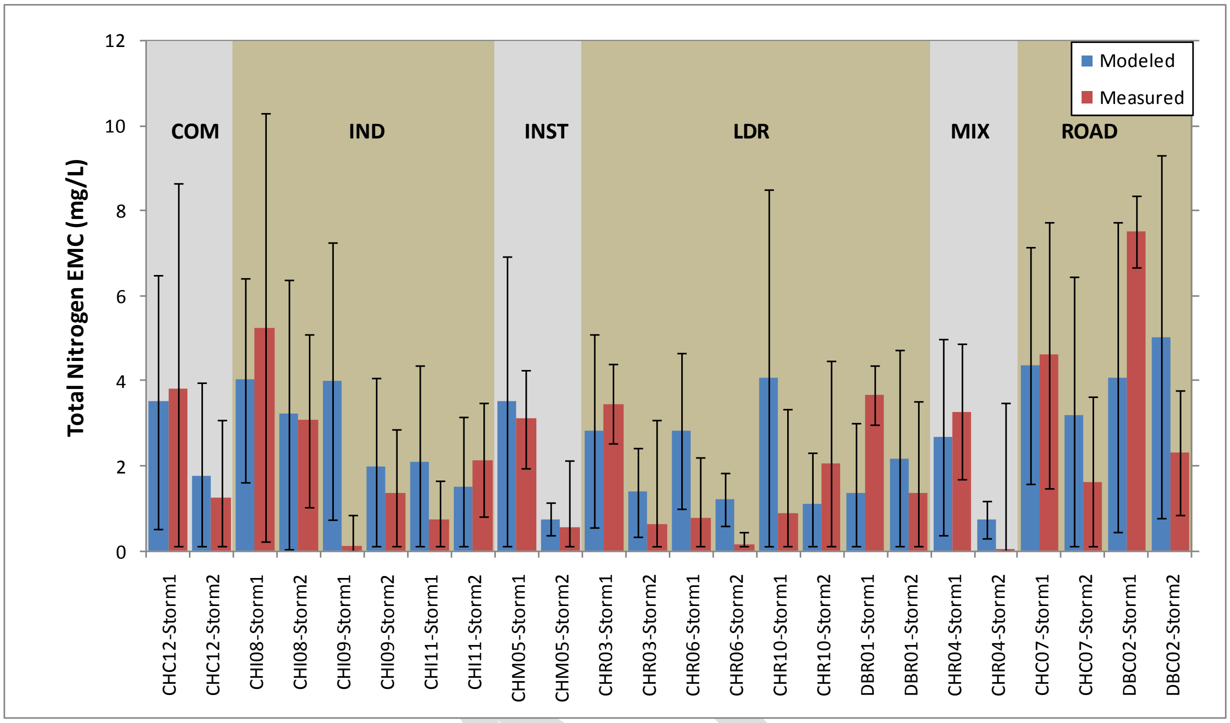


Figure 27. Land Use Total Nitrogen Calibration

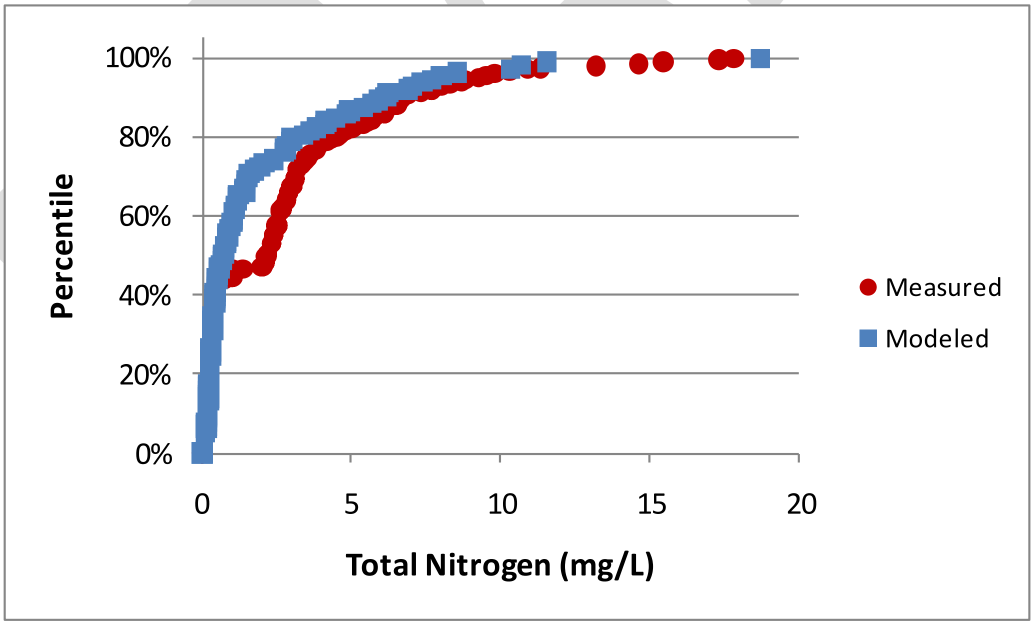


Figure 28. Cumulative Distribution of Measured and Modeled Total Nitrogen in Monitored Storms

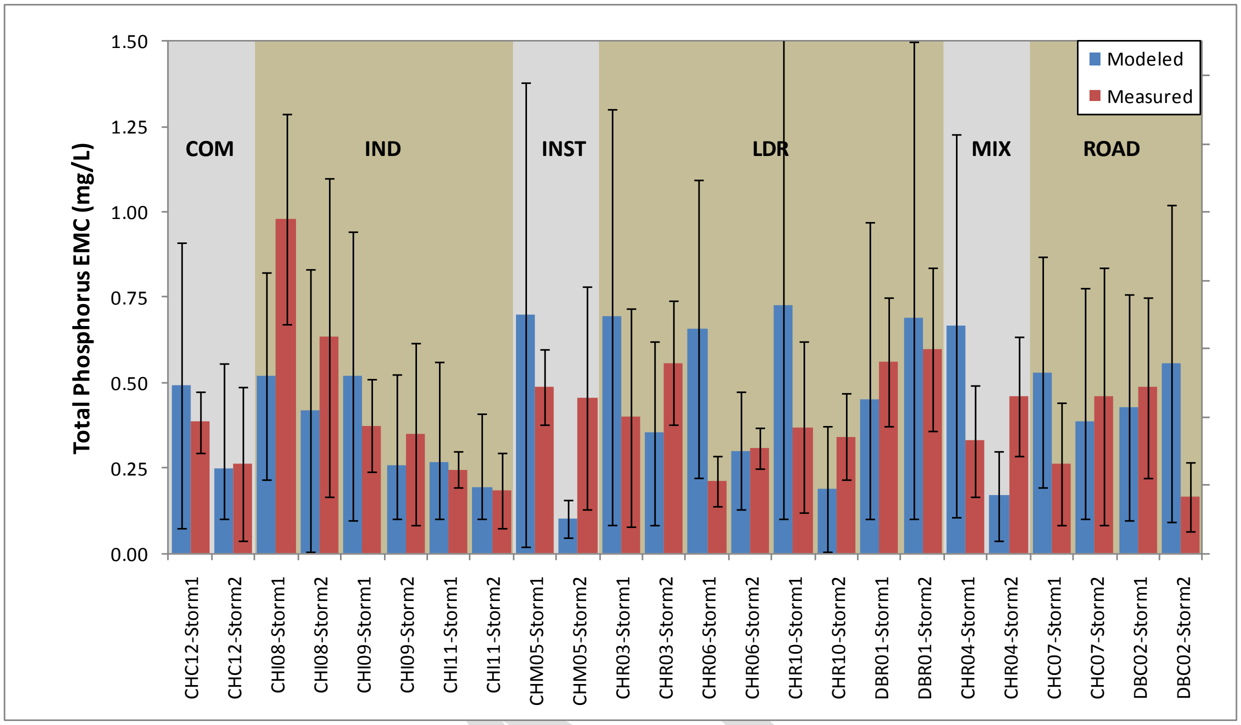


Figure 29. Land Use Total Phosphorus Calibration

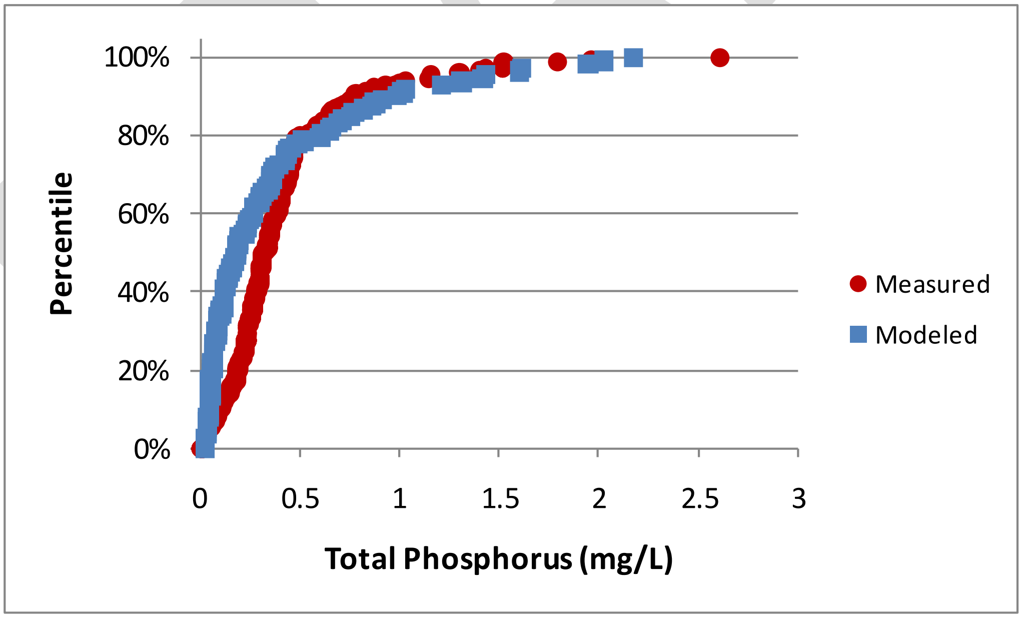


Figure 30. Cumulative Distribution of Measured and Modeled Total Phosphorus in Monitored Storms

2.4. Watershed Model Confirmation

Model confirmation (validation) entails testing a model against a separate dataset (or timeframe) than was used in the calibration. There was not a sufficient dataset to rigorously test the validation of the hydrology and water quality simulations. Hydrology validation was made by comparing intra-day hydrographs during the three monitored events. The sampling location at the MES precluded validation of nutrients and will be discussed in depth.

2.4.1. Hydrology

The modeled hydrology during the three monitored events compared well to the measured (Figure 31). The sub-hour complexity of the first storm was not resolved by the model in part because the model simulates at an hourly time step and overpredicted the sampled volume by 47 percent (Figure 32 and Figure 33).

The two subsequent monitored events compared more favorably with the monitored flows. The second simulated storm began at the same time as the monitored flows and only slightly (13 percent) underpredicted total volume. The timing of the third storm did not precisely match, but the shape of the modeled hydrograph compared well to the measured and overestimated the total storm volume by only 8 percent.

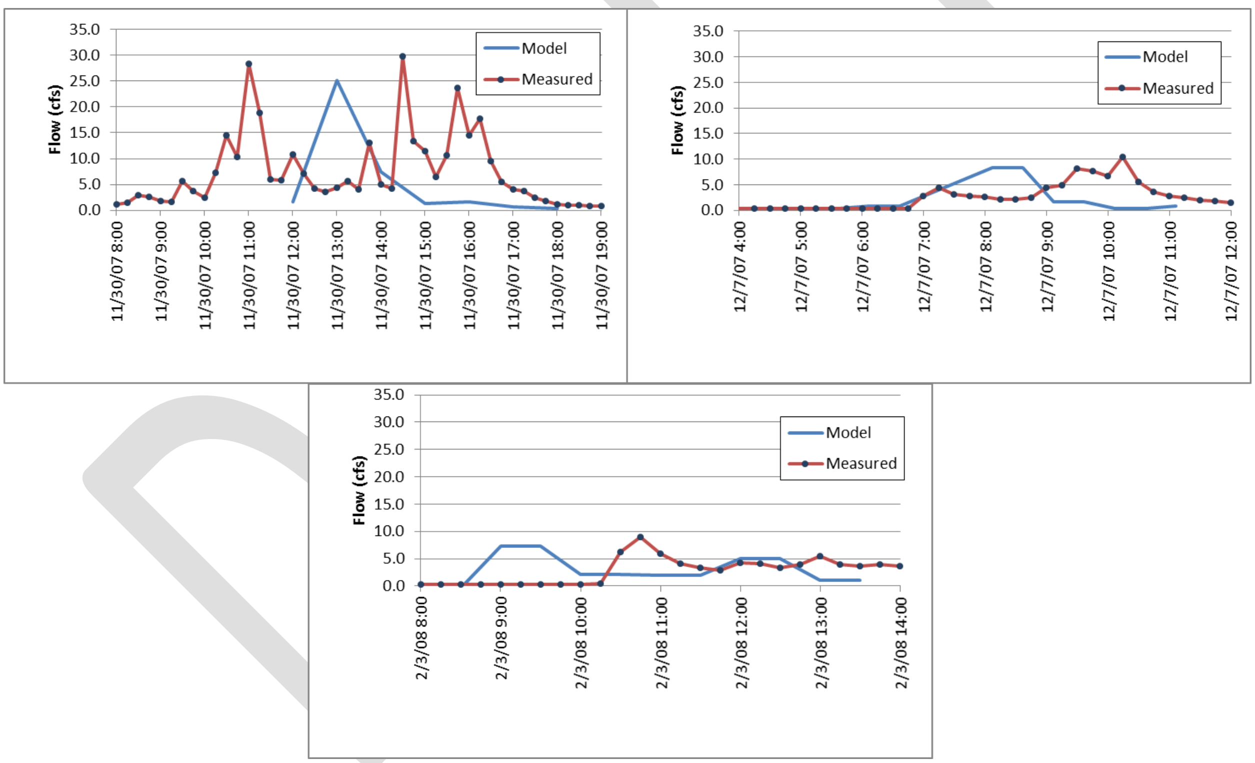


Figure 31. Storm Hydrographs for the Three Monitored Events at the MES

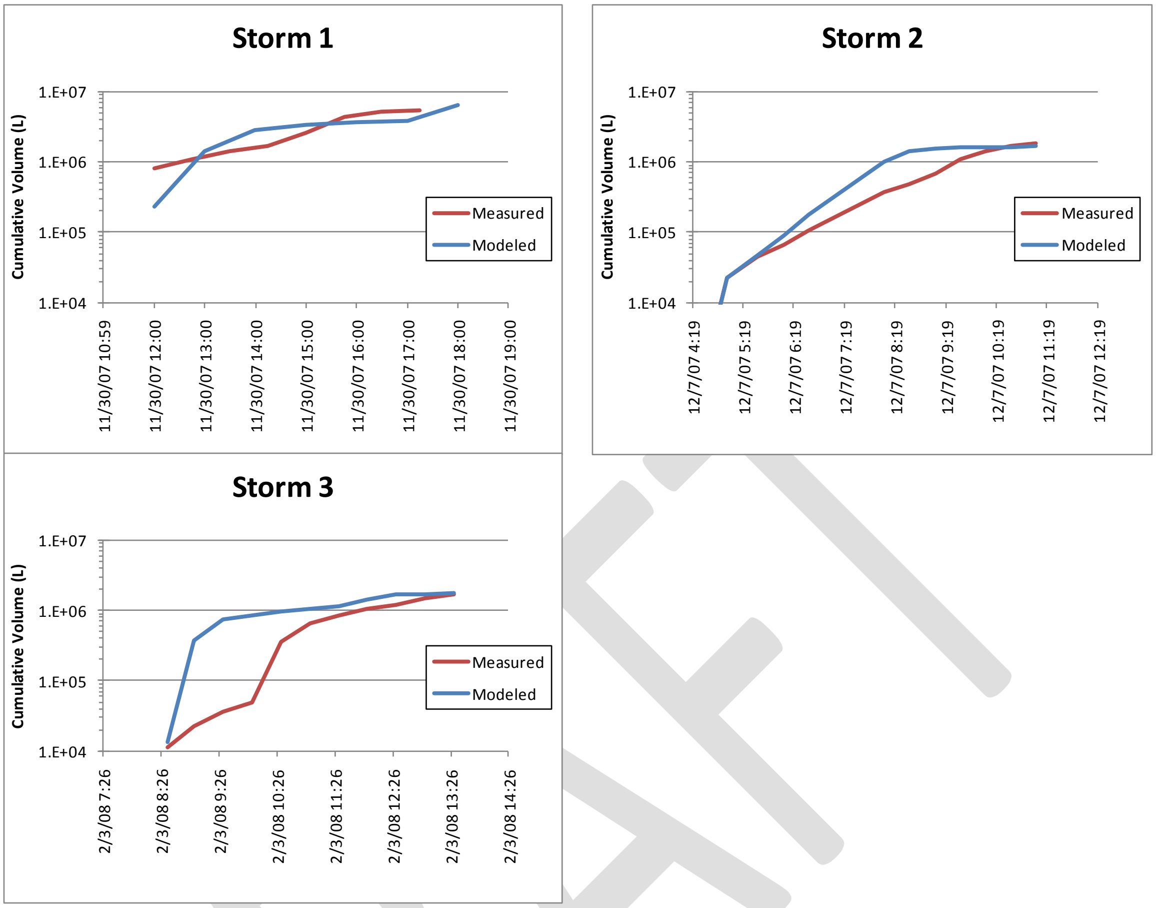


Figure 32. Storm Cumulative Volume Comparison for the Three Monitored Events at the MES

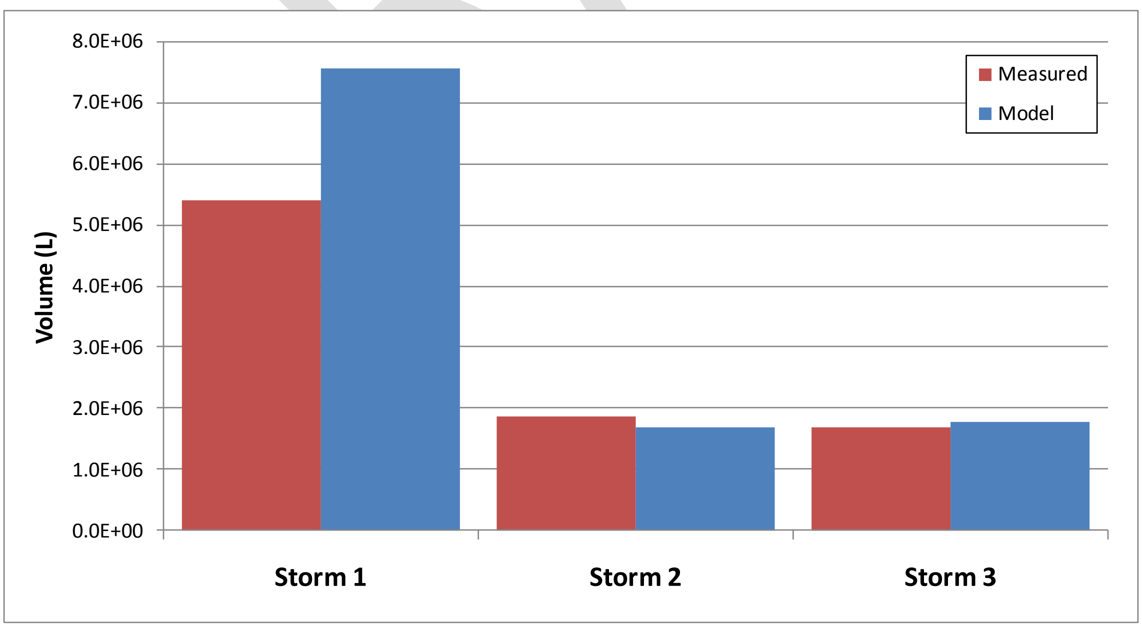


Figure 33. Storm Volume Comparison for the Three Monitored Events at the MES

2.4.2. Nutrients

The MES provided a location for the validation of the model parameters describing the nutrient dynamics on the land surfaces in the watershed. However, the location of the sampling point had factors that reduced nutrients in the stormwater runoff (Section 2.1.7.1), which precluded a validation of the stormwater runoff from the MES catchment.

The nutrient concentrations at MES were relatively constant throughout the monitoring. An upper limit imposed on the waters flowing from the vegetated channel was set at the median concentration of all stormwater samples (total nitrogen = 1.5 mg/L and total phosphorous = 0.3 mg/L). Although the imposition of limits on the stormwater did not match each sample point, the model compared well against nutrient concentrations throughout the storms, by storm EMC and cumulative storm loads (Figure 34, Figure 35, Figure 36, and Figure 37).

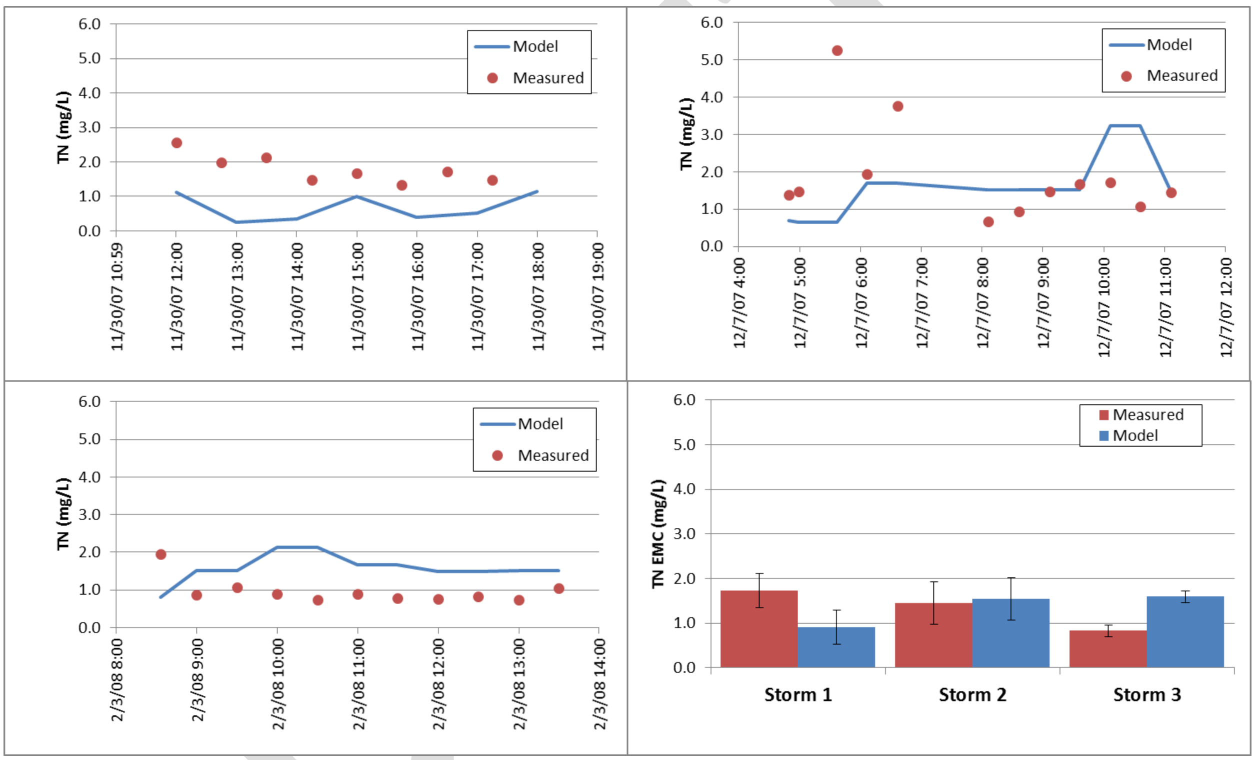


Figure 34. Total Nitrogen Storm Concentrations and Load for the Three Monitored Events at the MES

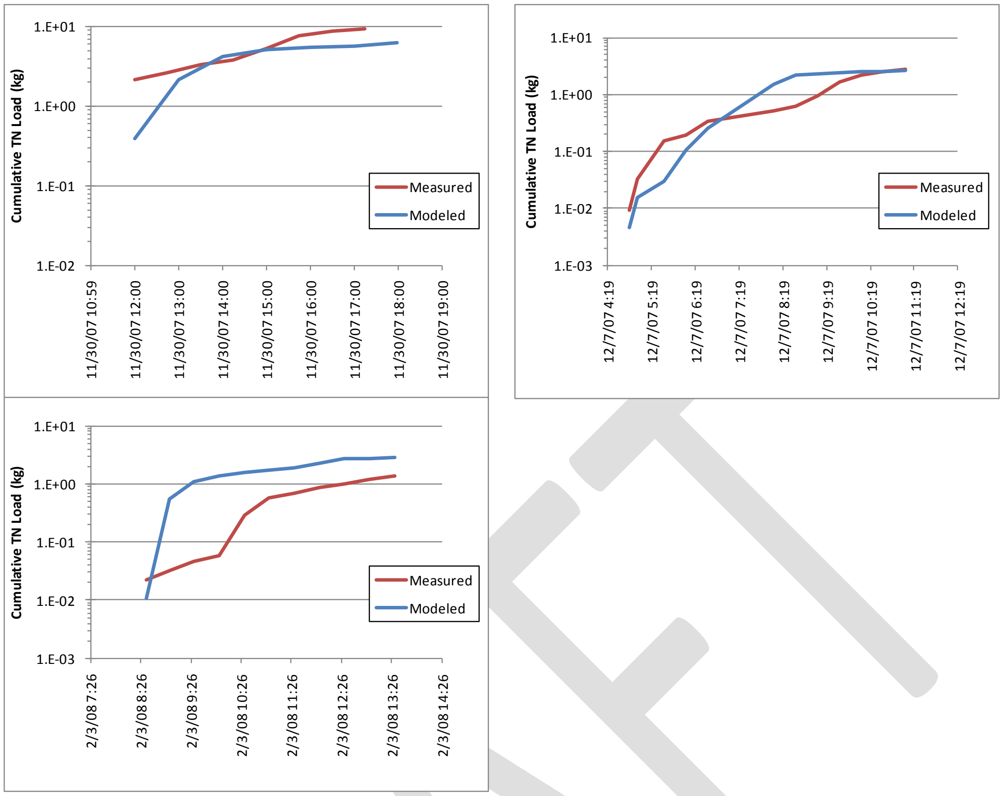


Figure 35. Total Nitrogen Cumulative Load during the Three Monitored Events at the MES

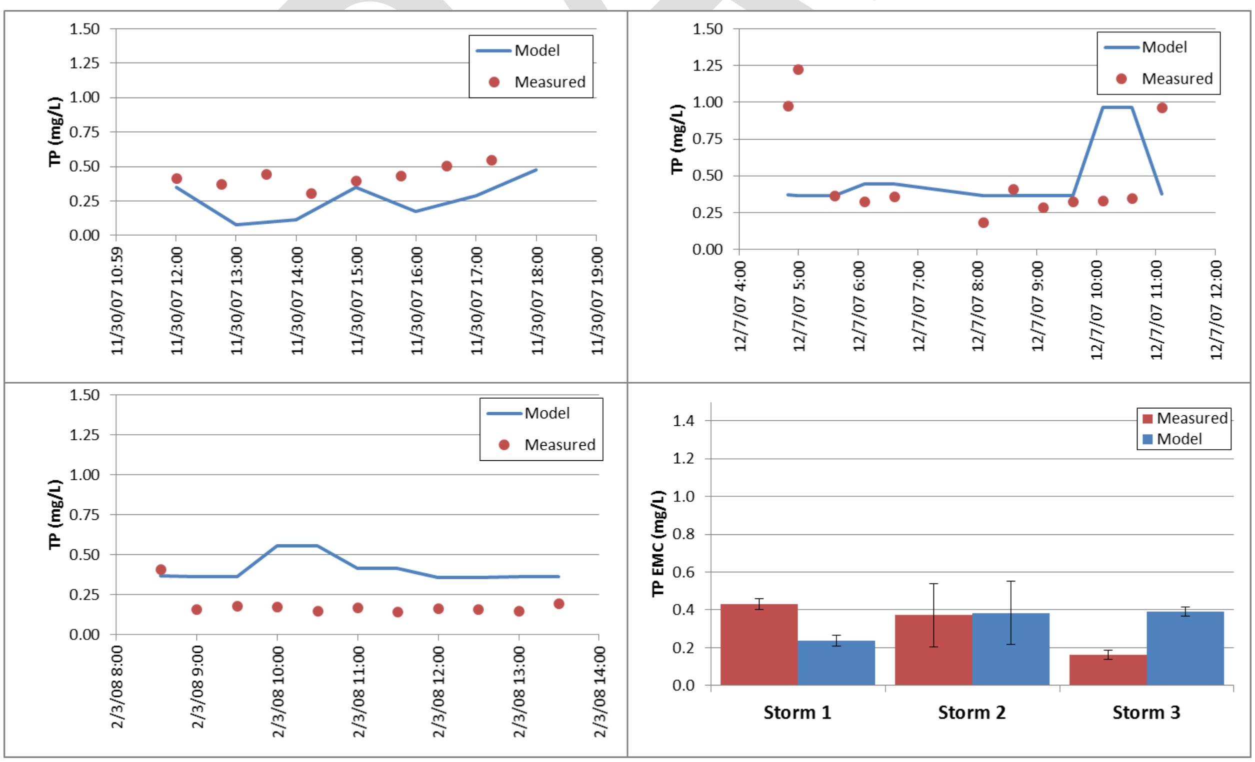


Figure 36. Total Phosphorus Storm Concentrations and Load for the Three Monitored Events at the MES

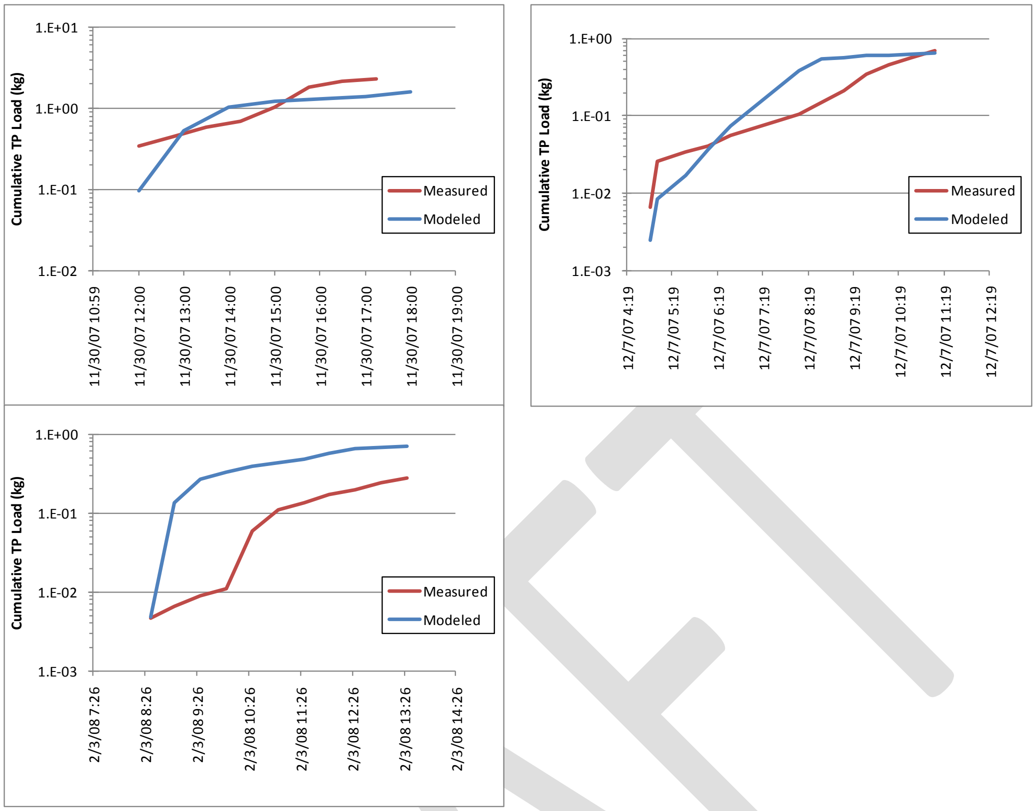


Figure 37. Total Phosphorus Cumulative Load during the Three Monitored Events at the MES

2.5. Watershed Loads

A decadal simulation of the watershed encompassing the entire drainage area was conducted to characterize the long-term nutrient loads to the Famosa Slough. The simulation began in water year (WY: October through September) 1998 to provide for model spin-up with the model output from WY2000–2010 analyzed.

Model results indicate that volumetric inputs to the Famosa Slough are relatively constant year-to-year. Specifically, between 2000 and 2010 the variability in volumetric inputs to the Famosa Slough (Figure 38) was less than the variation observed in rainfall (Figure 39). Median volumetric inputs were 1,170 ac-ft/yr (51,000 1000-ft^3/year) with a minimum of 1,050 ac-ft/yr (45,800 1000-ft^3/year) and a maximum of 1,600 ac-ft/yr (70,000 1000-ft^3/year). Annual nutrient load variability was similar to the volumetric variability (Figure 38 and Table 6). Median total nitrogen loads to the Famosa Slough were 1,030 kg/yr and total phosphorus loads were 480 kg/yr. This indicates that while the yearly rainfall is highly variable (Figure 39), the non-storm associated inputs constitute a significant portion of the annual inputs to Famosa Slough.

Table 6 illustrates that similar loading levels enter Famosa Slough annually despite different runoff amounts. The constant flow from irrigation and other anthropogenic sources is more important than large storm events. The dry weather watershed loads are a consistent source year-round.

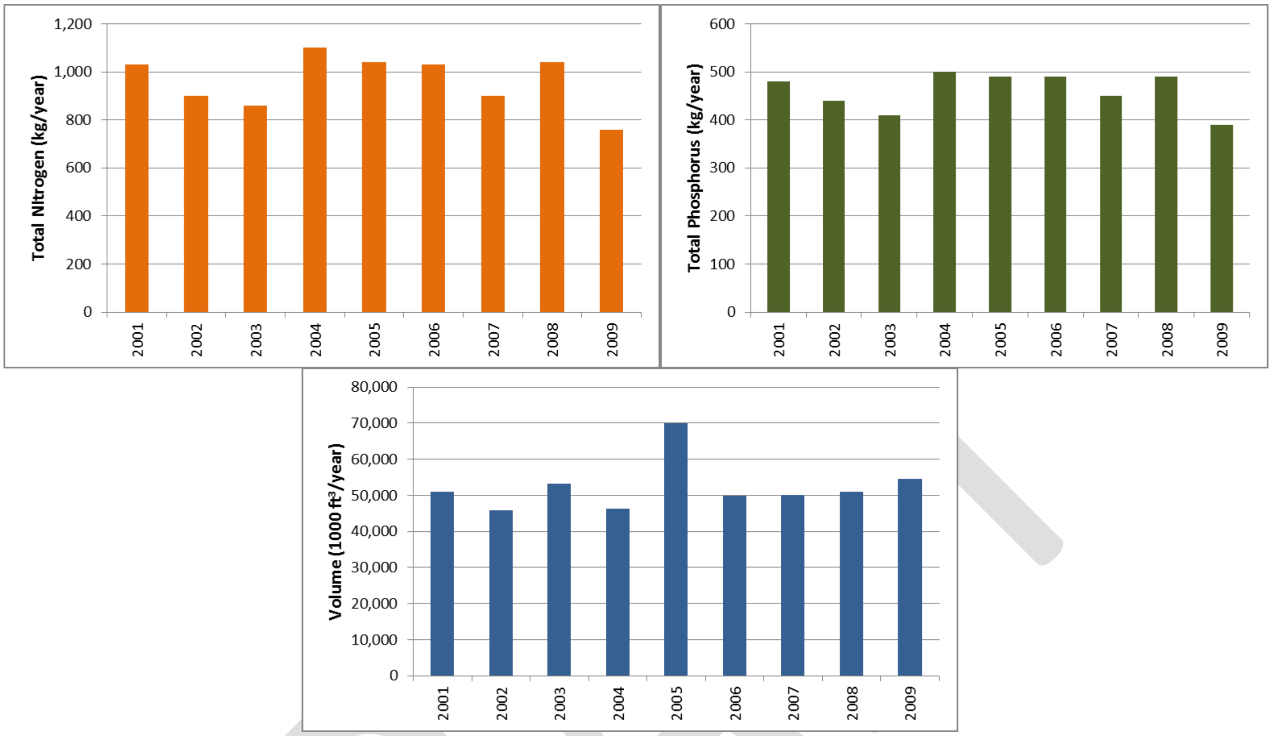


Figure 38. Annual Watershed Modeled Inputs to the Famosa Slough Watershed

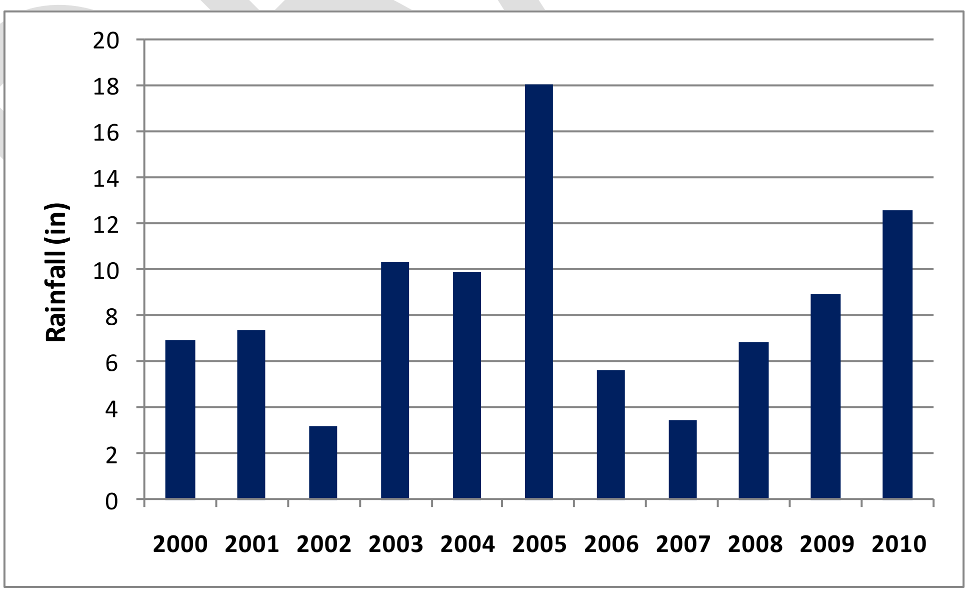


Figure 39. Annual Rainfall at San Diego Airport

Table 6. Average Annual Inputs to the Famosa Slough

Water Year	Total Nitrogen (kg/year)	Total Phosphorous (kg/year)	Runoff (1000 ft^3/year)
2000	1,030	480	51,000
2001	900	440	45,800
2002	860	410	53,300
2003	1,100	500	46,400
2004	1,040	490	70,000
2005	1,030	490	49,900
2006	900	450	50,200
2007	1,040	490	51,100
2008	760	390	54,600
2009	1,030	480	51,000

Monthly inputs (averaged for available years) to Famosa Slough (Figure 40) typically reflected the monthly rainfall patterns (Figure 41 and Table 7). Average volumetric monthly inputs show slight seasonal variability and illustrate the consistent anthropogenic baseflow that was monitored at the MES during the spring and summer months. Volumetric loads during the winter (December–February) were 32 percent of the total. This is similar to winter nutrient loads which were 35 and 26 percent of the total nitrogen and total phosphorus loads, respectively.

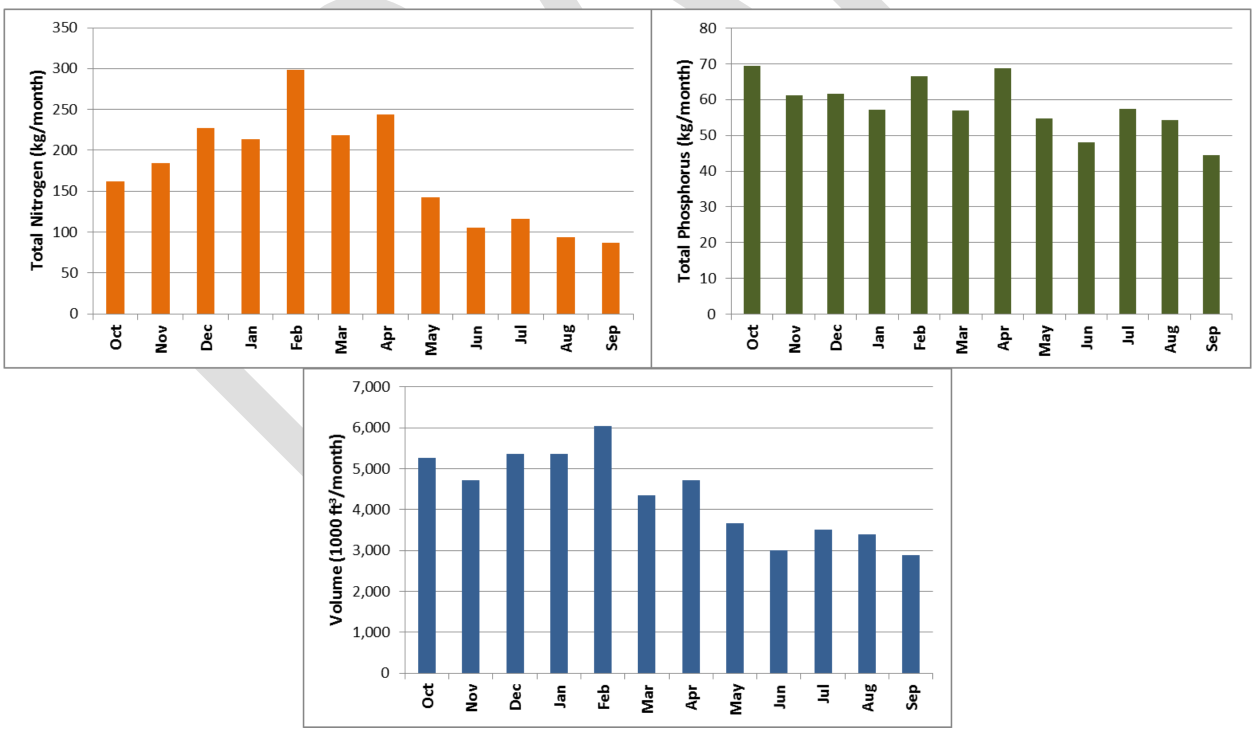


Figure 40. Average Monthly Watershed Inputs to the Famosa Slough Watershed

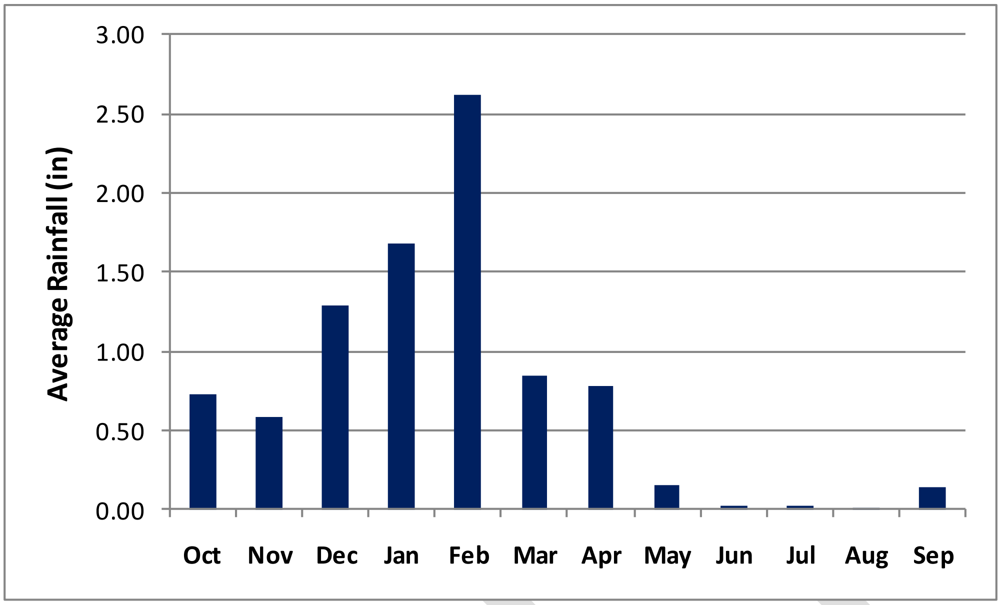


Figure 41. Average Monthly Rainfall at San Diego Airport

Table 7. Average Monthly Inputs to the Famosa Slough

Month	Total Nitrogen (kg/month)	Total Phosphorous (kg/month)	Runoff (1000 ft^3/month)
January	214	57	5,360
February	298	67	6,040
March	219	57	4,340
April	244	69	4,720
May	143	55	3,660
June	106	48	3,010
July	116	57	3,500
August	94	54	3,390
September	87	44	2,890
October	162	69	5,270
November	184	61	4,710
December	227	62	5,360

Residential areas had the greatest fraction of loads of the modeled land uses. Multi-family and single family residential areas contributed 47 percent of the volumetric inputs to Famosa Slough with open space, open recreation, and parks as the second largest contributor (40 percent) (Figure 42 and Table 8). The distribution of nutrient inputs to Famosa Slough followed the same pattern as the volumetric with residential areas contributing the largest portion of total nitrogen and total phosphorous (42 and 54 percent) and open land uses the second largest portion (30 and 36 percent) (Figure 43 and Figure 44). The greatest proportion of loads to Famosa Slough was from groundwater sources (groundwater and interflow) and was a result of anthropogenic sources (Figure 45).

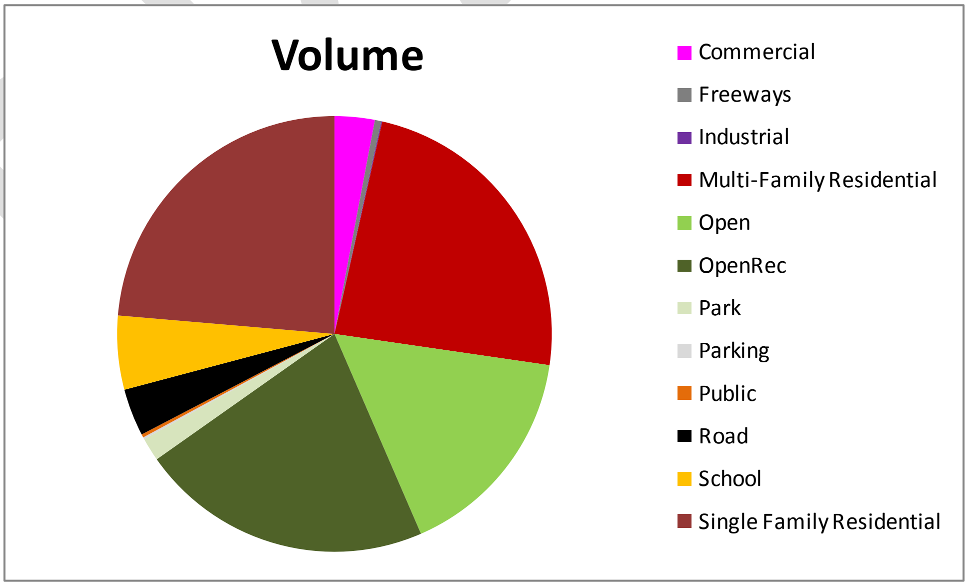


Figure 42. Land Use Volumetric Loads to the Famosa Slough

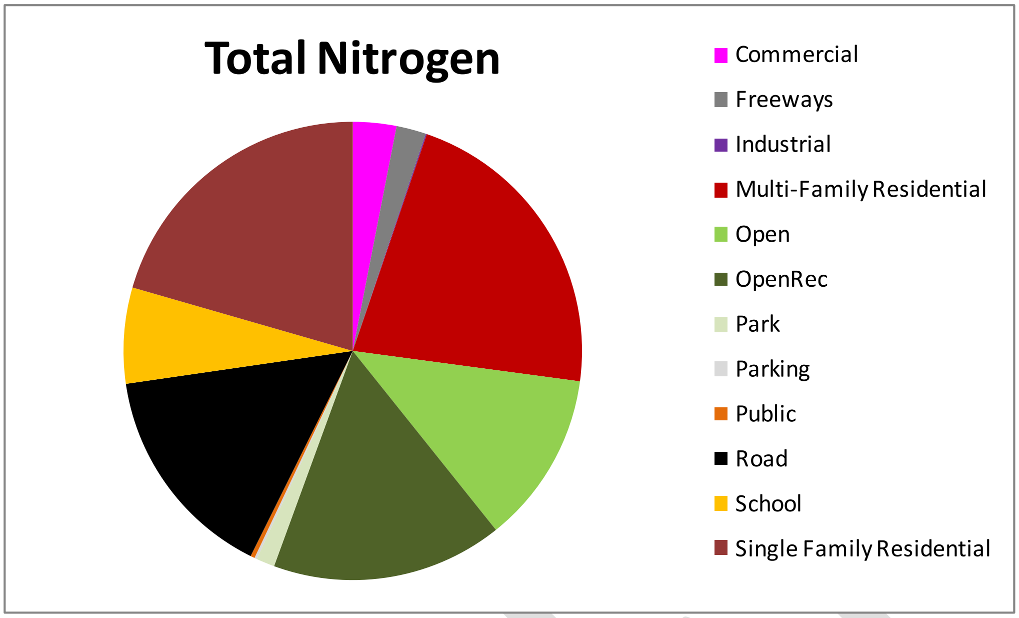


Figure 43. Land Use Total Nitrogen Loads to Famosa Slough

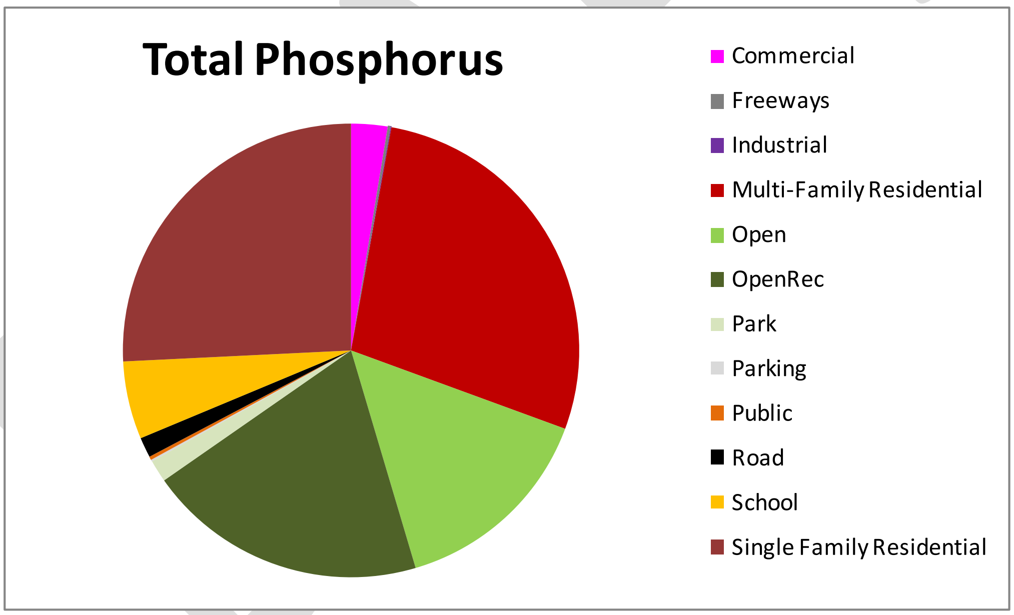


Figure 44. Land Use Total Phosphorous Loads to Famosa Slough

Table 8. Average Annual Land Use Inputs to Famosa Slough

Land Use	Total Nitrogen (kg/year)	Total Phosphorous (kg/year)	Runoff (1000 ft^3/year)
Commercial	53.4	22.3	1,568
Freeways	36.4	1.70	252
Industrial	1.30	0.60	39
Multi-Family Residential	381	240	12,524
Open	211	128	8,531
Open/Recreational	284	172	11,471
Park	22.7	13.6	911
Parking	3.00	1.10	79
Public	5.20	2.10	127
Road	267	12.4	1,848
School	118	47.7	2,886
Single Family Residential	357	223	12,451

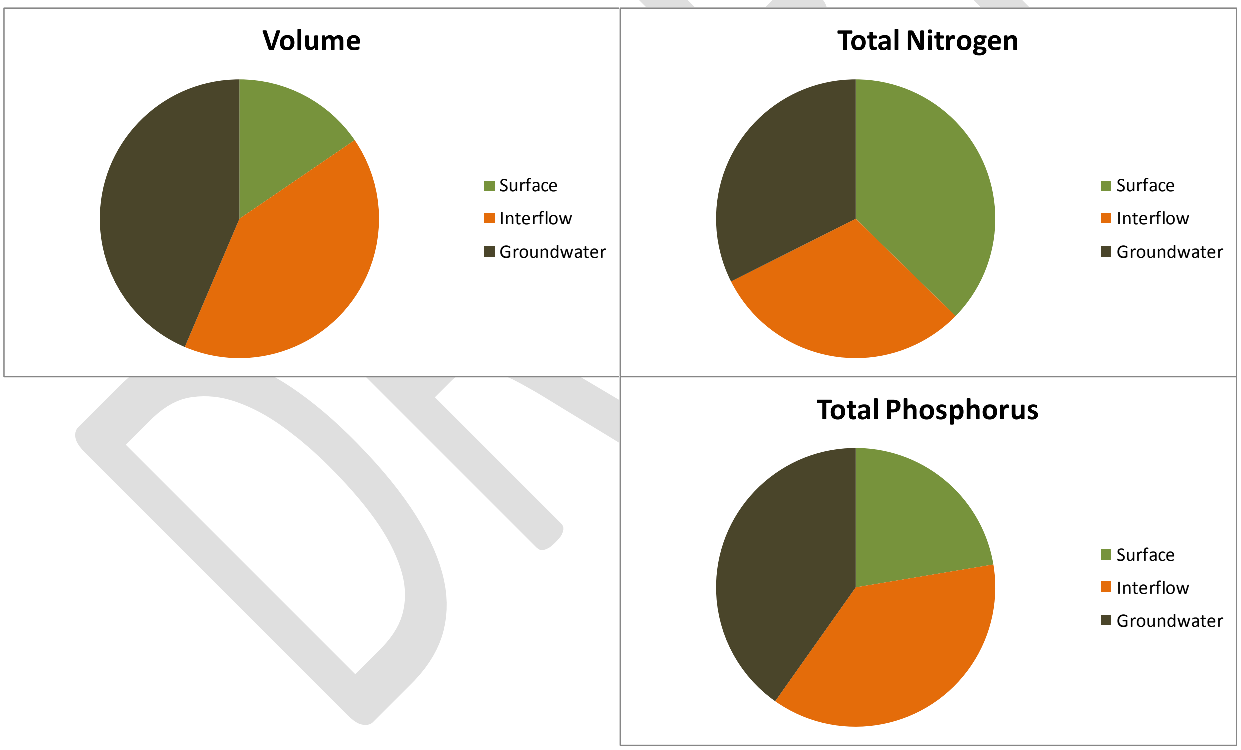


Figure 45. Loading Pathways to Famosa Slough

2.6. Watershed Model Summary and Conclusions

2.6.1. Hydrology

The LSPC model of the areas draining to Famosa Slough provides a useful representation of the watershed inputs. The hydrologic calibration mimicked the reported flows during the monitoring period. A few points need to be made about the model development and performance.

Only one year of monitoring data was available for calibration. Because of the paucity of storms in southern California, only a few storms were available for calibration. Although the model performed well for those events, it would be beneficial to have additional events to use for model validation.

The percent impervious by land use in the Famosa Slough watershed model was greater than in the nearby Chollas Creek watershed models. Percent impervious by land use is unique to each modeled watershed and areas near the beach tend to have a higher degree of imperviousness than like land uses further inland (Ackerman and Stein, 2008).

Flow estimations at the MES were derived from a Manning's equation using the water level. The minimum water depth at the MES was 0.74 inches, which corresponds to a flow of 0.12 cfs (from the Manning's equation). Discussions with Gretel Roberts (personal communications, Weston Solutions) indicated that a slight riser (pipe elevation) downstream of the monitoring location caused the water to pool at the MES. This could have caused an overestimation of the dry weather flows. However, the model was calibrated assuming the reported flows were reflective of the actual conditions at the MES.

2.6.2. Water Quality

The nutrient inputs to Famosa Slough were estimated using the available high quality information on stormwater runoff in the area. The flows at the MES exited from a storm drainpipe and entered the vegetated concrete trapezoidal channel, with the MES downstream of the vegetation.

The strength of a pollutograph monitoring program is that multiple locations are monitored for model calibration and validation. The 12 land use sites provided an excellent calibration dataset for the model land use nutrient parameters. The intention of the model design was to use the MES as a validation dataset. However, the vegetation upstream of the MES likely reduced the nutrient levels in the runoff. The nutrient levels at the MES were typically less than at the land use monitoring locations. Therefore, the vegetated channel was modeled as a BMP with an upper limit imposed on those concentrations. This precluded an independent validation of the model; however, the model's strong performance at the land use scale provides a measured level of confidence that the nutrient inputs to Famosa Slough are reasonable.

The greatest proportion of the average annual nutrient loads to Famosa Slough was from residential areas with most of those loads originating from groundwater inputs. The greatest mitigation of loads to Famosa Slough could be obtained by reducing the anthropogenic inputs during the dry season, which would reduce both volumetric and nutrient loads.

2.6.3. Watershed Model Application

After completing model calibration and confirmation for hydrology and water quality, the LSPC model was applied to obtain hourly flow and water quality concentrations from January 1, 2008 through December 31, 2008 for all of the subwatersheds draining to Famosa Slough. These model results were incorporated into the receiving water model of Famosa Slough. The calibration and validation of the hydrodynamic and water quality portions of the receiving water model are discussed in Section 3.

3. Receiving Water Model – EFDC

Famosa Slough was simulated using EFDC. The EFDC model was configured to simulate hydrodynamics and eutrophication dynamics in the Slough, Channel, and the tidal portion of the San Diego River from January to December 2008. Specifically, EFDC was used to simulate space and time varying distribution of water surface elevation, water velocity, water temperature, salinity, nutrients, phytoplankton, benthic macroalgae, floating macroalgae, macrophytes, and dissolved oxygen. This section describes the modeling framework, model configuration, and hydrodynamic and water quality model calibration.

3.1. EFDC Modeling Framework

EFDC is a general-purpose model package for simulating one-, two-, and three-dimensional flow, transport, and biogeochemical processes in surface water systems including rivers, lakes, estuaries, reservoirs, wetlands, and coastal regions. The EFDC model was originally developed at the Virginia Institute of Marine Science for estuarine and coastal applications. This model is now being supported by USEPA and has been used extensively to support TMDL development throughout the country. In addition to hydrodynamic, salinity, and temperature transport simulation capabilities, EFDC is capable of simulating cohesive and non-cohesive sediment transport, near field and far field discharge dilution from multiple sources, eutrophication processes, transport and fate of toxic contaminants in the water and sediment phases, and transport and fate of various life stages of finfish and shellfish. The EFDC model has been extensively tested, documented, and applied to environmental studies worldwide by universities, governmental agencies, and environmental consulting firms.

The structure of the EFDC model includes four major modules: (1) a hydrodynamic sub-model, (2) a water quality sub-model, (3) a sediment transport sub-model, and (4) a toxics sub-model. The water quality portion of the model simulates the spatial and temporal distributions of 22 water quality parameters including dissolved oxygen, suspended algae (3 groups), attached algae, various components of carbon, nitrogen, phosphorus and silica cycles, and bacteria. In this study, only the hydrodynamic and water quality sub-models, together with a sediment diagenesis model, were applied to simulate Famosa Slough for TMDL development.

3.2. Model Configuration

Model development requires defining the computational domain and boundary conditions. The general steps to set up the EFDC model for Famosa Slough included generating the modeling grid, defining meteorological conditions, estimating oceanic inputs, and linking the watershed (LSPC) model to EFDC. Key data sources were compiled to support development of the Famosa Slough model. Model development steps and data used to identify initial conditions, boundary assignments, and calibration of key model parameters are discussed below.

3.2.1. Model Iterations

The EFDC model of Famosa Slough was originally developed in 2011 and has been improved several times based on the TMDL modeling needs and objectives and the increased understanding of hydrodynamics and water quality processes likely to control water quality within the Slough, Channel, and the estuarine portion of the San Diego River.

The original 2011 version of the model spatial domain included only the Slough and Channel. A tidal boundary condition was specified at the channel outlet to the San Diego River. Tidal water level variations and incoming tidal water quality constituent concentrations were set at values measured at the channel outlet during 2008. As a result, both the hydraulic performance and water quality impacts of flooding and ebbing tidal flows passing through the three culverts connecting the channel outlet to San Diego River were combined within the tidal boundary conditions. The minimum benthic macroalgae biomass density within all model cells was set at 60 grams of carbon per square meter (g C/m^2) based on a calibration to the monitoring data for dissolved oxygen (DO) and nutrients. This model assumption forced the macroalgae to always grow at least to this density, regardless of nutrients or any other macroalgae growth limitations. Due to this forcing, benthic fluxes of nutrients and DO (expressed as sediment oxygen demand [SOD]) were all set to zero. This simplified modeling framework was found to be insensitive to reductions in watershed nutrient loads although it provided a reasonable calibration to the Slough and Channel monitoring data. Specification of zero benthic fluxes during calibration precluded an assessment of the beneficial impacts of benthic sediment remediation as a management option.

The first refinement, completed in December 2012, improved upon the tidal boundary conditions specified at the channel outlet to the San Diego River. The estuarine portion of the San Diego River, between the Pacific Ocean at Dog Beach and Interstate 5, was added to the EFDC model domain. Hydraulics of the three culverts connecting the channel outlet to the San Diego River were also included explicitly in the model using culvert rating curves. The tidal ocean boundary was moved to the actual ocean inlet, and measured tidal variations at La Jolla (Scripps Pier) were used instead of those measured at the channel outlet. Constant water quality constituent concentrations were specified at the new ocean boundary during flood portions of each tide cycle, based on available coastal monitoring water quality data. Freshwater discharges and water quality constituent loads entering the estuarine segment of the San Diego River from upstream were specified, based on historical flow and water quality monitoring data collected at the San Diego River Mass Loading Station by the Regional San Diego MS4 Copermittees. The model was recalibrated following addition of the more realistic ocean boundary conditions, explicit simulation of the biogeochemical processes occurring within the estuarine portion of the San Diego River and the explicit simulation of the culverts connecting to the channel. However, the minimum benthic macroalgae biomass density constraint of 60 g C/m^2 and zero sediment flux specification were not changed from the original version, thus limiting its use for assessment of impacts of watershed nutrient load reductions and benthic sediment remediation alternatives.

The second model refinement was conducted in 2013 and included enhancements that allow the model to be used to assess impacts of watershed nutrient reduction and benthic sediment remediation scenarios. The model domain was first split into several zones, wherein different water quality kinetics rate constants, e.g., macroalgae growth rates and sediment flux rates, could be specified for the Slough, Channel, and San Diego River estuary separately. This change is required to assess impacts of changes within only portions of the domain. The minimum macroalgae biomass density constraint was also removed and growth was allowed to vary depending on water column nutrient concentrations, temperature, and other limitations. In the previous model version, benthic fluxes were all set to zero. However, monitoring data suggest that benthic nutrient flux and SOD are key factors in nutrient cycling and macroalgae growth and respiration within the Slough and Channel. Accordingly, specified benthic nutrient fluxes were adjusted upward of those estimated during the monitoring in 2008 by temporally constant factors to stimulate growth of macroalgae within the Slough and Channel, but not in the San Diego River estuary. The model was then recalibrated to the 2008 monitoring data.

The second refinement was a significant improvement upon the previous versions; however, it was still subject to several constraints that limit its predictive capability for reasonably evaluating practical management scenarios. There were three key limitations. The first was that the model represented the floating macroalgae and benthic algae as a lumped parameter; however, in reality the two groups of macroalgae significantly differ from each other in their responses to light, temperature, and water depth. Lumping them together would lead to unreasonable prediction of the macroalgae dynamics, and would not allow the model to represent the competitive interactions between the two macroalgae groups. The second key limitation was that the model did not have the capability of predicting the benthic nutrient fluxes;

therefore, it relied on manipulation of benthic fluxes to fit the observed nutrient and DO data. The model was not able to predict the dynamic response of nutrient fluxes to watershed load reduction or other management scenarios, preventing the model from being used for assessment of management scenarios. The third limitation was that the model was not able to predict the diurnal temperature and DO fluctuation ranges, indicating that the representation of hydrodynamics and water quality was still deficient.

In light of the key limitations in the second refinement of the model, a third iteration of model improvement in 2014 was necessary to improve the predictive capability for reasonably evaluating potential management scenarios. Four key model improvements included: 1) improvement in the model predictive capability through separating the floating macroalgae and benthic macroalgae groups; 2) improvement in the model predictive capability through the addition of a sediment diagenesis model to directly simulate the interaction between watershed loading, ocean boundary loading, San Diego River loading, and benthic nutrient flux, and SOD; 3) revisit the unsatisfactory results of the previous version and improve model performance; and 4) revisit model parameters to identify any unreasonable parameter values from the previous updates and fix the corresponding problems. The following summarizes the key model enhancement/corrections that were included in the 2014 refinement.

a) EFDC code modification to simulate floating macroalgae

   A code modification was conducted to allow the EFDC model to simulate floating macroalgae using the first algae group, BC. The BC in the standard EFDC model simulates phytoplankton, and the modified code allowed the use of BC as a state variable for macroalgae when the corresponding transport flag was set to a value of 2. A value of 2 deactivates the advective and dispersive/diffusive transport for phytoplankton. The light limitation factor was removed for floating macroalgae based on the assumption that the floating macroalgae would occupy the surface of water and is always at the most desired light condition. The shading effect of floating macroalgae on the benthic macroalgae was represented by a light extinction factor, which was linearly related to the biomass of the floating macroalgae.

b) Develop a sediment diagenesis model

   Within the updated model, a sediment diagenesis model was developed to represent the interactions between the external nutrient loading, floating and benthic macroalgae, phytoplankton, and benthic nutrient flux and SOD dynamics. This addition allows the model to predict the water quality response to management scenarios in a more reliable and realistic way. For example, harvesting floating macroalgae results in a reduction in organic matter deposition to the sediment, which causes a reduction in benthic nutrient flux and SOD. Without the predictive sediment diagenesis model, the model was not able to evaluate the response of water quality and benthic flux to such management scenarios.

c) Correct a hydrodynamic switch in the EFDC model

   It was identified that the buoyancy parameter (BSC) in the EFDC hydrodynamic model was set to a value of 0. A value of 1 represents a more realistic condition when the model is sensitive to this parameter. Model sensitivity runs showed that temperature and other water quality results are sensitive to this parameter; therefore, this parameter was set to 1.

d) Correct culverts configurations

   Hydrodynamic simulation was improved by correcting and refining the configuration of the culverts between the San Diego River and the Channel and the Channel and the Slough. Model results show that the improvement in the rating curves based on water depth as opposed to relative elevation significantly improved the diurnal temperature fluctuation and the salinity and elevation results at the MES.

e) Correct multiple out-of-range parameter settings

The previous model had multiple key parameter values that were out of reasonable range to force calibration with observed data. For example, the decay rates for dissolved organic nitrogen and phosphorus were set to 1.0/day, which is almost an order of magnitude higher than the normal value of approximately 0.1/day. The macroalgae carbon to DO stoichiometric ratio was set to 5.0 and 8.0, respectively, for photosynthesis and respiration, while more reasonable values should be approximately 2.69. The higher values were set to artificially increase primary productivity and respiration to produce or consume significantly more DO to match observed values without the addition of diagenesis and the separation of macroalgae groups. The macroalgae growth rate was also set to 4.0/day, higher than the normal value of around 1.0/day. Although this resulted in better calibration results, it was unlikely this value would provide realistic representations when modeling management scenarios. The reaeration option was set to use the O'Connor equation, but the corresponding parameter was set to 0.5 instead of 3.933, which typically underestimates reaeration. Finally, the organic nitrogen and phosphorus decay rates were set to vary with phytoplankton concentration, which generally is not recommended unless strong evidence supports this parameterization. In this model refinement, all of these out-of-range parameters were initially corrected to provide reasonable starting values and then updated through the model calibration process.

f) Calibrate the integrated hydrodynamic and water quality model

After incorporating the floating macroalgae simulation capability and sediment diagenesis into the Famosa model, a final model calibration effort was conducted. The calibration was conducted by first setting all parameters within reasonable ranges and then fine-tuning the parameters until the model reasonably reproduced observed hydrodynamic and water quality data.

3.2.2. Model Dimensions and Grid Generation

The Famosa Slough receiving water model is composed of three portions: Slough, Channel, and the tidal reach of the San Diego River. The Slough and Channel are connected by hydraulic structures (culverts) that govern the direction of flow either into or out of the Slough. Two types of culverts are present at West Point Loma Boulevard (WPLB): two 4 × 6 foot box culverts and two 4-foot diameter reinforced concrete (RC) culverts. The Channel is connected to the San Diego River by three 5-foot diameter identical RC culverts. Figure 46 illustrates the general layout of the Slough, Channel, and the San Diego River.

Model grid generation used the March 2008 bathymetric survey of Famosa Slough that was performed as part of the TMDL monitoring study (Weston Solutions, 2009). These data include bottom elevations that were measured at several locations throughout the Slough and Channel. The depth-averaged model domain was represented as a grid consisting of 545 discrete quadrilateral computational cells (Figure 47). The tidal reach of the San Diego River, located between the ocean inlet at Dog Beach and the I-5 bridge, was represented as 28 discrete rectangular computational cells. The grid cells in the Slough and Channel have widths ranging from 6.2 to 36.3 meter and lengths ranging from 4.8 to 46.2 meters. The grid cells for San Diego River were coarser resolution (619 × 67 meters) because the river is only used for the interaction of freshwater from upstream river water and tidal water. These form the boundary condition of the Channel. Visual observations and discussions with City officials confirmed that the flap gates between the Channel and San Diego River were not closed during the 2007–2008 monitoring period (Weston Solutions, 2009).

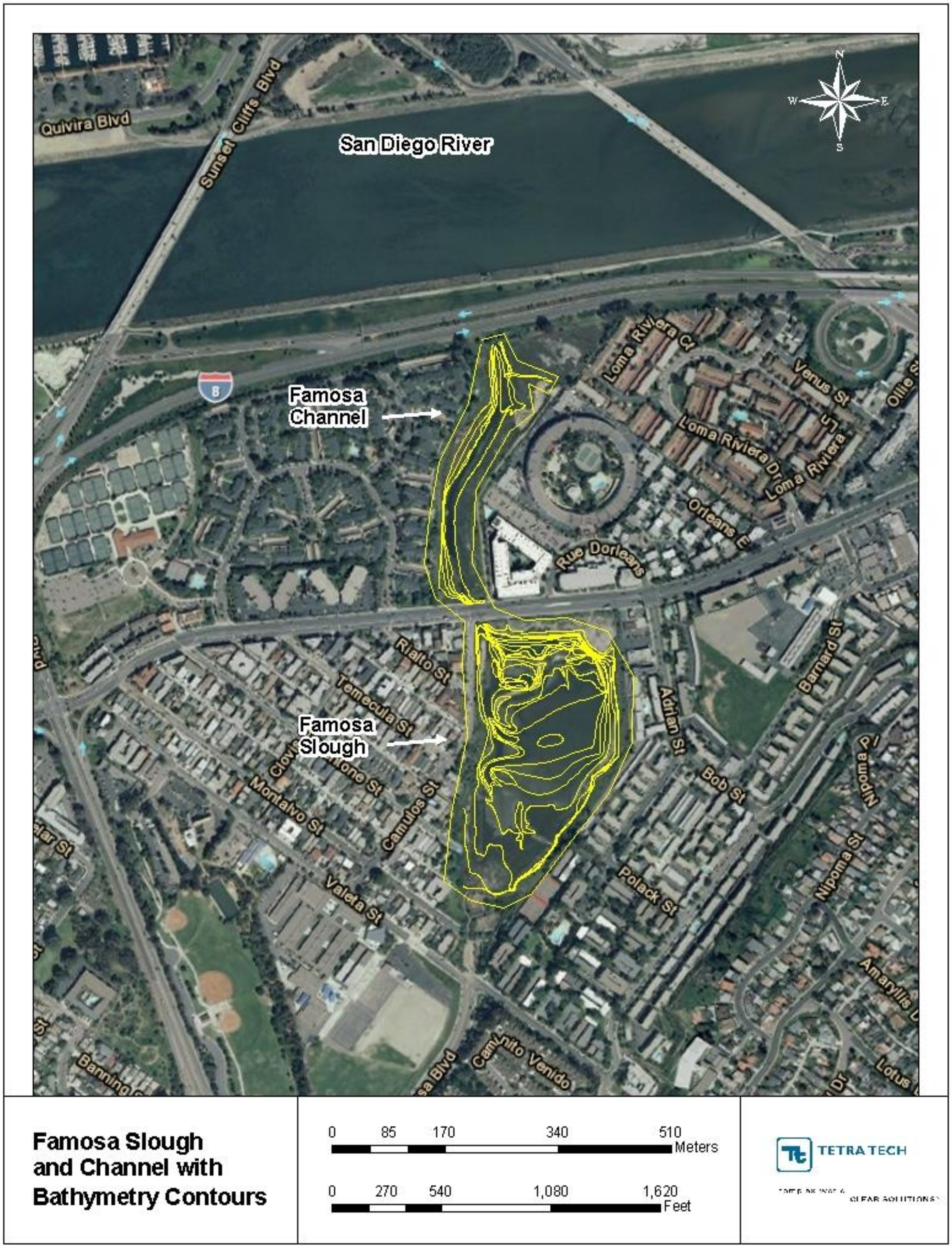


Figure 46. Layout of Famosa Slough

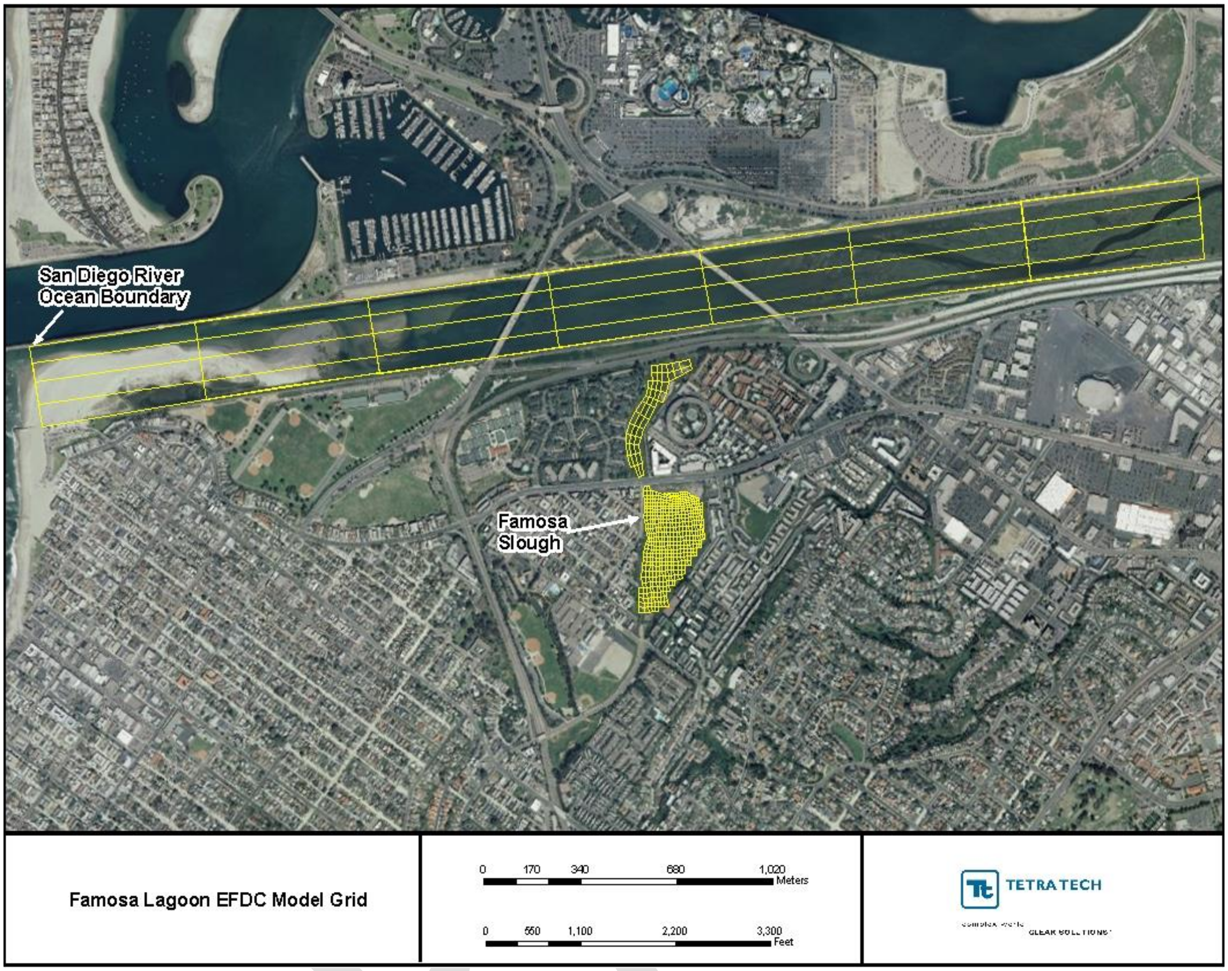


Figure 47. EFDC Grid for Slough, Channel, and the San Diego River

3.2.3. Representation of Exchange between Slough, Channel, and the San Diego River

The exchange of water and associated water quality variables between the San Diego River and Channel is controlled by three identical 5-foot diameter RC culverts. Accordingly, a rating curve was developed for these hydraulic structures (Figure 48). The exchange of water and associated water quality variables between Slough and Channel is also controlled by hydraulic structures. As mentioned in the previous section, there are two types of culverts that control this exchange. These two systems of culverts have different sizes, shapes, and invert levels. Accordingly, two separate rating curves were developed: one for the two 2-foot diameter RC culverts (Figure 49) and another for the two 4 × 6 foot box culverts RC-box culverts (Figure 50).

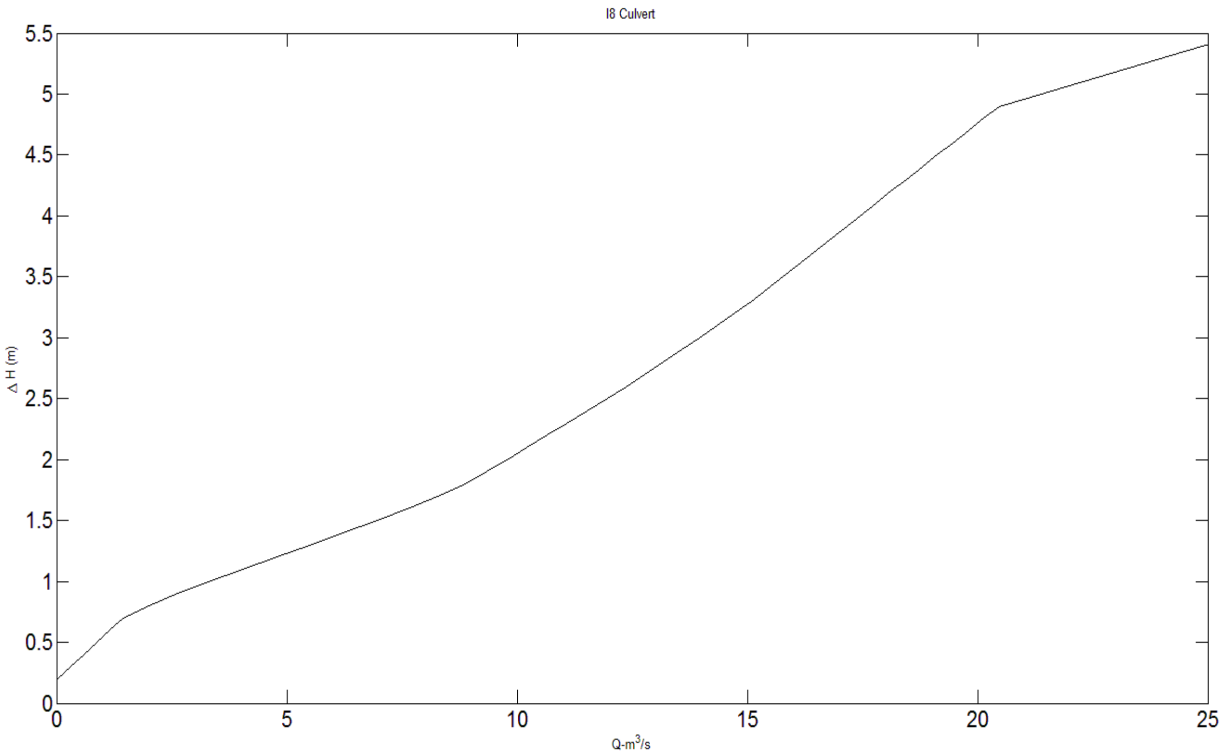


Figure 48. Flow Control Plot for the RC Culverts under I-8

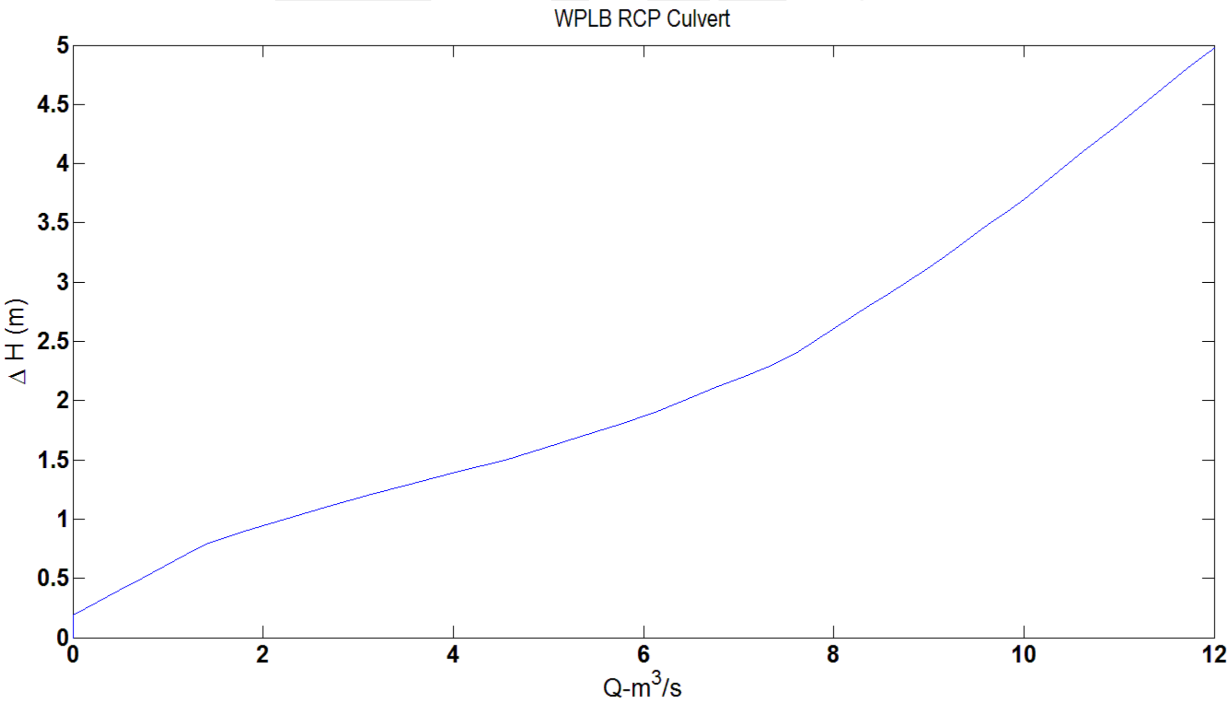


Figure 49. Flow Control Plot for the RC Culverts at WPLB

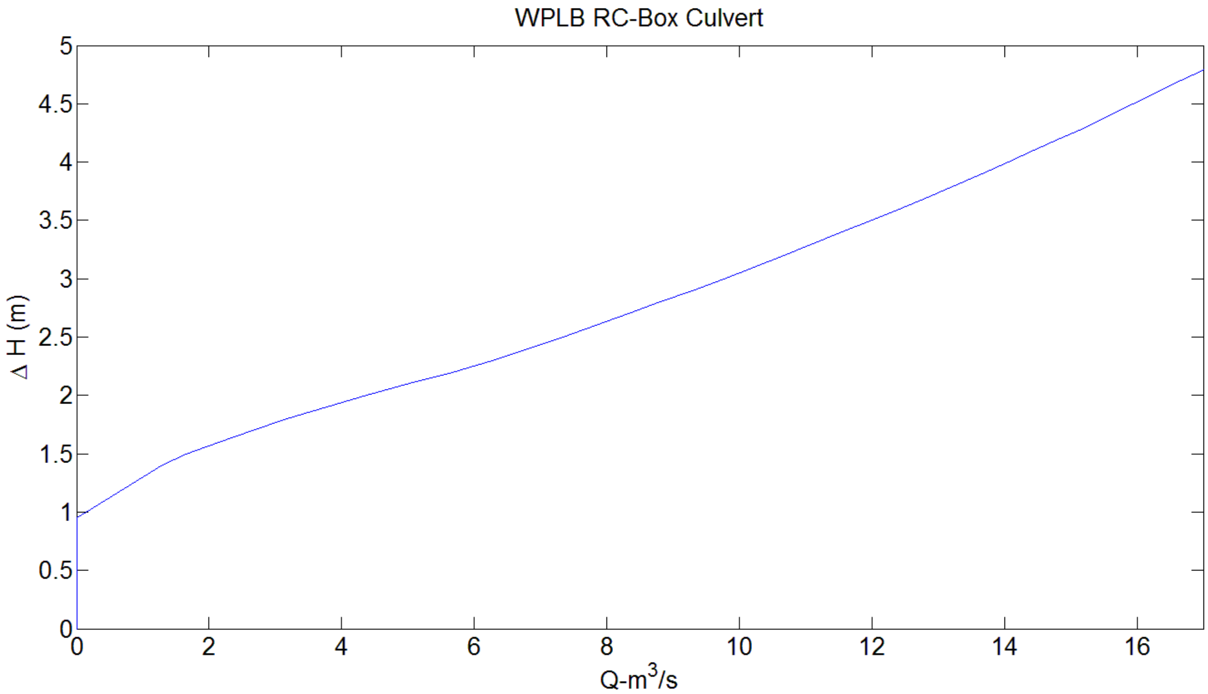


Figure 50. Flow Control Plot for the RC Box Culvert at WPLB

3.2.4. Boundary Conditions

Water quality within the Slough, Channel, and the San Diego River are continuously changing due to external forces, including: tides and material exchange between the Slough, San Diego River, and the Ocean, atmospheric air temperature, rainfall and solar radiation, and flow and nutrient loadings from the surrounding watershed and others. These external forces are represented in the model using boundary conditions. Proper boundary conditions must be specified to simulate water circulation and eutrophication dynamics using the EFDC model. Boundary conditions include watershed freshwater inflows and associated nutrient loadings directly to the Slough, Channel, and the San Diego River. Hydrodynamics and water quality transport within the San Diego River are also controlled by tidal boundary conditions, which include specification of tidal water level variations and water quality concentrations over time, at its interface with the Pacific Ocean.

3.2.4.1. Watershed Boundary Conditions

Watershed inflows determine the amount of freshwater and associated nutrient and heat (via water temperature) loads input to the Slough, Channel, and San Diego River. Watershed hydrology and nutrient loading were modeled using the LSPC model (Section 2). Freshwater flows from watersheds are calculated on the basis of geographical, hydrological, and meteorological factors (land use/cover, landscape parameters, soils, air temperature, rainfall, etc.). Flow rates and nutrient loading from different subwatersheds were assigned as boundary conditions to the EFDC model. The EFDC grid cells that receive flow and nutrient loading from different subwatersheds were determined based on the natural drainage of the subbasin. Salt loadings from the direct drainage areas were set to zero, and salt loadings from the ocean were specified based on a constant ocean salinity of 35 parts per thousand (PPT). The LSPC model simulated flow rates, total nitrogen, and total phosphorous loading rates. Time series of predicted watershed flows and loads (total nitrogen and phosphorous) were imported from a calibrated LSPC simulation output.

Partitioning of the LSPC predicted total phosphorus (TP) and total nitrogen (TN) loads into NH4-N, NO3-N, organic N forms, PO4-P, and organic P forms was based on a previous study (Weston Solutions, 2009).

3.2.4.2. San Diego River Boundary Conditions

Boundary input flows entering the San Diego River tidal reach from its tributary watershed were specified using daily flow rates published by USGS (USGS, 2012) for the San Diego River at the Fashion Valley Mall (upstream of the I-5 bridge). Daily loads of DO and the other EFDC water quality constituent state variables were subsequently determined based on the product of the USGS daily flows and average concentrations derived from the numerous water quality constituents measured between 2001 and 2008 at the San Diego River Mass Loading Site. This site is co-located with the USGS flow gage and water quality constituents that were measured 18 times between 2001 and 2008 including: DO, NO3-N, NH3-N, TKN, DP, TP, TOC, and DOC (Project Clean Water, 2012). Setting the river loading input using long-term average nutrient concentration introduces uncertainty in the model because loading from the San Diego River can be highly time variable. In the future, if additional data collection or San Diego River watershed modeling is available, the Famosa model could be further improved by incorporating temporal variability in the incoming loading from the San Diego River.

3.2.4.3. Open Ocean Boundary Conditions

In addition to the watershed, the ocean has both hydrodynamic and water quality influences on the Slough, Channel, and San Diego River. During incoming (flood) portions of each tidal cycle, ocean water is mixed with some of the San Diego River water, and water flows into the Channel and Slough. Conversely, some of the water from the Slough, Channel, and San Diego River exits the ocean boundary at Dog Beach, during ebb portions of each tidal cycle. Changes in ocean water surface elevation determine the direction of flow and the transport of water quality constituents within the model domain. Ocean water also increases or decreases the pollutant concentrations in Famosa Slough depending on water quality conditions along the ocean boundary. The impact of the ocean water hydrodynamics was represented in EFDC through specification of tidal boundary conditions using measured (6-minute interval) water surface elevations at Scripps Pier (La Jolla), measured (15-minute interval) water temperatures variations at the outlet of the Channel, and specification of constant values of salinity and other water quality constituents that are typical of coastal waters (Table 9). Ocean boundary conditions specified for incoming seawater DO were determined using measured (15-minute interval) water temperatures variations at the outlet of the Channel. Ocean boundary conditions specified for incoming seawater nutrients were determined based on coastal water quality data collected offshore of the San Diego River discharge, during the Southern California Bight 2003 Monitoring Program (Nezlin et al., 2007). Ocean conditions near the mouth of the San Diego River estuary were not available for input in the model, but Bight 2003 data used were compared to and verified with typical estuary data and the results were similar.

Table 9. Nutrient Ocean Boundary Conditions

Variable	Concentration (mg/L)
Ammonia-Nitrogen (NH_4-N)	0.04
Nitrate-Nitrogen (NO_3-N)	0.02
Organic Nitrogen (ON)	0.01
Phosphate (PO_4-P)	0.01
Organic Phosphorous (OP)	0.01

3.2.4.4. Representation of Water Column and Sediment Interactions

Deposited particulate organic matter in the sediment undergoes decaying and results in either a sink or a source of nutrients and DO to the water column. Benthic flux was found to be a major driver in the overall nitrogen budget of Famosa Slough (SCCWRP, 2010). A sediment diagenesis model was developed to dynamically link the benthic nutrient flux and SOD to watershed loading, San Diego River loading, ocean boundary loading, fate and transport of nutrients, floating and benthic macroalgae, macrophytes, and phytoplankton dynamics in the system. The sediment diagenesis model was coupled with the water column hydrodynamic and water quality models to form a predictive system of Famosa Slough.

3.2.4.5. Meteorological Boundary Conditions

Meteorological data are an important component of the EFDC model boundary conditions. Surface boundary conditions (atmosphere-water interface fluxes) are determined by the meteorological conditions. Data required for model setup include atmospheric pressure, air temperature, relative humidity, precipitation, cloud cover, solar radiation, wind speed, and wind direction.

Hourly measurements of atmospheric pressure, dry and wet bulb atmospheric temperatures, rainfall rate, wind speed and direction, and fractional cloud cover were obtained from NOAA National Climate Data Center for the San Diego Airport. San Diego Airport is 3 kilometers southeast of Famosa Slough (Figure 51).

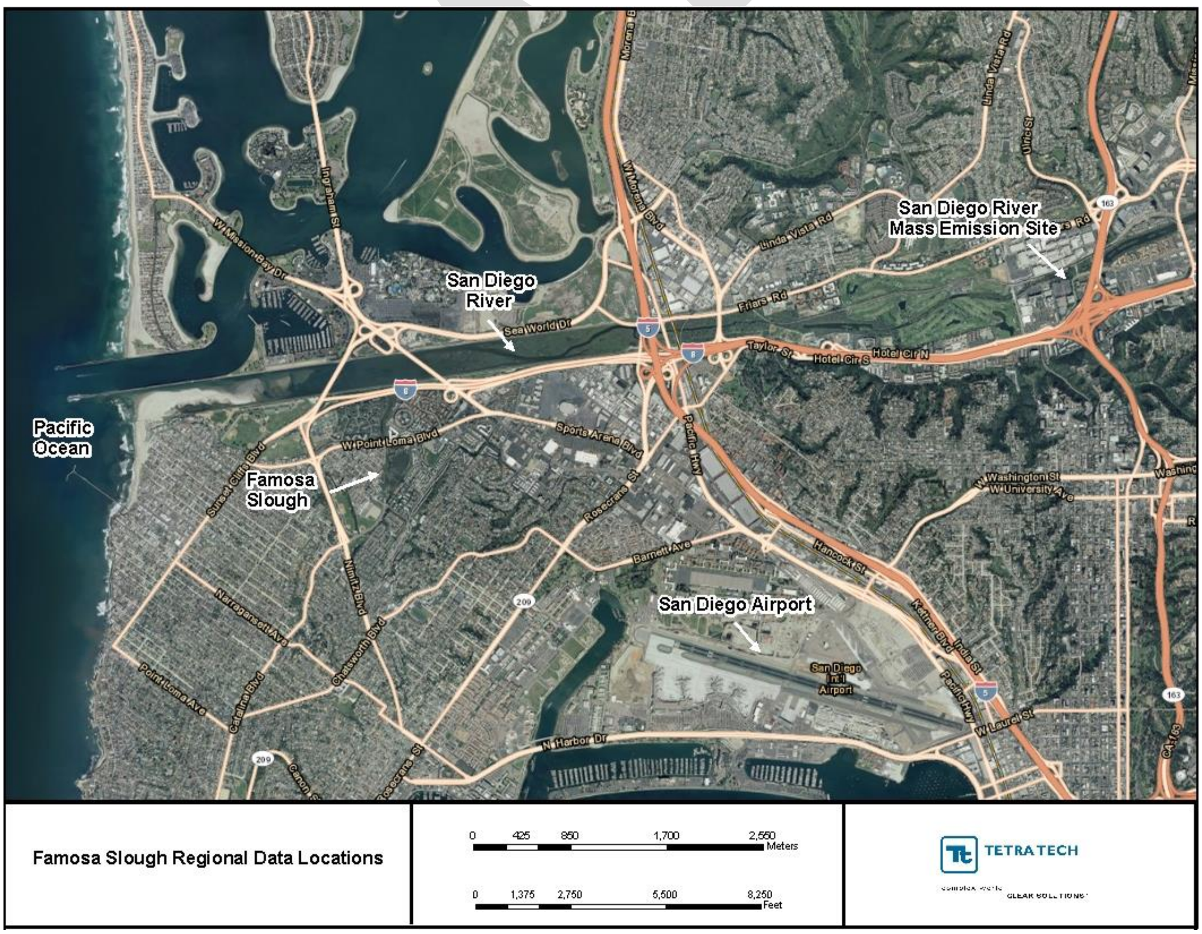


Figure 51. Famosa Slough Regional Data Locations

3.2.4.6. Initial Conditions

In hydrodynamic and water quality modeling, initial conditions provide a starting point for the model to march forward through time. For a dynamic model such as EFDC, initial conditions of water surface elevation, water temperature, salinity, and water column nutrient concentrations must be specified. Initial conditions were set to reasonable values based on modeling judgment. Sensitivity analyses showed that the hydrodynamic model performance is not sensitive to initial conditions. However, the initial condition values for sediment diagenesis are important for a reasonable simulation of the nutrient and biological dynamics in Famosa Slough. In this study, an iterative approach was adopted to derive the initial sediment condition, which uses the end of year simulated bed condition as the initial condition for the next calibration iteration. Using this approach, the initial condition for sediment diagenesis will gradually converge to a condition that reflects the complex interaction in the calibrated model. When the model parameterization is considered to be near the final calibration, the same model will be run for 3 years, and the end concentration in the bed will be used as the final estimate of the initial condition for the sediment diagenesis model. Similarly, the water quality initial condition was set to reflect the general spatial distribution in the system at the beginning of the year.

3.3. Model Calibration

Hydrodynamic model calibration involved the adjustment of open boundary forcing, bottom roughness, and bottom elevations to obtain a general best agreement between model predictions and observations of water surface propagation, salinity, and water temperature distributions. Similarly, the calibration process for water quality involves varying parameters and kinetics values within reasonable and observed ranges to reproduce measured spatial and time varying water quality distributions within Famosa Slough.

Figure 52 is a schematic diagram summarizing the key process pathways specific to eutrophication in the Famosa Slough model. The diagram shows the zones discussed in Section 3.2, the Slough, Channel, and the San Diego River estuary. The model includes the five boundary conditions discussed: watershed, river, ocean, bottom, and meteorological conditions. Model processes are represented within these zones and boundary conditions. Various fractions of carbon, nitrogen, and phosphorus are represented in the water column and cycling in and out of the boundary conditions. Primary producers are represented by three groups. The most significant primary producer found in Famosa Slough is macroalgae. The macroalgae group was divided into benthic macroalgae and floating macroalgae. Macrophytes are represented in the Channel, along with benthic macroalgae. A phytoplankton group was also represented in the model; however, macroalgae tend to out-compete phytoplankton in Famosa Slough, thus macroalgae is the key primary producer group for this model. Monitoring data show that watershed loads and benthic flux are the key nutrient inputs to the system and the model simulates these sources as well as their effects on primary producer dynamics and create the diel DO swings. The specific processes and model representation of the hydrodynamic and water quality variables are discussed in this section.

The model calibration process for Famosa Slough used data that were collected by SCCWRP (2010) and the Weston Solutions (2009). Figure 53 presents the location of the water quality monitoring stations used in model calibration. The majority of data collected during the monitoring effort were continuous monitoring data at three monitoring stations: Famosa Channel Outlet (OUTLET), Famosa Slough Outlet (SEG), and at the southern end of Famosa Slough (MES). Because of the large amount of data available, these monitoring stations were used for hydrodynamic and water quality model calibration. In addition to continuous monitoring at these three sites, Index Period monitoring was conducted during four seasonal events throughout 2008. Each event included grab sample collection for seven days over a period of two consecutive weeks at the three continuous monitoring stations and transects within the Channel and Slough. Descriptions and photographs of the sites and sampling events can be reviewed in Weston Solutions (2009).

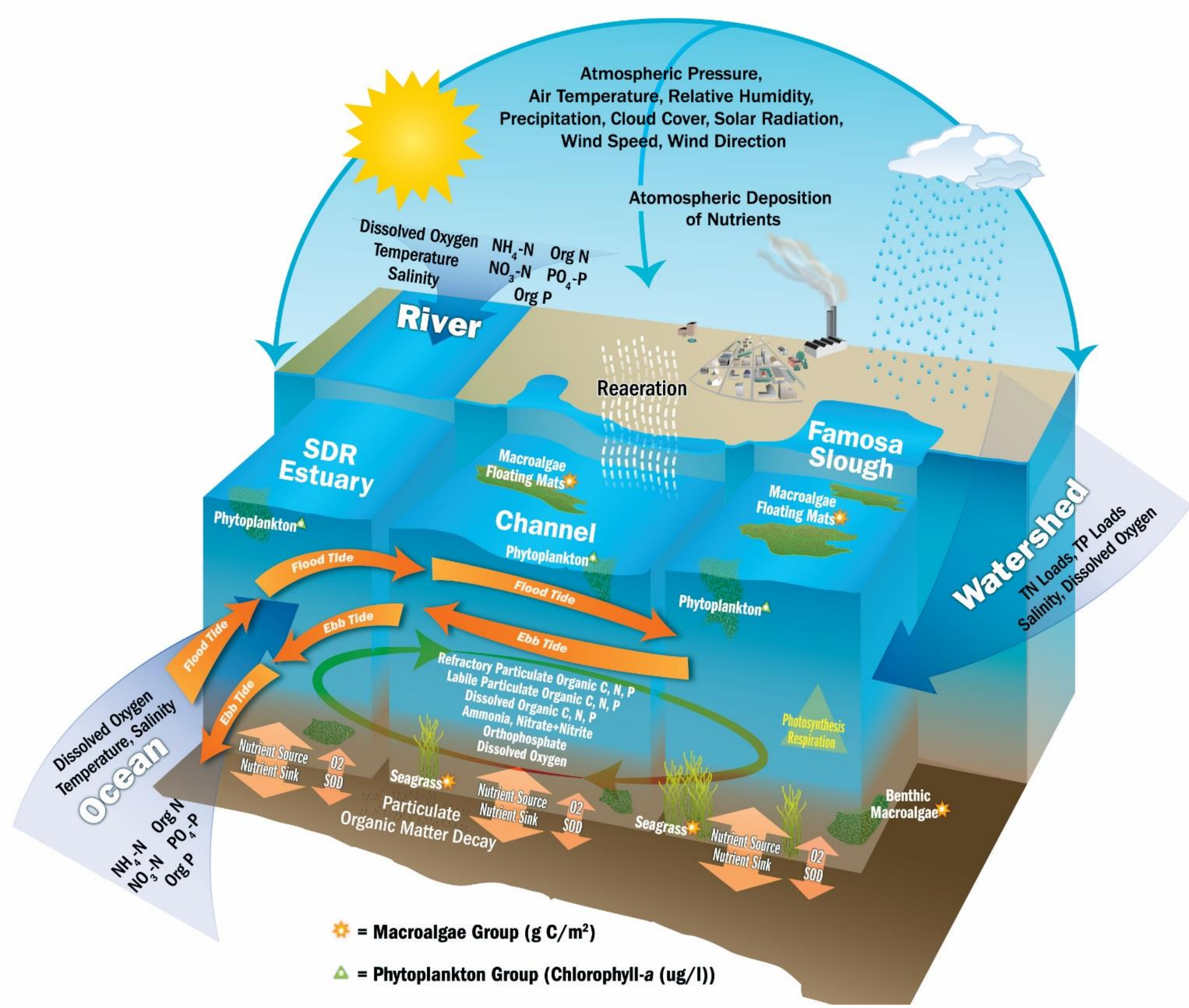


Figure 52. Schematic Diagram of Famosa Slough Receiving Water Model Processes

Figure 53. Location of Monitoring Stations within Famosa Slough

3.3.1. Hydrodynamic Calibration

During calibration of the hydrodynamics model, predicted water surface elevations (WSE), water temperatures, and salinities were compared to continuous sonde measurements of water depth, water temperature, and conductivity, at the three monitoring stations. Water temperature and conductivity data were also collected independently of the continuous sonde measurements using hand-held YSI meters, during the four Index Monitoring Periods (winter, spring, summer, and fall) in 2008.

Figure 54, Figure 55, and Figure 56 show comparisons of simulated and measured WSE, in meters above mean lower low water levels (MLLW) at the OUTLET, SEG, and MES monitoring locations, respectively, for the simulation period (January 1–December 31, 2008). Generally, there is good agreement between measured and predicted tidal water level variations at all three monitoring locations. A significant improvement in this round of refinement is that the model is capable of reproducing the elevation and salinity at the MES station better than the previous versions. Although the difference between modeled and observed data at the MES station is still significant, the model results generally provide a more consistent representation of the system such that whenever the tidal effect is high at the other two stations, the model results also show high tidal activity. The observed data, on the other hand, appear to lack consistency between the MES and the other two stations, suggesting that the data collected at the MES either reflects highly local phenomena that are beyond model representation, or the data itself might not be robust due to the sonde's location at the upper extent of the Slough. This improvement to the water depth provides for more accurate simulation of the observed diurnal fluctuation in water temperature (Figure 60 through Figure 62).

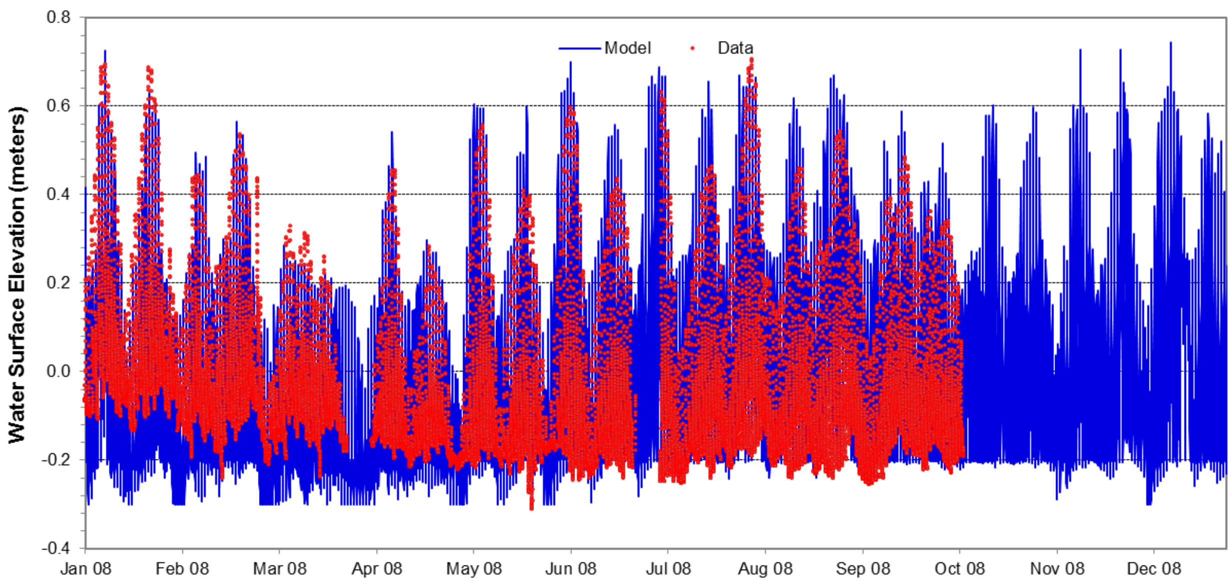


Figure 54. Comparison of Observed vs. Simulated Water Level Variations at Famosa Channel Outlet (OUTLET)

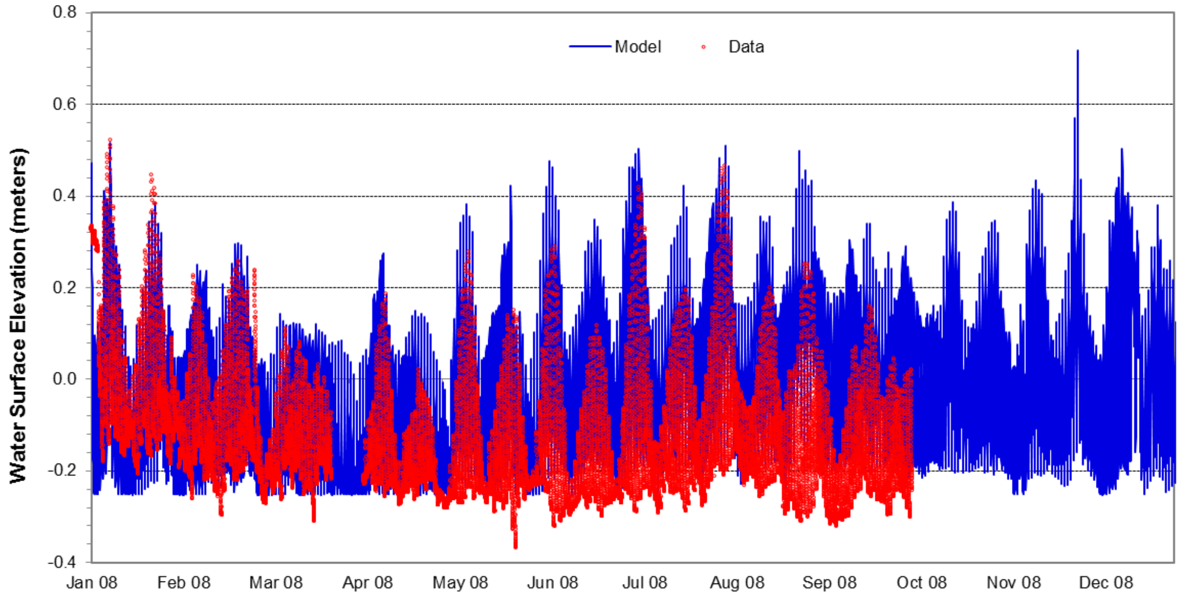


Figure 55. Comparison of Observed vs. Simulated Water Level Variations at Famosa Slough Outlet (SEG)

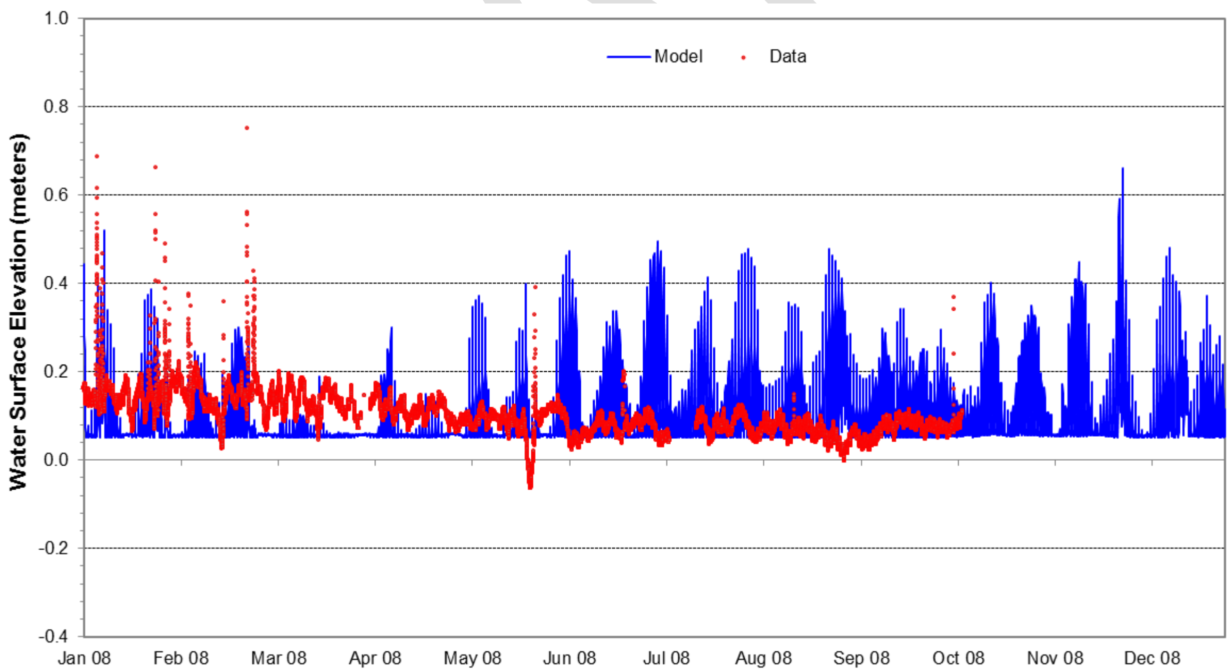


Figure 56. Comparison of Observed vs. Simulated Water Level Variations at Southern End Famosa Slough (MES)

Figure 57, Figure 58, and Figure 59 show comparisons of simulated and measured salinity at the OUTLET, SEG, and MES monitoring locations, respectively, for the simulation period. Measured and predicted salinities clearly show the impact of several significant rainfall/runoff events, which occurred during January and February of 2008 and are illustrated by the influx of freshwater and associated decrease in salinity. However, between March and October 2008, very little rainfall and fresh water runoff passed through the Slough and Channel, whereas the continuous salinity monitoring data periodically show relatively low salinities during this dry period (Figure 57 and Figure 58). Accordingly, the continuous sonde (15-minute interval) salinity monitoring data at all three monitoring locations are suspect after February 2008.

Simultaneously, independent, hand-held monitored (YSI) salinity data were also collected at these locations, during the four Index Periods in 2008 (Figure 57, Figure 58, and Figure 59). These salinity data, which are similar to the predictions at the OUTLET and SEG, further demonstrate that the continuous salinity data are suspect. Similar measurement discrepancies, as seen between the continuous sonde and the hand-held YSI probe salinity data, will also be discussed later in this report for DO. These measurement discrepancies are likely due to the sonde installations, which were in very shallow water that often receded near to or below the sonde elevation, during periods of low tide. These conditions could contribute to periodic fouling of the probe by surface floating debris or drying. Therefore, it is not expected that the model will reproduce the timing and fluctuation in salinity due to uncertainty in the sonde data collected. In general, the model results show that it is capable of catching the overall patterns, particularly sharp drops in salinity during the wet period, as well as the lower salinity at the MES station.

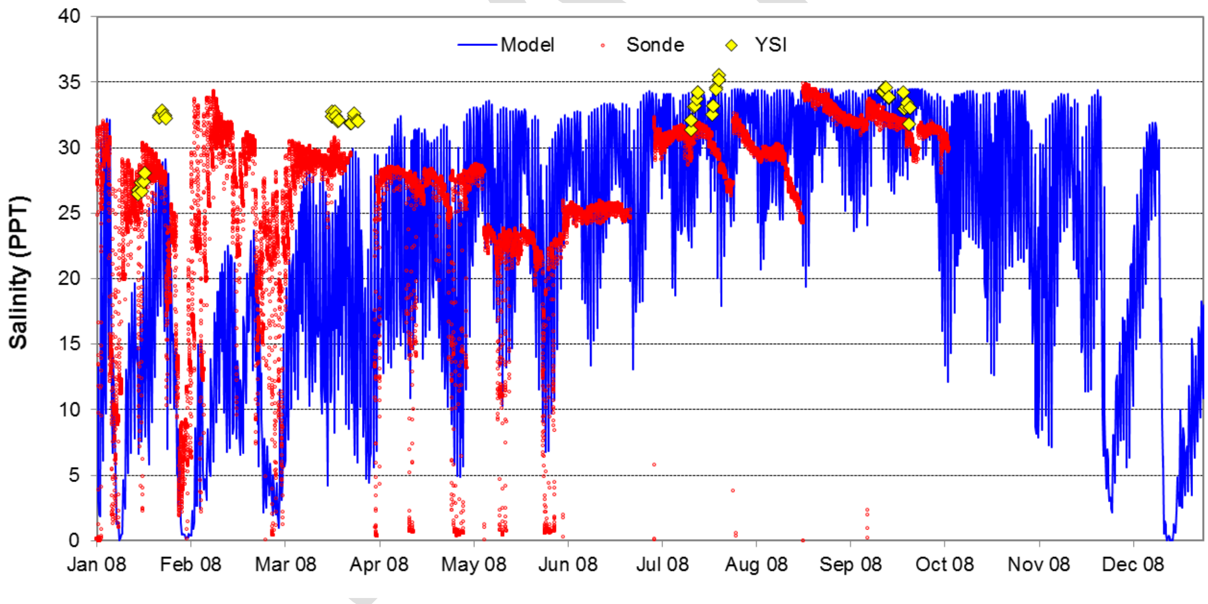


Figure 57. Comparison of Observed vs. Simulated Salinity Variations at Famosa Channel Outlet (OUTLET)

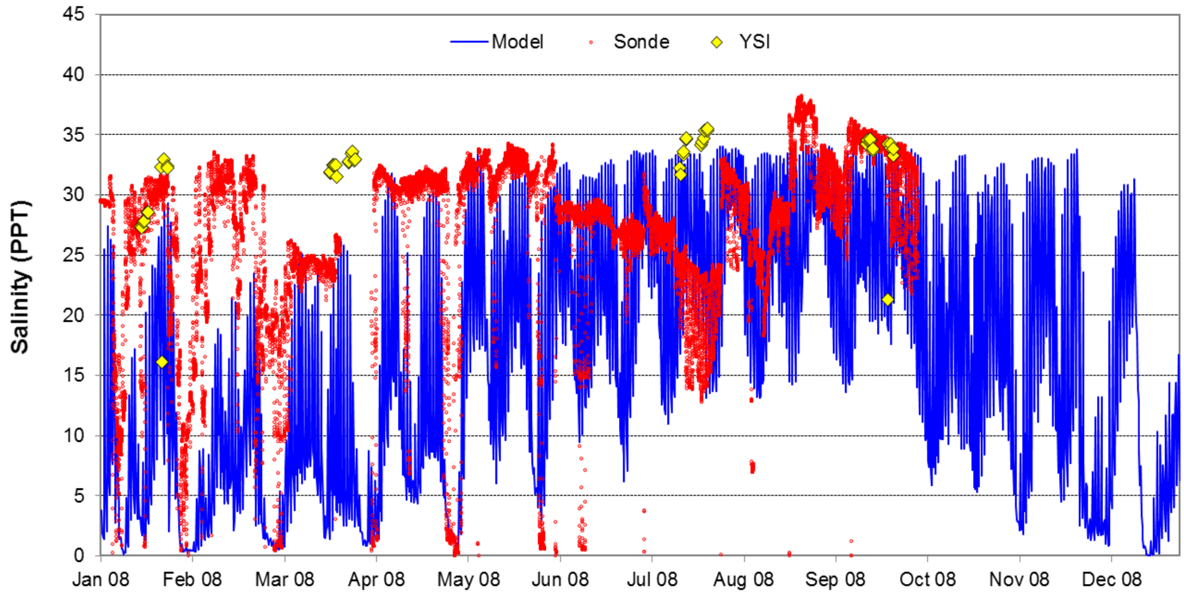


Figure 58. Comparison of Observed vs. Simulated Salinity Variations at Famosa Slough Outlet (SEG)

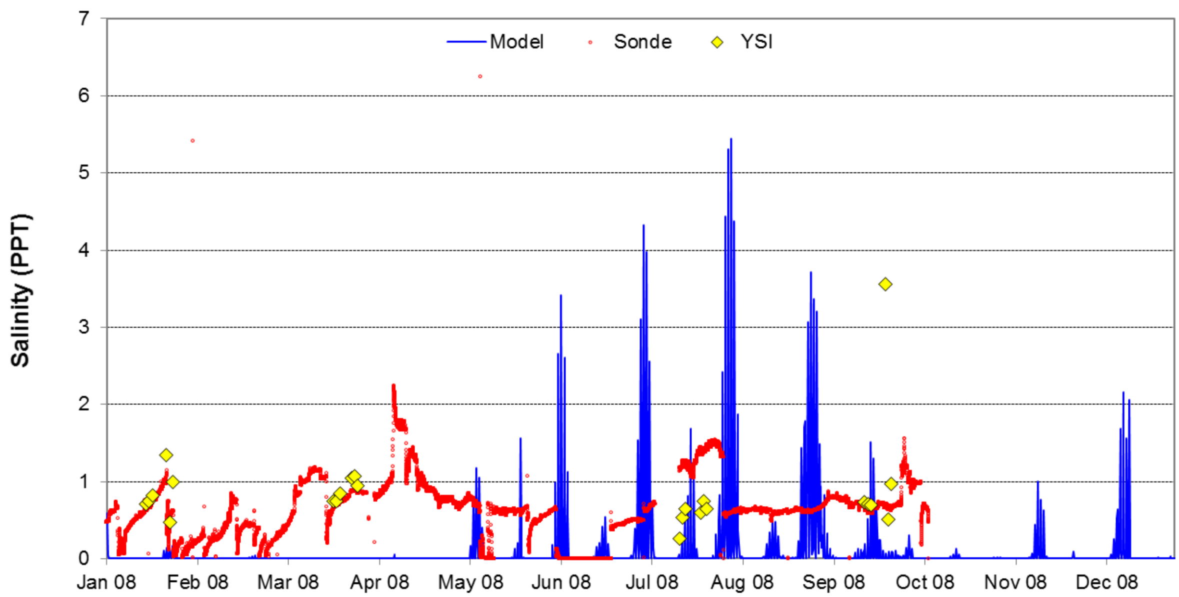


Figure 59. Comparison of Observed vs. Simulated Salinity Variations at Southern End Famosa Slough (MES)

Figure 60, Figure 61, and Figure 62 show comparisons of simulated and measured water temperature at the OUTLET, SEG and MES monitoring locations, respectively, for the simulation period. Generally, there is good agreement between measured and predicted water temperature variations at all three monitoring locations. A significant improvement in temperature simulation was achieved in the current model refinement. The model is capable of predicting the range of observed diurnal fluctuations. Previously, the model consistently underpredicted the diurnal range. The continuous (15-minute interval) temperature monitoring data collected at the MES location are suspect, between July and September 2008, as very little diurnal and day-to-day variability is evident only within this period. In addition, this period, which coincides with the warmer summer months, is expected to have higher temperatures, consistent with the model results. Overall, predicted temperature variations are consistent with the YSI probe data that were collected (Figure 60, Figure 61, and Figure 62).

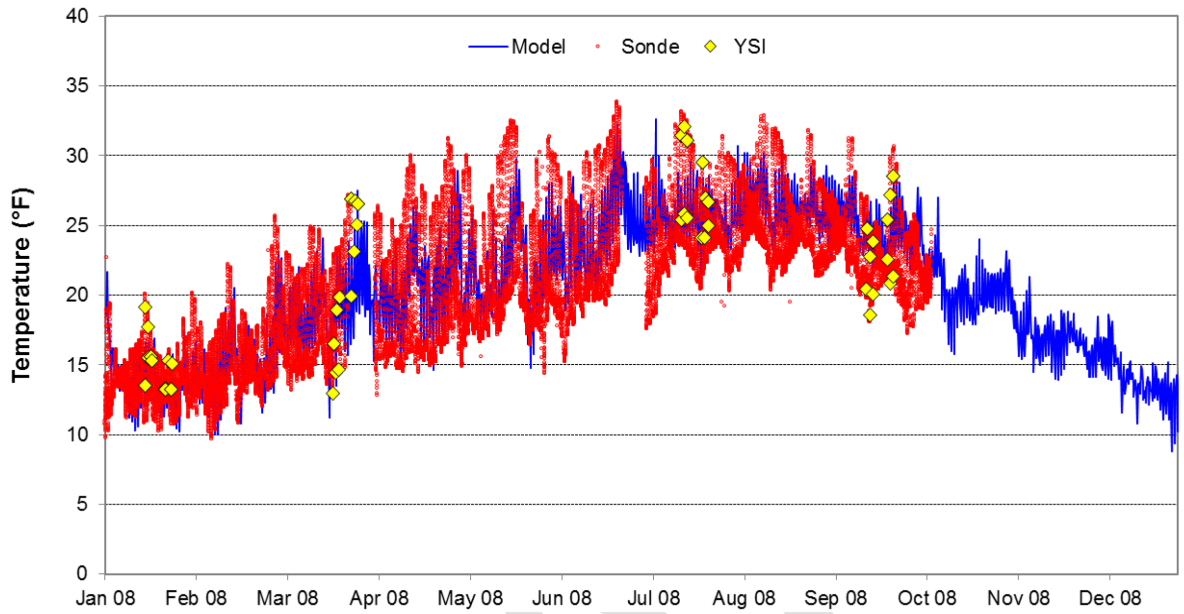


Figure 60. Comparison of Observed vs. Simulated Temperature Variations at Outlet of Famosa Channel (OUTLET)

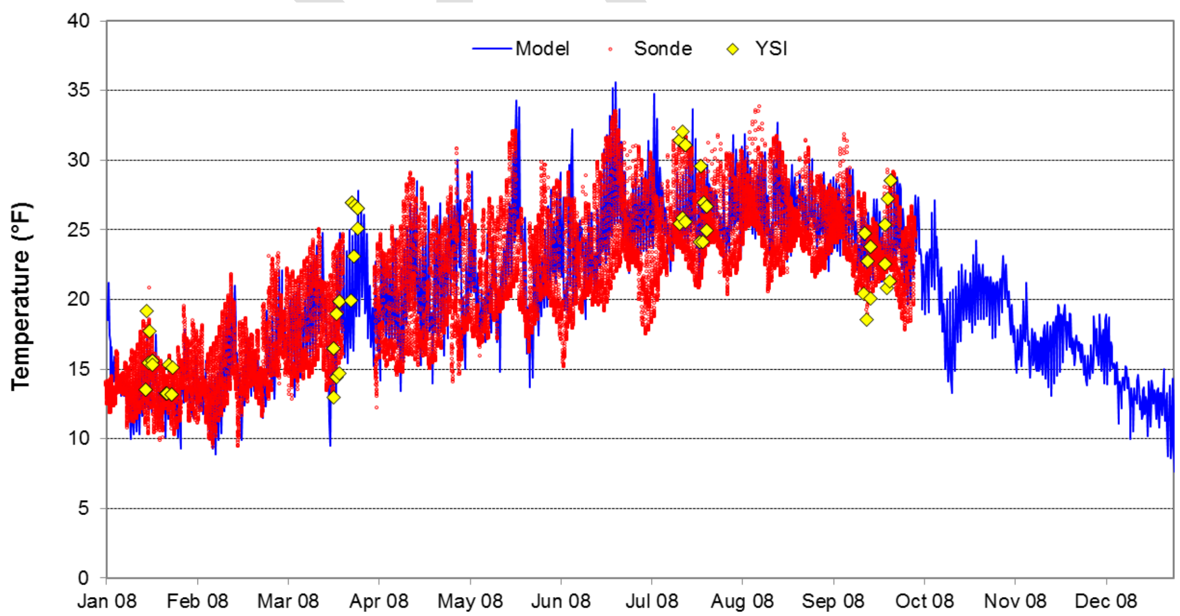


Figure 61. Comparison of Observed vs. Simulated Temperature Variations at Outlet of Famosa Slough (SEG)

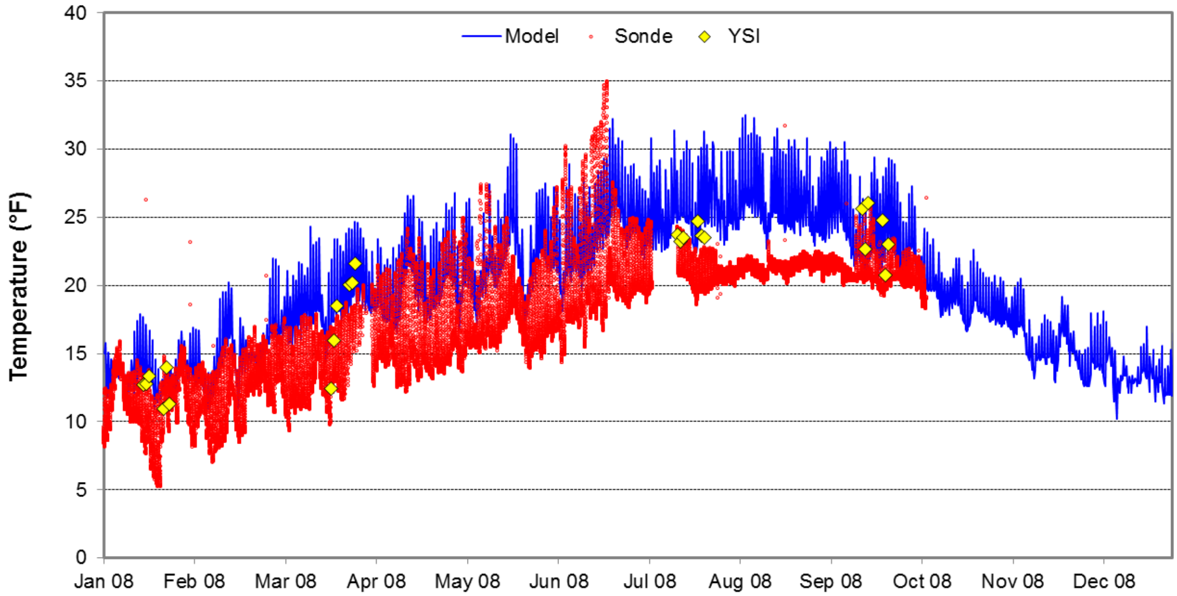


Figure 62. Comparison of Observed vs. Simulated Temperature Variations at Southern End Famosa Slough (MES)

In summary, the EFDC hydrodynamic calibration results shown in Figure 54 through Figure 62 suggest that the model adequately simulates the propagation of both freshwater and seawater inputs into and out of the Slough, Channel, and San Diego River. They also suggest the validity of the culvert rating curves used to control the exchange of water between the Slough, Channel, and San Diego River estuary.

3.3.2. Water Quality Model Calibration

The calibration process for water quality involves varying parameters and kinetics values within reasonable and observed ranges to reproduce observed spatial and time varying water quality distributions within the Slough, Channel, and San Diego River estuary. The following state variables simulated the eutrophication dynamics within Slough, Channel, and the San Diego River: phytoplankton algae, macroalgae/macrophyte, refractory and labile particulate organic carbon, dissolved organic carbon, refractory and labile particulate organic phosphorus, dissolved organic phosphorus, total phosphorus, refractory and labile particulate organic nitrogen, dissolved organic nitrogen, ammonia nitrogen, nitrate plus nitrite nitrogen, and dissolved oxygen. Table 10 presents a summary of the eutrophication kinetics used in the water quality calibration.

The model spatial domain was divided into four zones for specifying varying macroalgae algal growth to better characterize the spatial variability in macroalgae/macrophyte characteristics. The three key zones are the Slough, Channel, and San Diego River estuary. The fourth zone includes a small area immediately surrounding the MES station. This spatial variability was necessary to reproduce the observed patterns in nutrients and DO dynamics at different zones during calibration.

Table 10. Summary of Kinetic Parameters Used in Water Quality Modeling

Parameter	Value
Algal maximum growth rate	1.1/day
Benthic macroalgae maximum growth rate	0.5/day
Floating macroalgae maximum growth rate	1.2 to 1.9/day
Phosphorus half-saturation conc. - algae	0.001 mg/L
Phosphorus half-saturation conc. - macroalgae	0.001 mg/L
Nitrogen half-saturation conc. - algae	0.01 mg/L
Nitrogen half-saturation conc. - benthic macroalgae	0.01 mg/L
Settling velocity of algae	0.2 m/day
Settling velocity of particulate organic matter	0.5 m/day
Carbon-to-chlorophyll ratio of algae and macroalgae	60 gC/mg Chl
O'Conner-Dobbins Reaeration Rate Constant	3.933

3.3.2.1. Chlorophyll-*a*

Figure 63, Figure 64, and Figure 65 show comparisons of observed against simulated chlorophyll-*a* variations at the three primary monitoring stations (OUTLET, SEG, and MES, respectively). Both the predictions and measurements of chlorophyll-*a* indicate that phytoplankton algal levels are relatively low within the Slough, Channel, and San Diego River, and that phytoplankton algae likely have only a small influence on nutrient and DO levels within these water bodies.

Predicted chlorophyll-a levels are generally in the same range as observed measurements at the OUTLET and SEG monitoring locations. Several much higher measured chlorophyll-*a* values are shown in Figure 64 and Figure 65 and are likely the result of localized areas of high algal activity or possible sample contamination with non-phytoplanktonic plant matter. Predicted chlorophyll-*a* levels within the MES model cell were always very low compared to measurements at this location. This discrepancy is likely due to MES site being near the upland margin of the southern end of the Slough and is often very shallow and above the influence of tides. During dry weather, the small continuous base flows passing through this upland model cell from the watershed tend to transport algae further into the Slough before they can grow to significant levels. Due to the relative insignificance of phytoplankton algae on DO and nutrient resources within the Slough, the differences seen between predicted and measured chlorophyll-*a* levels at the monitoring locations are deemed to be acceptable.

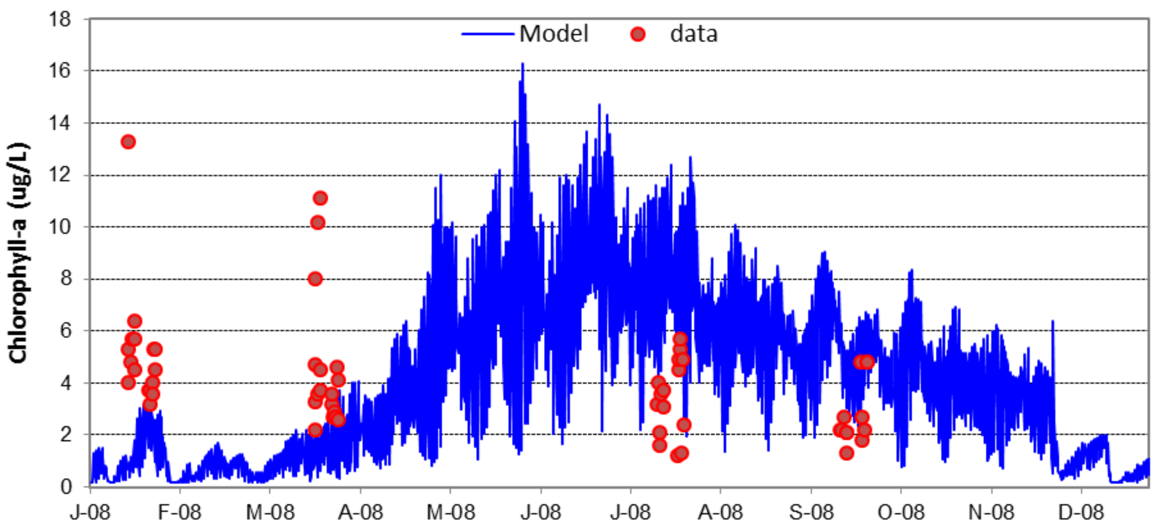


Figure 63. Comparison of Observed vs. Simulated Chlorophyll-*a* Variations at Outlet of Famosa Channel (OUTLET)

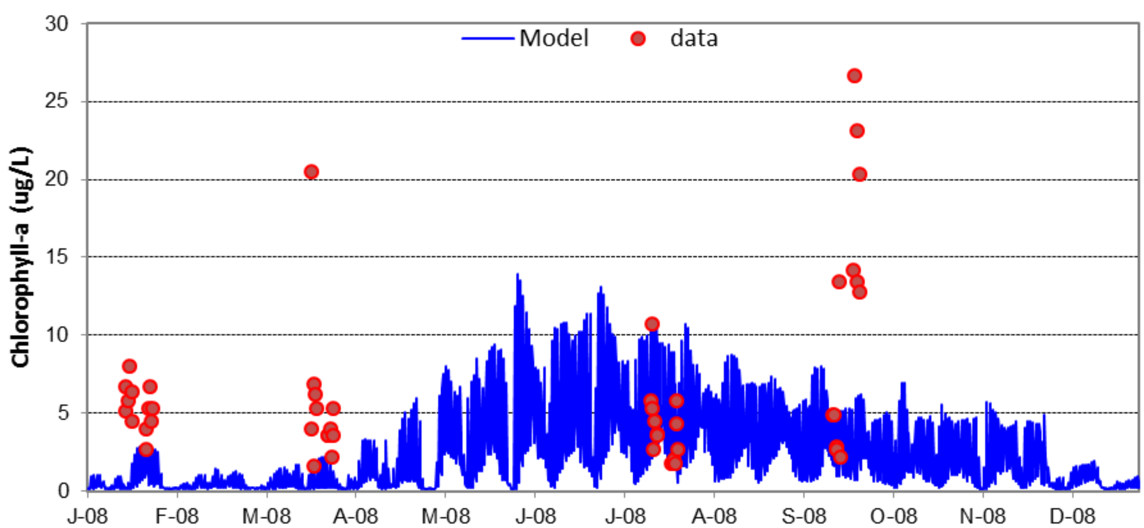
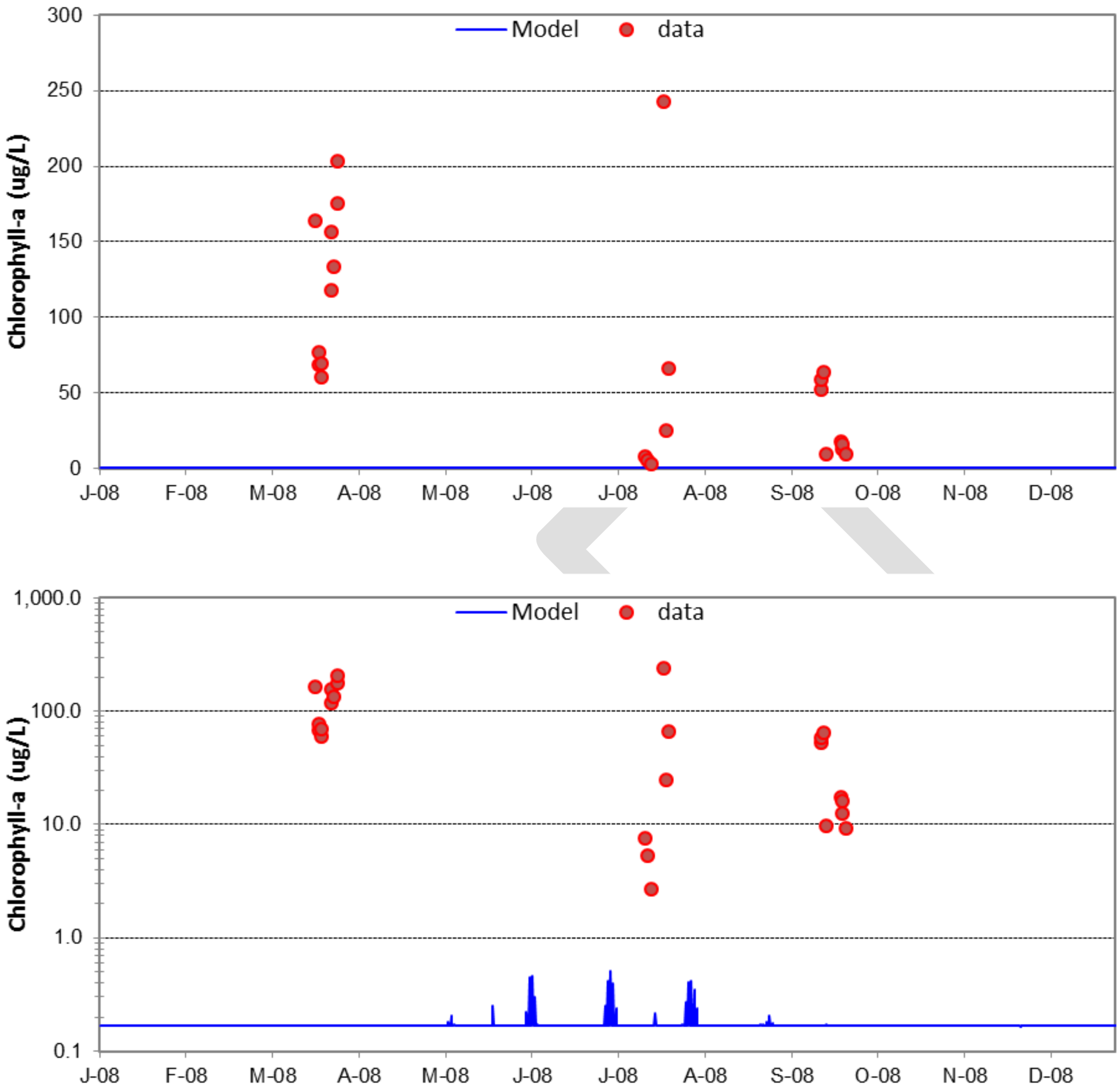


Figure 64. Comparison of Observed vs. Simulated Chlorophyll-*a* Variations at Outlet of Famosa Slough (SEG)



Note: Top plot is regular scale. Bottom plot is logarithmic scale.

Figure 65. Comparison of Observed vs. Simulated Chlorophyll-*a* Variations at Southern End Famosa Slough (MES)

3.3.2.2. Macroalgae

EFDC is capable of simulating primary producers in numerous forms, including three water column (transportable) phytoplankton algal groups and one benthic (stationary) algal group. EFDC can simulate one of the three available phytoplankton group as diatoms, wherein silicon is also included as a limiting nutrient. EFDC can also simulate one of the three available phytoplankton groups as blue-green algae, wherein atmospherically derived dissolved nitrogen gas within the water column might be reduced and used directly as an inorganic nitrogen nutrient source.

During the current calibration, the three available phytoplankton groups were reduced to one broad group, with metabolism controlled only by water temperature, light, and water column levels of nitrogen and phosphorus. Monitoring conducted between 2007 and 2008 (SCCWRP, 2010) suggests that benthic and surface algal forms—floating macro algal mats (summer), blue-green algal mats (fall), benthic macroalgae deposits, and benthic infaunal species—exist in the Slough during much of the year. In addition, photographs from monitoring indicate that rooted macrophytes (seagrass) are also present but were not quantified. Furthermore, it was concluded that these algal groups dominate DO resources, nutrient cycling, and observed levels of eutrophication within these water bodies.

EFDC was used to simulate these diverse groups of observed fixed surface and benthic algal species as two broad algal groups (floating macroalgae and benthic macroalgae) for the Slough. Benthic macroalgae and macrophytes were simulated for the Channel, which did not have observed floating macroalgae. Therefore, macrophytes in the Slough and floating macroalgae in the Channel are not explicitly included in the model.

Figure 66 plots the simulated macroalgae at the sampled transect against the observed data in the Slough. Because the transect covers a range a modeled grid cells, the model results at those cells are extracted and the minimum and maximum values were calculated and plotted to represent the range. Figure 66 indicates that the benthic macroalgae grows earlier in the year and dominates the floating macroalgae from March to May. The floating macroalgae biomass starts to grow in April and then outcompetes benthic algae after May through the end of the year. One measured value is available at this transect and is compared with the model result. The observed value—from SCCWRP (2010)—indicates a range of biomass value of 22 g C/m^2 to 41.8 g C/m^2. The range of values were calculated by applying a biomass to carbon conversion factor to the measured dry weight biomass. The conversion factor (0.22) for the Slough was developed using observed data in the Slough. The default value (0.45) was used for the Channel since observed data were not available and there are different types of algae and conditions between the Channel and Slough. This value can be changed in the future, if data becomes available. As shown, the model predicted macroalgae biomass at this transect matched the measured data very well for the period. The general match in magnitude between the model results and data suggest that the model perform reasonably well in achieving the macroalgae dynamics in the system.

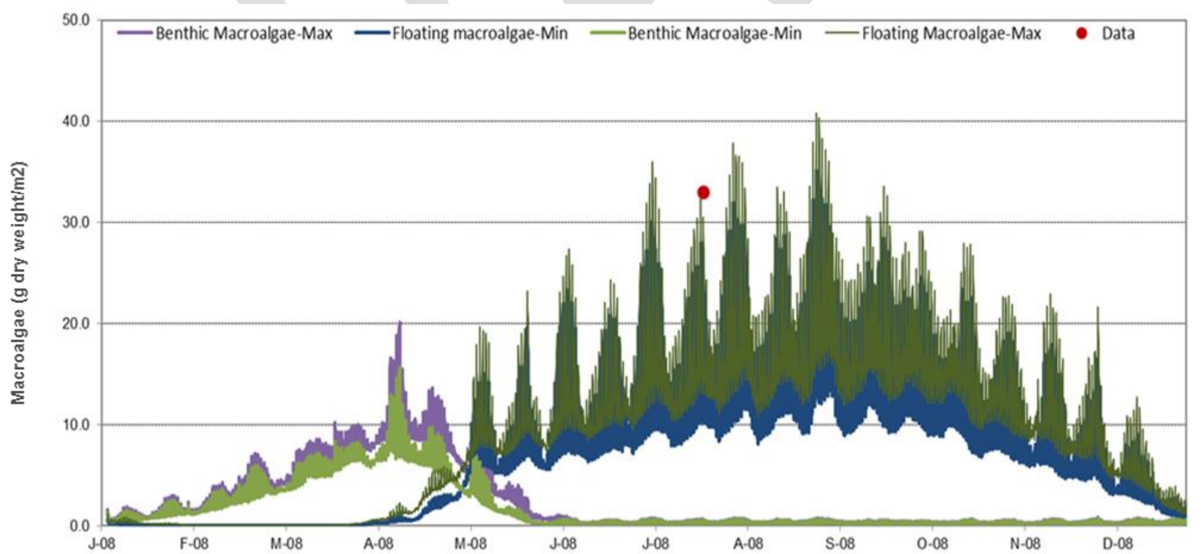


Figure 66. Simulated Macroalgae at the Monitored Transect in the Slough

3.3.2.3. Dissolved Oxygen

Figure 67, Figure 68, and Figure 69 show comparisons of observed against the simulated DO variations at the OUTLET, SEG, and MES monitoring locations. SCCWRP (2010) concludes that the large diurnal DO swings and very low nighttime DO levels seen in the measurements at all three monitoring stations were due, in a large part, to relatively high levels of benthic algae, floating surface algae mat, benthic blue-green algae mat, microphytobenthos, and rooted macrophytes (seagrass) photosynthetic and respiratory activity within the Slough. Both the predictions and measurements of DO suggest that the high levels of macroalgae density and metabolism within the Slough and Channel have a major influence on nutrient and DO variations within these water bodies. Considering significant uncertainty could exist in the DO sonde data, the model calibration focused on reproducing the general trend and magnitude represented by the observed DO data instead of the detailed short-term variations. As shown in these three figures, the model predicts both the seasonal DO variability well, particularly for the critical summer period June to August, and the model simulated diurnal DO ranges with the observed data at the SEG and OUTLET stations with very high accuracy. The performance of the updated model improved significantly at the SEG and OUTLET stations.

Similar variations in DO levels were observed during July of 2008, within the tidal reach of the San Diego River (Schiff et al., 2011). Daytime DO levels within the San Diego River estuary were measured in excess of 17 mg/L and water column chlorophyll-*a* levels were found to be low (< 6 µg/L), suggesting that benthic macroalgae could have a major impact on DO resources within this adjacent, interconnected waterbody.

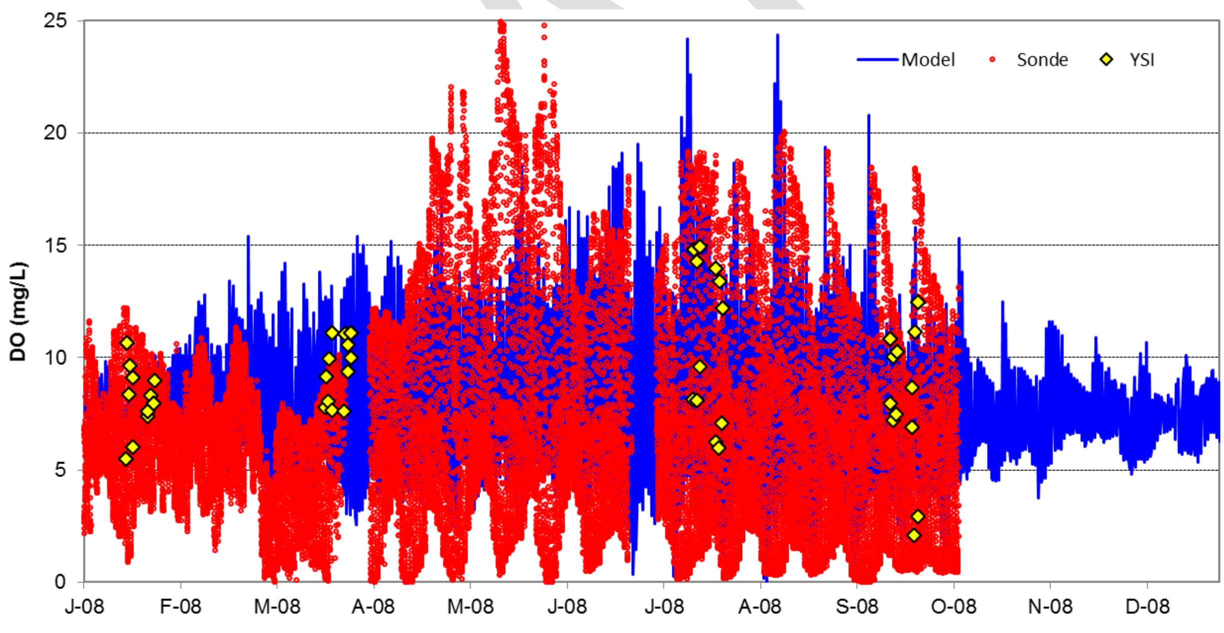


Figure 67. Comparison of Observed vs. Simulated DO Variations at Outlet of Famosa Channel (OUT)

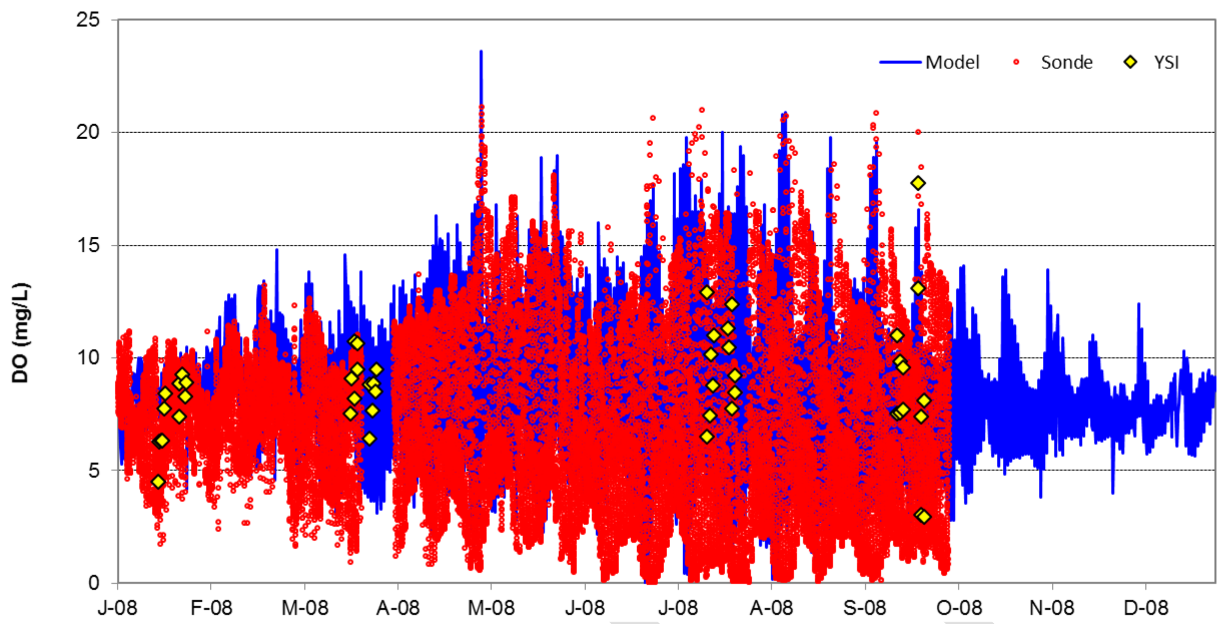


Figure 68. Comparison of Observed vs. Simulated DO Variations at Outlet of Famosa Slough (SEG)

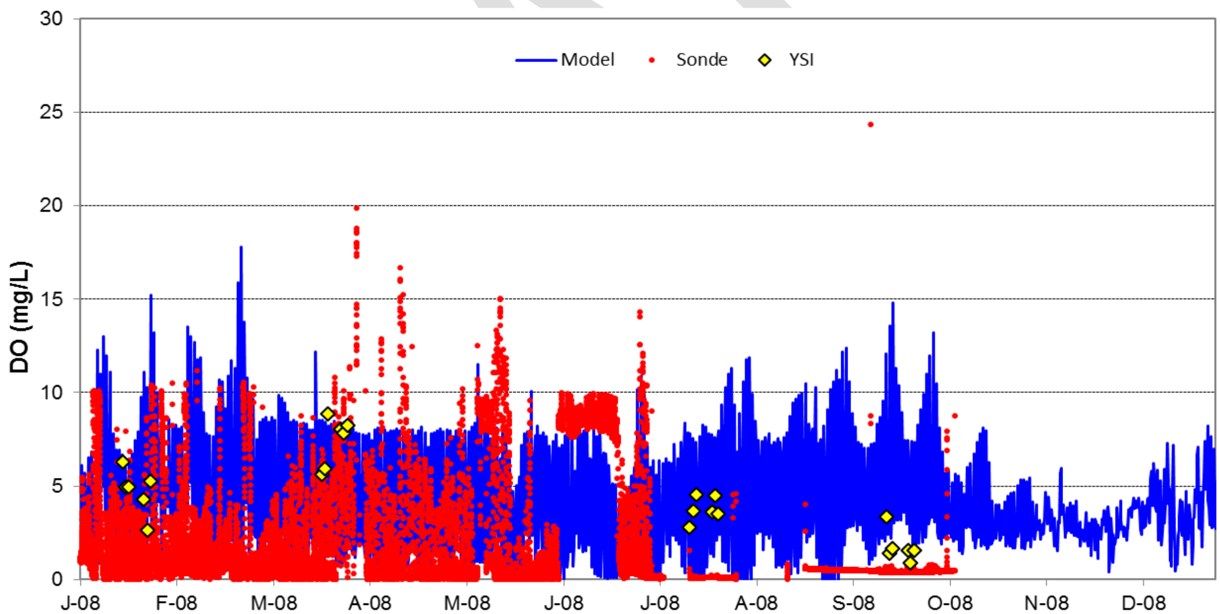


Figure 69. Comparison of Observed vs. Simulated DO Variations at Southern End Famosa Slough (MES)

It is difficult to judge the short-term agreement between the DO predictions and measurements due to the long time scales of Figure 70 through Figure 77 . Therefore, the timescales for these plots were limited to the approximate 10-day time span of each of the four Index Monitoring Periods—Index 1-winter (January 14–23, 2008), Index 2-spring (March 18–26, 2008), Index 3-summer (July 14–23, 2008), and Index 4-fall (September 15–24, 2008). These are described below.

Figure 70 through Figure 73 provide DO simulation results for the Famosa Channel Outlet, for the Index Monitoring Periods using results plotted every 6 hours [this is change from previous draft appendix versions, which used 1-hour output]. Generally, both the measured and predicted DO exhibit large diurnal variations, with high levels of DO super saturation in mid-afternoon (due to benthic algae photosynthesis), followed by a DO crash by the end of the night (due to benthic algae respiration and SOD). The model performs very well for the critical summer/fall periods and reasonably well for Index Periods 1 and 2. The previous version of the model failed to predict the peak DO during the summer period because it was incapable of balancing the watershed and internal nutrient sources with the macroalgae activities. In the current version of the model, the benthic nutrient source is not prescribed and manipulated, but is internally predicted based on the watershed loading and the fate and transport of the nutrients after entering Famosa Slough, as well as the interactions between the macroalgae, macrophytes, and phytoplankton. Therefore, the good performance in predicting the summer DO indicates that the model has represented the complex dynamic interactions reasonably well.

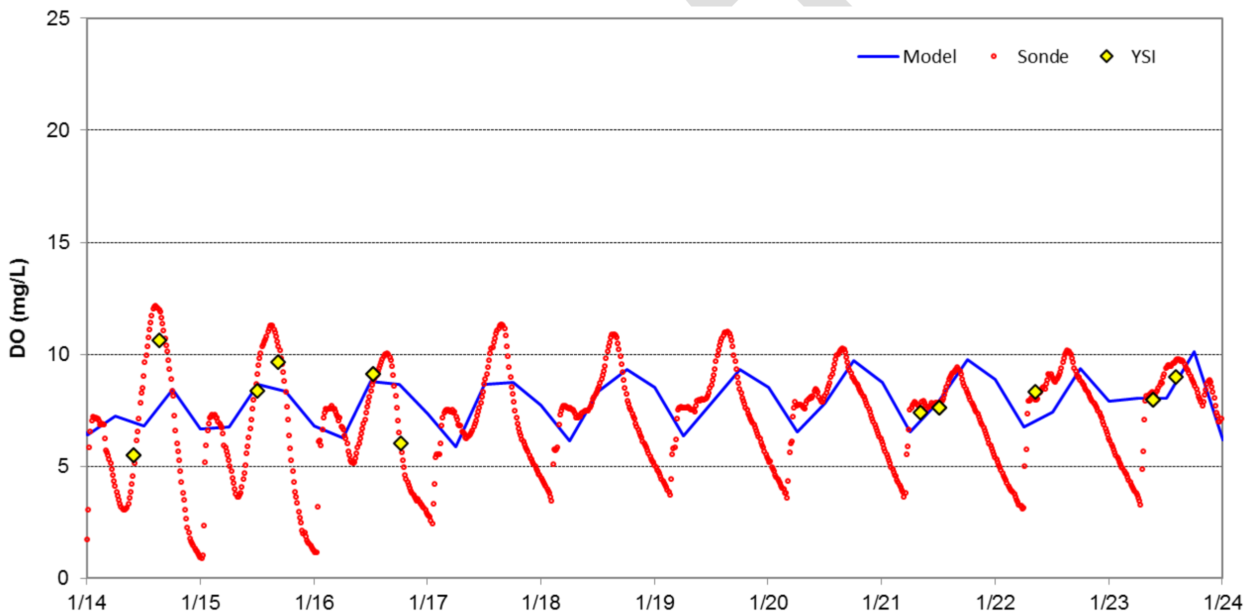


Figure 70. Comparison of Observed vs. Simulated DO Variations at Famosa Channel Outlet (OUTLET) Index 1

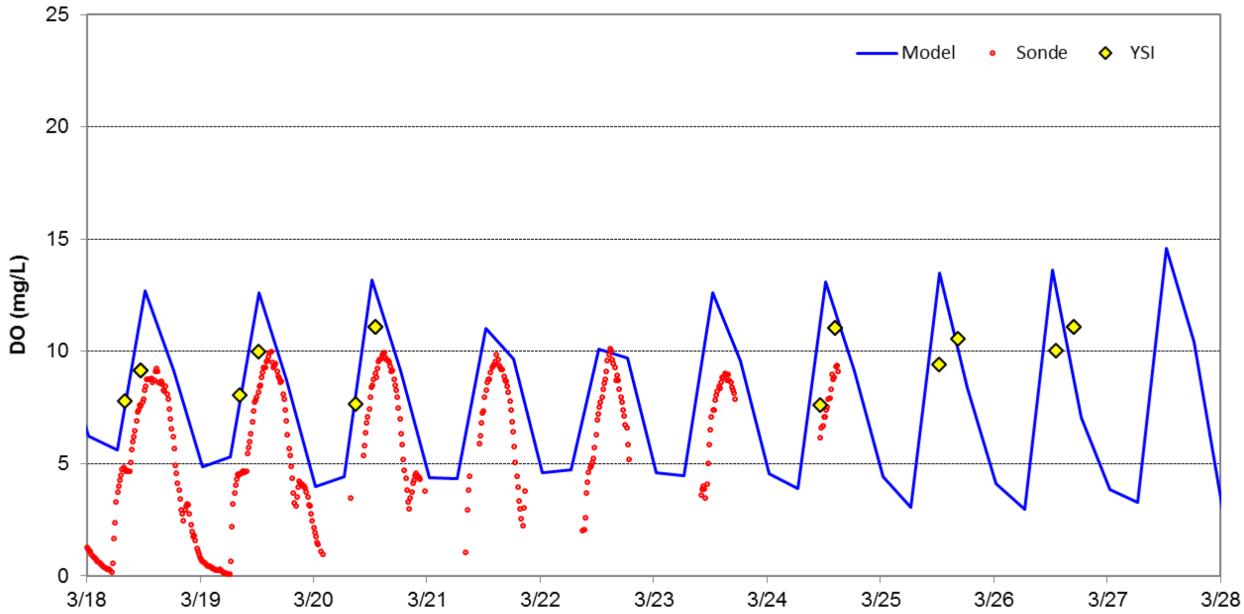


Figure 71. Comparison of Observed vs. Simulated DO Variations at Famosa Channel Outlet (OUTLET) Index 2

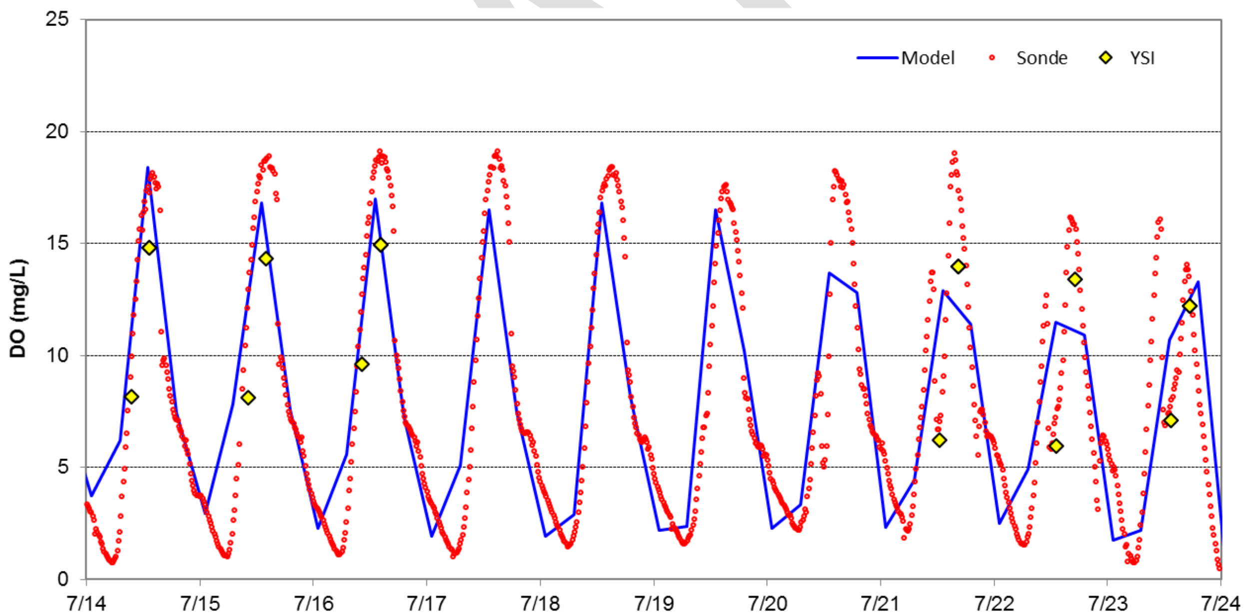


Figure 72. Comparison of Observed vs. Simulated DO Variations at Famosa Channel Outlet (OUTLET) Index 3

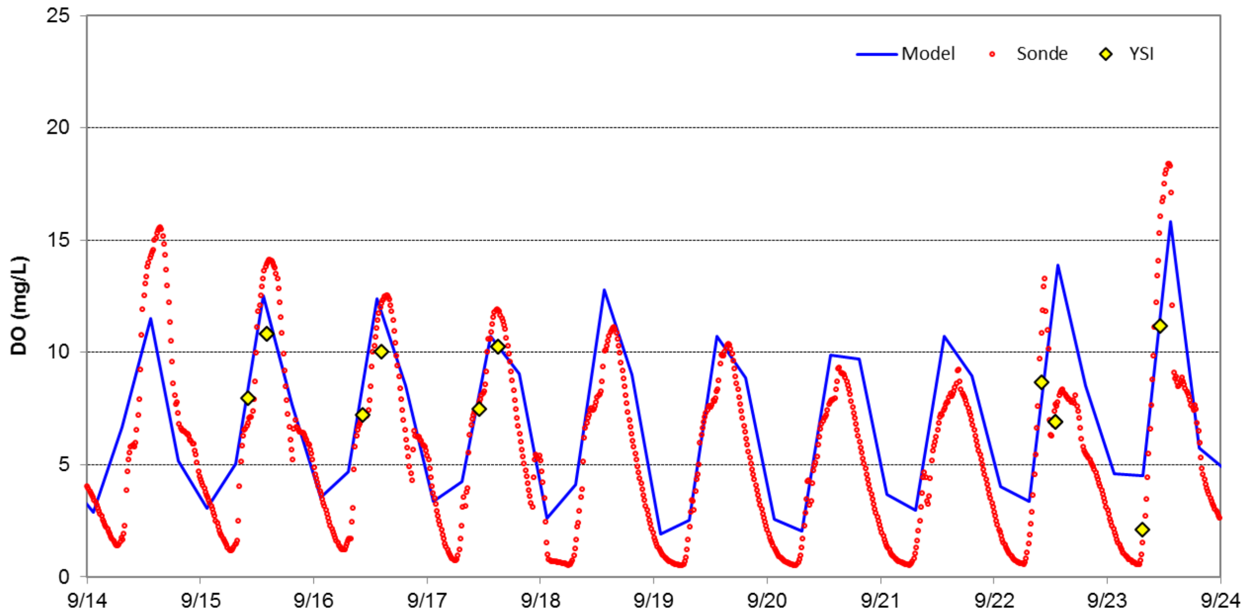


Figure 73. Comparison of Observed vs. Simulated DO Variations at Famosa Channel Outlet (OUTLET) Index 4

The Index Period DO results for the Famosa Slough Outlet (SEG) are given in Figure 74 through Figure 77 using results plotted every 6 hours [this is change from previous draft appendix versions, which used 1-hour output]. Generally, the comparison of observed and simulated data during all Index Periods at SEG indicates the model is representing the measured conditions reasonably well.

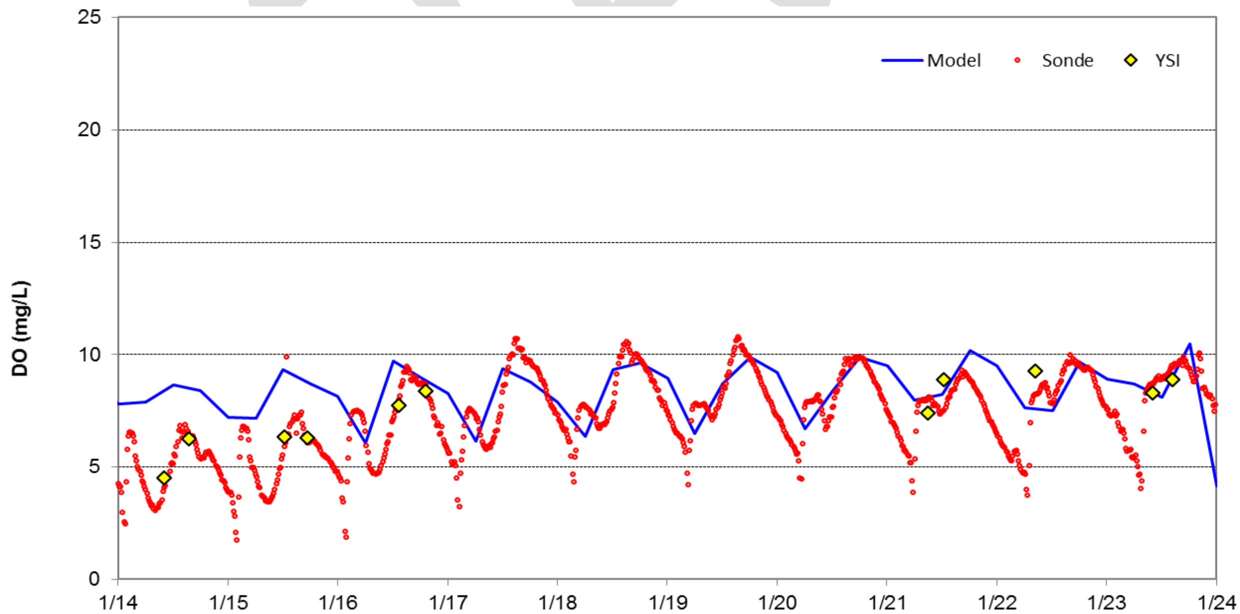


Figure 74. Comparison of Observed vs. Simulated DO Variations at Famosa Slough Outlet (SEG) Index 1

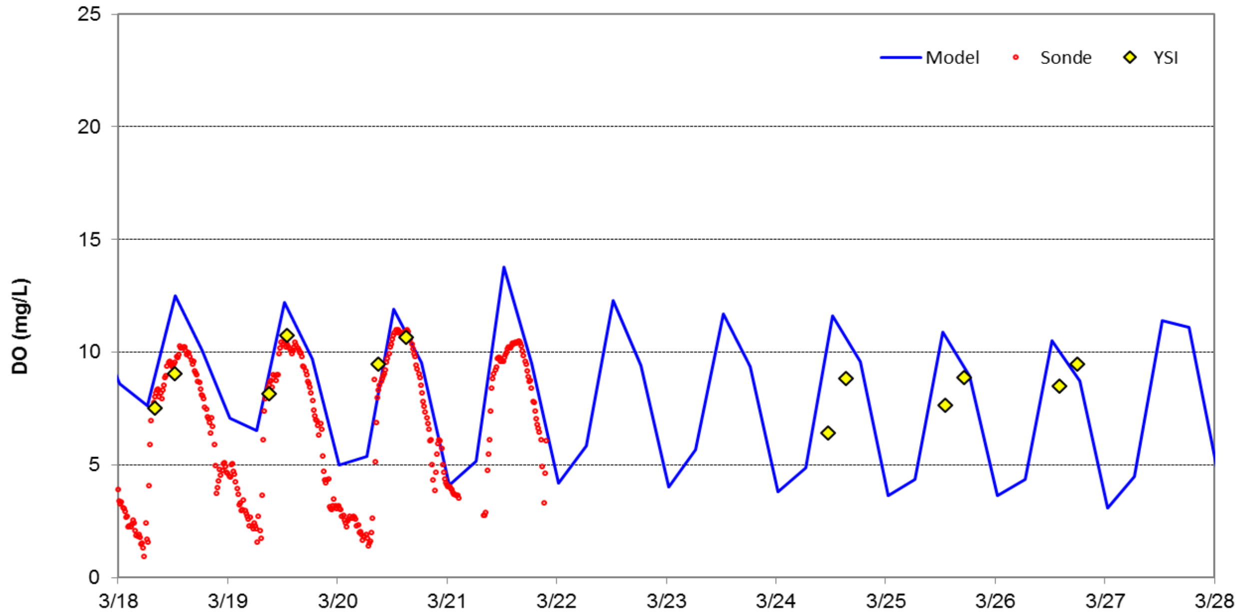


Figure 75. Comparison of Observed vs. Simulated DO Variations at Famosa Slough Outlet (SEG) Index 2

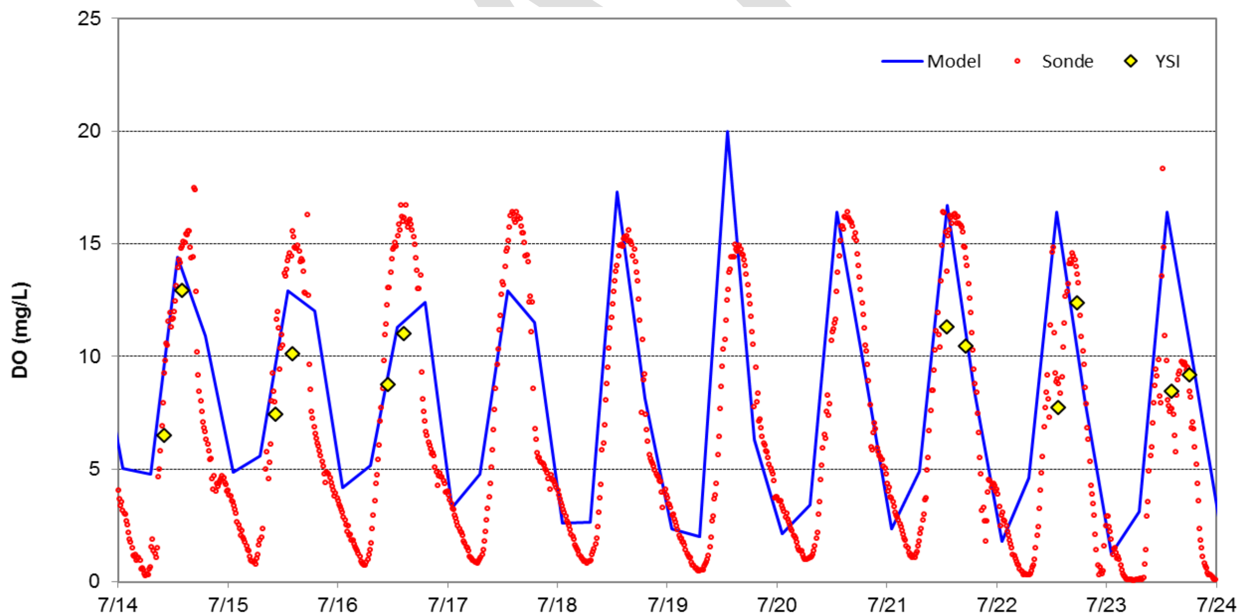


Figure 76. Comparison of Observed vs. Simulated DO Variations at Famosa Slough Outlet (SEG) Index 3

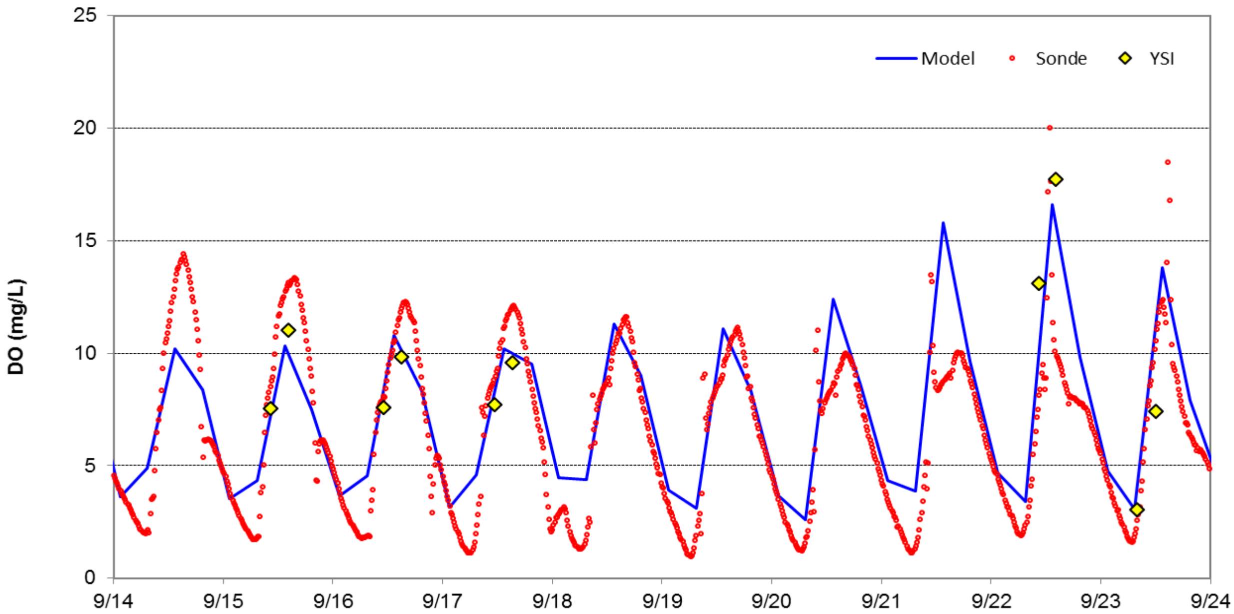


Figure 77. Comparison of Observed vs. Simulated DO Variations at Famosa Slough Outlet (SEG) Index 4

The Index Period DO results for the South End Famosa Slough (MES) locations are given in Figure 78 through Figure 81. The continuous sonde DO data at the MES site appears to be offline during Index Monitoring Periods 3 and 4 (Figure 80 and Figure 81), whereas the YSI data during this period are more similar to the model predictions. Yet, the YSI data for Index Periods 3 and 4 are lower than the predicted values. As discussed in the water elevation and salinity subsections, the area around the MES is not well represented by the model due to its shallow depth and that is primarily a nontidal, freshwater discharge. However, the area around the MES is not representative of the kinetics and processes that occur in the Slough and Channel, and thus these cells have little effect on the use of the model to assess management actions on water quality in the Slough. There is disparity between the model results and the observed data at the MES location, where the water elevation is shallow and often is too dry for the Sonde to function properly. The results of the grab samples contain more variability in the DO concentration. It is likely that the DO at the MES locations could be subject to significant local effects, while the model calculates the average conditions.

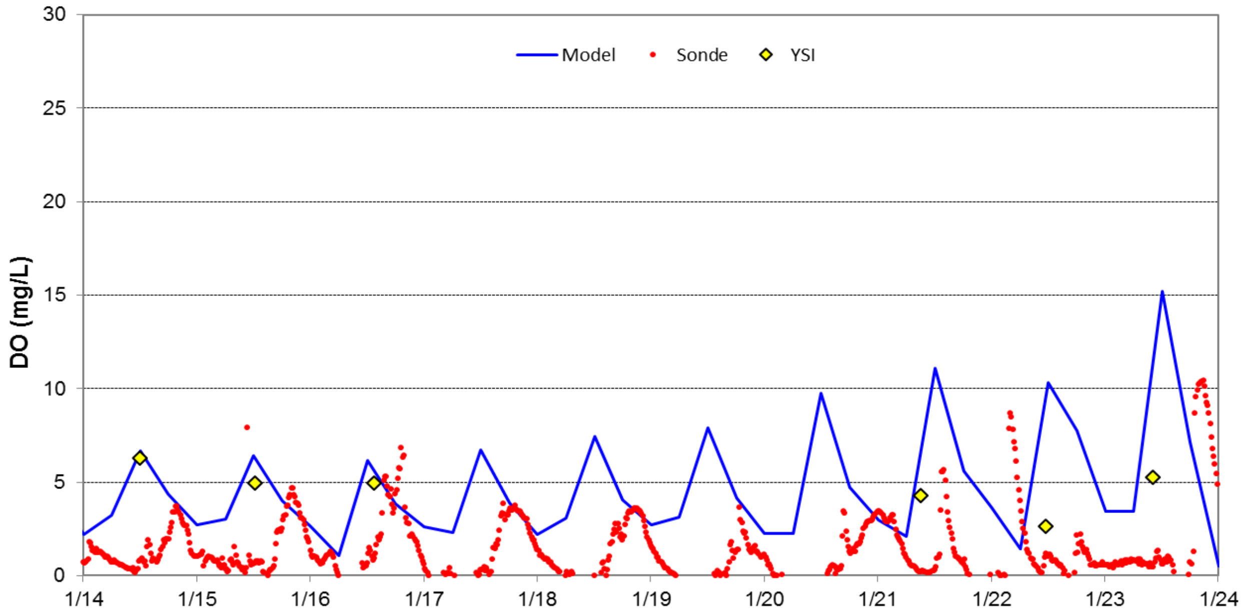


Figure 78. Comparison of Observed vs. Simulated DO Variations at South End Famosa Slough (MES) Index 1

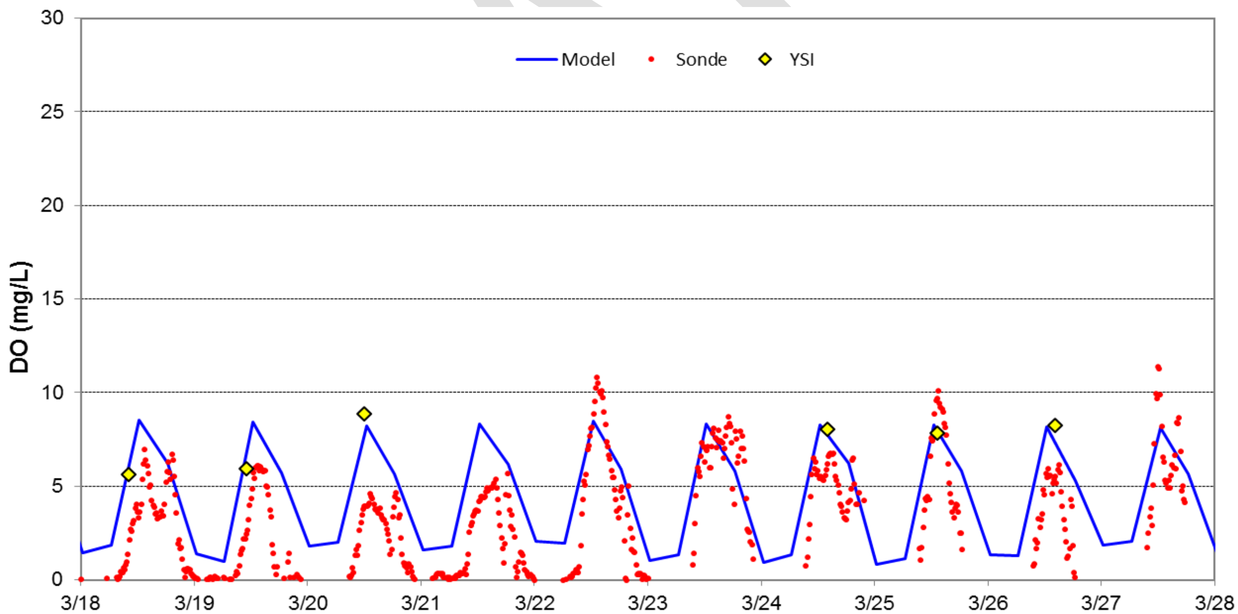


Figure 79. Comparison of Observed vs. Simulated DO Variations at South End Famosa Slough (MES) Index 2

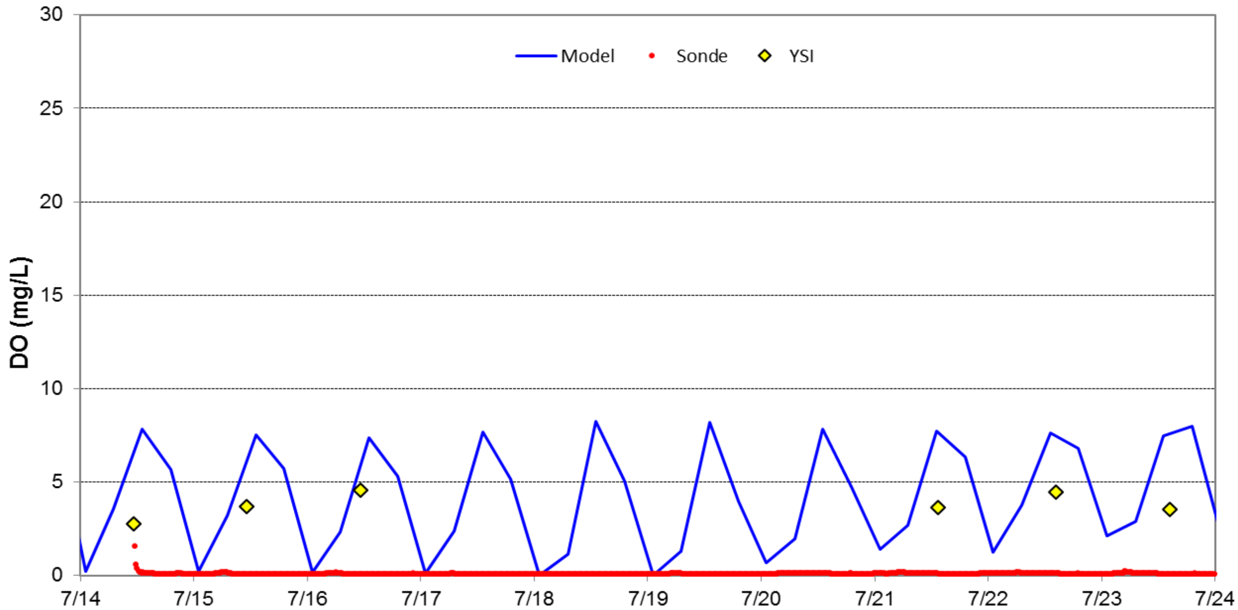


Figure 80. Comparison of Observed vs. Simulated DO Variations at South End Famosa Slough (MES) Index 3

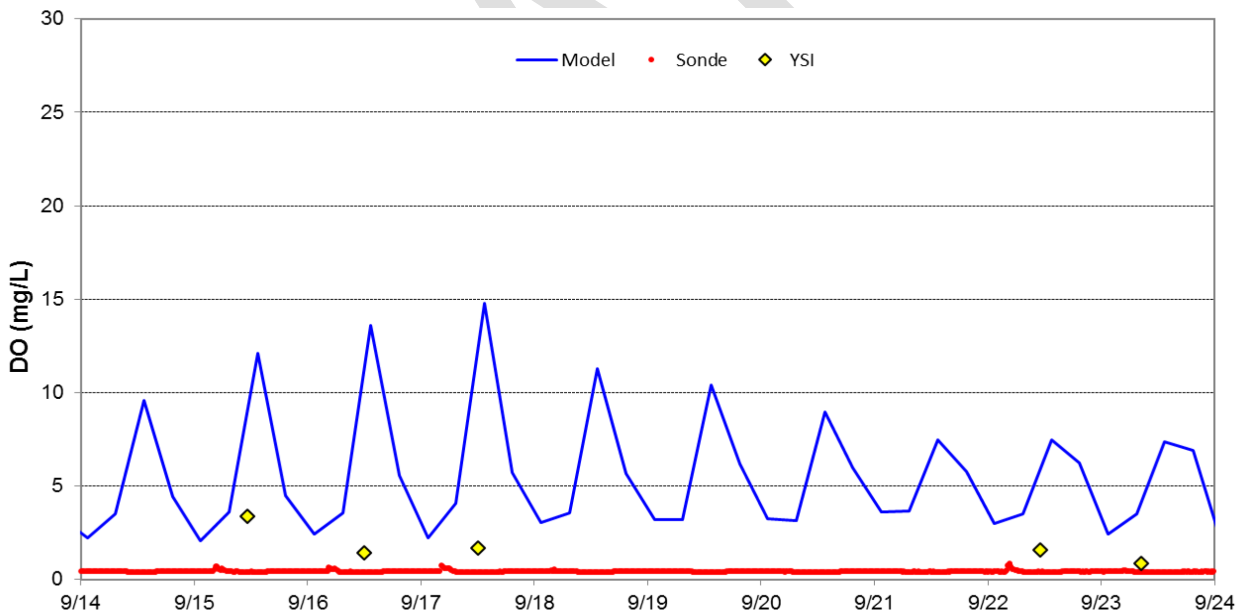


Figure 81. Comparison of Observed vs. Simulated DO Variations at South End Famosa Slough (MES) Index 4

The model results shown in Figure 70 through Figure 81 demonstrate the ability of the model to capture the observed DO dynamics at all three monitoring locations. The continuous sonde and YSI DO data further verify that the large diurnal DO swings and daytime super saturation levels occur within the Channel and Slough on a regular basis.

3.3.2.4. Nutrient Calibration Results

Figure 82 through Figure 96 compare EFDC predicted and measured concentrations of phosphorus constituents (PO4-P and TP) and nitrogen constituents (NH3-N, NO2+NO3-N and TN) at the OUTLET, SEG, and MES monitoring locations. Large spikes in levels of all the predicted nutrient constituents are seen when rainfall/runoff events occurred in January and February 2008. The measured nutrient data during 2008 do not reflect the impacts of these rainfall events, because they were collected during Winter Index Period 1, which was a dry weather period between storms. It is not possible to evaluate the short-term response of Slough and Channel nutrient concentration to rainfall due to lack of sufficient data. More data should be collected in future studies to reflect the temporal variability. This data can be used to further corroborate the model.

Figure 82 through Figure 86 compare the predicted and measured concentrations at the OUTLET. All of the constituents at the OUTLET are represented relatively well by the model. The model simulates the significant diurnal fluctuation that is occurring due to the highly productive nature of the Slough and the Channel. Macroalgae and macrophytes consume significant amounts of nutrients during the day. Because monitoring occurred during the day, when nutrient concentrations are depleted, the data, particularly during the later spring/summer/fall period, are generally low. This is fully represented by the model simulations.

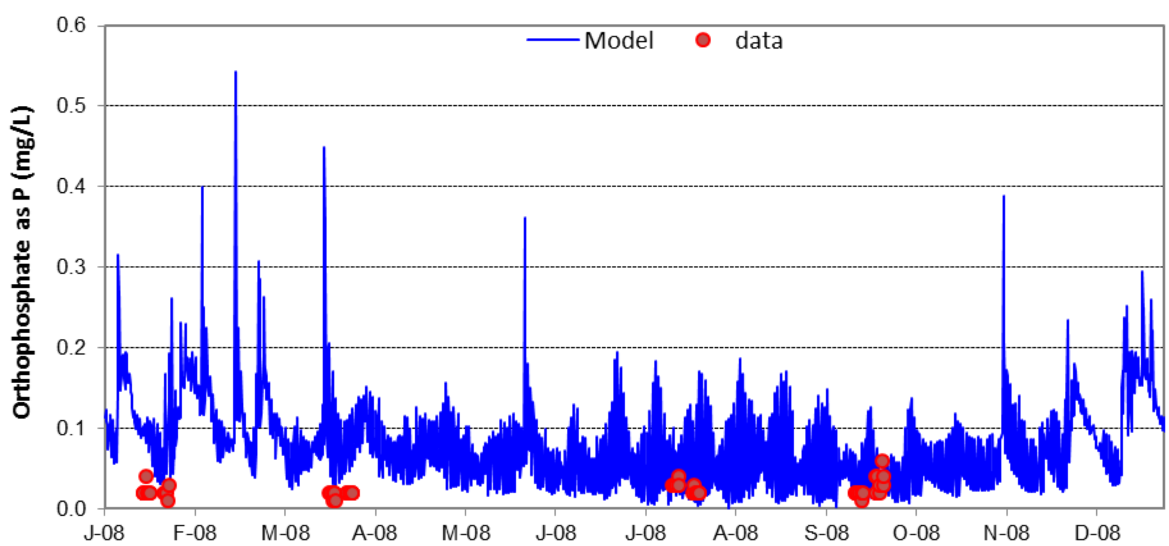


Figure 82. Comparison of Observed vs. Simulated PO4-P Variations at Famosa Channel Outlet (OUTLET)

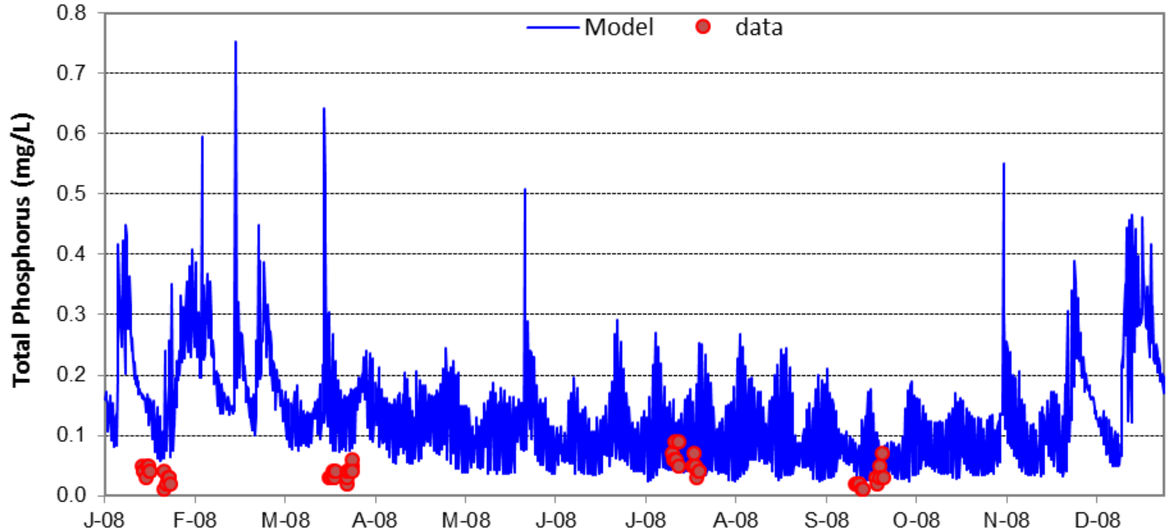


Figure 83. Comparison of Observed vs. Simulated TP Variations at Famosa Channel Outlet (OUTLET)

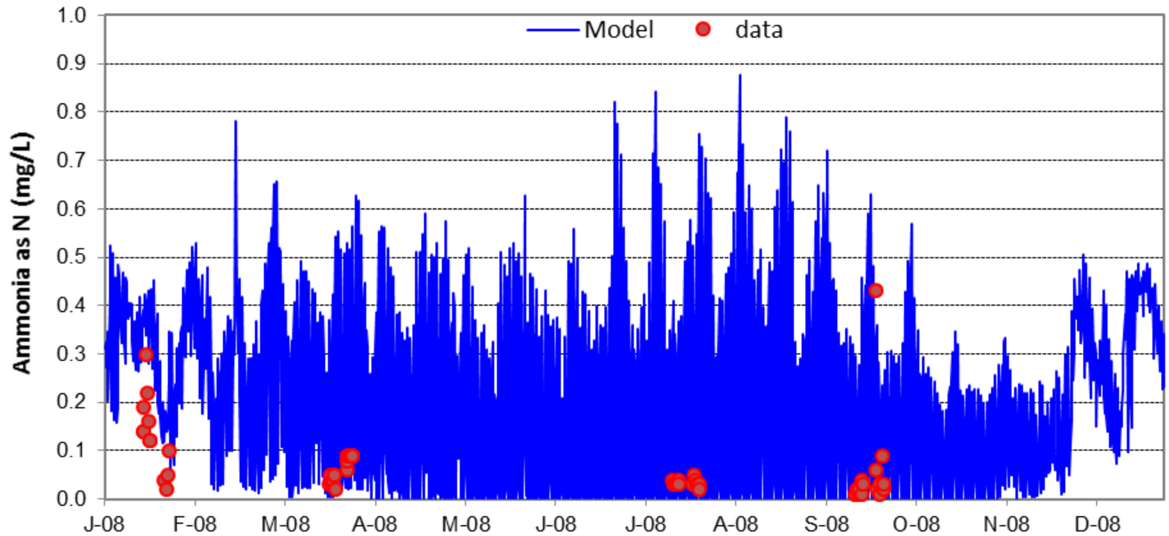


Figure 84. Comparison of Observed vs. Simulated NH3-N Variations at Famosa Channel Outlet (OUTLET)

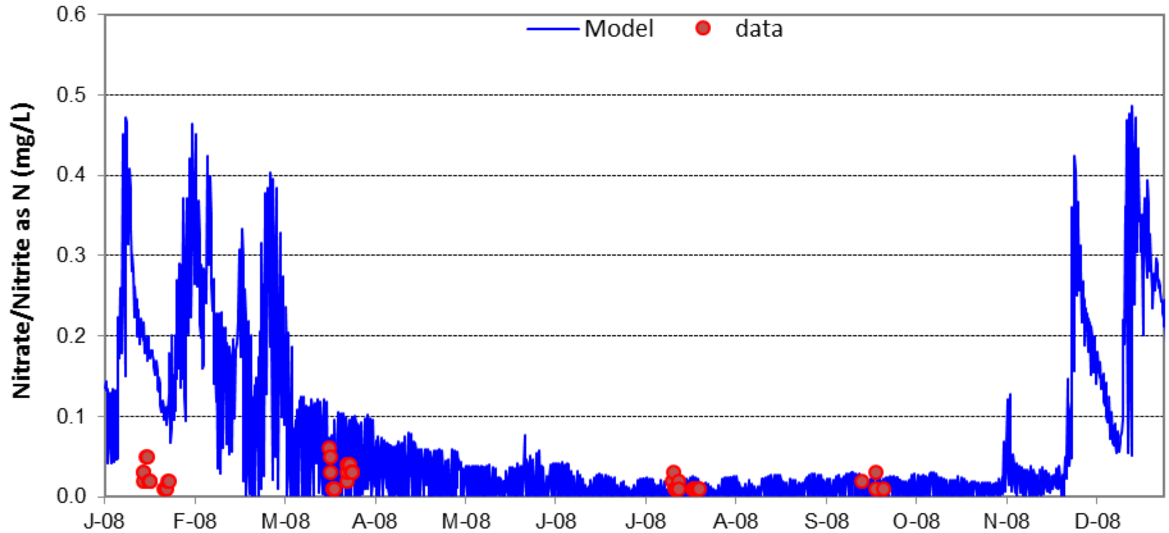


Figure 85. Comparison of Observed vs. Simulated NO2+NO3-N Variations at Famosa Channel Outlet (OUTLET)

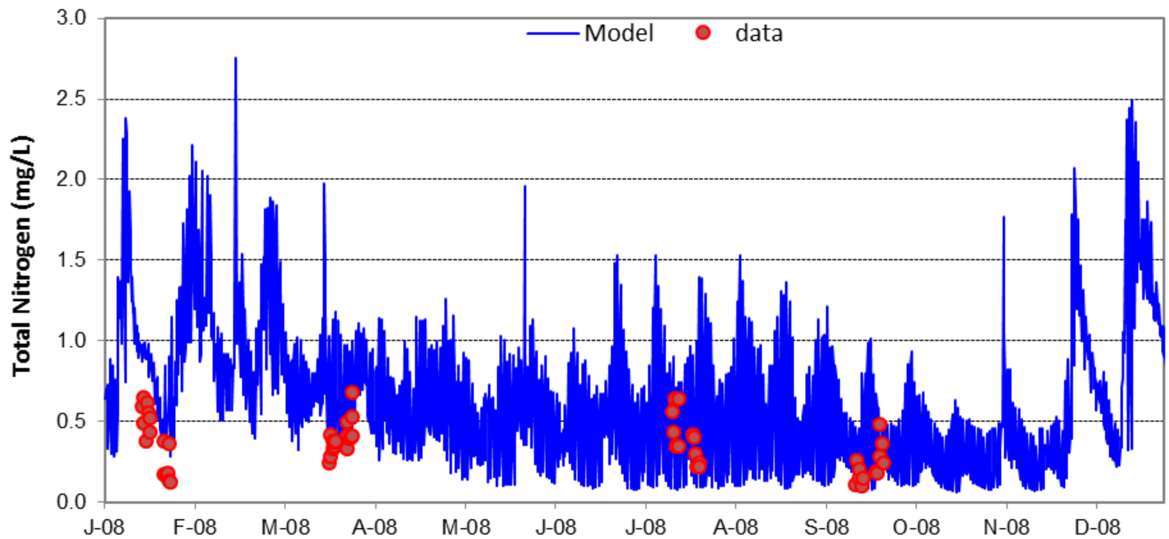


Figure 86. Comparison of Observed vs. Simulated TN Variations at Famosa Channel Outlet (OUTLET)

Figure 87 through Figure 91 compare the predicted and measured concentrations at SEG. The majority of the monitored constituents are predicted well by the model. Similar to the OUTLET, SEG results show significant diurnal fluctuations in nutrients, low concentrations during the day and high at night. Nutrient data, especially the dissolved inorganic nutrients, are generally low because the samples were collected during the day when nutrients are depleted by algal uptake. The model simulated diurnal range does cover the measured concentrations, suggesting a good representation.

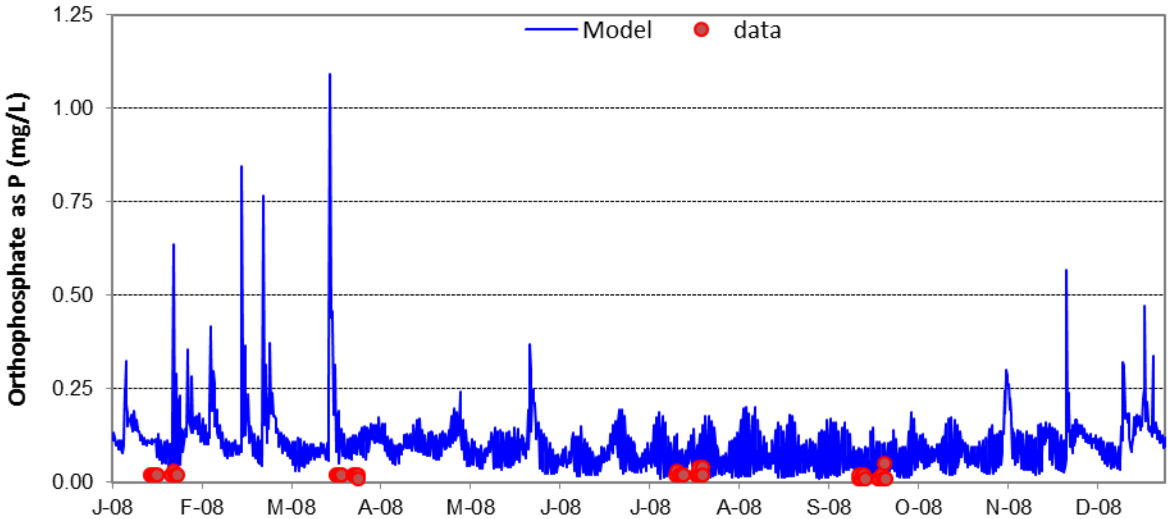


Figure 87. Comparison of Observed vs. Simulated PO4-P Variations at Famosa Slough Outlet (SEG)

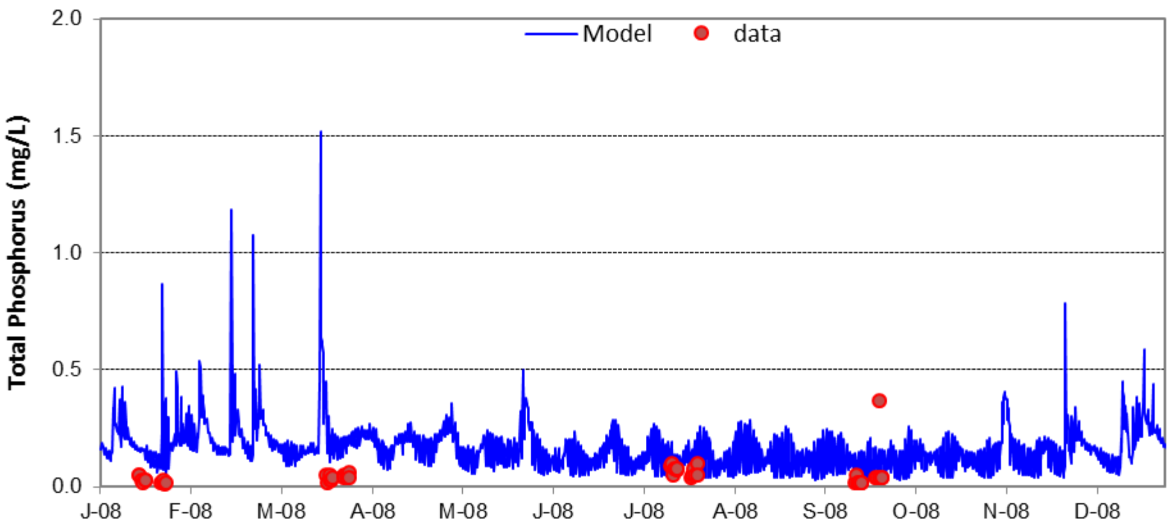


Figure 88. Comparison of Observed vs. Simulated TP Variations at Famosa Slough Outlet (SEG)

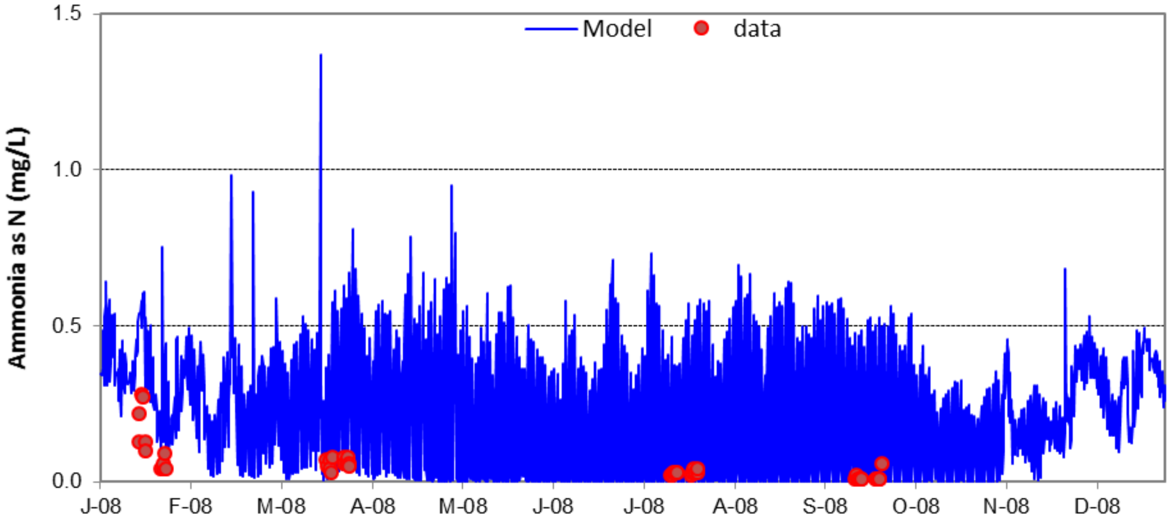


Figure 89. Comparison of Observed vs. Simulated NH3-N Variations at Famosa Slough Outlet (SEG)

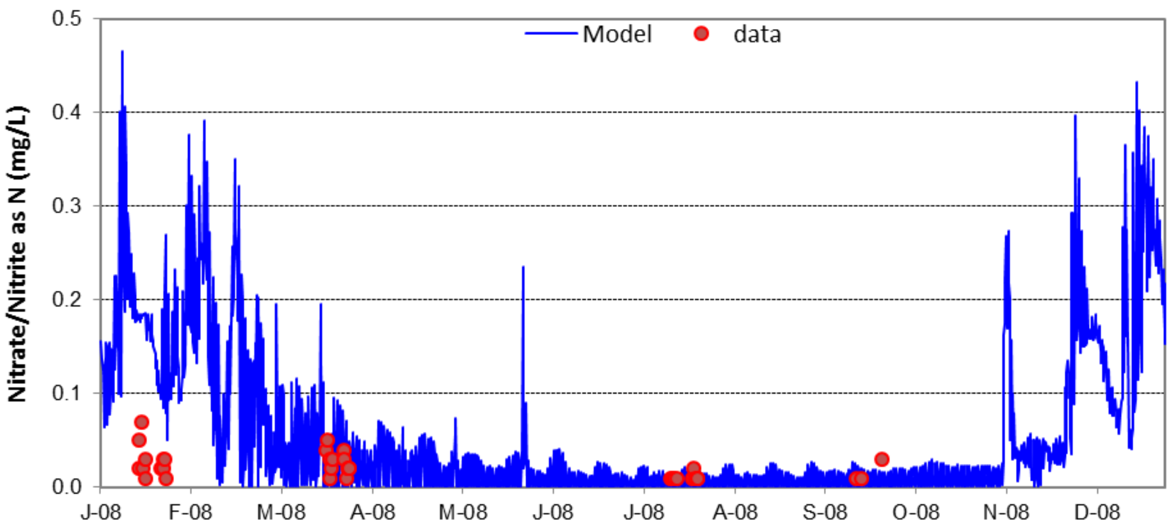


Figure 90. Comparison of Observed vs. Simulated NO2+NO3-N Variations at Famosa Slough Outlet (SEG)

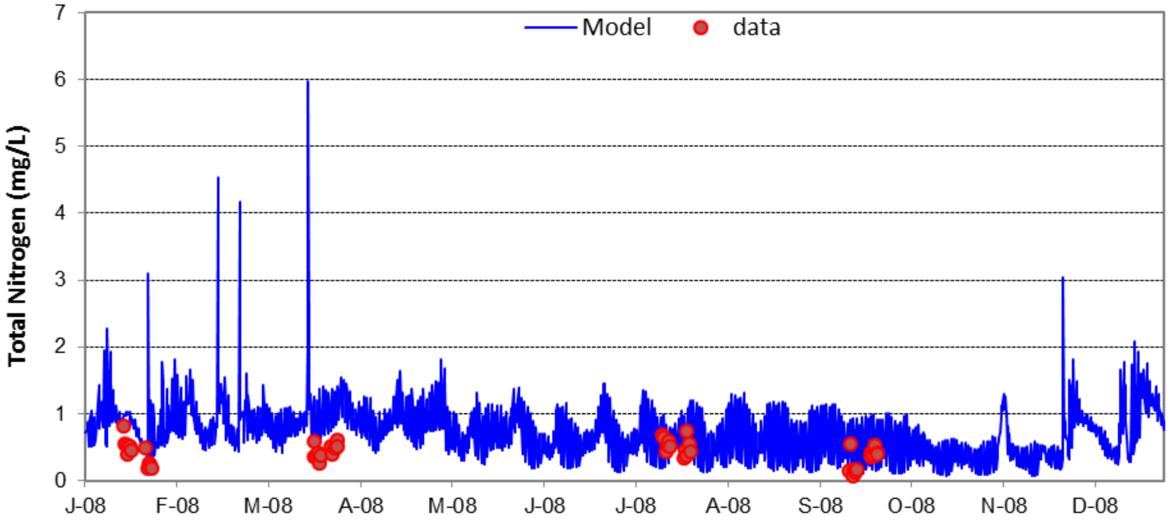


Figure 91. Comparison of Observed vs. Simulated TN Variations at Famosa Slough Outlet (SEG)

Figure 92 through Figure 96 compare the predicted and measured concentrations at the MES. Predicted concentrations at the three continuous monitoring locations were similar to measured values. The model no longer under predicts PO4-P and TP at MES unlike the previous model version. Simulated PO4-P and TP now match the observed data very well due to the improved representation in the nutrient-macroalgae-benthic flux dynamics. The spikes in the plots are caused by short period storm events, which introduce high-concentration flows into the system.

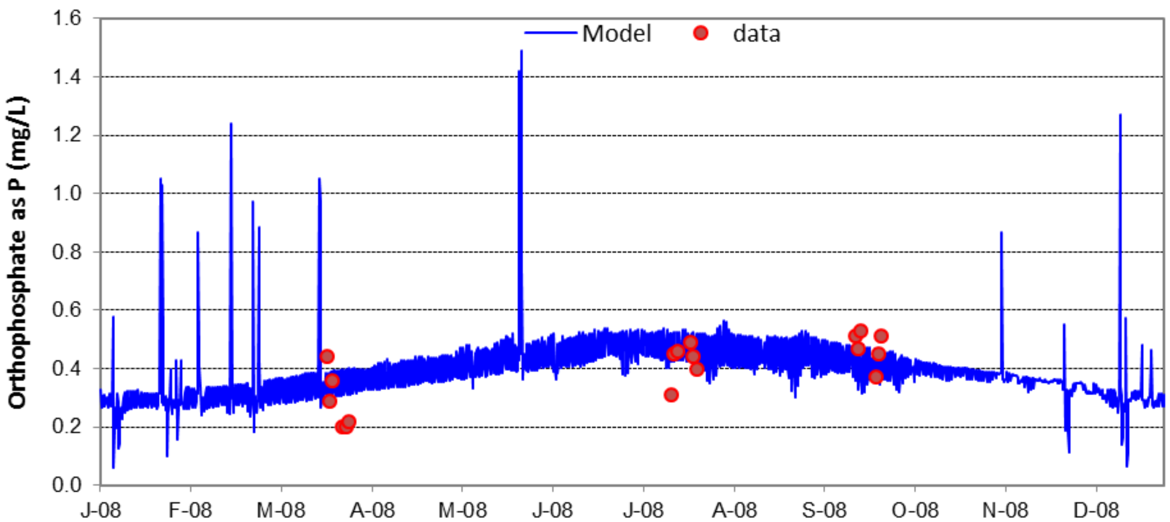


Figure 92. Comparison of Observed vs. Simulated PO4-P Variations at South End Famosa Slough (MES)

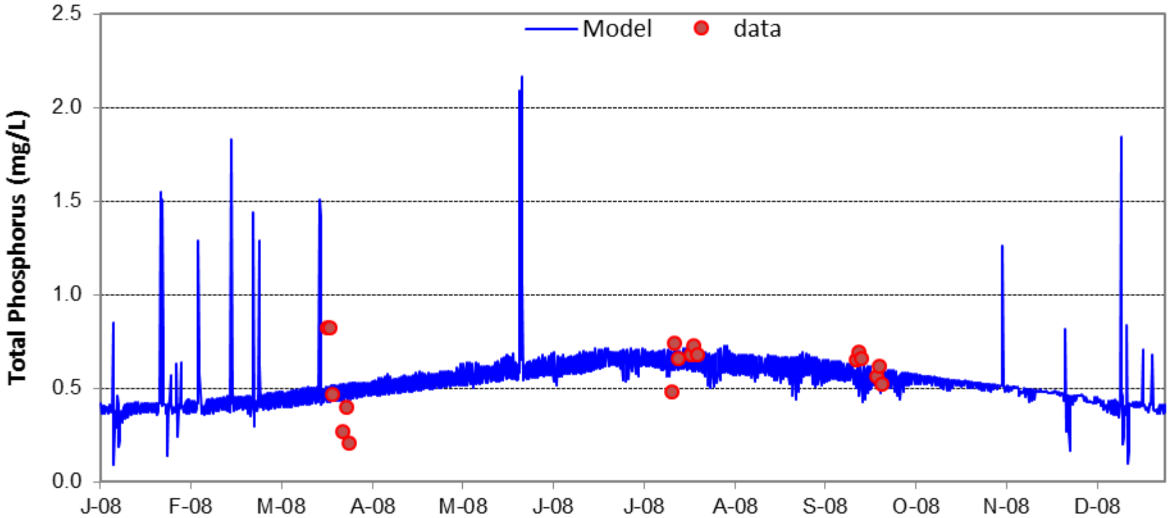


Figure 93. Comparison of Observed vs. Simulated TP Variations at South End Famosa Slough (MES)

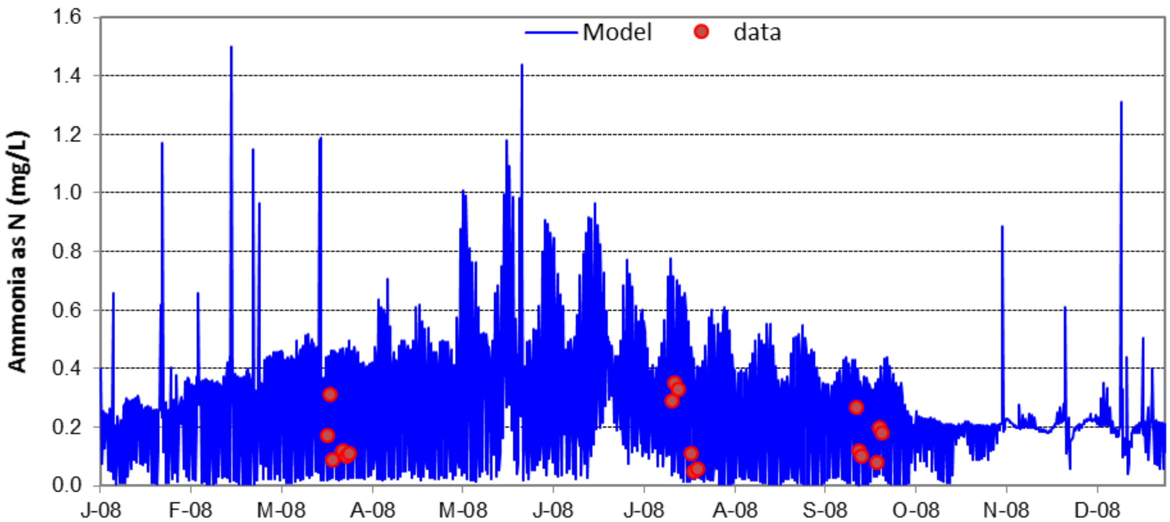


Figure 94. Comparison of Observed vs. Simulated NH3-N Variations at South End Famosa Slough (MES)

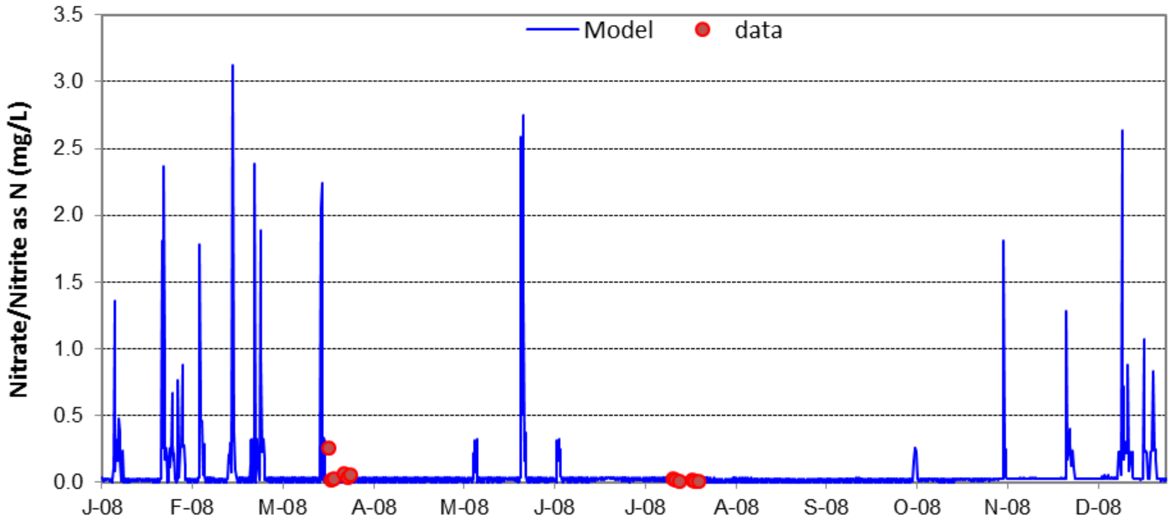


Figure 95. Comparison of Observed vs. Simulated NO2+NO3-N Variations at South End Famosa Slough (MES)

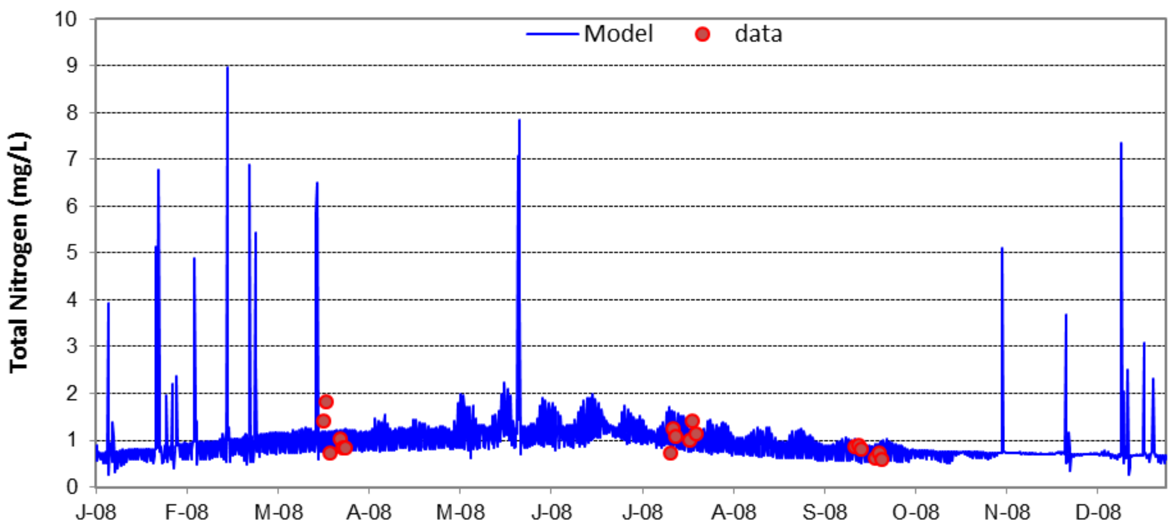


Figure 96. Comparison of Observed vs. Simulated TN Variations at South End Famosa Slough (MES)

3.4. Receiving Water Model Summary and Conclusions

A depth averaged hydrodynamic and water quality model was developed for the interconnected network of water bodies, including the Slough, Channel, and the San Diego River estuary. EFDC was used as a computational framework. The model was calibrated using data collected during 2008.

The hydrodynamic model performed reasonably well simulating water surface elevation, salinity, and temperature distributions measured within these water bodies. The EFDC water quality model was used to simulate chlorophyll-*a*, floating macroalgae biomass (Slough only), benthic macroalgae biomass, macrophytes (Channel only), nitrogen and phosphorus nutrients, and DO within the Slough, Channel, and the San Diego River estuary. A sediment diagenesis model was developed and coupled with the water column water quality model to dynamically represent the exchange of nutrient and DO between the bed sediment and water column. The water quality model predictions show good agreement with measured data, suggesting that the model is able to capture the overall nutrient and DO dynamics within these three interconnected water bodies. In particular, the model calibration confirms that DO and nutrient dynamics within the Slough are strongly influenced by the metabolic activity of benthic macroalgae and floating macroalgae. The DO and nutrient dynamics are closely correlated with the macrophyte and benthic algae activities in Channel. This improved version of the model has shown the capability of reaching the full range of diel DO swings for the majority of the time, indicating a reasonable simulation of these complex interactions between primary productivity, nutrient dynamics, and DO in the system. This allows the model to be useful in evaluating the efficacy and benefits of various potential management actions on water quality within the Slough and Channel.

4. Management Scenario Analysis

The calibrated model was applied to analyze a series of management scenarios to estimate potential water quality benefits. The purpose of these scenarios is to establish a quantitative understanding of the water quality response to various management options, thereby providing the basis for determining cost-effective implementation actions in the future. Initially, a series of exploratory management scenarios were performed to look at a range of different options (Section 4.1). Two management options were selected as the preferred options from these scenarios. Additional management scenarios explored the preferred management options in more detail (Section 4.2).

4.1. Exploratory Management Scenarios

4.1.1. Scenario Descriptions

The following scenarios that were evaluated as part of the exploratory scenario analysis include:

- **Scenario 1:** Baseline condition for the evaluation of all remaining management scenarios. Model setup was based on the calibrated hydrodynamic and water quality model using existing watershed, San Diego River, and open ocean boundary conditions. The boundary condition was recycled annually to develop a 10-year continuous simulation period. The number of modeled years was determined to be the length of time that would allow the model to reach near steady-state condition that reflects the response of benthic sediment to changes in watershed loading condition and other factors.
- **Scenario 2:** 95 percent reduction in watershed and San Diego River nutrient loads. No change to open ocean boundary conditions.
- **Scenario 4:** 80 percent reduction in watershed loads. No change to open ocean boundary conditions and San Diego River loads.
- **Scenario 5:** 80 percent reduction in San Diego River loads. No change to open ocean boundary conditions and watershed loads.
- **Scenario 6:** Once-a-year harvesting of floating macroalgae in the Slough on the peak date based on the baseline model results. Assumed removal of 90 percent of the floating macroalgae biomass instantaneously on the specified date.
- **Scenario 6b:** Once-a-year harvesting of floating macroalgae in the Slough on the peak date based on the baseline model results. Assumed removal of 95 percent of the floating macroalgae biomass instantaneously on the specified date.
- **Scenario 7:** Twice-a-year harvesting of floating macroalgae in the Slough on July 1 and September 1. Assumed 95 percent of the floating macroalgae biomass instantaneously on the specified date.
- **Scenario 8:** One time dredging throughout the Slough and the Channel, which represents removing 95 percent of the sediment bed nutrients at the beginning of the first simulation year. No change to the model bathymetry.
- **Scenario 9:** Reconfiguration of the model based on the recommended water circulation enhancements provided in the PWA report (i.e., separate east and west channels and install tidal gate to control flow directions at the culverts).

- **Scenario 10:** Combination of twice-a-year harvesting of floating macroalgae (Scenario 7) in the Slough and a 60 percent reduction in watershed loads. No change to open ocean boundary conditions, San Diego River loads, and other model components.

The scenario numbering follows the list of management scenarios that were originally listed for the project. Scenario 3 is not listed, but represents the iterative simulations that will be necessary to achieve the numeric TMDL targets when developed. To obtain an overall understanding about how the Slough and Channel responded to different management scenarios, simulated water quality was spatially averaged using the area of each model grid cell to determine a weighted average of the results. Note that the figures presented below may be slightly updated in the future to be consistent with the final model version.

4.1.2. Results

4.1.2.1. Slough

The spatially-averaged time series results were plotted for each scenario in Figure 97 through Figure 106. In the figures, CHC represents floating macroalgae biomass, MAC represents benthic macroalgae biomass, TOT_MAC represents total macroalgae biomass (benthic and floating macroalgae), and DOX represents dissolved oxygen (DO).

As shown, when the watershed and San Diego River nutrient loadings were reduced by 95 percent, floating and benthic macroalgae showed reduced biomass levels. Also, DO concentrations in the Slough no longer showed significant diurnal fluctuation, and the daily minimum DO concentration was significantly improved. Scenario 2 demonstrates significant benefits from substantial reduction of nutrient loading from both the watershed and San Diego River. Scenarios 4 and 5 were designed to explore whether a reduction in watershed loading or San Diego River loading alone can produce a significant response. The results show significant improvement from an 80 percent reduction in nutrient loading from the watershed alone. However, an 80 percent reduction in loading from the San Diego River only produces marginal improvement in water quality in the Slough, thereby suggesting that managing nutrients from the San Diego River might not be an effective option for achieving water quality improvements. The San Diego River does have more of an effect on the Channel due to its direct connection with the San Diego River inflows.

Scenarios 6 and 6b focused on evaluating the response to harvesting floating macroalgae throughout the system to further explore other management options that can significantly reduce floating macroalgae biomass during the critical summer period. The difference between Scenario 6 and 6b is that the former assumes a slightly lower removal (90 percent versus 95 percent). As shown, these two harvesting scenarios resulted in an overall reduction in biomass for both floating macroalgae and benthic macroalgae, in contrast to the original anticipation that benthic macroalgae could be enhanced due to the removal of floating macroalgae. This result can be expected because the floating macroalgae harvest was simulated during the late summer period when benthic macroalgae is at very low levels. Although removal of floating macroalgae alleviates the light limiting condition, harvesting also reduces the nutrient concentration in the system, which might depress the growth of benthic macroalgae. Combining these two factors, the light condition improvement might not be sufficient to offset the limitation from reduced nutrients, causing the benthic macroalgae also to decrease. Care should be taken in the interpretation of these results because of the complex dynamics between algal growth and competition for light, nutrients, and other factors. In some situations, it would be reasonable to expect that benthic algae biomass could increase depending on the combination of these factors, time of year, water levels, and other complex variables.

Although Scenarios 6 and 6b resulted in a noticeable reduction in macroalgae biomass, the response might not be significant enough to improve water quality conditions to an acceptable level. To further explore the algal harvesting alternative, Scenario 7 evaluated the potential benefits of twice-a-year harvesting to floating macroalgae. Under this scenario, floating macroalgae was hypothetically harvested at the beginning of the critical period and again later when biomass levels became elevated again. As shown in Figure 103, by harvesting floating macroalgae twice-a-year, macroalgae biomass was reduced significantly, suggesting that algal harvesting might be a viable alternative for improving water quality conditions. The figures shows no significant improvement in total nitrogen and phosphorus; this is because the major reduction in nutrients is due to the benthic flow that is in the form of inorganic nutrient components, while the total nutrients contain organic components from the watershed and the San Diego River, which are not reduced.

Another management option considered in this study was to dredge the nutrient enriched bed sediment to remove this significant internal source. Scenario 8 was designed to analyze this option, which essentially represents the removal of 95 percent of the sediment nutrient concentrations at the beginning of the 10-year simulation. This provides a clean bed sediment initial condition for the sediment diagenesis model, which then changes over time based on external load contributions. After the dredging, macroalgae, and DO concentrations all significantly improved in the Slough initially, which is consistent with the conclusions from previous studies that suggest benthic flux and SOD are significant contributors to the water quality problems in Famosa Slough. However, the model results also demonstrate that these benefits degrade rapidly over time and become insignificant after several years.

In addition to watershed load reduction, harvesting, and dredging, one option previously considered was to modify the circulation pattern in the Slough. A previous study conducted by PWA used a 1-dimensional hydrodynamic model to evaluate the effects of several enhancements to water circulation in the Slough. The study recommended installing a tidal gate and barriers to convert the two-way circulation through the culverts to a one-way circulation would improve flushing, and was hypothesized to have potential water quality benefits. While the study was reasonably designed conceptually, the modeling approach was not anticipated to produce reliable result because it represents the Famosa Slough as a 1-dimensional hydrodynamic model, without representing the spreading of water throughout the shallow marsh area. In addition, the model was a pure hydrodynamic model without representation of the complex water quality dynamics. These enhancements were modeled in this study (Scenario 9) using the full 2-dimensional hydrodynamic and water quality model. The model shows degraded water quality conditions because of these enhancements in terms of macroalgae biomass and DO. This result contradicts the previous recommendations mainly because the previous model oversimplifies the Famosa Slough into a 1-dimensional channel; therefore, the representation of the hydrodynamics is likely inaccurate. The current model reflects the wetting-and-drying caused by tidal impacts and freshwater inflows, and allows the water to spread and withdraw from shallow tidal marsh area, which is more realistic and representative. In this more realistic setting, the installation of a tide gate prevents water flushing from the west side culverts. This essentially slows down the exchange of water between the Slough and the Channel, retaining nutrient loading in the slough longer, which further worsens the macroalgae and DO impairment.

Based on the results of the previous scenarios, an additional scenario (Scenario 10) was evaluated, which included the combined effects from watershed load reduction and algal harvesting (95% removal estimated). The purpose of this scenario was to explore whether combined watershed management and harvesting can provide a more cost-effective option for restoring water quality in the Slough. In this scenario, a less extreme watershed load reduction (60 percent) was introduced together with a twice-a-year harvesting schedule. The results show significant water quality benefits, suggesting that it might be worthwhile to further explore combined management options for implementation.

To provide a more straightforward demonstration of the benefit of the different management scenarios, the model results were further summarized to provide spatially and temporally averaged statistics that would allow direct comparison between scenarios (Figure 107) during the critical summer period. During this period, floating macroalgae dominates and benthic algae is minimal. Overall, it verifies the observations of water quality benefits discussed above, except that it can be seen that under Scenario 7, the benthic macroalgae biomass slightly increased when twice-a-year harvesting is implemented. This is because the first harvest occurs in early summer, so harvesting the floating macroalgae at this time results in better light conditions for benthic macroalgae, thus slightly enhancing growth during this period. When the overall biomass is considered, as analyzed earlier, harvesting actually depresses benthic macroalgae, which dominate during the spring season. The seasonal average daily minimum DO results also show significant benefit when watershed loading is tremendously reduced. In addition, the negative impact of the circulation scenario on macroalgae and daily minimum DO is also manifested in Figure 107.

Figure 107 also shows that when the 60 percent watershed load reduction is coupled with twice-a-year harvesting, the water quality benefit in terms of macroalgae biomass and daily minimum DO is similar to the more extreme watershed load reduction scenario (95 percent reduction). This again verifies the potential benefit of combining multiple management options.

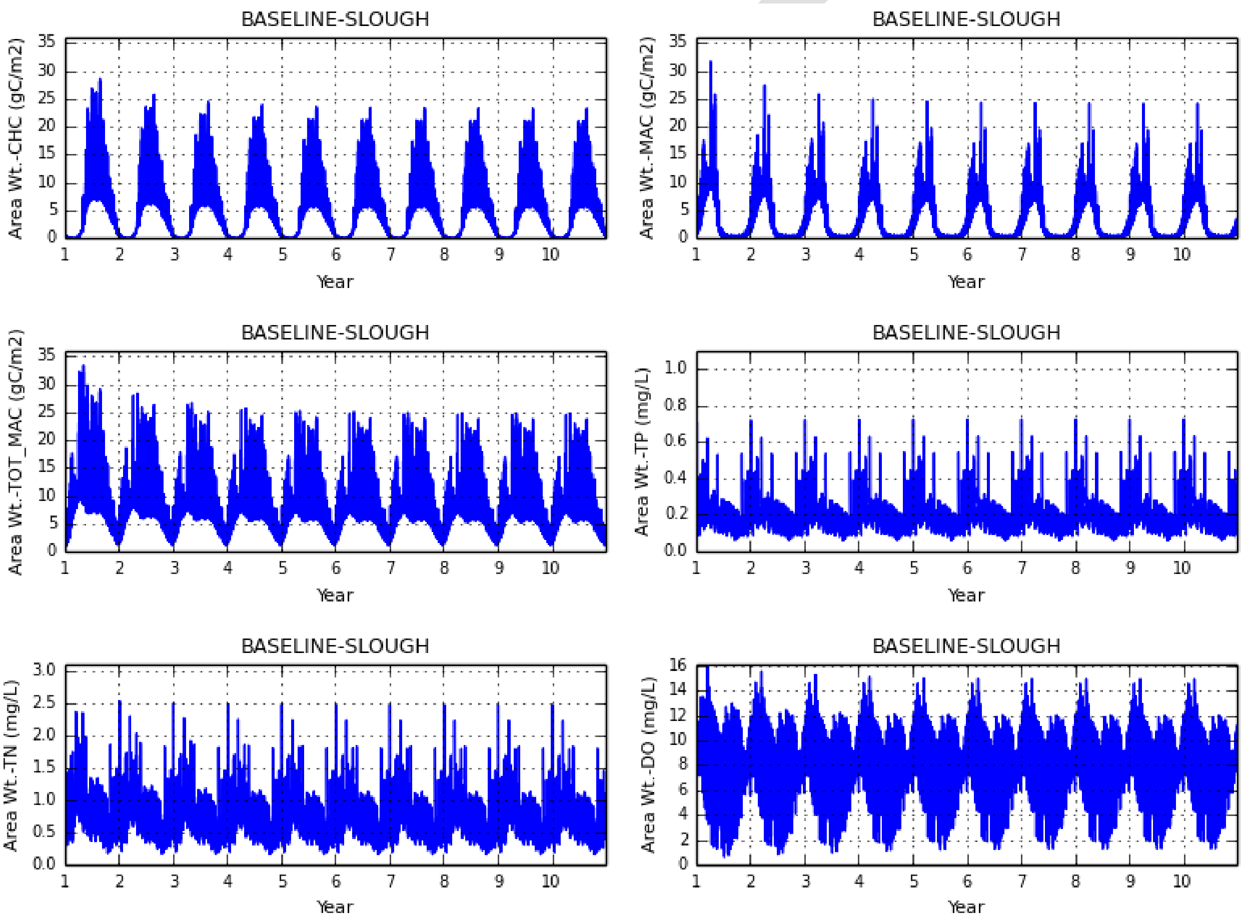


Figure 97. Average Water Quality in the Slough under Scenario 1 — Baseline Condition

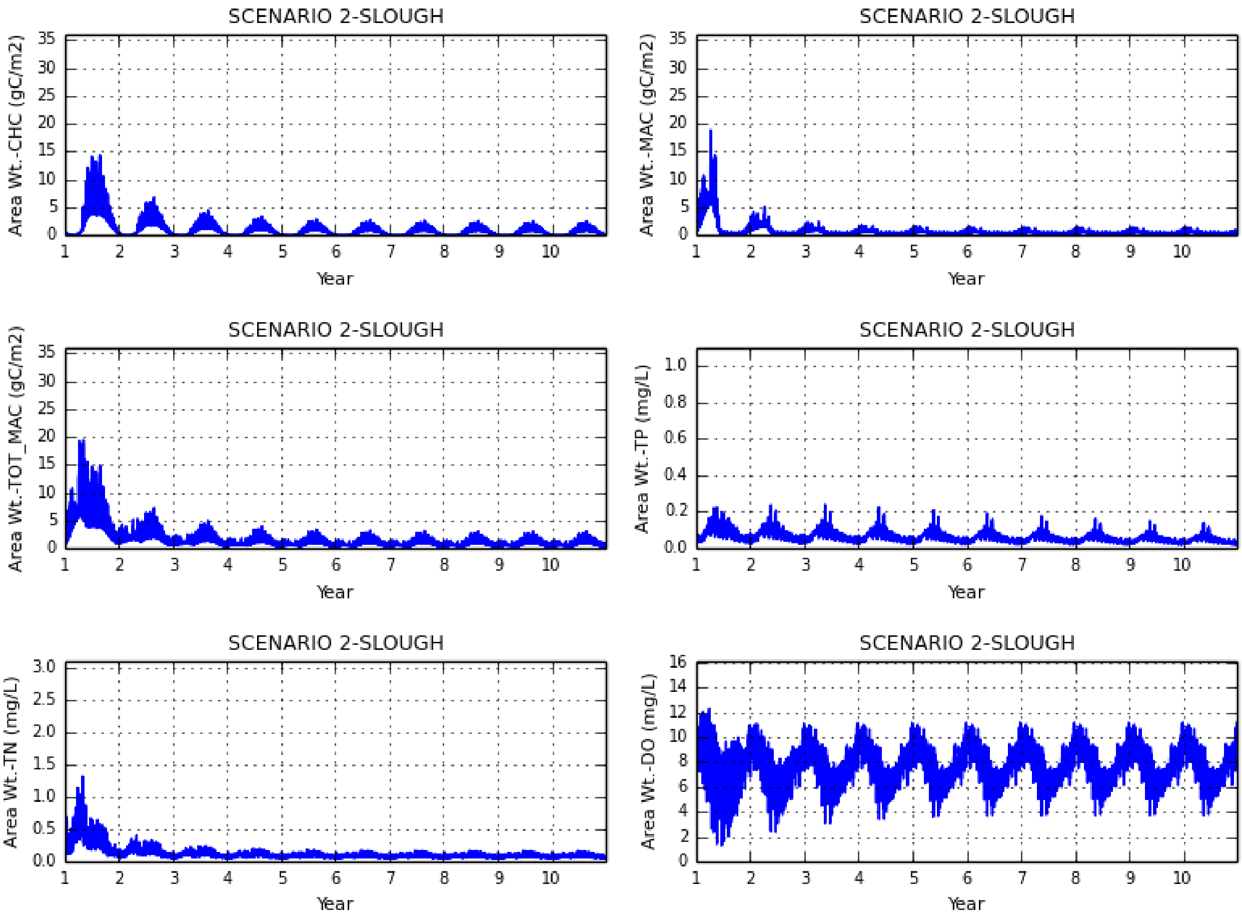


Figure 98. Average Water Quality in the Slough under Scenario 2

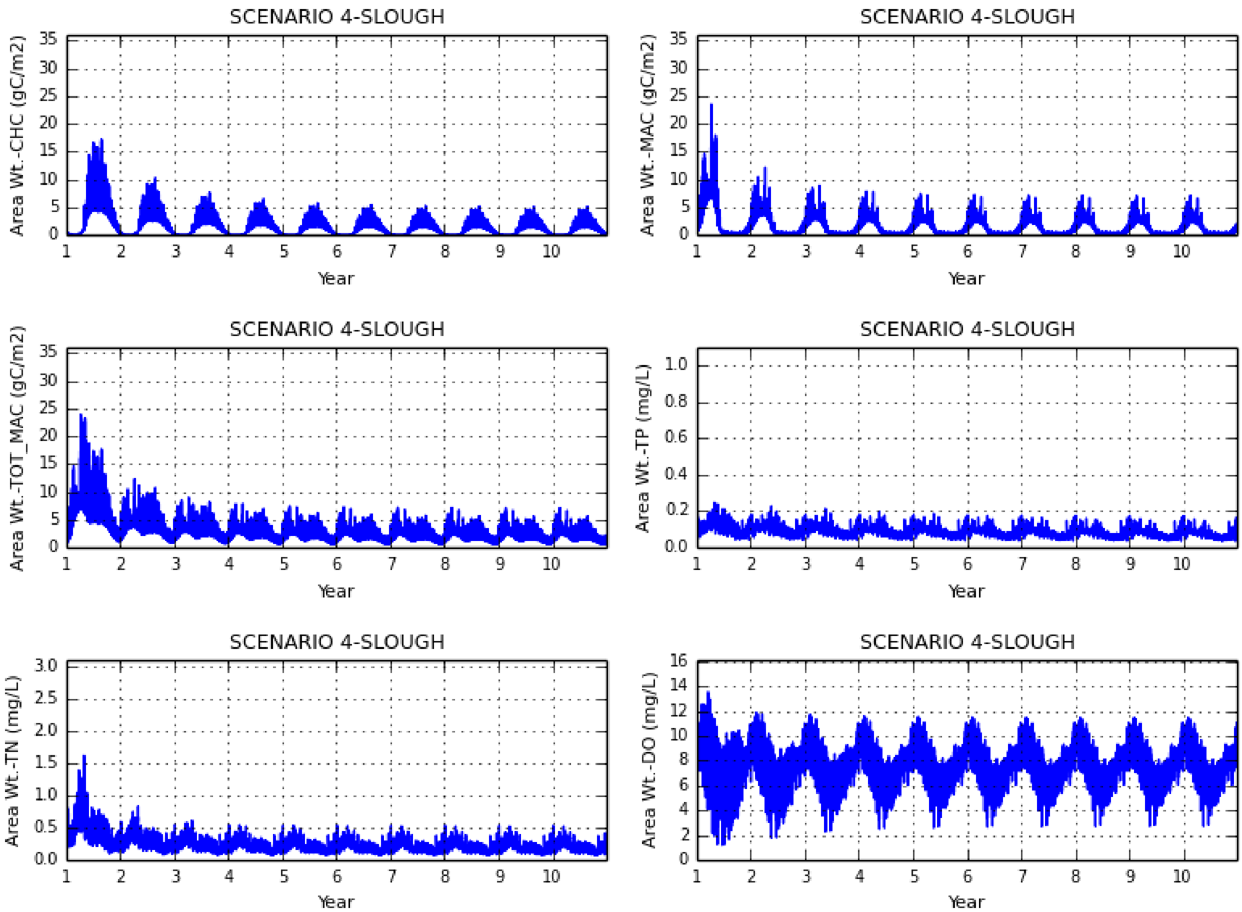


Figure 99. Average Water Quality in the Slough under Scenario 4

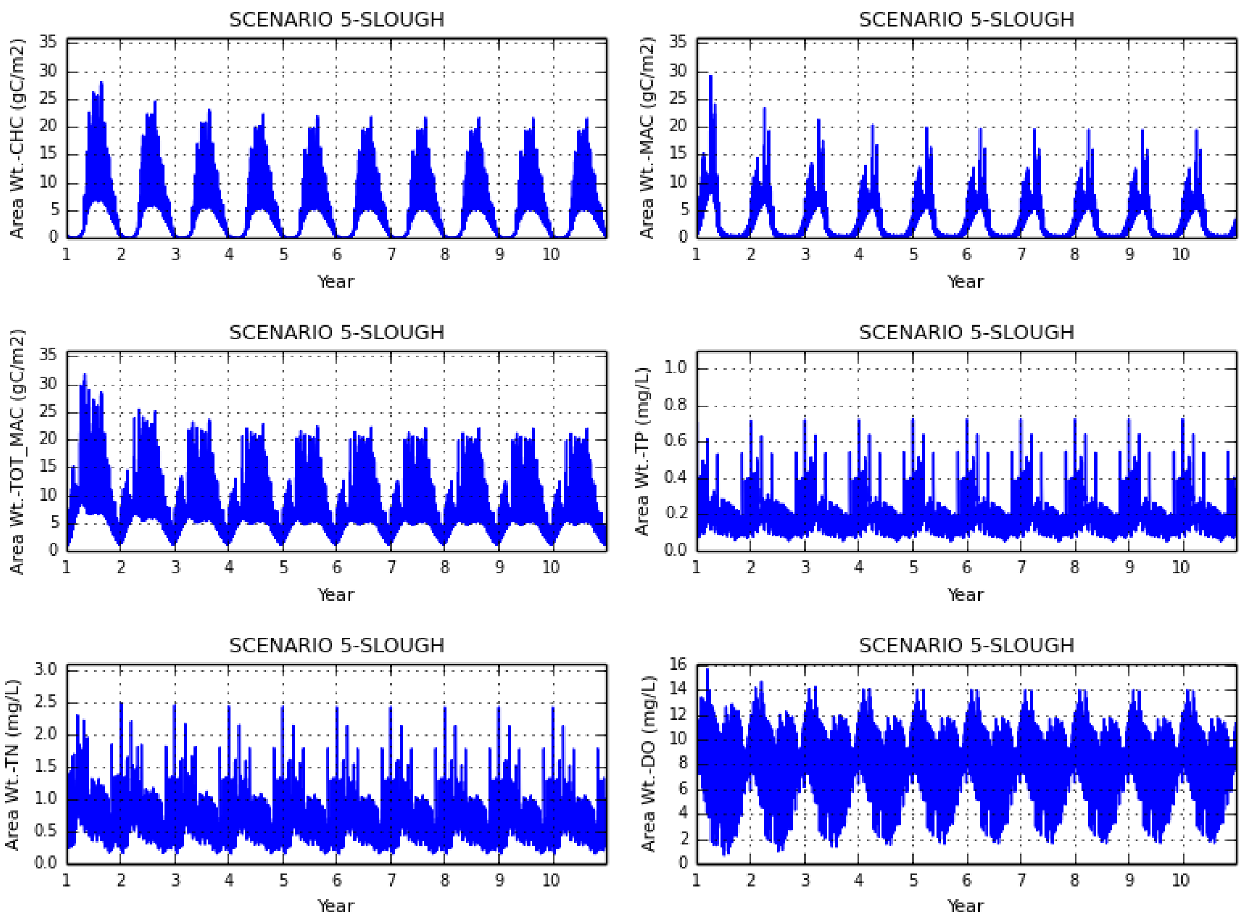


Figure 100. Average Water Quality in the Slough under Scenario 5

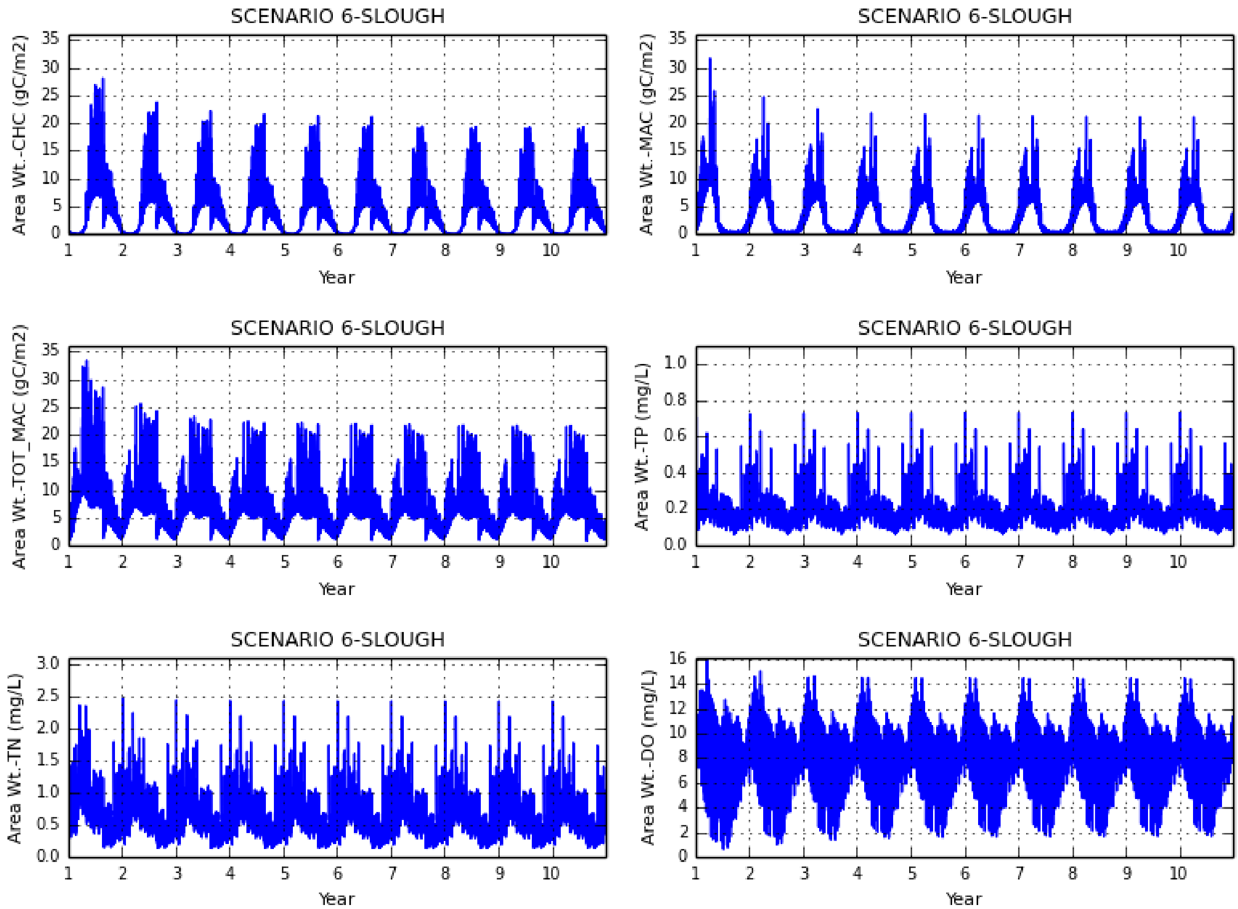


Figure 101. Average Water Quality in the Slough under Scenario 6

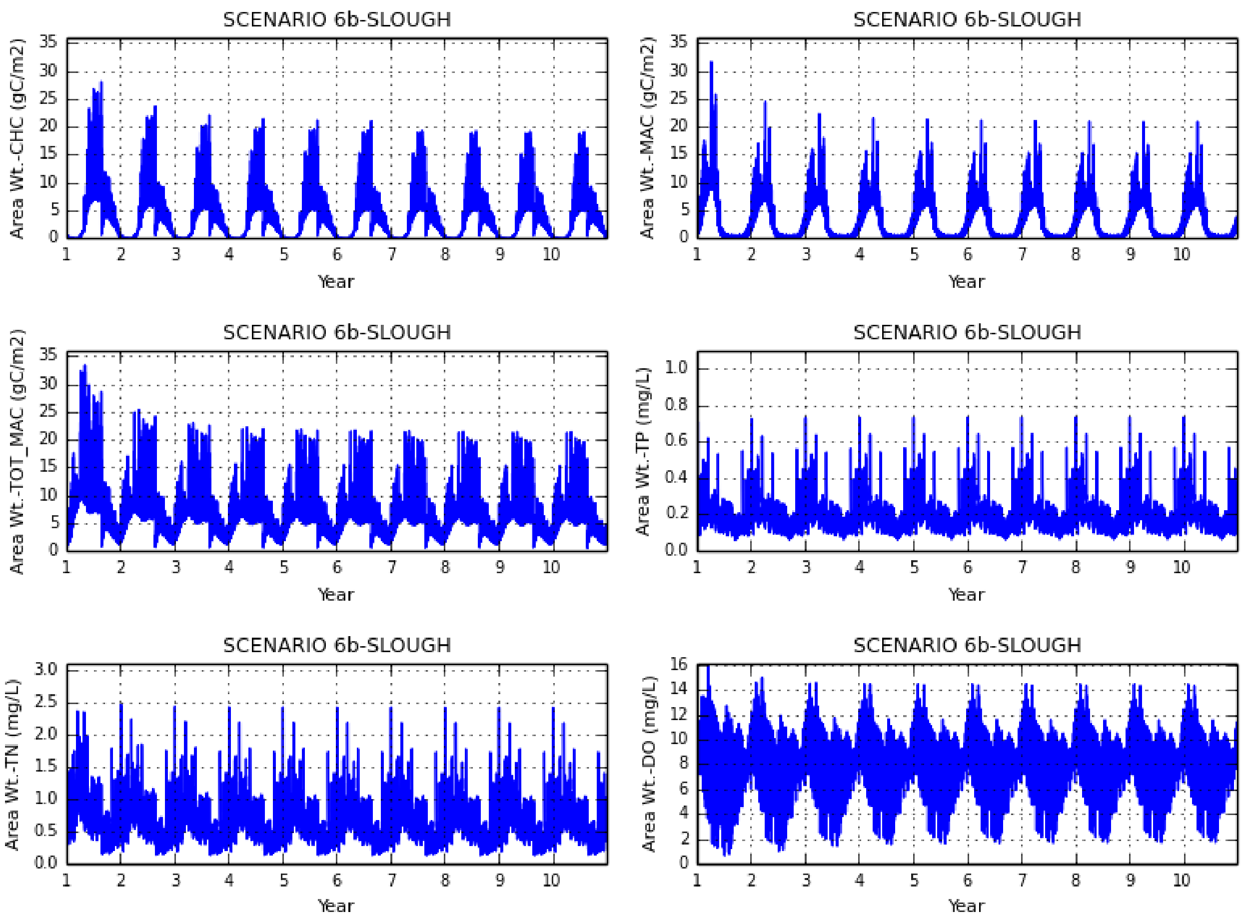


Figure 102. Average Water Quality in the Slough under Scenario 6b

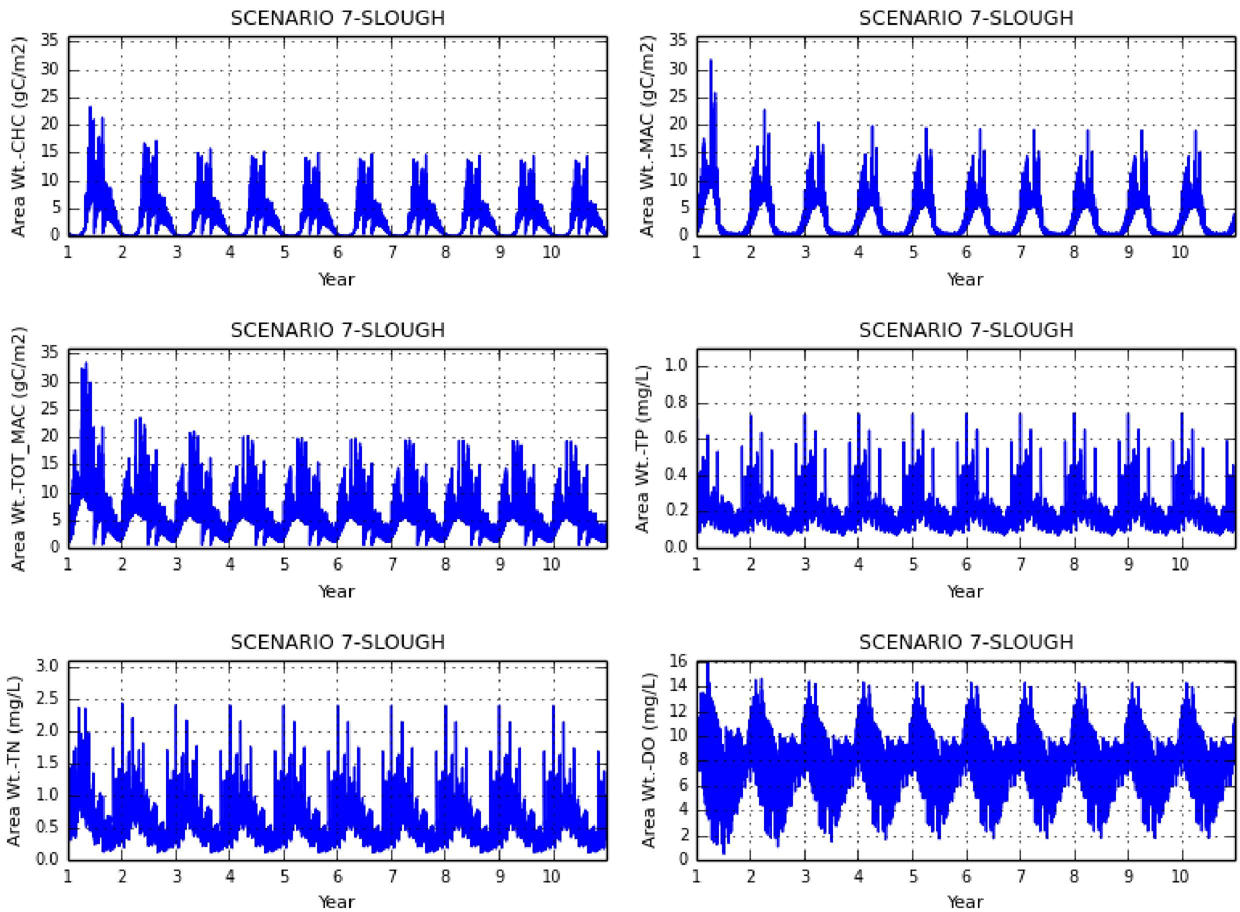


Figure 103. Average Water Quality in the Slough under Scenario 7

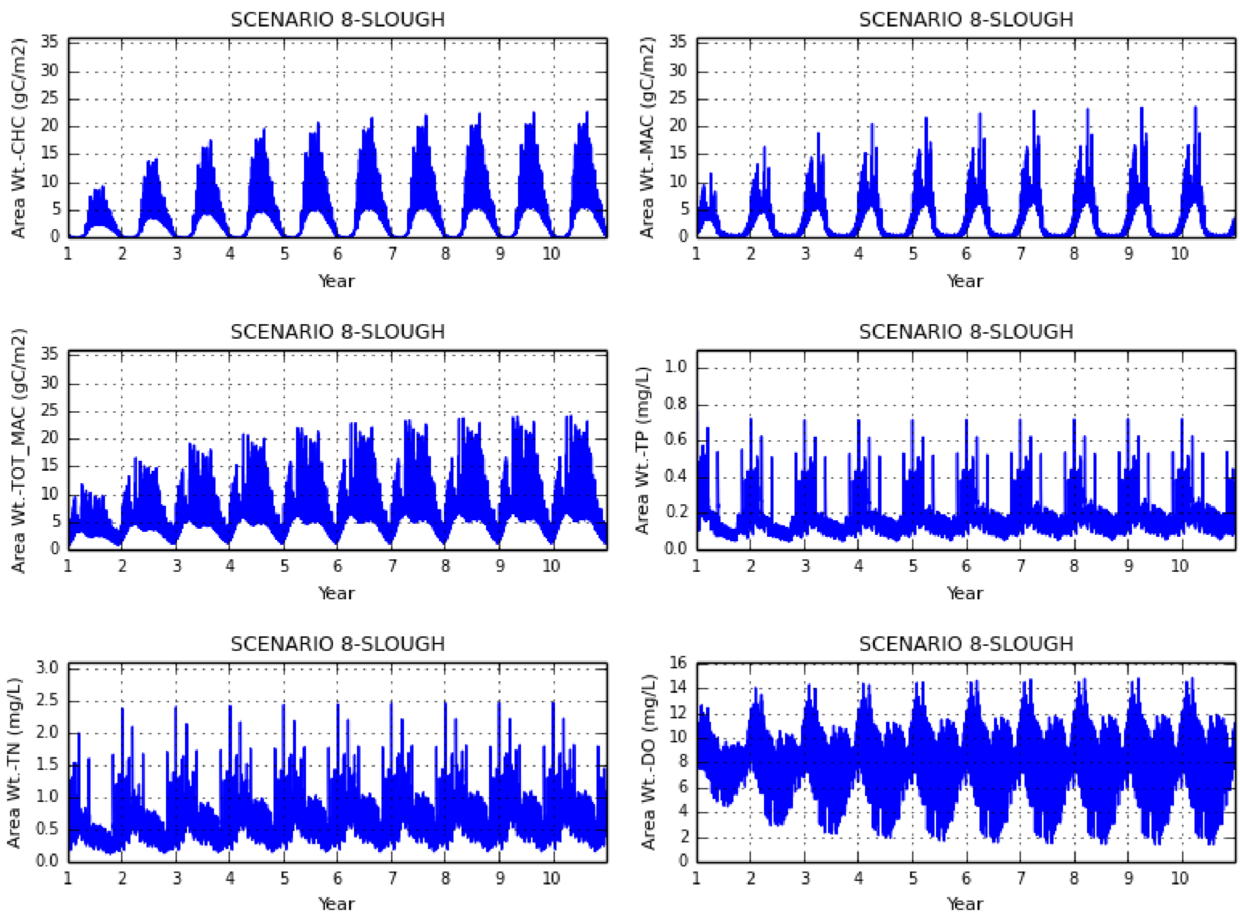


Figure 104. Average Water Quality in the Slough under Scenario 8

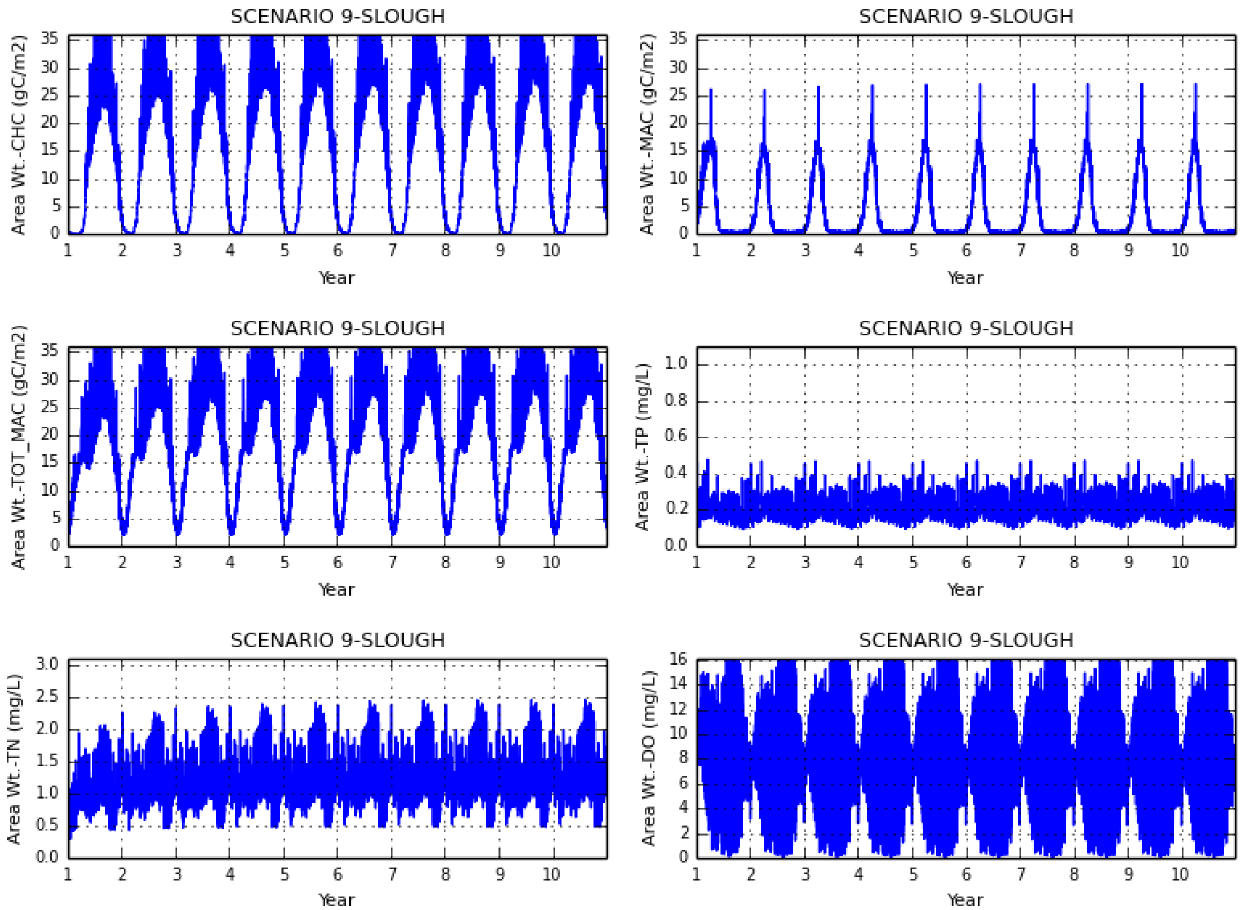


Figure 105. Average Water Quality in the Slough under Scenario 9

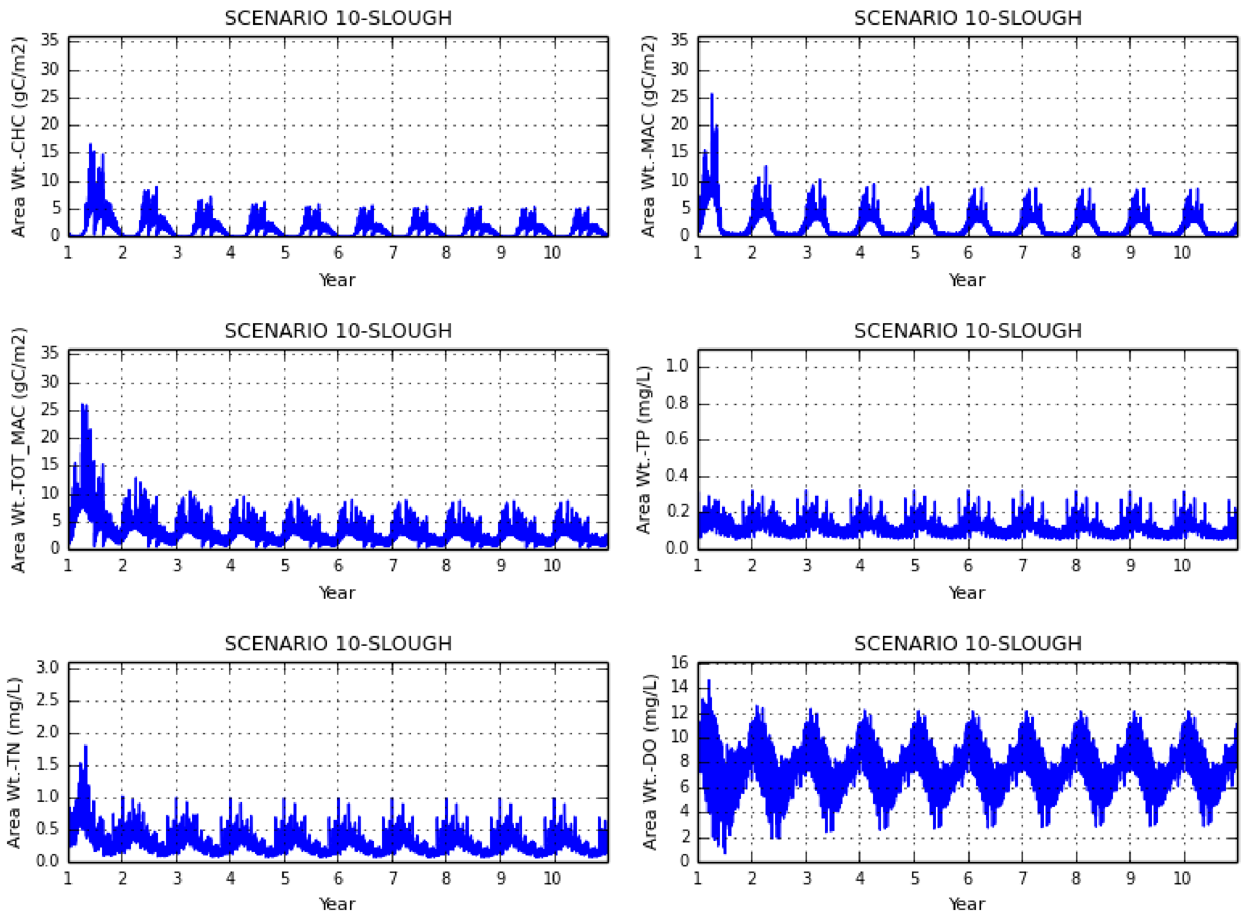


Figure 106. Average Water Quality in the Slough under Scenario 10

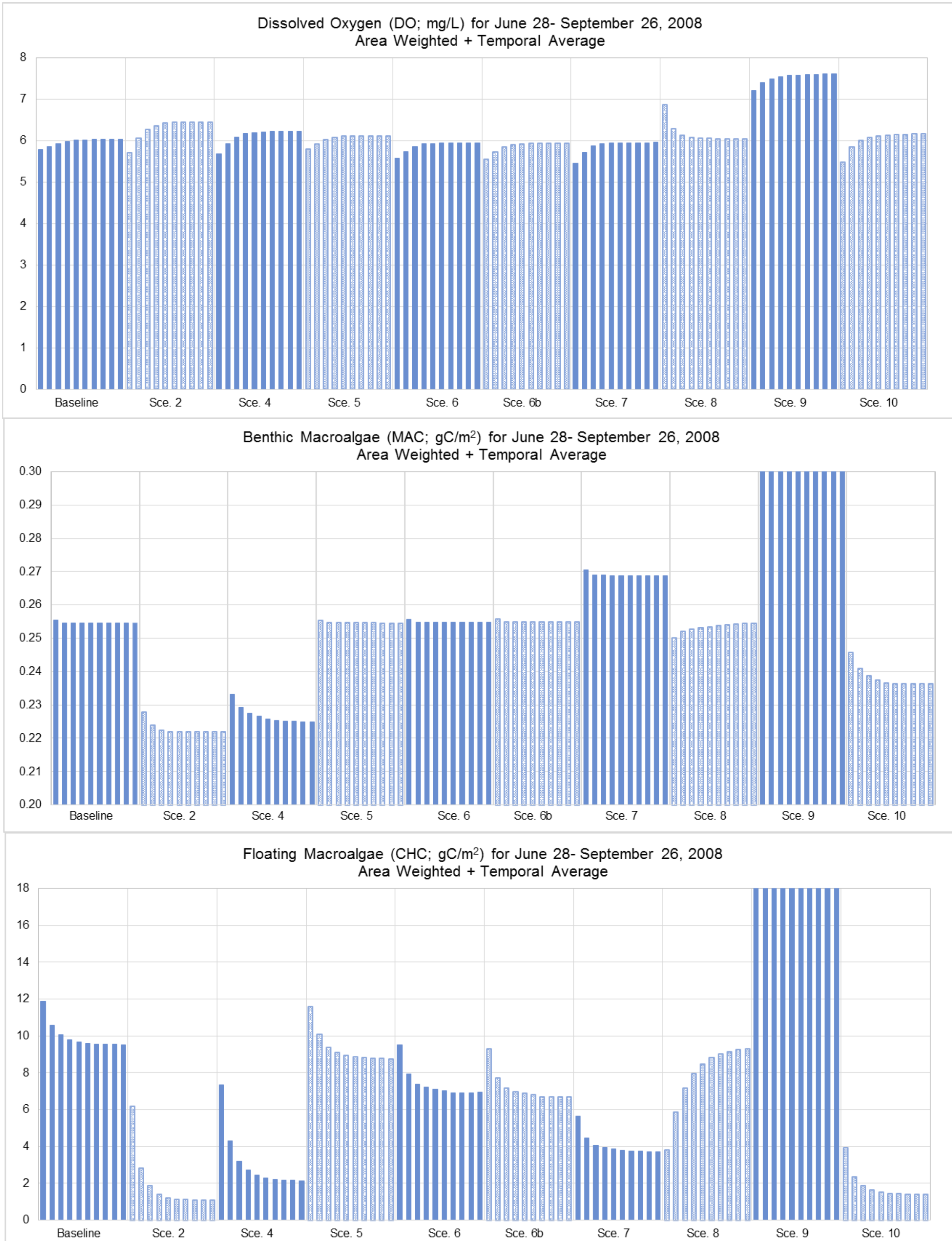


Figure 107. Spatially and Temporal Average Water Quality in the Slough for all Scenarios[3]

[3] DO was represented with temporal minimum, instead of average like the other constituents. Average minimum DO is the average of the minimum daily DO within the Slough.

4.1.2.2. Channel

The spatially-averaged time series results were then plotted for each scenario in Figure 108 through Figure 117. In the figures, CHC represents macrophyte biomass (since floating macroalgae is not observed in the Channel), MAC represents benthic macroalgae biomass, TOT_MAC represents the combined benthic macroalgae and macrophyte biomass, and DOX represents dissolved oxygen (DO).

When the watershed and San Diego River nutrient loadings were reduced by 95%, the response of benthic macroalgae/macrophytes in Channel is quite similar to that in the Slough, which had significantly reduced macroalgae biomass levels. Also, the range of DO diurnal fluctuations is significantly reduced, while the daily minimum DO concentration significantly improved. Scenario 2 demonstrates that tremendously reduced nutrient loadings from both the watershed and San Diego River can significantly benefit both the Slough and Channel.

The results for Scenario 4 demonstrate that an 80 percent reduction in nutrient loading from the watershed alone can also produce significant improvements in the Channel; this is again similar to the response in the Slough. In Scenario 5, an 80 percent reduction in loading from San Diego River produces better improvement in the Channel than in the Slough. This could be because the water in San Diego River directly enters the Channel through the culverts, and the effect dampens out after further passing into the Slough. Overall, the improvement in the Channel is not significant in comparison to that of Scenario 4, suggesting that load reductions from the watershed are considerably more effective than load reductions from San Diego River for the benefit of both the Slough and Channel.

The results for Scenarios 6 and 6b indicate that once-a-year harvesting causes weaker responses for benthic macroalgae/macrophytes biomass in the Channel than in the Slough, though overall the Slough and Channel show a similar trend of slightly reduced biomass and increased daily minimum DO.

Scenario 7 shows that by harvesting floating macroalgae twice-a-year in the Slough, benthic macroalgae/macrophyte biomass is reduced, suggesting that algal harvesting may be a viable alternative for improving water quality conditions. Unlike in the Slough where the benthic macroalgae is further depressed by more frequent harvesting of floating macroalgae, the Channel shows no detectable response in benthic macroalgae to the change in harvesting frequency. This could be because the Channel is directly linked to San Diego River through the culvert, so the depression in nutrients concentration due to harvesting might be alleviated through the exchange of water with San Diego River, leading to no detectable response in benthic algae.

The Channel also responds to dredging in a similar way as the Slough does, where after dredging, macroalgae and DO concentrations significantly improved initially, which is consistent with conclusions from previous studies that suggest benthic flux and SOD are significant contributors to the water quality problems in the Slough and the Channel. The model results also demonstrate that these benefits degrade rapidly over time and become insignificant after several years due to enrichment in the bed from watershed and San Diego River loading.

As for Scenario 9, the model also shows degraded water quality conditions in terms of higher benthic macroalgae/macrophytes biomass and lower daily minimum DO because of modifying the circulation patterns. Macroalgae biomass could increase in the Channel due to the longer retention time in the Slough, causing greater conversion of organic nutrients to inorganic nutrients. The inorganic nutrients then are transported to the Channel to support higher productivity, which correspondingly worsens the DO issue.

The results of Scenario 10 in the Channel generally follow those of the Slough, suggesting that a less extreme watershed load reduction (60 percent) combined with harvesting does provide significant water quality benefit to both the Slough and Channel.

Figure 118 presents the spatially and temporally averaged statistics in the Channel for all the scenarios during the critical summer period. During this period, macrophytes dominate and benthic algae is minimal. Overall, Figure 118 verifies the observations of water quality benefits previously discussed. In the Channel, Scenario 7 no longer shows an increased benthic macroalgae biomass following harvesting, as was seen for the Slough in Figure 107. This is likely because of the deeper water level in the Channel, which prevents the benthic algae from taking advantage of the reduced shading effect after the harvesting.

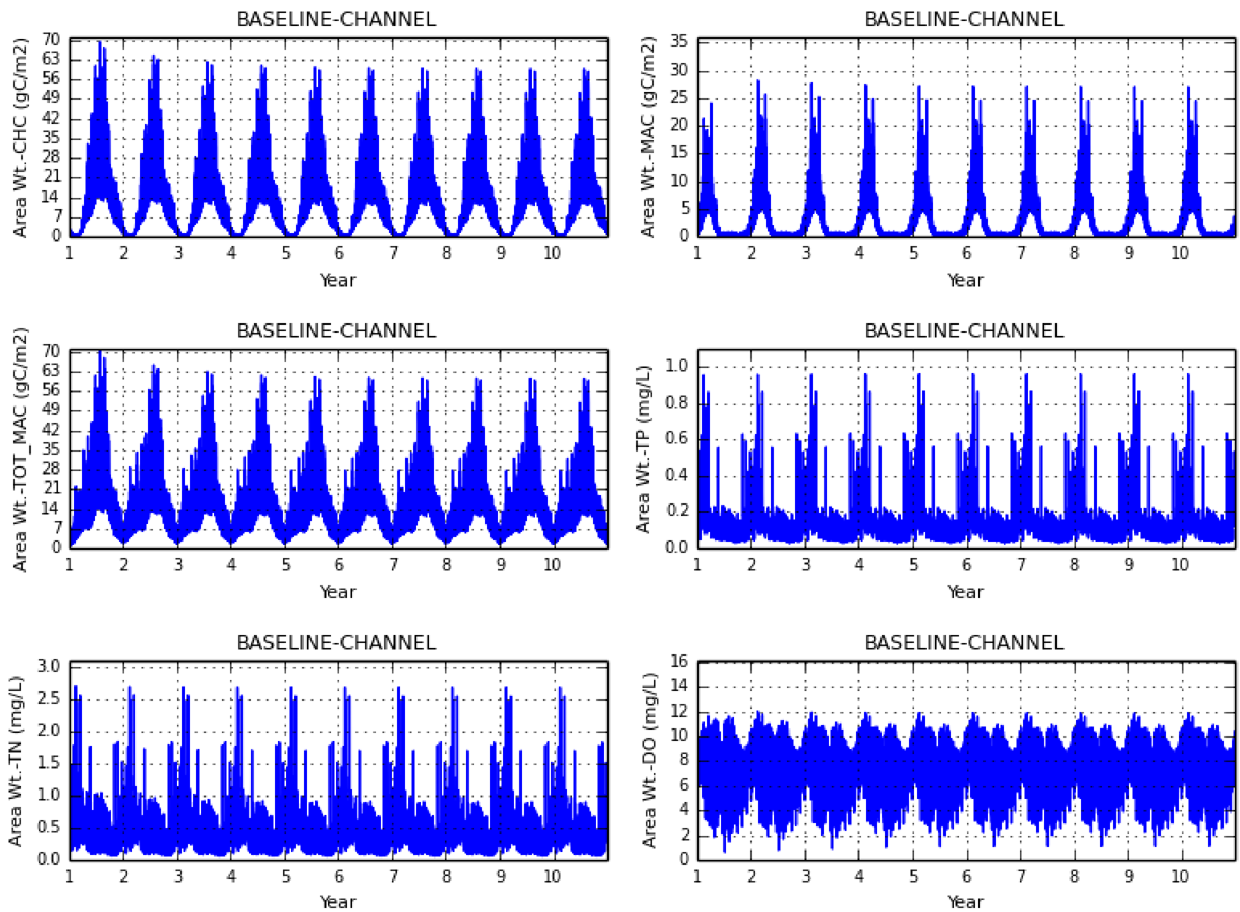


Figure 108. Average Water Quality in the Channel under Scenario 1 — Baseline Condition

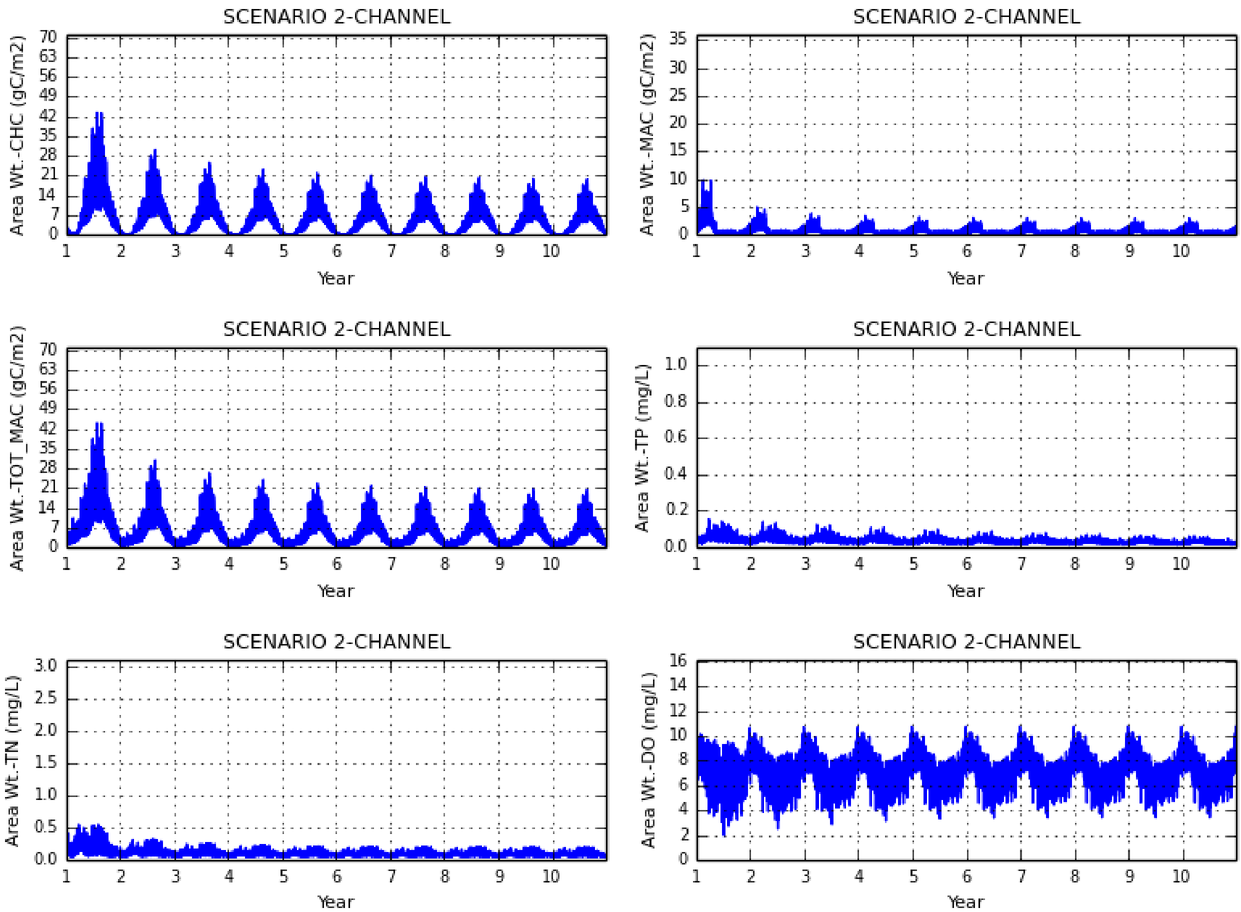


Figure 109. Average Water Quality in the Channel under Scenario 2

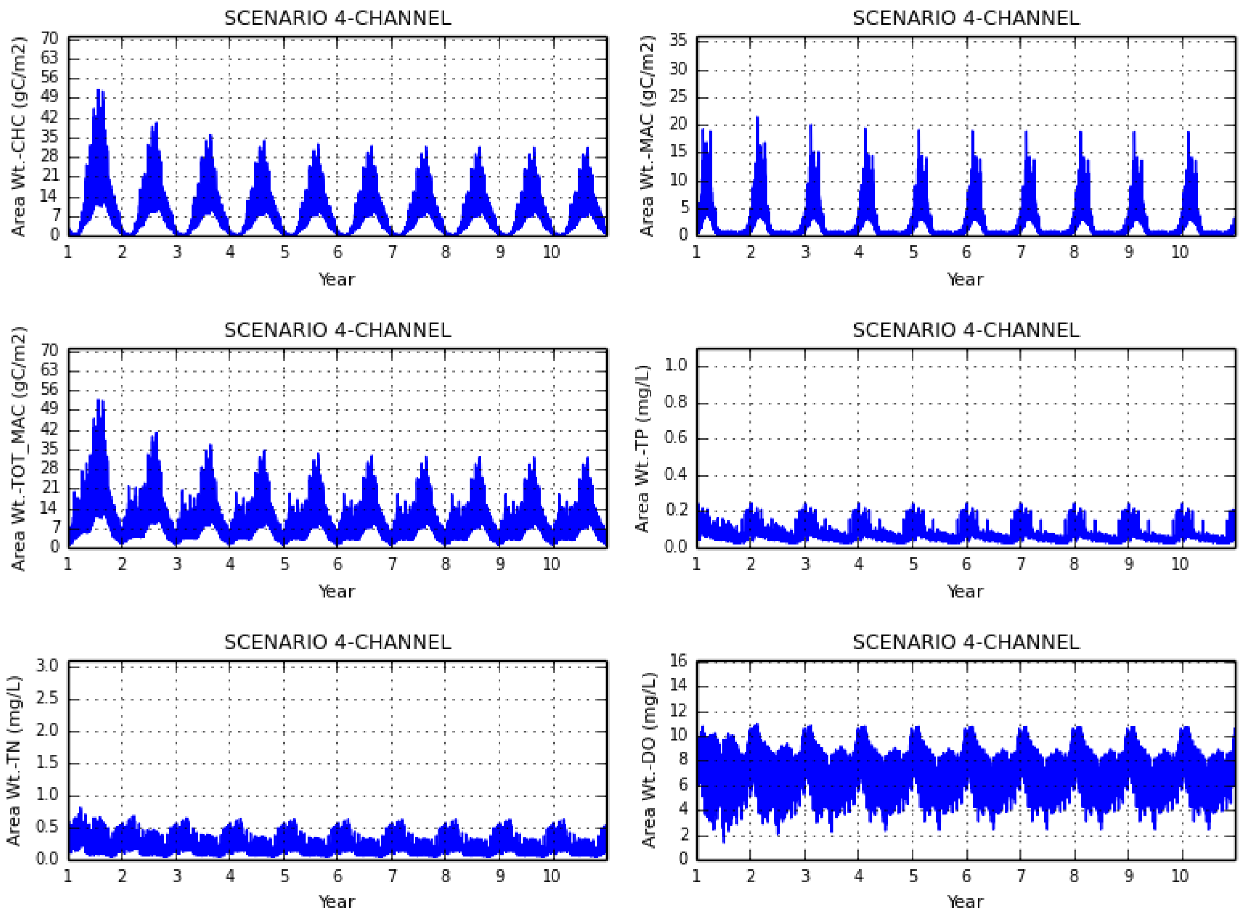


Figure 110. Average Water Quality in the Channel under Scenario 4

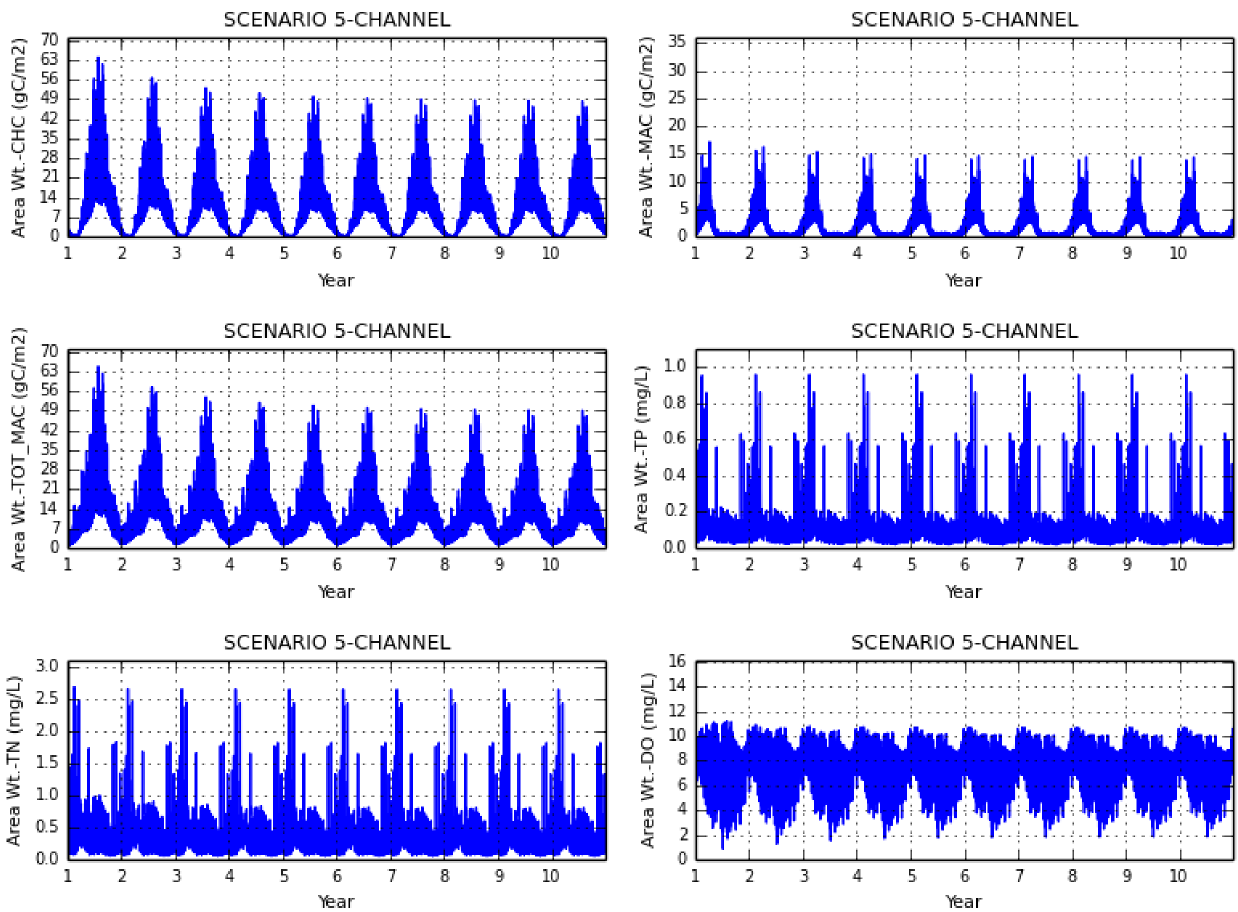


Figure 111. Average Water Quality in the Channel under Scenario 5

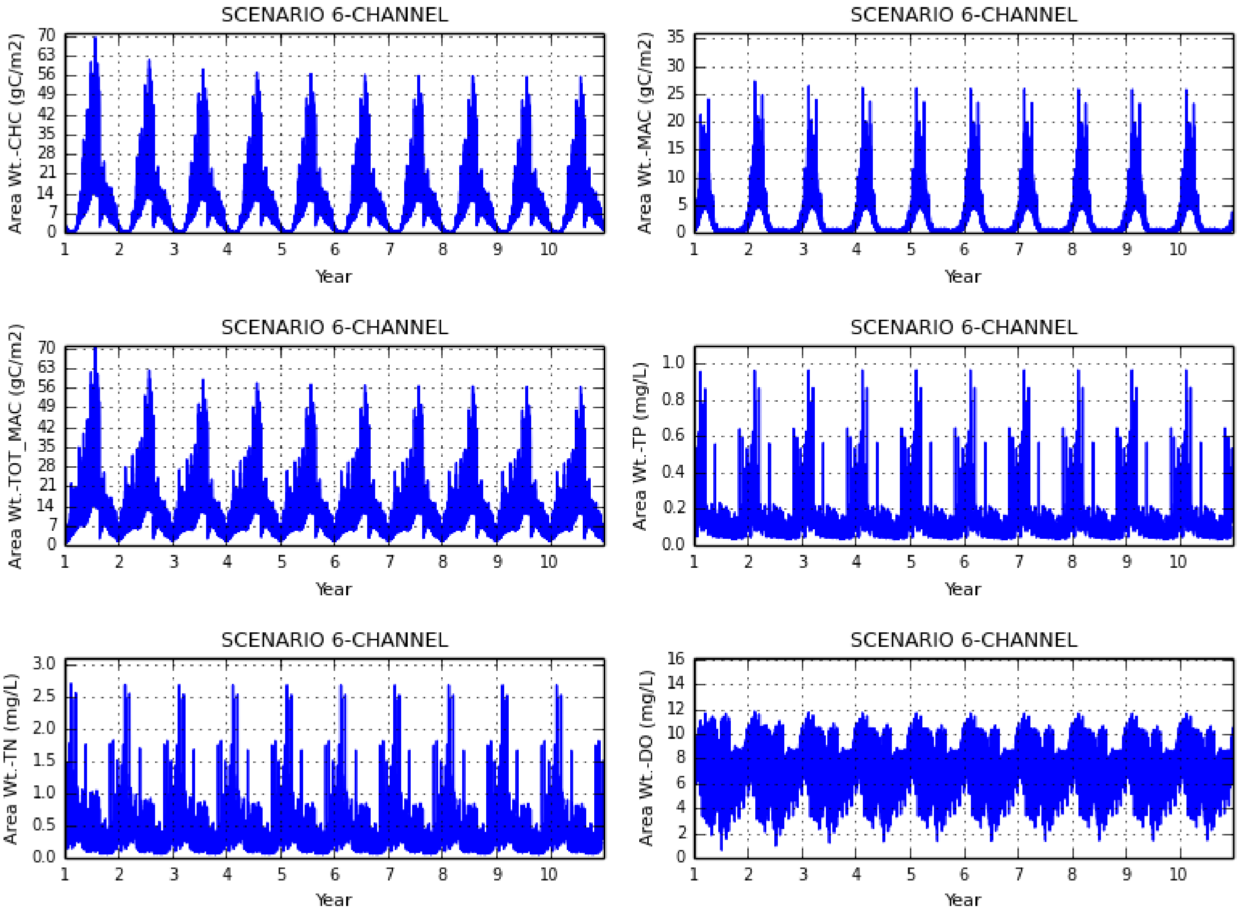


Figure 112. Average Water Quality in the Channel under Scenario 6

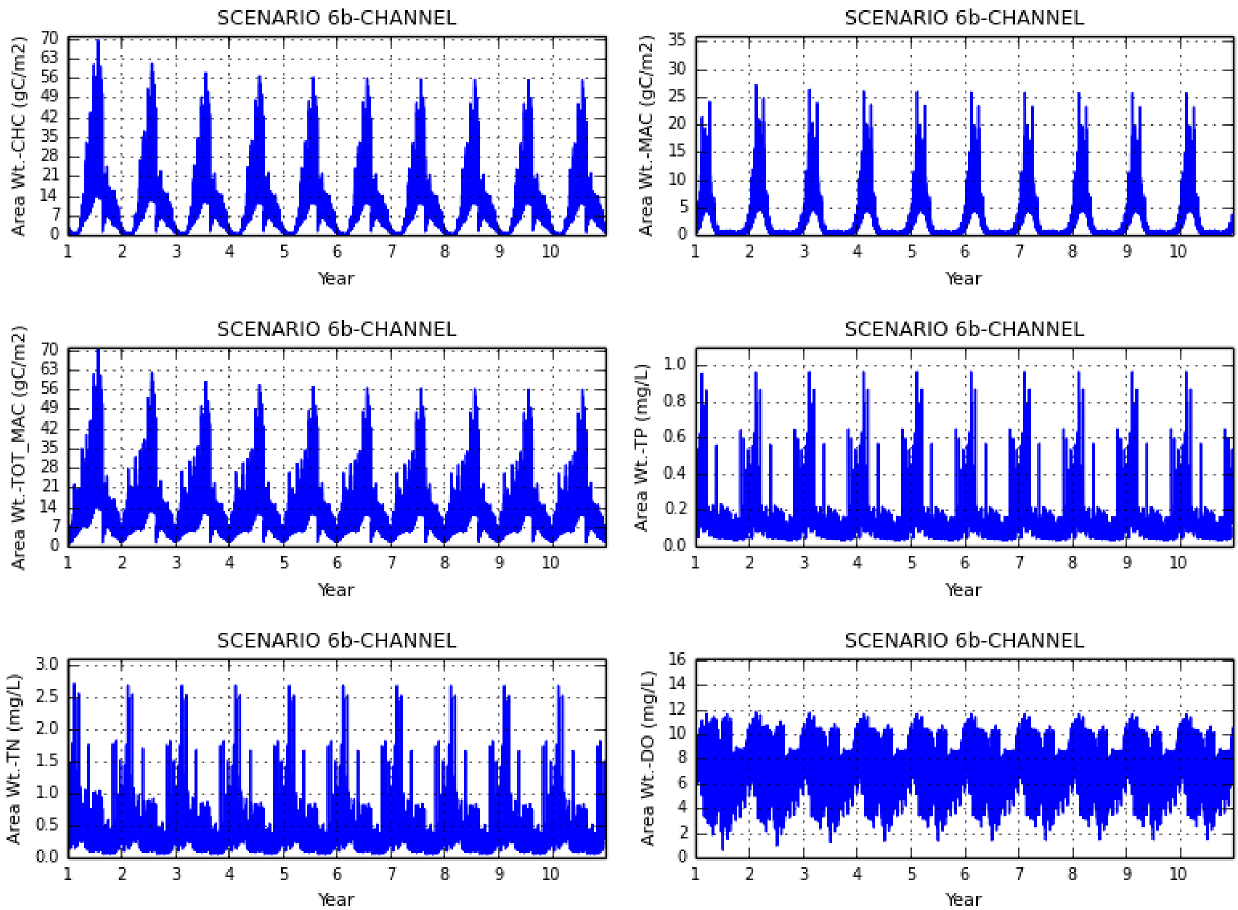


Figure 113. Average Water Quality in the Channel under Scenario 6b

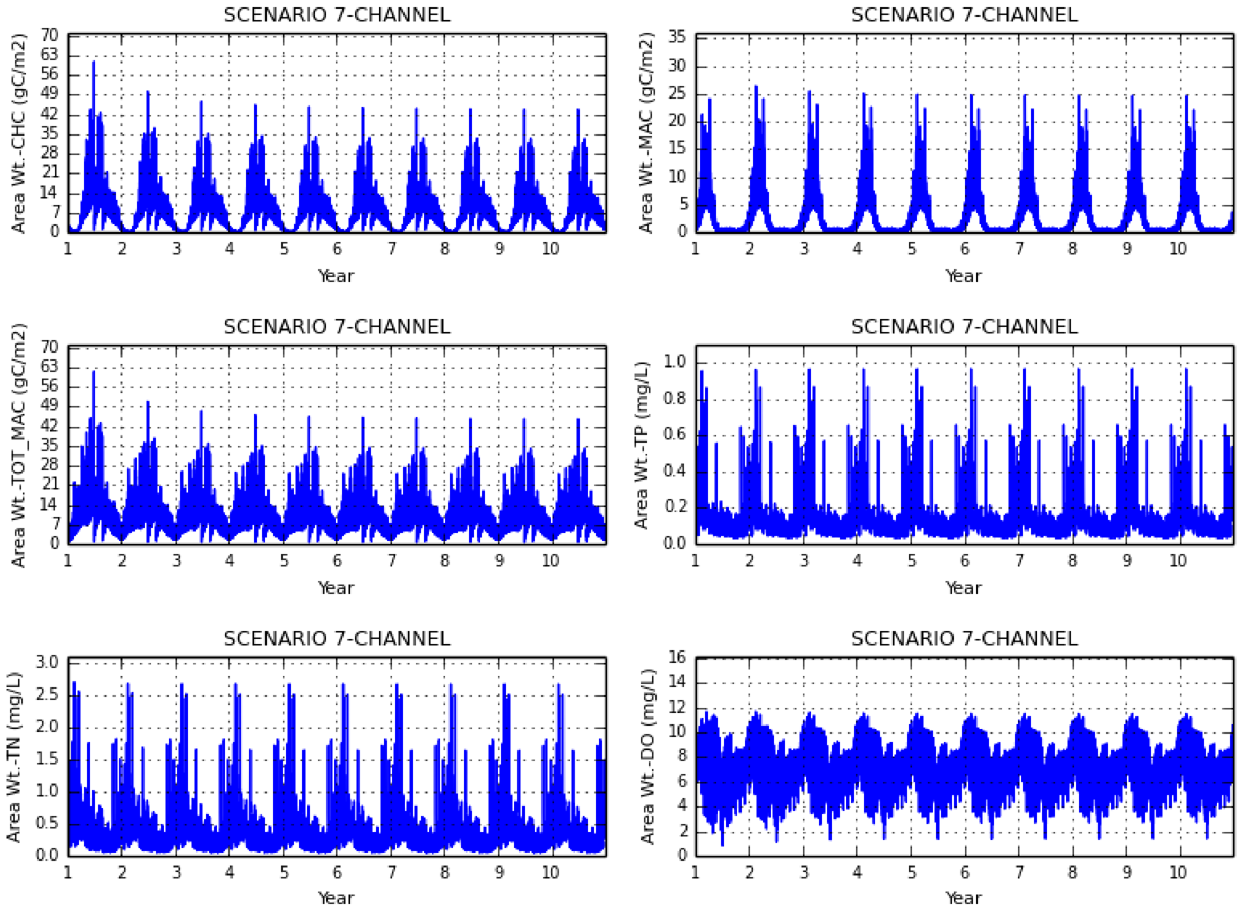


Figure 114. Average Water Quality in the Channel under Scenario 7

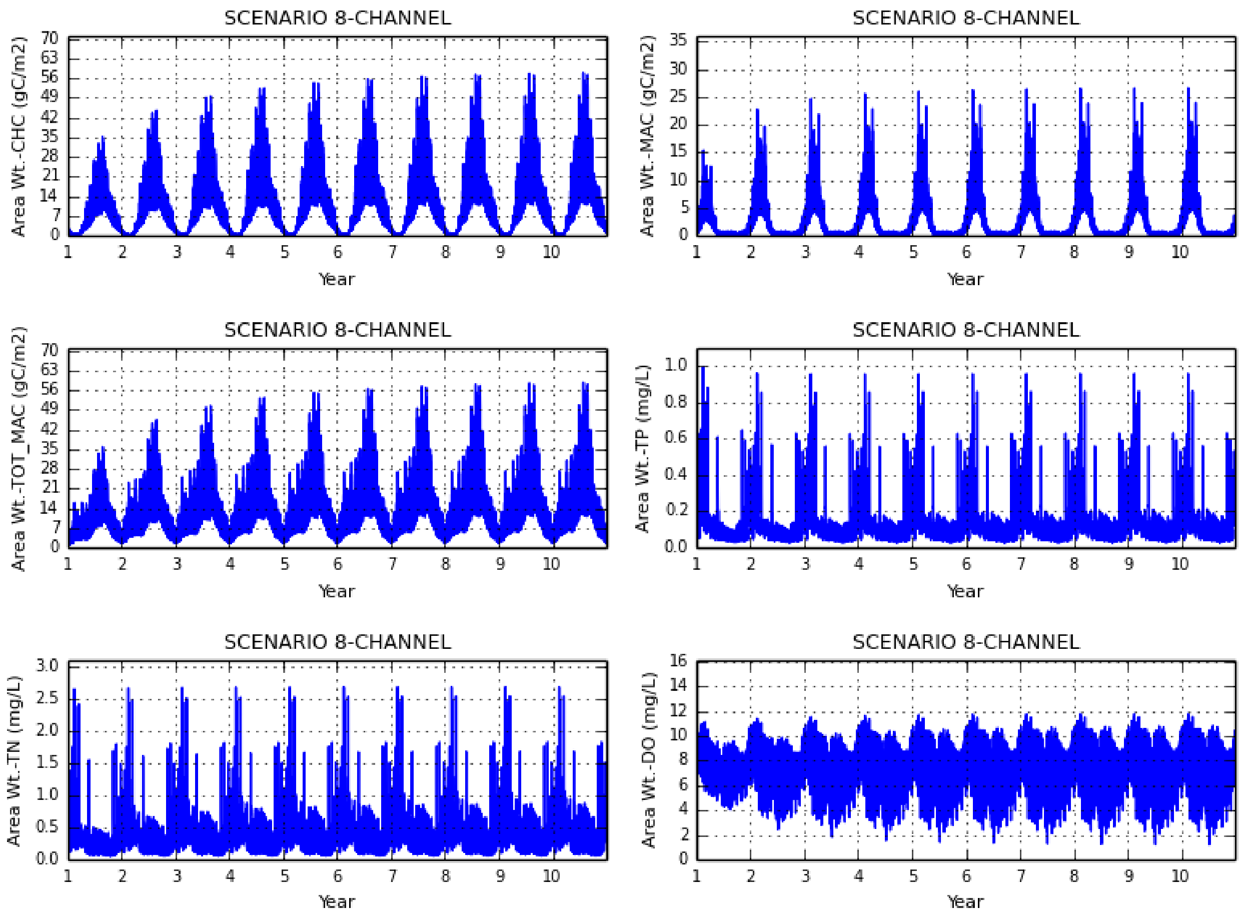


Figure 115. Average Water Quality in the Channel under Scenario 8

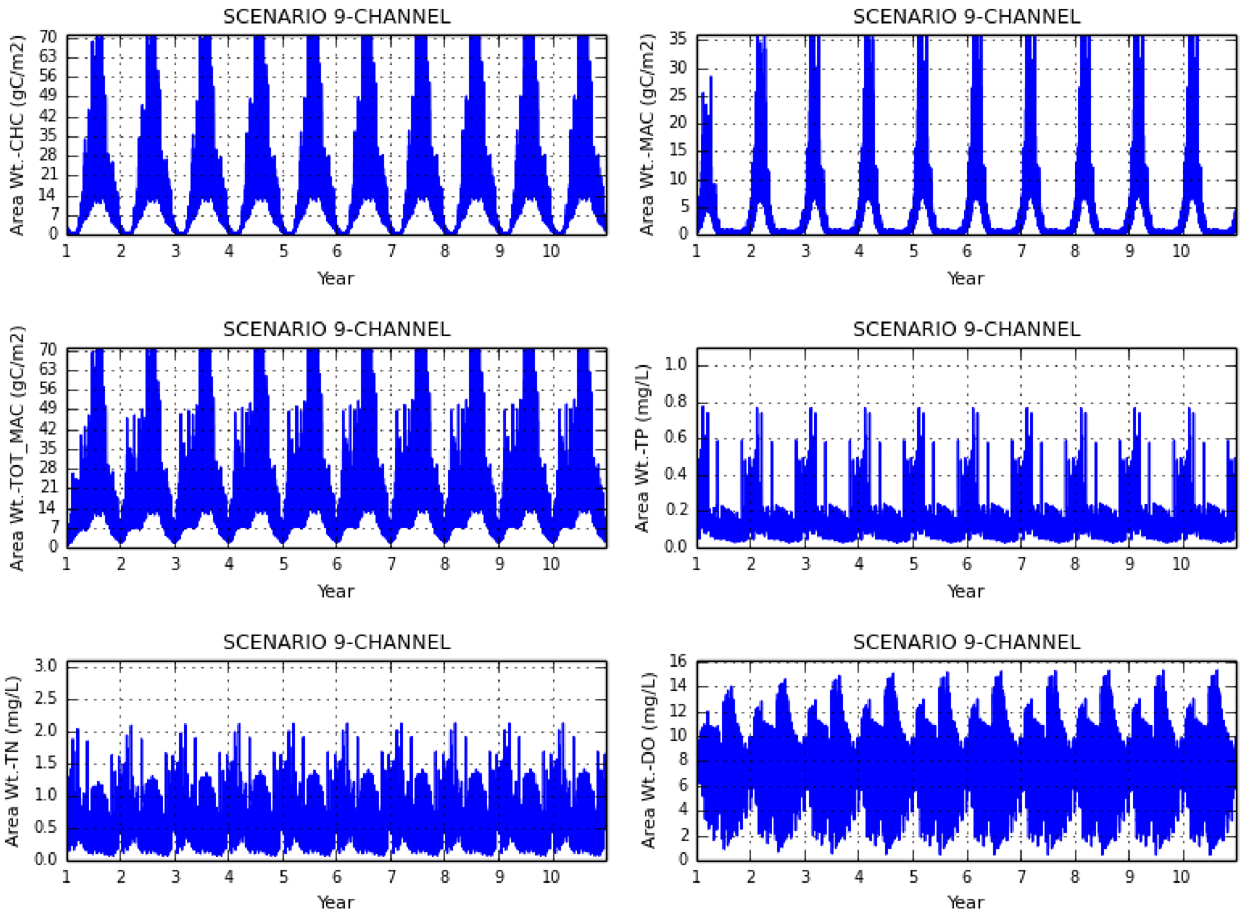


Figure 116. Average Water Quality in the Channel under Scenario 9

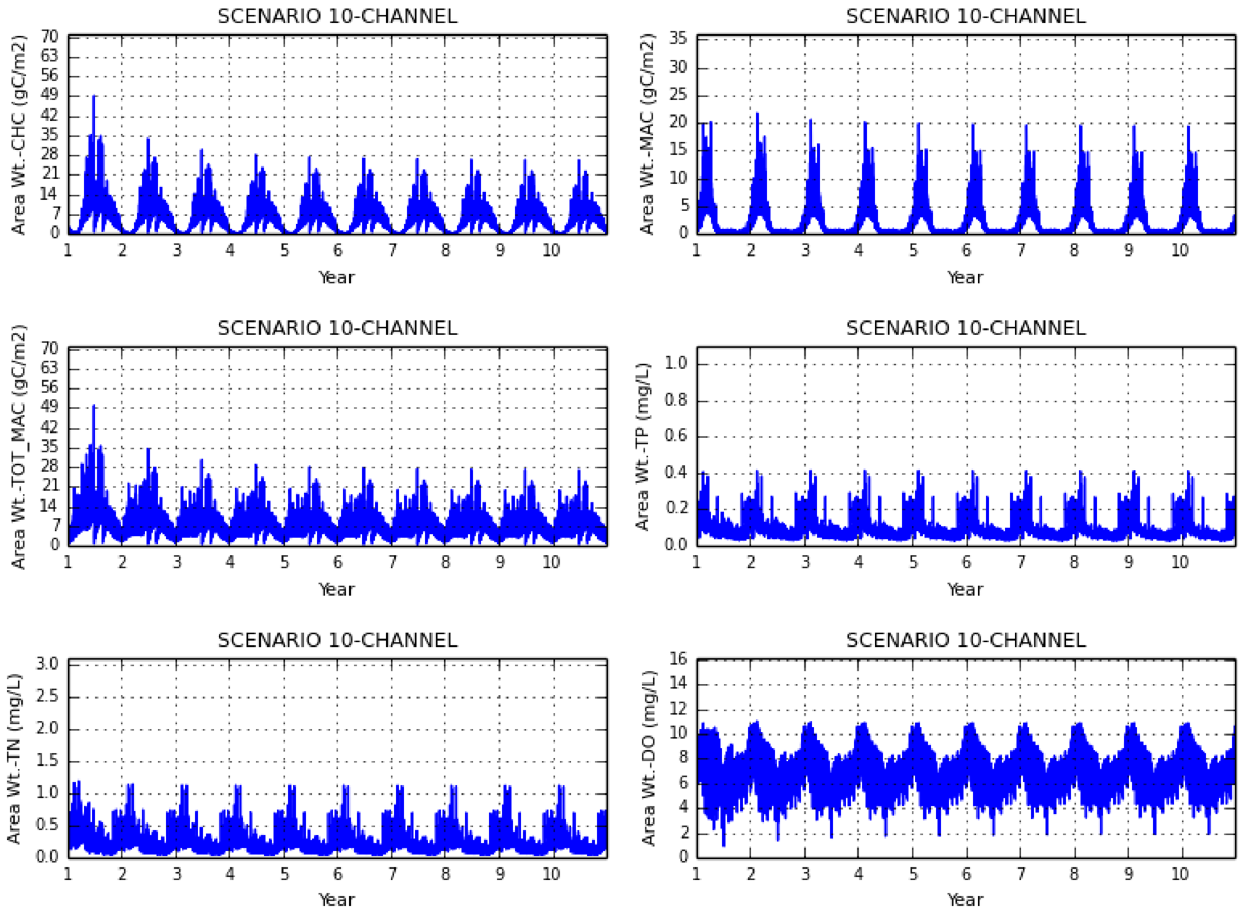


Figure 117. Average Water Quality in the Channel under Scenario 10

Figure 118. Spatially and Temporal Average Water Quality in the Channel for all Scenarios[4]

[4] DO was represented with temporal minimum, instead of average like the other constituents. Average minimum DO is the average of the minimum daily DO within the Channel.

4.1.2.3. DO Exceedances

DO percent exceedances were also assessed for the Slough and Channel. The percent exceedances represent the percent of weighted average, hourly-modeled values that exceed 5 mg/L for each year for each scenario. A 10 percent exceedance was considered during the discussion of results, which are presented below separately for the Slough and Channel.

The DO percent exceedances for the Slough are presented in numerical and graphical formats in Table 11 and Figure 119, respectively. The 10 percent is shown as the red dotted line in Figure 119. Most scenario years surpassed the 10 percent exceedance. For the majority of the scenarios, the percent exceedances decrease for each subsequent year. The majority of the years for Scenarios 2, 4, and 10 are within the 10 percent. The years below the 10 percent start with year 3 for Scenario 2, year 5 for Scenario 4, and year 4 for Scenario 10 and continue for the remaining years in each of these scenarios. Scenarios 2 and 10 result in the lowest average percent exceedances; however, Scenario 2 requires the most stringent load reduction in both the watershed and the San Diego River nutrient loads, whereas Scenario 10 requires twice-a-year harvesting of floating macroalgae in the Slough and a 60 percent reduction in watershed loads. Based on these criteria, Scenario 10 likely yields the lowest average percent exceedance with the least demanding requirements.

Table 11. DO Percent Exceedances (<5 mg/L) for the Slough for June 28–September 26, 2008

Year	Baseline	Sce. 2	Sce. 4	Sce. 5	Sce. 6	Sce. 6b	Sce. 7	Sce. 8	Sce. 9	Sce. 10
1	53.33	43.06	48.06	53.33	52.22	53.06	49.72	3.89	49.44	43.33
2	51.67	14.72	29.17	50.00	46.67	47.22	40.28	28.33	50.00	21.39
3	50.56	4.72	16.39	47.78	43.89	43.06	33.06	40.28	50.00	12.78
4	49.17	1.67	11.67	46.94	42.78	41.94	31.67	43.89	50.00	9.17
5	48.61	0.83	8.61	46.67	41.67	41.67	30.56	45.56	50.00	6.94
6	48.06	0.83	7.78	46.11	41.67	41.11	29.72	46.94	50.00	6.67
7	48.06	0.83	6.94	45.83	41.11	40.56	29.44	46.94	50.00	6.39
8	47.78	0.83	6.94	45.83	41.39	40.28	29.44	47.22	50.00	6.11
9	47.78	0.83	6.94	45.83	41.39	40.28	29.44	47.50	50.00	5.83
10	47.78	0.83	6.67	45.83	41.67	40.83	28.61	47.50	50.00	5.83
Average	**49.28**	**6.92**	**14.92**	**47.42**	**43.44**	**43.00**	**33.19**	**39.81**	**49.94**	**12.44**

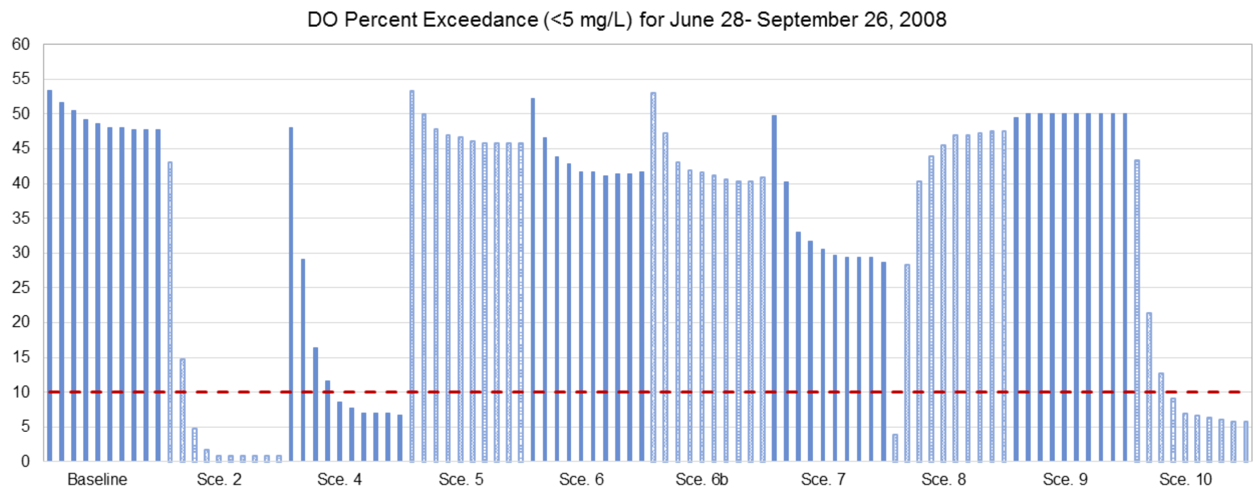


Figure 119. DO Percent Exceedance (<5 mg/L) for the Slough for June 28–September 26, 2008

The percent exceedances for the Channel are presented numerically and graphically in Table 12 and Figure 120, respectively. As mentioned previously, the 10 percent exceedance is represented as the red dotted line in Figure 120, and most scenarios' years exceed the 10 percent. For all scenarios except Scenarios 8 and 9, the percent exceedances decrease over time. For the Channel, only Scenario 2 reaches percent exceedances below the 10 percent, starting at year 5. However, the requirements for Scenario 2 are demanding. Although Scenario 10 does not have percent exceedances that comply with the 10 percent, it has the second lowest average percent exceedance, and its criteria are more feasible and less intensive. Therefore, for the Channel as well, Scenario 10 could be the preferred scenario when considering percent exceedance and scenario requirements.

Table 12. DO Percent Exceedance (<5 mg/L) for the Channel for June 28- September 26, 2008

Year	Baseline	Sce. 2	Sce. 4	Sce. 5	Sce. 6	Sce. 6b	Sce. 7	Sce. 8	Sce. 9	Sce. 10
1	50.28	39.17	44.72	49.17	50.83	50.83	47.78	11.11	49.17	41.94
2	49.72	22.22	35.00	45.83	47.78	47.50	41.94	32.78	50.00	30.83
3	48.89	13.06	29.17	43.61	45.00	44.17	37.22	39.44	50.28	25.56
4	47.78	10.56	26.39	42.22	44.17	44.17	34.72	42.78	50.28	21.67
5	47.22	7.78	24.17	41.94	44.17	43.61	33.61	43.89	50.28	20.28
6	46.67	7.78	23.33	41.94	43.61	42.78	33.61	44.72	50.28	19.72
7	46.67	7.78	22.22	41.94	43.33	42.22	33.61	44.72	50.28	18.61
8	46.39	7.50	22.22	41.67	43.61	42.50	33.61	45.83	50.28	18.33
9	46.39	7.22	22.22	41.67	43.61	42.50	33.61	45.83	50.28	18.33
10	46.39	7.22	21.94	41.67	42.78	42.78	33.33	45.83	50.28	18.33
Average	**47.64**	**13.03**	**27.14**	**43.17**	**44.89**	**44.31**	**36.31**	**39.69**	**50.14**	**23.36**

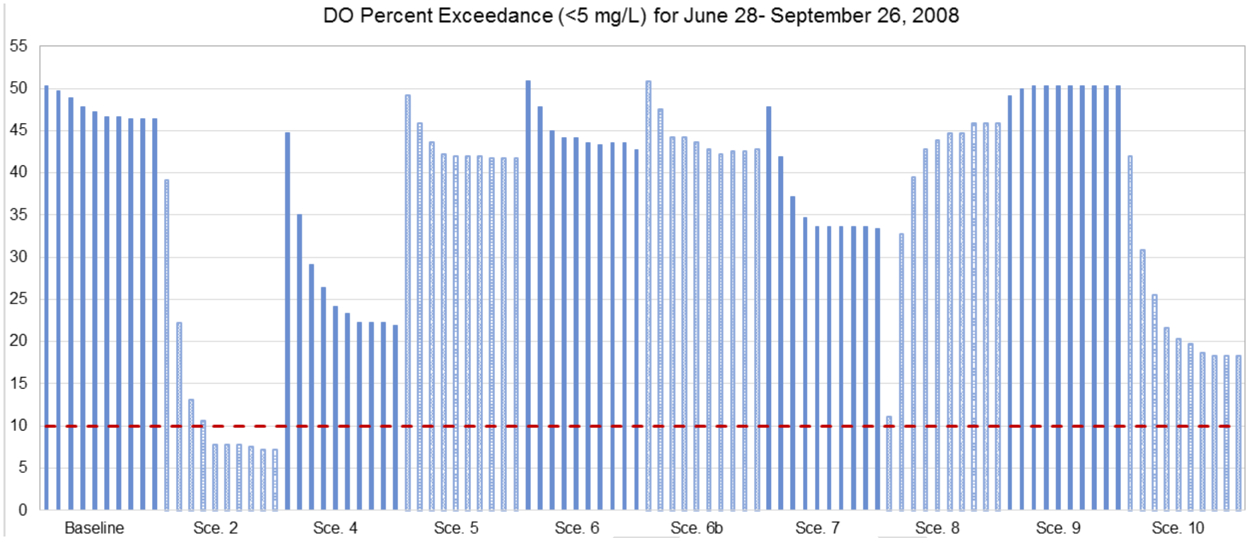


Figure 120. DO Percent Exceedance (<5 mg/L) for the Channel for June 28- September 26, 2008

4.1.2.4. Exploratory Scenario Results Discussion

The calibrated model was applied to analyze multiple management scenarios focusing on different aspects of controlling processes: watershed load reduction, San Diego River load reductions, macroalgae harvesting, dredging, water circulation modifications, and the combination of different options. Overall, the modeling analysis resulted in the following observations:

- Watershed nutrient load reductions can produce significant water quality benefits;
- Reductions in San Diego River loading alone results in negligible water quality benefits;
- Harvesting floating macroalgae in the Slough can have significant water quality benefits. The degree of effectiveness correlated with the number of harvest events per year during the critical period;
- Dredging (i.e., reduced sediment nutrient concentrations) can generate immediate water quality benefits; however, the benefits degraded rapidly without corresponding reductions in external loading;
- The water circulation modifications recommended in the previous PWA report did not demonstrate improved water quality conditions. This indicates the previous 1-dimensional modeling analysis was oversimplified and did not provide a realistic representation of Famosa Slough; and
- A combination of moderate watershed load reductions coupled with periodic macroalgae harvesting provided significant water quality benefits and represents a more cost-effective approach for improving conditions.

4.2. Preferred Management Option Scenarios

4.2.1. Scenario Descriptions

After the initial exploratory management scenarios were reviewed, it was determined that the preferred management options were (1) reductions to the watershed nutrient loads and (2) twice-a-year macroalgae harvesting (July 1 and September 1) in the Slough. In addition, nutrient reduction scenarios were performed during different climatological conditions to support targeted implementation. Specifically, nutrient reductions were evaluated year round (wet/dry), during wet periods[5], and during dry conditions. Under the harvesting scenarios, floating macroalgae was hypothetically harvested at the beginning of the critical period (July 1), then again later when biomass levels became elevated again (September 1). Note that macroalgae biomass estimates shown in this section represent the 95th percentile critical condition, as compared to the spatially averaged biomass estimates shown in the previous sections (which are significantly lower in magnitude).

Like the exploratory management scenarios, the initial scenario was for the baseline condition, which used the calibrated hydrodynamic and water quality model using existing conditions (no nutrient reductions and no harvesting). The remaining nine scenarios can be divided into two batches: load reductions only and load reductions plus macroalgae harvesting in the Slough. The load reduction scenarios can be further divided by climatological conditions (wet/dry, dry only, or wet only). Most load reductions (equally applied to nitrogen, phosphorus, and carbon) were run for both batches of scenarios and were applied to the entire watershed. After analyzing these results, it was determined that applying twice-a-year harvest can be significantly beneficial in relieving the burden of watershed load reduction.

4.2.2. Results

DO compliance was evaluated against the daily minimum concentration target. This is different from how the exploratory results were evaluated. To remove potential outliers from the model results, simulated DO concentrations that were less than the 10th percentile of all values were excluded from the raw data. This method is consistent with the California 303(d) listing guidance that allows for a percentage of monitoring results to be below the criteria and not be considered impaired (SWRCB, 2015). After excluding the 10th percentile, the DO concentration was averaged across space to obtain a spatially average DO time series, and then the daily minimum concentration of the spatially averaged time series was identified for each day. These daily minimum DO values were then averaged through the 90-day critical period to obtain the compliance evaluation metric.

The metric is calculated for the Slough and Channel separately. The metric calculation steps are

1. Extract the 6-hour model output for all cells.
2. Eliminate the DO values below the 10th percentile for all grid cells and all times during the critical period from July 1 to September 30.
3. Calculate spatial average time series (separate values for Slough and Channel) to obtain a single, spatially average DO time series to represent the average condition.
4. Identify the daily DO_{min} for each day during the critical period for the average time series.
5. Calculate the average DO_{min} of the critical period.

[5] Wet periods were defined as a day with 0.1 inches of rainfall plus the following three days. Dry days are days not identified as wet.

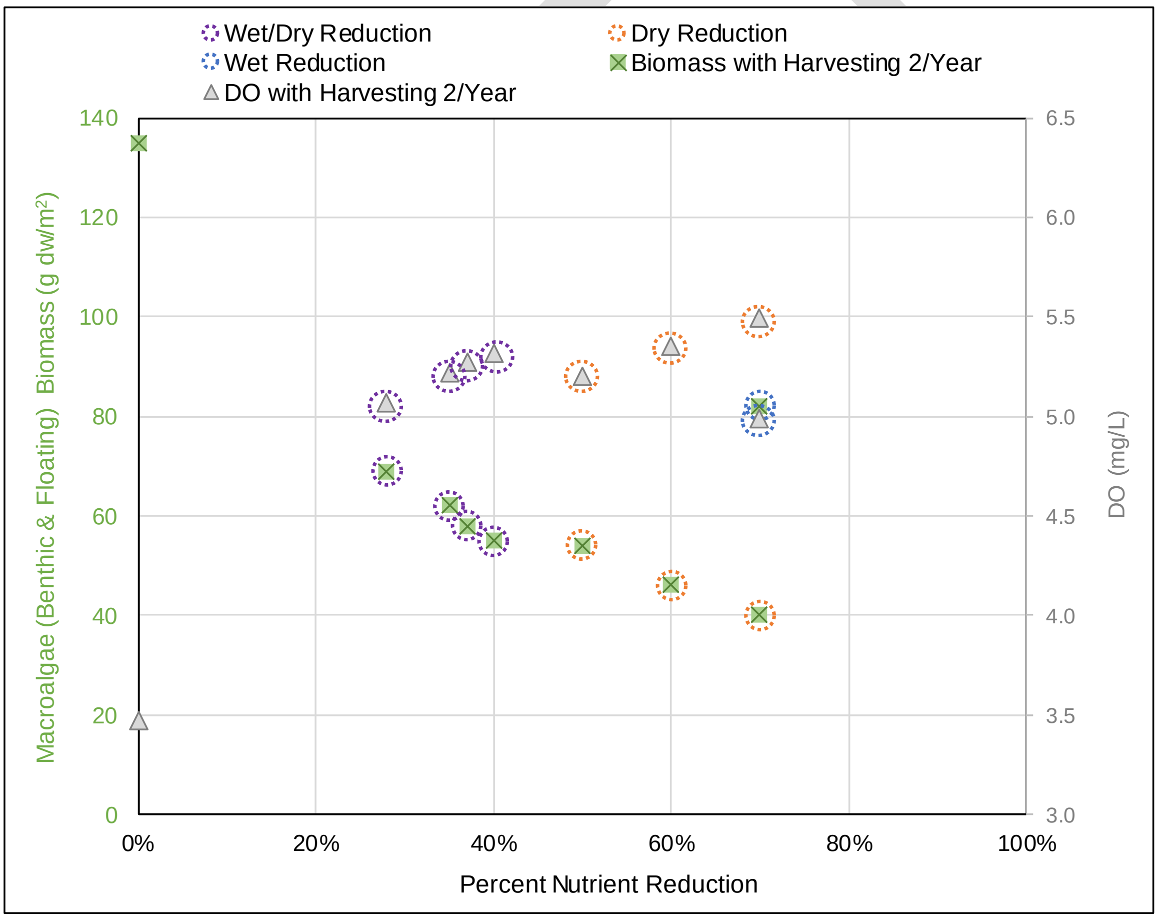
4.2.2.1. Slough

As expected, decreasing nutrient input increases the daily minimum DO (*Note*: The 0% reductions values do not include twice per year harvesting.

Figure 121) and decreases benthic and floating macroalgae biomass (*Note*: The 0% reductions values do not include twice per year harvesting.

Figure 121). There is a strong negative correlation between the total macroalgae biomass and the daily minimum DO, indicating that a high macroalgae biomass often accompanies low DO levels, and vice versa.

To be able to meet the DO numeric target, macroalgae would need to be controlled to a very low biomass, even with some watershed load reductions. Macroalgae biomass was reduced significantly through harvesting floating macroalgae twice-a-year, suggesting that algal harvesting could be useful for improving water quality conditions. Macroalgae was reduced to 58 g dry weight/m^2 and DO was above the numeric target with twice per year harvesting and a 37 percent year-round (wet/dry) reduction in watershed nutrient loads.



Note: The 0% reductions values do not include twice per year harvesting.

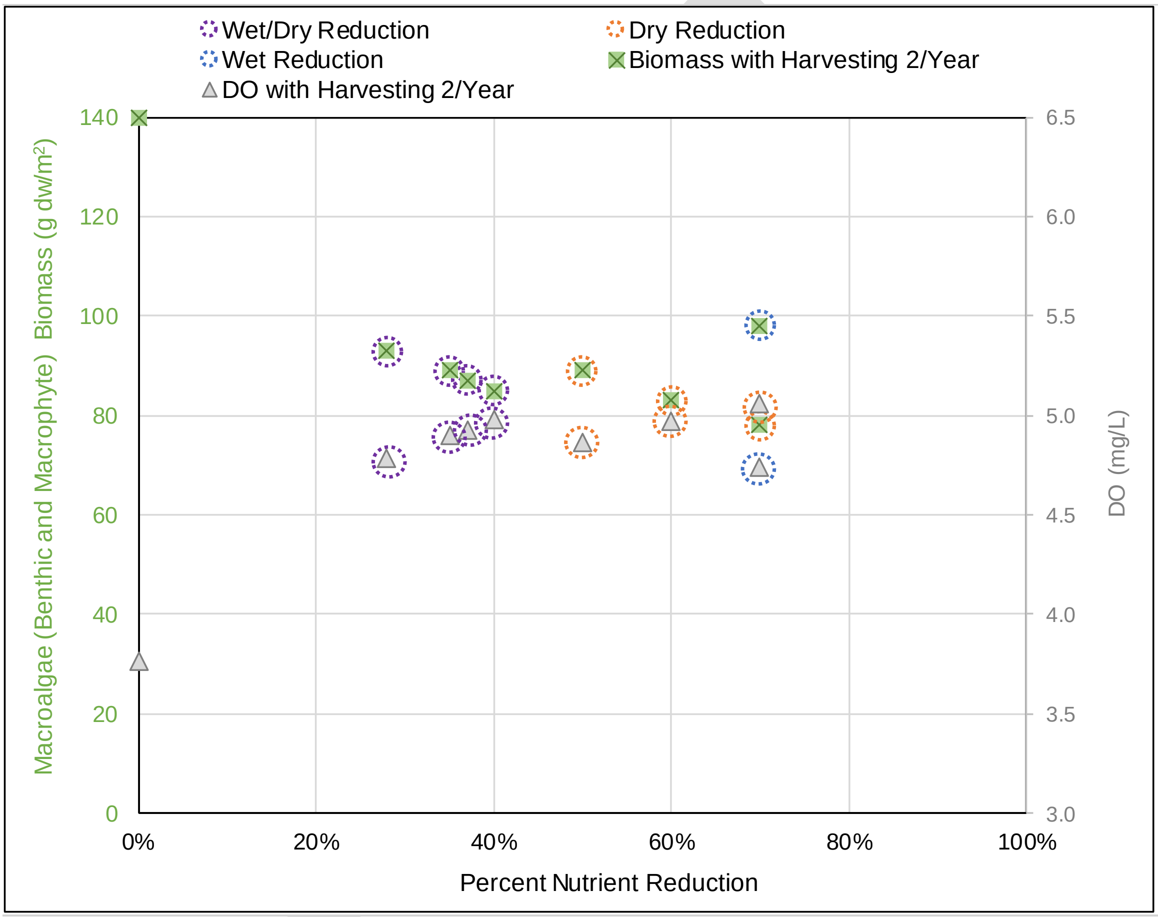
Figure 121. Average Daily DO_{min} and Total Macroalgae Biomass Plot of Management Scenario Analysis for the Slough

4.2.2.2. Channel

Similar to the results in the Slough, decreasing nutrient input and harvesting in the Slough increased the daily minimum DO in the Channel (Note: The 0% reductions values do not include twice per year harvesting.

Figure 122). Macroalgae biomass was reduced through twice-a-year harvesting floating macroalgae in the Slough, suggesting that upstream algal harvesting could be useful for improving downstream water quality conditions in the Channel (Note: The 0% reductions values do not include twice per year harvesting.

Figure 122).



Note: The 0% reductions values do not include twice per year harvesting.

Figure 122. Average Daily DO_{min} and Benthic Macroalgae/Macrophyte Biomass Plot of Management Scenario Analysis for the Channel

4.2.2.3. Scenario Results Discussion

The scenarios focused on evaluating the response to harvesting floating macroalgae throughout the system in conjunction with a reduction of watershed nutrient loads to the Channel and Slough during different climatological conditions. Scenario analyses focus largely on the Slough as there are no specific targets for the Channel. When comparing the harvest and no harvest scenarios in Table 13, the results clearly show that harvesting is necessary to reduce macroalgae biomass to acceptable levels in the Slough. In addition, combined reductions in watershed loading and harvesting were needed to achieve both the DO and macroalgae biomass targets in the Slough. When evaluating the impact of watershed reductions in different seasons, it was determined that reducing watershed loads during only wet periods was not sufficient to meet targets and over a 50 percent reduction was needed to attain targets when managing only dry weather watershed loads.

The scenarios showed that a twice-a-year macroalgae harvesting in the Slough in conjunction with a 37 percent reduction in year-round nutrient loads will improve DO levels to above 5 mg/L based on the metrics described above and will result in macroalgae biomass within acceptable levels (midpoint of the resistance threshold; Sutula, 2016) (Table 13). As the results show, the harvesting scenarios (for the Slough) resulted in an overall reduction in macroalgae biomass in the Slough, in contrast to the original anticipation that benthic macroalgae might be enhanced due to the removal of floating macroalgae. This result can be expected because the floating macroalgae harvest was simulated during late summer when benthic macroalgae is at very low levels. Although removal of floating macroalgae alleviates the light limiting condition, harvesting also reduces the nutrient concentration in the system, which might depress the growth of benthic macroalgae. Combining these two factors, the light condition improvement might not be sufficient to offset the limitation from reduced nutrients, causing the benthic macroalgae to also decrease. Care should be taken in the interpretation of these results because of the complex dynamics between algal growth and competition for light, nutrients, and other factors. It some situations, it would be reasonable to expect that benthic algae biomass could increase depending on the combination of these factors, time of year, water levels, and other complex variables.

There is a different meaning of biomass between measured data and from modeling results. Measured data is obtained from sampling the patches of macroalgae, while model result represent the average biomass in the model grid, which is equivalent to spreading the macroalgae to every single inch in the grid; therefore, the model-simulated biomass is generally lower than measured data, except for locations where in reality macroalgae covers every inch of the grid.

Table 13. Results of Management Scenario Analysis

Nutrient Reduction	2x/yr Harvest?	Season	Slough		Channel	
			Average Daily DO_{min} (mg/L) with 2/Year Harvesting	Macroalgae (Floating/Benthic) Biomass (g dw/m^2) with 2/Year Harvesting	Average Daily DO_{min} (mg/L) with 2/Year Harvesting	Benthic Macroalgae/ Macrophyte Biomass (g dw/m^2) with 2/Year Harvesting
0%	No	Wet/Dry	3.47	135	3.76	140
28%	No	Wet/Dry	4.66	98	4.61	110
28%	Yes	Wet/Dry	5.07	69	4.78	93
35%	Yes	Wet/Dry	5.22	62	4.9	89
37%	Yes	Wet/Dry	5.27	58	4.93	87
40%	Yes	Wet/Dry	5.32	55	4.98	85
50%	Yes	Dry	5.2	54	4.86	89
60%	Yes	Dry	5.35	46	4.97	83
70%	Yes	Dry)	5.49	40	5.06	78
70%	Yes	Wet	4.99	82	4.74	98

Note: Values in green font meet targets.

4.3. Model Scenario Summary and Conclusions

The calibrated model was applied to analyze multiple management scenarios focusing on different aspects of controlling processes: watershed load reduction, San Diego River load reductions, macroalgae harvesting, dredging, water circulation modifications, and the combination of different options. Exploratory scenarios were initially performed to identify appropriate more detailed management scenarios. Overall, the modeling analysis resulted in the following observations:

- A 37 percent year-round watershed nutrient load reduction showed significant water quality benefits;
- Harvesting floating macroalgae also supported improvements in water quality;
- A combination of watershed nutrient load reductions coupled with twice-a-year macroalgae harvesting provided significant water quality benefits and represents a more cost-effective approach for improving conditions.

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