Informing Biodiversity Conservation and Water Quality Management in the Morro Bay Watershed

A Group Project submitted in partial satisfaction of the requirements for the degree of Master of Environmental Science and Management for the Bren School of Environmental Science & Management

By

Heather Dennis
Stephanie Falzone
Hilary Walecka
Kari Zajac
Ashley Zavagno

Project Advisor: Ben Halpern

March 2015

Photo Credits

Boardwalk: Hilary Walecka
Morro manzanita: Peter Veilleux
Morro shoulderband snail: Bob Sloan, SWCA Environmental Consultants
Steelhead trout: National Oceanic and Atmospheric Administration
Salt-marsh bird's beak: David L. Magney
Oso manzanita: David Graber
Morro Bay Estuary sign: Stephanie Falzone

All other photos in this report were taken by members of this group project.

Base Map Credit

Sources: Esri, HERE DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

As authors of this Group Project report, we are proud to archive this report on the Bren School's website such that the results of our research are available for all to read. Our signatures on the document signify our joint responsibility to fulfill the archiving standards set by the Bren School of Environmental Science & Management.

Heather Dennis

Stephanie Falzone

Kari Zajac

Hilary Walecka

Ashley Zavagno

The mission of the Bren School of Environmental Science & Management is to produce professionals with unrivaled training in environmental science and management who will devote their unique skills to the diagnosis, assessment, mitigation, prevention, and remedy of the environmental problems of today and the future. A guiding principle of the School is that the analysis of environmental problems requires quantitative training in more than one discipline and awareness of the physical, biological, social, political, and economic consequences that arise from scientific or technological decisions.

The Group Project is required of all students in the Masters of Environmental Science and Management (MESM) Program. It is a three-quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Final Group Project Report is authored by MESM students and has been reviewed and approved by:

Ben Halpern

March, 2015

Acknowledgments

We would like to thank everyone who supported this project. We are especially thankful to our advisor, **Ben Halpern**, who was invaluable in supporting us through the project.

We would like to thank our client, the **Morro Bay National Estuary Program,** particularly **Jennifer Nix, Adrienne Harris, Lexie Bell, and Ann Kitajima**, who made this project possible.

We would also like to thank our external advisors for the project:

Bren School of Environmental Science & Management
Frank Davis

California Native Plant Society
Aaron Sims

We would like to thank the following people for their advice and direction:

Bren School of Environmental Science & Management
Arturo Keller

Bren School of Environmental Science & Management
Kendra Garner

California Department of Parks and Recreation
Mike Walgren

The Land Conservancy of San Luis Obispo County
Daniel Bohlman
Jon Hall

Coastal San Luis Resource Conservation District
Nicole Smith

Abstract

The Morro Bay watershed is located in coastal San Luis Obispo County, California and is critical for supporting regional biodiversity and the local economy. The 48,000-acre watershed drains into the Morro Bay estuary—one of the largest, relatively intact coastal wetland regions in California. The Morro Bay National Estuary Program works to protect and restore the health of the Morro Bay estuary and watershed through collaboration, restoration, conservation, and education. Key concerns within the watershed are water quality degradation and biodiversity loss. This project sought to identify areas of the watershed to prioritize for biodiversity conservation and water quality management. Biodiversity conservation results showed that variation in optimal reserve layouts varied strongly among conservation goals, indicating the importance of the Estuary Program carefully selecting species and habitat targets to ensure conservation actions achieve desired outcomes. Water quality analysis results showed the main concern in the northern region of the watershed is phosphate concentrations, while the main concerns in the southern part of the watershed are nitrate and *E. coli* concentrations. A literature review of potential climate change impacts revealed the importance of focusing on climate-smart conservation and restoration due to predicted drought stress outside historical bounds by 2100. To efficiently work towards conservation goals, the Estuary Program should begin conservation of parcels selected across multiple biodiversity conservation scenarios and strategically implement best management practices in identified source areas of water quality degradation, while considering how climate change will affect the watershed.

Executive Summary

The Morro Bay Watershed

The Morro Bay watershed is located in San Luis Obispo County on the central coast of California. This land drains to the Morro Bay estuary, a small 2300 acre estuary that was designated as an "estuary of national significance" in 1995 as a result of community based efforts to protect this resource (Morro Bay National Estuary Program 2015).

The area's biological significance can be seen in the variety of different habitats, including maritime chaparral, oak woodland, riparian scrub, pioneer dune, grasslands, wetlands, and estuarine habitats, which collectively support a diverse assemblage of species. This assemblage includes several endemic, threatened, and endangered species. The watershed and estuary also support the local economy through tourism, agriculture, ranching, aquatic recreation, and commercial fishing. Given the importance of the estuary and surrounding watershed, many government agencies, non-profits, and citizens are working to protect the region and address degradation of watershed resources.

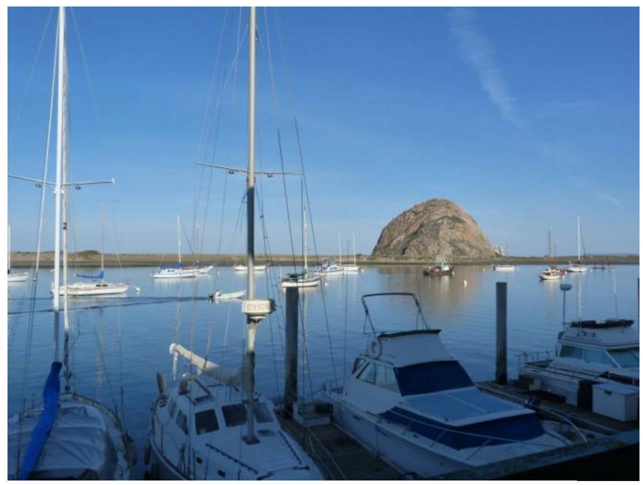

Photo 1. Morro Bay harbor and Morro Rock

Morro Bay National Estuary Program

The Morro Bay National Estuary Program (Estuary Program) is a non-regulatory, non-profit organization that brings together citizens, local governments, non-profits, agencies, and landowners to protect and restore the Morro Bay estuary (Morro Bay National Estuary Program 2015). The Estuary Program conducts monitoring and research, restores natural habitats, and educates residents and visitors about how to keep Morro Bay clean and healthy. The Estuary Program collaborates closely with many partners and landowners to accomplish shared goals. The Comprehensive Conservation and Management Plan, which the Estuary Program and their partners updated in 2012, identified the following priority issues for the estuary and watershed: 1) accelerated sedimentation, 2) bacterial contamination, 3) elevated nutrient levels, 4) toxic pollutants, 5) scarce freshwater resources, 6) preserving biodiversity, and 7) environmentally balanced uses.

Project Objectives

This project aimed to inform the development of a conservation plan for the Morro Bay watershed that supplements the Morro Bay National Estuary Program's Comprehensive Conservation and Management Plan (2012). Specifically, the project helped inform the prioritization of areas for conservation based on the following objectives:

1. Address biodiversity loss in the watershed by determining areas of highest conservation priority.

2. Through watershed modeling, identify areas contributing to poor water quality, in particular sources of nitrate, phosphate, total suspended sediment, and *E. coli*.

3. Evaluate the potential impact of future climate change in the Morro Bay watershed, and recommend climate smart conservation and restoration techniques to guide management efforts.

4. Identify data gaps and deficiencies to guide future data collection and monitoring prioritization.

Biodiversity Conservation Planning

Using the conservation planning software Marxan, it became clear that conservation goals strongly drove the variation in potential reserve layouts generated. Certain areas of the watershed were highlighted as important for conservation across multiple scenarios, even with varied objectives and input parameters. Some scenarios included heightened conservation goals for federally and state listed threatened and endangered species, while others used different cost metrics. These sites selected as highly important across all scenarios are recommended as the first sites to consider for conservation easements. Increasing the conservation targets for all species increased the number of parcels selected by Marxan for conservation. Setting very high targets for threatened and endangered species (conserving at least 80% of the known occurrences in the watershed) resulted in most of the parcels being required to meet the target. When this high target was limited to just five highly vulnerable species of interest, the number of parcels selected substantially dropped. Since setting conservation targets has a large influence on Marxan's results and is of critical importance in ensuring the long-term persistence of sensitive species, population viability analysis is recommended for particular species of concern to help set more appropriate conservation goals.

Watershed Quality Assessment through Watershed Modeling

Nitrate, phosphate, sediment, and *E. coli* levels were modeled for 13 catchments in the watershed from 2002-2014. All catchments had a modeled median nitrate concentration above the water quality standard, with the highest nitrate concentrations occurring in the southern, Los Osos Valley area of the watershed. The frequency and magnitude of phosphate exceedances of the water quality standard were highest in the northern, Chorro Valley area of the watershed. Total suspended sediment results exceed the water quality standard infrequently and mostly during storm events. Other techniques for identifying major source areas of sediment pollution are recommended. Finally, higher concentrations of *E.coli* were present in Los Osos Valley. The spatial distribution of these pollutants is likely due to topography, soil characteristics, and land use. BMPs (Best Management Practices) such as riparian buffers, rural road improvements, cattle fencing, and decreased fertilizer use are recommended to improve water quality.

Photo 2. Canoes and other watercraft stored at Cuesta Inlet

Climate Change

Climate change projections were analyzed for climatic water deficit, a measure of drought stress. The climatic water deficit projections for the highest concentration of carbon dioxide equivalents indicate that the watershed will be experiencing conditions drier than that of any period in recent history. Drier conditions could lead to more frequent wildfires and affect natural vegetation, cropland, and rangeland production. Focusing on riparian habitats and including climate change in the design of restoration projects could make the watershed more resilient in the face of climate change. Restoring riparian habitats would help to increase connectivity for many species and enhance these areas as cooler places for animals to move to during times with higher temperatures. Further research should focus on the vulnerability of species outside of riparian habitats, particularly plant species endemic to the watershed and the California Floristic Province.

Table of Contents

List of Figures

List of Tables

Abbreviations and Acronyms

Atlas: Morro Bay Atlas of Sensitive Species

BASINS: Better Assessment Science Integrating Point & Non-point Sources

BCM: Basin Characterization Model

BMP: Best Management Practices

CCMP: Comprehensive Conservation and Management Plan

CCSM: Community Climate System Model

CDWR: California Department of Water Resources

CIMIS: California Irrigation Management Information System

CMC: California Men's Colony

CCRWQCB: Central Coast Regional Water Quality Control Board

CSLRCD: Coastal San Luis Resource Conservation District

CWD: Climatic water deficit

DEM: Digital elevation model

DPS: Distinct Population Segment

EPA: Environmental Protection Agency

Estuary Program: Morro Bay National Estuary Program

FGOALS: Flexible Global Ocean-Atmosphere-Land System

FY: Fiscal year

GCM: General Circulation Model

IPCC: Intergovernmental Panel on Climate Change

IPSL: Institut Pierre-Simon Laplace

MIROC: Model for Interdisciplinary Research on Climate

mL: milliliter

MPN: Most Probable Number

NHD: National hydrography dataset

NRCS: Natural Resource Conservation Service

PVA: Population Viability Analysis

RCP: Representative concentration pathway

TDS: Total Dissolved Solids

TMDL: Total Maximum Daily Load

TSS: Total Suspended Sediment

USDA: United States Department of Agriculture

WARMF: Watershed Analysis Risk Management Framework

Water Board: Central Coast Regional Water Quality Control Board

WWTP: Wastewater Treatment Plant

1. Introduction

The Morro Bay Watershed

The Morro Bay watershed is located in San Luis Obispo County on the central coast of California between San Francisco and Los Angeles (Fig. 1). The 48,000 acre watershed contains the city of Morro Bay, towns of Los Osos and Baywood Park, Camp San Luis Obispo, the California Men's Colony, and property owned and managed by U.S. Forest Service, Cal Poly San Luis Obispo, Cuesta College, CA Department of Parks and Recreation, and private landowners (Smith et al. 2014). The watershed is divided into two main drainages: Chorro Creek in the north and Los Osos Creek in the south (Morro Bay National Estuary Program 2012a). Ultimately, the watershed drains into the Morro Bay estuary prior to reaching the Pacific Ocean (Morro Bay National Estuary Program 2012a). The towns of Los Osos and Morro Bay are the largest developed areas located within the watershed.

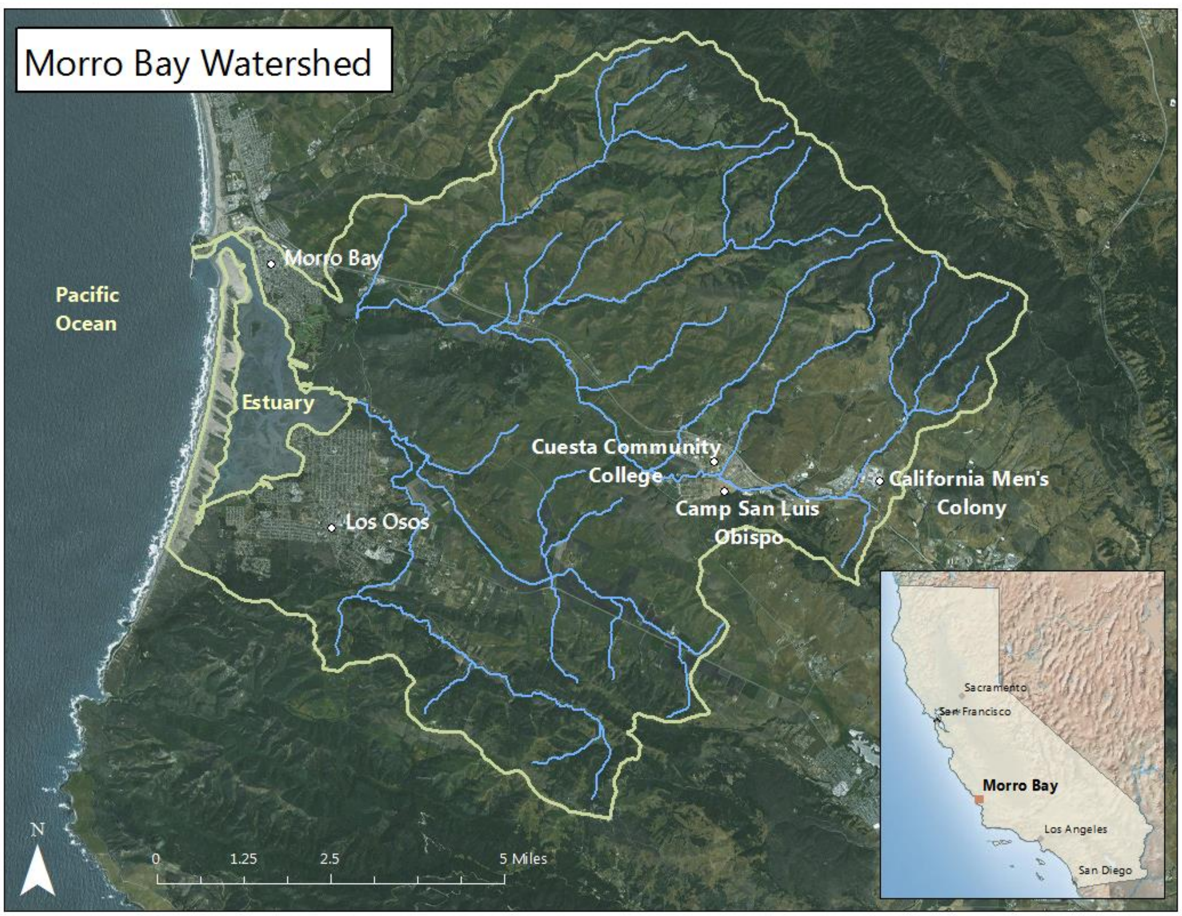

Figure 1. Morro Bay watershed location.

Project Client: Morro Bay National Estuary Program

The Morro Bay National Estuary Program (Estuary Program) was founded after the Morro Bay estuary was designated an "estuary of national significance" as a result of community-based efforts (Morro Bay National Estuary Program 2015). There are 28 National Estuary Programs in the country. The program was established under Section 320 of the 1987 Clean Water Act amendments as an Environmental Protection Agency (EPA) program (USEPA 2015) to protect estuaries with ecosystems, and economic activities that Congress deems "critical to the environmental and economic well-being of the nation" (USEPA 2015). A primary concern of the Estuary Program is to maintain clean water in the watershed and estuary for people and wildlife. The Estuary Program fosters collaboration between stakeholders to benefit the health of the estuary: "The Morro Bay National Estuary Program brings citizens, local government, non-profit organizations, agencies, and landowners together through collaboration and partnership to protect and restore the Morro Bay Estuary" (Morro Bay National Estuary Program 2012a). The Estuary Program strives to achieve a sustainable balance between conservation of watershed resources and environmentally conscious uses of those resources.

Morro Bay National Estuary Program Comprehensive Conservation and Management Plan

The Comprehensive Conservation and Management Plan (CCMP) for Morro Bay (2012), which must be developed by each estuary program (USEPA 2015), identifies priority issues for the ecological and economic resources of the estuary and watershed. The plan includes action plans to address each issue based on four main goals: water quality protection and enhancement; ecosystem restoration and conservation; public education, outreach, and stewardship; and fostering collaboration among regional stakeholders. The priority issues identified by the Estuary Program are: 1) accelerated sedimentation, 2) bacterial contamination, 3) elevated nutrient levels, 4) toxic pollutants, 5) scarce freshwater resources, 6) preserving biodiversity, and 7) environmentally balanced uses. The plan describes the impacts to beneficial uses, actions that have been taken, and trends for each priority issue. Action plans are described, many of which apply to multiple priority issues. Each action plan includes a timeframe, estimate of costs, list of partners, whether it is likely to be strongly affected by climate change, whether it has an education and outreach component, and how the implementation of the action plan will be tracked. This project focused on the priority issues of sedimentation, bacteria, nutrients, and preserving biodiversity, with recommendations intended to inform the Estuary Program where to focus their conservation and water quality management efforts.

Project Significance

Over 90% of California's historic coastal wetlands have been lost or highly altered (USEPA 2015). As one of the most significant and least disturbed coastal wetlands in southern California (Morro Bay National Estuary Program 2012a), preservation of the Morro Bay estuary and surrounding watershed is critical. Some of the most prominent issues for the watershed are biodiversity conservation, water quality degradation, and climate change. Land use changes in the 20th century, such as development of the cities of Morro Bay and Los Osos, conversion of scrub habitat and oak savanna to rangeland, and clearing and diking floodplains for conversion to cropland have contributed to accelerated sedimentation (Morro Bay National Estuary Program 2012a), and higher nutrient and bacteria levels in stream and estuary waters. The Estuary Program has worked with partners to mitigate these impacts through restoration and improved farming and grazing practices (Morro Bay National Estuary Program 2012a). To conserve biodiversity, the Estuary Program has worked to help implement conservation easements.

Photo 3. Wetlands where Chorro Creek flows into the estuary

While the impacts of water quality degradation are felt in the estuary, many of the problems originate or are inextricably linked to changes in the surrounding watershed, making effective management of the watershed crucial. The local economy depends on the bay to support water-based recreation, commercial fishing, and oyster cultivation (Morro Bay National Estuary Program 2012a). Furthermore, the watershed has value as open space for recreation and fertile agricultural and grazing land, such that improved management of the watershed will benefit both terrestrial and marine systems.

The estuary and surrounding watershed are home to a large number of sensitive, endemic, threatened, and endangered species, including several plant species which are only found within the watershed or coastal San Luis Obispo County. Given limited financial resources for implementing conservation easements and water quality improvement projects, prioritization of lands for conservation and restoration is vital to effectively using available funding and time. To help inform this process, we analyzed and synthesized available data to provide the Estuary Program with recommendations to inform where future efforts could be most effective in improving water quality and conserving biodiversity in the Morro Bay watershed.

Project Objectives

This project aimed to inform the development of a conservation plan for the Morro Bay watershed that supplements the Morro Bay National Estuary Program's Comprehensive Conservation and Management Plan (2012). Specifically, the project helped inform the prioritization for conservation areas based on the following objectives:

1. Address biodiversity loss in the watershed by determining areas of highest conservation priority.

2. Through watershed modeling, identify areas contributing to poor water quality, in particular sources of nitrate, phosphate, total suspended sediment, and *E. coli*.

3. Evaluate the potential impact of future climate change in the Morro Bay watershed, and recommend climate smart conservation and restoration techniques to guide management efforts.

4. Identify data gaps and deficiencies to guide future data collection and monitoring prioritization.

Approach

To meet these objectives, two tools were utilized: 1) Marxan, a conservation prioritization software and 2) WARMF (Watershed Analysis Risk Management Framework), a watershed model. Marxan informs biodiversity conservation by creating an efficient network of conserved areas that maximizes conservation benefit while minimizing economic costs. Marxan used observational data, including the location of sensitive species within the watershed. The WARMF watershed modeling and analysis program was used to model watershed processes. Thirteen catchments in the watershed were modeled for their nitrate, phosphate, sediment, and *E. coli* concentrations. Modeled water quality data was analyzed to identify how seasonal variations, and the frequency at which water quality standards are exceeded, vary spatially.

Climate models from the most recent IPCC (Intergovernmental Panel on Climate Change) report were used to provide several projections of drought stress for the watershed through 2100. A literature review was used to provide recommendations for climate-smart restoration and conservation in the Morro Bay watershed.

Data gaps were identified through the process of setting up Marxan and WARMF and while examining the assumptions and limitations of our results. These are outlined in recommendations sections of this report.

2. Biodiversity Conservation Planning

Biological Assets and Threats

The Morro Bay watershed is one of the last remaining intact and minimally impacted estuarine watershed systems in California. The watershed supports many diverse habitats and species including maritime chaparral, oak woodland, riparian scrub, and pioneer dune (Fig. 2). These habitats support rare and endemic species, producing an ecologically diverse landscape. Ecologically diverse landscapes are more productive, provide more ecosystem services, and are more resilient to disturbances such as fire, floods, and climate change (Cardinale et al. 2012, Tilman 1999, Tilman, Wedin, and Knops 1996, Loreau et al. 2001). It is therefore important to preserve biodiversity in the region.

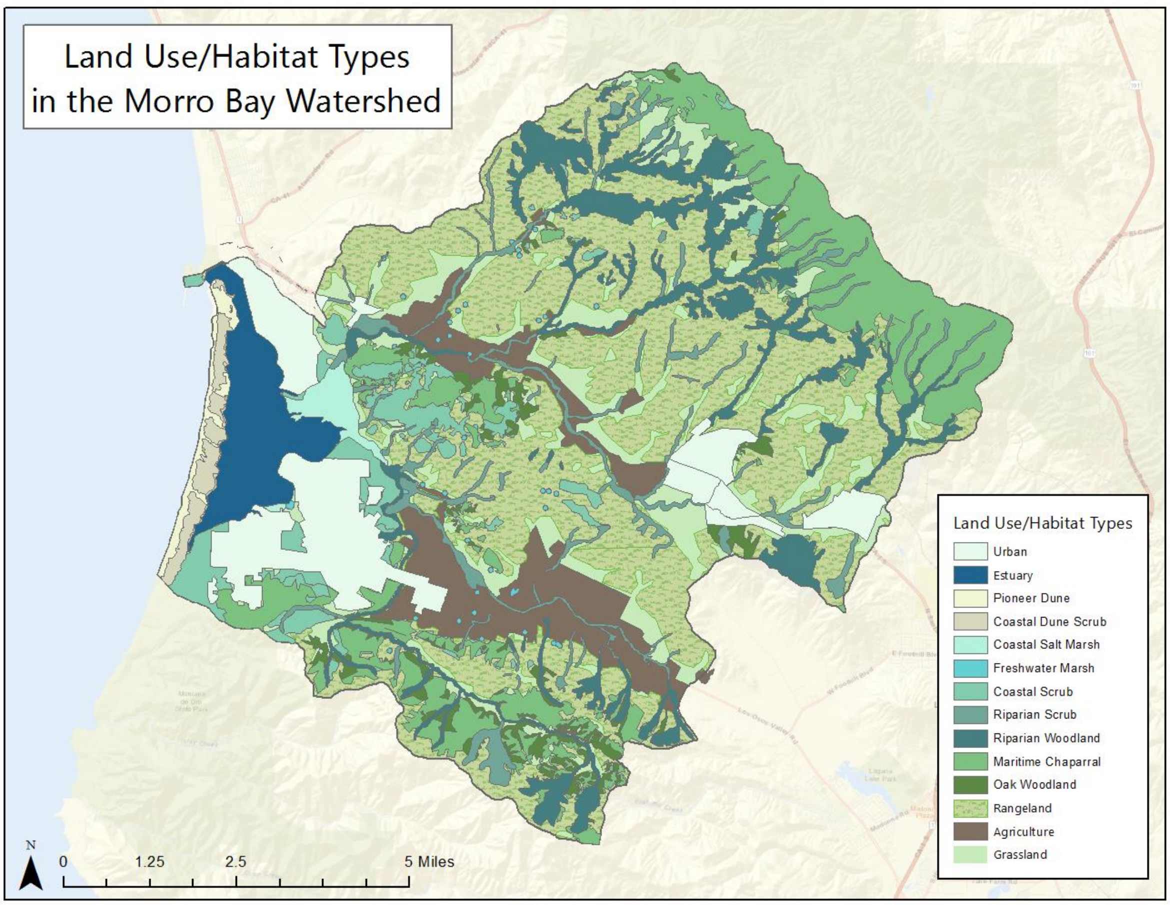

Figure 2. Habitat distribution as defined by the Morro Bay National Estuary Program (Morro Bay National Estuary Program 2012a; USCS 2010b; San Luis Obispo County 2000)

Ninety five sensitive species have been identified in the Morro Bay watershed through expert review, including 5 invertebrates, 2 fishes, 1 amphibian, 3 reptiles, 47 birds, 15 mammals, 17 plants, and 5 lichens (Sims 2010). Nineteen of these species are listed as either threatened or endangered under the California or federal endangered species act (Table 1). These species occupy all habitats present in the watershed. Some of these species are endemic to the region, including the Morro shoulderband snail (*Helminthoglypta walkeriana*), Morro Bay kangaroo rat (*Dipodomys heermanni morroensis*), and Morro manzanita (*Arctostaphylos morroensis*).

Table 1. California or federally threatened and endangered species that reside in the Morro Bay watershed.

Listed Status	Scientific Name	Common Name
Critically Endangered	*Helminthoglypta walkeriana*	Morro Shoulderband Snail
Endangered	*Eucyclogobius newberryi*	Tidewater Goby
Endangered	*Pelecanus occidentalis californicus*	California Brown Pelican
Endangered	*Falco peregrinus anatum*	Peregrine Falcon
Endangered	*Dipodomys heermanni morroensis*	Morro Bay Kangaroo Rat
Endangered	*Arenaria paludicola*	Marsh Sandwort
Endangered	*Suaeda californica*	California Seablite
Endangered	*Eriodictyon altissiumum*	Indian Knob Mountainbalm
Endangered	*Cordylanthus maritimus maritimus*	Salt Marsh Bird's Beak
Endangered	*Cirsium fontinale obispoense*	San Luis Obispo Fountain Thistle
Endangered	*Empidonax traillii*	Willow Flycatcher
Threatened	*Oncorhychus mykiss irideus*	Steelhead Trout - South Central California Coast DPS
Threatened	*Rana draytonii*	California Red-legged Frog
Threatened	*Charadrius alexandrinus nivosus*	Western Snowy Plover
Threatened	*Brachyramphus marmoratus*	Marbled Murrelet
Threatened	*Enhydra lutris nereis*	Southern Sea Otter
Threatened	*Eumetopias jubatus*	Stellar Sea Lion
Threatened	*Arctostaphylos morroensis*	Morro Manzanita
Threatened	*Dithyrea maritima*	Beach Spectaclepod

The estuary supports its own diverse array of species and habitats in addition to those of the watershed. One such habitat are eelgrass beds, which act as a nursery for young marine fish and invertebrates, improve water quality through filtering and slowing water, increase available oxygen for aquatic species, and provide a valuable food source for many species. The estuary also acts as an important stopping point on the Pacific flyway supporting many migratory birds including the black brandt (*Branta bernicula*).

Both the estuary and the surrounding watershed are affected by sedimentation, bacterial contamination, nutrient loading, toxic pollution, reduced freshwater flows and stagnation, habitat loss and fragmentation, invasive exotic species, and climate change (Morro Bay National Estuary Program 2012). These impacts threaten the long-term survival of many of the species within the watershed. This project sought to address some of these continued threats by identifying areas to conserve species richness in the watershed as a proxy for biodiversity.

Biodiversity Conservation Planning with Marxan

Marxan was originally developed in Australia as a marine spatial planning tool and was successfully used to create the Great Barrier Reef Marine Reserve and the Channel Islands Marine Reserve (Fernandes et al. 2005; Airamé et al. 2003). Although much of its use has been in the marine field, it is equally applicable in freshwater and terrestrial settings. It uses an heuristic algorithm known as "simulated annealing", which finds several near optimal solutions to ecological and economic constraints with the goal of achieving the greatest amount of set conservation feature(s) at the lowest cost (Ball, Possingham, and Watts 2009; Game and Grantham 2008). Heuristic algorithms, as opposed to exact algorithms, offer many near optimal solutions rather than one exact solution. This can help by making the software run faster and providing multiple options that could be beneficial in addressing various goals, constraints and stakeholder interests. Furthermore, weighing tradeoffs between conservation goals and economic constraints has been shown to better achieve conservation goals in the long run than conservation-only models (Murdoch et al. 2010).

The three primary inputs needed to run Marxan are conservation features and their associated targets, planning unit data regarding cost and location, and location of conservation features within the planning units. Conservation features are any assets that the user wishes the conserve. Most commonly, these features are species or habitats of interest as was the case in this analysis. The conservation feature targets can be thought of as the amount of a feature the user wants to conserve. Planning units are the spatial entities that the region of interest is divided into. These units can be shapes of uniform area such as hexagons or can be pre-established delineations such as parcels. These are what Marxan uses to construct its reserve networks. Each planning unit is then assigned an associated cost value. This cost value can be a true economic cost or a proxy for cost such as area. For this analysis, economic costs were used as they were felt to better reflect the value of given parcels. The final input is the location of the conservation features within the created planning units. From these three pieces of information, which are described by their formal model names in Table 2 below, Marxan can create a variety of cost efficient conservation reserve network options.

Table 2. Files required to run Marxan and their descriptions as defined by the Marxan manual.

Marxan File Name	File Explanation
Planning Unit File	List of all planning units (which can be parcels or an equal area shape) and their associated costs
Conservation Feature File	List of sensitive species (or habitats) that occur in the region of interest and target assigned to each individual species
Planning Unit vs. Conservation Feature File	Record of which species (or habitats) occur in every planning unit in the region of interest

While one of the goals of this project was "conserving biodiversity," this is not specific or quantitative enough to input into the model directly. Instead, the user must decide what metric of biodiversity is going to be used. For this analysis, total species richness was used as an indicator for biodiversity. Other common metrics include species diversity, species abundance, and habitat richness. One constraint of Marxan is that it does not prescribe an appropriate target for ensuring long-term persistence of a species. Ideally, one would have detailed biological information about the species of concern to set biologically appropriate targets. Because this information is often not available for all species and due to other social, economic, and political constraints, it is often advisable to run various scenarios in Marxan. The results can then be compared and the sensitivity of the input parameters can be assessed.

Methods

Creating the Planning Unit File: delineating the watershed into parcels and assigning costs

The planning unit file in Marxan determines how the region of interest will be divided and the cost of each unit (Table 2). For this analysis, parcels were chosen as the planning units. The most common alternative is an equal area hexagon. Hexagons have the advantage that there are equal distances between the centroid of each unit, but the disadvantage is that they are arbitrary shapes and locations and often intersect property boundaries. For this analysis parcels were used because conservation easements are negotiated and evaluated directly with landowners. Furthermore, the Estuary Program has strong working relationships with many of the landowners within the watershed.

Since parcels are of unequal shape and size, there is the concern that larger parcels will be preferentially selected. This is accounted for in Marxan with the higher associated costs of larger parcels. There is also the concern that for large parcels, not all of the land is of equal conservation value. To address this, 100m buffers were added to all streams within the watershed. This allowed for Marxan to only select the riparian zones of parcels if they were the regions contributing the greatest species richness. A 100 meter buffer was recommended by Hawes and Smith (2005) and Wenger (1999) as the optimal buffer size for protecting riparian species, wide ranging mammals, and birds.

The price of each parcel was obtained from the San Luis Obispo County assessor's office, with price represented as both the 2013/2014 FY net value and land value of each parcel. The net value was composed of the land value and the value of any improvements made on a parcel such as homes, barns, offices, etc. Some of the parcels within the watershed are state or federally owned and had an assessed value of $0. To directly include these within the analysis would bias the results because state and federal lands would almost always be selected first given that Marxan views them as "free". Still, many of state and federal lands contribute greatly to conservation goals and thus should not be ignored.

To address how to include state and federal lands without biasing the analysis, alternative methods of inclusion within Marxan were explored. The two options Marxan presented are "locking in" a parcel or "locking out" a parcel.

Locked in parcels are parcels which Marxan treats as already being part of the reserve network and are always present in the final result. Because they are already part of the reserve network, Marxan does not need to evaluate them based on cost, which avoids the cost bias. In addition, these parcel's automatic inclusion in the reserve network means the conservation features present in these parcels are contributing to the user's selected conservation targets or goals. This designation can also be applied to parcels in which conservation easements have already been created.

Locked out parcels are those that are always excluded from the reserve network. This is typically done when a parcel has no conservation value such as a small residential lot, or with areas in which conservation easements cannot likely be created such as cemeteries and hospitals. Marxan essentially treats these parcels as if they do not exist and therefore no conservation features that may be present on these parcels will contribute to selected conservation targets.

Most state and federally owned parcels were locked into the analysis based on the presumed conservation value of the land as determined by aerial imagery. Only federal or state parcels with clearly no conservation value (e.g. hospitals, cemeteries, highly developed, etc.) were locked out of the analysis. While state and federal lands are clearly not all of equal conservation value or equally managed, Marxan has no means of assessing these realities. Given the option to lock in or out a parcel, these parcels' contribution to conservation targets was substantial enough to warrant their inclusion (locked in). Small urban parcels less than two acres were excluded from the analysis (locked out) because they are unlikely to be put into conservation easements and do not significantly contribute to conservation targets. For more information about locked in and locked out parcels and the locked in parcels' contribution to conservation goals, see Appendix B.

Creating the Conservation Feature File: assigning conservation targets for species and habitats of interest

The conservation features of interest in this analysis were sensitive species and important habitats (Table 2). Species data were obtained from the *Morro Bay Atlas of Sensitive Species* (Atlas) written by Aaron Sims in collaboration with Michael Walgren and Lisa Andreano, and the California Natural Diversity Database (California Department of Fish and Wildlife 2014, Sims 2010). Both datasets provided occurrence data for sensitive species. The Atlas also included preferred habitat data for many species, which illustrate areas of likely occurrence for a species. Preferred habitat data was only used in the absence of actual observed occurrence data, given its lower level of certainty. A total of 95 species and 12 habitats were used for this analysis. All data older than 20 years were removed from the analysis as they are unlikely to represent current distributions. Twenty years was selected as the cutoff based on recommendation by Aaron Sims and standard definition used by the California National Heritage Program (California Department of Fish and Wildlife 2014).

Species that only reside in the estuary or in the ocean outside the bay were not included in the analysis because the estuary is already federally protected as an "estuary of national significance." This is not suggesting that management and restoration efforts cannot be applied to estuary, but rather for Marxan's purposes no further protection measures can be added. Including estuary-only species would therefore not affect the selection of parcels within the final reserve network.

Each species and habitat included in the analyses requires an explicit conservation target. Conservation targets were defined as the percentage of occurrences of a species/habitat that needed to be included in the final reserve network. The conservation target can be thought of as a conservation goal for a particular species or habitat. Although some species were sighted multiple times within the same parcel, all data were converted to presence or absence within a parcel. Given varying levels of survey effort and ease of sighting, it was deemed too uncertain to draw abundance estimates from the number of occurrences per parcel. Species targets were initially set at 30% as this is a typical value found in the literature for biodiversity conservation using Marxan (Watts et al. 2009; Delavenne et al. 2012). Setting targets too high can severely constrain Marxan outputs and thus be uninformative (in general, nearly all parcels get selected). All habitats were given a reduced starting target of 10% because they were highly correlated and overlapped with species occurrences. To ensure adequate representation of all important habitats and test the hypothesis about the degree of overlap, habitats were given a smaller target than species in this analysis. While most of these habitats would likely be selected based only on species targets even without a specific habitat target, due to their ability to support rare and sensitive species it was important to test this assumption given that a minimum coverage of all rare habitats was desired.

Creating the Planning Unit versus Conservation Feature File: locating species and habitats within the delineated parcels

Marxan requires information on which conservation features (species/habitats) are found within each planning unit (Table 2). This file was generated in ArcGIS 10.2 by intersecting the parcel boundaries with the occurrences of every species/habitat in the conservation feature file. Duplicate occurrences of species in the same parcel were removed to standardize all species/habitat data to presence/absence.

Creating the Input Parameter File: setting global software constraints

The supplementary InEdit software was used to generate an input file for use in Marxan. The parameters in this file can be changed as needed to adjust for differing scenarios. A list of these parameters can be found in Appendix B. Each scenario was run with 1,000 iterations and no boundary length modifier, which would have selected connected parcels to decrease the ratio of edge to area. One thousand iterations was determined to be a sufficient number of runs to detect trends in parcel selection without generating excessively long model run times. The boundary length modifier was deemed unnecessary as the region of interest is relatively small and enforcement of a patchy network of sites is not a concern. Additionally, a cost threshold was not used in this model. The Estuary Program has not set budget for conservation in the watershed, eliminating the need to add a cost threshold.

Sensitivity Analysis

To test the sensitivity of results to choice of targets, analyses were also run with a range of other targets. Table 3 shows target values for each scenario explored.

Table 3. List of the 9 scenarios run in Marxan as part of a sensitivity analysis. Each scenario was run with a land value and a net value planning unit file parameter to total 18 individual scenarios.

Scenario	Species Target	Habitat Target
Basic Scenario	30%	10%
Decreased Habitat	30%	0%
Increased Habitat	30%	20%
Decreased Species	20%	0%
Increased Species	40%	0%
Estuary Program Species of Concern	60% Estuary Program Species, 30% all other species	0%
Estuary Program Species of Concern	80% Estuary Program Species, 30% all other species	0%
Endangered and Threatened Species	60% Endangered and Threatened Species, 30% all other species	0%
Endangered and Threatened Species	80% Endangered and Threatened Species, 30% all other species	0%

Results

Basic Scenario

The basic scenario for Marxan shows the parcels that were selected for conservation with a 30% species target and a 10% habitat target (Fig. 3). The frequency of selection of parcels is a proxy for their importance in achieving an efficient reserve network that meets all targets. The majority of parcels recommended by Marxan are located in the central and southern section of the watershed. The white areas displayed in Figure 3 represent parcels that were locked into the Marxan selected reserve and were automatically included in the network.

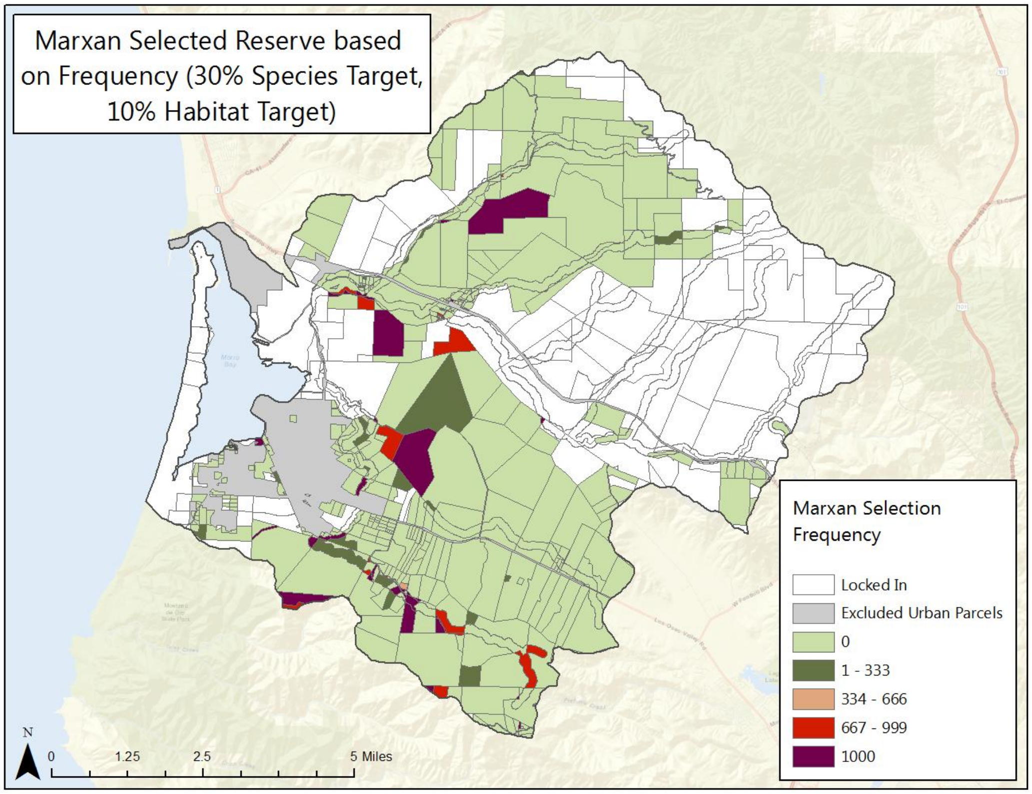

Figure 3. Basic scenario result of Marxan summed solution output with 30% species target, 10% habitat target and land value.

Cost and Habitat Targets

Results were insensitive to the metric of cost or the inclusion of habitat targets (see Appendix B). All further analyses therefore used land cost and adjusted species targets.

Species Target Adjustments

To test the influence of species targets on results, the baseline species target of 30% was adjusted to 20% and 40%. As would be expected, increasing the species target resulted in more parcels being chosen (Figs. 4, 5 and 6). When the target was increased, both the frequency of parcels chosen and the number of parcels chosen to conserve increased because more parcels were needed to meet the growing target. In particular, the number of selected parcels increased in the southern part of the watershed along Los Osos Creek as the species target increased. However, while more parcels were needed to meet the increasing target, many of the same parcels were selected across the scenarios.

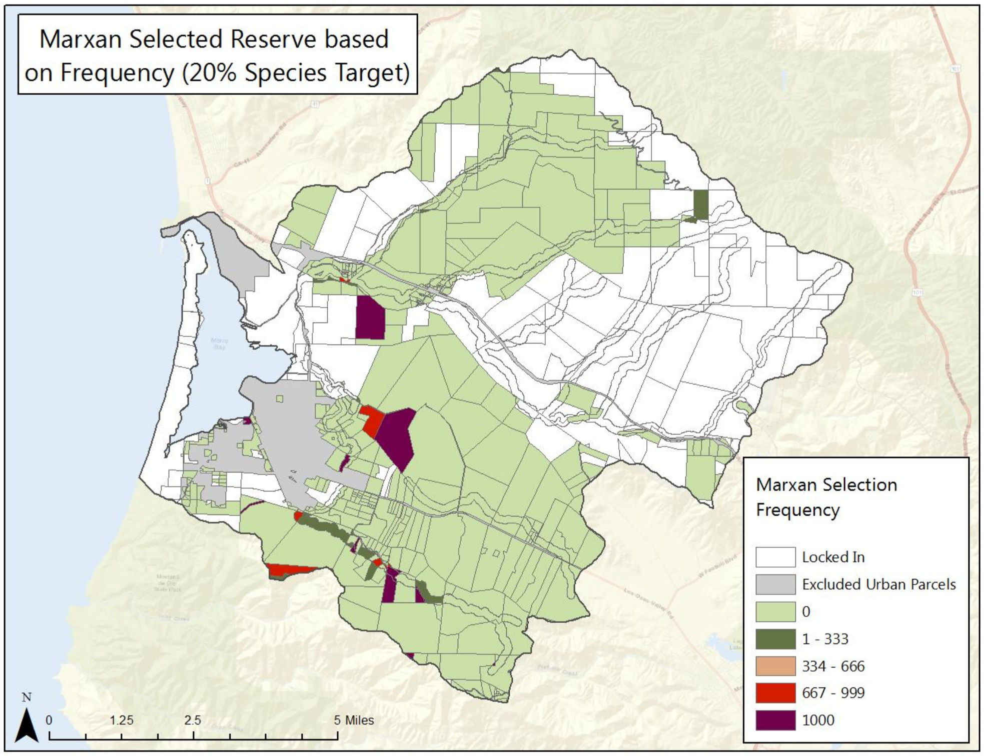

Figure 4. Marxan summed solution outputs of parcels chosen for conservation with a 20% species target.

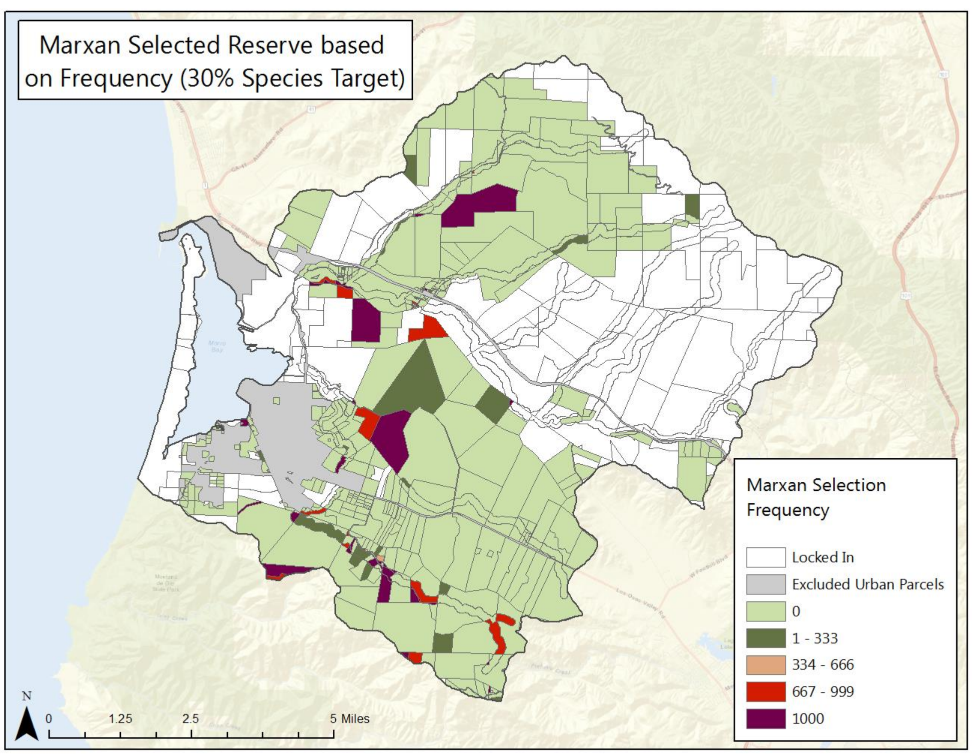

Figure 5. Marxan summed solution outputs of parcels chosen for conservation with a 30% species target.

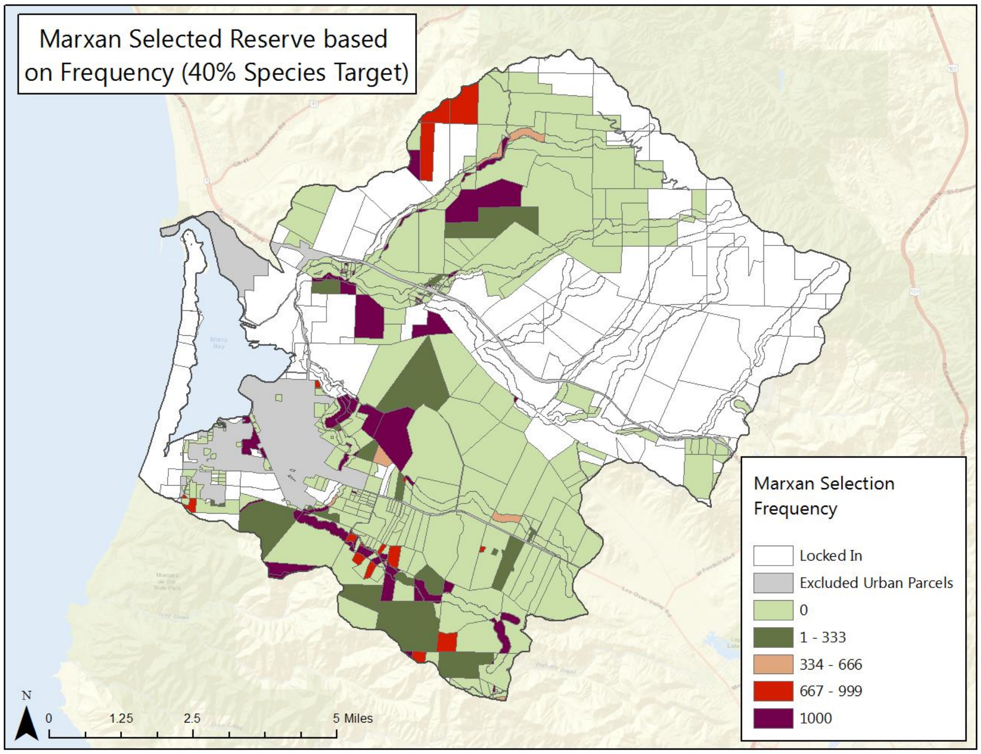

Figure 6. Marxan summed solution outputs of parcels chosen for conservation with a 40% species target.

Higher Targets for Endangered and Threatened Species

Particularly vulnerable species may need an increased level of protection to ensure their long-term persistence. To address this, the conservation targets for 17 federally and state listed threatened and endangered species in the watershed were increased to 60% and 80% conservation targets, while all other species' targets remained at 30%. Increasing the target resulted in a dramatic increase in the number and frequency of parcels chosen (Figs. 7 and 8). Even the lower 60% target resulted in a large number of parcels being selected and very little flexibility in potential network arrangements (most parcels were selected in every model run).

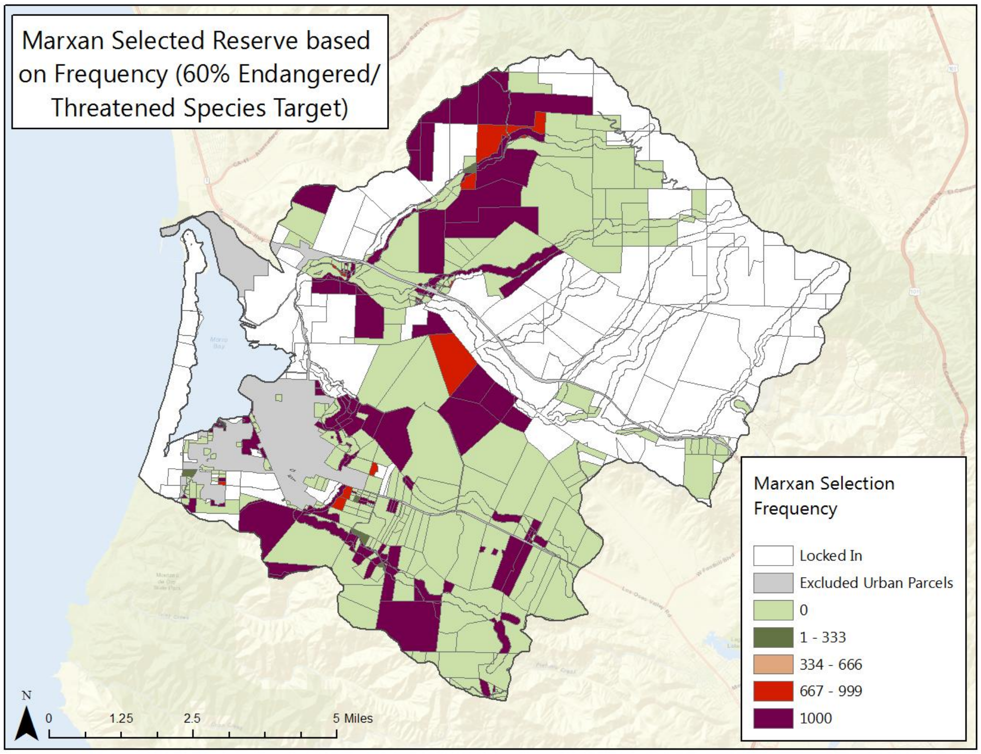

Figure 7. Marxan summed solution result from a 60% endangered and threatened species target. All other species have a 30% target.

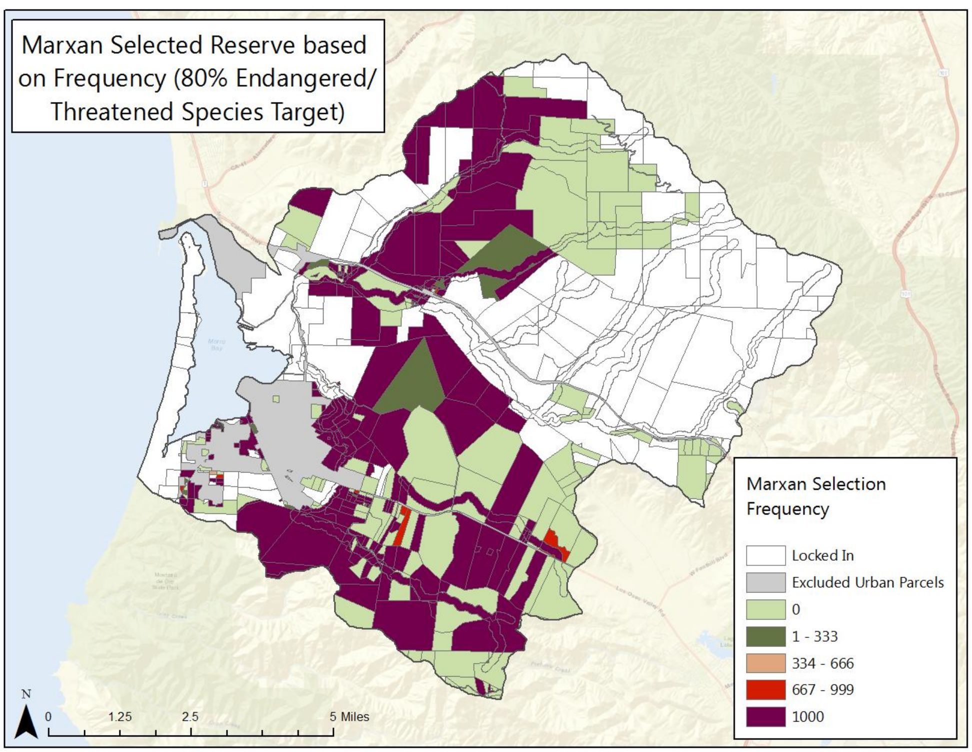

Figure 8. Marxan summed solution result from an 80% endangered and threatened species target. All other species have a 30% target.

Higher Targets for Estuary Program Species of Interest

Because the higher targets for endangered/threatened species produced little flexibility and a very large number of parcels to protect, a scenario was run with higher targets for only five species with a substantial portion of their statewide distribution concentrated in the Morro Bay watershed. Local experts also identified these five species as species of concern for the Estuary Program. The five species used for this analysis were: Morro shoulderband snail (*Helminthoglypta walkeriana*), salt marsh bird's beak (*Cordylanthus maritimus maritimus*), steelhead trout (*Oncorhynchus mykiss*), Morro manzanita (*Arctostaphylos morroensis*), and Oso manzanita (*Arctostaphylos osoensis*). Oso Manzanita, while not a federally or state listed species, is only known to occur at two sites within the watershed and thus was included in this analysis. Although the Morro Bay kangaroo rat (*Dipodomys heermanni morroensis*) is endemic to the region, it has not been observed in the field for nearly 30 years and is presumed extinct. It was therefore not included in the analysis.

In these two analyses, the five species' targets were increased to 60% and 80% respectively with all other species targets remaining at 30%. Riparian zones in the northern watershed stand out as areas of importance in Figures 9 and 10. Furthermore, the southern boundary of the watershed, near Montaña de Oro state park, is a high priority. With the exception of these differences, the results are similar to those in the basic scenario.

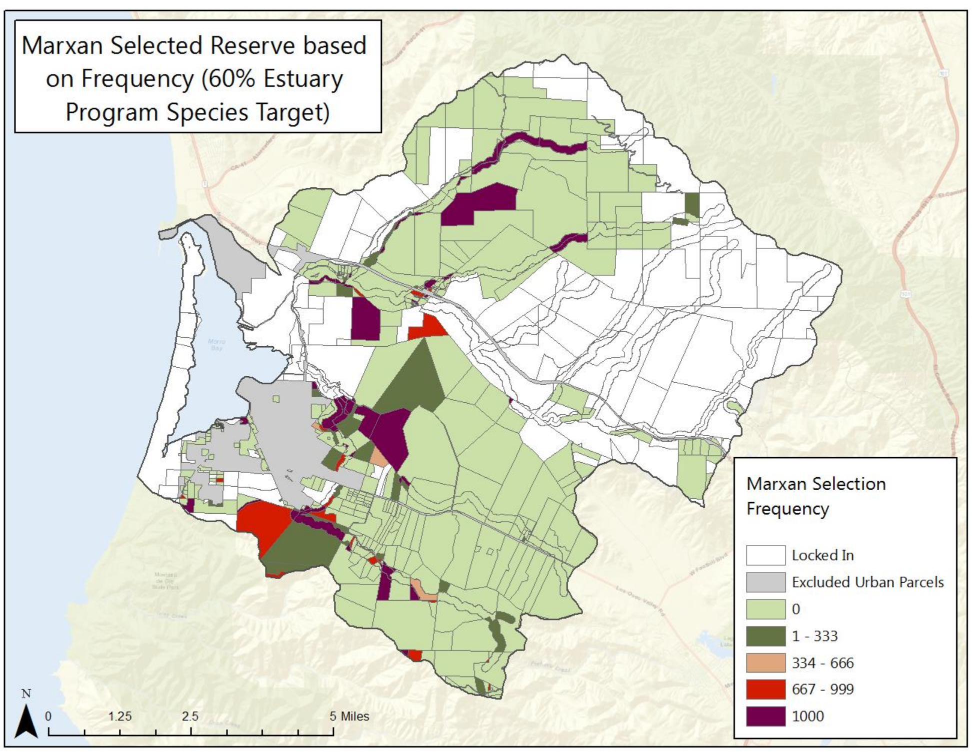

Figure 9. Marxan summed solution result from a 60% Estuary Program species target. All other species have a 30% target.

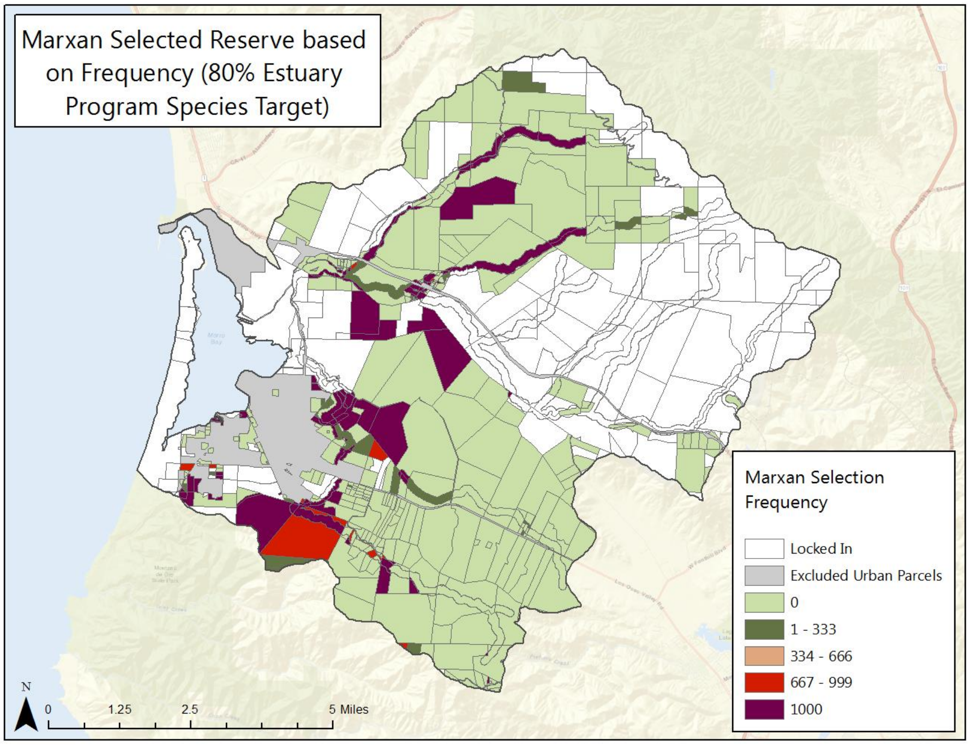

Figure 10. Marxan summed solution result from an 80% Estuary Program species target. All other species have a 30% target.

Discussion

Several distinct patterns were detected across results from the analyses, many of which were apparent from the basic scenario (Fig. 3). In general, parcels were selected based on species targets in a pattern that also reflects the spatial distribution of habitats throughout the watershed. The southern end of the watershed, where the majority of the parcels selected for conservation are clustered, contains the most intact and varied habitats and consequently supports the largest abundance and variety of species. The Los Osos Valley is primarily composed of agriculture and rangeland (Fig. 2), but the riparian corridors have remained relatively intact and continue to support many species. Few parcels in the northern section of the watershed were selected. These results were expected due to intensive grazing practices in the region that have resulted in habitat degradation through erosion and non-native grass cover.

The land value, rather than the net value that includes development, was used to evaluate potential optimal and efficient solutions given that the Estuary Program will most likely be working with landowners to establish conservation easements rather than purchasing the land directly. Changing cost metrics made close to no difference in the final results (Appendix B, Figs. 41 and 42). This is likely because many selected parcels are undeveloped which likely contributed to their habitat suitability. In these cases, there was no difference in land and net cost because no improvements had been made to the parcel.

A large percentage of the watershed is state and federal lands and locked into the analysis. This has important implications. With a 30% species target, approximately 56% of species had their targets met completely by occurrences within the locked in parcels. With a lower target of 20%, even more species (66%) are fully covered. However, not all public lands are managed to conserve biodiversity and these results may overestimate the contribution of these lands to protecting these species.

Given the high overlap between key habitats and the distribution of many species, there was little difference in results when habitats were included or excluded as explicit conservation targets. Consequently, they were removed from the final analyses.

Altering species targets had important consequences for optimal parcels selected. Relatively small changes up or down by 10% in species targets led to notable changes (Figs. 4 and 6). Decreasing the target allowed more species to be fully represented by locked in parcels, requiring fewer additional parcels to meet the objective. The higher targets intuitively required more land. Figure 6 shows that not only does the total number of parcels selected increase as the species target increases, but also the frequency in which parcels are selected increases as represented by darker colors. This means that achieving higher conservation targets leads to less flexible reserve layouts.

Changing the species target also highlighted that the same subset of parcels was selected consistently in almost all scenarios. This demonstrates that these parcels are indispensable to achieving even modest conservation goals. Some of these sites were chosen even though the cost of acquiring the parcel is relatively high. This indicates the high conservation value of these parcels. These parcels, highlighted in blue in Figure 11 below, are recommended as first priority sites for conservation because they were selected despite changing input parameters.

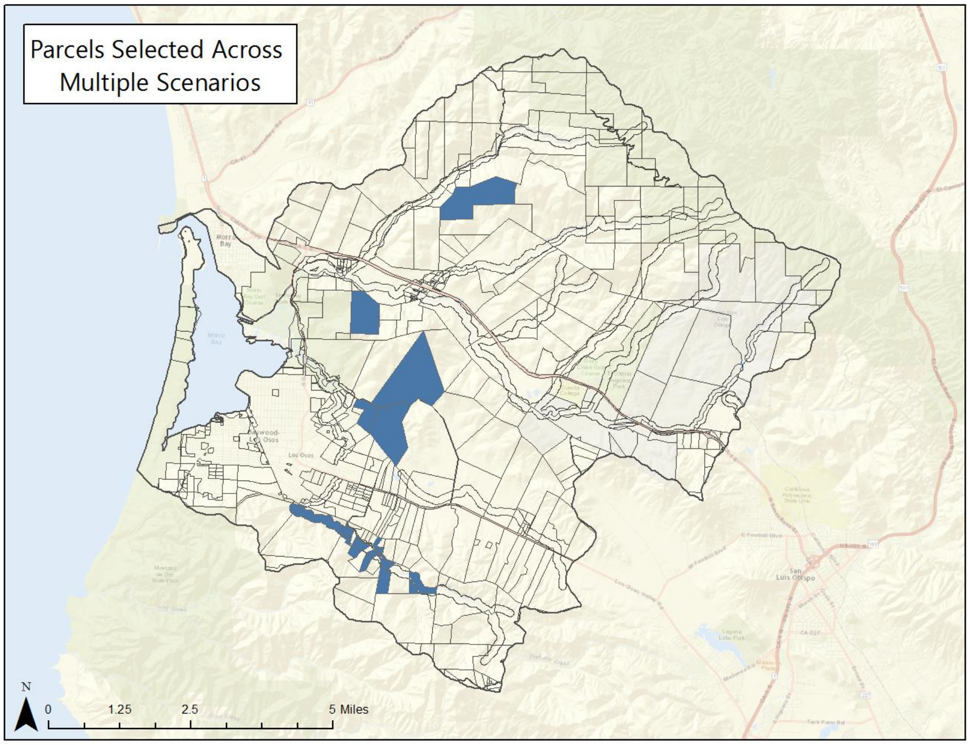

Figure 11. Parcels selected across multiple scenarios. Blue parcels were chosen for conservation in almost all scenarios despite changing parameters.

Setting higher targets for threatened and endangered species resulted in more than half of the watershed being selected in all runs. This illustrates the tradeoffs between higher certainty in protecting species and the flexibility in the reserve network (Figs. 7 and 8). This result is impractical because eliciting the cooperation of landowners to enact conservation easements on their property or selling their property to conservation organizations would prove daunting, if not impossible, with such a large quantity of properties. This degree of conservation would constrain landowners stifle and the local economy.

One endangered species, the willow flycatcher (*Empidonax traillii*), had a large range well beyond the Morro Bay watershed. In addition, the species' range includes over half of the area within the watershed. *E. trailli's* mobility likely contributed to its widespread sightings. Because of this, a scenario was run which reduced *E. trailli's* target back to 30% while keeping all other endangered and threatened species target at 80%. When the *E. traillii*'s target was reduced, there was marked difference in the quantity of parcels being selected (Figs. 12 and 13). This indicates that *E. traillii* was a driving force behind the large quantity of parcels chosen for the endangered/threatened species scenario. Although actions within the Morro Bay watershed can contribute to persistence of wider-ranging species, efforts will likely have the largest benefit if focused on species more limited to the region.

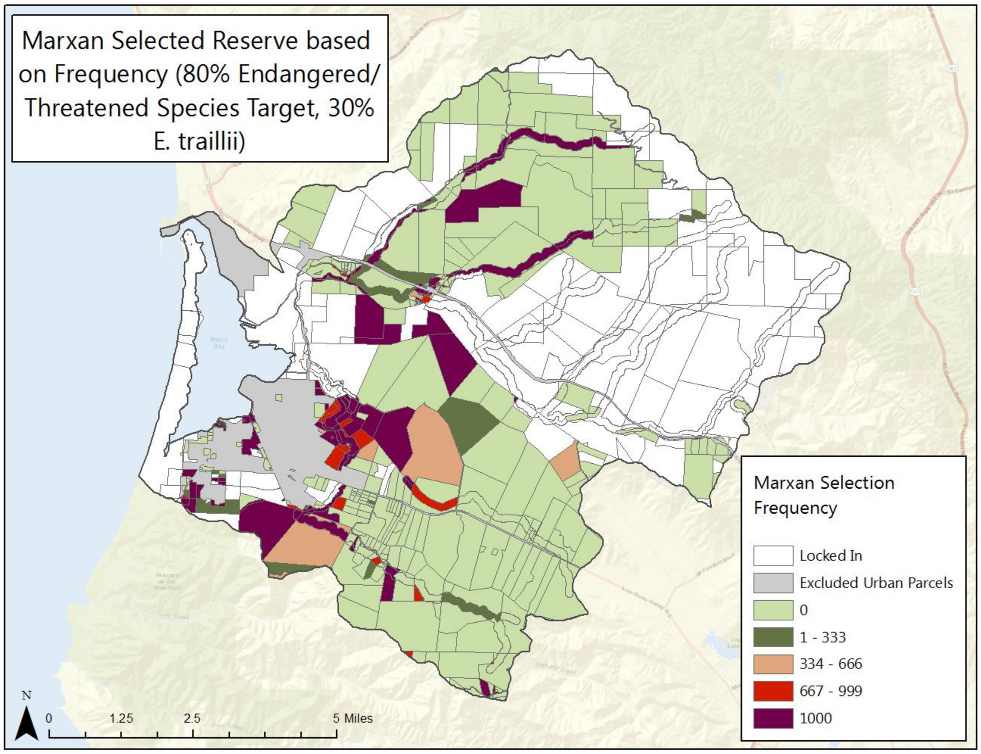

Figure 12. 80% endangered/threatened species target except *Empidonax traillii* which had a 30% target. All other species had a 30% target.

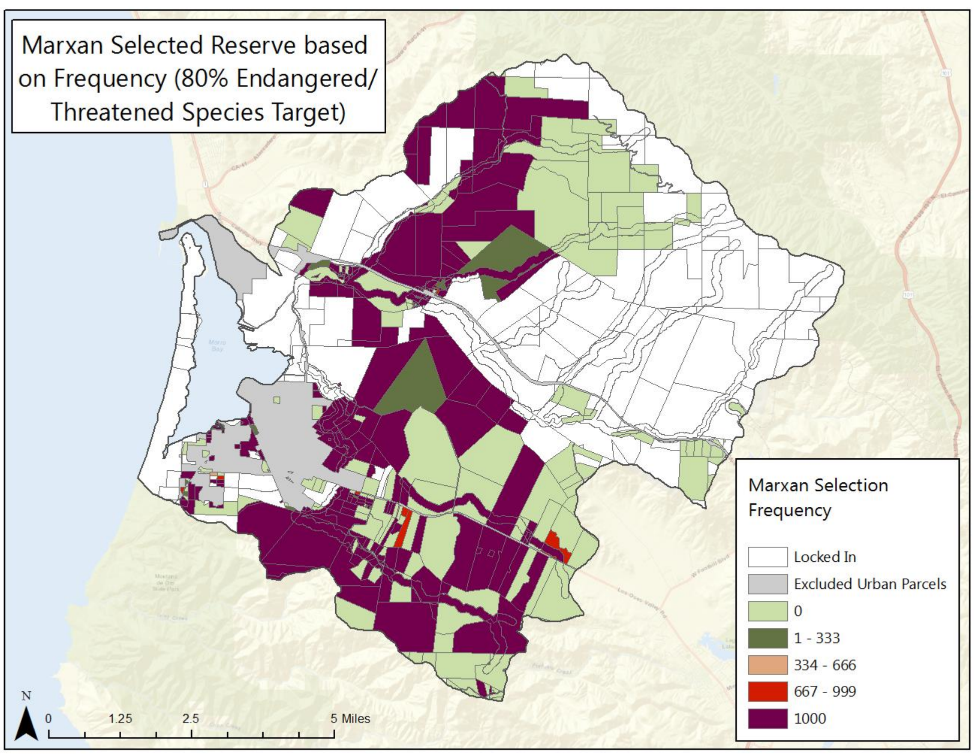

Figure 13. 80% endangered/threatened species target. All other species had a 30% target.

When targets were increased to 60% or 80% for the 5 endangered and threatened species that have critical habitat in the watershed (Morro shoulderband snail, Oso manzanita, saltmarsh bird's beak, steelhead trout, Morro manzanita), there was a reduction in the number of parcels required to meet these targets (Figs. 9 and 10).

While a similar number of parcels were selected in the basic scenario and the 60% and 80% Estuary Program species scenarios, which parcels were selected differed noticeably. Two areas that stood out in the Estuary Program species scenarios are the riparian corridors along tributaries in the northern watershed and parcels along the southern border of the watershed near Montaña de Oro State Park (Fig. 10). The riparian corridors were likely selected because they are important for the local steelhead population. If different species of concern were chosen, the reserve layout would likely appear different.

Marxan Analysis Constraints

Data Gaps

Several data gaps were identified that may have affected the analysis. The following is a list of data gaps that exist for species, habitat, and parcel data in the Morro Bay watershed:

1. *Updated species surveys.* A number of species were not used in the analysis because the data did not meet the criteria of being less than 20 years old. Updated species surveys would insure the most current location of species and their existence in the watershed. These species could be added to the Marxan analysis to provide more comprehensive results.

2. *Accurate species abundance data.* From the Atlas and CNDDB data it is difficult to infer accurate and unbiased abundance counts for the species of interest. This is because it is unclear how often certain species were surveyed for and the level of effort of each survey. Having this data would have allowed parcels with greater numbers of individuals of a given species to have higher conservation value within Marxan.

3. *Habitat quality data.* Knowledge of the quality of habitat provided in the watershed would add to the certainty of the analysis. While surveying species and habitats is understandably resource intensive, this data would have allowed parcels with higher habitat quality to have higher conservation value within Marxan.

4. *Updated version of county parcel outlines.* The most recent county parcels outlines were not available for this analysis. Parcels outlines were manually moved in ArcGIS to match 2014 property boundaries as seen on the San Luis Obispo PermitView website. This resulted in some error and obtaining the most recent county parcel outlines would represent a more accurate division of the watershed.

Key Assumptions and Limitations

See Appendix B for full list of assumptions and limitations for Marxan.

Limitations

- *Presence/Absence versus Abundance*. A key limitation to the analyses presented is the use of species presence, rather than abundance. As mentioned above in data gaps, prioritization efforts would ideally include abundance information so that the parcels with higher abundances would be prioritized over those with lower abundances.
- *Sensitive species versus all species*. Only sensitive species were included in the analysis instead of all species in the watershed. First, this was the only data with reliable accuracy and resolution available. Secondly, sensitive species are those at greatest risk and thus in need of greater protection measures than common species.
- *Higher conservation targets limit flexibility of Marxan results*. While a user may want to conserve a greater percentage of occurrences of certain species, this will limit Marxan's flexibility in creating efficient reserve designs. By needing almost all of the occurrences of a given species, Marxan will have to always select all of parcels in which this species is found. Higher conservation targets should be used judiciously when there is substantial justification that a species needs such a high target to ensure its long-term survival.
- *Species richness as an indicator for biodiversity*. Species richness was used as an indicator of conservation value. Measures of diversity, such as the Shannon diversity index, could not be used because they require relative abundance data to assess species evenness, which were not available. Given this limitation, species richness was seen as the best suitable metric.

Assumptions

- *Using economic cost of parcels.* It was assumed that the economic cost of the parcel was the most accurate metric available to assess the cost of parcels. Area could have been used as a proxy, but this ignores other factors that contribute to the cost of a parcel (fertility of land, proximity to shoreline, development potential, etc.) In addition, it was assumed that the assessed economic value of a parcel was a suitable cost metric even though conservation easements would likely be created rather than the outright purchase of properties. This is because when conservation easements are evaluated, the economic value of the land is considered when determining landowner tax breaks and other relevant factors. The most accurate and current cost data was used from the 2013/2014 fiscal year from the San Luis Obispo County Assessor's Office.
- *Exclusion of connectivity analysis.* Marxan includes a tool called the boundary length modifier that attempts to cluster selected parcels. This in some ways can address connectivity by reducing the chances of Marxan creating a patchwork reserve network. It does not explicitly address, however, the mobility and dispersal abilities of specific species and how these traits affect the assessment of connectivity. For

that, other tools such as Linkage Mapper, are needed. Since the Morro Bay watershed is a relatively small watershed, use of the boundary length modifier was deemed unnecessary. Most of the watershed is open space with limited roads and development. Consequently even parcels that do not directly abut are unlikely to have significant barriers to movement and dispersal, particularly for more mobile species such as the birds and mammals. Even without the use of the boundary length modifier the reserve networks generated in the aforementioned results are relatively clustered.

Recommendations

The variety of results from Marxan present the Estuary Program with a number of options for conservation reserve design, all of which would further conservation efforts in the watershed. Before deciding on which scenario to implement, it is important for the Estuary Program to precisely define their conservation goals and consider their economic and social constraints. These will ultimately shape which Marxan scenario is most appropriate in addressing their needs. While considering their own goals and constraints, the Estuary Program should begin conservation in the parcels selected across all scenarios (Fig. 11) regardless of which scenario they choose to ultimately adopt. In addition, the Estuary Program should consider establishing easements on the smaller parcels that were selected many times. These parcels are as a whole less expensive and may be easier to establish easements on, but still contain a substantial number of species. Larger parcels, which may be harder to establish easements on, should be worked towards as resources become available.

The Estuary Program should also consider conducting population viability analyses (PVA) on a few species of interest to increase understanding of biologically appropriate targets for these species. There is no definitive information stating that meeting a 30% target for all species of interest in the watershed would guarantee their long-term persistence. While higher targets may better guarantee a species long-term survival, it may not be necessary to implement higher conservation targets if species are likely to persist at lower levels. These higher targets also come with higher costs, which is why efficient allocation of conservation resources is pivotal. A PVA can be resource intensive, but is likely feasible to conduct for a small subset of particularly vulnerable species, such as the five selected for the Estuary Program species of interest. A PVA would provide quantitative biological evidence for setting a particular species target and more reliably ensure the long-term persistence of a species. This will aid in refining conservation goals and ensuring the continued survival of species.

3. Water Quality Assessment Through Watershed Modeling

Introduction

Water quality and watershed ecological function are interdependent on one another (Billen et al. 2001). This intersection makes the people and wildlife of the Morro Bay watershed dependent on clean water for recreation, drinking, fishing, and healthy habitats. The Estuary Program has acknowledged the importance of supporting high quality waterbodies in the watershed by citing "water quality protection and enhancement" as one of their main goals (Morro Bay National Estuary Program 2012b). To achieve this goal, several issues must be addressed including accelerated sedimentation, bacterial contamination, and elevated nutrient levels (Morro Bay National Estuary Program 2012b).

In the watershed, Chorro and Los Osos Creeks are listed under the Clean Water Act Section 303(d) as impaired for nutrients, sediments, and pathogens, Warden Creek is listed as impaired for nutrients and pathogens, and Dairy Creek is listed for pathogens. This project aimed to identify areas in the watershed where efforts should be prioritized to enhance water quality and decrease the concentrations of nitrate, phosphate, sediment, and *E. coli* in streams, which contribute pollution to the estuary.

To identify which locations of the watershed negatively impact water quality in streams, the watershed modeling and analysis tool WARMF (Watershed Analysis Risk Management Framework) was used. WARMF modeled nitrate as N, orthophosphate as phosphate, total suspended sediment, and *E.coli* levels on a daily basis for 13 catchments in the watershed over a 12-year period (2002-2014).

Watershed Characteristics

Many factors affect water quality within the watershed including topography, soils, land use, air quality, and climate. Topography defines how water travels from higher to lower elevations. Two main drainage valleys characterize the watershed: Chorro Valley and Los Osos Valley (Fig. 14). Chorro Creek drains the northern two-thirds of the watershed. Five main tributaries flow into Chorro Creek: San Bernando, San Luisito, Walters, Pennington, and Dairy Creek. Los Osos Valley drains the lower one-third of the watershed and includes Los Osos and Warden Creeks.

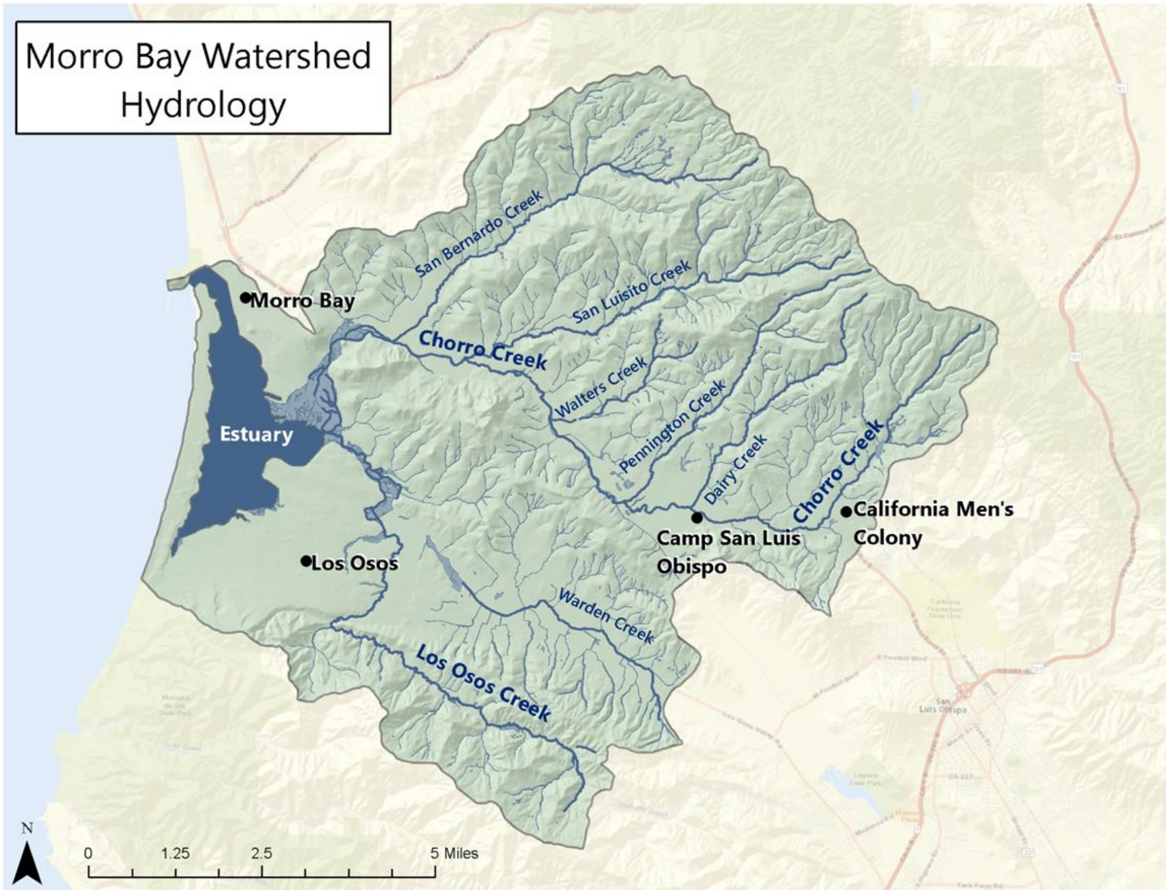

Figure 14. Creeks and points of interest in the Morro Bay watershed.

As water flows through the watershed, it gathers sediments, nutrients, and bacteria, which then accumulate into streams and ultimately drain into and pollute the estuary. These pollutants come from different point and non-point sources in the watershed including roads, agriculture, rangeland, private land, US Forest Service land, California Department of Fish and Wildlife land, California State Park land, the city of Morro Bay (population 10,370), the towns of Los Osos and Baywood Park (combined population of 15,151), Cuesta Community College, Cal Poly property, California Men's Colony Prison (CMC) wastewater treatment plant (WWTP), and National Guard Camp San Luis Obispo. Land cover class in the Morro Bay watershed is shown in Figure 15.

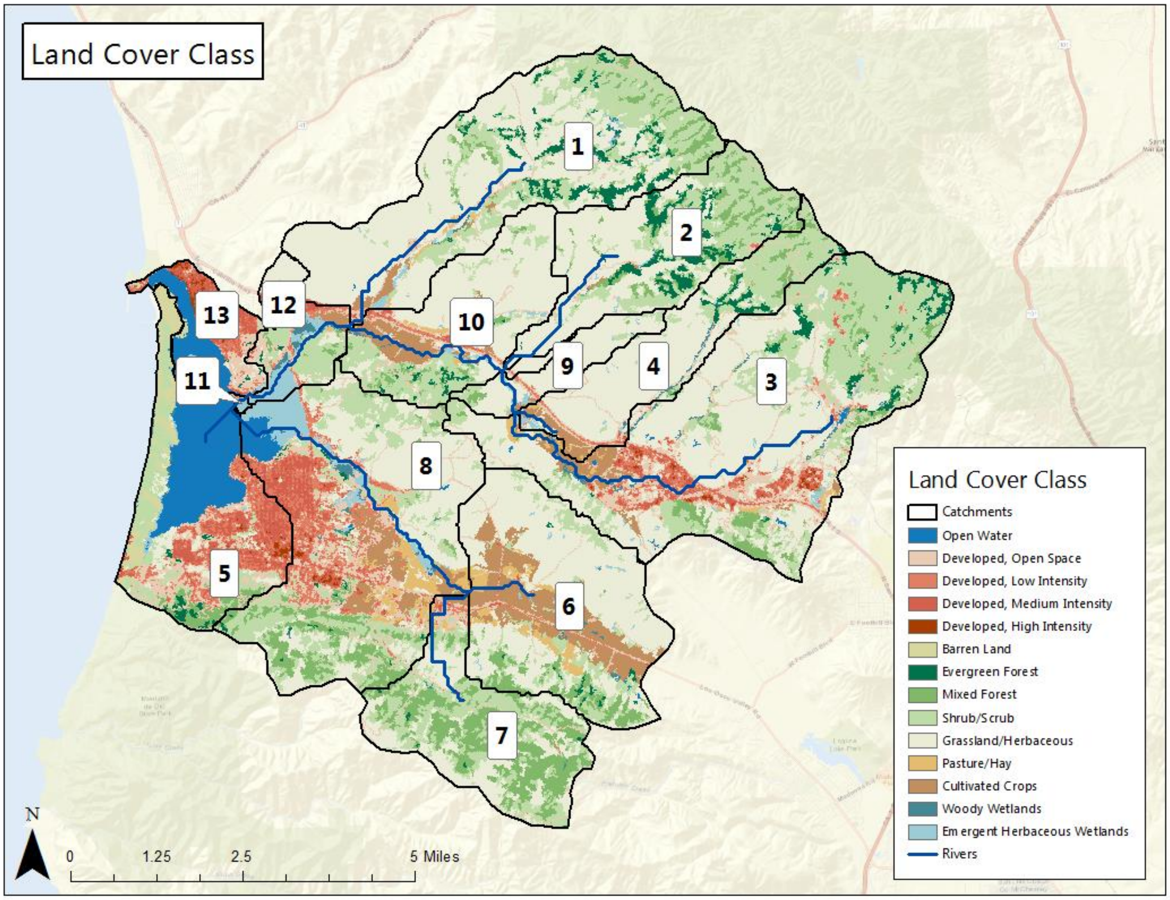

Figure 15. Land use/cover classification in the Morro Bay watershed (US Geological Survey 2014).

A total of 68.2% of the 48,000 acre watershed is characterized as agricultural land (Nicole Smith et al. 2014). Within the northern Chorro Valley region of the watershed, rangeland and cattle dominate land-use, while in the southern Los Osos Valley region agriculture is more predominant, as shown in Figure 16. Cattle and calves are the dominant livestock in the county, with 714 ranches holding 58,095 individual cows (USDA, National Agricultural Statistics Service 2012). Assuming a 1,000 pound beef cow produces 60 pounds of manure per day, this rangeland is a significant non-point source of nitrogen, phosphorous, and fecal coliform within the watershed (Coastal San Luis Resource Conservation District 2008). As of 2012, there were 2,666 farms within San Luis Obispo County, with an average individual farm size of 502 acres, producing an annual total crop value of $861,803,000 (USDA, National Agricultural Statistics Service 2012). Resulting non-point sources include runoff from cropland and rangeland containing pesticides, fertilizers, nitrogen, phosphorous, and fecal coliform.

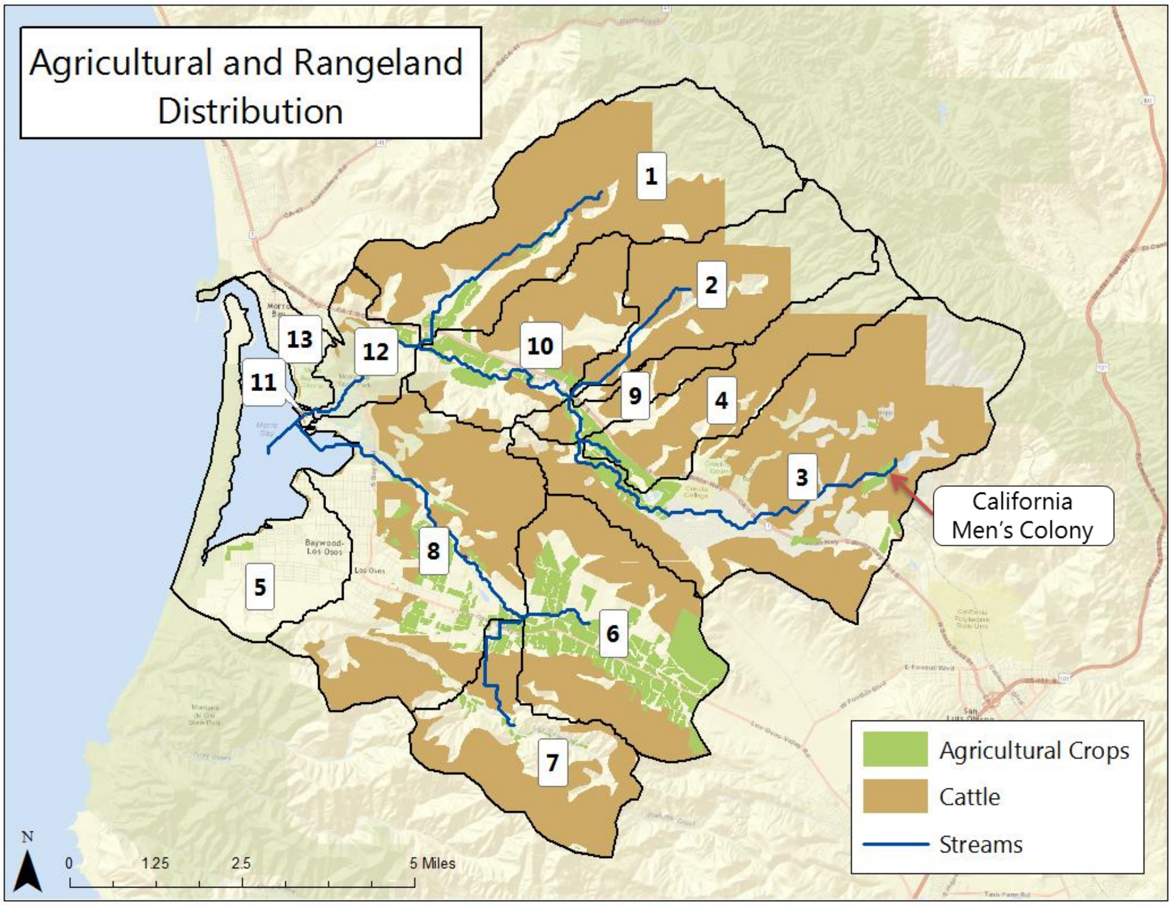

Figure 16. San Luis Obispo County agricultural and rangeland distribution (USDA, National Agricultural Statistics Service 2012).

Soil characteristics in the watershed impact water quality of the streams. Soils in the watershed are typical of grasslands in the southern coast ranges of California: vertisols and mollisols. Shallow, well drained soils characterize higher elevations and deep, poorly drained soils characterize areas closer to the wetland, as shown by the distribution of soil hydrologic groups in Figure 17**.** Soil hydrologic groups are an indicator of the infiltration rate and runoff potential of the soil, impacting how much water, sediments, and pollutants are transferred in surface flows to waterways (NRCS 2014a). Soils in Group A have the highest infiltration rate and lowest runoff potential and those in Group D have the slowest infiltration rate and highest runoff potential (Table 4).

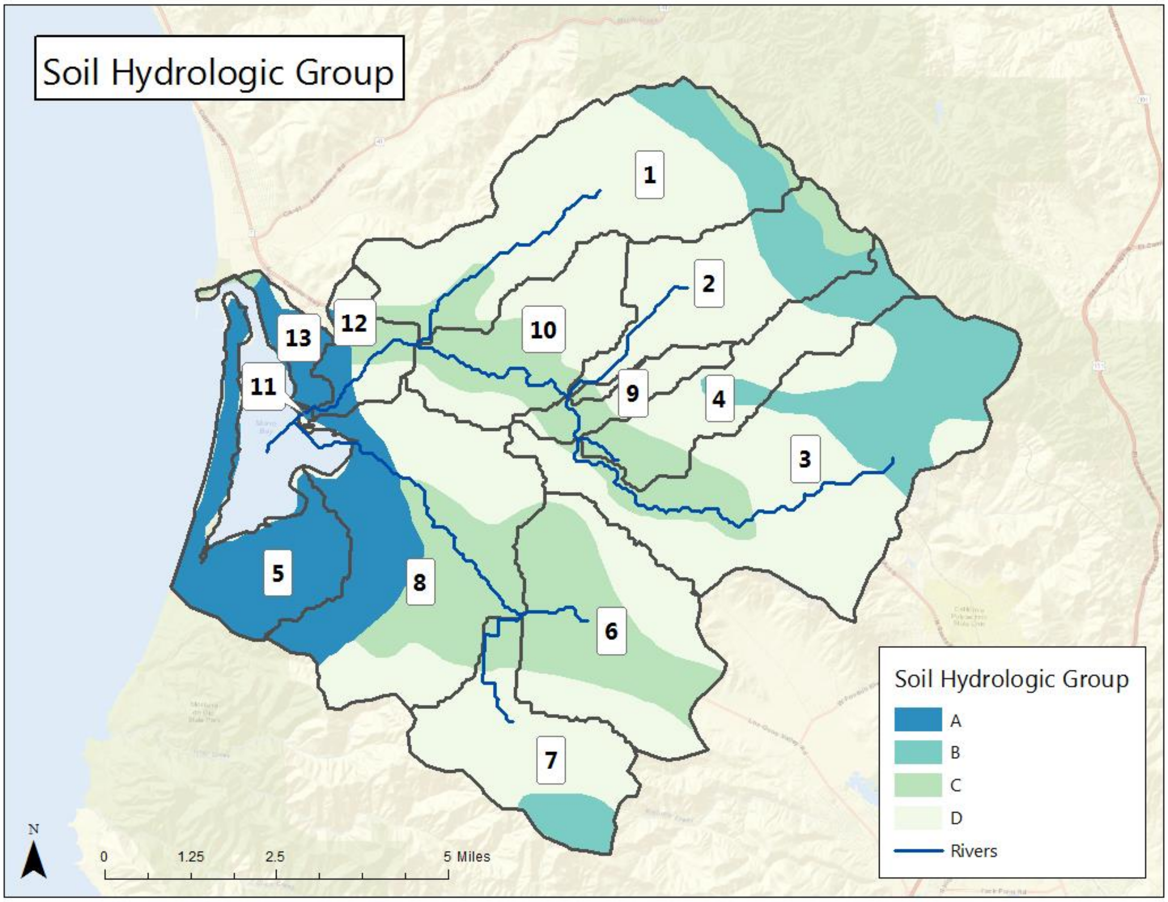

Figure 17. Soil hydrologic groups (Natural Resource Conservation Service 2015). Soil hydrologic group A has the highest infiltration rate and lowest runoff potential and soil hydrologic group D has the slowest infiltration and highest runoff potential.

Table 4. Soil hydrologic group descriptions adapted from (Natural Resource Conservation Service 2015).

Group	Meaning
A	Low runoff potential. Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively drained sands or gravels.
B	Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well-drained soils with moderately fine to moderately coarse textures. E.g., shallow loess, sandy loam.
C	Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine textures. E.g., clay loams, shallow sandy loam.
D	High runoff potential. Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with clay near the surface, and shallow soils over nearly impervious material.

Much of the watershed includes highly erodible soils (Fig.18). Soil erodibility indicates the susceptibility of soil to erosion and the amount and rate of runoff, both of which impact water quality. Soil erodibility in the Morro Bay watershed is shown in Figure 18, with higher values of soil erodibility indicating that those soils are the most erodible and produce large amounts and rates of runoff (NRCS 2014b).

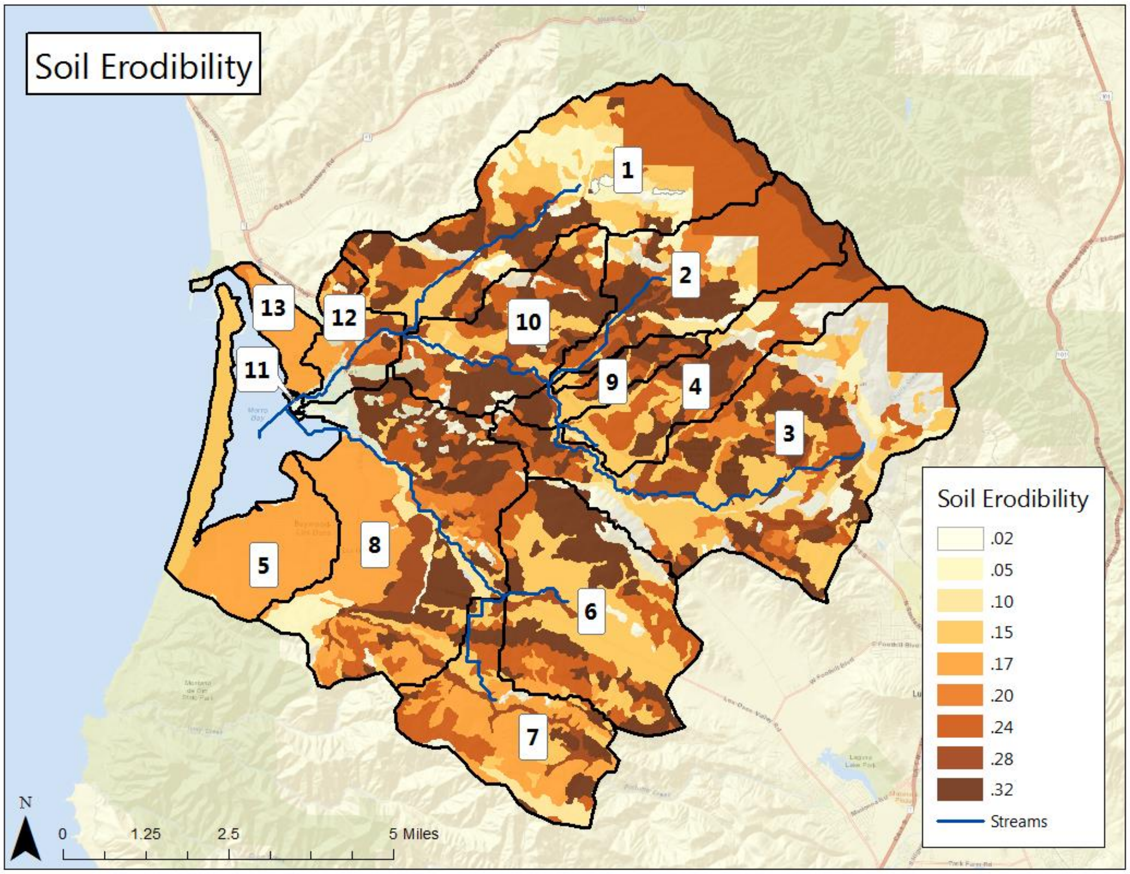

Figure 18. Soil erodibility in the Morro Bay watershed (Natural Resource Conservation Service 2015).

The Mediterranean climate in the watershed also affects water quality by allowing contaminants to accumulate on land during the warm dry summers and then wash into the waterways during storm events in the mild wet winters. This causes dramatic peaks in contaminant concentrations. Drought can exacerbate these effects. In Morro Bay, December to March are the wettest months (on average receiving 2.7-3.7 inches of precipitation), while June through August receives very little precipitation (receiving an average of 0.01-0.08 inches). On average, the watershed receives about 17.5 inches of precipitation annually (NOAA National Climatic Data Center 2014).

Methods

Watershed Modeling with Watershed Analysis Risk Management Framework

WARMF (Watershed Analysis Risk Management Framework) is a watershed modeling and analysis tool developed in the 1990s by Systech Engineering, Inc. as a decision support system (Herr and Chen 2012). Combining land use, hydrologic processes, watershed position, nutrient balance, and soil characteristic information, major source areas for nutrients can be identified in a watershed and relative sensitivity of water quality variables to alterations in land use can be examined (Pionke, Gburek, and Sharpley 2000; Basnyat et al. 1999). The WARMF model was chosen for this project because it models water quality parameters for which there is limited data, on a per catchment basis on a daily time-step, allowing spatial analysis and identification of areas that are best suited for water quality protection or restoration.

WARMF allows for both short and long term modeling to address total maximum daily loads (TMDLs) of nutrients, sediments, and effects of point sources on a watershed scale (USEPA 2013a). The program allows for watershed and site specific data including elevation, land use, soil characteristics, meteorology, air quality, point sources, stream hydrology, and observed water quality. These parameters are input into catchments and corresponding stream reaches within a delineated watershed boundary through the use of five integrated program modules: engineering, consensus, TMDL, data, and knowledge.

Watershed Model Setup and Calibration

Main aspects and methodologies of WARMF model set up and calibration are outlined in this section. A more detailed discussion of the model can be found in Appendix C.

A WARMF model includes the following data inputs:

- Digital Elevation Model
- River Network Data
- Land Use
- Soil Characteristics
- Observed Hydrology
- Observed Water Quality
- Meteorological Data
- Air Quality Data
- Point Source Data
- Land Application Data

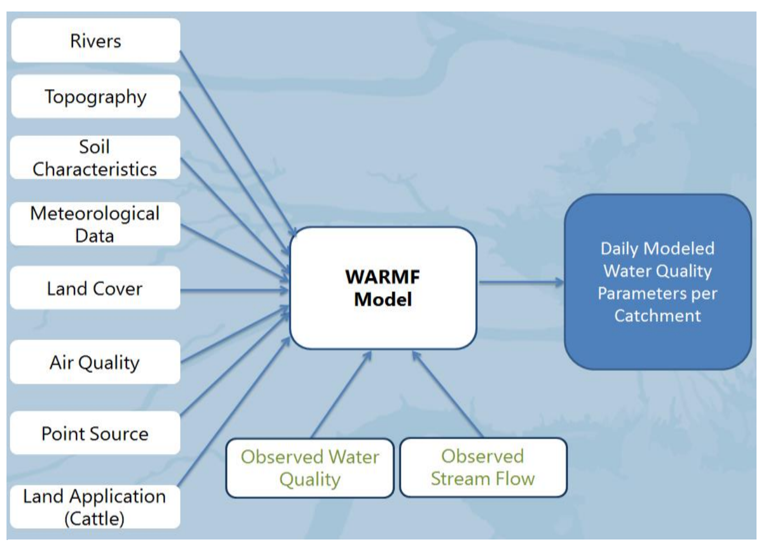

Figure 19. Conceptual model of the WARMF model.

Best available data sources were used from the United States Geological Survey (USGS) and Environmental Protection Agency (EPA) and accessed through Better Assessment Science Integrating point & Non-point Sources (BASINS). BASINS is a multipurpose environmental analysis framework designed to aid in watershed management and water quality studies through data organization and analysis (USEPA 2013b). It is designed to supply the user with these capabilities at a HUC-8 level scale. Because the Morro Bay watershed is significantly smaller than its HUC-8 watershed (Central Coastal California), data on a smaller spatial scale was used from the Estuary Program's monitoring programs and other local sources as detailed below. All of these datasets are of equally fine scale as that available from the Estuary Program database and several are from more recently updated datasets.

Delineation into Catchments through Topography and River Network

BASINS delineated 13 catchments within the Morro Bay watershed boundary (Fig. 20). This division of land into catchments was based upon digital elevation model data (DEM), the national hydrography dataset (NHD), and cataloging unit boundary limits clipped to the Morro Bay watershed area of interest. The delineation simplified the available NHD river network system to a format WARMF is capable of modeling. This resulted in elimination of several tributaries to the major creeks within the watershed and is a recognized and unavoidable limitation of this analysis.

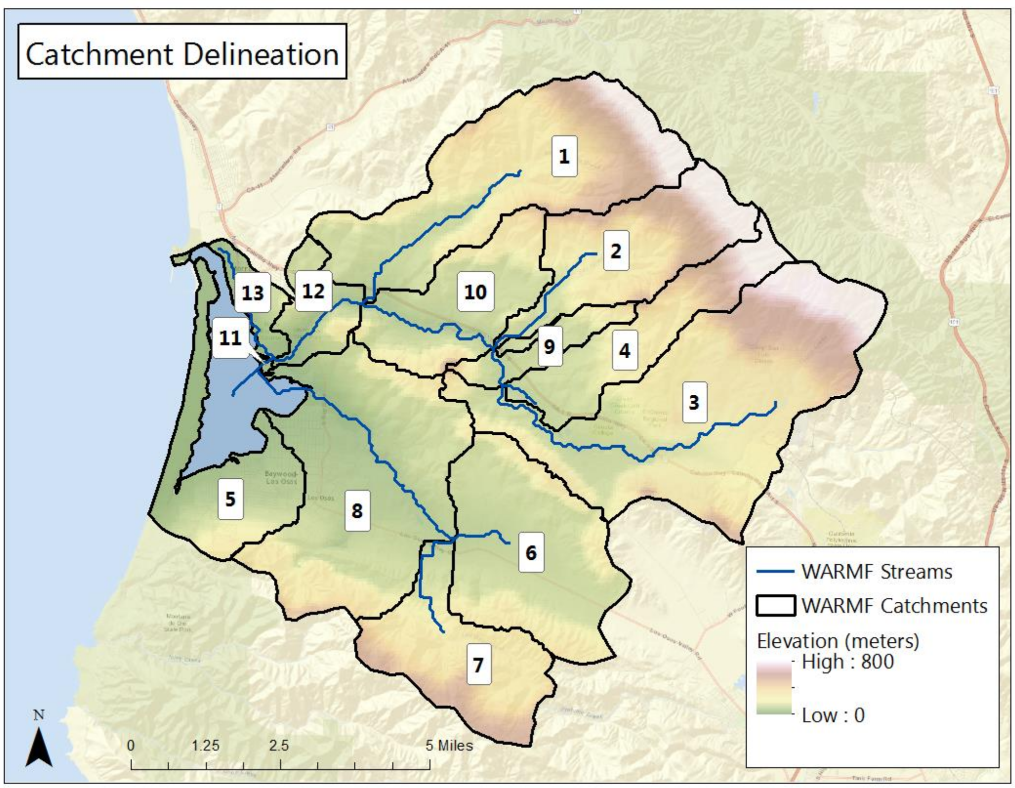

Figure 20. BASINS delineated catchments and rivers.

BASINS delineated 13 catchments, but the analysis focused on 11 of the 13, excluding catchments 5 and 13 from the results and analysis. Coastal watersheds pose challenges for BASINS delineation. Although catchments 5 and 13 were delineated with rivers flowing through them, the river segment in catchment 5 flows through the estuary and not through the land in that catchment. The river segment in catchment 13 is the subtidal channel. No rivers actually flow through the land in catchments 5 and 13, so the hydrology cannot be modeled accurately in WARMF. Due to the lack of river hydrology in these catchments, these catchments were excluded from our results and analysis.

Observed Water Quality and Observed Streamflow Data

WARMF utilizes observed stream flow and water quality data to calibrate modeled output. The Estuary Program is dedicated to year-round and seasonal monitoring efforts throughout the watershed. Monitoring is conducted by staff and volunteers recording water quality parameters and observed hydrology by stream flow measurements at pre-determined stations. WARMF allows for one observed water quality station (independent of point source inclusion) and one observed hydrology station per catchment. Seven stations were selected for both water quality and hydrology data to input into the model based on the criteria of geographic distribution throughout the watershed (most downstream station selected for each catchment), delineated catchments, and longevity of available dataset over the 12 year modeling period from 2002-2014 (Figs. 21 and 22). After consulting with experts in this field, one decade of monitored data was deemed an appropriate time period for analysis given historic development and land-use changes in the watershed.

Photo 5. Water quality monitoring station at Chorro Creek.

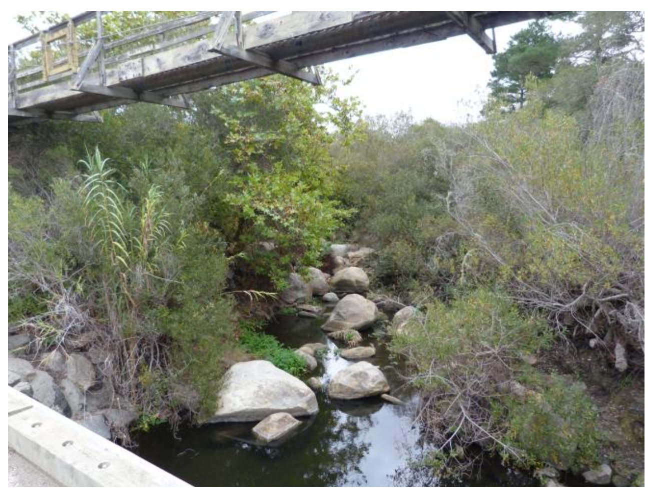

Photo 4. Creek monitored by the station pictured left.

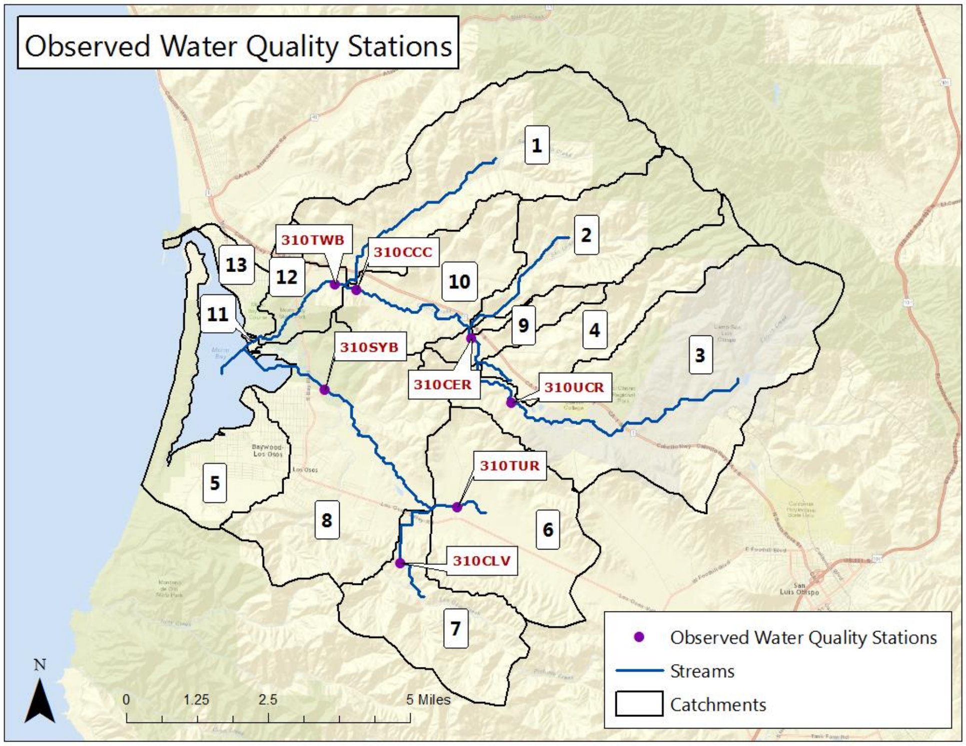

Figure 21. Observed water quality station locations. Stations used in catchments 8 and 10 are different for hydrology and water quality. For more site location information, see Appendix C.

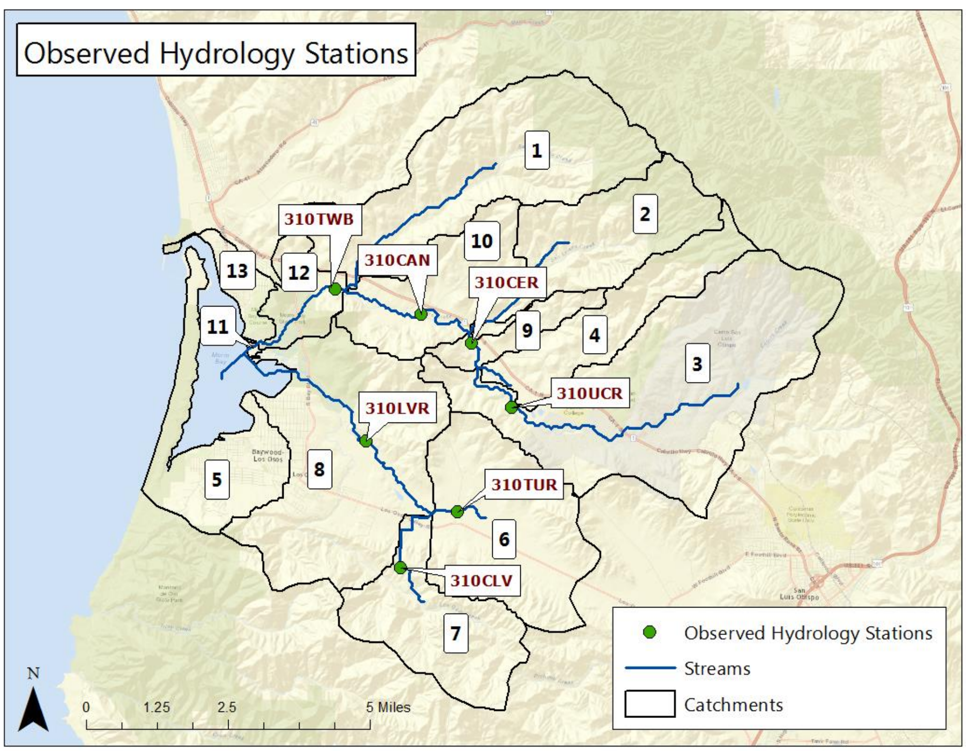

Figure 22. Observed hydrology station locations. Stations used in catchments 8 and 10 are different for hydrology and water quality. For more site location information, see Appendix C.

Observed values for the following twelve water quality parameters were input into the model: water temperature, pH, ammonia, nitrate as nitrogen, orthophosphate as phosphate, *E. coli*, dissolved oxygen (DO), total phosphorus, total Kjeldahl nitrogen, total nitrogen, salinity as converted to total dissolved solids, and turbidity as converted to total suspended sediments.

The Estuary Program has historically monitored for two types of fecal indicator bacteria: total coliform and *E. coli*. Total coliform is a variety of bacteria species found in feces and in nature. Though formerly regarded as an indicator species, this parameter's usefulness depends upon what proportion of total coliforms reported through monitoring efforts are fecal versus natural in origin (USEPA 2012a). *E. coli*, however, is a species of fecal coliform found only in the feces of humans and warm-blooded animals and is recommended by the EPA as the best indicator of health risk from water contact (USEPA 2012a). Based on the use of *E. coli* in the latest water quality standards, and that total coliform is no longer used as a fecal indicator, *E. coli* was the parameter modeled in WARMF.

Additional Data Inputs

Table 5. Additional WARMF model input with their associated sources, scales, resolutions, and spatial/temporal frequency.

Data Input	Dataset/Parameters	Agency	Scale/Frequency
Stream Network	National Hydrography Dataset (NHD)	USGS	High resolution, 1:24,000; simplified by WARMF
Topography	Digital Elevation Model (DEM)	USGS	30 meter resolution
Soil Characteristics	Conductivity, Field Capacity, Saturation Moisture	USDA, NRCS	1:12,000, 1 value per catchment per parameter
Meteorological	Precip, Min/Max Temp, Cloud Cover, Dewpoint Temp, Air Pressure, Wind Speed	California Irrigation Management Information System (CIMIS), CDWR	Daily measurements for each parameter, 2002-2014
Land Cover	National Land Cover Dataset 2011	USGS	30 meter resolution 16-class land cover classification scheme

Data Input	Dataset/Parameters	Agency	Scale/Frequency
Air Quality	Wet Deposition: pH, NH_4, Ca, Mg, K, Na, SO_4, NO_3, Cl Dry: SO_2, NH_4, Ca, Mg, K, Na, SO_4, NO_3, Cl	Wet: EPA CASNET Dry: NADP	Weekly measurements for each parameter, 2002-2014
Point Source	Flow, Temp, DO, Turbidity, Specific Conductance, PO_4, Nitrate as N, Total Coliform, *E. coli*	Morro Bay National Estuary Program	97 data points, 2007-2014 directly below point source
Land Application (Cattle)	Nitrogen, Phosphorous, *E. coli*, Rangeland Distribution	CSLRCD, SLO County Agricultural Commission	N, P, and *E.coli* per catchment based on percent rangeland land-use category

Calibration

Following the input of all available data into the model, it was necessary to calibrate watershed hydrology using the WARMF model hydrologic autocalibration tool. Given the sparse observed water quality datasets used in this model, hydrologic autocalibration was deemed sufficient for overall model application through literature review. The hydrologic autocalibration process adjusts parameters used in model flow simulation and was performed on a sub-watershed level. Three subwatersheds were defined in the model: Upper Chorro subwatershed, Lower Chorro subwatershed, and Los Osos subwatershed as shown in Figure 23. Several 1000 loop autocalibration scenarios were run for each subwatershed until mean modeled and observed flow values converged and relative error values were deemed acceptable for the scope of the project given the limited observed data available.

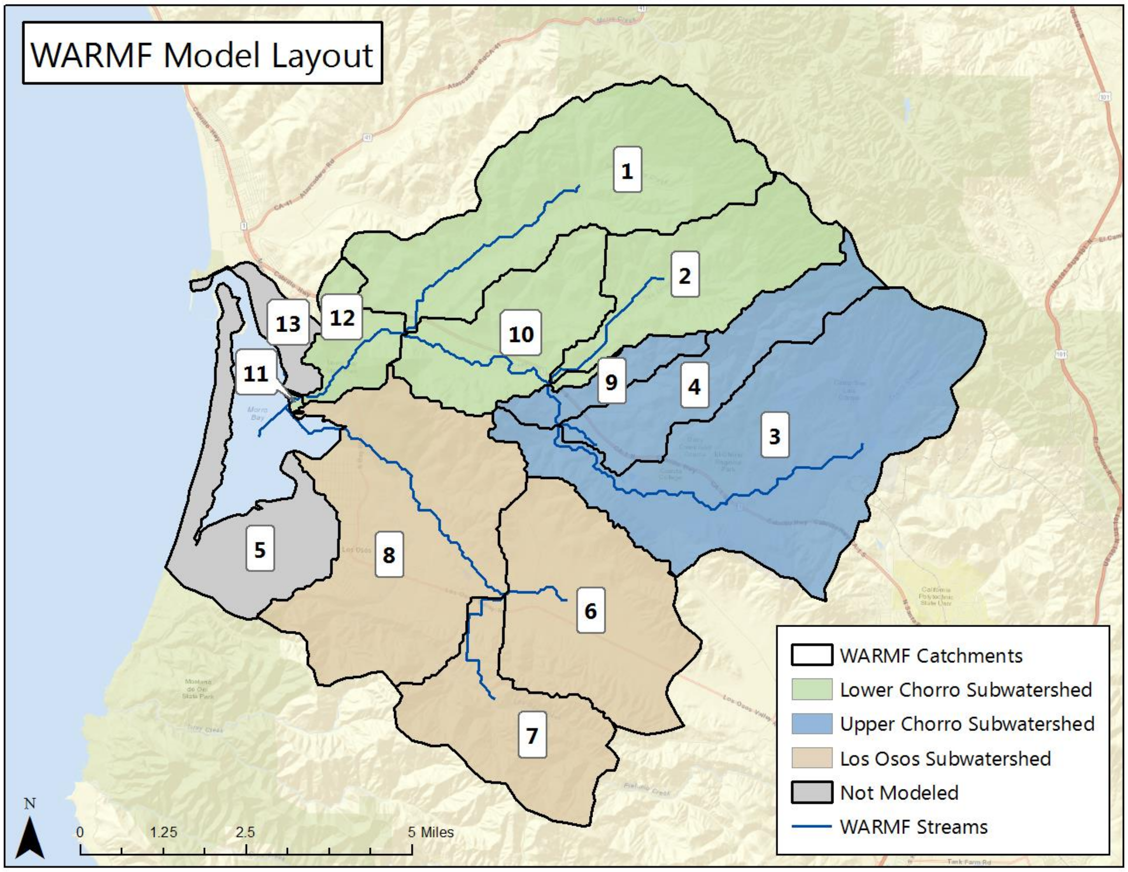

Figure 23. Model autocalibration subwatershed layout.

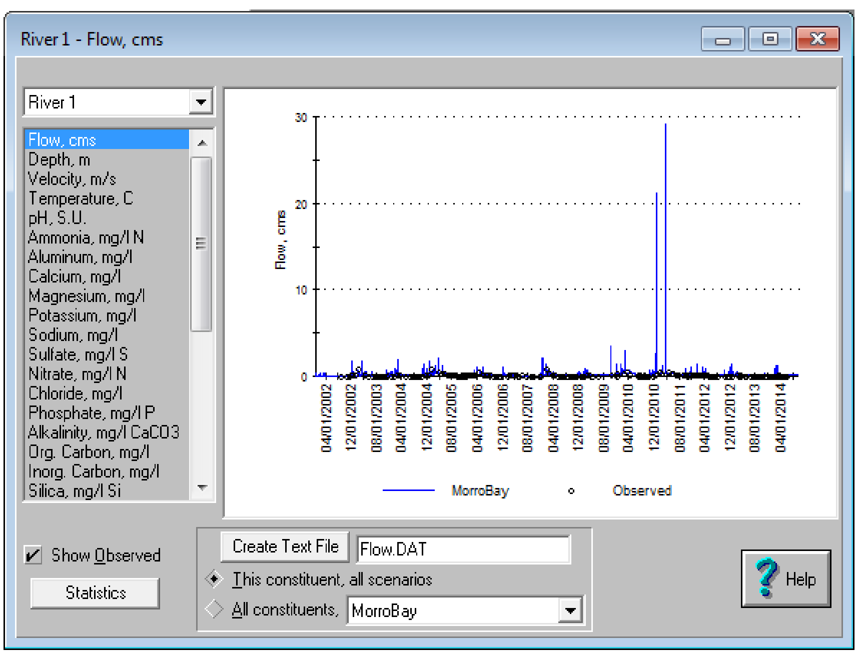

Figure 24. Example results of model of flow for catchment 10 following calibration.

Focus of Analysis

Our analysis focused on nitrate, phosphate, total suspended sediment, and *E. coli* concentrations in the watershed to address priority issues identified by the Estuary Program. Other water quality parameters considered for analysis were dissolved oxygen and temperature. However, the standards for these parameters are very rarely exceeded (Kitajima 2014), and were therefore not analyzed spatially or included in the report discussion.

Among the measures of sediment that exist, WARMF is only capable of modeling total suspended sediment. Although the Estuary Program currently does not monitor this parameter at a sufficient scale for input to WARMF due to monitoring site, rainfall, and longevity limitations, they do monitor turbidity at stations throughout the watershed. Turbidity is defined as extent of light scattering in water due to suspended matter or impurities interfering with clarity, while the EPA defines total suspended sediment as a water quality parameter measuring particulate organic and inorganic matter that suspend within water (Spear et al. 2008). Although WARMF is not capable of modeling turbidity as a water quality parameter, due to the Estuary Program's interest in sedimentation we deemed it necessary to examine these processes in some way. The Watershed Institute of California State University Monterey Bay published a report in 2008 wherein they converted an historical turbidity dataset to local suspended sediment at Elkhorn Slough. Through this study, an equation was produced ($y = 0.7674x + 55.391$) for converting turbidity data to total suspended sediment data in the Elkhorn Slough (Spear et al. 2008). After consulting with experts, this conversion was applied to Estuary Program's turbidity data for input to WARMF due to the geographical and ecological similarities between the Elkhorn Slough and the Morro Bay watershed.

For nitrate, phosphate, sediment, and *E.coli*, we calculated the median concentration over the 2002-2014 period in both the wet (October-March) and dry season (April-September) for modeled results. We chose to analyze medians instead of means because of outliers in the modeled data. For each parameter the average annual days of exceedance of the water quality standard were calculated. The water quality standards used for each parameter in our analysis are included in Table 6.

Table 6. Water quality standard values and sources used in watershed analysis.

Parameter	Water Quality Standard	Source	Notes
Nitrate	1 mg/L	Central Coast Regional Water Quality Control Board	303(d) listing guidance value for aquatic life
Phosphate	0.36 mg/L	Central Coast Ambient Monitoring Program	Informal attention level adapted for Morro Bay watershed from the Pajaro watershed
Sediment	74 mg/L	Central Coast Regional Water Quality Control Board	Aquatic life in cold water, adjusted from turbidity to total suspended sediment (as described above)
E. coli	410 MPN/100mL	EPA 2012 Recreational Water Quality Criteria	Statistical threshold value for recreation

Results and Discussion

Nitrate

Nitrates within the watershed were modeled in WARMF and compared against a water quality standard of 1 mg/L, as defined by the Central Coast Water Quality Control Board (CCRWQCB) (Regional Water Quality Control Board, Central Coast Region 2011). Results show that all catchments frequently exceed the water quality standard (Fig. 25). Only catchment 8 had fewer than 300 days per year that exceed the water quality standard. This indicates that nitrate is of concern across the entire watershed.

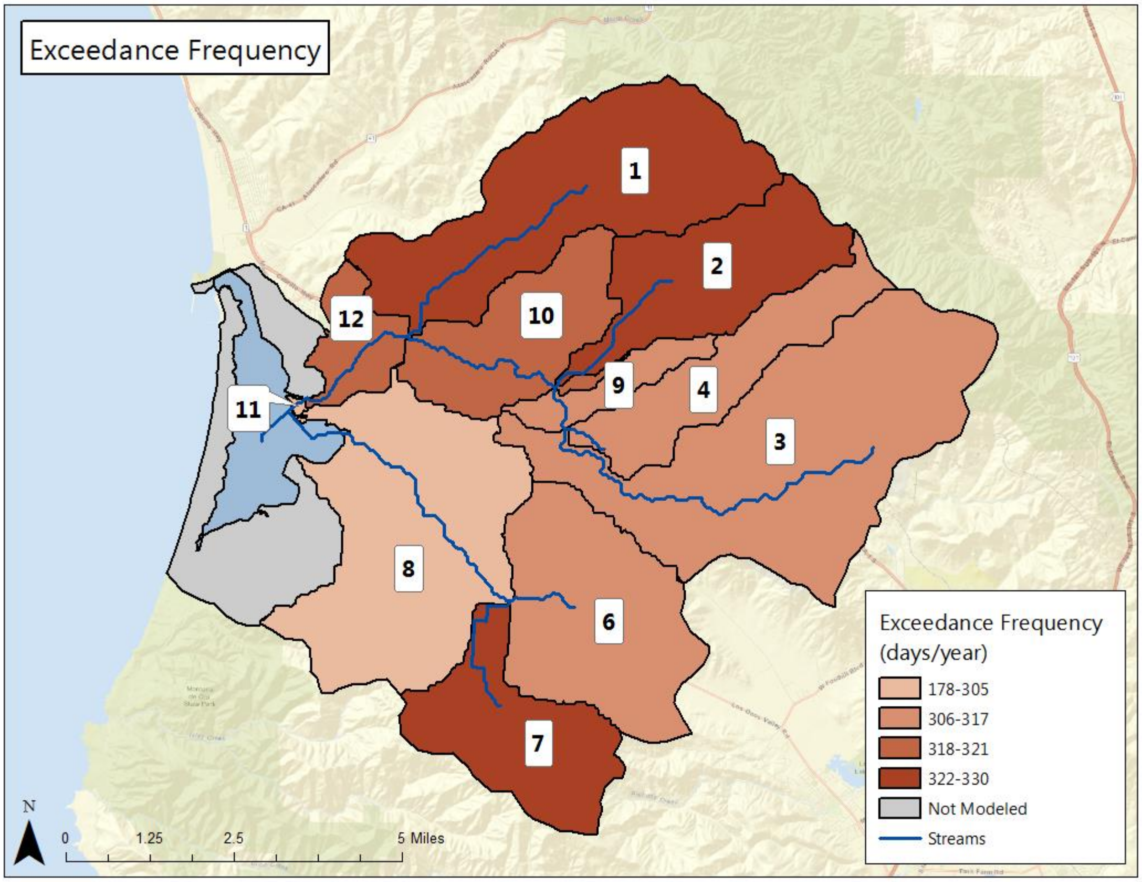

Figure 25. Average annual days of nitrate as nitrogen water quality standard (1 mg/L) exceedance from 2002-2013.

Results show that even though the whole watershed frequently exceeds the standard, the catchments in Los Osos Valley more drastically overshoot the water quality standard, specifically catchments 6, 7, and 8, as shown in Figures 26 and 27. Chorro Valley exceedances typically hover just above the water quality standard. The catchments of most concern for nitrate were similar in the dry and wet season.

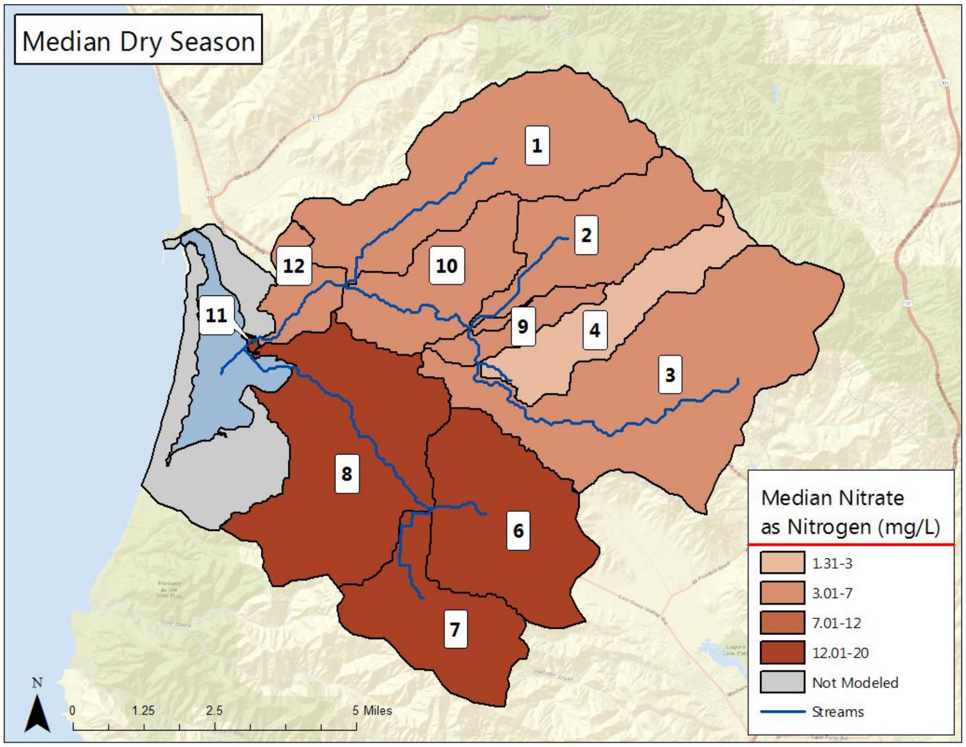

Figure 26. Modeled median dry season (April-September) nitrate as nitrogen concentration (mg/L) from 2002-2014. Red bar in legend indicates water quality standard of 1 mg/L.

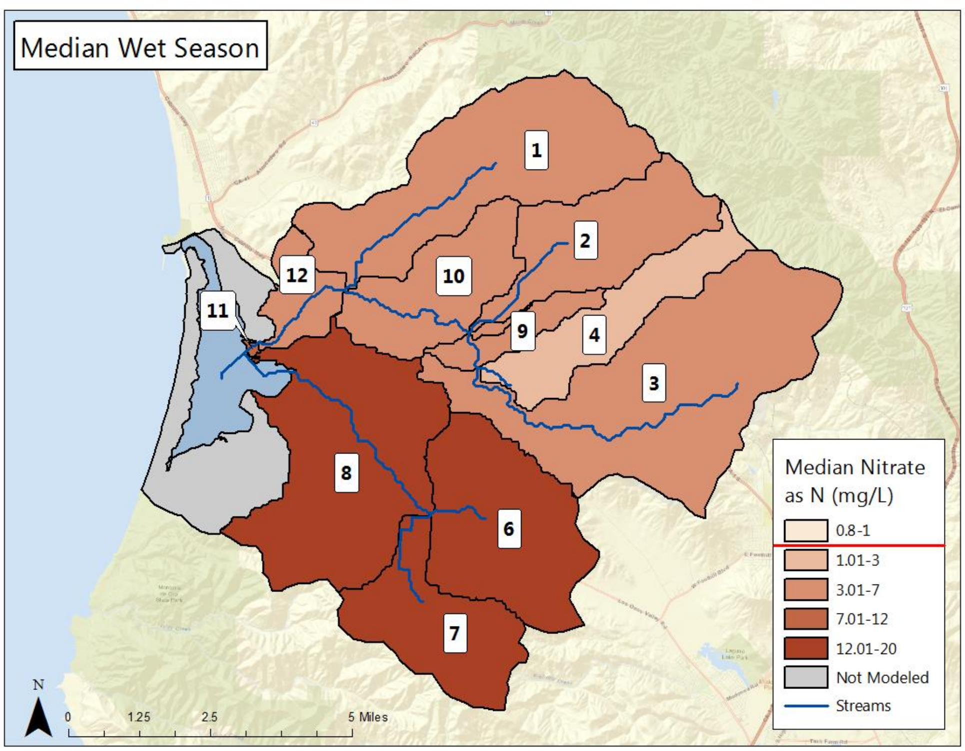

Figure 27. Modeled median wet season (October-March) nitrate as nitrogen concentration (mg/L) from 2002-2014. Red bar in legend indicates water quality standard of 1 mg/L.

The highest concentrations in the watershed were in Los Osos Valley. This is likely due to the concentration of cropland operations as shown in Figure 16. Fertilizers are a source of man-made nitrate pollution and the concentration of row-crops operating in Los Osos Valley may be causing these elevated levels (USEPA 2012d). The Chorro Valley exceedances, which typically hover just above the water quality standard, are likely due to the low but constant inputs of nitrates from the California Men's Colony wastewater treatment plant in Catchment 3 (Fig. 16) as well as the expansive cattle operations present in Chorro Valley. Wastewater treatment plants and animal manure are also sources of man-made nitrate pollution and these presences in Chorro Valley can be contributing to these levels. Addressing fertilizer inputs, effluent from the Men's Colony, and cattle management in the watershed may reduce elevated nitrate levels in the watershed.

Phosphate

Results for modeled orthophosphate as phosphate levels in the watershed showed that catchments in Chorro Valley had both a higher frequency and magnitude of phosphate exceedances than Los Osos Valley (Figs.29, 30 and 31). The water quality standard used for orthophosphate as phosphate was 0.36 mg/L, the informal attention level for phosphate created for the Pajaro watershed but adapted for the Morro Bay watershed (Kitajima 2014). Catchments in Chorro Valley all had over 260 days of exceedances per year and catchments in Los Osos Valley had 68 or fewer days of exceedances (Fig. 28).

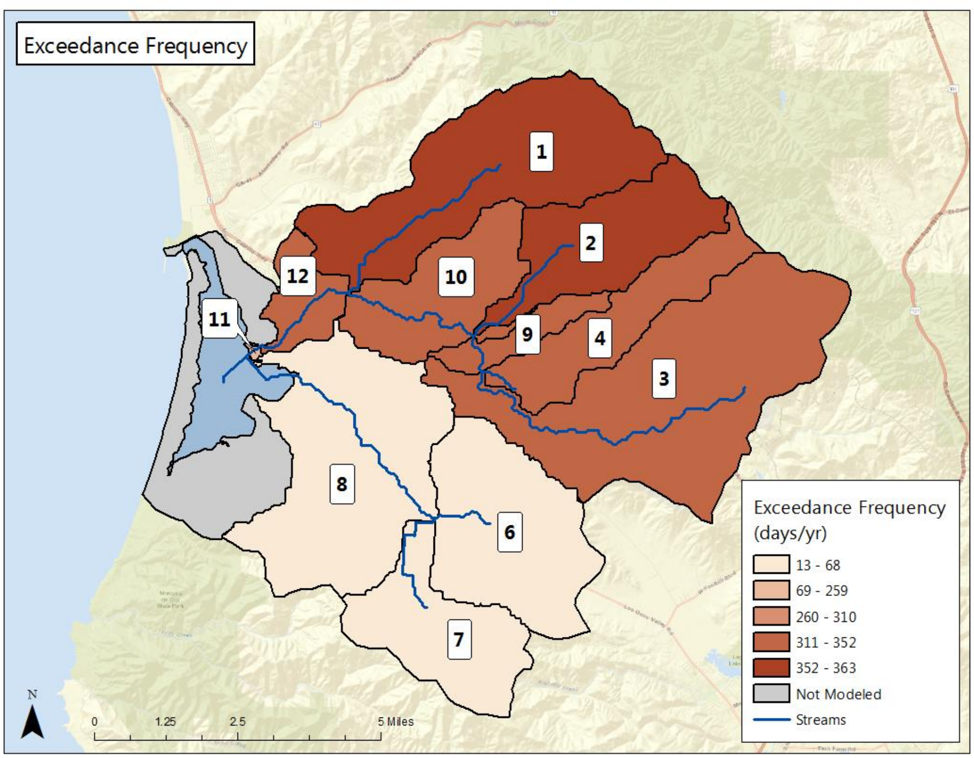

Figure 28. Average annual days of orthophosphate as phosphate water quality standard (0.36 mg/L) exceedance from 2002-2013.

Catchments in Chorro Valley also had higher median levels of phosphate than Los Osos Valley catchments in both the dry and wet season (Figs. 29 and 30). All catchments in Chorro Valley had medians exceeding the water quality standard and all catchments in Los Osos Valley had medians below the water quality standard. The catchments of most concern for phosphate were similar in the dry and wet season.

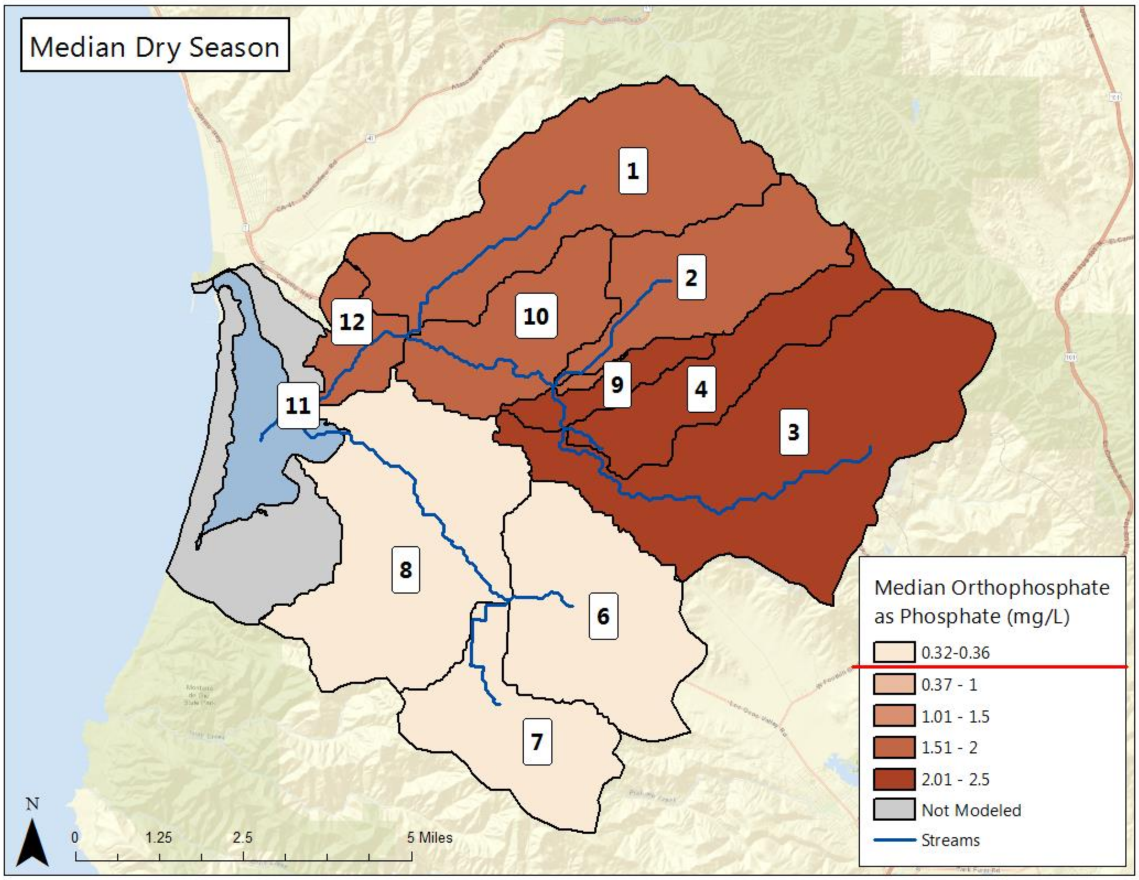

Figure 29. Median dry season (April-September) orthophosphate as phosphate concentrations (mg/L) from 2002-2014. Red bar in legend indicates water quality standard 0.36 mg/L.

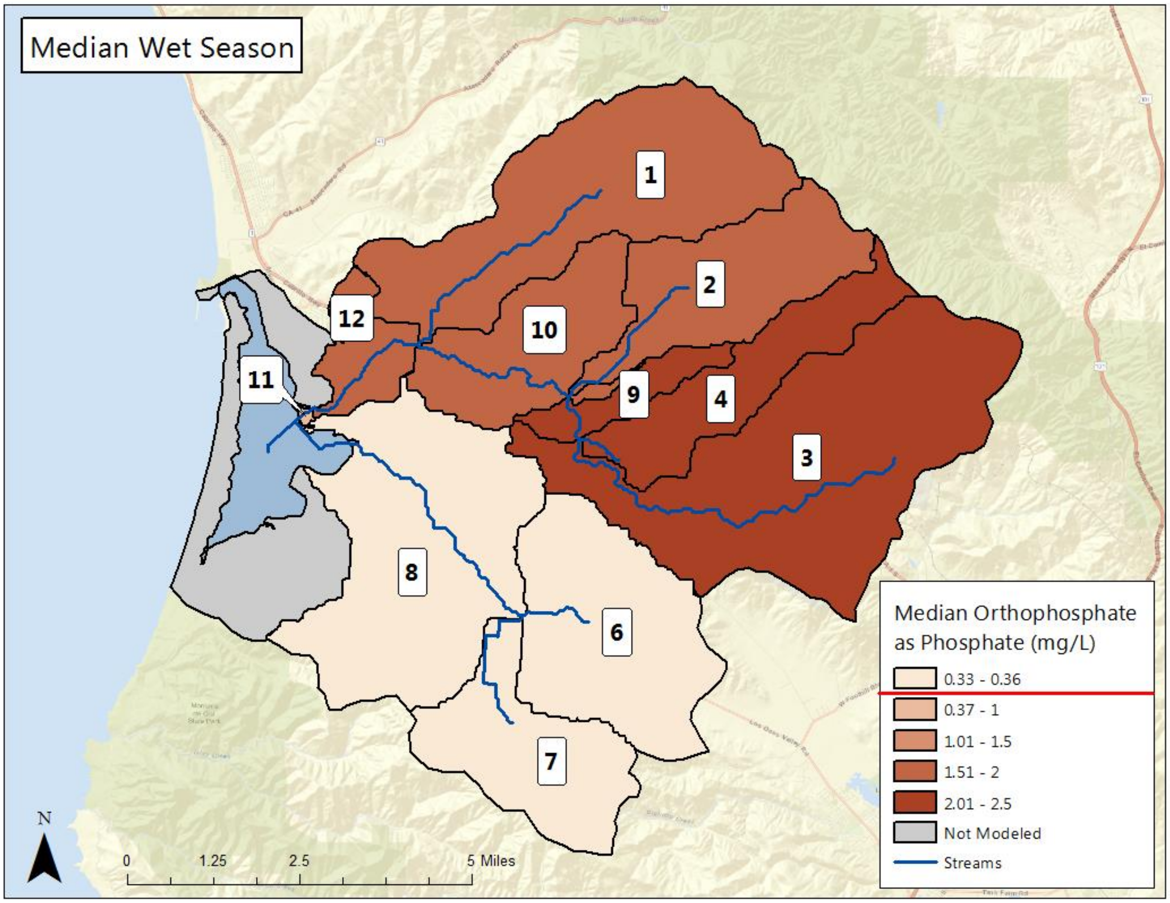

Figure 30. Median wet season (October-March) orthophosphate as phosphate concentrations (mg/L) from 2002-2014. Red bar in legend indicates water quality standard 0.36 mg/L.

Our results indicate that the highest modeled phosphate levels are within catchments 3, 4, and 9, which are the closest catchments to the Men's Colony, which is in catchment 3. The Men's Colony wastewater treatment plant has previously been identified as a major contributor to phosphate within the watershed and even after a tertiary treatment upgrade in 2007, no appreciable reduction in phosphate has been observed in Chorro Creek downstream of the outflow point (Kitajima and Gillespie 2012). This suggests that effluent from the Men's Colony is still a driving force of phosphate loading in the watershed. In addition, Chorro Valley's nexus of steeper slopes and concentration of cattle operations likely contribute to the higher levels of observed phosphate within the Chorro Valley (Fig. 16).

Total Suspended Sediment

Sedimentation within the watershed was modeled in WARMF as total suspended sediment concentration with a water quality standard of 74 mg/L, as per the CCRWQCB (Regional Water Quality Control Board, Central Coast Region 2011). Results show infrequent sediment exceedances across the watershed and seasonal medians that are within the threshold year-round as shown in Figures 31, 32 and 33. Seasonal medians were modeled below the water quality standard (74 mg/L) year-round. However, an increase in concentration was seen in the wet season relative to the dry season in catchments 9, 10, 12, and 13 in the Chorro Valley subwatershed.

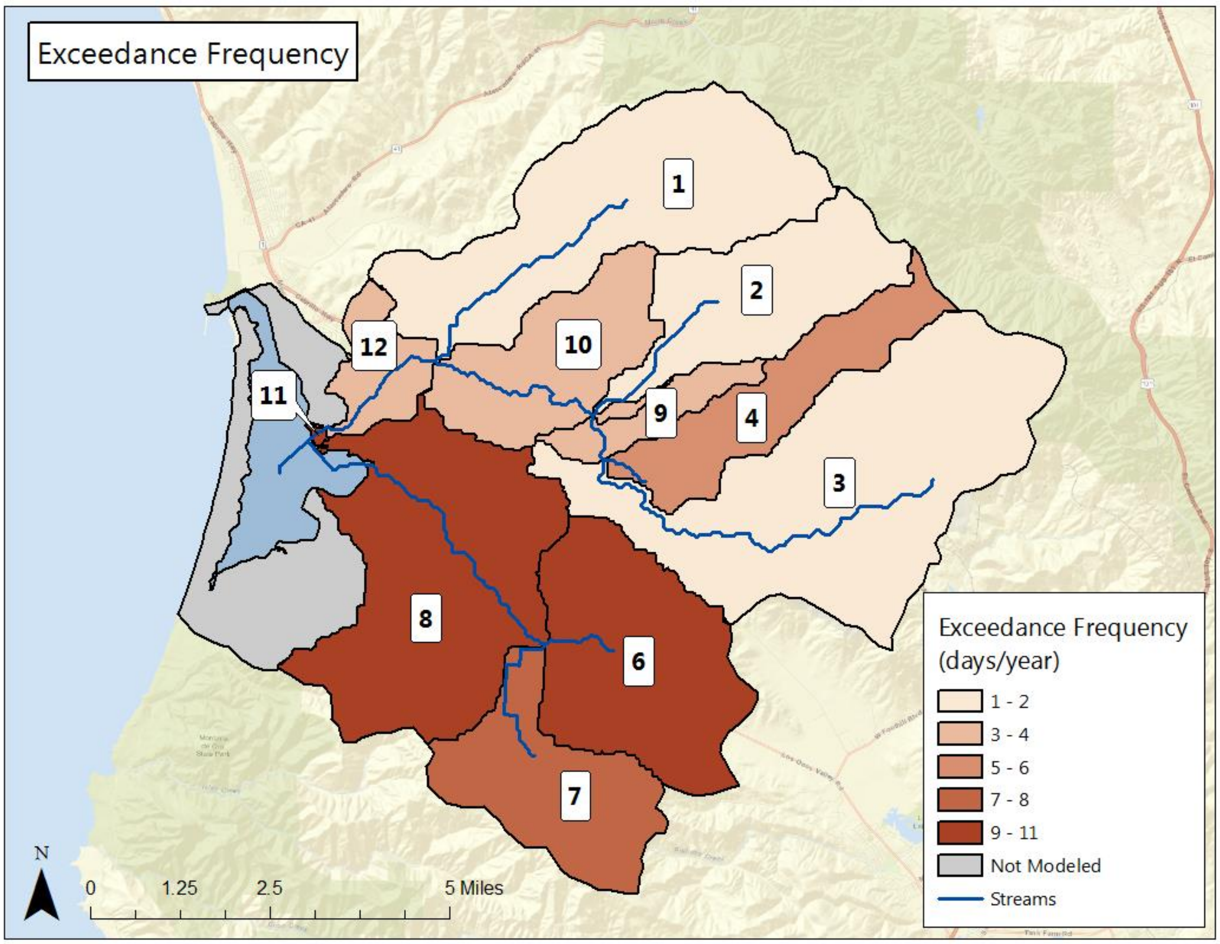

Figure 31. Average annual days of total suspended sediment water quality standard (74 mg/L) exceedance from 2002-2013.

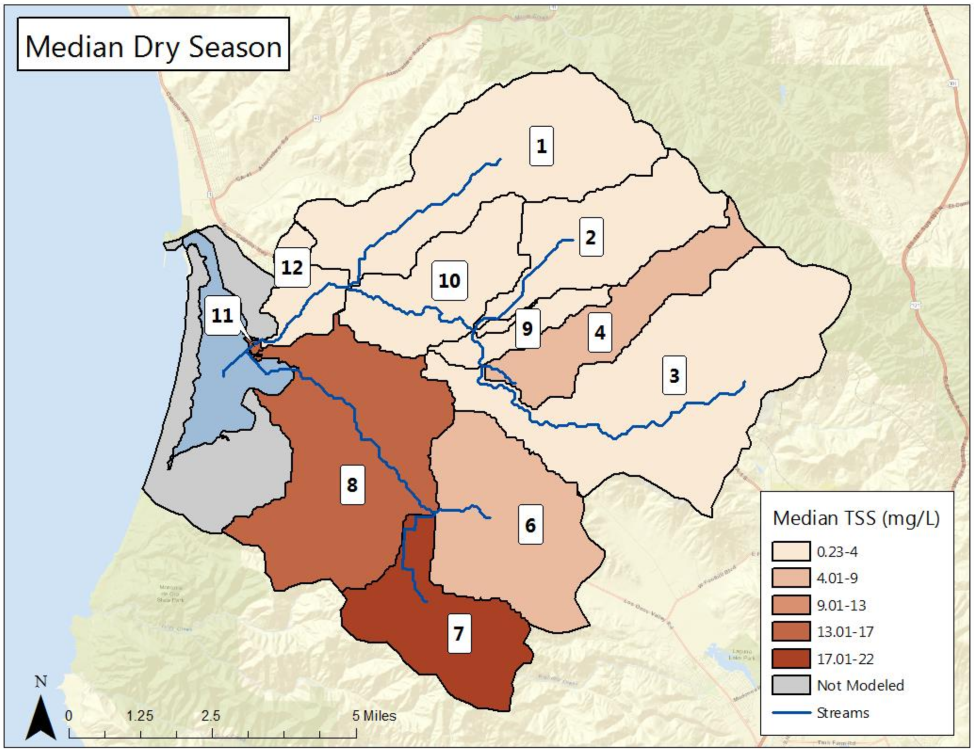

Figure 32. Median dry season (April-September) total suspended sediment concentrations (mg/L) from 2002-2014. Red bar in legend indicates water quality standard 74 mg/L.

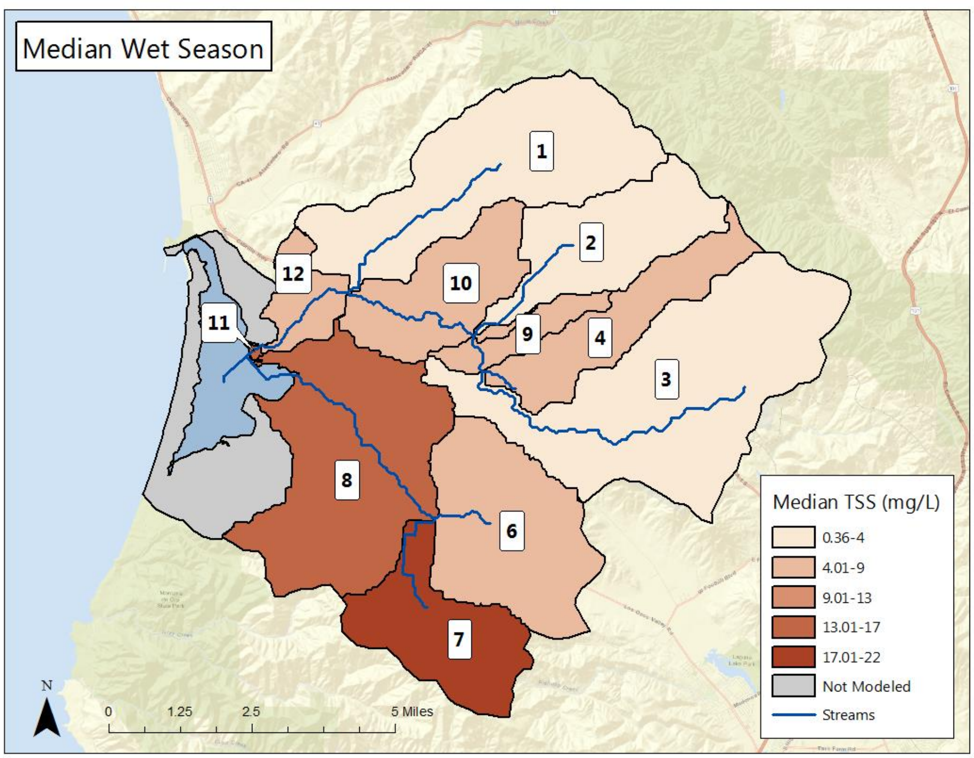

Figure 33. Median wet season (October-March) total suspended sediment concentrations (mg/L) from 2002-2014. Red bar in legend indicates water quality standard 74 mg/L

These results are consistent with literature stating that storm events are stronger metrics for evaluating total suspended sediment issues in a watershed (USEPA 2012b). Because sediment loads are tightly linked to peak storm events, of which there are few in central California due to the Mediterranean climate, the modeled 11 or fewer days of exceedance across the watershed is not surprising. Results of average annual days of total suspended sediment concentration water quality standard exceedance highlighted catchments 6 and 8 in Los Osos Valley at the highest frequency of 9-11 days. This is consistent with seasonal median values likely skewed due to exceedance event frequency. Catchment 7 exceeded the standard 7-8 days annually from 2002-2013 and catchment 4 exceeded the standard 5-6 days annually. This highlights the importance of focusing on upstream causes of erosion, particularly in catchments 6 located upstream in the Los Osos Valley from the estuary and likely sources of downstream sedimentation. Though results indicate catchment 8 may also be a source of upstream erosion, further investigation revealed a tidally influenced monitoring site leads to constantly elevated sediment levels due to extremely fine substrate (Kitajima 2014). Thus, monitored and elevated sediment concentrations do not accurately represent upland sediment loading.

These results indicate that neither frequency of exceedance nor seasonal median concentrations reflect the amount of sediment being transported during peak storm events. Other methods should be pursued to identify source areas for this parameter to address the Estuary Program's priority issues.

E. coli

E. coli concentrations were modeled in WARMF and compared relative to a water quality standard of 410 MPN/100 mL, a standard from the EPA's Recreational Water Quality Standards (USEPA 2012c). Exceedances were modeled highest and most frequent in Los Osos Valley (Fig. 34). Several Los Osos Valley subwatershed catchments (5, 6, and 8) had the highest annual frequency of exceedance events. Although the Chorro Valley subwatershed medians were modeled below the standard year-round (Figs. 35 and 36), several catchments exceeded the standard with moderate frequency and should be examined for water quality management. Average annual days of E. coli water quality standard exceedance from 2002-2013 are shown in Figure 34**.** The Chorro Valley subwatershed was modeled below water quality standard year round. All catchments in the Los Osos Valley subwatershed had higher *E. coli* concentrations in the wet season as compared to the dry season. Catchment 6 was modeled to have the highest level of water quality standard exceedance in both seasons at 770-900 MPN/100 mL. Although catchment 7 in lower Los Osos was modeled below the water quality standard for *E. coli* in both seasons, concentrations did increase in the wet season.

Previous *E. coli* analyses undertaken by Estuary Program has concluded that the worst bacteria levels in the watershed are on the tributaries to Chorro Creek and that main stem Chorro Creek and Los Osos Valley may have minimal bacteria issues (Kitajima 2014). This project's watershed analysis yielded different results for a variety of reasons. As previously discussed, WARMF simplified the river network due to model limitations. As a result, observed water quality stations in Chorro Valley used in the model were all on main stem Chorro Creek. However, if nutrient levels were of sufficient concern in Chorro tributaries, these results would be represented in downstream monitoring stations along Chorro Creek. Modeled *E. coli* results do show catchments 3, 9, 4, 10, and 12 as having elevated exceedances. This likely represents the effects of elevated levels in Chorro tributaries. All results were modeled based on observed measurements. Thus, results indicate that *E. coli* may be a previously unidentified issue in Los Osos Valley due to elevated seasonal means and high exceedance frequency.

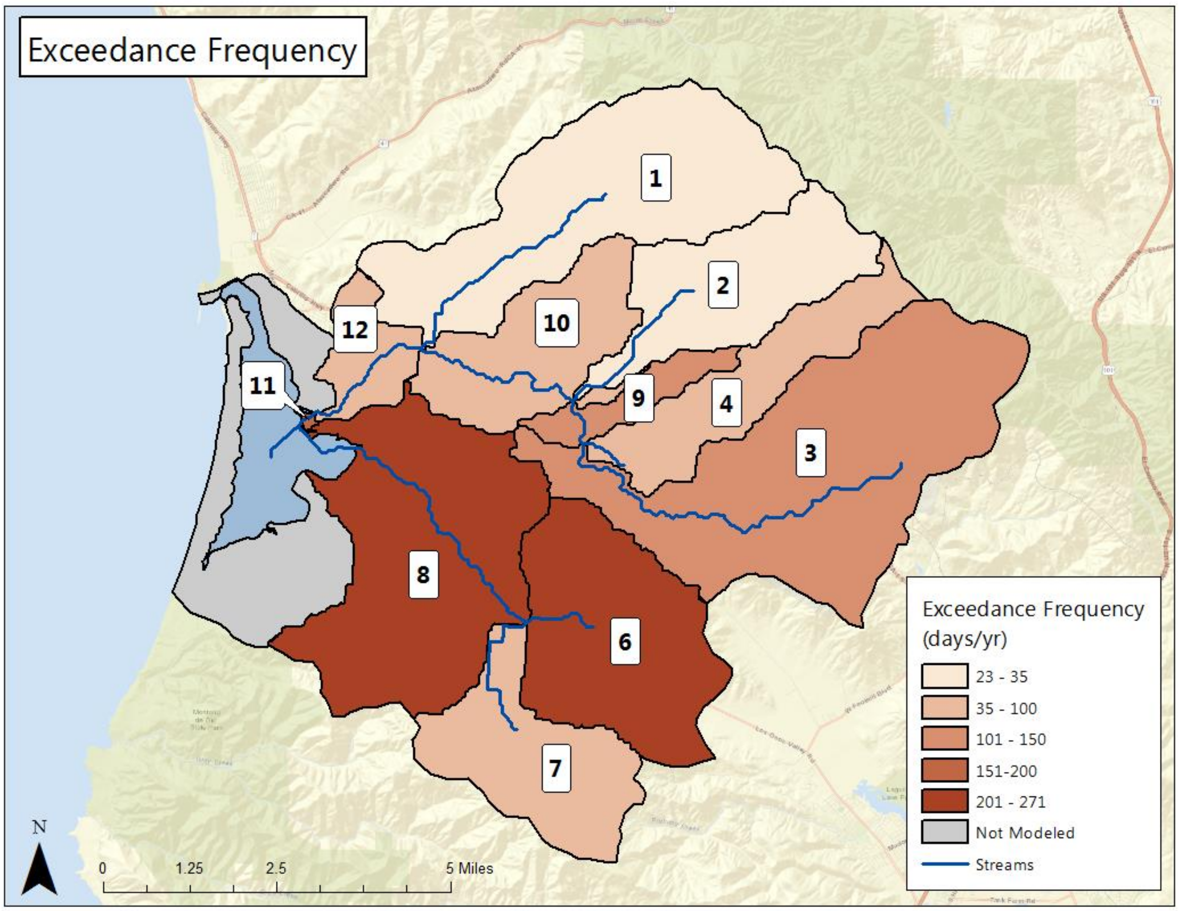

Figure 34. Average annual days of *E. coli* water quality standard (410 MPN/100 mL) exceedance from 2002-2013.

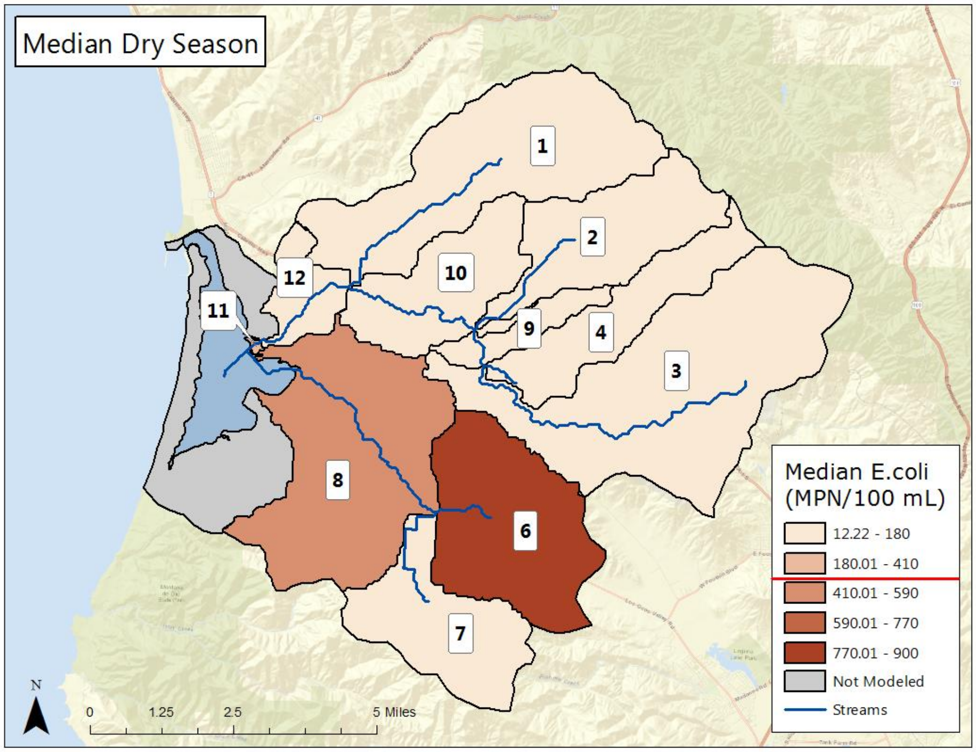

Figure 35. Median dry season (April-September) *E. coli* concentrations (MPN/ 100 mL) from 2002-2014. Red bar in legend indicates water quality standard 410 MPN/100 mL. (USEPA 2012c).

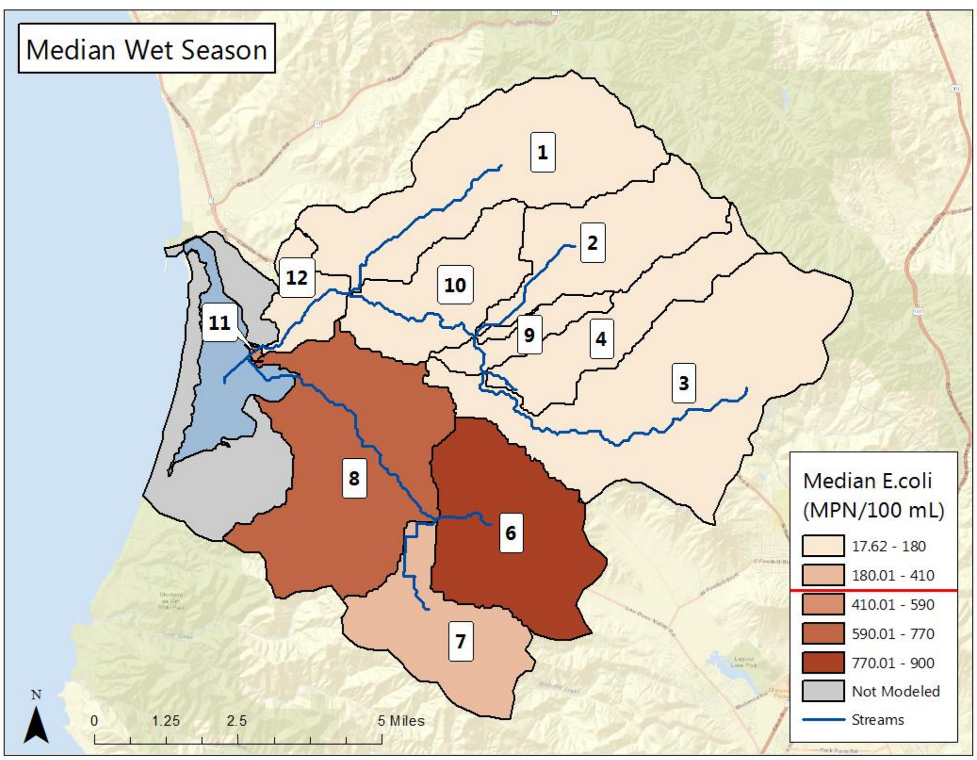

Figure 36. Median wet season (October-March) *E. coli* concentrations (MPN/100 mL) from 2002-2014. Red bar in legend indicates water quality standard 410 MPN/100 mL.

There are two contributing factors that are likely driving this result. First, very few cattle exclusion-fencing projects have been undertaken in Los Osos Valley as shown in Figure 37. The majority of exclusion fencing projects are concentrated on Chorro Creek and its tributaries. Cattle excrement has been shown to contribute to elevated *E. coli* levels within the watershed, and exclusion fencing has proven to be an effective solution. In addition, the town of Los Osos, which extends into catchment 8, is currently transitioning from septic to a sewer system and the use of septic is likely contributing to the elevated E. coli.

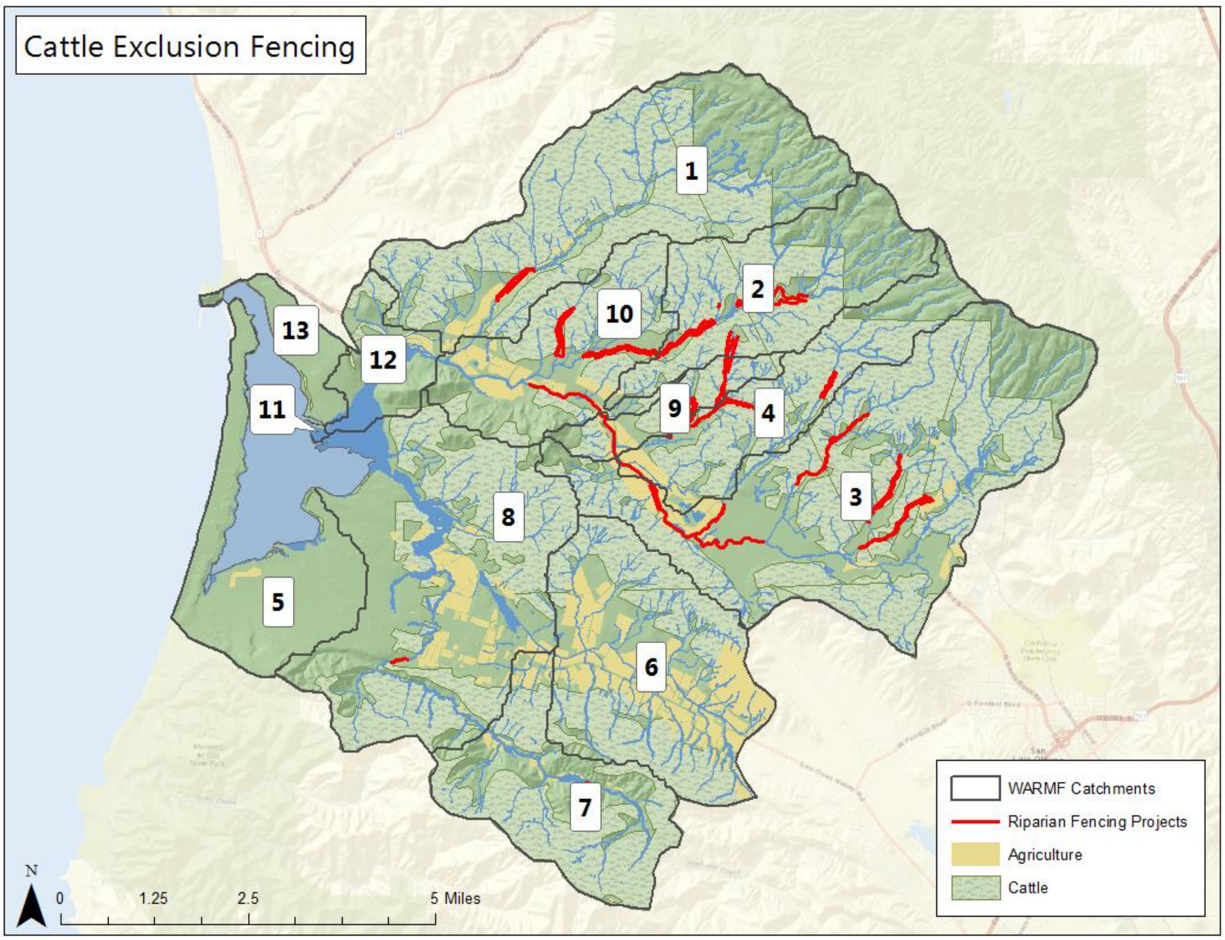

Figure 37. Distribution of cattle exclusion fencing projects as related to agriculture and cattle distribution.

All Los Osos Valley catchments were modeled above the water quality standard concentration of 410 MPN/100 mL except catchment 7, which crosses the standard only in the wet season (USEPA 2012a). Catchments 5, 7, and 8 increased in concentration in the wet season, with catchment 6 modeled at highest concentration year round. While seasonal comparison of *E. coli* concentrations in the watershed highlights spatial differences in problem regions, inspection of annual days of standard exceedance helps identify areas that, while generally below the standard seasonally, experience daily exceedance events that may be cause for water quality improvement consideration. As expected from seasonal medians, Los Osos Valley catchments were modeled with the highest frequency of exceedance. While Chorro Valley seasonal medians did not exceed the standard, three catchments (3, 9, and 13) were shown to exceed the standard over 100 days per year. Three additional catchments in Chorro Valley were in exceedance 35-100 days annually with only two Chorro catchments at the lowest frequency of exceedance. This highlights the importance of considering the Chorro Valley subwatershed in *E. coli* management considerations even though seasonal medians do not strongly indicate this need.

These results are consistent with land-use, geological, and agricultural data throughout the watershed. Catchments 6 and 8, modeled with highest seasonal medians and exceedance frequencies, are primarily developed land and rangeland, categories shown to contribute significantly to *E. coli* concentration due to animal or human waste contamination (U.S. Census Bureau 2014). As shown in Figure 16, Chorro Valley has significant areas of cropland and rangeland, which explains peaks in exceedance frequencies due to storm events washing fecal bacteria from cows into the stream system. However, Los Osos Valley has significant human density and rangeland, thus contributing dual sources of fecal bacteria and explaining the spatially represented *E. coli* concentrations seen in the results.

WARMF Analysis Constraints

Assumptions and Limitations

A WARMF generated watershed model is inherently coupled with assumptions and limitations due to model capacity, data resolution, and computer power demands. A review of the assumptions and limitations is listed here, but for detailed WARMF methods and assumptions, see Appendix C.

The BASINS automatic delineation tool used to define catchments and streams for WARMF resulted in 13 catchments with corresponding stream reaches and associated catchment area and slope and stream reach, length, slope, depth, width, minimum elevation, and maximum elevation. These parameters were calculated based on high resolution DEM and NHD datasets, however WARMF simplifies the stream network due to capacity limitations. This resulted in exclusion of some tributaries from WARMF analysis and shifted focus on this watershed analysis to mainstem Chorro and Los Osos Creeks. The associated assumption to this limitation is that nutrient and pollutant loading from upstream tributaries should be reflected in observed water quality and streamflow monitoring stations along the mainstem creeks. While this limited our spatial analysis to larger identification areas, it is assumed this narrowed identification is valuable.

WARMF allows one observed water quality and one observed hydrology station per catchment. However, with thirteen delineated catchments within a 48,000-acre watershed model results should still be representative given sufficient spacing of monitoring stations.

Additionally, point source data can be added to the model regardless of whether an observed water quality station is already input to the catchment.

Data Gaps

Data limitations were a potential source of uncertainty. The best available data was used; however, more frequent and widespread observed water quality and flow parameters could strengthen the model. Specifically, increased monitoring of suspended sediment concentration from the current 3 sites to sites throughout the watershed will increase capacity to address sedimentation to the estuary and determine key source areas.

Targeting evenly representative and spaced monitoring stations may give the Estuary Program a better understanding of the processes in the watershed. Increased monitoring of upland Chorro Creek tributaries may provide valuable insight regarding source areas of parameters of concern. Specifically, monitoring upper San Bernardo Creek and San Luisito Creek above sites 310SBE and 310SLU may prove valuable. Many monitoring sites lack regularly consistent and long-term data. Continual and long-term monitoring of sites should be prioritized to ensure data represents reality. For this analysis, all sites had fewer than 350 observed data points over the 12-year period being examined. While many data gaps can likely be explained due to creeks seasonally running dry, this phenomenon must be better documented to differentiate between creek seasonality and gaps in data collection.

Additional uncertainties stem from daily precipitation data sourced from outside the watershed due to limited data availability. The Estuary Program recommended this data source after traditional meteorological data sources proved too coarse in scale for value in this analysis. These values may not fully reflect coastal precipitation effects and thus may incorrectly inform modeled hydrologic flow. It was not possible to access accurate agricultural, pesticide, and fertilizer data due to limited data availability and budget constraints. It was assumed that the land-use data input was representative of these practices throughout the watershed. Finally, land application data used in the model was based on expert consultation with the CSLRCD and estimates and may not fully reflect nitrate as nitrogen, orthophosphate as phosphate, and fecal indicator bacteria impacts of cattle in the watershed. It was assumed that the estimated impact of cattle was more valuable than eliminating this variable due to the high percentage of rangeland found in the watershed and the intimate link between large mammals and water quality processes.

Catchments 5 and 13 at the edge of the watershed bordering the Pacific Ocean were assumed to have much higher uncertainty in model output due to their location, lack of observed river network data upon which to calibrate, and inclusion of the estuary.

Finally, detailed information regarding farming and grazing practices in the watershed is currently largely unknown. After contacting many local organizations and experts, we were able to only get a very general sense of cattle rangeland extent, fertilizer management, pesticide usage, and irrigation practices. All of these variables have large impacts on water quality throughout the watershed and collecting further, more detailed information on these practices should be prioritized.

Recommendations

Watershed analyses revealed several key locations for the estuary program to focus future water quality protection and restoration efforts. The priority concern identified in Chorro Valley is phosphate levels. To address this pollutant, the Estuary Program should work with partners and stakeholders to address phosphates coming from the California Men's Colony WWTP. The tertiary treatment upgrade undertaken in 2007 has proven to have little to no effect on phosphate levels in effluent to Chorro Creek and should be addressed to decrease concentrations throughout the subwatershed. Additionally, cattle fencing and rural road management may help to reduce these concentrations. In 2014, the Estuary Program began an extensive rural road enhancement project. The progress and impact of these enhancements must be monitored to ensure effectiveness in decreasing nutrient loading to streams.

The priority concerns identified in Los Osos Valley are nitrate and *E. coli* levels. To address these concerns, the Estuary Program should consider working to assess and manage fertilizer inputs from cropland in Los Osos. Additionally, increased installation of cattle-exclusion projects in Los Osos may decrease quantity of cattle waste that makes it into the streams and subsequently decrease bacteria loading. Finally, monitoring the continued transition of the town of Los Osos off of septic will ensure maintenance or decrease of observed *E.* coli concentrations.

Finally, further measures should be taken to identify major source areas of sediment loading to streams during peak storm events to better address sedimentation throughout the watershed.

Spatially addressing these sources of water quality degradation will allow the Estuary Program the ability to make a positive impact on recreation, clean drinking water, estuary health, and the habitats and wildlife populations found within the watershed.

4. Climate Change in Conservation and Restoration Planning

Climate change is causing species ranges to shift and is altering ecological dynamics (Heller and Zavaleta 2009). Any conservation planning effort should consider climate change in order to be effective in the long-term. One of the main concerns is that current conserved lands will become unsuitable in the future and that species need a way to shift their ranges if necessary, making connectivity between reserves increasingly important. Conservation planning and restoration will need to be more forward-looking. The Estuary Program should consider including climate change into their conservation and restoration planning process. This literature review and analysis seeks to inform the Estuary Program of the latest climate models and some of the research and work being done to integrate climate change into conservation.

Projected Climate Change in the Morro Bay Watershed

Earlier projections for climate change in San Luis Obispo County come from a report by the GEOS Institute and the Local Government Commission, who wrote an integrated climate adaptation plan for San Luis Obispo County that was published in 2010. The general expectations for climate change in the county are: hotter, drier, longer summers, more severe storms, increased wildfire frequency, and sea level rise (Koopman, Meis, and Corbett 2010). The General Circulation Models (GCMs) used for the Koopman et al. analysis were CSIRO, MIROC, and HadCM under the "business as usual" A2 emissions scenario, which were based on modeling efforts from the Intergovernmental Panel on Climate Change (IPCC) fourth assessment. The model was then downscaled to 8 km for analysis in the county.

The potential impacts that were identified for the Morro Bay watershed were risk of increased sedimentation in Morro Bay, saltwater intrusion and flooding in Chorro and Los Osos Creeks, and declines in coastal prairie, dune scrub, and isolated endangered species such as sea blight, salt marsh bird's beak, and the Morro shoulderband snail (Koopman, Meis, and Corbett 2010). The decreased coastal fog could also lead to loss of the elfin forest, while acidification and changes in ocean currents threaten the estuary's eelgrass beds (Koopman, Meis, and Corbett 2010). An increase in fires combined with more storms would increase sedimentation in the watershed, making streams less suitable for steelhead which require clear, cold water with a high dissolved oxygen concentration. Saltwater intrusion and sedimentation are already water quality concerns, thus addressing those issues would be beneficial for reducing current stresses and for climate change adaptation.

Since the publication of the report by Koopman, et al., the IPCC released its fifth climate assessment, with GCMs that now show more agreement about how precipitation will change in California (Davis et al. 2013). An analysis similar to the one done by Koopman et al. (2010) would need to be done for San Luis Obispo County using fifth assessment climate models to determine how much the impacts predicted in that report have changed with these new climate projections. This analysis will provide a brief explanation of the new assessment models and an example of how they can be used to predict changes in drought stress.

These new climate models use four representative concentration pathways (RCPs) instead of emission scenarios that previous GCMs used, which were known as A2 and B1. They are referred to as representative concentration pathways because they represent the range of radiative forcing values found in the literature and because they use concentration instead of emissions (van Vuuren et al. 2011). The four RCPs are described in Table 7, which is modified from van Vuuren et al. 2011.

Table 7. Representative concentration pathway descriptions.

RCP	Radiative Forcing Value	CO_2 Equivalent Concentration	Description
2.6	2.6 W/m^2	~490 ppm	Peak in radiative forcing at 3 W/m2 before 2100, declines to 2.6 W/m^2 by 2100
4.5	4.5 W/m^2	~650 ppm	Stabilization at 4.5 W/m^2 by 2100 without overshoot
6	6.0 W/m^2	~850 ppm	Stabilization at 6.0 W/m^2 by 2100 without overshoot
8.5	8.5 W/m^2	~1370 ppm	Radiative forcing rises for 8.5 W/m^2 by 2100

The Basin Characterization Model

The Basin Characterization Model (BCM) was developed by Alan Flint and Lorraine Flint of the US Geological Survey and published in 2012. The BCM is a regional water balance model that mechanistically models the pathways of precipitation as evaporation and plant transpiration; infiltration and potential recharge; and runoff (Micheli et al. 2012). Water balance components are calculated based on climate, topography, soils, geology, and solar energy balance. Climate futures are a combination of a GCM and an RCP, which were then downscaled to 270 m and put into the BCM. The model was first used for analyzing watershed response to climate change in the San Francisco Bay Area, and has been extended to the entirety of California. The 2011 version of the model used GCMs from the fourth IPCC assessment and has since been updated to the 2014 version, using GCMs from the fifth IPCC assessment.

The scale of the BCM is based on the resolution of the digital elevation model, which is 270 m (DiPietro and Flint 2012), a much finer scale than the projections from Koopman et al, which was at an 8km scale. (2010). Some variables such as potential and actual evapotranspiration, and climatic water deficit can be evaluated at the scale of hillslopes using the BCM, but for most applications it is recommended to consider areas no smaller than a planning watershed (DiPietro and Flint 2012). Data for BCM climate scenarios is freely available from the California Landscape Conservation Cooperate Climate Commons website. Data can be downloaded and then clipped to a particular study area, as was done for this analysis (DiPietro and Flint 2012).

Climatic Water Deficit Projections for the Morro Bay Watershed

Climatic water deficit (CWD) is the amount by which potential evapotranspiration exceeds actual evapotranspiration (Micheli et al. 2012). It is an important ecological variable for vegetation because it combines the effects of solar radiation, evapotranspiration, and air temperature, resulting in an estimate of drought stress on the soil and plants (Micheli et al. 2012). CWD starts to accumulate in May, peaks in July, and decreases in September, but is summed annually for the water year (October to September) (Micheli et al. 2012). CWD is especially important for vegetation management and agriculture in the watershed because it can be thought of as the supplemental amount of water needed to maintain the current vegetation type (Lorraine E. Flint and Alan L. Flint 2012). Increased CWD can contribute to mortality in vegetation from drought stress and lead to changes in vegetation composition, especially the conversion of woodlands to grasslands (Weiss et al. 2013). Higher CWD can also increase fire risk, which is already a concern for the watershed.

To analyze BCM projections for the Morro Bay watershed, data was downloaded and zonal statistics were performed using the outline of the watershed to get the mean, standard deviation, and range. No large-scale spatial patterns were apparent in the watershed for climatic water deficit, so the CWD was averaged over the entire watershed for each 30 year time period. Stronger spatial patterns are more likely with air temperature projections, as the temperature currently tends to be higher inland compared to the coast, and remains cooler over the estuary. The time periods for analysis are described in Table 8 (Weiss et al. 2013).

Table 8. Climate change projection time periods used in the Basin Characterization Model.

Time Period	Dates	Description
Baseline	1951-1980	Last 30-year period of relatively stable climate. Includes the most severe historical 2 year drought (1976-77)
Recent	1981-2010	Already showing some climate changes
Near century	2010-2039	Use with caution because model runs do no consistently model El Nino, La Nina, and Pacific Decadal Oscillation.
Mid-century	2040-2069	Substantial warming becomes apparent and emissions scenarios diverge more strongly, while still being within the scope of long-term management.
End century	2070-2099	Futures diverge strongly according to model and emissions scenario. Substantial vegetation shifts are possible but this time period is beyond typical planning horizons.

The following GCMs were analyzed for RCP 8.5, with the addition of 4.5 and 6.0 for the MIROC GCM:

- Community Climate System Model (CCSM) 4 RCP 8.5
- Flexible Global Ocean-Atmosphere-Land System (FGOALS) model G2 RCP 8.5
- Institut Pierre-Simon Laplace (IPSL) CM5 RCP 8.5
- Model for Interdisciplinary Research on Climate (MIROC) 4.5, 6.0, and 8.5

The IPSL GCM is relatively hotter and drier, while predictions from FGOALS are for less warming and slightly wetter conditions. CCSM projections are in between those two GCMs. Figure 38 shows a comparison between different RCPs for the MIROC model, which in the watershed results in a higher climatic water deficit for RCP 6.0 than for RCP 8.5. Figure 39 compares different models at the same RCP of 8.5.

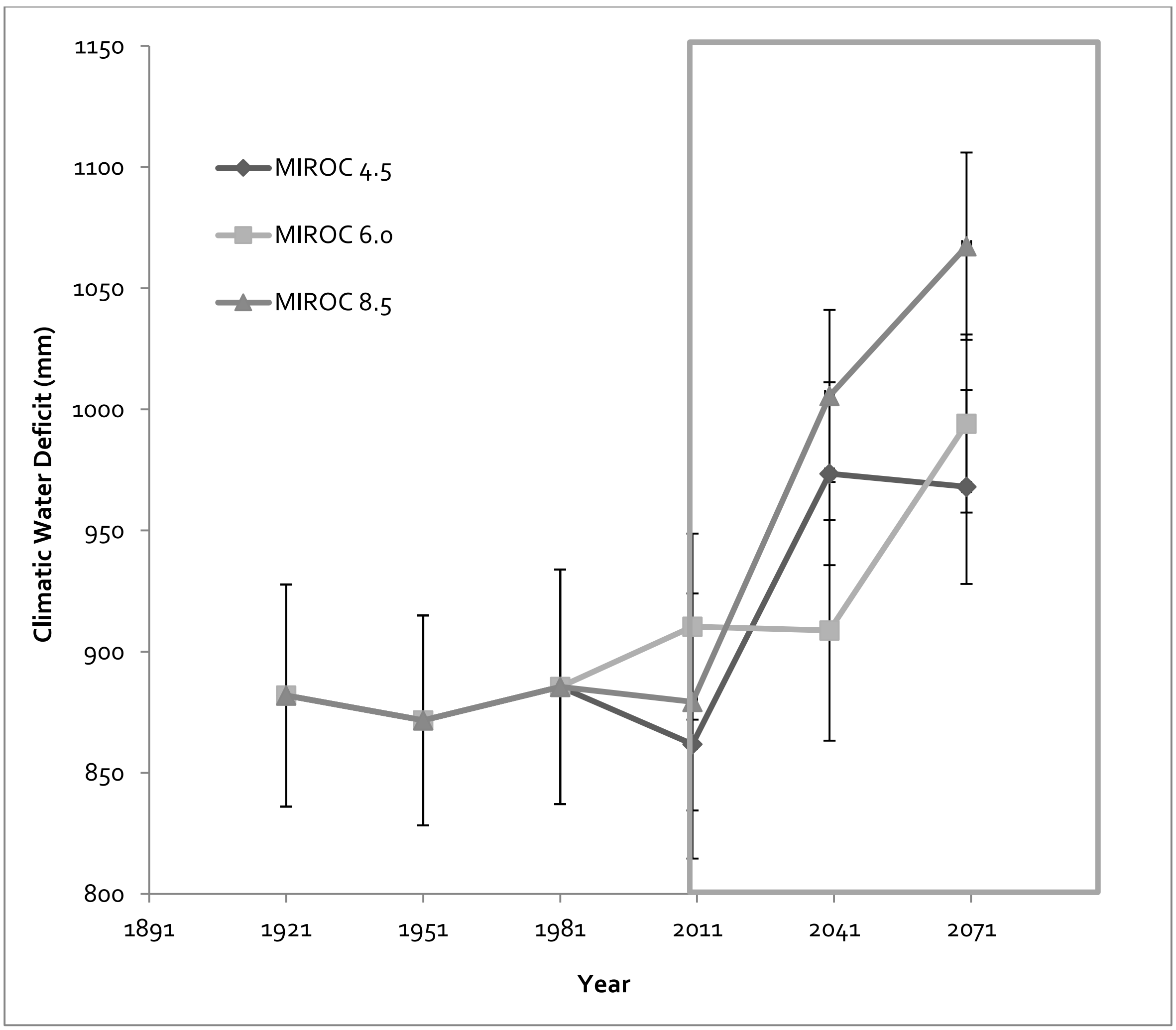

Figure 38. Climatic Water Deficit Projections with MIROC model. The area inside the grey box depicts modeled results.

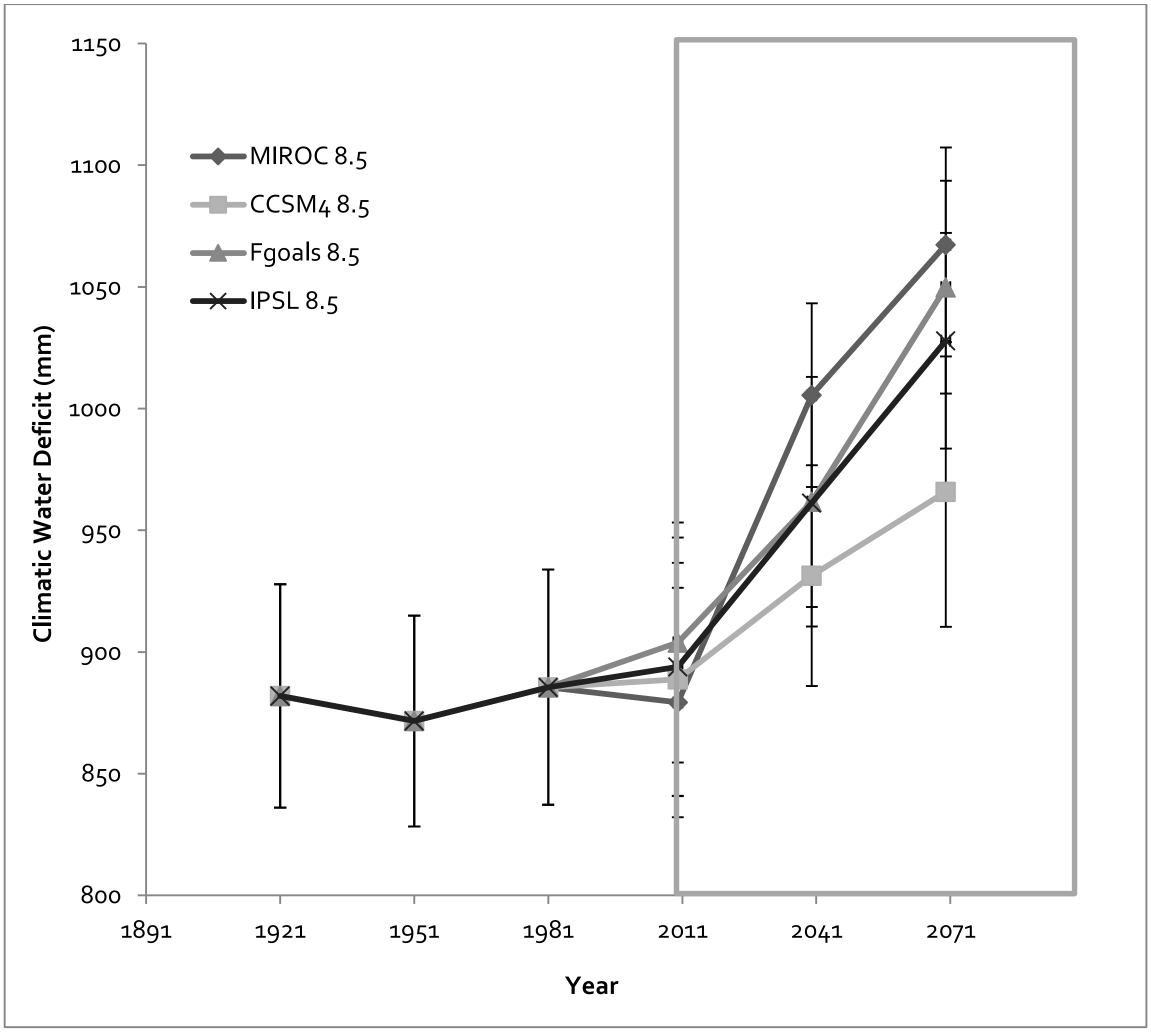

Figure 39. Climatic water deficit projections for different models at RCP 8.5. The area inside the grey box depicts modeled results.

Climatic water deficit is highest in both graphs in the MIROC RCP 8.5 scenario. The 2.6 W/m^2 RCP was not shown because it is too optimistic and not likely to be realized. In this watershed, the CCSM 4 model predicted the smallest increases in CWD, with FGOALS slightly higher than the IPSL model. Overall, these results predict that the watershed will be in a range of CWD that has not been experienced historically. Examining CWD with the Basin Characterization Model is a good place for the Estuary Program to start analyzing climate change on their watershed scale, as it is perhaps the highest resolution couple climate-hydrology model dataset available (Weiss et al. 2013). The dataset has been used to evaluate the resilience of landscapes to climate change and could also be used for analyzing changes to hydrology in the watershed.

Climate-Smart Conservation

The National Wildlife Federation defines climate-smart conservation as " the intentional and deliberate consideration of climate change in natural resource management, realized through adopting forward-looking goals and explicitly linking strategies to key climate impacts and vulnerabilities" (Stein et al. 2014). For the Estuary Program, this means conservation planning to address current and future threats to increase resilience, and taking actions that will be beneficial under a variety of climatic conditions.

Reducing Additional Stresses

Climate change can exacerbate threats such as invasive species because some species may benefit from increases in carbon dioxide concentrations and changes in precipitation patterns and temperatures (Lawler 2009). The Estuary Program is concerned that climate change will make conditions more favorable for invasive species. They completed an Invasive Species Plan in 2010 (Morro Bay National Estuary Program 2012b). Other stressors are the loss of habitat, habitat fragmentation and pollution. Most threatened species are being negatively affected by multiple factors. Removing additional stresses on species and ecosystems can therefore increase resilience to climate change by reducing the overall impact from multiple stressors.

Expanding Reserves

Recommendations for reserve planning in the face of climate change include acquiring areas that are predicted have high species richness, acquiring new reserves between existing reserves to allow species to migrate more easily as climate changes, and acquiring larger reserves instead of many smaller areas (Heller and Zavaleta 2009). Expanding existing networks of reserves can increase resilience by adding redundancy and more places where species can persist (Lawler 2009). For the Estuary Program, looking outside the boundaries of the watershed will be important for understanding how important the habitat in the watershed is important for each species. For species that are endemic to the watershed and coastal San Luis Obispo County, or rely heavily on the estuary, conservation within the watershed is more critical to their survival than for more wide-ranging species. For other species, the causes of their decline or the majority of their range may be located outside of the watershed and the Estuary Program may not need to conserve the majority of their habitat within the watershed to conserve that species.

Groves (2012) describes an adaptation approach that conserves the diversity of the landscape as defined by the topography and soils. Lawler also recommends that to allow for resilience under a variety of climate scenarios, reserves should be located so they can capture a heterogeneous set of habitats that are diverse topographically, edaphically, and hydrological (Lawler 2009). This approach would be used to complement other systematic conservation planning processes that also focus on species. This strategy assumes that the diversity and distribution of species is driven by geophysical variables, and is not as effective of a strategy for preserving birds and mammals that are not tied as strongly to a particular soil type and microhabitat (Groves et al. 2012). If the objectives are to conserve particular species or communities, such as threatened plant and animal species, or Baywood fine sands habitat, then approaches will be needed that are more tailored to those species or habitats and their particular stressors.

Adding buffers around existing reserves is also recommended. In coastal areas larger reserves will be especially important so that species can shift inland as sea level rises (Lawler 2009). Expanding reserves is a complementary strategy to improving landscape connectivity (Heller and Zavaleta 2009).

Enhancing Connectivity

In a comprehensive review of the past twenty-two years of climate change adaptation research, Heller and Zavaleta (2009) found that the most frequent recommendation was to increase connectivity. Increasing connectivity has at least two purposes: to allow species and communities to naturally adapt by shifting their distribution, and to enhance the resilience to change (Groves et al. 2012). Even assuming climate change was not an issue, improving connectivity among habitat patches or reserve networks has been recommended, especially for species with large home ranges (Groves et al. 2012).

The process of enhancing connectivity can be difficult because there is a lack of understanding about what types and locations of connectivity are required to allow species to move, and whether those will change as climate changes (Groves et al. 2012). Because corridors are species-specific and depend on behavior and affinities for habitat types (Lawler 2009), connectivity is best analyzed for specific species. For example, one could analyze connectivity before and after adding in Marxan selected parcels to determine how much the addition of those parcels contributes to allowing each species of concern to adapt and move in the watershed.

Hodgson et al. (2009) emphasized that connectivity is not the only attribute that should be considered and that conservation planning should focus on conserving existing high quality habitats, removing other sources of threat, and maintaining and restoring larger habitat areas. A new kind of connectivity is needed for resilience to climate change that would connect warmer and colder areas, drier and wetter areas, and areas that are different instead of only connecting similar habitats (Hodgson et al. 2009). Also, there are uncertainties as to the effectiveness of increasing connectivity because connectivity can be species-specific and the ability of a species to use a corridor depends on species-specific behavior and their affinity for particular habitats (Lawler 2009). When increasing connectivity there is also the risk of increasing the ability of invasive species to spread. This should be considered in conservation planning analyses.

Climate Change and Restoration

Restoration can provide multiple benefits for conservation and climate change adaptation. In addition to creating and enhancing habitat for some species, riparian restoration can decrease stream temperatures in the future (Heller and Zavaleta 2009) and provide connectivity (Lawler 2009). Reducing stream temperature is especially important for salmonids such as steelhead trout that require cold water. Restoring floodplains and wetlands can create areas for storage of water when flows are higher (Lawler 2009). Adding trees along riparian zones can provide shade that will decrease evaporation of streams during drier periods, which is important for fish as well as amphibian species and turtles.

Restoration of riparian habitats becomes more significant with climate change for several reasons. Riparian habitats are adapted to hydrologic disturbance and can tolerate variability in environmental conditions, which will likely become more variable with climate change (Seavy et al. 2009). Riparian ecosystems also connect low and high elevation areas of the landscape and provide corridors along which wildlife can move. Their cooler temperature when shaded can provide refugia for species during especially hot days (Seavy et al. 2009).

However, the focus of restoration may need to shift from recreating historic assemblages of species to focusing on potential future ecosystem services (Lawler 2009). Using ecosystem services as an approach focuses more on function and process, but information about how these services will be affected by climate change is needed in order to use this strategy. Restoration goals will be a moving target because of changes in hydrology and species distributions caused by climate change, so a shift in focus to restore ecosystem services instead of particular species will help prepare ecosystems for new conditions and new sets of species (Lawler 2009). If a species-focus is used, then accurate predictions of which species will be suitable at sites in the future is needed for restoration planning.

Point Blue Conservation Science installed their first "climate-smart" restoration site planting in December 2011 and January 2012. The goals of their restoration design were to select plants that were resilient to extreme weather events and that would provide resources for wildlife for as long as possible. To develop the planting palette, factors to consider were identified including: tolerating full or partial sun; tolerating clay soil, tolerating wet conditions, tolerating dry conditions, being fire adapted, being evergreen, whether it provides fruit, nectar, or seeds, and seed; and flower phenology (Parodi et al. 2014). A tool using Excel was created that includes a list of possible plants and generates graphs showing how well the chosen palette meets each of these conditions. A graph of plant resources during the year is also generated so that the user can change the planting palette and see how it changes the phenology of the restoration site and whether there are enough plant species to survive in a variety of conditions.

Although many more species were used than in a traditional restoration project, seeds were still sourced from within the watershed. Sourcing seeds from outside the local area should be decided by a larger group of stakeholders because of the risks of outbreeding depression and changing the gene pool of any rare plants that are in isolated populations. The tool and guide were created for Marin and Sonoma counties, but could be adapted for San Luis Obispo County by working with the Point Blue Conservation Science and local experts with knowledge of plant phenology in the watershed. For the Estuary Program to start using a more climate oriented approach, the goals for restoration projects would need to first be identified and the factors when choosing plants would need to be selected based on current and future projections of climate change in the watershed, which could come from the BCM model. A climate-smart approach would allow their restoration projects to be better able to withstand the variability and drier conditions that can be expected in the watershed with climate change.

5. Conclusions

The culmination of our biodiversity and water quality analysis led us to valuable conclusions addressing the biodiversity and water quality conservation goals of the Estuary Program. These are typically treated as separate objectives and these results present the Estuary Program with the opportunity to explore the synergies of how multiple conservation goals, such as biodiversity conservation and water quality management, can be combined together into a single conservation plan to achieve multiple goals (see Appendix E). The Estuary Program should also include climate-smart conservation principles in the further design and implementation of conservation and restoration projects to make the watershed more resilient to climate change and conserve species and habitats now, and into the future.

References

Airamé, Satie, Jenifer E. Dugan, Kevin D. Lafferty, Heather Leslie, Deborah A. McArdle, and Robert R. Warner. 2003. "Applying Ecological Criteria to Marine Reserve Design: A Case Study from the California Channel Islands." *Ecological Applications* 13 (sp1): 170–84.

Anderson, Kathryn, and Diana Weinhold. 2008. "Valuing Future Development Rights: The Costs of Conservation Easements." *Ecological Economics* 68 (1-2): 437–46. doi:10.1016/j.ecolecon.2008.04.015.

Ball, Ian R., Hugh P. Possingham, and Matthew E. Watts. 2009. "Chapter 14 - Marxan and Relatives: Software for Spatial Conservation Prioritization." In *Spatial Conservation Prioritisation: Quantitative Methods and Computational Tools*, 185–95. Oxford, UK: Oxford University Press.

Basnyat, Prakash, Lawrence D. Teeter, Kathryn M. Flynn, and B. Graeme Lockaby. 1999. "Relationships between Landscape Characteristics and Nonpoint Source Pollution Inputs to Coastal Estuaries." *Environmental Management* 23 (4): 539–49.

Billen, Gilles, Josette Garnier, André Ficht, and Christine Cun. 2001. "Modeling the Response of Water Quality in the Seine River Estuary to Human Activity in Its Watershed over the Last 50 Years." *Estuaries* 24 (6): 977–93.

Boyd, James, Kathryn Caballero, and David Simpson. 2000. "The Law and Economics of Habitat Conservation: Lessons from an Analysis of Easement Acquisitions." Board of Trustees of the Leland Stanford Junior University Stanford Environmental Law Journal. http://www.lexisnexis.com/hottopics/lnacademic/?sterms=PUBLICATION(Stanford+environmental+law+journal)&verb=sr&csi=139090&sr=AUTHOR(Boyd)%2BAND%2BTITLE(Law+and+economics+of+habitat+conservation%3A+Lessons+from+an+analysis+of+easement+acquisitions%2C+the)%2BAND%2BDATE%2BIS%2B2000.

California Department of Fish and Wildlife. 2014. "California Natural Diversity Database (CNDDB)." http://www.dfg.ca.gov/biogeodata/cnddb/.

Cardinale, Bradley J., J. Emmett Duffy, Andrew Gonzalez, David U. Hooper, Charles Perrings, Patrick Venail, Anita Narwani, et al. 2012. "Biodiversity Loss and Its Impact on Humanity." *Nature* 486 (7401): 59–67. doi:10.1038/nature11148.

CA State Parks. 2015. "Morro Bay State Park." *California Department of Parks and Recreation*. http://www.parks.ca.gov/?page_id=594.

Coastal San Luis Resource Conservation District. 2008. *Morro Bay On-Farm Coastal Water Qualoty Implementation Project ("Project Clearwater")*. 06-128-533-0.

Davis, Frank W., Jason Kreitler, Oliver Soong, David Stoms, Stephanie Dashiell, Carrie Schloss, Lee Hannah, Whitney Wilkinson, and John Dingman. 2013. *Cumulative Biological Impacts Framework for Solar Energy Projects in the California Desert*.

Delavenne, J., K. Metcalfe, R. J. Smith, S. Vaz, C. S. Martin, L. Dupuis, F. Coppin, and A. Carpentier. 2012. "Systematic Conservation Planning in the Eastern English Channel: Comparing the Marxan and Zonation Decision-Support Tools." *ICES Journal of Marine Science* 69 (1): 75–83. doi:10.1093/icesjms/fsr180.

DiPietro, Deanne, and Lorraine E. Flint. 2012. "The Basin Characterization Model Downscaled Climate and Hydrology Dataset | California Climate Commons." *California Landscape Conservation Cooperative Climate Commons*. August 16. http://climate.calcommons.org/article/featured-dataset-california-basin-characterization-model.

Fernandes, Leanne, Jon Day, Adam Lewis, Suzanne Slegers, Brigid Kerrigan, Dan Breen, Darren Cameron, et al. 2005. "Establishing Representative No-Take Areas in the Great Barrier Reef: Large-Scale Implementation of Theory on Marine Protected Areas." *Conservation Biology* 19 (6): 1733–44. doi:10.1111/j.1523-1739.2005.00302.x.

Game, Edward T., and Hedley S. Grantham. 2008. "Marxan User Manual - For Marxan Version 1.8.10." University of Queensland, St. Lucia, Queensland, Australia and Pacific Marine Analysis and Research Association.

Groves, Craig R., Edward T. Game, Mark G. Anderson, Molly Cross, Carolyn Enquist, Zach Ferdaña, Evan Girvetz, et al. 2012. "Incorporating Climate Change into Systematic Conservation Planning." *Biodiversity and Conservation* 21 (7): 1651–71. doi:10.1007/s10531-012-0269-3.

Hawes, Ellen, and Markelle Smith. 2005. "Riparian Buffer Zones: Functoins and Recommended Widths." *Yale School of Forestry and Environmental Studies*, April. http://www.eightmileriver.org/resources/digital_library/appendicies/09c3_Riparian%20Buffer%20Science_YALE.pdf.

Heller, Nicole E., and Erika S. Zavaleta. 2009. "Biodiversity Management in the Face of Climate Change: A Review of 22 Years of Recommendations." *Biological Conservation* 142 (1): 14–32. doi:10.1016/j.biocon.2008.10.006.

Herr, J.W., and C.W. Chen. 2012. "WARMF: Model Use, Calibration, and Validation." *American Society of Agricultural and Biological Engineers* 55 (4): 1387–96.

Hodgson, Jenny A., Chris D. Thomas, Brendan A. Wintle, and Atte Moilanen. 2009. "Climate Change, Connectivity and Conservation Decision Making: Back to Basics." *Journal of Applied Ecology* 46 (5): 964–69. doi:10.1111/j.1365-2664.2009.01695.x.

Kitajima, Ann. 2014. *Morro Bay National Estuary Program Summary Report 2014*. Morro Bay National Estuary Program.

Kitajima, Ann, and Annie Gillespie. 2012. *Morro Bay National Estuary Program's Implementation Effectiveness Program For the Morro Bay Watershed: Data Summary Report -- 2012*. http://www.mbnep.org/Library/Files/DataSummaries/2012_Data_Summary_Report_final.pdf.

Koopman, Marie E., Kate Meis, and Judy Corbett. 2010. "Integrated Climate Change Adaptation Planning in San Luis Obispo County."

Lawler, Joshua J. 2009. "Climate Change Adaptation Strategies for Resource Management and Conservation Planning." *Annals of the New York Academy of Sciences* 1162 (1): 79–98. doi:10.1111/j.1749-6632.2009.04147.x.

LCSLO. 2014. "The Land Conservancy of San Luis Obispo County." *The Land Conservancy of San Luis Obispo County*. http://lcslo.org/.

Loreau, Michel, Shahid Naeem, Pablo Inchausti, J. Bengtsson, J. P. Grime, A. Hector, D. U. Hooper, et al. 2001. "Biodiversity and Ecosystem Functioning: Current Knowledge and Future Challenges." *Science* 294 (5543): 804–8.

Lorraine E. Flint, and Alan L. Flint. 2012. *Simulation of Climate Change in San Francisco Bay Basins, California: Case Studies in the Russian River Valley and Santa Cruz Mountains*. US Geological Survey.

Micheli, Elisabeth, Lorraine Flint, Alan Flint, Stuart Weiss, and Morgan Kennedy. 2012. "Downscaling Future Climate Projections to the Watershed Scale: A North San Francisco Bay Case Study." *San Francisco Estuary and Watershed Science* 10 (4). http://escholarship.org/uc/item/01n4z228.

Morro Bay National Estuary Program. 2012a. *Morro Bay National Estuary Program: Comprehensive Conservation Management Plan-2012 Update, Snapshot*. http://www.mbnep.org/Library/Files/CCMP/CCMP%20Update/CCMP_Snapshot_2013-04.pdf.

———. 2012b. *Morro Bay National Estuary Program: Comprehensive Conservation Management Plan--2012 Update*. http://www.mbnep.org/Library/Files/CCMP/CCMP%20Update/CCMP_Update_2013-04.pdf.

———. 2015. "About the Morro Bay National Estuary Program." http://www.mbnep.org/more-about-the-morro-bay-national-estuary-program/.

Murdoch, W., J. Ranganathan, S. Polasky, and J. Regetz. 2010. "Using Return on Investment to Maximize Conservation Effectiveness in Argentine Grasslands." *Proceedings of the National Academy of Sciences* 107 (49): 20855–62. doi:10.1073/pnas.1011851107.

Natural Resource Conservation Service. 2015. "USDA, NRCS Soil Survey." *NRCS Soil Survey*. http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/survey/geo/.

Nicole Smith, Lorraine Clark, James Tomas, Laura Edwards, Kelly Gleason, Jillian Cole, Jacob Hernandez, Amy Smart, and Erin White. 2014. "SLO County RCD Watershed Planning Project.pdf." SLO COunty RCD.

NOAA National Climatic Data Center. 2014. *1981-2010 Climate Normals*. Accessed October 19. http://www.ncdc.noaa.gov/cdo-web/datatools/normals.

NRCS. 2014a. "NRCS Hydrologic Soil Group Definitions : CHI Support." Accessed October 24. http://support.chiwater.com/support/articles/35662-nrcs-hydrologic-soil-group-definitions.

———. 2014b. "Highly Erodible Land Defs | NRCS." Accessed October 24. http://www.nrcs.usda.gov/wps/portal/nrcs/detail/pr/soils/?cid=nrcs141p2_037282.

Parodi, John J., Leia Giambastiani, Nathaniel E. Seavy, Isaiah M. Thalmayer, Eliza Lasky, and Thomas Gardali. 2014. "A How-T Guide and Metadata for the Riparian Restoration Design Database: Marin and Sonoma Counties." Point Blue Conservation Science.

Pionke, Harry B., William J. Gburek, and Andrew N. Sharpley. 2000. "Critical Source Area Controls on Water Quality in an Agricultural Watershed Located in the Chesapeake Basin." *Ecological Engineering* 14 (4): 325–35.

Regional Water Quality Control Board, Central Coast Region. 2011. "Water Quality Control Plan for the Central Coastal Basin." State Water Resources Control Board.

Seavy, Nathaniel E., Thomas Gardali, Gregory H. Golet, F. Thomas Griggs, Christine A. Howell, Rodd Kelsey, Stacy L. Small, Joshua H. Viers, and James F. Weigand. 2009. "Why Climate Change Makes Riparian Restoration More Important than Ever: Recommendations for Practice and Research." *Ecological Restoration* 27 (3): 330–38.

Sims, Aaron E. 2010. *Atlas of Sensitive Species of the Morro Bay Area*. Morro Bay National Estuary Program & California State Parks. http://www.mbnep.org/Library/Files/ATLAS_FINAL2_low.pdf.

Spear, Brian, Douglas Smith, Bryan Largay, and John Haskins. 2008. *Turbidity as a Surrogate Measure for Suspended Sediment Concentration in Elkhourn Slough, CA*. WI-2008-04. California State University Monterey Bay: The Watershed Institute.

Stein, B.A., P. Glick, N. Edelson, and A. Staudt. 2014. "Climate-Smart Conservation: Putting Adaptation Principles into Practice." National Wildlife Federation.

Tilman, David. 1999. "The Ecological Consequences of Changes in Biodiversity: A Search for General Principles 101." *Ecology* 80 (5): 1455–74.

Tilman, David, David Wedin, and Johannes Knops. 1996. "Productivity and Sustainability Influenced by Biodiversity in Grassland Ecosystems." *Nature* 379 (6567): 718–20.

U.S. Census Bureau. 2014. "Morro Bay (city) QuickFacts from the US Census Bureau." Accessed October 31. http://quickfacts.census.gov/qfd/states/06/0649362.html.

USDA, National Agricultural Statistics Service. 2012. *2012 Census of Agriculture - County Data*. http://agcensus.usda.gov/Publications/2007/Full_Report/Volume_1,_Chapter_1_State_Level/Nebraska/nev1.pdf.

USEPA. 2012a. "5.11 Fecal Bacteria." *Water: Monitoring & Assessment*. http://water.epa.gov/type/rsl/monitoring/vms511.cfm.

———. 2012b. "What Are Suspended and Bedded Sediments (SABS)." *What Are Suspended and Bedded Sediments (SABS)?*. http://water.epa.gov/scitech/datait/tools/warsss/sabs.cfm.

———. 2012c. *Recreational Water Quality Criteria*.

———. 2012d. "Monitoring & Assessmnet: 5.7 Nitrates." March 6. http://water.epa.gov/type/rsl/monitoring/vms57.cfm.

———. 2013a. "Watershed Analysis Risk Management Framework (WARMF)." *Watershed Analysis Risk Management Framework (WARMF)*. http://www.epa.gov/athens/wwqtsc/html/warmf.html.

———. 2013b. "BASINS (Better Assessment Science Integrating Point & Non-Point Sources)." *BASINS (Better Assessment Science Integrating Point & Non-Point Sources)*. http://water.epa.gov/scitech/datait/models/basins/index.cfm.

———. 2015. "Estuaries and Coastal Watersheds | Estuaries and Coastal Watersheds | US EPA." Accessed March 8. http://water.epa.gov/type/oceb/nep/index.cfm#tabs-2.

US Geological Survey. 2014. "National Land Cover Database 2011 (NLCD 2011)." *Multi-Resolution Land Characteristics Consortium (MRLC)*. May. http://www.mrlc.gov/nlcd2011.php.

Van Vuuren, Detlef P., Jae Edmonds, Mikiko Kainuma, Keywan Riahi, Allison Thomson, Kathy Hibbard, George C. Hurtt, et al. 2011. "The Representative Concentration

Pathways: An Overview." *Climatic Change* 109 (1-2): 5–31. doi:10.1007/s10584-011-0148-z.

Watts, Matthew E., Ian R. Ball, Romola S. Stewart, Carissa J. Klein, Kerrie Wilson, Charles Steinback, Reinaldo Lourival, Lindsay Kircher, and Hugh P. Possingham. 2009. "Marxan with Zones: Software for Optimal Conservation Based Land- and Sea-Use Zoning." *Environmental Modelling & Software* 24 (12): 1513–21. doi:10.1016/j.envsoft.2009.06.005.

Weiss, Stu, Alan Flint, Lorraine Flint, Healy Hamilton, Miguel Fernandez, and Lisa Micheli. 2013. *High Resolution Climate-Hydrology Scenarios for San Francisco's Bay Area*.

Wenger, Seth. 1999. "A Review of the Scientific Literature on Riparian Buffer Width, Extent, and Vegetation." Office of Public Service & Outreach Institute of Ecology. University of Georgia. https://www.utexas.edu/law/centers/cppdr/services/Improving%20Streams%20web/Work%20Groups/Public%20Lands/Wegner_1999_Review_of_buffer_width.pdf.

Appendix A. Estuary Program Partners

The Estuary Program frequently works with other organizations to raise funds and implement conservation and restoration projects. Other entities own land or regulate water quality in the watershed. These partnerships played an important role in the completion of this project as expert consultants and will likely be involved with the possible future acquisition of conservation easements and collaboration with landowners. A few of those groups are described below.

The Land Conservancy of San Luis Obispo County

The Land Conservancy of San Luis Obispo County has operated within the Morro Bay watershed for 30 years with the mission of setting aside local lands for wildlife, recreation, farming, and ranching (LCSLO 2014). They fulfill their mission by conserving lands through acquisitions, easements, and urban planning, caring for those lands through restoration activities, and promoting their work through community events and education (LCSLO 2014). The Land Conservancy is one of the agencies within the watershed with the ability to purchase and acquire easements and is therefore important in conservation and watershed management.

California State Parks

The California State Parks system owns and operates a large area within the Morro Bay watershed as part of Morro Bay State Park. The mission of the State Parks system is to help preserve the regions biological diversity and natural resources (CA State Parks 2015). Within Morro Bay State Park, the state implements small-scale restoration activities that may impact watershed management and health by impacting processes such as terrestrial runoff, sedimentation, and groundwater stores.

Central Coast Regional Water Quality Control Board

The Central Coast Regional Water Quality Control Board aims to develop and enforce water quality objectives and implement plans to protect the central coast region's waters (Regional Water Quality Control Board, Central Coast Region 2011). The 2011 Water Quality Control Plan for the Central Coastal Basin (Basin Plan) investigates how surface and groundwater quality in the Central Coast should be managed by looking at beneficial water uses, describing what those uses mean for water quality objectives and management, recommending an implementation plan to meet these objectives, suggesting plans and policies to protect central coast water quality (Regional Water Quality Control Board, Central Coast Region 2011). This plan is implemented through waste discharge requirements enforced by the Regional Water Quality Control Board as well as through encouraging water use stewardship throughout the region (Regional Water Quality Control Board, Central Coast Region 2011). Most of the standards that the Estuary Program uses when evaluating water quality originate in the Basin Plan, and were also used for this project.

Coastal San Luis Resource Conservation District

The Coastal San Luis Resource Conservation District (CSLRCD) works to protect and enhance natural resources in Coastal San Luis Obispo County through education, restoration and collaboration with local stakeholders. They seek to work directly with farmers, ranchers, and landowners to protect soil, water, and natural habitats. Through these collaborations, CSLRCD has generated several vital studies and relationships to quantify impacts of ranching and agriculture on watershed hydrology and ecology.

Appendix B. Detailed Marxan Methods — Generating Input Files

Dividing the Watershed into Parcels and Updating Parcel Boundaries File

To obtain the parcel boundaries, an outline of the Morro Bay watershed obtained from the Estuary Program was used in Google Earth to determine the parcel outlines. This file was then converted to a shapefile for use in ArcGIS. Unfortunately, these parcel outlines were not current and did not accurately reflect all of the parcel boundaries in the watershed as of 2014. In order to obtain the current parcel boundary shapefile, it would have been necessary to purchase this information file from ParcelQuest, a third party private company, because San Luis Obispo County no longer owns the rights to distribute parcel data. The ParcelQuest data would have cost $2,500 to acquire, which is outside of the project budget. Consequently, it was decided that the best course of action available was to manually edit the outdated parcel boundary file.

Boundaries were manually edited in ArcGIS by making visual comparisons between the outdated parcel boundary shapefile and the San Luis Obispo County PermitView website's current parcel boundaries. Due to the nature of manually adjusting polygon edges in ArcGIS, it was impossible to get an exact match to the PermitView site. Therefore, there were small discrepancies in the shape and area of the parcels in the edited shapefile. These differences were usually small (less than 1-2 acres) which was deemed an acceptable range of error.

Creating Locked In/Locked Out Parcels and Buffers

State and Federally owned parcels had a land value of $0 and an area of 0 acres. While there was no way to obtain another monetary estimate, the San Luis Obispo PermitView website was used to find an acreage estimate based on a GIS geometric calculation. These $0 parcels were *locked in or out* of the Marxan analysis. A parcel was chosen to be *locked in* if there was a suitable amount of habitat and suitable land use for conservation within the parcel. Parcels that had over 50% urban areas were *locked out* of the analysis. Golf courses were considered "suitable" habitat. If they had $0 value, they were *locked in* to the analysis. Additionally, all federal and state open space and Camp San Luis Obispo were locked into the analysis due to their high conservation value. Parcels with conservation or open space easements already existing on the property were also selected to be *locked in* to the Marxan analysis.

Some parcels were excluded from analysis. These were small urban parcels (land use code: residential single family, residential multifamily, residential suburban, commercial, and city) of less than two acres. They were excluded from the analysis because urban land was assumed to have little value for species biodiversity. Additionally, it is unlikely that these types of properties will be put into conservation easements. After excluding urban parcels, there were approximately 430 parcels for analysis.

A 100 meter buffer was created on each side of major rivers and tributaries. Major waterways were those listed as "channels" in the Wetland and Riparian survey shapefile provided by the Estuary Program. This buffer size was recommended by Hawes and Smith (2005) Wenger and (1999) as the best buffer size for protecting riparian species, wide ranging mammals, and birds. Given the abundance of riparian species within the watershed, a buffer seemed advantageous in identifying priority areas, particularly in some of the larger parcels where the entire parcel may not have equal conservation value. These buffers also provide smaller, more manageable units within which the Estuary Program can implement different conservation or restoration measures. Once the buffer was created, there were approximately 670 parcels for analysis. With all of this data generated, it was combined into the appropriate file type and format for input into Marxan (see Marxan manual for more specifics about file type and format).

Conservation Features and Targets

The conservation features of interest in this analysis were sensitive species and habitats important for these species. Species data to determine species richness was obtained from the Morro Bay Atlas of Sensitive Species (Atlas) written by Aaron Sims (2008), in collaboration with Michael Walgren and Lisa Andreano, and the California Natural Diversity Database (California Department of Fish and Wildlife 2014). The CNDDB is for all of California; therefore the data was clipped to the watershed boundary. The CNDDB only contains data for sensitive species and records occurrences. It gives no measure of abundance, density, etc. Atlas data contained preferred habitat, occurrences, and general distribution data for all sensitive species in the watershed. Both occurrences and general distribution were measures of recorded sightings of a species. Preferred habitat is a measure of habitats known to be used or preferred by a particular species. The preferred habitat data was generated and ground-truthed by Michael Walgren and Lisa Andreano at California Department of Parks and Recreation (CDPR). For the occurrence and general distribution data, several sources were often used including CDPR and CNDDB. All data was reviewed for accuracy by Michael Walgren and Lisa Andreano.

After filtering the data, a shapefile combining the Atlas and CNDDB data was created in ArcGIS. The Atlas and CNDDB datasets were combined to provide the greatest volume of data for Marxan. This shapefile was used to generate the species list that was then input into the conservation feature file for Marxan. In this file, each species was given a unique identification number and a target of 30% of the total number of occurrences within the watershed. Thirty percent was selected as the starting value as it is a commonly used value in the Marxan literature (Watts et al. 2009; Delavenne et al. 2012). Occurrences were used instead of area because although a parcel may contain a species, the entire area of the parcel may not be suitable habitat.

Important habitats for species were also added to the conservation feature file. Many of these habitats would be selected by Marxan because they support rare and sensitive species.

It was important, however, to give extra weight to particularly valuable habitats to ensure that they had a minimum level of inclusion in the final output. These habitats, and their locations within the watershed, were identified in the Atlas. Baywood fine sands, serpentine soils, and ponds were also added to the habitat list in the conservation feature file from the Atlas because they were deemed valuable for the persistence of the watershed's sensitive species. Several habitats that were mapped in the Atlas were excluded from the conservation feature file because the habitat was not within the boundaries of the parcels or it was not determined to be valuable species habitat. Excluded habitats include: urban, agricultural, Monterey Pine (not native), eucalyptus (not native), and coastal estuarine habitat (only covered the estuary). All habitats were given a target of 10% because preserving habitats was not the primary objective for the analysis. While there is obvious overlap between species and habitat targets, setting targets too high can stifle Marxan by reducing the flexibility of the model.

Conservation Feature Penalty Factor

The conservation feature penalty factor determines the size of the penalty assigned to the overall Marxan scenario score. The Marxan manual recommends using the lowest value possible of the same order of magnitude as the number of conservation features present. For example if there are 60 conservation features in the watershed the penalty factor should be set at 10. If there are 150 conservation features the penalty factor should be set at 100. The penalty factor should only be increased from the recommended value if Marxan is failing to meet the targets of many of the conservation features.

For this analysis, there were 107 conservation features and so the initial penalty factor was set to 100. With this value, Marxan was failing to meet the target of several of the conservation features. Because of this, the penalty factor was increased to 200. This value balanced too high of penalties while still driving Marxan to meet the vast majority of its targets.

Location of Species in Parcels

The planning unit versus conservation feature file informs Marxan which conservation features are found within each planning unit. To generate the initial data for this file, the Atlas polygons, CNDDB, habitats, and soils shapefiles were intersected with the parcel shapefile in ArcGIS. This output indicated in which parcels species occur. A similar process was done for the point data from the Atlas. Once the files were intersected, the attribute table was exported into Excel. Because there were many repeat sightings of the same species in a parcel, it was necessary to delete the duplicate values since only presence/absence data was being used, not abundance. Once the duplicates were removed, each unique combination of conservation feature and planning unit was given an occurrence of 1. The vertical/relational format of this file was used rather than the horizontal/tabular format because it was closer in layout to the output from ArcGIS and required less manipulation.

Conservation Achieved Through Locked In Parcels

Since the locked in parcels composed a significant portion of the watershed, it was necessary to explore what portion of the conservation targets were met through the locked in parcels alone. When this was investigated, it was found that a large portion of the conservation targets were being met by the locked in parcels, as shown by three selected scenarios in Figure 40. This is encouraging because it suggests that many of the species are already being protected. Conversely, not all of these areas are well managed or protected in perpetuity. These may be issues to explore further in these parcels.

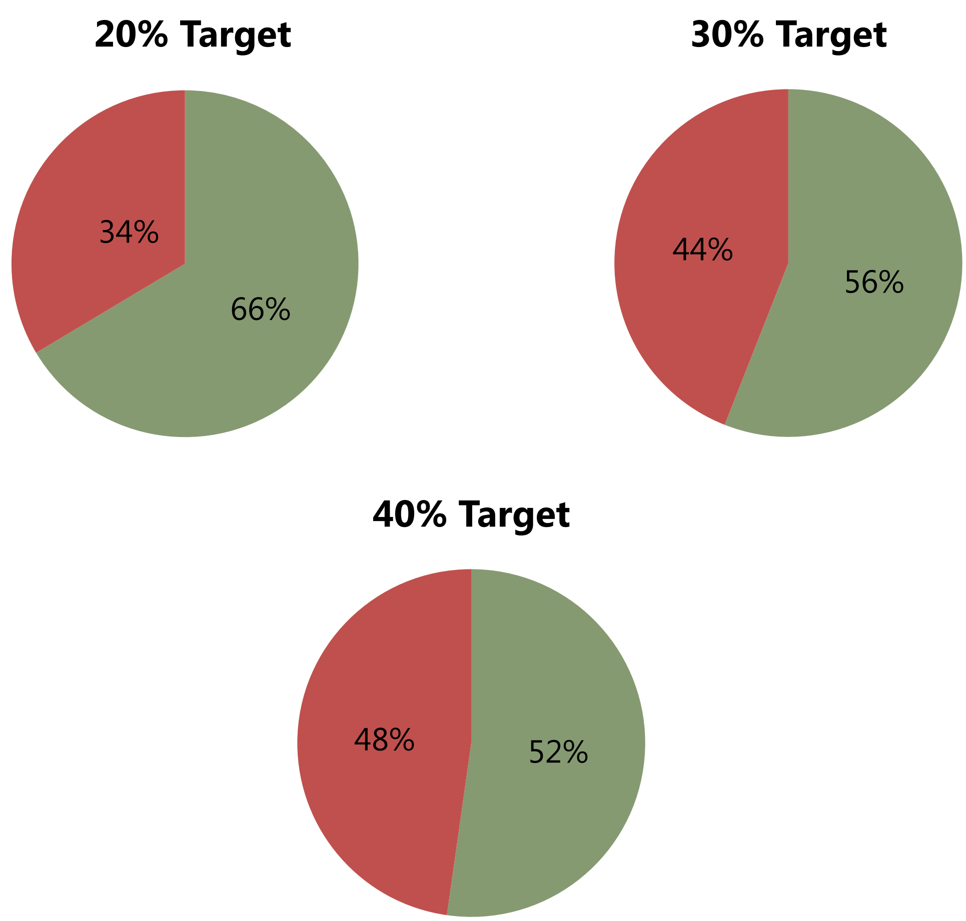

Figure 40. Percentages of conservation feature targets (n=107) met (green) and not (met) by locked in parcels alone in 20% all species, 30% all species, and 40% all species scenarios.

Input Parameter File

Once the planning unit file, conservation feature file, and planning unit versus conservation feature file were generated, the input file is needed to set the overall model parameters. The supplementary InEdit software was used to generate this file for use in Marxan. The parameters in this file can be changed as needed to adjust for running differing scenarios. All models were run with 1000 iterations, no boundary length modifier, and no cost threshold. A 10,000 iterations scenario was tested but did not prove substantially different from the 1,000 iterations equivalent scenario. Consequently, 1,000 iterations was deemed a sufficient number of runs in order to detect trends in parcel selection without generating excessively long model run times. The boundary length modifier was deemed unnecessary as the region of interest is relatively small and enforcement of a patchy network of sites is not a concern. The cost threshold was not used due to the fact that the Estuary Program does not have a strict budget and that they will not likely be purchasing the parcels, but rather helping to enact easements. Targets were considered "met" if the proportion of the target met was greater than 95%. This was to allow for some pragmatic flexibility in achieving targets. All other values were set to defaults (Table 9).

Table 9. Marxan required input parameters and values used for this analysis. Any parameters not listed were left at default values.

Input File Parameter	Parameter Value
Input File Type	New Freeform Style (default)
Run Options	Simulated Annealing with Iterative Improvement (recommended)
Iterative Improvement	2 Step Iterative Improvement (default)
Annealing Controls: # of Iterations	1000000 (default)
Annealing Controls: Temperature Decreases	10000 (default)
Adaptive Annealing	Yes (recommended)
Species Missing If Proportion of Target Lower Than	0.95

Sensitivity Analysis

A sensitivity analysis was conducted on the basic scenario of 30% species target and 10% habitat target in order to test the sensitivity of the model and to gain understanding of which factors were driving the results. The following scenarios were conducted in Marxan with both land value and net value cost parameters resulting in a total of 18 different scenarios:

- Basic Scenario: 30% target for species, 10% target for habitats
- Removed all habitats (0%) target
- All habitats 20% target

- All species 40% target
- All species 20% target
- Estuary Program species of concern 60% target
- Estuary Program species of concern 80% target
- Endangered and Threatened Species 60% target
- Endangered and Threatened Species 80% target

Land versus Net Cost

San Luis Obispo County assessor's office provided two FY 2014 cost values for each parcel when assessing the costs of the parcels within the watershed – net and land value. To compare both costs, the basic scenario was run with the same species and habitat targets but with the two differing values. When comparing the results of these two scenarios, there were very few discernible differences, as shown in Figures 41 and 42. Almost all of the same parcels were selected in both scenarios. However, the frequencies of selection varied slightly. This illustrates the insensitivity of the model to costs. Because land value is the more commonly used in easement valuation and there were few differences in comparing the two cost values, land value was used for further analyses (Boyd, Caballero, and Simpson 2000; Anderson and Weinhold 2008).

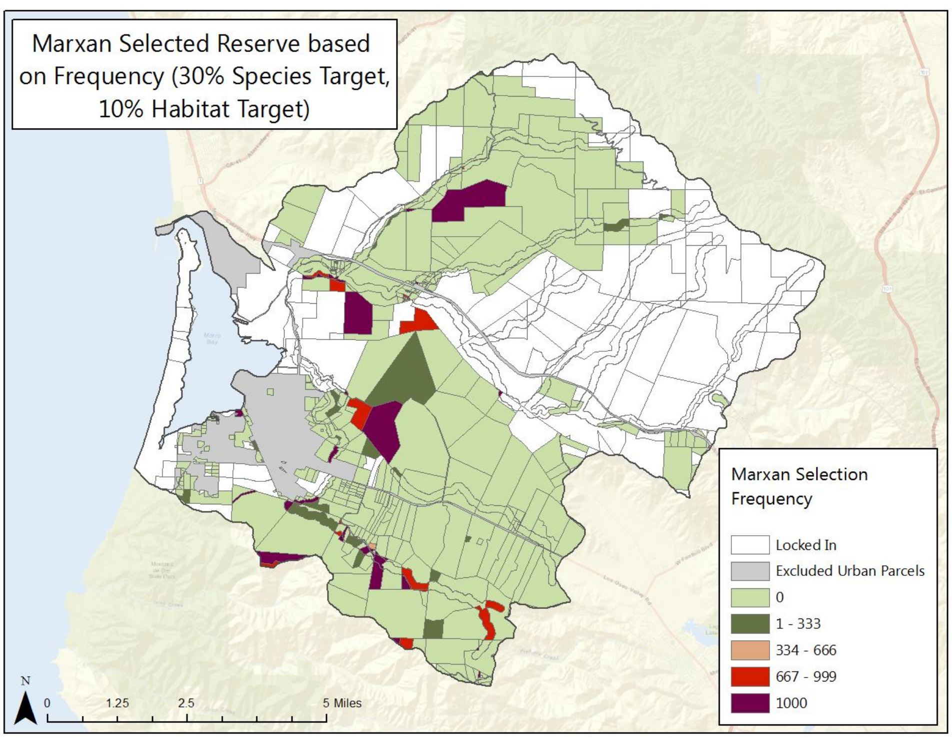

Figure 41. Marxan summed solution outputs of parcels chosen for conservation with a 30% species target, 10% habitat target, and land cost.

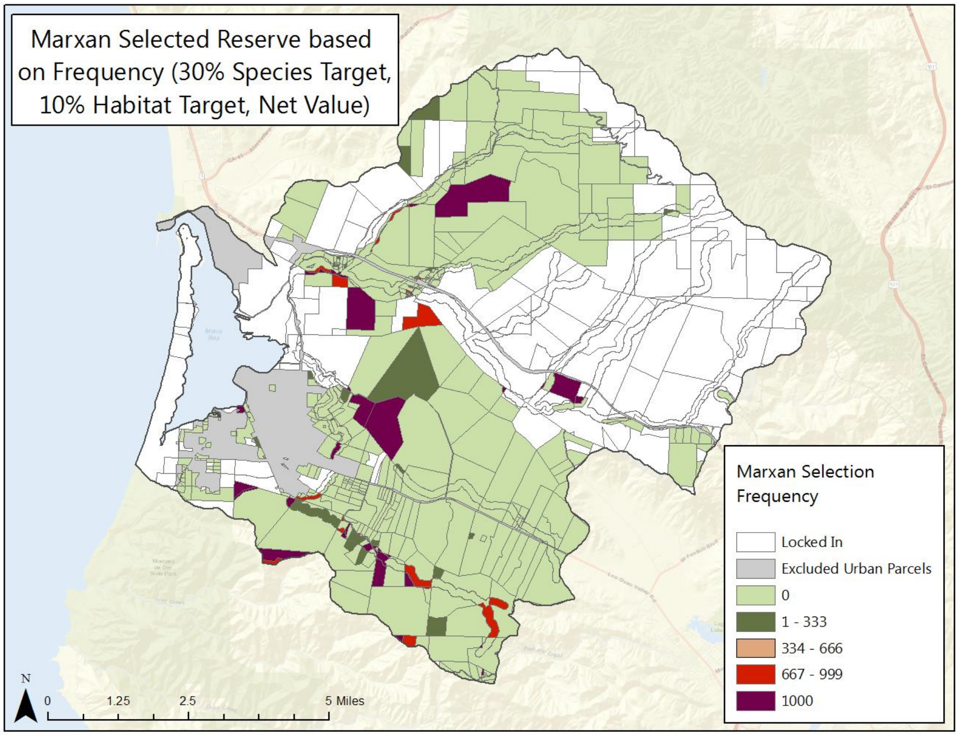

Figure 42. Marxan summed solution outputs of parcels chosen for conservation with a 30% species target, 10% habitat target, and net cost.

Habitat Targets Adjustments

Habitats were predicted to overlap with the distribution with sensitive species because species occupy these important habitats. To test this hypothesis, initial habitat targets were changed from 0% to 10% and 20%. As shown in Figures 43, 44 and 45, neither the increase nor decrease in habitat target resulted in many notable changes to which parcels were selected or the parcel selection frequency. Based on this result, habitat targets were removed from further analyses.

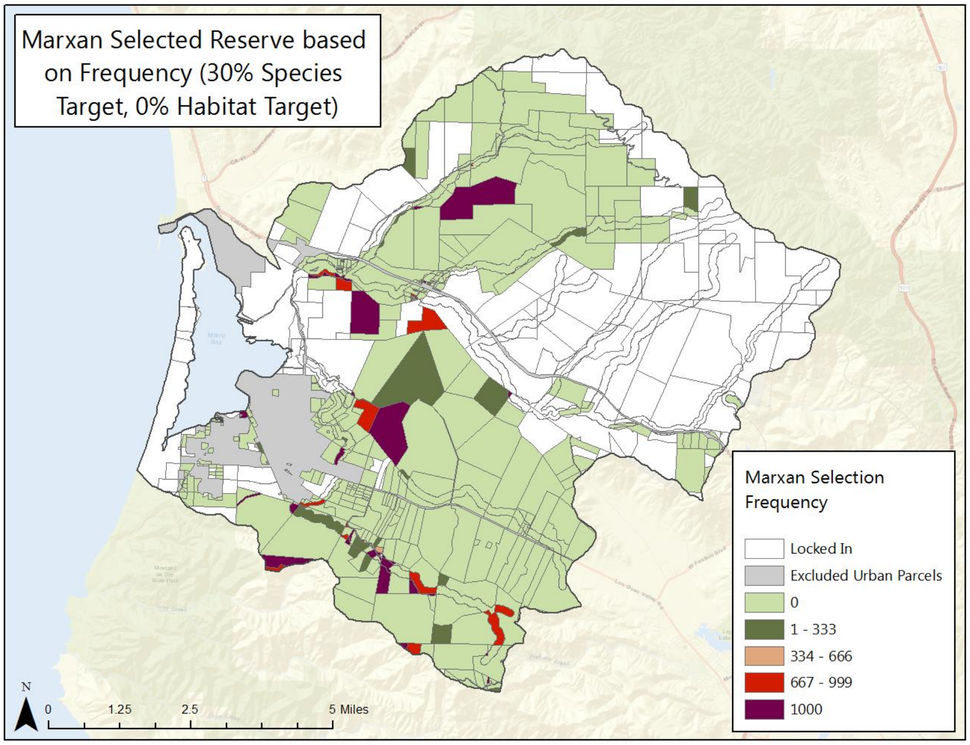

Figure 43. Marxan summed solution outputs of parcels chosen for conservation with a 0% habitat target.

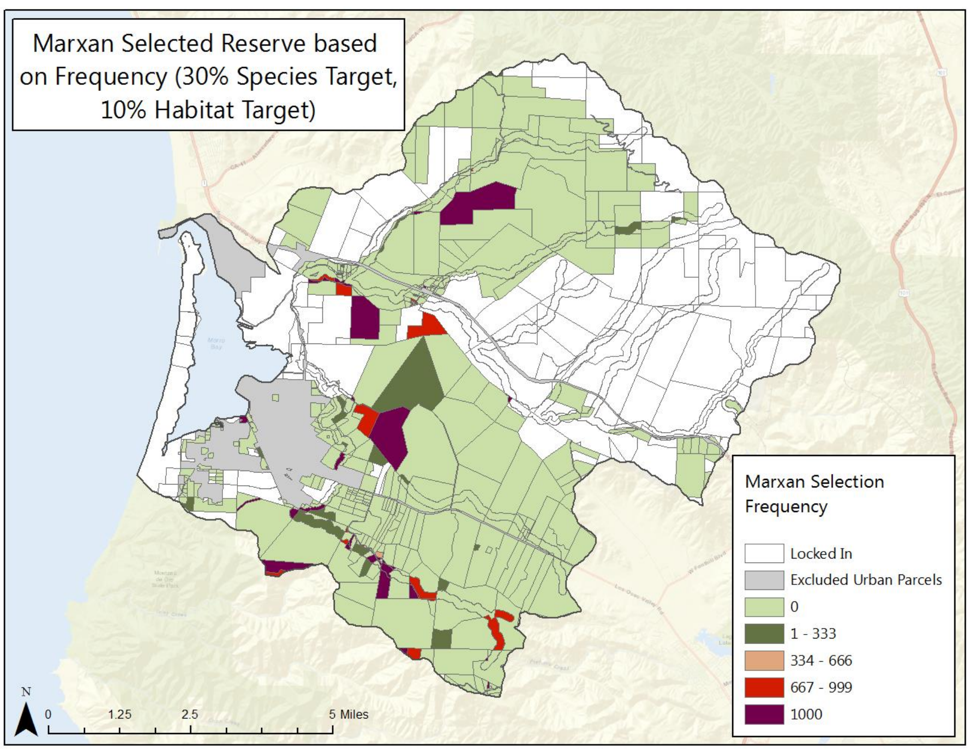

Figure 44. Marxan summed solution outputs of parcels chosen for conservation with a 10% habitat target.

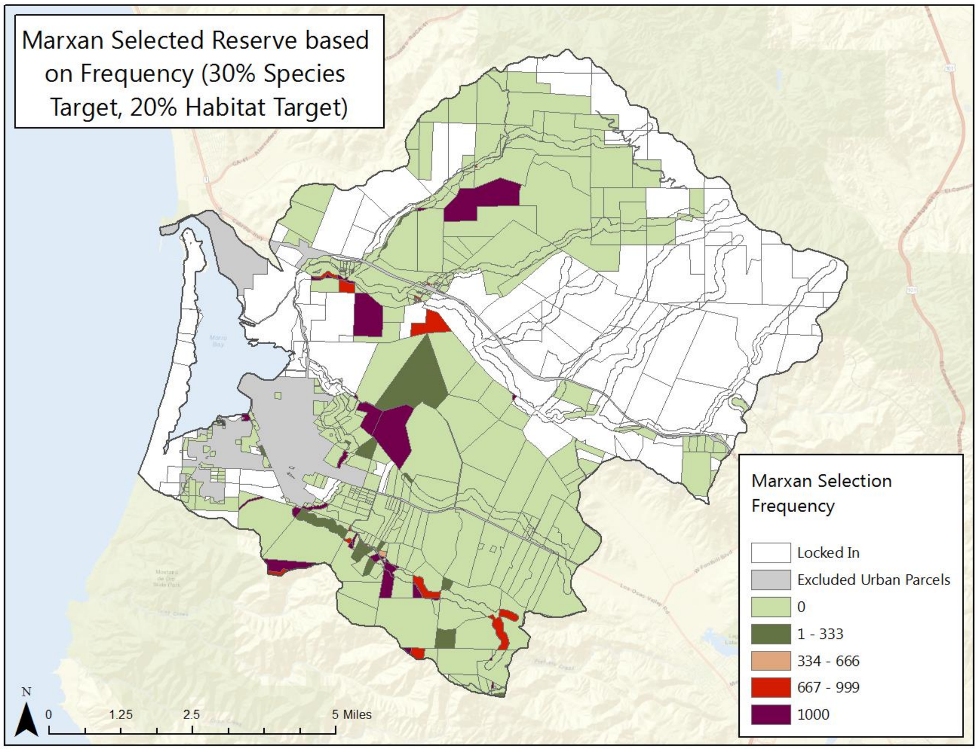

Figure 45. Marxan summed solution outputs of parcels chosen for conservation with a 20% habitat target.

Assessor's Parcel Number for Parcels Selected in all Marxan Scenarios

Below is a table of parcels that were selected in most Marxan scenarios. It is recommended that the Estuary Program begin conservation in these parcels regardless of the scenario that best fits their goals and constraints.

Table 10. List of all Assessor's Parcel Number's for parcels chosen repeatedly by Marxan and the acreage of each of these parcels.

Assessor's Parcel Number	Acres
067-011-003	313.46
067-011-047	87.4455
067-021-002	540.868
067-131-013	6.76362
067-131-014	4.34848
067-132-014	23.6848
067-132-021	10.1128
067-132-023	7.6721
067-132-037	22.7686
067-161-011	57.6939
067-161-015	17.4904
073-171-010	217.137
073-191-015	375.546
067-131-002	95.1062
067-131-005	11.6504
067-131-013	13.559
067-131-014	5.7231
067-132-014	10.1518
067-132-016	2.15231
067-132-022	1.45633
067-132-023	1.90176
067-132-037	22.3222
067-161-005	1.56335
067-161-011	18.2106
067-161-014	49.1749

Marxan Assumptions and Limitations

Limitations

- *Presence/Absence versus Abundance*. A key limitation to the analyses presented is the use of species presence, rather than abundance. As mentioned above in data gaps, prioritization efforts would ideally include abundance information so that the parcels with higher abundances would be prioritized over those with lower abundances.
- *Locking in or out public lands.* Because the assessed value of public lands is $0, it presented a challenge for including public lands that have conservation value without biasing the analysis. Public lands of conservation value were "locked in" to avoid bias, but this does not address concerns such as varying habitat qualities and management efforts or the ability to create conservation easements on public lands. Marxan does not have the capacity to include such concerns, and as such, these issues will need to be addressed with other tools.
- *Sensitive species versus all species*. Only sensitive species were included in the analysis not all species in the watershed. Firstly, this was the only data with reliable accuracy and resolution available. Secondly, sensitive species are those at greatest risk and thus in need of greater protection measures than common species.
- *Higher conservation targets limit flexibility of Marxan results*. While a user may want to conserve a greater percentage of occurrences of certain species, this will limit Marxan's flexibility in creating efficient reserve designs. By needing almost all of the occurrences of a given species, Marxan will have to always select all of parcels in which this species is found. Higher conservation targets should be used judiciously when there is substantial justification that a species needs such a high target to ensure its long-term survival.
- *Species richness as an indicator for biodiversity*. Species richness was used as an indicator of conservation value. Measures of diversity, such as the Shannon diversity index, could not be used because they require relative abundance data to assess species evenness, which were not available. Given this limitation, species richness was seen as the best suitable metric.
- *Whole parcel is selected by Marxan.* One limitation of using Marxan is that it can only choose to include or not include a whole planning unit within a reserve network. For parcels this is problematic become some large parcels may not be of equal conservation value across their entire area. In reality, easements can be constructed on portions of parcels, which Marxan is unable to account for. Without habitat quality data, it was infeasible to subdivide parcels based on their mosaic of conservation value, with one notable exception. Riparian corridors are universally acknowledged as being valuable habitat for a wide array of species. Based on this knowledge, parcels that included creeks were subdivided into the main portion of the parcel and a 100m buffered riparian corridor. This allowed Marxan to select only the riparian portion of a parcel if it as was indeed the region contributing the greatest conservation value.

Assumptions

- *True absences versus lack of surveying.* Areas in which species were not recorded were assumed to be true absences, rather than areas that just haven't been surveyed. This assumption was made because no information was provided to suggest that either possibility was more valid, and it was the only feasible option to perform the analysis. Because of this assumption, some parcels may have been excluded that would help meet conservation targets.
- *Using economic cost of parcels* – It was assumed that the economic cost of the parcel was the most accurate metric available to assess the cost of parcels. Area could have been used as a proxy, but this ignores other factors that contribute to the cost of a parcel (fertility of land, proximity to shoreline, development potential, etc.) In addition, it was assumed that the assessed economic value of a parcel was a suitable cost metric even though conservation easements would likely be created rather than the outright purchase of properties. This is because when conservation easements are evaluated the economic value of the land is considered when determining landowner tax breaks and other relevant factors. The most accurate and current cost data was used from the 2013/2014 fiscal year from the San Luis Obispo County Assessor's Office.
- *Parcels versus equal area hexagons*. Both parcels and equal area hexagons have distinct advantages and disadvantages as planning units. Parcels have the advantage of representing the actually divisions of the watershed, but are of unequal area. Their unequal areas make it more difficult to directly compare their conservation values. Also, larger parcels are more likely to have higher species richness just due to their larger size rather than any intrinsic differences in conservation value. This is in part mitigated by the higher economic costs typically associated with larger parcels. Even given this, parcels were used since conservation easements are enacted on specific properties and negotiated with individual landowners. Hexagons would intersect property lines making enacting easements on specific hexagons more difficult.
- *Land vs. net value*. Land value was assumed to be a more appropriate economic cost metric since it the more commonly used value when evaluating conservation easements (Boyd, Caballero, and Simpson 2000; Anderson and Weinhold 2008).
- *Connectivity was not addressed.* Marxan includes a tool called the boundary length modifier that attempts to cluster selected parcels. This in some ways can address connectivity by reducing the chances of Marxan creating a patchwork reserve network. It does not explicitly address, however, the mobility and dispersal abilities of specific species and how these traits affect the assessment of connectivity. For that, other tools such as Linkage Mapper, are needed. Since the Morro Bay watershed is a relatively small watershed, use of the boundary length modifier was not deemed necessary. Most of the watershed is open space with limited roads and development. Consequently even parcels that do not directly abut are unlikely to have significant barriers to movement and dispersal, particularly for more mobile species such as the birds and mammals. Even without the use of the boundary length modifier the reserve networks generated in the aforementioned results are relatively clustered.

Appendix C. Detailed WARMF Methods

BASINS Project Creation and Delineation

The first step in generating a WARMF watershed model begins with creating a Better Assessment Science Integrating point & Non-point Sources (BASINS) 4.0 project to obtain data and delineate the area of interest. BASINS is a multipurpose environmental analysis system designed to help regional, state, and local agencies perform watershed and water quality based studies through a spatial graphical user interface (GUI). All data we obtained through BASINS was collected for the HUC8 level watershed containing the Morro Bay watershed (Central Coast; HUC8 code 18060006). All spatial data was then clipped in GIS to the Estuary Program's watershed boundary shapefile. Non-spatial datasets were edited to include one data within the watershed in Matlab and excel.

The following datasets were accessed using BASINS for the HUC8 watershed using spatial reference Universal Transverse Mercator (UTM) Zone 10:

- Digital Elevation Model (DEM)
- National Elevation Dataset (NED)
- National Hydrography Dataset (NHD)
- National Land Cover Dataset (NLCD; ultimately accessed more recent data from USGS)

Once data was downloaded onto the local drive BASINS folder to be utilized in building the watershed model, we used the automatic watershed delineation tool in BASINS to delineate a smaller mask of the HUC8 watershed including the Morro Bay watershed area of interest. The area was delineated based on the downloaded DEM, NHD, and cataloguing unit boundary (mask of HUC8 watershed) layers. Units were changed to square kilometers for delineation purposes. The result was 13 delineated catchments within the Morro Bay watershed boundary (Fig. 46).

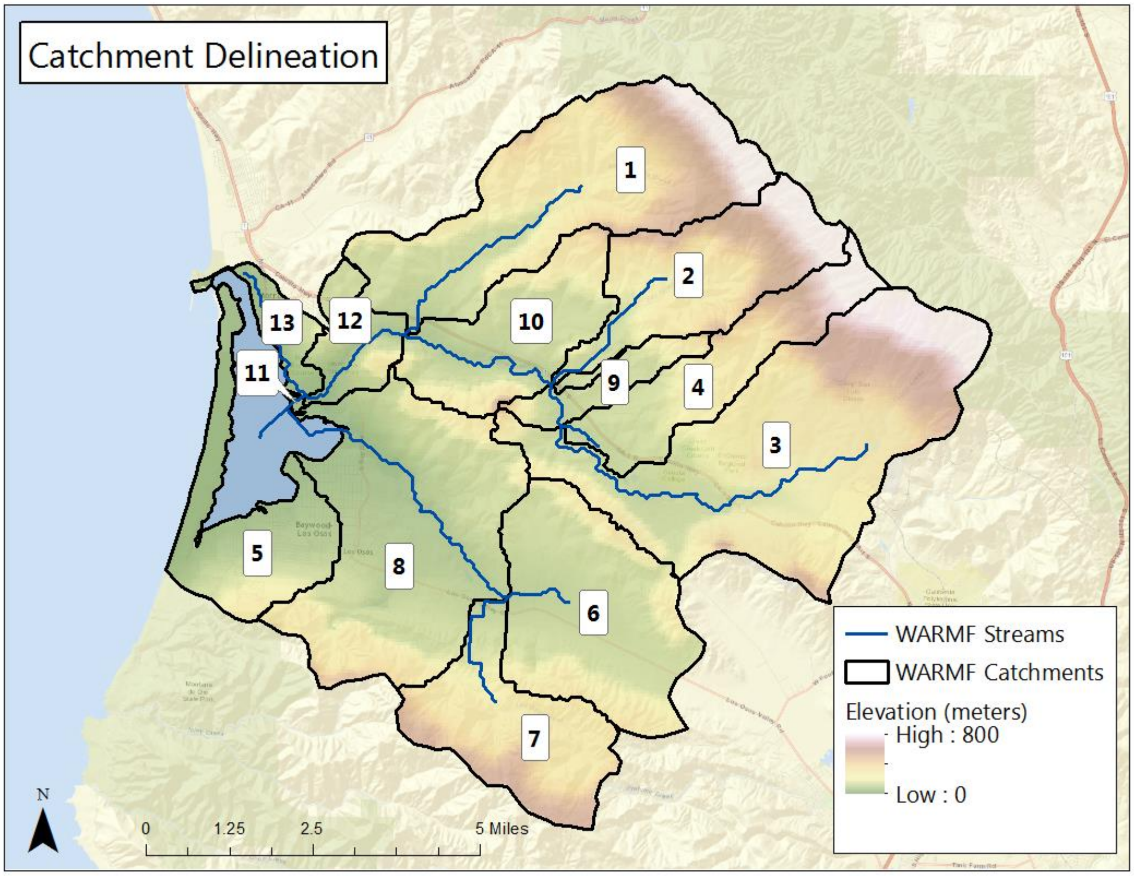

Figure 46. BASINS delineated catchments and rivers within the Morro Bay watershed. Due to the increases accuracy and detail of NED relative to DEM, we attempted to delineate with the NED layer. However, the coastal geographical location of the Morro Bay watershed resulted in catchments delineating without significant portions of land immediately bordering the ocean. For this reason, we opted to move forward with delineation using the DEM layer.

Reprojection of Watershed Delineation and River Network

Prior to beginning to build our watershed model in WARMF, it was necessary to reproject the delineation and river network files to decimal degrees in ArcGIS. BASINS generated watershed delineation and river network layers were added to ArcGIS from the local drive BASINS folder for the HUC8 watershed and clipped to the Estuary Program's watershed boundary file. These layers were then reprojected to a geographical coordinate system to import to WARMF.

WARMF

At this point, we began to build our watershed model in WARMF. We first imported the watershed delineation file as the watershed catchment layer with the following pairings from the ArcGIS attribute table to WARMF catchment layer characteristics:

- Streamlink→Catchment ID
- Area_M→Catchment Area
- Aveslope→Catchment Slope

Next, the river network file was imported as the stream network layer in WARMF with the following pairings:

- Linkno→River ID
- Dslinkno→Downstream River ID
- Length→River Length
- Slope→River Slope
- Elevlow→River Minimum Elevation
- Elevhigh→River Maximum Elevation
- Meanwidth→River Width
- Meandepth→River Depth

Once these initial watershed model layers were imported, we verified hydrologic connectivity of the river network by viewing tributary connections in the model to ensure the model was prepared for data input.

Land Use Data

There are multiple ways to input land use data into WARMF. We chose to input data by percent of each land use for each catchment manually in the input module of our model. The first step in this process was downloading the most up to date NLCD data available from USGS. Data accessed through BASINS was from 2001 and the Estuary Program data was from 2008. In the interest of producing the most accurate results possible, we chose to download the 2011 NLCD data. This data was then process in ArcGIS using the catchment delineation file. Using the ArcGIS toolbox, we intersected the NLCD land use layer with the watershed delineation layer. We then dissolved the intersection by streamlink (catchment) and gridcode and added area and percent area fields in the attribute table of the NLCD data. We used the calculate geometry tool to generate the area in square kilometers of each land use type in each catchment. We then used the field calculator to generate the percent area of each catchment represented by each land use type. This attribute table was then exported as a DataBase File, opened in Microsoft Excel, and formatted in Matlab. Final formatted percent land use category by catchment data was then entered for each of the 13 catchments in WARMF and ensured to equal 100% through small adjustments in the category with the highest percentage.

Table 11. Land use category distribution by catchment generated from NLCD 2011 land cover data and processed in Matlab and ArcGIS.

	Catchment Number												
Land Use Category	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Deciduous	0	0	0	0	0	0	0	0	0	0	0	0	0
Coniferous	5.89	9.45	2.11	3.33	0.48	0.7	0.31	0.47	0	1.25	0	0.71	0.47
Mixed Forest	4.6	10.3	4.14	3.78	3.49	4.64	34.1	8.27	2.38	2.94	0	2.79	0.1
Orchard	0	0	0	0	0	0	0	0	0	0	0	0	0
Cropland/Pasture	2.22	0.27	3.66	4.89	0	27.6	1.65	9.29	1.27	9.92	0	4.95	0
Confined Feeding	0	0	0	0	0	0	0	0	0	0	0	0	0
Rangeland	82.72	78.13	70.9	79.15	12.19	62.32	58.6	47.07	87.32	74.49	0.61	46.47	19.64
Forested Wetland	0.36	0.19	0.77	0.93	0.3	0.37	0.2	0.67	0.47	0.29	0	5.46	0.67
Non-Forested Wetland	1	0.23	0.49	1.15	0.9	0.43	0	5.2	4.23	1.35	32.37	17.15	1.98
Tundra	0	0	0	0	0	0	0	0	0	0	0	0	0
Barren	0.04	0	0.01	0	1.93	0	0	0	0	0	0	0	4.23
Residential	3.14	1.43	17.29	6.69	41.86	3.91	5.14	26.62	4.27	9.76	9.08	22.38	41.93
Commercial/Industrial	0	0	0.34	0.01	0.95	0	0	0.26	0	0	0.18	0.09	3.11
Water	0.03	0	0.29	0.07	37.9	0.03	0	2.15	0.06	0	57.76	0	27.87
Totals	100	100	100	100	100	100	100	100	100	100	100	100	100

Meteorological Data

Due to the relatively small geographic area included in the Morro Bay watershed, the most common sources of meteorological data including NOAA National Climatic Data Center yielded no results within the watershed. However, current precipitation and meteorological data is available from the California Department of Water Resources: California Irrigation Management Information System (CIMIS). CIMIS station #52 is located east of the watershed, at the California Polytechnic State University, San Luis Obispo Campus. No current meteorological monitoring stations are present within the watershed boundaries, however the Morro Bay National Estuary Program frequently utilizes CIMIS data from station 52. We downloaded CIMIS data for January 1, 2002-September 30, 2014; the duration of the time period we wished to model in WARMF. WARMF requires the following parameters for meteorological data input: precipitation (cm), minimum temperature (C), maximum temperature (C), cloud cover, dewpoint temperature (C), air pressure (mbar), and wind speed (m/s).

Because WARMF requires certain meteorological parameters for data input, several key assumptions were made in formatting this data. A temporally limited meteorological dataset exists from the San Luis Obispo County Regional Airport beginning in 2006. Because the CIMIS dataset did not include air pressure and clod cover, these data points were taken from the SLO County Regional Airport dataset. To account for missing data from 2002-2006, cloud cover and air pressure were plotted in excel for 2006-2014 to identify patterns. This revealed relative consistency of these parameters with some seasonality. It was deemed reasonable to use data from 2006-2009 for data gaps from 2002-2005. For missing data points throughout the dataset, averages were taken of the closest 30 surrounding data points to fit the need for continuous data to input to WARMF. Finally, necessary unit conversions were made to ensure temperatures were in Celsius.

Table 12. Meteorological and air quality site location metadata used in generation of WARMF model.

Type of Data	Site	Source	Record Start	Record End	Parameters Measured	Latitude	Longitude
Meteorological	CIMIS Station #52	California Department of Water Resources: California Irrigation Management Information System (CIMIS)	1/1/2002	9/30/2014	Precipitation (cm), Minimimum Temperature (C), Maximum Temperature (C), Cloud Cover, Dewpoint Temperature (C), Air Pressure (mbar), Wind Speed (m/s)	35.3054	-120.662
Air Quality: Dry Deposition	Pinnacles National Park PIN414	EPA CASNET	1/1/2002	9/30/2014	pH, NH_4, Ca, Mg, K, Na, SO_4, NO_3, Cl	36.4832	-121.1569
Air Quality: Wet Deposition	Pinnacles National Park Bear Valley CA66	National Atmospheric Deposition Program	1/1/2002	9/30/2014	SO_2, NH_4, Ca, Mg, K, Na, SO_4, NO_3, Cl	36.4834	-121.157

Soils Data

The first step in formatting NRCS soils data for input to WARMF was done in ArcGIS using the original BASINS generated delineation file. We joined BASINS statsgoc and stagol DataBase files by MUID (soil identification code) to calculate the average conductivity by converting statsgo to a raster and using zonal statistics to generate the average conductivity by catchment. We then used a soils workbook generated by Bren PhD student Kendra Garner to populate a table of vertical and horizontal conductivity by catchment and soil layer. This approach was then reapplied to generate saturation moisture and field capacity soil characteristics. These parameters were then manually input by catchment and soil layer and later adjusted to aid in flow calibration.

Vertical and Horizontal Conductivity

Table 13. Horizontal and vertical soil conductivity by catchment and soil layer generated from NRCS soils data and process in Matlab and ArcGIS.

	PERML (in/hr)	cm/day	Soil Layer 1	Soil Layer 2	Soil Layer 3	Soil Layer 4	Soil Layer 5
Catchment 1	1.8	Vert. Conduct.	110	99	88	77	66
		Horz. Conduct.	22	20	18	15	13
Catchment 2	1.8	Vert. Conduct.	110	99	88	77	66
		Horz. Conduct.	22	20	18	15	13
Catchment 3	1.7	Vert. Conduct.	104	93	83	73	62
		Horz. Conduct.	21	19	17	15	12
Catchment 4	1.7	Vert. Conduct.	104	93	83	73	62
		Horz. Conduct.	21	19	17	15	12
Catchment 5	6	Vert. Conduct.	366	329	293	256	219
		Horz. Conduct.	73	66	59	51	44
Catchment 6	0.9	Vert. Conduct.	55	49	44	38	33
		Horz. Conduct.	11	10	9	8	7
Catchment 7	1.9	Vert. Conduct.	116	104	93	81	69
		Horz. Conduct.	23	21	19	16	14
Catchment 8	2.3	Vert. Conduct.	140	126	112	98	84
		Horz. Conduct.	28	25	22	20	17
Catchment 9	1.4	Vert. Conduct.	85	77	68	60	51
		Horz. Conduct.	17	15	14	12	10
Catchment 10	1.3	Vert. Conduct.	79	71	63	55	48
		Horz. Conduct.	16	14	13	11	10
Catchment 11	6	Vert. Conduct.	366	329	293	256	219
		Horz. Conduct.	73	66	59	51	44
Catchment 12	2	Vert. Conduct.	122	110	98	85	73
		Horz. Conduct.	24	22	20	17	15
Catchment 13	4.4	Vert. Conduct.	268	241	215	188	161
		Horz. Conduct.	54	48	43	38	32

Field Capacity and Saturation Moisture

Table 14. Field capacity and saturation moisture by catchment generated from NRCS soils data and process in Matlab and ArcGIS.

	Field Capacity	Saturation Moisture
Catchment 1	0.11762886456	0.13927834673
Catchment 2	0.12083333135	0.14449999581
Catchment 3	0.12097221986	0.14388888619
Catchment 4	0.12347825876	0.14586956281
Catchment 5	0.05000000075	0.07000000030
Catchment 6	0.13960526080	0.15960526545
Catchment 7	0.11641509297	0.13773584535
Catchment 8	0.10605041893	0.12504201771
Catchment 9	0.12785714120	0.14785714235
Catchment 10	0.13075471515	0.15075471716
Catchment 11	0.05000000075	0.07000000030
Catchment 12	0.11944444291	0.13944444516
Catchment 13	0.07400000021	0.09399999827

Air Quality Data

WARMF requires weekly or monthly air quality data including both wet deposition and dry deposition. No current air quality monitoring stations exist within the watershed, however air quality data was obtained for the closest station deemed representative of Morro Bay conditions. Dry and wet deposition data was obtained from a monitoring station in Pinnacles National Park through the USEPA's Clean Air Status and Trends Network (CASTNET) and the National Atmospheric Deposition Program (NADP). Data was formatted in Microsoft Excel for January 1, 2002-September 30, 2014 and copy-pasted into the data module of WARMF as an air quality data file.

Observed Hydrology Data

The primary organization responsible for monitoring flow gauging stations within the Morro Bay watershed is the Estuary Program. No US Geological Survey National Water Information Systems (USGS NWIS) stations are present within the watershed boundaries of interest for this management plan. There are 19 flow gauging sites in the Morro Bay watershed, with 15 sites located in the Chorro Basin and 4 sites located within the Los Osos Basin (Table 12).

Dates of monitoring for these sites vary greatly due to the nature of this non-profit organization and the high level of resources needed to maintain the program and the ephemeral nature of many sites. Additionally, there is significant private land ownership within the watershed. While the Estuary Program does monitor on private land through landowner agreement, this data is unavailable to the public due to non-disclosure agreements and therefore cannot be included in this analysis.

Flow Site Selection

The Estuary Program has 19 sites for both flow and water quality throughout the watershed, however WARMF only allows for 1 site per catchment. Because many of the Estuary Program monitoring sites are clustered or on tributaries not represented in WARMF projected rivers, some selection and modification was necessary. In all cases, we selected the sites furthest downstream with the longest term and highest quantity dataset. The following is a brief overview of which observed hydrology stations were chosen and why:

Catchments with no observed hydrology stations: 1, 2, 4, 5, 11, 13

Catchment 3:

- Chose 310UCR because on Chorro Creek immediately below point source outflow
- 2002-2014, 115 data points

Catchment 6:

- Chose 310TUR is only station in the catchment
- 2011-2012, 16 data points

Catchment 7:

- Chose 310 CLV
- 2008-2013, 27 data points
- Only station in catchment

Catchment 8:

- Chose 310LVR 2003-2011 (large gaps in monitoring), 19 data points
- Only alternative was 310WRP, 2012-2013, 13 data points

Catchment 9:

- Chose 310CER because it is the only site in the catchment
- 2003-2014, 216 data points

Catchment 10:

- Chose 310CAN due to long term dataset and many more data points
- 310CCC 2009-2014, 56 data points
- 310CAN 2002-2014, 171 data points
- 310SBE 2002-2013, 76 data points

Catchment 12:

- Chose 310TWB because it is the only station in the catchment
- 2002-2014, 177 data points

Once sites were selected, flow rates were converted to cubic feet per second in Microsoft Excel and then copy-pasted into the data module of WARMF individually by site. If necessary, latitude and longitude of sites were adjusted to ensure they fell on WARMF rivers.

Observed Water Quality Data

As with observed hydrology data, we relied on Estuary Program collected water quality data within the Morro Bay watershed. The only EPA STORET data within the watershed was collected by the Estuary Program and included in data we received from them. For this reason, we went through a similar selection and formatting process in observed water quality data input as discussed with observed hydrology methods.

Water Quality Site Selection

The following is a brief overview of which observed hydrology stations were chosen and why:
Catchments with no observed water quality stations: 1, 2, 4, 5, 11, 13
Catchment 3:

- Chose 310UCR because on Chorro Creek immediately below outflow of point source
- 200 data points from 2002-2014

Catchment 6:

- Chose 310TUR due to downstream location
- 2002-2013, 225 data points

Catchment 7:

- Chose 310CLV because it is the only station in the catchment and downstream location
- 2008-2013, 100 data points

Catchment 8:

- Chose 310SYB due to long-term dataset and location, 2002-2014, 258 data points
- 310LVR, 2002-2011, 23 data points
- 310WRP, 2011-2014, 70 data point

Catchment 9:

- Chose 310CER because it is the only station in the catchment
- 2003-2014, 320 data points

Catchment 10:

- Chose 310CCC due to downstream location, 2004-2014, 180 data points
- 310CAN, 2002-2014, 380 data points

Catchment 12:

- Chose 310TWB because it is the only station in the catchment
- 2002-2014, 350 data points

Water Quality Conversions and Assumptions

Once sites were selected, several key conversions were done in Microsoft Excel and then copy-pasted the data was copy-pasted into the module of WARMF individually by site. If necessary, latitude and longitude of sites were adjusted to ensure they fell on WARMF rivers. The following parameters were converted for WARMF input:

- DO converted from ppm to mg/L
- Turbidity (NTU) converted to TSS (mg/L) using equation from Elkhorn Slough
- Salinity converted from ppt to ppm and used as TDS in WARMF

The following parameters were utilized in our WARMF model:

- Water temperature, pH, Ammonia as N, Nitrate as N, Orthophosphate as PO_4, Total coliform, DO, Total Phosphorus, Total Kjeldahl Nitrogen, Total Nitrogen, Salinity, Total Suspended Sediment

For days with double entries of water quality data, we chose the value with more data or the closest value to nearby dates.

Table 15. Observed water quality and observed hydrology site location metadata used in generation of WARMF model.

Site No.	Site	Water Body	Record Start	Record End	Parameters Measured	Original Latitude	Original Longitude	WARMF Latitude	WARMF Longitude
310CAN	Chorro Canet Road	Chorro Creek	8/22/2010	6/2/2014	Flow, Temperature, DO (ppm), DO (% sat), Turbidity (NTU), Specific Conductance (uS/cm), PO4 (mg/L), pH, nitrate as N, Total Coliform, *E. coli*	35.353214	-120.7888	35.3532	-120.7888
310CCC	Chorro Creek upstream from Chorro Flats	Chorro Creek	12/18/2009	5/20/2014	Flow, Temperature, DO (ppm), DO (% sat), Turbidity (NTU), Specific Conductance (uS/cm), pH, PO4 (mg/L), Total Coliform, *E. coli*	35.35762	-120.8123	35.3577	-120.8088
310CER	Chorro Ecological Reserve	Chorro Creek	5/11/2003	6/25/2014	Flow, Temperature, DO (ppm), DO (% sat), Turbidity (NTU), Specific Conductance (uS/cm), PO4 (mg/L), pH from, nitrate as N (mg/L), Total Coliform, *E.coli*	35.347417	-120.7729	35.3461	-120.7731
310CLV	Los Osos Creek, Clark Valley Road	Los Osos Creek	3/20/2008	5/24/2013	Flow, Temperature, DO (ppm), DO (% sat), Turbidity (NTU), Specific Conductance (uS/cm), pH, PO4 (mg/L), Total Coliform, *E.coli*	35.287882	-120.8024	35.2883	-120.7935
310SYB	Los Osos Creek at Turri Rd no littering sign	Los Osos Creek	6/23/2002	6/13/2014	Flow, Temperature, DO (ppm), DO (% sat), Turbidity (NTU), Specific Conductance (uS/cm), PO4 , pH, Total Coliform, *E. coli*	35.3320691	-120.8181	35.3321	-120.8181
310TUR	Warden Creek crossing under Turri Road	Warden Creek	3/3/2011	5/16/2012	Flow, Temperature, DO (ppm), DO (% sat), Turbidity (NTU), Specific Conductance (uS/cm), PO4 (mg/L), pH, Total Coliform, *E. coli*	35.302376	-120.7762	35.3029	-120.7764
310TWB	Chorro Creek at South Bay Blvd.	Chorro Creek	5/21/2002	5/8/2014	Flow, Temperature, DO (ppm), DO (% sat), Turbidity (NTU), Specific Conductance (uS/cm), PO4 (mg/L), pH, nitrate as N, Total Coliform, *E. coli*	35.354282	-120.828	35.3589	-120.8161
310UCR	Upper Chorro Reserve	Chorro Creek	6/25/2007	6/22/2014	Flow, Temperature, DO (ppm), DO (% sat), Turbidity (NTU), Specific Conductance (uS/cm), PO4 (mg/L), pH, nitrate as N, Total Coliform, *E. coli*	35.338617	-120.7675	35.3386	-120.7652

Point Source Data

The California Men's Colony, located in the northeast quadrant of the watershed, is the only point source of interest for the model. Although the facility itself is located near the upper reach of Chorro Creek in catchment 3, the outflow is released downstream at Camp San Luis Obispo, a California Army National Guard facility. The USEPA maintains point source data for the outflow from the Men's Colony, however lack of recorded metadata detailing units of measurement and lack of long-term monitoring led us not to use the input of this point source data into our model. Rather, we chose to assume that the 310UCR monitoring station located in close proximity downstream of the point source outflow accounts for the impacts of the California Men's Colony on watershed chemistry and hydrology.

Calibration

Once all available data is input into WARMF, it is necessary to calibrate watershed hydrology using the WARMF model hydrologic autocalibration tool. Given the sparse observed water quality datasets used in this model, hydrologic autocalibration was deemed sufficient for overall model application. The hydrologic autocalibration process adjusts parameters used in model flow simulation and was performed on a sub-watershed level. Three subwatersheds were defined in the model: Upper Chorro subwatershed, Lower Chorro subwatershed, and Los Osos subwatershed as shown in Figure 59. Before utilizing the autocalibration tool, soil characteristics were adjusted as instructed by experts in the field and literature so gradually converge observed and modeled flow to proximity deemed reasonable to then begin hydrologic calibration. Several 1000 loop autocalibration scenarios were run for each subwatershed until mean modeled and observed flow values converged and r-squared and relative error values were deemed acceptable for the scope of the project given the limited observed data available.

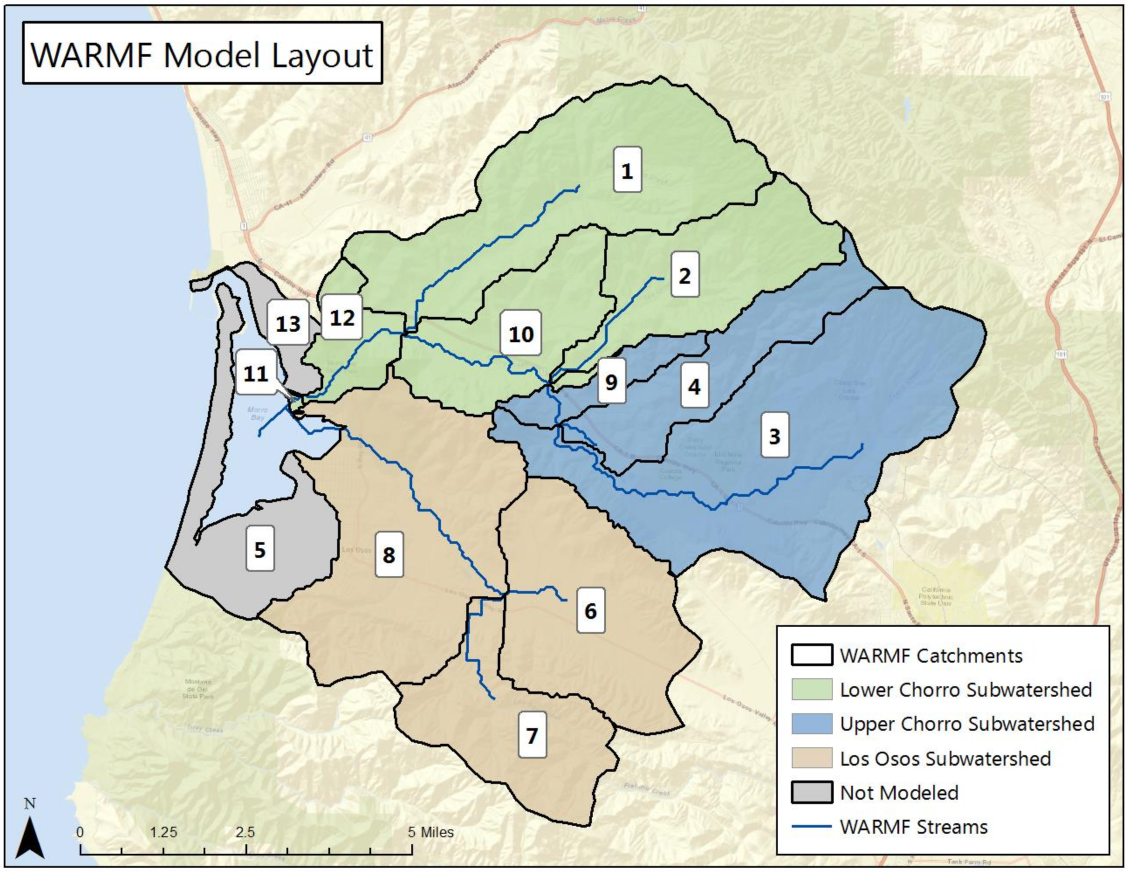

Figure 47. Model autocalibration subwatershed layout.

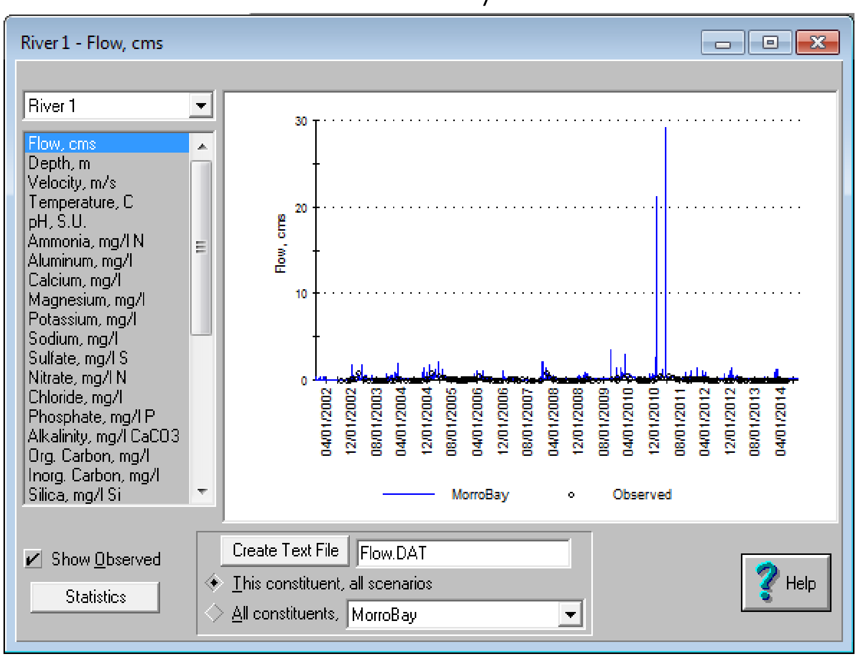

Figure 48. Model autocalibration example results of flow for catchment 10 following calibration.

Calibrated Vertical and Horizontal Conductivity Coefficients

Table 16. Horizontal and vertical soil conductivity coefficients by catchment and soil layer following hydrologic autocalibration.

	cm/day	Soil Layer 1	Soil Layer 2	Soil Layer 3	Soil Layer 4	Soil Layer 5
Catchment 1	Vert. Conduct.	100	87.5	88.75	140	105
	Horz. Conduct.	200	200	200	200	200
Catchment 2	Vert. Conduct.	100	87.5	88.75	140	105
	Horz. Conduct.	200	200	200	200	200
Catchment 3	Vert. Conduct.	100	87.5	88.75	140	105
	Horz. Conduct.	200	200	200	200	200
Catchment 4	Vert. Conduct.	100	87.5	88.75	140	105
	Horz. Conduct.	200	200	200	200	200
Catchment 5	Vert. Conduct.	100	87.5	88.75	140	105
	Horz. Conduct.	200	200	200	200	200
Catchment 6	Vert. Conduct.	100	90	100	100	90
	Horz. Conduct.	168	200	174	176	174
Catchment 7	Vert. Conduct.	100	70	100	100	90
	Horz. Conduct.	163	100	100	100	100
Catchment 8	Vert. Conduct.	100	90	100	100	90
	Horz. Conduct.	168	100	100	100	100
Catchment 9	Vert. Conduct.	100	87.5	88.75	140	105
	Horz. Conduct.	200	200	200	200	200
Catchment 10	Vert. Conduct.	100	87.5	88.75	140	105
	Horz. Conduct.	200	200	200	200	200
Catchment 11	Vert. Conduct.	100	87.5	88.75	140	105
	Horz. Conduct.	200	200	200	200	200
Catchment 12	Vert. Conduct.	100	87.5	88.75	140	105
	Horz. Conduct.	200	200	200	200	200
Catchment 13	Vert. Conduct.	100	87.5	88.75	140	105
	Horz. Conduct.	200	200	200	200	200

Calibrated Field Capacity and Saturation Moisture Coefficients

Table 17. Field capacity and saturation moisture coefficients by catchment and soil layer following hydrologic autocalibration.

	cm/day	Soil Layer 1	Soil Layer 2	Soil Layer 3	Soil Layer 4	Soil Layer 5
Catchment 1	Field Capacity	0.15	0.15	0.15	0.184	0.267
	Saturation Moisture	0.5	0.5	0.411	0.209	0.419
Catchment 2	Field Capacity	0.15	0.15	0.15	0.184	0.267
	Saturation Moisture	0.5	0.5	0.411	0.209	0.419
Catchment 3	Field Capacity	0.15	0.15	0.15	0.184	0.267
	Saturation Moisture	0.5	0.5	0.411	0.209	0.419
Catchment 4	Field Capacity	0.15	0.15	0.15	0.184	0.267
	Saturation Moisture	0.5	0.5	0.411	0.209	0.419
Catchment 5	Field Capacity	0.15	0.15	0.15	0.184	0.267
	Saturation Moisture	0.5	0.5	0.411	0.209	0.419
Catchment 6	Field Capacity	0.15	0.15	0.15	0.15	0.15
	Saturation Moisture	0.3	0.3	0.3	0.3	0.3
Catchment 7	Field Capacity	0.175	0.15	0.15	0.15	0.15
	Saturation Moisture	0.3	0.3	0.3	0.3	0.3
Catchment 8	Field Capacity	0.2	0.15	0.15	0.15	0.15
	Saturation Moisture	0.3	0.3	0.3	0.3	0.3
Catchment 9	Field Capacity	0.15	0.15	0.15	0.184	0.267
	Saturation Moisture	0.5	0.5	0.411	0.209	0.419
Catchment 10	Field Capacity	0.15	0.15	0.15	0.184	0.267
	Saturation Moisture	0.5	0.5	0.411	0.209	0.419
Catchment 11	Field Capacity	0.15	0.15	0.15	0.184	0.267
	Saturation Moisture	0.5	0.5	0.411	0.209	0.419
Catchment 12	Field Capacity	0.15	0.15	0.15	0.184	0.267
	Saturation Moisture	0.5	0.5	0.411	0.209	0.419
Catchment 13	Field Capacity	0.15	0.15	0.15	0.184	0.267
	Saturation Moisture	0.5	0.5	0.411	0.209	0.419

Calibrated Precipitation Weighting Coefficients

Table 18. Precipitation coefficients by catchment following hydrologic autocalibration.

	Precipitation Weighting
Catchment 1	1.001
Catchment 2	1.001
Catchment 3	1.001
Catchment 4	1.001
Catchment 5	1.001
Catchment 6	1.05
Catchment 7	1.05
Catchment 8	1.1
Catchment 9	1.001
Catchment 10	1.001
Catchment 11	1.011
Catchment 12	1.011
Catchment 13	1.001

Model Statistical Strength

Table 19. Statistical strength shown by r-squared and relative error values for each parameter by catchment. Statistics only generated for catchments with observed water quality site locations.

	Nitrate as N	**Orthophosphate as PO4**	**TSS**	***E. coli***
Catchment	*Relative Error*	*Relative Error*	*Relative Error*	*Relative Error*
3	3.893	-0.474	-31.12	1259
7	--	-0.131	-10.77	1461
8	--	-0.235	-34.27	437.4
9	4.589	-0.192	-47.99	750.3
10	5.24	-0.298	-34.11	853
12	5.784	0.158	-46.33	688.6

Appendix D. Detailed WARMF Results

Nitrate as Nitrogen

Table 20. WARMF nitrate as nitrogen results by catchment. Calculated seasonal medians for wet and dry seasons shown in mg/L and average annual days of exceedance shown in days/year.

Catchment	Median Wet (mg/L)	Median Dry (mg/L)	Average Days Exceedance Per Year
1	4.2	5.6	326
2	4.7	5.4	328
3	3.7	3.9	318
4	2.1	2.1	318
5	0.8	1.3	178
6	16.2	19.7	312
7	15.5	18	330
8	13.9	16.6	306
9	3.6	4	318
10	3.9	4.3	322
11	11.9	14.2	303
12	4	4.4	323
13	4.5	5	322

Orthophosphate as P

Table 21. WARMF orthophosphate as phosphate results by catchment. Calculated seasonal medians for wet and dry seasons shown in mg/L and average annual days of exceedance shown in days/year.

Catchment	Median Wet (mg/L)	Median Dry (mg/L)	Average Days Exceedance Per Year
1	1.6	1.6	359
2	1.6	1.7	362
3	2.2	2.4	352
4	2.3	2.3	349
5	0.5	0.5	259
6	0.4	0.4	13
7	0.3	0.3	53
8	0.3	0.3	69
9	2.1	2.3	351
10	1.7	2	353
11	0.4	0.4	243
12	1.6	1.8	352
13	1.2	1.5	310

Total Suspended Sediment

Table 22. WARMF total suspended sediment concentration results by catchment. Calculated seasonal medians for wet and dry seasons shown in mg/L and average annual days of exceedance shown in days/year.

Catchment	Median Wet (mg/L)	Median Dry (mg/L)	Average Days Exceedance Per Year
1	2.1	1.5	2
2	0.7	0.2	1
3	2.3	2.3	2
4	5	5	4
5	0.4	0.4	5
6	7.9	7.6	9
7	20.9	21.5	7
8	15.8	15.9	10
9	5.5	2.7	3
10	5.1	2.5	3
11	14.8	14.5	11
12	5.4	3.5	3
13	11.7	4.2	8

E. coli

Table 23. WARMF *E. coli* results by catchment. Calculated seasonal medians for wet and dry seasons shown in MPN/mL and average annual days of exceedance shown in days/year.

Catchment	Median Wet (MPN/mL)	Median Dry (MPN/mL)	Average Days Exceedance Per Year
1	63.8	35	32
2	17.6	12.2	23
3	138.1	94.2	107
4	143.3	124.1	64
5	463.4	403.2	174
6	822.3	890.3	271
7	195.1	156.4	59
8	638.3	457.7	202
9	139.2	93.9	100
10	116.5	75.5	83
11	587.8	404.6	191
12	118.7	76.1	76
13	175.9	118.9	102

Hydrographs

Catchment 1

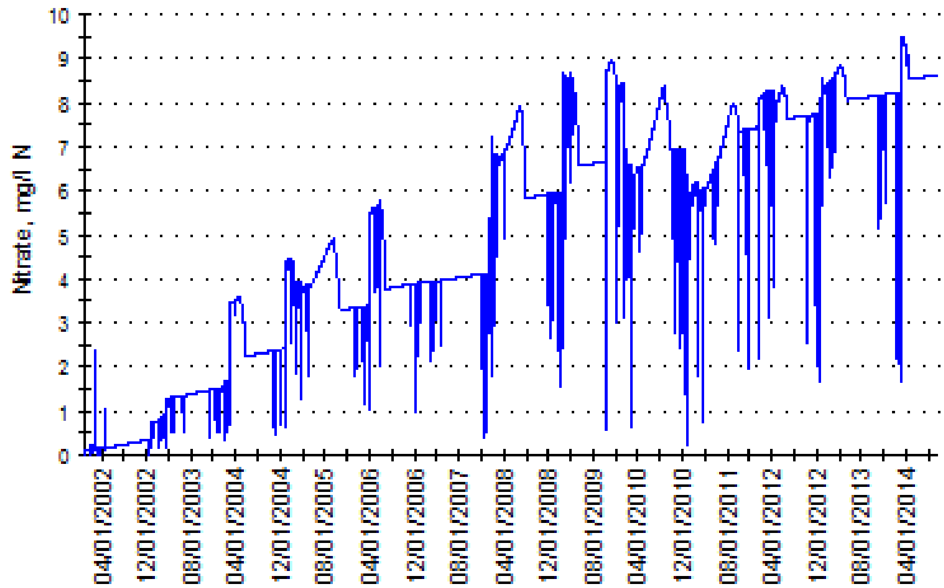

Figure 49. Modeled nitrate as nitrogen concentrations (mg/L) in catchment 1 from 2002 to 2014. No observed data available in this catchment.

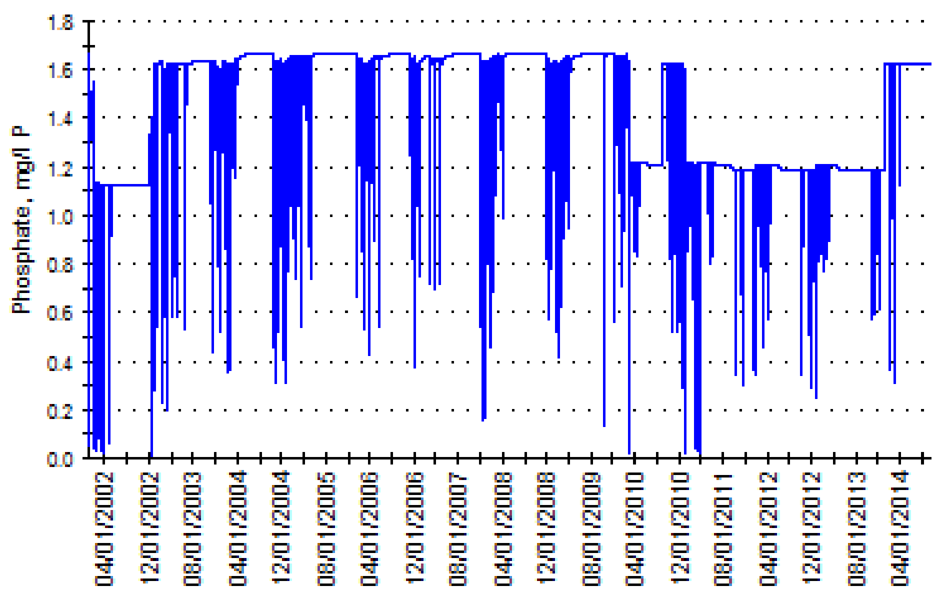

Figure 50. Modeled orthophosphate as phosphate concentrations (mg/L) in catchment 1 from 2002 to 2014. No observed data available in this catchment.

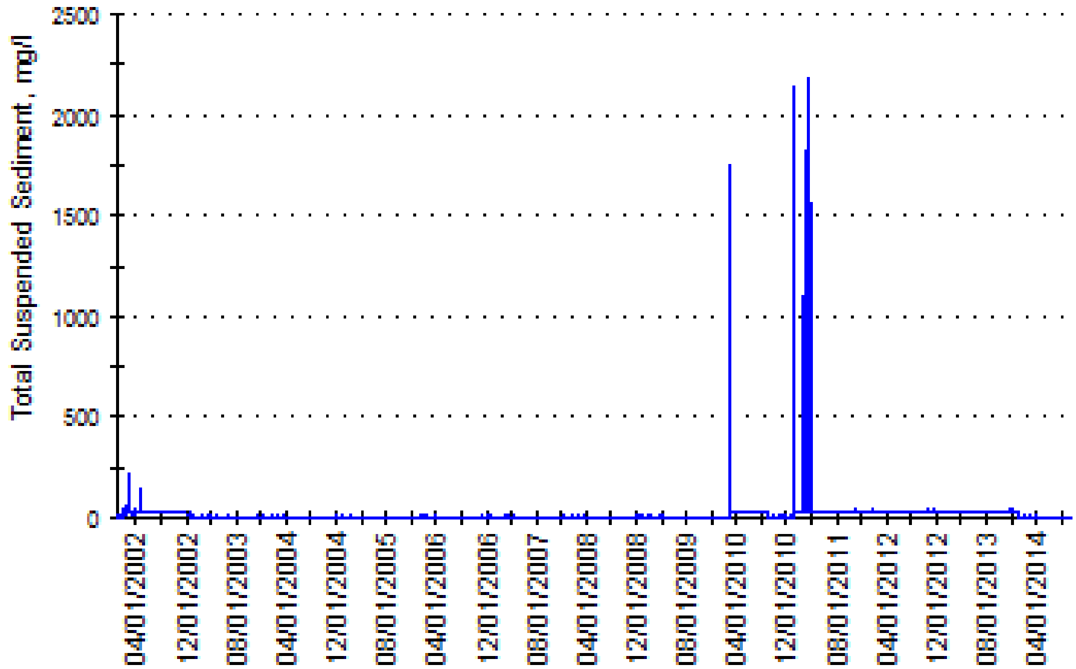

Figure 51. Modeled total suspended sediment concentrations (mg/L) in catchment 1 from 2002 to 2014. No observed data available in this catchment.

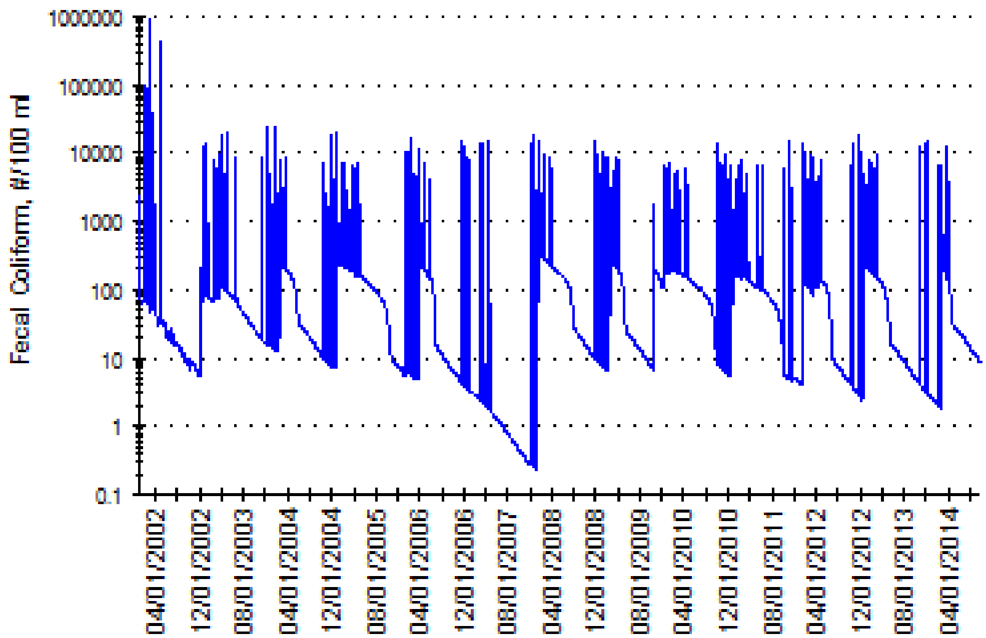

Figure 52. Modeled *E. coli* concentrations (MPN/mL) in catchment 1 from 2002 to 2014. No observed data available in this catchment.

Catchment 2

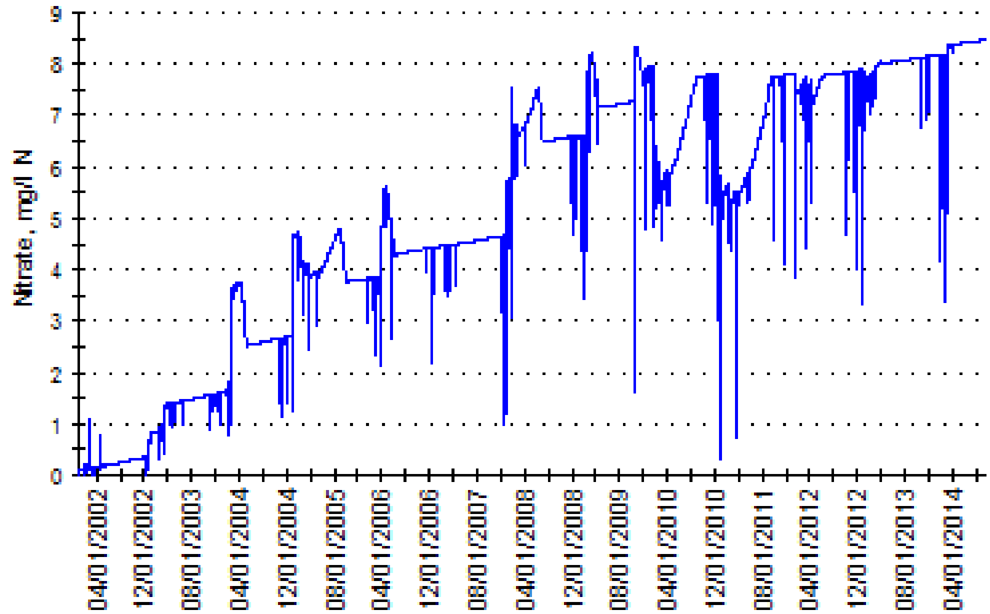

Figure 53. Modeled nitrate as nitrogen concentrations (mg/L) in catchment 2 from 2002 to 2014. No observed data available in this catchment.

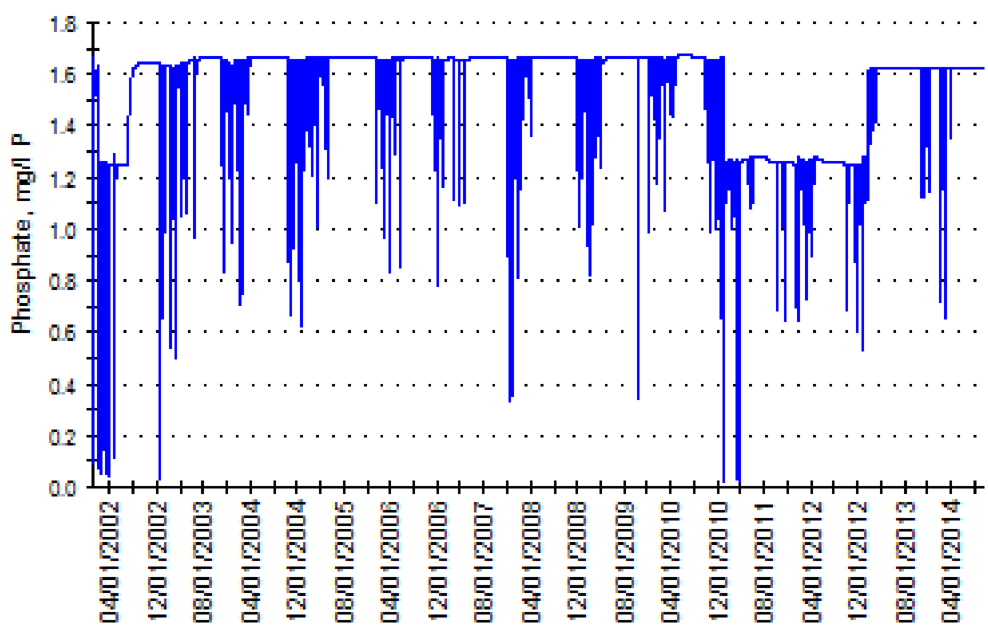

Figure 54. Modeled orthophosphate as phosphate concentrations (mg/L) in catchment 2 from 2002 to 2014. No observed data available in this catchment.

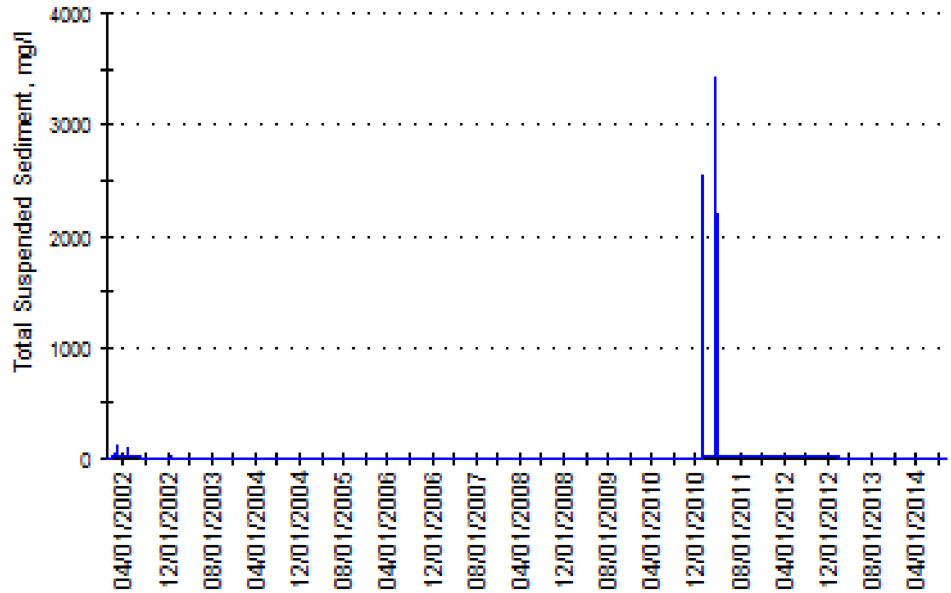

Figure 55. Modeled total suspended sediment concentrations (mg/L) in catchment 2 from 2002 to 2014. No observed data available in this catchment.

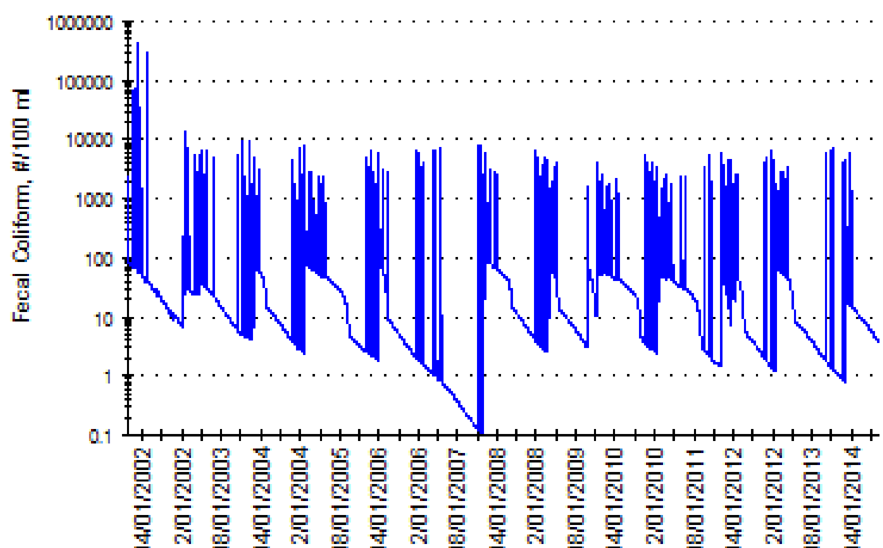

Figure 56. Modeled *E. coli* concentrations (MPN/mL) in catchment 2 from 2002 to 2014. No observed data available in this catchment.

Catchment 3

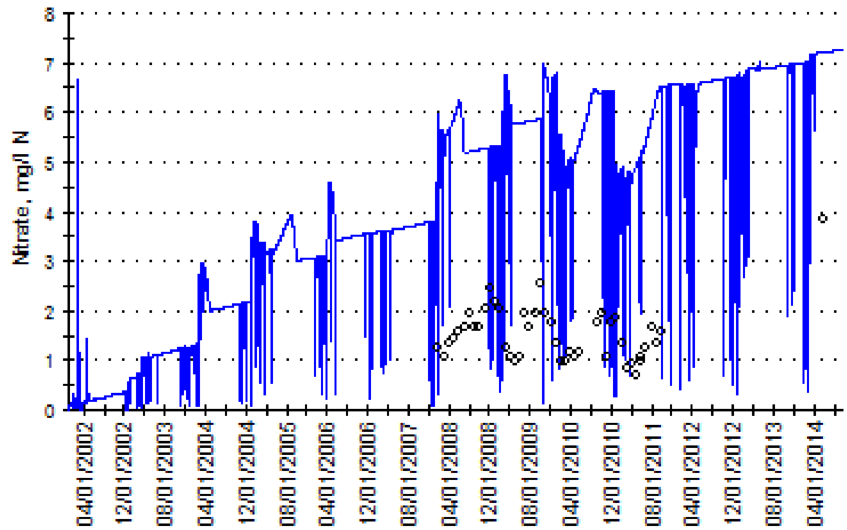

Figure 57. Modeled nitrate as nitrogen concentrations (mg/L) in catchment 3 from 2002 to 2014 (blue line). Hollow black dots represent observed concentrations in the catchment.

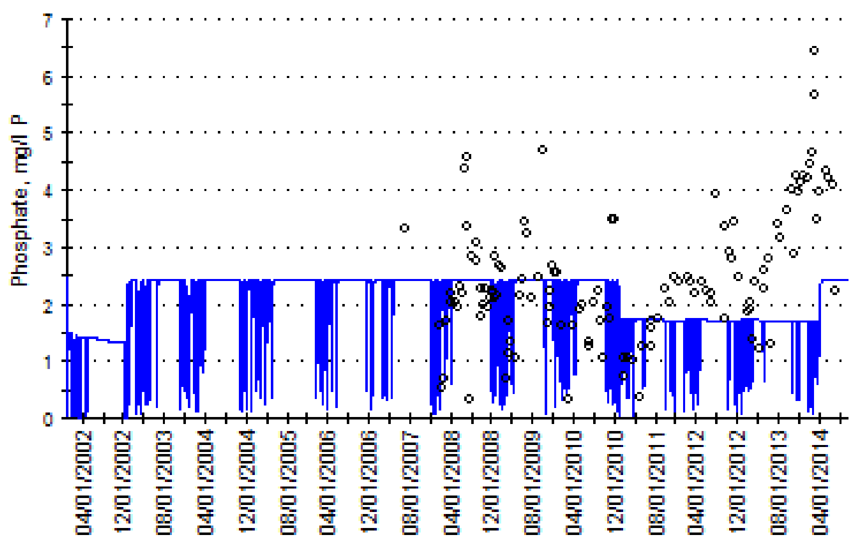

Figure 58. Modeled orthophosphate as phosphate concentrations (mg/L) in catchment 3 from 2002 to 2014 (blue line). Hollow black dots represent observed concentrations in the catchment.

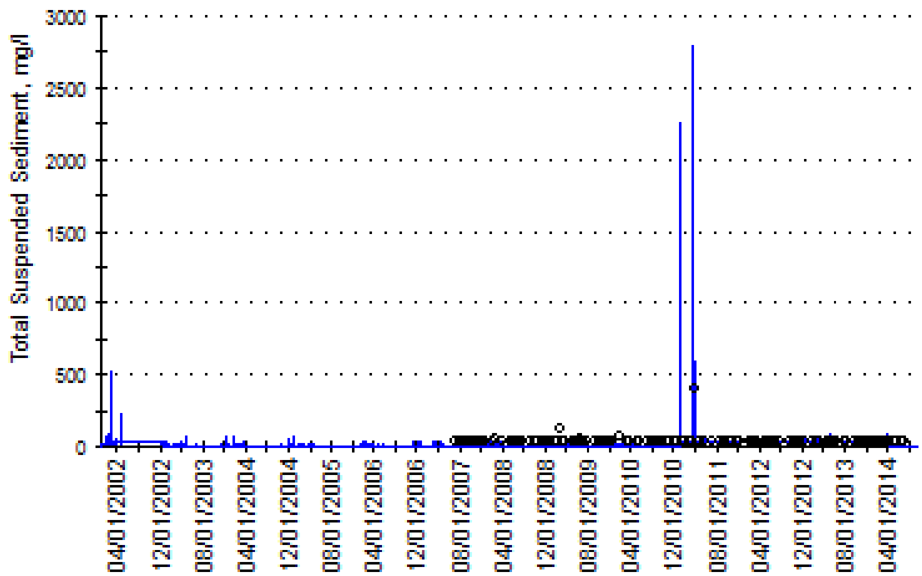

Figure 59. Modeled total suspended sediment concentrations (mg/L) in catchment 3 from 2002 to 2014 (blue line). Hollow black dots represent observed concentrations in the catchment.

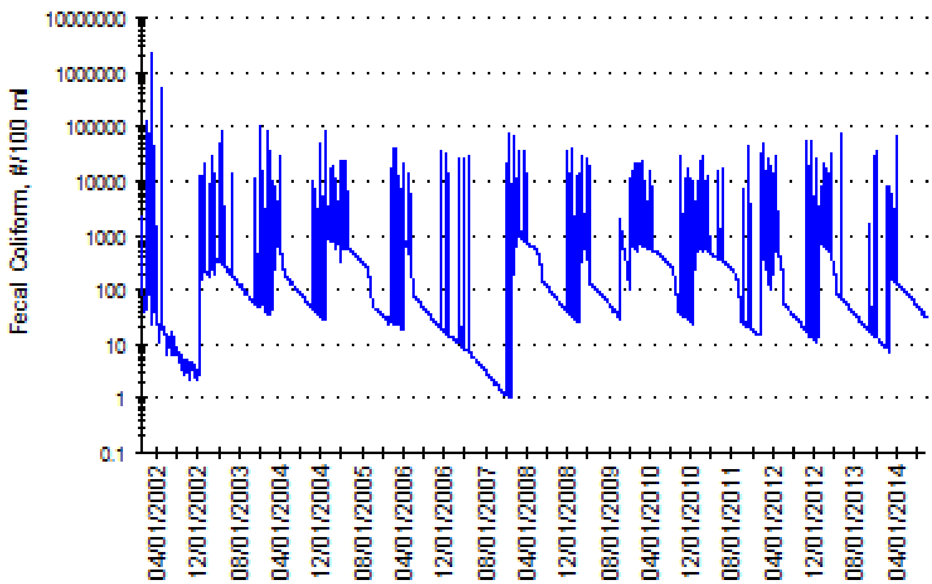

Figure 60. Modeled *E. coli* concentrations (MPN/mL) in catchment 3 from 2002 to 2014. No observed data available in this catchment.

Catchment 4

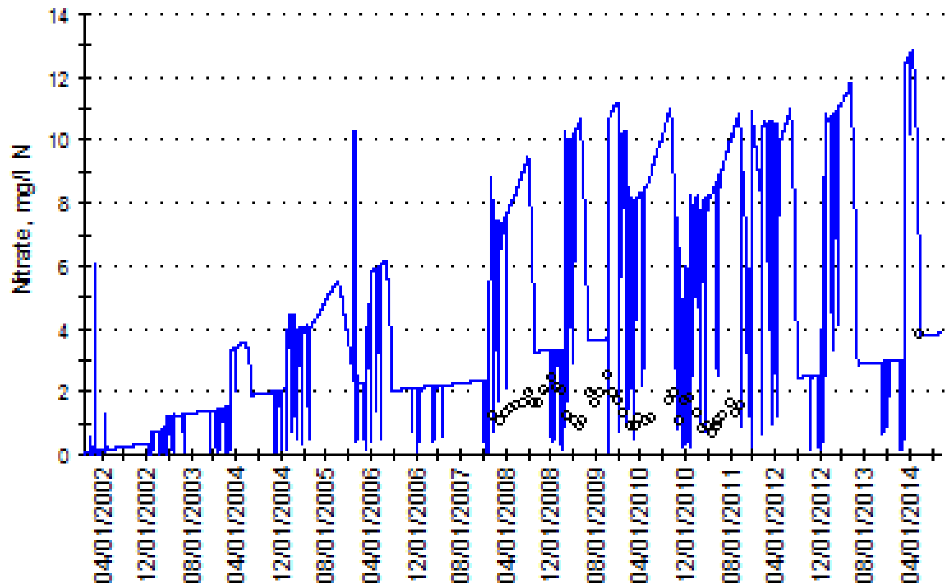

Figure 61. Modeled nitrate as nitrogen concentrations (mg/L) in catchment 4 from 2002 to 2014 (blue line). Hollow black dots represent observed concentrations in the catchment.

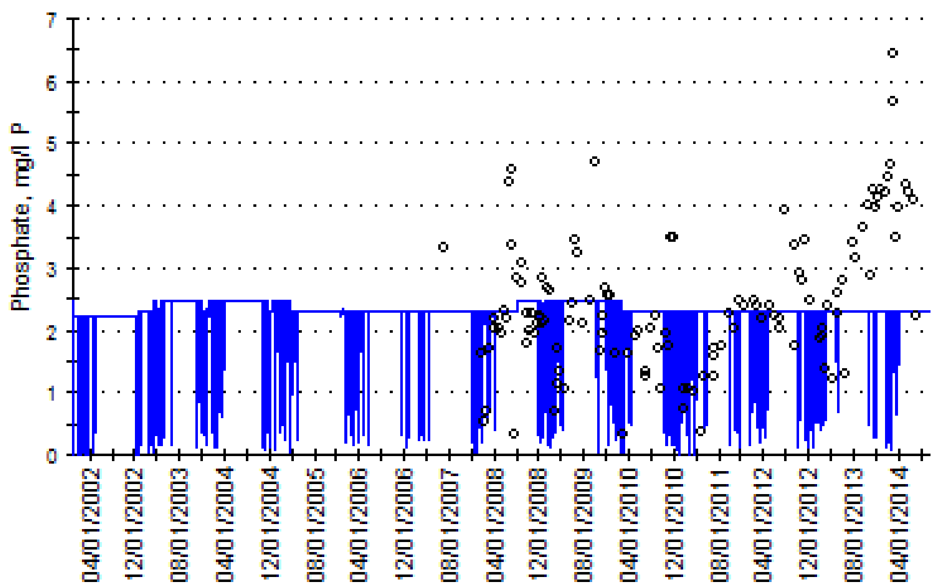

Figure 62. Modeled orthophosphate as phosphate concentrations (mg/L) in catchment 4 from 2002 to 2014 (blue line). Hollow black dots represent observed concentrations in the catchment.

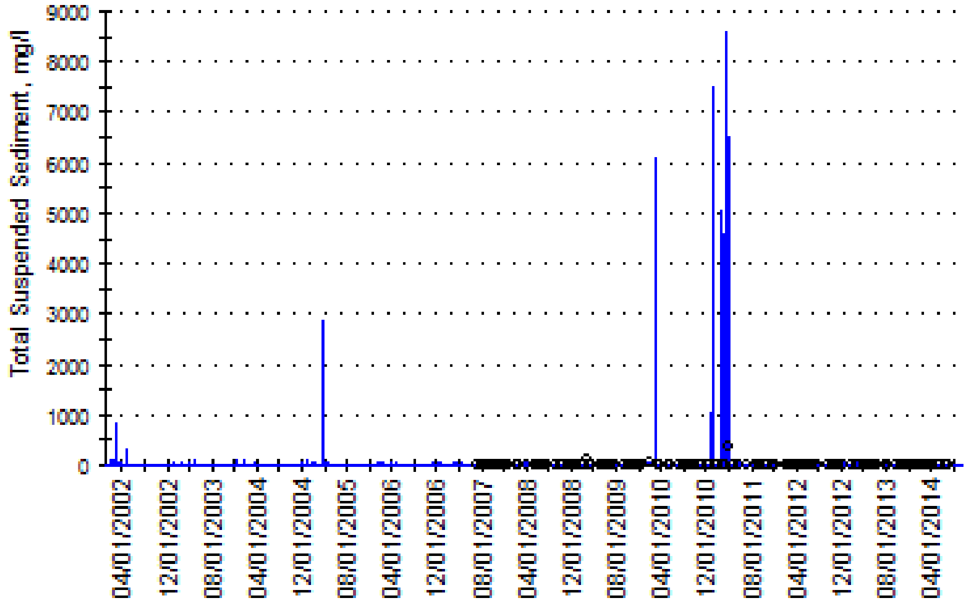

Figure 63. Modeled total suspended sediment concentrations (mg/L) in catchment 4 from 2002 to 2014 (blue line). Hollow black dots represent observed concentrations in the catchment.

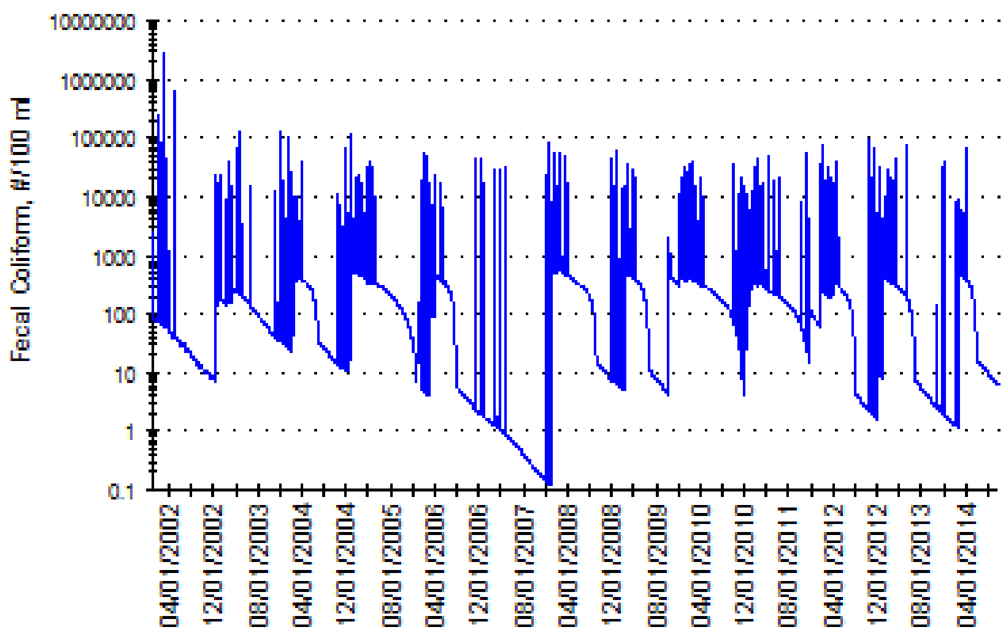

Figure 64. Modeled *E. coli* concentrations (MPN/mL) in catchment 4 from 2002 to 2014. No observed data available in this catchment.

Catchment 5

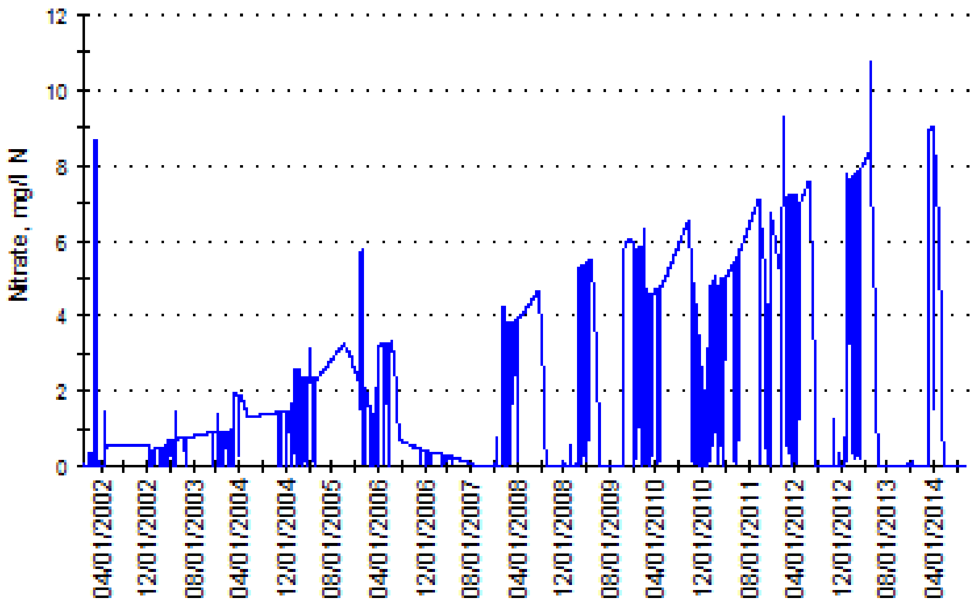

Figure 65. Modeled nitrate as nitrogen concentrations (mg/L) in catchment 5 from 2002 to 2014. No observed data available in this catchment.

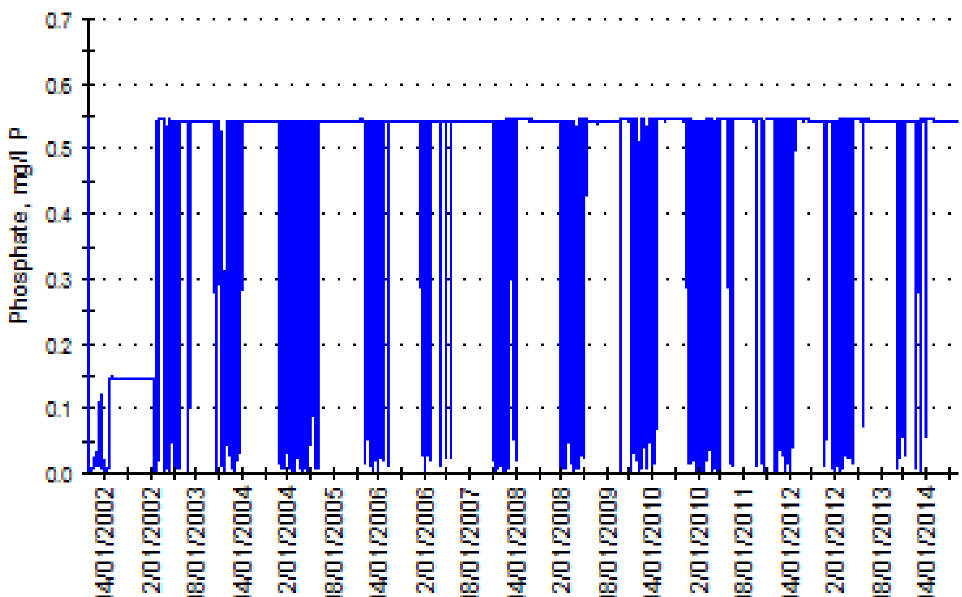

Figure 66. Modeled orthophosphate as phosphate concentrations (mg/L) in catchment 5 from 2002 to 2014. No observed data available in this catchment.

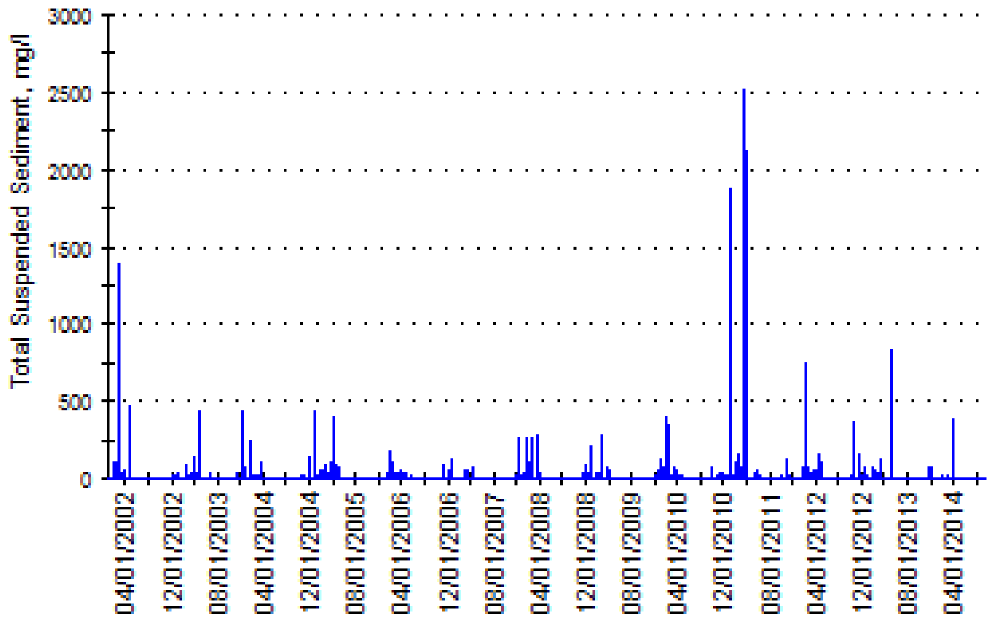

Figure 67. Modeled total suspended sediment concentrations (mg/L) in catchment 5 from 2002 to 2014. No observed data available in this catchment.

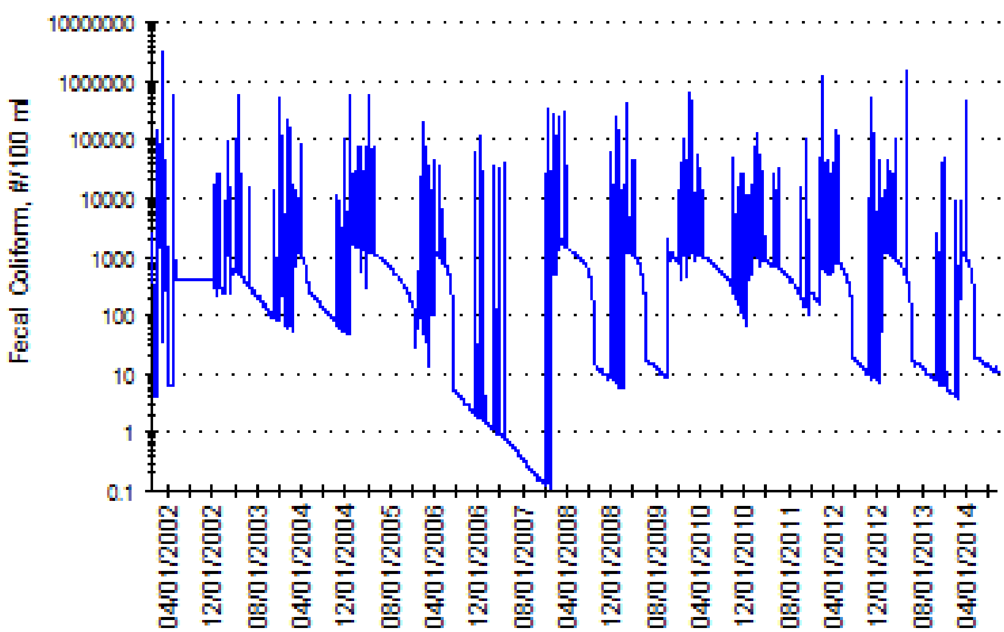

Figure 68. Modeled *E. coli* concentrations (MPN/mL) in catchment 5 of the Morro Bay watershed from 2002 to 2014. No observed data available in this catchment.

Catchment 6

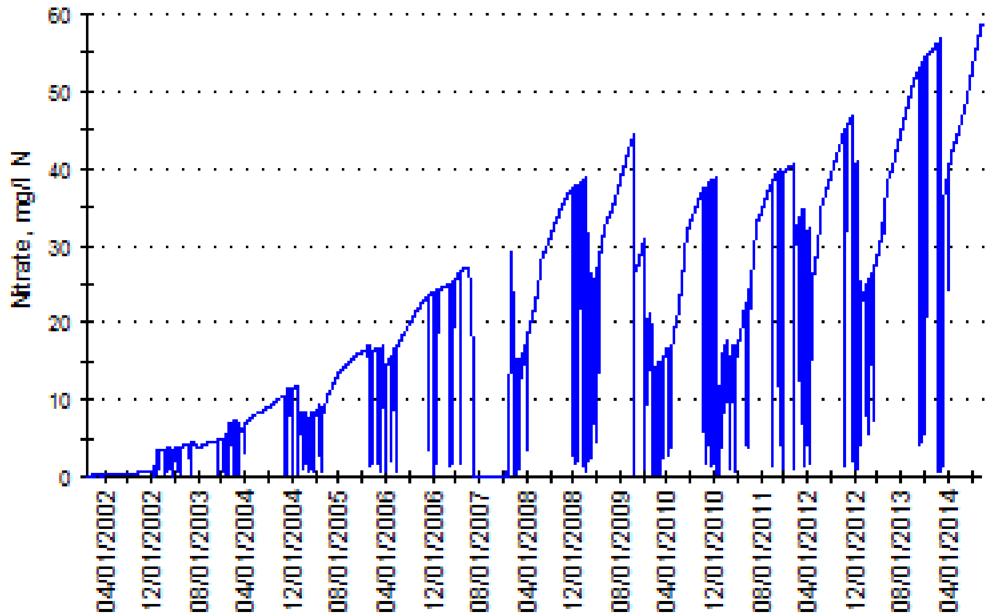

Figure 69. Modeled nitrate as nitrogen concentrations (mg/L) in catchment 6 from 2002 to 2014. No observed data available in this catchment.

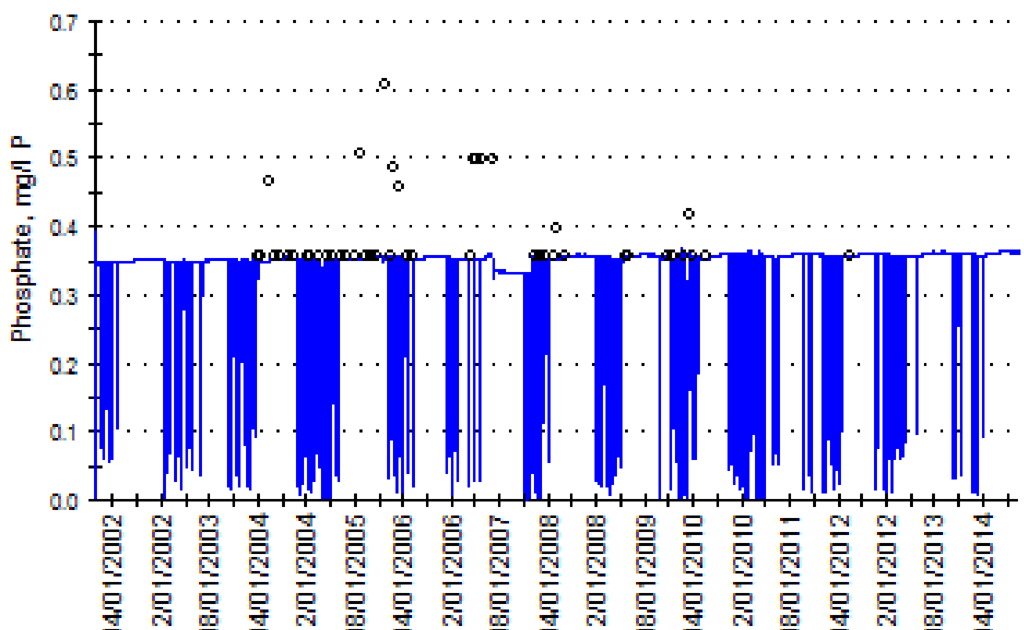

Figure 70. Modeled orthophosphate as phosphate concentrations (mg/L) in catchment 6 from 2002 to 2014 (blue line). Hollow black dots represent observed concentrations in the catchment.

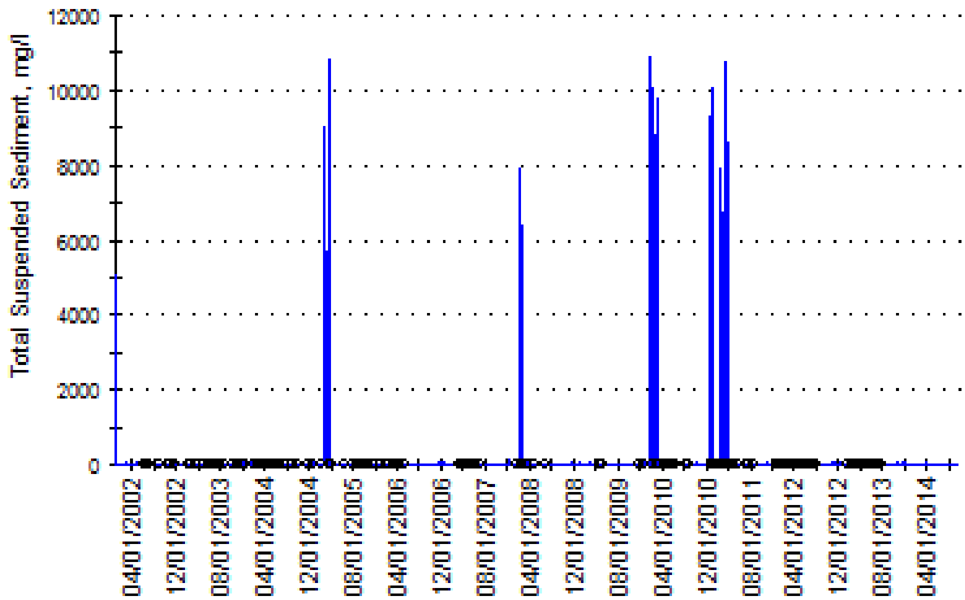

Figure 71. Modeled total suspended sediment concentrations (mg/L) in catchment 6 from 2002 to 2014 (blue line). Hollow black dots represent observed concentrations in the catchment.

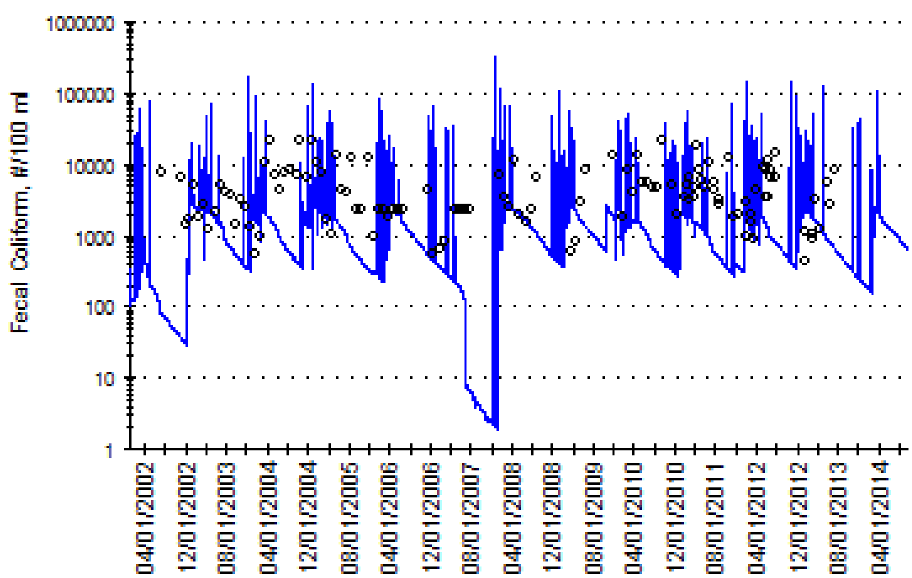

Figure 72. Modeled *E. coli* concentrations (MPN/mL) in catchment 6 from 2002 to 2014 (blue line). Hollow black dots represent observed concentrations in the catchment.

Catchment 7

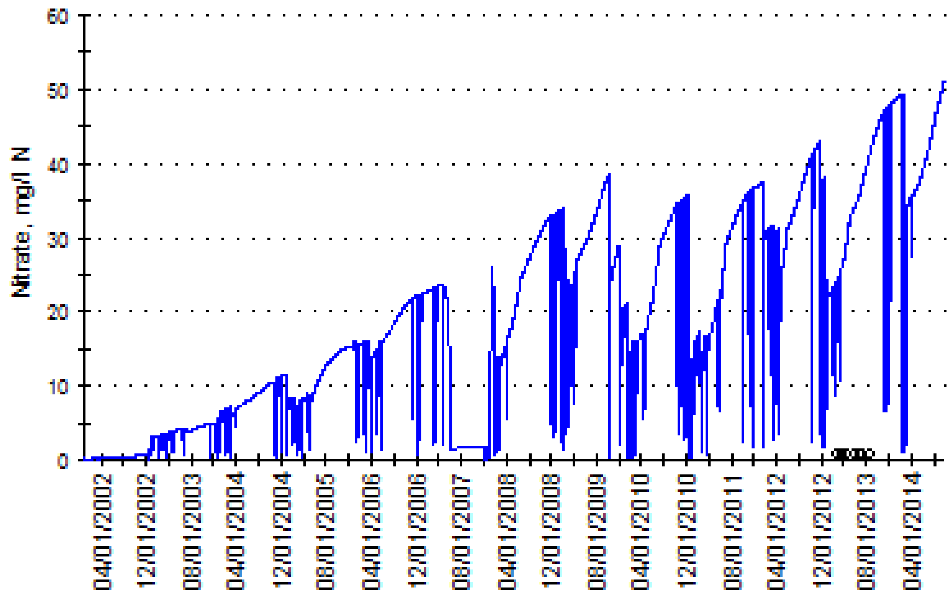

Figure 73. Modeled nitrate as nitrogen concentrations (mg/L) in catchment 7 from 2002 to 2014 (blue line). Hollow black dots represent observed concentrations in the catchment.

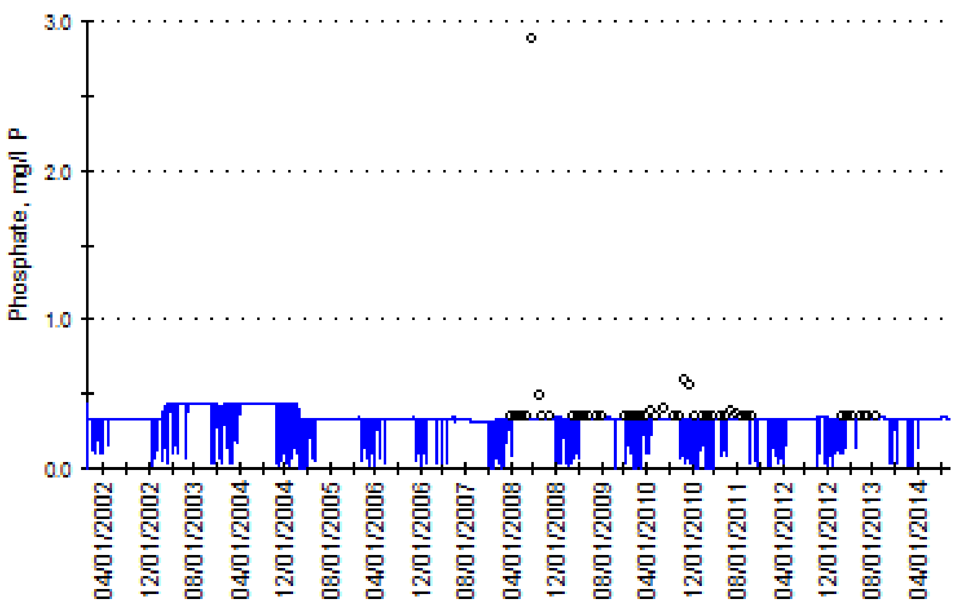

Figure 74. Modeled orthophosphate as phosphate concentrations (mg/L) in catchment 7 from 2002 to 2014 (blue line). Hollow black dots represent observed concentrations in the catchment.

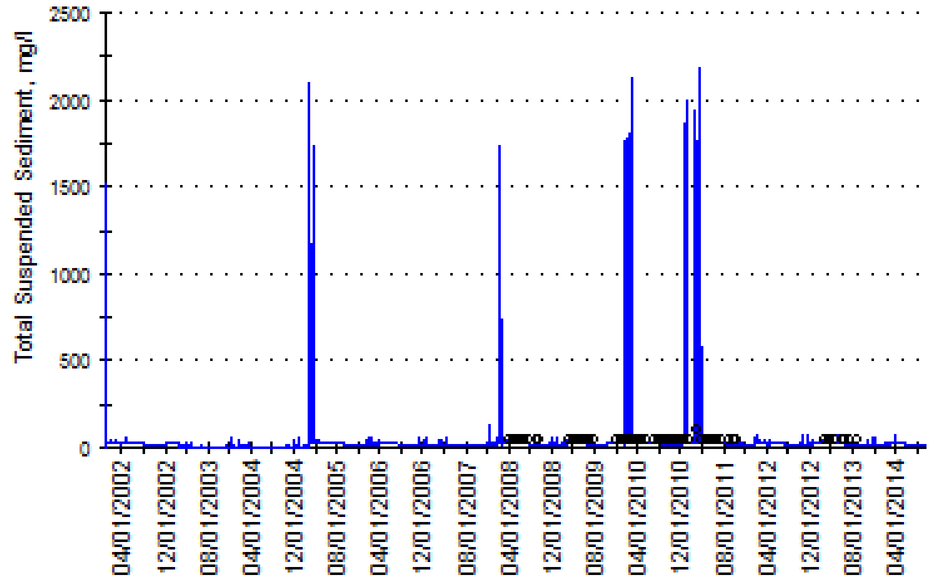

Figure 75. Modeled total suspended sediment concentrations (mg/L) in catchment 7 from 2002 to 2014 (blue line). Hollow black dots represent observed concentrations in the catchment.

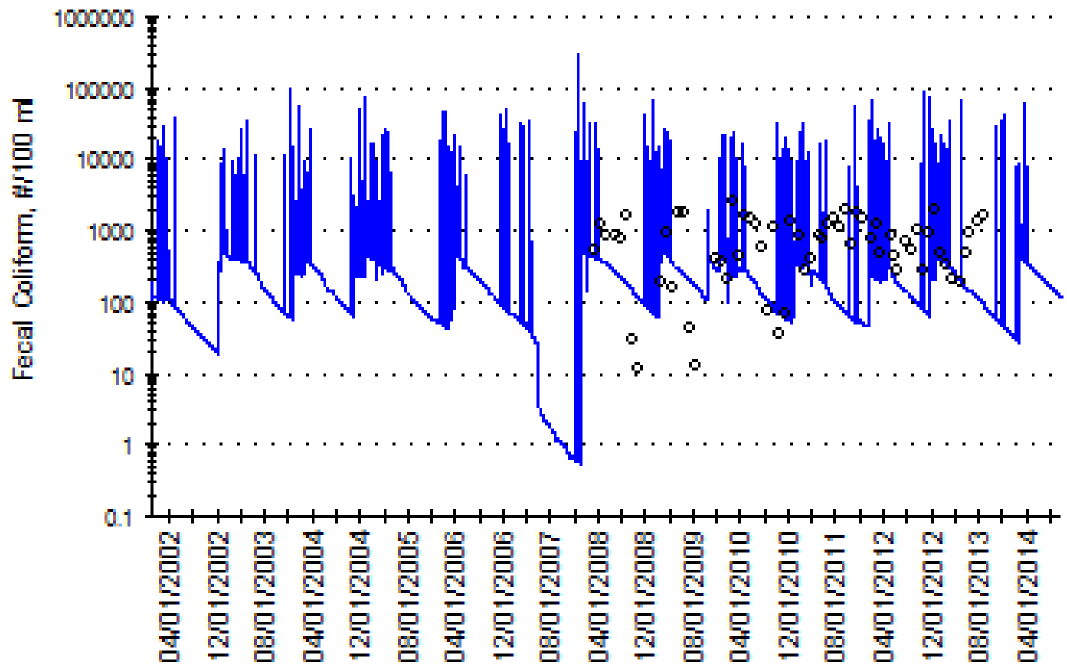

Figure 76. Modeled *E. coli* concentrations (MPN/mL) in catchment 7 from 2002 to 2014 (blue line). Hollow black dots represent observed concentrations in the catchment.

Catchment 8

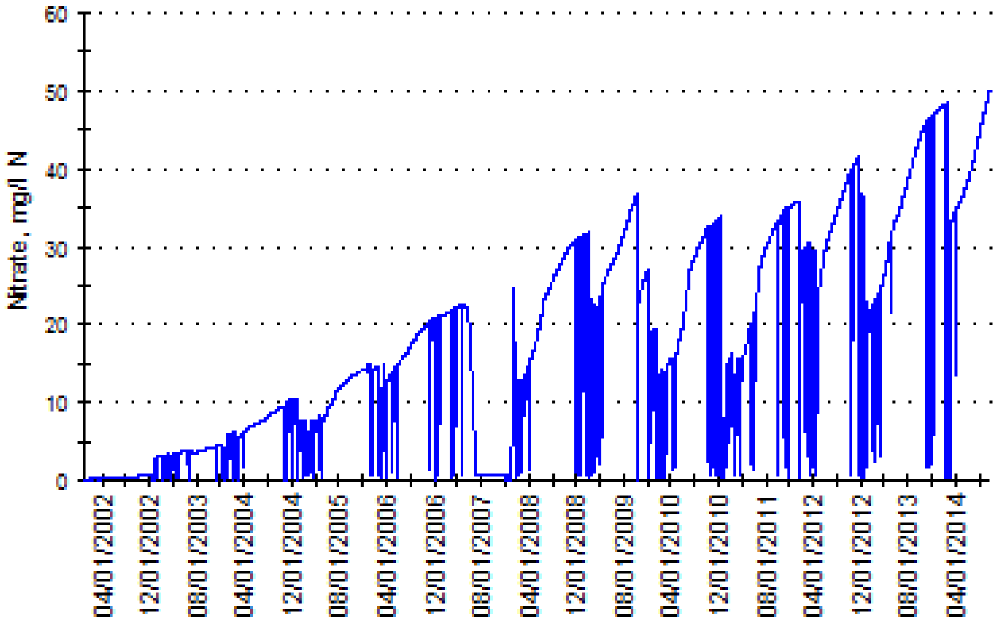

Figure 77. Modeled nitrate as nitrogen concentrations (mg/L) in catchment 8 from 2002 to 2014. No observed data available in this catchment.

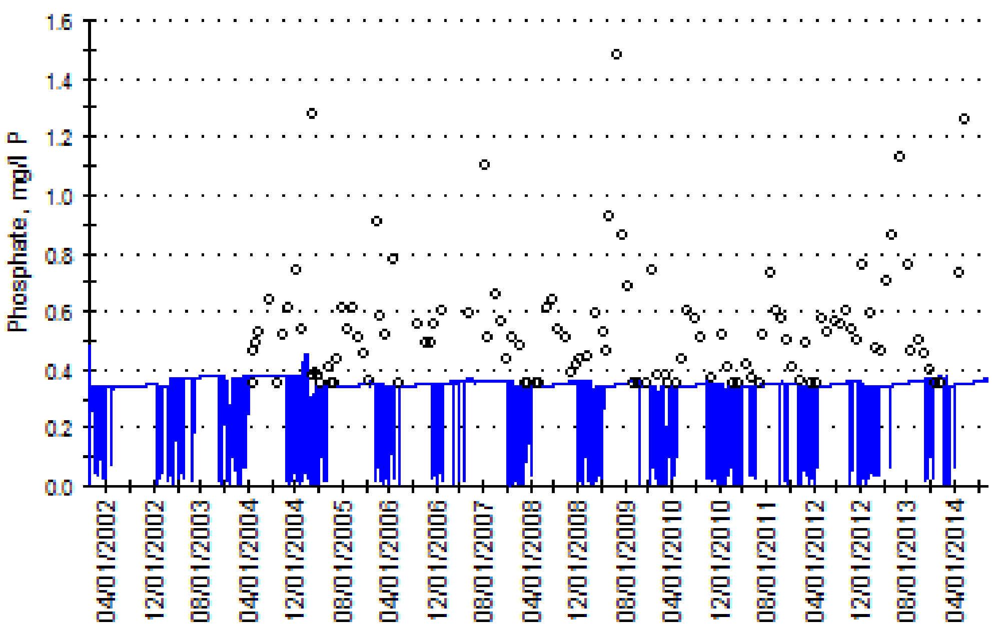

Figure 78. Modeled orthophosphate as phosphate concentrations (mg/L) in catchment 8 from 2002 to 2014 (blue line). Hollow black dots represent observed concentrations in the catchment.

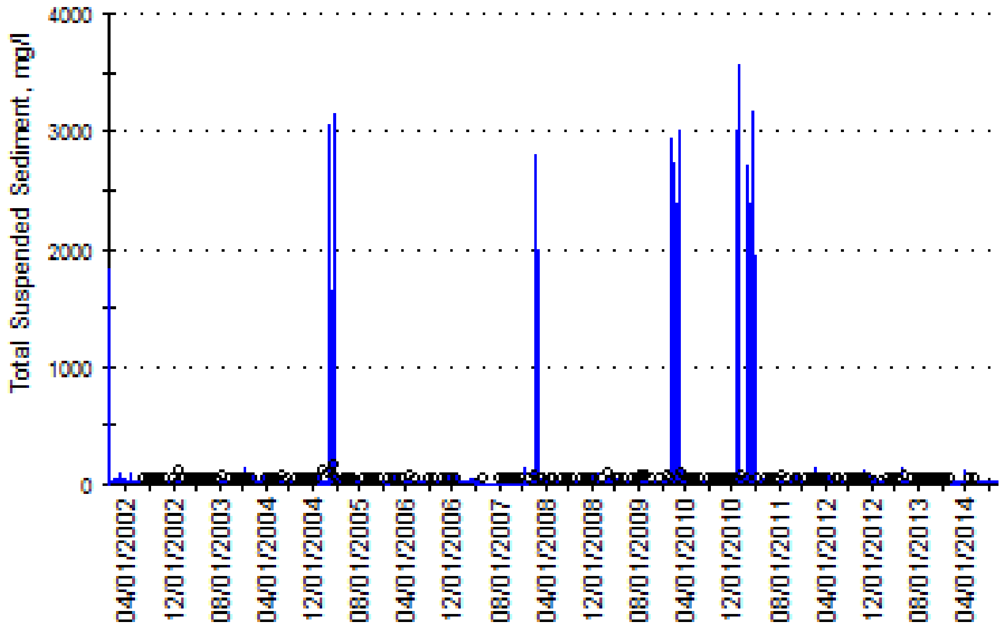

Figure 79. Modeled total suspended sediment concentrations (mg/L) in catchment 8 from 2002 to 2014 (blue line). Hollow black dots represent observed concentrations in the catchment.

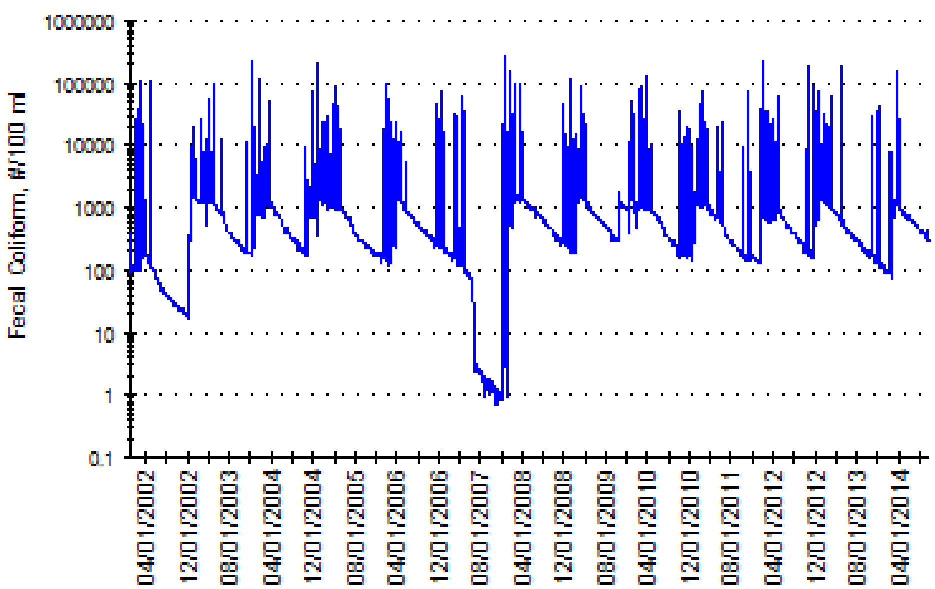

Figure 80. Modeled *E. coli* concentrations (MPN/mL) in catchment 8 from 2002 to 2014. No observed data available in this catchment.

Catchment 9

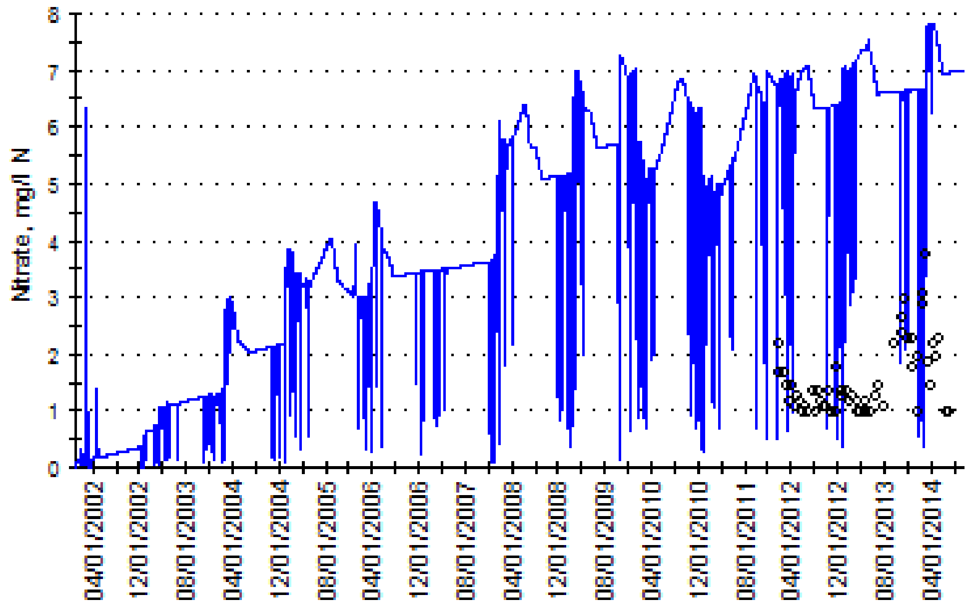

Figure 81. Modeled nitrate as nitrogen concentrations (mg/L) in catchment 9 from 2002 to 2014 (blue line). Hollow black dots represent observed concentrations in the catchment.

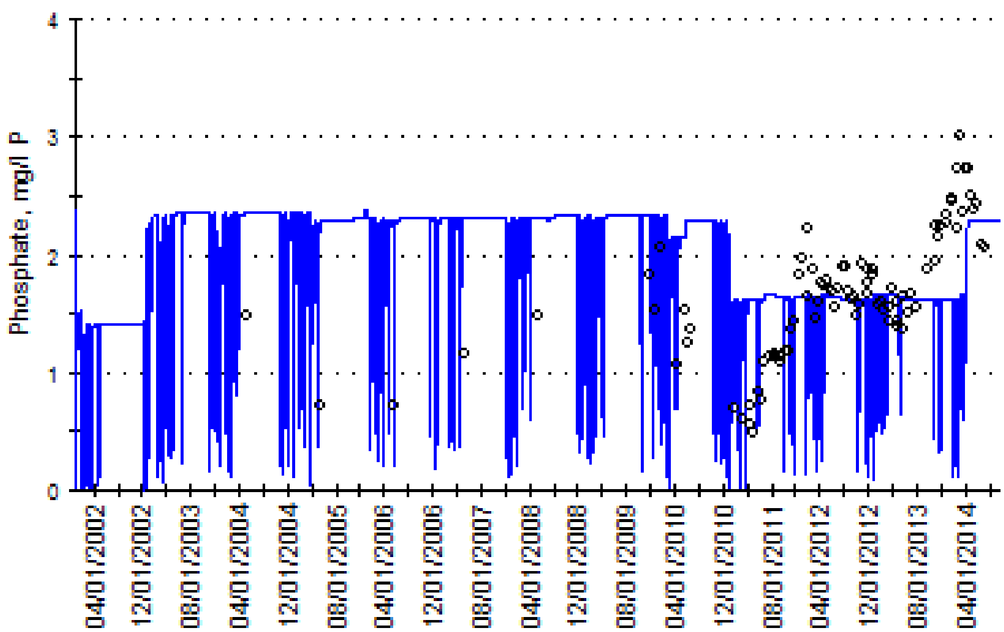

Figure 82. Modeled orthophosphate as phosphate concentrations (mg/L) in catchment 9 from 2002 to 2014 (blue line). Hollow black dots represent observed concentrations in the catchment.

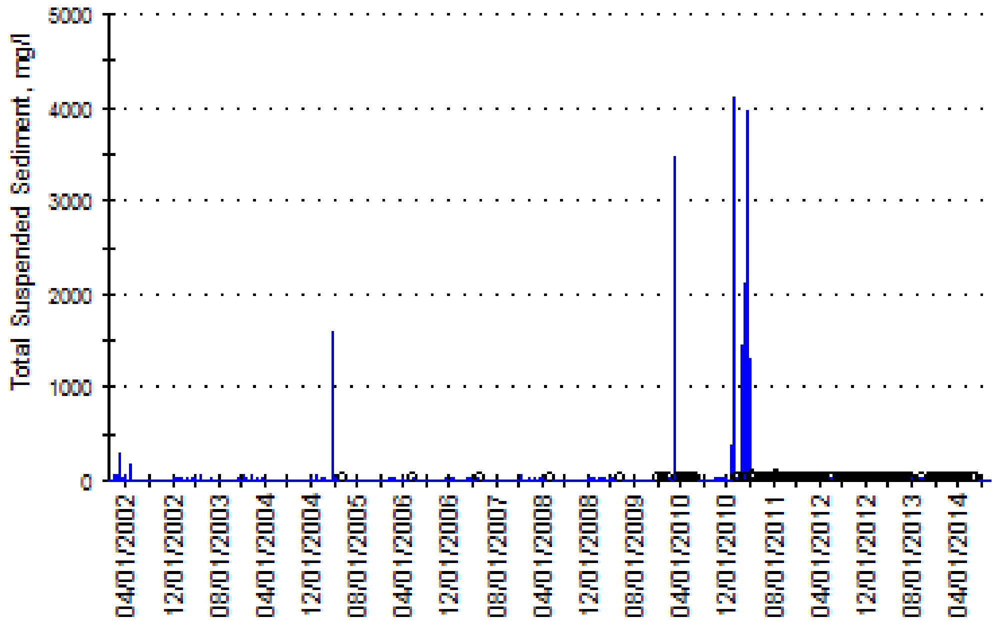

Figure 83. Modeled total suspended sediment concentrations (mg/L) in catchment 9 from 2002 to 2014 (blue line). Hollow black dots represent observed concentrations in the catchment.

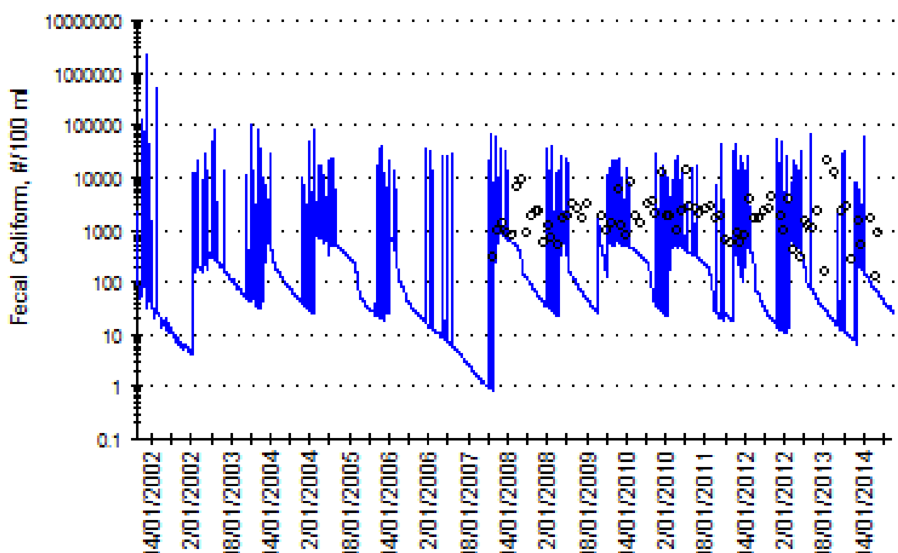

Figure 84. Modeled *E. coli* concentrations (MPN/mL) in catchment 9 from 2002 to 2014 (blue line). Hollow black dots represent observed concentrations in the catchment.

Catchment 10

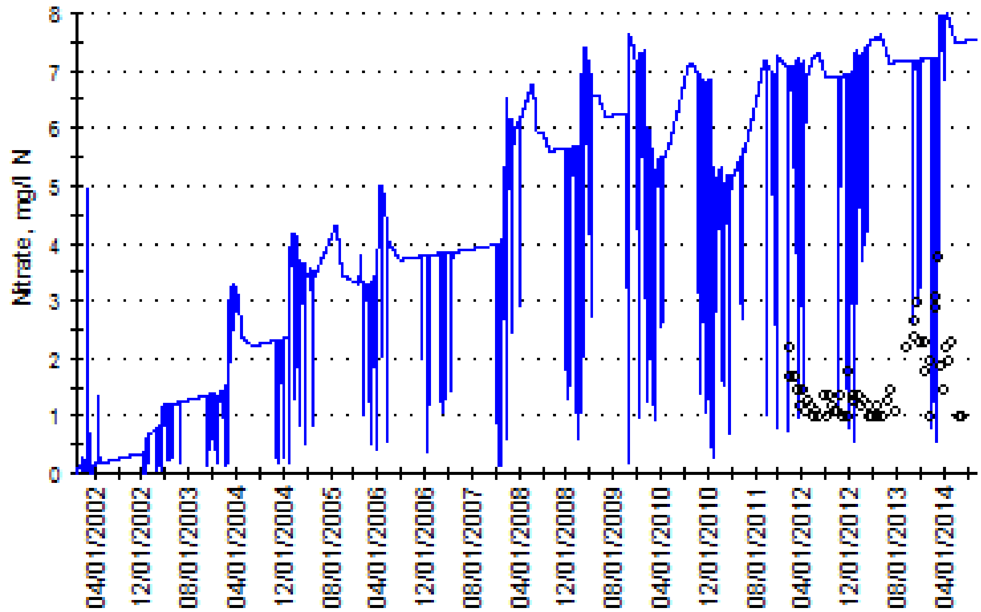

Figure 85. Modeled nitrate as nitrogen concentrations (mg/L) in catchment 10 from 2002 to 2014 (blue line). Hollow black dots represent observed concentrations in the catchment.

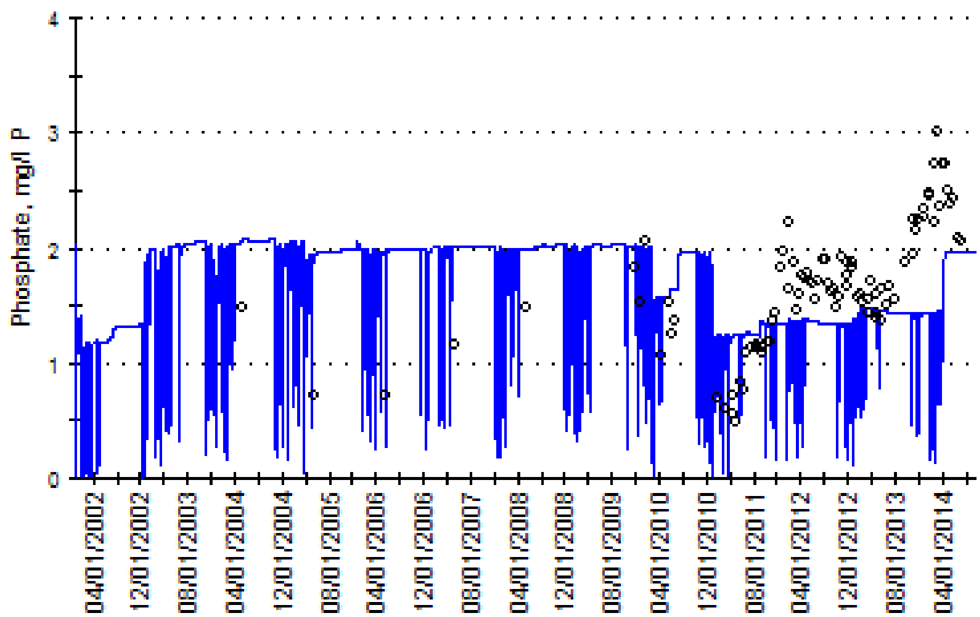

Figure 86. Modeled orthophosphate as phosphate concentrations (mg/L) in catchment 10 from 2002 to 2014 (blue line). Hollow black dots represent observed concentrations in the catchment.

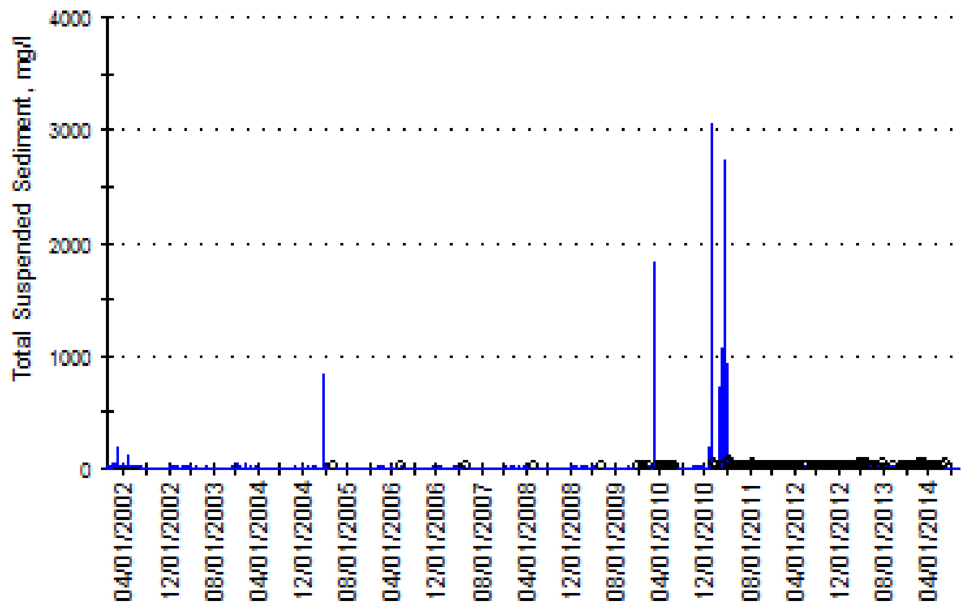

Figure 87. Modeled total suspended sediment concentrations (mg/L) in catchment 10 from 2002 to 2014 (blue line). Hollow black dots represent observed concentrations in the catchment.

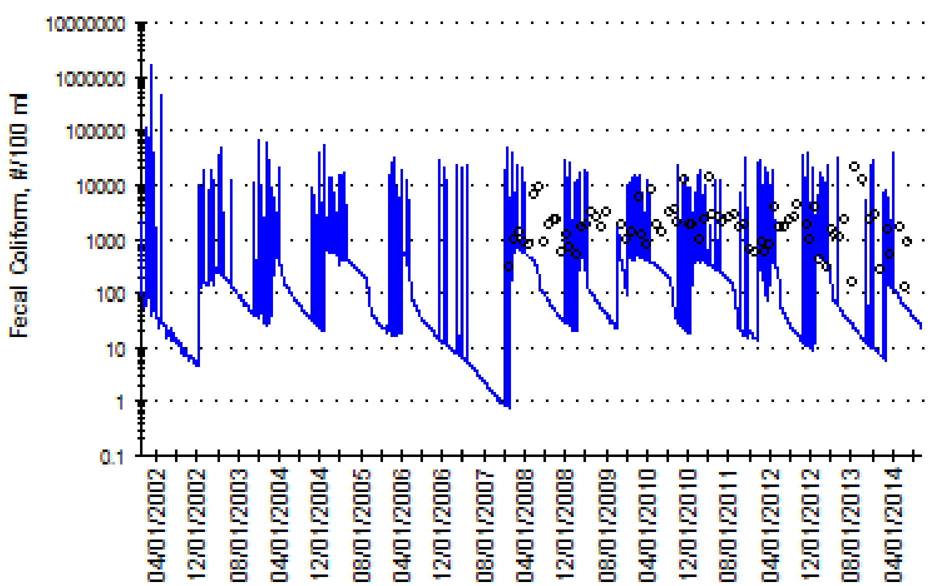

Figure 88. Modeled *E. coli* concentrations (MPN/mL) in catchment 10 from 2002 to 2014 (blue line). Hollow black dots represent observed concentrations in the catchment.

Catchment 11

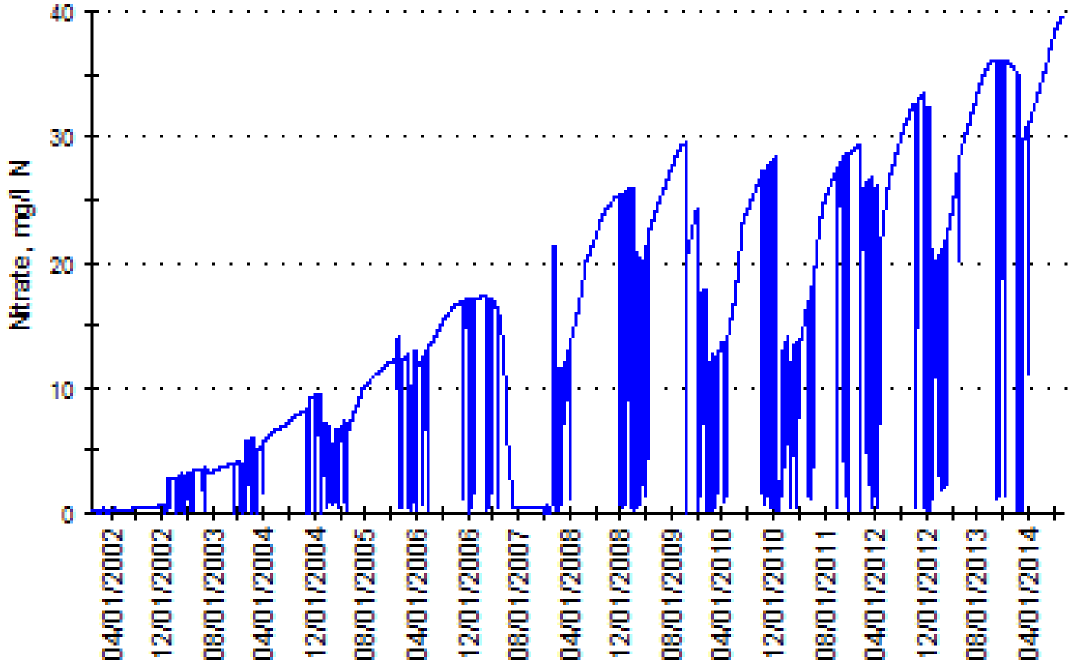

Figure 89. Modeled nitrate as nitrogen concentrations (mg/L) in catchment 11 from 2002 to 2014. No observed data available in this catchment.

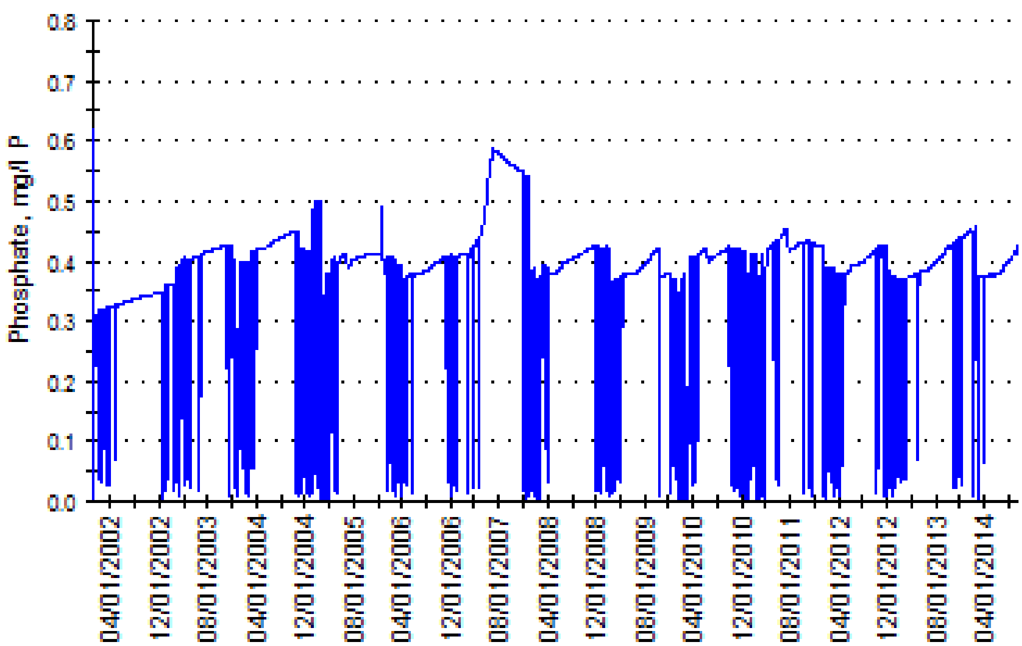

Figure 90. Modeled orthophosphate as phosphate concentrations (mg/L) in catchment from 2002 to 2014. No observed data available in this catchment.

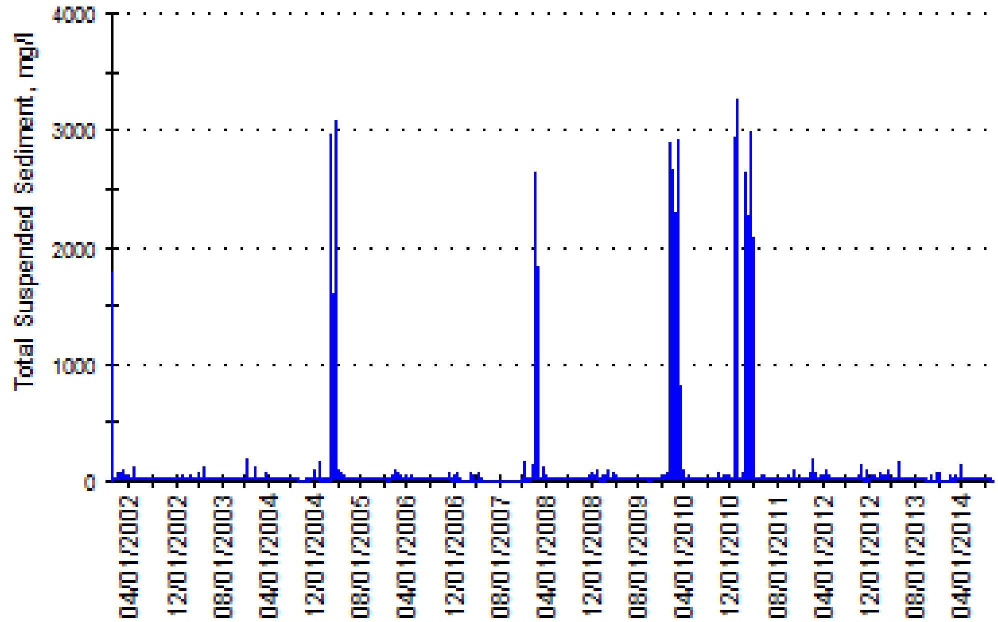

Figure 91. Modeled total suspended sediment concentrations (mg/L) in catchment 11 from 2002 to 2014. No observed data available in this catchment.

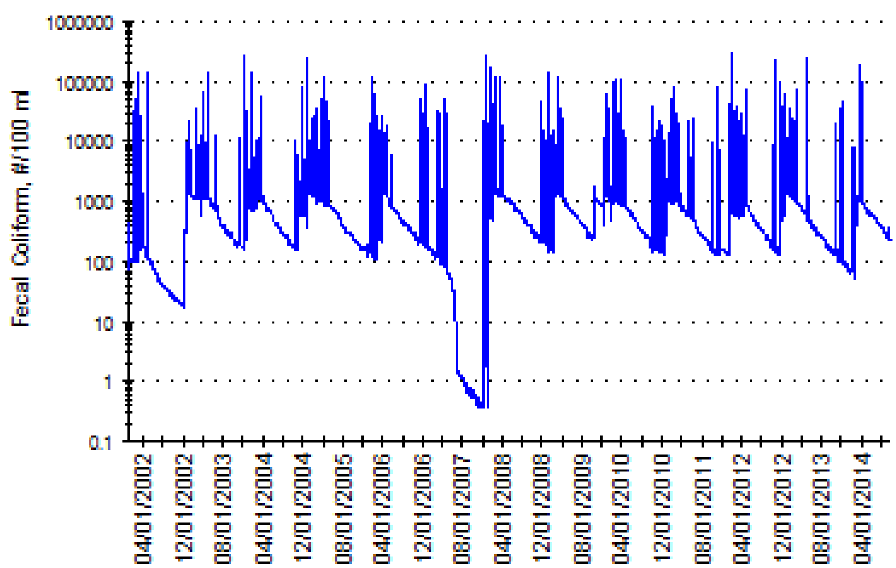

Figure 92. Modeled *E. coli* concentrations (MPN/mL) in catchment 11 from 2002 to 2014. No observed data available in this catchment.

Catchment 12

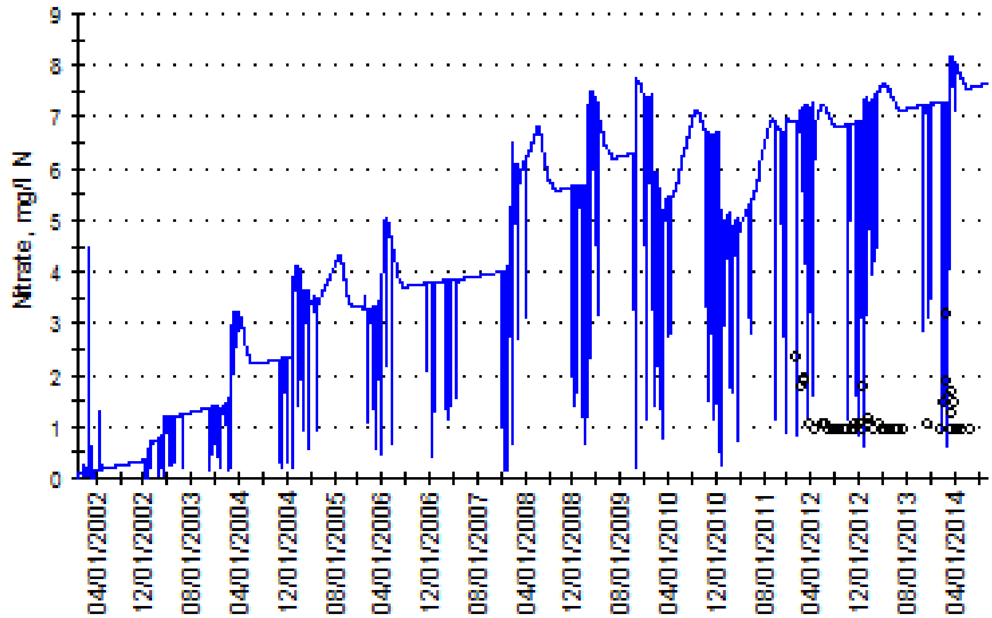

Figure 93. Modeled nitrate as nitrogen concentrations (mg/L) in catchment 12from 2002 to 2014 (blue line). Hollow black dots represent observed concentrations in the catchment.

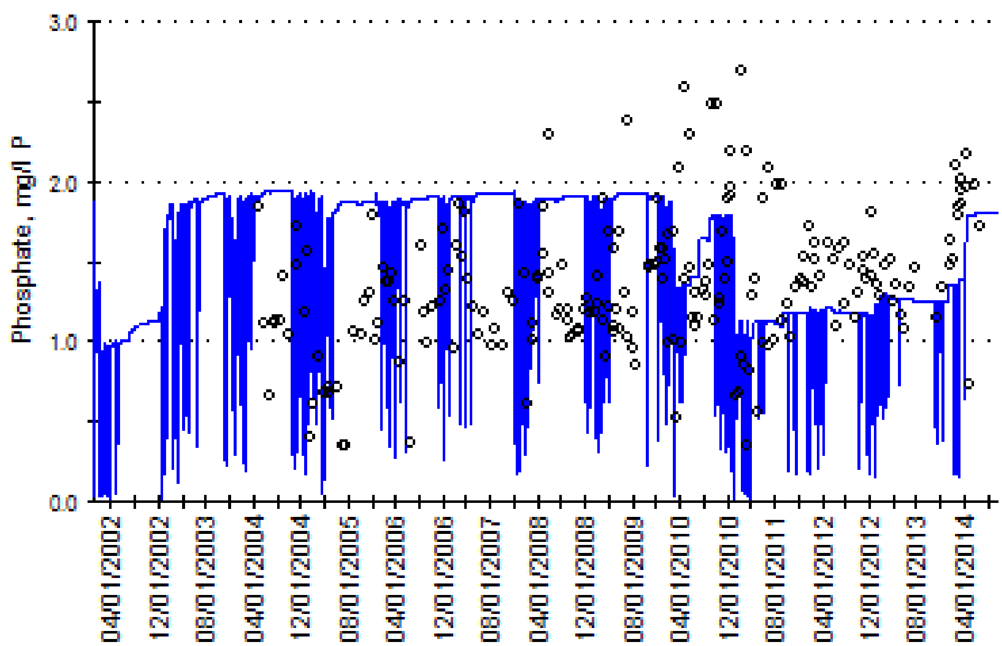

Figure 94. Modeled orthophosphate as phosphate concentrations (mg/L) in catchment 12 from 2002 to 2014 (blue line). Hollow black dots represent observed concentrations in the catchment.

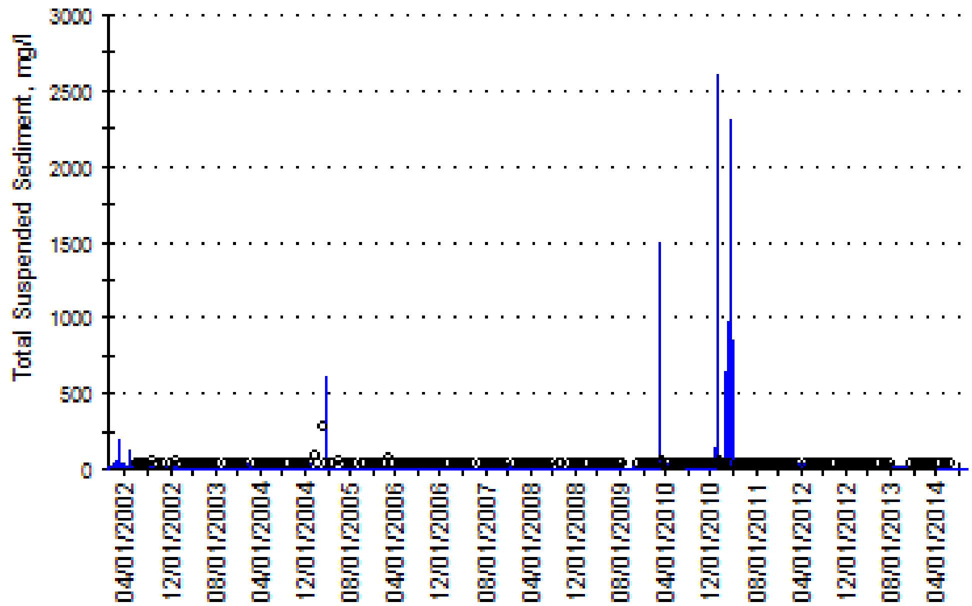

Figure 95. Modeled total suspended sediment concentrations (mg/L) in catchment 12 from 2002 to 2014 (blue line). Hollow black dots represent observed concentrations in the catchment.

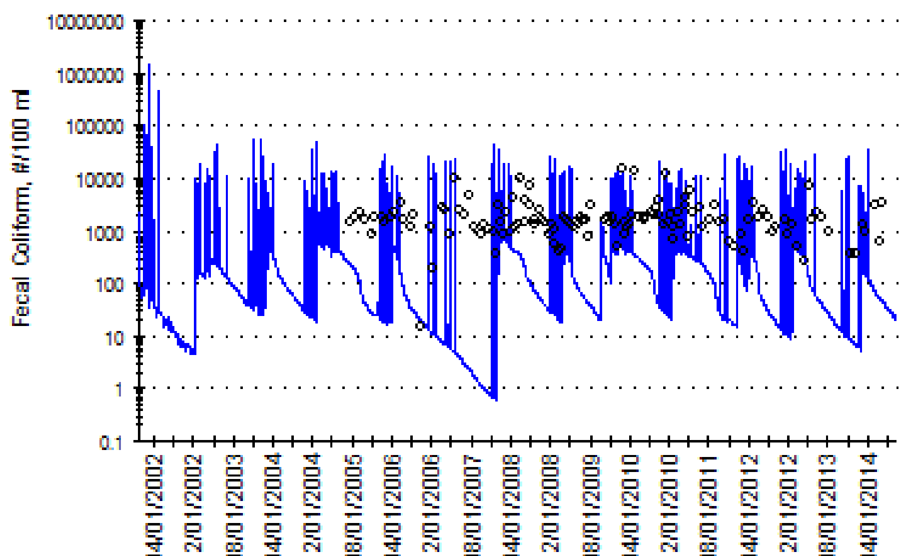

Figure 96. Modeled *E. coli* concentrations (MPN/mL) in catchment 12 from 2002 to 2014 (blue line). Hollow black dots represent observed concentrations in the catchment.

Catchment 13

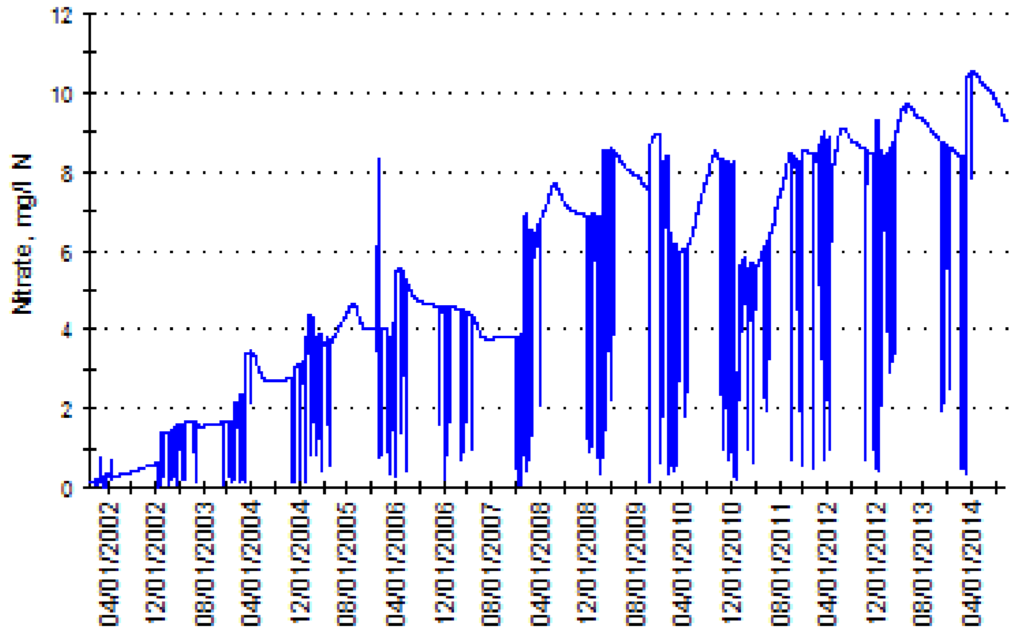

Figure 97. Modeled nitrate as nitrogen concentrations (mg/L) in catchment 13 from 2002 to 2014. No observed data available in this catchment.

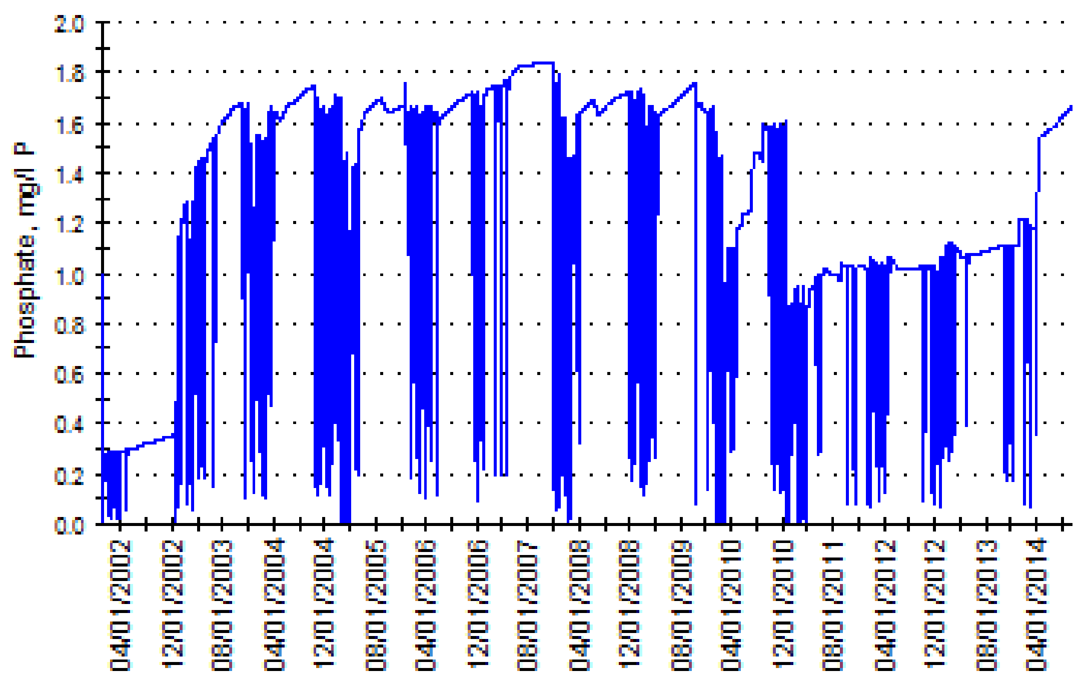

Figure 98. Modeled orthophosphate as phosphate concentrations (mg/L) in catchment 13 from 2002 to 2014. No observed data available in this catchment.

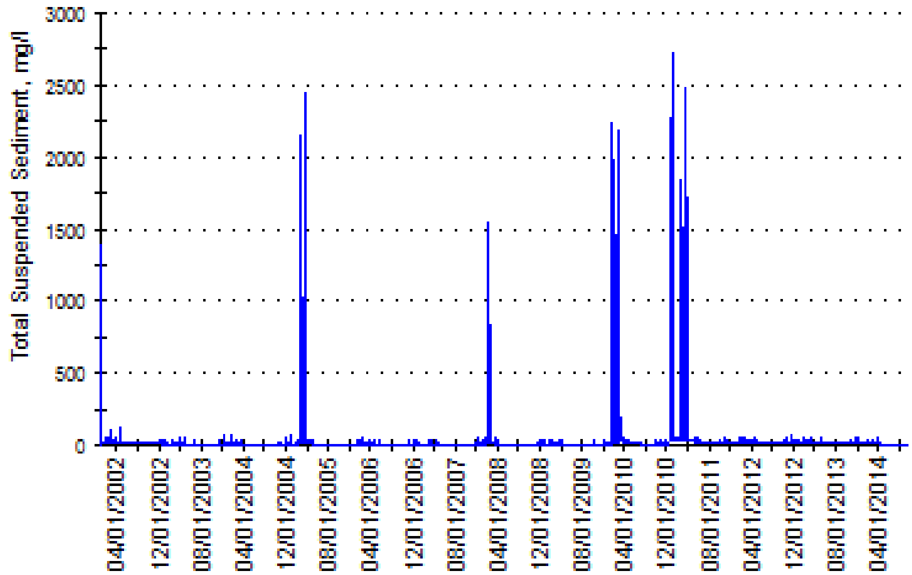

Figure 99. Modeled *E. coli* concentrations (MPN/mL) in catchment 13 from 2002 to 2014. No observed data available in this catchment.

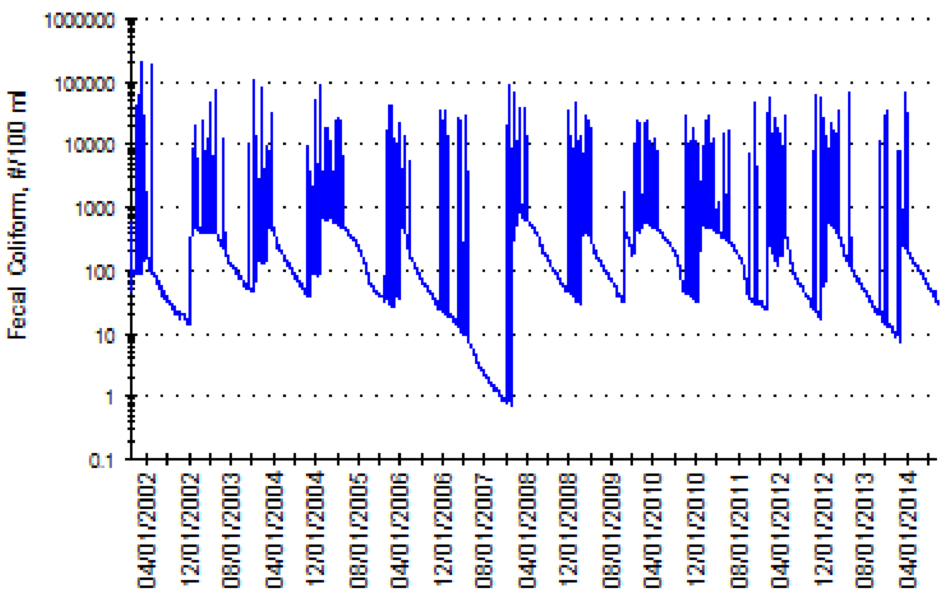

Figure 100. Modeled *E. coli* concentrations (MPN/mL) in catchment 13 from 2002 to 2014. No observed data available in this catchment.

Appendix E. Combination of Biodiversity and Watershed Analyses

The Morro Bay National Estuary Program typically addresses biodiversity conservation and water quality management as separate objectives. This portion of the project aimed to find the best combined solution by merging these objectives into a single prioritization model.

Methods

To combine Marxan and WARMF, the watershed catchments were overlaid with the parcels selected by Marxan in the basic scenario model (30% species target, Figure 101) and the Estuary Program species of interest scenario (80% Estuary Program species target, Figure 102). The area of land covered by all Marxan selected parcels was calculated for each catchment that had over 5% coverage by parcels. Catchments that met this criterion were 7, 8, and 10 in the Basic Marxan scenario and catchments 8 and 10 in the Estuary Program species of interest scenario. The total parcel areas were then converted to percentages of parcel land cover in each catchment in order to insert the information into WARMF (Table 24). The percent of parcels in each catchment represent the amount of land that would be placed into conservation if the Marxan results were implemented by the Estuary Program. Percent of parcels was subtracted from rangeland land use category and added to the mixed forest category to reflect implementation of conservation easements. Decreasing rangeland land use category in WARMF resulted in the model incorporating fewer cows in that catchment because the land application data used to reflect cattle within each catchment is based upon the percent rangeland category. Thus, reducing rangeland reduces cattle presence as would likely occur were land converted to conservation. Additionally, a scenario with a 40% decrease in rangeland in catchments 7, 8 and 10 was conducted on the basic Marxan scenario to determine if an exceptionally large change in land use would have greater effects on water quality.

Table 24. Percent of area (ft^2) covered by conserved parcels in the watershed catchments.

Marxan Scenario	Catchment Number	Percent of Parcels in Catchment	Original Rangeland	Modified Rangeland	Original Mixed Forest	Modified Mixed Forest
Basic	7	11.9%	58.6%	46.7%	34.1%	46%
	8	15.7%	47.07%	31.37%	8.27%	23.97%
	10	9.4%	74.49%	65.09%	2.94%	12.34%
Estuary Program Species of interest	8	27.3%	47.07%	19.77%	8.27%	35.57%
	10	24.0%	74.49%	50.49%	2.94%	26.94%

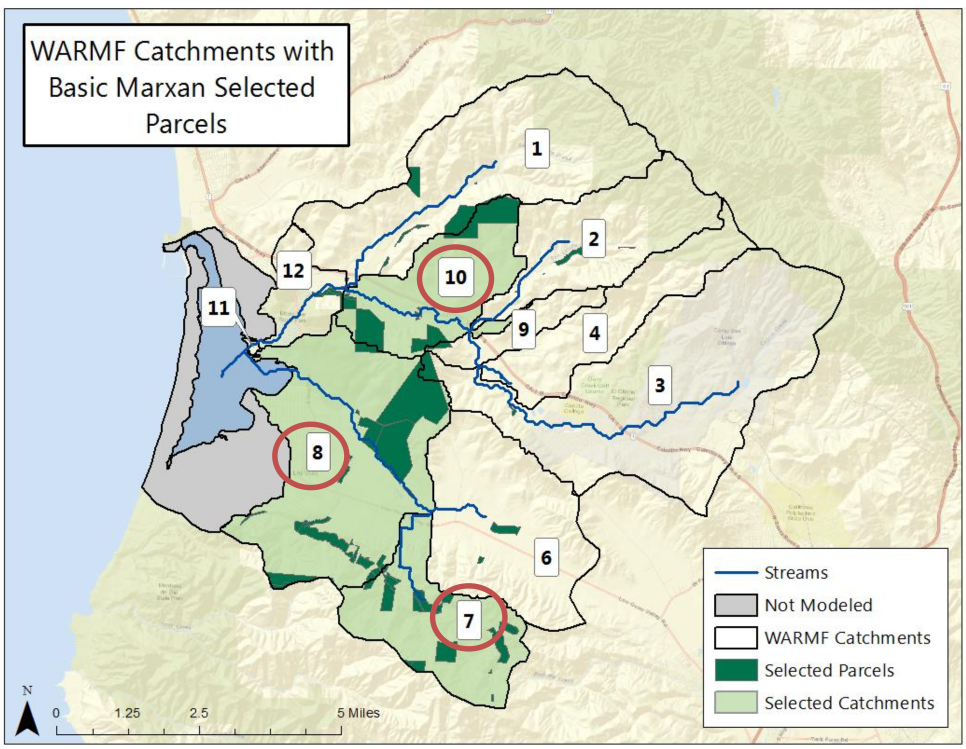

Figure 101. WARMF catchments with basic Marxan selected parcels. Selected parcels are shown in dark green and overlaid with the watershed model's catchment boundaries. The catchments used for analysis are circled in red, and had at least 5% of their area covered by selected parcels

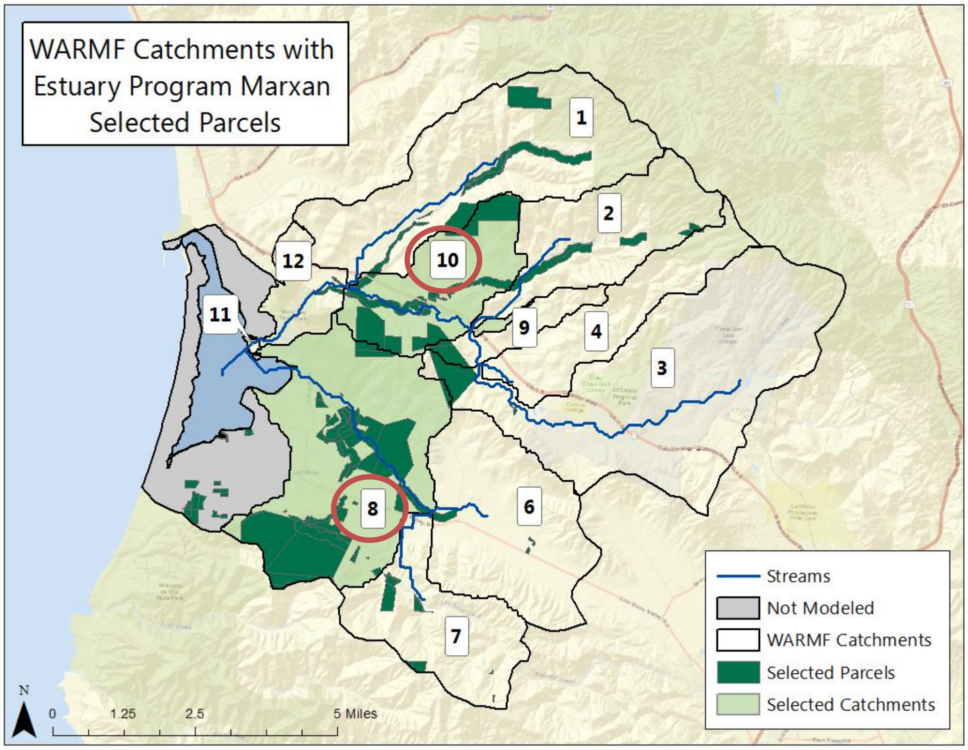

Figure 102. WARMF catchments with Estuary Program Marxan selected parcels. Selected parcels are shown in dark green and overlaid with the watershed model's catchment boundaries. The catchments used for analysis are circled in red, and had at least 5% of their area covered by selected parcels.

The land category in WARMF was changed from rangeland to mixed forest because the majority of the land use in the chosen catchments was rangeland. Due to model land use category limitations, mixed forest was the best suitable option for changing land use. Additionally, rangeland has a negative effect on water quality, inputting nitrogen and phosphorous into the waterways. Therefore, reducing rangeland should result in improved water quality. Modifying the land use category to one that has a higher conservation value will lower the exceedances of the various WARMF model parameters and model improved water quality in the watershed. Mixed forest land use cover was chosen as the land use category for conservation because WARMF has no shrub or grassland category. It was thus determined that mixed forest land type would be the most appropriate land use category for conservation purposes. This approach models the effects on water quality of placing all of the Marxan selected parcels into conservation. Changing land use categories as a form of model combination provides a spatial display of WARMF outputs and determines the water quality effects of placing Marxan selected parcels in conservation easements.

Results

For both scenarios, changing land cover from rangeland to mixed forest resulted in very minimal modeled change in water quality across all four parameters. Below are two hydrographs for phosphate in catchment 8 from 2002-2014. The one on the top is for the basic scenario, with a 12% land use change, and the one on the bottom is for the Estuary Program species of interest scenario, with a 27% land use change.

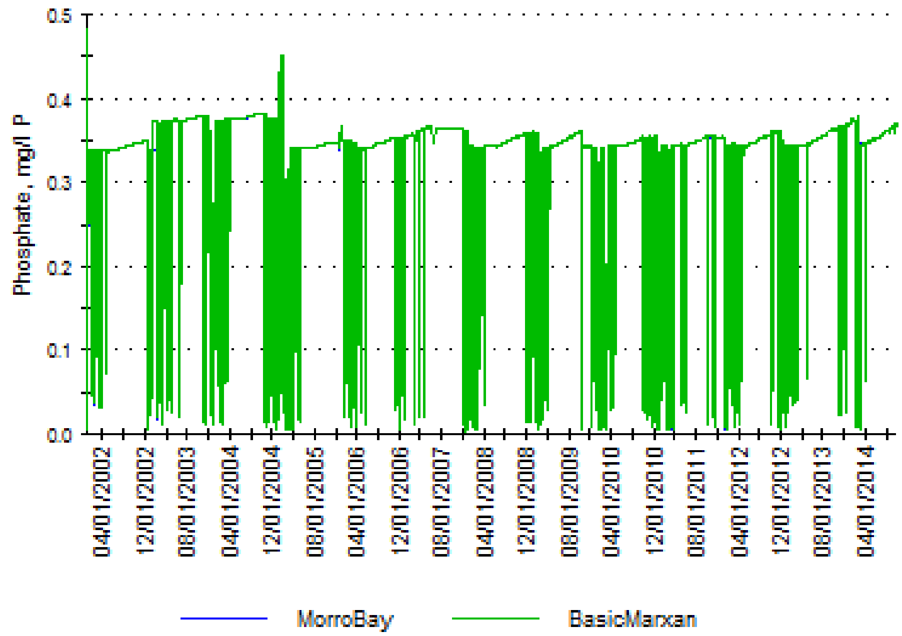

Figure 103. WARMF hydrograph of basic Marxan scenario land use change. Green line represents land use change scenario and blue line represents original WARMF model.

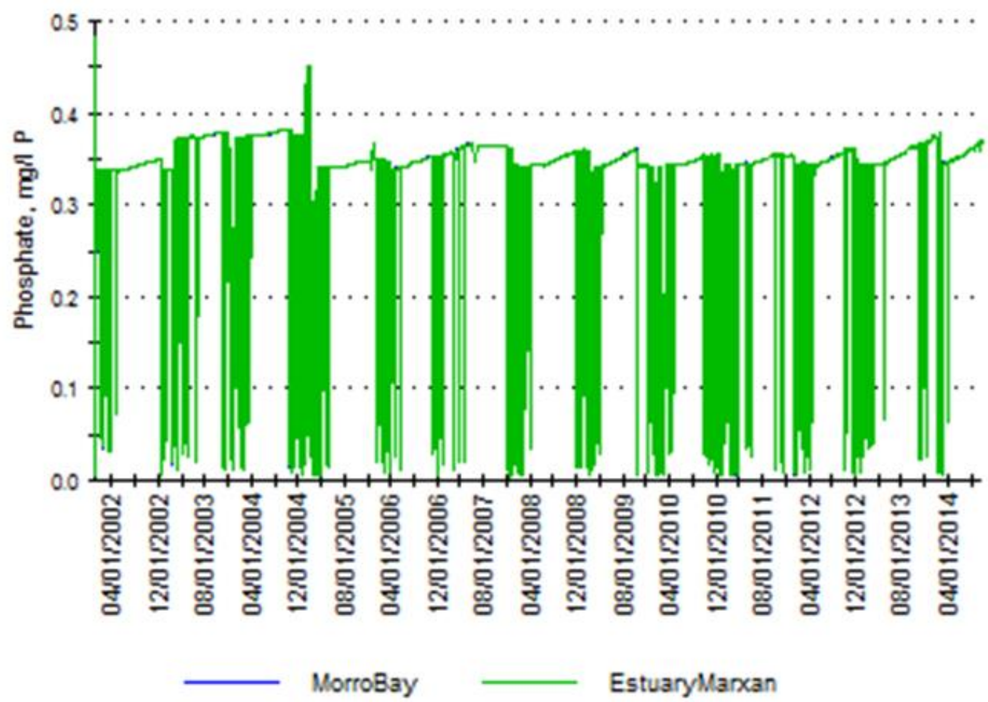

Figure 104. WARMF hydrograph of Estuary Program species of interest Marxan scenario land use change. Green line represents land use change scenario and blue line represents original WARMF model.

The green line in Figures 103 and 104 represent the new WARMF scenario that included the land use shifts. As the legend shows, a blue line represents the original Morro Bay watershed model scenario. The lines entirely overlap each other, showing very minimal change in water quality based on this land use scenario. It is likely the land use changes made were too small to see a change in water quality. **Table 25** shows the exact numerical impacts of these scenarios on water quality parameters and the general trends observed.

Table 25. Combination model results by scenario.

	Original	Basic Marxan	Estuary Program	Large Change	Trend
N (mg/L)	17.66	20.63	20.93	28.18	Increase
P (mg/L)	0.312	0.312	0.312	0.32	Increase
Sediment (mg/L)	50.04	49.02	48.77	45.96	Decrease
E. coli	2311	2311	2311	2313	Increase

Because converting rangeland to mixed forest had minimal effect, agricultural land was converted to mixed forest to assess which land use may be having the largest impact on water quality degradation.

For this scenario, all agricultural land in Los Osos valley was converted to mixed forest. Catchment 6 had 27% cropland, while catchment 7 had 1.6% and catchment 8 had 10% cropland. All hydrographs shown for this analysis are from catchment 8, which is the most downstream catchment in Los Osos valley. From this land use change, more of a difference is modeled in water quality and decreases are observed in all four parameters. The two shown below in Figures 105 and 106 are nitrate and phosphate, which are lower due to the removal of fertilizer application from the model.

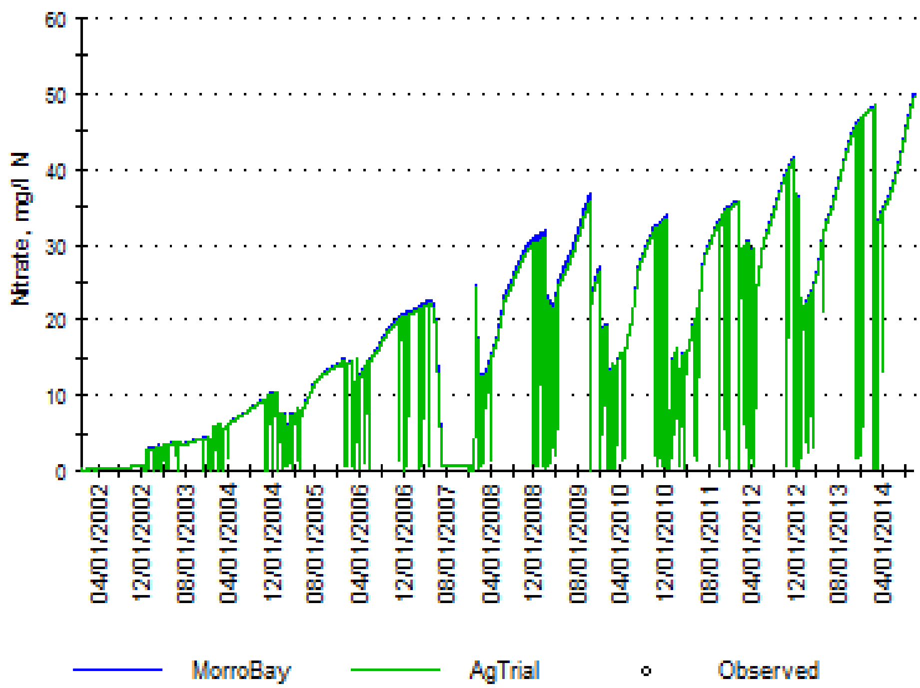

Figure 105. WARMF hydrograph of scenario reflecting nitrate impacts of conversion of agricultural land use in Los Osos to mixed forest. Green line represents land use change scenario and blue line represents original WARMF model.

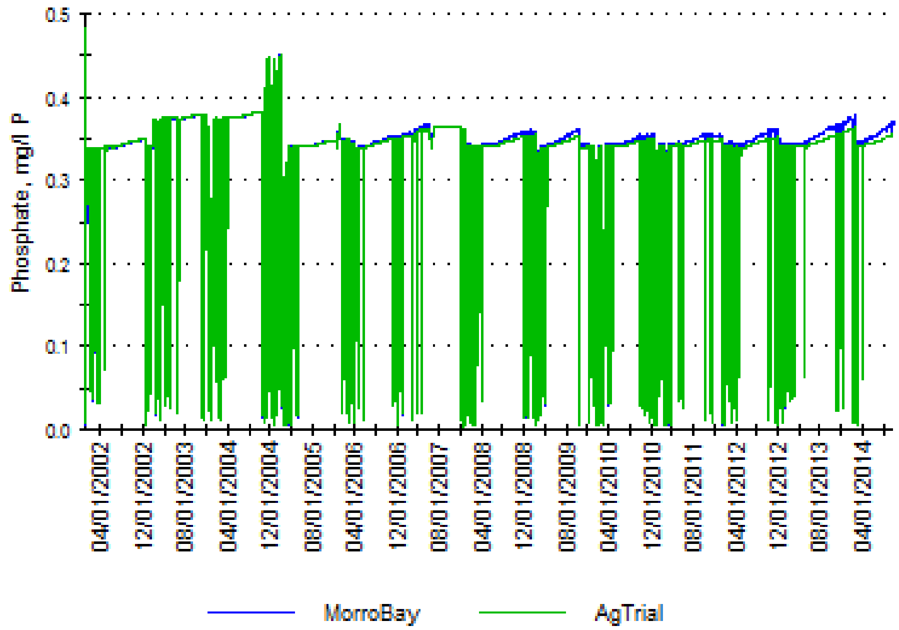

Figure 106. WARMF hydrograph of scenario reflecting phosphate impacts of conversion of agricultural land use in Los Osos to mixed forest. Green line represents land use change scenario and blue line represents original WARMF model.

Sediment and *E.coli* are also lower in this scenario, with visible decreases in sediment during large storm events, as shown in the hydrograph below in Figure 107. The peaks in *E. coli* concentration are equally as high as with agriculture, but *E. coli* concentrations are lower during other months compared to the original watershed model.

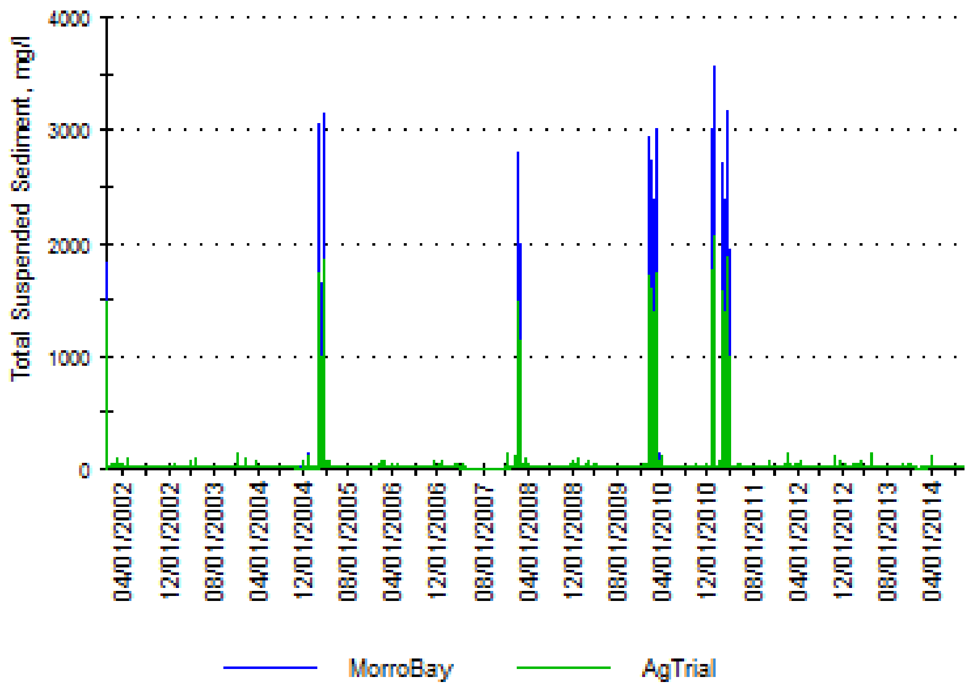

Figure 107. WARMF hydrograph of scenario reflecting sediment impacts of conversion of agricultural land use in Los Osos to mixed forest. Green line represents land use change scenario and blue line represents original WARMF model.

Conclusions

These results indicate that decreasing the amount of rangeland had a minimal effect on water quality, likely because agricultural inputs were still contributing a large amount of pollution to the Los Osos valley. Only when agriculture was converted to another use were noticeable impacts modeled. After consulting with experts, it is concluded that these minimal results are likely due to WARMF being incapable of properly modeling slight land use changes on the small watershed scale.