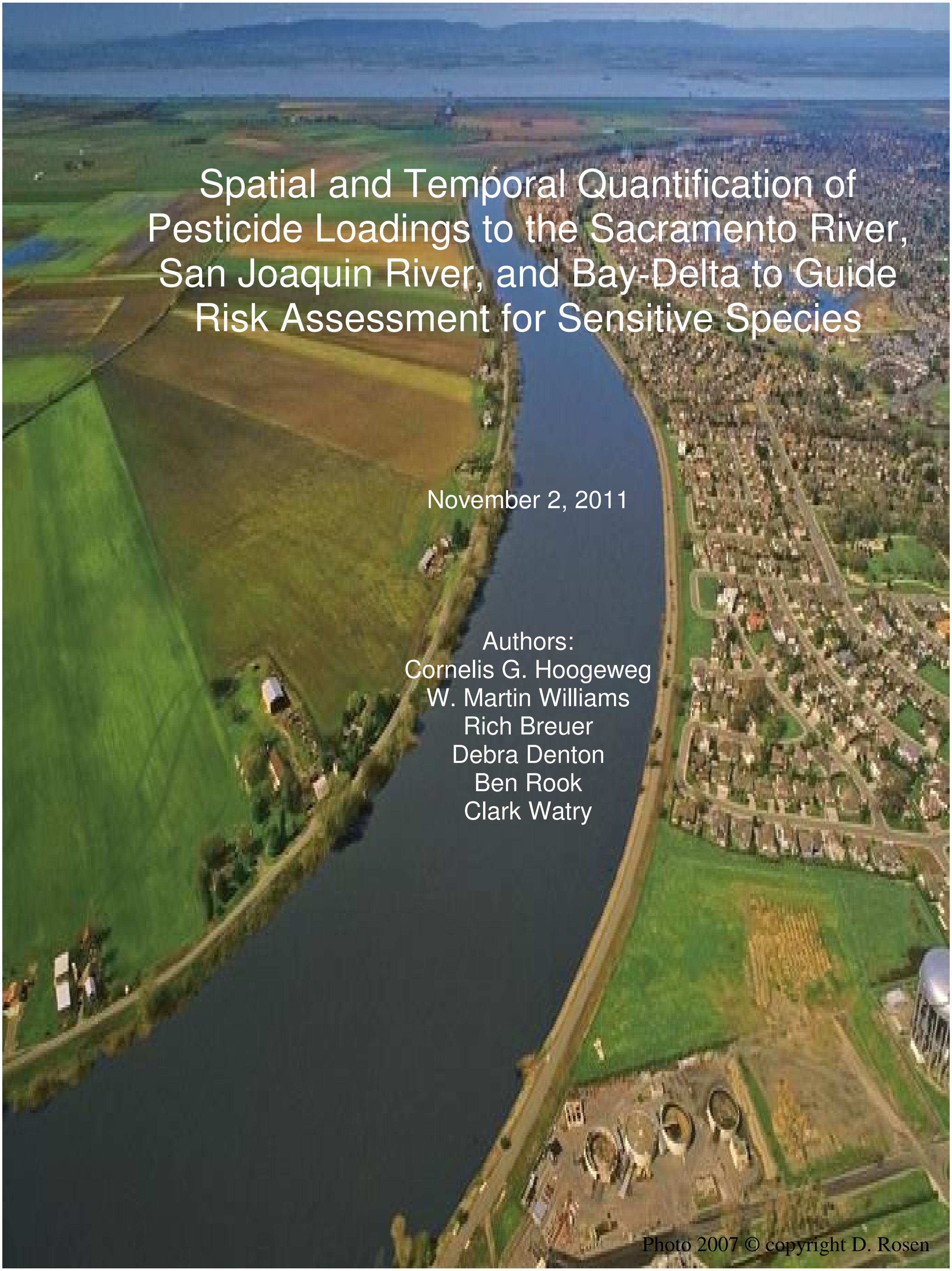

Spatial and Temporal Quantification of Pesticide Loadings to the Sacramento River, San Joaquin River, and Bay-Delta to Guide Risk Assessment for Sensitive Species

November 2, 2011

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Spatial and Temporal Quantification of Pesticide Loadings to the Sacramento River, San Joaquin River, and Bay-Delta to Guide Risk Assessment for Sensitive Species

REPORT

DATA REQUIREMENT:	Not Applicable
AUTHORS:	Cornelis G. Hoogeweg, Ph.D. W. Martin Williams, P.E. Rich Breuer Debra Denton, Ph.D. Ben Rook Clark Watry
STUDY COMPLETION DATE:	November 2 (Final)
PERFORMING LABORATORIES:	Waterborne Environmental, Inc. 897-B Harrison Street, S.E. Leesburg, VA USA 20175 University of California, Davis One Shields Avenue Davis, CA 95616
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GOOD LABORATORY PRACTICE COMPLIANCE STATEMENT

This report "Spatial and Temporal Quantification of Pesticide Loadings to the Sacramento River, San Joaquin River, and Bay-Delta to Guide Risk Assessment for Sensitive Species" presents the data and methods used to generate spatial and temporal co-occurrence information of pesticides and species of concern. This project does not meet the GLP definition of a study, and therefore 40CFR160 does not apply.

Study Director: There is no GLP Study Director for this volume.

______________________________ __________________

Rich Breuer Date
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Retention of data
The data used to generate this report are currently stored at the facility of Waterborne Environmental, Inc., 897-B Harrison Street, S.E., Leesburg, VA 20175. This information will be transferred to the sponsor representative, Department of Water Resources, 1416 9th Street, Sacramento, CA 95814 at a later date.

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Acknowledgements

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Acronyms and Abbreviations

a.i.	Active ingredient
AERU	Agriculture & Environment Research Unit
Ag	Agriculture
ARS	Agricultural research service
BMP	Best management practices
CalPIP	California Pesticide Information Portal
CAS	Chemical Abstracts Service
CCC	criterion continuous concentration
CDFG	California Department of Fish and Game
CDL	California Digital Library
CDPR	California Department of Pesticide Regulation
CDWR	California Department of Water Resources
CIMIS	California Irrigation Management Information System
CIWMC	California Interagency Watershed Mapping Committee
CMC	Criterion maximum concentration
CRC	California rice commission
CRPW	California Rice Production Workshop
CVRWQCB	Central Valley Regional Water Quality Control Board
EC	European Commission
EFED	Environmental Fate and Effects Division
EMA	Environmental Management for Agriculture
EU	European Union
FMMAP	Farm Management Mapping Plan
FMMP	Farmland Mapping and Monitoring Program
GIS	Geographical information system
GLP	Good Laboratory Practices
H	Humboldt Meridian
HUC	Hydrologic Unit Code
HydroDEM	A digital elevation model using Hydrologic boundaries
M	Mt. Diablo Meridian
NASS	National Agricultural Statistics Service
NED	National Elevation Dataset
NHD+	National Hydrography Dataset Plus
NRCS	Natural Resources Conservation Service
OPP	Office of Pesticide Programs
OPPTS	Office of Prevention, Pesticides, and Toxic Substances
Ot	Other
PAD	Passage Assessment Database
PCO	pest control operators
PHMB	Polyhexamethylene biguanide
PLSS	Public land survey system

POD	Pelagic organism decline
PPD	Pesticide properties database
PRZM	Pesticide root zone model
PUR	Pesticide Use Reporting
PWG	Pyrethroid Working Group
QAPP	Quality assurance project plan
RICEWQ	Rice water quality model
S	San Bernardino
SCS	Soil Conservation Service
SOC	Species of concern
SSURGO	Soil survey geographic (database)
STATSGO	State soil geographic soil survey
SWAMP	Surface Water Ambient Monitoring Program
SWAT	Soil and Water Assessment Tool
SWMM	Storm Water Management Model
T&ES	Threatened and Endangered Species
TAP	Technical Advisory Panel
TIE	Toxicity identification evaluation
TMDL	Total maximum daily load
UCDAS	University of California, Department of Agricultural Sciences
Ur	Urban
USDA	US Department of Agriculture
USEPA	US Environmental Protection Agency
USES	Uniform System for the Evaluation of Substances
USFWS	U.S. Fish and Wildlife Service
USGS	US Geological Survey
VAA	Value-added attributes
Wa	Water
WBD	Watershed Boundary Dataset

Executive Summary

The main objective of this project was to determine the relative ranking of potential areas of concern with respect to pesticide exposure to sensitive and endangered aquatic species in the Sacramento River watershed, San Joaquin River watershed and Bay-Delta estuary in California. An area of concern is defined as an area where and when one or more species of concern are likely to be present when environmental concentrations may exceed toxicological benchmarks.

To determine potential areas of concern, a co-occurrence assessment was conducted that included 12 Federal and/or State listed threatened and endangered pelagic species (henceforth referred to as species of concern) and 40 different pesticides. Estimating temporal and spatial co-occurrence is a time consuming and intricate undertaking in a complex and dynamic landscape.

The investigation involved the use of simulation modeling, historical water quality monitoring data, and Geographic Information System (GIS) analysis in a weight-of-evidence context. The pesticides selected for analysis (Table E1) include herbicides, fungicides, and insecticides, and were based on a list of pesticides published by the Central Valley Regional Water Quality Control Board in 2009 estimated to pose the highest overall risk to aquatic life.

Table E1. Pesticides selected for analysis

Chemical Name	CAS NUMBER	Type
(S)-Metolachlor	87392-12-9	Herbicide
Abamectin	71751-41-2	Insecticide
Bifenthrin	82657-04-3	Insecticide
Bromacil	314-40-9	Herbicide
Captan	133-06-2	Fungicide
Carbaryl	63-25-2	Insecticide
Chlorothalonil	1897-45-6	Fungicide
Chlorpyrifos	2921-88-2	Insecticide
Cyhalofop-Butyl	122008-85-9	Herbicide
Clomazone	81777-89-1	Herbicide
Copper Hydroxide	20427-59-2	Fungicide
Copper Sulfate	7758-98-7	Fungicide
Cyfluthrin	68359-37-5	Insecticide
Cypermethrin	52315-07-8	Insecticide
Deltamethrin	52918-63-5	Insecticide
Diazinon	333-41-5	Insecticide
Dimethoate	60-51-5	Insecticide
Diuron	330-54-1	Herbicide
Esfenvalerate	66230-04-4	Insecticide
Hexazinone	51235-04-2	Herbicide

Chemical Name	CAS NUMBER	Type
Imidacloprid	105827-78-9	Insecticide
Indoxacarb	173584-44-6	Insecticide
Lambda-cyhalothrin	1465-08-6	Insecticide
Malathion	121-75-5	Insecticide
Mancozeb	8018-01-7	Fungicide
Maneb	12427-38-2	Fungicide
Methomyl	16752-77-5	Insecticide
Naled	300-76-5	Insecticide
Oxyfluorfen	42874-03-3	Herbicide
Paraquat Dichloride	1910-42-5	Herbicide
Pendimethalin	40487-42-1	Herbicide
Permethrin	52645-53-1	Insecticide
Propanil	709-98-8	Herbicide
Propargite	2312-35-8	Insecticide
Pyraclostrobin	175013-18-0	Fungicide
Simazine	122-34-9	Herbicide
Thiobencarb	28249-77-6	Herbicide
Tralomethrin	66841-25-6	Insecticide
Trifluralin	1582-09-8	Herbicide
Ziram	137-30-4	Fungicide

Species of concern for this study include nine threatened and endangered fish, amphibians, and invertebrates. Seasonal runs of Chinook salmon were treated as distinct species for this analysis, thereby accounting for essentially 12 unique species.

1. Chinook Salmon (*Oncorhynchus tshawytscha*)
   - Sacramento River winter-run
   - Central Valley spring-run
   - Central Valley fall run
   - Central Valley late fall run
2. Central Valley steelhead (*Oncorhynchus mykiss*)
3. Southern North American Green Sturgeon (*Acipenser medirostris*)
4. Delta Smelt (*Hypomesus transpacificus*)
5. Striped Bass (*Morone saxatilis*)
6. San Francisco Longfin Smelt (*Spirinchus thaleichthys*)
7. Threadfin Shad (*Dorosoma petenense*)
8. California Red-legged Frog (*Rana draytonii*)
9. California Freshwater Shrimp (*Syncaris pacifica*)

Daily pesticide concentrations were predicted at the Public Land Survey Section (PLSS) section from runoff, erosion and drift sources. Pesticides loads were estimated using 10-years of historical pesticide use data obtained from the California Department of Pesticide Regulation's Pesticide Use Reporting (PUR) database. Application sites represented in the simulations included fruit, vegetable, grain, nuts, rice, and urban/residential landscape maintenance, and structural pest control. Loadings from agricultural uses were predicted using the Pesticide Root Zone Model (PRZM) and the Rice Water Quality Model (RICEWQ). PRZM was also used to estimate runoff from urban/residential applications. Drift was only assumed to occur in agricultural settings and was estimated using a linear equation accounting for application method, application area, and surface water area in the PLSS.

Approximately 9,115,000 pesticide applications were represented in the simulations, accounting for a total applied mass of 98,279,000 lbs of active ingredient (a.i.) for the 40 chemicals. Approximately 14.2% of the applied amount was predicted to reach surface waters via runoff, erosion, drift, and discharge. This is likely an over-prediction because conservative methods and assumptions were used for the assessment. Runoff from agriculture accounted for over 86% of the mass losses loadings. Erosion and drift from agricultural applications accounted for approximately 5.0% and 4.4% of mass loadings. Another 4.3% was predicted to discharge and runoff from rice paddies. Urban runoff accounted for less than 1%. The urban analysis was limited to an evaluation of only four of the 40 pesticides included in the study. Additionally, evaluators need to consider even those contributions of low percentage are not indicative of a lesser emphasis importance to the system.

A toxicological threshold was produced for each pesticide. Where available, the threshold was based on the acute benchmark developed by the U.S. Environmental Protection Agency's Office of Pesticide Programs (OPP) for the most sensitive aquatic non-plant species. An additional safety factor was applied to achieve OPP's level of concern for threatened and endangered species.

Indicator days (days during which at least one pesticide was estimated to exceeded the toxicity threshold) showed distinct spatial-temporal patterns. Indicator days for urban regions were predicted to occur primarily during the late fall through early spring period. Indicator days for agricultural areas occur predominately during the spring/summer crop growing season. Indicator days for rice growing areas were prevalent in the latter part of the crop season.

Co-occurrence was estimated at the PLSS level by overlaying monthly distributions of indicator days with monthly distributions of species richness. Monthly distributions of species abundance were developed for each species for rivers and streams in the study area. Co-occurrence was also estimated using historical water quality monitoring data collected from 250+ monitoring stations in the study area.

Species richness was determined to be nearly constant from January to July. From August to December, the species richness varied by month and location. November was lowest in terms of species richness. The maximum (100th percentile) of species richness was 0.917 (11 out of the 12 species were present in at least one PLSS section) and the 90th percentile was 0.5 (six species).

Areas with very high co-occurrence (exceeding the 90th percentile values for species richness and indicator days) are concentrated in the southern Delta Estuary in San Joaquin County and smaller regions in the Northern Delta Estuary in Sacramento County and western Yolo County. Areas with high co-occurrence (exceeding the 80th percentile values for species richness and indicator days) are present in clusters scattered on the outskirts of the main agricultural areas in the Sacramento River and San Joaquin River Watershed and in the northern section of the Bay-Delta Watershed. Many of these areas have limited or no monitoring data for the forty pesticides evaluated during this study.

Using the co-occurrence approach, risk managers can determine which criteria (percentile levels) should be used to determined potential areas of concern. Results can be used to identify and rank areas of highest risk, aid in placement of BMPs, and support current and future monitoring programs by strategic placement of sampling locations and frequency. Ultimately, it is hoped that this project will improve decision making and optimize resource spending of groups which seek to improve long-term sustainability of aquatic habitats in the study area.

1.0 Introduction

1.1 Project Background

A decline in pelagic species in the San Francisco Bay Delta region has been reported, causing speculation as to whether contaminants may be playing a role in pelagic organism decline (POD), and if so, to what extent. POD contaminant studies are typically focused on toxicity identification evaluation and the examination of biomarkers as indicators of lethal and sub-lethal effects. Using the results from those studies, researchers are in a better position to help answer the question about whether contaminants play a role. Unfortunately, some of these studies lack focus due to a shortage of spatial and temporal information on the presence of contaminants or endangered species (e.g., Bay Institute, 2003; Fleishman, 2011; McNally et al., 2010). Current monitoring programs that might be in a position to provide this data include the Central Valley Water Quality Control Board's Irrigated Lands Regulatory Program, the State Water Resources Control Board's Surface Water Ambient Monitoring Program (SWAMP), and the Sacramento River Watershed Monitoring program do not have the resources to monitor and conduct studies on the scale that this issue requires. The large array of contaminants over the vast size of the area in question provides too great of a resource and cost challenge for these groups. This project was designed to provide investigators with much needed information about pesticide peak loadings to ultimately aid efforts to determine if contaminants have contributed to the decline of pelagic organisms in the Bay-Delta.

1.2 Objective

The objective of this project was to quantify the spatial and temporal co-occurrence of pesticide residues and pelagic species in the Sacramento River, San Joaquin River, Bay-Delta estuary and their tributaries to guide decision making and prioritize resource spending of groups which seek to improve long-term sustainability of aquatic habitats in the Bay-Delta. A variety of programs and groups are likely to benefit from this project include the Pelagic Organism Decline workgroup, the State Water Board's SWAMP and Aquatic Herbicide Program, the Central Valley Water Quality Control Board's Irrigated Lands Regulatory Program (ILRP) and Total Maximum Daily Load (TMDL) programs. The results can also be used to identify and rank areas of highest risk, aid in strategic placement of Best Management Practices (BMP) in the study area, and support current and future monitoring programs by strategic placement of sampling locations and frequency.

This objective was addressed through a combination of tools, including geographical information system (GIS), simulation modeling, and an evaluation of existing in-stream monitoring. Uncertainty is inherent in any risk assessment method; however, in combination, these tools provide risk assessors with a "weight-of-evidence" approach for regulatory decision making. This project will benefit watershed-wide and regional programs in multiple ways, such as

- Providing further knowledge of the fate and transport of agricultural chemicals (e.g., copper, organophosphates) and emerging pesticides (e.g., pyrethroids) in the Sacramento River, San Joaquin River, Bay-Delta Estuary, and headwater tributaries;
- Overlaying pesticide loading results with the identification and location of sensitive fish species critical habitats;
- Identifying and ranking areas and timing of highest risk and pesticide source areas contributing to those risks;
- Aiding in the development of plans to improve water quality by the strategic placement of BMPs that reduce pesticide loadings;
- Supporting current and future monitoring programs (including recommendations on strategic locations and sampling frequency);
- Providing a link to life cycle models currently under development for striped bass and delta smelt and to existing models for salmonids; and
- Providing a data-link to support other water quality models and population models.

1.3 Document Structure

This report is divided into nine major sections:

- Section 1.0 introduces the project, the background, and the project objectives.
- Section 2.0 describes the materials and method used in this project, including chemical selection, compilation of monitoring data, the development of ecotoxicological benchmarks, and the development of a spatial and temporal database on the abundance of species of concern. Also described are the approaches used to model pesticide loadings from agricultural runoff, rice paddy discharges, urban runoff, and drift. This section also outlines the methodology to determine spatial-temporal co-occurrence.
- Section 3.0 provides an overview of the modeling results, the co-occurrence analysis, and the area-of-concern determination. The section also provides a discussion section in which several of the objectives are addressed, and a section dealing with uncertainty in the modeling results.
- Section 4.0 provides the conclusions of this project.
- Section 5.0 presents recommendations for future action.
- Section 6.0 is the reference section containing references for report, journal articles, software manuals, and data sources used in this project.
- Section 7.0 is the table section, which contains the tables that are referenced in the main report sections.
- Section 8.0 contains the many figures that are referenced in the main report sections.
- Section 9.0 contains the appendices which include a wide variety of information on species descriptions, data development, data processing steps, and post-processing routines.

2.0 Materials and Methods

2.1 Overview

As stated in Section 1 of this report, the main objectives of this project is to determine the relative ranking of potential areas of concern with respect to pesticide exposure to sensitive and endangered aquatic species in the Sacramento River watershed, San Joaquin River watershed and Bay-Delta estuary in California. An area of concern is defined as an area where and when one or more species of concern (SOC) are likely to be present when environmental concentrations may exceed toxicological benchmarks.

To determine potential areas of concern, a co-occurrence assessment was conducted that included 12 Federal and/or State listed threatened and endangered pelagic species (henceforth referred to as species of concern) and 40 different pesticides. Estimating temporal and spatial co-occurrence is a time consuming and intricate undertaking in a complex and dynamic landscape. Figure 1 provides a high-level and simplified overview of the assessment process. The numbers in the flow diagram refer to sections of the report that provide detailed information on the specific topic.

The first step in the assessment is to characterize the study area. As part of the characterization, spatial and physical datasets were developed that describe the physical landscape and provide input data to the environmental fate models. Datasets used in the assessment included watershed boundaries to define the study area, land use to determine agricultural and urban areas, pesticide use data to determine where pesticides have been applied, climate to describe weather conditions affecting pesticide fate in the environment, and hydrology that describe receiving water bodies.

For each of the 40 pesticides considered in this assessment, environmental-fate properties were collected, along with nine years (2000–2008) of historical pesticide applications. Ecotoxicological benchmarks were established to determine if the calculated pesticide concentrations in surface water would pose a risk.

Collected information on landscape, soils, climate, pesticide properties and applications were processed and readied for use with environmental fate models PRZM and RICEWQ. Both environmental-fate models predict edge-of-field mass. PRZM was also used to estimate pesticide runoff from urban areas. Drift mass contributions were calculated using a linear equation.

Total daily pesticide mass loadings from the agricultural fields, rice paddies, and urban areas were combined such that a single daily mass load for each pesticide was calculated at the PLSS section level. To compute a daily concentration, the daily mass loadings were "mixed" into the streams and rivers present in the PLSS section. The volume of water in a PLSS section was computed by assigning fixed stream geometry as a function of stream order and calculating the length of each stream order in the PLSS. Daily concentrations were then compared to ecotoxicological benchmarks. If the estimated environmental concentration exceeded the benchmark, it was considered an indicator event and used in the co-occurrence analysis.

The frequency of indicator events was calculated for each month, for each pesticide, and for each PLSS section. This information was used in conjunction with monthly estimates of species presence to determine co-occurrence. An area with high co-occurrence score are considered to be a potential area of concern.

In addition to the co-occurrence assessment, available water quality monitoring data were collected from over 250 locations in the study area for the period 2000–2009. Use of monitoring data provided additional information as to the location of potential areas of concern within the study area, and they provide a reality check of the estimated environmental concentration.

The remainder of Section 2 describes in detail the datasets and processing steps developed and used in this assessment. Results of the assessment, including pesticide mass loadings, frequency of indicator events, species abundance, co-occurrence and potential areas of concern are described in Section 3.

2.2 Data Development

2.2.1 Watersheds

Three watersheds determine the boundary of the study area: the Sacramento River watershed, the San Joaquin River watershed, and the Bay-Delta watershed (Figure 1). The GIS layer representing these three watersheds was created from the GeoSTAC Hydrologic Unit Code (HUC) Level 6 data (Waterborne, 2005). A subset of the HUC layer was created by selecting all catchments that were part of the hydrologic regions representing the three watersheds. Next, the Bay-Delta region was manually modified by removing catchments that do not drain into the Bay-Delta and adding a few of the Central Coast catchments that do drain in the Bay-Delta. Similarly, a few catchments on the northern part of the Sacramento River region were removed because they did not drain to the Sacramento River. The resulting layer contains the study boundary and the internal watershed boundaries for the three main catchments. The primary functions of this layer were to a) visually show the boundary of the study area on a map and b) act as a "cookie cutter" when clipping GIS data to the study area.

2.2.2 Land Use

As part of this project, historical pesticide uses for a 9 year period were modeled. Because pesticide use it closely tied in with the crops and thus the agricultural landscape, a dataset that is capable of mapping on an annual or bi-annual basis the land use is required. Although many useful land-use and land-cover datasets are available (e.g., National Land Cover Datasets, Cropland Data Layer, GAP 2009 (USGS, 2010)) for land use analysis, they are not updated frequently enough to map annual or bi-annual land use changes. The Farmland Mapping and

Monitoring Program (FMMP; State of California, 2009) produces maps and statistical data used for analyzing impacts on California's agricultural resources on annual or bi-annual basis for several counties in the State. The maps are updated every two years with the use of a computer mapping system, aerial imagery, public review, and field reconnaissance. Data for counties that overlap the study area was downloaded for the following years: 2000, 2002, 2004, 2006, and 2008. For some counties, there was no updated information for several years, as many as 4 or 6 years in some cases.

The county-level FMMP layers were merged to create a single layer for a single year. This resulted in five FMMP layers. Next, these layers were combined into a single dataset (Figure 3). This combined dataset contained for each polygon the land use information for 2000, 2002, 2004, 2006, and 2008. Missing data were gap-filled based on the year of the last known land use. For example, if the land use was known for the year 2000 but not for the year 2002, it was assumed that in 2002 the land unit was the same as in 2000.

Because the FMMP contains a detailed agricultural classification for the agricultural areas, the overall classification was simplified in the following manner:

- FMMP agricultural classes were considered agriculture (Ag)
- FMMP urban classes were remapped to urban (Ur)
- FMMP water classes were remapped to water (Wa)
- All other FMMP classes were remapped to other (Ot)

2.2.3 Soils

The soils parameters were identified from the Soil Survey Geographic (SSURGO) database (USDA-NRCS, 2009). The SSURGO dataset is a digital general soil association map developed by the National Cooperative Soil Survey and distributed by the Natural Resources Conservation Service (NRCS; formerly Soil Conservation Service [SCS]) of the U.S. Department of Agriculture (USDA). SSURGO consists of a broad based inventory of soils and non-soil areas that occur in the landscape and that can be cartographically shown at the scale mapped. The SSURGO soil database (spatial and tabular) was used to identify and characterize the soils within the study area.

Using the national SSURGO database, a soils map layer was created by extracting (using the CLIP geoprocessing tool in ArcMap) the study area from the national layer. For a few counties in California, detailed soil survey data were not available. For these areas, the state geographic soil survey (STATSGO; USDA, 1994) layer was used. The STATSGO layer was first cut (CLIP) to the study area. Second, the STASTGO layers was cut (ERASE) to the areas that do not have SSURGO data. In the final step, the SSURGO and STATSGO maps were merged into a single soil map (Figure 4). This soil map was used throughout the project.

In addition to the soil map, soil attribute data were extracted from the SSURGO and STASGO databases. Soil attribute data such as organic matter content, horizon depth, and particle size distribution were used by the environmental fate models. Appendix A lists the approach used to extract data from the master SSURGO/STASTGO database.

2.2.4 Climate

Daily climatic information was obtained from the California Irrigation Management Information System (CIMIS; CDWR, 2010), for the period 2000–2009. Environmental fate models used in this project required daily weather inputs, specifically, precipitation, average temperature, and evapotranspiration. CIMIS provided these required inputs.

CIMIS historical weather data were used for two reasons 1) CIMIS provides data for the same timeframe over which pesticide application data are available and 2) a detailed network of local weather stations in the study area is present. Nineteen weather stations (Figure 5) were selected for use in this study based on the criteria that they were still active and had few data gaps (Appendix B). For each weather station area of influence was developed using the Thiessen polygon technique. Each Thiessen polygon defines an area of influence around its sample point, so that any location inside the polygon is closer to that point than any of the other sample points. Development of the historic daily climate data for the study area used a two-tiered approach. In the first tier a GIS dataset, representing the area of interest, was developed, and in the second tier the daily weather data were collected and processed for use with the environmental fate models. The detailed steps are provided in Appendix B.

2.2.5 Public Land Survey System

The Public Land Survey Section (PLSS) layer is a polygon coverage depicting the meridian, township, range and sections contained in the Public Land Survey System grid for the State of California. Townships are roughly thirty-six square miles and are numbered north (N) and south (S) from an established baseline. Likewise, ranges are numbered east (E) west (W) from an established meridian. California uses three baseline/meridians: Humboldt (H), Mt. Diablo (M) and San Bernardino (S). Meridian, township, and range values are combined in the redefined field MTR to facilitate dissolve functions. Inclusion of the PLSS layer in this project was critical because the pesticide use reporting system uses the PLSS section level to report on pesticide usage.

The spatial PLSS dataset that was used in this project was created by the Teale Data Center in 1999 and was downloaded from the Cal-Atlas geospatial clearinghouse (State of California, 2008). The downloaded PLSS layer was added to the GIS and re-projected to the Albers Equal Area USGS projection before being clipped to the study area (Figure 6).

2.2.6 Hydrology

Hydrology in the study area is represented by using the USGS/EPA's National Hydrography Dataset Plus (NHD+; Figure 7) medium resolution (1:100,000 scale; USGS, 2006). NHD+ is an integrated suite of application-ready geospatial datasets that incorporates many of the best features of the NHD and the National Elevation Dataset (NED). NHD+ includes a stream network (based on the 1:100,000 scale NHD), improved networking, naming, and "value-added attributes" (VAA's). NHD+ also includes elevation-derived catchments (drainage areas) produced using a drainage enforcement technique first broadly applied in New England, and thus dubbed "The New-England Method." This technique involves "burning-in" the 1:100,000 scale NHD and when available building "walls" using the national Watershed Boundary Dataset (WBD). For the purpose of this project, stream name, stream type (Figure 8), and stream order (Figure 9) were of particular interest.

2.2.7 Master Index Layer

The environmental fate models used in this project require soil, climate, and chemical application rate input. Since these input change over time and space, the developed GIS were combined to determine all unique combinations of PLSS sections, nearest weather station, soils, and land use. This resulted in a GIS data layer with over 1,000,000 features (Figure 10). For each of the features the following information is readily available:

- PLSS section identifier
- Soil map unit
- Weather station
- Land use (representing land use for 2000, 2002, 2004, 2006 and 2008)

Ancillary information such a county name, region name, weather station name are also available but are only used for visualization purposes.

2.3 Pesticide Selection

2.3.1 Selected Pesticides

In 2009, the Central Valley Regional Water Quality Control Board (CVRWQCB) published a list of pesticides that pose the highest overall relative risk to beneficial aquatic life in surface water within the Central Valley Pesticide Basin Plan Amendment Project Area (CVRWQCB, 2009). The methodology applied to develop the list consisted of a three-step approach:

1. An initial list of pesticides of interest, based on the total annual reported amounts (CDPR, 2008a) of pesticides used in the Project Area, was culled from the over 300 pesticides reportedly used in the Project Area.

2. The initial list was narrowed to a target list, based on aquatic life toxicity data and other parameter information.
3. The pesticides in the target list were prioritized into two sub-lists—one each for moderate and high overall relative-risk levels—based on water solubility data, water concentration data, and pesticide use trends.

The high and moderate relative risk level pesticide lists were combined in a single list for the purpose of this project and modified to meet the collective needs of the Technical Advisory Panel (TAP). Several chemicals were removed from replaced with other chemicals Fipronil was removed due to registration cancellations for agricultural uses. PHMB was removed as its use is limited to swimming pools. Copper sulphate, copper hydroxide, clomazone, thiobencarb, and cyhalofop-butyl were added to the list. Copper is acutely toxic to salmonids and their prey at very low concentrations (5.9 µg/L). Additionally, the sublethal impact of copper to fish olfaction occurs in the low µg/L range (Hecht et al., 2007; McIntyre et al., 2008). Both copper-based pesticides are in the top 15 of the total amount of pesticide used in 2006, with each over 2,900,000 lbs applied (CDPR, 2008b).

The chemicals evaluated in this study (Table 1) include widely used fungicides, herbicides, insecticides, and algaecides. Table 2 provides an overview of the annual use in the study area of the selected pesticides from 2000-2008. During this period, the overall total use (expressed in lbs active ingredient) decreased from 13.3 million to 8.3 million lbs in the study area. The highest use chemicals were copper sulfate, copper hydroxide, propanil, thiobencarb, and pendimethalin. In the same period over 1,698,130 applications were made and recorded in the PUR database for the test area. In the period 2000–2008, the selected 40 chemicals were applied on 169 different crops and land uses. The use sites are listed in Table 3. Not all of these use sites were considered for modeling in this project (e.g., storage, mushroom house).

Table 3 reflects trends in pesticide use in California from 2000-2009. The Central Valley and the state of California as a whole show similar trends in pesticide use over the time period, with the lowest pesticide usage in 2001 and peak usage in 2005. The average pesticide use for the state of California and the Central Valley is 174.14 and 122.56 million pounds, respectively. As expected, the Central Valley makes up a large percentage (70%) of the statewide pesticide use.

2.3.2 Pesticide Properties

Physical and chemical properties are used in the simulation models to predict the persistence and mobility of the chemicals. The procedure established at the onset of the study (Waterborne, 2010) was to use pesticide properties recommended for modeling from the ARS Pesticide Property Database (USDA-ARS, 2009) and to fill in missing values from other sources. The ARS Pesticide Properties Database (PPD) is a compendium of chemical and physical properties of 334 widely used pesticides. Information included in the database focuses on 16 of the most important properties that affect pesticide transport and degradation characteristics.

The European FOOTPRINT pesticide properties database (AERU, 2009) was used to fill gaps in information that were not readily available from the ARS database. The database is a comprehensive relational database of pesticide physicochemical and ecotoxicological data. The database was developed by the Agriculture & Environment Research Unit (AERU) at the University of Hertfordshire, as part of the EU-funded FOOTPRINT project. The database is a revised and greatly expanded version of the database that originally accompanied the EMA (Environmental Management for Agriculture) software used in the UK. FOOTPRINT is frequently used by the CDPR (Y. Lou, personal communication, 09/28/2010) for environmental-fate properties for use in computer models.

Chemicals properties unavailable from the USDA-ARS PPD and FOOTPRINT PPD were obtained from individual pesticide registration assessments conducted by the U.S. Environmental Protection Agency's Office of Pesticide Programs (OPP).[1] OPP assessments summarize laboratory and field environmental fate studies submitted for pesticide registration under CFR 40 Part 150, Subdivision N guidelines. These studies are assessed by USEPA with respect to their adequacy in fulfilling registration requirements with respect to GLP compliance, testing methods and materials, analytical recoveries, and reporting.

The procedure described above was used for the majority of the chemicals. However, procedures varied for determining properties for pyrethroids and rice pesticides because information required for these chemicals was relatively sparse in the USDA-ARS and the FOOTPRINT pesticide property databases. For pyrethroids, the primary data sources were pesticide registration assessments conducted by OPP in the past several years. Properties reported by Laskowski (2002) were used when values were unavailable from OPP assessments. OPP will typically conduct modeling as part of their registration assessment. When available, model input values determined by OPP were used for this study (cypermethrin, permethrin). For several pyrethroids (bifenthrin, deltamethrin, esfenvalerate), a modeling assessment was not available because OPP had only published their preliminary problem formulation for these chemicals. Therefore, model input values were calculated for this study using OPP's procedures for determining input parameter values for modeling (USEPA, 2009b) from the chemical properties listed in OPP's initial problem formulation. Laskowski (2002) included calculations following OPP's input parameter procedures in his paper. These values were used for the remaining pyrethroids (cyfluthrin and lambda-cyhalothrin).

The ARS and FOOTPRINT databases do not focus on aquatic degradation processes, which govern chemical persistence in flooded rice fields. Therefore, properties for rice pesticides were obtained from OPP's registration assessment. Properties used to simulate degradation in water were hydrolysis, aerobic aquatic metabolism, and aquatic photolysis if available. For aqueous hydrolysis, values associated with a pH of 7 were used. Anaerobic soil metabolism was used to

[1] http://www.epa.gov/pesticides/reregistration/status.htm

simulate degradation in sediment when the paddy was flooded. Aerobic soil metabolism was used to simulate degradation in sediment when the paddy was not flooded.

Table 4 presents the pesticide properties used for the simulations. Table 4 includes the chemical common name, CAS number, molecular weight, and the values used for solubility, vapor pressure, Henry's Law constant, organic carbon-water partition coefficient, aerobic soil metabolism, soil photolysis, anaerobic soil metabolism, hydrolysis, aerobic aquatic metabolism, aquatic photolysis, and anaerobic soil metabolism. Table 4 also indicates which pesticides used for rice simulations, which pesticides are pyrethroids, and pesticides simulated for the urban assessment. The source of the information is indicated by a letter standing for ARS (A), FOOTPRINT (F), EPA-OPP (O), Laskowski (L), or calculated as part of this study following OPP input parameter guidelines.

The properties used for the PRZM simulations are solubility, Koc, and aerobic soil metabolism. The properties used for RICEWQ are solubility, Koc, aerobic soil metabolism, aerobic aquatic metabolism, anaerobic aquatic metabolism, hydrolysis, and aquatic photolysis. The anaerobic aquatic metabolism and aerobic soil metabolism values were used to simulate degradation in soil under flooded and not flooded conditions, respectively.

Pesticide loadings from urban uses were estimated for bifenthrin, cyfluthrin, cypermethrin, and permethrin. For these chemicals, washoff coefficients were derived as part of this study by calibrating Pesticide Root Zone Model (PRZM) to match the results of laboratory washoff studies. Procedures and results are discussed in the urban modeling section.

Pyrethroid washoff studies were used to derive washoff coefficients for hard surfaces (Harbourt et al., 2009; Jiang et al., 2010; Jorgensen and Young, 2010). Washoff coefficients were obtained by calibrating the percent of applied active ingredient in washoff to values measured during the study. Results of the calibrations are provided in Table 5.

Washoff coefficients for bifenthrin, cyfluthrin, and lambda-cyhalothrin were derived from a study by Jorgensen and Young (2010). The only surface medium tested was concrete; therefore, the calculated washoff coefficient values were used for structures and pavement. Rainfall simulations were run at a rate of either 25 or 50 mm/hour for the duration of one hour at various set times ranging from 1.5 hours to 49 days. The products were applied at their maximum label rates to concrete slabs measuring 80 x 80 x 5 cm. The trial selected to calculate the washoff coefficient was run with a rainfall intensity of 50 mm/hr for one hour one day after application.

Washoff coefficients for cypermethrin were calculated from a washoff study by the Pyrethroid Working Group (Harbourt et al., 2009). The washoff percentages measured from different replication trials were averaged and used for the calibration. For simulating washoff from impervious areas on the ground (walkways, patios, driveways, and roads), values associated with clean unpainted concrete were used. Cypermentrhin runoff from unpainted concrete was higher than that for asphalt and therefore more conservative for the purposes of this study.

Cypermethrin washoff from dirty painted wood was higher than that for the other building materials and therefore used to derive washoff coefficients for structural applications to buildings. The dimensions of both the concrete slab and dirty wood measured 228.6 mm x 609.6 mm (9 x 24 inches). Rainfall was simulated at a rate of 25.4 mm/hr (1.0 in/hr) for one hour one day after treatment.

A washoff coefficient for permethrin was derived from a study by Jiang et al., 2010. The test material was prepared by adding 50 g of concrete slurry into small glass jars (50 mm inner diameter x 35 mm height) to create a concrete disk measuring approximately 13 mm thick. The disks were conditioned for a period of around two months to reduce alkalinity and cure the product. Permethrin (Orthro-BugBGon Max®, Scotts) was applied to the concrete surface and then left out under direct sunlight. Pesticide washoff was measured by placing 30 mL of water into the glass jar, sealing it and then shaking it for 10 minutes.

2.3.3 Historical Pesticide Applications

California's PUR program is recognized as the most comprehensive in the world. In 1990, California became the first state to require full reporting of agricultural pesticide use in response to demands for more realistic and comprehensive pesticide use data. Under the program, all agricultural pesticide use must be reported monthly to county agricultural commissioner's, who in turn, report the data to CDPR. The PUR data offers the pesticide chemical application information in CA such as location, rate, active ingredient name, product name, site type and date/time. The site type can tell the crop types or non-agricultural types of the field where the application was done.

Historical pesticide applications reported within the study area for the forty different chemicals for the period 2000–2008 were used for the study. A master pesticide application database was created to aggregate all the individual yearly PUR data into a single database. This was primarily done for ease of handling and querying the data. In addition, the information was processed to allow multiple PUR entries to be simulated to the same soil type and crop combination within a PLSS in a single model simulation. PRZM does not allow the area treated to vary within a simulation. Therefore, a consistent application area was used for the simulation and application rates were normalized to preserve the correct application mass. Details on developing the dataset are provided in Appendix C.

2.3.4 Ecotoxicological Benchmarks

2.3.4.1 Introduction / Data Sources

Reference values were derived for the 40 chemicals using test results from standardized laboratory test guidelines. The primary data source was the USEPA OPP Aquatic Life Benchmarks database (USEPA, 2010a). This database provided benchmarks for fish acute, fish chronic, invertebrate acute, invertebrate chronic, nonvascular plant acute, and vascular plant acute endpoints, as well as the endpoints for the majority of the chemicals.

Information for deltamethrin was used as a surrogate for tralomethrin since deltamethrin is the primary photolytic degradates of tralomethrin in aquatic systems. This is consistent with the USEPA OPP risk assessment approach for tralomethrin as indicated in the Environmental Fate and Effects Division (EFED) revised registration review problem formulation document for tralomethrin (USEPA, 2010b).

Two of the chemicals considered here were copper-based pesticides (copper hydroxide and copper sulfate). The toxicity of copper is influenced by a number of physicochemical characteristics such as water hardness, pH, and dissolved organic matter. Water hardness is a key factor in the toxicity of copper due to its influence on speciation and bioavailability of copper. Consequently, a concern for developing criteria for applicability in the Sacramento River Basin relates to the ambient water hardness. A representative hardness of 40 mg/L as CaCO3 was used for the Sacramento River Basin watershed based on the TMDL for upper Sacramento River for cadmium, copper, and zinc (CVRWQCB, 2002). To help confirm this number, water hardness for the river basin was determined based on data found in the US Geological Survey Sacramento River Valley database[2] (J. Domagalski, U.S. Geological Survey, Sacramento, CA, personal communication). This database did not contain water hardness measurements, but did contain measured concentrations of calcium and magnesium, from which water hardness could be estimated. Minimum and maximum calcium and magnesium concentrations were plugged into an online hardness calculator to estimate minimum and maximum hardness concentrations for each section of the basin.[3] The hardness concentrations estimated for the basin ranged from 15.3 to 70.3 mg/L. The mean of the minimum and maximum water hardness concentration estimates from all the sites was 39.5 mg/L, similar to the above estimate of 40 mg/L (Table 7).

Once a representative hardness for the Sacramento River Basin watershed had been estimated (40 mg/L), USEPA aquatic life ambient water quality criteria documents for copper were consulted for guidance on the development of criteria (USEPA, 1996, 2007). These documents provided hardness equations that could be used to develop an acute criterion maximum concentration (CMC) and a chronic criterion continuous concentration (CCC). The equations are as follows:

$$\mathrm{CMC} = e(0.9422[\ln(H)] - 1.700)$$

$$\mathrm{CCC} = e(0.8545[\ln(H)] - 1.702)$$

[2] http://ca.water.usgs.gov/sac_nawqa/waterindex.html
[3] http://www.lenntech.com/ro/water-hardness.htm

where H = hardness. Using these equations, the values for these endpoints were determined to be 5.9 and 4.3 µg/L for the CMC and CCC, respectively.

Toxicity information needed to be drawn from a variety of data sources for five other chemicals. Benchmark values for two of the chemicals (abamectin and indoxacarb) were provided by EPA-OPP to EPA Region 9 (P. TenBrook, U.S. EPA Region 9, San Francisco, CA, personal communication, 2011). For indoxacarb, the data used to derive the benchmark values were from the enriched formulation (Avaunt) which is a 3:1 mix of the active S-enantiomer and the inactive R-enantiomer. However, since the S-enantiomer rapidly degrades to the more active form, JT333, the benchmark data from this degradate were used as a surrogate for the indoxacarb benchmark data in the determination of reference values for indoxacarb. The data used to derive the benchmark values for cyhalofop butyl were derived from two sources: acute data were from a CDPR Public Report (CDPR, 2003) and chronic data were from a European Union evaluation report (EC, 2002). Data used to derive pyraclostrobin benchmark values were taken from an E.U. Commission Review Document (EC, 2004). The data for cyhalofop butyl and pyraclostrobin were in the form of toxicity values from the source documents. In order to normalize these values for the determination of the reference values these toxicity values were adjusted as per the toxicity values which were used to calculate the benchmark values in the USEPA OPP benchmark database (USEPA, 2007). These criteria are presented in Table 8. Appendix D contains a few sample benchmark calculations.

2.3.4.2 Calculation of Reference Values

Once the benchmark values had been determined, the data was ready for derivation of the reference values. Reference values were determined for both acute and chronic endpoints for standard evaluations as well as acute and chronic endpoints for threatened and endangered species evaluations.

The lowest acute and chronic benchmark values available were used to determine the reference values. The available benchmark values were for fish, invertebrate, nonvascular plant (e.g., algae) and/or vascular plant endpoints. For those chemicals where the fish or invertebrate data were the most sensitive, the following procedure was used to determine the reference values:

- EPA-OPP (Tier I) acute reference value were equivalent to the lowest acute benchmark for aquatic species (non-plant species that is)
- T&ES (threatened and endangered species) acute reference value were equivalent to 1/10th of the lowest acute benchmark

The USPEA-OPP Aquatic Life Benchmarks database (USEPA, 2010a) used the standard risk presumptions for pesticide risk assessment (Table 8).

The reference values were determined according to the above methodology and are presented in Table 9. The methodology for calculating the reference values is meant to provide a starting point for discussion of the most appropriate method for determining these values. The questions and discussion will hopefully be mostly centered on the best way to determine acute reference values for threatened and endangered species. Currently, the methodology follows the general procedure used by the USEPA-OPP EFED in their risk assessment process for crop protection products. The threatened and endangered species acute values presented are typically at 1/20th of the lowest EC50, which is the standard level of concern for endangered species in the EFED risk assessment. This works well for those chemicals for which the aquatic benchmark values were used. There is also room for discussion of the applicability of the chronic reference values. According to the USEPA-OPP EFED procedure, no extrapolation factors are applied to standard or threatened and endangered species risk assessment levels of concern for chronic assessments.

2.4 Pesticide Loads

Pesticide loadings for this study were calculated as edge-of-field loadings from drift, runoff, and erosion sources. Runoff, discharge, and erosion loads were predicted for rainfall and irrigation events. The unit of analysis, the estimate the pesticide loadings, was the PLSS section. There was no attempt to model the transport or conveyance in creeks, streams, and rivers because of the complexity of the drainage system and water management practices of the study area.

2.4.1 Pesticide Loads from Agriculture

2.4.1.1 Model selection

The Pesticide Root Zone Model (PRZM) was selected for this study based on its ability to simulate relevant governing factors and the preference for its use by the USEPA (2004). PRZM is a dynamic, compartmental model developed by USEPA for use in simulating water and chemical movement in unsaturated soil systems within and below the plant root zone (Suaréz, 2005). The model simulates time-varying hydrologic behavior on a daily time step, including physical processes of runoff, infiltration, erosion, and evapotranspiration. The chemical transport component of PRZM calculates pesticide uptake by plants, surface runoff, erosion, decay, vertical movement, foliar loss, dispersion and retardation. PRZM includes the ability to simulate pesticide metabolites and irrigation.

PRZM is the standard model used for ecological and drinking water risk assessments for pesticides by the U.S. Environmental Protection Agency's Office of Pesticide Programs (USEPA, 2004). The model has undergone an extensive validation effort against numerous field-scale runoff and leaching studies conducted for pesticides in the United States (Suarez, 2005; Jones and Russell, 2001). The model has been integrated into several watershed assessments in the U.S., including the Sacramento River watershed (Snyder et al., 2004). The model has also been incorporated into pesticide risk assessment procedures in Europe (FOCUS, 2004).

PRZM is a "unit-area" model in that the area simulated by a single PRZM situation must be represented as a homogeneous area. For this study, over 8,700,000 individual PRZM simulations were conducted with each simulation representing a unique combination of weather conditions, soil, crop, irrigation type, and pesticide application history to produce "edge-of-field" estimates of pesticide runoff. Although PRZM is a field-scale model that predicts pesticide fate for a single soil, crop and pesticide combination it can be combined with a GIS and can be used in large-scale assessments. It was in conjunction with a GIS that PRZM was used in this study. Using the GIS all unique crop and soil combinations were determined within each PLSS section. These unique soil/crop combinations and the historical pesticide applications from the PUR database were then used to calculate edge-of-field mass loadings with the PRZM model.

2.4.1.2 Soils parameters

The soil parameters were identified from the soil survey geographic database (USDA, 2009). Since it was not possible to identify the exact spatial location of the pesticide application within a single PLSS section, all soil types that intersected agricultural land use in the PLSS section were used for modeling. Results were scaled in proportion to the percentage a specific soil that existed in a SSURGO polygon, a fraction of agricultural land, to reflect the relative proportion that a given soil is associated with a PLSS section.

2.4.1.3 Crop Parameters

169 different crops[4] were listed in the PUR database on which the 40 chemicals were used. To facilitate the model effort, the crops were classified and mapped to a crop scenarios developed by the USEPA for pesticide registration assessment (USEPA, 2004) as shown in Table 10. Instead of modeling 169 different crops, now 29 different crops are modeled because of similarities in crop canopy, rooting depth, and other crop growth parameters.

Cropping dates for emergence, maturation, and harvest and other crop parameters for interception storage, maximum coverage, active root depth, aerial coverage, maximum canopy height, and others were derived from USEPA Standard Tier 2 scenarios (USEPA, 2004) and are provided in Table 11.

2.4.1.4 Weather Data

Simulations were conducted for 10-years of historical weather (2000-2009) to evaluate runoff loadings under low, moderate, and high rainfall events. To reduce the runtime of the PRZM

[4] Crop in the PUR database is referred to as a use site. However use sites include non-agricultural settings such a right-of-way, structural, recreation areas, etc. In this study the term "crop" will be used for pesticide application within the agricultural realm.

model, only two years of weather was used in each simulation, specifically the year of application and the following year. Development of the weather data set is described in section 2.2.4

2.4.1.5 Chemical Environmental Fate Properties

The following properties from Table 4 were used for the PRZM simulations: solubility, organic carbon-water partition coefficient (Koc), and aerobic soil metabolism. A detailed narrative and a listing of the environmental-fate properties of the used pesticides is provided in section 2.3.2

2.4.1.6 Chemical Applications

Chemical uses were obtained from the PUR database (CDPR, 2004), accessed from the California Pesticide Information Portal (CalPIP). The PUR database contains detailed information about chemical applications (application dates, application amounts, application types, and others) at the section (1 square mile) resolution. This includes records of application dates, chemical type, land use, application amount (lbs a.i.), and application type (aerial or ground) at each PUR section (CO_MTRS). A comprehensive description of the PUR data processing for use in the selected environmental fate models is given in section 2.3.3. Applications were specified as soil applied (PRZM chemical application method CAM=1).

2.4.1.7 Irrigation schemas

In a typical agricultural setting a crop is irrigated using flood, furrow, drip, sprinkler or another irrigation type. The California Department of Water Resources (CDWR; Orang *et al.*, 2008), conducted a detailed survey at the county-level to characterize irrigation methods in the State. Results from this survey were used to assign a dominant irrigation type per crop, rather than attempting to statistically assign a fraction of the runs one irrigation type and another fraction a different irrigation type. Table 12 lists the irrigation types used for each crop in this project. For each crop the modeled irrigation is listed (PRZM irrigation type and description), the PRZM leaching factor, irrigation depth and minimum irrigation application rate. PRZM irrigation type 8 (furrow irrigation) is a new irrigation setting developed for this project.

PRZM is capable of handling low flow irrigation types easily; however, furrow irrigation, although embedded in the model, does not work well in predicting pesticide losses in irrigation tailwater. Therefore, the furrow irrigation in WINPRZM was re-coded to better simulate the transport of pesticides from furrow irrigation. The new routine adds a new irrigation option, IRFLAG=8. This flag allows for WINPRZM to calculate the amount of irrigation water to be added to generate a predetermined amount of runoff (i.e. tailwater). Tailwater losses of 20% represents a realistic upper limit for furrow irrigation in California (J. Wrysinski, Yolo County Resource Conservation District, personal communication, 2007).

The algorithm requires two model runs to mimic furrow irrigation. One run simulates pesticide fate and transport from the crop row and the other run simulates pesticide fate and transport from the furrow. The calculated runoff and erosion fluxes from both runs are combined and used to compute a surface water concentration. For the purpose of this project it was assumed that the cropped row to furrow ratio was 1:1. Therefore, 50% of the field was cropped and 50% was furrow. Appendix D shows the code the PRZM uses to handle furrow irrigation.

2.4.2 Pesticide Losses from Rice

2.4.2.1 Introduction

In the period 2000–2009 between 470,000 and 590,000 acres of rice were harvested in California (Figure 12). The lowest acres harvested were in 2001 and the highest in 2004. Ninety-five percent (95%) of the rice acreage is within Butte, Colusa, Glenn, Sutter, Yolo, and Yuba counties, located within the Sacramento River watershed's Central Valley (Figure 25). About 80% of land planted in rice in California is of the "Calrose" medium grain variety, while around 10%-11% of land is planted in premium quality medium and short grain rice. The remaining percentage of land is dedicated to short and long varieties as well as special varieties such as sweet rice, Arborio types, and aromatic long grains (CRPW, 2004).

2.4.2.2 Model Selection

The rice water quality model, RICEWQ (Williams et al., 2008) was used to simulate pesticide applications to rice based on its ability to simulate the unique water management practices associated with rice production and because of the relative ease in using the model for bulk scenario processing. RICEWQ simulates pesticide transport from rice paddies based on water and pesticide mass balance. Water mass balance takes into account precipitation, evaporation, seepage, irrigation, and drainage. Pesticide mass balance can accommodate dilution, advection, volatilization, partitioning between water/sediment, decay in water and sediment, burial in sediment, and re-suspension from sediment. The model has been endorsed by the European community (MED-RICE, 2003) and has been validated with a number of field and watershed applications in Australia, Italy, Greece, Italy, Japan, and the U.S. (Capri and Miao, 2002; Christen et al., 2005, 2006; Chung et al., 2008; Ferrari et al., 2005; Infantino et al., 2008; Karpouzas et al, 2005a, 2005b; Karpouzas et al, 2006a, 2006b; Luo, 2011; Miao et al., 2003a, 2003b, 2004; Ngoc et al., 2008; Warren et al., 2004).

2.4.2.3 Pesticide Properties

Pesticide application data were obtained from the PUR database. The PUR also provides information on the method of application, acres treated, and application rate. Applications in the PUR were differentiated between Asian rice (*Oryza sativa*) and wild rice *(Zazina spp*). Pesticide applications to rice were simulated for the period 2000–2008.

Rice pesticides addressed in this study are carbaryl, s-cypermethrin, lambda-cyhalothrin, malathion (wild rice only), pendimethalin, propanil, and thiobencarb. These chemicals are a subset of those selected for the larger study as a whole. Oxyflurofen, trifluralin, and paraquat dibromide were initially included in the list of rice pesticides because the PUR database reported applications of these compounds on rice. However, these have been removed for rice modeling because they are not registered for use on rice. The PUR entries for oxyflurofen were legal label uses to clean up weeds bordering the fields. Rice growers were doing the applications, so reported the use as rice. PUR entries for malathion use on Asian rice were not simulated because registrations of malathion on Asian rice have been discontinued. Applications of malathion use on wild rice were simulated.

Environmental fate properties used for the simulations are provided in Table 4. For rice pesticides, environmental fate properties reported in Registration Eligibility Decisions (or Interim Registration Eligibility Decisions) of the U.S. Environmental Protection Agency's Office of Pesticide Programs[5] were used for model simulations. Where unavailable, properties for pyrethroids were based on conservative values recommended for modeling by Laskowski (2002). Values unavailable from the USEPA or Laskowski references were obtained from the USDA Pesticide Property Database (USDA-ARS, 2009) followed by the European FOOTPRINT database (AERU, 2009).

Degradation processes represented in the water column include aqueous hydrolysis, aquatic metabolism, and aquatic photolysis. Solubility was used as an upper limit for concentration in the water column. Degradation in flooded sediment was represented by anaerobic aquatic metabolism if available. Otherwise, the anaerobic soil metabolism half-life was multiplied by two. The aerobic soil metabolism value was used when the fields were not flooded. If values were not provided in the above referenced sources for a specific property, the property was assumed to be stable.

2.4.2.4 Calendar of Operations

Figure 26 shows a typical timeline for rice operations in California. The preferred date range for the planting of medium grain rice in California starts around April 20 and goes through May 25, however the optimal planting date is closer to May 10 for most public varieties. A two-month window is typical for most of the events listed in Figure 26. Therefore, for modeling purposes, the mid-point date for seed bed preparation was used as a base scenario and each simulation was offset ± 14 days with the offset assigned by random number generator using a rectangular distribution.

California rice growers practice aerial wet seeding and planting takes place within days after the initial flood. Irrigation is regulated to maintain one to two inches of depth (UCDAS, 1980) initially and then raised to maintain a target depth of five inches (CRC, 2010b, 2010c) after two weeks.

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[5] http://www.epa.gov/pesticides/reregistration/status.htm.

Generally, water is held until preparation for harvest. Interim drainage may occur if necessary to establish seedlings or for weed treatment with a contact herbicide.[6] Farmers may drain or partially drain during the first two weeks when rice plants are young to alleviate stress from cold water or winds. However, most farmers discharge to a holding basin and the drain down is not released downstream. Certain pesticides have minimum water holding requirements before drainage, including the final drainage, can occur to allow pesticide degradation to a level protective of aquatic life (CDPR, 2010, CVRWQCB, 2010, CRC, 2010a). Permits are required for releasing water prior to this requirement. Drainage usually occurs mid-August to Mid-September and may take a week drain a rice field.

The pesticides of interest are predominately applied to flooded fields. Propanil is a contact herbicide and requires drain down prior to application. Pendimethalin is the only compound used for drill-seeded (dry seeded) rice in California. Applications of pendimethalin occur before the initial flush (One Grower Publishing, 2009). Drain down was not represented in this study because water released during the initial drain is typically held in the field and not discharged to the adjacent drainage system.

Wild rice (*Zazina spp*) is planted as early in the spring as possible and harvested in July and August. Wild rice is grown in water for the entire growing season with a minimum of 6-8 inches of water depth, but can tolerate up to 12 inches. There are fewer herbicides registered for use on wild rice compared to Asian rice so deeper water depth is critical for weed control.[7] Production of wild rice, and pesticide use on wild rice, is considerably less than that of Asian rice. Therefore, for the purpose of this study, the calendar of operations water management for wild rice was represented the same as for Asian rice.

2.4.2.5 Soil Properties

Soils represented in the study were identified through a GIS process of overlaying PUR coordinates, SSURGO, and the California Digital Library (CDL) 2007 databases. PUR applications are provided at the PLSS (township-range-section) resolution, which will usually contain multiple soil series. The 2007 CDL indicates rice as a land use and was used to rule out areas within the PLSS that could not have received the application. All soils indicated as rice in the CDL will be used for the simulations and model results were weighted according to the relative acreage of these soils within the PLSS. Soil properties required for modeling include soil bulk density, organic carbon, field capacity, wilting point, initial soil moisture, and seepage rate.

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[6] J. Wrysinski, Yolo County Resource Conservation District, personal communication, October 19, 2010 and November 2, 2010.

[7] http://www.epa.gov/pesticides/reregistration/status.htm.

Soil properties used for modeling were obtained or derived from the SSURGO database. Field capacity and wilting point were calculated as a function of sand, clay, and organic matter content, and bulk density according to the following equation (Rawls and Brakensiek, 1982).

$$\theta_x = a + (b \times \%\text{Sand}) + (c \times \%\text{Clay}) + (d \times \%\text{Organic Matter}) + (e \times \text{Bulk Density})$$

in which θ_x is water retention $cm^3\ cm^{-3}$ for a given matrix potential (field capacity = -0.33 bar and wilting point = -15.0 bar); *a-e* are regression coefficients, and *Bulk_Density is* measured in $g\ cm^{-3}$(Rawls and Brakensiek, 1982). Simulations were started on January 1, which corresponds to the rainy season. As a result the initial soil moisture was set to the average of field capacity and wilting point. Initial soil moisture is not a sensitive value because the model can reach a state of dynamic equilibrium prior to simulating pesticide application.

Vertical seepage rates were assigned the saturated hydraulic conductivity associated with the soil series hydrologic soil group. The hydrologic soil group is an indicator of soil permeability and runoff potential in which A soils are more prone to infiltration and D soils are more prone to runoff.

Hydrologic Soil Group	Seepage Rate (cm/day)
A	0.87
B	0.61
C	0.19
D	0.04

Source: National Engineering Handbook, Volume 4, Table 7.2

2.4.2.6 Post-Harvest Handling of Crop Residue

Crop residues are treated with a mixture of practices, including baling, leaving the rice stubble to decompose for the winter, and burning. The most common practice is to allow the rice stubble to decompose under wet conditions which are also favorable to aquatic fowl. The California Air Resources Board restricts the burning of plant residues to a maximum of 25% of the total acreage, statewide. Farmers wishing to burn residues must also obtain a permit to burn within their Air Quality Management District, which is subject to a particulate tolerance level. Because of this additional restriction, only about 15% of rice fields are burned each year. Fields are drained and disked around February or March to incorporate any remaining crop residues and aerate the soil. Therefore, model scenarios were configured to leave residue in the field after harvest.

2.4.2.7 Other Properties

Other input parameter values, sources and rationale are provided in Table 13. Certain parameter values, such as diffusion rates and water/sediment mixing zone, are based on the experience of the authors of RICEWQ calibrating the model to field monitoring studies. Values were selected to be on the conservative end of estimates for pesticide exposure modeling (i.e., higher end of values in the water column and therefore higher potential for release to downstream receiving waters).

2.4.3 Pesticide Losses from Urban/Residential Uses

2.4.3.1 Background

Predicting the fate and transport of pesticides in urban settings requires consideration of factors that are not typically addressed in agricultural settings. With the exception of home vegetable gardens, urban pesticides are not used to improve the quality of produce or increase yield, but are used for turf management, the protection of ornamental plants, and the protection of buildings and other structures. Urban streams may experience pesticide exposure from direct or inadvertent application to hard surfaces (e.g., building siding, asphalt and concrete), dry-weather runoff from sprinklers and garden hoses (described by some as "urban drool"), and unique application methods such as perimeter application of insecticides to buildings. While urban drainage systems typically have responsive drainage systems due to presence of impervious areas, they sometimes encompass mitigation features such as storm water detention (dry) and retention (wet) basins. Although, originally designed to reduce storm water velocities and peak discharges, these features also provide water quality benefits for pesticides.

The USEPA has modified its agricultural "standard pond" scenario with PRZM-EXAMS to simulate pesticide runoff from an idealized suburban development (USEPA, 2004). The scenario maintains the geometry of a 10-ha watershed draining into 1-ha by 2-m pond, but includes separate, tandem PRZM simulations to simulate pesticide runoff from pervious (lawn) and impervious (roof, sidewalk, driveway, and road) areas. The scenario assumes 50% of the pervious area receives pesticide applications and 5.7% of the impervious areas receive overspray or are intentionally treated. The concentrations predicted from the pervious and impervious simulations are summed to produce the exposure assessment.

Research has recently focused on pyrethroid runoff from urban areas in California (Moran and TenBrook, 2011; Amweg 2005; Weston and Lydy 2010). This research has led to laboratory experiments to better characterize pyrethroid washoff under various formulations, hard surface media, application rates, and set times (Harbourt et al., 2009; Jiang et al., 2010; Jorgenson and Young, 2010). The washoff studies provide empirical data for developing washoff coefficients for use in the PRZM and SWMM models, thereby overcoming some of the limitations identified by Cheplick et al. (2006).

Unfortunately, on the limitations of available information on pesticide use in residential/urban settings within the study area dramatically increases the uncertainty in estimating pesticide runoff. California does not maintain the equivalent detail recording urban pesticide use that exists for agricultural uses. The use that is reported is for professional pest control operators (PCO) and exists at the county level as opposed to the PLSS. Urban use categories in the PUR include: structural pest control, landscape maintenance, rights-of-ways, public health pest control, and regulatory pest control (e.g., California Department of Food and Agriculture pest eradication). Uses not reported in the PUR include residential/home use, industrial use, and institutional use (Singhasemanon, 2004).

Sales data are not available on a watershed basis, only on a statewide basis, and since urban commerce usually spans watersheds, sales within a watershed does not necessarily relate to usage in that watershed.

The modeling framework for urban scenarios builds off of the conceptual model presented by Moran and TenBrook (2011). Given the lack of detailed information on the spatial and temporal use of pyrethroids in urban/residential settings, this study relied on county-level PUR data for professional applicator use and an approximate estimate for homeowner use. Previous work by TDC Environmental was used to make broad assumptions on the relative volume of homeowner use (TDC, 2010). Assumptions on the application location and timing for both professional and homeowner use and the allocation to pervious and impervious areas were based on specific surveys conducted in California (where available) and elsewhere (as supplemental information).

One very informative survey was an urban pesticide use survey of professional pesticide management companies conducted by the Pyrethroid Working Group (PWG) at the request of the CDPR (PWG, 2010). The survey included questions designed to identify the specific use patterns in which pyrethroids are applied, the percentage of pyrethroid use associated with each use pattern, the percentage of pyrethroids applied to residential properties versus commercial properties, and seasonal timing of applications for each use pattern.

DPR also worked with the University of California to conduct several homeowner surveys in several locations of California (Wilen, 2001, 2002; Flint, 2003). These surveys provide information on residential pesticide use by homeowners and commercial applicators. The studies include information on who applies outdoor pest control products by residence type (single detached home, attached home, and apartment) and ownership (own vs. rent).

2.4.3.2 Pesticides of interest

Urban/residential pesticides of interest for this study are bifenthrin, cypermethrin, cyfluthrin, and permethrin. The first three were selected based on having the highest urban uses and most often contributing to toxicity in California urban creek sediments (TDC, 2010). Permethrin, although less toxic, was included because it has the highest outdoor use of pyrethroid insecticides (TDC, 2010; PWG, 2010).

2.4.3.3 Professional applications

Use by licensed applicators was quantified from the PUR database. Non-agricultural use categories in the PUR for the chemicals of interest are provided in Table 14. Uses identified as commodity fumigation, food processing plant, fumigation, other, and public health were not included because these uses are likely indoor uses and/or very little use has occurred for these categories. The remaining categories were assigned to one of three categories for modeling: structural, landscape maintenance, or other. Based on the PWG surveys of PCOs, approximately 83% of pounds reported were applied outdoors (PWG, 2010). For the purposes of the present study, these remaining categories were assumed to be entirely outdoor use.

It is important to represent a realistic distribution of pyrethroid application to pervious and impervious areas. Structural applications were allocated to both buildings (impervious) and ground (combination of pervious and impervious). Applications for landscape maintenance were assumed to occur primarily to pervious areas with assumptions for overspray onto sidewalks, driveways, and roads (impervious). Rights-of-way, turf/sod, and uncultivated non-agricultural were assumed to be applied entirely to pervious areas.

For structural treatments, the PWG survey provides a distribution of the amount of pyrethroid that is applied up a building versus out along the ground. Overall, approximately 70% of active ingredient is applied out from the building and 30% is applied on the structure. These values were derived by area-weighting survey results. For the fraction applied on the ground, 50% was assumed to be onto impervious areas (e.g., driveways, walkways, and patios) and 50% onto pervious areas (lawn and landscape beds). In reality, some degree of washoff from hard surfaces is likely run onto pervious areas; however, as a conservative assumption for the purposes of this study, predictions of hard-surface washoff were assumed to become pesticide loadings into adjacent aquatic systems.

For lawn treatments, overspray onto sidewalks, driveways, and roadways were represented. A detailed investigation of potential application sites within the study area is beyond the scope of this analysis. Therefore, for the purposes of this study, the allocation of residues to pervious and impervious areas was based on the standard quarter-acre lot used by the USEPA in their assessments of pesticide exposure to the California red-legged frog and other California listed species (USEPA, 2009a). For lawn treatments, USEPA assumes overspray a 3-ft overspray onto sidewalks, driveways, and roadways. USEPA's scenario is based on a 10-ha watershed for which 50% is lawn and 5.68% is impervious area that receives overspray. For the purposes of the present study, the percentage of applied chemical allocated to impervious areas is 11.4% (=5.68% divided by sum of 5.68% plus 50%). Pesticide runoff had the potential to occur from both the pervious and impervious areas as a result of rainfall or irrigation. Daily rainfall records for the simulation year were obtained from the CMIS weather station assigned to the PLSS being simulated. Irrigation was specified to occur at a rate of 0.33 inches every other day onto pervious and overspray areas for March through November.

The PUR database provides urban pesticide use data at the county-level, not the PLSS level. As such, the calculate pesticide losses in the urban environment need to be redistributed over the known urban areas in a county, but only those urban areas that fall within the study area. Several counties partly overlap the study. Because of the partial overlap county-level pesticide mass loadings were area corrected. To determine the fraction of urban land for a county within the study area a GIS overlay analysis was conducted. The National Land Cover 2006 (USGS, 2011) data set (USGS, 2011) was selected to represent urban areas in the counties overlapping the study area. Determining the area weighted correction factor was a two-step process. First total area of urban land in each county was determined, and next the total area of urban land for each county within the study area. Last, the total urban area for each county in the study area was divided by the total urban area in each county. The resulting number is an area weighted corrected factor ranging from 0–1.0 (Table 15).

2.4.3.4 Homeowner use

Homeowner use is not documented in the PUR; however, an approximate amount of use can be inferred from sales data. Homeowner use was only simulated for bifenthrin because nearly all use of the other pyrethroids modeled in this study (cyfluthrin, cypermethrin, and permethrin) in urban areas in California is applied by professional applicators. Approximately 80% of bifenthrin use in the state is estimated to be applied by professional applicators (TDC, 2010). Therefore, homeowner use of bifenthrin was estimated at 25% of professional use (20/80=0.25). Homeowner use was assumed to follow professional use patterns with respect to allocation to structural versus landscape maintenance, distribution to pervious and pervious surfaces, and therefore separate model simulations were not required for homeowner applications. Instead, pyrethroid mass loadings of bifenthrin predicted from professional use were increased by 25%.

2.4.3.5 Pesticide properties

Pesticide properties used for the urban scenarios were discussed previously in Section 2.3.2. Values used in the simulations are summarized in Table 16. Washoff studies conducted by the PWG, UC Berkeley, and UC Davis were used to derive adsorption coefficients (Kd values) for model simulations of impervious materials (PWG, 2010; Jiang et al., 2010; Jorgenson and Young, 2010).

Runoff from pervious areas was simulated using Koc values reported by USEPA[8] and Laskowski (2002). Since residential soils are amended, all simulations were conducted using the Teirra soil series from USEPA's residential scenario for California (USEPA, 2010c). The simulation uses an organic carbon content of 35.6% for the surface horizon based on USEPA procedures for modeling pesticide behavior on turf.

2.4.4 Spray Drift

Pesticides have the potential to move offsite during application from spray drift. The chemical mass applied to directly to a water body from drift is a function of the application rate, the method of application, the pesticide formulation, wind speed, wind direction, humidity,

[8] http://www.epa.gov/pesticides/reregistration/status.htm

barometric pressure, height and velocity of the application apparatus, the proximity of the water body to the treated field, and the presence or absence and effectiveness of interception barriers. From the PUR database, only the application rate and a general description of the application method are known. Therefore, for the purpose of this study, a simple linear equation was developed that calculates drift. The drift load (M_{drift}) associated with an application is estimated as follows:

$$M_{\text{drift}} = \text{Rate} \times D_{\text{FRACT}} \times \sum_{i=1}^{n} (L_i \times W_i) \times \frac{\text{PUR}_{\text{area}}}{\text{Ag}_{\text{area}}}$$

Where

M_{drift} = Mass loading (kg) resulting from drift for a single pesticide

Rate = pesticide application rate (kg /ha^{-1}) for the pesticide

D_{FRACT} = Drift fraction (unit less), based on values used by the USEPA for pesticide risk assessment (USEPA, 2009b). For aerial applications a drift of 5% of the application rate is assumed. For ground applications, a drift of 1% of the application rate is assumed,

L_i = Stream length (m) associated with the treated field. Since we don't know where the application occurred, we need to assign a width for the L_i,

W_i = Width of the stream (m),

$\text{PUR}_{\text{area}}/\text{Ag}_{\text{area}}$ = area-weighted correction (unit less) for the treated area, PUR area (ha), and the PLSS land area (ha).

2.4.5 Daily Mass Loading

The daily pesticide mass loading is a composite of up to four main processes that each contributes a mass fraction to the system. These processes are

- Runoff from the field (dissolved and adsorbed to eroded soil),
- Discharges and runoff from rice paddies,
- Drift from spray, and
- Runoff from urban areas.

Each of these contributing factors, in turn is the sum of many soils, applications, and runoff from urban landscape segments such as previous and impervious areas.

2.4.5.1 Runoff mass

Because the actual location of the pesticide application was unknown, all soils in a given PLSS section had to be included in the modeling effort. To properly assign a fraction that each soil contributes to total daily mass, loading correction factors needed to be taken into account.

1. Soil-Agricultural Fraction. This fraction represents the area (as fraction) that each soil polygon represents of the total soil under agricultural areas in the PLSS section. This fraction was calculated using the GIS. First the total land area (water features were excluded) for the PLSS section was calculated using the summary statistics geoprocessing tool. Next, the total area for each soil map unit in the PLSS section was computed using the statistics geoprocessing tool. By dividing the result from the second calculation by the first, the fraction that each soil presents at the PLSS section was calculated. This fraction was used to correct the PRZM results and scale them properly based on area the soil represents in the PLSS section. Since the landscape patterns changes every two years, this calculation was repeated for all years for which land-use data were available, i.e., 2000, 2002, 2004, 2006, and 2008.

2. Soil Component Percent. Each soil map unit in the SSURGO and STATSGO database can contain one or more soil components. For each component in the soil map unit a typical percentage is provided that that map unit component represents of the total map unit. Therefore, the mass contribution from that soil was multiplied by the map unit component percentage.

3. Area Correction. Due to missing data, not all soil components in each map unit were considered in the simulations. Therefore, a back calculation was executed to determine what the fraction of each soil map unit component truly was. This fraction was combined with the soil map unit component percentage into a single correction factor for the mass contribution.

The daily total runoff mass loading for all soils (N) for a single pesticide at the PLSS section were calculated as:

$$M_{\mathrm{ag}} = \sum_{i=1}^{N} M_{\mathrm{PRZM}} \times SA_f \times S_c \times A_{\mathrm{app}}$$

Where

M_{ag} = total daily runoff mass (kg) for a single pesticide,

M_{PRZM}= predicted mass (kg ha^{-1}) from the field calculated by the PRZM model,

SA_f = Soil-agricultural fraction (unit less),

S_c = Soil area correction (unit less),

A_{app} = Area treated (ha).

In addition to the mass loadings from pesticides dissolved in runoff water, mass loadings resulting from sediment transport was calculated as well. The mass loading contribution from sediment transport for the PLSS from all soils (N) was calculated as

$$M_{\text{sed}} = \sum_{i=1}^{N} M_{\text{PRZM}} \times SA_f \times S_c \times A_{\text{app}} \times (1 - \text{PRBEN})$$

Where

M_{sed} = total daily sediment mass (kg) for a single pesticide,

M_{PRZM} = predicted mass (kg ha^{-1}) from the field calculated by the PRZM model,

SA_f = Soil-agricultural fraction (unit less),

S_c = Soil area correction (unit less),

A_{app} = Area treated (ha),

PRBEN = Desorption fraction from eroded sediment (unit less).

PRBEN is used to represent the fraction of pesticide mass desorbed from eroded sediment. A PRBEN value of 0.5 was used for all chemicals except those having an extremely high affinity for adsorption (i.e., pyrethroids and paraquat dibromide). For these chemicals (Koc > 100,000 cc/g), a PRBEN of 0.85 was used. A value of 0.5 is the default value used by USEPA for pesticide risk assessment (Burns, 2004). A PRBEN value of 0.85 was assumed based on the strong adsorption of pyrethroids to soil particles.

2.4.5.2 Discharge and runoff from Rice Paddies

The mass contribution from discharge and runoff from rice paddies for PLSS section for all soils (N) was calculated as

$$M_{\text{rice}} = \sum_{i=1}^{N} M_{\text{ricewq}} \times SA_f \times S_c \times A_{\text{app}}$$

Where

M_{rice} = total daily runoff and discharge mass (kg) for a single pesticide,

M_{ricewq} = predicted mass (kg ha^{-1}) from the field from the RiceWQ model,

SA_f = Soil-agricultural fraction (unit less),

S_c = Soil area correction (unit less),

A_{app} = Area treated (ha).

2.4.5.3 Urban Areas

Pesticide mass loadings for urban areas were calculated at the county level. The primary reason for this was that the PUR database provided the urban use data at the county level, rather than at the PLSS section level. Therefore, the county-level data needed to be redistributed to the section level. Using the GIS, for each PLSS section in the study area the total area of urban land was calculated for the period 2000–2008. This allowed us to incorporate changes in the landscape by the following steps:

1. Using the GIS statistical summary tool, for each PLSS section the total urban area (m^2) was calculated.
2. Using the National Land Cover 2006 (NLCD06), the fraction of urban land use for each county in the watershed was determined. Many counties fall only partly in the study area and therefore not all urban areas within a county fall within the study area. As such, the computed mass loading at the county level were corrected for that. The fraction of urban for each county that falls within a watershed is listed in Table 15.
3. For each county, the sum of the fraction of land use for all PLSS section was determined and used to correct the fraction of urban at the PLSS section level to the county level.

The process flow of distributing county-level estimated pesticide mass loadings is depicted in Figure 27. With this information to the mass contribution from urban areas was computed as:

$$M_{\text{urban}} = \sum_{i=1}^{N} (M_{\text{UP}} \times Sf) \times C_{\text{frct}} \times \frac{F_{\text{PLSS}}}{\sum_{i=1}^{m} F_{\text{PLSS}}}$$

Where

M_{urban} = total daily pesticide mass (kg) from urban areas from a single pesticide,

Sf = Use site fraction (unit less)

M_{UP}= Daily mass loading (kg) from urban area using the PRZM model,

$Cfrct$ = Fraction (unit less) of urban land use of a county that falls within the study area,

F_{PLSS} = Fraction (unit less) of urban land in the PLSS section.

2.4.5.4 Total Daily Mass

The total daily mass (M_i) for a single pesticide as the PLSS section level is now computed as:

$$M_i = M_{\mathrm{ag}} + M_{\mathrm{sed}} + M_{\mathrm{rice}} + M_{\mathrm{drift}} + M_{\mathrm{urban}}$$

Where

M_i = total daily mass (kg) for pesticide *i*,

M_{ag} = total daily mass (kg) for pesticide *i* from runoff,

M_{rice} = total daily mass (kg) for pesticide *i* from rice paddy discharge,

M_{drift} = total daily mass (kg) for pesticide *i* from drift,

M_{urban} = total daily mass (kg) from urban runoff.

2.5 Hazard Assessment

2.5.1 Concentration

Pesticide concentrations were calculated on a daily time step at the PLSS section level. For each pesticide first the total daily mass contribution was calculated and next it was mixed in a volume of water. As such the concentration was computed as:

$$[C_i] = \frac{M_i}{V_i}$$

Where

M_i = total daily mass (kg) for a chemical i in a PLSS section,

V_i = volume of water (m^3) in the in the PLSS section.

2.5.2 Water Volume

In order to calculate a daily concentration based on the pesticide mass loading (M_i) a water volume was defined. The water volume (V) is based on the total stream length within each PLSS section. *V* is calculated based on the linear length of each stream order in the PLSS according to the following equation:

$$V = \sum_{i=1}^{n} (L_i \times W_i \times D_i)$$

Where

L_i = the length,

W_i = the width,

D_i = the depth,

i = one of n channel segments.

For the purpose of this assessment, the stream geometry was fixed by stream order. Therefore each stream order had a fixed width and depth. Lengths were derived from NHD+ dataset. With the exception of the larger river segments, the width of the channel is not specified in NHD+. For man-made agricultural ditches, the dimensions were obtained from expert opinion. For a natural stream, the geometry was obtained from EPA Reach File 1 (RF1; USEPA, 1982). Using the RF1 streams that are present in the study area, a linear regression equation was developed (Figure 28) to determine the depth of a stream given the width. This relationship was used to compute the depth of each stream order based on assumed standard width. Exceptions to the standard width included part of the San Joaquin River, the Sacramento River, the American River, and the Feather River. Google maps were used to check what a representative river width would be for each stream order. The stream geometry for ditches and river is listed in Table 17.

None of the available river or stream GIS datasets contained sufficient information on the total stream length of agricultural ditches. Therefore, the average length of these ditches needed to be determined from other sources. CA DWR creates an annual high-resolution land-use map for a few selected counties in the state of California. The data from the 2006 Colusa County land-use map were used to determine to total length of hydrologic features (streams, river, and ditches) for 200 PLSS sections. The computed total length was than compared with the total stream length from the NHD+ dataset and the difference was calculated for each section. The average difference (5,069 m) was assumed to be the additional length of ditches required to add to the total stream length in each PLSS section. In order to avoid overestimating the ditch length, the average ditch length was multiplied by the fraction of agricultural land in each PLSS section. The final equation to calculate the total volume of water in each PLSS section is:

$$V_{\text{PLSS}} = \sum L_i \times W_i \times D_i + \left(V_{\text{ditch}} \times \text{Ag}_f\right)$$

Where

L_i = length of stream order i (m),

W_i = width of stream order i (m),

D_i = depth of stream order i (m),

V_{ditch} = volume (m^3) of the standard ditches,

Ag_f = fraction of agricultural lands (-).

2.5.3 Indicator Events

Ecological risk is often estimated numerically using the Risk Quotient (RQ) approach, which is expressed as the ratio of the estimated environmental concentration (EEC) to a toxicity benchmark. For the purpose of this study, we define any instance in which the RQ $\geq$1 as an "indicator event." An indicator event does not imply that toxicity will occur because of the degree of uncertainty in the EEC, the safety margin in the benchmark, and because species presence is not considered in the equation. An indicator event is one in which toxicity has the potential to occur if the species is present at the location when the event occurs.

2.6 Species of Concern

2.6.1 Selection

California has a rich and diverse biosystem. Currently there are 123 animal species and 178 plant species listed as threatened or endangered by the U.S. Fish and Wildlife Service (USFWS, 2011). In additional the State of California maintains a separate list of local species of concern. As of 2011 the California Department of Fish and Game lists 220 plants (CDFG, 2011a) and 81 animal species (CDFG, 2011b) as threatened, endangered or rare in the State. Since it was not feasible to study all species, and the focus of this study was directed toward the decline in pelagic species, the following nine aquatic species of concern (SOC) were selected:

1. Chinook Salmon (*Oncorhynchus tshawytscha*)
    - Sacramento River winter-run
    - Central Valley spring-run
    - Central Valley fall run
    - Central Valley late fall run
2. Central Valley steelhead (*Oncorhynchus mykiss*)
3. Southern North American Green Sturgeon (*Acipenser medirostris*)
4. Delta Smelt (*Hypomesus transpacificus*)
5. Striped Bass (*Morone saxatilis*)
6. San Francisco Longfin Smelt (*Spirinchus thaleichthys*)
7. Threadfin Shad (*Dorosoma petenense*)
8. California Red-legged Frog (*Rana draytonii*)
9. California Freshwater Shrimp (*Syncaris pacifica*)

The California Red-legged Frog and California Freshwater Shrimp were included in this study to meet the collective concerns of the project's Technical Advisory Panel.

The Chinook has four distinct runs in California. Therefore, it was deemed necessary to include all four runs as part of the co-occurrence analysis. Each run was treated as a separate species. As such, the spatial-temporal co-occurrence analysis includes 12 SOCs.

2.6.1.1 Chinook salmon (Oncorhynchus tshawytscha)

Four varieties of the Chinook salmon were studied:

- <u>Sacramento River winter-run.</u> The Sacramento River winter-run Chinook salmon ESU includes all naturally spawned populations in the Sacramento River and its tributaries, and two artificial propagation programs; winter-run Chinook salmon from the Livingston Stone National Fish Hatchery and winter-run Chinook salmon in a captive brood stock program maintained at Livingston Stone National Fish Hatchery and the University of California, Davis, Bodega Marine Laboratory (Moyle, 2002; Moyle et al., 2008).

- <u>Central Valley spring-run.</u> The Central Valley spring-run Chinook salmon ESU includes all naturally spawned populations in the Sacramento River and its tributaries, including the Feather River and one artificial propagation program; the California Department of Fish and Game (CDFG) Feather River Hatchery spring-run Chinook salmon program. There are only three remaining independent populations; Mill, Deer, and Butte Creeks, which are in close geographic proximity to each other (Moyle, 2002; Moyle et al., 2008). Historic spring-run populations likely numbered 0.5–1.5 million in the Central Valley (Yoshiyama et al., 1998); however, current abundance has averaged ~16,000 fish since 1992 (Moyle et al., 2008).

- <u>Central Valley fall run.</u> The Central Valley fall-run Chinook salmon ESU includes all populations in the Sacramento and San Joaquin River basins and their tributaries. Fall-run Chinook salmon are the most abundant run in the Central Valley and are the principal run raised in hatcheries (Moyle, 2002; Williams, 2006); however, the fall-run Chinook salmon population has declined during the last several years from an average of 450,000 (1992–2005), to less than 200,000 fish in 2006 and to about 90,000 spawners in 2007. The population includes both wild and hatchery-origin fish, and the proportion of hatchery fish can be as high as 90% depending on location, year, and surveyor bias (Barnett-Johnson et al., 2007).

  Fall-run Chinook salmon habitat requirements are generally similar to those of California coastal Chinook salmon, but juveniles make more extensive use of off-channel habitats where they grow faster because of warmer water temperatures and abundant food (Moyle et al., 2008; Sommer et al., 2001).

- Central Valley late fall run. Because they are closely related to Central Valley fall-run Chinook salmon, Central Valley late fall-run Chinook salmon are managed under the fall-run ESU; however, late fall-run fish were recognized as a distinct run after the construction of Red Bluff Diversion Dam in 1966 (Moyle et al., 2008), and are considered genetically distinct from other Central Valley runs (Williams, 2006). Late fall-run Chinook are found mainly in the Sacramento River, where spawning and rearing occurs between Red Bluff Diversion Dam and Redding (Moyle et al. 2008). The historic abundance of late fall-run Chinook is not known, but during 1967–1976, the run above Red Bluff Diversion Dam averaged ~22,000 fish. Recent estimates (1992–2007) have averaged 20,777 fish, with a high of over 80,000 fish in 1998 (Moyle et al., 2008).

2.6.1.2 Central Valley steelhead (Oncorhynchus mykiss)

The Central Valley steelhead DPS includes all naturally spawned anadromous steelhead below natural and manmade impassable barriers in the Sacramento and San Joaquin Rivers and their tributaries, including two artificial propagation programs; the Coleman National Fish Hatchery and the California Department of Fish and Game (CDFG) Feather River Hatchery (Moyle, 2002; Moyle et al., 2008). No good estimates of current abundance are available; however, estimates made in the early 1990s suggest that ~10,000 fish were present in the Central Valley (McEwan and Jackson, 1996). More recent data from the Sacramento River suggests a precipitous decline from an average of 6,574 fish in 1967–1991, to less than 1,500 fish from 1992–2008 (Moyle et al., 2008).

2.6.1.3 Southern North American Green Sturgeon (Acipenser medirostris)

Similar to other sturgeon species, green sturgeon are large in size (max. 270 cm TL and 175 kg),[9] have a sub-terminal barbeled mouth, lines of bony plates (scutes) on their sides, and a heterocercal tail (Moyle et al., 1995). Green sturgeon can be distinguished from other related species by their dorsal row of 8–11 scutes, lateral rows of 23–30 scutes, two bottom rows of 7–10 scutes, dorsal fin with 33–36 rays, anal fin with 22–28 rays, large scutes behind the dorsal and anal fins[10] (Moyle et al., 1995; Moyle, 2002), and barbels closer to the mouth than the tip of the snout (Moyle et al., 1995; Moyle, 2002). Body color is olive-green with an olive stripe on each side (Moyle et al., 1995; Moyle, 2002). Scutes are generally lighter in color than the body[11] (Moyle et al., 1995; Moyle, 2002).

2.6.1.4 Delta Smelt (Hypomesus transpacificus)

The delta smelt is listed as threatened under both the federal and California state Endangered Species Acts (ESAs) (USFWS, 1993). Habitat for juvenile and adult delta smelt is found in the

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[9] http://ucce.ucdavis.edu/datastore/datastoreview/showpage.cfm?usernumber=35&surveynumber=241
[10] http://ucce.ucdavis.edu/datastore/datastoreview/showpage.cfm?usernumber=35&surveynumber=241
[11] http://ucce.ucdavis.edu/datastore/datastoreview/showpage.cfm?usernumber=35&surveynumber=241

estuarine waters of the lower Delta and Suisun Bay, where salinity ranges between 2–7 ppt; however, delta smelt can tolerate salinity ranges from 0–19 ppt. Delta smelt typically occupy open, shallow water habitats, but can also be found in the main channel in the region where fresh and brackish water mix (Moyle, 2002). Severe alterations in the composition and abundance of the primary producer and primary/secondary consumer assemblages in the Delta have been implicated in the recent decline of Delta smelt and other native fish species (USFWS, 1996; Kimmerer, 2002).

2.6.1.5 Striped Bass (Morone saxatilis)

Striped bass were first introduced into the San Francisco Estuary in 1879. Another introduction was made in 1882, and by 1888, a commercial fishery targeting striped bass was present (Dill and Cordone, 1997; Moyle, 2002). Currently, striped bass have spread throughout the Sacramento-San Joaquin Delta and water bodies connected to the Delta and California Aqueduct. Striped bass are one of the most common fish in the San Francisco Estuary; however, populations have declined in recent years. Climactic factors, water diversions, pollutants, reduced estuarine productivity, and exploitation are all considered factors contributing to declines (Moyle, 2002).

2.6.1.6 San Francisco Longfin Smelt (Spirinchus thaleichthys)

Historically, Longfin Smelt populations were found in the Klamath, Eel, and San Francisco estuaries, and in Humboldt Bay. In the Central Valley, Longfin Smelt are rarely found upstream of Rio Vista or Medford Island in the Delta. Adults concentrate in Suisun, San Pablo, and North San Francisco Bays (Moyle, 2002). The abundance of Longfin Smelt in the San Francisco estuary has fluctuated over time; however, abundance has been in decline since the early 1980s, and was very low during the drought years of the 1990s and recent wet years (Rosenfield and Baxter, 2007; Sommer et al., 2007). The 2007 Fall Mid-Water Trawl (FMWT) index had the lowest index value (13) recorded since the survey began in 1967. The highest index value between 1988 and 2008 was 8,205 in 1995. The index in 2008 was 139 (CDFG, 2008). Severe alterations in the composition and abundance of the primary producer and primary/secondary consumer assemblages in the Delta have been implicated in the recent decline of longfin smelt and other native fish species (USFWS, 1996; Kimmerer, 2002).

2.6.1.7 Threadfin Shad (Dorosoma petenense)

Threadfin shad were introduced into ponds in San Diego County by the California Department of Fish and Game (CDFG) in 1953 (Dill and Cordone, 1997; Moyle, 2002). Following the 1953 plant, additional fish were planted in lakes and reservoirs across the state, thereby allowing the species to spread into the Sacramento-San Joaquin system and the Delta (Moyle, 2002). Further unauthorized plants have expanded the species' range to include most of California west of the Sierra Nevada (Moyle, 2002).

2.6.1.8 California Red-legged Frog (Rana draytonii)

The California red legged frog (*Rana aurora draytonii*) was listed as threatened by the U.S. Fish and Wildlife Service (USFWS) in 1996, and a recovery plan was finalized in 2002 (USFWS, 2002). Critical habitat designation was published in the Federal Register (71 FR 19243-19346) in 2006, and included eight recovery areas. This critical habitat designation also included a special rule, under section 4(d) of the Endangered Species Act (ESA), exempting routine ranching activities from critical habitat protection (USFWS, 2006). Currently, 50 critical habitat units totaling 662,312 ha are designated in a revised version of the 2006 critical habitat designation (USFWS 2010).

2.6.1.9 California Freshwater Shrimp (Syncaris pacifica)

The California freshwater shrimp (*Syncaris pacifica* Holmes) is the State's only native stream-dwelling shrimp. The only extant member of the genus *Syncaris*, it was listed as endangered by the State in 1980 and then by the federal government in 1988. Historic distribution of the California freshwater shrimp is unknown; past surveys found the species in 17 stream segments within Marin, Napa, and Sonoma counties (Eng, 1981). However, more recent surveys have found the species in a few additional areas (USFWS, 2007). California freshwater shrimp have evolved to survive a broad range of stream and water temperature conditions. They prefer low-elevation (less than 116 m), low-gradient (generally less than 1%) perennial freshwater streams and intermittent streams with perennial pools where banks are structurally diverse with undercuts, exposed roots, and overhanging woody debris or vegetation (USFWS, 1998). Depths of 30–90 cm are ideal. No data are available for defining temperature and flow tolerances (USFWS, 2007). Detailed species description for all considered SOCs can be found in Appendix E.

2.6.2 Species Presence and Life Cycle

For a typical co-occurrence analysis, the USFWS critical habitat data (USFWS, 2009) could be used. However, this portal only lists federal threatened and endangered species, and data are not available for all species, for example, California freshwater shrimp. In addition, the critical habitat data lack a clear temporal aspect. Given these limitations, a more specific dataset for each species was required. The datasets had to adhere to the following criteria:

- For each river segment, presence absence must be know
- For each river segment the monthly species abundance must be know

Given these criteria, a life-history table was developed for each species. Detailed life-cycle and presence information was obtained from a variety of sources, but primarily from Moyle (2002) and Moyle *et al.* (2008). In additional to the life-history tables, a GIS dataset was developed that showed that relative abundance by month for the main rivers segment. It is critical to know that the developed fish species range maps are considered high-water year ranges; some of the stream reaches included are ephemeral and would not contain adults or juveniles during low-water years.

For the California Red-legged frog, only the life-history table was developed. The distribution and abundance representations relied on the USFWS critical habitat data.

Appendix F details the steps for the development of the life-cycle tables and GIS datasets for each of the 12 SOCs.

2.7 Water Quality Monitoring Data

Surface water quality monitoring data provided information for where pesticides have been detected in the past, the magnitude of the observed pesticide concentrations, and the frequency of detection. Monitoring data also enables the validation and reality check of computed environmental concentrations for pesticides in surface water. As part of this co-occurrence assessment, water quality monitoring data for the 40 pesticides of interest were collected, processed, and stored in a database for subsequent processing. Sample data was collected for surface water for the period 2000–2009. Data sources that were accessed for this effort included:

- California State Water Resources Control Board
- Central Valley Regional Water Quality Control Board
- California Department of Pesticide Regulation
- Sacramento River Watershed Program
- United States Geological Survey NAWQA program

Available monitoring data were downloaded, typically in text limited format, and converted into a standardized MS Excel spreadsheet for additional processing (e.g., specifying information on location and the source of the data), formatting, and QC. Finally the data was loaded into the final database. Tables included in the database are:

- Sites table, which contains information concerning the monitoring location. The data collected for each site included site name, site ID, location, region name, and program/project name.
- Source table, which provides information regarding the source (origin) of the data, including agency and web site.
- Water Quality table, which contains the actual monitoring data. The categories for this data are site ID, sample date and time, measured concentration (and units), level of detection, matrix (groundwater, surface water, etc), sample ID and any pertinent comments.

2.8 Spatial-Temporal Co-occurrence

2.8.1 Co-occurrence index matrix

In order to develop a co-occurrence index or matrix, it must be defined what is co-occurring? If only two entities (e.g., two species or a species and chemical) are being studies, a number of different methods can be applied to determine co-occurrence (e.g., C score or checker box approach; Gotti, 2000; Manly, 1995, Moriarty, 2011, Stone and Roberts, 1990). However, when more than two entities are involved to establish co-occurrence methods are insufficient to quantify this. A variety of questions were addressed as part of the co-occurrence method development, these questions included:

- What is more important; the species or the pesticide?
- Do we consider all events where RQ ≥ 1?
- What if two pesticides have RQ ≥ 1 on the same day?
- Do we know which pesticide affects which species?
- What time period do we consider?
- Can we calculate a fraction of events exceeding the benchmarks?
- Are we doing an absolute or relative ranking?

In this study the following two groups are considered in the co-occurrence assessment: species of concern and pesticides in surface waters. It should be emphasized that multiple species and pesticides are involved. For co-occurrence to happen, the species and the pesticide(s) must be present at the same location at the same time. In this assessment the same location is considered to be the same PLSS section. A monthly time step was used for the temporal scale because species data is provided at a monthly basis. The PLSS was used for the spatial scale because pesticide loads and indicator events estimated at this resolution. Co-occurrence was also estimated at point locations where concentrations exceeded benchmarks.

2.8.1.1 Species Information

Species information generated for this study includes estimated presence and abundance by month. Since the number of species can be determined for each PLSS section, species richness was used for the co-occurrence analysis. Species richness is defined as the number of species present within a biological community (Encyclopædia Britannica, 2011*)*. If a large number of species (N) are present within the community, the species richness will be a large number. However, since not every species is present at a given location or time, only a fraction of the species should be considered in the co-occurrence assessment. The species richness fraction, S_n is calculated as

$$S_n = M/N$$

Where

N is the number of species considered in the study

M is number of species present in the month considered

Rather than using the species richness fractions in the assessment, fractions for 10th, 20th, .., 90th and 100th percentiles were determined for all locations (PLSS sections) and all months (January–December). The advantage of using percentile levels is that is it positions the species richness fractions for any location and month properly within all possible options determined in the study. As such, this provides a relative ranking of all species richness fractions. This also enables the user to compare months with one and another and the meaning of the percentiles remains the same for all months.

2.8.1.2 Pesticide Information

Available pesticide information includes the daily concentration in surface water. However, a concentration by itself has little meaning in that it does not provide information about any potential risk the pesticide may pose to a species. In the Risk Assessment process (EPA, 2011); risk is typically expressed using the Risk Quotient or RQ. The RQ is calculated as:

$$RQ = Exposure / Toxicity$$

Where

Exposure is the estimated environmental concentration (kg/m^3)
Toxicity is established effects level (kg/m^3)

The methodology for calculating exposure is detailed in Section 2.5.1. Toxicity thresholds are explained in Section 2.4.3. Specifically, a RQ ≥ 1 is of interest for this study, and as explained in Section 2.5.3 is considered an "indicator event." One dilemma faced in the development of the co-occurrence methodology for this study was whether to conduct the analysis based on the calculated frequency of indicator events or indicator days. Since when than one chemical may cause an indicator event in the same location on the same day, co-occurrence was evaluated using indicator days for this study. An indicator day is a day in which at least one indicator event occurs.

The total number of indicator days was computed for each PLSS section for each month. The total was expressed as a frequency by calculating the fraction of indicators for the month of being analyzed (I_n):

$$I_n = I(10 \times N_d)$$

Where

I = number of indicator days for a given month

N_d = number of days in that month.

N_d is multiplied by 10 because the 10-year simulation period contains (e.g., 10 Januarys, 10 Julys, etc.).

Rather than using the indicator day fractions in the assessment, fractions were expressed by percentile (e.g., 10th, 20th, .., 90th and 100th percentiles). The advantage of using percentile levels is that it can accommodate a range of conditions (e.g., a maximum indicator day fraction of 0.02 or a maximum indicator day fraction of 0.96) . As such, this provides a relative ranking of all fractions and months can easily be compared. Percentiles also provide a consistent metric if other assessment intervals were to be used (e.g., seasonal or annual assessments). Also by including all possible fractions, we scale the numbers relative. If the number of indicator days were to change due to, for example, considering fewer pesticides in the assessment, the approach still provides a relative ranking of the fractions, which is now valid for that new population.

2.8.1.3 Multi-dimensional Matrix

At this point we know the percentiles representing the species richness and the number of indicator days. However, these two numbers are not correlated, but merely co-exist at the same location and time to varying degrees. Rather than combining both numbers into a single score or joint probability, a 2-dimensional co-occurrence matrix was developed (Figure 29a). Indictor day percentiles are presented along the abscissa (horizontal axis) and species richness percentiles are along the ordinate (vertical axis). The matrix is presented as a 10 x 10 grid. Instead of graphing percentiles, bins representing percentiles intervals are used. For example, 10th percentile is bin 1, the 20th percentile is bin 2, etc. The bin number starts at zero and increases from left to right and from top to bottom. Zero means that there are no species or indicator days.

The next step is to number the all bin combinations (Figure 29b) in the matrix. For example, the 40th percentile for species richness, represented by bin 4, is combined with the 70th percentile or bin 7 for the indicator days to produce a matrix cell of "47" (not forty seven). For the co-occurrence assessment, the percentile values (fractions) can be used. Conversion to bins is simple to enhance visualization and understanding of the co-occurrence. The species richness and indicator day percentiles can be converted to bins and mapped. That way, areas can be ranked, if needed. The higher the bin numbers to greater the potential.

The matrix values range from "00" to "1010", where "00" means that neither species nor indicators days are present nor "1010" means that species and indicator day are more likely to co-occur. Because the bins are scaled to the population, the maximum fractions (and thus 100th percentiles) are not necessarily 1.0, but could be smaller. This approach enables the user to determine for the considered populations areas where, relatively speaking, more frequent co-occurrences of pesticides and species are located in the landscape.

Values in the co-occurrence have different meaning and depend on how the user (risk assessor) would use them and what the focus of the assessment would be. For example, 73 (seven three) means that at least the 70th percentile of the species richness was exceeded and at least the 30th percentile of the indicator day. The co-occurrence in this case is slanted towards the species richness. In other words, because the species richness is greater (higher number of species is present) only a few areas will be represented. A fisheries and aquatic resources agency, for example, might highlight these areas because they have the potential for greater impact because more species are affected and need to be protected. Whereas 37 (three seven) means that co-occurrence is driven by at least the 30th percentile of the species richness and at least the 70th percentile of the pesticides indicator days. The co-occurrence is slanted toward the pesticide indicator days in this case. In other words, areas with the higher number of indicator days are emphasized. So, to a pesticide regulatory agency or monitoring assessment agency these areas have a higher potential of pesticides getting into aquatic environment, and thus might be areas needing mitigation.

3.0 Results and Discussion

Although one of the main objectives of this study is to develop a framework for determining potential co-occurrence of pesticide loadings and species of concern (SOC), insight into individual components of the assessment provides a better understanding contributing factors. Datasets generated within this project resulted in an overwhelming amount of information (e.g., >150,000,000 pesticide mass loading events and >750,000 data records for SOCs) that cannot be presented in detail within this report. However, high-level results are provided, specifically, for the distribution of pesticide mass loadings, species abundance, co-occurrence, water quality monitoring efforts, and potential areas of concern. In some instances additional focus is provided (e.g., for the Delta Smelt) as examples of more detailed assessments that can be performed using the underlying datasets. The datasets and co-occurrence framework are the intended deliverable of this study for use in assessments beyond those presented within this report.

3.1 Pesticide Applications

In the period 2000–2008 over 8,971,000 agricultural "applications" (Table 18) were simulated using PRZM or RICEWQ. An additional 143,000 urban applications were simulated using PRZM for urban areas. An application is defined herein as a unique combination of PLSS section, pesticide, soil, weather station, application date, and rate. A simulated application is not the same as a recorded application in the PUR database because the location of the recorded PUR application is not exactly knows within a PLSS section; therefore, all potential soil-crop combinations were modeled and the results were area weighted according to the relative amount of each soil within the PLSS. This resulted in a greater number of applications than truly occurred in the period 2000–2008. The annual number of agricultural applications, according to the definition above, varied between 859,000 (2001) to 1,127,000 (2006).

The total numbers of simulations are presented in the final four columns of Table 18. These are lower than the number of applications because many of PUR entries could be represented with a single model run because they share the same application date, crop, soil, and weather file.

The modeled pesticide applications occurred in 14,474 PLSS sections (Figure 30) in the period 2000–2008. Figure 30 identifies the PLSS as being agricultural, urban or mixed land use. Agricultural applications dominate the database, however due to presenting results at the PLSS level, there appears to be more urban than was actually modeled. A fraction of the applications occurred in rural areas, especially in the southern Bay-Delta Region and the San Joaquin River watershed. Figure 31 shows a close up of the application area with urban areas transposed. This map shows that frequently small urban pockets are present in sections that are dominated by agriculture. Therefore, many sections have mixed land but are dominated by agricultural land use.

On an annual basis the modeled application amount varied from 8,000,000 lbs (2008) to 13,350,000 lbs (2000). Applications on rice paddies account for 35.2% to 46.0% of the total amount, other agricultural crops accounted for 52.8% to 63.4% to the total applied amount and urban application accounted for 0.9% to 1.7% of the total applied amount (Table 19).

3.2 Pesticide Loadings

The 9,115,000 modeled applications represent a total applied mass of 98,279,000 lbs of active ingredient (a.i.) for the 40 chemicals considered in this study. Approximately 14.2% of the applied amount was predicted to reach surface waters via surface runoff, erosion, drift, and discharge from rice paddies (Table 19). Runoff from agriculture accounts for over 86% of the mass losses loadings. Erosion and drift from agricultural applications accounted for approximately 5.0% and 4.4% of the mass loadings. Another 4.3% was predicted to discharge and runoff from rice paddies. Urban runoff accounted for less than 1%.

When the mass losses for drift, runoff and erosion are compared with the total amount applied on agricultural fields (excluding urban and rice paddies), 23.7% of the applied mass was predicted to reach surface water. Losses from rice application were estimated to be 1.5% of the applied amount on rice and urban losses were predicted to be 0.4% of the applied amounts. The mass loses from rice paddies is likely to be slightly higher than listed because all the drift mass losses, including those from applications to rice paddies, were included in the agricultural mass losses.

A primary reason why the runoff contributions are so dominant is likely due to the furrow and flood irrigation. Several conservative assumptions were used in representation of furrow irrigation in this study: 1) if furrow irrigation is the predominant irrigation method for the crop, all model simulations for that crop were represented as furrow irrigation; 2) the irrigation routine was configured to generate 20% loss of applied water as tailwater; 3) 50% of the field was assumed to be furrow. This in turn may have resulted into higher than expected mass loadings from runoff. Mass loading contributions from drift and erosion were 5.0% to 4.3% respectively.

Urban mass loadings were relatively low and likely due to the large partition coefficient (Kd) of the pesticides used in the urban environment. Although, over 1,226,000 lbs of a.i. for four different chemicals were applied in the urban areas from 2000–2008, less than 4,800 lbs a.i. was predicted to runoff in the urban environment into surface water bodies.

Figure 32 presents total mass loadings for the 40 chemicals during the 10-year (2000–2009) simulation period (see also Table 20). The counties having the highest mass loadings are Glenn, Butte, Sutter, Yuba, Yolo, San Joaquin, Stanislaus, and Merced.

3.3 Indicator Days

Ecological risk is often estimated numerically using the Risk Quotient (RQ) approach. The RQ is expressed as the ratio of the estimated environmental concentration (EEC) to a toxicity benchmark. For the purpose of this study, a day with at least one instance in which the RQ ≥1 is defined as an "indicator day". An indicator day does not imply that toxicity will occur because of the degree of uncertainty in the EEC, the safety margin in the benchmark, and because species presence is not considered in the equation. An indicator day is one in which toxicity has the potential to occur if the species is present at the location at the same time as when the event occurs.

Figure 33 shows the distribution of total number of indicator events exceeding the T&ES (threatened and endangered species) reference value (Table 9) at the PLSS section level for the 40 pesticides and 10 years considered in this co-occurrence assessment. The maximum number of indicator events in a PLSS section is 2,876. Many of the potential indicator days occurred in the San Joaquin River watershed. Locations within the San Joaquin River watershed with the highest frequency of indicator events are in southern Merced County, northern Stanislaus, and central San Joaquin County.

Urban areas in the Bay Delta watershed, Sacramento County and in Shasta County also have a high number of indicator days. This high number is primarily caused by a low calculated water volume in those regions. This in turn resulted in higher mass per unit water and therefore a higher concentration. In addition, the toxicity benchmarks for urban pesticides were among the lowest of the pesticides considered in this study. All these factors combined contribute to a higher number of indicator days,

Although overall number of indicator map provides an overview of potential locations, where these occur, it does not provide a temporal aspect. Figure 34 shows for randomly selected PLSS sections the fraction of indicator days by month. From this figure can be deduced that the number of indicator days is highly variable by location and by month. The decrease in the number of indicator days in the months of July and October is likely due harvest of the crops in that time period. Pesticides are likely used in limited quantities during this period.

A frequency distribution for all calculated fractions the indicator days (by month) for the period 2000–2009 shows a tri-modal pattern (Figure 35). Overall the distribution appears to follow a log-normal curve but at roughly 0.15 and 0.5 additional peaks are present. The multi-modal pattern also is visible in the cumulative distribution curve. This multi-modal pattern is most likely caused by the urban applications, specifically those modeling runs in which impervious surfaces (sidewalks, driveways) are irrigated and contribute to additional mass loadings in nearby surface water bodies. Using the distribution curve, 10th, 20th , .., 90th and 100th (maximum) percentile fraction were determined (Table 21). The 80th percentile represents those months (and sections) where half of the time an indicator event took place. The 90th percentile is slightly higher at 0.589 and the maximum is 0.994. The latter indicates that there are a few instances (sections and months) in which nearly every day is an indicator day. Thus nearly daily a pesticide concentration may cause a toxic event. The PLSS section with the highest fraction of indicator days is located in Stanislaus County and was calculated for the month of July.

The spatial-temporal trend of the percentile-level for the indicator days is depicted in Figure 36 to Figure 47. Analysis of the figures shows that from January (Figure 36) to August (Figure 43) the percentile level increase in the agricultural areas along the San Joaquin River, Sacramento River and south section of the Bay-Delta Watershed. From September (Figure 44) to December (Figure 47) the percentile levels decrease in these agricultural areas. The highest and most numerous number of indicator days were predicted to be in the San Joaquin River Watershed in June through August. In these months a majority of the agricultural areas fall in the upper percentile range (90^{th}–100^{th} percentile).

In urban areas and the central and northern part of the Bay-Delta watershed, the trend (higher number of indicator days in the summer) appears to be the opposite. Higher percentile levels were calculated in the winter and early spring season, than they decrease during the summer months (Figure 41, Figure 42, Figure 43, and Figure 44) and increase again in the fall and early winter (Figure 45, Figure 46, and Figure 47).

Another discernable trend was detected in the rice production regions, specifically in the Sacramento River watershed. From February (Figure 37) to April (Figure 39) and July (Figure 42) through September (Figure 44), various regions in the Sacramento River watershed have a low number of indicator days (low percentile levels). These areas coincide with rice production regions. Slightly elevated percentile levels have been calculated for the period October to December (Figure 45, Figure 46, and Figure 47). This is due to pesticide being discharged and runoff from bare rice paddies. During the rice growing season, rice paddies generate fewer indicator days compared to surrounding regions as is shown for the month of July (Figure 42).

3.4 Species Distribution and Richness

Another intermediate step in determining co-occurrence of pesticides and SOCs in the study area was the assessment of the spatial-temporal distribution of the species presence and species richness. The species distribution provides information as to where the SOCs are present in the study area and the richness is an indicator of the likeness that species are to occurrence in a given river segment in a PLSS section on a monthly basis.

The species distribution range for each of the nine species, including four salmon runs, is shown in Figure 48 to Figure 59, specifically:

1. Chinook Salmon (*Oncorhynchus tshawytscha*)
    - Sacramento River winter-run: Figure 48

- Central Valley spring-run: Figure 49
- Central Valley fall run: Figure 50
- Central Valley late fall run: Figure 51

2. Central Valley steelhead (*Oncorhynchus mykiss*): Figure 52
3. Southern North American Green Sturgeon (*Acipenser medirostris*): Figure 53
4. Delta Smelt (*Hypomesus transpacificus*): Figure 54
5. Striped Bass (*Morone saxatilis*): Figure 55
6. San Francisco Longfin Smelt (*Spirinchus thaleichthys*): Figure 56
7. Threadfin Shad (*Dorosoma petenense*): Figure 57
8. California Red-legged Frog (*Rana draytonii*): Figure 58
9. California Freshwater Shrimp (*Syncaris pacifica*): Figure 59

For most species, the distribution is limited by presence of partial and full barriers that prohibit movement of aquatic species further upstream. As such, many species are not present in the streams at higher elevation but are limited to streams within the traditional agricultural areas in the Central Valley and the lower elevations in the mountains.

Although the species distribution (or range) maps indicate where the species is present, it does not provide information as to when the species is present. For example, the Delta Smelt life-cycle (Figure 19) suggests, this species is present in the study area year around and its relative abundance does not change throughout the year. The species range map (Figure 54) shows that the Delta Smelt is primarily found in the Delta region. However, recent research indicates that the Delta Smelt also has been found in the Sacramento Slough and the Sacramento Deep Water Channel (V. Conner, SFWCA, personal communication, March 2011). This is both outside its traditional range and outside the established critical habitat data (USFWS, 2011).

Temporal aspects of species distribution are strongly reflected in the fall run of the Central Valley Chinook. The life-cycle (Figure 15) suggested that this species present in high abundance from late October until December and again from Mid February until Mid May. From late July through August the abundance is at its lowest. The Chinook is primarily found in the larger streams (Figure 50); however, this species will populate smaller streams if they can be reached (B. Rook-Cramer Fish Sciences, Personal communication, March 2011). The range of the Chinook salmon is generally speaking in the entire study area but limit to those reaches that do not have full barriers that prohibit movement further upstream.

The California Red-legged Frog life-cycle (Figure 23) suggested this species is present year around in the designated critical habitats. Unlike the other species considered in this assessment, the frog primary habitat it not in the main streams and rivers of the study areas. The Red-legged Frog occurs in vast areas of the Bay-Delta Watershed and small pockets in the Sacramento River and San Joaquin watersheds.

The distribution range of the California Freshwater Shrimp (Figure 59) is very limited. This species is found in a few streams in Sonoma and Napa County. The life-cycle (Figure 24) indicates that the Freshwater Shrimp is present all year in these streams.

The frequency distribution of the species richness (Figure 60) depicts that in most PLSS sections and month 30 (0.3) to 50 (0.5) percent of the species are present. Only a limited number of areas more than half of the species are expected to be present in any given PLSS section and month.

Because the frequency distribution of the species richness is dominated by the 0.3 to 0.5 range, the calculated percentiles (Table 22) show little variation. For examples 10^{th} to 30^{th} percentile are 0.250 and the 40^{th} to 80^{th} percentiles are 0.333. The maximum (100^{th} percentile) species richness percentile value is 0.917. This indicates that no area has all 12 species present. This is due to the fact the California Red-legged Frog is not found in the Bay-Delta Estuary and the California Freshwater Shrimp has a very limited distribution.

A series of maps depicts the monthly calculated species richness for January (Figure 61) through December (Figure 72). From January (Figure 61) to July (Figure 67) there appears to be little temporal variability in the species richness. In these months the highest species richness occurs in the Bay-Delta Estuary and the Sacramento River. The Southern part of the San Joaquin River surprisingly lacks species richness throughout the months. A few other areas are low in species richness as well but those are critical habitat for the California Red-legged Frog. In the period from August (Figure 68) to December (Figure 72), the species richness fluctuates. For example in August in great parts of the study region the species richness decreases, except for the Bay-Delta Estuary. From September (Figure 69) through October (Figure 70) the species richness increases followed by another decrease in November (Figure 71). November appears to be the month with overall the lowest species richness.

3.5 Co-Occurrence Assessment

In the previous two sections the “input” data for the Co-Occurrence Matrix has been presented in terms of spatial-temporal distribution of percentiles. As was described in Section 2.8 the Holmes co-occurrence uses a relative ranking based on percentile distributions. The higher the individual percentile level, the higher the likelihood of co-occurrence. However for co-occurrence to transpire, both the species and the indicator day coincide in time and space. If one or the other is not present, no co-occurrence is feasible.

In this assessment, 14,474 PLSS sections were determined to have at least a single pesticide application and for 15,415 PLSS sections the species richness was calculated. When these two datasets are combined (overlapped) only 6,741 (46.6%) PLSS sections have both a value for indicator days and species richness. As such any subsequent figures showing the co-occurrence should be interpreted with care because:

- Only PLSS sections with both a SOC present and a predicted exposure value above a benchmark are considered,
- For only a limited number of PLSS sections the SOC distribution is known, and
- The SOC distribution is primarily limited to the higher order streams and species presence in smaller streams is not included in the distribution map and richness maps.

Although the Holmes co-occurrence can be used for many different types of assessment, as part of this effort, the co-occurrence was determined for two example case studies:

> Case 1--Worst case scenario. In this scenario regions in the study area where both the indicator days and species richness exceeds the 90th percentile were determined. The 90th percentile was used because this is often used in risk assessments as an indicator for worst case. Using the Holmes co-occurrence matrix approach the 90th percentile is 0.5 and 0.589 for species richness and indicator days, respectively.
>
> Case 2—Average scenario. In this scenario regions in the study area where both the indicator days and species richness exceeded the 50th percentile were determined. The 50th percentile for indicator days was 0.206 and for species richness it was 0.333. However, 0.333 essentially represents the 40th to 80th percentile range for the species richness (Table 22).

3.5.1 Case 1—Worst Case Scenario

To demonstrate the utility of the co-occurrence approach first the regions with the 90th percentile indicator days were determined. Many areas that fall within the 90th percentile group are scattered predominantly throughout the San Joaquin River Watershed and to a lesser degree the Sacramento River Watershed (Figure 73). The figure depicts all areas irrespective of the month. The 90th percentile species richness (Figure 74) indicates that the Bay-Delta Estuary and the Sacramento Rivers are the areas with the highest species numbers. When both maps are combined into a single map (Figure 75) areas that have both the 90th percentile levels are found in San Joaquin County and a few scatters PLSS sections mainly in Solano, Sacramento, and Yolo County. This indicates that very few area (82 PLSS sections) comply with the criteria set for the worst case scenario. A temporal analysis showed that in the period from March to August PLSS sections fall within the 90th percentile range. May has the largest number of PLSS section (35) that complies with the set criteria. In the other months (January–February and September–December), no sections adhere to the criteria for the worst case scenario.

3.5.2 Case 2--Average Scenario

In this second case study or co-occurrence assessment, regions adhering to the 50th percentile levels for indicator days and species richness were determined. The results shown in Figure 76 indicate that throughout the year many areas adhere to the set criteria for the 50th percentile case. Areas include urban regions (Bay-Delta Watershed), Bay-Delta estuary, sections of the

Sacramento and Feather River, and large areas in Tehama County. However on a monthly time-step areas that adhere to the set criteria vary widely and appear to follow the indicator day trend (section 3.3). From January (Figure 77) to April (Figure 80) 50th percentile regions are found in the urban areas of the Bay-Delta Watershed, Sacramento, northern part of the Bay-Delta Estuary and regions in Shasta County. Scattered throughout the study area various individual or small clusters of PLSS sections can be found as well. In April, the initial effects of agricultural activities become visible along the San Joaquin River. From May (Figure 81) through July (Figure 83) 50th percentile areas are found along the main rivers and streams in the Study area. From August (Figure 84) through November (Figure 87) the 50th percentile areas are decreasing. In November only a handful (5) sections were determined to have co-occurrence of indicator days and species richness at the 50th percentile level. In December (Figure 88) the number of PLSS sections adhering the set criteria for the case study once again increase and follow a pattern that is similar to January to March.

3.6 Water Quality Monitoring Data

The state of California is actively monitoring for numerous pesticides in surface water. Using available public data from e.g. USGS NAWQA, DPR’s, and the State Water Quality Control Boards, surface water monitoring data and data collection by Bay-Delta Science Partners, monitoring data for 32 of the 40 pesticides was collected for the period 2000–2009. The developed dataset is by no means complete, but still contains over 30,000 records for 250+ monitoring locations. Water quality monitoring data is included in this project to provide weighted evidence for determining potential locations of areas of concern.

Monitoring station locations in the study area are depicted in Figure 89. Although there are over 250 monitoring location in the study area, some areas are sparsely represented. For example, sections along the Sacramento River in Glenn and Colusa County and along the northern reaches of the Feather River. The Delta Region in San Joaquin and Contra Costa County has a dense monitoring network. The northern part of the Delta in Sacramento County has very few monitoring stations.

Monitoring stations with the highest number of collected samples are location along the American River in Sacramento County, along the San Joaquin River in Stanislaus County, and in the southern section of San Joaquin County (Figure 89).

When observed concentrations are compared to the T&ES acute ecotoxicological threshold (Figure 90) the number of reported concentrations above the set benchmarks ranged from 52 to 188 and 185 monitoring locations have observed concentrations that at least once exceeded the set threshold for T&ES.

The percentage of samples that exceed the T&ES benchmark shows a different story (Figure 91). In most cases less than 20% of the collected samples exceed the benchmark. This indicates that in most instances only a few pesticide mass loading events results in a surface water concentration that exceeded the set toxicity threshold. Only in Stanislaus County more frequent exceedances occurred. The one location Stanislaus County that falls in the highest category (41.3%-100%) of exceeding a T&ES benchmark is based on a single sample.

3.7 Potential Areas of Concern

3.7.1 Definition

A potential area of concern is a region in the study area that adheres to one or both of the following criteria:

- Species of concern (SOC) are likely to present when indicator events are predicted to occur, and/or
- Species of concern (SOC) are likely to present when monitoring data indicate environmental concentrations have exceeded toxicological benchmarks and/or,

Other criteria, including loss of habitat, indirect effects, and other such stressors are beyond the scope of this initial investigation.

3.7.2 Assessment

Uncertainty is associated with each component of the criteria for identifying potential areas of concern including: 1) knowledge of species temporal and spatial presence, 2) the ability to accurately predict the occurrence of indicator events, and 3) the adequacy of sufficient of monitoring data. As a result, weight-of-evidence is necessary to reliably identify or dismiss a geographical area, or period of the year, as being a potential concern. That is, if indicator events are not predicted to occur and monitoring data is sufficiently robust to confirm this, the level of concern in an area can be perceived as low. However, if frequent co-occurrences transpire, and the analytical results from monitoring data report concentrations above a benchmark, the level of concern for an area can be perceived as increased.

A starting potential point for identifying the areas of highest potential concern is the map showing sections exceeding the 90th percentile co-occurrence for the study area (Figure 75). Potential areas of concern are scattered along the main branch of the Sacramento River, a few along the Feather River, the northern part of the Delta region (Southwestern Sacramento County), and the southern part of the Delta in San Joaquin County. Also a few small clusters of high co-occurrence values are found along stream west of the Sacramento Deep water Canal.

However, relying on just the 90th percentile areas of the co-occurrence alone without including known monitoring locations may result in an incomplete picture. If monitoring is conducted downstream of these regions, sufficient information may be available to determine if no additional research needs to be conducted at these locations. Figure 92 shows the known monitoring location in conjunction with the worst case scenario locations and a close up of the Bay-Delta Estuary region is depicted in Figure 93. Figure 92 and Figure 93 show that in close proximity and along the main branches of the Sacramento and San Joaquin River no monitoring stations appear to be present. Monitoring sites are located within the ditch and lower stream order network within the agricultural areas but not along the main rivers. As such any of the worst case areas could be suitable candidates for additional research especially when considered that for several of the monitoring locations at least 10% of the samples exceeded the set toxicity thresholds for aquatic organism.

A slightly less conservative approach to determine potential areas of concern is to determine the 80th percentile co-occurrence areas. In this case, PLSS sections within the study area exceed the 80th percentile values for indicator days (0.589) and species richness (0.333). Regions that adhere to the 80th percentile criteria are scattered along the “outskirts” of the agricultural areas in the Sacramento River and San Joaquin River watersheds and within the Delta Estuary (Figure 94). A few sections can also be found in Sonoma, and Napa Counties. At this level, differences between sites with “high” co-occurrence and presence/absence of monitoring stations become more prominent, especially in the Northern Bay-Delta Watershed and the Sacramento Watershed. Figure 94 also indicates that most co-occurrence areas are located outside the agricultural areas with a dense drainage network. Many PLSS sections in close proximity to e.g. the Sacramento River were not identified as potential areas of concern. The primary reason for this is that the species data did not include lower order streams and the large ditch/canals in the agricultural area. In the wet season, these water bodies can be used by the SOCs as habitat, even if this occurs during the rearing season. At the same time, the use of the PLSS section as the unit of analysis is a limitation. The main limitations include not being able to route pesticides downstream and account for a large water volume in which the pesticide can mix and degrade during transport.

In order to provided a more comprehensive assessment of the potential areas of concern, based on the 80th percentile regions, additional information such as number of samples, percentage of samples exceeding the T&ES benchmark, and number of chemicals sampled by monitoring location must be taken into account (Figure 95). Using combinations of the co-occurrence regions with the number of pesticides samples at each monitoring location or with the percentage of samples exceeding the T&ES ecotoxicological benchmark the following can be determined:

a) Do areas with high co-occurrence coincide with monitoring locations with frequent events above the benchmark exist?
b) Is sufficient (correct chemicals and frequent periodic samples) sampling conducted in areas with high co-occurrence?
c) Do areas exists with a high co-occurrence score but no or limited sampling data are available? and

d) Do areas exist with high-co-occurrence scores and few benchmark exceedances in the monitoring data but a large number of samples?

An assessment of Figure 95 shows that there are several regions in the study area where high co-occurrence has been determined, but no monitoring stations are present. These regions include:

- Bay-Delta Watershed
    - Sonoma Creek (Sonoma County)
    - Napa River (Napa County)
    - Ledgewood Creek (Solano County)
- Sacramento River Watershed
    - Southern Colusa Basin Drainage Canal south of Sand Creek(Western Colusa County)
    - Willow Creek (Western Colusa and Glenn County)
    - Thomas Creek and Elder Creek (Tehama County)
    - Kusal Slough and nearby creeks (Butte County)
    - Butte Creek (south of Durham Slough) (Butte County)
    - North Honcut Creek (Butte County)
- San Joaquin River Watershed
    - Cosumnes River/Dry Creek/Mokelmne River confluence area (Sacramento County)
    - Southern Delta Estuary (San Joaquin County)

The above listed locations could be considered as the obvious regions for further research and study. Due to the scattered nature of the co-occurrence locations, which in turn is partly caused by lack of species richness data in the smaller streams, additional sites may exist.

Although the San Joaquin River Watershed has many areas that fall within the 80th percentile regions, ample monitoring stations are present. These monitoring station collected information for 10–23 of the 40 monitored chemicals, they collected a large number of samples and they have detected concentrations exceeding the set toxicity benchmark. In the Sacramento River Watershed, fewer monitoring locations are present, but a larger number of pesticides have been sampled at most locations.

Several regions in the study area have monitoring stations, but sample infrequently (low number of samples) or only for a few pesticides. These regions include:

- Sacramento River Watershed
    - Burch Creek (Tehama County)
    - Feather River (Yuba County)
- San Joaquin River Watershed
    - North Side Canal spill to Merced River (Merced County)

- Bay-Delta Watershed
    - Suisin Creek Region (Solano County)

It is feasible that additional monitoring stations exit within the study area but these stations did not collected data for any of the 40 pesticides considered in this study. As such these stations were not included in the assessment.

The 80th percentile regions are an “arbitrary” level. Different level of concern could have been used in the assessment. The 80th percentile level for the species richness represents the same fraction as the 40th percentile. Therefore any co-occurrence assessment between the 40th and 80th percentile are driven by the indicator days. It is obvious that at the 40th percentile level for indicator days (fraction is 0.153) more areas would be included as “potential” areas of concern (Figure 96).

In the previous assessments, no attempted was made to provide a relative ranking of areas of co-occurrence using the composite matrix scores. An example of the relative ranking of potential areas of concern in provided in Figure 97. This figure depicts the maximum co-occurrence score for each PLSS section. Any area for which the score either starts with a zero (0) or ends with a zero (0), except areas classified as 1010, do not have co-occurrence. Either the species or the indicator days are not present. The results indicate that in this area,

- Many areas do not have a co-occurrence. This is due to a lack of species richness based on the composite score.
- The co-occurrence is driven by the species richness. The composite score is 9x–10x where x = 1–10.

Using the embedded color matrix, areas can be quickly ranked and areas of greatest potential concern can be visually identified.

Using the co-occurrence matrix, but excluding the species richness data, the 90th percentile area within, for example Delta Smelt Critical Habitat can be determined. The figure depicts that the 90th percentiles (for all months) are primarily clustered in the southern section of the Delta Estuary and a few regions in the northern section in Sacramento Country. Areas in Sacramento County appear to be lacking monitoring stations and therefore could be considered locations for additional studies.

3.8 Uncertainty

Uncertainty is inherent in any risk assessment due to limitations in fully understanding the complex physical, chemical, and biological system under investigation. Typical sources of uncertainty include lack of data, generalization of input data, and the ability to mimic the natural world with models. Because of the large scale nature of this project, datasets of various scales, accuracy, and precision were merged, and many assumptions were needed to address discrepancies and to compensate for missing information. These assumptions introduced uncertainty into the risk assessment and co-occurrence analysis. In this section of the report some of the critical sources of uncertainty and the impact on the analysis are discussed.

3.8.1 Land use information

Although the FMMP agricultural land use datasets are spatially detailed and provide a temporal aspect to the project, this data set was not available for all counties in the study area (Figure 98 and Figure 99). As a result some pesticide loading data was not included in the final co-occurrence analysis. Specifically data for Calaveras and Tuolumne County in the San Joaquin River watershed were lacking. In the Sacramento River watershed parts of Lassen, Plumas and Sierra County were not mapped. These regions typically represent areas with marginal agriculture. The impact for the project is limited. Since mass loadings in these regions are not being routed downstream, no hotspots are determined.

A second impact of using the FMMP layer is that in some sections, a pesticide application occurred in the past but that is was on such a small area (<10 acres) that the area was not mapped as agriculture in the state. As such these applications may have inadvertently been omitted from analysis and did not contribute to co-occurrence assessment. It was determined that 353 PLSS sections in which a PUR application was documented were affected in this manner. The determined was made by linking the pesticide master run table back to PLSS sections which contained the fraction of land use for each PLSS section for 2000–2008.

Other land use datasets such as the National Land Cover (NLCD), Cropland Data Layer (CDL) and Gap Analysis Program (GAP) were considered. The NCLD 2001 (2006 became available early 2011) was considered too old and did not represent more recent land use practices. The CDL and the GAP datasets were considered but only a single year was presented. Because it was desired to represent temporal changes in the landscape, these datasets were not used.

3.8.2 Soils information

Although the combined SSURGO and STATSGO soils database were screened for soils profiles that were likely to cause issues when used in the environmental-fate models. Any soil profile lacking information (such as organic matter, sand or silt percentage) was removed from the master soil profile dataset. These profiles would result in a model run that would not generate pesticide masses. In addition1275 soil profile (24.7% of all soil profiles) were flagged because the properties would result in a crashed model run. These 1275 soil profiles, affected 5,997 model runs or 0.15% of the total number of model runs, but are also impacted 6 PLSS sections severely. For six sections no runs were conducted at all because the soils were not suitable for modeling.

The SSURGO dataset for the State of California was incomplete. Calaveras and Tuolumne County are not part of the digital database. Therefore, soils data from the STATSGO database was used to gap fill SSURGO.

3.8.3 Pesticide application location

California's PUR database is considered the authoritative source of pesticides applications in the State. Pesticide applications are reported at two levels in the PUR system. Agricultural applications are reported at the PLSS section level and non-agricultural applications are reported at the county level.

Although the reporting level of the PUR for agricultural applications is at the PLSS section level it is still unknown where in this roughly 640 acres area the application occurred. A single application on, e.g., 50 acres treated could be anywhere in the section. It could be close to a water (thus higher drift loadings can be expected), or it could be farther away from the water body (thus lower or no drift loading can be expected). The overall effects of the unknown location of the application are unknown and were not quantified in this study.

At the county-level, the assumption was made that a given application had an equal chance of occurring anywhere in the county. This resulted in distributing the known county-level applications with a weighted-area approach to each of the PLSS section with urban areas. The weight depended on the total area of urban in the section, the greater the urban area, the greater the weight. The weighting factor was expressed as the fraction of urban in the PLSS section. This variable ranged from 0–1. It is unlikely that pesticide applications are equally distributed in the urban landscape. More likely is it that certain regions in the county have more use than others. As such, potential urban areas with higher pesticide loadings were smoothed out in the process.

In addition to not knowing the exact location of the application, it was also assume that fields were directly adjacent to streams. As such presence of any best management practice, such as vegetative filter strip, buffers, etc. were not accounted for in this assessment. Therefore the presented estimates are conservative. Additionally the applications did not following label requirements for each pesticide. For example if a label requires an offset of 80 ft from a surface water body, this information was not taken into account.

3.8.4 Pesticide properties

Environmental fate properties used in the model simulations were obtained from several sources. A decision matrix was developed in the proposal stage of this study in which the USDA Pesticide Property Database (USDA PPD) would be the primary database for input parameter selection based on being an established compilation of environmental fate properties for pesticides plus having a peer-reviewed process for chemical property selection. The European FOOTPRINT database was selected as a secondary source for the same reason. Data collection from other data sources was originally limited to situations when significant gaps were identified in the USDA and FOOTPRINT sources because the effort required to collect and review this information was outside of the project scope and budget.

The resulting chemical properties selected for modeling resulted in a number of data gaps as shown in Table 4. The majority of the missing values are related to soil photolysis and aquatic processes. Soil photolysis, foliar degradation, and volatilization were not represented in the PRZM simulations. Volatilization was not represented in the RICEWQ simulations. Rules were used to estimate certain properties when values were missing. Aerobic aquatic metabolism half-lives, when missing, were assumed to equal twice the value for soil metabolism. Anaerobic aquatic half-lives were used to represent pesticide degradation in rice paddy sediment. Missing values were assumed to equal twice the value of aerobic aquatic metabolism, if available, or four times the value for aerobic soil metabolism if aerobic aquatic metabolism values were missing. Processes were assumed to be stable for other properties missing values in Table 4.

Chemical behavior is often governed by the properties of the surrounding environment, including temperature, soil moisture, pH, and other biological and physicochemical influences on degradation and partitioning. Degradation rate constants did not reflect these influences, which may over estimate, and in some cases under estimate chemical persistence.

Model coefficients for pesticide washoff from hard surfaces were based on three washoff studies. Research in this area is new and the three studies were conducted under different protocols. The ability of these studies to reasonably mimic rainfall- or irrigation-induced runoff is unknown.

3.8.5 Furrow Irrigation

It was assumed that a single crop had 100% furrow irrigation. The CDWR study indicated that this is actually less and various regions in the study area may be dominated by micro-drip and micro sprinklers instead of furrow irrigation. The latter irrigation methods would result in a decrease of the predicted runoff mass loadings.

The assumption that furrow make up 50% of the field, was very conservative. It is likely that this caused the higher runoff and erosion contribution than expected.

Furrow irrigation is one if furrow irrigation is the predominant irrigation method for the crop, all model simulations for that crop were represented as furrow irrigation; 2) the irrigation routine was configured to generate 20% loss of applied water as tailwater; 3) 50% of the field was assumed to be furrow.

3.8.6 Toxicity benchmarks

There are inherent uncertainties when using standardized test data for an assessment designed to be protective of all species. The limited number of species used in testing is not inclusive of all species that may be exposed. Species-to-species differences in sensitivity and the low number of species tested may or may not capture the true range of toxicity (e.g., may not capture the most sensitive species). This analysis used the test species required under EPA OPP's registration process rather than test species commonly tested for the Clean Water Act (CWA) program. For example, OPP Environmental Fate and Effects Division (EFED) program for invertebrate species requires *Daphnia magma* rather than *Ceriodaphnia dubia* or *Hylalella azteca* which are often found to be more sensitive (generate lower toxicity values). So, future work could involve using CWA's final criteria continuous concentration (chronic criteria) and criteria maximum concentration (acute criteria) for evaluation of pesticides above these criterion values for future evaluations. For instance, in the development of T&ES aquatic benchmark criteria, the lowest toxicity value is corrected based on a specified level of concern to be more protective. The methodology for calculating the proposed reference values is meant to provide a starting point for discussion of the most appropriate method for determining these values. The questions and discussion will hopefully be mostly centered on the best way to determine acute reference values for threatened and endangered species. Currently, the methodology follows the general procedure used by the USEPA OPP in their risk assessment process for crop protection products. The proposed threatened and endangered species acute values presented are typically at $1/20^{th}$ of the lowest EC50, which is the standard level of concern for endangered species in the EFED risk assessment. This works well for those chemicals for which the aquatic benchmark values were used. There is also room for discussion of the applicability of the chronic reference values. According to the USEPA OPP EFED procedure, no extrapolation factors are applied to standard or threatened and endangered species risk assessment levels of concern for chronic assessments.

3.8.7 Species distributions

The species range and abundance maps in used in this study included only the major rivers and streams in the area. Some small streams that would be considered ephemeral or intermittent were omitted. Increasing the stream network resolution would add more of these ephemeral or intermittent steams. This creates a dilemma, since in a wet year, it is realistic to assume that if a species is present in the main stream that it would also be present in smaller streams (with the species-specific caveats below), whereas in a dry water year, it is unlikely that that this assumption is realistic. Given this, and because of the fact that there are no good reach descriptions saying what is/isn't ephemeral or intermittent for some of the smaller streams, the provided species ranges assumed a wet water year.

Spring-Run Chinook. It was assumed that this species is present in connected streams within the general range outlined in the delta on the distribution map. Once you get away from the delta, the species is really limited to larger rivers until it reaches spawning rivers upstream (i.e., limit to larger rivers like the Napa and Sacramento–once you get to upper Sacramento tributaries where the species is present, these tributaries are used for spawning and the distribution can be considered all connected streams).

Fall-Run Chinook. This species is basically everywhere; therefore, it was assumed that it is present in connected streams within the general range outlined on the distribution map.

Late Fall-Run Chinook. It was assumed that this species is present in connected streams within the general range outlined in the delta on the distribution map. Once you get away from the delta, the species is really limited to larger rivers until it reaches spawning rivers upstream (i.e., limit to larger rivers like the Napa, Sacramento, Feather, and Yuba until you get to the extreme upstream reaches–in some of the other upper Sacramento tributaries where the species is present, these tributaries are used for spawning and the distribution can be considered all connected streams).

Winter-Run Chinook. Assume that this species is present in connected streams within the general range outlined in the delta on the distribution map. Once you get away from the delta, the species is really limited to larger rivers until it reaches spawning and rearing rivers upstream (i.e., limit to larger rivers like the Napa and Sacramento–once you get to upper Sacramento tributaries where the species is present, these tributaries are used for spawning or rearing and the distribution can be considered all connected streams).

Delta smelt. It was assumed that this species is present in connected streams within the general range outlined in the delta on the distribution map. Once you get away from the delta, the species is really limited to larger rivers (i.e., only main portion of Napa, Sacramento, Mokelumne, and San Joaquin once you get out of the delta).

Freshwater Shrimp. This species is only present in the reaches outlined on the distribution map. Do not make any assumptions about presence/absence in connected streams.

Green Sturgeon. Assume that this species is present in connected streams within the general range outlined in the delta on the distribution map. Once you get away from the delta, the species is really limited to larger rivers (i.e., only the main portion of Napa, Sacramento, Feather, and Yuba)

Longfin Smelt. Assume that this species is present in connected streams within the general range outlined in the delta on the distribution map. Limit distribution in Napa River area to mainstream Napa River.

Red-Legged Frog. Assume that this species is present in areas outlined as critical habitat and waters that fall within those areas.

Steelhead. This species is basically everywhere, so assume that this species is present in connected streams within the general range outlined on the distribution map.

Striped Bass. This species is basically everywhere; therefore it was assumed that this species is present in connected streams within the general range outlined on the distribution map.

Threadfin Shad. This species is basically everywhere; therefore, it was assumed that this species is present in connected streams within the general range outlined on the distribution map.

3.8.8 Hydrography

The study area at large is an extremely complex hydrodynamic system. In areas of low relief, water flow is governed by hydraulic gradients that do not always correspond with topography. The precise drainage in this type of system may never be known except perhaps at the very local level. In addition, a finer network of ditches and canals exists that couldn't be detailed within the scope of this study, which added uncertainty to several aspects of the study, including species presence, spray drift reception, chemical dilution, and the hydraulic transport of pesticide residues.

Estimating the water volume at the PLSS section was an uncertain effort in this study. Because water in California's Central Valley is so heavily managed using the common industry approach in which stream geometry is a function of drainage area was not feasible. Instead standardized stream geometry was used to estimate the water volume in each PLSS section. In addition, water volume contributions from rainfall events and irrigation runoff events were ignored. As a result the stream volume remained constant throughout the simulation period. However, this is not expected in the real-world. Using a fixed volume of water does have the advantage that the process to develop the stream geometry is transparent and can easily be reproduced by others. The main drawback is that it is not realistic. In the dry season the current water volume mostly is over estimated whereas in the wet season, the water volume is under estimated.

Although more detailed stream geometry and flow information is available this information was not readily available to the project team. Most of the information is currently available in paper format only. Over the course of 2011 this information will become available to users via the CA SWAMP program.

A significant limitation in this study was the inability to route chemical loads from the edge of field to downstream receiving waters. Therefore, concentration predictions were not calculated beyond the PLSS section. Concentrations were based on the loads estimated to occur on that day. Carryover residues from previous events were not considered.

Several hydrologic datasets exists (e.g. ESRI detailed rivers, USGS NHD and the USGS/EPA NHD+) that can be used to develop a river network to route pesticides downstream. The main issue is that many of these datasets are fairly detailed (even at the medium resolution). In order for datasets to be useful in the modeling effort, only the main tributaries should be considered, however, this may results in a lower water volume per PLSS section. At the same time, monitoring locations must be factored in. Not only locations that sample for water quality parameters but also those that contain river flow information. The latter is used to calibrate the models to historical flow data. This in turn ensures a realistic representation of the system. A potential simple approach would be to consider the monitoring locations to be the outlet for each catchment. The one drawback is that in selected areas, a dense monitoring network exists and thus small catchment areas will be associated with those monitoring locations. Once the river network has been developed, the catchment can be associated with the network. Aggregation of the NHD/NHD+ catchment is a suitable approach. Application of the CALWater 2.2 (REF) catchments in the study is not recommended because they are simply too large.

The final piece that needs to be resolved is the application location and its assignment to a catchment. Using GIS it is feasible to combine PLSS section and catchments and simply assign part of the PLSS section to one catchment and the other part(s) to other catchments. However this does not really resolve the underlying issue that the exact application location is still unknown. California's PUR database reports agricultural pesticide usage at the PLSS section level for agricultural uses, but the actual location within the section is still unknown. The simplest solution would be to determine to which catchment each PLSS section belongs. It provides a simplification and may route more pesticides down a river than actually occurs but is facilities that processing and mitigates the uncertainty of the application location within the PLSS section.

3.8.9 Urban Scenarios

Given the lack of detailed information on the spatial and temporal use of pyrethroids in urban/residential settings, this study relied on country-level PUR data for professional applicator use. The assignment of use site categories to structural, landscape maintenance, or other categories may not coincide with allocation fractions assumed for pervious and impervious areas.

The allocation of structural applications between building and ground were based on a single survey of professional applicators. A weighted average was calculated from the variable allocations reported in the survey. The ground portion was assumed to be equally proportioned to pervious and impervious areas.

Very little information exists on homeowner uses outside of limited sales information. As a result, homeowner use was assumed to be 25% of reported professional uses and consistent with professional uses with respect to allocation to pervious and impervious surfaces(Moran 2010).

Assumptions on the application location within the county were based on a single "urban" land use category from the FMMP. Other land use categories that provide a broader land use classification (e.g., NLCD) were initially tried, but they end result would have been an inappropriate application to road surfaces in rural areas. There was no way to identify specific application sites. Therefore, the county use estimates were allocated evenly to all urban areas in the county.

In reality, urban use sites are highly variable. For this study, USEPA-OPP's residential scenario (USEPA, 2009a; 2010c) was used as prototype for landscape applications. The scenario is an idealized representation of a ¼ acre single family lot with specific dimensions for sidewalks, driveways, and pervious areas. The scenarios assume that applications will result in a 3-ft overspray onto impervious areas, which is likely to be excessive for professional applicators and homeowners. Pervious areas in OPP's scenarios are assumed to have an organic carbon content of 35.6%.

Empirical data on pyrethroid washoff from hard surfaces has only recently started being available (Harbourt et al., 2009; Jiang et al., 2010; Jorgensen and Young; 2010). The procedures used for these studies are not identical. Not only were they affected by product formulation and washoff mechanisms, but the methods also created systematic differences among the measurements. This variation may affect the viability of comparing the modeled estimates of the pyrethroids, making comparison of results among pyrethroids invalid.

Concentrations were not predicted for a number of urban PLSS because hydrography data for those sections are not present in the NHD database.

3.8.10 Agronomic practices

Regional, year-to-year, and field-to-field differences in cropping dates (e.g., planting, growth cycle, and harvest), irrigation methods, or other agronomic practices were not represented in the scenarios. Standard configurations were used in the representation of dry land agricultural scenarios. The configurations were those established by USEPA-OPP for California conditions. Crops for which OPP has no scenarios were associated with the most representative scenario.

All pesticide applications were represented as direct applications to bare soil because the stage of crop predicted from the crop growth model in PRZM may not coincide with stage corresponding to the PUR application date. Bare soil results in a conservative estimate of pesticide runoff.

With the exception of those crops simulated as furrow irrigation, irrigation practices were those specified in OPP's scenarios. Furrow irrigation was simulated for crops that use that form of irrigation as the predominant irrigation method. All irrigation events simulated by furrow irrigation were designed to produce a conservative amount (20%) of applied water as tailwater runoff.

Pesticide loadings were also conservative in that management practices or other landscape features that reduce pesticide runoff to nontarget areas (e.g., infield practices, edge-of-field vegetative filters, drainage ditches) were not represented in the scenarios.

Rice scenarios were also represented by a standardized scenario, except that the calendar of operations varied between scenarios over a 14-day window and that pendimethlin applications were associated with dry seeded rice. Certain rice pesticides have a minimum holding requirement, including cypermethrin, lambda-cyhalothrin, propanil, malathion, and thiobencarb. Pesticide discharges for these chemicals may have been over estimated because scenarios were not checked to see if this condition was met.

3.8.11 Simulation models

Models are mathematical representations of complex physical, chemical, and biological processes. Areas of greatest uncertainty from a model setup standpoint, as discussed above, relate to the inability to accurately represent field-to-field variability in the calendar of operations, management practices, field-proximity to water, and pesticide residue conveyance beyond the field edge. Additional uncertainty resides in the ability of the models to accurately represent the interaction of physical, chemical, and biological processes. Algorithms in PRZM and RICEWQ vary in their level of sophistication and contain theoretical and empirical components. Model validation was not conducted as part of this study. However, both models have been verified against field studies (Capri and Miao, 2002; Christen et al., 2005, 2006; Chung et al., 2008; Ferrari et al., 2005; Infantino et al., 2008; Karpouzas et al, 2005a, 2005b; Karpouzas et al, 2006a, 2006b; Luo, 2011; Miao et al., 2003a, 2003b, 2004; Ngoc et al., 2008; Warren et al., 2004, Jones and Russell, 2001, Snyder et al., 2004, Suarez, 2005). The use of PRZM in simulated pyrethroid washoff from hard surfaces has not been tested beyond their use in calibrating the washoff coefficients from the studies by Harbourt et al. (2009), Jorgenson and Young (2010), and Jiang et al. (2010). The extent that models should be limited to providing relative differences between scenarios or providing accurate predictions of concentrations depend on the level of verification associated with it use for specific applications. The applications of the models for this study were not used to provide accurate predictions of pesticide concentrations, but to provide a relative ranking of areas in the study area to focus future research needs.

3.8.12 Monitoring Data

As part of this effort publicly available monitoring data was collected from several different online sources in the State of California and the USGS. Because each source stores the data in a different manner (e.g., different site name, reports non-detects differently) it is likely that some duplicate sites and duplicate records exist in the database that was used for the analysis. As such there is a potential that for a few sites the number of reported samples do not accurately reflect the true number. Duplication of sites and data can go either way in terms of reporting. If at the same site different chemicals were analyzed the total number of samples and chemicals analyzed it likely to be too low. If true duplicate data exist, the reported numbers are likely to high. Although every effort was undertaken to collected as much as possible readily available public monitoring data, it should be understood that additional information may be out in the public domain that was not included in this assessment. Data collected by private industry or academia is likely not included the developed dataset.

4.0 Conclusions

4.1 Conclusions

The main objective of this study was to quantify the potential spatial and temporal co-occurrence of pesticide residues and threatened and endangered species in the Sacramento River, San Joaquin River, and Bay-Delta estuary. To accomplish this goal, the study utilized simulation modeling, GIS, and monitoring data in a weight-of-evidence context to address the temporal and spatial co-occurrence of forty widely used herbicides, fungicides, and insecticides with twelve aquatic and semi-aquatic species. A co-occurrence matrix was developed to combine monthly species richness with the monthly distribution of pesticide exposure events (indicator days).

The ability to assess co-occurrence was found to be technically feasible in the majority of information needed to conduct the study was readily available from public sources. However, data gaps exist, especially at the local level, which limits the use of this study as a relative indicator of where co-occurrence may occur.

The co-occurrence method developed for this assessment is flexible and scalable and can be used to answer a variety of potential questions depending on the needs of the risk assessor. For example, the method can be applied to evaluate specific species, specific geographical areas, or specific classes.

Co-occurrence predictions do not mean that adverse effects will occur. The best use of this study is to identify and prioritize areas for additional analysis and study. Results can be used to identify and rank areas of highest potential risk, aid in placement of BMPs, and support current and future monitoring programs by strategic placement of sampling locations and frequency.

Approximately 14.2% of the applied pesticide mass was predicted to reach surface waters via runoff, erosion, discharge and drift. This is likely to be an overestimate because of the conservative assumptions used in the analysis. Roughly 86% of the mass losses were predicted to occur from agricultural runoff and irrigation tailwater. Approximately 4.3% of mass was estimated to be from rice paddy discharge. Erosion and spray drift contributed approximately 5.0% and 4.4 % of mass loadings, respectively. Less than 1% of mass loadings originated from urban areas. The urban analysis was limited to an evaluation of only four of the 40 pesticides included in the study. Additionally, evaluators need to consider even those contributions of low percentage are not indicative of a lesser emphasis importance to the system.

Areas with the highest species richness are the Delta Estuary and the Sacramento River. Up to 11 of the 12 species may be present in sections of this area. Due to limited ranges of the California Freshwater Shrimp, Delta Smelt and the California Red-legged Frog there was no single location in the study area where all species were present. It was not possible to anticipate and address in detail the range of questions surfacing from this assessment. As a result, preliminary conclusions were based on two generalized filters (90th percentile values for species richness and indicator days and 80th percentile values for species richness and indicator days).

Areas with very high co-occurrence (exceeding the 90th percentile values for species richness and indicator days) of pesticides in surface water and species richness are in the southern Delta Estuary in San Joaquin County, scattered small regions in the Northern Delta Estuary in Sacramento County, and in western Yolo County.

Areas with high co-occurrence (exceeding the 80th percentile values for species richness and indicator days) are present in clusters scattered on the outskirts of the main agricultural areas in the Sacramento River and San Joaquin River watersheds and in the northern section of the Bay-Delta watershed.

At least 11 areas identified as having high potential co-occurrence have not been monitored for the chemicals of interest. At least 4 areas in the study area should require additional monitoring.

4.2 Ancillary

In addition to the more science-based information, this project also developed a variety of datasets that could be used in other projects. Datasets include:

- GIS datasets containing land use, hydrology, climate, model results, monitoring results, and PLSS, boundaries. The land use dataset describes the temporal land use from 2000–2009 on an annual basis.

- A series of 12 species GIS datasets that describe on a monthly basis the presence and relative abundance of the 12 species of interest.

- Meteorological files for the Sacramento and San Joaquin river watersheds containing daily weather data from 2000–2009 for nineteen CIMIS weather stations.

- Daily mass loadings database based on PRZM output data containing the results for the historical application of 40 pesticides on all agricultural soils in the study area.

- Daily mass loadings database based on PRZM output data containing the results for the historical application of 4 pesticides on all urban areas in the study area.

- Water quality monitoring dataset for sampling locations within the watershed with publically available water quality data.

- Co-occurrence dataset that contains the monthly fractions of species richness and fractions of indicator days at the PLSS section level.

5.0 Recommendations

This study provides a foundation for a variety of risk assessment applications. Numerous follow-up activities can be performed to utilize the co-occurrence methodology, improve elements of uncertainty, conduct refined assessments, simulate "what-if" scenarios, and to expand the data platform to address additional species and water quality constituents.

5.1 Data Mining

- Source identification. Provide a more detailed review of areas of potential concern to identify the specific pesticides and loading mechanism behind the predicted indicator events. This information would help focus future studies, including refinement of model assumptions, evaluation of appropriate BMPs, and recommendations for future monitoring.

- Focused studies. Provide individual assessments for a particular chemical, species, or geographical area (e.g., Colusa Basin Drain).

- Graphical user interface. The queries performed for this study were conducted by GIS analysts. The development of a user interface would allow queries to be performed by scientists and risk-assessors that do not have extensive GIS training.

5.2 What-if Scenarios

- Mitigation assessment. Simulate regional implementation of label changes and best management practices (e.g., buffer zones) and predictions of pre- and post-implementation.

- Future trends. Simulate projected changes in climate or trends in pesticide uses (increases and/or reductions). For example, mass loadings associated with an increased use of pyrethroids or decreased use of organophosphate pesticides can be predicted by replacing PUR records with projected use rates and specifying the physicochemical properties of the alternative pesticide.

5.3 Monitoring Programs

The following recommendations are made to improve monitoring of pesticides in the Sacramento River, San Joaquin River and Bay-Delta watershed:

- Determine if additional datasets exist that contain information on the specific chemicals of interest.

- Existing monitoring programs should be modified to determine if the appropriate constituents are being sampled at the appropriate frequency and timing to evaluate water quality impacts and improvements to achieve the most effective use of resources. This may include reducing monitoring in certain locations.

- Sample list of pesticides that are currently not part of any of the monitoring programs. The data evaluated in this study produced no sample results for the following eight chemicals:

    - Abamectin
    - Copper (e.g., from copper hydroxide and/or copper sulfate)
    - Mancozeb
    - Maneb
    - Pyraclostrobin
    - Tralomethrin
    - Ziram

  Monitoring exists for copper ions in the study area, but it is difficult to assess whether detections are the result of agricultural uses of copper hydroxide or copper sulphate without identifying the location of other potential sources.

- Increase sampling for the number of pesticides in the following regions:

    - Sacramento River Watershed
        - Burch Creek (Tehama County)
        - Feather River (Yuba County)
    - San Joaquin River Watershed
        - North Side Canal spill to Merced River (Merced County)
    - Bay-Delta Watershed
        - Suisun Creek Region (Solano County)

- Implement new or additional monitoring stations in the following regions (Figure 100):

    - Bay-Delta Watershed
        - Sonoma Creek (Sonoma County)
        - Napa River (Napa County)
        - Ledgewood Creek (Solano County)
    - Sacramento River Watershed
        - Southern Colusa Basin Drainage Canal south of Sand Creek (Western Colusa County)

        - Willow Creek (Western Colusa and Glenn County)
        - Thomas Creek and Elder Creek (Tehama County)
        - Kusal Slough and nearby creeks (Butte County)
        - Butte Creek (south of Durham Slough) (Butte County)
        - North Honcut Creek (Butte County)
    - San Joaquin River Watershed
        - Cosumnes River/Dry Creek/Mokelumne River confluence area (Sacramento County)
        - Southern Delta Estuary (San Joaquin County)

- Begin monitoring for pesticides in Southern Sacramento County where high co-occurrences have been predicted. Currently, in this area no known monitoring is occurring.

5.4 Technical Refinements

This study revealed several data limitations that could be resolved to advance large-scale risk assessments in California's Central Valley. Although the recommendations are specifically for the study area, they also apply to other risk assessment studies as well. Data coverage and availability in general needs to be addressed, specifically:

- Hydrography. Very little information is available for smaller streams and ditches, and connectivity to other segments is incomplete where hydrography has been mapped. The development of a connected river network (and associated catchments) would allow species locations to be extrapolated into smaller segments, provide a more complete network for drift and dilution estimations, and allow routing models to be developed to estimate concentrations in a mass balance context within the PLSS and in downstream receiving waters.

  The catchments are a required element so that agricultural fields can be associated with a stream. The NHD+ river network and catchments could be used for this purpose but the catchments should be increased in size. Currently too many small catchments are present and PLSS sections map overlap with multiple catchments.

- Species Range Maps. Develop range maps for aquatic species (linear features) using a modern hydrologic dataset, e.g., NHD+ version 2 (to be released in the summer of 2011). The use of the older Digital Line Graphs files for this type of work should be abandoned. This also provided a much better integration with new government sanctioned hydrologic data.

Ideally, species ranges and abundance maps would include artificial paths (canal/ditches), and lower order streams throughout the Central Valley. Omitting the lower order streams resulted in significant data gaps during the co-occurrence analysis.

- PLSS Catchment. Assign PLSS sections in the Central Valley to a single (updated) NHD+ catchment. This would enable modelers to model historical and future pesticide application at the PLSS section level and properly assign them to a river segment or catchment for routine pesticides downstream.

- Farm Mapping and Monitoring Program. Include Calaveras and Tuolumne County in future updates of the dataset.

- Irrigation. The predominant irrigation practice for a specific crop was used for all simulations involving that crop. This may over or under estimate pesticide losses depending on the irrigation practice. A weighted distribution at the county level may results in more realistic predictions.

  The version of PRZM used in this study was re-coded to predict pesticide losses from furrow irrigation. This routine should be verified against field studies and further developed and be able to account for different furrow dimensions. Currently the model uses a 50/50 split between furrow and field and pre-set tailwater of 20% of applied water, but those parameters should become user-defined inputs. The method should also be calibrated against field data to see how well it performs.

- Urban Scenarios. Conduct additional washoff studies that better mimic formulation, application sites, and rainfall events. Provide a better characterization of use application sites for model scenarios. Verify predictive abilities by comparing model results to field datasets.

- Toxicity Benchmarks. Benchmarks could involve using Clean Water Act's final criteria continuous concentration (chronic criteria) and criteria maximum concentration (acute criteria) for evaluation of pesticides above these criterion values for future evaluations. For example, a copper specific toxicity endpoint maybe used to protect for salmonids. Due to the sensitivity of salmonid sensory systems, the ecological significance of their impairment, and the documented presence of elevated concentrations of dissolved copper in salmonid habitats, it may be necessary to evaluate with the species specific toxicity value rather than using OPP toxicity benchmark values to fully protect for salmonids.

- Chemical Properties. Provide a more rigorous review of chemical properties to represent omitted processes (e.g., foliar degradation and photolysis) and to consider chemical persistence to specific environmental conditions (e.g., soil pH).

5.5 Study Expansion

- Routing model. Indicator events were predicted at the PLSS layer. Existing watershed models have been developed for larger tributaries in the study area (Lou and Zhang, 2010, MacWilliams et al, 2008, Systech Water resources, 2010, USACE, 2011). These models can be used to estimate concentrations in the large channel systems by integrating models or other algorithms to connect and route through smaller tributaries.

- Metabolites and additive pesticides. Indicator events were estimated based on exposure to individual pesticides. Examining potential pesticide to pesticide and/or other chemical interactions and risk can be examined. Exposure to metabolites and pesticides of similar mode of action can be addressed.

- Indirect effects. Benchmarks were based on acute endpoints for the lowest fish or invertebrate. Inclusion of plant toxicity data can be used as an indicator of indirect effects on loss of prey or habitat refugia.

- Additional pesticides or water quality constituents. Additional datasets can be added to evaluate additional pesticides, nutrients, sediment, or chemicals (e.g., pharmaceuticals and personal care products).

- Additional species. Provide spatial and temporal distributions for additional threatened and endangered species.

Life cycle and population models. Ecosystem assessments can be evaluated by linking results to models currently under development for striped bass and delta smelt, as well as existing models for salmonids.

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6.0 TABLE SECTION

Table 1 Selected pesticides

ID	ChemName	CAS NUMBER	Type
1	(S)-Metolachlor	87392-12-9	Herbicide
2	Abamectin	71751-41-2	Insecticide
3	Bifenthrin	82657-04-3	Insecticide
4	Bromacil	314-40-9	Herbicide
5	Captan	133-06-2	Fungicide
6	Carbaryl	63-25-2	Insecticide
7	Chlorothalonil	1897-45-6	Fungicide
8	Chlorpyrifos	2921-88-2	Insecticide
9	Cyhalofop-Butyl	122008-85-9	Herbicide
10	Clomazone	81777-89-1	Herbicide
11	Copper Hydroxide	20427-59-2	Fungicide
12	Copper Sulfate	7758-98-7	Fungicide
13	Cyfluthrin	68359-37-5	Insecticide
14	Cypermethrin	52315-07-8	Insecticide
15	Deltamethrin	52918-63-5	Insecticide
16	Diazinon	333-41-5	Insecticide
17	Dimethoate	60-51-5	Insecticide
18	Diuron	330-54-1	Herbicide
19	Esfenvalerate	66230-04-4	Insecticide
20	Hexazinone	51235-04-2	Herbicide
21	Imidacloprid	105827-78-9	Insecticide
22	Indoxacarb	173584-44-6	Insecticide
23	Lambda-cyhalothrin	1465-08-6	Insecticide
24	Malathion	121-75-5	Insecticide
25	Mancozeb	8018-01-7	Fungicide
26	Maneb	12427-38-2	Fungicide
27	Methomyl	16752-77-5	Insecticide
28	Naled	300-76-5	Insecticide
29	Oxyfluorfen	42874-03-3	Herbicide
30	Paraquat Dichloride	1910-42-5	Herbicide
31	Pendimethalin	40487-42-1	Herbicide
32	Permethrin	52645-53-1	Insecticide
33	Propanil	709-98-8	Herbicide
34	Propargite	2312-35-8	Insecticide
35	Pyraclostrobin	175013-18-0	Fungicide
36	Simazine	122-34-9	Herbicide
37	Thiobencarb	28249-77-6	Herbicide
38	Tralomethrin	66841-25-6	Insecticide
39	Trifluralin	1582-09-8	Herbicide
40	Ziram	137-30-4	Fungicide

Table 2 Total Use (lbs) for the selected chemicals in CA for 2000-2008.

Chemical Name	2000	2001	2002	2003	2004	2005	2006	2007	2008
(S)-Cypermethrin	343	317	197	2,329	3,672	5,617	6,228	5,462	4,925
(S)-Metolachlor	57,713	83,583	127,187	134,543	169,340	176,679	195,425	204,969	169,082
Abamectin	0	0	0	0	2,135	3,014	3,773	4,471	5,579
Beta-Cyfluthrin	0	0	0	0	0	0	2	941	1,152
Bifenthrin	4,019	5,160	5,883	5,619	6,656	6,864	10,066	35,854	30,980
Bromacil	477	580	774	1,704	460	2,115	1,002	1,951	2,562
Bromacil, Lithium Salt	5	0	0	0	0	0	0	0	0
Captan	317,990	151,071	135,466	166,461	99,739	149,700	203,980	212,106	104,170
Captan, Other Related	7,308	3,472	3,246	3,974	2,306	3,484	4,927	5,031	2,445
Carbaryl	127,433	84,185	48,778	53,846	100,709	66,903	52,884	51,462	31,165
Chlorothalonil	170,208	109,712	179,414	172,029	173,970	249,235	362,474	305,265	216,472
Chlorpyrifos	399,498	341,082	343,785	417,269	484,841	545,856	527,740	478,821	399,108
Clomazone	0	0	550	33,766	49,625	39,199	61,363	79,676	80,899
Copper Hydroxide	1,913,310	1,341,087	1,412,603	1,661,579	1,182,946	1,763,210	1,455,318	1,357,148	876,149
Copper Sulfate (Anhydrous)	10	0	0	1	0	668	843	452	0
Copper Sulfate (Basic)	350,729	319,075	400,278	386,343	439,131	358,883	424,057	320,757	208,368
Copper Sulfate (Pentahydrate)	3,355,961	2,843,752	2,382,026	3,439,613	3,096,082	2,563,949	2,793,527	1,750,050	1,326,917
Cyfluthrin	1,939	3,367	3,445	3,911	4,108	3,431	2,861	1,534	1,635
Cyhalofop Butyl	0	5,490	8,453	26,412	58,768	25,001	32,765	36,796	27,336
Cypermethrin	545	701	527	442	905	1,382	565	565	350
Deltamethrin	50	15	16	1	15	21	2	109	53
Diazinon	205,460	147,484	166,463	153,966	153,246	105,367	101,005	80,823	62,443
Dimethoate	93,227	93,573	78,027	78,275	103,728	88,936	82,506	101,757	76,476
Diuron	240,682	171,591	225,169	261,342	275,455	194,718	251,280	167,735	125,076
Esfenvalerate	14,252	13,138	14,980	16,926	15,400	16,242	17,537	24,781	20,152
Gamma-Cyhalothrin	0	0	0	0	0	57	25	159	77

Table 2 Total Use (lbs) for the selected chemicals in CA for 2000-2008. (Cont.)

Chemical Name	2000	2001	2002	2003	2004	2005	2006	2007	2008
Hexazinone	60,354	63,866	74,113	86,346	84,333	67,908	82,109	54,648	80,438
Imidacloprid	9,872	10,870	13,563	8,819	9,758	12,223	11,930	16,422	23,014
Indoxacarb	197	4,332	4,689	11,812	5,572	13,127	16,094	8,905	18,215
Lambda-Cyhalothrin	21,516	10,716	44,050	8,371	11,590	12,627	12,787	13,942	16,880
Malathion	68,000	93,457	110,299	75,167	77,870	73,455	80,241	104,081	83,034
Mancozeb	162,747	105,038	80,156	124,831	87,953	169,758	214,938	113,274	78,671
Maneb	606,307	296,881	311,091	413,265	342,146	446,752	476,622	473,369	265,583
Methomyl	170,571	97,151	84,509	113,049	61,882	95,881	74,944	70,668	49,877
Metolachlor	60,272	9,799	817	1,267	1,796	874	1,359	1,893	9,419
Naled	37,687	38,301	25,620	25,381	16,018	27,607	27,701	21,966	9,401
Oxyfluorfen	186,055	136,086	154,822	194,574	258,123	252,159	297,937	291,888	270,904
Paraquat Dichloride	324,648	257,931	318,534	336,346	363,941	340,339	397,257	337,691	289,723
Pendimethalin	59,867	58,269	52,647	44,694	60,446	92,485	158,792	303,618	469,839
Permethrin	47,608	44,471	48,356	44,182	49,340	48,877	61,474	51,780	27,160
Propanil	1,359,223	1,420,598	1,469,944	1,382,787	1,691,663	1,418,100	1,497,168	1,856,207	1,723,223
Propargite	589,264	548,240	517,355	532,830	531,417	472,905	320,395	277,170	173,658
Pyraclostrobin	0	0	0	9,262	27,461	50,919	62,690	46,666	44,542
Simazine	227,104	171,599	200,621	219,159	216,827	161,775	172,193	141,810	103,882
Thiobencarb	1,006,585	644,762	844,331	585,546	521,556	448,182	310,346	289,032	254,797
Tralomethrin	19	17	1	0	1	0	0	0	0
Trifluralin	622,727	309,482	363,839	363,627	378,622	391,838	395,487	337,630	245,991
Ziram	510,951	453,670	489,469	543,681	390,547	532,665	715,524	502,026	320,065
TOTAL	13,392,733	10,493,974	10,746,093	12,145,347	11,612,098	11,500,991	11,980,138	10,543,362	8,331,883

Table 3 Reported use sites in the PUR database for the selected 40 chemicals.

Site Name	Site Name	Site Name	Site Name
Alfalfa	Clover	Citrus	Mint
Almond	Collard	Mushroom*	Mizuna
Animal Premise*	Commodity Fumigation*	Mushroom House*	Radish
Apple	Corn (Forage - Fodder)	Mushroom Soil*	Rangeland
Apricot	Corn, Grain	Mustard	Raspberry
Arrugula	Corn, Human Consumption	Nectarine	Recreation Area
Artichoke, Globe	Cotton	N-Grnhs Flower	Research Commodity*
Asian Pear	Cucumber	N-Grnhs Plants In Containers	Rice
Asparagus	Dandelion Green	N-Grnhs Transplants	Rice (Grain Crop)
Barley	Dill	N-Outdr Flower	Rice, Wild
Basil, Sweet	Ditch Bank	N-Outdr Plants In Containers	Rights Of Way
Bean, Dried	Eggplant	N-Outdr Transplants	Ryegrass
Bean, Succulent	Endive (Escarole)	Nuts	Safflower
Bean, Unspecified	Fennel	Oat	Shallot
Beet	Fig	Oat (Forage - Fodder)	Small Fruits/Berry
Blackberry	Forage Hay/Silage	Okra	Soil Fumigation/Preplant*
Blueberry	Forest, Timberland	Olive	Sorghum (Forage - Fodder)
Bok Choy	Gai Choy	Onion, Dry	Sorghum/Milo
Boysenberry	Gai Lon	Onion, Green	Soybean
Broccoli	Garbanzo Bean	Orange	Spinach
Brussels Sprout	Garlic	Orchard Floor	Squash
Buildings/Non-Ag Outdoor	Grain	Parsley	Squash, Summer
Cabbage	Granary	Pastureland	Squash, Winter
Cabbage, Savoy	Grape	Peach	Squash, Zucchini
Cantaloupe	Grape, Wine	Peanut	Stone Fruit
Carrot	Grapefruit	Pear	Storage Area/Box*
Cauliflower	Grass, Seed	Peas	Strawberry
Celeriac	Kale	Pecan	Structural Pest Control
Celery	Kiwi	Pepper, Fruiting	Sudangrass
Cherry	Kohlrabi	Pepper, Spice	Sugarbeet
Chestnut	Landscape Maintenance	Persimmon	Sunflower
Chicory	Leek	Pimento	Sweet Potato
Chinese Cabbage (Nappa)	Lemon	Pistachio	Swiss Chard
Chinese Greens	Lettuce, Head	Plum	Tangelo
Chive	Lettuce, Leaf	Pluot	Tangerine
Christmas Tree	Melon	Pome Fruit	Timothy
Tobacco	Turnip	Vegetables, Leafy	Water Area

Table 3 Reported use sites in the PUR database for the selected 40 chemicals. (Cont.)

Site Name	Site Name	Site Name	Site Name
Tomatillo	Uncultivated Ag	Vertebrate Control	Watercress
Tomato	Uncultivated Non-Ag	Turf/Sod	Watermelon
Tomato, Processing	Unknown*	Turkey*	Wheat
Pumpkin	Vegetable	Walnut	Wheat (Forage - Fodder)
Radicchio			

*PUR use site not included in the study

Table 4 Pesticide Properties

Chemical	Rice model	Urban	Pyrethroid	CAS Number	Molecular weight (g/mol)	Source	Solubility (mg/L)	Source	Vapor Pressure (mm Hg)	Source	Henry's Law Constant (atm-m^3/mol)	Source	Koc (mL/g)	Source	Aerobic soil metabolism (days)	Source	Soil photolysis (days)	Source	Anaerobic soil metabolism (days)	Source	Hydroloysis at pH7 (days)	Source	Aerobic aquatic metabolism (days)	Source	Aquatic photolysis (days)	Source	Anaerobic aquatic metabolism (days)	Source
(S)-metolachlor				87392-12-9	283.8	F	480	F	5.55E-09	F	2.17E-08	F	226	F	15	F			48	F	stable	F			0.2	F	95	c
Abamectin				71751-41-2	873.1	A	5	A	3.00E-13	A	3.45E-10	A	5,000	A	28.7	F			89	F	stable	A					178	c
Bifenthrin		U	P	82657-04-3	422.9	E	0.000014	E	1.80E-07	E	7.20E-03	E	239,000	E	161.8	ct	147	E	568	c	stable	E	323.6	c	stable	E	647.2	c
Bromacil				314-40-9	261.1	A	1024	A	7.50E-09	A	1.48E-10	A	33	A	275	A					30.1	A			346.5	A	0	c
Captan				133-06-2	300.6	A	5.1	A	1.80E-11	A	6.41E-09	A	151	A	0.8	F					0.6	F					0	c
Carbaryl	R			63-25-2	201.2	E	32	E	1.36E-07	E	1.28E-08	E	229	E	4	E	stable	E	72	E	12.0	E	4.9	E	12.0	E	72	E
Chlorothalonil				1897-45-6	265.9	A	0.6	A	1.14E-10	A	2.17E-07	A	5,000	A	15.7	F			0	F	stable	A			63.0	A	0.2	c
Chlorpyrifos				2921-88-2	350.6	A	1.18	A	3.75E-09	A	7.33E-06	A	9,930	A	30.5	A			37	F	29.4	A					73	c
Clomazone				81777-89-1	239.7	A	1100	A	2.85E-08	A	4.09E-08	A	274	A	87	A			54	F	stable	A					108	c
Copper Hydroxide				20427-59-2	97.6	F	0.506	F	1.50E-15	F			12,000	F	10000	F					stable	F					0	c
Copper Sulphate				12527-76-3	461.3	F	3.42	F	5.10E-19	F			9,500	F	10000	F					stable	F					0	c
Cyfluthrin		U	P	68359-37-5	434.3	L	0.0023	L	1.50E-08	L	3.70E-06	L	124,000	L	28	L	5.02	L	101	L	183.0	L	56	c	0.7	L	112	c
Cyhalofop-butyl				122008-85-9	357.4	F	0.44	F	7.95E-11	F	9.39E-09	F	5,247	F	0.2	F			0.13	F	97.0	F			27.0	F	0.26	c
Cypermethrin	R	U	P	52315-07-8	416.3	E	0.0076	E	3.19E-09	E	3.14E-07	E	141,700	E	62	E	stable	E	62	E	stable	E	11.3	E	36.2	E	19.3	E
Deltamethrin			P	52918-63-5	505.2	E	0.0002	E	9.32E-11	E	3.10E-07	E	204,000	E	57.6	ct	stable	E	108	c3	stable	E	217.9	ct	84.0	E	435.8	c
Diazinon				333-41-5	304.4	A	60	A	2.12E-08	A	7.11E-07	A	1,520	A	39	A			17	A	138.6	A			5.1	A	34	c
Dimethoate				60-51-5	229.3	A	23800	A	3.60E-10	A	1.36E-11	A	20	A	3	A			15	F	693.0	A					30.4	c
Diuron				330-54-1	233.1	A	42	A	1.38E-11	A	5.03E-10	A	477	A	372	A			48	F	495.0	A			43.3	A	96	c
Esfenvalerate			P	66230-04-4	419.9	E	0.006	E	9.45E-11	E	1.38E-12	E	85,700	E	225	c3	stable	E	231	c3	stable	E	450	c	9.0	E	900	c
Fipronil				120068-37-3	437.2	F	3.78	F	3.00E-12	F	2.28E-09	F	577	F	142	F			68	F	stable	F			0.3	F	136	c
Hexazinone				51235-04-2	252.3	A	29800	A	4.50E-11	F	1.09E-12	A	54	F	90	F					stable	F			301.3	A	0	c
Imidacloprid				138261-41-3	255.7	F	610	F	6.00E-16	F	1.68E-15	F	225	F	187	F			129	F	stable	F			0.2	F	258	c
Indoxacarb				173584-44-6	527.8	F	0.2	F	9.00E-12	F	5.92E-10	F	6,450	F	5	F			6	F	22.0	F			3.0	F	12	c
Lambda-cyhalorthrin	R		P	91465-08-6	449.9	L	0.005	L	1.60E-09	L	1.90E-07	L	326,000	L	58.9	L	53.7	L	118	c	stable	L	28.2	L	24.5	L	56.4	c
Malathion	R			121-75-5	330.4	A	130	A	3.57E-06	A	1.13E-08	A	1,200	A	1	A	stable	E		F	6.3	A	14	E	42.0	E	0	c
Mancozeb				8018-01-7	271.3	F	6.2	A	2.64E-14	A	5.82E-09	A	6,000	A	2	A			76	F	2.3	A			0.1	A	152	c
Maneb				12427-38-2	265.3	A	6	A	2.10E-11	F	2.05E-10	F	1,310	F	5	F			8	F	1.0	A					16.8	c
Methomyl				16752-77-5	162.2	A	58000	A	1.13E-09	A	1.97E-11	A	32	A	30	A			4	F	stable	A			5.0	A	7.4	c
Naled				300-76-5	381.0	A	1.5	A	3.90E-08	A	6.51E-05	A	157	A	4	A					1.0	A					0	c
Oxyfluorfen				42874-03-3	361.7	A	0.116	A	4.95E-11	A	9.87E-07	A	100,000	A	186	F					stable	A			3.0	A	0	c
Paraquat dichloride				1910-42-5	257.2	A	620000	A	1.50E-11	F	3.95E-14	F	16,200	A	365	F					stable	F					0	c
Pendimethalin	R			40487-42-1	281.3	A	0.275	A	9.00E-06	A	1.21E-05	A	13,400	A	123	F	stable	E	stable	E	stable	A			21.0	E	60	E
Permethrin		U	P	52645-53-1	391.3	E	0.0055	E	1.50E-08	E	1.40E-06	E	28,200	E	111	E	stable	E	222	E	stable	E	48.2	E	80.0	E	239	E
Propanil	R			709-98-8	218.1	A	152	A	9.07E-07	A	1.72E-09	A	400	A	0.5	R	stable	E	3	E	stable	E	3	E	103.4	A	6	c
Propargite				2312-35-8	350.5	A	0.6	A	9.00E-12	A	3.45E-08	A	41,000	A	40	A			19	F	77.9	A			3150.0	A	37.4	c
Pyraclostrobin				175013-18-0	387.8	F	1.9	F	3.90E-14	F	5.24E-11	F	11,000	F	62	F			28	F	stable	F			1.7	F	56	c
Simazine				122-34-9	201.7	A	6.2	A	4.50E-12	A	9.67E-10	A	140	A	89	A			33	F	stable	A			385.0	A	66	c
Thiobencarb	R			28249-77-6	257.8	A	19	E	4.30E-05	E	1.10E-06	E	485	E	1.5	E	37	E	94.9	F	32.0	E			8.0	E	0.125	E
Trifluralin				1582-09-8	335.3	A	0.32	A	2.19E-08	A	1.51E-05	A	7,200	A	169	A			6	F	31.5	A			0.4	A	11	c
Ziram				137-30-4	305.8	A	0.03	A	1.50E-12	A	9.87E-08	A	400	A	30	F			0.25	F	0.7	F			0.3	F	0.5	c

A = ARS
F = Footprint
E = EPA RED/IRED
L = Laskowski, 2002
c = calculated

R = Included in rice scenarios
U = Included in urban scenarios
P = Pyrethroid

Table 5 Pesticide properties used to simulate washoff from hard surfaces for urban scenarios.

Chemical	Pervious Kd	Impervious Kd	Source / Comment
Bifenthrin	48	48	Jorgensson & Young, 2010. Concrete.
Cyfluthrin	1.7	1.7	Jorgensson & Young, 2010. Concrete.
Cypermethrin	30	100	Harbourt et al., 2009. PWG concrete and dirty painted wood
Deltamethrin	29.2	29.2	Jorgensson & Young, 2010. Concrete.
Esfenvalerate	41	41	Jorgensson & Young, 2010. Concrete.
Lambda-cyhalorthrin	54	54	Jorgensson & Young, 2010. Concrete.
Permethrin	0.6	0.6	Xiang and Spurlock, 2010. Concrete. Fit to events 1 and 12

Table 6 Example of the master run file used to manage the PRZM simulations

CO_MTRS	Year_	MetID	Chem_ID	Crop_ID	SoilID	CountOf applic_dt	FirstOf OBJECTID	Acre_Treated _Run_Sum
01M01S04E31	2000	12	16	21	479	2	1	109
01M01S04E31	2000	12	16	21	500	2	3	109
01M01S04E31	2000	12	26	1	479	3	5	163
01M01S04E31	2000	12	26	1	500	3	8	163
01M01S04E31	2000	12	26	21	479	1	11	55
01M01S04E31	2000	12	26	21	500	1	12	55
01M01S04E31	2000	12	39	1	479	2	13	55
01M01S04E31	2000	12	39	1	500	2	15	55
01M01S04E31	2000	12	39	21	479	2	17	90
01M01S04E31	2000	12	39	21	500	2	19	90
01M01S04E31	2000	12	7	1	479	1	21	15
01M01S04E31	2000	12	7	1	500	1	22	15
01M01S04E31	2001	12	17	1	479	2	23	336
01M01S04E31	2001	12	17	1	500	2	25	336
01M01S04E31	2001	12	26	1	479	1	27	164
01M01S04E31	2001	12	26	1	500	1	28	164
01M01S04E31	2001	12	29	1	479	2	29	336
01M01S04E31	2001	12	29	1	500	2	31	336
01M01S04E31	2002	12	26	1	479	2	33	376
01M01S04E31	2002	12	26	1	500	2	35	376
01M01S04E31	2002	12	39	1	479	2	37	393

CO_MTRS: PLSS section id; YEAR_: year application occurred, MetID: Array number for the weather station to use, Chem_ID: array number of the chemical to use; Crop_ID: array number of the crop to use, SoilIS: Array number of the soil profile to use; CountofApplic_Dt; Counter used to determine the number of applications in a single PRZM file; FirstOFObjectID; Row number of the first application to include in the PRZM input file; Acre_Treated_Run_Rum: Total are treated with a chemical in a single year on a single crop.

Table 7 Sacramento River Basin Hardness Estimation for Use in the Copper-based Pesticide CMC/CCC Calculation (Averaging over all sites)

Mineral (mg/L)	Sac River Red Bluff CA		Sac River Colusa CA		Yuba River Marysville CA		Feather River Nicolaus CA		Sac River Verona CA		Amer River Sacramento CA		Sac River Freeport CA		Overall Min/Max	
	MAX[1]	MIN[2]	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN
CALCIUM	12	8.9	15	9.1	11	4.3	11	5	15	5.4	6.4	4	13	4.8	15	4
MAGNESIUM	6	3.9	7.1	3.9	4.5	1.6	5.5	2.3	8	2.5	3	1.3	7.4	1.7	8	1.3
Hardness (as CaCO3)[3]	54.6	38.2	66.6	38.7	46.0	17.3	50.1	21.9	70.3	23.8	28.3	15.3	62.8	19.0	70.3	15.3
												Mean of Overall				39.5
												Used for CMC/CCC				40.0

[1] MAX = Maximum value from data set or based on maximum values in data set (i.e., hardness)
[2] MIN = Minimum value from data set or based on minimum values in data set (i.e., hardness)
[3] Maximum hardness values were estimated using the maximum calcium and maximum magnesium concentrations; minimum hardness values were estimated using the minimum calcium and minimum magnesium concentrations.

Table 8 USEPA Risk Presumptions for Aquatic Animals[1]

Risk Presumption	RQ	LOC	Subsequent Extrapolation Factor
Acute High Risk	EEC1/LC50 or EC50	0.5	2X
Acute Endangered Species	EEC/LC50 or EC50	0.05	20X
Chronic Risk	EEC/MATC or NOEC	1	

[1] http://www.epa.gov/oppefed1/ecorisk_ders/toera_risk.htm

Table 9 CALFED Reference Values for Forty Pesticide Active Ingredients

Common name	CAS Number	Pesticide Type	Reference Values (ppb) EPA-OPP Acute	ETS Acute	Chronic	Source of Acute/Chronic Value[1]
Abamectin	71751-41-2	Insecticide	0.17	0.017	0.006	IA/IC
Bifenthrin	82657-04-3	Insecticide	0.075	0.0075	0.0013	FA/IC
Bromacil	314-40-9	Herbicide	6.8	0.68	3000	AA/FC
Captan	133-06-2	Fungicide	13.1	1.31	16.5	FA/FC
Carbaryl	63-25-2	Insecticide	0.85	0.085	0.5	IA/IC
Chlorothalonil	1897-45-6	Fungicide	1.8	0.18	0.6	IA/IC
Chlorpyrifos	2921-88-2	Insecticide	0.05	0.005	0.04	IA/IC
Clomazone	81777-89-1	Herbicide	167	16.7	350	AA/FC
Copper hydroxide	20427-59-2	Fungicide	5.9	0.59	4.3	IA/IC
Copper sulphide	7758-99-8	Insecticide/Aglaecide	5.9	0.59	4.3	IA/IC
Cyfluthrin	68359-37-5	Insecticide	0.0125	0.00125	0.007	IA/IC
Cyhalofop butyl	122008-85-9	Herbicide	245	24.5	134	FA/FC
Cypermethrin	52315-07-8	Insecticide	0.195	0.0195	0.069	FA/IC
Deltamethrin	52918-63-5	Insecticide	0.055	0.0055	0.0041	IA/IC
Diazinon	333-41-5	Insecticide	0.11	0.011	0.17	IA/IC
Dimethoate	60-51-5	Insecticide	21.5	2.15	0.5	IA/IC
Diuron	330-54-1	Herbicide	2.4	0.24	26	AA/FC
Esfenvalerate	66230-04-4	Insecticide	0.025	0.0025	0.017	IA/IC
Hexazinone	51235-04-2	Herbicide	7	0.7	17000	AA/FC
Imidacloprid	105827-78-9	Insecticide	35	3.5	1.05	IA/IC
Indoxacarb	173584-44-6	Insecticide	12	1.2	3.6	FA/IC
Lambda cyhalothrin	91465-08-6	Insecticide	0.0035	0.00035	0.002	IA/IC
Malathion	121-75-5	Insecticide	0.3	0.03	0.035	IA/IC
Mancozeb	8018-01-7	Fungicide	47	4.7	N/A	AA/na
Maneb	12427-38-2	Fungicide	13.4	1.34	N/A	AA/na
Methomyl	16752-77-5	Insecticide	2.5	0.25	0.7	IA/IC
(s)-Metolachlor	87392-12-9	Herbicide	8.0	0.8	30	AA/FC
Naled	300-76-5	Insecticide	25	2.5	0.045	AA/IC
Oxyfluorfen	42874-03-3	Herbicide	0.29	0.029	1.3	AA/FC
Paraquat	1910-42-5	Herbicide	0.396	0.0396	N/A	AA/na
Pendimethalin	40487-42-1	Herbicide	5.2	0.52	6.3	AA/FC
Permethrin	52645-53-1	Insecticide	0.01	0.001	0.0014	IA/IC
Propanil	709-98-8	Herbicide	16	1.6	9.1	AA/FC
Propargite	2312-35-8	Insecticide	37	3.7	9	IA/IC
Pyraclostrobin	175013-18-0	Fungicide	0.0015	0.00015	0.002	FA/FC
Simazine	122-34-9	Herbicide	36	3.6	960	AA/FC
Thiobencarb	28249-77-6	Herbicide	17	1.7	1	AA/IC
Tralomethrin	66841-25-6	Insecticide	0.055	0.0055	0.0041	IA/IC
Trifluralin	1582-09-8	Herbicide	7.52	0.752	1.14	AA/FC
Ziram	137-30-4	Fungicide	9.7	0.97	39	FA/IC

[1]Describes which endpoint provided the most sensitive value; FA = Fish Acute; IA = Invertebrate Acute; FC = Fish Chronic; IC = Daphnid Chronic. N/A = Not available; na = not available.

Table 10 Mapping of use sites in PUR to EPA standard scenarios.

PUR site Name	EPA Scenario Name	General Crop	Crop_ID
ALFALFA	CA alfalfa_NirrigOP	Alfalfa	1
ALMOND	CA almond_NirrigC	Almond	2
ANIMAL PREMISE	#N/A	#N/A	#N/A
APPLE	CAfruit_NirrigC	Fruit	8
APRICOT	CAfruit_NirrigC	Fruit	8
ARRUGULA	CAColeCrop no_irrig	Cole Crop	4
ARTICHOKE, GLOBE	CARowCrop no_irrig	Row Crop	21
ASIAN PEAR	CAfruit_NirrigC	Fruit	8
ASPARAGUS	CAColeCrop no_irrig	Cole Crop	4
BARLEY	CA wheat no irrig	Wheat	26
BASIL, SWEET	CAColeCrop no_irrig	Cole Crop	4
BEAN, DRIED	CARowCrop no_irrig	Row Crop	21
BEAN, SUCCULENT	CARowCrop no_irrig	Row Crop	21
BEAN, UNSPECIFIED	CARowCrop no_irrig	Row Crop	21
BEET	CARowCrop no_irrig	Row Crop	21
BLACKBERRY	CAfruit_NirrigC	Fruit	8
BLUEBERRY	CAfruit_NirrigC	Fruit	8
BOK CHOY	CAColeCrop no_irrig	Cole Crop	4
BOYSENBERRY	CAfruit_NirrigC	Fruit	8
BROCCOLI	CAColeCrop no_irrig	Cole Crop	4
BRUSSELS SPROUT	CAColeCrop no_irrig	Cole Crop	4
BUILDINGS/NON-AG OUTDROOR	CA impervious RLF	Impervious	11
CABBAGE	CAColeCrop no_irrig	Cole Crop	4
CABBAGE, SAVOY	CAColeCrop no_irrig	Cole Crop	4
CANTALOUPE	CA Melon no irrig	Melon	13
CARROT	CARowCrop no_irrig	Row Crop	21
CAULIFLOWER	CAColeCrop no_irrig	Cole Crop	4
CELERIAC	CAColeCrop no_irrig	Cole Crop	4
CELERY	CARowCrop no_irrig	Row Crop	21
CHERRY	CAfruit_NirrigC	Fruit	8
CHESTNUT	CA almond_NirrigC	Almond	2
CHICORY	CAColeCrop no_irrig	Cole Crop	4
CHINESE CABBAGE (NAPPA)	CAColeCrop no_irrig	Cole Crop	4
CHINESE GREENS	CAColeCrop no_irrig	Cole Crop	4
CHIVE	CAColeCrop no_irrig	Cole Crop	4
CHRISTMAS TREE	CA Forestry	Forestry	7
CILANTRO	CAColeCrop no_irrig	Cole Crop	4
CITRUS	CAcitrus_NirrigC	Citrus	3
CLOVER	CA ranglandandhay	Rangeland	18

Table 10 Mapping of use sites in PUR to EPA standard scenarios (Cont.)

PUR site Name	EPA Scenario Name	General Crop	Crop_ID
COLLARD	CAColeCrop no_irrig	Cole Crop	4
COMMODITY FUMIGATION	#N/A	#N/A	#N/A
CORN (FORAGE - FODDER)	CAcornOP	Corn	5
CORN, GRAIN	CAcornOP	Corn	5
CORN, HUMAN CONSUMPTION	CAcornOP	Corn	5
COTTON	Cacotton_NirrigC	Cotton	6
CUCUMBER	CA Melon no irrig	Melon	13
DANDELION GREEN	CA turf no irrig	Turf	25
DILL	CAColeCrop no_irrig	Cole Crop	4
DITCH BANK	CA rightofway	Right of Way	20
EGGPLANT	CA Melon no irrig	Melon	13
ENDIVE (ESCAROLE)	CAColeCrop no_irrig	Cole Crop	4
FENNEL	CARowCrop no_irrig	Row Crop	21
FIG	CAfruit_NirrigC	Fruit	8
FORAGE HAY/SILAGE	CA ranglandandhay	Rangeland	18
FOREST, TIMBERLAND	CA Forestry	Forestry	7
GAI CHOY	CA Forestry	Forestry	7
GAI LON	CAColeCrop no_irrig	Cole Crop	4
GARBANZO BEAN	CARowCrop no_irrig	Row Crop	21
GARLIC	CA Garlic	Garlic	9
GRAIN	CA wheat no irrig	Wheat	26
GRANARY	CA wheat no irrig	Wheat	26
GRAPE	CAWine Grapes no irrig	Grapes	10
GRAPE, WINE	CAWine Grapes no irrig	Grapes	10
GRAPEFRUIT	CAcitrus_NirrigC	Citrus	3
GRASS, SEED	CA turf no irrig	Turf	25
KALE	CAColeCrop no_irrig	Cole Crop	4
KIWI	CAfruit_NirrigC	Fruit	8
KOHLRABI	CAColeCrop no_irrig	Cole Crop	4
LANDSCAPE MAINTENANCE	CA rightofway	Right of Way	20
LEEK	CAColeCrop no_irrig	Cole Crop	4
LEMON	CAcitrus_NirrigC	Citrus	3
LETTUCE, HEAD	CAlettuceC	Lettuce	12
LETTUCE, LEAF	CAlettuceC	Lettuce	12
MELON	CA Melon no irrig	Melon	13
MINT	OR Mint	Mint	28
MIZUNA	CARowCrop no_irrig	Row Crop	21
MUSHROOM	#N/A	#N/A	#N/A
MUSHROOM HOUSE	#N/A	#N/A	#N/A
MUSHROOM SOIL	#N/A	#N/A	#N/A

Table 10 Mapping of use sites in PUR to EPA standard scenarios (Cont.)

PUR site Name	EPA Scenario Name	General Crop	Crop_ID
MUSTARD	CARowCrop no_irrig	Row Crop	21
NECTARINE	CAfruit_NirrigC	Fruit	8
N-GRNHS FLOWER	CA Nursery	Nursery	14
N-GRNHS PLANTS IN CONTAINERS	CA Nursery	Nursery	14
N-GRNHS TRANSPLANTS	CA Nursery	Nursery	14
N-OUTDR FLOWER	CA Nursery	Nursery	14
N-OUTDR PLANTS IN CONTAINERS	CA Nursery	Nursery	14
N-OUTDR TRANSPLANTS	CA Nursery	Nursery	14
NUTS	CA almond_NirrigC	Almond	2
OAT	CA wheat no irrig	Wheat	26
OAT (FORAGE - FODDER)	CA wheat no irrig	Wheat	26
OKRA	CAColeCrop no_irrig	Cole Crop	4
OLIVE	CA Olive no irrig	Olive	15
ONION, DRY	CA Onion STD	Onion	16
ONION, GREEN	CA Onion STD	Onion	16
ORANGE	CAcitrus_NirrigC	Citrus	3
ORCHARD FLOOR	CAfruit_NirrigC	Fruit	8
PARSLEY	CAColeCrop no_irrig	Cole Crop	4
PASTURELAND	CA ranglandandhay	Rangeland	18
PEACH	CAfruit_NirrigC	Fruit	8
PEANUT	CARowCrop no_irrig	Row Crop	21
PEAR	CAfruit_NirrigC	Fruit	8
PEAS	CARowCrop no_irrig	Row Crop	21
PECAN	CA almond_NirrigC	Almond	2
PEPPER, FRUITING	CAColeCrop no_irrig	Cole Crop	4
PEPPER, SPICE	CAColeCrop no_irrig	Cole Crop	4
PERSIMMON	CAfruit_NirrigC	Fruit	8
PIMENTO	CAColeCrop no_irrig	Cole Crop	4
PISTACHIO	CA almond_NirrigC	Almond	2
PLUM	CAfruit_NirrigC	Fruit	8
PLUOT	CAColeCrop no_irrig	Cole Crop	4
POME FRUIT	CAfruit_NirrigC	Fruit	8
POMEGRANATE	CAfruit_NirrigC	Fruit	8
POTATO	CA potato no irrig	Potato	17
PRUNE	CAfruit_NirrigC	Fruit	8
PUMPKIN	CA Melon no irrig	Melon	13
RADICCHIO	CARowCrop no_irrig	Row Crop	21
RADISH	CARowCrop no_irrig	Row Crop	21
RANGELAND	CA ranglandandhay	Rangeland	18

Table 10 Mapping of use sites in PUR to EPA standard scenarios (Cont.)

PUR site Name	EPA Scenario Name	General Crop	Crop_ID
RASPBERRY	CAfruit_NirrigC	Fruit	8
RECREATION AREA	CA turf no irrig	Turf	25
RESEARCH COMMODITY	#N/A	#N/A	#N/A
RICE	NA	RICE	31
RICE (GRAIN CROP)	NA	RICE (GRAIN CROP)	33
RICE, WILD	NA	RICE, WILD	32
RIGHTS OF WAY	CA rightofway	Right of Way	20
RYEGRASS	CA wheat no irrig	Wheat	26
SAFFLOWER	CARowCrop no_irrig	Row Crop	21
SHALLOT	CAColeCrop no_irrig	Cole Crop	4
SMALL FRUITS/BERRY	CAfruit_NirrigC	Fruit	8
SOIL FUMIGATION/PREPLANT	#N/A	#N/A	#N/A
SORGHUM (FORAGE - FODDER)	CA turf no irrig	Turf	25
SORGHUM/MILO	CARowCrop no_irrig	Row Crop	21
SOYBEAN	CARowCrop no_irrig	Row Crop	21
SPINACH	CAlettuceC	Lettuce	12
SQUASH	CA Melon no irrig	Melon	13
SQUASH, SUMMER	CA Melon no irrig	Melon	13
SQUASH, WINTER	CA Melon no irrig	Melon	13
SQUASH, ZUCCHINI	CA Melon no irrig	Melon	13
STONE FRUIT	CAfruit_NirrigC	Fruit	8
STORAGE AREA/BOX	#N/A	#N/A	#N/A
STRAWBERRY	CA Strawberry no plastic	Strawberry	22
STRUCTURAL PEST CONTROL	CA impervious RLF	Impervious	11
SUDANGRASS	CA turf no irrig	Turf	25
SUGARBEET	CAsugarbeet_NirrigOP.txt	Sugarbeet	23
SUNFLOWER	CARowCrop no_irrig	Row Crop	21
SWEET POTATO	CA potato no irrig	Potato	17
SWISS CHARD	CAColeCrop no_irrig	Cole Crop	4
TANGELO	CAfruit_NirrigC	Fruit	8
TANGERINE	CAcitrus_NirrigC	Citrus	3
TIMOTHY	CAColeCrop no_irrig	Cole Crop	4
TOBACCO	CARowCrop no_irrig	Row Crop	21
TOMATILLO	CAtomato_NirrigC	Tomato	24
TOMATO	CAtomato_NirrigC	Tomato	24
TOMATO, PROCESSING	CAtomato_NirrigC	Tomato	24
TURF/SOD	CA turf no irrig	Turf	25
TURKEY	#N/A	#N/A	#N/A
TURNIP	CAColeCrop no_irrig	Cole Crop	4

Table 10 Mapping of use sites in PUR to EPA standard scenarios (Cont.)

PUR site Name	EPA Scenario Name	General Crop	Crop_ID
UNCULTIVATED AG	CA ranglandandhay	Rangeland	18
UNCULTIVATED NON-AG	CA ranglandandhay	Rangeland	18
UNKNOWN	#N/A	#N/A	#N/A
VEGETABLE	CARowCrop no_irrig	Row Crop	21
VEGETABLES, LEAFY	CAColeCrop no_irrig	Cole Crop	4
VERTEBRATE CONTROL	#N/A	#N/A	#N/A
WALNUT	CA almond_NirrigC	Almond	2
WATER AREA	#N/A	#N/A	#N/A
WATERCRESS	CAColeCrop no_irrig	Cole Crop	4
WATERMELON	CA Melon no irrig	Melon	13
WHEAT	CA wheat no irrig	Wheat	26
WHEAT (FORAGE - FODDER)	CA wheat no irrig	Wheat	26

Table 11 PRZM crop parameters based on EPA standard scenarios

Crop Name	PFAC (-)	SFAC (-)	INICRP	ANETD (cm)	ISCOND	CINTCP	AMXDR (CM)	COVMAX (%)	ICNAH
Alfalfa	0.73	0	1	17.5	1	0.25	60	100	2
Almond	0.73	0	1	17.5	1	0.25	120	90	1
Citrus	0.73	0	1	17.5	3	0.25	60	80	2
Cole cro	0.75	0	1	17.5	3	0.25	46	100	3
Corn	0.73	0	1	17.5	1	0.25	90	100	3
Cotton	0.73	0	1	17.5	1	0.2	65	100	1
Forestry	0.76	0.12	1	17.5	3	0.25	66	100	3
Fruit	0.73	0	1	17.5	1	0.25	30	90	3
Garlic	0.68	0	1	17.5	1	0.1	46	80	2
Grapes	0.73	0	1	17.5	3	0.25	100	70	3
Impervio	0.77	0	1	17.5	1	0	0	0	1
Lettuce	0.79	0	1	17.5	1	0.25	12	90	3
Melons	0.7	0	1	17.5	1	0.25	46	100	3
Nursery	0.7	0	1	32.5	1	0.1	32.5	60	1
Olives	0.7	0	1	32.5	3	0.25	60	90	3
Onion	0.7	0.55	1	17.5	1	0.05	35	80	1
Potato	0.7	0	1	25	3	0.15	91	100	3
Rangelan	0.75	0	1	17.5	3	0.2	30	90	3
Resident	0.77	0	1	17.5	2	0.15	25	100	2
Right of	0.77	0	1	17.5	1	0.1	15	10	3
Row crop	0.75	0	1	17.5	3	0.25	46	100	3
Strawber	0.75	0	1	17.5	1	0.1	48	80	2
Sugarbee	0.75	0	1	17.5	1	0.2	90	100	1
Tomato	0.73	0	1	17.5	1	0.1	90	90	1
Turf	0.77	0	1	17.5	2	0.1	15	100	2
Wheat	0.7	0	1	32.5	3	0.15	30	100	3
Wine gra	0.75	0	1	17.5	3	0.25	122	30	3
Mint	0.74	0.36	1	17.5	1	0.25	30	100	1

Table 11 PRZM crop parameters based on EPA standard scenarios (Cont.)

Crop Name	A(Crop)	B(Crop)	C (Crop)	D (Crop)	A (NonCrop)	B (NonCrop	C (NonCrop)	D (NonCrop)	WFMAX (cm)	HTMAX (kg m^2)
Alfalfa	64	76	84	88	71	81	88	91	0	50
Almond	49	69	79	84	77	86	91	94	0	750
Citrus	49	69	79	84	63	78	85	89	0	400
Cole cro	70	80	87	90	74	83	89	92	0	30
Corn	70	80	87	90	74	83	89	92	0	300
Cotton	70	80	87	90	74	83	89	92	0	122
Forestry	45	66	77	83	45	66	77	83	0	5486
Fruit	49	69	79	84	63	78	85	89	0	300
Garlic	70	80	87	90	74	83	89	92	0	45.7
Grapes	49	69	79	84	63	78	85	89	0	244
Impervio	98	98	98	98	98	98	98	98	0	0
Lettuce	70	80	87	90	74	83	89	92	0	30
Melons	49	69	79	84	63	78	85	89	0	25
Nursery	49	69	79	84	63	78	85	89	0	183
Olives	70	80	87	90	74	83	89	92	0	457.2
Onion	70	80	87	90	74	83	89	92	0	30
Potato	70	80	87	90	74	83	89	92	0	60
Rangelan	54	70	80	85	65	78	86	89	0	91
Resident	54	70	80	85	65	78	86	89	0	7.6
Right of	54	70	80	85	65	78	86	89	0	15
Row crop	70	80	87	90	74	83	89	92	0	38
Strawber	49	69	79	84	63	78	85	89	0	46
Sugarbee	70	80	87	90	74	83	89	92	0	46
Tomato	70	80	87	90	74	83	89	92	0	30
Turf	54	70	80	85	65	78	86	89	0	1.3
Wheat	64	76	84	88	71	81	88	91	0	153
Wine gra	68	77	83	87	72	81	88	92	0	213.4
Mint	70	80	87	90	74	83	89	92	0	90

Table 11 PRZM crop parameters based on EPA standard scenarios (Cont.)

Crop Name	EMD	EMM	IYREM	Mad	MAM	IYRMAT	HAD	HAM	IYRHAR	INCROP
Alfalfa	16	1	61	28	12	61	31	12	61	1
Almond	16	1	61	2	8	61	13	9	61	1
Citrus	1	1	61	2	1	61	31	12	61	1
Cole cro	1	1	61	22	2	61	1	3	61	1
Corn	1	4	61	27	7	61	8	9	61	1
Cotton	1	5	61	20	9	61	11	11	61	1
Forestry	1	1	61	2	1	61	31	12	61	1
Fruit	16	1	61	1	4	61	1	8	61	1
Garlic	1	10	60	15	5	61	30	7	61	1
Grapes	1	2	61	1	3	61	31	8	61	1
Impervio	1	1	61	2	1	61	31	12	61	1
Lettuce	16	2	61	5	5	61	12	5	61	1
Melons	16	5	61	1	8	61	2	8	61	1
Nursery	1	3	61	1	4	61	1	11	61	1
Olives	1	1	61	2	1	61	31	12	61	1
Onion	16	1	61	1	6	61	15	6	61	1
Potato	16	2	61	15	5	61	15	6	61	1
Rangelan	1	11	60	1	4	61	1	5	61	1
Resident	1	1	61	1	2	61	31	12	61	1
Right of	1	9	61	1	11	61	2	11	61	1
Row crop	1	1	61	1	4	61	8	4	61	1
Strawber	1	1	61	1	6	61	1	7	61	1
Sugarbee	1	2	61	31	5	61	1	8	61	1
Tomato	1	3	61	1	7	61	1	9	61	1
Turf	1	1	61	2	1	61	31	12	61	1
Wheat	1	1	61	31	3	61	15	6	61	1
Wine gra	1	3	61	1	4	61	1	8	61	1
Mint	15	4	61	25	7	61	1	8	61	1

Table 11 PRZM crop parameters based on EPA standard scenarios (Cont.)

Crop Name	ERFLAG	USLELS	USLEP	IREG	SLOPE (%)	C-Facts NO	Begin C-Fact
Alfalfa	4	0.2	1	1	1	24	1
Almond	4	0.2	1	1	1	24	5
Citrus	4	0.2	0.21	1	1	24	9
Cole cro	4	0.2	1	1	1	29	13
Corn	4	0.2	1	1	1	25	17
Cotton	4	0.2	1	1	1	25	21
Forestry	4	28.83	1	2	40	24	25
Fruit	4	0.2	1	2	1	24	29
Garlic	4	0.2	1	1	1	25	33
Grapes	4	0.2	1	1	1	26	37
Impervio	4	5.18	1	2	15	24	41
Lettuce	4	0.2	0.5	1	1	26	45
Melons	4	0.2	0.3	1	1	25	49
Nursery	4	10.3	1	1	22.5	26	53
Olives	4	0.2	1	1	1	24	57
Onion	4	0.2	0.5	1	1	25	61
Potato	4	0.2	1	1	1	27	65
Rangelan	4	0.2	1	2	1	24	69
Resident	4	0.37	1	2	2.5	24	73
Right of	4	1.1	1	2	5	24	77
Row crop	4	0.2	0.6	1	1	29	81
Strawber	4	0.2	0.5	1	1	25	85
Sugarbee	4	0.2	1	1	1	26	89
Tomato	4	0.2	1	1	1	25	93
Turf	4	1.8	0.5	1	7.5	24	97
Wheat	4	0.2	1	1	1	24	101
Wine gra	4	0.2	1	2	1	24	105
Mint	4	0.69	1	2	4	29	109

Note: PFAC = Pan Factor (-), SFAC = Snow Factor (-); INICRP = Initial crop number (-); ANETD = Minimum depth from which evaporation is extract (cm); ISCOND = Surface condition of the initial crop; CINTCP = Maximum interception storage of the crop (cm); AMXD = Maximum rooting depth of the crop (cm); COVMAX = Maximum aerial coverage of the crop (%); ICNAH = Surface condition of the crop after harvest; A(Crop), B(Crop), C (Crop), D (Crop) = Curve number for soils under cropped conditions; A (NonCrop), B (NonCrop), C (NonCrop), D (NonCrop) = Curve number for soil under non-cropped condictions; WFMAX = Maximum dry weight of the crop at full canopy (kg m-2); HTMAX = Maximum crop height (cm); EMM, EMM, IYREM = Crop emergency day, month and year; Mad, MAM, IYRMAT = Crop maturity day, month and year; HAD, HAM, IYRHAR = Crop harvest day, month and year; INCROP = Crop number (-); ERFLAG = Erosion flag; USLELS = Universal soil loss equation topographic factor (-); USLEP = Universal soil loss equation practice factor; IREG = Location of the; NRCS = 24-hr hyetograph; SLOPE = Slope of the field (-); C-Facts NO = Number of C-factors (-); Begin C-Fact = Begin day of C-factor

Table 12 Assigned irrigation types by crop.

Crop ID	Crop	PRZM IRTYP	Description	FLEACH (-)	PCDEPL (-)	RATEAP (cm)
1	Alfalfa	8	Flood	0.1	0.55	0.2
2	Almond	4	Drip	0.1	0.55	0.121
3	Citrus	4	Drip	0	0.55	0.056
4	Cole crops	8	Furrow 50/50	0.1	0.55	0.2
5	Corn	8	Furrow 50/50	0.1	0.55	0.2
6	Cotton	8	Furrow 50/50	0.1	0.55	0.2
7	Forestry	0	No Irrigation	0.1	0.55	0.2
8	Fruit	4	Drip	0.1	0.55	0.056
9	Garlic	3	Sprinkler	0.1	0.66	0.068
10	Grapes	4	Drip	0	0.55	0.056
11	Impervious	0	No Irrigation	0.1	0.55	0.2
12	Lettuce	8	Furrow 50/50	0.1	0.55	0.2
13	Melons	8	Furrow 50/50	0.1	0.55	0.2
14	Nursery	4	Sprinkler	0	0.5	0.046
15	Olives	4	Drip	0	0.5	0.037
16	Onion	8	Furrow 50/50	0.1	0.55	0.2
17	Potato	3	Sprinkler	0.1	0.5	0.1
18	Rangeland/Hay	0	No Irrigation	0.1	0.55	0.2
19	Residential	3	Sprinkler	0.1	0.5	0.1
20	Right of Way	0	No Irrigation	0.1	0.55	0.2
21	Row crop	8	Furrow 50/50	0.1	0.55	0.2
22	Strawberry (no plastic)	4	Drip	0	0.5	0.026
23	Sugarbeet	8	Furrow 50/50	0.1	0.55	0.2
24	Tomato	8	Furrow 50/50	0.1	0.55	0.2
25	Turf	3	Sprinkler	0.1	0.5	0.1
26	Wheat	8	Flood	0.1	0.55	0.2
27	Wine grapes	4	Drip	0	0.6	0.056
28	Mint	3	Sprinkler			
31	Rice					

Table 13 RICEWQ Input Parameters, Sources, and Rationale

Parameter	Value Used	Source/Rationale
Simulation		
RICEWQ model version	1.73	Commercially distributed version. Williams et al., 2008
Simulation duration (years)	9	Daily weather file
Agronomic Activity Timing		
Initial flood (2.5 to 5 cm)–wet seeded	3-May*	UCDAS, 1980
Rice sowing	6-May*	10 days prior to emergence
Initial flush (2.5 to 5 cm)–dry seeded***	13-May*	UCDAS, 1980
Rice seedling emergence	16-May*	Bird, *et al.*, 1992; UCDAS, 2010
Full irrigation (10 to 15 cm)–dry seeded***	16-May*	CRC, 2010b, 2010c, full flood at emergence
Full irrigation (10 to 15 cm)–wet seeded	18-May*	CRC, 2010b, 2010c
First drain	n/a**	Chemical dependent
Reflood	n/a**	Chemical dependent
Rice maturation	11-July*	CRC, 2010d; Bird, *et al.*, 1992
Stop irrigation prior to final drain	25-Aug*	1 week prior to final drain
Final drain	1-Sep*	Yolo RCD, 2010; CRC, 2010d; UCDAS, 2010
Harvest	1-Oct*	Bird, *et al.*, 1992; CRC, 2010d; UCDAS, 2010
Hydrologic parameters		
Surface area of paddy (ha)	1	Output post-processed for larger field sizes
Maximum paddy drainage rate (cm/d)	2.5	Greppi *et al.*, 1998
Irrigation rate (cm/d)	1.25	UCDAS, 1980
Depth of paddy outlet (cm)	20	5 cm above irrigation level
Initial depth of paddy (cm)	0.0	Depth on 01-January
Seepage rate in paddy (cm/d)	soil specific	Function of Hyd Soil Group (SSURGO)
Paddy berm height (cm)	50.8	UCDAS, 1980
Paddy soil parameters		
Depth of active soil layer (cm)	5	USEPA Standard scenario default
Soil bulk density (g/cm^3)	soil specific	SSURGO database
Organic carbon (% wt/wt)	soil specific	SSURGO database
Field capacity (cm/cm)	soil specific	Calculated with Rawls and Brackensiek equation
Wilting point (cm/cm)	soil specific	Calculated with Rawls and Brackensiek equation
Soil moisture (cm/cm)	soil specific	Midpoint of field capacity and wilting point
Mixing velocity (diffusion) (m/day)	0.001	Within range of 0 to 0.1 m/day (Arnold *et al.*, 1991)
Mixing depth for direct partitioning (cm)	0.1	Conservative value (Williams *et al*., 2011)
Suspended sediment concentration (mg/L)	20	Professional judgement
Burial velocity (m/day)	0	Not used
Settling velocity (m/day)	2	Guy, 1977 (Calculated for silts and clays)
Crop Parameters		
Maximum crop coverage fraction	0.80	PIRANHA (Bird, *et al*., 1992)
Foliar washoff rate (fraction/cm precip.)	0.50	USEPA default
Harvest flag	-1	Residues left alone

*Dates will be offset ± 2 weeks by random number generator assuming a rectangular window.
** Drain down and interim drainage not represented because not typical and most farmers have holding basins.
*** Pendimethlin only (dry seeded)

Table 14 Non-agricultural use categories in the county-level PUR for the urban pesticides of interest

		Modeled Surface Media			*Total lbs chemical used*						
site_name	Assignment	% Building	% Pavement	% Grass	(S)-CYPERMETHRIN	BETA-CYFLUTHRIN	BIFENTHRIN	CYFLUTHRIN	CYPERMETHRIN	PERMETHRIN	PERMETHRIN, OTHER RELATED
AIRPORT	Structural	30	35	35				3.34			
BUILDINGS/NON-AG OUTDROOR	Structural	30	35	35				0.14	55.79	3.20	
COMMODITY FUMIGATION	Ignore	0	0	0		1.30	3.16	13.85	28.24	22.49	0.19
COUNTY AG COMM	Assume structural	30	35	35			0.16	0.02	1.27	4.62	
FOOD PROCRESSING PLANT	Ignore	0	0	0		1.35		0.10			
FUMIGATION, OTHER	Ignore	0	0	0		0.14		57.40	1.21		
INDUSTRIAL SITE	Structural	30	35	35		0.05		1.91	2.07		
LANDSCAPE MAINTENANCE	Landscape	0	11.4	88.6	0.00	12,487	6,333	4,308	8,322	77,457	0.02
PUBLIC HEALTH	Ignore	0	0	0		0.67	21.81	4.76	1.57	6,483	
REGULATORY PEST CONTROL	Assume structural	30	35	35		0.55	11.18	87.29	6,129	9,077	0.00
RESEARCH COMMODITY	Assume structural	30	35	35	0.23	0.31	54.29	3.83	8.79	55.96	
RIGHTS OF WAY	Other	0	0	100	0.83	2,724	12.92	207.86	136.28	200.25	0.00
STORAGE AREA/BOX	Structural	30	35	35		1.10		0.15			
STRUCTURAL PEST CONTROL	Structural	30	35	35	0.19	14,283	126,133	115,998	681,015	480,381	2.75
TURF/SOD	Other	0	0	100			9.12				
UNCULTIVATED NON-AG	Other	0	0	100				18.51		0.99	
VERTEBRATE CONTROL	Structural	30	35	35		42.00	29.73	25.53	19.01	197.76	

Table 15 Fraction of county urban land within the study area

County ID	NAME	NLCD 2006 Urban Fraction
01	Alameda	1.00
02	Alpine	0.30
03	Amador	1.00
04	Butte	1.00
05	Calaveras	1.00
06	Colusa	1.00
07	Contra Costa	1.00
09	El Dorado	0.81
10	Fresno	0.07
11	Glenn	0.92
14	Inyo	0.00
17	Lake	0.87
18	Lassen	0.24
20	Madera	1.00
21	Marin	0.78
22	Mariposa	1.00
23	Mendocino	0.00
24	Merced	1.00
25	Modoc	0.47
26	Mono	0.00
27	Monterey	0.00
28	Napa	1.00
29	Nevada	0.75
31	Placer	0.92
32	Plumas	1.00
34	Sacramento	1.00
35	San Benito	0.52
38	San Francisco	0.53
39	San Joaquin	1.00
41	San Mateo	0.79
43	Santa Clara	1.00
44	Santa Cruz	0.00
45	Shasta	1.00
46	Sierra	0.79
47	Siskiyou	0.10
48	Solano	1.00
49	Sonoma	0.25
50	Stanislaus	1.00
51	Sutter	1.00
52	Tehama	1.00
53	Trinity	0.00
55	Tuolumne	1.00
57	Yolo	1.00
58	Yuba	1.00

Table 16 Measured washoff values and calibrated Kd coefficients for different building materials.

		SOL		KOC		DKRATE		DKRATE		KD		
Chemical	CAS Number	Solubility (mg/L)	Source	Koc (mL/g)	Source	Aerobic soil metabolism (days)	Source	Soil photolysis (days)	Source	Hard Surface Washoff Coefficent: Pavement	Hard Surface Washoff Coefficent: Building	Source
Bifenthrin	82657-04-3	1.40E-05	E	239,000	E	161.8	Et	147	E	48	48	J
Cyfluthrin	68359-37-5	0.0023	L	124,000	L	28	L	5.02	L	1.7	1.7	J
Cypermethrin	52315-07-8	0.0076	E	141,700	E	62	E	stable	E	30	100	P
Lambda-cyhalorthrin	91465-08-6	0.005	L	326,000	L	58.9	L	53.7	L	54	54	J
Permethrin	52645-53-1	0.0055	E	28,200	E	111	E	stable	E	0.6	0.6	X

E = EPA RED/IRED
L = Laskowski, 2002
J = Jorgenson & Young, 2010
X = Xiang et al., 2010

t = calculated (upper 10th C.I.)

Pervious simulations
Impervious simulations

Table 17 Stream geometry for ditches and rivers in the CALFED study area.

Stream order	Average Width (m)	RF1 Depths for average Width (m)
Ditch1 (Sacramento River)	0.25	0.175
Ditch 1 (San Joaquin)	1.0	0.20
Ditch 2 (Sacramento River)	0.52	0.33
Ditch 2 (San Joaquin)	3.0	0.20
Channel (Assumed)	5.0	2.0
NHD 1	1	0.036
NHD 2	2	0.047
NHD 3	5	0.079
NHD 4	10	0.134
NHD 5	20	0.243
NHD 6	25	0.297
NHD 7	35	0.406
NHD 8	40	0.461
NHD 9	50	0.570
NHD 10	125	1.387
NHD 11	225	2.477
NHD 12+	225	2.477

Table 18 Total simulated applications and model runs by year

Year	Number of agricultural applications	Number of rice applications	Number of urban applications	Total simulated applications	Number of PRZM simulations	Number of RiceWQ simulations	Number of urban simulations	Total number of simulations
2000	701,611	259,588	13,753	974,952	303,399	120,451	1,618	425,468
2001	620,593	238,612	14,502	873,707	271,941	113,706	1,613	387,260
2002	638,665	237,361	15,289	891,315	276,786	112,027	1,745	390,558
2003	695,565	252,154	14,991	962,710	287,587	116,359	1,719	405,665
2004	782,565	272,398	15,336	1,070,299	327,554	125,859	1,748	455,161
2005	837,598	250,983	15,469	1,104,050	347,249	116,477	1,790	465,516
2006	877,401	250,071	17,969	1,145,441	366,927	111,075	2,129	480,131
2007	858,866	239,809	18,330	1,117,005	353,811	106,368	2,068	462,247
2008	749,589	208,400	18,334	976,323	327,960	99,411	2,086	429,457
Total	**6,762,453**	**2,209,376**	**143,973**	**9,115,802**	**2,863,214**	**1,021,733**	**16,516**	**3,901,463**

Table 19 Amount (lbs) and percent of total applied active ingredient.

System Year	Rice lbs†	Other Agriculture lbs	Urban lbs	All lbs	Rice	Other Agriculture	Urban
2000	5,532,905	7,703,657	115,312	13,351,874	41.4%	57.7%	0.9%
2001	4,728,515	5,613,861	121,610	10,463,985	45.2%	53.6%	1.2%
2002	4,443,529	5,885,422	129,666	10,458,617	42.5%	56.3%	1.2%
2003	5,191,425	6,361,440	118,203	11,671,067	44.5%	54.5%	1.0%
2004	5,219,539	5,993,652	142,580	11,355,772	46.0%	52.8%	1.3%
2005	4,275,531	6,823,479	139,424	11,238,434	38.0%	60.7%	1.2%
2006	4,467,960	7,054,753	195,034	11,717,747	38.1%	60.2%	1.7%
2007	3,499,226	6,313,382	138,588	9,951,196	35.2%	63.4%	1.4%
2008	3,233,546	4,710,885	126,525	8,070,956	40.1%	58.4%	1.6%
Total	40,592,176	56,460,530	1,226,941	98,279,647	41.3%	57.4%	1.2%

† Lbs modeled may not perfectly reflect total amount reported by PUR because flagged PUR records were removed from the input data

Table 20 Chemical mass loadings for the period 2000–2009

Mass Source	Total Mass (Lbs)	% of Total Loss	% of applied
Drift	695,687	4.98%	0.66%
Erosion	619,196	4.43%	0.59%
Rice discharges	606,139	4.34%	0.58%
Runoff	12,045,057	86.18%	11.45%
Urban Runoff[1]	9,895	0.07%	0.01%
Total Loading	13,975,972		13.29%

[1]Urban includes both runoff and erosion mass

Table 21 Statistics for the indicator day distribution

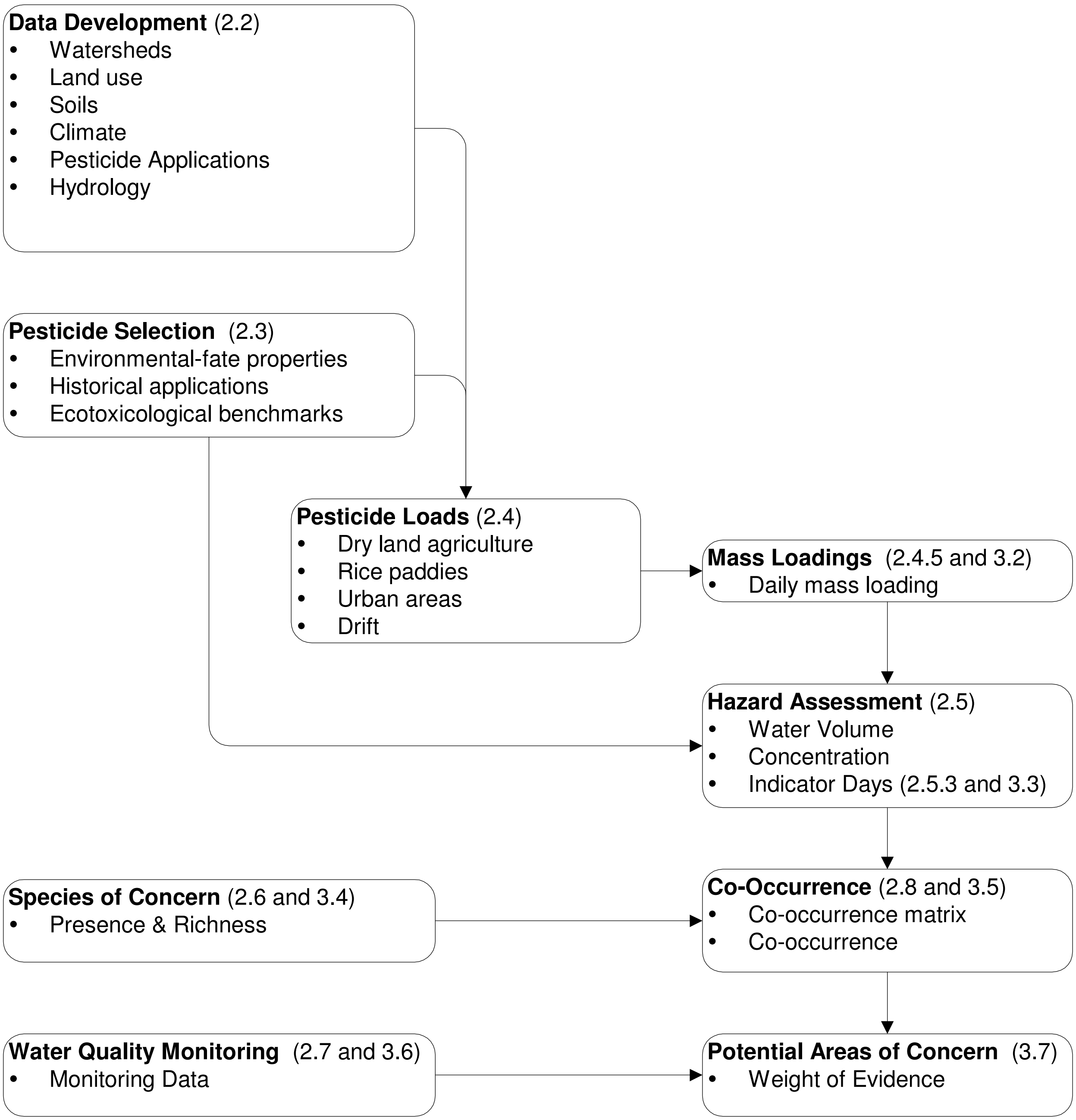
Percentile	Fraction	Bin	Bin Range
10	0.017	1	0 - 0.017
20	0.055	2	0.018 - 0.055
30	0.100	3	0.056 - 0.100
40	0.153	4	0.101 - 0.153
50	0.206	5	0.154 - 0.206
60	0.303	6	0.207 - 0.303
70	0.447	7	0.304 - 0.447
80	0.500	8	0.448 - 0.500
90	0.589	9	0.501 - 0.589
100	0.994	10	0.590 - 0.994

Table 22 Statistics for species richness distribution

Percentile	Fraction	Bin	Bin Range
10	0.250	1	0.001 - 0.250
20	0.250	2	0.001 - 0.250
30	0.250	3	0.001 - 0.250
40	0.333	4	0.251 - 0.333
50	0.333	5	0.251 - 0.333
60	0.333	6	0.251 - 0.333
70	0.333	7	0.251 - 0.333
80	0.333	8	0.251 - 0.333
90	0.500	9	0.334 - 0.500
100	0.917	10	0.501 - 0.917

7.0 FIGURE SECTION

Figure 1 Project process flow diagram



** Numbers in the diagram indicate report sections associated with the topic*

Figure 2 Study area boundaries and main river watersheds in the area of interest

Figure 3 Generalized land use in the study area based on the 2006 Farm Mapping and Monitoring Program

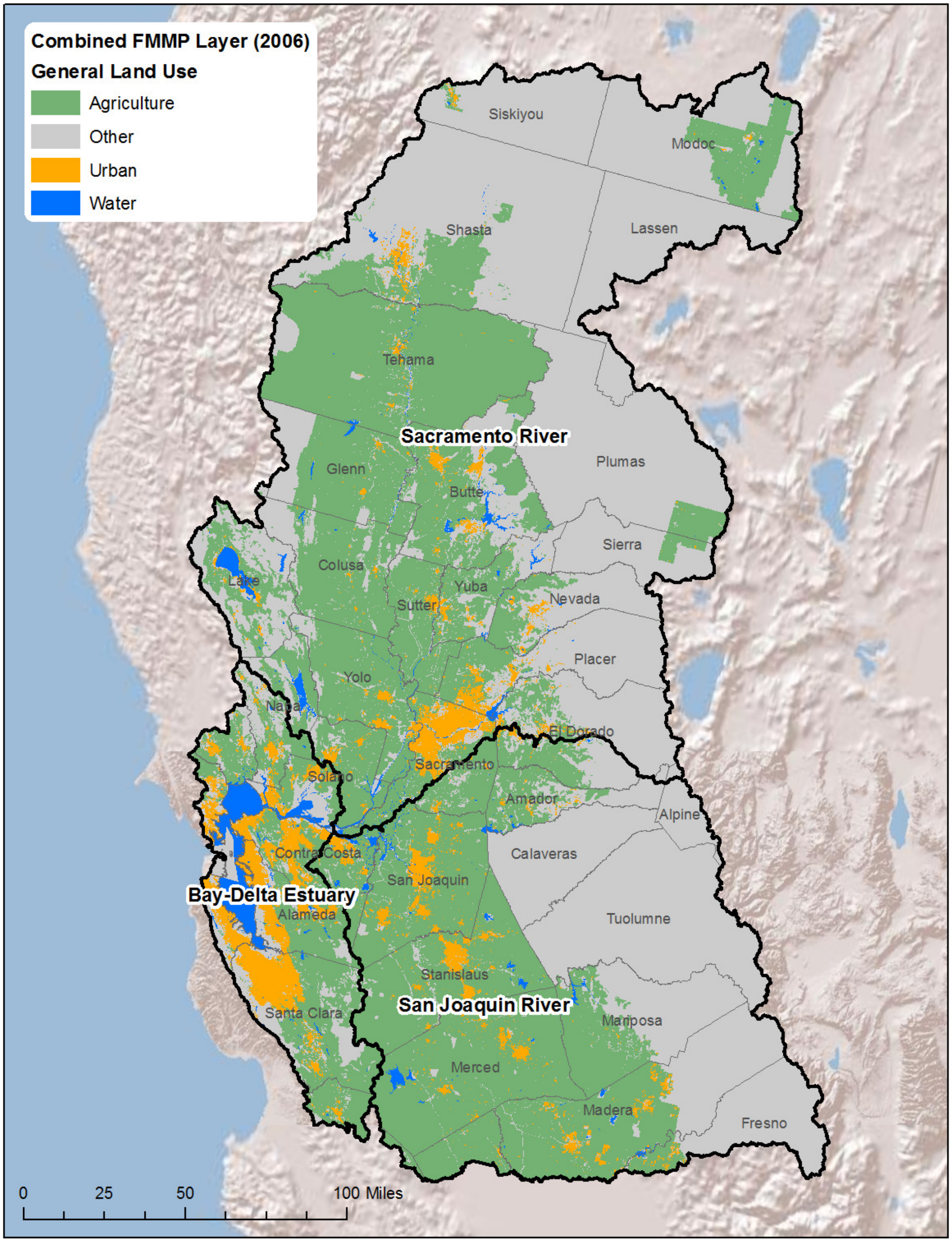


Figure 4 Detailed soil map for the study area

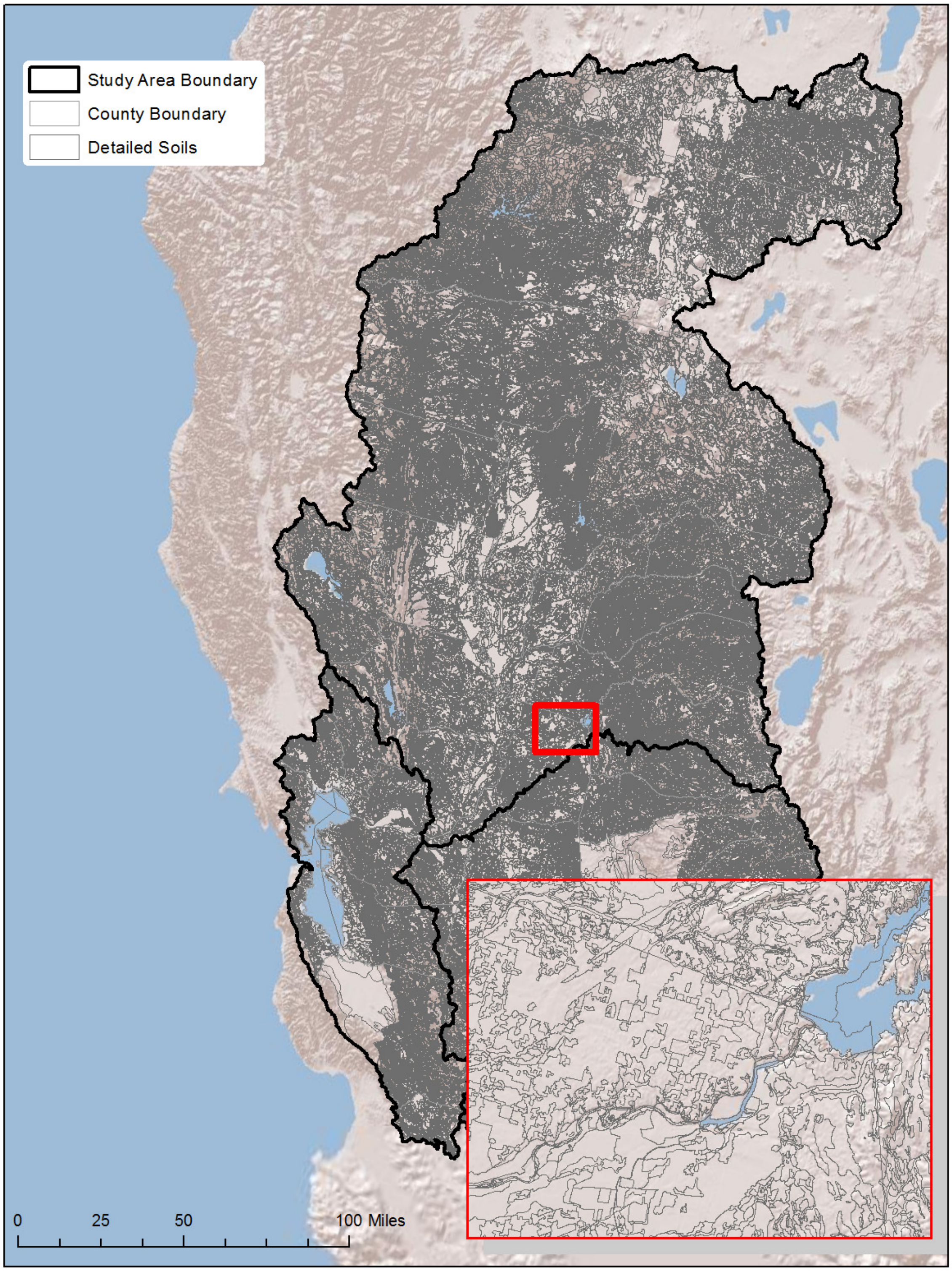


Figure 5 Weather stations and the area of influence

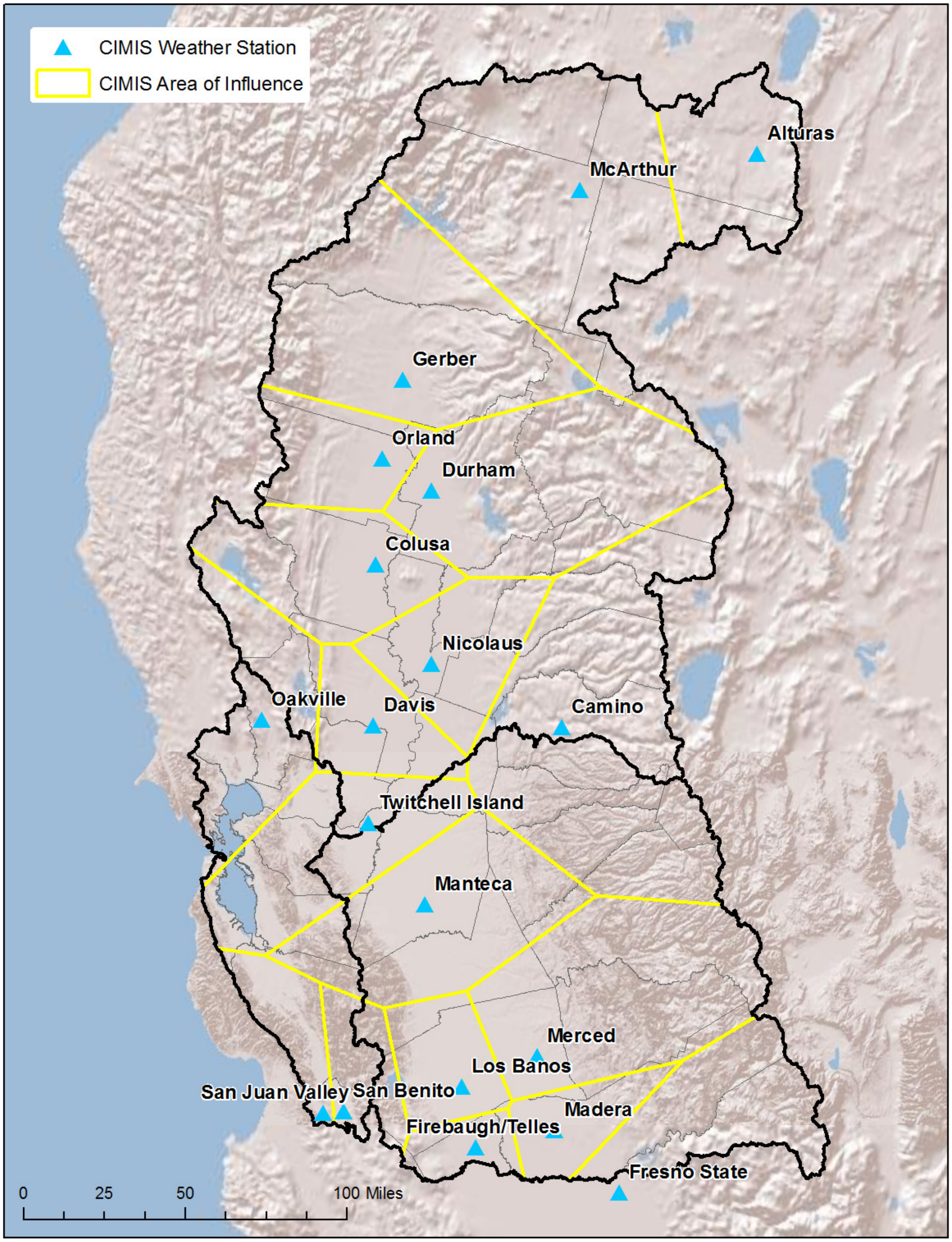


Figure 6 Public Land Survey System (PLSS) section

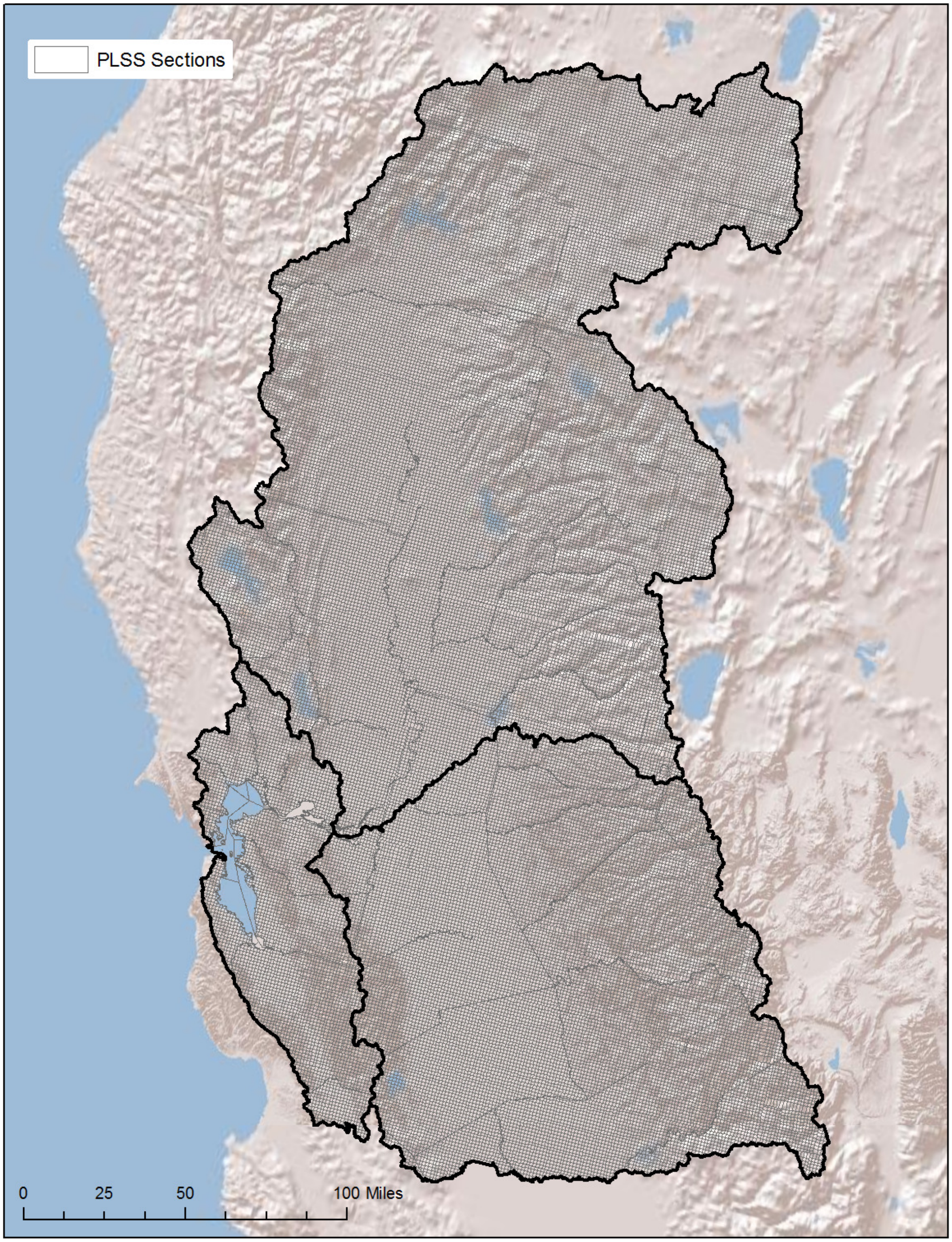


Figure 7 Hydrology in the study area

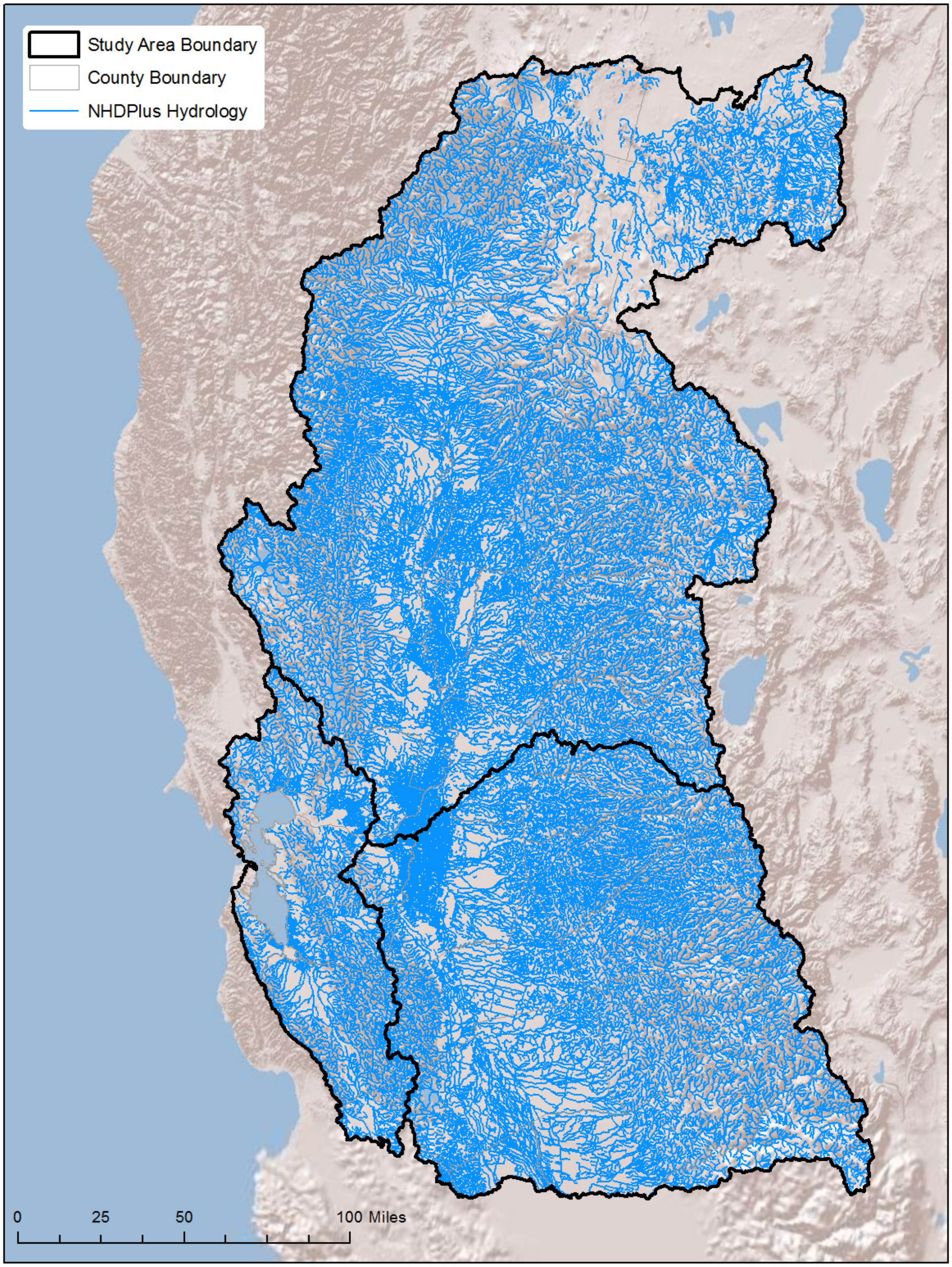


Figure 8 Generalized stream types in the study area

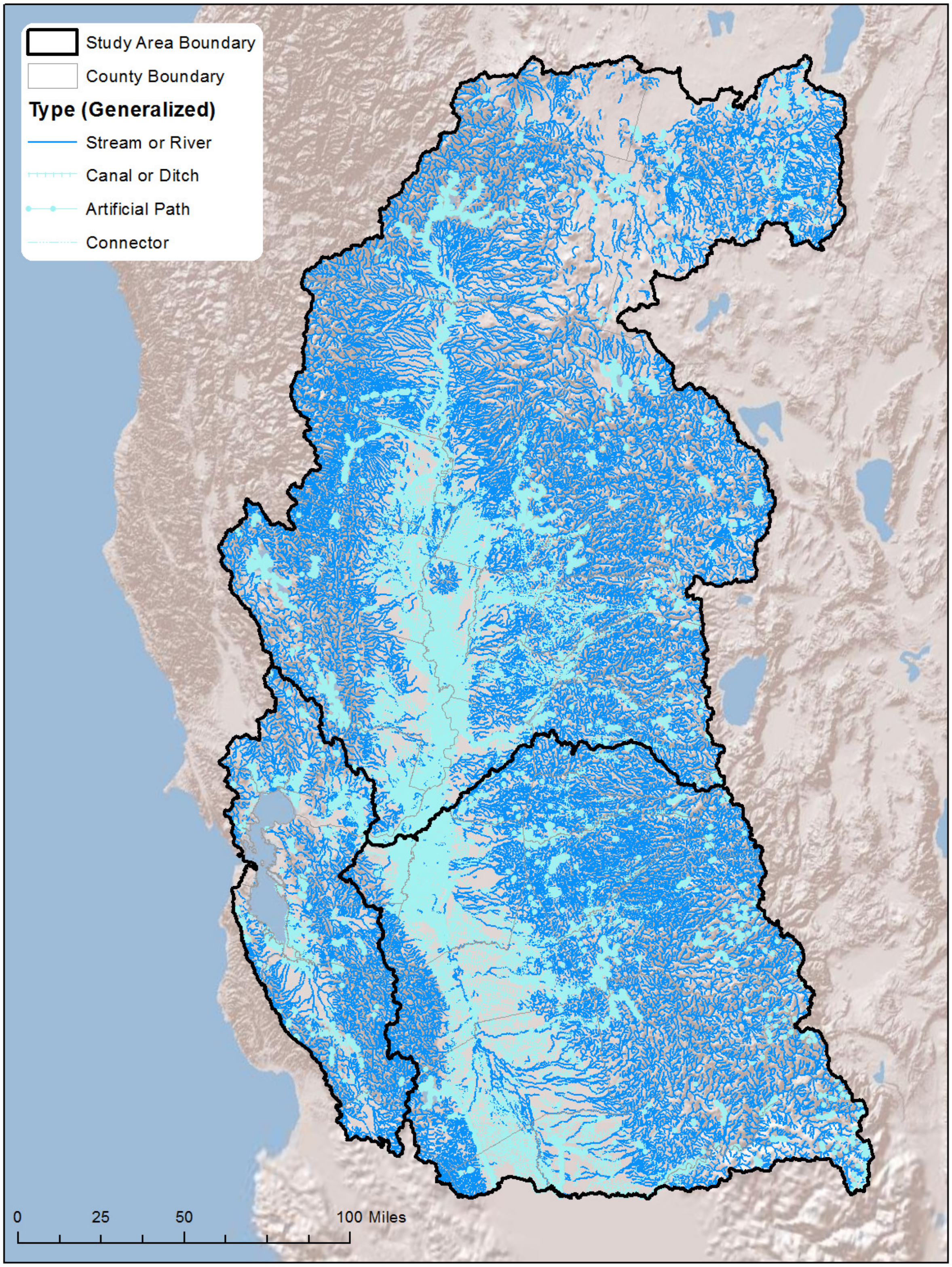


Figure 9 NHD Stream Order, including ditches and canals

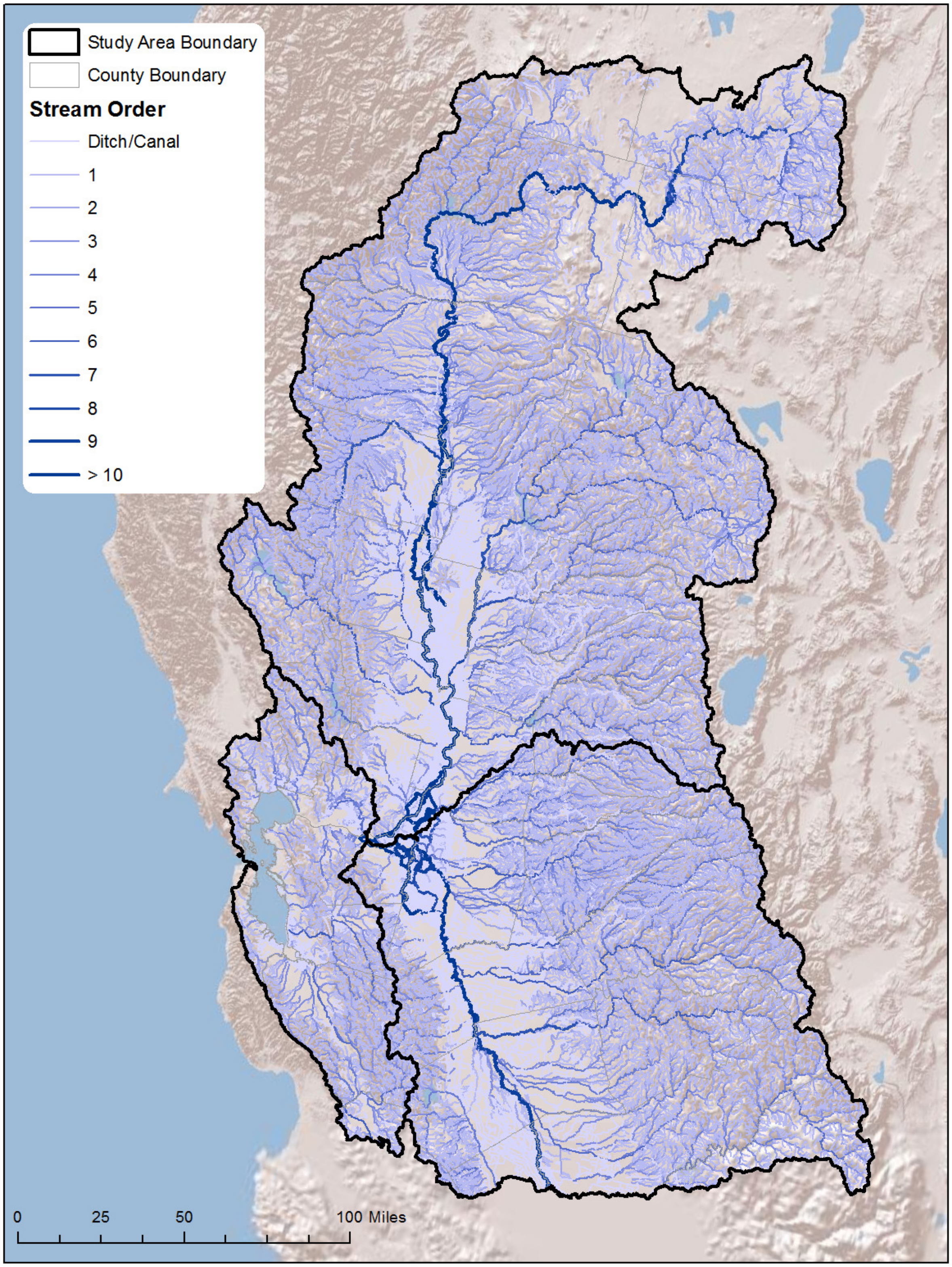


Figure 10 Detailed view of the land use in the delta region based on the 2006 Farm Monitoring and Mapping Program

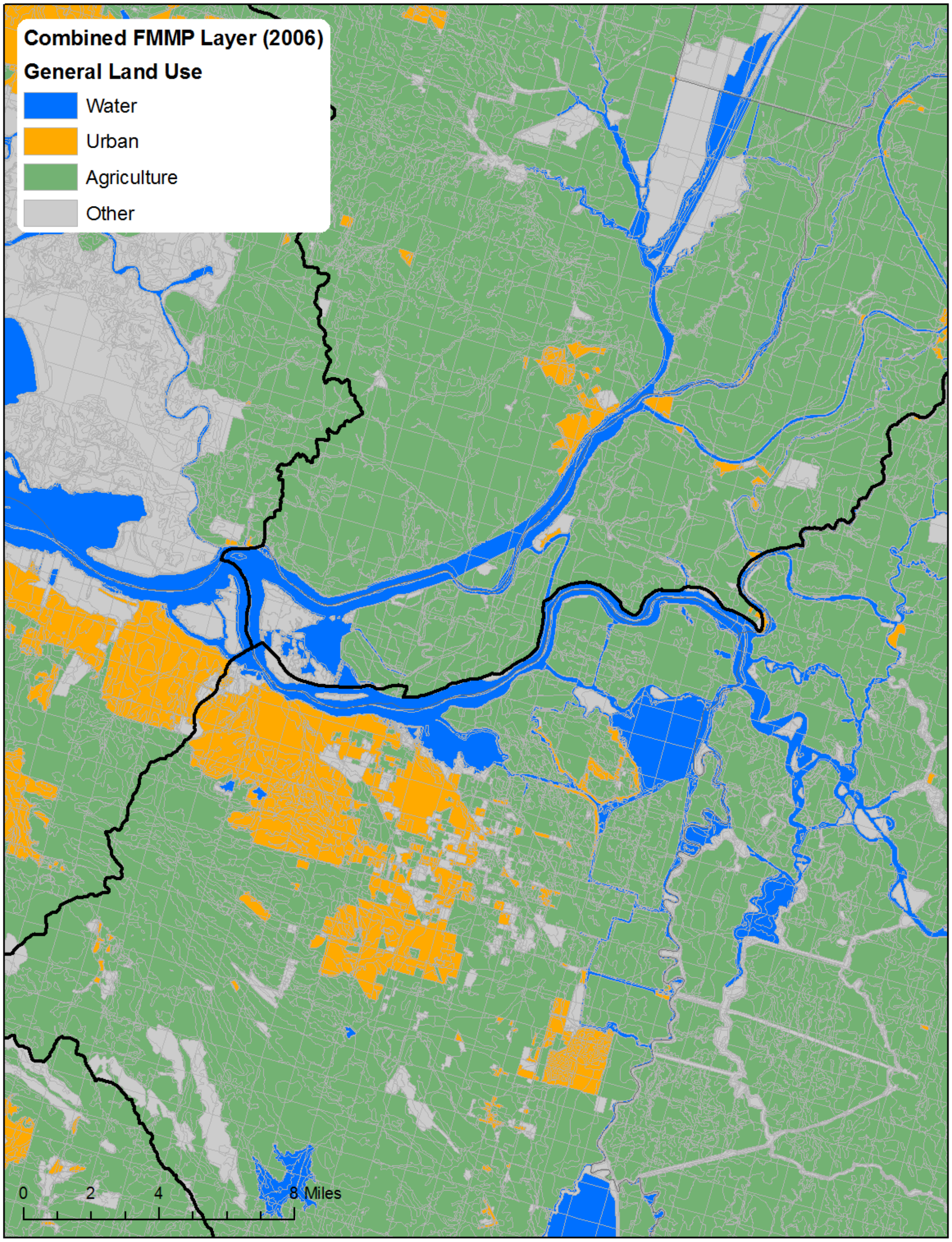
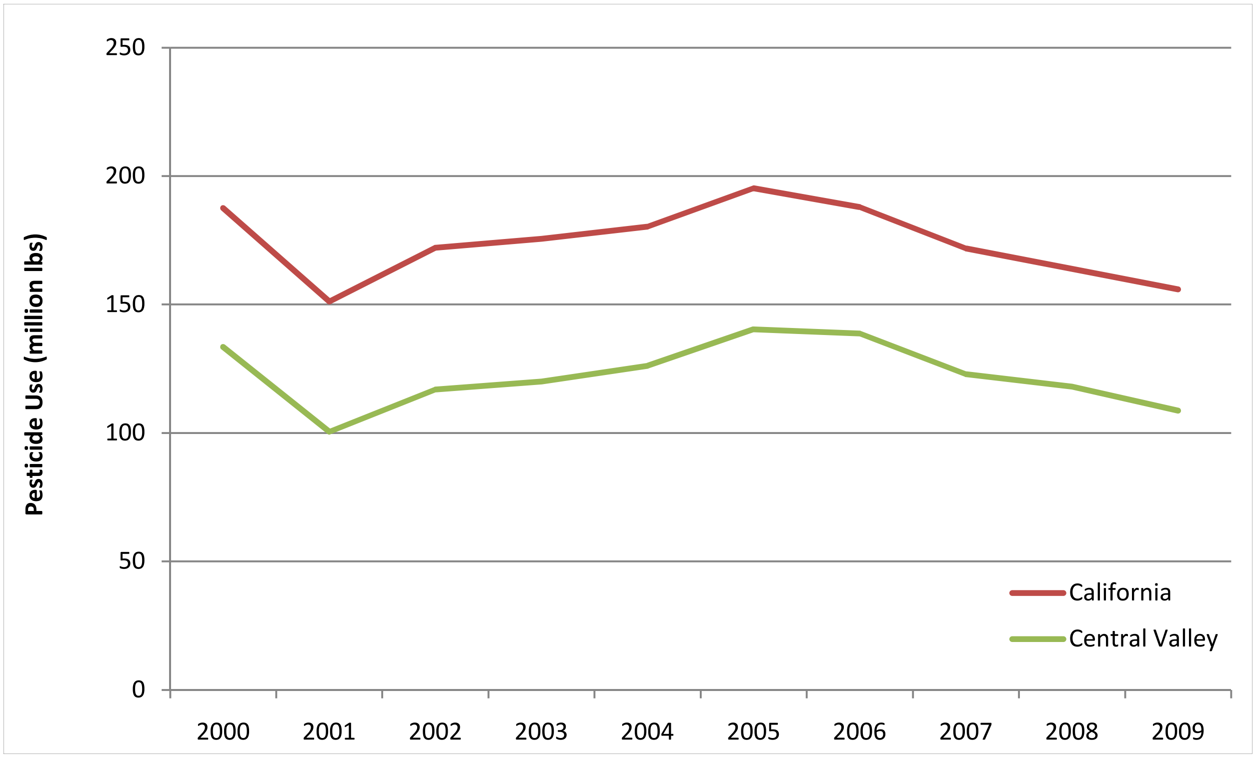
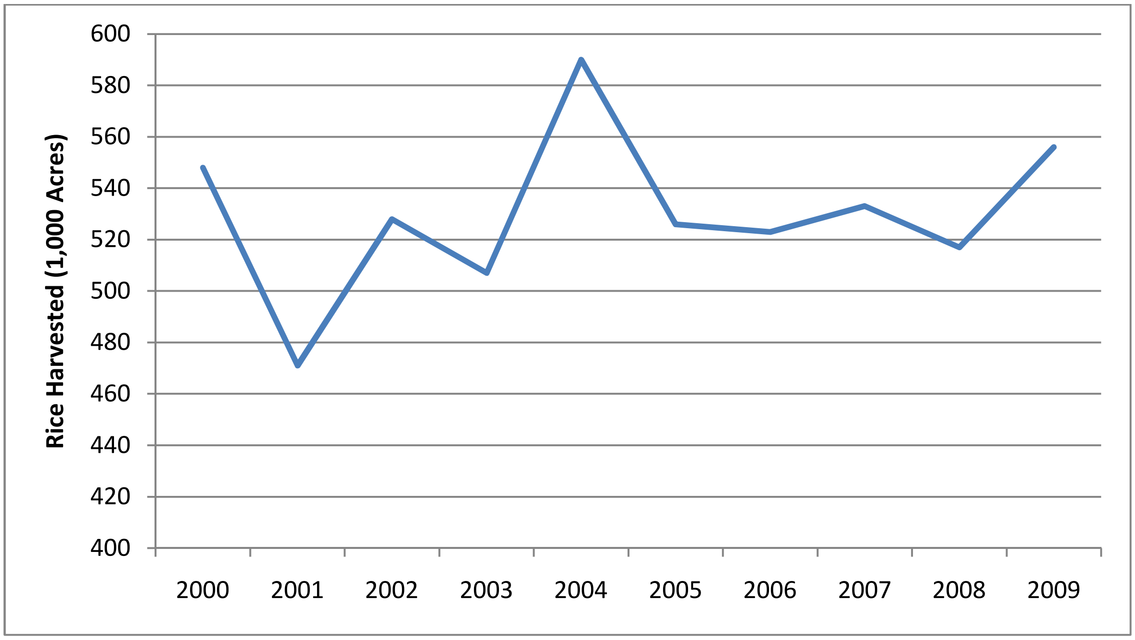


Figure 11 Pesticide use trend in California and the Central Valley for 2000–2009



Data source: CA PUR 2011

Figure 12 Total area of rice harvested in California in the period 2000 - 2009



Data source: California Agricultural Statistics Service (2011)

Figure 13 Life-cycle of the Chinook Salmon (*Oncorhynchus tshawytscha*) Sacramento River winter-run

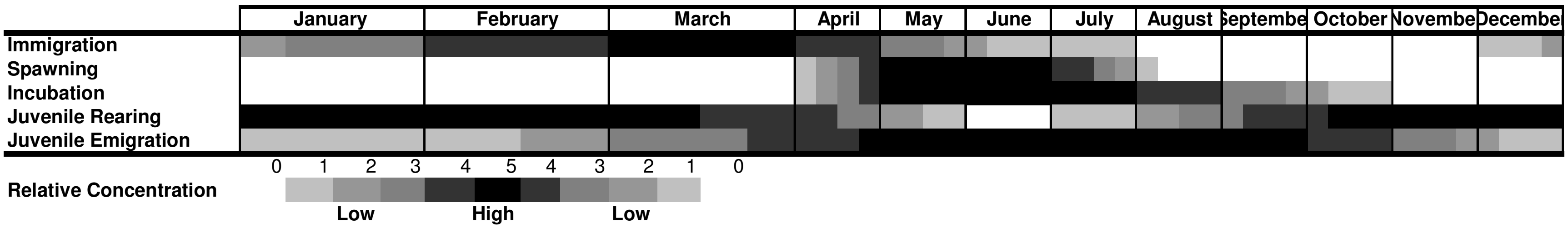


Figure 14 Life-cycle of the Chinook Salmon (*Oncorhynchus tshawytscha*) Central Valley spring-run

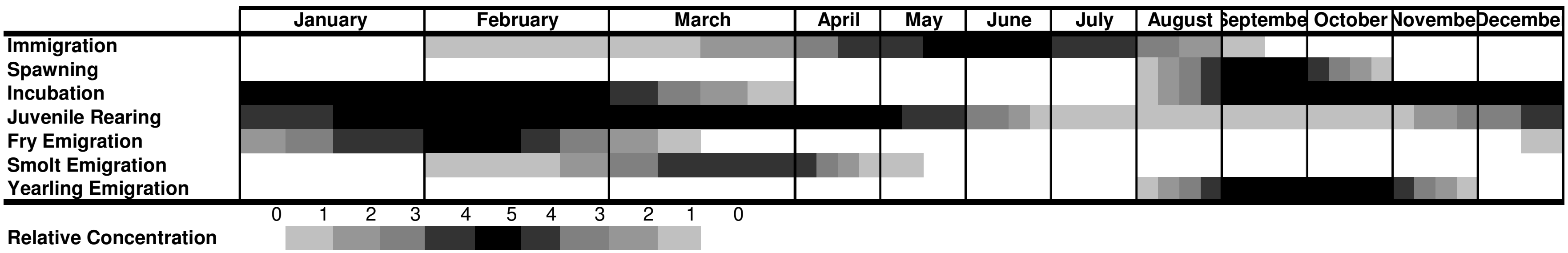


Figure 15 Life-cycle of the Chinook Salmon (*Oncorhynchus tshawytscha*) Central Valley fall run

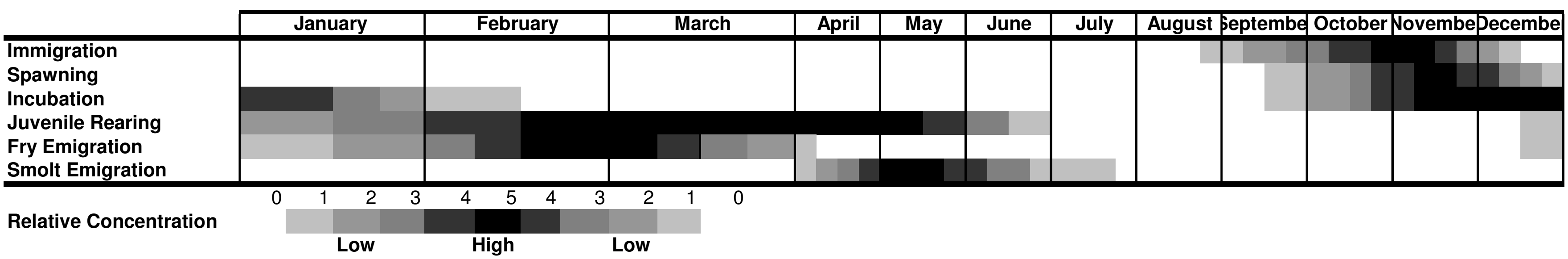


Figure 16 Life-cycle of the Chinook Salmon (*Oncorhynchus tshawytscha*) Central Valley late fall run

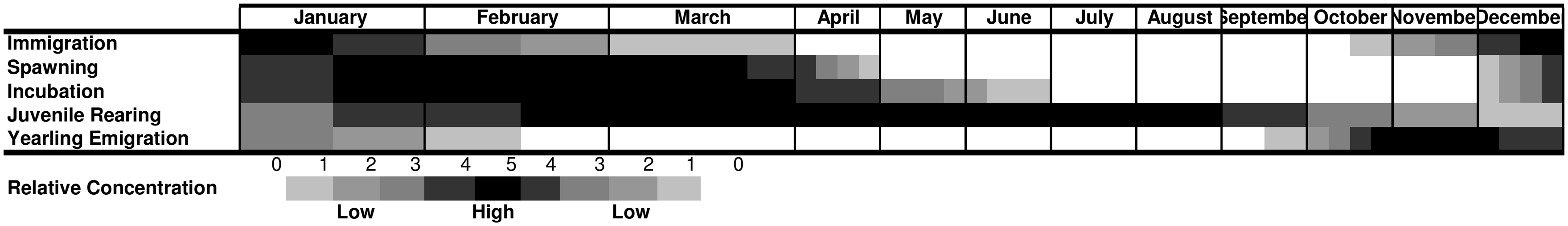


Figure 17 Life-cycle of the Central Valley steelhead (*Oncorhynchus mykiss*)

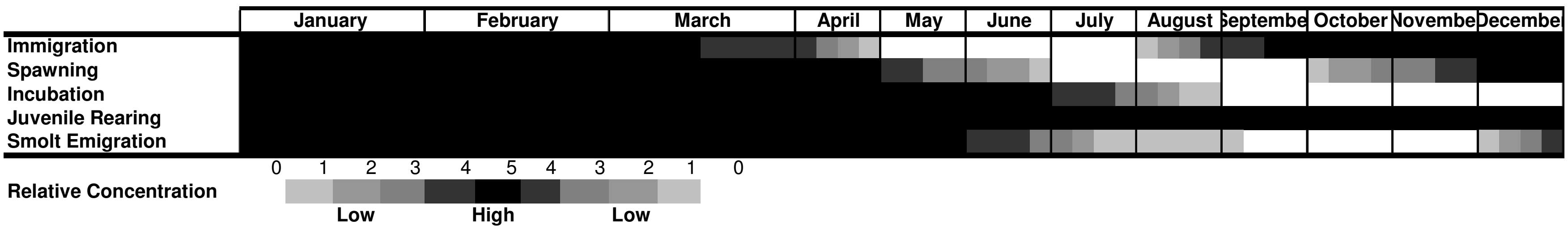


Figure 18 Life-cycle of the Southern North American Green Sturgeon (*Acipenser medirostris*)

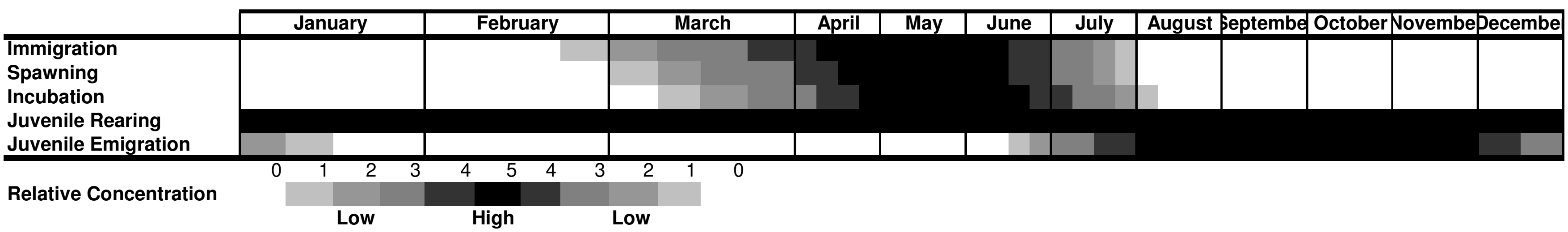


Figure 19 Life-cycle of the Delta Smelt (*Hypomesus transpacificus*)

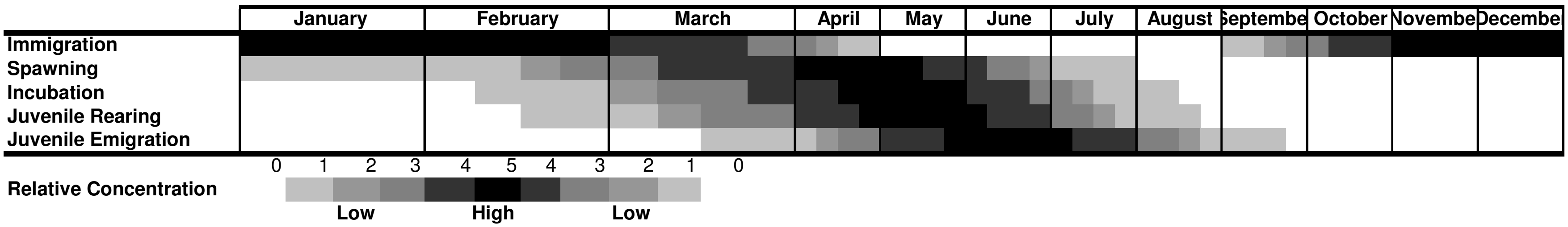


Figure 20 Life-cycle of the Striped Bass (*Morone saxatilis*)

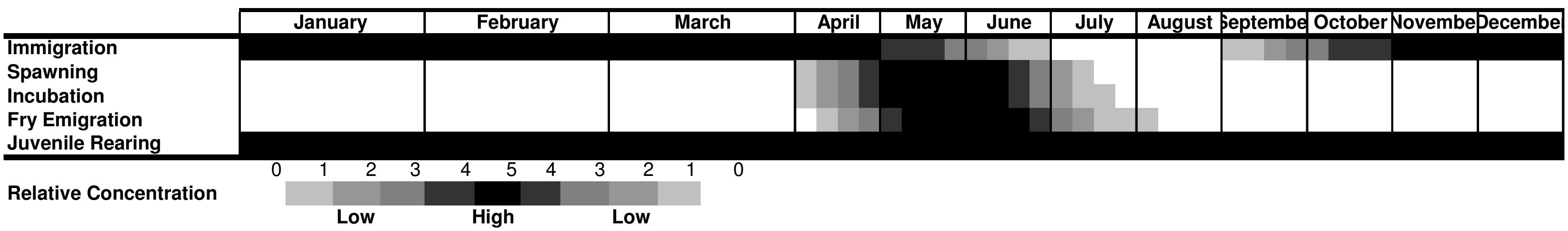


Figure 21 Life-cycle of the San Francisco Longfin Smelt (*Spirinchus thaleichthys*)

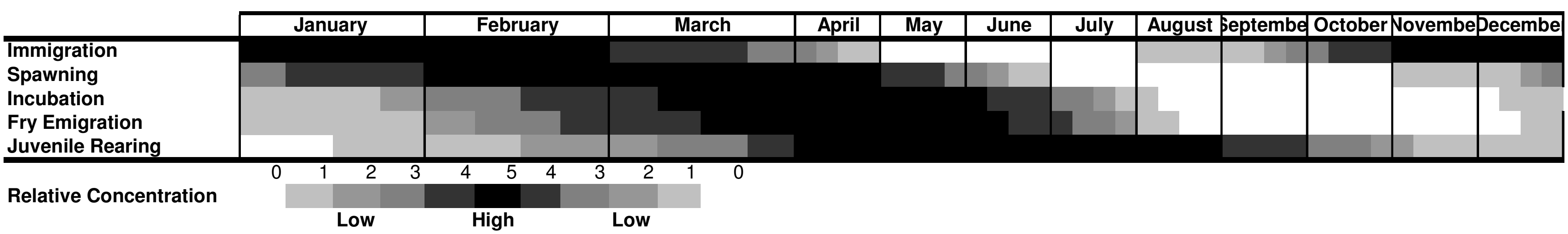


Figure 22 Life-cycle of the Threadfin Shad (*Dorosoma petenense*)

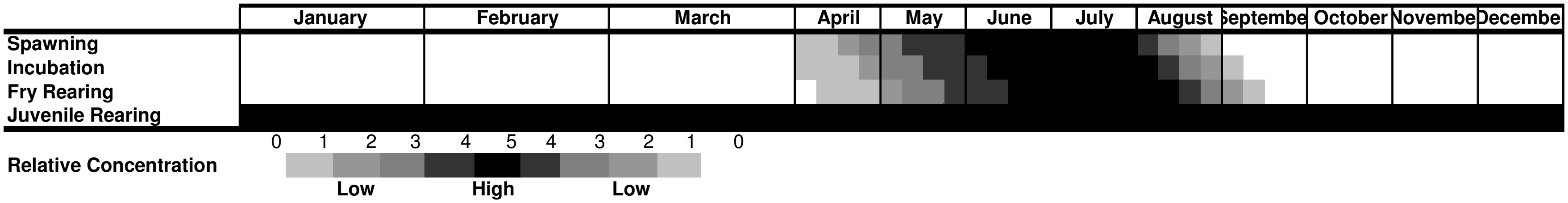


Figure 23 Life-cycle of the California Red-legged Frog (*Rana draytonii*)

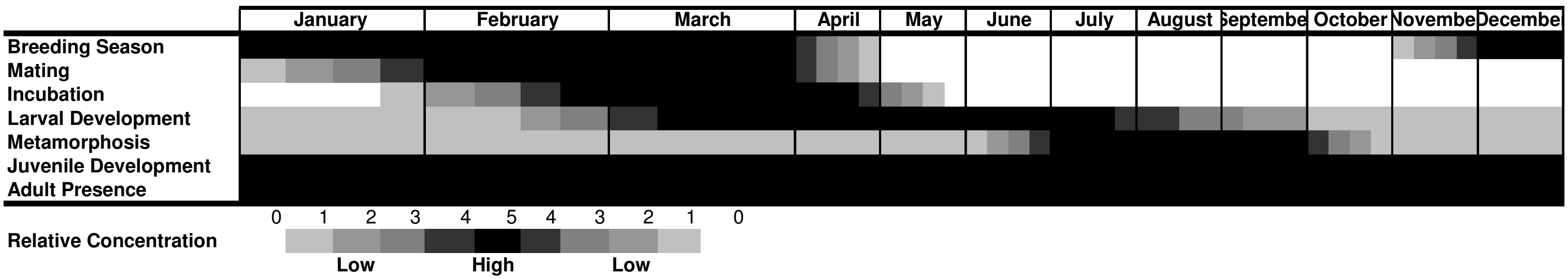


Figure 24 Life-cycle of the California Freshwater Shrimp (*Syncaris pacifica*)

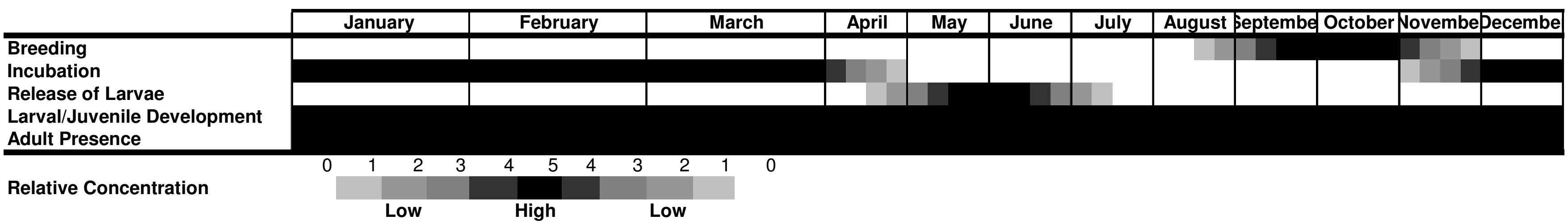


Figure 25 Acres planted in rice in 2009

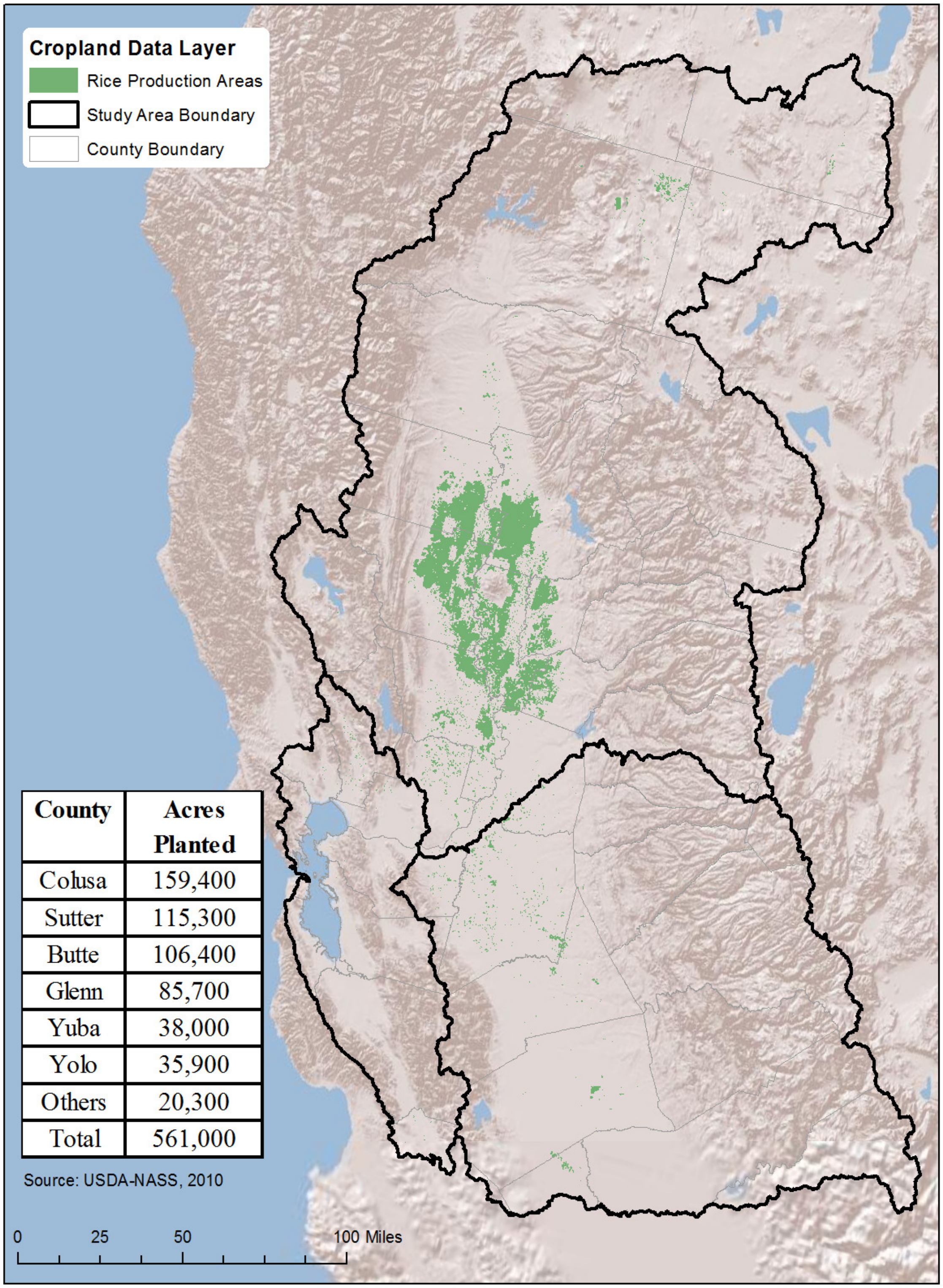
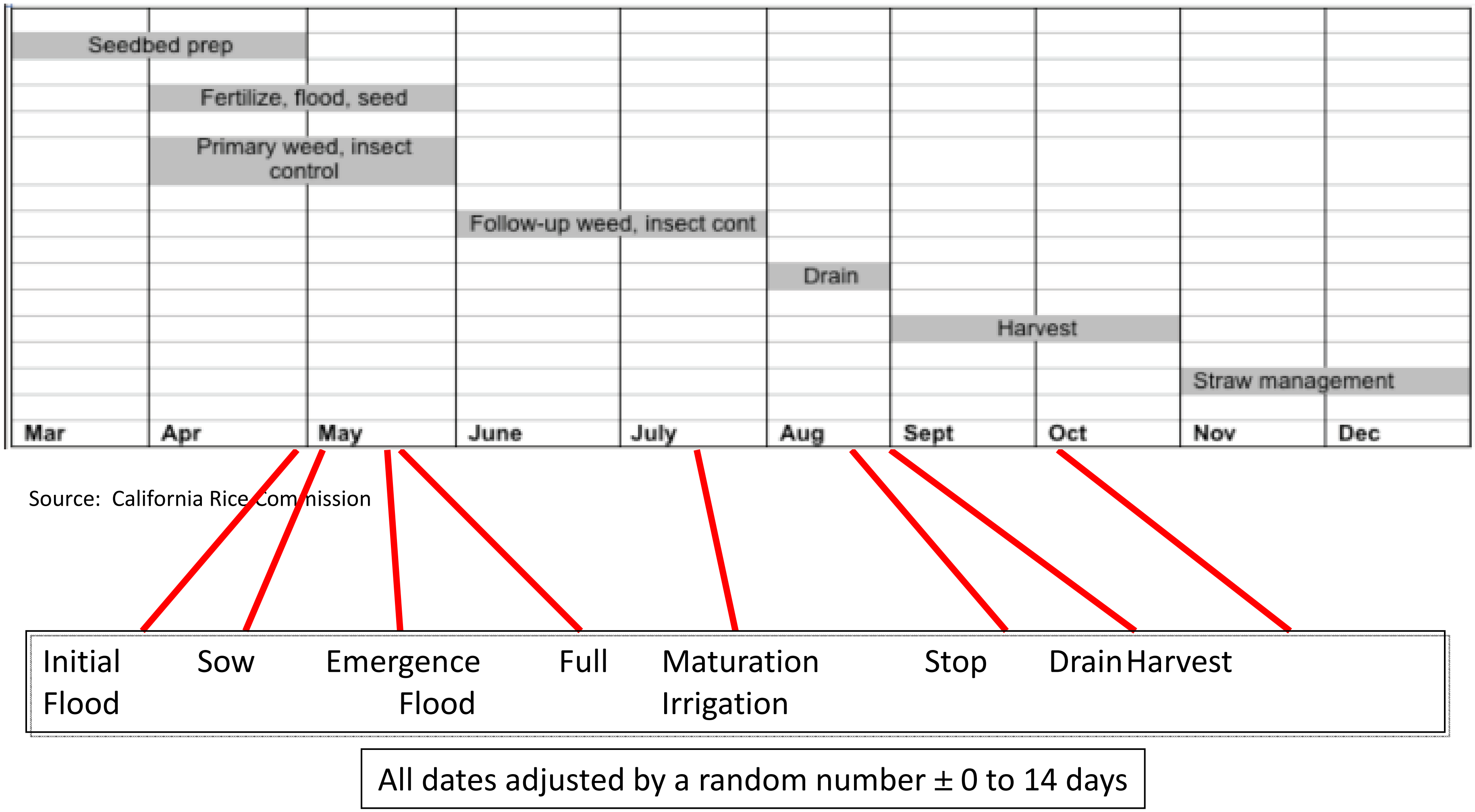


Figure 26 Calendar of Operations for Rice Production in California



Source: California Rice Commission

Figure 27 Process flow of distributing county-level mass loadings of pesticides to the PLSS section level

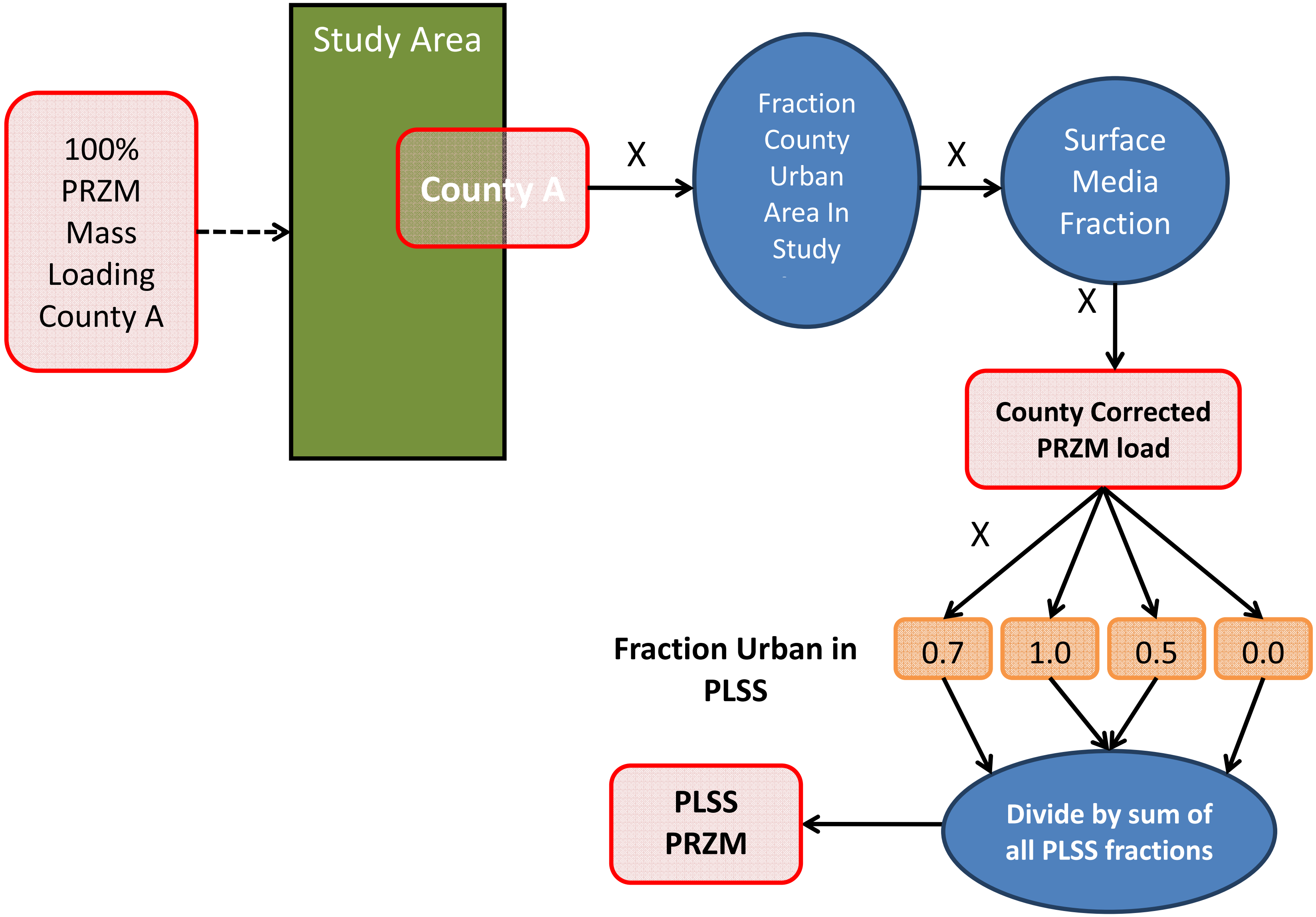


Figure 28 RF1 relationship between stream width and depth for stream in the CALFED study area

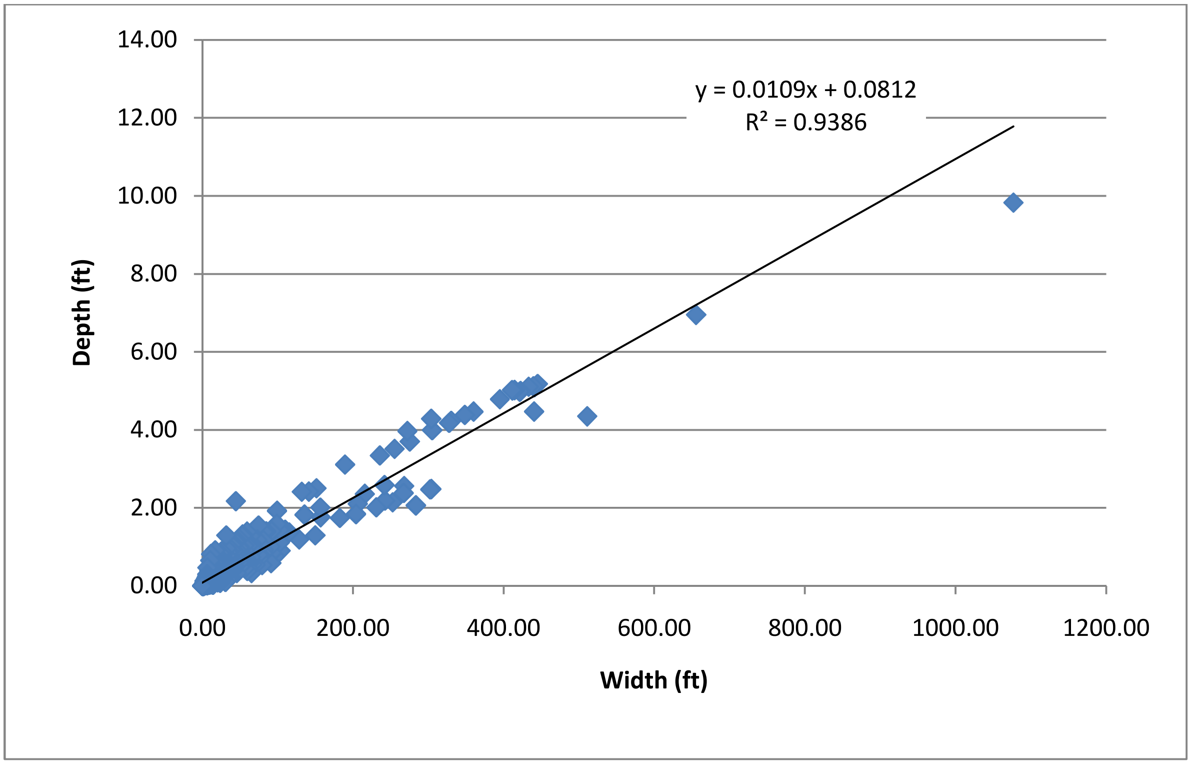
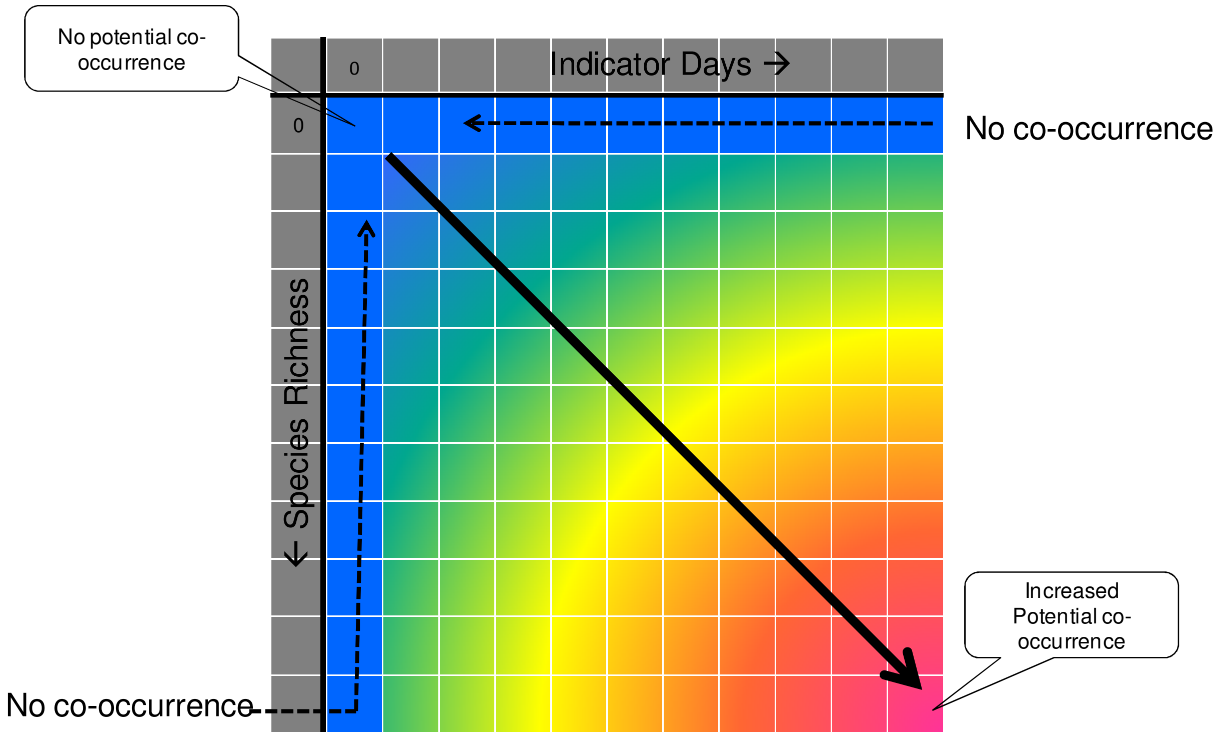


Figure 29 Holmes Co-occurrence matrix (a) basic design, (b) filled in

(a)



(b)

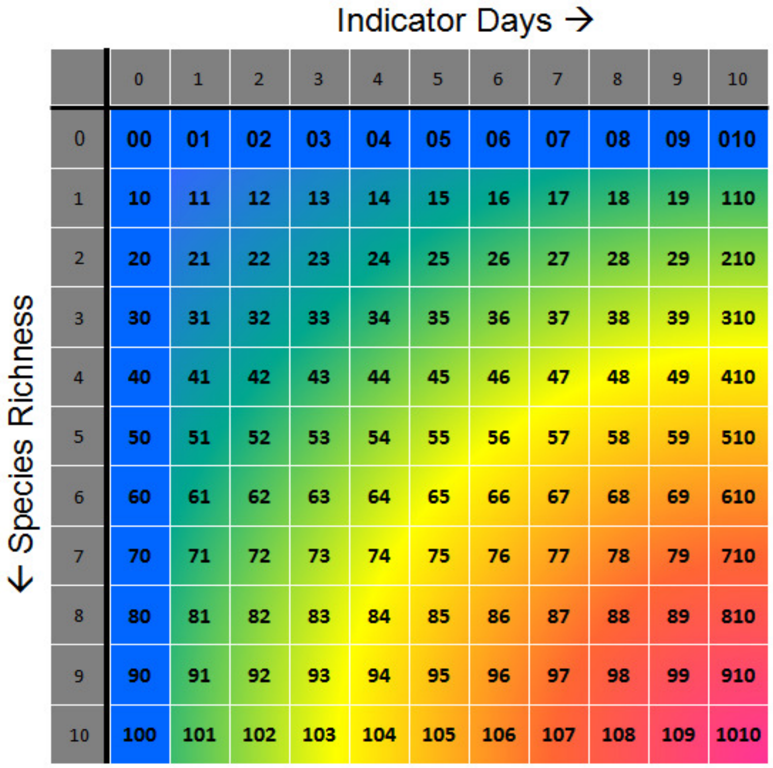

Indicator Days →
← Species Richness
0 1 2 3 4 5 6 7 8 9 10
0 00 01 02 03 04 05 06 07 08 09 010
1 10 11 12 13 14 15 16 17 18 19 110
2 20 21 22 23 24 25 26 27 28 29 210
3 30 31 32 33 34 35 36 37 38 39 310
4 40 41 42 43 44 45 46 47 48 49 410
5 50 51 52 53 54 55 56 57 58 59 510
6 60 61 62 63 64 65 66 67 68 69 610
7 70 71 72 73 74 75 76 77 78 79 710
8 80 81 82 83 84 85 86 87 88 89 810
9 90 91 92 93 94 95 96 97 98 99 910
10 100 101 102 103 104 105 106 107 108 109 1010

Figure 30 Application locations considered in the study

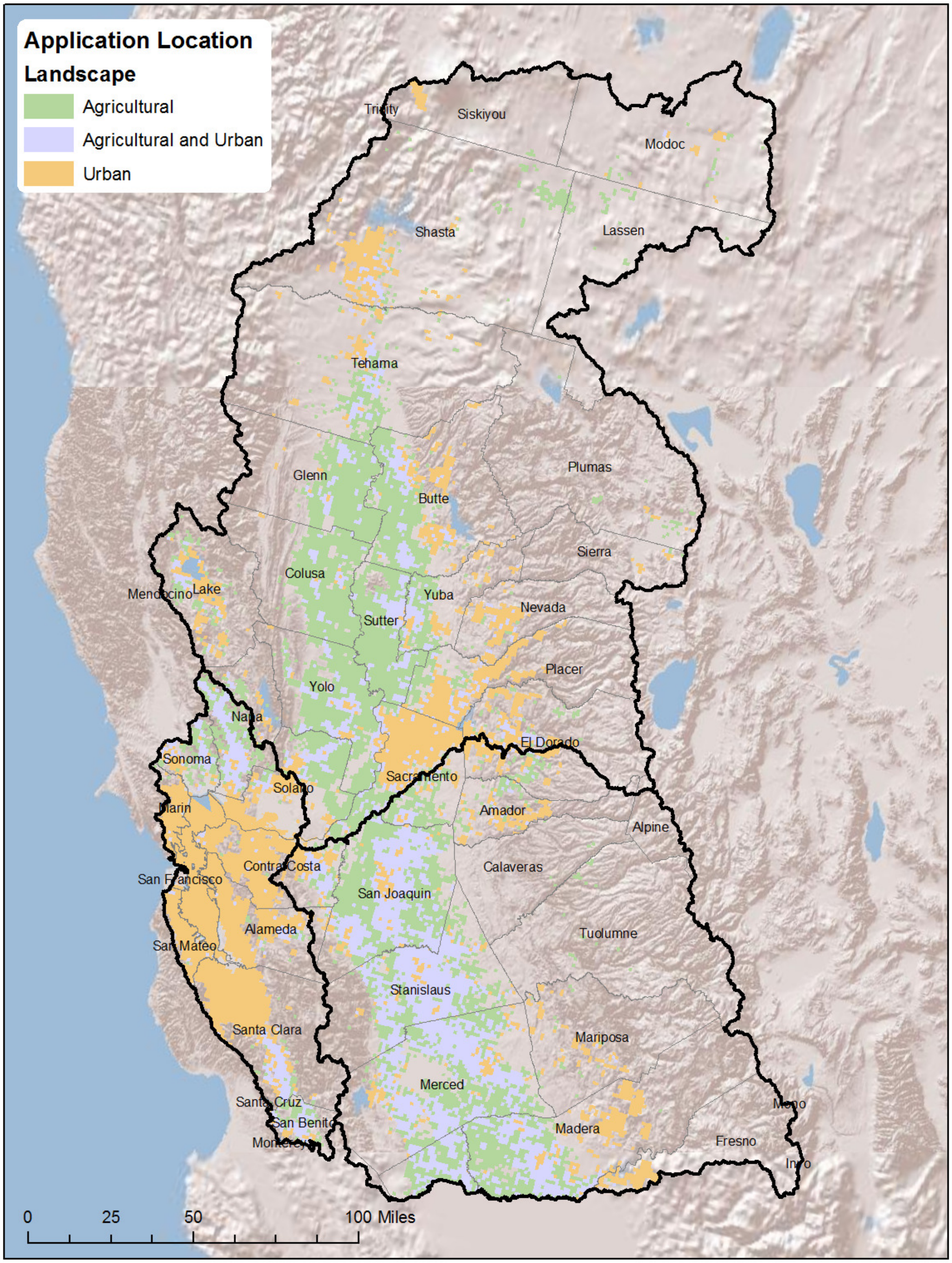


Figure 31 Section where agricultural and urban applications were simulated with urban areas transposed on the map.

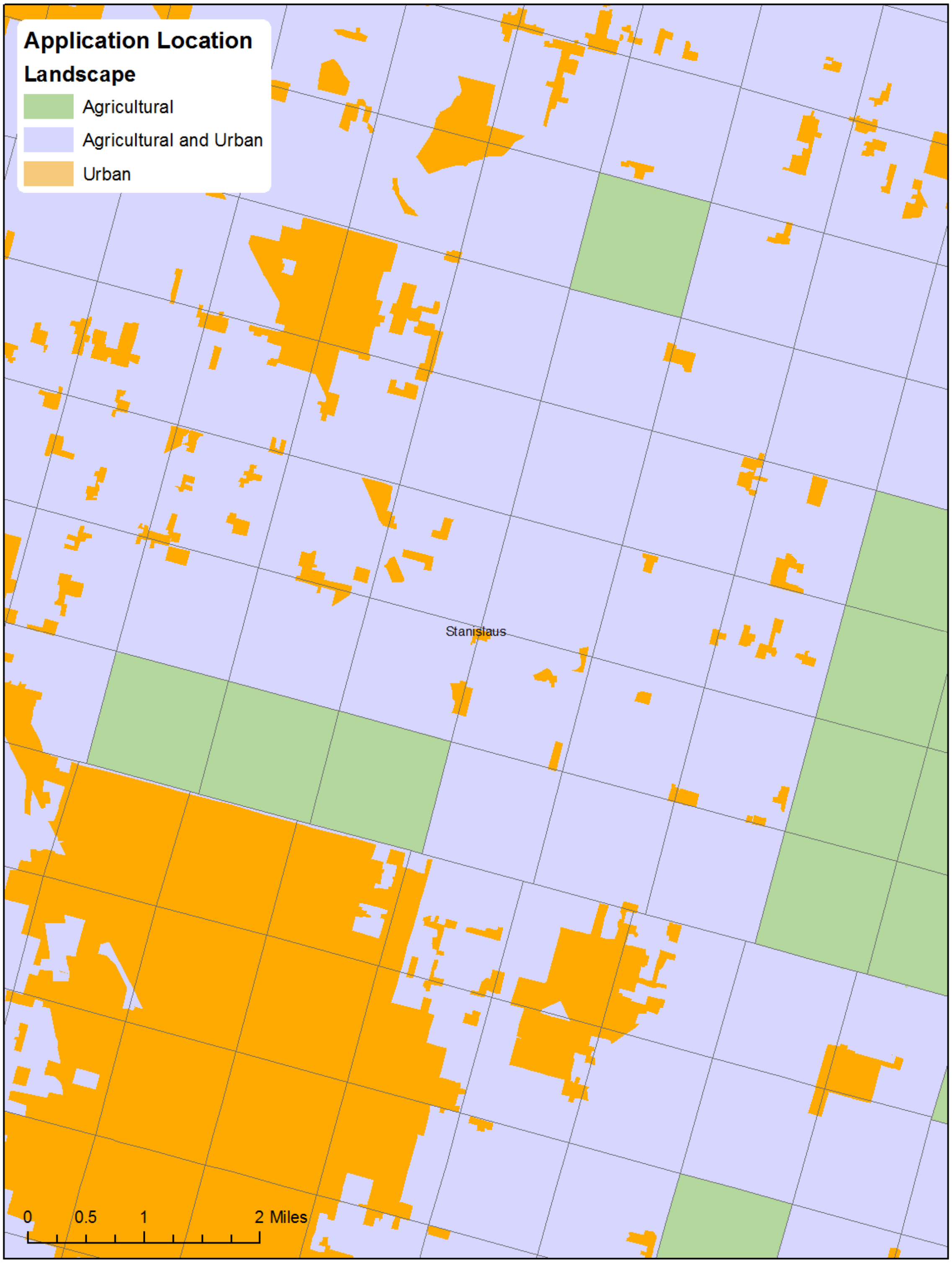


Figure 32 Total mass loading for 40 chemicals in the period 2000–2009

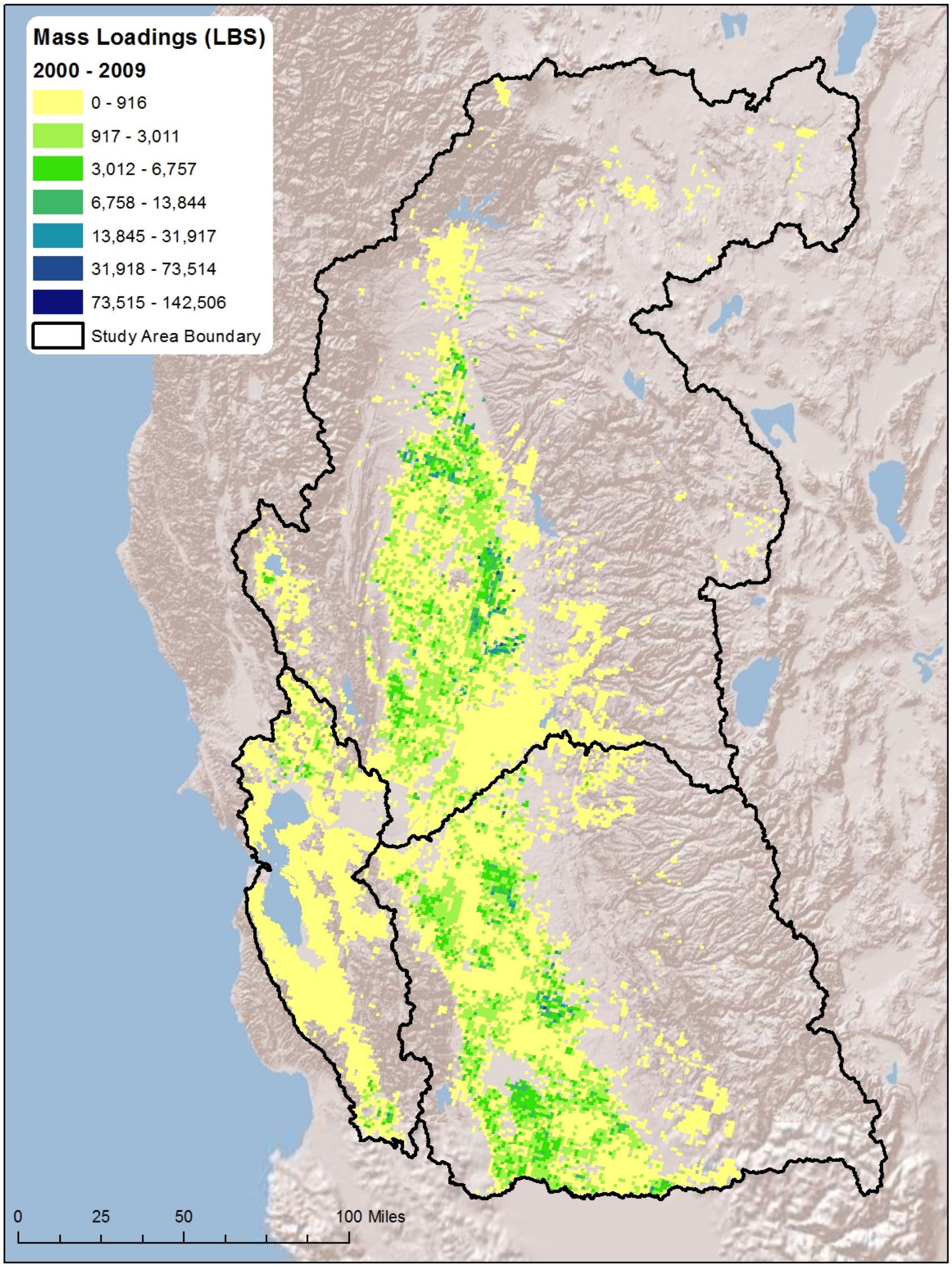


Figure 33 Spatial distribution of Indicator Days exceeding T&ES benchmarks for species of concern for the period 2000–2009

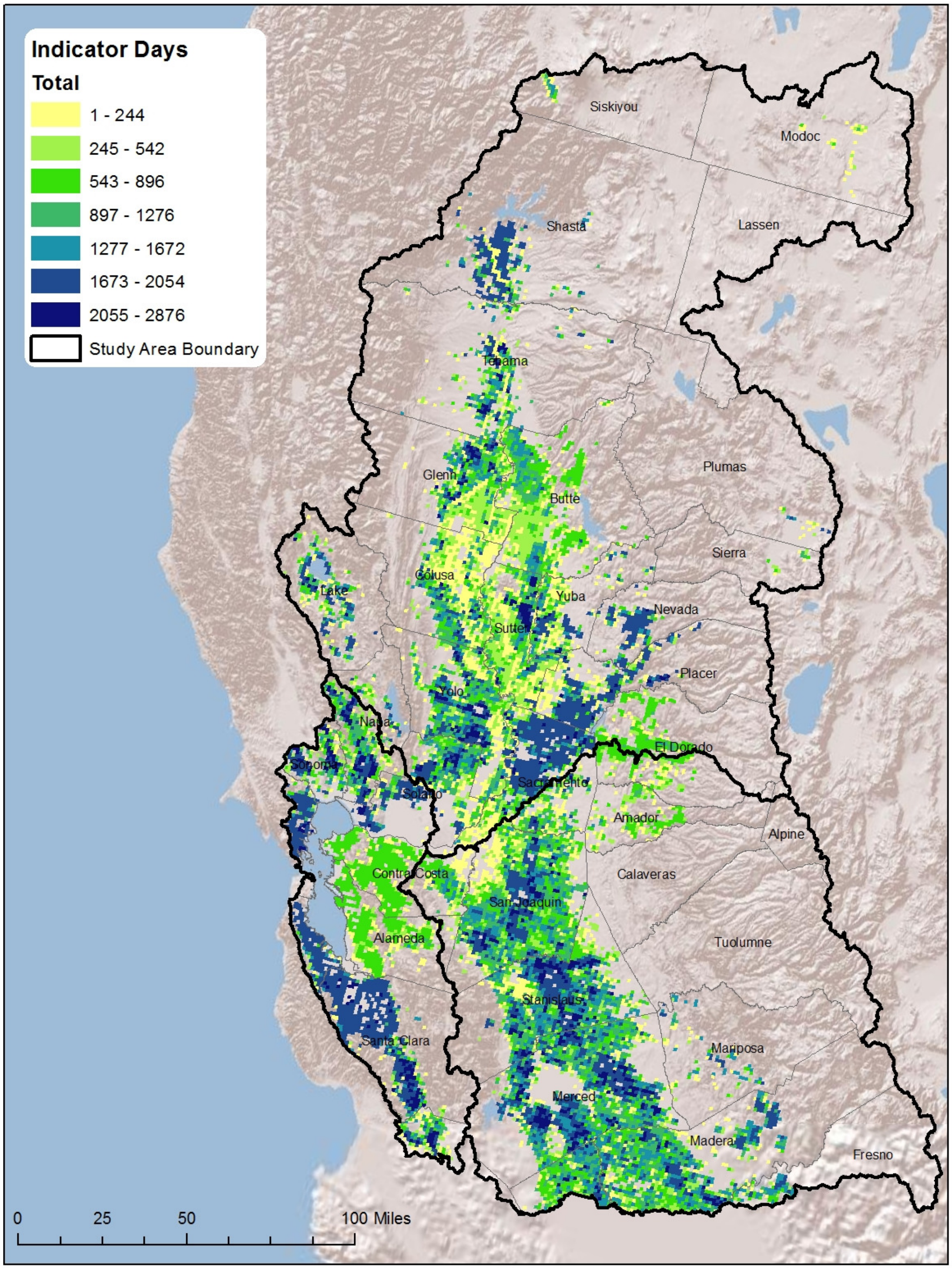


Figure 34 Temporal trend of the number of indicator days by month for randomly selected PLSS sections in the study area

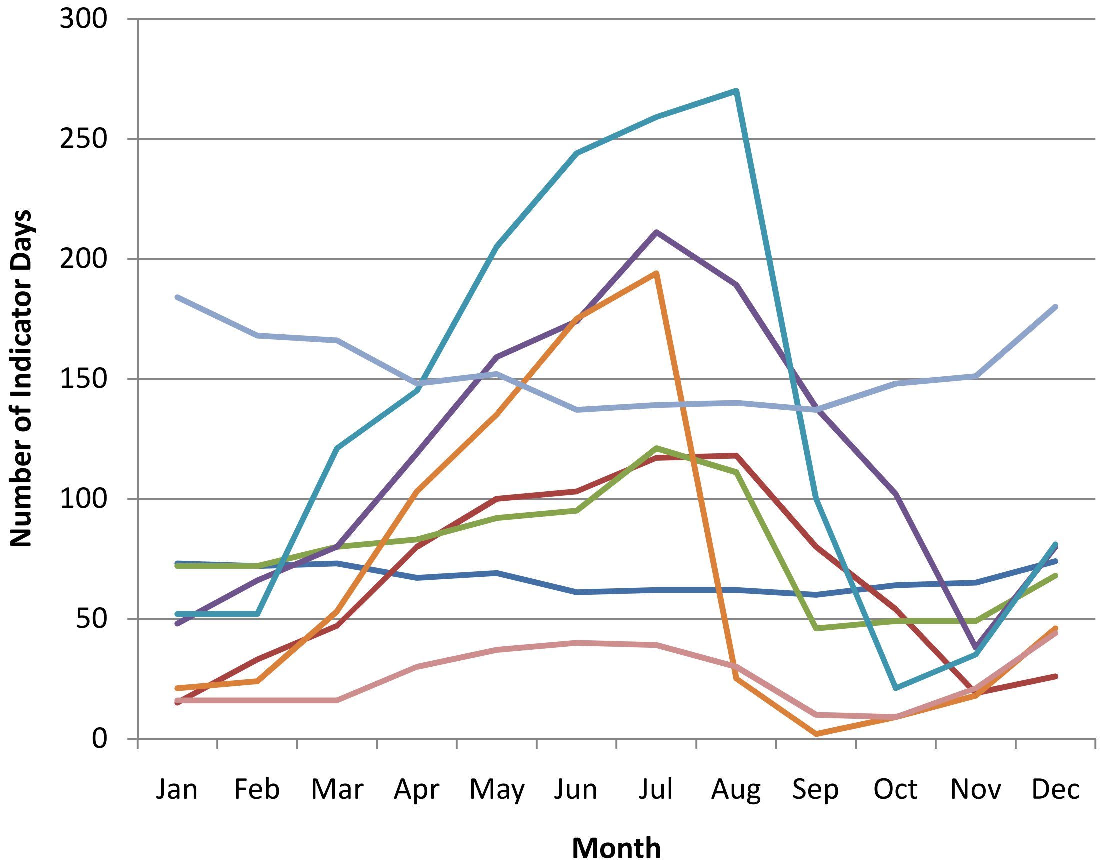


Figure 35 Frequency and cumulative distribution of all Indicator Days

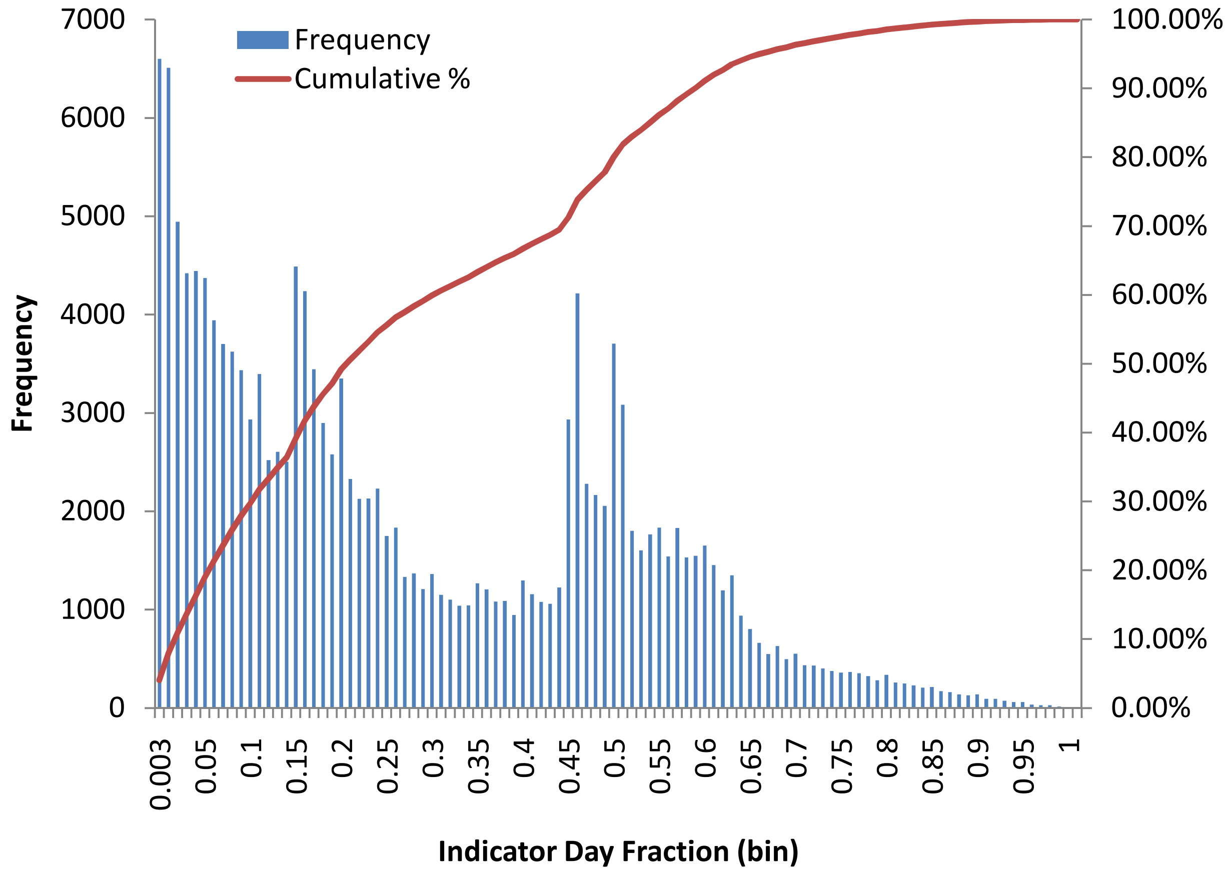


Figure 36 Spatial distribution of the percentile level of Indicator days for January for the period 2000–2009

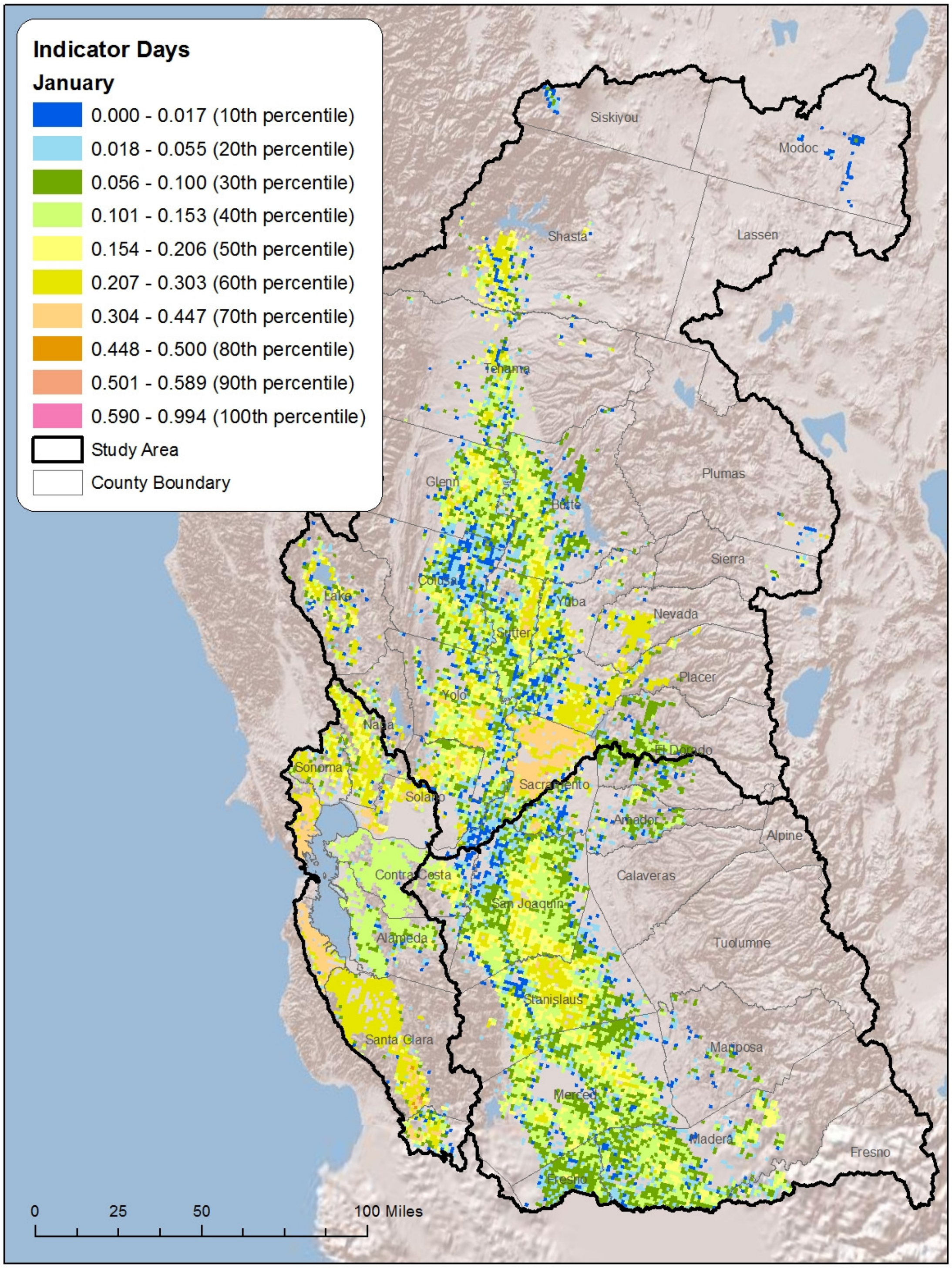


Figure 37 Spatial distribution of the percentile level of Indicator days for February for the period 2000–2009

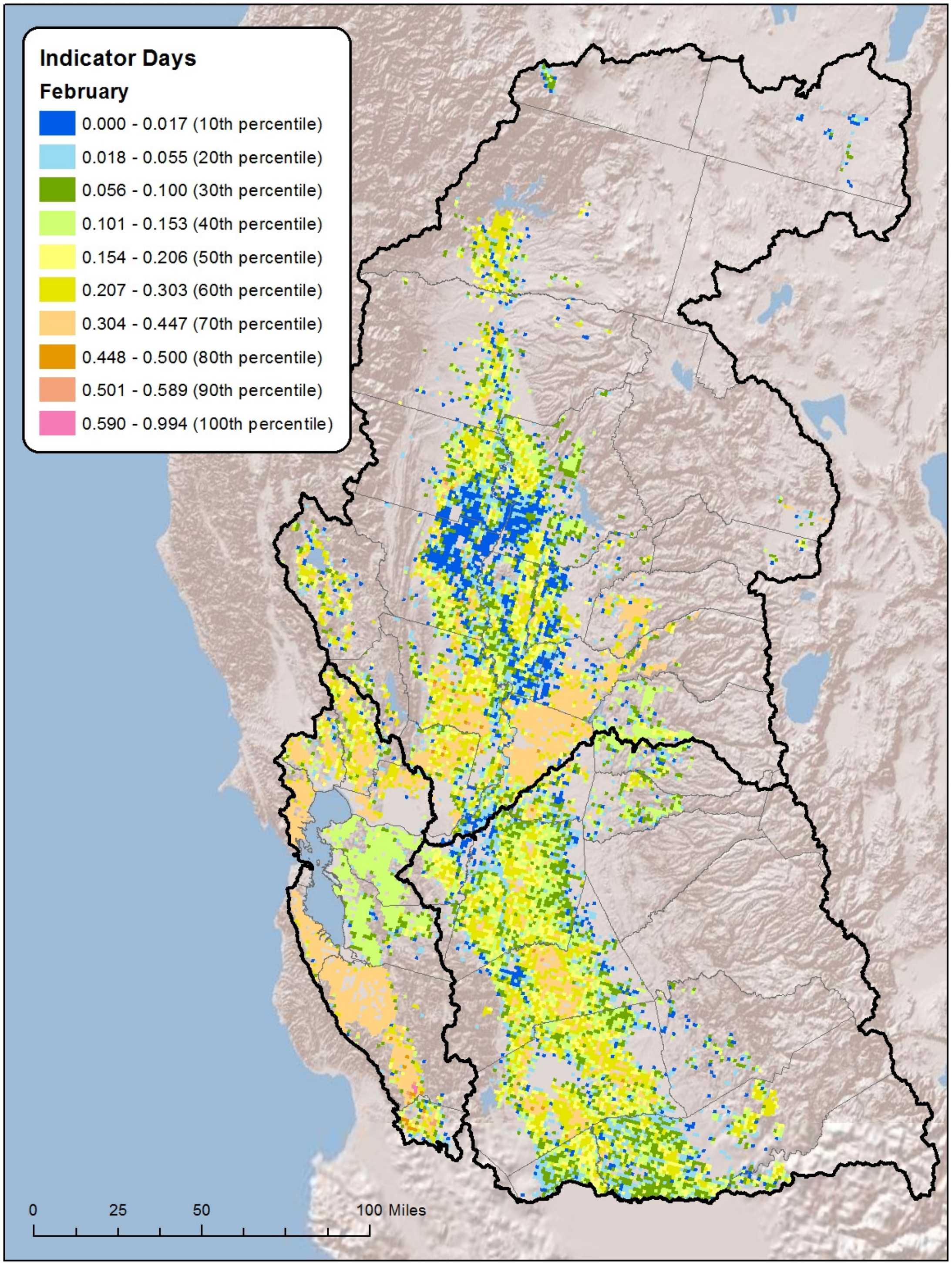


Figure 38 Spatial distribution of the percentile level of Indicator days for March for the period 2000–2009

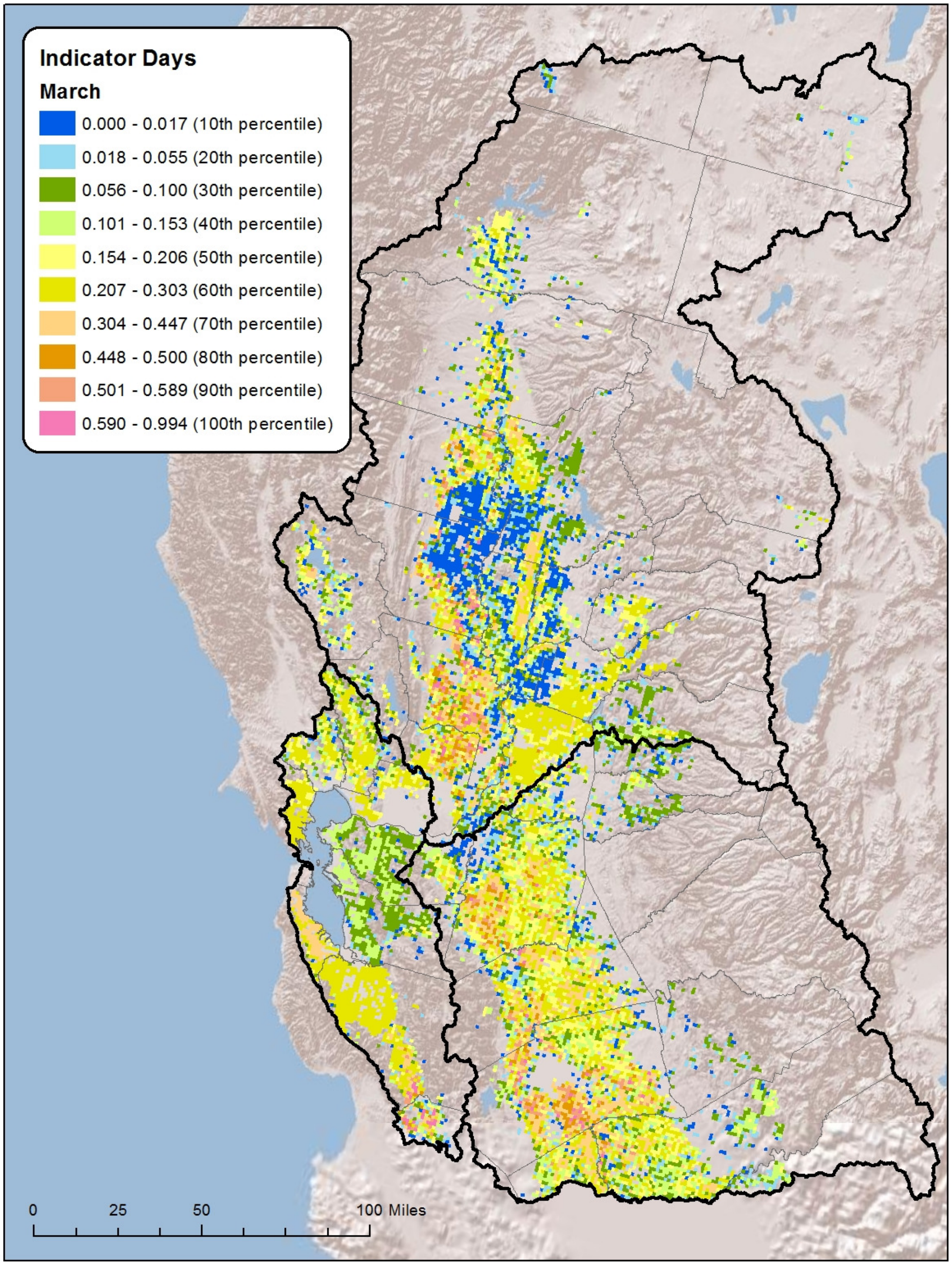


Figure 39 Spatial distribution of the percentile level of Indicator days for April for the period 2000–2009

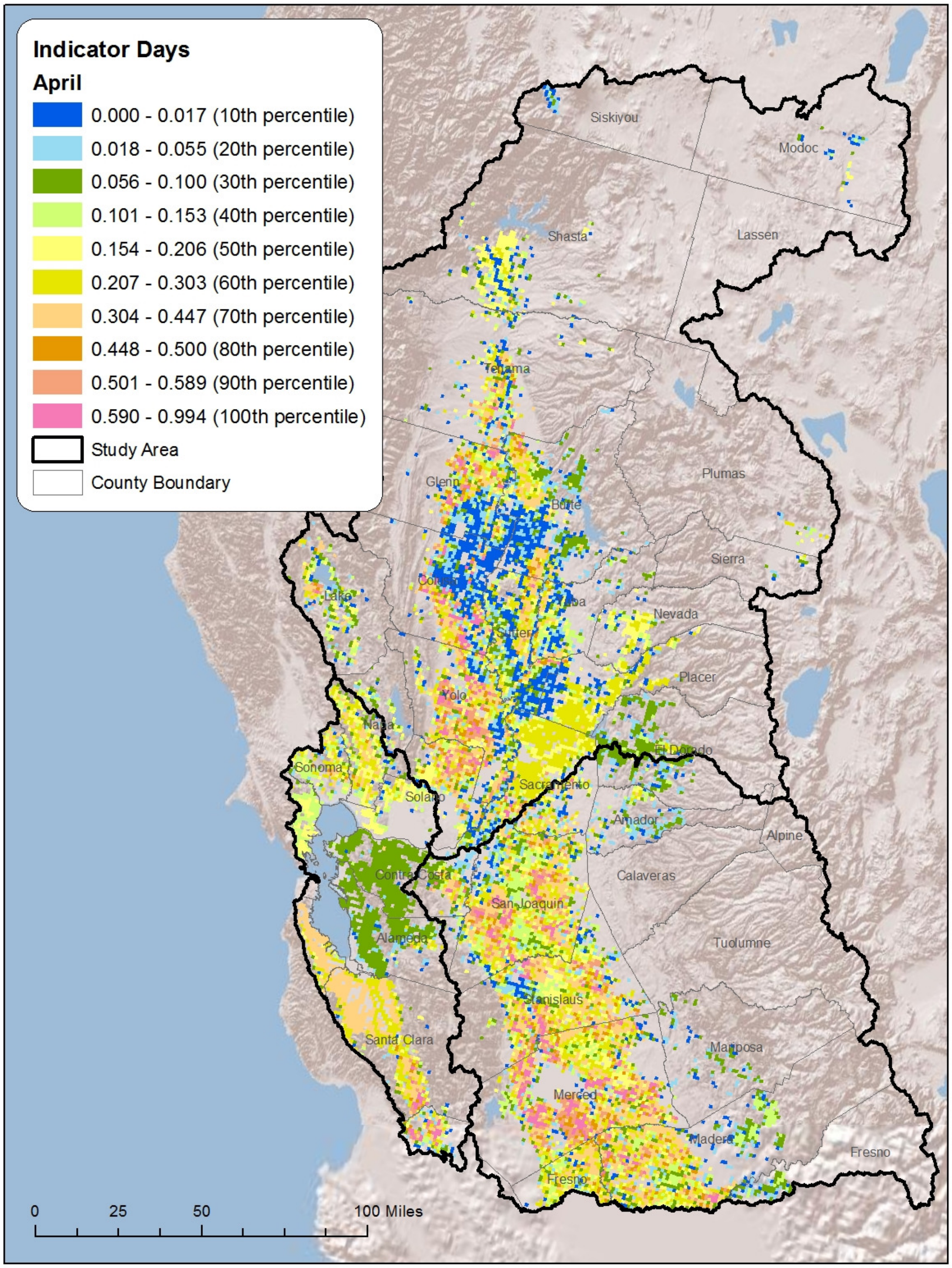


Figure 40 Spatial distribution of the percentile level of Indicator days for May for the period 2000–2009

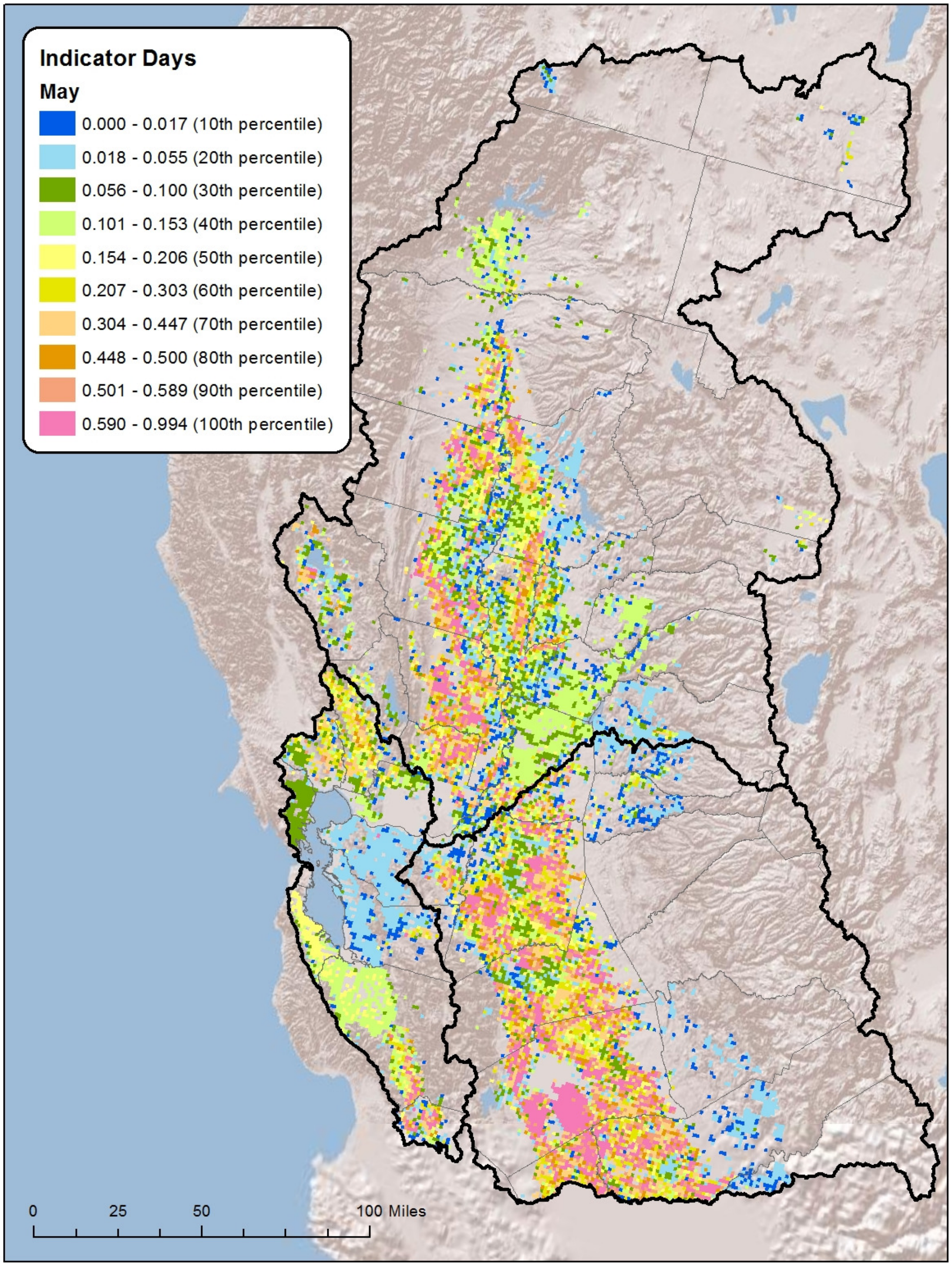


Figure 41 Spatial distribution of the percentile level of Indicator days for June for the period 2000–2009

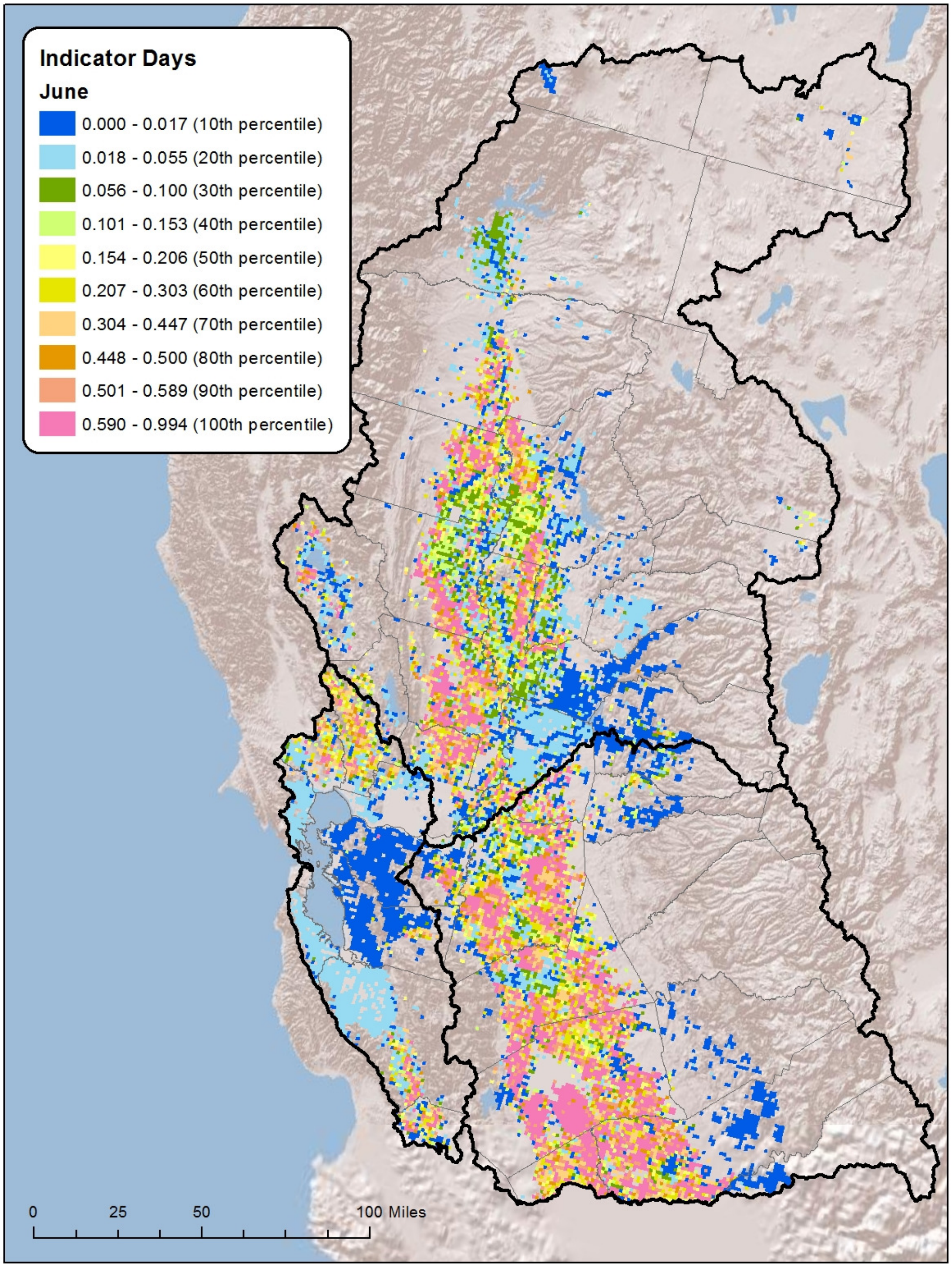


Figure 42 Spatial distribution of the percentile level of Indicator days for July for the period 2000–2009

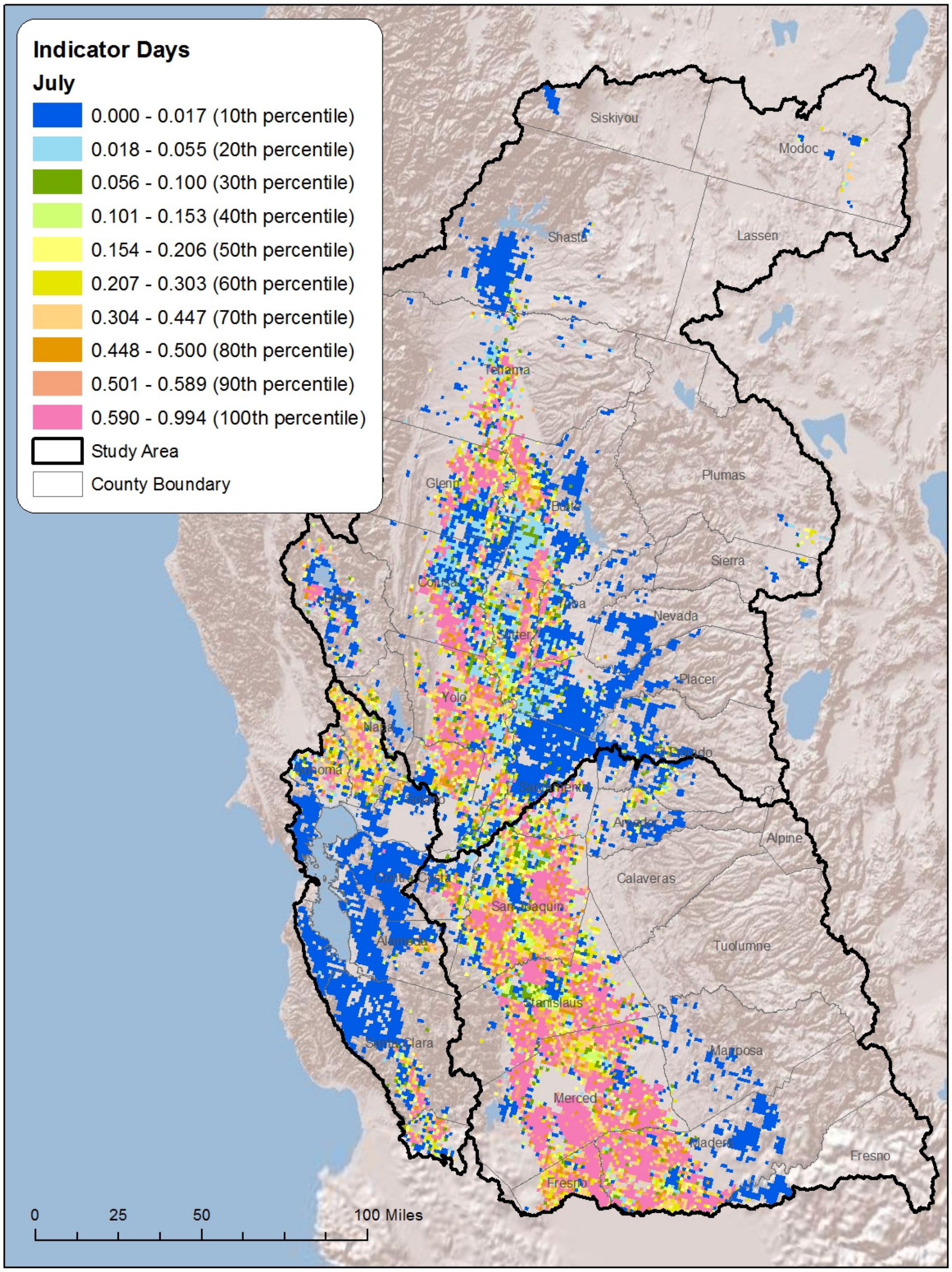


Figure 43 Spatial distribution of the percentile level of Indicator days for August for the period 2000–2009

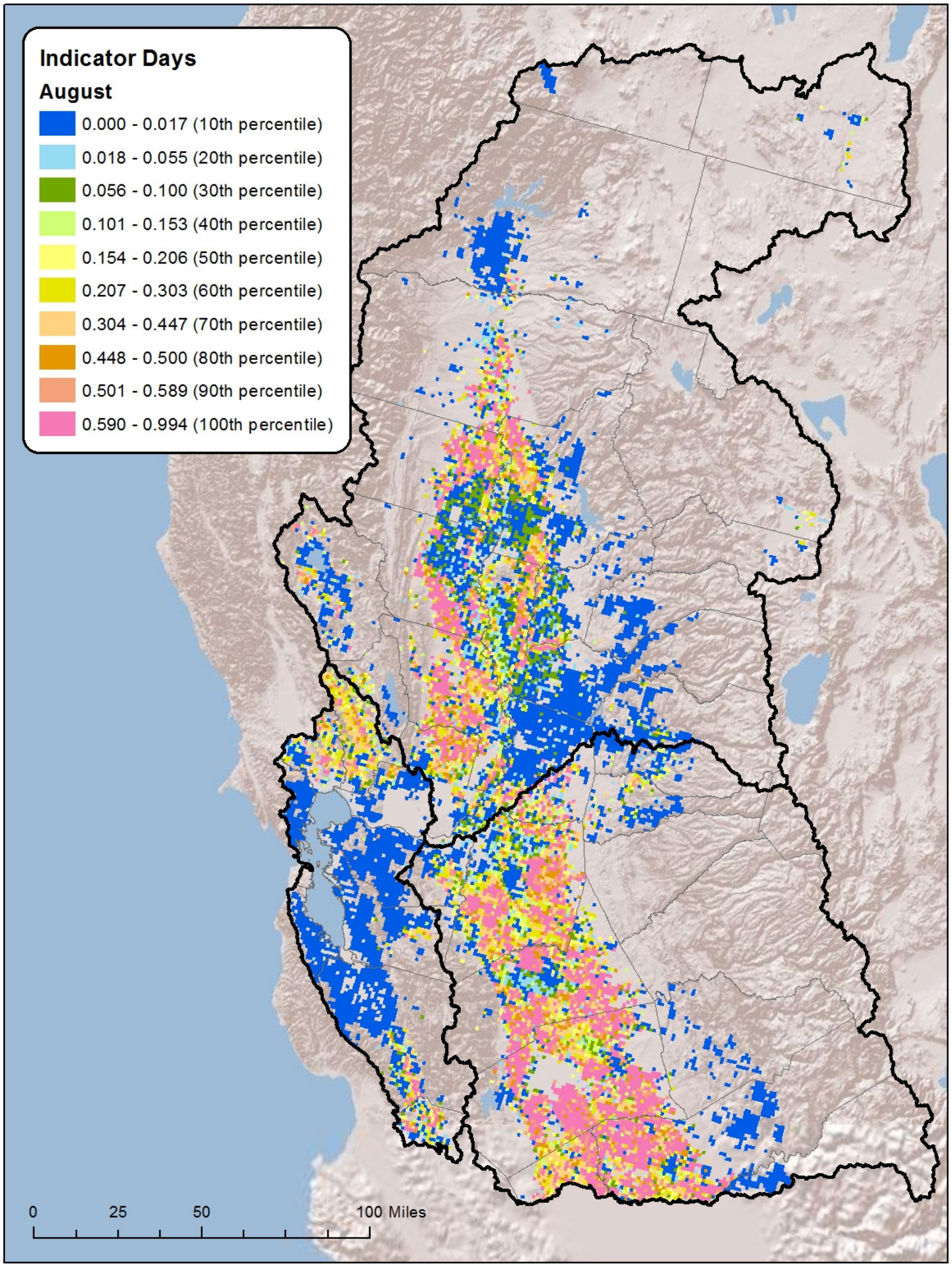


Figure 44 Spatial distribution of the percentile level of Indicator days for September for the period 2000–2009

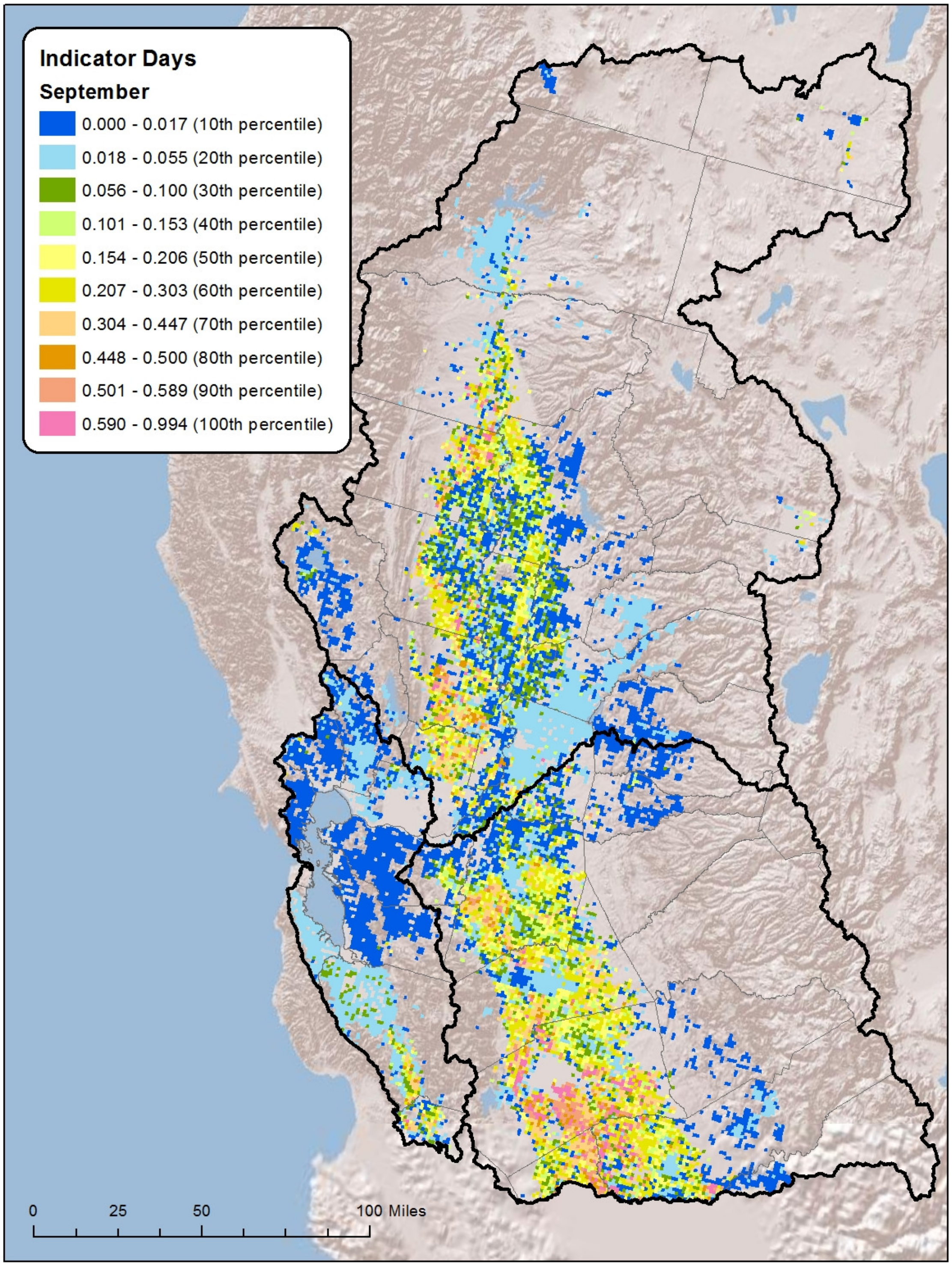


Figure 45 Spatial distribution of the percentile level of Indicator days for October for the period 2000–2009

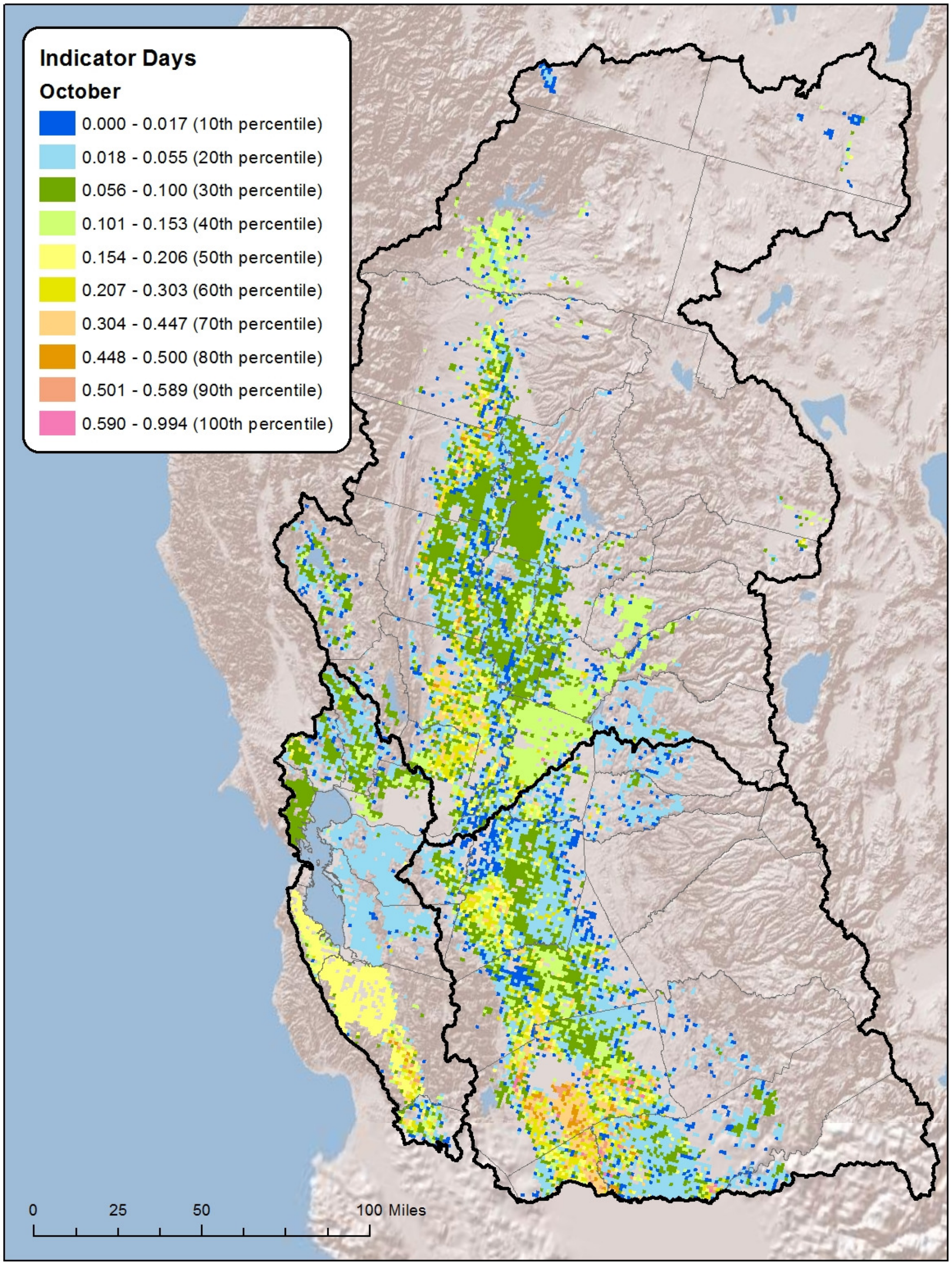


Figure 46 Spatial distribution of the percentile level of Indicator days for November for the period 2000–2009

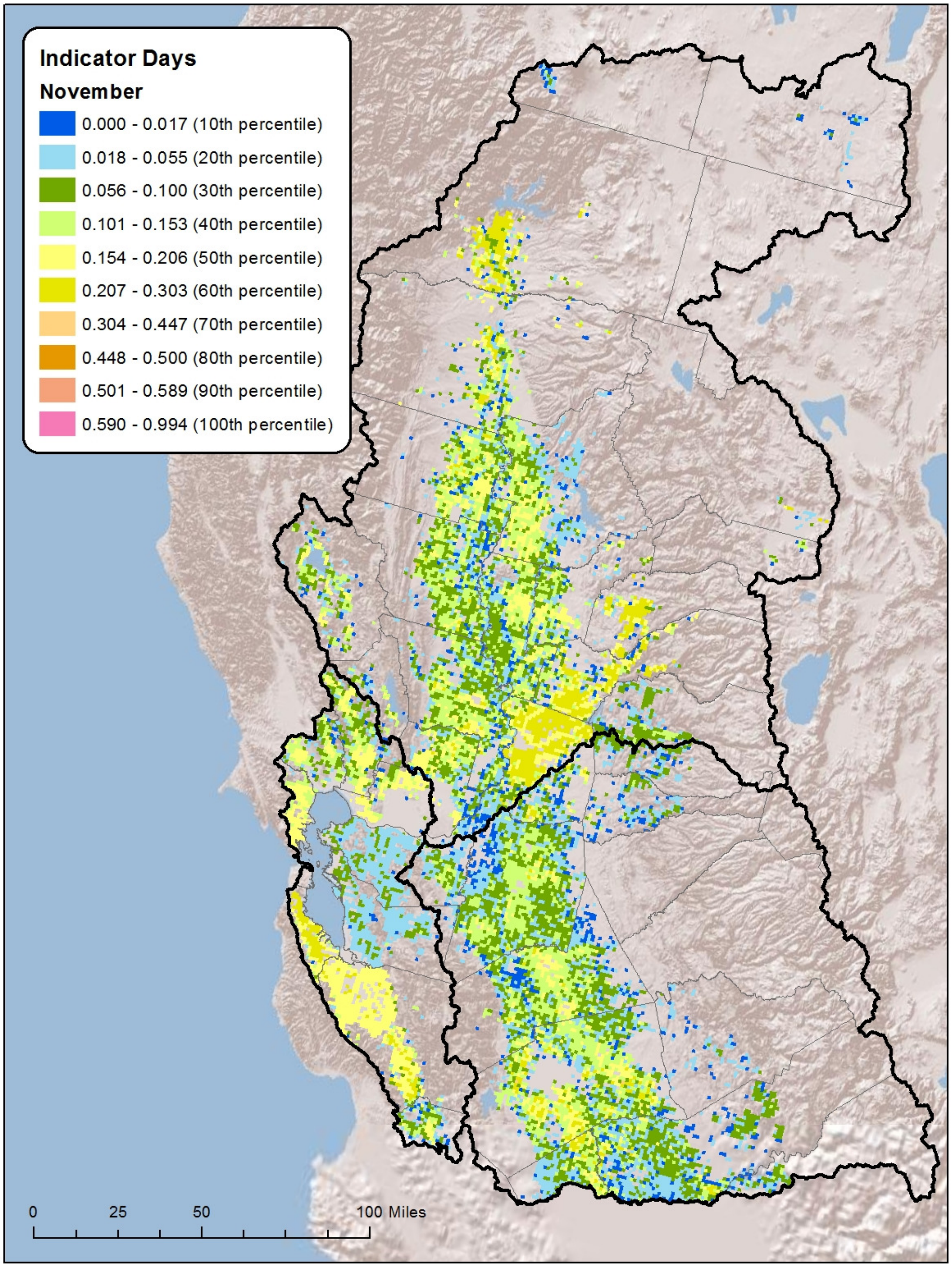


Figure 47 Spatial distribution of the percentile level of Indicator days for December for the period 2000–2009

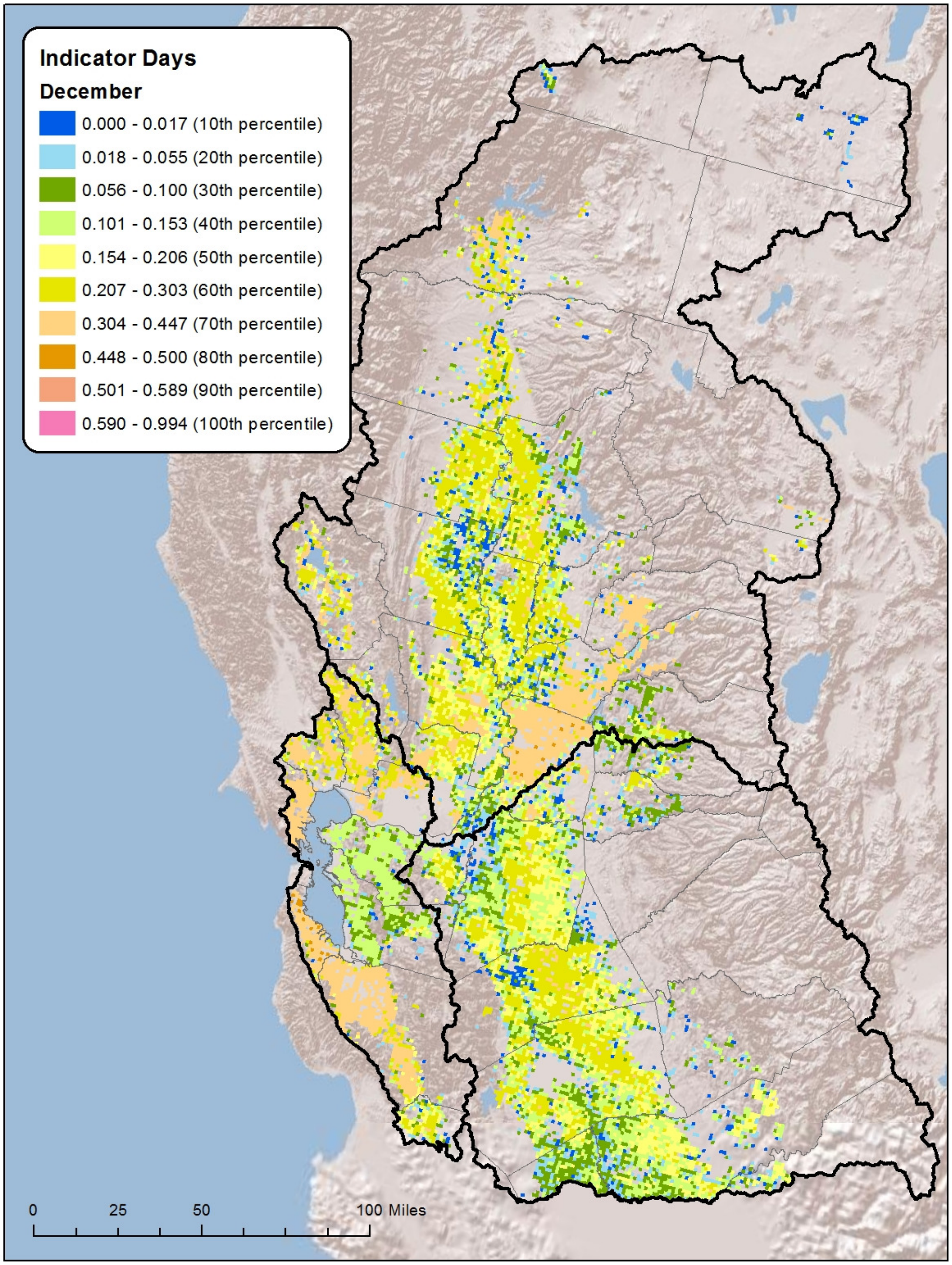
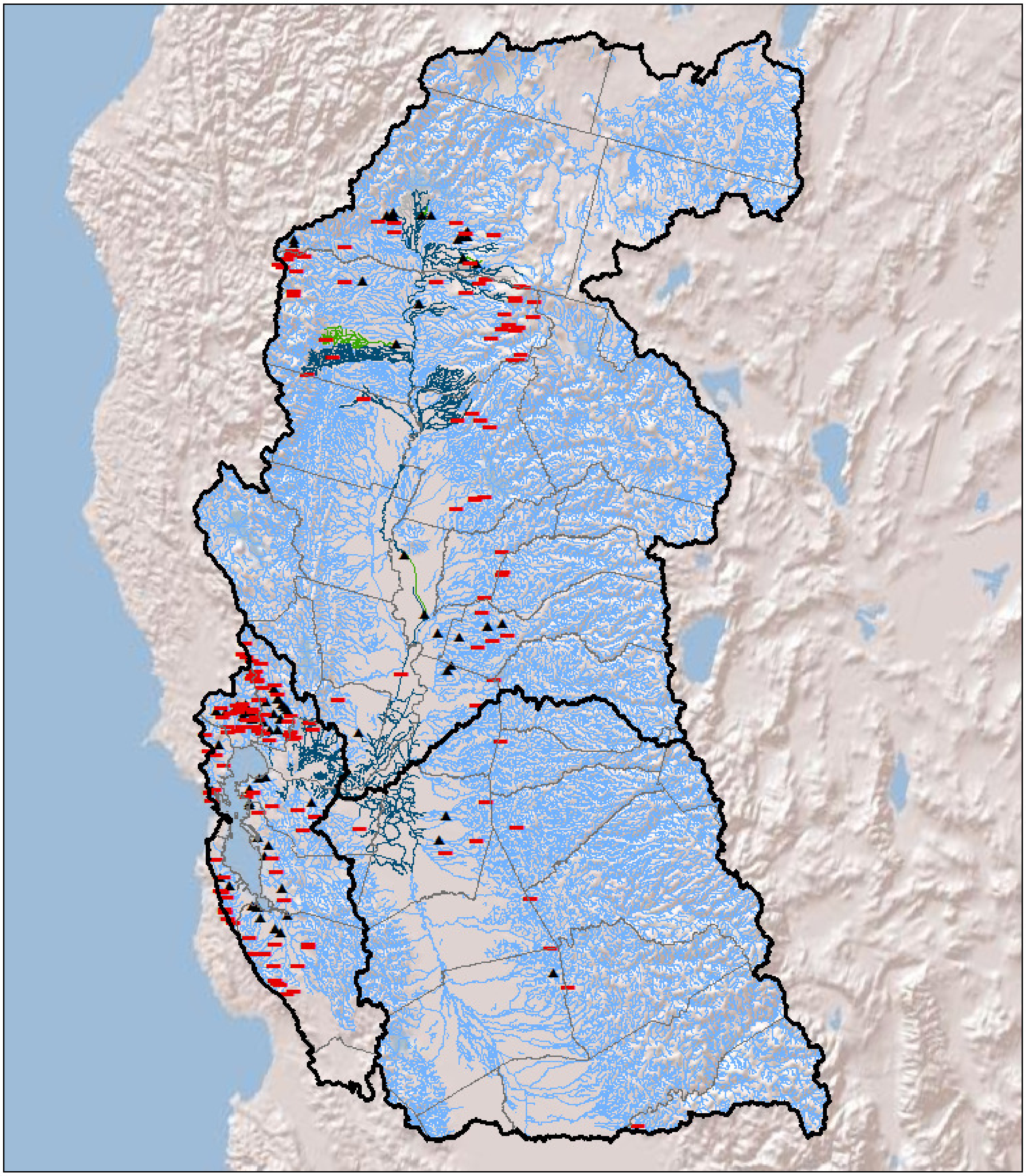


Figure 48 Chinook Salmon (*Oncorhynchus tshawytscha*) Sacramento River winter-run



Presence of Chinook Central Valley Late Winter Run

Reach is above a Barrier with Unknown Status
Reach is above a Partial Barrier
Reach is above a Total Barrier
Reach has no Barrier Limiting Range
Total Barriers
Partial Barriers

Figure 49 Chinook Salmon (*Oncorhynchus tshawytscha*) Central Valley spring-run

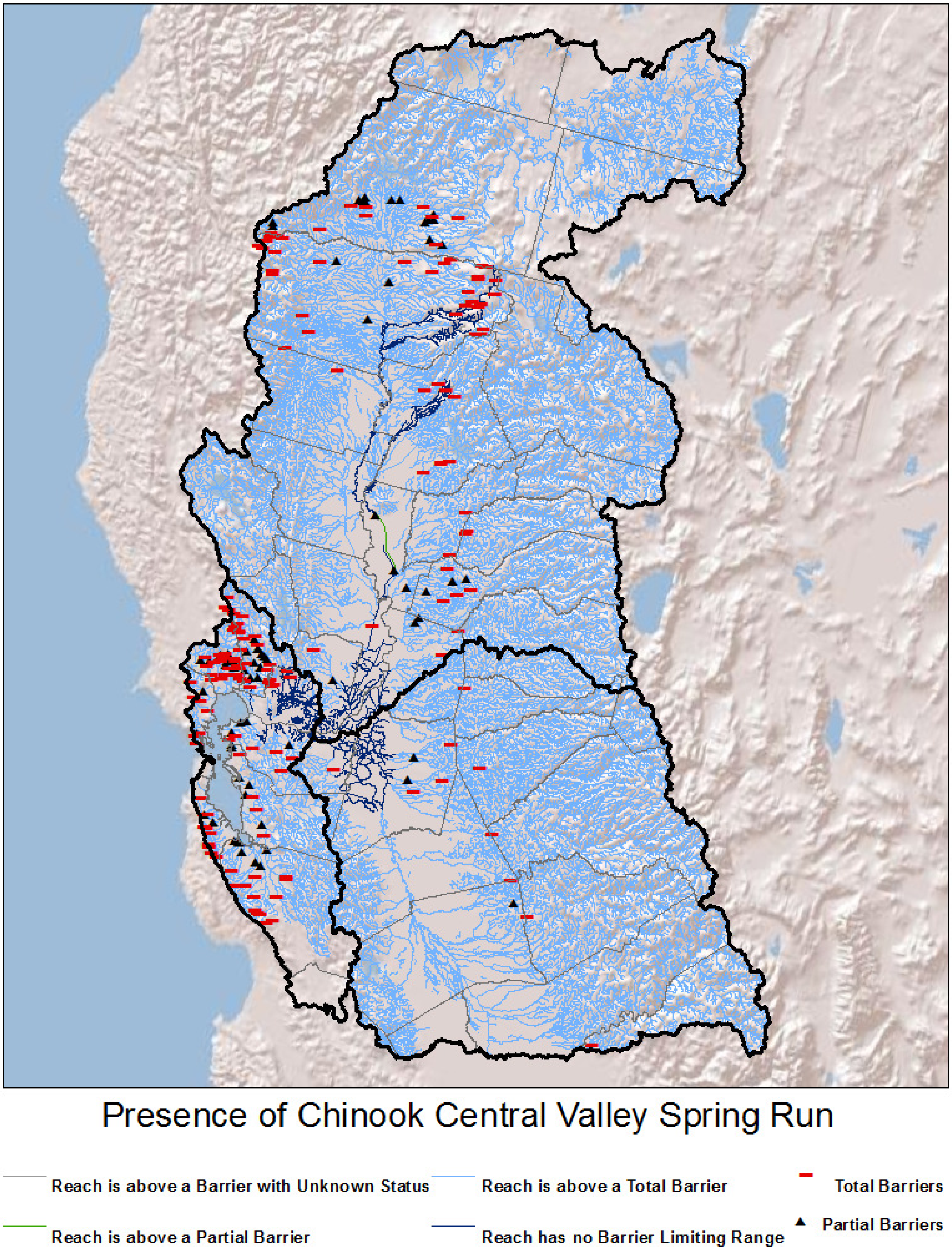
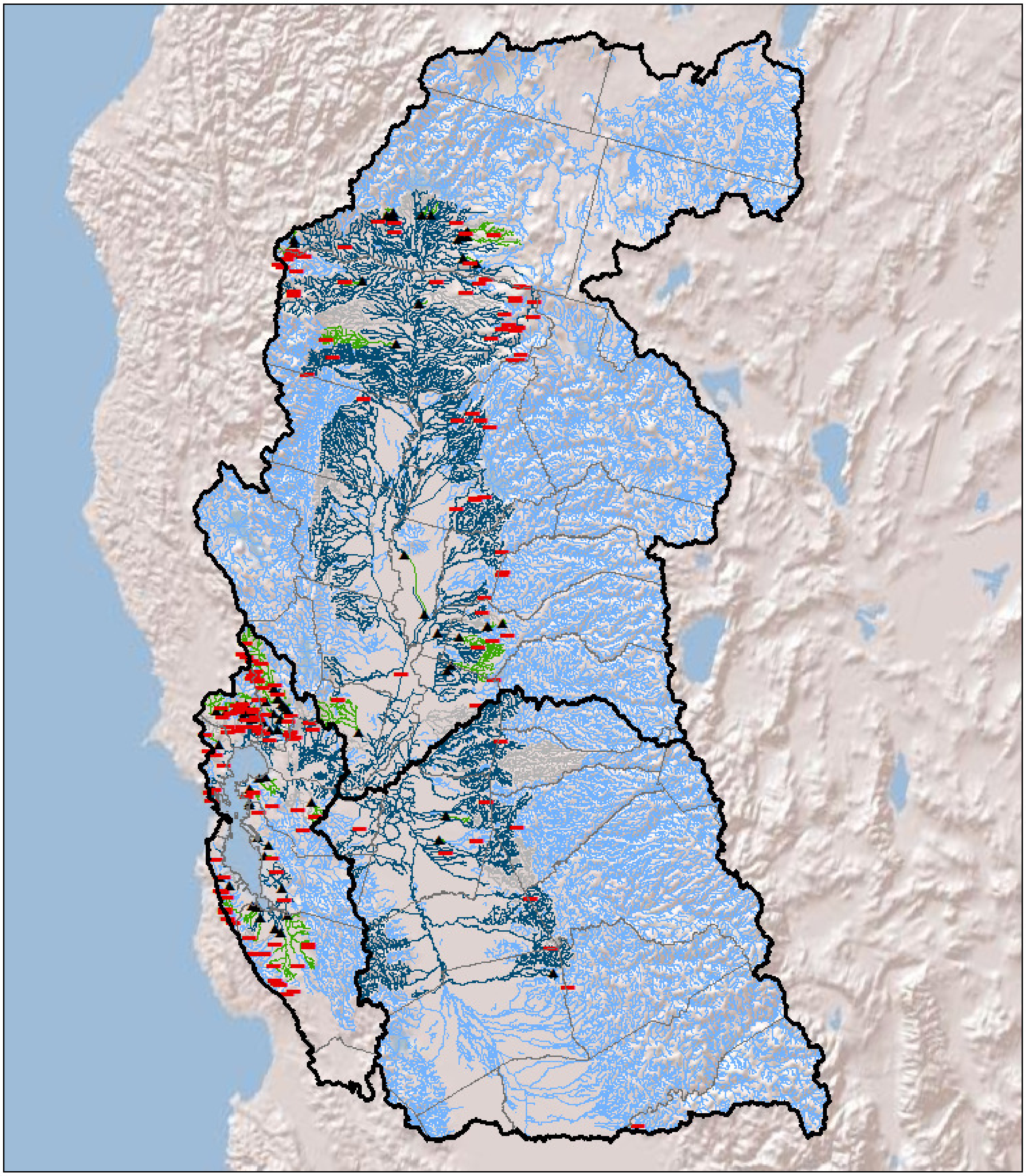


Figure 50 Chinook Salmon (*Oncorhynchus tshawytscha*) Central Valley fall run



Presence of Chinook Central Valley Fall Run

Reach is above a Barrier with Unknown Status
Reach is above a Total Barrier
Total Barriers
Reach is above a Partial Barrier
Reach has no Barrier Limiting Range
Partial Barriers

Figure 51 Chinook Salmon (*Oncorhynchus tshawytscha*) Central Valley late fall run

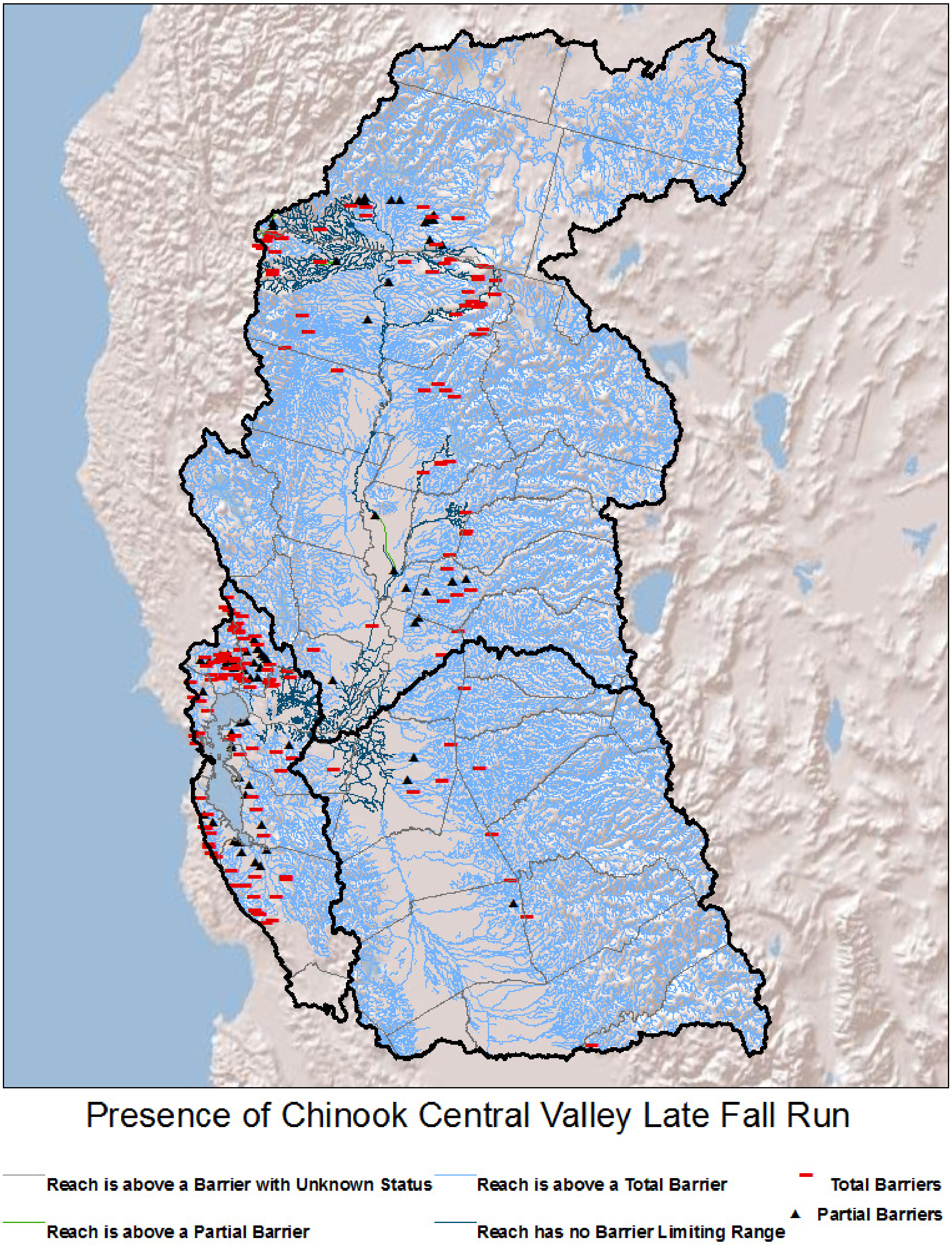


Figure 52 Central Valley steelhead (*Oncorhynchus mykiss*)

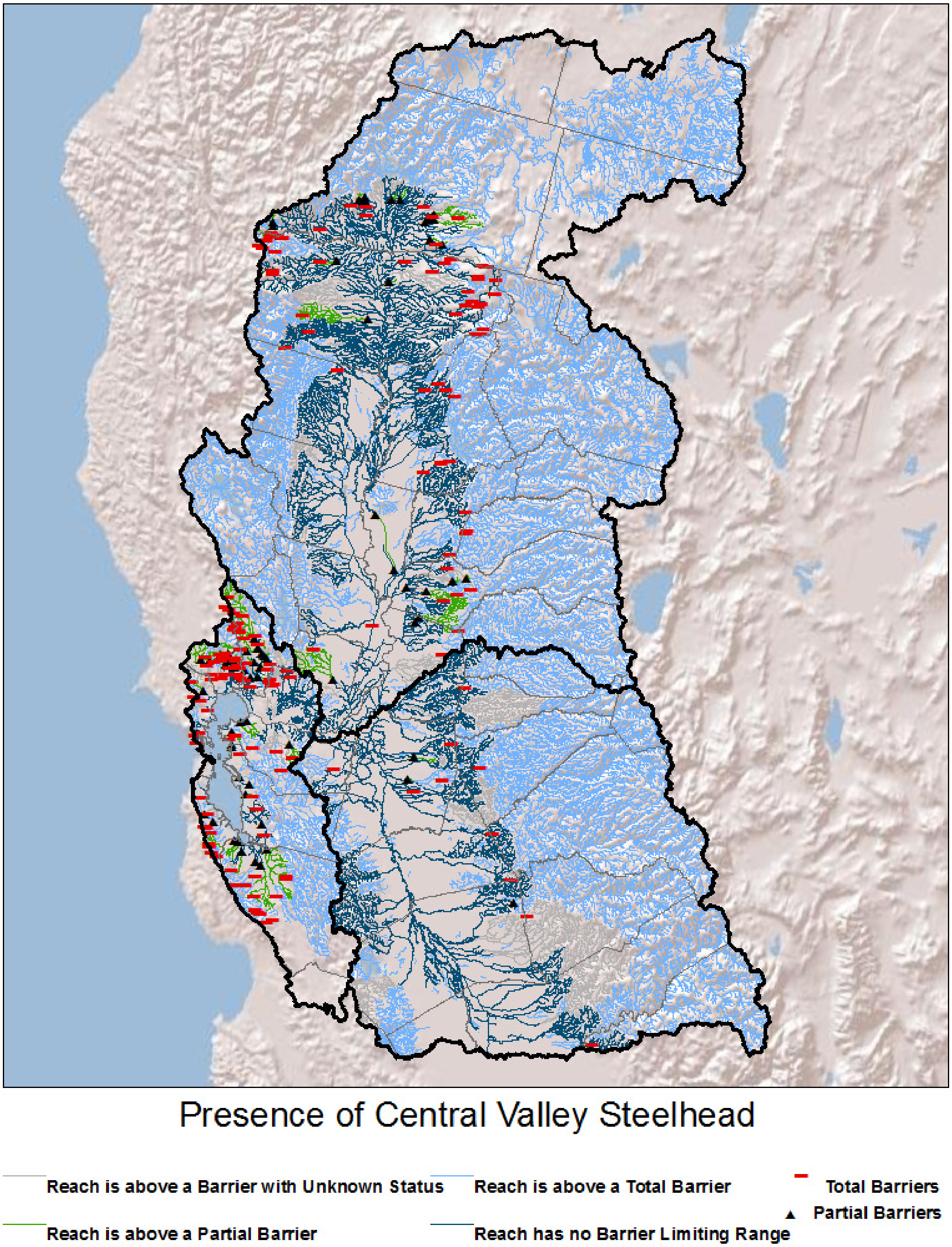


Figure 53 Southern North American Green Sturgeon (*Acipenser medirostris*)

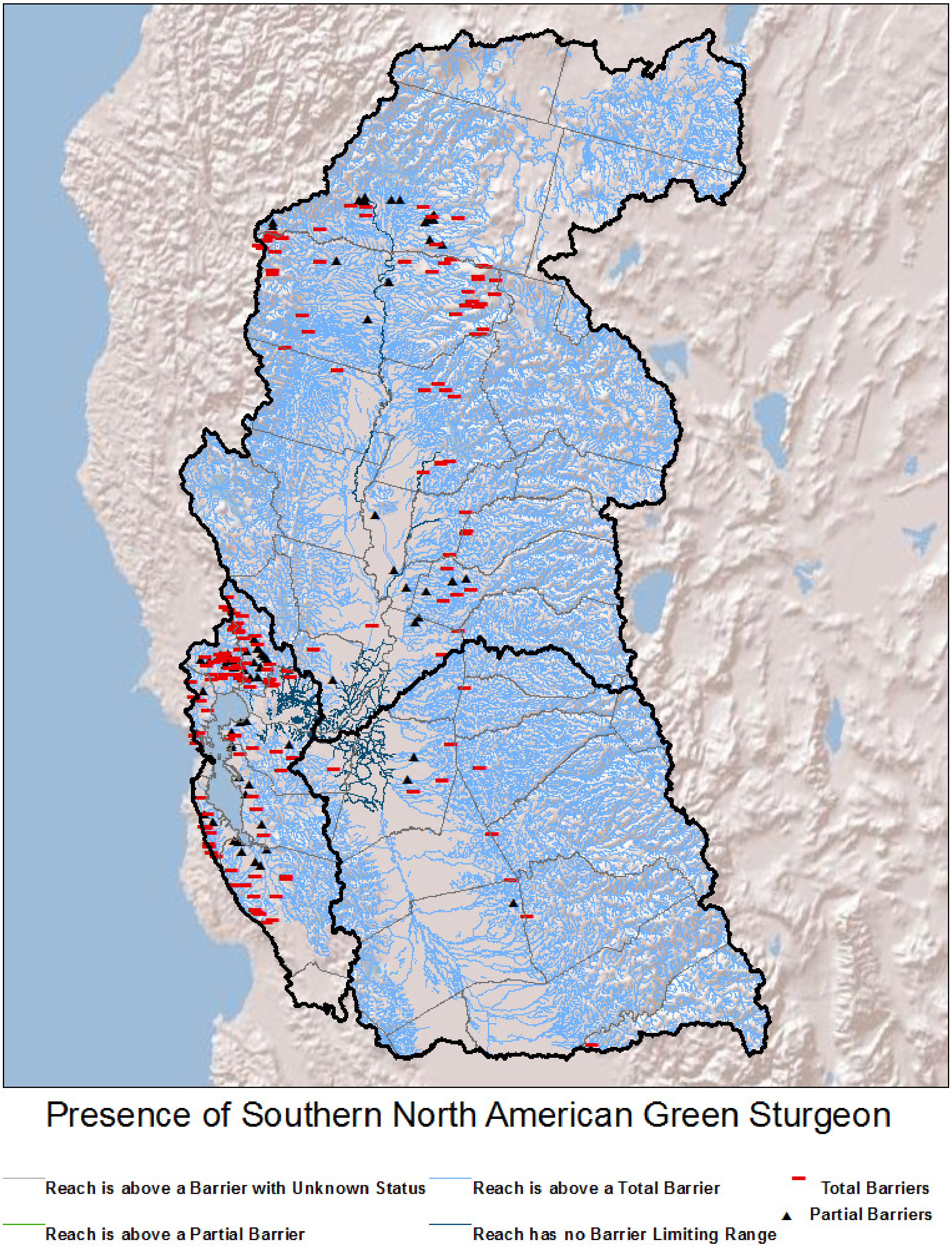


Figure 54 Delta Smelt (*Hypomesus transpacificus*)

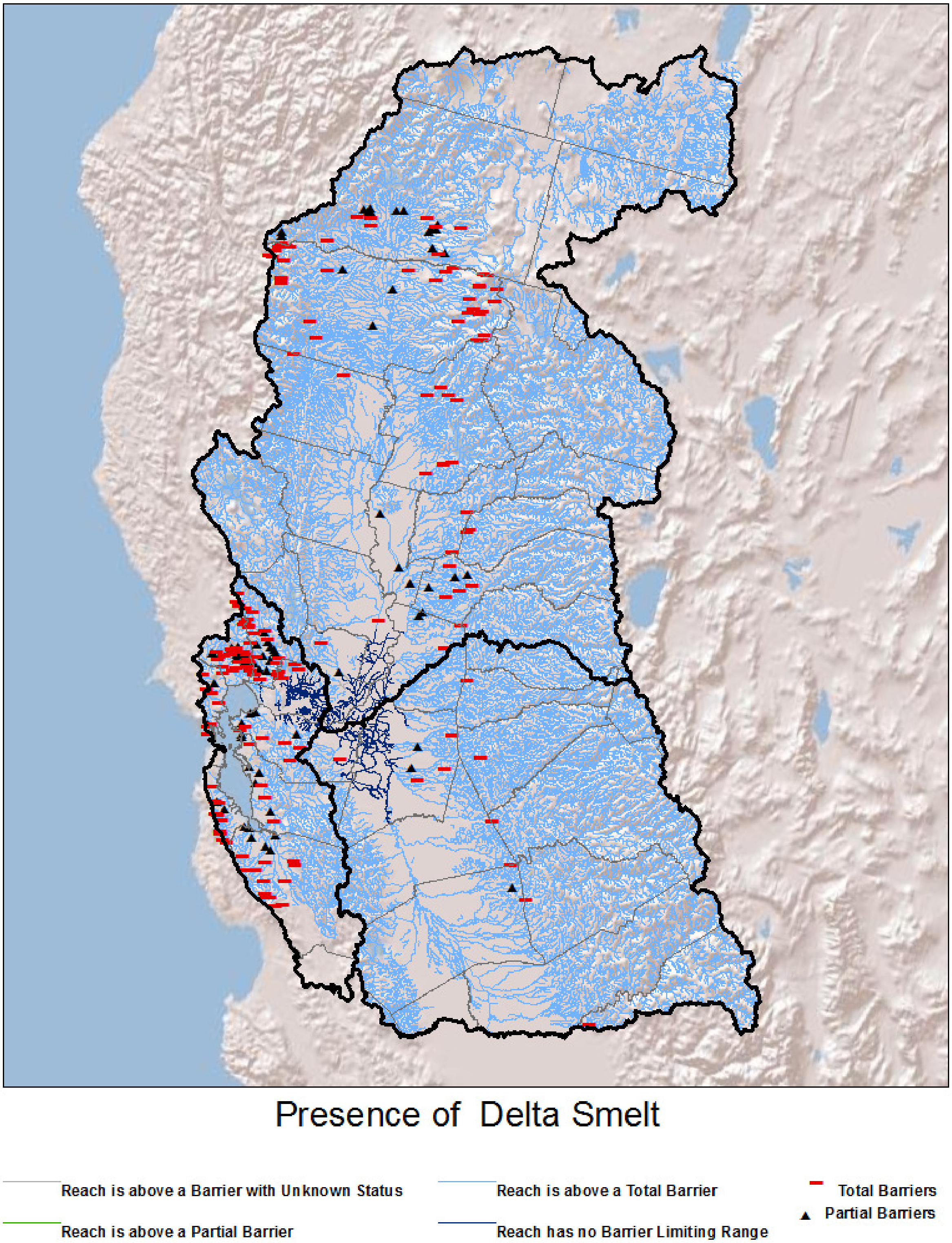


Figure 55 Striped Bass (*Morone saxatilis*)

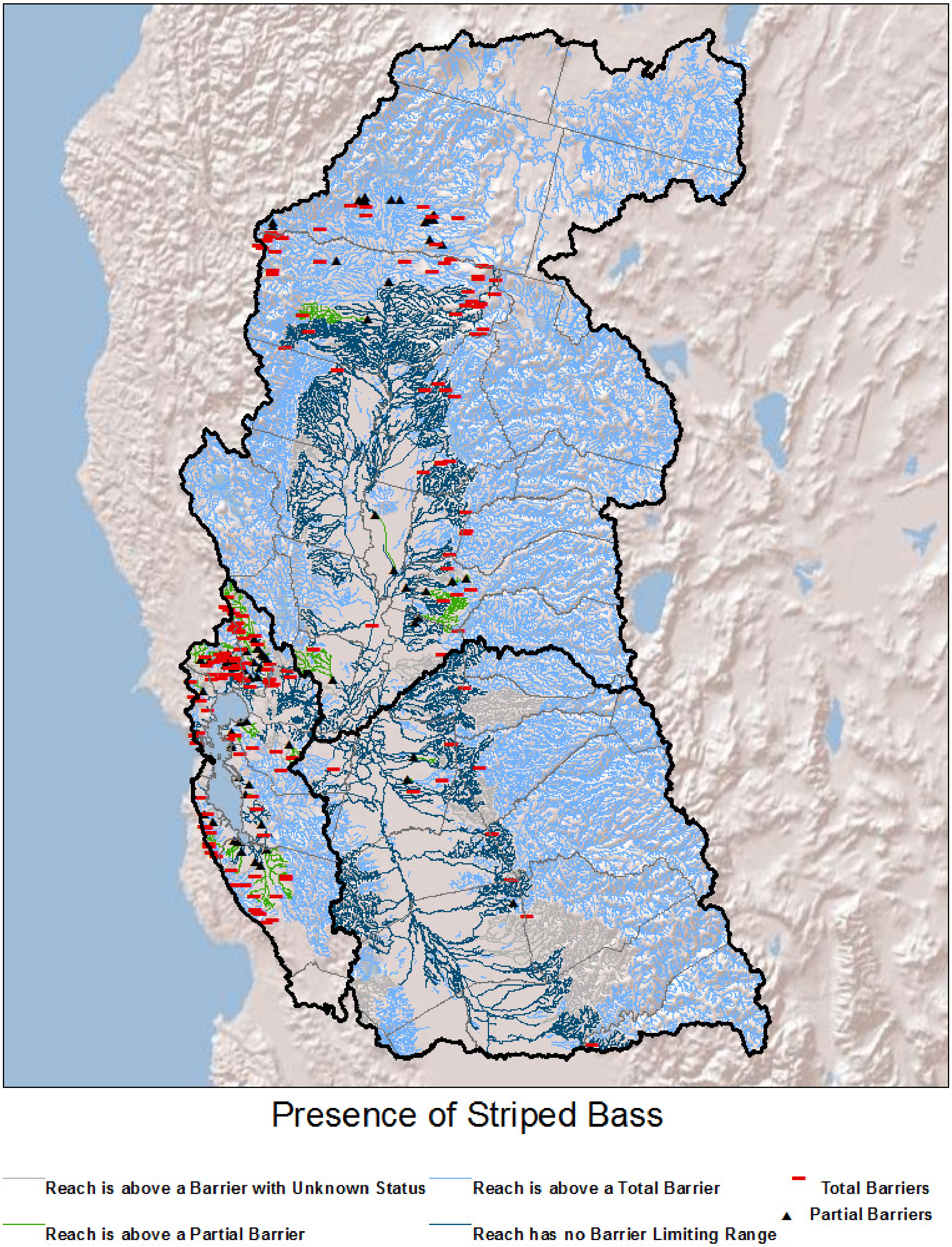
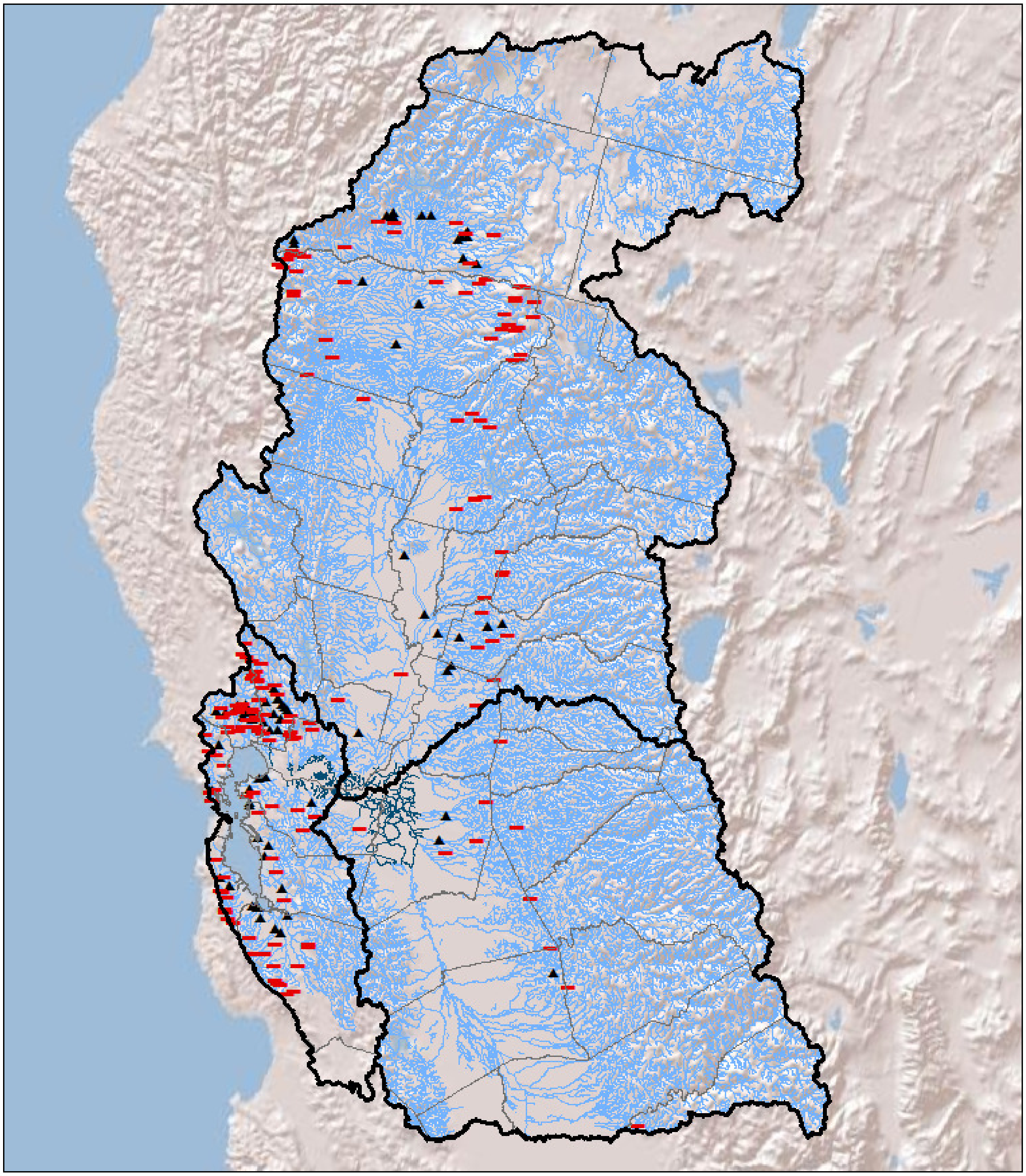


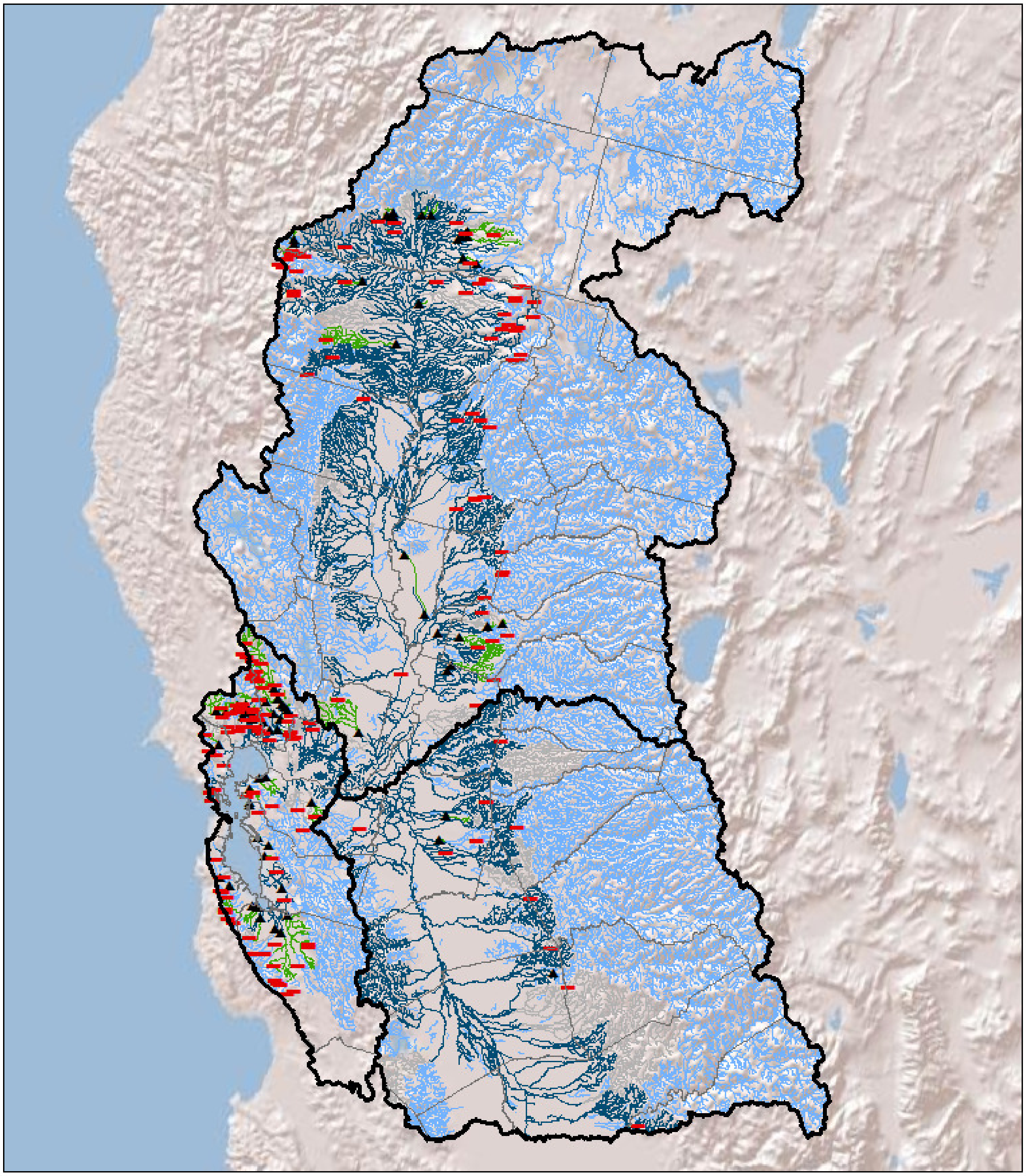
Figure 56 San Francisco Longfin Smelt (*Spirinchus thaleichthys*)



Presence of San Francisco Longfin Smelt

Reach is above a Barrier with Unknown Status
Reach is above a Total Barrier
Total Barriers
Partial Barriers
Reach is above a Partial Barrier
Reach has no Barrier Limiting Range

Figure 57 Threadfin Shad (*Dorosoma petenense*)



Presence of Threadfin Shad

Reach has no Barrier Limiting Range
Reach is above a Total Barrier
Total Barriers
Partial Barriers
Reach is above a Partial Barrier
Reach has no Barrier Limiting Range

Figure 58 California Red-legged Frog (*Rana draytonii*)

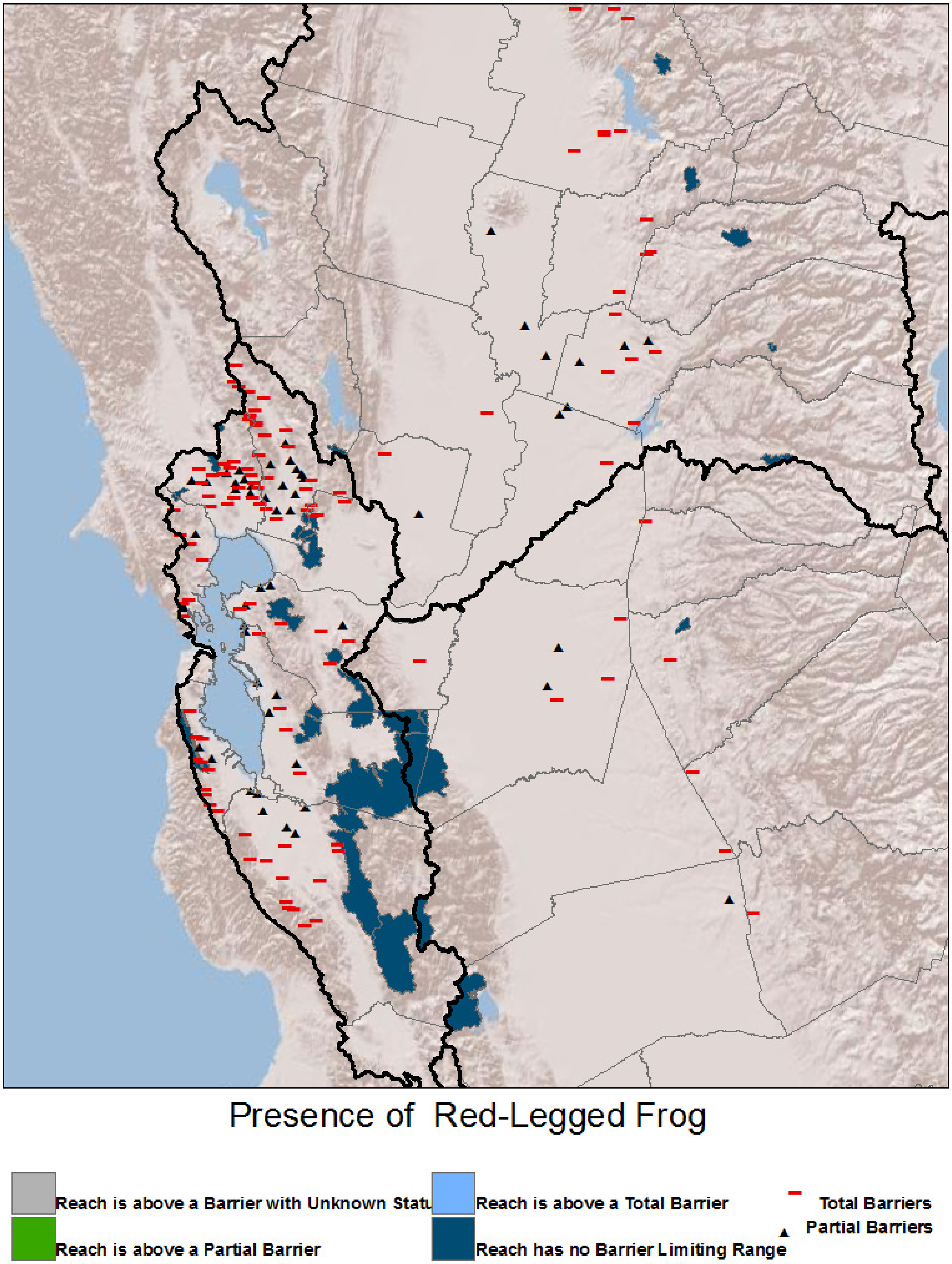


Figure 59 California Freshwater Shrimp (*Syncaris pacifica*)

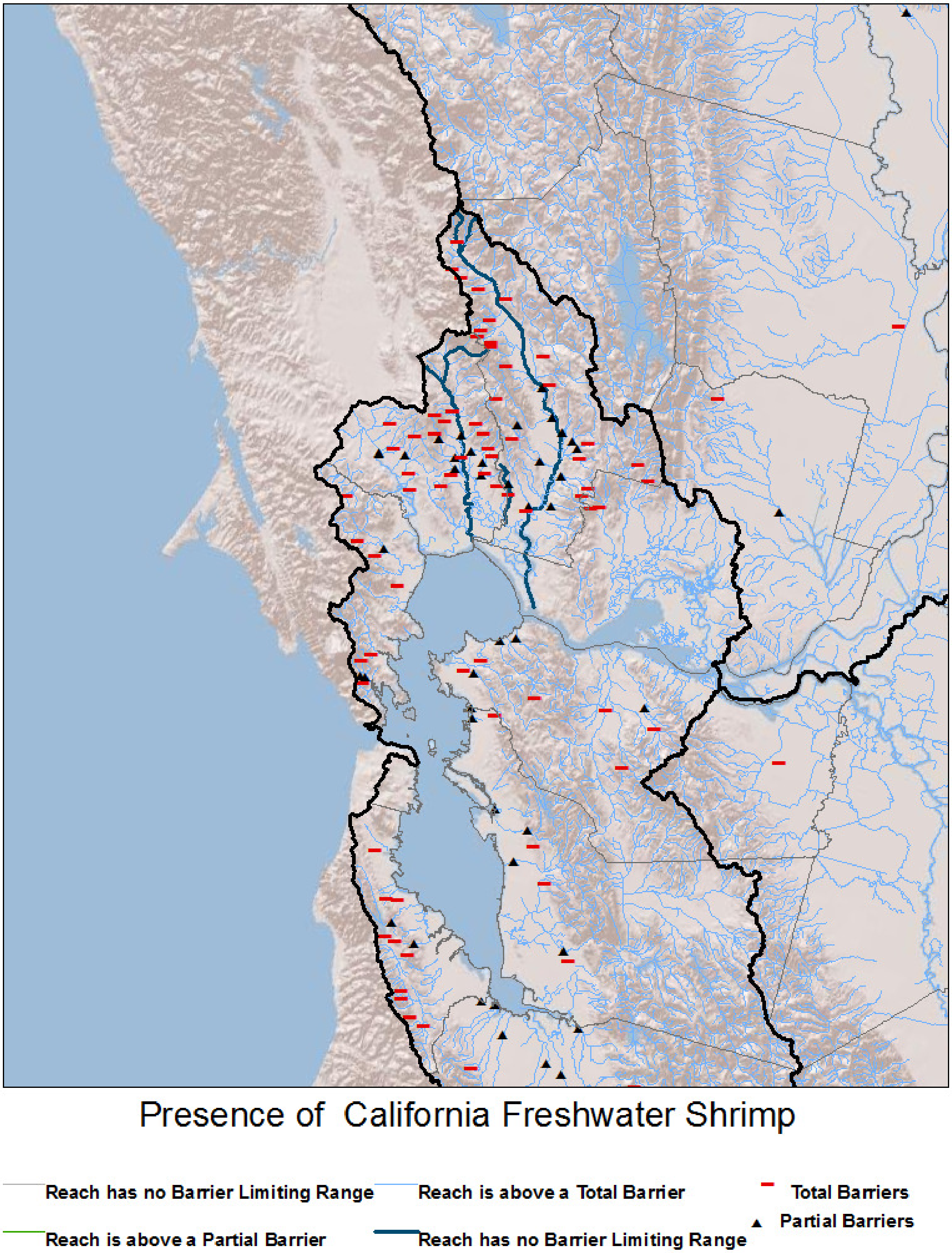


Figure 60 Frequency and cumulative distribution of the Species Richness

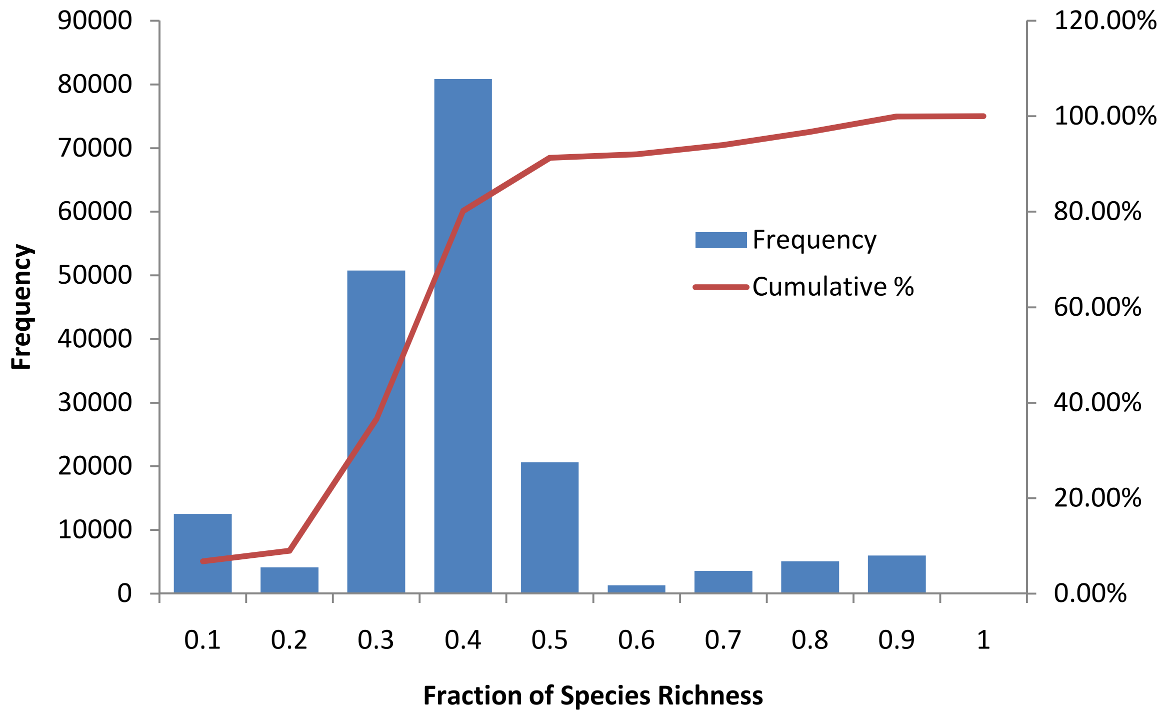


Figure 61 Species Richness - January

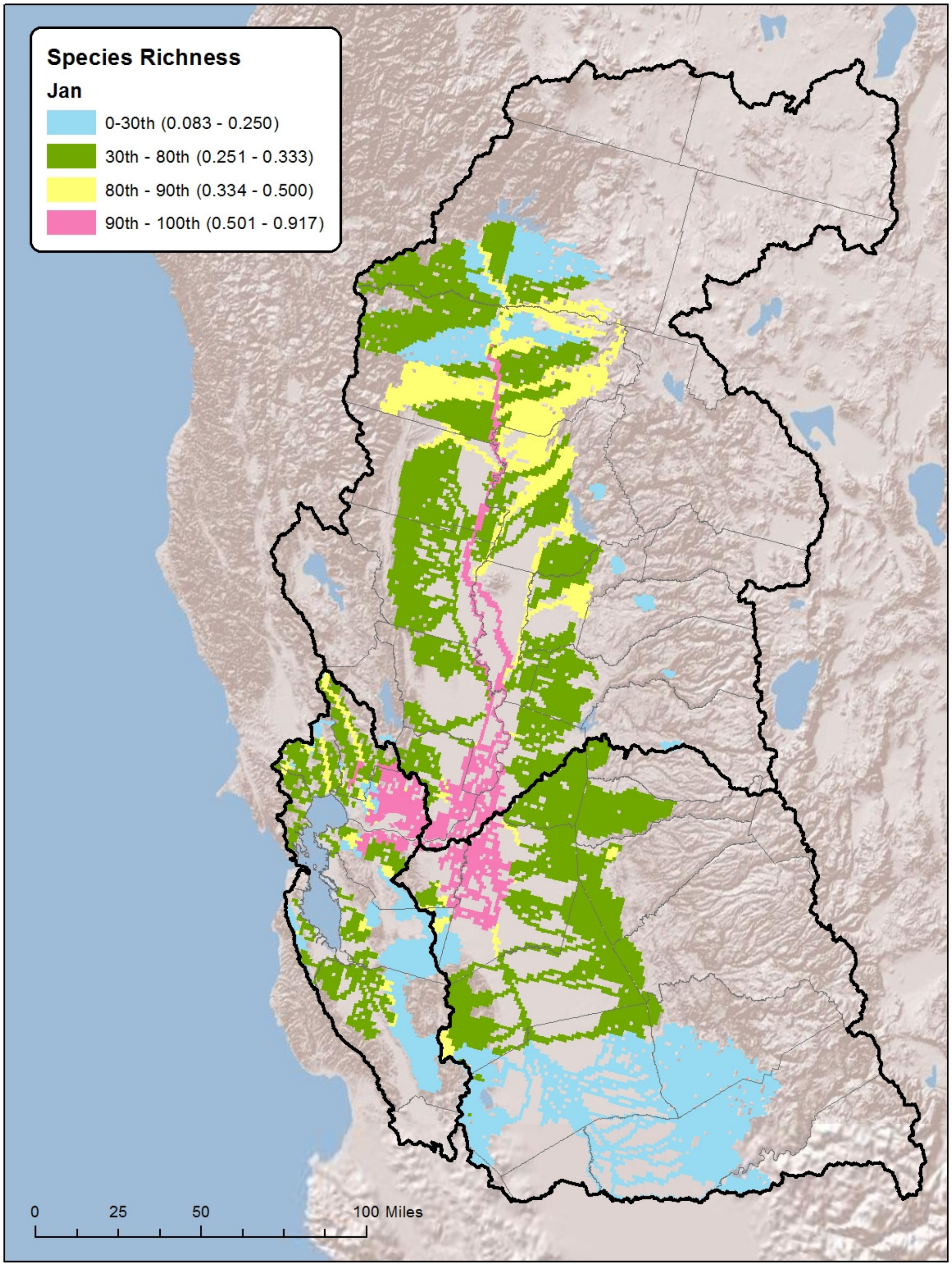


Figure 62 Species Richness–February

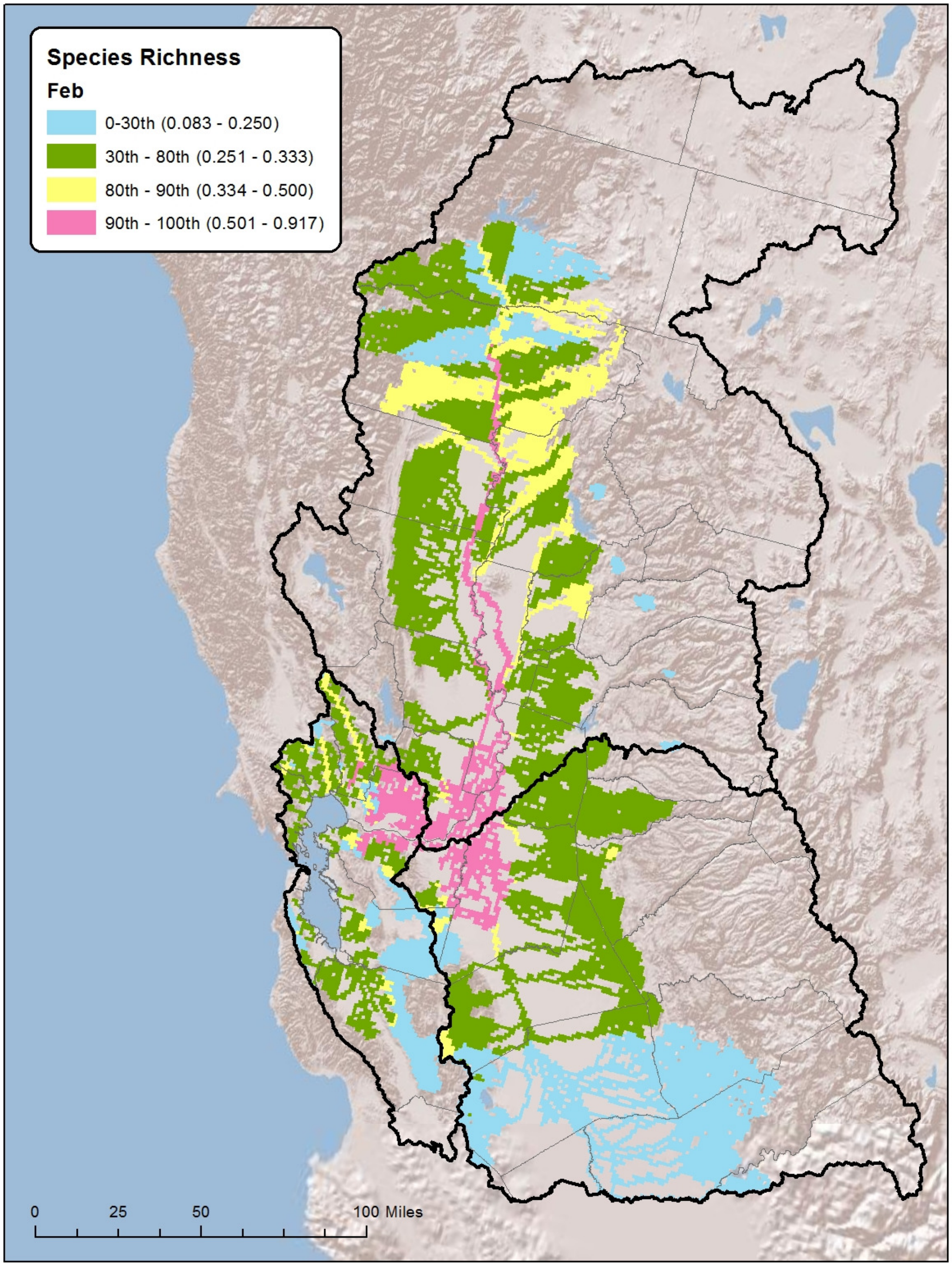


Figure 63 Species Richness - March

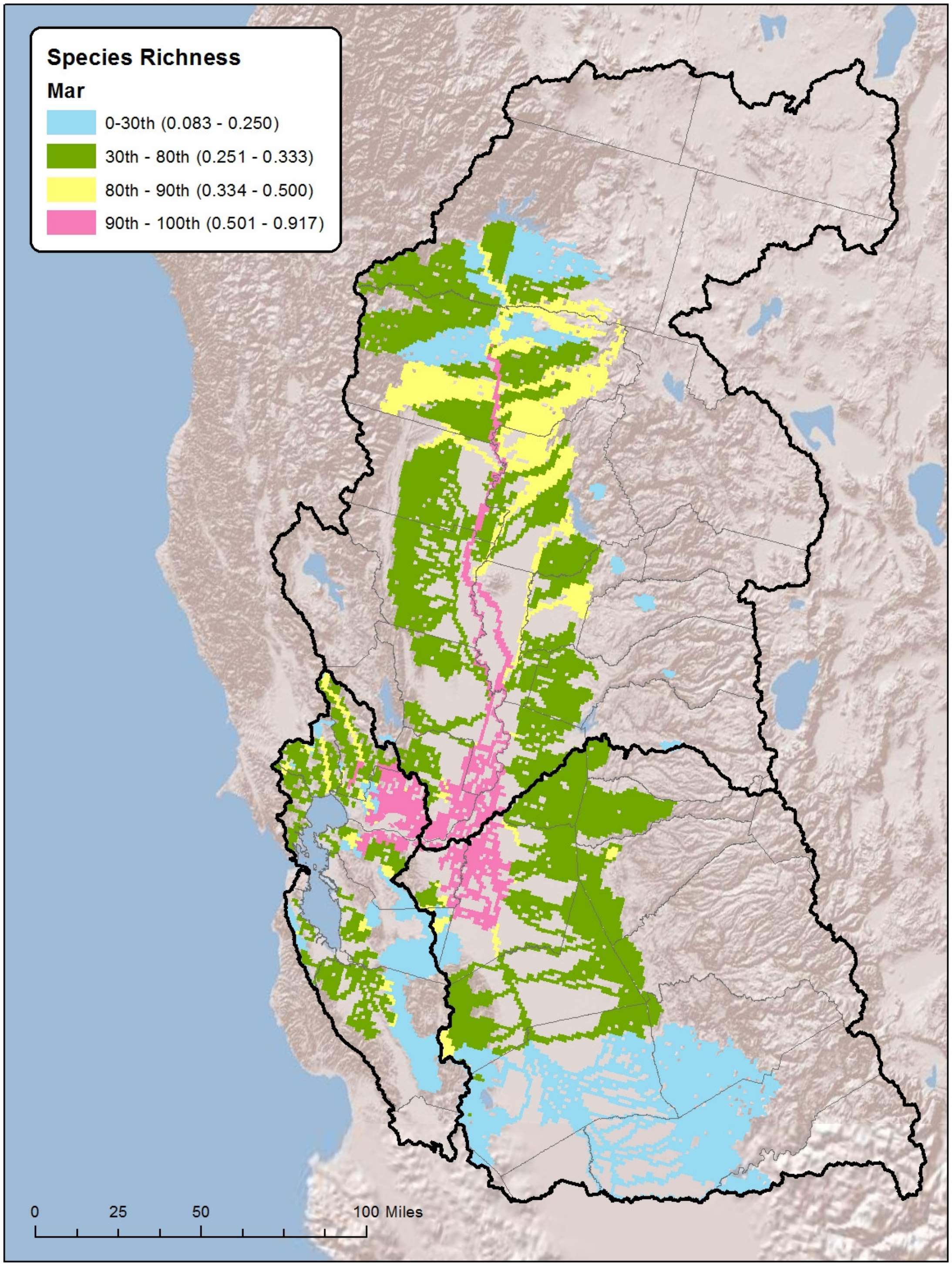


Figure 64 Species Richness - April

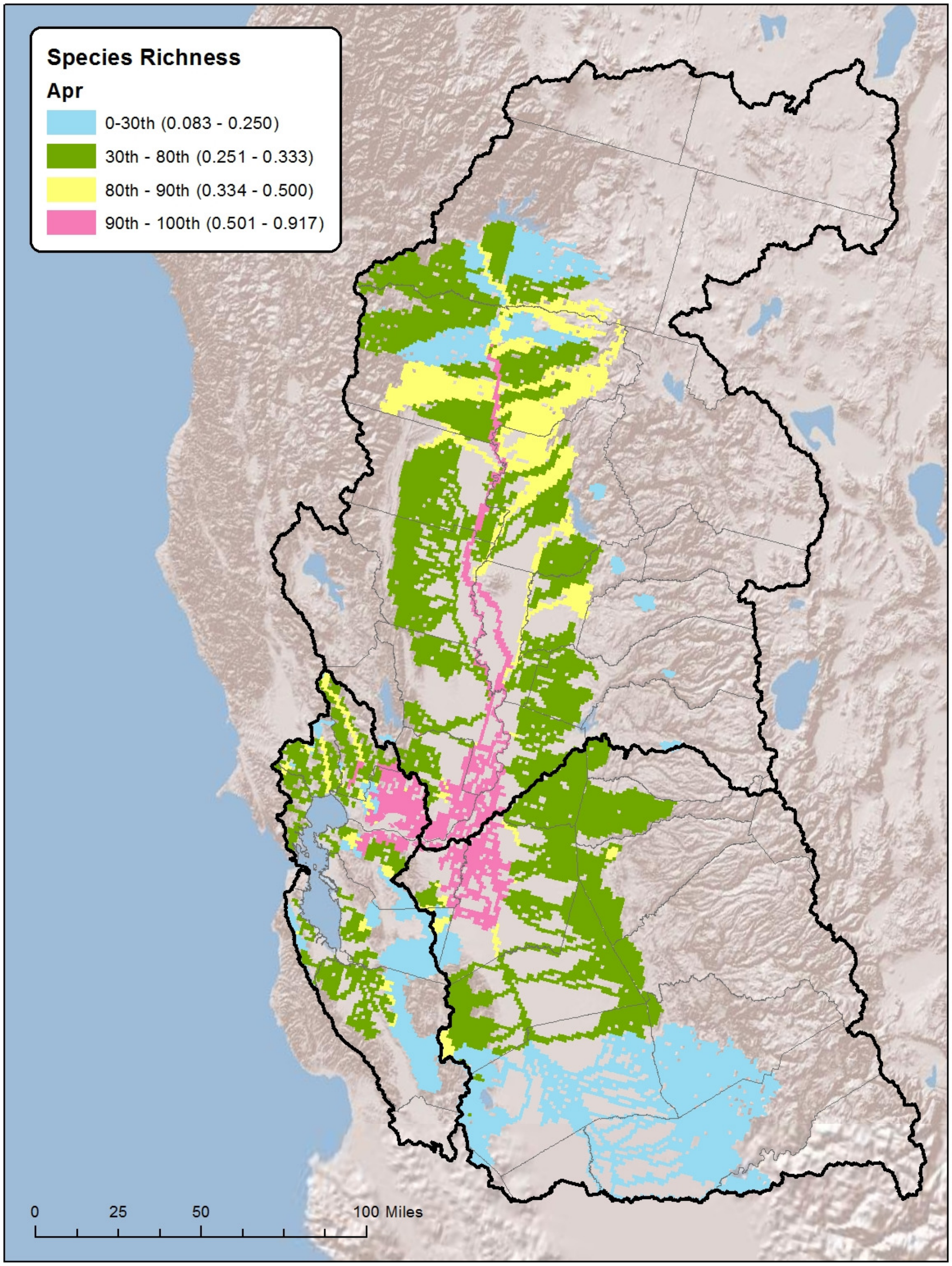


Figure 65 Species Richness - May

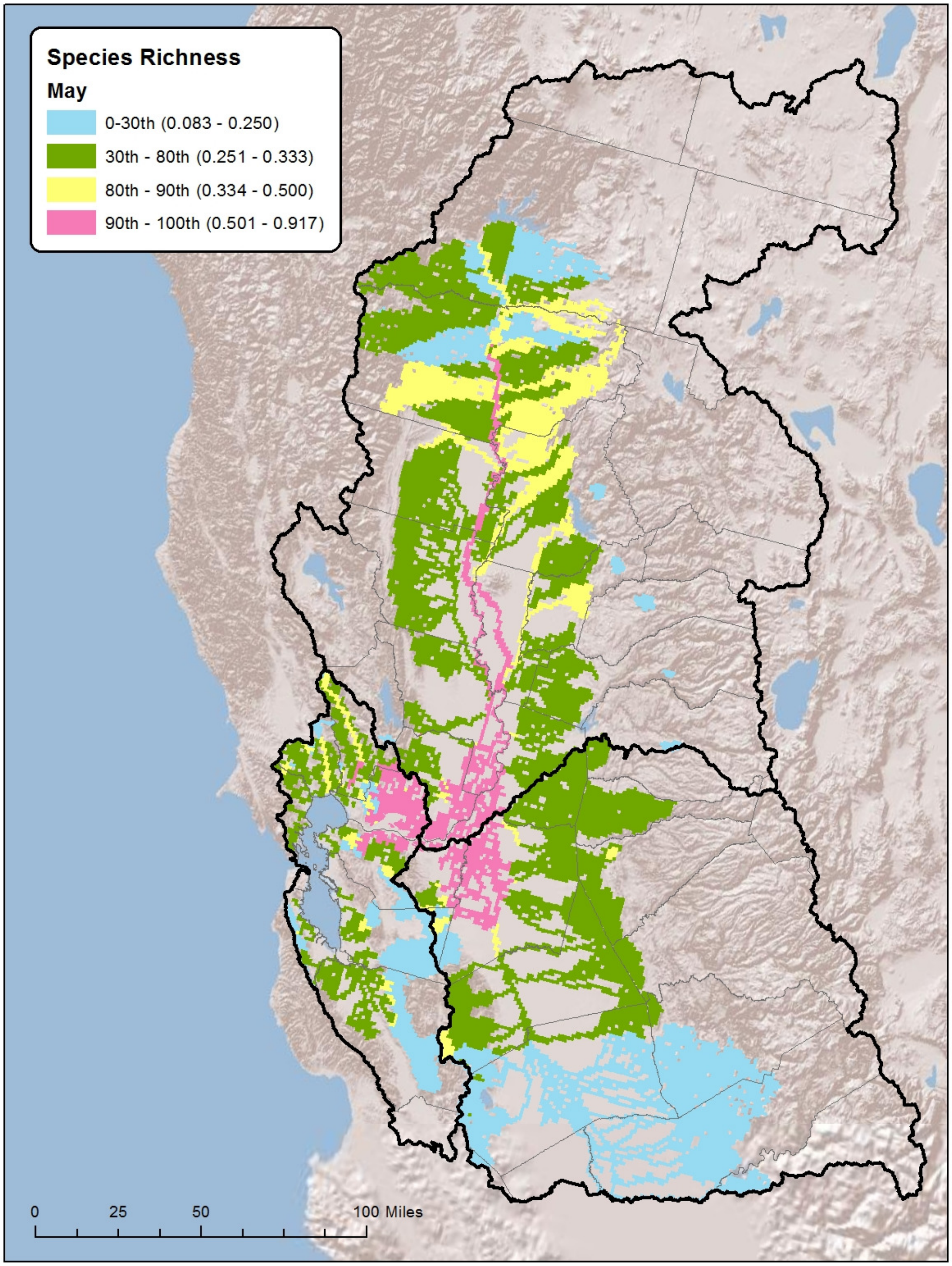


Figure 66 Species Richness - June

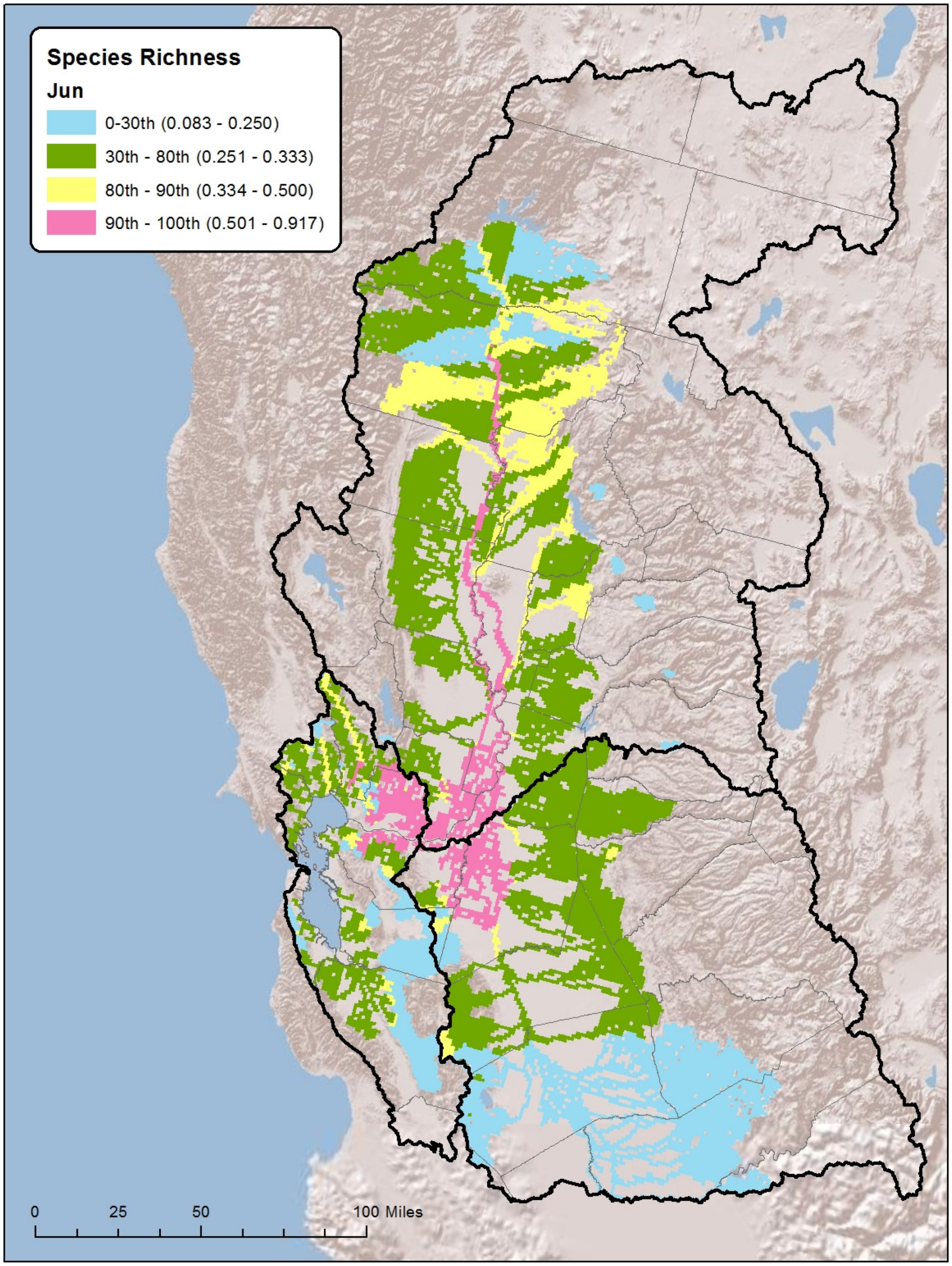


Figure 67 Species Richness - July

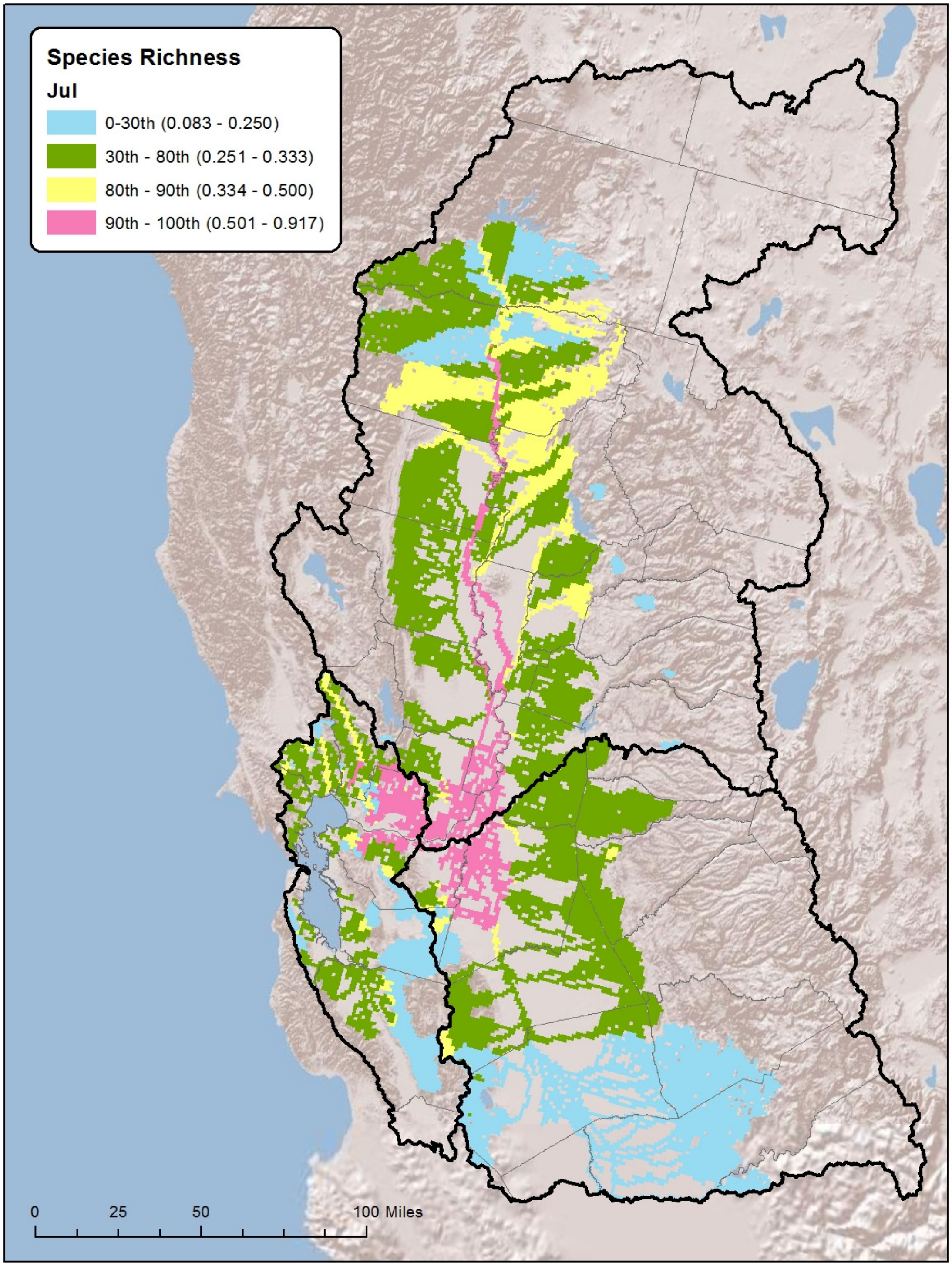


Figure 68 Species Richness - August

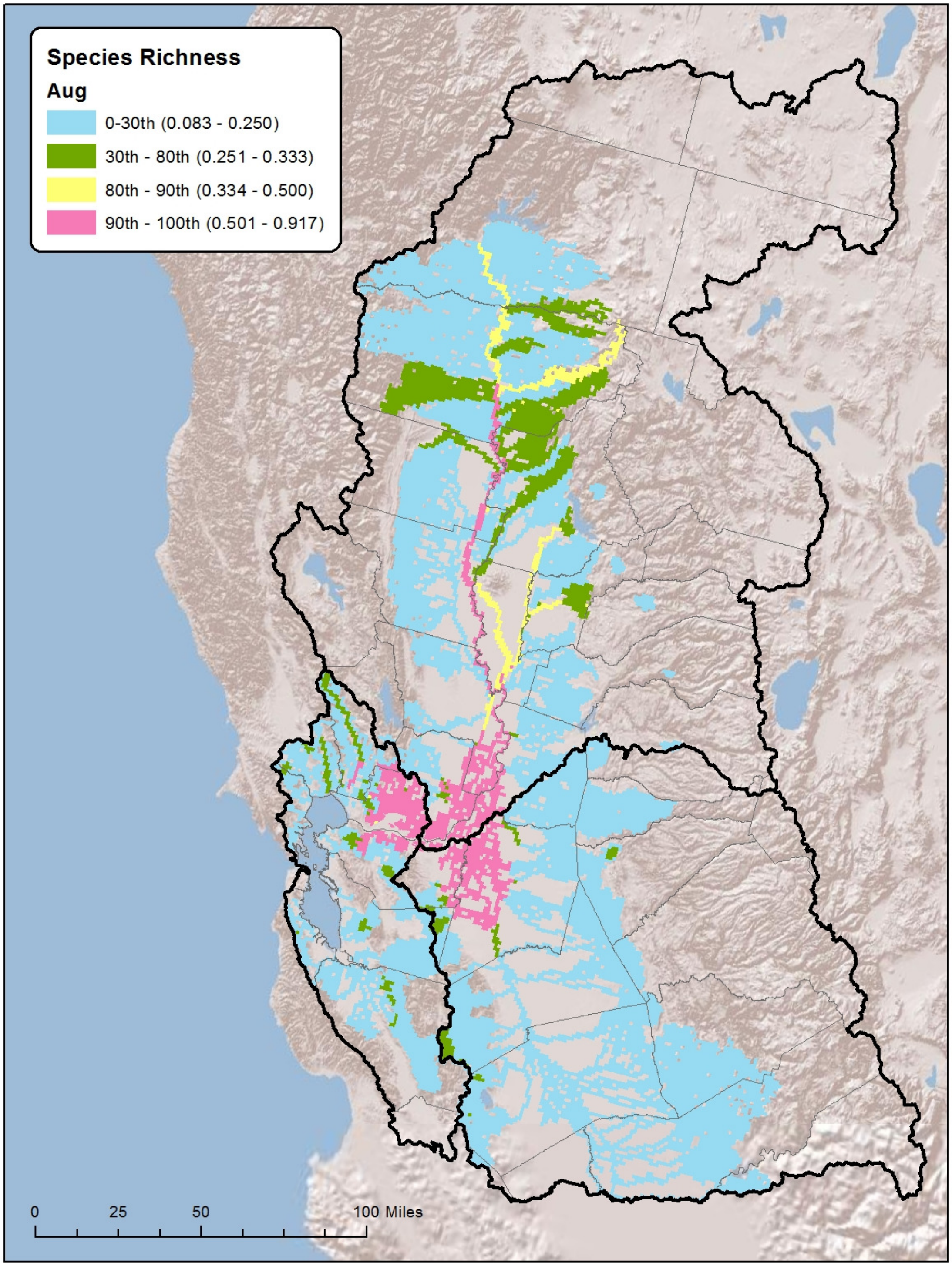


Figure 69 Species Richness - September

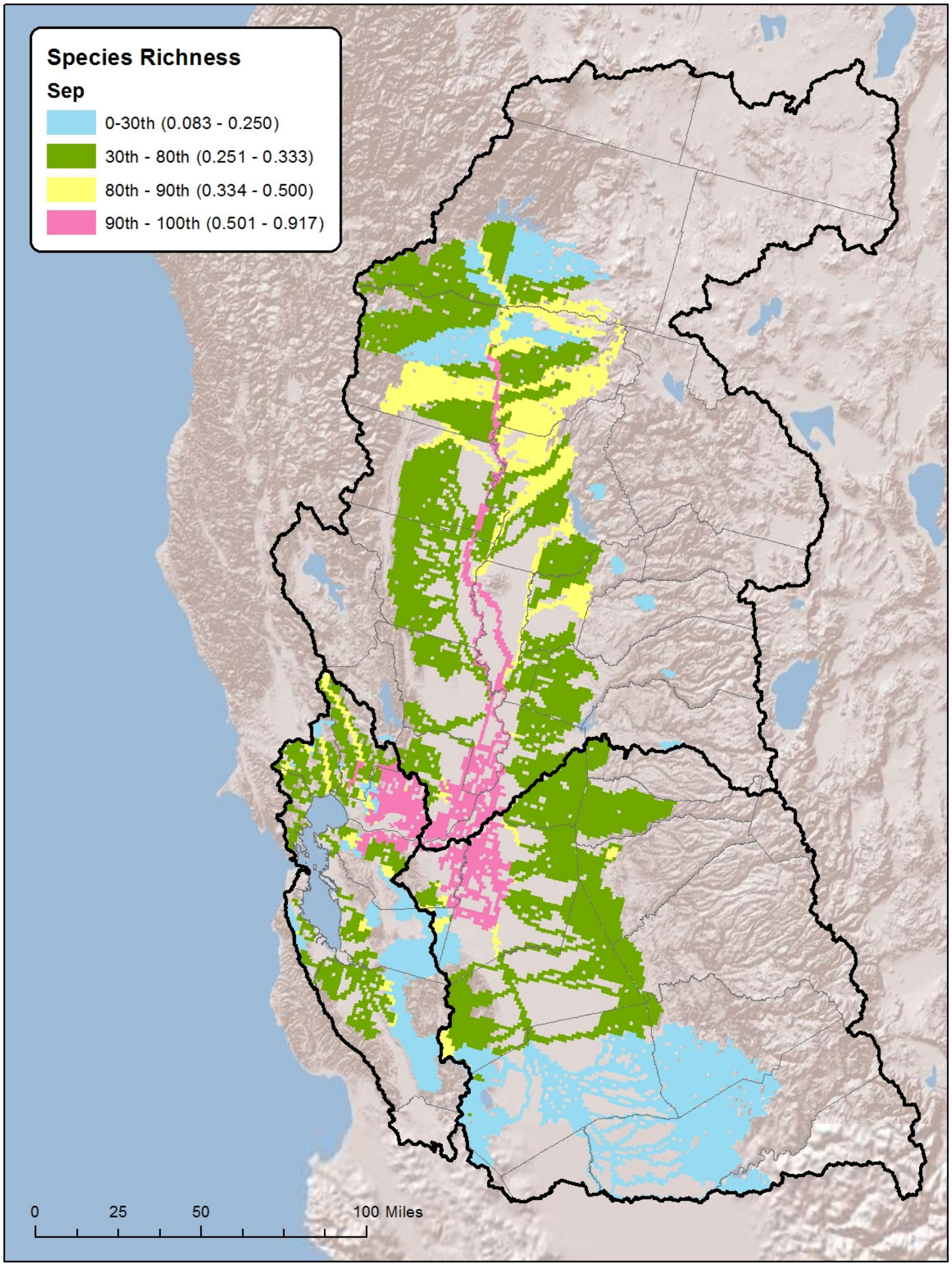


Figure 70 Species Richness - October

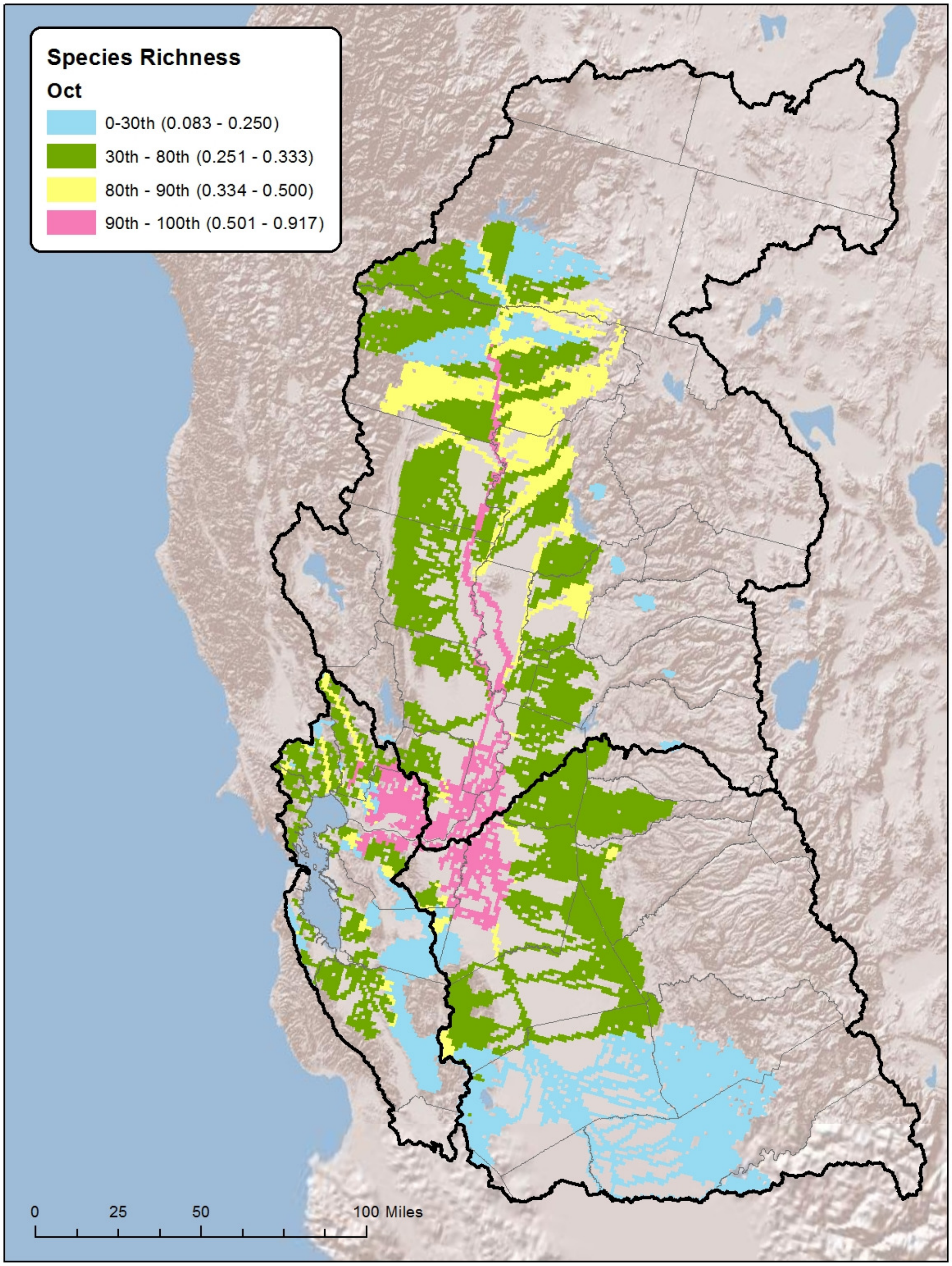


Figure 71 Species Richness - November

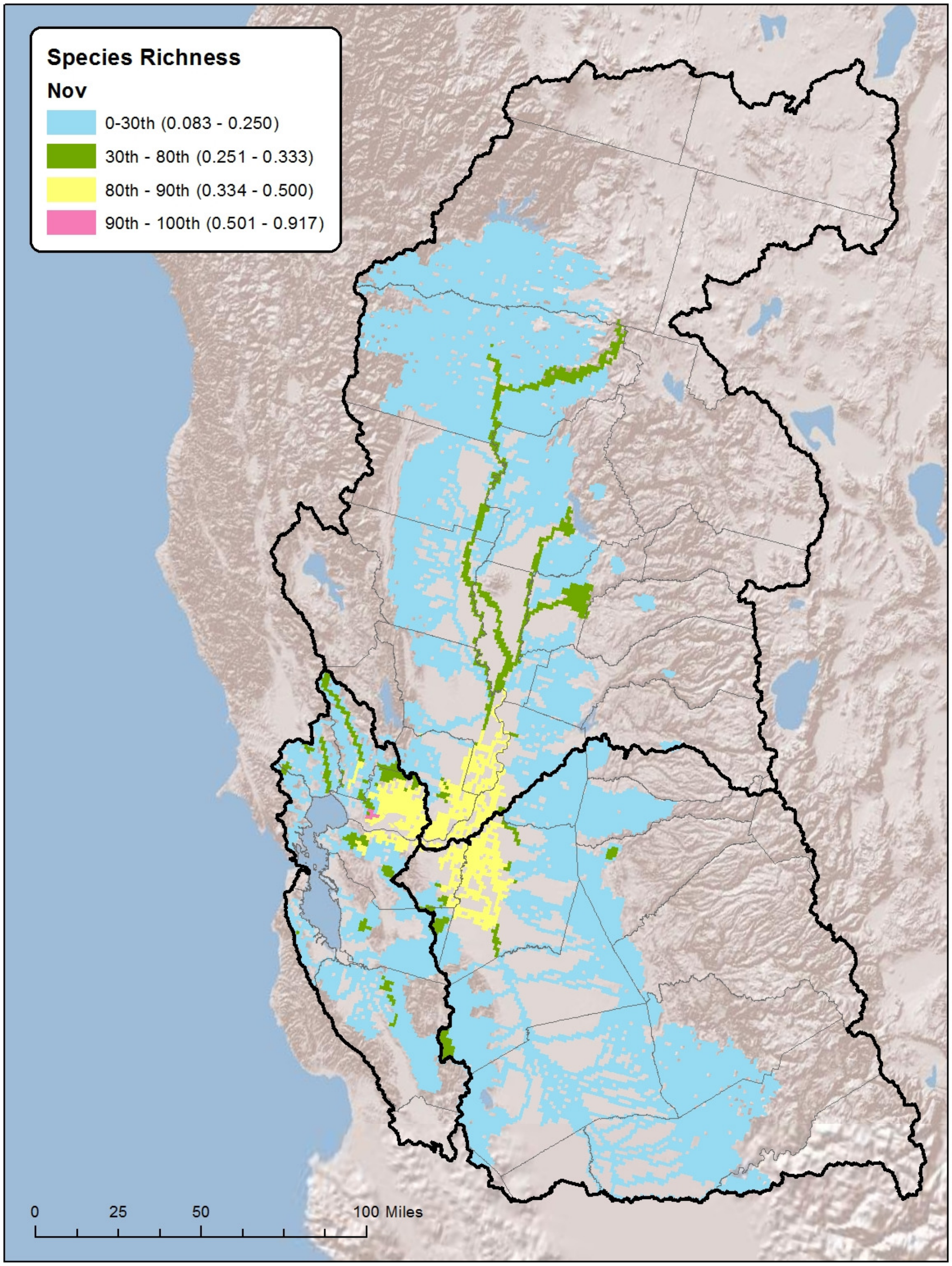


Figure 72 Species Richness - December

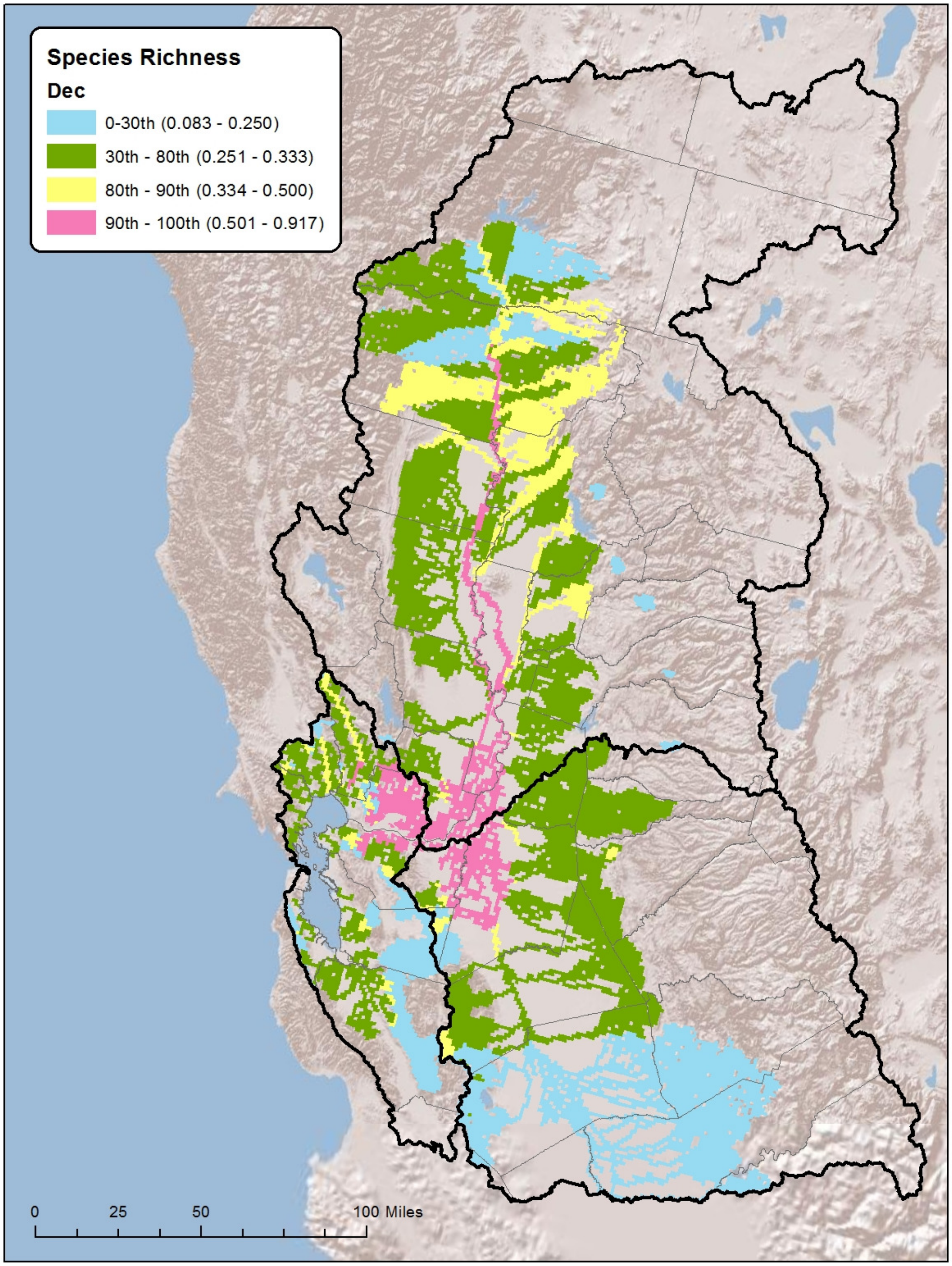


Figure 73 Spatial distribution of the 90th percentile indicator days for January through December

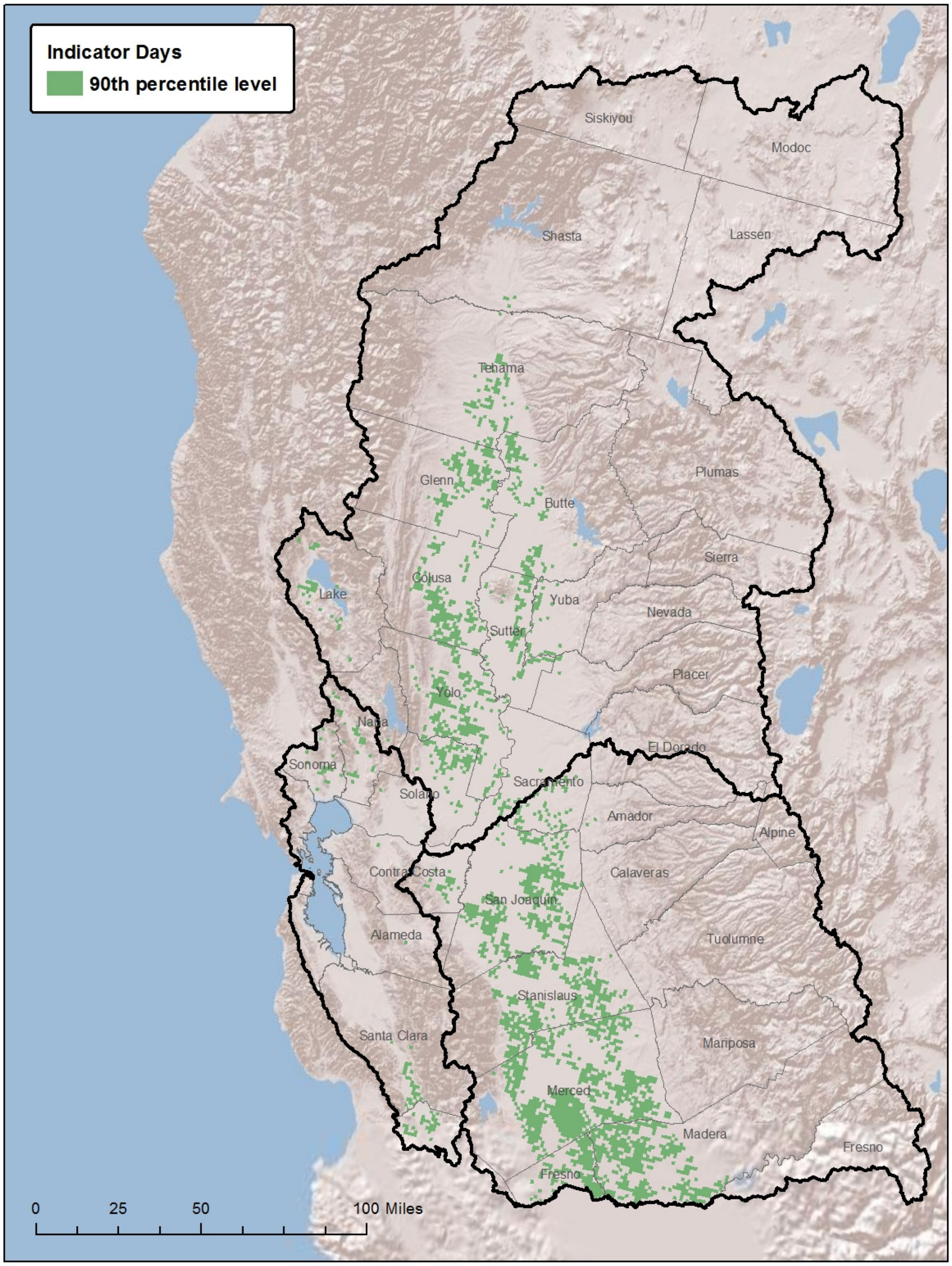


Figure 74 Spatial distribution of the 90th percentile species richness for January through December

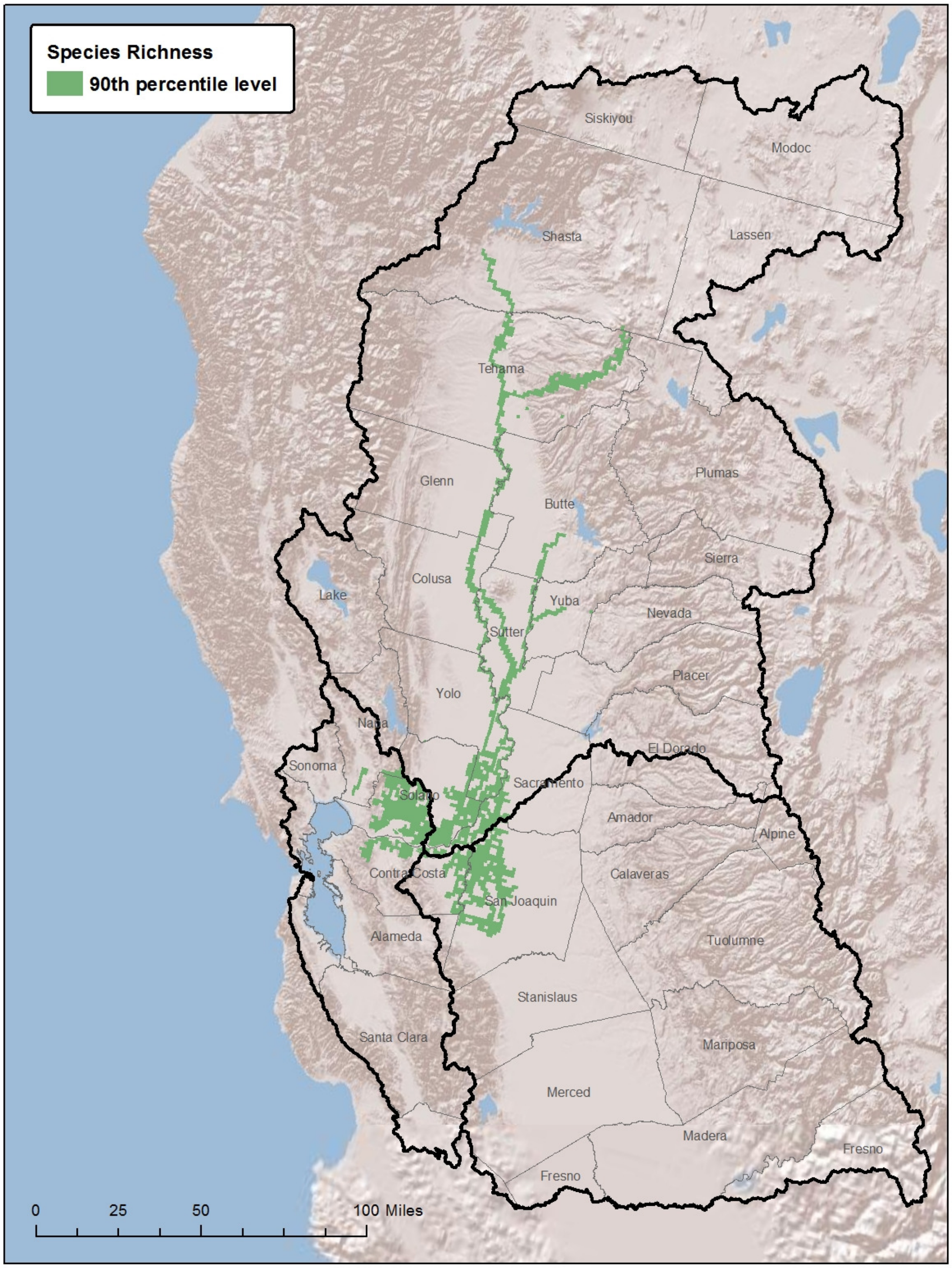


Figure 75 Spatial distribution of the 90th percentile species richness and indicator days for January through December

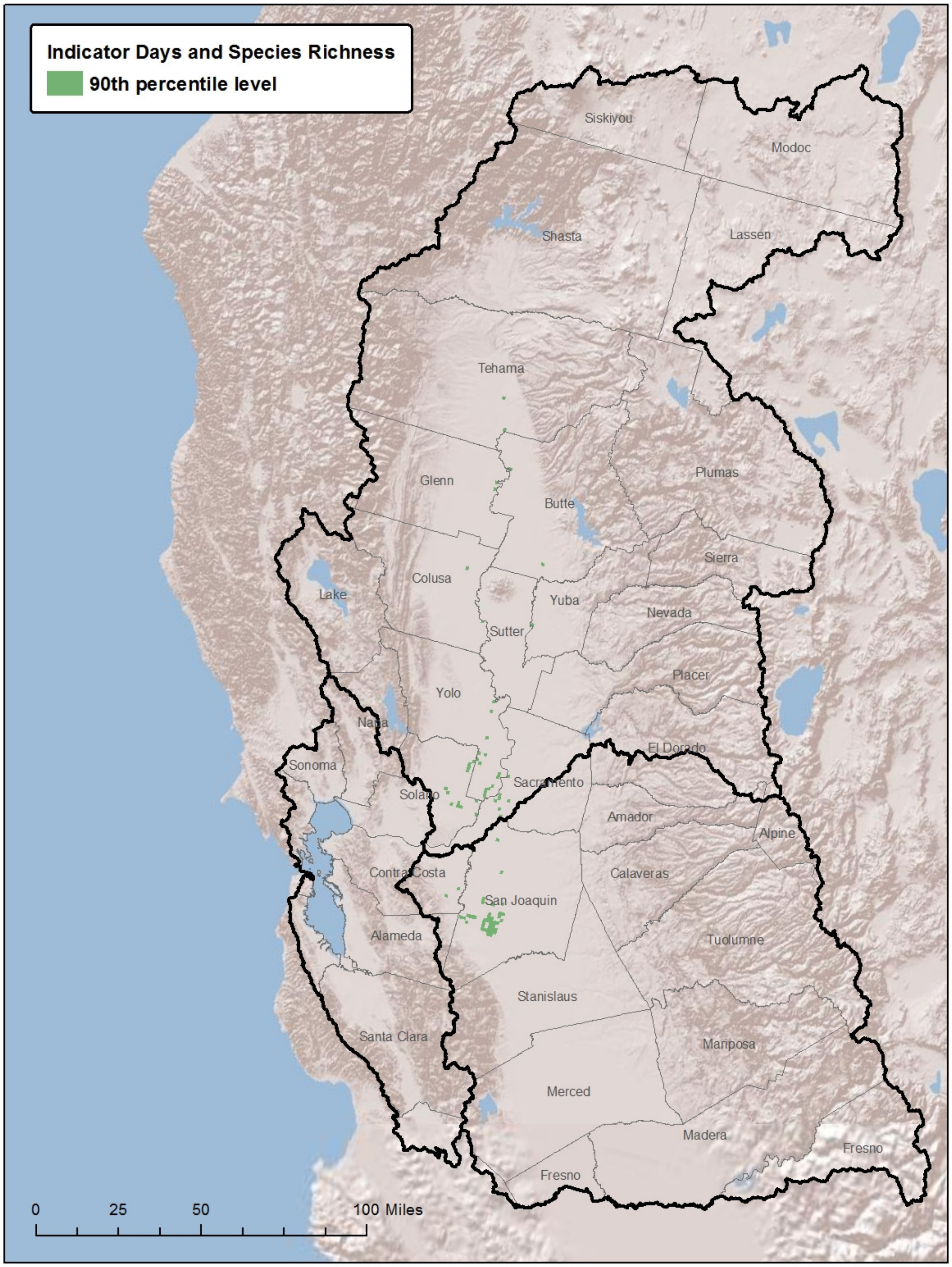


Figure 76 Co-occurrence of species of concern and indicator events for the period 2000–2009

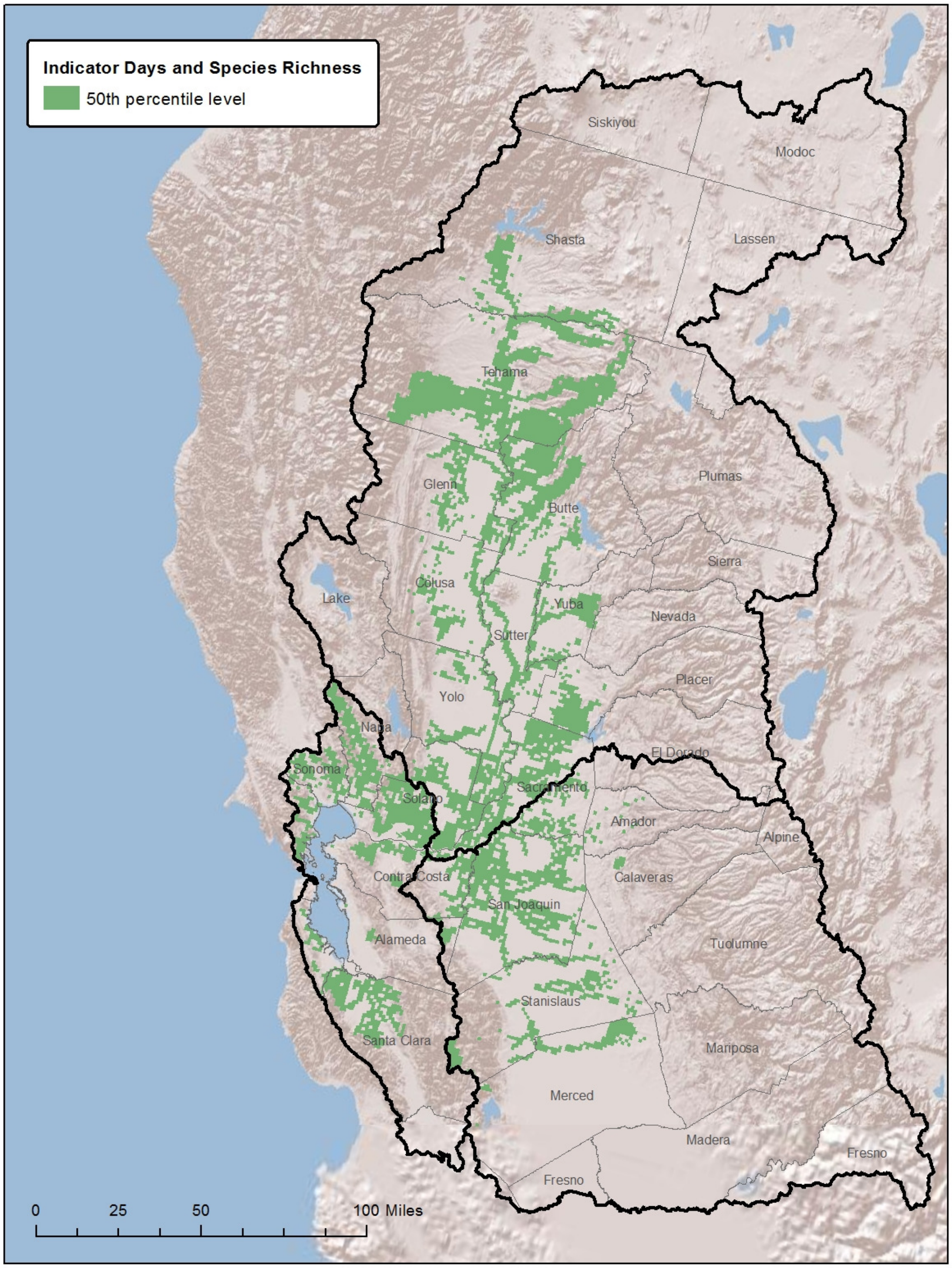


Figure 77 Co-occurrence of species of concern and indicator events for the month of January in the period 2000–2009

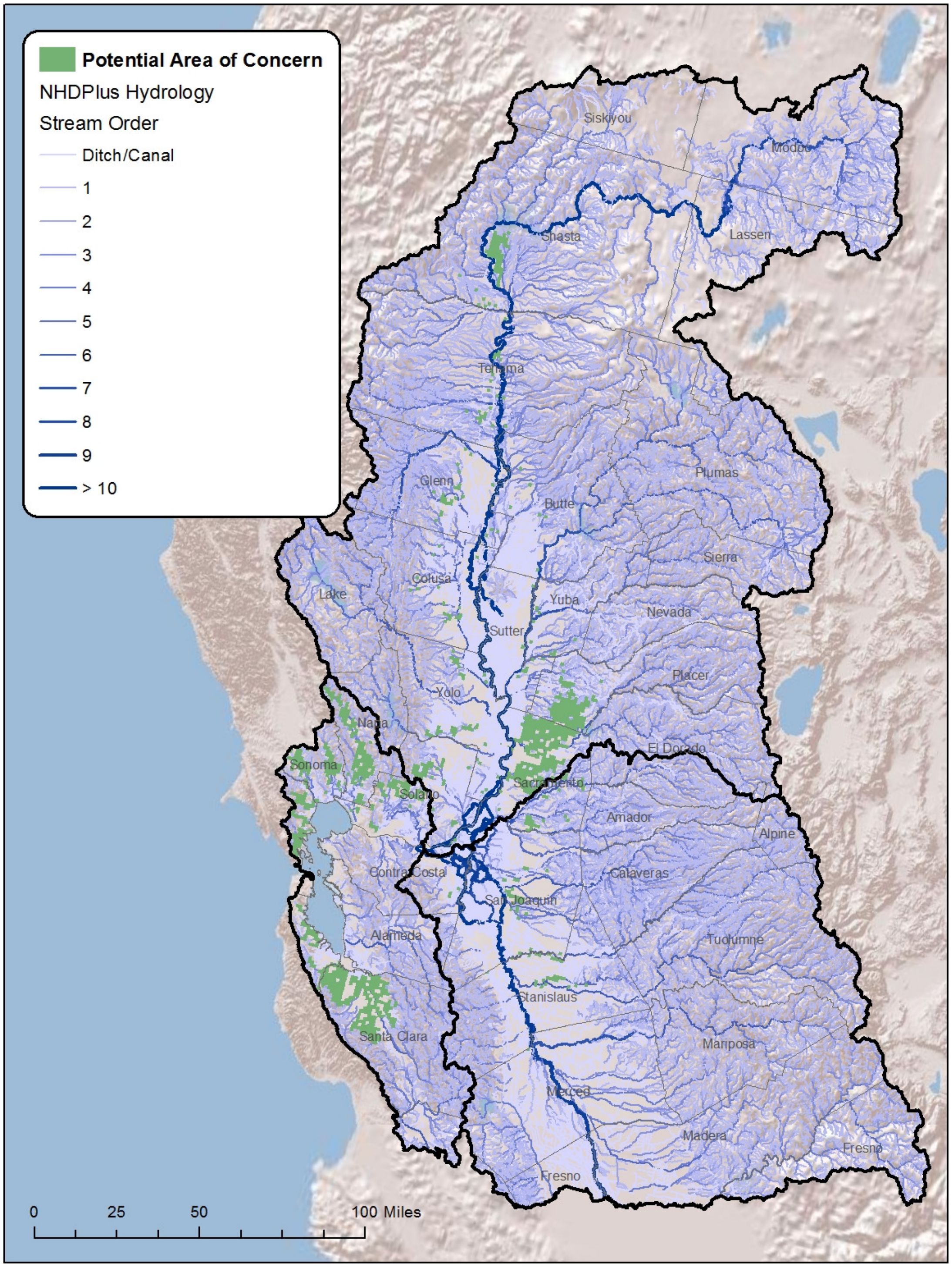


Figure 78 Co-occurrence of species of concern and indicator events for the month of February in the period 2000–2009

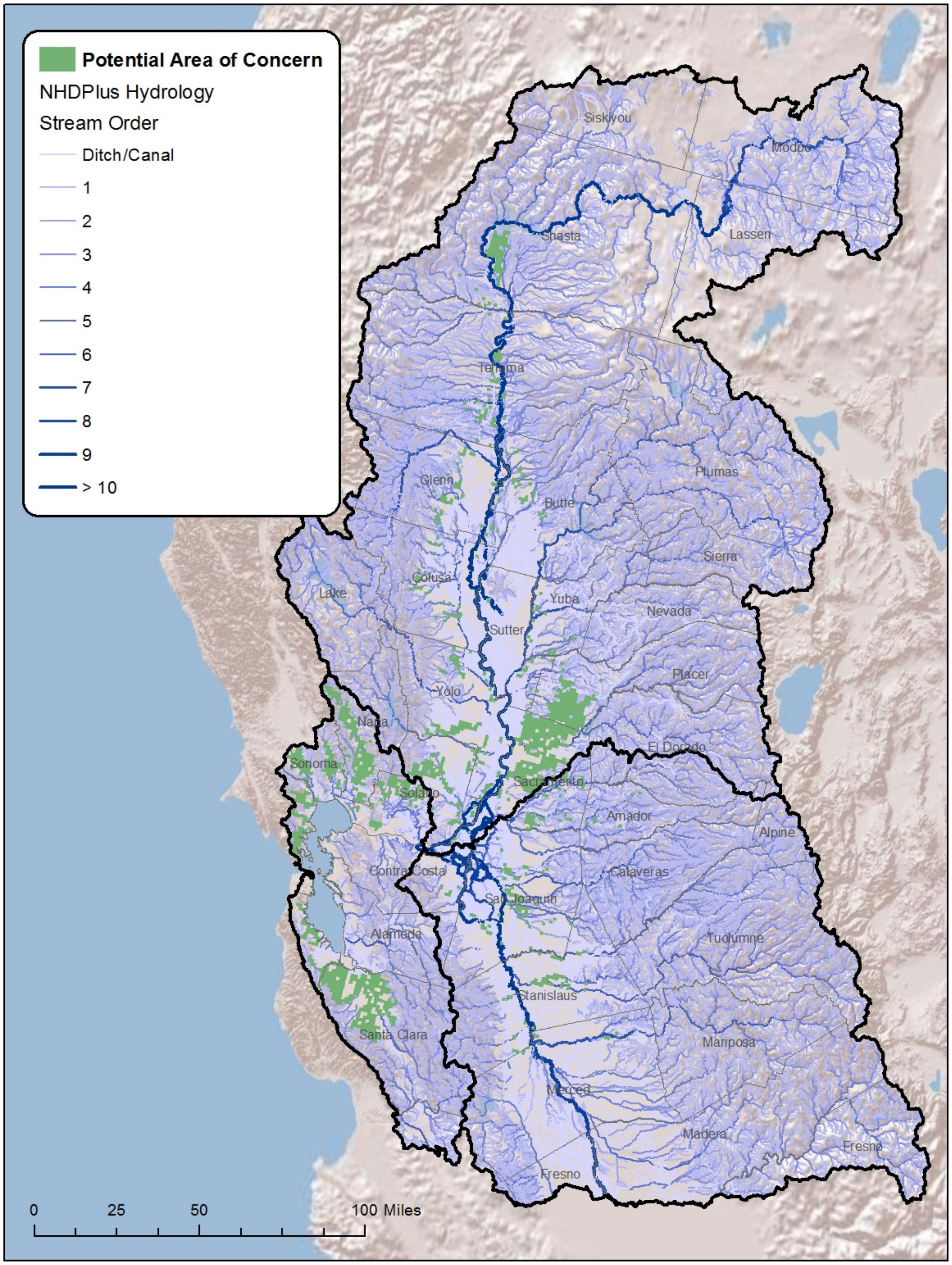


Figure 79 Co-occurrence of species of concern and indicator events for the month of March in the period 2000–2009

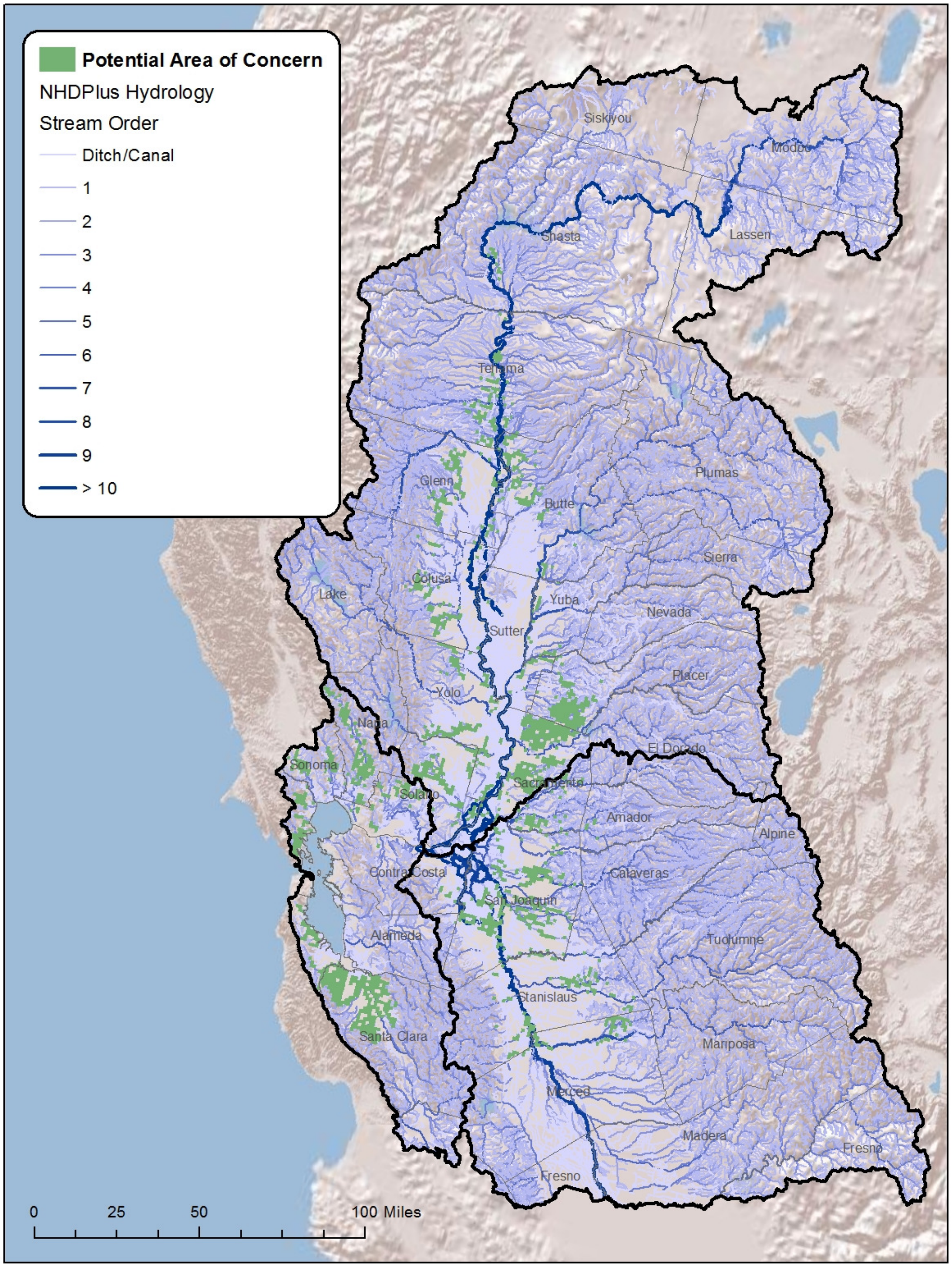


Figure 80 Co-occurrence of species of concern and indicator events for the month of April in the period 2000–2009

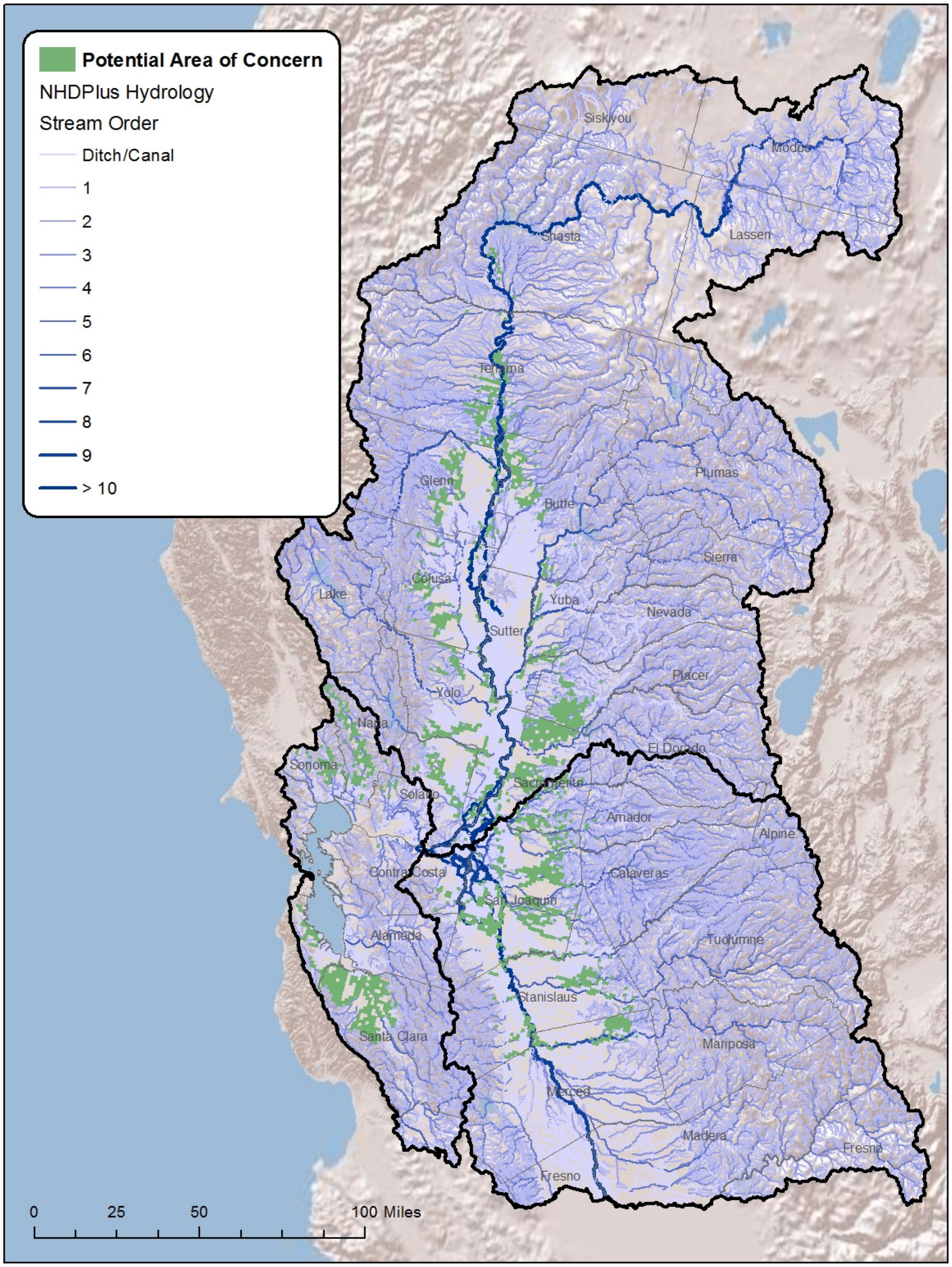


Figure 81 Co-occurrence of species of concern and indicator events for the month of May in the period 2000–2009

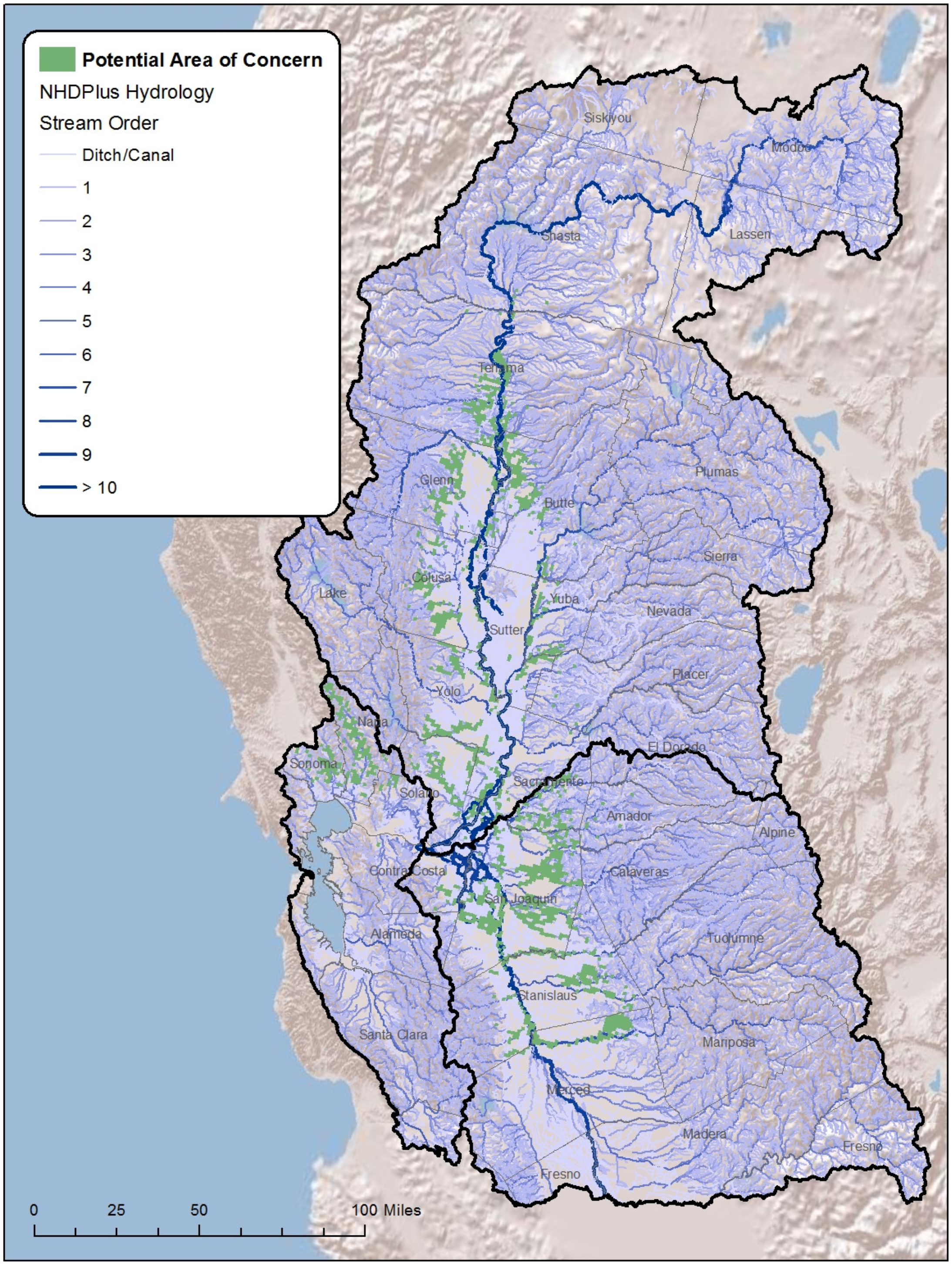


Figure 82 Co-occurrence of species of concern and indicator events for the month of June in the period 2000–2009

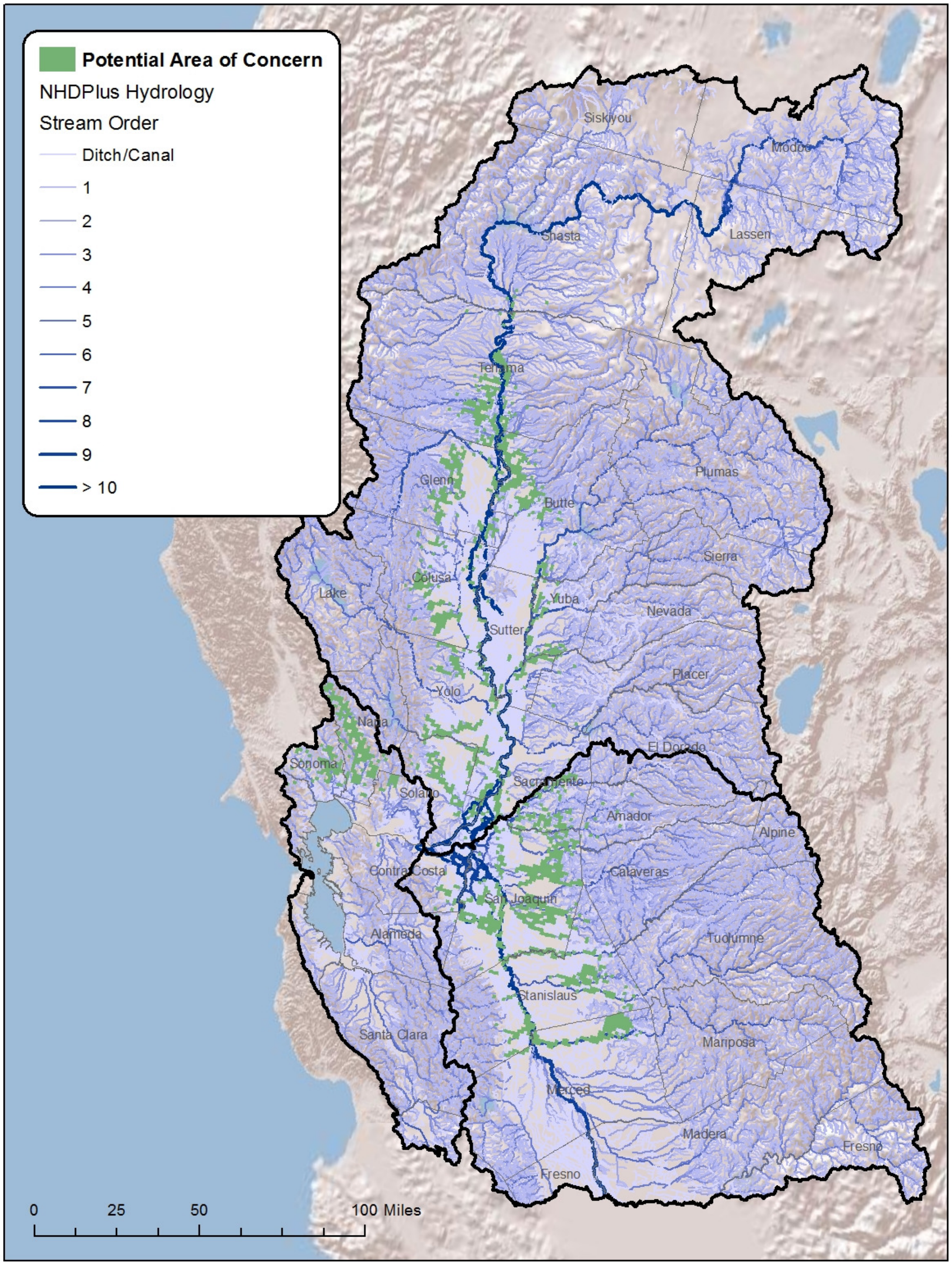


Figure 83 Co-occurrence of species of concern and indicator events for the month of July in the period 2000–2009.

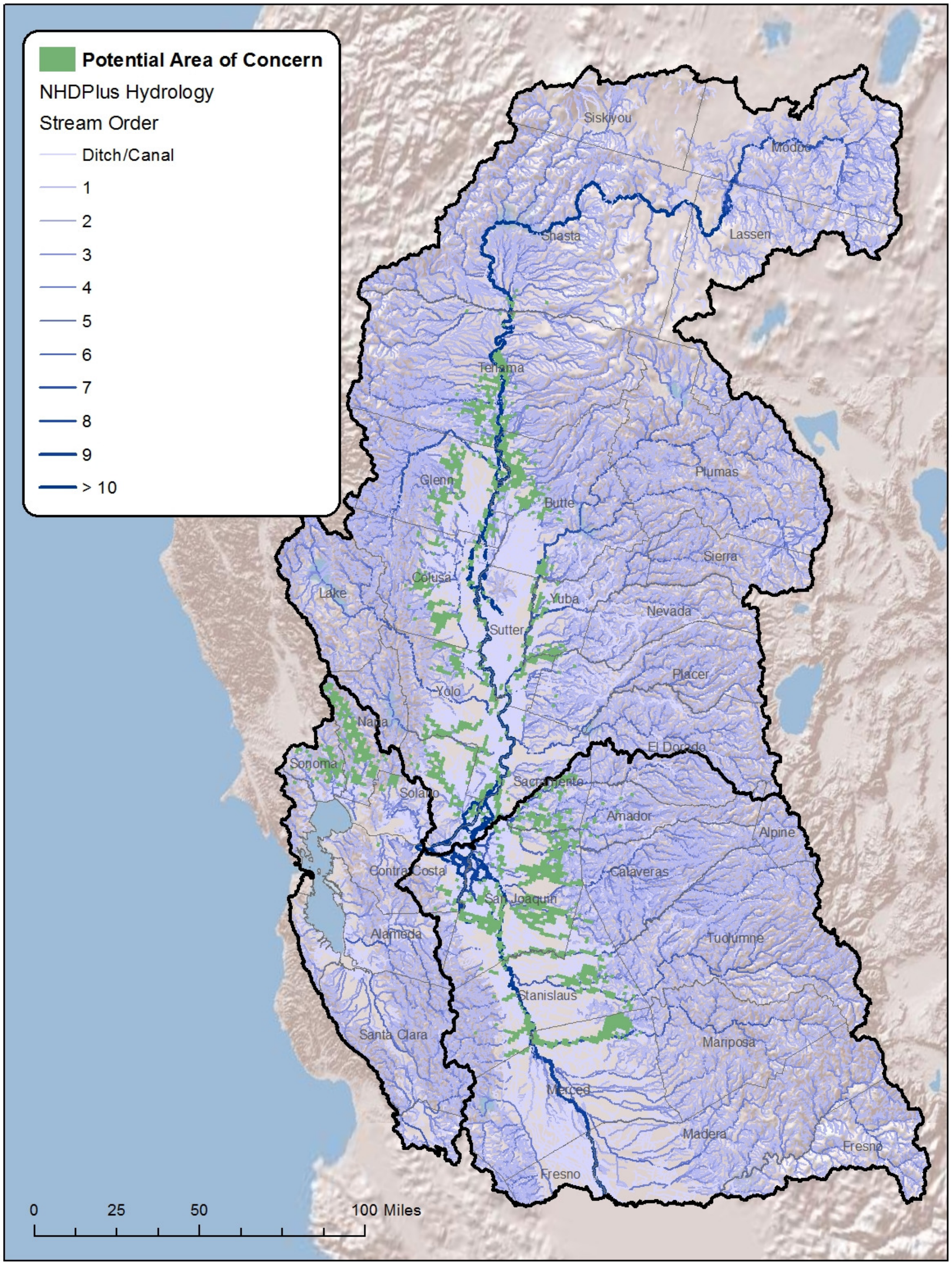


Figure 84 Co-occurrence of species of concern and indicator events for the month of August in the period 2000–2009.

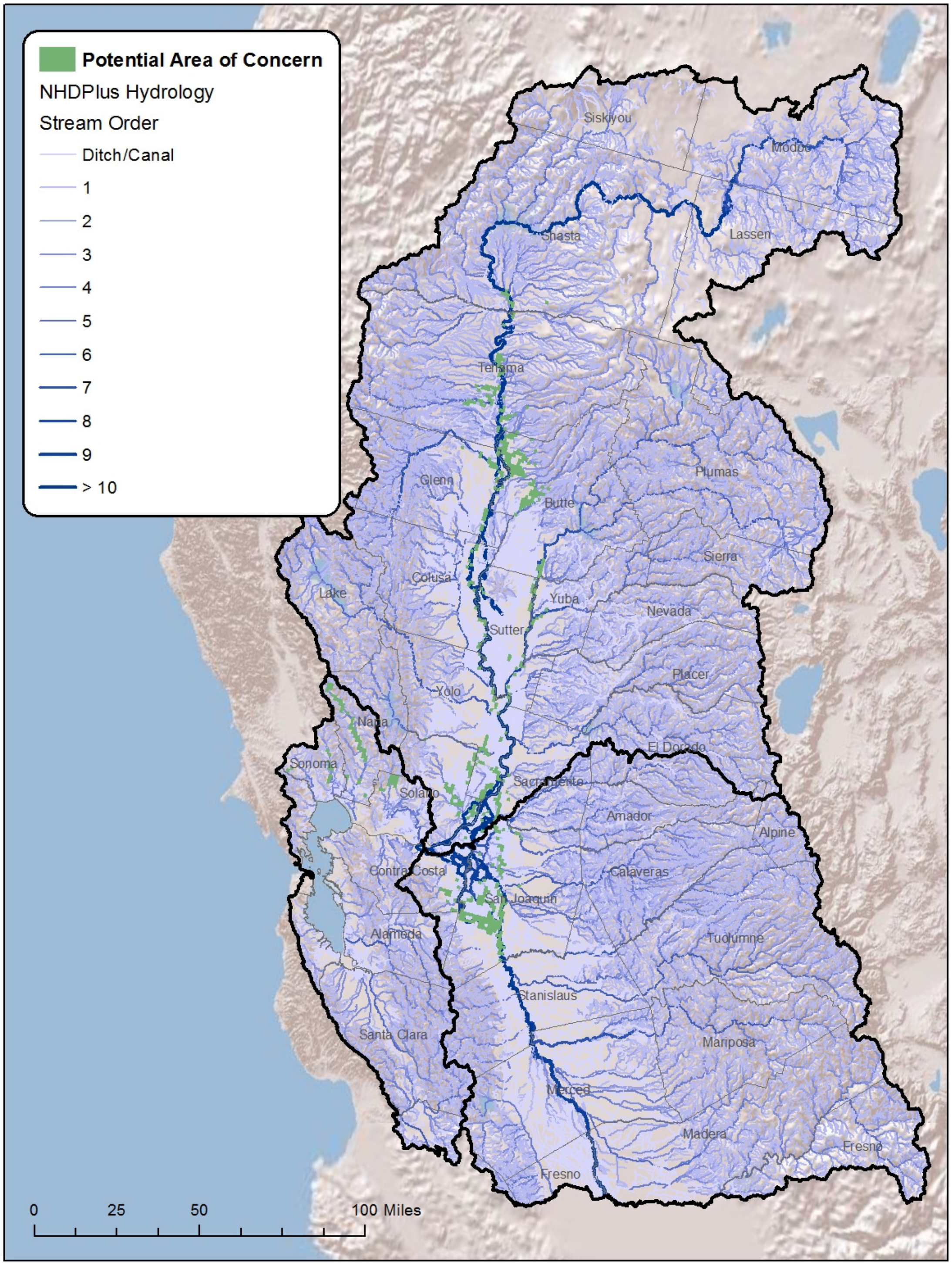


Figure 85 Co-occurrence of species of concern and indicator events for the month of September in the period 2000–2009

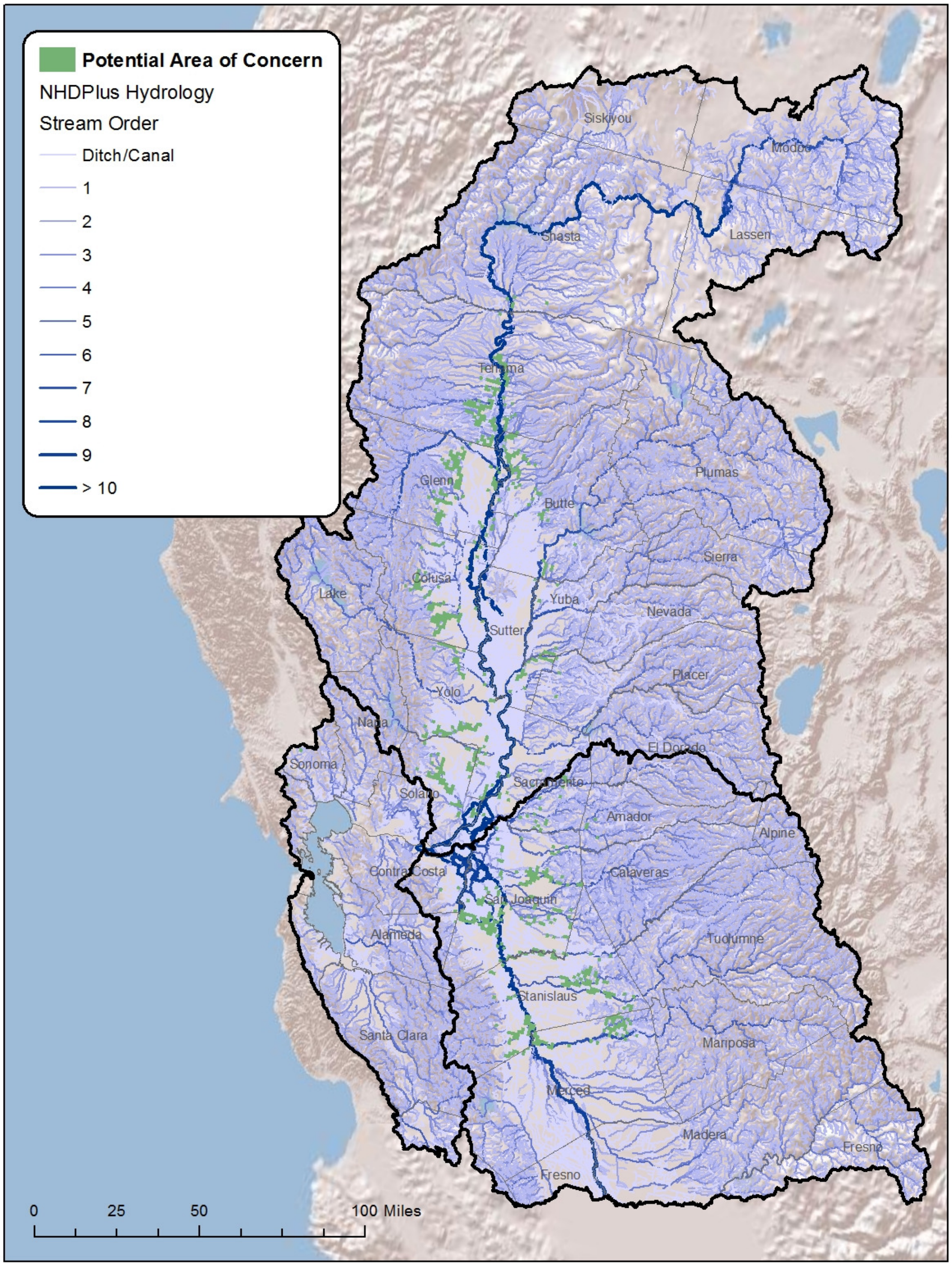


Figure 86 Co-occurrence of species of concern and indicator events for the month of October in the period 2000–2009

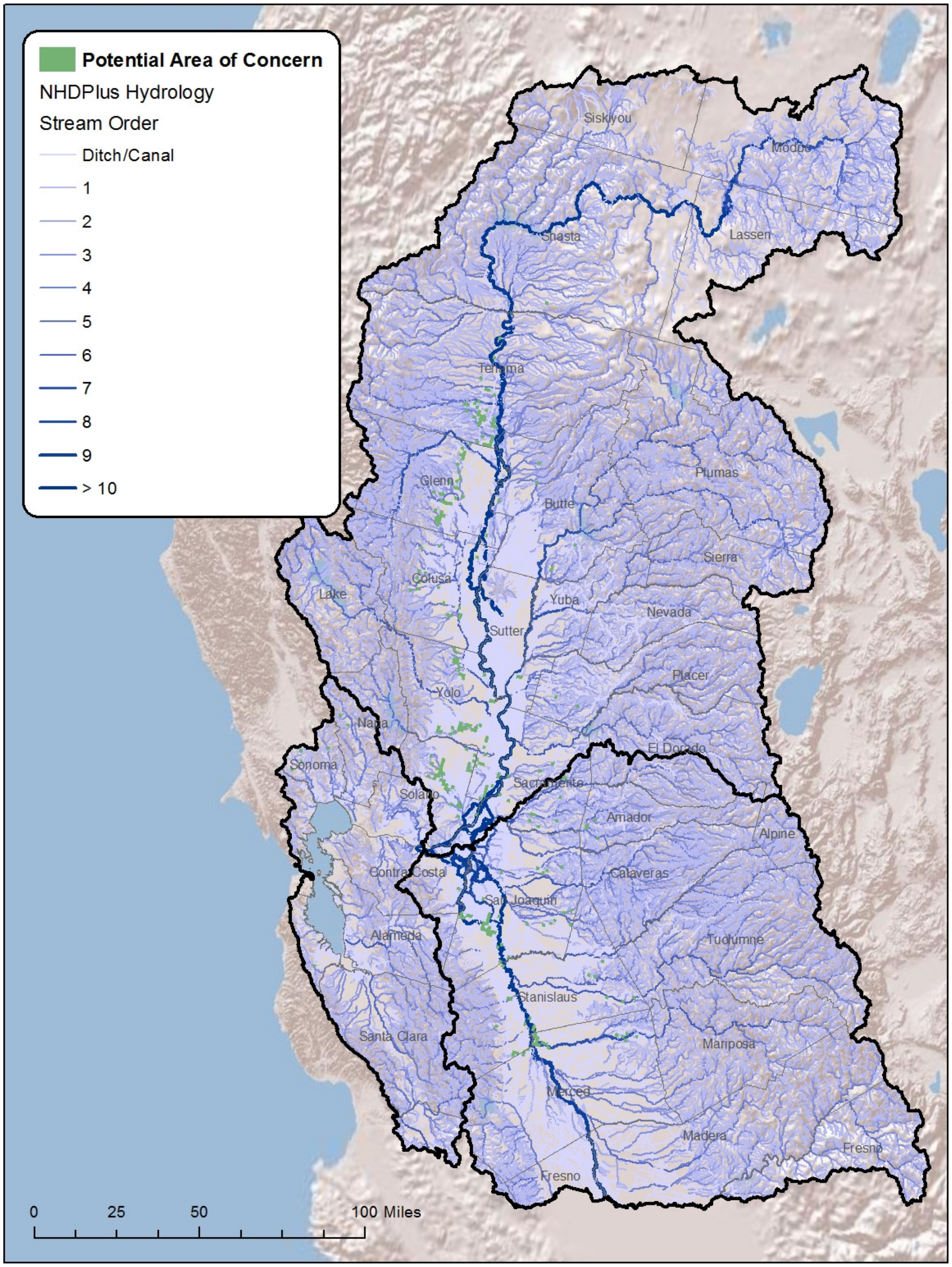


Figure 87 Co-occurrence of species of concern and indicator events for the month of November in the period 2000–2009

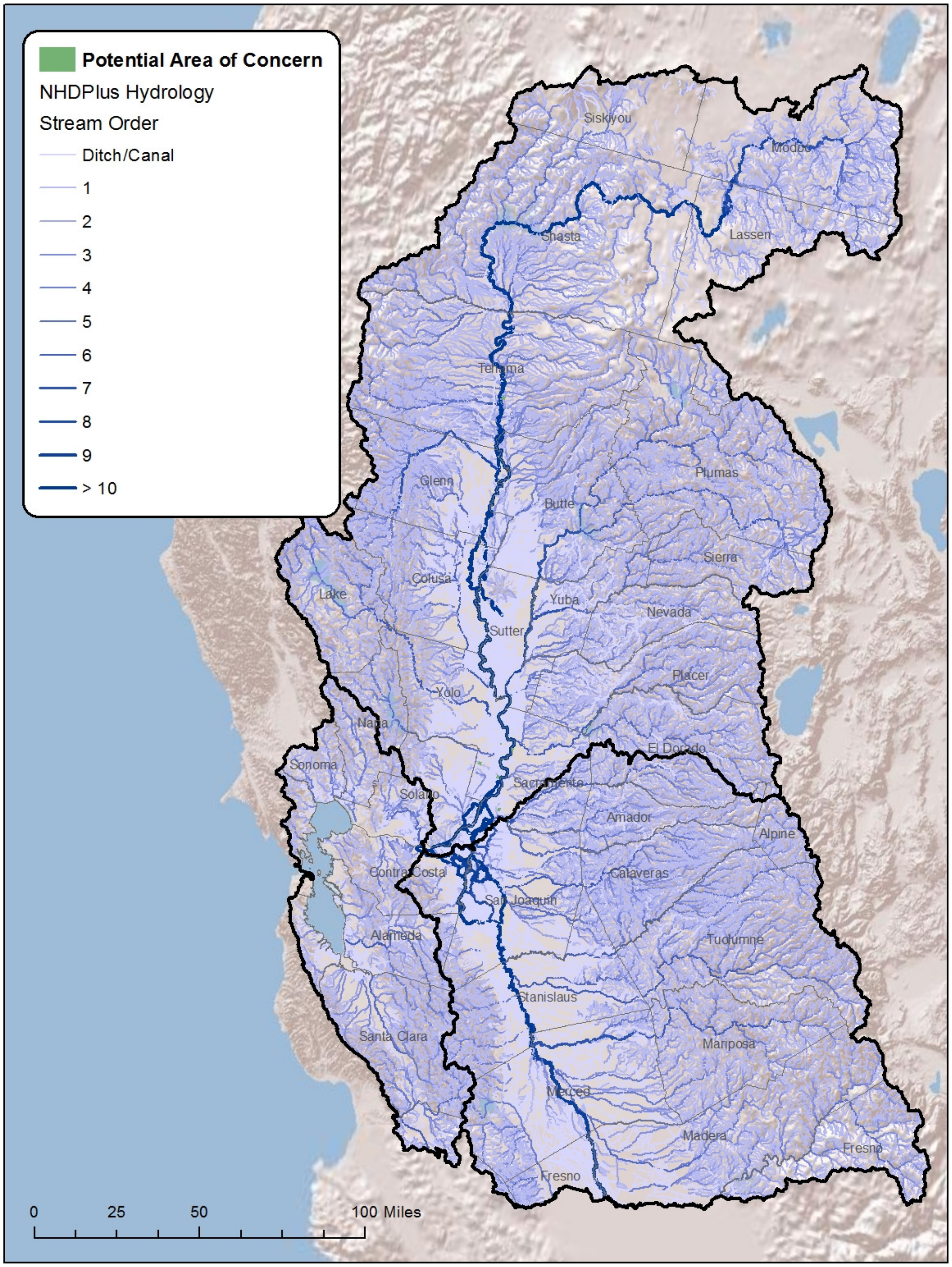


Figure 88 Co-occurrence of species of concern and indicator events for the month of December in the period 2000–2009

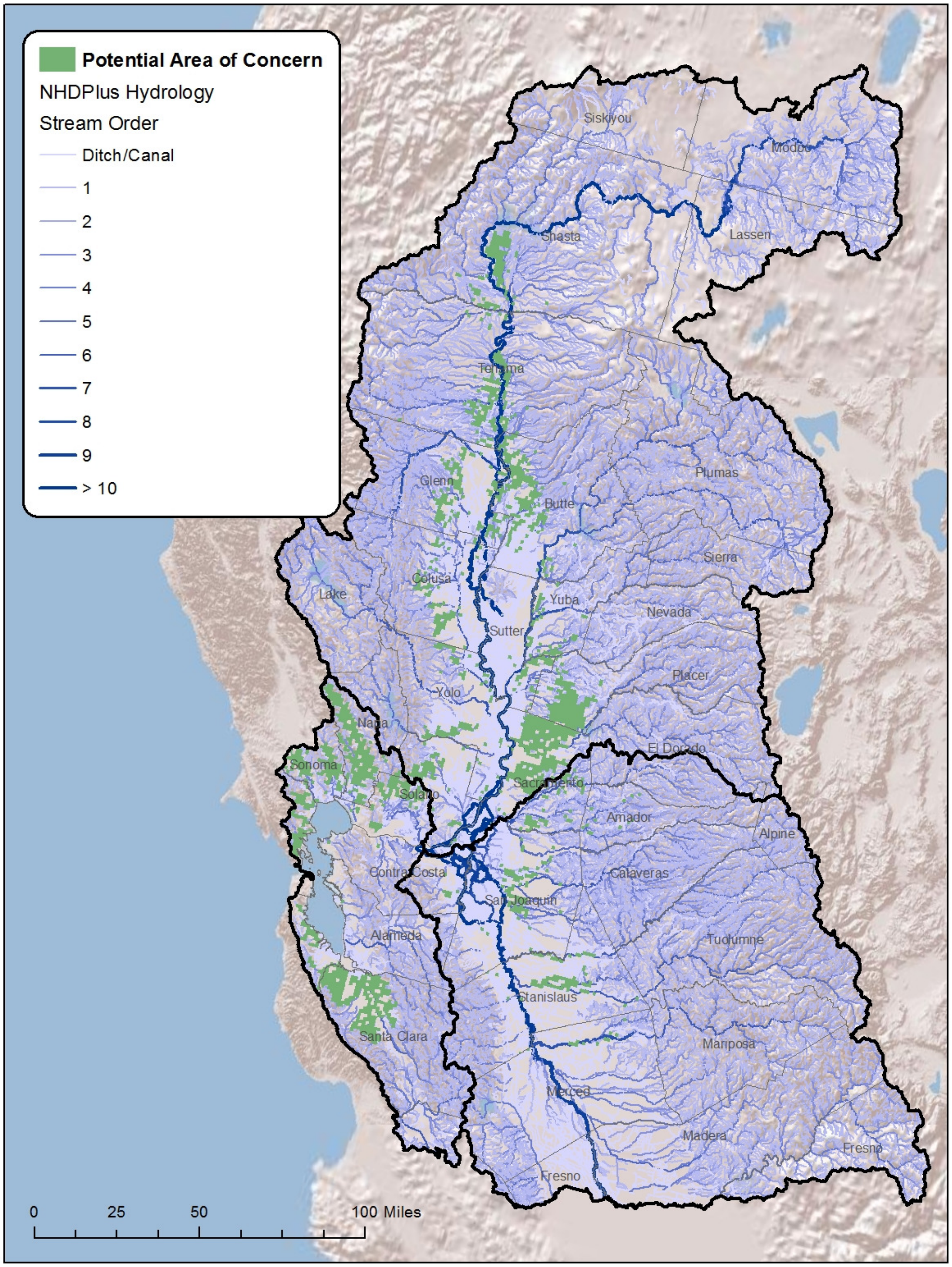


Figure 89 Total number of samples collected for 32 chemicals of interest in the period 2000–2009

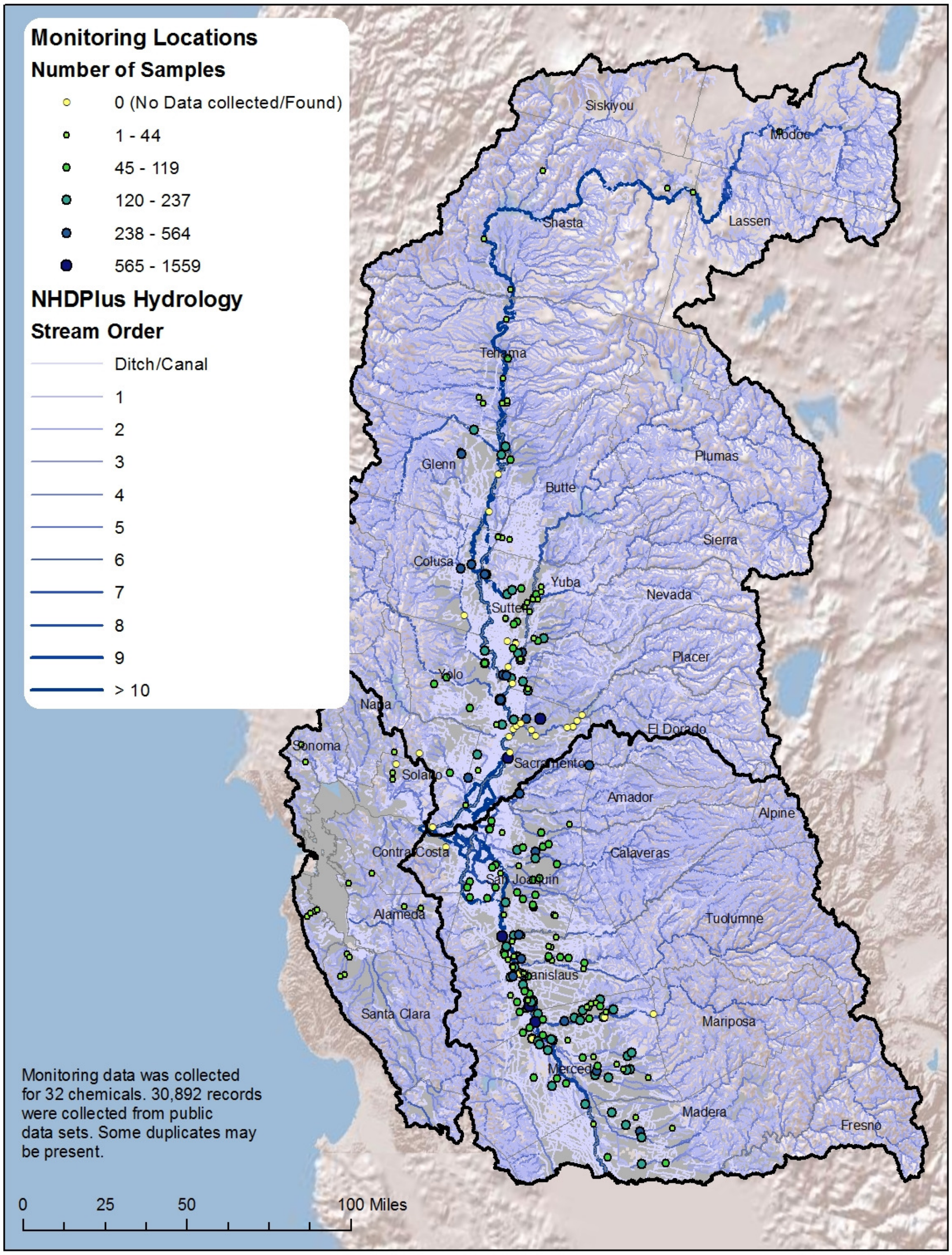


Figure 90 Number of samples exceeding the T&ES ecotoxicological benchmarks in the period 2000–2009

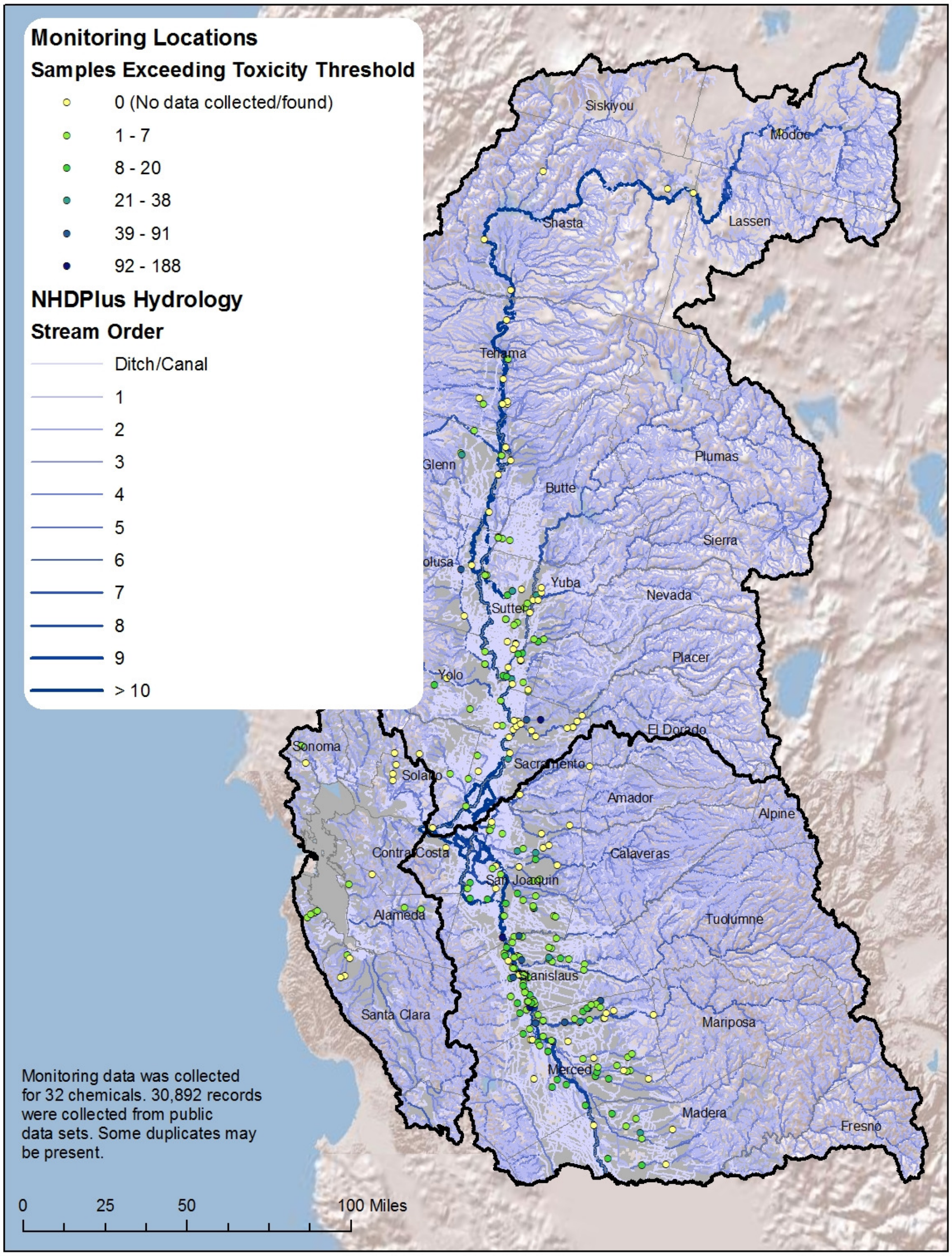


Figure 91 Percentage of collected monitoring samples exceeding the T&ES benchmark

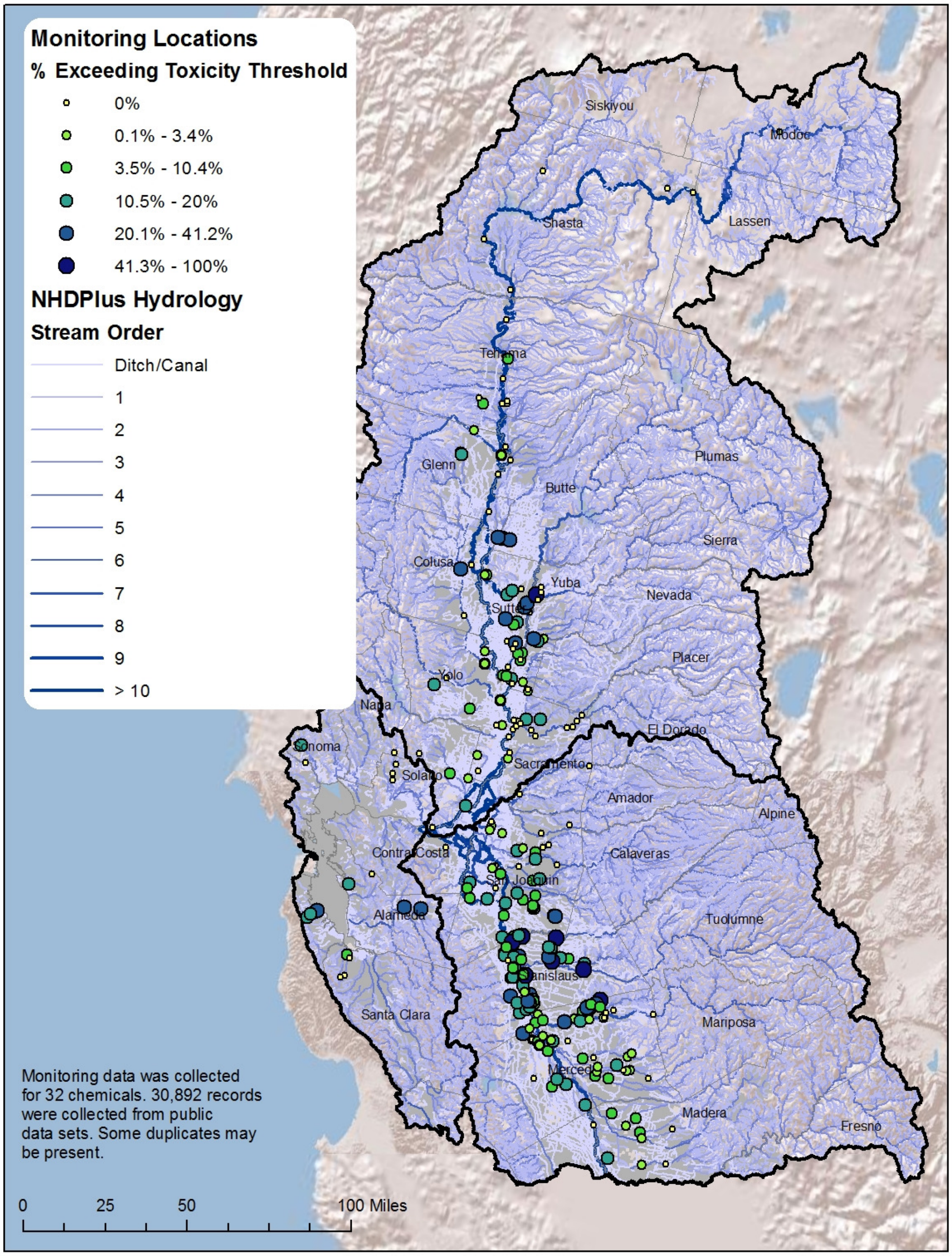


Figure 92 Percentage of all collected samples that exceeded to T&ES ecotoxicological benchmark in conjunction with the 90th percentile co-occurrence

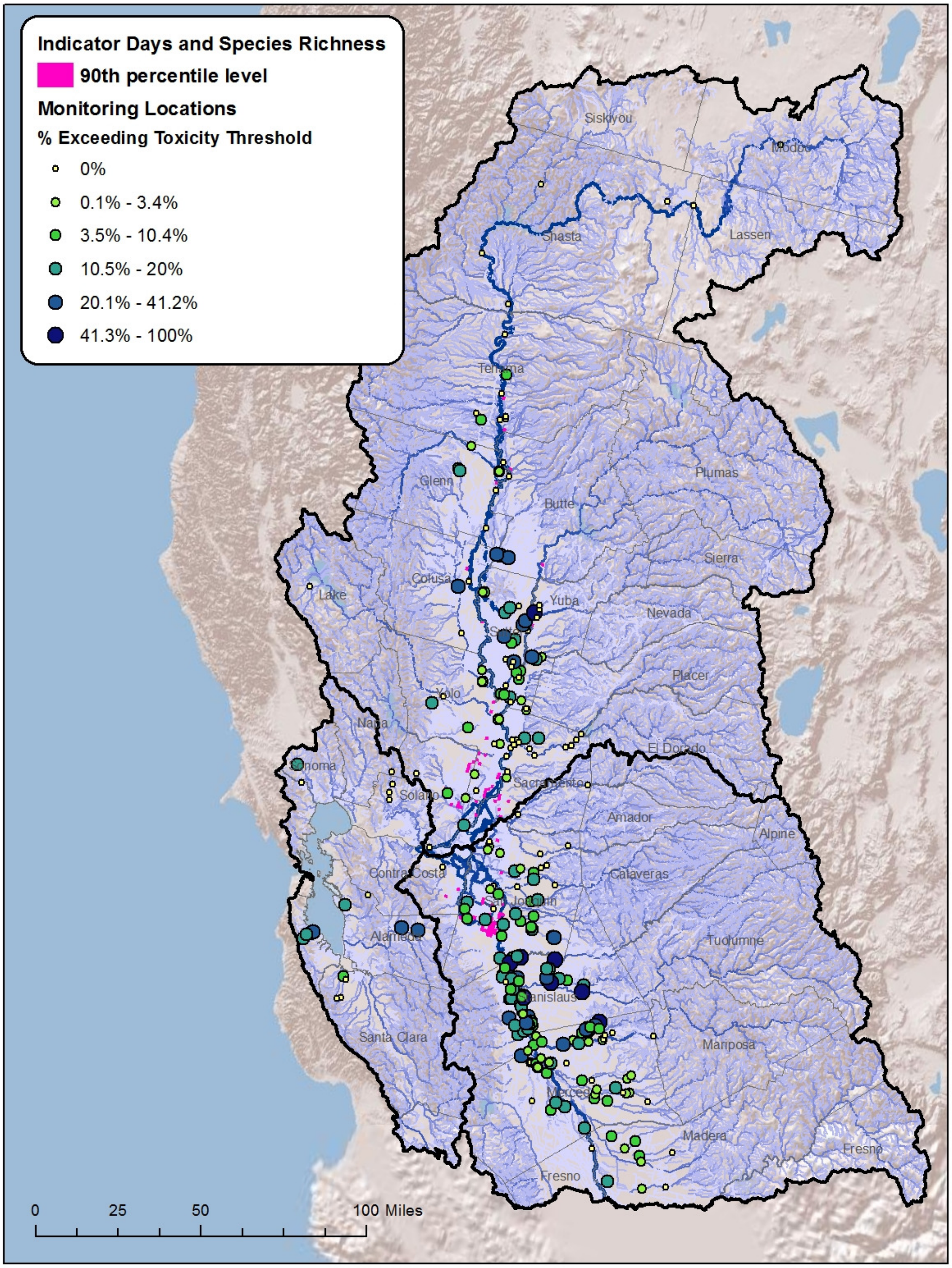


Figure 93 Percentage of all collected samples that exceeded to T&ES ecotoxicological benchmark in conjunction with the 90th percentile co-occurrence (Delta-estuary close-up view)

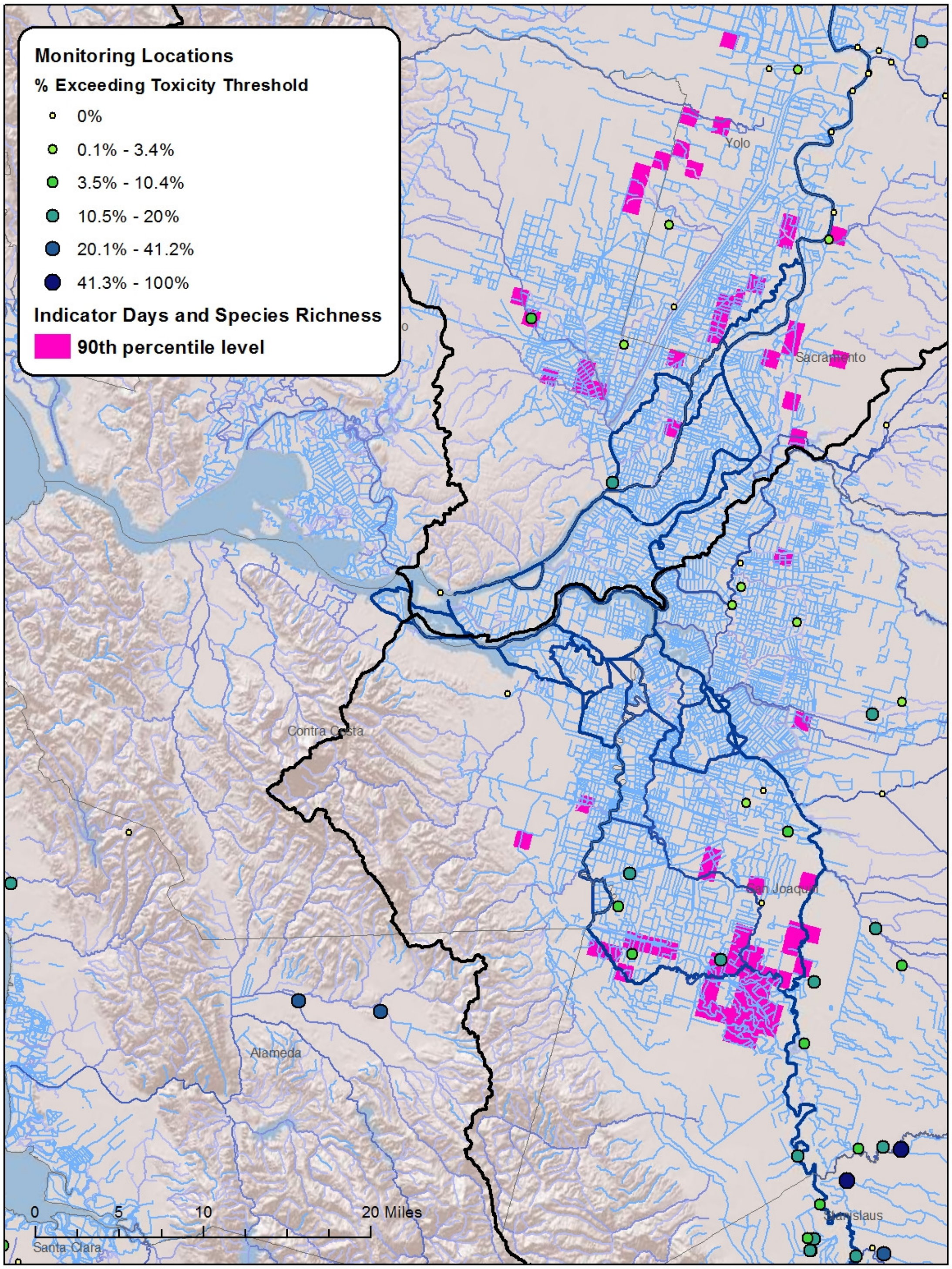


Figure 94 Percentage of all collected samples that exceeded to T&ES ecotoxicological benchmark in conjunction with the 80th percentile co-occurrence

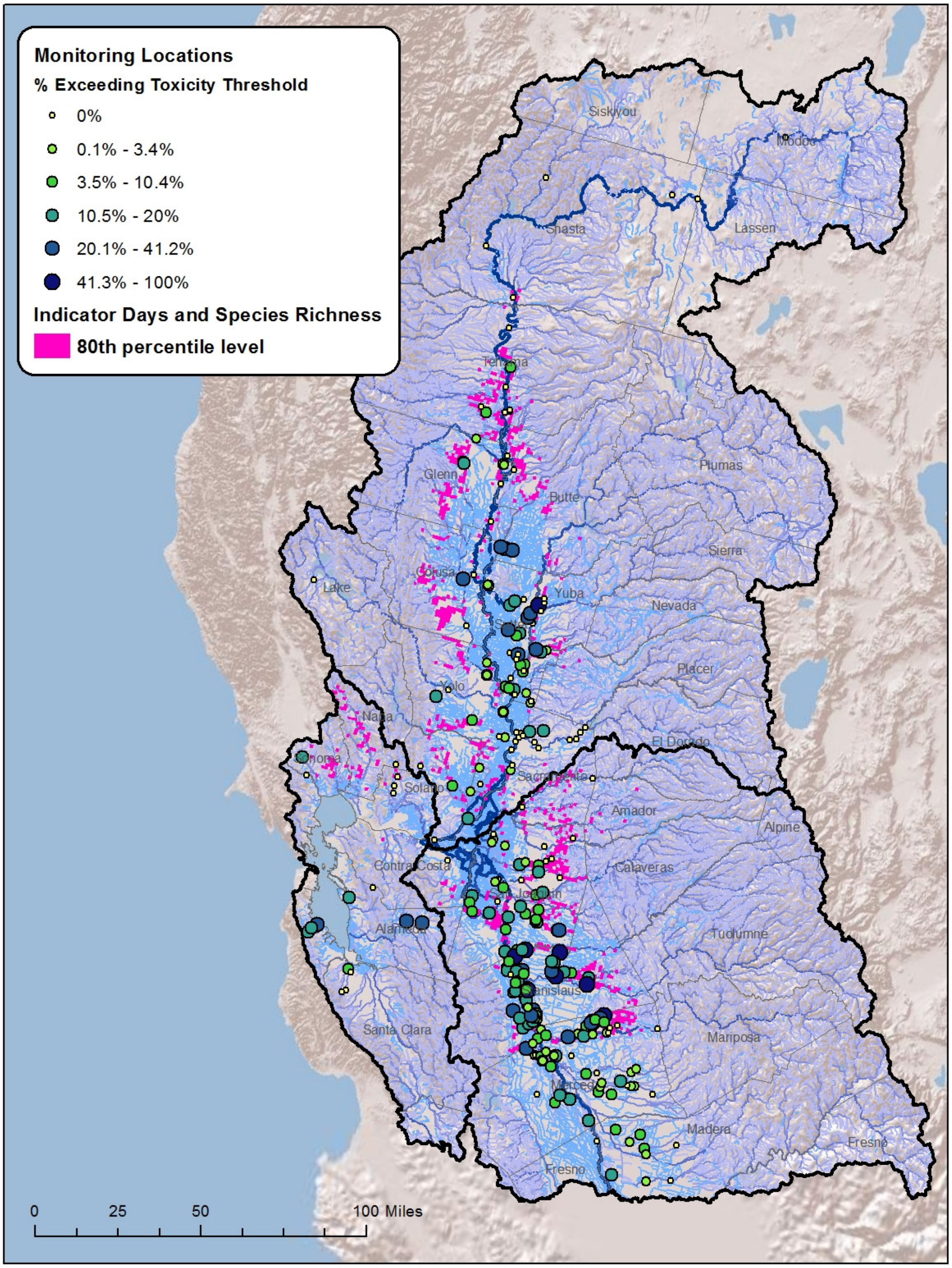


Figure 95 80^{th} percentile regions and monitoring data (a) number of samples, (b) percent exceedances, and (c) number of chemicals sampled

(a) (b) (c)

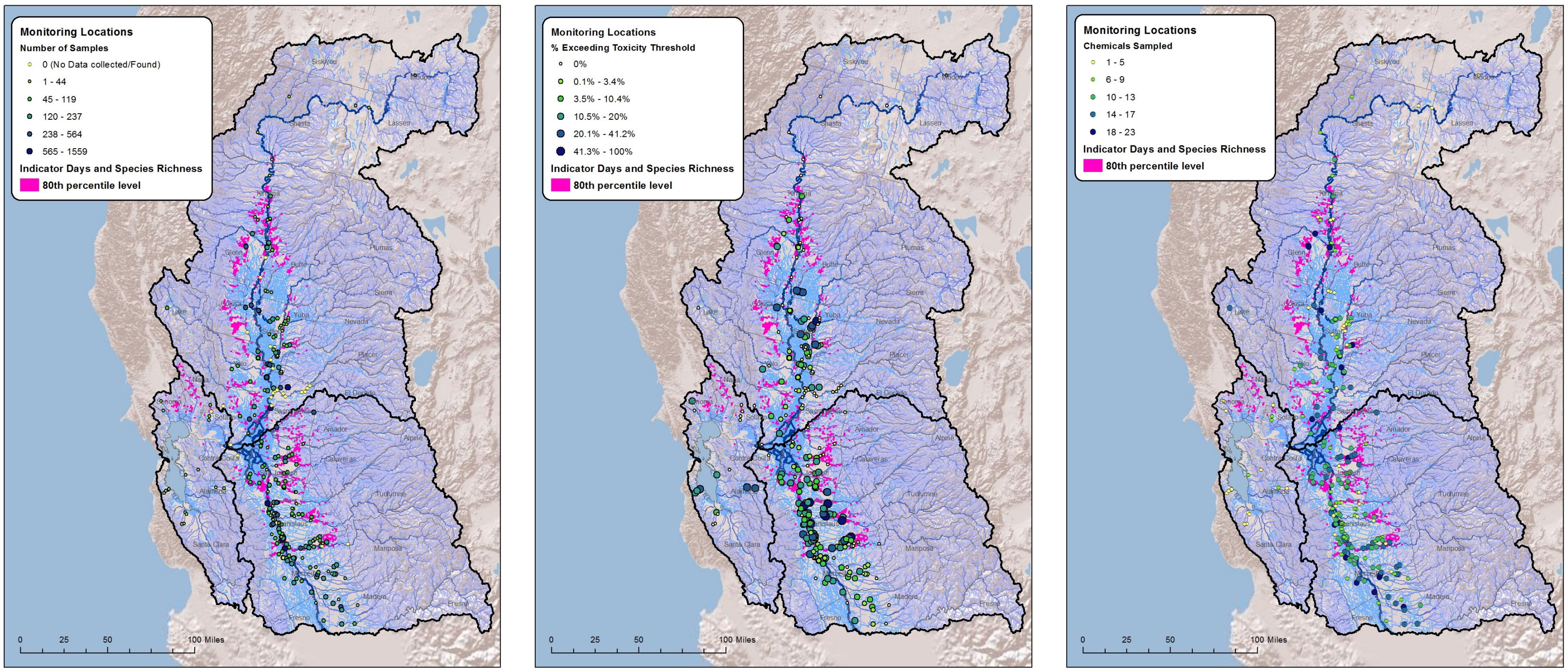


Figure 96 Percentage of all collected samples that exceeded the T&ES ecotoxicological benchmark in conjunction with the 40th percentile co-occurrence

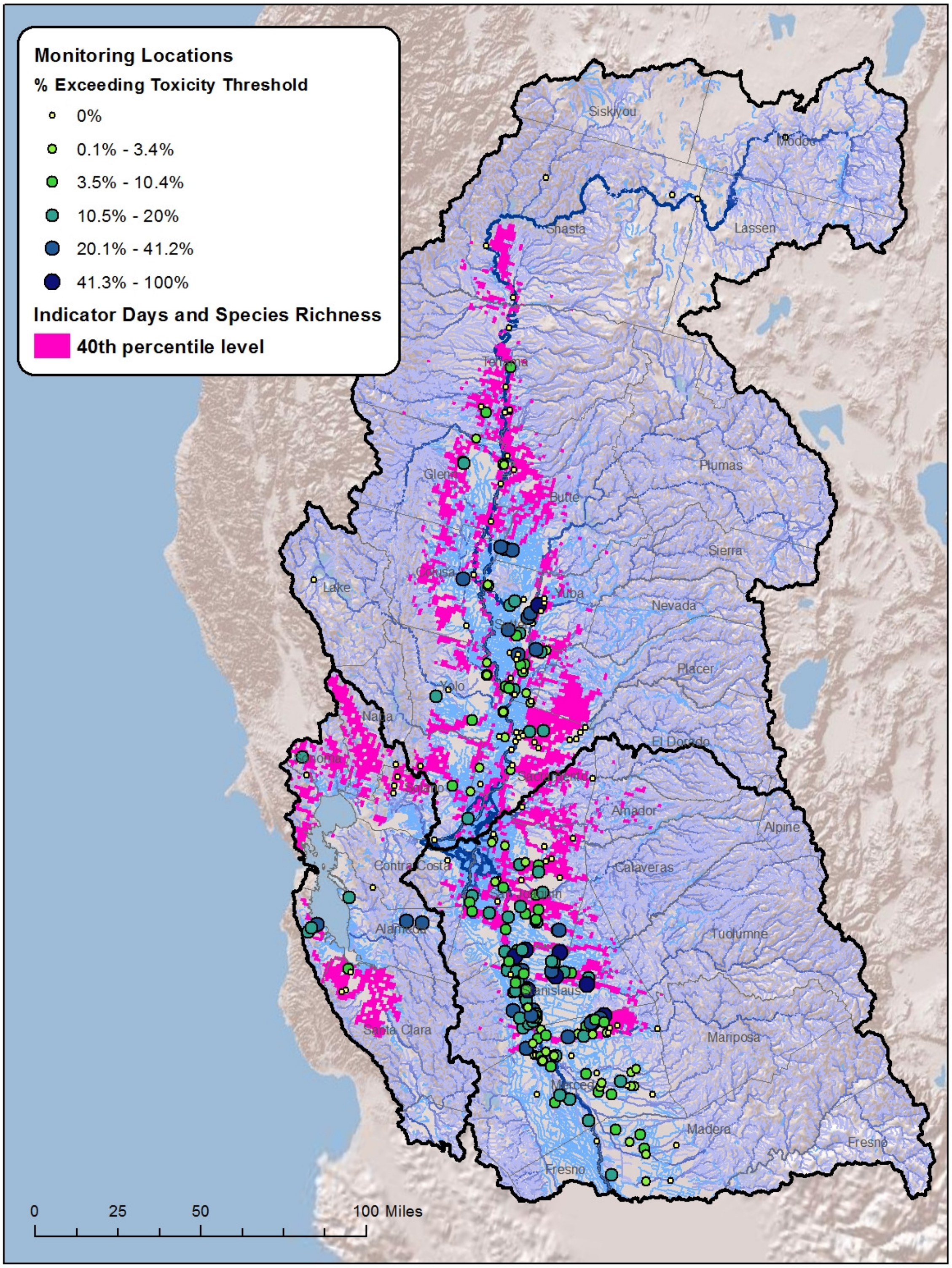


Figure 97 Example of ranked areas using the co-occurrence matrix

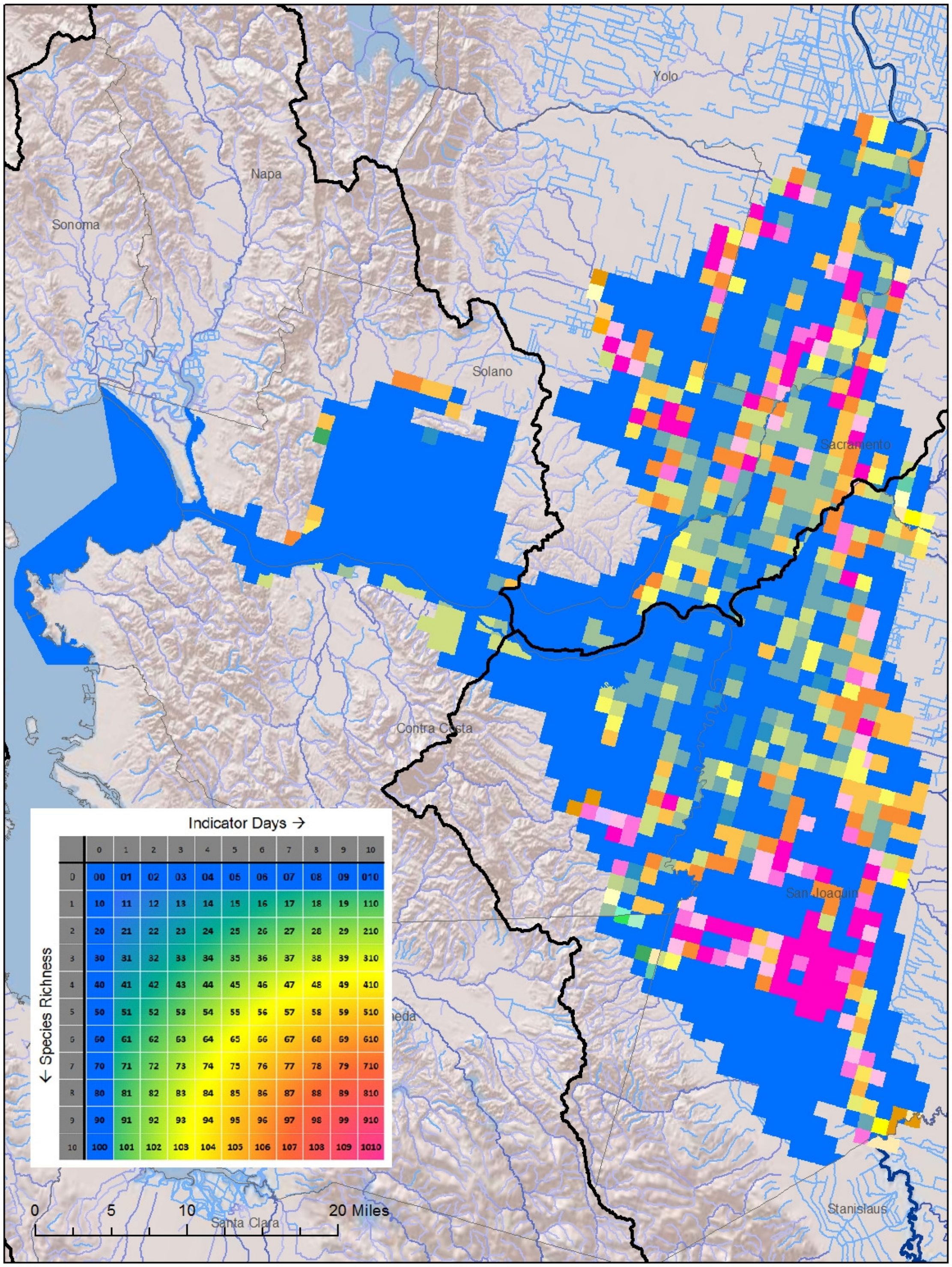


Figure 98 90th percentile indicator day area within the Delta Smelt habitat

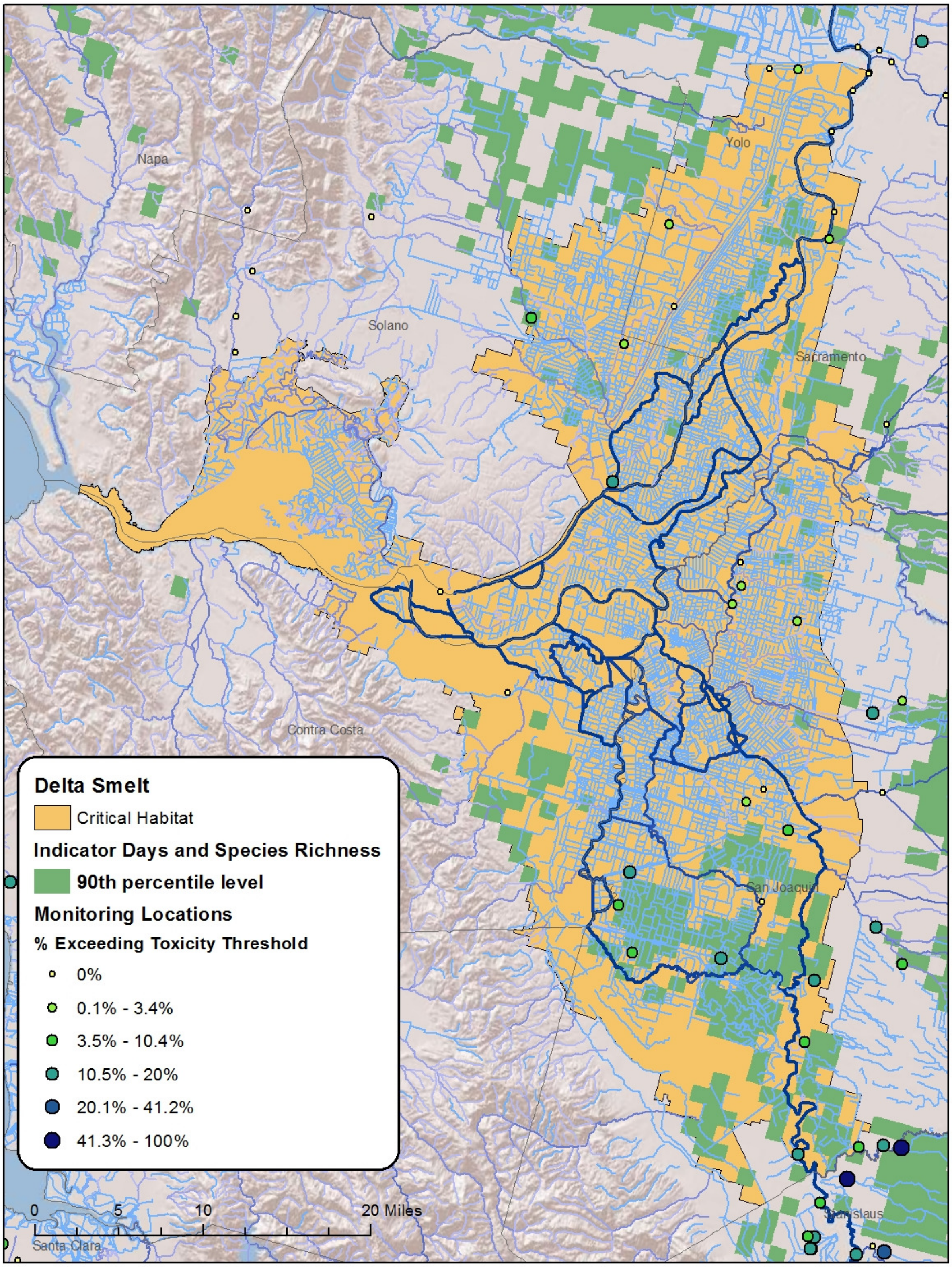


Figure 99 Land use data gaps

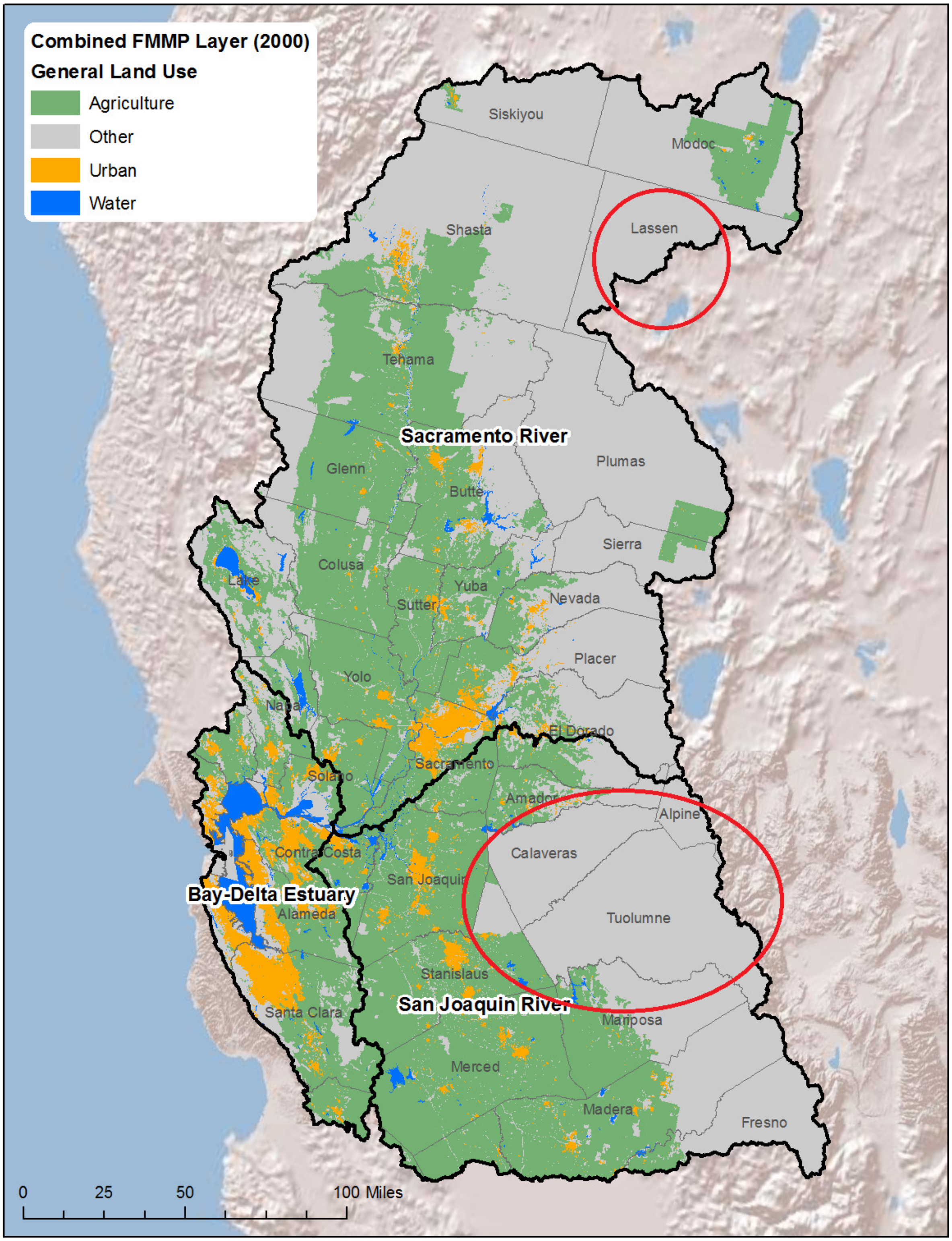
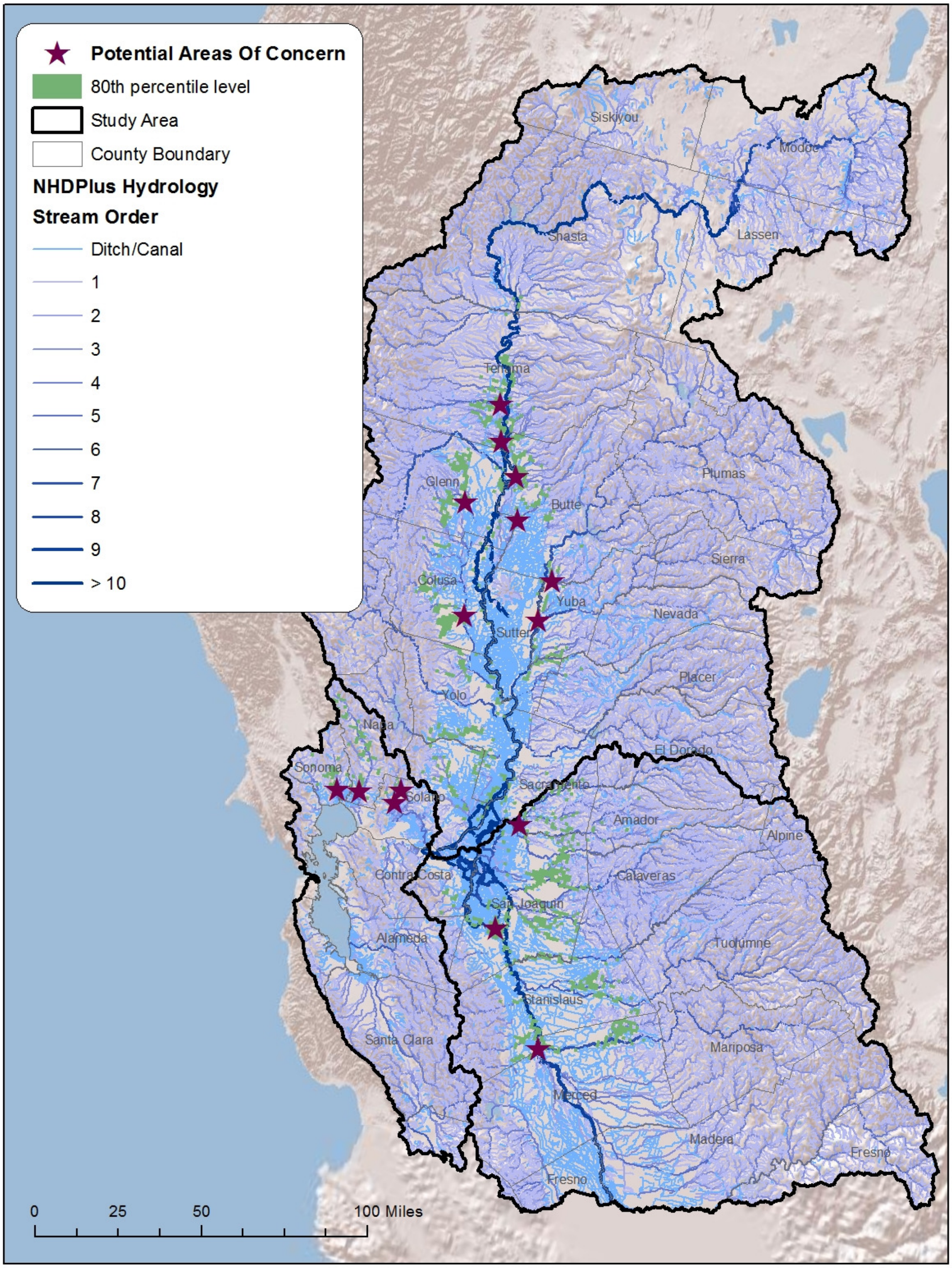


Figure 100   Potential Areas of Concern



8.0 APPENDIX SECTION

APPENDIX A.—Extraction of soil parameters from the SSURGO database

The SSURGO soil layer (ssurgo_2009_ap), was linked to the SSURGO component table to determine which soil series (MUKEY) should be used. A subset of the component table, COMPONET_AP, was created by exporting the selected records into the new table.

Using SQL Server 2008, the relevant soil property data (table) were extracted (QUERY 1) from the SSURGO CHORIZON table and combined with the data from the COMPONENT table (Appendix D).

Using a FORTRAN program named baysoils.f90 the combined SSURGO and STATSGO soils data were formatted for use with the PRZM input file builder. As a result, for each unique soil all records are placed on a single line in the file.

Query 1 SQL Query to extract data from the SSURGO database

```
select

CALFED_COMPONENT_AP.mukey,

CALFED_COMPONENT_AP.cokey,

CALFED_COMPONENT_AP.comppct_r,

CALFED_COMPONENT_AP.compname,

CALFED_COMPONENT_AP.slope_l,

CALFED_COMPONENT_AP.slope_h,

CALFED_COMPONENT_AP.slope_r,

CALFED_COMPONENT_AP.slopelenusle_r,

CALFED_COMPONENT_AP.hydgrp,

chorizon.kwfact,

chorizon.hzdepb_r,

chorizon.hzdept_r,

chorizon.sandtotal_r,

chorizon.silttotal_r,

chorizon.claytotal_r,
```

```
chorizon.dbovendry_r,
chorizon.om_r,
chorizon.ksat_r,
chorizon.awc_r,
chorizon.wthirdbar_r,
chorizon.wfifteenbar_r,
chorizon.ph1to1h2o_r,
chorizon.chkey
into CALFED_SOILS_PRZM
from CHORIZON,CALFED_COMPONENT_AP
where CHORIZON.cokey = CALFED_COMPONENT_AP.cokey
order by calfed_component_ap.cokey;
```

APPENDIX B.—CIMIS Weather Data Processing

Development of the historic daily climate data for the study area used a 2-tiered approach. In the first tier a GIS dataset, representing the area of interest was developed and in the second tier the daily weather data were collected and processed for use with the environmental-fate models.

Tier 1: creation of the GIS dataset was accomplished using the following approach:

- Download a list of CIMIS weather station from the CIMIS website (ftp://ftpcimis.water.ca.gov/pub/CIMIS_STATIONS_1207.xls)
- Determine which stations fall within the study area
- For the stations of interest determine if daily data is available for the period 2000–2008
- Extract the name and location for the remaining stations from the MS Excel spreadsheet into a comma delimited file for display in the GIS
- Use the "show x,y" data option to display the weather stations as dots on the map
- Export the event theme to feature class named "cimis_stations_sa"
- Using a GIS overlay process, each public land survey section (PLSS) was assigned the nearest weather station.

Tier 2: Development of the daily weather files

- For each of the selected weather stations download the daily weather data from the website for 01/01/2000–12/31/2009. Variables of interest included:
- Precipitation
- Evapotranspiration (aka reference ETo)
- Temperature
- Solar Radiation
- Wind speed
- Import daily data in a MS Excel spreadsheet for quality control.
- In MS Excel the daily data was checked for completeness and if data was missing gap fill procedure were used:
- If a single date was missing, one or more variables, the average of the preceding and next day were used
- If multiple dates were missing, data from the nearest neighboring station was used to gap fill the data.
- Export the data from MS Excel to a comma delimited text file.
- A FORTRAN program, cimis2przm.f90, was written to convert the daily CIMIS weather data to the PRZM required format. The program also ensured that the proper units for the daily weather variables were used as mandated by PRZM (Carousel et al., 2003).

APPENDIX C.—PUR database processing steps

The PUR data can be represented spatially using COUNTY_CD, BASE_LN_MER, TOWNSHIP, RANGE, and SECTION fields from the Use Data Chemical table. The aggregation of these fields called CO_MTRS can be related to PLSS spatial data and enables PUR data to be spatially represented (USGS, 1999).

Although the PUR collects the information in a standardized manner, the data is still very diverse and must be standardized (e.g., all use the same unit for area treated). A series of queries were executed to organize the data for this study within the PUR database for each year. The associated SQL queries can be found in the Appendix C. The basic steps of the standardization process included:

1. Acquire the PUR data for the years between 2000 and 2008, from CDPR.
2. Import individual year data into an MS Access database.
3. Make sure data field names and types are consistent among tables in the database so that associated tables can be linked to each other.
4. Next a new table was created named UDCmaster, which is a copy of the Use Data Chemical table.
5. Add the CO_MTRS (PLSS section level identifier) field to Udcmaster to provide a reference to the PLSS section level.
6. Add Acre_Treated_Updated field to Udcmaster table to contain the standardized area treated and populate the field initially with with Acre_Treated if Unit_Treated is A (i.e., acres)
7. Populate Acre_Treated_Update field for those Unit_Treated being equal to S (i.e., square feet) with Acre_Treated and convert the value to be in acres
8. Select only specific study chemicals from the chemical table for this study
9. List the data from Udcmaster table that had the study chemical application, and also list the site type (aka crop) of the application
10. Limit the list generated by Step 9 (above) to only those sections within the study area using CO_MTRS, and generate the new table

Once all the above steps were complete for yearly PUR databases, a master database was created to aggregate all the individual yearly results into a single database. This was primarily done for ease of handling and querying the data in a single database. In addition the information in the PUR database had to be processed in such a manner that PRZM can readily accept the input and that multiple application could be simulated in a single PRZM run. The main requirement for this is that the area treated is the same. PRZM cannot handle different application areas in a single run. It was decided to normalize the application area treated and thus the rate on an annual basis. Therefore, for each year first was determined the total area treated with a single chemical and next the rate was updated to reflect this.

1. Create a master database in MS Access and link into it, each of the final queried yearly tables from individual 2000–2008 databases.
2. Bring in a refined crop table, containing specific crops of interest for this study.
3. Join the crop table with each of the yearly tables queried, to select only those combinations of study chemicals and study crops on which they are used, within the sections (CO_MTRS) of the study area.
4. Create a yearly Primary table that has an aggregation of pesticide applications by section, chemical, crop and application date, along with a summation of Lbs_Chemical_Used and Acre_Treated_Updated values for those aggregated records (Appendix C).
    a. Few fields are added to this table–Acre_Treated_Run_Sum, Application_Rate, Unique_ID, and Very_ Unique_ID.
    b. Unique_ID field is updated by creating a combination of the section, chemical, and crop. It creates somewhat unique records having the same section, chemical, and crop.
5. Add a Record_ID field to the Primary table created in Step 4 (above) and populated with AutoIncrement values (Appendix C).
6. Populate the Very_Unique_ID field created in Step 4 (above) with a combination of section, chemical, crop, and Record_ID values (Appendix C).
7. Create a yearly Temp table with only the aggregation of section, chemical, crop, and the newly created Unique_ID. Also a sum of the Acre_Treated_Updated values is calculated for the aggregated combination of section, chemical, crop and Unique_ID (Appendix C). Note: the aggregation created in this Step is slightly different from the one created earlier in Step 4 (above).
8. Joining the Primary and Temp tables created in Steps 4 and 7 (above), on the section, crop, Unique_ID fields; the Acre_Treated_Run_Sum values are updated in the yearly Primary table. This is where the Temp table is used (Appendix C).
9. The Application_Rate field in the Primary table is now updated by dividing the aggregated sum values of Lbs_Chemical_Used with the newly calculated values of Acre_Treated_Run_Sum from the previous Step (Appendix C).
10. Now a yearly Secondary table is created from the yearly Primary table (created in Step 4, above), and it has an aggregation of Unique_ID, Acre_Treated_Run_Sum, and Record_ID values from the yearly Primary table (Appendix C).
11. Record_ID field is added to the Secondary table created in Step 10 (above) and populated with AutoIncrement values (Appendix C).

Creating a master application file for modeling

Now that all pertinent chemical application information (location, chemical, crop, date, rate and area treated are available) a master run file was created that also included reference to the soil type and weather station to be used. The master run and application file is a required part in the model process. These files tie the individual components (pesticide applications, properties, soils to use, crop properties, and climate data) together in a single table (Table 6). This table in turn is used to create the input files for the models. Both PRZM and RICEWQ use the same information and therefore a single master run table was created. For the actual simulations, in the PRZM Model a flag was set to use only crop that are not rice and similarly in the RICEWQ model only rice was simulated.

For each PLSS section (co_mtrs in the PUR tables), using the GIS the soils series and weather stations that should be used in each PRZM and RICEWQ run were determined by combining these layers into a single GIS layer (See section 2.1 for details on all GIS layers). The resulting dataset was imported into MS Access and used to link the pesticide applications on the PLSS section to each soils and weather station. This resulted in a master application file containing over 8,700,000 unique applications in the period 2000–2008. The data in the master file were sorted by PLSS section, chemical, soil, crop and date. A second table was created by grouping this information and determining the first record number and the number of records (applications) for a given combination of PLSS section, chemical, crop, soil within the same year. This table is the master Run File and manages all PRZM and RICEWQ input file creations.

APPENDIX D.—PRZM Furrow irrigation

The following code is used to determine the total amount of irrigation needed to be applied to achieve excess irrigation (i.e. tailwater) based on soil properties and antecedent moisture levels:

INABS=SMDEF

RUNOF=SMDEF*RATEAP

where: SMDEF=soil moisture deficit, amount of water needed to raise soil moisture content in top 15cm to field capacity

RUNOF= SMDEF * percent excess water applied to achieve desired tailwater

Then, resolve the following equation for precipitation:

RUNOF= (PRECIP+SMELT-INABS)**2/(PRECIP+ SMELT+ (4* INABS)

where: PRECIP =precipitation

SMELT = snow melt (value is zero for these runs)

INABS = initial abstraction

Resolving for PRECIP

TERM1=INABS**2-(RUNOF*4.*INABS)

TERM2=((2*INABS)-RUNOF)

XXTHRUFL=(TERM2+(TERM2**2-4*TERM1)**0.5)/2.0

where: XXTHRUFL = amount of irrigation to apply

The CALFED master control program then makes two WINPRZM runs for each simulation that required furrow irrigation and adds them together to estimate the total runoff/erosion from the field. In these simulations the furrows were estimated to be 50 percent of the field so the application was evenly divided between furrow and non-furrow portions.

APPENDIX E.—Example Calculations of Reference Values

Case1 : USEPA OPP Aquatic Life Benchmarks available, most sensitive species is a fish or invertebrate:

	Lowest OPP Aquatic Life Benchmarks (ppb)		PROPOSED CALFED Acute Reference Values (ppb)		PROPOSED CALFED Chronic Reference Values (ppb)	
	Invertebrate Acute	Invertebrate Chronic	Tier I Reference Value	T & ES Reference Value	Tier I Reference Value	T & ES Reference Value
METHOMYL	2.5	0.7	2.5	0.25	0.7	0.7

USEPA OPP Aquatic Life Benchmarks were available for this chemical. The most sensitive acute and chronic endpoints were for invertebrates and these benchmark values were used to derive the proposed acute and chronic reference values. The Tier I acute reference value was equal to the invertebrate acute benchmark value (to which a 2X safety factor had already been applied, while the Tier I T & ES acute reference value equaled 1/10 of the invertebrate acute benchmark value. The Tier I and T & ES chronic reference values were equivalent to the chronic invertebrate benchmark value.

APPENDIX F.—Detailed Species Description

Chinook Salmon (Oncorhynchus tshawytscha)

There were four varieties studied, and they are listed below:

- Sacramento River winter-run. The Sacramento River winter-run Chinook salmon ESU includes all naturally spawned populations in the Sacramento River and its tributaries, and two artificial propagation programs; winter-run Chinook salmon from the Livingston Stone National Fish Hatchery and winter-run Chinook salmon in a captive brood stock program maintained at Livingston Stone National Fish Hatchery and the University of California, Davis, Bodega Marine Laboratory (Moyle, 2002; Moyle et al., 2008).

  Winter-run Chinook salmon occur in areas that have a continuous supply of cold water, such as the spring-fed streams of the basalt and porous lava region of northeastern California (Moyle et al., 2008). They occur only in the Sacramento River basin because they require water temperatures cold enough in summer to enable successful incubation, but warm enough in winter to support juvenile rearing (Moyle et al., 2008; Stillwater Sciences, 2006). Winter-run Chinook salmon historically migrated high into the watersheds of the McCloud, Pit, and upper Sacramento Rivers to spawn. This habitat became inaccessible following the construction of Shasta Dam in the 1940s (Moyle et al., 2008).

  Winter-run Chinook salmon life-history (Figure 13) timing differs considerably from the other three Central Valley Chinook salmon races. Their spawning migration extends from January to May with a peak in mid-March. They enter fresh water as sexually immature adults and migrate up the Sacramento River to the reaches below Keswick Dam, where they hold for several months until spawning in April through early August (Moyle et al., 2008; Williams, 2006). Optimal holding temperatures range from 10–16°C, and optimal water velocities range from 0.47–1.25 m/s (USFWS, 2003). Incubation, which is the most temperature-sensitive life-history stage, occurs during the hottest part of the year; May through August (Moyle et al., 2008). To ensure moderate redd temperatures, winter-run Chinook salmon spawn at depths of 1–7 m (Moyle, 2002). Fry emerge from the gravel from July through mid-October (Moyle et al., 2008; Williams, 2006; Yoshiyama et al., 1998). After emergence, juveniles are restricted in their rearing habitat to those reaches that maintain cool summer temperatures. According to Williams (2006), most fry migrate past Red Bluff Diversion Dam in summer or early-fall, but many rear in the river below Red Bluff for several months before they reach the Delta in early-winter. Juvenile entry into the Delta occurs from January to April. Little is known about current juvenile usage of the San Francisco estuary, but a recent study by the U.S. Army Corps of Engineers (USACE) indicates that residence time is limited and outmigration through this region is swift (Moyle et al., 2008).

The biggest single cause of winter-run Chinook salmon decline was the loss of access to spawning areas caused by construction of Shasta and Keswick dams in the 1940s. Other, ongoing factors include having only one existing population with a low population size, climate variability (e.g., drought), unscreened or inadequately screened water diversions, predation, pollution (e.g., from the Iron Mountain Mine), adverse flow and water quality conditions leading to high water temperatures, fisheries management, passage barriers (e.g., Red Bluff Diversion Dam), and degraded spawning habitat (Moyle, 2002; Moyle et al., 2008).

- Central Valley spring-run. The Central Valley spring-run Chinook salmon ESU includes all naturally spawned populations in the Sacramento River and its tributaries, including the Feather River and one artificial propagation program; the California Department of Fish and Game (CDFG) Feather River Hatchery spring-run Chinook salmon program. There are only three remaining independent populations; Mill, Deer, and Butte Creeks, which are in close geographic proximity to each other (Moyle, 2002; Moyle et al., 2008). Historic spring-run populations likely numbered 0.5–1.5 million in the Central Valley (Yoshiyama et al., 1998); however, current abundance has averaged ~16,000 fish since 1992 (Moyle et al., 2008).

  Returning Central Valley spring-run Chinook migrate upstream as sexually immature fish in spring, hold through the summer in deep pools, spawn in early fall, and migrate downstream as juveniles after either a few months or a year in fresh water (Moyle et al., 2008). The spawning migration extends from February to early July, with peaks in mid-April in Butte Creek and mid-May in Deer and Mill Creeks (Williams, 2006). Central Valley spring-run Chinook attain maturity at 2–4 years of age. The life-cycle history is depicted in Figure 14 They generally migrate higher into watersheds than other runs in order to find deep pools where cooler temperatures allow over-summering (Moyle et al., 2008). Spawning often occurs in the tailwaters of their final holding pool (Moyle, 2002). Preferred spawning habitat is at depths of 25–100 cm and at water velocities of 30–80 cm/sec (Williams, 2006). Incubation lasts 40–60 days and is extremely sensitive to temperature, with high egg mortality at temperatures above 14–16°C. Fry emerge in another 4–6 weeks (Williams, 2006). Emigration can begin within hours of emergence, after a few months of natal rearing, or after over-summering in natal streams (Hill and Webber, 1999; Moyle et al., 2008; Stillwater Sciences, 2006). As Central Valley spring-run Chinook travel downstream, they may rear in the lower reaches of non-natal tributaries and along main-stem margin habitats; particularly smaller fish that need to grow larger before ocean entry (Moyle et al., 2008). Juveniles feed mainly on zooplankton, benthic invertebrates, terrestrial drift, and the larvae of other fishes, especially suckers (Moyle, 2002; Moyle et al., 2008).

Primary limiting factors to Central Valley spring-run Chinook include loss of most historic spawning habitat due to impassable dams, degradation of remaining habitat, and genetic threats from the Feather River Hatchery spring-run Chinook salmon program. Other limiting factors include unscreened or inadequately screened water diversions, excessively high water temperatures, predation by non-native species, urbanization and rural development, logging, grazing, agriculture, mining, estuarine alteration, and fisheries management (Moyle, 2002; Williams, 2006; Moyle et al., 2008).

- <u>Central Valley fall run.</u> The Central Valley fall-run Chinook salmon ESU includes all populations in the Sacramento and San Joaquin River basins and their tributaries. Fall-run Chinook salmon are the most abundant run in the Central Valley and are the principal run raised in hatcheries (Moyle, 2002; Williams, 2006); however, the fall-run Chinook salmon population has declined during the last several years from an average of 450,000 (1992–2005), to less than 200,000 fish in 2006 and to about 90,000 spawners in 2007. The population includes both wild and hatchery-origin fish, and the proportion of hatchery fish can be as high as 90% depending on location, year, and surveyor bias (Barnett-Johnson et al., 2007).

  Fall-run Chinook salmon habitat requirements are generally similar to those of California coastal Chinook salmon, but juveniles make more extensive use of off-channel habitats where they grow faster because of warmer water temperatures and abundant food (Moyle et al., 2008; Sommer et al., 2001).

  Fall-run Chinook salmon migrate to spawning grounds as sexually mature adults and usually spawn 1–2 months after entry. Peak spawning is from October to November, but spawning can continue through December. Fry typically emerge from December through March and rear in natal streams for 1–7 months; usually moving downstream into the main rivers within a few weeks after emergence. Both fry and smolts can be found in the San Francisco estuary. Fish spend 2–5 years at sea before returning to spawn (Moyle et al., 2008). The life-cycle history is depicted in Figure 15.

  Limiting factors affecting fall-run Chinook salmon include hatcheries, harvest, and reduced spawning and rearing habitat due to agriculture and water management actions (West Coast Chinook Salmon Biological Review Team, 1999). Additionally, juveniles are constantly exposed to pollutants discharged into rivers from both agricultural and urban sources. A potentially major source of mortality in San Joaquin populations is the highly toxic water associated with the Stockton Deepwater Ship Channel, which results from a combination of agricultural wastewater, sewage treatment discharges, and other sources (Moyle et al., 2008).

- <u>Central Valley late fall run.</u> Because they are closely related to Central Valley fall-run Chinook salmon, Central Valley late fall-run Chinook salmon are managed under the fall-run ESU; however, late fall-run fish were recognized as a distinct run after the construction of Red Bluff Diversion Dam in 1966 (Moyle et al., 2008), and are considered genetically distinct from other Central Valley runs (Williams, 2006). Late fall-run Chinook are found mainly in the Sacramento River, where spawning and rearing occurs between Red Bluff Diversion Dam and Redding (Moyle et al. 2008). The historic abundance of late fall-run Chinook is not known, but during 1967–1976, the run above Red Bluff Diversion Dam averaged ~22,000 fish. Recent estimates (1992–2007) have averaged 20,777 fish, with a high of over 80,000 fish in 1998 (Moyle et al., 2008).

Late fall-run Chinook salmon habitat requirements are generally similar to those of California coastal Chinook salmon, and optimal conditions are similar to the physical and chemical characteristics of the unregulated Sacramento River above Shasta Dam (Moyle et al., 2008).

Mature late fall-run Chinook salmon migrate to spawning grounds in December and January, but have been recorded from November through April (Williams, 2006). Most spawning occurs shortly after fish arrive on spawning grounds (December and January), but can extend into April during some years (Williams, 2006). Fry emergence typically starts in April and can last until early June (Moyle et al., 2008). Juveniles rear in the river for 7–13 months before moving downstream, but peak emigration typically occurs in October (Moyle et al., 2008). The life-cycle history is depicted in Figure 16

Limiting factors affecting late fall-run Chinook salmon include hatcheries, harvest, and reduced spawning and rearing habitat due to agriculture and water management actions (West Coast Chinook Salmon Biological Review Team, 1999; Moyle et al., 2008).

Central Valley steelhead (Oncorhynchus mykiss)

The Central Valley steelhead DPS includes all naturally spawned anadromous steelhead below natural and manmade impassable barriers in the Sacramento and San Joaquin Rivers and their tributaries, including two artificial propagation programs; the Coleman National Fish Hatchery and the California Department of Fish and Game (CDFG) Feather River Hatchery (Moyle, 2002; Moyle et al., 2008). No good estimates of current abundance are available; however, estimates made in the early 1990s suggest that ~10,000 fish were present in the Central Valley (McEwan and Jackson, 1996). More recent data from the Sacramento River suggests a precipitous decline from an average of 6,574 fish in 1967–1991, to less than 1,500 fish from 1992–2008 (Moyle et al., 2008).

The habitat requirements of Central Valley steelhead are similar to those of central California coast steelhead. Water quality is a critical factor during the freshwater residence time, with cool, clear, and well-oxygenated water needed for maximum survival (Moyle, 2002). Juvenile steelhead (ages 1+ and 2+) occupy deeper water than fry, and show a stronger preference for pool habitats with ample cover, and for rapids and cascades (Dambacher, 1991). Juveniles generally occupy habitat with large structures, such as boulders, undercut banks, and large woody debris, that provide feeding opportunities, segregation of territories, refuge from high water velocities, and cover from fish and bird predators (Moyle et al., 2008).

Central Valley steelhead exhibits flexible reproductive strategies that allow for persistence in spite of variable flow conditions (McEwan, 2001). Peak adult migration historically occurred from late-September to late-October, with some creeks, such as Mill Creek, showing a small mid-February run (Hallock, 1989). Optimal spawning temperatures are 4–11˚C (McEwan and Jackson, 1996). Emergent fry migrate into shallow water (<36 cm) areas, such as the stream edge or low gradient riffles, often in open areas with coarse substrates (Everest and Chapman, 1972, Everest et al. 1986, and Fontaine 1988). In the late-summer and fall, juveniles move into higher-velocity, deeper, mid-channel areas (Everest and Chapman, 1972; Fontaine, 1988; Hartman, 1965). Age data from a sample of 100 fish taken in 1954 indicated that steelhead spent 1 (29%), 2 (70%), or 3 (1%) years in freshwater before migrating out of the basin to the ocean (Hallock et al., 1961). Juvenile Central Valley steelhead generally migrate from late-December through the beginning of May, with a peak in mid-March (Moyle et al., 2008). The full life-cycle history is depicted in Figure 17.

Central Valley steelhead are opportunistic predators of aquatic and terrestrial insects, small fish, frogs, and mice; however, their primary diet consists of benthic aquatic insect larvae, particularly caddisflies (*Trichoptera*), midges (*Chironomidae*), and mayflies (*Ephemeroptera*) (Merz, 2002). Depending on season and steelhead size, they may also eat salmon eggs, juvenile salmon, sculpins, and suckers (Merz, 2002).

The primary limiting factor for Central Valley steelhead is the inaccessibility of historic spawning and rearing habitat due to major dams. Other limiting factors include small passage barriers, water development and land use activities, levees and bank protection, dredging and sediment disposal, mining, contaminants, fisheries management practices, hatcheries, inadequately screened water diversions, and predation by nonnative species (McEwan, 2001; Moyle, 2002; Moyle et al., 2008).

Southern North American Green Sturgeon (Acipenser medirostris)

Similar to other sturgeon species, green sturgeon are large in size (max. 270 cm TL and 175 kg),[12] have a sub-terminal barbeled mouth, lines of bony plates (scutes) on their sides, and a heterocercal tail (Moyle et al., 1995). Green sturgeon can be distinguished from other related species by their dorsal row of 8–11 scutes, lateral rows of 23–30 scutes, two bottom rows of 7–10 scutes, dorsal fin with 33–36 rays, anal fin with 22–28 rays, large scutes behind the dorsal and anal fins[13] (Moyle et al., 1995; Moyle, 2002), and barbels closer to the mouth than the tip of the snout (Moyle et al., 1995; Moyle, 2002). Body color is olive-green with an olive stripe on each

[12] http://ucce.ucdavis.edu/datastore/datastoreview/showpage.cfm?usernumber=35&surveynumber=241
[13] http://ucce.ucdavis.edu/datastore/datastoreview/showpage.cfm?usernumber=35&surveynumber=241

side (Moyle et al., 1995; Moyle, 2002). Scutes are generally lighter in color than the body[14] (Moyle et al., 1995; Moyle, 2002).

Green sturgeon are native to North America, and have been recorded in the Pacific Ocean from the Bearing Sea (north) to Ensenada, Mexico (south); however, individuals are only found in rivers from British Columbia (north) to the Sacramento River, California (south) (Moyle et al., 1995; Moyle, 2002). Despite the fact that no spawning occurs in the Columbia River (Moyle et al., 1995), the largest green sturgeon population in North America is found in the Columbia River estuary, with individuals observed as far as 225 km inland (Moyle, 2002). In California, green sturgeon are considered threatened (Moyle et al., 1995) or of special concern (Moyle, 2002). Relatively few green sturgeon have been reported from the southern California coast (Moyle et al., 1995), whereas annual population estimates have ranged from 140–1,600 adults in the Bay-Delta region (Moyle, 2002), with greater numbers reported from the northern California coast (Moyle et al., 1995). Historically, spawning populations existed in the Sacramento, Eel, and Klamath-Trinity River systems (Moyle et al., 1995; Moyle, 2002); however, no recorded spawning has taken place in the Eel River system since 1967 (Moyle, 2002). In the Sacramento River system, green sturgeon spawn both in the mainstem Sacramento River up to Redd Bluff, and in the Feather River (Moyle et al., 1995). Records of juvenile fish captured at Santa Clara Shoal, Sacramento County, suggest that spawning may also occur in the San Joaquin River system; however, green sturgeon captured in this area likely came from the Sacramento River (Moyle et al., 1995). The full life-cycle history is depicted in Figure 18.

Green sturgeon are considered anadromous, but are the most marine species of sturgeon[15] (Moyle, 2002; NOAA, 2009). Adults generally only enter freshwater to spawn; however, juveniles may remain in freshwater rivers up to 1–4 years after hatching (Moyle, 2002; NOAA, 2009). Limited information suggests that adult green sturgeon spawn every 2–4 years (NOAA, 2009). Spawning migrations begin in late-February, with spawning occurring from March through July (Moyle, 2002; NOAA, 2009). Peak spawning typically occurs from mid-April to mid-June (Moyle, 2002; NOAA, 2009) when water temperatures reach 8–14°C (Moyle, 2002). Spawning occurs in deep, fast-moving water over substrates ranging from clean sand to bedrock (Moyle et al., 1995; Moyle, 2002). Females produce 60,000–140,000 eggs, and hatching occurs in 200 hours at 12.7°C (Moyle, 2002). Upon hatching, green sturgeon larvae are 8–19 mm TL (Moyle, 2002), and remain in freshwater rivers for 1–4 years before outmigrating (NOAA, 2009). Outmigration occurs primarily during summer and fall when fish reach 30–66 cm TL (Moyle, 2002). Initially, fish remain in coastal estuaries, but may migrate out of estuaries as they grow (Moyle et al., 1995; Moyle, 2002). Fish from 70–120 cm TL are considered marine, which suggests that males and females mature and return to spawn at 3–9 and 3–13 years, respectively (Moyle, 2002).

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[14] http://ucce.ucdavis.edu/datastore/datastoreview/showpage.cfm?usernumber=35&surveynumber=241
[15] http://ucce.ucdavis.edu/datastore/datastoreview/showpage.cfm?usernumber=35&surveynumber=241

Delta Smelt (Hypomesus transpacificus)

The delta smelt is listed as threatened under both the federal and California state Endangered Species Acts (ESAs) (USFWS, 1993). Habitat for juvenile and adult delta smelt is found in the estuarine waters of the lower Delta and Suisun Bay, where salinity ranges between 2–7 ppt; however, delta smelt can tolerate salinity ranges from 0–19 ppt. Delta smelt typically occupy open, shallow water habitats, but can also be found in the main channel in the region where fresh and brackish water mix (Moyle, 2002).

Adult delta smelt begin a spawning migration, which may encompass several months, and move into the upper Delta during December or January. Spawning occurs between January and July, with peak spawning during April through mid-May (Moyle, 2002). Spawning occurs in shallow edgewaters in the upper Delta channels; including the Sacramento River above Rio Vista, Cache Slough, Lindsey Slough, and Barker Slough. During drought conditions, spawning has also been observed in the Sacramento River up to Garcia Bend (Wang and Brown, 1993). Eggs are broadcast over the bottom, where they attach to firm sediment, woody material, and vegetation. Hatching occurs in 9–13 days, and larvae begin feeding 4–5 days later. Newly hatched larvae contain a large oil globule that makes them semi-buoyant, thereby allowing them to stay off, but near the bottom. Larval delta smelt feed on rotifers and other zooplankton. As their fins and swim bladder develop, they move higher up in the water column. Larvae and juveniles gradually move downstream toward rearing habitat in the estuarine mixing zone (Wang, 1986). The full life-cycle history is depicted in Figure 19.

From 1969–1981, the mean delta smelt Townet Survey (TNS) and Fall Mid-Water Trawl (FMWT) indices were 22.5 and 894, respectively. Both indices suggest that delta smelt abundance declined abruptly in the early-1980s (Moyle et al., 1992). From 1982–1992, the mean delta smelt TNS and FMWT indices dropped to 3.2 and 272, respectively. The population rebounded somewhat in the mid-1990s (Sweetnam, 1999); however, delta smelt numbers have trended precipitously downward since 2000 (Bennett, 2005).

Severe alterations in the composition and abundance of the primary producer and primary/secondary consumer assemblages in the Delta have been implicated in the recent decline of Delta smelt and other native fish species (USFWS, 1996; Kimmerer, 2002).

Striped Bass (Morone saxatilis)

Striped bass were first introduced into the San Francisco Estuary in 1879. Another introduction was made in 1882, and by 1888, a commercial fishery targeting striped bass was present (Dill and Cordone, 1997; Moyle, 2002). Currently, striped bass have spread throughout the Sacramento-San Joaquin Delta and water bodies connected to the Delta and California Aqueduct (Moyle, 2002).

Striped bass move regularly between marine and fresh water, and spend most of their life in estuaries. They are extremely tolerant of a wide range of environmental conditions. They can withstand temperatures up to 34ºC, but become stressed when temperatures exceed 25ºC. They can also withstand abrupt temperature changes (up to 27ºC) that coincide with changes from marine to fresh water (Moyle, 2002).

Striped bass have three basic requirements for successful completion of their life cycle: (1) a large, cool river for spawning with enough flow to keep embryos and larvae suspended off the bottom until they become free-swimming; (2) a large body of water with small fish for forage; and (3) a productive estuary where larvae and juveniles can feed on aquatic invertebrates (Moyle, 2002).

Striped bass spawning usually begins in April when water temperatures reach 14°C, and peaks in May and early June. Optimum temperatures for spawning are between 15–20ºC. In the Sacramento River, most spawning occurs from Colusa to below the mouth of the Feather River. In the San Joaquin River, successful spawning only occurs in years with high flow (Moyle, 2002). Striped bass spawn in groups of 5–30 males and 1–2 females (Miller and McKechnie, 1968; Moyle, 2002). Fertilized eggs hatch in 48 hours at 19ºC. After 7–8 days, larvae become free-swimming and begin feeding on small zooplankton (Wang, 1986; Moyle, 2002). As striped bass continue to grow, they become more dependent on fish as a food source, and by the time they are adults, their diet consists of a wide variety of both fresh and marine species (Thomas, 1967; Moyle, 2002). The full life-cycle history is depicted in Figure 20.

Striped bass are one of the most common fish in the San Francisco Estuary; however, populations have declined in recent years. Climactic factors, water diversions, pollutants, reduced estuarine productivity, and exploitation are all considered factors contributing to declines (Moyle, 2002).

San Francisco Longfin Smelt (Spirinchus thaleichthys)

Historically, longfin smelt populations were found in the Klamath, Eel, and San Francisco estuaries, and in Humboldt Bay. In the Central Valley, longfin smelt are rarely found upstream of Rio Vista or Medford Island in the Delta. Adults concentrate in Suisun, San Pablo, and North San Francisco Bays (Moyle, 2002).

Longfin smelt are anadromous, euryhaline, and nektonic (free-swimming). Adults and juveniles are found in estuaries and can tolerate salinities from 0 ppt to pure seawater. The salinity tolerance of longfin smelt larvae and early juveniles ranges from 1.1–18.5 ppt. After the early juvenile stage, they prefer salinities in the 15–30 ppt range (Moyle, 2002). Longfin smelt in the San Francisco estuary spawn in fresh or slightly brackish water (Moyle, 2002). Prior to spawning, these fish aggregate in deepwater habitats available in the northern Delta, including primarily the channel habitats of Suisun Bay and the Sacramento River (Rosenfield and Baxter, 2007). Catches of gravid adults and larval longfin smelt indicate that the primary spawning locations for these fish are in or near the Suisun Bay channel, the Sacramento River channel near Rio Vista, and (at least historically) Suisun Marsh (Wang, 1991; Moyle, 2002; Rosenfield and Baxter, 2007). Moyle (2002) indicated that longfin smelt may spawn in the San Joaquin River as far upstream as Medford Island. In the Delta, longfin smelt spend most of their life cycle in deep, cold, brackish-to-marine waters of the Delta and nearshore environments (Moyle, 2002; Rosenfield and Baxter, 2007). They are capable of living their entire life-cycle (Figure 21) in fresh water, as demonstrated by landlocked populations.

Pre-spawning adults are generally restricted to brackish (2–35 ppt) or marine habitats. In the fall and winter, yearlings move upstream into fresh water to spawn. Spawning may occur as early as November, and larval surveys indicate that it may extend into June (Moyle, 2002). The exact nature and extent of spawning habitat are still unknown for this species (Moyle, 2002), although major aggregations of gravid adults occur in the northwestern Delta and eastern Suisun Bay (Rosenfield and Baxter, 2007).

Embryos hatch in 40 days at 7°C and are buoyant. They move into the upper part of the water column and are carried into the estuary. High outflows transport the larvae into Suisun and San Pablo Bays. In low outflow years, larvae move into the western Delta and Suisun Bay. Higher outflows are reflected positively in juvenile survival and adult abundance. Rearing habitat is highly suitable in Suisun and San Pablo Bays, in part because juveniles require brackish water in the 2–18 ppt range. Longfin smelt are pelagic foragers that feed extensively on copepods, amphipods, and shrimp (Moyle, 2002).

The abundance of longfin smelt in the San Francisco estuary has fluctuated over time; however, abundance has been in decline since the early 1980s, and was very low during the drought years of the 1990s and recent wet years (Rosenfield and Baxter, 2007; Sommer et al., 2007). The 2007 Fall Mid-Water Trawl (FMWT) index had the lowest index value (13) recorded since the survey began in 1967. The highest index value between 1988 and 2008 was 8,205 in 1995. The index in 2008 was 139 (CDFG, 2008).

Severe alterations in the composition and abundance of the primary producer and primary/secondary consumer assemblages in the Delta have been implicated in the recent decline of longfin smelt and other native fish species (USFWS, 1996; Kimmerer, 2002).

Threadfin Shad (Dorosoma petenense)

Threadfin shad were introduced into ponds in San Diego County by the California Department of Fish and Game (CDFG) in 1953 (Dill and Cordone, 1997; Moyle, 2002). Following the 1953 plant, additional fish were planted in lakes and reservoirs across the state, thereby allowing the species to spread into the Sacramento-San Joaquin system and the Delta (Moyle, 2002). Further unauthorized plants have expanded the species' range to include most of California west of the Sierra Nevada (Moyle, 2002).

Threadfin shad are found in open areas of lakes and ponds, and the backwaters of rivers. In the Sacramento-San Joaquin Delta, the species persists at temperatures exceeding 22–24ºC, and can tolerate temperatures as low as 8ºC (Griffith, 1978; Moyle, 2002). Although threadfin shad are primarily found in fresh water, they can persist in marine systems (Burns, 1966; Moyle, 2002).

Threadfin shad usually spawn at the end of their second summer when they reach 10–13 cm TL. In California, spawning is from April through August, with a peak in June when water temperatures exceed 20ºC (Wang, 1986; Moyle, 2002). Fertilized eggs are released and stick to floating objects, where they are protected against exposure to fluctuating water levels (Wang, 1986; Moyle, 2002). Fertilized embryos hatch in 3–6 days, and assume a planktonic larval stage for 2–3 weeks. Metamorphosis from the larval to juvenile stage occurs when fish reach 2 cm TL. Juveniles form and remain in schools for the remainder of their lives (Moyle, 2002). The full life-cycle history is depicted in Figure 22.

Threadfin shad are highly planktivorous, and the ability of populations to increase exponentially has allowed the species to spread rapidly by natural methods. The rapid growth of threadfin shad populations can have substantial impacts on native aquatic communities, where they can reduce both the abundance of zooplankton and native fish species. Similar to other planktivores, threadfin shad populations in the Sacramento-San Joaquin Delta have declined since the late-1970s to early-1980s (Moyle, 2002).

California Red-legged Frog (Rana draytonii)

The California red legged frog (*Rana aurora draytonii*) was listed as threatened by the U.S. Fish and Wildlife Service (USFWS) in 1996, and a recovery plan was finalized in 2002 (USFWS, 2002). Critical habitat designation was published in the Federal Register (71 FR 19243-19346) in 2006, and included eight recovery areas. This critical habitat designation also included a special rule, under section 4(d) of the Endangered Species Act (ESA), exempting routine ranching activities from critical habitat protection (USFWS, 2006). Currently, 50 critical habitat units totaling 662,312 ha are designated in a revised version of the 2006 critical habitat designation (USFWS 2010).

The California red-legged frog is one of two subspecies of *Rana aurora*, and is the largest native frog in the western United States (USFWS, 2002). Adults are brown with spots and range 85–138 mm in length; measured from the tip of the snout to the rear of the vent. The posterior abdomen and hind legs of adults are often red or salmon pink; whereas the back is characterized by small black flecks and large irregular dark blotches with indistinct outlines on a brown, gray, olive, or reddish-brown background color (USFWS, 2002). The full life-cycle history is depicted in Figure 23.

The California red-legged frog is endemic to California and Baja Mexico, and historically inhabited 46 counties in California, including the Central Valley and both coastal and interior mountain ranges (USFWS, 1996). Currently, its range has been reduced by ~70%, and the species resides in only 22 counties in California (USFWS, 1996). The species has an elevational range of near sea level to ~1,500 m (Jennings and Hayes, 1994). A total of 243 streams or drainages currently support red-legged frog populations, with the greatest numbers in Monterey, San Luis Obispo, and Santa Barbara counties (USFWS, 1996).

California red-legged frogs utilize habitat with perennial or near-perennial water and dense vegetation. Shade and water of moderate depth appear to be important habitat features (Jennings et al., 1997). The species is generally restricted to freshwater and slightly brackish water (<9.0% salinity). Juveniles are active during both the day and night; whereas adults are mainly nocturnal (Jennings et al., 1997). Juveniles feed primarily on invertebrates; whereas adults feed on invertebrates, small fish and mammals, and other frogs (Jennings et al., 1997). According to the Recovery Plan (USFWS, 2002), California red-legged frogs breed from November through late-April (Storer, 1925). Females produce egg-masses numbering 2,000–6,000 eggs, each ranging in size from 2.0–2.8 mm (Jennings and Hayes, 1994). Depending on water temperature, embryos usually hatch 10–14 days after fertilization (Fellers, 2005).

Introduced bullfrogs, crayfish, and non-native fish species are significant factors in the decline of the California red-legged frog. Bullfrogs are not only an important predator of California red-legged frogs, but also important competitors for prime habitat (Lawler et al., 1999). Native predators include raccoons, great blue herons, American bitterns, black-crowned night herons, red-shouldered hawks, and garter snakes (Jennings et al. 1997). Other threats to the California red-legged frog include habitat loss or modification, climate change, and disease (Davidson et al., 2001; USFWS, 2002).

California Freshwater Shrimp (Syncaris pacifica)

The California freshwater shrimp (*Syncaris pacifica* Holmes) is the State's only native, stream-dwelling shrimp. The only extant member of the genus *Syncaris*, it was listed as endangered by the State in 1980 and then by the federal government in 1988. A member of the family Atyidae, the crustacean generally reaches no more than 50 mm postorbital length (Eng, 1981; USFWS, 2007). Members of the Atyidae family can be distinguished from other crustacean families by the length of their pincer-like claws (chelae) and presence of terminal bristles (setae) at the tips of the first and second chelae. The California freshwater shrimp can be distinguished from other California shrimp by the presence of a short spine above the eye and the angled articulation of the second chelae with the carpus (Eng, 1981). California freshwater shrimp feed primarily on decomposing plants and other detrital material (Serpa, 1996). Juvenile appearance is clear to transparent; whereas adults are mostly translucent with small dark spots that clutter the body outline (Eng, 1981).

Reproduction has not been formally described; however, observations of females holding eggs in September and November through winter suggest that reproduction occurs in autumn. Females typically produce 50–120 eggs. Young are released in May–June at an average size of 6 mm. Juveniles reach maturity by the end of their second year of growth (Eng, 1981; USFWS, 1998). The full life-cycle history is depicted in Figure 24.

Historic distribution of the California freshwater shrimp is unknown; past surveys found the species in 17 stream segments within Marin, Napa, and Sonoma counties (Eng, 1981); however, more recent surveys have found the species in a few additional areas (USFWS, 2007). California freshwater shrimp have evolved to survive a broad range of stream and water temperature conditions. They prefer low-elevation (less than 116 m), low-gradient (generally less than 1%) perennial freshwater streams and intermittent streams with perennial pools where banks are structurally diverse with undercuts, exposed roots, and overhanging woody debris or vegetation (USFWS, 1998). Depths of 30–90 cm are ideal. No data are available for defining temperature and flow tolerances (USFWS, 2007).

Existing populations of the California freshwater shrimp are threatened by non-native fish species, loss of habitat, and exposure to water pollution (USFWS, 1998). A recovery plan for the California freshwater shrimp was finalized by the U.S. Fish and Wildlife Service (USFWS) in 1998. The California freshwater shrimp recovery plan (USFWS, 1998) objectives are two-fold: (1) to recover and delist the California freshwater shrimp when numbers increase sufficiently and suitable habitat is secured and managed within the 17 watersheds harboring shrimp; and (2) to enhance habitat conditions for native aquatic organisms that currently coexist or have occurred historically with the California freshwater shrimp. A 5-year status review of the California freshwater shrimp was completed by the USFWS in 2007. They recommended “no change” in status (USFWS, 2007).

APPENDIX G.—Development of the Life Cycle History for the species of concern considered in this study

CENTRAL VALLEY FALL-RUN CHINOOK METHODS

Life-History Table

The life-history table for Central Valley Fall-Run Chinook was developed from the following references:

Moyle, P.B. 2002. Inland fishes of California, revised and expanded. University of California Press, Berkley, CA.

Moyle, P.B., J.A. Israel, and S.E. Purdy. 2008. Salmon, steelhead, and trout in California: status of an emblematic fauna. U.C. Davis Center for Watershed Sciences. 316 pages.

Williams, J.G. 2006. Central Valley salmon: a perspective on Chinook and steelhead in the Central Valley of California. San Francisco Estuary and Watershed Science Vol. 4.

Yoshiyama, R.M., F.W. Fisher, and P.B. Moyle. 1998. Historical abundance and decline of Chinook salmon in the Central Valley region of California. North American Journal of Fisheries Management 18:487-521.

First, we assumed a 12-month year with each month consisting of four weeks (i.e., each month broken into four parts).

Second, detailed life-history information from the above sources was used to assign relative abundance indices (both colors and numbers) ranging from 0 (white)(not present) to 5 (black)(abundant) to the following life-history stages on a weekly basis:

- Immigration
- Spawning
- Incubation
- Juvenile Rearing
- Fry Emigration
- Smolt Emigration

Third, weekly relative abundance indices were averaged based on month for each of the above life-history stages (i.e., four values for each month converted to one average value for each month).

Fourth, maximum values were used to convert the above life-history stages to the following life-history stages (i.e., multiple life-history stages condensed to three categories–it was requested that life-history stages be condensed due a lack of detailed toxicity information for modeling multiple, more discrete life-history stages):

Juvenile (calculated as the maximum relative abundance value of Incubation, Juvenile Rearing, Fry Emigration, and Smolt Emigration)

Adult (calculated as the maximum relative abundance value of Immigration and Spawning)

All (calculated as the maximum relative abundance value of Incubation, Juvenile Rearing, Fry Emigration, Smolt Emigration, Immigration, and Spawning)

- All final relative abundance values were rounded to the nearest whole number (0–5)

APPENDIX H.—Distribution and Relative Abundance GIS File

The distribution and relative abundance GIS file for Central Valley Fall-Run Chinook was developed from the following sources:

http://ice.ucdavis.edu/aquadiv/fishcovs/cs.gif

Moyle, P.B. 2002. Inland fishes of California, revised and expanded. University of California Press, Berkley, CA.

Moyle, P.B., J.A. Israel, and S.E. Purdy. 2008. Salmon, steelhead, and trout in California: status of an emblematic fauna. U.C. Davis Center for Watershed Sciences. 316 pages.

Historically most abundant race of Chinook in the Central Valley (Moyle 2002)

High rate of straying allows for spawning populations to be established in streams not normally used for spawning during wet years (Moyle 2002)

Widely distributed throughout the Central Valley and found upstream as far as the first impassable dam on the Sacramento River side and the Merced River on the San Joaquin River side (Moyle et al. 2008)

Different sources list different distributions, but in general, this race is distributed throughout the central valley up to the first impassable barrier on the Sacramento River side and the Merced River (based on most recent source) on the San Joaquin River side

First, we developed a study area GIS file (STUDY_AREA.shp) using a California Watersheds GIS file from the California Interagency Watershed Mapping Committee (IWMC) (*available at* http://www.ca.nrcs.usda.gov/ features/calwater/#Data). Study area included watersheds for anything draining into the Bay-Delta.

Second, we developed a study area hydrography GIS file using the study area GIS file and an overlay procedure to clip a California Hydrography GIS file (HYDRO100K.shp) (*available at* http://www.calfish.org/ DataandMaps/CalFishDataDownloads/ tabid/93/Default.aspx) to the study area GIS file.

Third, we developed a study area barrier GIS file (CV_BARRIERS.shp) using the study area GIS file and an overlay procedure to clip a Fish Passage Assessment Database (PAD) GIS file (*available at* http://www.calfish.org/DataandMaps/ CalFishDataDownloads/ tabid/93/Default.aspx) to the study area.

Fourth, the study area barrier and hydrography GIS files were displayed together and used to develop a study area limit to anadromy GIS file (CV_LIMIT_ANAD.shp). Categories in the barrier GIS file were used to split and label stream reaches in the hydrography GIS file into three categories: (1) 1 = Anadromous Fish Present; (2) 2 = Anadromous Fish Possibly Present; and (3)

3 = Anadromous Fish Not Present (column labeled Pres_Abs in the CV_LIMIT_ANAD.shp file). Anadromous Fish Not Present was given to stream reaches above barrier points classified as complete barriers, partial barriers (without mention of fish passage facilities), and natural limits to anadromy. Anadromous Fish Possibly Present was given to stream reaches above barrier points classified as dams with unknown passage status. Anadromous Fish Present was given to stream reaches below barrier points used to classify stream reaches as Anadromous Fish Not Present and Anadromous Fish Possibly Present. In some cases, barrier points classified as partial barriers or dams with unknown passage status were known to have anadromous fish present in more upper stream reaches (personal experience and literature), so these points were not considered to be boundaries between the Anadromous Fish Present and Anadromous Fish Possibly Present categories. Partial barriers with specific mention of fish passage facilities were not considered to be barriers to anadromy.

Fifth, the study area limit to anadromy GIS file was copied and renamed (FINFALL_CHNK.shp). Stream reaches from this file where then split based on species-specific range information from the above sources and coded as above (1–3) based on Presence (1), Possible Presence (2), and No Presence (3)(column labeled Pres_Abs in the FINFALL_CHNK.shp file).

Sixth, the attribute table of the fall-run Chinook GIS file was exported to MS Excel and a series of IF-THEN statements was used to assign relative abundance indices to each stream reach based on the Pres_Abs column (coded 1, 2, or 3) and additional columns added for each life-history stage and month of the year.

Seventh, the resulting MS Excel table was imported back into GIS and appended to the fall-run Chinook GIS file attribute table to create a Central Valley Fall-Run Chinook Presence-Absence and Relative Abundance GIS file (FINFALL_CHNK.shp). The attribute table for this GIS file contains presence-absence (Pres_Abs column coded 1, 2, or 3), and relative abundance data for fall-run Chinook (columns labeled Juv_Month, Adult_Month, and All_Month coded 0–5 based on a combination of presence-absence of fall-run Chinook and relative abundance of each life-history stage–see above). Data can be displayed visually by toggling desired columns on/off and displaying relative abundance values (i.e., columns labeled Life-History Stage_Month) using unique values. The OCEAN.shp file was obtained from GreenInfo (http://www.greeninfo.org/), and is only used for display purposes. Similarly, the CA_OUTLINE.shp file is only used for display purposes, and was obtained from the U.S. Bureau of Reclamation.

- All fish species range maps should be considered high-water year ranges; some of the stream reaches included are ephemeral and would not contain adults or juveniles during low-water years

APPENDIX I.—CENTRAL VALLEY LATE FALL-RUN CHINOOK METHODS

Life-History Table

The life-history table for Central Valley Late Fall-Run Chinook was developed from the following references:

Moyle, P.B., R.M. Yoshiyama, J.E. Williams, and E.D. Wikramanayake. 1995. Fish species of special concern in California. Prepared for the State of California by the Department of Wildlife and Fisheries Biology, University of California Davis. 227 pages.

Moyle, P.B. 2002. Inland fishes of California, revised and expanded. University of California Press, Berkley, CA.

Moyle, P.B., J.A. Israel, and S.E. Purdy. 2008. Salmon, steelhead, and trout in California: status of an emblematic fauna. U.C. Davis Center for Watershed Sciences. 316 pages.

Williams, J.G. 2006. Central Valley salmon: a perspective on Chinook and steelhead in the Central Valley of California. San Francisco Estuary and Watershed Science Vol. 4.

Yoshiyama, R.M., F.W. Fisher, and P.B. Moyle. 1998. Historical abundance and decline of Chinook salmon in the Central Valley region of California. North American Journal of Fisheries Management 18:487-521.

First, we assumed a 12-month year with each month consisting of four weeks (i.e., each month broken into four parts).

Second, detailed life-history information from the above sources was used to assign relative abundance indices (both colors and numbers) ranging from 0 (white)(not present) to 5 (black)(abundant) to the following life-history stages on a weekly basis:

Immigration

Spawning

Incubation

Juvenile Rearing

Yearling Emigration

Third, weekly relative abundance indices were averaged based on month for each of the above life-history stages (i.e., four values for each month converted to one average value for each month).

Fourth, maximum values were used to convert the above life-history stages to the following life-history stages (i.e., multiple life-history stages condensed to three categories–it was requested that life-history stages be condensed due a lack of detailed toxicity information for modeling multiple, more discrete life-history stages):

Juvenile (calculated as the maximum relative abundance value of Incubation, Juvenile Rearing, and Yearling Emigration)

Adult (calculated as the maximum relative abundance value of Immigration and Spawning)

All (calculated as the maximum relative abundance value of Incubation, Juvenile Rearing, Yearling Emigration, Immigration, and Spawning)

- All final relative abundance values were rounded to the nearest whole number (0–5)

Distribution and Relative Abundance GIS File

The distribution and relative abundance GIS file for Central Valley Late Fall-Run Chinook was developed from the following sources:

Moyle, P.B., R.M. Yoshiyama, J.E. Williams, and E.D. Wikramanayake. 1995. Fish species of special concern in California. Prepared for the State of California by the Department of Wildlife and Fisheries Biology, University of California Davis. 227 pages.

Moyle, P.B. 2002. Inland fishes of California, revised and expanded. University of California Press, Berkley, CA.

Moyle, P.B., J.A. Israel, and S.E. Purdy. 2008. Salmon, steelhead, and trout in California: status of an emblematic fauna. U.C. Davis Center for Watershed Sciences. 316 pages.

Historic distribution of late fall-run Chinook is not known, but probably spawned in the upper Sacramento River and major tributaries blocked by Shasta Dam (Moyle et al. 1995)

It is likely that the San Joaquin River also supported a late fall-run that is now extinct (Moyle 2002)

Found mainly in Sacramento River where most spawning and rearing of juveniles takes place in the reach between Red Bluff Diversion Dam and Redding (Keswick Dam)(Moyle et al. 1995; Moyle 2002; Moyle et al. 2008)

Small numbers in Battle, Cottonwood, Clear, and Mill Creeks, and the Yuba and Feather Rivers (Moyle et al. 1995; Moyle et al. 2008)

Run in Battle Creek is most likely fish returning to Battle Creek Fish Hatchery (Moyle et al. 1995; Moyle et al. 2008)

First, we developed a study area GIS file (STUDY_AREA.shp) using a California Watersheds GIS file from the California Interagency Watershed Mapping Committee (IWMC) (*available at* http://www.ca.nrcs.usda.gov/ features/calwater/#Data). Study area included watersheds for anything draining into the Bay-Delta.

Second, we developed a study area hydrography GIS file using the study area GIS file and an overlay procedure to clip a California Hydrography GIS file (HYDRO100K.shp) (*available at* http://www.calfish.org/ DataandMaps/CalFishDataDownloads/ tabid/93/Default.aspx) to the study area GIS file.

Third, we developed a study area barrier GIS file (CV_BARRIERS.shp) using the study area GIS file and an overlay procedure to clip a Fish Passage Assessment Database (PAD) GIS file (*available at* http://www.calfish.org/DataandMaps/ CalFishDataDownloads/ tabid/93/Default.aspx) to the study area.

Fourth, the study area barrier and hydrography GIS files were displayed together and used to develop a study area limit to anadromy GIS file (CV_LIMIT_ANAD.shp). Categories in the barrier GIS file were used to split and label stream reaches in the hydrography GIS file into three categories: (1) 1 = Anadromous Fish Present; (2) 2 = Anadromous Fish Possibly Present; and (3) 3 = Anadromous Fish Not Present (column labeled Pres_Abs in the CV_LIMIT_ANAD.shp file). Anadromous Fish Not Present was given to stream reaches above barrier points classified as complete barriers, partial barriers (without mention of fish passage facilities), and natural limits to anadromy. Anadromous Fish Possibly Present was given to stream reaches above barrier points classified as dams with unknown passage status. Anadromous Fish Present was given to stream reaches below barrier points used to classify stream reaches as Anadromous Fish Not Present and Anadromous Fish Possibly Present. In some cases, barrier points classified as partial barriers or dams with unknown passage status were known to have anadromous fish present in more upper stream reaches (personal experience and literature), so these points were not considered to be boundaries between the Anadromous Fish Present and Anadromous Fish Possibly Present categories. Partial barriers with specific mention of fish passage facilities were not considered to be barriers to anadromy.

Fifth, the study area limit to anadromy GIS file was copied and renamed (FINLATEFALL_CHNK.shp). Stream reaches from this file where then split based on species-specific range information from the above sources and coded as above (1–3) based on Presence (1), Possible Presence (2), and No Presence (3)(column labeled Pres_Abs in the FINLATEFALL_CHNK.shp file).

Sixth, the attribute table of the late fall-run Chinook GIS file was exported to MS Excel and a series of IF-THEN statements was used to assign relative abundance indices to each stream reach based on the Pres_Abs column (coded 1, 2, or 3) and additional columns added for each life-history stage and month of the year.

Seventh, the resulting MS Excel table was imported back into GIS and appended to the late fall-run Chinook GIS file attribute table to create a Central Valley Late Fall-Run Chinook Presence-Absence and Relative Abundance GIS file (FINLATEFALL_CHNK.shp). The attribute table for this GIS file contains presence-absence (Pres_Abs column coded 1, 2, or 3), and relative abundance data for late fall-run Chinook (columns labeled Juv_Month, Adult_Month, and All_Month coded 0–5 based on a combination of presence-absence of late fall-run Chinook and relative abundance of each life-history stage–see above). Data can be displayed visually by toggling desired columns on/off and displaying relative abundance values (i.e., columns labeled Life-History Stage_Month) using unique values. The OCEAN.shp file was obtained from GreenInfo (http://www.greeninfo.org/), and is only used for display purposes. Similarly, the CA_OUTLINE.shp file is only used for display purposes, and was obtained from the U.S. Bureau of Reclamation.

- All fish species range maps should be considered high-water year ranges; some of the stream reaches included are ephemeral and would not contain adults or juveniles during low-water years

APPENDIX J.—CENTRAL VALLEY SPRING-RUN CHINOOK METHODS

Life-History Table

The life-history table for Central Valley Spring-Run Chinook was developed from the following references:

Moyle, P.B., R.M. Yoshiyama, J.E. Williams, and E.D. Wikramanayake. 1995. Fish species of special concern in California. Prepared for the State of California by the Department of Wildlife and Fisheries Biology, University of California Davis. 227 pages.

Moyle, P.B. 2002. Inland fishes of California, revised and expanded. University of California Press, Berkley, CA.

Moyle, P.B., J.A. Israel, and S.E. Purdy. 2008. Salmon, steelhead, and trout in California: status of an emblematic fauna. U.C. Davis Center for Watershed Sciences. 316 pages.

Williams, J.G. 2006. Central Valley salmon: a perspective on Chinook and steelhead in the Central Valley of California. San Francisco Estuary and Watershed Science Vol. 4.

Yoshiyama, R.M., F.W. Fisher, and P.B. Moyle. 1998. Historical abundance and decline of Chinook salmon in the Central Valley region of California. North American Journal of Fisheries Management 18:487-521.

First, we assumed a 12-month year with each month consisting of four weeks (i.e., each month broken into four parts).

Second, detailed life-history information from the above sources was used to assign relative abundance indices (both colors and numbers) ranging from 0 (white)(not present) to 5 (black)(abundant) to the following life-history stages on a weekly basis:

Immigration

Spawning

Incubation

Juvenile Rearing

Fry Emigration

Smolt Emigration

Yearling Emigration

Third, weekly relative abundance indices were averaged based on month for each of the above life-history stages (i.e., four values for each month converted to one average value for each month).

Fourth, maximum values were used to convert the above life-history stages to the following life-history stages (i.e., multiple life-history stages condensed to three categories–it was requested that life-history stages be condensed due a lack of detailed toxicity information for modeling multiple, more discrete life-history stages):

Juvenile (calculated as the maximum relative abundance value of Incubation, Juvenile Rearing, Fry Emigration, Smolt Emigration, and Yearling Emigration)

Adult (calculated as the maximum relative abundance value of Immigration and Spawning)

All (calculated as the maximum relative abundance value of Incubation, Juvenile Rearing, Fry Emigration, Smolt Emigration, Yearling Emigration, Immigration, and Spawning)

- All final relative abundance values were rounded to the nearest whole number (0–5)

APPENDIX K.—Distribution and Relative Abundance GIS File

The distribution and relative abundance GIS file for Central Valley Spring-Run Chinook was developed from the following sources:

Lindley, S.T., R.S. Schick, E. Mora, P.B. Adams, J.J. Anderson, S. Greene, C. Hanson, B.P. May, D. McEwan, R.B. MacFarlane, C. Swanson, and J.G. Williams. 2007. Framework for assessing viability of threatened and endangered Chinook salmon and steelhead in the Sacramento-San Joaquin Basin. San Francisco Estuary and Watershed Science 5(1).

Moyle, P.B., R.M. Yoshiyama, J.E. Williams, and E.D. Wikramanayake. 1995. Fish species of special concern in California. Prepared for the State of California by the Department of Wildlife and Fisheries Biology, University of California Davis. 227 pages.

Moyle, P.B. 2002. Inland fishes of California, revised and expanded. University of California Press, Berkley, CA.

Moyle, P.B., J.A. Israel, and S.E. Purdy. 2008. Salmon, steelhead, and trout in California: status of an emblematic fauna. U.C. Davis Center for Watershed Sciences. 316 pages.

In California, spring-run Chinook were once abundant in all major river systems, with populations in at least 26 streams in the Sacramento-San Joaquin system (Moyle et al. 1995)

Once nearly abundant as fall-run Chinook and were the primary run in the San Joaquin watershed (Moyle 2002)

Main populations were all extirpated by dam construction in the 1940s and 1950s (Moyle et al. 1995)

Three remaining independent populations occur in Mill, Deer, and Butte Creeks (Lindley et al. 2007; Moyle et al. 2008)

Other populations are mostly hatchery strays and are not considered to be independent populations (Lindley et al. 2007; Moyle et al. 2008)

First, we developed a study area GIS file (STUDY_AREA.shp) using a California Watersheds GIS file from the California Interagency Watershed Mapping Committee (IWMC) (*available at* http://www.ca.nrcs.usda.gov/ features/calwater/#Data). Study area included watersheds for anything draining into the Bay-Delta.

Second, we developed a study area hydrography GIS file using the study area GIS file and an overlay procedure to clip a California Hydrography GIS file (HYDRO100K.shp) (*available at* http://www.calfish.org/ DataandMaps/CalFishDataDownloads/ tabid/93/Default.aspx) to the study area GIS file.

Third, we developed a study area barrier GIS file (CV_BARRIERS.shp) using the study area GIS file and an overlay procedure to clip a Fish Passage Assessment Database (PAD) GIS file (*available at* http://www.calfish.org/DataandMaps/ CalFishDataDownloads/ tabid/93/Default.aspx) to the study area.

Fourth, the study area barrier and hydrography GIS files were displayed together and used to develop a study area limit to anadromy GIS file (CV_LIMIT_ANAD.shp). Categories in the barrier GIS file were used to split and label stream reaches in the hydrography GIS file into three categories: (1) 1 = Anadromous Fish Present; (2) 2 = Anadromous Fish Possibly Present; and (3) 3 = Anadromous Fish Not Present (column labeled Pres_Abs in the CV_LIMIT_ANAD.shp file). Anadromous Fish Not Present was given to stream reaches above barrier points classified as complete barriers, partial barriers (without mention of fish passage facilities), and natural limits to anadromy. Anadromous Fish Possibly Present was given to stream reaches above barrier points classified as dams with unknown passage status. Anadromous Fish Present was given to stream reaches below barrier points used to classify stream reaches as Anadromous Fish Not Present and Anadromous Fish Possibly Present. In some cases, barrier points classified as partial barriers or dams with unknown passage status were known to have anadromous fish present in more upper stream reaches (personal experience and literature), so these points were not considered to be boundaries between the Anadromous Fish Present and Anadromous Fish Possibly Present categories. Partial barriers with specific mention of fish passage facilities were not considered to be barriers to anadromy.

Fifth, the study area limit to anadromy GIS file was copied and renamed (FINSPRING_CHNK.shp). Stream reaches from this file where then split based on species-specific range information from the above sources and coded as above (1–3) based on Presence (1), Possible Presence (2), and No Presence (3)(column labeled Pres_Abs in the FINSPRING_CHNK.shp file).

Sixth, the attribute table of the spring-run Chinook GIS file was exported to MS Excel and a series of IF-THEN statements was used to assign relative abundance indices to each stream reach based on the Pres_Abs column (coded 1, 2, or 3) and additional columns added for each life-history stage and month of the year.

Seventh, the resulting MS Excel table was imported back into GIS and appended to the spring-run Chinook GIS file attribute table to create a Central Valley Spring-Run Chinook Presence-Absence and Relative Abundance GIS file (FINSPRING_CHNK.shp). The attribute table for this GIS file contains presence-absence (Pres_Abs column coded 1, 2, or 3), and relative abundance data for spring-run Chinook (columns labeled Juv_Month, Adult_Month, and All_Month coded 0–5 based on a combination of presence-absence of spring-run Chinook and relative abundance of each life-history stage–see above). Data can be displayed visually by toggling desired columns on/off and displaying relative abundance values (i.e., columns labeled Life-History Stage_Month) using unique values. The OCEAN.shp file was obtained from

GreenInfo (http://www.greeninfo.org/), and is only used for display purposes. Similarly, the CA_OUTLINE.shp file is only used for display purposes, and was obtained from the U.S. Bureau of Reclamation.

- All fish species range maps should be considered high-water year ranges; some of the stream reaches included are ephemeral and would not contain adults or juveniles during low-water years

APPENDIX L.—CENTRAL VALLEY WINTER-RUN CHINOOK METHODS

Life-History Table

The life-history table for Central Valley Winter-Run Chinook was developed from the following references:

Moyle, P.B. 2002. Inland fishes of California, revised and expanded. University of California Press, Berkley, CA.

Moyle, P.B., J.A. Israel, and S.E. Purdy. 2008. Salmon, steelhead, and trout in California: status of an emblematic fauna. U.C. Davis Center for Watershed Sciences. 316 pages.

Williams, J.G. 2006. Central Valley salmon: a perspective on Chinook and steelhead in the Central Valley of California. San Francisco Estuary and Watershed Science Vol. 4.

Yoshiyama, R.M., F.W. Fisher, and P.B. Moyle. 1998. Historical abundance and decline of Chinook salmon in the Central Valley region of California. North American Journal of Fisheries Management 18:487-521.

First, we assumed a 12-month year with each month consisting of four weeks (i.e., each month broken into four parts).

Second, detailed life-history information from the above sources was used to assign relative abundance indices (both colors and numbers) ranging from 0 (white)(not present) to 5 (black)(abundant) to the following life-history stages on a weekly basis:

Immigration

Spawning

Incubation

Juvenile Rearing

Juvenile Emigration

Third, weekly relative abundance indices were averaged based on month for each of the above life-history stages (i.e., four values for each month converted to one average value for each month).

Fourth, maximum values were used to convert the above life-history stages to the following life-history stages (i.e., multiple life-history stages condensed to three categories–it was requested that life-history stages be condensed due a lack of detailed toxicity information for modeling multiple, more discrete life-history stages):

Juvenile (calculated as the maximum relative abundance value of Incubation, Juvenile Rearing, and Juvenile Emigration)

Adult (calculated as the maximum relative abundance value of Immigration and Spawning)

All (calculated as the maximum relative abundance value of Incubation, Juvenile Rearing, Juvenile Emigration, Immigration, and Spawning)

- All final relative abundance values were rounded to the nearest whole number (0–5)

APPENDIX M.—Distribution and Relative Abundance GIS File

The distribution and relative abundance GIS file for Central Valley Winter-Run Chinook was developed from the following sources:

http://www.swr.noaa.gov/winter.htm

Moyle, P.B. 2002. Inland fishes of California, revised and expanded. University of California Press, Berkley, CA.

Moyle, P.B., J.A. Israel, and S.E. Purdy. 2008. Salmon, steelhead, and trout in California: status of an emblematic fauna. U.C. Davis Center for Watershed Sciences. 316 pages.

Unique to the Sacramento River (Moyle 2002)

Adapted for spawning and rearing in the clear, spring-fed rivers of the upper Sacramento River basin (Moyle 2002)

Today, Shasta Dam denies access to historic habitats (Moyle 2002)

Current single population holds and spawns at the base of Keswick Dam (Moyle et al. 2008)

Rearing occurs in the Sacramento River, tributaries, and the Bay-Delta (Moyle et al. 2008)

First, we developed a study area GIS file (STUDY_AREA.shp) using a California Watersheds GIS file from the California Interagency Watershed Mapping Committee (IWMC) (*available at* http://www.ca.nrcs.usda.gov/ features/calwater/#Data). Study area included watersheds for anything draining into the Bay-Delta.

Second, we developed a study area hydrography GIS file using the study area GIS file and an overlay procedure to clip a California Hydrography GIS file (HYDRO100K.shp) (*available at* http://www.calfish.org/ DataandMaps/CalFishDataDownloads/ tabid/93/Default.aspx) to the study area GIS file.

Third, we developed a study area barrier GIS file (CV_BARRIERS.shp) using the study area GIS file and an overlay procedure to clip a Fish Passage Assessment Database (PAD) GIS file (*available at* http://www.calfish.org/DataandMaps/ CalFishDataDownloads/ tabid/93/Default.aspx) to the study area.

Fourth, the study area barrier and hydrography GIS files were displayed together and used to develop a study area limit to anadromy GIS file (CV_LIMIT_ANAD.shp). Categories in the barrier GIS file were used to split and label stream reaches in the hydrography GIS file into three categories: (1) 1 = Anadromous Fish Present; (2) 2 = Anadromous Fish Possibly Present; and (3) 3 = Anadromous Fish Not Present (column labeled Pres_Abs in the CV_LIMIT_ANAD.shp file). Anadromous Fish Not Present was given to stream reaches above barrier points classified as complete barriers, partial barriers (without mention of fish passage facilities), and natural limits to anadromy. Anadromous Fish Possibly Present was given to stream reaches above barrier points classified as dams with unknown passage status. Anadromous Fish Present was given to stream reaches below barrier points used to classify stream reaches as Anadromous Fish Not Present and Anadromous Fish Possibly Present. In some cases, barrier points classified as partial barriers or dams with unknown passage status were known to have anadromous fish present in more upper stream reaches (personal experience and literature), so these points were not considered to be boundaries between the Anadromous Fish Present and Anadromous Fish Possibly Present categories. Partial barriers with specific mention of fish passage facilities were not considered to be barriers to anadromy.

Fifth, the study area limit to anadromy GIS file was copied and renamed (FINWINTER_CHNK.shp). Stream reaches from this file where then split based on species-specific range information from the above sources and coded as above (1–3) based on Presence (1), Possible Presence (2), and No Presence (3)(column labeled Pres_Abs in the FINWINTER_CHNK.shp file).

Sixth, the attribute table of the winter-run Chinook GIS file was exported to MS Excel and a series of IF-THEN statements was used to assign relative abundance indices to each stream reach based on the Pres_Abs column (coded 1, 2, or 3) and additional columns added for each life-history stage and month of the year.

Seventh, the resulting MS Excel table was imported back into GIS and appended to the winter-run Chinook GIS file attribute table to create a Central Valley Winter-Run Chinook Presence-Absence and Relative Abundance GIS file (FINWINTER_CHNK.shp). The attribute table for this GIS file contains presence-absence (Pres_Abs column coded 1, 2, or 3), and relative abundance data for winter-run Chinook (columns labeled Juv_Month, Adult_Month, and All_Month coded 0–5 based on a combination of presence-absence of winter-run Chinook and relative abundance of each life-history stage–see above). Data can be displayed visually by toggling desired columns on/off and displaying relative abundance values (i.e., columns labeled Life-History Stage_Month) using unique values. The OCEAN.shp file was obtained from GreenInfo (http://www.greeninfo.org/), and is only used for display purposes. Similarly, the CA_OUTLINE.shp file is only used for display purposes, and was obtained from the U.S. Bureau of Reclamation.

- All fish species range maps should be considered high-water year ranges; some of the stream reaches included are ephemeral and would not contain adults or juveniles during low-water years

APPENDIX N.—CENTRAL VALLEY STEELHEAD METHODS

Life-History Table

The life-history table for Central Valley Steelhead was developed from the following references:

Hallock, R.J. 1989. Upper Sacramento River steelhead (*Oncorhynchus mykiss*), 1952-1988. Report to the U.S. Fish and Wildlife Service. 85 pages. *cited in* Moyle, P.B., J.A. Israel, and S.E. Purdy. 2008. Salmon, steelhead, and trout in California: status of an emblematic fauna. U.C. Davis Center for Watershed Sciences. 316 pages.

McEwan, D. 2001. Central Valley steelhead. pages 1-44 *in* R.L. Brown, ed. Contributions to the biology of Central Valley salmonids. CDFG Fish Bull. 179.

Moyle, P.B. 2002. Inland fishes of California, revised and expanded. University of California Press, Berkley, CA.

Moyle, P.B., J.A. Israel, and S.E. Purdy. 2008. Salmon, steelhead, and trout in California: status of an emblematic fauna. U.C. Davis Center for Watershed Sciences. 316 pages.

First, we assumed a 12-month year with each month consisting of four weeks (i.e., each month broken into four parts).

Second, detailed life-history information from the above sources was used to assign relative abundance indices (both colors and numbers) ranging from 0 (white)(not present) to 5 (black)(abundant) to the following life-history stages on a weekly basis:

Immigration

Spawning

Incubation

Juvenile Rearing

Smolt Emigration

Third, weekly relative abundance indices were averaged based on month for each of the above life-history stages (i.e., four values for each month converted to one average value for each month).

Fourth, maximum values were used to convert the above life-history stages to the following life-history stages (i.e., multiple life-history stages condensed to three categories–it was requested that life-history stages be condensed due a lack of detailed toxicity information for modeling multiple, more discrete life-history stages):

Juvenile (calculated as the maximum relative abundance value of Incubation, Juvenile Rearing, and Smolt Emigration)

Adult (calculated as the maximum relative abundance value of Immigration and Spawning)

All (calculated as the maximum relative abundance value of Incubation, Juvenile Rearing, Smolt Emigration, Immigration, and Spawning)

- All final relative abundance values were rounded to the nearest whole number (0–5)

APPENDIX O.—Distribution and Relative Abundance GIS File

The distribution and relative abundance GIS file for Central Valley Steelhead was developed from the following sources:

McEwan, D. 2001. Central Valley steelhead. pages 1-44 *in* R.L. Brown, ed. Contributions to the biology of Central Valley salmonids. CDFG Fish Bull. 179.

Moyle, P.B. 2002. Inland fishes of California, revised and expanded. University of California Press, Berkley, CA.

Moyle, P.B., J.A. Israel, and S.E. Purdy. 2008. Salmon, steelhead, and trout in California: status of an emblematic fauna. U.C. Davis Center for Watershed Sciences. 316 pages.

Once widely distributed throughout the Sacramento-San Joaquin system (Moyle 2002)

Spawning habitat greatly reduced by construction of dams (Moyle 2002; Moyle et al. 2008)

High degree of hatchery straying and intermixing with resident rainbow trout populations (Moyle 2002)

Different sources list different distributions, but in general, steelhead are distributed throughout the central valley up to the first impassable barrier (see McEwan 2001)

First, we developed a study area GIS file (STUDY_AREA.shp) using a California Watersheds GIS file from the California Interagency Watershed Mapping Committee (IWMC) (*available at* http://www.ca.nrcs.usda.gov/ features/calwater/#Data). Study area included watersheds for anything draining into the Bay-Delta.

Second, we developed a study area hydrography GIS file using the study area GIS file and an overlay procedure to clip a California Hydrography GIS file (HYDRO100K.shp) (*available at* http://www.calfish.org/ DataandMaps/CalFishDataDownloads/ tabid/93/Default.aspx) to the study area GIS file.

Third, we developed a study area barrier GIS file (CV_BARRIERS.shp) using the study area GIS file and an overlay procedure to clip a Fish Passage Assessment Database (PAD) GIS file (*available at* http://www.calfish.org/DataandMaps/ CalFishDataDownloads/ tabid/93/Default.aspx) to the study area.

Fourth, the study area barrier and hydrography GIS files were displayed together and used to develop a study area limit to anadromy GIS file (CV_LIMIT_ANAD.shp). Categories in the barrier GIS file were used to split and label stream reaches in the hydrography GIS file into three categories: (1) 1 = Anadromous Fish Present; (2) 2 = Anadromous Fish Possibly Present; and (3) 3 = Anadromous Fish Not Present (column labeled Pres_Abs in the CV_LIMIT_ANAD.shp file). Anadromous Fish Not Present was given to stream reaches above barrier points classified as complete barriers, partial barriers (without mention of fish passage facilities), and natural limits to anadromy. Anadromous Fish Possibly Present was given to stream reaches above barrier points classified as dams with unknown passage status. Anadromous Fish Present was given to stream reaches below barrier points used to classify stream reaches as Anadromous Fish Not Present and Anadromous Fish Possibly Present. In some cases, barrier points classified as partial barriers or dams with unknown passage status were known to have anadromous fish present in more upper stream reaches (personal experience and literature), so these points were not considered to be boundaries between the Anadromous Fish Present and Anadromous Fish Possibly Present categories. Partial barriers with specific mention of fish passage facilities were not considered to be barriers to anadromy.

Fifth, the study area limit to anadromy GIS file was copied and renamed (FINSTEELHEAD.shp). Stream reaches from this file where then split based on species-specific range information from the above sources and coded as above (1–3) based on Presence (1), Possible Presence (2), and No Presence (3)(column labeled Pres_Abs in the FINSTEELHEAD.shp file).

Sixth, the attribute table of the steelhead GIS file was exported to MS Excel and a series of IF-THEN statements was used to assign relative abundance indices to each stream reach based on the Pres_Abs column (coded 1, 2, or 3) and additional columns added for each life-history stage and month of the year.

Seventh, the resulting MS Excel table was imported back into GIS and appended to the steelhead GIS file attribute table to create a Central Valley Steelhead Presence-Absence and Relative Abundance GIS file (FINSTEELHEAD.shp). The attribute table for this GIS file contains presence-absence (Pres_Abs column coded 1, 2, or 3), and relative abundance data for steelhead (columns labeled Juv_Month, Adult_Month, and All_Month coded 0–5 based on a combination of presence-absence of steelhead and relative abundance of each life-history stage–see above). Data can be displayed visually by toggling desired columns on/off and displaying relative abundance values (i.e., columns labeled Life-History Stage_Month) using unique values. The OCEAN.shp file was obtained from GreenInfo (http://www.greeninfo.org/), and is only used for display purposes. Similarly, the CA_OUTLINE.shp file is only used for display purposes, and was obtained from the U.S. Bureau of Reclamation.

- All fish species range maps should be considered high-water year ranges; some of the stream reaches included are ephemeral and would not contain adults or juveniles during low-water years

APPENDIX P.—DELTA SMELT METHODS

Life-History Table

The life-history table for Delta Smelt was developed from the following references:

Moyle, P.B. 1992. Life history and status of delta smelt in the Sacramento-San Joaquin Estuary, California. Transactions of the American Fisheries Society 121:67-77.

Moyle, P.B. 2002. Inland fishes of California, revised and expanded. University of California Press, Berkley, CA.

Bennett, W.A. 2005. Critical assessment of the delta smelt population in the San Francisco Estuary, California. San Francisco Estuary and Watershed Science 3(2).

First, we assumed a 12-month year with each month consisting of four weeks (i.e., each month broken into four parts).

Second, detailed life-history information from the above sources was used to assign relative abundance indices (both colors and numbers) ranging from 0 (white)(not present) to 5 (black)(abundant) to the following life-history stages on a weekly basis:

Immigration

Spawning

Incubation

Juvenile Rearing

Juvenile Emigration

Third, weekly relative abundance indices were averaged based on month for each of the above life-history stages (i.e., four values for each month converted to one average value for each month).

Fourth, maximum values were used to convert the above life-history stages to the following life-history stages (i.e., multiple life-history stages condensed to three categories–it was requested that life-history stages be condensed due a lack of detailed toxicity information for modeling multiple, more discrete life-history stages):

Juvenile (calculated as the maximum relative abundance value of Incubation, Juvenile Rearing, and Juvenile Emigration)

Adult (calculated as the maximum relative abundance value of Immigration and Spawning)

All (calculated as the maximum relative abundance value of Incubation, Juvenile Rearing, Juvenile Emigration, Immigration, and Spawning)

- All final relative abundance values were rounded to the nearest whole number (0–5)

APPENDIX Q.—Distribution and Relative Abundance GIS File

The distribution and relative abundance GIS file for Delta Smelt was developed from the following sources:

http://ice.ucdavis.edu/aquadiv/fishcovs/dsm.gif

Hamilton, S., D. Murphy, J. Merz, B. Cavallo, J. Melgo, and P. Rueger. *In Prep*. A spatial perspective for delta smelt: considerations for conservation planning.

Moyle, P.B. 1992. Life history and status of delta smelt in the Sacramento-San Joaquin Estuary, California. Transactions of the American Fisheries Society 121:67-77.

Moyle, P.B. 2002. Inland fishes of California, revised and expanded. University of California Press, Berkley, CA.

Bennett, W.A. 2005. Critical assessment of the delta smelt population in the San Francisco Estuary, California. San Francisco Estuary and Watershed Science 3(2).

Moyle, P.B. 2002. Inland fishes of California, revised and expanded. University of California Press, Berkley, CA.

In general, this species is found in the Bay-Delta region and a small distance up the Sacramento and San Joaquin Rivers (actual area occupied depends on time of year and high or low outflow conditions)

The most up-to-date data available was the data from Hamilton et al. (*In Prep*), which looked at the historical distribution of delta smelt in all survey methods used by state and federal agencies

We used data from Hamilton et al. (*In Prep*) to create the delta smelt GIS file and checked that file with the sources above for accuracy and consistency

In general, data from Hamilton et al. (*In Prep*) was consistent with the sources above; however, Hamilton et al. (*In Prep*) identified a slightly larger range than previously reported

First, we developed a study area GIS file (STUDY_AREA.shp) using a California Watersheds GIS file from the California Interagency Watershed Mapping Committee (IWMC) (*available at* http://www.ca.nrcs.usda.gov/ features/calwater/#Data). Study area included watersheds for anything draining into the Bay-Delta.

Second, we developed a study area hydrography GIS file using the study area GIS file and an overlay procedure to clip a California Hydrography GIS file (HYDRO100K.shp) (*available at* http://www.calfish.org/ DataandMaps/CalFishDataDownloads/ tabid/93/Default.aspx) to the study area GIS file.

Third, we developed a study area barrier GIS file (CV_BARRIERS.shp) using the study area GIS file and an overlay procedure to clip a Fish Passage Assessment Database (PAD) GIS file (*available at* http://www.calfish.org/DataandMaps/ CalFishDataDownloads/ tabid/93/Default.aspx) to the study area.

Fourth, the study area barrier and hydrography GIS files were displayed together and used to develop a study area limit to anadromy GIS file (CV_LIMIT_ANAD.shp). Categories in the barrier GIS file were used to split and label stream reaches in the hydrography GIS file into three categories: (1) 1 = Anadromous Fish Present; (2) 2 = Anadromous Fish Possibly Present; and (3) 3 = Anadromous Fish Not Present (column labeled Pres_Abs in the CV_LIMIT_ANAD.shp file). Anadromous Fish Not Present was given to stream reaches above barrier points classified as complete barriers, partial barriers (without mention of fish passage facilities), and natural limits to anadromy. Anadromous Fish Possibly Present was given to stream reaches above barrier points classified as dams with unknown passage status. Anadromous Fish Present was given to stream reaches below barrier points used to classify stream reaches as Anadromous Fish Not Present and Anadromous Fish Possibly Present. In some cases, barrier points classified as partial barriers or dams with unknown passage status were known to have anadromous fish present in more upper stream reaches (personal experience and literature), so these points were not considered to be boundaries between the Anadromous Fish Present and Anadromous Fish Possibly Present categories. Partial barriers with specific mention of fish passage facilities were not considered to be barriers to anadromy.

Fifth, the study area limit to anadromy GIS file was copied and renamed (FINDELTA_SMELT.shp). Stream reaches from this file where then split based on species-specific range information from the above sources and coded as above (1–3) based on Presence (1), Possible Presence (2), and No Presence (3)(column labeled Pres_Abs in the FINDELTA_SMELT.shp file).

Sixth, the attribute table of the delta smelt GIS file was exported to MS Excel and a series of IF-THEN statements was used to assign relative abundance indices to each stream reach based on the Pres_Abs column (coded 1, 2, or 3) and additional columns added for each life-history stage and month of the year.

Seventh, the resulting MS Excel table was imported back into GIS and appended to the delta smelt GIS file attribute table to create a Delta Smelt Presence-Absence and Relative Abundance GIS file (FINDELTA_SMELT.shp). The attribute table for this GIS file contains presence-absence (Pres_Abs column coded 1, 2, or 3), and relative abundance data for delta smelt (columns labeled Juv_Month, Adult_Month, and All_Month coded 0–5 based on a combination of presence-absence of delta smelt and relative abundance of each life-history stage–see above). Data can be displayed visually by toggling desired columns on/off and displaying relative abundance values (i.e., columns labeled Life-History Stage_Month) using unique values. The OCEAN.shp file was obtained from GreenInfo (http://www.greeninfo.org/), and is only used for display purposes. Similarly, the CA_OUTLINE.shp file is only used for display purposes, and was obtained from the U.S. Bureau of Reclamation.

- All fish species range maps should be considered high-water year ranges; some of the stream reaches included are ephemeral and would not contain adults or juveniles during low-water years

APPENDIX R.—FRESHWATER SHRIMP METHODS

Life-History Table

The life-history table for Freshwater Shrimp was developed from the following references:

Eng, L.L. 1981. Distribution, life history, and status of the California freshwater shrimp, *Syncaris pacifica* (Holmes). California Department of Fish and Game. Inland Fisheries Endangered Species Program Special Publication 81-1.

U.S. Fish and Wildlife Service. 1998. California freshwater shrimp (*Syncaris pacifica* Holmes) recovery plan. Portland, Oregon. 104 pages.

First, we assumed a 12-month year with each month consisting of four weeks (i.e., each month broken into four parts).

Second, detailed life-history information from the above sources was used to assign relative abundance indices (both colors and numbers) ranging from 0 (white)(not present) to 5 (black)(abundant) to the following life-history stages on a weekly basis:

Breeding

Incubation

Release of Larvae

Larval/Juvenile Development

Adult Presence

Third, weekly relative abundance indices were averaged based on month for each of the above life-history stages (i.e., four values for each month converted to one average value for each month).

Fourth, maximum values were used to convert the above life-history stages to the following life-history stages (i.e., multiple life-history stages condensed to three categories–it was requested that life-history stages be condensed due a lack of detailed toxicity information for modeling multiple, more discrete life-history stages):

Juvenile (calculated as the maximum relative abundance value of Incubation, Release of Larvae, and Larval/Juvenile Development)

Adult (calculated as the maximum relative abundance value of Breeding and Adult Presence)

All (calculated as the maximum relative abundance value of Incubation, Release of Larvae, Larval/Juvenile Development, Breeding, and Adult Presence)

- All final relative abundance values were rounded to the nearest whole number (0–5)

APPENDIX S.—Distribution and Relative Abundance GIS File

The distribution and relative abundance GIS file for Freshwater Shrimp was developed from the following sources:

Eng, L.L. 1981. Distribution, life history, and status of the California freshwater shrimp, *Syncaris pacifica* (Holmes). California Department of Fish and Game. Inland Fisheries Endangered Species Program Special Publication 81-1.

U.S. Fish and Wildlife Service. 1998. California freshwater shrimp (*Syncaris pacifica* Holmes) recovery plan. Portland, Oregon. 104 pages.

In Bay-Delta watersheds, found in streams flowing into San Pablo Bay, including the Napa River and Garnett, Sonoma, Yulupa, and Huichica Creeks (USFWS 1998)

First, we developed a study area GIS file (STUDY_AREA.shp) using a California Watersheds GIS file from the California Interagency Watershed Mapping Committee (IWMC) (*available at* http://www.ca.nrcs.usda.gov/ features/calwater/#Data). Study area included watersheds for anything draining into the Bay-Delta.

Second, we developed a study area hydrography GIS file using the study area GIS file and an overlay procedure to clip a California Hydrography GIS file (HYDRO100K.shp) (*available at* http://www.calfish.org/ DataandMaps/CalFishDataDownloads/ tabid/93/Default.aspx) to the study area GIS file.

Third, we developed a study area barrier GIS file (CV_BARRIERS.shp) using the study area GIS file and an overlay procedure to clip a Fish Passage Assessment Database (PAD) GIS file (*available at* http://www.calfish.org/DataandMaps/ CalFishDataDownloads/ tabid/93/Default.aspx) to the study area.

Fourth, the study area barrier and hydrography GIS files were displayed together and used to develop a study area limit to anadromy GIS file (CV_LIMIT_ANAD.shp). Categories in the barrier GIS file were used to split and label stream reaches in the hydrography GIS file into three categories: (1) 1 = Anadromous Fish Present; (2) 2 = Anadromous Fish Possibly Present; and (3) 3 = Anadromous Fish Not Present (column labeled Pres_Abs in the CV_LIMIT_ANAD.shp file). Anadromous Fish Not Present was given to stream reaches above barrier points classified as complete barriers, partial barriers (without mention of fish passage facilities), and natural limits to anadromy. Anadromous Fish Possibly Present was given to stream reaches above barrier points classified as dams with unknown passage status. Anadromous Fish Present was given to stream reaches below barrier points used to classify stream reaches as Anadromous Fish Not Present and Anadromous Fish Possibly Present. In some cases, barrier points classified as partial barriers or dams with unknown passage status were known to have anadromous fish present in more upper stream reaches (personal experience and literature), so these points were not considered to be boundaries between the Anadromous Fish Present and Anadromous Fish Possibly Present categories. Partial barriers with specific mention of fish passage facilities were not considered to be barriers to anadromy.

Fifth, the study area limit to anadromy GIS file was copied and renamed (FW_SHRIMP.shp). Stream reaches from this file where then split based on species-specific range information from the above sources and coded as above (1–3) based on Presence (1), Possible Presence (2), and No Presence (3)(column labeled Pres_Abs in the FW_SHRIMP.shp file). Three creeks not included in the limit to anadromy file (Garnett, Yulupa, and Huichica) were added to the freshwater shrimp file at this time; using a finer resolution hydrography shapefile than necessary for fish species (*available at* http://www.calfish.org/ DataandMaps/CalFishDataDownloads/ tabid/93/Default.aspx).

Sixth, the attribute table of the freshwater shrimp GIS file was exported to MS Excel and a series of IF-THEN statements was used to assign relative abundance indices to each stream reach based on the Pres_Abs column (coded 1, 2, or 3) and additional columns added for each life-history stage and month of the year.

Seventh, the resulting MS Excel table was imported back into GIS and appended to the freshwater shrimp GIS file attribute table to create a Freshwater Shrimp Presence-Absence and Relative Abundance GIS file (FW_SHRIMP.shp). The attribute table for this GIS file contains presence-absence (Pres_Abs column coded 1, 2, or 3), and relative abundance data for freshwater shrimp (columns labeled Juv_Month, Adult_Month, and All_Month coded 0–5 based on a combination of presence-absence of freshwater shrimp and relative abundance of each life-history stage–see above). Data can be displayed visually by toggling desired columns on/off and displaying relative abundance values (i.e., columns labeled Life-History Stage_Month) using unique values. The OCEAN.shp file was obtained from GreenInfo (http://www.greeninfo.org/), and is only used for display purposes. Similarly, the CA_OUTLINE.shp file is only used for display purposes, and was obtained from the U.S. Bureau of Reclamation.

- As noted above, three creeks not included in the limit to anadromy file (Garnett, Yulupa, and Huichica) were added to the freshwater shrimp file; using a finer resolution hydrography shapefile than necessary for fish species (*available at* http://www.calfish.org/ DataandMaps/CalFishDataDownloads/ tabid/93/Default.aspx)

APPENDIX T.—GREEN STURGEON METHODS

Life-History Table

The life-history table for Green Sturgeon was developed from the following references:

NOAA. 2009. Endangered and threatened wildlife and plants: final rulemaking to designate critical habitat for the threatened southern distinct population segment of North American green sturgeon; final rule. National Oceanic and Atmospheric Administration, Federal Register Vol. 74, No. 195. 53 pages.

Moyle, P.B., R.M. Yoshiyama, J.E. Williams, and E.D. Wikramanayake. 1995. Fish species of special concern in California. Prepared for the State of California by the Department of Wildlife and Fisheries Biology, University of California Davis. 227 pages.

Moyle, P.B. 2002. Inland fishes of California, revised and expanded. University of California Press, Berkley, CA.

First, we assumed a 12-month year with each month consisting of four weeks (i.e., each month broken into four parts).

Second, detailed life-history information from the above sources was used to assign relative abundance indices (both colors and numbers) ranging from 0 (white)(not present) to 5 (black)(abundant) to the following life-history stages on a weekly basis:

Immigration

Spawning

Incubation

Juvenile Rearing

Juvenile Emigration

Third, weekly relative abundance indices were averaged based on month for each of the above life-history stages (i.e., four values for each month converted to one average value for each month).

Fourth, maximum values were used to convert the above life-history stages to the following life-history stages (i.e., multiple life-history stages condensed to three categories–it was requested that life-history stages be condensed due a lack of detailed toxicity information for modeling multiple, more discrete life-history stages):

Juvenile (calculated as the maximum relative abundance value of Incubation, Juvenile Rearing, and Juvenile Emigration)

Adult (calculated as the maximum relative abundance value of Immigration and Spawning)

All (calculated as the maximum relative abundance value of Incubation, Juvenile Rearing, Juvenile Emigration, Immigration, and Spawning)

- All final relative abundance values were rounded to the nearest whole number (0–5)

Distribution and Relative Abundance GIS File

The distribution and relative abundance GIS file for Green Sturgeon was developed from the following sources:

http://ice.ucdavis.edu/aquadiv/fishcovs/gst.gif

NOAA. 2009. Endangered and threatened wildlife and plants: final rulemaking to designate critical habitat for the threatened southern distinct population segment of North American green sturgeon; final rule. National Oceanic and Atmospheric Administration, Federal Register Vol. 74, No. 195. 53 pages.

Moyle, P.B., R.M. Yoshiyama, J.E. Williams, and E.D. Wikramanayake. 1995. Fish species of special concern in California. Prepared for the State of California by the Department of Wildlife and Fisheries Biology, University of California Davis. 227 pages.

Moyle, P.B. 2002. Inland fishes of California, revised and expanded. University of California Press, Berkley, CA.

Populations inhabit the Sacramento-San Joaquin Delta, Sacramento, Feather, and Yuba Rivers (NOAA 2009; Moyle et al. 1995; Moyle 2002)

Spawn above and below Red Bluff Diversion Dam on the Sacramento River and are suspected to spawn below Fish Barrier Dam on the Feather River and Daguerre Dam on the Yuba River (NOAA 2009)

Juveniles have been found in the lower San Joaquin River, but these fish are suspected of coming from the Sacramento River (Moyle et al. 1995)

First, we developed a study area GIS file (STUDY_AREA.shp) using a California Watersheds GIS file from the California Interagency Watershed Mapping Committee (IWMC) (*available at* http://www.ca.nrcs.usda.gov/ features/calwater/#Data). Study area included watersheds for anything draining into the Bay-Delta.

Second, we developed a study area hydrography GIS file using the study area GIS file and an overlay procedure to clip a California Hydrography GIS file (HYDRO100K.shp) (*available at* http://www.calfish.org/ DataandMaps/CalFishDataDownloads/ tabid/93/Default.aspx) to the study area GIS file.

Third, we developed a study area barrier GIS file (CV_BARRIERS.shp) using the study area GIS file and an overlay procedure to clip a Fish Passage Assessment Database (PAD) GIS file (*available at* http://www.calfish.org/DataandMaps/ CalFishDataDownloads/ tabid/93/Default.aspx) to the study area.

Fourth, the study area barrier and hydrography GIS files were displayed together and used to develop a study area limit to anadromy GIS file (CV_LIMIT_ANAD.shp). Categories in the barrier GIS file were used to split and label stream reaches in the hydrography GIS file into three categories: (1) 1 = Anadromous Fish Present; (2) 2 = Anadromous Fish Possibly Present; and (3) 3 = Anadromous Fish Not Present (column labeled Pres_Abs in the CV_LIMIT_ANAD.shp file). Anadromous Fish Not Present was given to stream reaches above barrier points classified as complete barriers, partial barriers (without mention of fish passage facilities), and natural limits to anadromy. Anadromous Fish Possibly Present was given to stream reaches above barrier points classified as dams with unknown passage status. Anadromous Fish Present was given to stream reaches below barrier points used to classify stream reaches as Anadromous Fish Not Present and Anadromous Fish Possibly Present. In some cases, barrier points classified as partial barriers or dams with unknown passage status were known to have anadromous fish present in more upper stream reaches (personal experience and literature), so these points were not considered to be boundaries between the Anadromous Fish Present and Anadromous Fish Possibly Present categories. Partial barriers with specific mention of fish passage facilities were not considered to be barriers to anadromy.

Fifth, the study area limit to anadromy GIS file was copied and renamed (FINGREEN_STURGEON.shp). Stream reaches from this file where then split based on species-specific range information from the above sources and coded as above (1–3) based on Presence (1), Possible Presence (2), and No Presence (3)(column labeled Pres_Abs in the FINGREEN_STURGEON.shp file).

Sixth, the attribute table of the green sturgeon GIS file was exported to MS Excel and a series of IF-THEN statements was used to assign relative abundance indices to each stream reach based on the Pres_Abs column (coded 1, 2, or 3) and additional columns added for each life-history stage and month of the year.

Seventh, the resulting MS Excel table was imported back into GIS and appended to the green sturgeon GIS file attribute table to create a Green Sturgeon Presence-Absence and Relative Abundance GIS file (FINGREEN_STURGEON.shp). The attribute table for this GIS file contains presence-absence (Pres_Abs column coded 1, 2, or 3), and relative abundance data for green sturgeon (columns labeled Juv_Month, Adult_Month, and All_Month coded 0–5 based on a combination of presence-absence of green sturgeon and relative abundance of each life-history stage–see above). Data can be displayed visually by toggling desired columns on/off and displaying relative abundance values (i.e., columns labeled Life-History Stage_Month) using unique values. The OCEAN.shp file was obtained from GreenInfo (http://www.greeninfo.org/), and is only used for display purposes. Similarly, the CA_OUTLINE.shp file is only used for display purposes, and was obtained from the U.S. Bureau of Reclamation.

- All fish species range maps should be considered high-water year ranges; some of the stream reaches included are ephemeral and would not contain adults or juveniles during low-water years

APPENDIX U.—LONGFIN SMELT METHODS

Life-History Table

The life-history table for Longfin Smelt was developed from the following references:

CDFG. 2009. A status review of the longfin smelt (*Spirinchus thaleichthys*) in California. California Department of Fish and Game, Report to the Fish and Game Commission. 131 pages.

Moyle, P.B., R.M. Yoshiyama, J.E. Williams, and E.D. Wikramanayake. 1995. Fish species of special concern in California. Prepared for the State of California by the Department of Wildlife and Fisheries Biology, University of California Davis. 227 pages.

Moyle, P.B. 2002. Inland fishes of California, revised and expanded. University of California Press, Berkley, CA.

First, we assumed a 12-month year with each month consisting of four weeks (i.e., each month broken into four parts).

Second, detailed life-history information from the above sources was used to assign relative abundance indices (both colors and numbers) ranging from 0 (white)(not present) to 5 (black)(abundant) to the following life-history stages on a weekly basis:

Immigration

Spawning

Incubation

Fry Emigration

Juvenile Rearing

Third, weekly relative abundance indices were averaged based on month for each of the above life-history stages (i.e., four values for each month converted to one average value for each month).

Fourth, maximum values were used to convert the above life-history stages to the following life-history stages (i.e., multiple life-history stages condensed to three categories–it was requested that life-history stages be condensed due a lack of detailed toxicity information for modeling multiple, more discrete life-history stages):

Juvenile (calculated as the maximum relative abundance value of Incubation, Fry Emigration, and Juvenile Rearing)

Adult (calculated as the maximum relative abundance value of Immigration and Spawning)

All (calculated as the maximum relative abundance value of Incubation, Fry Emigration, Juvenile Rearing, Immigration, and Spawning)

- All final relative abundance values were rounded to the nearest whole number (0–5)

Distribution and Relative Abundance GIS File

The distribution and relative abundance GIS file for Longfin Smelt was developed from the following sources:

http://ice.ucdavis.edu/aquadiv/fishcovs/lfs.gif

CDFG. 2009. A status review of the longfin smelt (*Spirinchus thaleichthys*) in California. California Department of Fish and Game, Report to the Fish and Game Commission. 131 pages.

Moyle, P.B., R.M. Yoshiyama, J.E. Williams, and E.D. Wikramanayake. 1995. Fish species of special concern in California. Prepared for the State of California by the Department of Wildlife and Fisheries Biology, University of California Davis. 227 pages.

Moyle, P.B. 2002. Inland fishes of California, revised and expanded. University of California Press, Berkley, CA.

Rarely found upstream of Rio Vista in the Sacramento River or Medford Island in the San Joaquin River (Moyle et al. 1995; Moyle 2002)

Rarely collected outside the estuary (Moyle et al. 1995)

First, we developed a study area GIS file (STUDY_AREA.shp) using a California Watersheds GIS file from the California Interagency Watershed Mapping Committee (IWMC) (*available at* http://www.ca.nrcs.usda.gov/ features/calwater/#Data). Study area included watersheds for anything draining into the Bay-Delta.

Second, we developed a study area hydrography GIS file using the study area GIS file and an overlay procedure to clip a California Hydrography GIS file (HYDRO100K.shp) (*available at* http://www.calfish.org/ DataandMaps/CalFishDataDownloads/ tabid/93/Default.aspx) to the study area GIS file.

Third, we developed a study area barrier GIS file (CV_BARRIERS.shp) using the study area GIS file and an overlay procedure to clip a Fish Passage Assessment Database (PAD) GIS file (*available at* http://www.calfish.org/DataandMaps/ CalFishDataDownloads/ tabid/93/Default.aspx) to the study area.

Fourth, the study area barrier and hydrography GIS files were displayed together and used to develop a study area limit to anadromy GIS file (CV_LIMIT_ANAD.shp). Categories in the barrier GIS file were used to split and label stream reaches in the hydrography GIS file into three categories: (1) 1 = Anadromous Fish Present; (2) 2 = Anadromous Fish Possibly Present; and (3) 3 = Anadromous Fish Not Present (column labeled Pres_Abs in the CV_LIMIT_ANAD.shp file). Anadromous Fish Not Present was given to stream reaches above barrier points classified as complete barriers, partial barriers (without mention of fish passage facilities), and natural limits to anadromy. Anadromous Fish Possibly Present was given to stream reaches above barrier points classified as dams with unknown passage status. Anadromous Fish Present was given to stream reaches below barrier points used to classify stream reaches as Anadromous Fish Not Present and Anadromous Fish Possibly Present. In some cases, barrier points classified as partial barriers or dams with unknown passage status were known to have anadromous fish present in more upper stream reaches (personal experience and literature), so these points were not considered to be boundaries between the Anadromous Fish Present and Anadromous Fish Possibly Present categories. Partial barriers with specific mention of fish passage facilities were not considered to be barriers to anadromy.

Fifth, the study area limit to anadromy GIS file was copied and renamed (FINLONGFIN_SMELT.shp). Stream reaches from this file where then split based on species-specific range information from the above sources and coded as above (1–3) based on Presence (1), Possible Presence (2), and No Presence (3)(column labeled Pres_Abs in the FINLONGFIN_SMELT.shp file).

Sixth, the attribute table of the longfin smelt GIS file was exported to MS Excel and a series of IF-THEN statements was used to assign relative abundance indices to each stream reach based on the Pres_Abs column (coded 1, 2, or 3) and additional columns added for each life-history stage and month of the year.

Seventh, the resulting MS Excel table was imported back into GIS and appended to the longfin smelt GIS file attribute table to create a Longfin Smelt Presence-Absence and Relative Abundance GIS file (FINLONGFIN_SMELT.shp). The attribute table for this GIS file contains presence-absence (Pres_Abs column coded 1, 2, or 3), and relative abundance data for longfin smelt (columns labeled Juv_Month, Adult_Month, and All_Month coded 0–5 based on a combination of presence-absence of longfin smelt and relative abundance of each life-history stage–see above). Data can be displayed visually by toggling desired columns on/off and displaying relative abundance values (i.e., columns labeled Life-History Stage_Month) using unique values. The OCEAN.shp file was obtained from GreenInfo (http://www.greeninfo.org/), and is only used for display purposes. Similarly, the CA_OUTLINE.shp file is only used for display purposes, and was obtained from the U.S. Bureau of Reclamation.

- All fish species range maps should be considered high-water year ranges; some of the stream reaches included are ephemeral and would not contain adults or juveniles during low-water years

APPENDIX V.—RED-LEGGED FROG METHODS

Life-History Table

The life-history table for Red-Legged Frog was developed from the following references:

USFWS. 1996. Endangered and threatened wildlife and plants: determination of threatened status for the California red-legged frog. Federal Register 61(101):25813-25833.

USFWS. 2002. Recovery plan for the California red-legged frog (*Rana aurora draytonii*). U.S. Fish and Wildlife Service, Region 1. Portland, Oregon. 173 pages.

USFWS. 2010. Endangered and threatened wildlife and plants; revised designation of critical habitat for the California red-legged frog. Federal Register 75(51):12816-12959.

First, we assumed a 12-month year with each month consisting of four weeks (i.e., each month broken into four parts).

Second, detailed life-history information from the above sources was used to assign relative abundance indices (both colors and numbers) ranging from 0 (white)(not present) to 5 (black)(abundant) to the following life-history stages on a weekly basis:

Breeding Season

Mating

Incubation

Larval Development

Metamorphosis

Juvenile Development

Adult Presence

Third, weekly relative abundance indices were averaged based on month for each of the above life-history stages (i.e., four values for each month converted to one average value for each month).

Fourth, maximum values were used to convert the above life-history stages to the following life-history stages (i.e., multiple life-history stages condensed to three categories–it was requested that life-history stages be condensed due a lack of detailed toxicity information for modeling multiple, more discrete life-history stages):

Juvenile (calculated as the maximum relative abundance value of Incubation, Larval Development, Metamorphosis, and Juvenile Development)

Adult (calculated as the maximum relative abundance value of Breeding Season, Mating, and Adult Presence)

All (calculated as the maximum relative abundance value of Incubation, Larval Development, Metamorphosis, Juvenile Development, Breeding Season, Mating, and Adult Presence)

- All final relative abundance values were rounded to the nearest whole number (0–5)

Distribution and Relative Abundance GIS File

The distribution and relative abundance GIS file for Red-Legged Frog was developed from the following sources:

USFWS. 2002. Recovery plan for the California red-legged frog (Rana aurora draytonii). U.S. Fish and Wildlife Service, Region 1. Portland, Oregon. 173 pages.

USFWS. 2010. Endangered and threatened wildlife and plants; revised designation of critical habitat for the California red-legged frog. Federal Register 75(51):12816-12959.

First, we developed a study area GIS file (STUDY_AREA.shp) using a California Watersheds GIS file from the California Interagency Watershed Mapping Committee (IWMC) (*available at* http://www.ca.nrcs.usda.gov/ features/calwater/#Data). Study area included watersheds for anything draining into the Bay-Delta.

Second, we developed a study area critical habitat GIS file using the study area GIS file and an overlay procedure to clip a red-legged frog critical habitat GIS file (*available at* http://crithab.fws.gov/) to the study area GIS file (polygons were checked against the sources above before proceeding).

Third, the study area critical habitat GIS file was copied and renamed (RLEG_FROG.shp). Polygons from this file where then coded using the system used for fish species and freshwater shrimp (1–3) based on Presence (1), Possible Presence (2), and No Presence (3)(column labeled Pres_Abs in the RLEG_FROG.shp file).

Fourth, the attribute table of the red-legged frog GIS file was exported to MS Excel and a series of IF-THEN statements was used to assign relative abundance indices to each polygon based on the Pres_Abs column (coded 1, 2, or 3) and additional columns added for each life-history stage and month of the year.

Fifth, the resulting MS Excel table was imported back into GIS and appended to the red-legged frog GIS file attribute table to create a Red-Legged Frog Presence-Absence and Relative Abundance GIS file (RLEG_FROG.shp). The attribute table for this GIS file contains presence-absence (Pres_Abs column coded 1, 2, or 3), and relative abundance data for red-legged frog (columns labeled Juv_Month, Adult_Month, and All_Month coded 0–5 based on a combination of presence-absence of red-legged frog and relative abundance of each life-history stage–see above). Data can be displayed visually by toggling desired columns on/off and displaying relative abundance values (i.e., columns labeled Life-History Stage_Month) using unique values. The OCEAN.shp file was obtained from GreenInfo (http://www.greeninfo.org/), and is only used for display purposes. Similarly, the CA_OUTLINE.shp file is only used for display purposes, and was obtained from the U.S. Bureau of Reclamation.

- The red-legged frog GIS file contains polygons of critical habitat and relative abundance, and is in a different format than fish species and freshwater shrimp files

- When working with the red-legged frog shapefile, one can assume that critical habitat = occupied range (there are likely other areas occupied; however, additional data is unavailable)

APPENDIX W.—STRIPED BASS METHODS

Life-History Table

The life-history table for Striped Bass was developed from the following references:

Moyle, P.B. 2002. Inland fishes of California, revised and expanded. University of California Press, Berkley, CA.

First, we assumed a 12-month year with each month consisting of four weeks (i.e., each month broken into four parts).

Second, detailed life-history information from the above sources was used to assign relative abundance indices (both colors and numbers) ranging from 0 (white)(not present) to 5 (black)(abundant) to the following life-history stages on a weekly basis:

Immigration

Spawning

Incubation

Fry Emigration

Juvenile Rearing

Third, weekly relative abundance indices were averaged based on month for each of the above life-history stages (i.e., four values for each month converted to one average value for each month).

Fourth, maximum values were used to convert the above life-history stages to the following life-history stages (i.e., multiple life-history stages condensed to three categories–it was requested that life-history stages be condensed due a lack of detailed toxicity information for modeling multiple, more discrete life-history stages):

Juvenile (calculated as the maximum relative abundance value of Incubation, Fry Emigration, and Juvenile Rearing)

Adult (calculated as the maximum relative abundance value of Immigration and Spawning)

All (calculated as the maximum relative abundance value of Incubation, Fry Emigration, Juvenile Rearing, Immigration, and Spawning)

- All final relative abundance values were rounded to the nearest whole number (0–5)

Distribution and Relative Abundance GIS File

The distribution and relative abundance GIS file for Striped Bass was developed from the following sources:

http://ice.ucdavis.edu/aquadiv/fishcovs/sb.gif

Moyle, P.B. 2002. Inland fishes of California, revised and expanded. University of California Press, Berkley, CA.

Native to streams and bays of the Atlantic coast (Moyle 2002)

In the Sacramento Valley, striped bass regularly penetrate upstream as far as barrier dams, such as Red Bluff Diversion Dam on the Sacramento River (Moyle 2002)

In general, this fish species can be found anywhere in the Central Valley up to Red Bluff Diversion Dam on the Sacramento River and Friant Dam on the San Joaquin River; impassable barriers are the only limitations

First, we developed a study area GIS file (STUDY_AREA.shp) using a California Watersheds GIS file from the California Interagency Watershed Mapping Committee (IWMC) (*available at* http://www.ca.nrcs.usda.gov/ features/calwater/#Data). Study area included watersheds for anything draining into the Bay-Delta.

Second, we developed a study area hydrography GIS file using the study area GIS file and an overlay procedure to clip a California Hydrography GIS file (HYDRO100K.shp) (*available at* http://www.calfish.org/ DataandMaps/CalFishDataDownloads/ tabid/93/Default.aspx) to the study area GIS file.

Third, we developed a study area barrier GIS file (CV_BARRIERS.shp) using the study area GIS file and an overlay procedure to clip a Fish Passage Assessment Database (PAD) GIS file (*available at* http://www.calfish.org/DataandMaps/ CalFishDataDownloads/ tabid/93/Default.aspx) to the study area.

Fourth, the study area barrier and hydrography GIS files were displayed together and used to develop a study area limit to anadromy GIS file (CV_LIMIT_ANAD.shp). Categories in the barrier GIS file were used to split and label stream reaches in the hydrography GIS file into three categories: (1) 1 = Anadromous Fish Present; (2) 2 = Anadromous Fish Possibly Present; and (3) 3 = Anadromous Fish Not Present (column labeled Pres_Abs in the CV_LIMIT_ANAD.shp file). Anadromous Fish Not Present was given to stream reaches above barrier points classified as complete barriers, partial barriers (without mention of fish passage facilities), and natural limits to anadromy. Anadromous Fish Possibly Present was given to stream reaches above barrier points classified as dams with unknown passage status. Anadromous Fish Present was given to stream reaches below barrier points used to classify stream reaches as Anadromous Fish Not Present and Anadromous Fish Possibly Present. In some cases, barrier points classified as partial barriers or dams with unknown passage status were known to have anadromous fish present in more upper stream reaches (personal experience and literature), so these points were not considered to be boundaries between the Anadromous Fish Present and Anadromous Fish Possibly Present categories. Partial barriers with specific mention of fish passage facilities were not considered to be barriers to anadromy.

Fifth, the study area limit to anadromy GIS file was copied and renamed (FINSTRIPED_BASS.shp). Stream reaches from this file where then split based on species-specific range information from the above sources and coded as above (1–3) based on Presence (1), Possible Presence (2), and No Presence (3)(column labeled Pres_Abs in the FINSTRIPED_BASS.shp file).

Sixth, the attribute table of the striped bass GIS file was exported to MS Excel and a series of IF-THEN statements was used to assign relative abundance indices to each stream reach based on the Pres_Abs column (coded 1, 2, or 3) and additional columns added for each life-history stage and month of the year.

Seventh, the resulting MS Excel table was imported back into GIS and appended to the striped bass GIS file attribute table to create a Striped Bass Presence-Absence and Relative Abundance GIS file (FINSTRIPED_BASS.shp). The attribute table for this GIS file contains presence-absence (Pres_Abs column coded 1, 2, or 3), and relative abundance data for striped bass (columns labeled Juv_Month, Adult_Month, and All_Month coded 0–5 based on a combination of presence-absence of striped bass and relative abundance of each life-history stage–see above). Data can be displayed visually by toggling desired columns on/off and displaying relative abundance values (i.e., columns labeled Life-History Stage_Month) using unique values. The OCEAN.shp file was obtained from GreenInfo (http://www.greeninfo.org/), and is only used for display purposes. Similarly, the CA_OUTLINE.shp file is only used for display purposes, and was obtained from the U.S. Bureau of Reclamation.

- All fish species range maps should be considered high-water year ranges; some of the stream reaches included are ephemeral and would not contain adults or juveniles during low-water years

APPENDIX X.—THREADFIN SHAD METHODS

Life-History Table

The life-history table for Threadfin Shad was developed from the following references:

Moyle, P.B. 2002. Inland fishes of California, revised and expanded. University of California Press, Berkley, CA.

First, we assumed a 12-month year with each month consisting of four weeks (i.e., each month broken into four parts).

Second, detailed life-history information from the above sources was used to assign relative abundance indices (both colors and numbers) ranging from 0 (white)(not present) to 5 (black)(abundant) to the following life-history stages on a weekly basis:

Spawning

Incubation

Fry Rearing

Juvenile Rearing

Third, weekly relative abundance indices were averaged based on month for each of the above life-history stages (i.e., four values for each month converted to one average value for each month).

Fourth, maximum values were used to convert the above life-history stages to the following life-history stages (i.e., multiple life-history stages condensed to three categories–it was requested that life-history stages be condensed due a lack of detailed toxicity information for modeling multiple, more discrete life-history stages):

Juvenile (calculated as the maximum relative abundance value of Incubation, Fry Rearing, and Juvenile Rearing)

Adult (calculated as the maximum relative abundance value of Spawning)

All (calculated as the maximum relative abundance value of Incubation, Fry Rearing, Juvenile Rearing, and Spawning)

- All final relative abundance values were rounded to the nearest whole number (0–5)

Distribution and Relative Abundance GIS File

The distribution and relative abundance GIS file for Threadfin Shad was developed from the following sources:

http://ice.ucdavis.edu/aquadiv/fishcovs/tsf.gif

Moyle, P.B. 2002. Inland fishes of California, revised and expanded. University of California Press, Berkley, CA.

Native to streams flowing into the Gulf of Mexico, south to Belize (Moyle 2002)

Established in the Sacramento-San Joaquin system and estuary (Moyle 2002)

In general, this fish species can be found anywhere in the Central Valley up to the first impassable barrier; with unauthorized plants above many barriers (basically everywhere)

First, we developed a study area GIS file (STUDY_AREA.shp) using a California Watersheds GIS file from the California Interagency Watershed Mapping Committee (IWMC) (*available at* http://www.ca.nrcs.usda.gov/ features/calwater/#Data). Study area included watersheds for anything draining into the Bay-Delta.

Second, we developed a study area hydrography GIS file using the study area GIS file and an overlay procedure to clip a California Hydrography GIS file (HYDRO100K.shp) (*available at* http://www.calfish.org/ DataandMaps/CalFishDataDownloads/ tabid/93/Default.aspx) to the study area GIS file.

Third, we developed a study area barrier GIS file (CV_BARRIERS.shp) using the study area GIS file and an overlay procedure to clip a Fish Passage Assessment Database (PAD) GIS file (*available at* http://www.calfish.org/DataandMaps/ CalFishDataDownloads/ tabid/93/Default.aspx) to the study area.

Fourth, the study area barrier and hydrography GIS files were displayed together and used to develop a study area limit to anadromy GIS file (CV_LIMIT_ANAD.shp). Categories in the barrier GIS file were used to split and label stream reaches in the hydrography GIS file into three categories: (1) 1 = Anadromous Fish Present; (2) 2 = Anadromous Fish Possibly Present; and (3) 3 = Anadromous Fish Not Present (column labeled Pres_Abs in the CV_LIMIT_ANAD.shp file). Anadromous Fish Not Present was given to stream reaches above barrier points classified as complete barriers, partial barriers (without mention of fish passage facilities), and natural limits to anadromy. Anadromous Fish Possibly Present was given to stream reaches above barrier points classified as dams with unknown passage status. Anadromous Fish Present was given to stream reaches below barrier points used to classify stream reaches as Anadromous Fish Not Present and Anadromous Fish Possibly Present. In some cases, barrier points classified as partial barriers or dams with unknown passage status were known to have anadromous fish present in more upper stream reaches (personal experience and literature), so these points were not considered to be boundaries between the Anadromous Fish Present and Anadromous Fish Possibly Present categories. Partial barriers with specific mention of fish passage facilities were not considered to be barriers to anadromy.

Fifth, the study area limit to anadromy GIS file was copied and renamed (FINTHREADFIN_SHAD.shp). Stream reaches from this file where then split based on species-specific range information from the above sources and coded as above (1–3) based on Presence (1), Possible Presence (2), and No Presence (3)(column labeled Pres_Abs in the FINTHREADFIN_SHAD.shp file).

Sixth, the attribute table of the threadfin shad GIS file was exported to MS Excel and a series of IF-THEN statements was used to assign relative abundance indices to each stream reach based on the Pres_Abs column (coded 1, 2, or 3) and additional columns added for each life-history stage and month of the year.

Seventh, the resulting MS Excel table was imported back into GIS and appended to the threadfin shad GIS file attribute table to create a Threadfin Shad Presence-Absence and Relative Abundance GIS file (FINTHREADFIN_SHAD.shp). The attribute table for this GIS file contains presence-absence (Pres_Abs column coded 1, 2, or 3), and relative abundance data for threadfin shad (columns labeled Juv_Month, Adult_Month, and All_Month coded 0–5 based on a combination of presence-absence of threadfin shad and relative abundance of each life-history stage–see above). Data can be displayed visually by toggling desired columns on/off and displaying relative abundance values (i.e., columns labeled Life-History Stage_Month) using unique values. The OCEAN.shp file was obtained from GreenInfo (http://www.greeninfo.org/), and is only used for display purposes. Similarly, the CA_OUTLINE.shp file is only used for display purposes, and was obtained from the U.S. Bureau of Reclamation.

- All fish species range maps should be considered high-water year ranges; some of the stream reaches included are ephemeral and would not contain adults or juveniles during low-water years