UNIVERSITY OF CALIFORNIA

SANTA BARBARA

CHARACTERIZING THE ECOLOGICAL RISK TO THE TIDEWATER GOBY FROM PYRETHROID USE IN COASTAL CALIFORNIA

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

BY

CHESTER LINDLEY

JIA LIU

MICHAEL PATTON

ALEXANDER PRESCOTT

NATALIE SHAHBOL

Bren School of Environmental Science & Management
UNIVERSITY OF CALIFORNIA, SANTA BARBARA

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ARTURO KELLER

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Characterizing the Ecological Risk to the Tidewater Goby from Pyrethroid Use in Coastal California

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Chester Lindley

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Alexander Prescott

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Jia Liu

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Natalie Shahbol

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Michael Patton

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

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Dr. Arturo Keller

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Abbreviations

AMA: agricultural management assistance
BCF: bioconcentration factor
BMP: best management practice
BS: bluegill sunfish
CASQA: California Stormwater Quality Association
CDFA: California Department of Food and Agriculture
CDFW: California Department of Fish and Wildlife
CDPR: California Department of Pesticide Regulation
CEDEN: California Environmental Data Exchange Network
DD: degree day
DO: dissolved oxygen
DOC: dissolved organic carbon
EC: effective concentration
EEC: expected environment concentrations
EPA: United States Environmental Protection Agency
FIFRA: Federal Insecticide, Fungicide, and Rodenticide Act
Halaco: Halaco Engineering Company
IPM: Integrated Pest Management
Koc: soil organic carbon-water partitioning coefficient
LARWQCB: Los Angeles Regional Water Quality Control Board
LC: lethal concentrations
LC-MS: liquid chromatography–mass spectrometry
MPA: maximum possible area
MTRS: meridian township and range, section
MVA: metapopulation viability analysis
NOAEC: no observed adverse effect concentration
NOEC: the no observed effect concentration
NPDES: National Pollutant Discharge Elimination System
NPS: non-point source
NRCS: Natural Resource Conservation Services Program
NTT: Nutrient Tracking Tool
OLW: Ormond Lagoon Watershed
PMP: pest management professionals
ppb: parts per Billion
ppt: parts per Trillion
PRZM: Pesticide Root Zone Model
PUR: Pesticide Use Reports
PWC: Pesticide in Water Calculator

PWG: Pyrethroid Working Group
RAs: responsibility areas
RUPs: Restricted Use Products
SS: suspended solids
STEPL: Spreadsheet Tool for Estimating Pollutant Load
SWAMP: Surface Water Ambient Monitoring Program
TC: threshold concentration
TMDL: total maximum daily load
TWG: tidewater goby
UCCE: UC Cooperative Extension
USDA: United States Department of Agriculture
USFWS: United States Fish and Wildlife Service
USGS: United States Geographic Survey
VCAILG: Ventura County Agricultural Irrigated Lands Group
VCSQMP: Ventura Countywide Stormwater Quality Management Program
VCWPD: Ventura County Watershed Protection District
VVWM: Variable Volume Water Model
WQMP: Water Quality Management Plan

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Abstract

In recent years, pyrethroid pesticides have been increasingly contributing to toxicity in California's waters, where in the last 5 years concentration of pyrethroids in the environment have doubled in many urban waterways. Due to the increases in use and concentrations, pyrethroids have been detected in waterways at levels that may be toxic to many fish, including the federally-endangered tidewater goby (*Eucyclogobius newberryi* and *Eucyclogobius kristinae*). Ventura County's Ormond Lagoon is among one of many coastal California watersheds potentially impacted by high levels of pyrethroids, and these high levels may have resulted in fish kills in Ormond Lagoon. While there have been efforts to reduce the impacts of pyrethroids through structural and behavioral regulations, a comprehensive understanding and study of the impacts of pyrethroids on the tidewater goby has not been conducted. To address this knowledge gap, the objectives of this study were to: 1) Characterize and summarize pyrethroid use, environmental concentrations, and relevant regulations in coastal California; 2) Create geospatial representations that integrate pesticide application and tidewater goby critical habitat data to develop heat maps of pyrethroid use throughout coastal California watersheds; 3) Calculate expected environmental concentrations of bifenthrin, permethrin, and fenpropathrin in Ormond Lagoon's surface water, pore water, and sediments using localized conditions; and 4) Recommend urban and agricultural best management practices to reduce the off-site runoff potential of pyrethroids in coastal California.

Executive Summary

In recent years, an emerging class of pesticides known as pyrethroids are being increasingly applied for pest management in agriculture and for structural pest control throughout California. Detections and concentrations of pyrethroids have been rapidly increasing in California's waters and sediments, particularly in urban areas (Phillips, 2016). However, there is a knowledge gap on the level of risk pyrethroids pose to aquatic species, particularly when pyrethroids are sorbed strongly to sediments. While toxicity studies have assessed pyrethroid impacts on aquatic species and have found that even small concentrations of pyrethroids can be toxic, there have been no direct studies on the tidewater goby (TWG), a federally endangered fish found in coastal lagoons throughout California.

This project was motivated by the two fish kills that occurred in Ventura County's Ormond Lagoon Watershed (OLW). In the past three years, there have been two incidences of fish kills in the Oxnard and Port Hueneme regions in waters hydrologically connected to TWG critical habitats. These fish kill events have been linked to high pyrethroid concentrations and are occurring where TWG are highly likely to be found. The magnitude of pyrethroids entering Ormond Lagoon from the watershed is undetermined, as are the peak and chronic concentrations in the water body. The unknown magnitude of loadings and environmental concentrations results in an unknown risk to the TWG population that the United States Fish and Wildlife Service (USFWS) seeks to accurately quantify.

The primary objective of this study was to estimate pyrethroid impacts on TWG and to recommend best management practices (BMPs) to reduce pyrethroid impacts on TWG habitats. To achieve these tasks, we characterized and summarized coastal California pyrethroid use, environmental concentrations, and relevant pyrethroid-related regulations. In addition, we developed geospatial representations of total and specific pyrethroid use and TWG populations in coastal California. At a finer spatial resolution, we estimated aquatic and sediment-bound pyrethroid concentrations, and the risk it poses to TWG in Ormond Lagoon. With this information, we recommended BMPs to reduce pyrethroids impacts on aquatic life in coastal California.

After identifying pyrethroid use hotspots in coastal California watersheds, our team estimated expected concentrations (EEC) for TWG using OLW as a case study. The United States Environmental Protection Agency's (EPA) Pesticide in Water Calculator (PWC) model was used to predict pyrethroid concentrations in OLW and the risk they pose to TWG. Pyrethroid selection for further model analysis was supported by pyrethroid data collected by our group from both dry and wet weather samples. The model simulations were run for the three most common pyrethroids applied in Ventura County: bifenthrin, permethrin, and fenpropathrin. The model results were used to identify direct and indirect TWG acute and chronic toxicity thresholds. Since there is no data available on pyrethroid toxicity to TWG, surrogate species, such as the bluegill sunfish (BS) fry were used to estimate acute and

chronic TWG toxicity levels. With the use of PWC, our team identified exceedances of these toxicity levels over a 30-year time period.

Finally, we recommended structural and behavioral BMPs for both the agricultural and urban sectors of coastal California. The BMP models used were specifically calibrated for locations within OLW but can be scaled and applied to other regions in coastal California. These recommendations aim to reduce the risk from both agricultural and urban pyrethroid use to critical habitat for the TWG and other species throughout coastal watersheds in California by reducing the offsite transport of pyrethroids from application areas.

Our results indicate that pyrethroids are being applied at high rates in coastal watersheds with TWG critical habitat, and that this pattern potentially poses a risk to TWG populations. The highest application rates of pyrethroids in watersheds with TWG critical habitat were found in the Salinas, Santa Monica Bay, and Santa Maria watersheds. The Calleguas watershed, which contains Ormond Lagoon, had only the seventh highest amount of pyrethroids applied. Based on the PWC modeling of OLW, it was determined that acute toxic events in the aqueous phase are likely to occur multiple times a year from bifenthrin, permethrin, and/or fenpropathrin. Additionally, toxic concentrations to TWG prey such as *Hyella Azteca* are likely to be found on a daily basis. Ecological wide toxic effects to at least 30% aquatic species are expected to be experienced annually. The relatively small amount of pesticides applied in the OLW and Calleguas Watershed indicate that environmental risk is likely to be greater in watersheds with greater use. The patterns observed at the watershed level can be useful for identifying which areas in coastal California could be at risk and should be targeted for further studies and management.

To reduce the impact of pyrethroids on TWG populations, our team recommends the following structural BMPs: vegetative filter strips (VFS) and bioswales for urban areas and VFS and sediment basins for agricultural areas. Behavioral BMPs are more challenging to quantify, especially for urban application, as there is limited data on urban use. Some behavioral BMPs, such as ecosystem-based Integrated Pest Management (IPM), has been successful in reducing pyrethroid use and risks that pyrethroid pose. Other behavioral BMPs we recommend are applying pyrethroids as granules instead of in liquid form to reduce pyrethroid runoff, creating a system of stricter enforcement of pyrethroid applications before the wet season begins, and using pyrethroid alternatives. By implementing these BMPs, Ormond Lagoon can experience less pyrethroid runoff and foster a healthier ecosystem for TWG and other wildlife.

By using available data and modeling techniques, our project estimates pyrethroid concentrations and ways to reduce their impact on receiving water bodies. The techniques used for this project can be replicated for other regions also experiencing the damages of increased environmental pyrethroid presence and concentrations. This project highlights major gaps in data and the need to expand on data collection, especially in quantifying impacts from the urban sector and identifying toxicity levels for a wider class of fish species.

Our work serves as an analysis on effects of pyrethroids on TWG and provides recommendations for scientists, policy-makers, and managers to address and reduce negative ecological impacts of pyrethroids. Specifically, USFWS and other stakeholders such as watershed managers, public agencies, and pesticide applicators may benefit from the products of this project.

1 Significance

Twice since 2015, the Ventura Field Office of the USFWS has reported local fish kills which have linked the fish mortality to pyrethroid exposure (California Department of Fish and Wildlife 2015; Jenny Marek, personal communication, 12 January 2017). The use of pyrethroids is rapidly increasing for both structural pest control and agricultural pest management purposes, resulting in increased prevalence in the environment across the state (EPA, 2016). Although pyrethroids are significantly less toxic to humans and mammals than their organophosphate pesticide predecessors, pyrethroids are acutely and chronically toxic to many aquatic species including amphibians, fish, and aquatic invertebrates, particularly when found in the water column (EPA, 2016). TWG spend a considerable amount of time in their life cycle in close contact with the sediments and sediment pore water for both reproduction and feeding, making them particularly vulnerable to sediment-bound pyrethroids. Although the ecological risk associated with sediment-bound pyrethroids remains unclear, there is indication of adverse effects (Weston, 2004).

Because of the proven and potential harm pyrethroids pose on aquatic species, particularly the TWG, USFWS seeks to better understand the nature and magnitude of its risk as it relates to local and regional TWG species recovery. The ecological risk associated with pyrethroids effects not only TWG, but a wide range of flora and fauna. TWG have federal protections because of their endangered status which makes them an excellent ‘umbrella species’. Umbrella species are species chosen for conservation activities that may also provide protection to other species in the same ecological community. Because of this, the benefits of managing and reducing the environmental concentrations of pyrethroids are not limited to the TWG, but includes other endangered and endemic species such as the unarmored threespine stickleback and the southern California steelhead. The wetlands and estuaries, which provide habitat for the TWG, have been significantly degraded and reduced due to urbanization, sprawl, and development through the 20th and 21st century, emphasizing the need for appropriate protections against emerging impacts.

2 Project Objectives

- Characterize and summarize pyrethroid use, environmental concentrations, and relevant regulations in coastal California
- Create geospatial representations that integrate pesticide application and TWG critical habitat data to develop heatmaps of pyrethroid use throughout coastal California watersheds
- Calculate expected environmental concentrations (EECs) of bifenthrin, permethrin, and fenpropathrin in Ormond Lagoon’s surface water, pore water, and sediments using localized conditions
- Recommend urban and agricultural BMPs to reduce the off-site runoff potential of pyrethroid applications in coastal California

3 Background

3.1 Ormond Lagoon

3.1.1 Site Overview

Ormond Lagoon is situated along the south coast of California spanning the cities of Port Hueneme and Oxnard (Figure 3.1). The lagoon was once home to a large, complex, and productive wetland ecosystem, but has experienced considerable ecological degradation in recent decades due to environmental contaminants, lagoon draining, and invasive species. There are several land-uses in the surrounding area including agricultural, industrial, and residential developments. Over 75% of wetlands along the Southern California coast have been lost due to development, so the productivity and protection of Ormond Lagoon is of high importance (SFEI, 2014). The conversion of wetland areas into recreational beaches has reduced the size and functionality of the local and regional coastal ecosystem. Industrial and agricultural land-use has also increased levels of contaminants in water flowing into Ormond Lagoon. Directly adjacent to Ormond Lagoon is a defunct metal recovery smelter formerly operated by Halaco Engineering Company (Halaco), which has contributed toxic heavy metals and radionuclides to the lagoon through environmental negligence and mismanagement. The Halaco site was added to the Superfund National Priorities List in 2007 and sporadic site remediation continues to this day (EPA, 2016). These dynamic threats to Ormond Lagoon put the species that rely on this habitat, including the TWG, at risk of further environmental quality degradation.

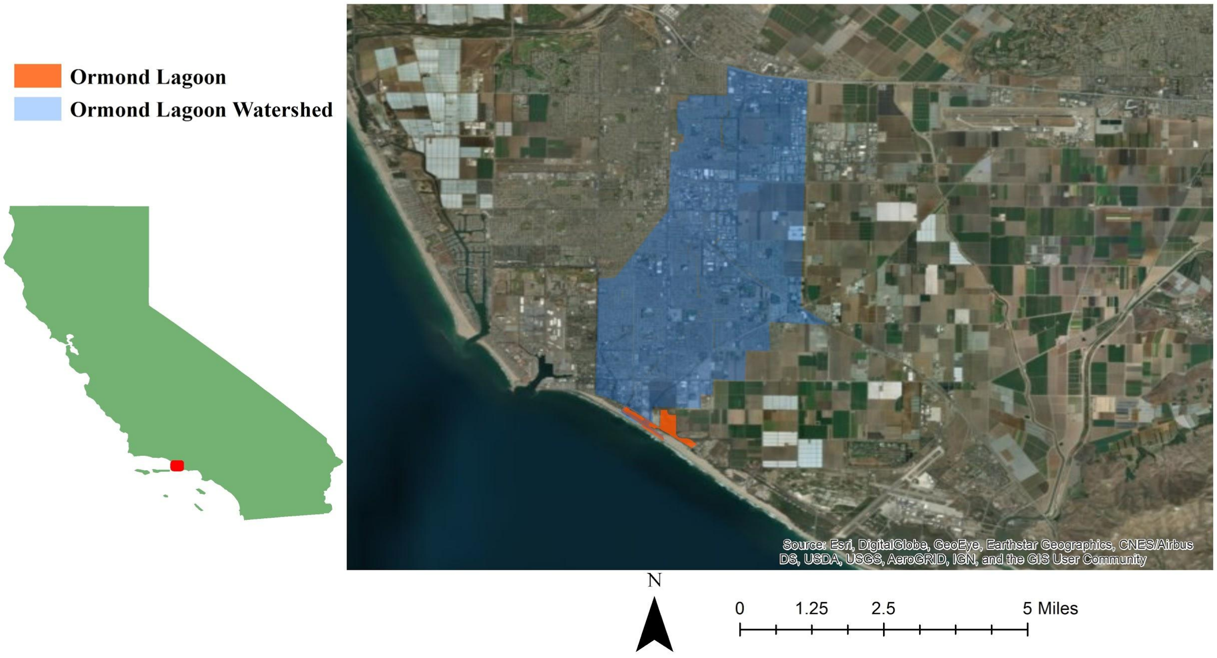


Figure 3.1. Location of Ormond Lagoon, California.

3.1.2 Fish Kill Events

Ormond Lagoon is fed by channelized drains that can bring runoff, sediments, and pollution from surrounding areas into the lagoon. The Oxnard Industrial Drain, the J-Street Drain, and the Hueneme Drain receive a mixture of agricultural, industrial, and residential runoff, and flow directly into Ormond Lagoon. Among the many pollutants carried in this runoff are pyrethroids. The California Department of Fish and Wildlife (CDFW) has investigated multiple fish kill events related to bifenthrin in the drainage area. On July 20, 2015 USFWS reported a fish kill in the J-Street Drain. While no TWG were directly collected from this event, it is possible they were part of the fish kill but were not observed because of their small size, transparent brown color, and lack of swim bladder. Included in their loss report is the following description of necropsy pathology:

> "Bifenthrin was detected in each gill and liver sample….While it is not possible to determine the concentration of bifenthrin in the water at the time of the fish kill, due to insufficient time for the contaminant to reach equilibrium in the fish and water, the presence of a very highly toxic material in both the gills and liver of fish that died acute death makes it very likely that this loss was caused by exposure to bifenthrin. The presence of 4 other pyrethroids in the gills of the sculpin is likely due to the persistence of pyrethroids in sediment and the sculpin being a benthic feeder." (CDFW, 2015)

Similar events in the watershed occurred in the years following, with another major fish kill occurring in 2016 (Personal Communication, Jenny Marek). There is currently no system in place to measure the highly toxic aquatic pyrethroid pulses that occur during precipitation events in the watershed. Additionally, because of high sorption capacity of pyrethroids to organic carbon, the ecological risk is not limited to the acute peaks in aquatic concentrations, but also chronic toxicity particularly in the benthic region. The bioavailability of sorbed pyrethroids is unquantified, but benthic feeders such as the aforementioned sculpin and TWG are likely to have greater exposure to pyrethroids than species feeding and spawning in the water column.

3.2 Pyrethroid Uses and Properties

Pyrethroids are an extensive class of synthetic insecticides derived from the naturally occurring pyrethrin, an insecticide found in the Chrysanthemum flowers (Melendez, 2012). There are dozens of pyrethroid derivatives that make up over 3,500 registered products that are heavily used in the commercial, agricultural, and residential sectors (Melendez, 2012). This wide range of products, each with their own distribution of uses, efficient regulation and study is difficult. A pyrethroid of particular concern is bifenthrin, due to rapid increases in use as well as the most widespread detections in the environment. Bifenthrin is synthesized for the control of a wide range of foliar insects, subterranean termites, and wood infesting insects (Dong, 1995). There are over 600 products containing bifenthrin available in the US, including sprays, granules, and aerosols (Dong, 1995). In 2015, the top pyrethroids applied in Coastal California include bifenthrin, permethrin, and beta-cyfluthrin (Figure 3.2).

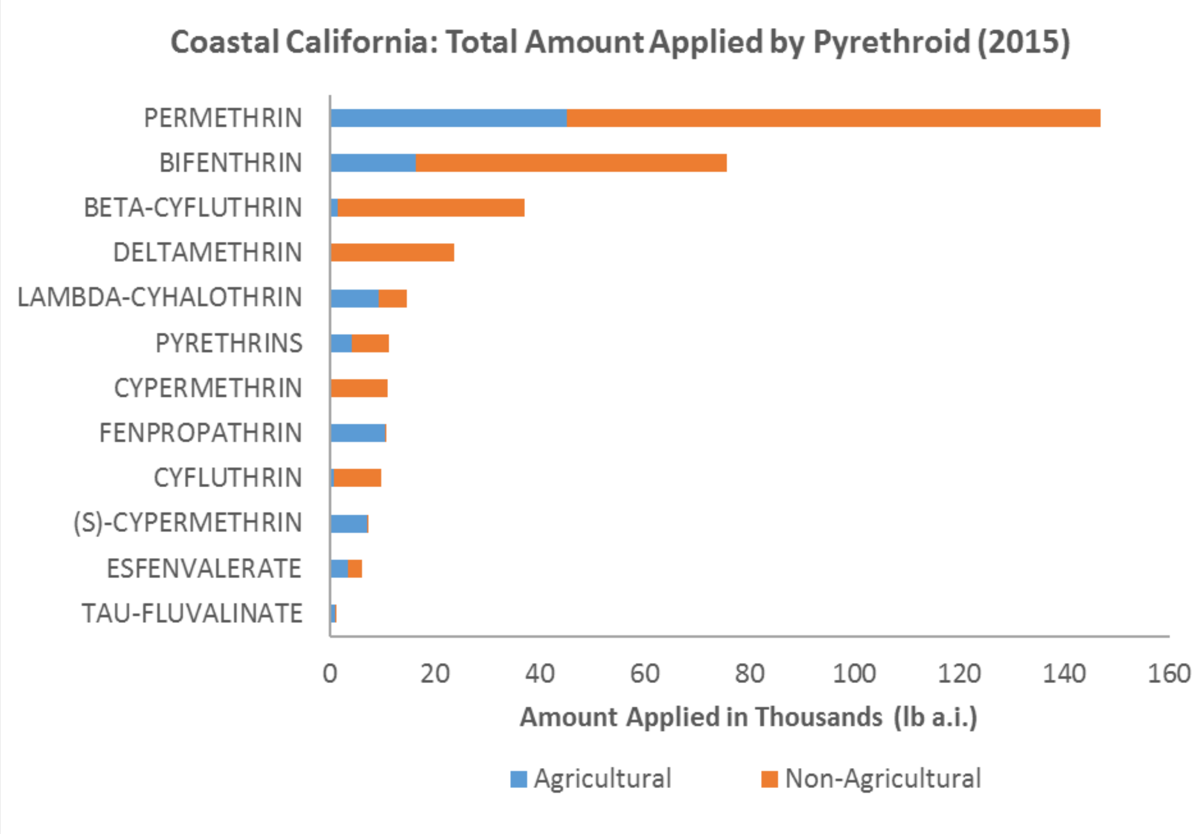


Figure 3.2. *Top pyrethroids used in the coastal counties of California during 2015. Non-agricultural pesticide use only considers applications by licensed pest control operators. Data provided by the California Department of Pesticide and Regulations Pesticide Use Reports.*

The coastal counties of California have a myriad of land uses including intensive agricultural, open spaces, and urban development, each with differing pyrethroid use patterns. This project scope includes pyrethroid use only in coastal California, since TWG are only found in coastal estuaries. While the Central Valley is a heavy user of pyrethroids, its unique temporal use patterns would confound the pyrethroid use statistics relevant to the TWG. For this project, all coastal California counties that support a TWG habitat were analyzed with their respective pyrethroid uses (Figure 3.3). The predominant source of pyrethroids, whether it be agricultural or non-agricultural, is county- dependent. For example, Ventura County supplies one third of California's annual strawberry production (Office of Agricultural Commissioner, 2016). Additionally, there are 116 licensed commercial pest control businesses in the county (SPCB, 2018).

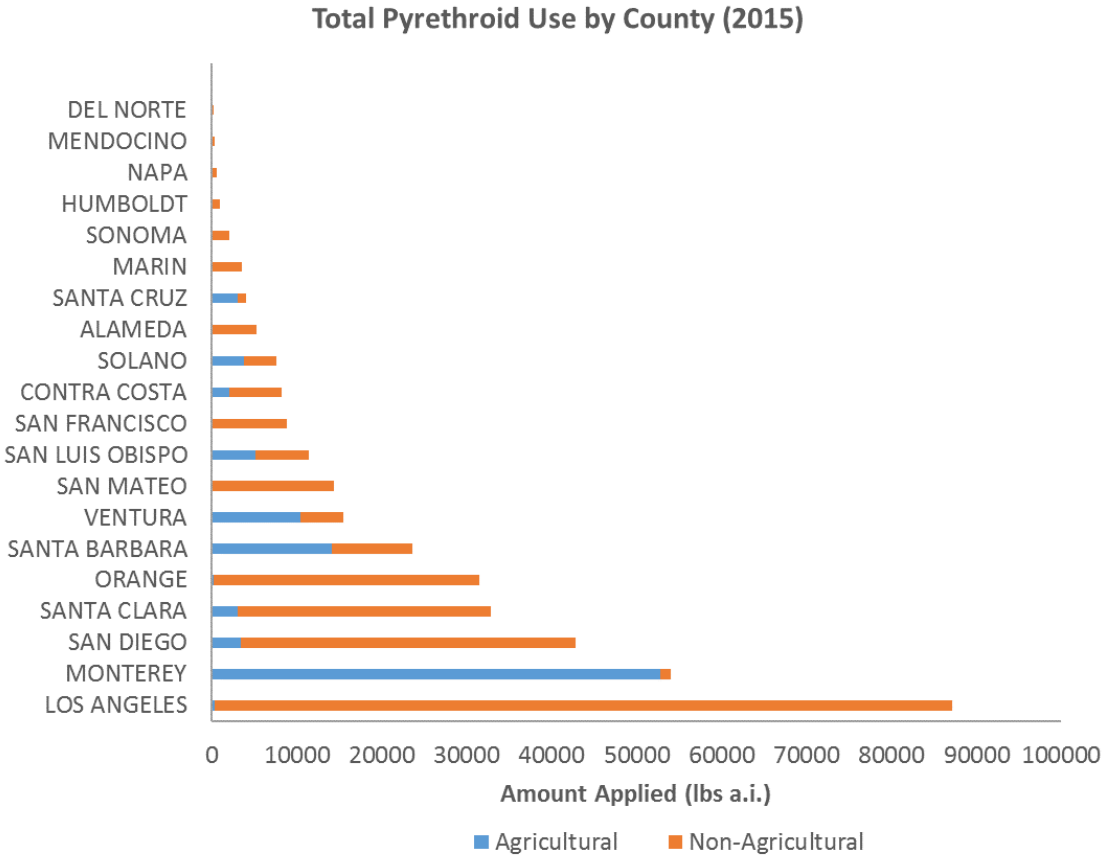


Figure 3.3. *Total pounds of pyrethroids applied in the coastal counties of California in 2015. Non-agricultural pesticide use only considers applications by licensed pest control operators. All data was provided by California Department of Pesticide Regulation Pesticide Use Reports.*

3.2.1 Chemical Properties

The environmental fate and transport of pyrethroids can be characterized by a strong affinity for soil and other organic material as well as considerable environmental persistence (Appendix A). Pyrethrins and synthetic pyrethroids are highly hydrophobic compounds that have an extremely low solubility in water. Pyrethroids have a high affinity to sorb to organic carbon in the soil, sediment, water, and dissolved particulate matter. This allows pyrethrins and synthetic pyrethroids to easily bind to sediment and be transported during erosion, irrigation, or runoff events. Synthetic pyrethroids are also moderately resistant to degradation. For example, the aerobic half-life values measured for bifenthrin is generally greater than 100 days (Fecko, 1999). The bioconcentration factor (BCF) for bifenthrin is high, therefore the compound is likely to bioaccumulate in aquatic species. Additionally, pyrethroids have a low volatilization potential and short atmospheric half-life. These properties allow pyrethroids to accumulate in sediments, which can lead to toxic conditions for benthic species such as the TWG.

3.2.2 Pyrethroid Use Patterns

CDPR is the primary agency for tracking and regulating the use of pyrethroids. They divide pest control activities into agricultural and non-agricultural pesticide use. However, non-agricultural pesticide use only considers applications by licensed pest control operators and is grouped into countywide monthly sums, resulting in spatial resolution that is difficult to work with on a local scale. Therefore, a third category, personal use, is also considered.

3.2.2.1 Agricultural Use

Pyrethroids are used on a wide variety of crops for invertebrate pest control. Agricultural use accounts for 28% of total pyrethroid use for the coastal counties of California. The most pyrethroid intensive crops in 2015 were lettuce and strawberries (Figure 3.4). On the Central Coast and Ventura County, bifenthrin is used heavily for strawberry production to control lygus bugs (*Lygus hesperus),* two spotted spider mites (*Tetranychus urticae*), greenhouse whiteflies (*Trialeurodes vaporariorum*), and western flower thrips (*Frankliniella occidentalis*). These are considered important arthropod pests to strawberries and can cause significant yield losses (UC IPM, 2017).

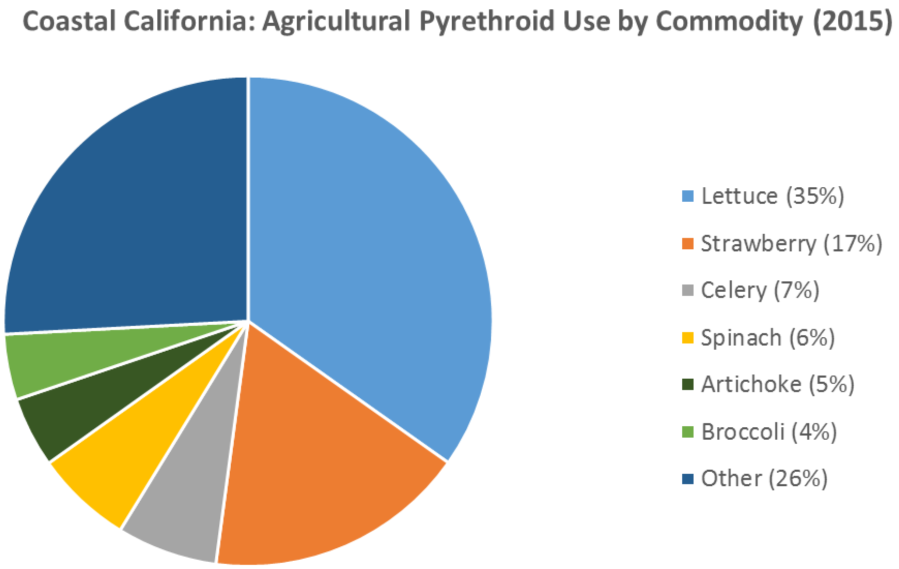


Figure 3.4. *The most pyrethroid intensive crops in coastal counties of California by total pounds applied during 2015. All data was provided by California Department of Pesticide Regulation Pesticide Use Reports.*

3.2.2.2 Non-Agricultural Use

Non-agricultural uses include structural pest control, institutional and industrial control, landscape maintenance, and right of ways applications by licensed pest control operators. Overall, non-agricultural professional use accounts for 72% of total pyrethroid applications in the coastal counties of California. By far, the top use in California during 2015 was for structural pest control, largely driven by the commercial pest management industries' treatment of ants (Figure 3.5). In California, 65-80% of all pest services provided by Pest Management Professionals (PMPs) dealt with ant control, of these treatments 85% were to deal with the Argentine ant (*Linepithema humile*; Field et al., 2007).

A pesticide use survey of PMPs in Southern California conducted in 2010 found that 8 out of 11 top pesticides used for commercial pest treatment were pyrethroids. Bifenthrin was the most popular, used 75% of the time, while permethrin had the most pounds applied of any single active ingredient. The survey also found that the majority of applications were of liquid products applied in perimeter or spot treatments outdoors (CDPR, 2009).

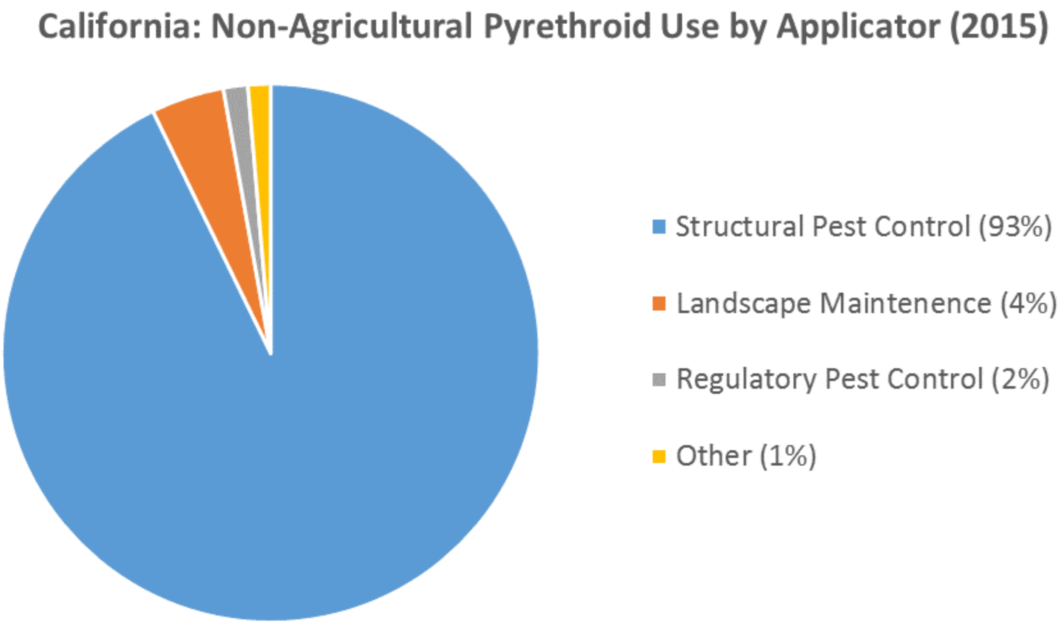


Figure 3.5. *Percentage of non-agricultural pyrethroid use by total pounds applied in 2015. All data was provided by California Department of Pesticide Regulation Pesticide Use Reports.*

3.2.2.3 Personal Use

Pyrethroids have become a dominant insecticide sold for residential and personal use. Products such as Ortho Home Defense or Bug-B-Gon are granted unrestricted residential use due to lower concentrations of bifenthrin (0.05% and 0.3%, respectively) and are sold at common stores such as Home Depot (Personal Observation, 2018). Although at a lower concentration, these products can still have detrimental environmental effects. Weston et al. 2005 estimated that Ortho Bug-B-Gon applied at the recommended rate on a 100 m^2 lawn would need a dilution with at least 2.2 million liters of water before the concentration would no longer be at toxic levels to sensitive aquatic species. However, there is a dearth of data on total use and application rate because pesticide use by homeowners is not documented by CDPR. Previous studies conducted in 2010 using pesticide sales data found that homeowner personal use is estimated to be around 20% of total non-agricultural urban use (TDC, 2010). Additionally, a CDPR survey found that of insecticides sold in retail stores in California, 46% were pyrethroids and bifenthrin, permethrin, and lambda-cyhalothrin were the most popular active ingredients (Osienki et al., 2010).

3.2.2.4 Seasonality of Pyrethroid Use

The seasonality of pyrethroid use will have important implications on the risk to aquatic species. Because of the high rate of pyrethroid presence throughout the state and their widespread uses, the seasonality of pyrethroid use is highly variable. It is also important to note that there has never been an extensive study on the seasonality on personal pyrethroid use in coastal California. While exploring the seasonality of total pyrethroids and bifenthrin in 2015, it is apparent that an overall increase in use during the summer months largely driven by agricultural use but non-agricultural use remains the same (Figure 3.6). Interestingly, the seasonality of bifenthrin for the coast of California has a large peak in non-agricultural use in December. Overall, each county and chemical have unique seasonality based on type of pests and weather conditions found in the area. These relationships will be explored further in the discussion section.

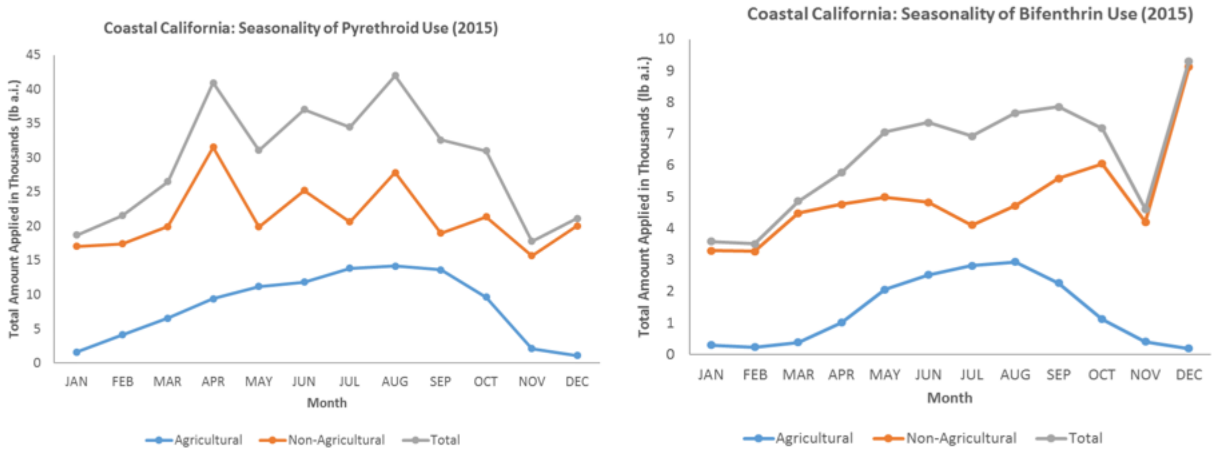


Figure 3.6. *The seasonality of total pyrethroid and bifenthrin use for the coast of California in 2015. Non-agricultural pesticide use only considers applications by licensed pest control operators. Data provided by the California Department of Pesticide and Regulations Pesticide Use Reports.*

3.2.3 Ventura County Statistics

To further study the dynamics of pesticide use, Ventura County and OLW were used as a case studies.

3.2.3.1 Agricultural Use

Ventura County is ranked as the 9th highest county in California in total pesticide use (CDPR, 2015). Ventura County applied over 15,000 pounds of pyrethroids in 2015, with bifenthrin being the most commonly applied pyrethroid (6,048 pounds; Figure 3.7).

Bifenthrin is used fairly evenly between the non-agricultural (56%) and agricultural (44%) sectors (Figure 3.8). The higher percentage of agricultural use relative to the other coastal counties of California is largely attributable to Ventura's extensive strawberry production (26.7%; Figure 3.9). Because of this duality in use, discovering the origins of bifenthrin contamination in sediments and water of Ventura County is difficult. However, in the production of strawberry, fenpropathrin is also applied with bifenthrin to limit pest resistance to a single pyrethroid (UC IPM, 2017). This accounts for high fenpropathrin use for the agricultural sector in Ventura County. This relationship allows for fenpropathrin to serve as an indicator for agricultural origin of bifenthrin contamination.

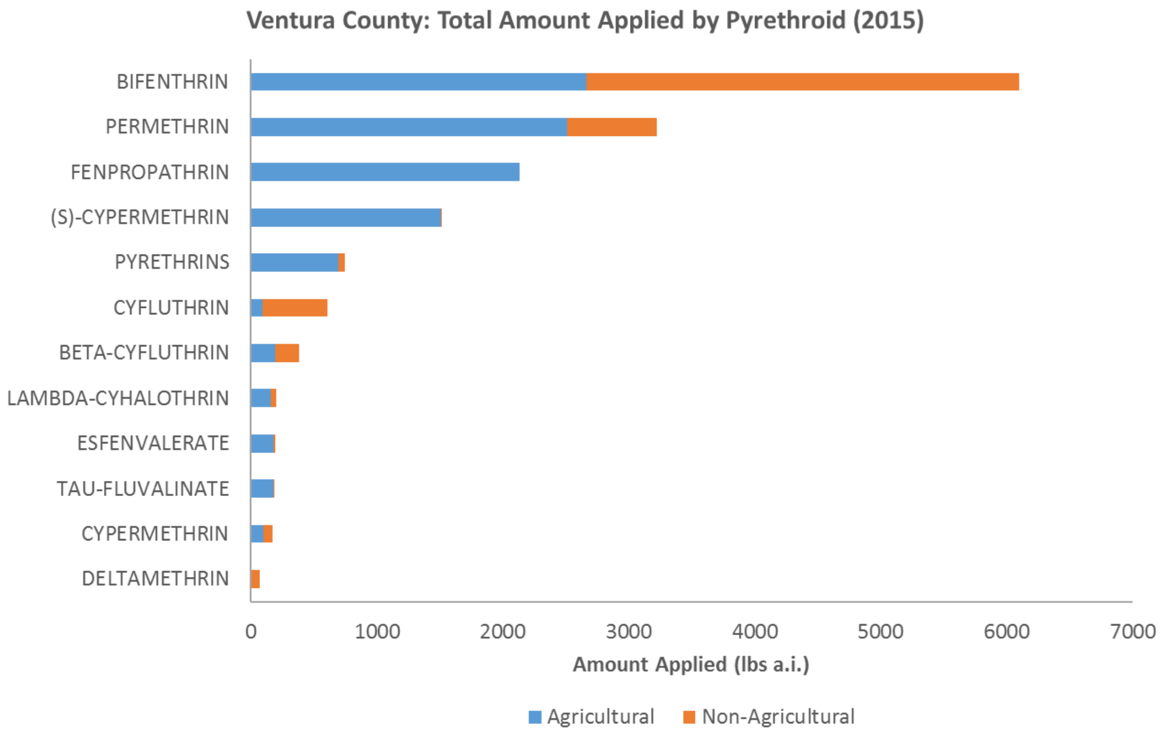


Figure 3.7. *Top pyrethroids used in the Ventura County in 2015. Non-agricultural pesticide use only considers applications by licensed pest control operators. Data provided by CDPR PUR reports.*

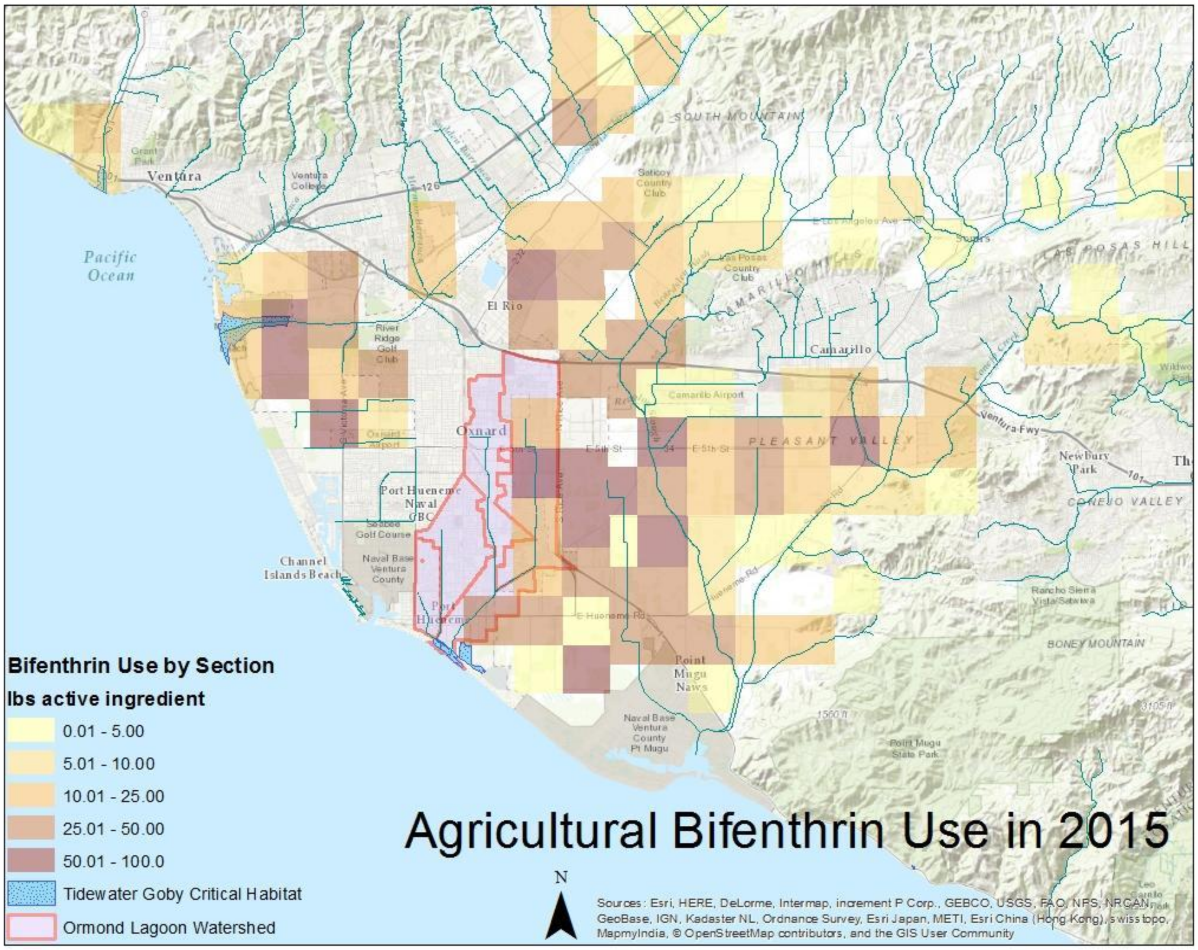


Figure 3.8. *Agricultural bifenthrin use around OLW. The PUR reports were aggregated to the Public Land Survey Section Level.*

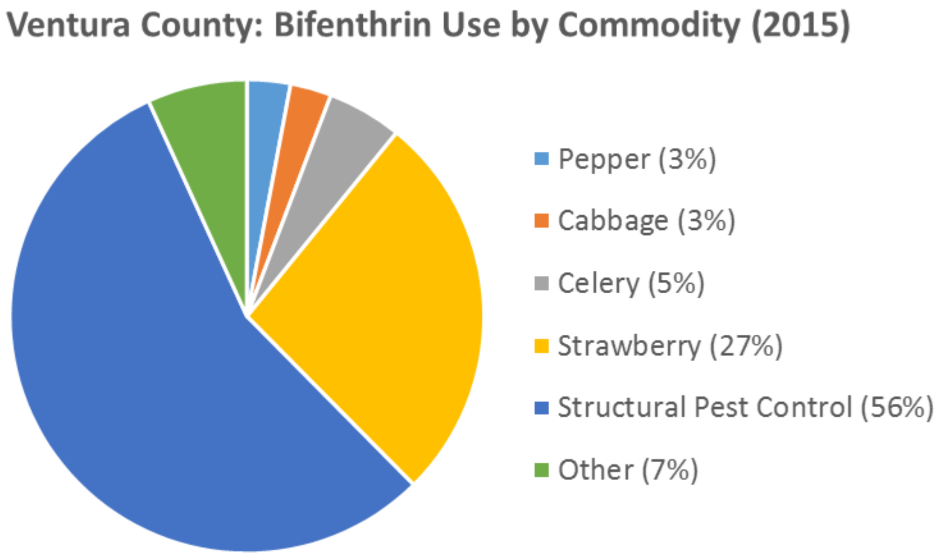


Figure 3.9. *Percentage of total pounds of bifenthrin applied in Ventura County in 2015. All data was provided by California Department of Pesticide Regulation Pesticide Use Reports.*

3.2.3.2 Non-Agricultural Use

The majority of total bifenthrin use in Ventura was for structural pest control (55%; Figure 3.9). Additionally, bifenthrin use for non-agricultural pest control has been increasing over the past year, partially due to the decline in organophosphate pesticide application (Figure 3.10). Increased use of bifenthrin in the non-agricultural sector is particularly concerning because of the timing of the applications. In 2015, Ventura County experienced two peaks in bifenthrin use (Figure 3.11). The first peak in May was driven by agricultural production, while the second peak in October was driven by structural pest control. This timing occurs right before the wet season of Ventura, where the majority of the rainfall and runoff occurs. Therefore, further research is needed to establish the cause of this peak and ways to reduce its effect on coastal waters.

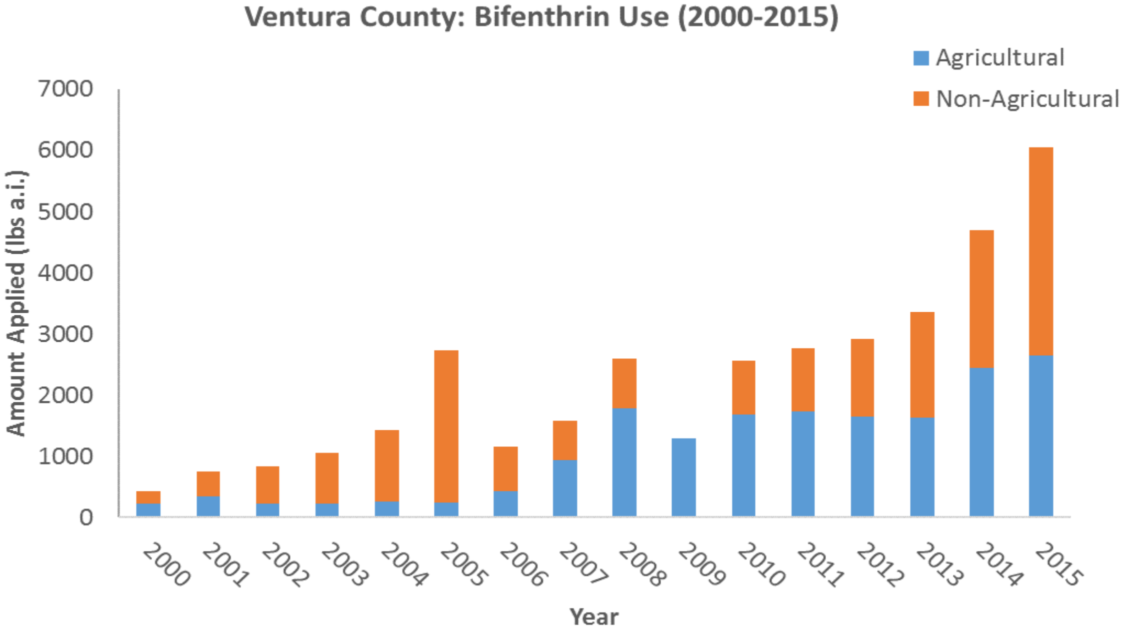


Figure 3.10. *Bifenthrin use, split into non-agricultural and agricultural uses, for Ventura County from 2000- 2015. Non-agricultural pesticide use only considers applications by licensed pest control operators. All data was provided by California Department of Pesticides Regulations Pesticide Use Reports.*

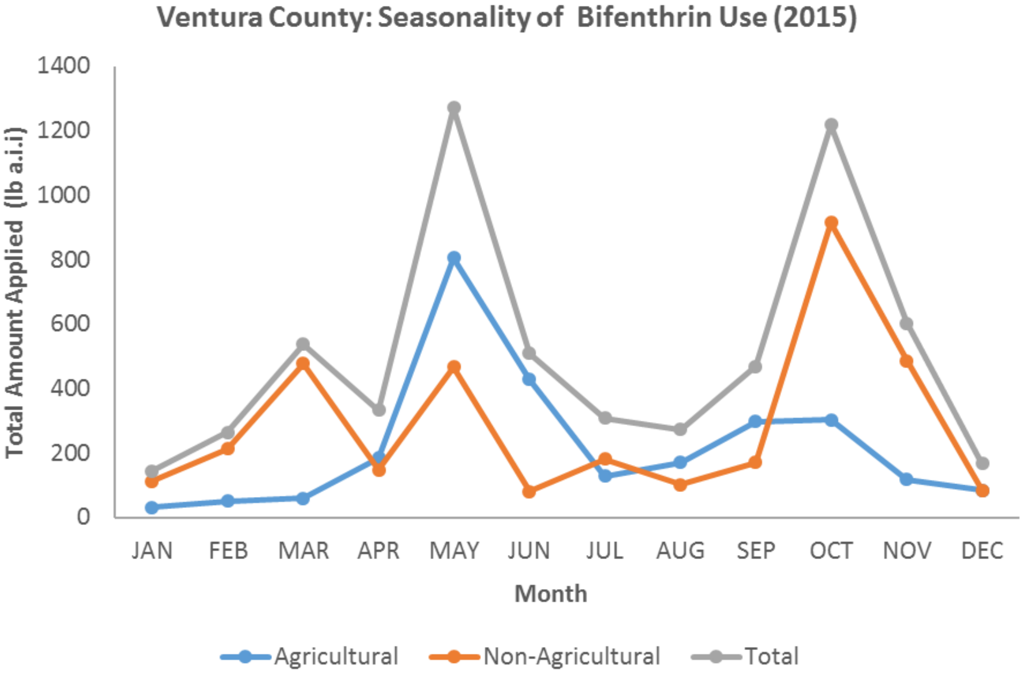


Figure 3.11. *The seasonality of bifenthrin use for the Ventura during 2015. Non-agricultural pesticide use only considers applications by licensed pest control operators. All data was provided by California Department of Pesticide Regulation Pesticide Use Reports.*

3.2.4 *Current Regulations*

There are many regulations that govern the use of pyrethroid pesticides. Some regulations have been developed specifically for pyrethroids, as is the case with the 2012 California surface water regulations regarding urban use of pyrethroids. Other regulations more generally apply to the use of pesticides and are mandated from a number of federal and state agencies. In both urban and agricultural settings, regulations try to reduce the risk of pyrethroids to human and environmental health.

In certain regions and watersheds of California, regulators are trying to reduce pyrethroid contamination through the use of Total Maximum Daily Loads (TMDLs). State waterboards in different regions have developed these TMDLs to limit the damage in specific waterways and prevent adversely affecting any “beneficial use” of the waterway (Strauss, 2011). The EPA in California set a target in the Oxnard Drain 3 to limit the chronic levels of bifenthrin to 0.0006 ug/L as part of an amended consent decree. In the Oxnard Drain there is no current regulation regarding pyrethroid concentrations in sediment, or in fish tissue, as there is for other chemicals. Other regulatory agencies have also included pyrethroids in TMDL regulations, notably in the Salinas watershed where sediment toxicity is included. These areas still have high levels of pyrethroid use, making them susceptible to toxicity from runoff, especially in the areas with flashy rain events that lead to high peak concentrations, but low average levels of pyrethroids.

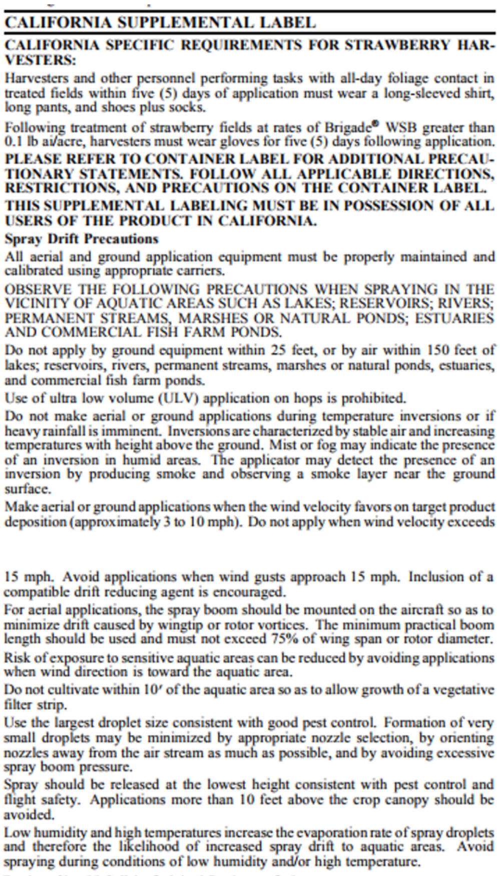
3.2.5 *Urban Regulations*

California implemented new regulations for urban application of pyrethroids in 2012. After seeing pyrethroid use increase in California, CDPR started a process to reevaluate a number of pyrethroid pesticides in 2006. In 2012, after scientific studies explored the risks and transport of pyrethroids, CDPR announced new regulations regarding 17 pyrethroids that would target outdoor residential use by commercial applicators (Prichard, 2014). These regulations required application types that would limit the amount of pyrethroids applied on impervious surfaces to pin-streams, crack and crevice treatment, or spot treatment only. The new regulations also prohibited spraying pyrethroids prior to rain events or near any standing water (Appendix B). CDPR believes that these regulations targeting urban pyrethroid use would be the most effective way to limit pyrethroid contamination of surface water (Prichard, 2014). However, sampling performed by the Surface Water Ambient Monitoring Program (SWAMP) has not yet seen a decrease in concentrations in urban watersheds since 2012 (Phillips, 2016). At the time of that declaration, no further regulations for urban or agricultural uses were planned.

3.2.6 *Agricultural Regulations*

Agriculturally, pyrethroids fall under management from a number of federal and state agencies. The EPA, USDA, and CDPR all play a role in setting regulations for the type of pesticides that can be applied in agricultural settings. Currently the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) provides framework for the sales and listing of pesticides for use in agriculture, and also allows for cooperative efforts between the federal agencies like the EPA and states, in this case CDPR, to work collectively on pesticide management.

The EPA is responsible for determining which products warrant special attention and restricted use. Currently there are over 300 products listed as Restricted Use Products (RUPs) that contain one or more pyrethroids (EPA, 2017). Regulations over RUPs require listing, labeling, and sales of listed pesticides to certified and trained buyer. In California, workers who apply pesticides must be over 18 years old, and must be certified applicators, to promote proper application and safety instructions for the specific pesticide and crop (3 CCR section 6764). Applicators using pyrethroids on or near food crops must also adhere to USDA regulations stipulating testing and the amount of pesticides that can be present on food. Product specific regulations for pyrethroids are explained on product labels. These restrictions often include environmental factors such as prohibiting application near water bodies, before imminent rain events, and if wind velocity exceeds a given speed (Figure 3.12).



CALIFORNIA SUPPLEMENTAL LABEL

CALIFORNIA SPECIFIC REQUIREMENTS FOR STRAWBERRY HARVESTERS:

Harvesters and other personnel performing tasks with all-day foliage contact in treated fields within five (5) days of application must wear a long-sleeved shirt, long pants, and shoes plus socks.

Following treatment of strawberry fields at rates of Brigade® WSB greater than 0.1 lb ai/acre, harvesters must wear gloves for five (5) days following application.

PLEASE REFER TO CONTAINER LABEL FOR ADDITIONAL PRECAUTIONARY STATEMENTS. FOLLOW ALL APPLICABLE DIRECTIONS, RESTRICTIONS, AND PRECAUTIONS ON THE CONTAINER LABEL.

THIS SUPPLEMENTAL LABELING MUST BE IN POSSESSION OF ALL USERS OF THE PRODUCT IN CALIFORNIA.

Spray Drift Precautions

All aerial and ground application equipment must be properly maintained and calibrated using appropriate carriers.

OBSERVE THE FOLLOWING PRECAUTIONS WHEN SPRAYING IN THE VICINITY OF AQUATIC AREAS SUCH AS LAKES; RESERVOIRS; RIVERS; PERMANENT STREAMS, MARSHES OR NATURAL PONDS; ESTUARIES AND COMMERCIAL FISH FARM PONDS.

Do not apply by ground equipment within 25 feet, or by air within 150 feet of lakes; reservoirs, rivers, permanent streams, marshes or natural ponds, estuaries, and commercial fish farm ponds.

Use of ultra low volume (ULV) application on hops is prohibited.

Do not make aerial or ground applications during temperature inversions or if heavy rainfall is imminent. Inversions are characterized by stable air and increasing temperatures with height above the ground. Mist or fog may indicate the presence of an inversion in humid areas. The applicator may detect the presence of an inversion by producing smoke and observing a smoke layer near the ground surface.

Make aerial or ground applications when the wind velocity favors on target product deposition (approximately 3 to 10 mph). Do not apply when wind velocity exceeds 15 mph. Avoid applications when wind gusts approach 15 mph. Inclusion of a compatible drift reducing agent is encouraged.

For aerial applications, the spray boom should be mounted on the aircraft so as to minimize drift caused by wingtip or rotor vortices. The minimum practical boom length should be used and must not exceed 75% of wing span or rotor diameter.

Risk of exposure to sensitive aquatic areas can be reduced by avoiding applications when wind direction is toward the aquatic area.

Do not cultivate within 10′ of the aquatic area so as to allow growth of a vegetative filter strip.

Use the largest droplet size consistent with good pest control. Formation of very small droplets may be minimized by appropriate nozzle selection, by orienting nozzles away from the air stream as much as possible, and by avoiding excessive spray boom pressure.

Spray should be released at the lowest height consistent with pest control and flight safety. Applications more than 10 feet above the crop canopy should be avoided.

Low humidity and high temperatures increase the evaporation rate of spray droplets and therefore the likelihood of increased spray drift to aquatic areas. Avoid spraying during conditions of low humidity and/or high temperature.

Figure 3.12. *Example of product specific label for strawberries.*

3.2.7 Detections in the Environment

Due to the ubiquitous and high use of pyrethroids in California, there have been increases in both detections and concentrations in the environment. This trend is mainly found in urban areas, between 2010 and 2013 monitoring by the SWAMP found that the concentrations of pyrethroids doubled in urban waterways (Figure 3.13; Phillips, 2016). Bifenthrin is the most frequently detected pyrethroid in both water and sediment samples due to its increased stability in aquatic environments (Figure 3.14; Weston, 2005; TDC, 2010; Amweg, 2006). The California Stormwater Quality Association (CASQA), in a summary of various monitoring studies for pyrethroids in urban areas, found that bifenthrin was detected in 69% of sediment samples and 64% of water samples.

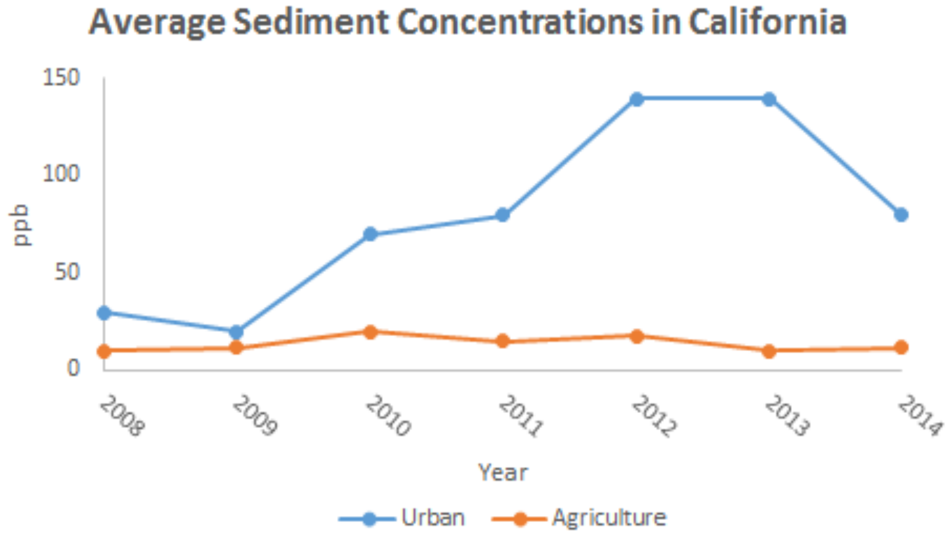
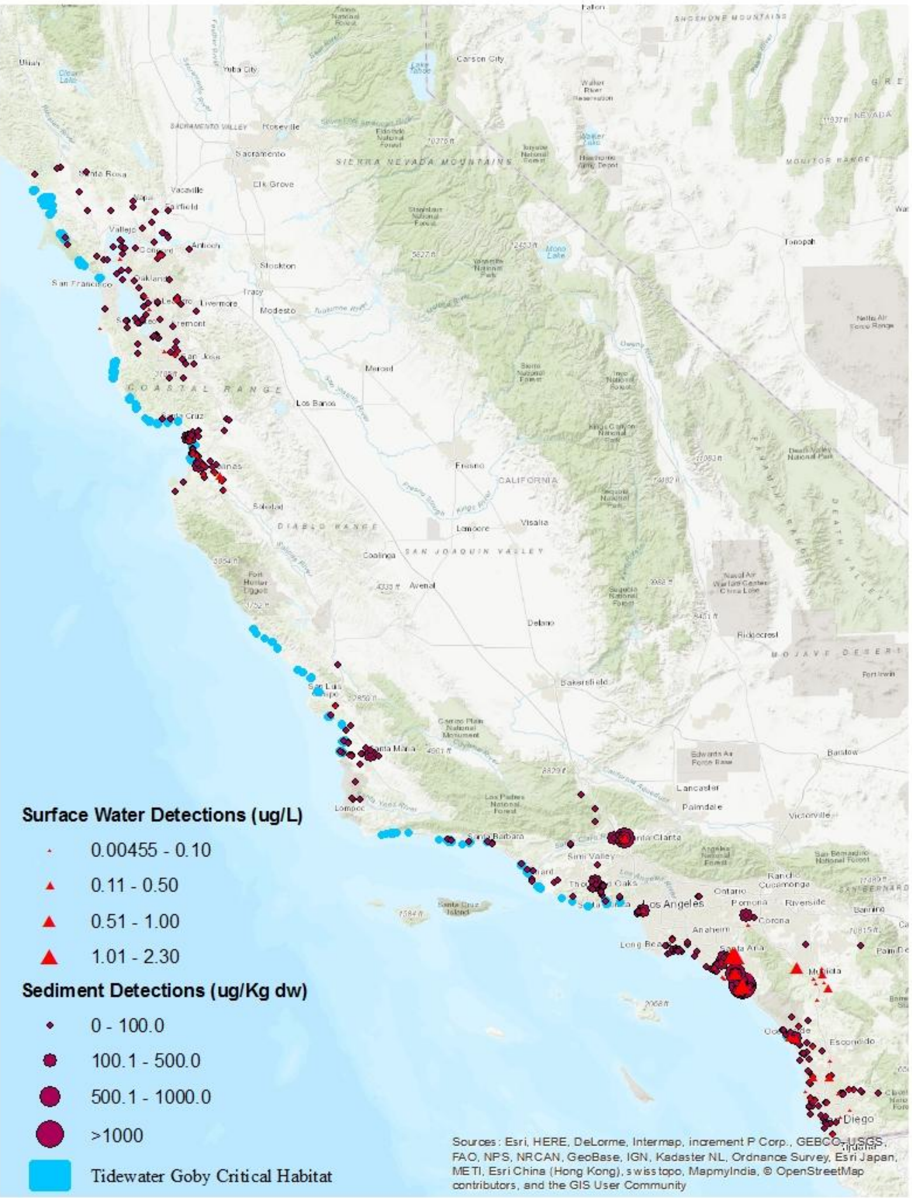


Figure 3.13. *Summary of sediment concentrations (ppb) sampled during the Surface Water Ambient Monitoring. (Source: Phillips, 2016)*



Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Figure 3.14. *Bifenthrin detections in the surface waters (over toxicity threshold for H. Aztecta, 0.00455 ug/L) and sediments in the coastal counties of California. The area north of San Francisco had very few detections so was excluded. Sediment detections are in micrograms/kilogram dry weight. All data provided by the California Environmental Data Exchange Network and CDPR testing.*

Pyrethroids are also often found at concentrations toxic to sensitive aquatic invertebrates. *H. azteca,* a crustacean found throughout North America, has become a standard for environmental toxicity testing for aquatic invertebrates. The CASQA study concluded that "under average conditions in urban waterways in California, pyrethroids are typically present in sediments at levels toxic to sensitive aquatic macroinvertebrates such as *Hyalella azteca"* (Ruby, 2013). Additionally, in studies conducted in Sacramento, CA, nearly all sediment samples tested were considered toxic to sensitive aquatic invertebrates, and bifenthrin was considered the primary contributor to the toxicity (Amweg, 2006; Weston et al., 2005). These studies focused on creeks draining from residential areas indicative of many areas in California. The authors indicated that structural pest control and homeowner use of lawn care were the primary sources of the pesticides (Weston et al., 2005).

3.2.7.1 Agricultural

Pyrethroid concentrations in agricultural areas remain lower than urban watersheds in the 5-year trend review of California's watersheds by SWAMP. However, bifenthrin application slightly increased in some agricultural watersheds (Phillips, 2016). Studies conducted by the CDPR and California Department of Food and Agriculture (CDFA) indicate that while pyrethroid use is not as widespread in agricultural watersheds, some areas still have significant levels of pyrethroids detected. In agricultural regions in California (Salinas River, Sacramento Valley, Northern San Joaquin Valley, and Imperial Valley), CDPR found that 60% of samples had detectable pyrethroids and 30% of sediment samples were toxic to benthic invertebrates. The Salinas River region had the highest detection frequency of 85% (CDPR, 2006).

3.2.7.2 Ventura County

The trends found throughout California are also seen in Ventura County. Pyrethroids were detected in 74% of water samples and 100% of sediment samples taken from the Santa Clara River and Calleguas Creek watersheds. Bifenthrin was the most widely detected pyrethroid, but permethrin was detected at the highest concentrations. This study also found that concentrations were significantly correlated with suspended solids (SS) in the water body (Delgado-Moreno et al., 2011). Ventura County Agricultural Irrigated Lands Group (VCAILG) is responsible for the compliance and monitoring of the irrigated farms of Ventura County's conditional waiver. They conduct annual monitoring of agricultural drainage sites throughout Ventura County for pesticide contamination. In their Water Quality Management Plan (WQMP) of 2017, they found 15 wet weather and 3 dry weather exceedances in bifenthrin concentrations and detection occurred at all 12 monitoring sites (VCAILG, 2017b).

3.2.7.3 Ormond Lagoon

As part of the TMDL program for sediment toxicity, annual monitoring is performed at Oxnard Drain 3, a canal parallel to shore carrying water from agricultural drains and Ormond Lagoon. The monitoring concluded that sediment toxicity is caused by bifenthrin and chlorpyrifos. In 2010, bifenthrin was found in 5 of 15 sediment samples (EPA, 2010).

3.2.7.4 Monitoring Gaps

Due to the chemical properties and reactivity of pyrethroids, long term monitoring for pyrethroid contamination is difficult. Because pyrethroids are carried to surface waters and sediments bound to SS or organic matter during erosion events, the maximum concentration may only occur at pulse and highly variable times associated with storm events. Therefore, to detect the highest concentrations, sampling must be timed with storm events flushing the landscape of accumulated pyrethroids. This requirement makes the accurate and widespread detection of pyrethroids at their most environmentally significant concentrations difficult. For example, as part of the Ventura County Municipal Separate Storm Sewer System National Pollutant Discharge Elimination System (NPDES) permit monitoring, pyrethroids are monitored annually in August and April after storm events. This study found that no significant levels of pyrethroids were detected, but bifenthrin, pendimethalin, permethrin, and dichloran were found (VCWPD, 2012). This study likely missed the greatest environmental concentration of pyrethroids in surface waters and sediments since of the majority of precipitation falls in the winter months, and pyrethroids would have already been flushed out from the landscape. Additionally, the low solubility and high toxicity of pyrethroids makes detections in the parts per trillion level (ppt) environmentally significant. Many studies are performed with analytical detection limits that are not low enough to detect pyrethroids in environmentally important concentrations, and regular monitoring is not conducted due to the need of expensive and accurate instruments to detect such low concentrations. Commercial analytical methods that can reliably detect pyrethroids are not currently available, making the equipment required to detect pyrethroids at meaningful levels difficult for many organizations to attain.

3.3 Tidewater Goby

The tidewater goby (*Eucyclogobius newberryi* and *Eucyclogobius kristinae*) is a small (~50 mm long), elongated, olive-brown fish, living endemically in coastal lagoons, creeks, and marshes of California (Miller and Lea, 1972; Swenson, 1999; Swift et al., 1989). With a lifespan of about one year, the TWG has two peaks of spawning which happen in early spring and late summer (Swift et al., 1989). The species has a reverse sexual behavior, as female TWG compete for breeding with males, and males are responsible for caring for fertilized eggs (Swenson, 1999). TWG is also characterized as having a benthic lifestyle, feeding on benthic invertebrates, and burrowing in the sand during spawning to make vertical nests for their eggs. The optimal diet of TWG consists of ostracods, chironomid larvae, and gammarid amphipod (*Corophium spinicorne*). Other preys include polychaetes, oligochaetes, isopods, gammarid amphipod (*Eogammarus ramellus*), copepods, mysids, and invertebrate eggs (Swenson, 1997).

The TWG is distributed in both northern and southern localities in California. It has long been defined as *Eucyclogobius newberryi* under genus *Eucyclogobius*, until a recent study isolated TWG in the southern localities from northern populations in taxonomy and determined the southern species as *Eucyclobius kristinae* (Swift et al., 2016). This project covers research on both the northern and southern species. Habitats of TWG are confined to major stream drainages where the topographic and hydrological features are conducive to the formation of sandy beaches (USFWS, 2005). TWG are subject to local extirpation but can recolonize habitats with some frequency following large storms that flush them out of their immediate habitat, which suggest the species is sensitive to local climate and hydrological changes.

The TWG is ecologically valuable as a secondary consumer in natural environments, whose behavior may alter the population and structure of other organisms, especially their preys and predators. USFWS listed the TWG as endangered in 1994 after a considerable decline of its population and extirpation at a number of its formerly occupied sites (USFWS, 1994). Subsequently, a 5-year Recovery Plan was implemented to ensure the sustainability of TWG. Since the northern species (*Eucyclogobius newberryi*) had a successful recovery, USFWS has been considering downlisting the northern species from “endangered” to “threatened” (USFWS, 2014). However, more efforts are needed to recover populations of the southern species (*Eucyclogobius kristinae*). Currently, a metapopulation viability analysis (MVA) is being developed by researchers from the University of California, Los Angeles to evaluate the viability of TWG. By identifying habitat characteristics and local anthropogenic stressors, MVA can help to predict seasonal extinction and colonization behaviors of TWG (Spies, 2016). The result from MVA will contribute substantially to determine the future action from USFWS towards the conservation of TWG. To inform a MVA, more research is required to determine natural or anthropogenic stressors that may influence the TWG population. Traditional survival stresses on TWG include habitat loss, environmental properties change, disease, predation, competition with exotic species, and exploitation. In addition to these stresses, a new potential threat on the TWG has been found from increasing pesticide use in agricultural and urban lands.

3.3.1 Pyrethroid Toxicity

Potential impacts of pyrethroid toxicity on the TWG were broken into two categories: direct and indirect. The three most common pyrethroids (bifenthrin, permethrin, and fenpropathrin) applied in Ventura County, were assessed to analyze both acute and chronic effects on selected fishes and invertebrates. Since the acute toxic effects of pyrethroids on TWG have not been tested, we assessed sheepshead minnow (*Cyprinodon variegatus*), fathead minnow (*Pimephales promelas*), and bluegill sunfish (*Lepomis macrochirus*) as potential surrogates. We also analyzed toxicity data from *H. Azteca,* an invertebrate that TWG prey on, in order to explain indirect impacts of pyrethroids. Additionally, information on other fish and invertebrates was also provided to discuss broader effects of pyrethroids on aquatic species. All toxicity values used in the sections below can be found in Appendix C.

3.3.1.1 Direct toxicity

Various fish species were sorted by class and order to identify the most comparable species to TWG for direct toxicity from pyrethroids (Appendix C). Sheepshead minnow, fathead minnow, and BS are among the fish species that are relatively well-studied in terms of direct toxicity from pyrethroids and are most comparable to the TWG based on taxonomy and ecology. Sheepshead minnow and the TWG have several similarities, including size, diet and life habits, such as burrowing in the sand. However, sheephead populations are primarily found in Texas (Nico and Fuller, 2018), which indicates this species has little overlap with TWG habitats. BS is present in coastal California (Pam and Cannister, 2018) and shares a similar diet and reproductive system as TWG (Barkoh and Timothy, 1987; Swenson, 1996; Santucci and David, 2003; Swift et al., 1989). Since the adult BS is nearly 6 times the size of TWG, BS fry was determined to be a more appropriate surrogate (Cargnelli and Mart, 1996; Miller and Lea 1972). The fathead minnow is around the same size as TWG (Orlando et al., 2004); however, BS is closer in genetic relation to TWG.

3.3.1.2 Acute lethal dose

Lethal Concentration$_{50}$ (LC), the concentration expected to kill 50% of the population of a given species, is used to compare the toxicity of different pyrethroids. LC$_{50}$ values of bifenthrin for aquatic fish range from 0.21 to 18.65 µg/L (USDA Forest Service, 2015; Drenner et al., 1993; Fojut et al., 2012; Harper et al., 2008). In general, the acute toxicity thresholds of permethrin to observed fish species is lower than the thresholds of bifenthrin, except in sheepshead minnow, which is more sensitive to permethrin. For sheepshead minnow, fenpropathrin is the most toxic among the three pyrethroids examined. However, the acute toxicity of fenpropathrin to BS is the lowest.

LC$_{50}$ values are often influenced by the duration of exposure. The LC$_{50}$ of permethrin for rainbow trout increased from 6.43 to 25.8 µg/L when duration of exposure was reduced from 96 to 24 hrs, respectively (Kumaraguru and Besmish, 1981; Holcombe et al., 1982). The life stage of tested species can also affect LC$_{50}$. The LC$_{50}$ for bifenthrin of zebrafish embryo is two orders of magnitude larger than the same assessment for zebrafish fry. LC$_{50}$ values of the three pyrethroids to BS fry were compared (Table 3.1). Bifenthrin is more toxic than permethrin to BS fry. There are no studies on fenpropathrin toxicity to BS fry, but for juvenile BS, fenpropathrin is the least toxic of the three pyrethroids.

Table 3.1. *Acute toxicity of three pyrethroids to BS. (Source: USDA Forest Service, 2015; Başer et al., 2003; Kegley et al., 2012)*

Life stage	Duration	Bifenthrin (µg/L)	Permethrin (µg/L)	Fenpropathrin (µg/L)
fry	48 h	0.65	1.8	ND
fry	96 h	0.35	0.9	ND
juvenile	96 h	ND	ND	2.2

ND= Not Determined

3.3.1.3 Sub-lethal effects

Pyrethroids also have sub-lethal effects on aquatic species, some of which were determined by previous studies. For example, during a 24-hr trial exposure to bifenthrin at 0.14 µg/L, larval fathead minnows displayed a reduction in swimming performance, air gulping, movement, and motor skills. When exposed to control water over 24 hours, larval fish recovered and behaved normally (Beggel et al., 2010). In the same study, the no observed effect concentration (NOEC) of bifenthrin was found to be 0.07 µg/L. Similarly, Heather et al. 2008 detected a NOEC of 5 µg/L and calculated a threshold concentration (TC) of 11.18 µg/L for bifenthrin toxicity to adult sheepshead minnow after 96-hr exposure.

3.3.1.4 Chronic effects

Compared to acute exposures, research on long-term toxicity of pyrethroids is not well studied. With the absence of available data on chronic effects, the EPA used a chronic no observed adverse effect concentration (NOAEC) for bifenthrin of 0.004 µg active ingredient/L (a.i./L), which was derived from acute general pyrethroid toxicity on all fish (USDA Forest Service, 2015). The long-term dose values may be overestimations of the toxicity values of many pyrethroids and ignore the differences of chemical exposure responses among species. Hansen et al. 1983 reported a permethrin NOEC of 10 µg/L for sheepshead minnow after 28-day exposure. Although this result was not consist with a LC_{50} of 7.8 µg/L found in other studies, it suggested that chronic NOAEC should be a few orders of magnitude higher than 0.004 µg a.i./L (Appendix C).

3.3.1.5 Indirect toxicity

TWG rely on aquatic invertebrates as major food sources, and aquatic invertebrates are very sensitive to bifenthrin and other pyrethroids. Both short-term and long-term toxicity of pyrethroid on invertebrates affect TWG populations indirectly. This section discusses indirect toxicity of bifenthrin, permethrin, and fenpropathrin to the TWG derived from research on acute and chronic toxicities of aquatic invertebrates in TWG habitats.

3.3.1.6 Acute lethal and sub-lethal effects

Studies showed that *H. azteca* was one of 41 aquatic invertebrates that were most sensitive to bifenthrin (USDA Forest Service, 2015). With an acute half maximal effective concentration (EC_{50}) of 2.91 ng/L and LC_{50} of 4.55 ng/L for bifenthrin, *H. azteca* was much more sensitive than other invertebrates. The toxicity tests for permethrin revealed an LC_{50} of 48.9 ng/L (Brander et al., 2009), indicating a lower toxicity value to *H. azteca.* An LC_{50} of fenpropathrin was not determined in water exposure. However, by comparing sediment-associated LC_{50}, the toxicity of fenpropathrin was found at a level in between bifenthrin and permethrin toxicity values (Table 3.2).

Table 3.2. *LC_{50} of three pyrethroids to H. Azteca. (Source: ECOTOX Database, EPA, 2018; Ding et al., 2011; Amweg et al. 2006)*

Duration	Bifenthrin (µg/L)	Permethrin (µg/L)	Fenpropathrin (µg/L)
Water Column			
96 h	4.55 ng/L	20 ng/L	ND
10 d	1.30 ng/L	48.9 ng/L	ND
Sediment			
10 d	4.5 ng/g dry weight	90.3 ng/g dry weight	24.3 ng/g dry weight
10 d	0.18 µg/g OC	4.88 µg/g OC	1.57 µg/g OC

ND= Not Determined

Since the TWG preys on invertebrates, we summarized the toxicity of bifenthrin, permethrin, and fenopropathin on species commonly found in TWG diets. Although the life stage of materials and duration of exposure varies from study to study, all three pyrethroids were highly toxic to invertebrate species (Table 3.3; Pesticide Action Network, 2006).

Table 3.3. *Acute toxicity of three pyrethroids to TWG prey. (Source: USDA Forest Service, 2015; Pesticide Action Network, 2006)*

Pyrethroid	Species	Duration	LC_{50} (µg /L)
Bifenthrin	*Americamysis bahia*	96 h	0.00397
	Chironomus tentans	10 d	0.4
Permethrin	*Cyria sp.*	48 h	5
	Chironomus decorus	24 h	4.5
	Chironomus riparius	24 h	16.6
	Chironomus tentans	96 h	10.4
Fenpropathrin	*Chironomus tentans*	10 d	0.02

3.3.1.7 Chronic effects

The EPA also reports NOAEC and LOAEC for bifenthrin exposed to several invertebrates authorized for toxicity analysis in EPA protocols (Appendix C). However, long-term NOECs for permethrin and fenpropathrin have not yet been determined for these invertebrates. With a NOAEC of 0.17 ng/L and a LOAEC of 0.34 ng/L, *H. azteca* is the most sensitive species to bifenthrin as determined in the long-term assessments. A threshold target of 0.0006 µg/L (0.6 ng/L) of bifenthrin for OLW was discussed in above sections (VCAILG, 2017b). Even if samples are found below LOAEC, *H. azteca* might still be toxic to these pyrethroids at lower levels.

4 Methods

CDPR Pesticide Use Reports (PUR) data was relied on heavily throughout the project for PWC and geospatial model inputs, pyrethroid use summaries, and BMP recommendations. The primary exclusions from the data are consumer home and garden use, and any institutional uses applied by a non-licensed applicator. The data is updated annually and there is a two-year lag in availability. Therefore, all analysis for this report is from 2015 PUR data. A summary of the CDPR PUR data is provided below:

In 1990, California began implementing the most extensive pesticide reporting program in the world, and now requires the reporting of pesticide use for the following:

- Production of any agricultural commodity except livestock
- Treatment of post-harvest agricultural commodities
- Landscape maintenance in parks, golf courses, cemeteries and similar sites defined in California code as agricultural use
- Roadside and railroad rights-of-way
- Poultry and fish production
- Application of a restricted material
- Application by licensed pest control operators which includes agricultural and structural applicators and professional landscape gardeners

Additionally, CDPR divides pesticide applications into agricultural and non-agricultural uses, where each has its own reporting requirements. Agricultural applications are reported to the square mile or Public Land Survey's Section and daily level. Agricultural uses consist of production agriculture, such as crop production, and nonproduction agricultural, which includes rights-or-ways and landscaped areas. Non-agricultural applications include home, industrial, institutional (hospitals, office buildings, schools), structural, vector control, and veterinary. Non-agricultural uses are summarized to the monthly and county level and applications only applied by a licensed PMP is recorded.

4.1 GeoSpatial Model

In order to assess the risk pyrethroids pose to TWG populations, a geospatial heatmap of pyrethroid use at the watershed level for the coast of California was developed (Figure 4.1). CDPR PUR data was utilized for this heat map. These data are split into two use categories: agricultural and non-agricultural. Agricultural use was then situated based on the finest resolution data from CDPR, in terms of mass (pounds) applied by unit area (one mile square blocks). These blocks were clipped and summed at the HUC-8 watershed level. Non-agricultural use by HUC-8 watersheds were calculated using per-capita use rates from county level data. The per capita rates were multiplied by the population of each watershed calculated from the most recent 2010 census blocks. The agricultural and non-agricultural data for each watershed were then summed to quantify the total amount of pyrethroids applied in coastal watersheds and represented graphically. This process was repeated for total bifenthrin use, use by month, and at a finer HUC-12 watershed level for the area surrounding the Ormond Lagoon study site. CDPR PUR data was subsetted using the R program and all spatial processing was performed in ArcGIS 10.5.1.

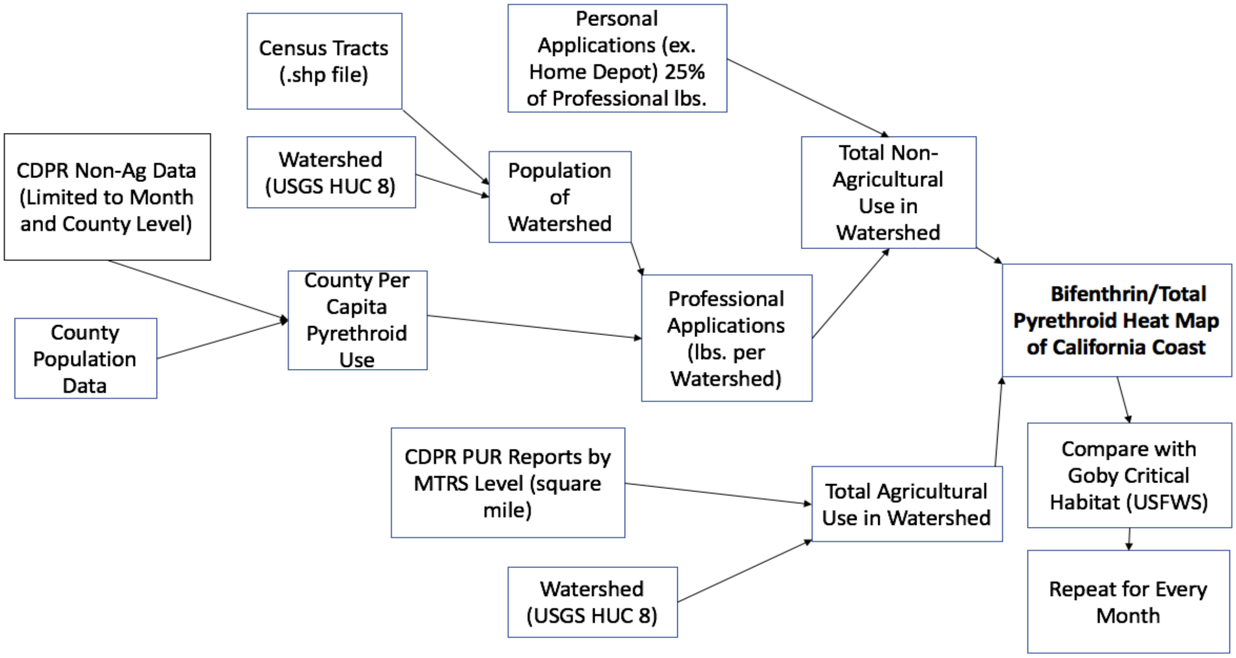


***Figure 4.1**. Conceptual Model for the geo-spatial model of pyrethroid and bifenthrin use.*

Data Sources

CDPR PUR Data

Accessed at :http://calpip.cdpr.ca.gov/main.cfm.

Using the CalPip Portal on the CDPR website 2015 agricultural and non-agricultural data for the counties containing a coastal watershed was downloaded. The data was then formatted to only pyrethroid applications in the R program.

County Population and Census Tract Data

Accessed at: *https://www.census.gov/geo/maps-data/data/tiger-line.html*

The most recent census tract data was provided by the U.S Census in 2010. This data was used to find the per capita use of pyrethroids.

Watershed Data

Accessed at: https://datagateway.nrcs.usda.gov/

HUC8 for the coast of California, and HUC12 for Ventura County watershed delineations were downloaded from the U.S Geographic Survey.

Tidewater Goby Critical Habitat
Accessed at: https://ecos.fws.gov/ecp/report/table/critical-habitat.html
TWG Critical Habitat locations and size was found using the USFWS .shp file for critical habitats in California.

4.2 PWC Model

Environmental aquatic transport models can provide EECs of substances and are particularly beneficial when there is a lack of recorded observations. This is the case for pyrethroids in the environment in general, as well as more specifically in coastal California and OLW.

Although many environmental exposure and transport models were considered, PWC was selected for our environmental modeling. This selection was supported by the history of the model's use assessing environmental pyrethroid concentrations, its relatively easy user interface, and its capability of reporting daily concentration values.

PWC is described as an interface "shell" that incorporates the Pesticide Root Zone Model (PRZM) and the Variable Volume Water Model (VVWM), developed by the EPA (Young, 2015). PWC can estimate EECs of pesticides in water bodies when informed by detailed physical-chemical, properties application rates, meteorological, and geographical data. This model, and the transport processes that inform its calculations, have been used recently by EPA and CDPR to model pyrethroid pesticide environmental concentrations at the national and state level (Luo, 2017). However, the generalizations included in the previous modeling attempts by CDPR and EPA regulators reduced its accuracy and applicability when determining the risk to TWG in specific watersheds. Assumptions regarding land-use, average extent of permeable surfaces on residential properties, density of residential areas, and the application schedules of pyrethroids were significantly divergent from expected OLW parameters.

Three pyrethroids were selected for modeling: bifenthrin, permethrin, and fenpropathrin. Bifenthrin and permethrin are the most heavily applied pyrethroids at the county level when aggregating both agricultural and structural pest management active ingredients loadings. Fenpropathrin was selected because it is used at relatively high levels for agricultural applications exclusively.

Informing the PWC of locally accurate conditions required significant sourcing and pre-processing of data. The sections that follow contain explanations of the sources for relevant data, pre-processing data manipulation, post-processing data manipulation, and logical assumptions made at each step. A comprehensive list of model inputs, calculations, and tables can be found in Appendix D. The model output consists of daily average concentrations in the water column, daily peak concentrations in the water columns, and daily average concentrations in the benthic zone.

4.2.1 Chemical Parameters

The model simulations for each pyrethroid addressed requires a suite of detailed chemical and physical information, which describes its molecular structure, behavior and environmental reactivity. Among the parameters necessary to inform the environmental simulations are metrics related to environmental degradation, soil half-life and photolysis half-life, and physical parameters such as solubility and vapor pressure (Appendix D).

4.2.2 Watershed Extent

There is no formal USGS hydrologic unit for OLW. Delineating the boundaries of the OLW required a combination of research from floodplain prediction maps and Google Earth Pro.

The J Street Drain/ Ormond Beach Lagoon Coastal Engineering Report prepared for the Ventura County Watershed Protection District (VCWPD) in November of 2008 served as a crucial reference in understanding the watershed extent of Ormond Lagoon and the subcatchments of the urban drains that feed it (VCWPD, 2008). Among the critical figures included in the report was the City of Oxnard Floodplain Analysis. The floodplain prediction noted the extent of areas that drained to the four channels terminating in Ormond Lagoon: the Oxnard Industrial Drain, Rice Road Drain, J-Street Drain, and Hueneme Drain. Google Earth Pro was used to trace the boundaries. Google Earth Pro is a user-friendly tool and made it possible to quantify the drainage basin areas for modeling analysis (Figure 4.2).

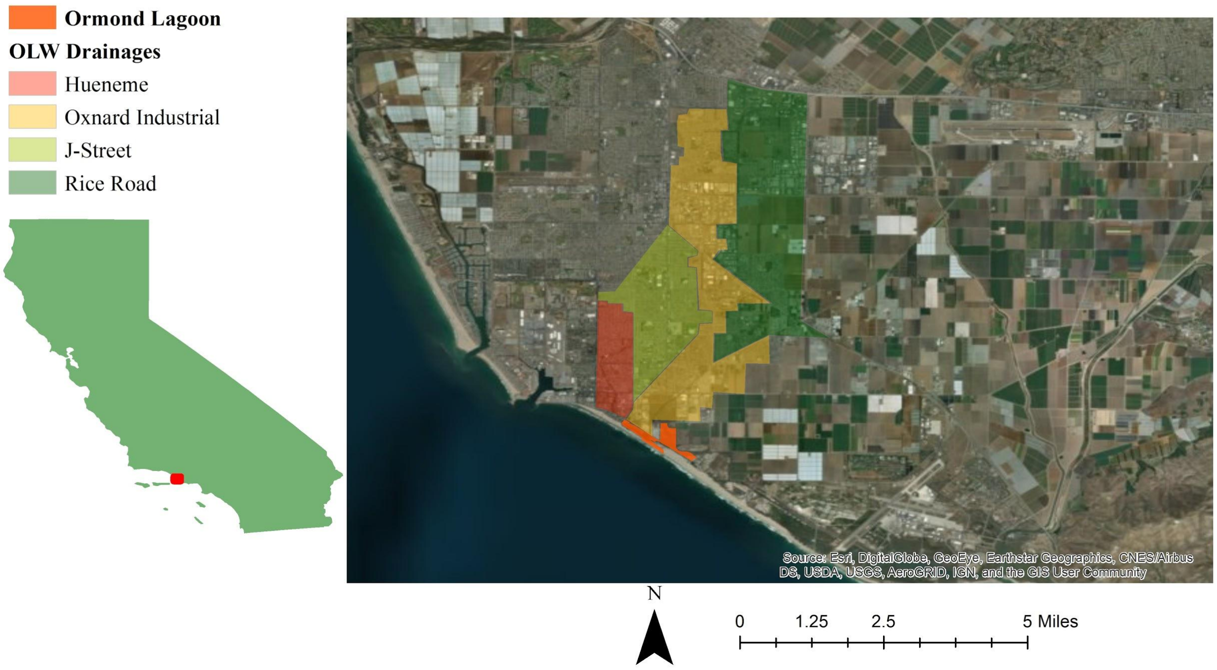


Figure 4.2. *OLW boundary with sub-drainages. Sub drainages include Hueneme (pink), Oxnard Industrial (yellow), J-Street (light green), and Rice Road (dark green).*

4.2.3 Land-Uses

After the total area of OLW was assessed, major land-uses of the watershed were quantified. The purpose of quantifying the land-use extents within the watershed into agricultural, commercial, residential, and open land areas is to better understand the possible areas of applications for pyrethroids in the OLW. Each of the 4 major divisions noted above involve different use patterns and legal restrictions on pyrethroid use. These areas also include differences in their hydrology, mainly the erosivity and infiltration capacity of different ground surfaces. Due to the relatively small size of the watershed (8,011 acres), detailed delineation of land-use extents was possible using Google Earth Pro. Using the "create polygon feature", areas of each land-use type were drawn, quantified, and combined to assess total watershed land-use division extents (area, percent of watershed; Figure 4.3): agriculture (1,114 acres, 13.90%), residential (4,763 acres, 59.45%), commercial/industrial (1956 acres, 24.41%), and open (179 acres, 2.23%).

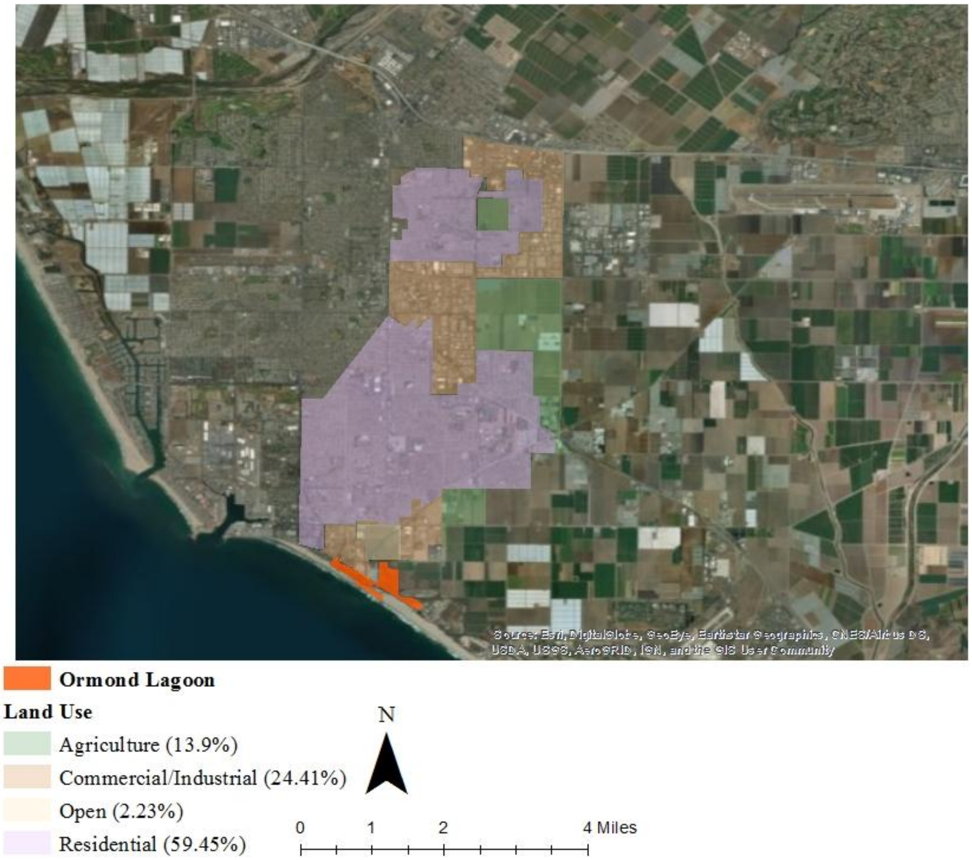


Figure 4.3. *OLW boundary with land uses. Land uses include agriculture (green), commercial/ industrial (orange), open (clear), and residential (pink).*

4.2.4 Application Areas PWG

After quantifying the extents of the 4 major pyrethroid application use pattern and regulation land-use areas, we quantified the actual areas of pyrethroid application. In any given land use type, only a small percent of the total area would be expected to receive pyrethroid application, i.e. a 1-inch perimeter band on the siding of a residential house.

4.2.4.1 Residential

Applications of bifenthrin and permethrin on residential plots fall under two distinct regulatory schemes regarding the licensing of the applicator, professional and personal users. Fenpropathrin is not used for structural pest control. Professional bifenthrin and permethrin applications are explicitly mandated by the California Code of Regulations, Title 3, Division 6, Chapter 4, Subchapter 5, Article 1, Section 6970 (Appendix B). In compliance with these regulations, application extents were calculated for the average OLW residential plot. Four specific applications types were calculated for residential applications: impervious pin stream perimeter and wall treatments, pervious perimeter and wall treatments, impervious patio perimeter treatments, and impervious sidewalk and driveway treatments.

Using Google Earth Satellite Imagery, an average residential plot was calculated to have specific dimensions related to the size of the house, the extent of perimeter draining to impervious/pervious surfaces, and the total paved surface extent (Appendix D).

Based on the OLW standard residential plot and applications specified by the California Code of Regulations, the total possible application areas per residential plot was calculated (Table 4.1; Appendix D).

Table 4.1. *OLW residential plot application areas per plot. Extent of pyrethroid applications per receiving residential plot used in the PWC.*

Parameter	Value and Unit
Perimeter and Wall Pinstream, Impervious	40.9 ft^2
Perimeter and Wall Pinstream, Pervious	75 ft^2
Patio Perimeter	10.3 ft^2
Driveway/Sidewalk Perimeter	13.4 ft^2

Bifenthrin and permethrin solutions are also available as over-the-counter pest control products. There are no state or federal regulations that mandate use patterns and on-product suggestions vary widely. In lieu of consistent personal application treatment extent data, personal applications were assumed to cover the same possible extent per residential plot as professional applications. A Pyrethroid Working Group (PWG) survey result suggested that just 75.9% of households in California use outdoor pest control products, including applications by professional applicators, homeowners, or both (Winchell, 2014). PWG concluded that the fraction of outdoor insecticide applications represented by bifenthrin or permethrin use is 27.1%, meaning that 27.1% of the 75.9% of total pyrethroid control user use bifenthrin or permethrin, resulting in 20.5% of the total population. Watershed wide application extents within residential properties were normalized by this factor.

4.2.4.2 Commercial

Using Google Earth satellite imagery, an average commercial plot in the OLW were calculated (Table 4.2). Both personal and professional uses on commercial properties were expected to have the same possible application areas for both bifenthrin and permethrin.

Table 4.2. *OLW commercial plot application areas per plot. Commercial plot measurements used in calculations to determine pyrethroid application extents and the extent of pyrethroid applications per receiving commercial plot used in the PWC.*

Parameter	Value and Unit
Total Plot Area	108,900 ft^2
Building Area	35,537 ft^2
Building Side Length	188.5 ft
Perimeter and Wall Pinstream, Impervious	125.7 ft^2

The actual extents of bifenthrin and permethrin applications represent both the commercial and residential applications across the OLW. The extents covered in one plot for residential and commercial plots respectively, were multiplied by the number of plots in the watershed, to find the total application extents. These values were normalized by the expected rate use (20.5%) among Southern California. Extents were aggregated by applicator type and ground surface drainage (Appendix D).

4.2.4.3 Agriculture

Bifenthrin, permethrin, and fenpropathrin are all actively used for agricultural pest control management. The specific crops they are used for and the extents of those crops across the watershed were found using CDPR PUR data available at the meridian township and range, section (MTRS) level. The Public Land Survey System, used by the Bureau of Land Management, is a surveying method that divides land into equal parts. There are 5 MTRSs (S01N22W02, S01N22W11, S01N22W14, S01N22W22, and S02N22W35), that encompass the agriculture of OLW.

This processing was completed in the R program, by using bifenthrin, permethrin, and fenpropathrin subsets as agricultural applications within OLW MTRSs. PUR data provides crop acreage, the extent of the field that the pesticide was applied to, and crop type. These data were used to find the extent of each crop-chemical combination and then were aggregated by pyrethroid type (Appendix D). Strawberry, raspberry, celery, lettuce, and cut flowers are crops grown in OLW receiving bifenthrin, permethrin, and/or fenpropathrin applications.

4.2.4.4 Application Loads and Schedules

After calculating the extents of the different types of pyrethroid applications, the load size and scheduling of applications were determined.

Structural

Since non-agricultural or structural applications of pyrethroids are reported by CDPR at the county and monthly level, the Ventura County total loadings were scaled to the OLW by population. As of 2015, Ventura County has 850,536 residents, while the OLW has a population of 114,534 persons, as determined by US Census data (US Census, 2010). Using this method, a per capita adjustment, OLW loadings comprise about 13% of the county population and thus would receive approximately 13% of the county structural pest control pyrethroids. Since only professional applications are reported and monitored by CDPR, the PWG survey was used to estimate that personal or over-the-counter applications of pyrethroids are approximately 25% of the professionally applied loads (TDC, 2010). Application loads and schedules were calculated and inputted into the PWC as kilograms per hectare in 4 different model runs: professional impervious, professional pervious, personal impervious, and personal pervious (Appendix D).

Agricultural

To obtain the agricultural loading totals and application schedules for bifenthrin, permethrin, and fenpropathrin in the OLW, CDPR PUR data was downloaded and manipulated. The original PUR data was provided for each application, in pounds of total active ingredient per day. These values were aggregated in kilograms of active ingredient applied per pyrethroid (Table 4.3). Data manipulation included converting provided values to kilograms per hectare units using the crop extents previously determined for every individual agriculture pyrethroid application. A comprehensive list of agricultural applications is provided in Appendix D.

Table 4.3. *Annual agricultural application of OLW in 2015. Loads used in PWC model for bifenthrin, permethrin, and fenpropathrin.*

Pyrethroid	Crop Type	Total Ingredient (kg)	Application Rate (kg/ha)
Bifenthrin	Strawberry	62.240	0.300
	Raspberry	2.657	0.055
	Celery	1.270	0.053
Permethrin	Cut Flowers	4.43	0.13
	Celery	12.62	0.21
	Lettuce	1.46	0.03
Fenpropathrin	Strawberry	61.79	0.35
	Raspberry	0.70	0.12

Lagoon Hydrology

Satellite imagery from Google Earth was used to estimate an average lagoon open water surface area. Years of observation range from 1994 to 2016, resulting in an average surface area of 95,177.67 m^2 (Appendix D).

A stream level gauge, operated by the VCWPD in the J-Street Drain near the Ormond Lagoon mouth was used to estimate lagoon depth. Observations from November 2012 through July 2017 were used to find an average depth of 1.5 meters (VCWPD, 2008; Appendix D).

Climate

The PWC requires daily meteorological files, as compiled by EPA. Of the 237 nationwide weather stations available, the Long Beach weather station was selected based on geographic proximity and marine weather patterns. These standardized weather files span 30 years from 1960-1990 and include over 40 measured parameters. Input files are in a .dvf file format.

4.2.5 Post Output Processing

PWC exports model simulation results as daily values for the duration of the weather files period, 1/1/1960 - 12/31/1990. The dates are useful at the month level to see trends between the seasons over a 30-year period. Daily values are reported for average aqueous concentration in the water column, average aqueous concentration in the benthic zone, and peak aqueous concentration in the water column. Values are initially reported in kg/m^3 but were converted to parts per billion (ppb) for more effective communication of results. Each application type is modeled separately, so model simulations of the same pyrethroid were combined and summed to find total EECs for each specific pyrethroid.

Using the soil organic carbon-water partitioning coefficient (Koc), daily average water concentrations in the benthic zone can be used to estimate concentration in the sediments in ppb (the total mass of bifenthrin/ dry mass of sediment per unit volume). The mean reported Kocs used were: 236,750 for bifenthrin, 81,600 for permethrin, and 5,000 for fenpropathrin (EPA, 2016). From sediment samples collected on October 27, 2017, we determined organic factors in the sediment that ranged from 0.75% in Ormond Lagoon to 3.87% in the Oxnard Industrial Drain.

4.3 Sampling

In order to better understand current pyrethroid levels and populate the PWC model with the most current environmental parameters, our team conducted two field sampling studies in the OWL on October 27, 2017 and January 26, 2018. The October 2017 sampling event was conducted after an extended period of dry conditions, while the January 2018 sampling event was conducted within three weeks after a 5-inch rain event in Ventura County. Samples were taken from 8 sites, 6 of which were located at drainages within the

Ormond Lagoon and 2 located within the lagoon itself (Figure 4.4). Within Ormond Lagoon there are 3 main drains, and two samples were taken near each of the 3 drains. During the October 2017 sampling event, 2 water samples and 2 sediment samples were collected from each sampling site. Water samples were taken with 25-ml plastic centrifuge tubes and sediment samples were taken with 4-oz glass jars. We used a HD40D meter to collect *in situ* data on temperature, conductivity, pH, and dissolved oxygen (DO). During the January 2018 sampling event, only one water sample and one sediment sample were collected from each site by using 1-liter plastic jars and 16-oz glass jars.

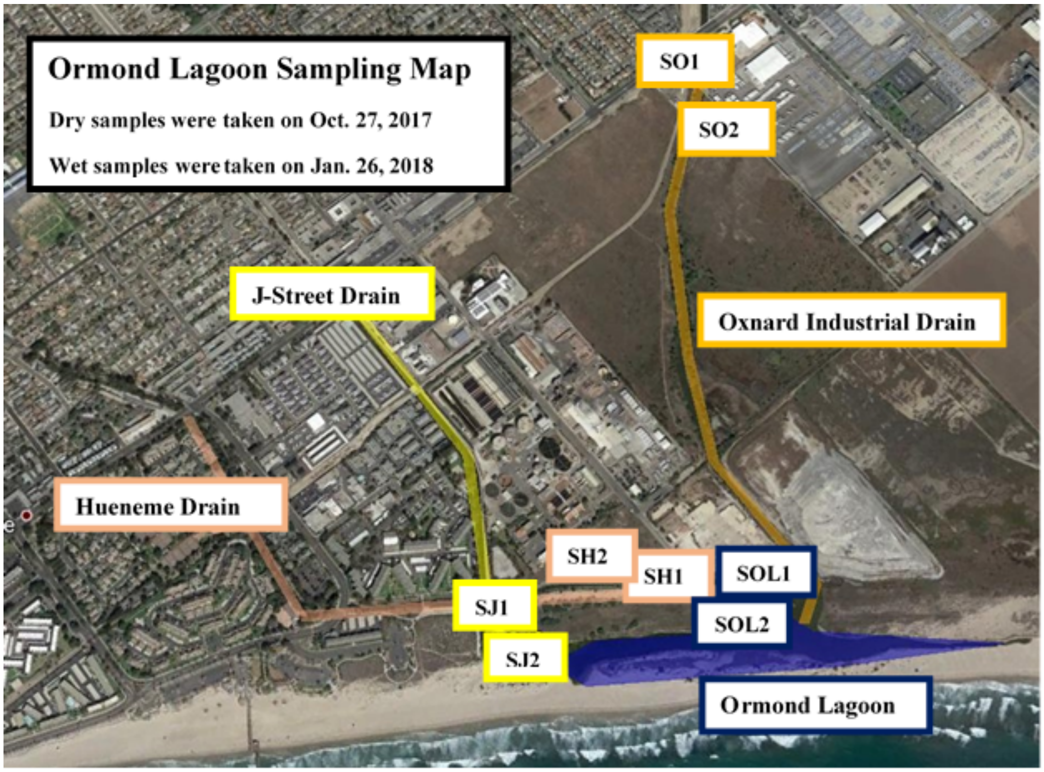


Figure 4.4. OLW sampling map. *SO1&SO2: Sampling sites at the Oxnard Industrial Drain; SJ1&SJ2: Sampling sites at J-street Drain; SO1&SO2: Sampling sites at Oxnard Industrial Drain; SH1&SH2: Sampling sites at Hueneme Drain; SOL1&SOL2: Sampling sites in Ormond Lagoon.*

Before analyzing for pyrethroids, water samples and sediment samples were stored at 4°C and -20°C, respectively. Water sample parameters measured include dissolved organic carbon (DOC), SS, and chlorophyll. Sediment sample parameters measured included bulk density, porosity, and organic fraction. Both DOC and chlorophyll concentrations were calculated from results of absorbance by using UV-vis spectroscopy. SS were determined by using GF/F filters with 0.45-micron pore size. For sediment samples, bulk density was defined as the ratio of dry weight of sediment to the known volume of sediment. Porosity was calculated as the ratio between the volume of interstitial water and the known total volume of the sediment. Organic matter was determined using the calcination method, placing samples under a Muffle furnace at 450°C for 4 hours.

Pyrethroid concentrations were determined in both October 2017 and January 2018 samples by using liquid chromatography–mass spectrometry (LC-MS). Pyrethroids that were included in the test were bifenthrin, cyfluthrin, cypermethrin, esfenvalerate, fenpropathrin, cyhalothrin, permethrin, pyrethrin, and flauvalinate. Further details on methods of details are found in the sampling plan (Appendix E).

4.4 Best Management Practices

In order to provide relevant recommendations to mitigate the ecological impact of pyrethroids in the environment, a literature review and modeling tools were used to identify the most appropriate BMPs for pyrethroid applicators in coastal California. The literature review included BMPs that have been implemented in regions in coastal California where pyrethroids are heavily applied, including a more detailed literature review on existing BMPs implemented in Ventura County. This review was split between existing structural and behavioral BMPs. Structural BMPs are defined as physical structures that assist in controlling or mitigating pyrethroid runoff into waterways. Behavioral BMPs are behavioral changes by applicator or distributors of pyrethroids. After identifying both behavioral and agricultural BMPs, we indicated whether implemented or recommended BMPs are suitable for the urban or agricultural sector.

In addition to the literature review that informed our team on the most appropriate BMP recommendations for pyrethroid runoff reduction, two different tools were used for recommending site-specific structural BMPs for the agricultural sector of OLW. We used the Spreadsheet Tool for Estimating Pollutant Load (STEPL), which employs simple algorithms to calculate nutrients and sediment loads from different land uses and load reductions to calculate the load reductions from different BMPs (EPA, 2018). Site-specific information such as land uses, were used to calculate the most economically feasible options for BMP implementation in OLW. The Nutrient Tracking Tool (NTT) was also used to determine the effectiveness of VFSs and sediment basins as structural BMPs by using a field in OLW as a case study. NTT is a web-based, site-specific application that estimates nutrient and sediment losses for crop at the field or watershed level (Tarleton, 2018). The NTT was run for a 15ft VFS with two different plants species (orchard grass and bermuda grass) as filter strips. The trials for both VFS were run for scenarios that would treat 0-100% of the selected sample field. The results from both STEPL and NTT were used to estimate costs and load reductions, if implemented. It is important to note that the options for NTT crop did not include any crops found in Ventura County. Therefore, blueberries and dry beans were used as the target crop fields. Since the crops in Ventura County are different than the modeled crops, values should only be used as a broad estimate.

With our literature review and site-specific results from STEPL and NTT, our team was able to identify the most suitable BMPs for pyrethroid applicators in coastal California. The methods performed to identify the most suitable BMPs for the modeling tools can be replicated for other regions. Detailed literature review and modeling parameters can be found and replicated (Appendix G).

5 Results

5.1 GeoSpatial Model

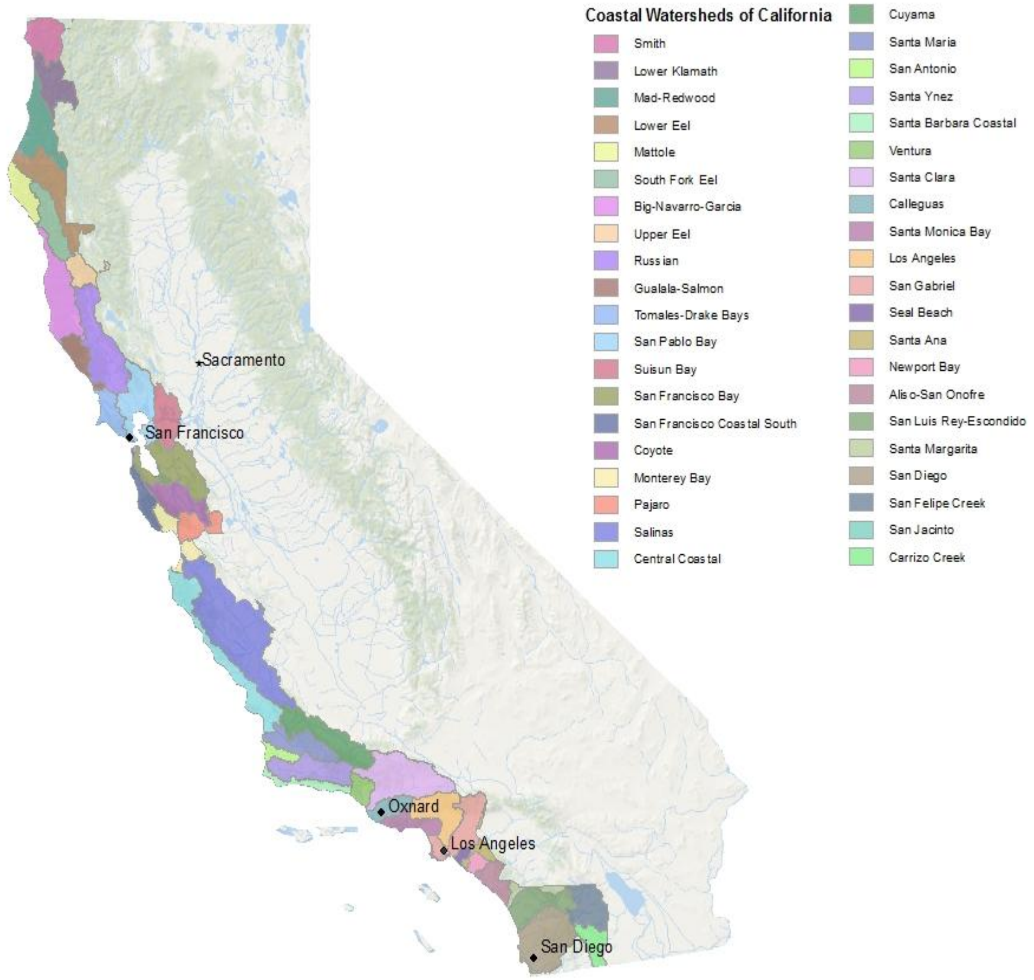


Figure 5.1. *The coastal watersheds of California. HUC 8 watershed delineations and watershed names from the USGS. Data retrieved from USGS.*

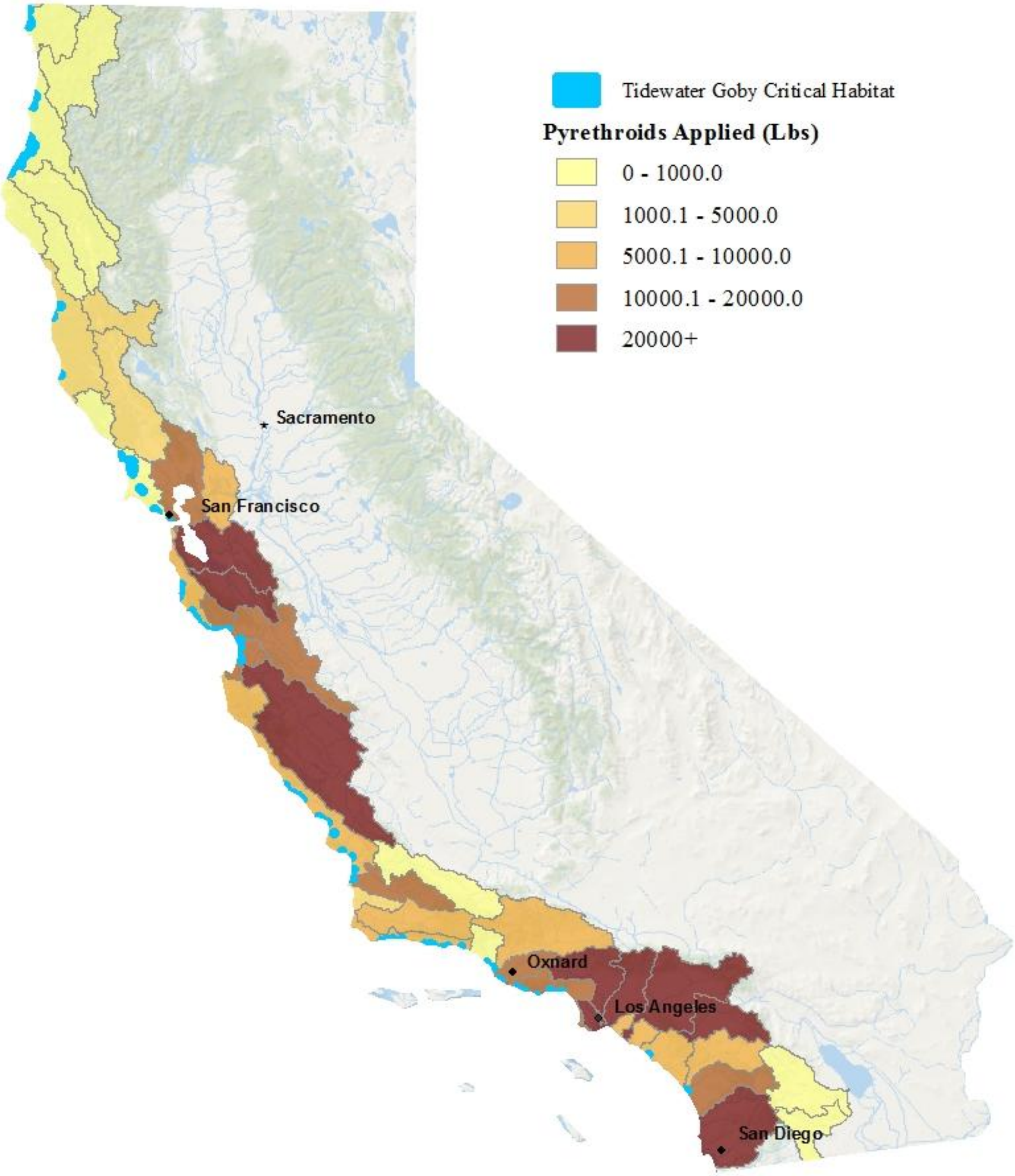


__Figure 5.2.__ Total pounds of pyrethroids applied at the HUC-8 watershed level in 2015. Darker colors represent higher application. Tidewater Goby critical habitat (not to scale) is provided for reference. Data retrieved from CDPR and USFWS.

Considerable spatial variability in pyrethroid application exists across coastal watersheds. Hotspots from non-agricultural sources include the San Francisco area (San Francisco Bay and Coyote watershed), Los Angeles area (Los Angeles, San Gabriel, Santa Ana, and San Jacinto watersheds), and San Diego area (San Diego watershed). The large urban populations in each of these watersheds contributes to the high non-agricultural application rates. However, none of the watersheds contain TWG critical habitat. The watersheds north of San Francisco are not heavy users of pyrethroids.

Table 5.1 provides a table of watersheds with TWG critical habitat (a full table of all coastal watersheds is provided in Appendix H). The Salinas watershed had ~42,000 lbs of pyrethroids applied in 2015, making it the watershed with the highest use of pyrethroids with TWG critical habitat. This use was largely driven by agriculture, which accounted for 93% of total pyrethroids applied. Additional watersheds containing TWG critical habitat and high pyrethroid use (> 5000 lbs) are the Santa Monica Bay, Santa Maria, Pajaro, Monterey Bay, San Luis Rey Escondido, Calleguas, Aliso-San Onofre, Santa Clara, San Francisco Coastal South, and the Santa Barbara Coastal (in order from highest to lowest lbs applied). In these watersheds there appears to be wide variation between the percent of non-agricultural and agricultural use.

Table 5.1. Watersheds containing TWG critical habitat ranked by total pyrethroid use in 2015.

Watershed	Area of Goby Critical Habitat (acres)	Total Pyrethroid (lbs)	Peak Pyrethroid Application Month	% Non-Agriculture Pyrethroid Use	Total Bifenthrin (Lbs)	% Non-Agriculture Bifenthrin Use
Salinas	464	42487	August	7.00%	5460	43.10%
Santa Monica Bay	75.1	19253	August	100.00%	4445	100.00%
Santa Maria	456	15085	July	27.50%	3066	38.70%
Pajaro	191	14906	August	25.00%	2779	47.40%
Monterey Bay	245	13607	August	15.50%	2761	15.30%
San Luis Rey-Escondido	58	13323	May	79.90%	4385	87.90%
Calleguas	168.5	11221	May	35.70%	4574	57.80%
Central Coastal	405.7	8698	July	57.60%	4872	90.00%
Aliso-San Onofre	14.3	7427	April	99.00%	1651	98.00%
Santa Clara	269	7187	October	55.90%	2228	67.00%
San Francisco Coastal South	510	5968	January	97.30%	135	92.00%
Santa Barbara Coastal	224	5191	April	92.30%	778	98.00%
Big-Navarro-Garcia	122.8	1677	May	99.60%	324	100.00%
San Antonio	3	1154	April	62.10%	145	78.00%
Ventura	54.5	938	April	85.00%	491	90.00%
Tomales-Drake Bays	3022	936	June	98.50%	26	100.00%
Mad-Redwood	3019.9	749	September	100.00%	321	100.00%
Lower Eel	39.1	508	September	99.60%	170	100.00%
Gualala-Salmon	108.1	206	June	100.00%	31	100.00%
Smith	2704	136	May	28.70%	20	100.00%

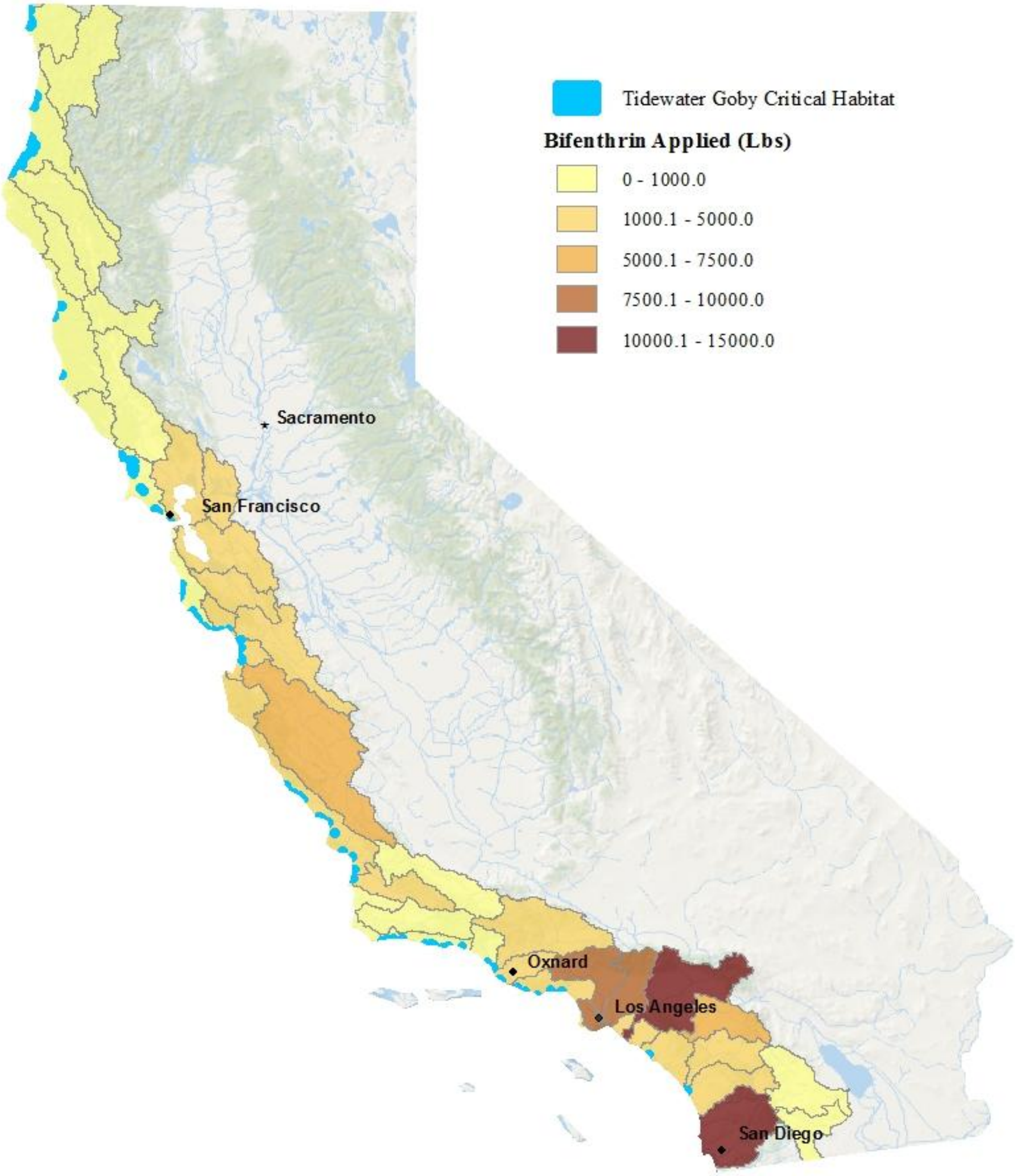


Figure 5.3. *Total pounds of bifenthrin applied at the watershed level in 2015. Darker colors represent higher application. Data retrieved from CDPR.*

Like pyrethroids, bifenthrin use varies considerably along the coast of California. The watershed with the largest amount of bifenthrin applied in 2015 and TWG critical habitat is the Salinas watershed. When looking only at bifenthrin, a greater percentage (43%) was applied for non-agricultural uses compared to total pyrethroids, where only 7% was non-agricultural. The Calleguas watershed is the third highest watershed with TWG critical habitat in terms of total bifenthrin use but is seventh in total pyrethroid use. Again, of all watersheds, the Santa Ana and San Diego watersheds were the highest users of bifenthrin (~14,500 lbs and ~10,000 lbs, respectively).

Watersheds of concern, due to presence of TWG critical habitat, and large amounts of bifenthrin use include Salinas, Central Coastal, Calleguas, Santa Monica Bay, San Luis Rey-Escondido, Santa Maria, Pajaro, Monterey Bay, Santa Clara, and the Aliso- San Onofre watershed (listed in order of highest total lbs applied). Again, the watersheds north of San Francisco do not appear to have any significant bifenthrin use.

Along with spatial variations of pesticide use in California, there are important differences when considering application on a monthly basis. Eight of the twenty watersheds with TWG critical habitat experienced their peak pyrethroid application in April or August (Table 5.1). The watersheds with peaks in April were all predominantly from non-agricultural use, while three of the four watersheds that peaked in August were mostly through agricultural application.

These monthly temporal changes become particularly clear when looking at statewide heatmaps for an entire year (Figure 5.4). These monthly maps show high rates of use in spring through summer months, which include April and August, the two months of highest overall pyrethroid use. During these periods watersheds from San Francisco Bay south to Salinas all experience high use. The watersheds around Los Angeles remain relatively high for each month. These maps also show months of relatively low use in January, February, November, and December.

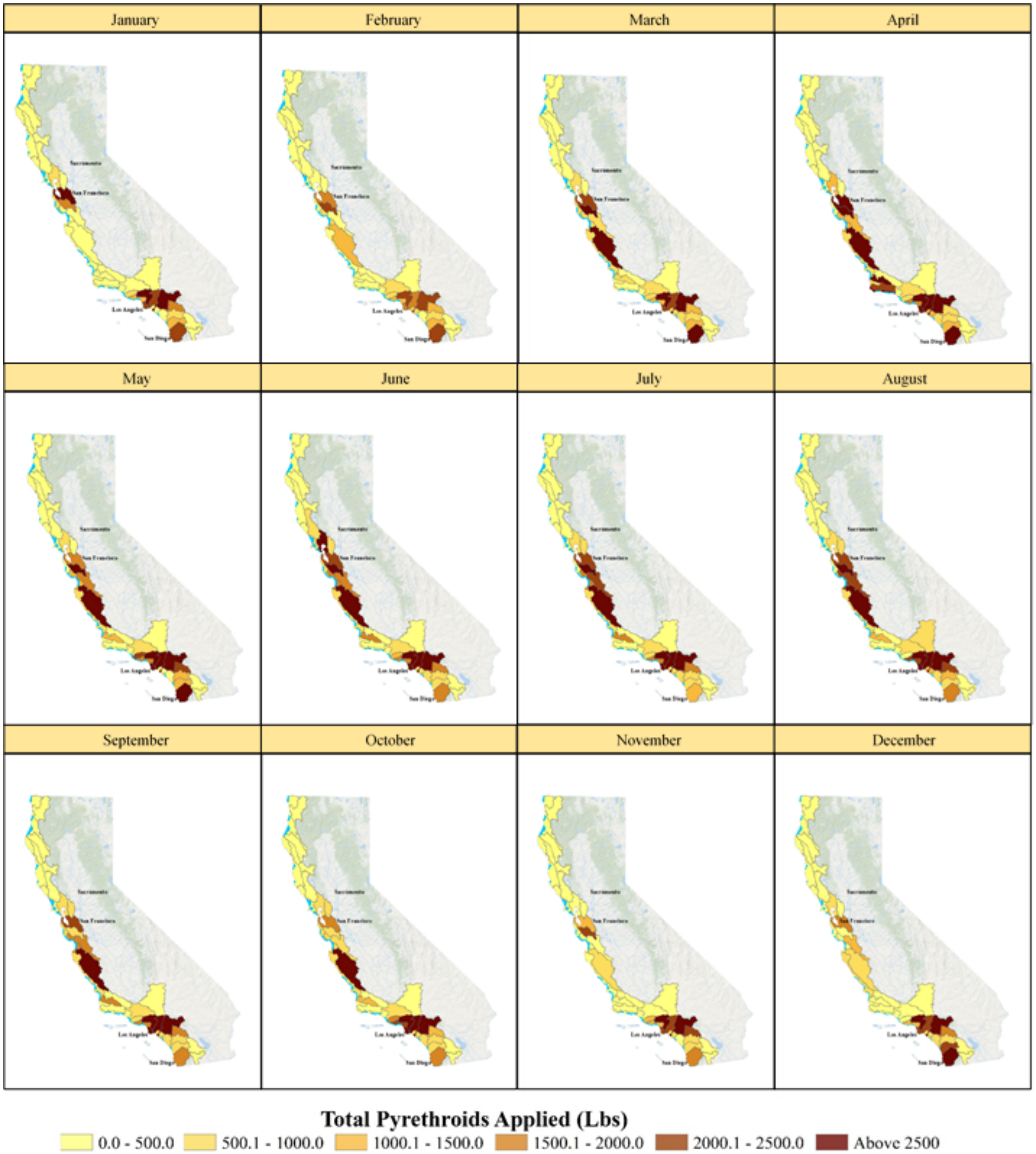
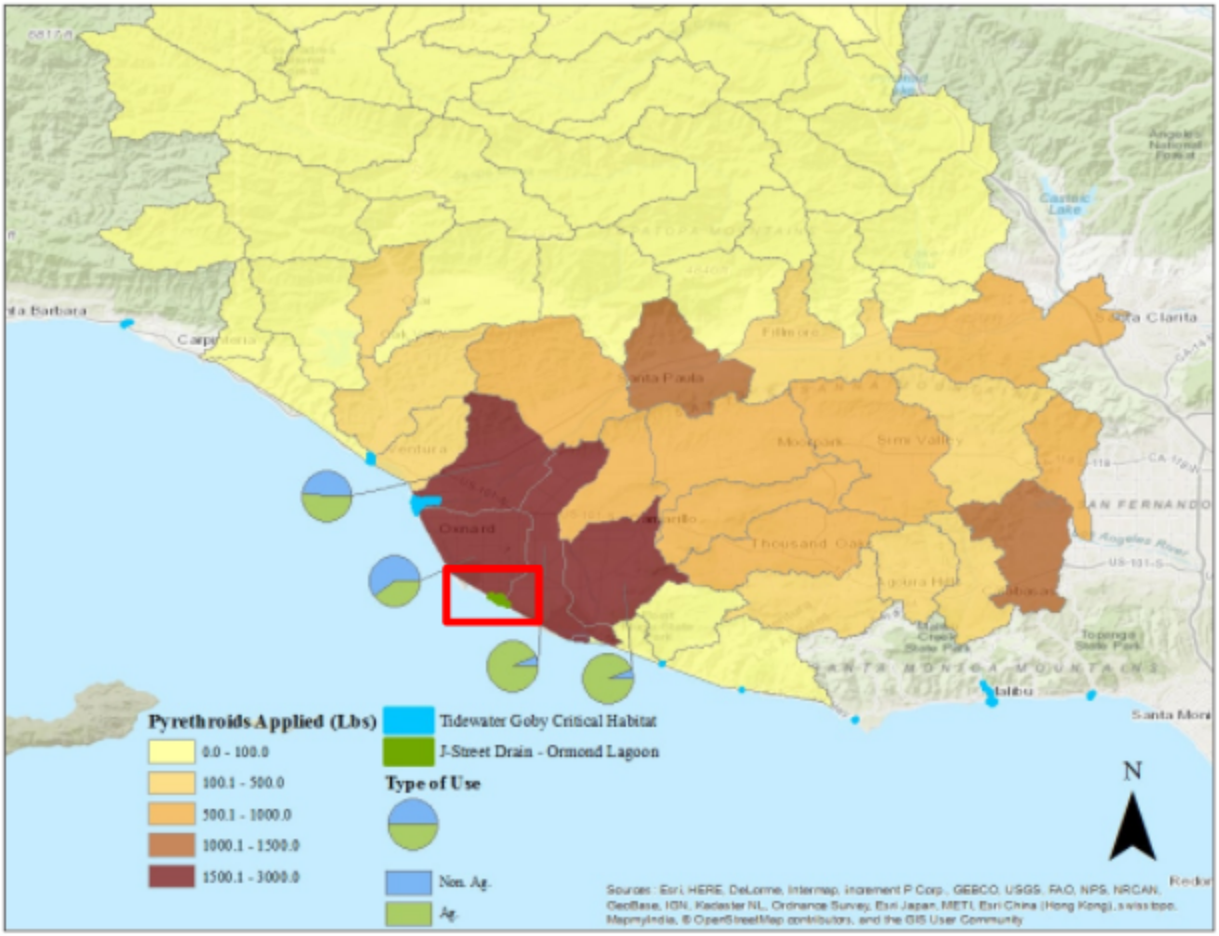


Figure 5.4. *Monthly temporal applications (lbs) of pyrethroids across coastal California in 2015.*

5.1.1 Ormond Lagoon

When looking more specifically at the watersheds surrounding Ormond Lagoon it is clear that there is also considerable spatial and application type variability. The watersheds with the highest application rate of total pyrethroids were the four watersheds closest to Ormond Lagoon (Figure 5.5). The pyrethroids applied in the two watersheds to the southeast of Ormond Lagoon were predominantly from agricultural use. The northwestern two watersheds were more evenly or slightly skewed towards non-agricultural use, likely representing the more developed landscape these watersheds cover. The three watersheds closest to Ormond Lagoon clearly show the highest levels of pyrethroid application, and distinct trends for agricultural and non-agricultural uses.



Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Figure 5.5. *Total pyrethroids applied in 2015 at Huc12 level watersheds around Ormond Lagoon. Data retrieved from CDPR and USFWS.*

The watershed closest to Ormond Lagoon clearly shows the highest levels of bifenthrin application, which is similar to total pyrethroids (Figure 5.6). The predominantly agricultural use watersheds to the southeast are not as high as they are for total pyrethroids, but urban watersheds in Thousand Oaks show higher relative use of bifenthrin than total pyrethroids

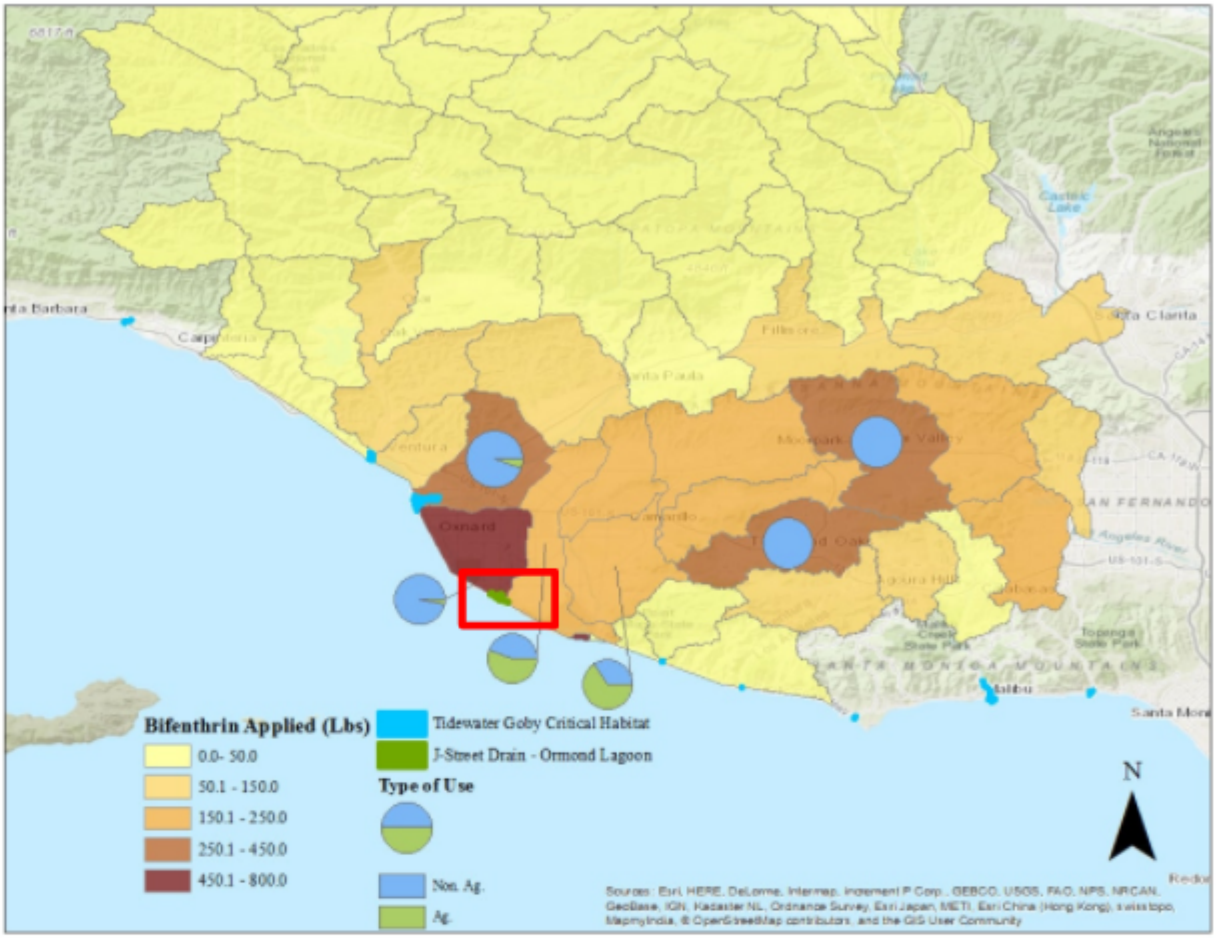


Figure 5.6. *Total bifenthrin applied in 2015 at Huc12 level watersheds around Ormond Lagoon. Data retrieved from CDPR and USFWS.*

5.2 PWC Model

Due to the absence of pyrethroid toxicity data regarding TWG, the effects of bifenthrin, permethrin, and fenpropathrin in the environment on surrogate species were assessed (Appendix C). BS fry was used as the surrogate to which our results are interpreted for. Within the same order, Perciformes, BS has the closest genetic relation with TWG of the species assessed with recorded pyrethroid toxicity assessments. Furthermore, juvenile fishes of both species prey on shrimps, aquatic insects, and worms (Barkoh and Timothy, 1987; Swenson 1997). Other similarities including burrowing in sediments in shallow water for spawning and an overlap of spawning seasons, from late spring to summer (Santucci and David, 2003; Swift et al., 1989). Although the adult size of BS (~30 cm) differs from TWG (~5 cm), BS fry are approximately the same size as TWG and were therefore considered a representative surrogate for toxicity (Cargnelli and Mart, 1996; Miller and Lea 1972). Of the species considered for TWG surrogate species, BS fry are relatively more sensitive to pyrethroids when compared to other assessed species like the sheepshead minnow or the rainbow trout (USDA Forest Service, 2015; Fojut et al., 2012; Harper et al., 2008; Başer et al., 2003; Schimmel et al., 1983). This indicates that our reported exceedances and estimate impact on TWG are likely to be conservative.

5.2.1 Bifenthrin

Over the course of the 30-year PWC model simulation, the expected daily peak aqueous concentration in the water column for bifenthrin exceeds the BS fry 96-hr LC_{50} (0.35 ug/L) 30 times, and the BS fry 48-hr LC_{50} (0.65 ug/L) 4 times (Figure 5.7; Appendix D). Assuming the surrogate toxicity thresholds are somewhat representative of TWG, we can assume that on average every year there will be a pulse of bifenthrin rich water that will be likely to have significant adverse effects. Of the 30 expected environmental aqueous concentrations in the water column in excess of 0.35 ug/L bifenthrin, 83% occur between November and February, with January as the most frequent month of simulated exceedances. Importantly, November, December, January, and February comprise 4 of the 5 wettest months on average (Weather.com, 2018). Additionally, in all 30 exceedances of 0.35 ug/L, over 80% of the contributing bifenthrin originates from strawberry production.

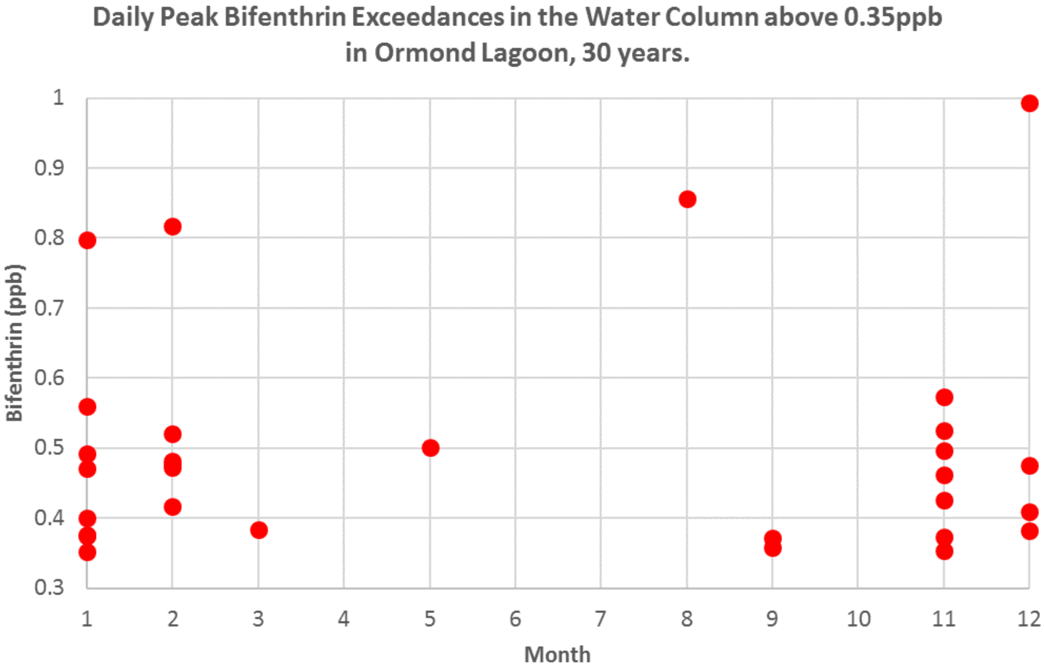


Figure 5.7. *Daily peak bifenthrin exceedances in the water column above 0.35 ug/L in OLW over 30 years.*

Bifenthrin concentrations in the sediments follow a different but equally distinct pattern. The highest daily average concentration of bifenthrin in the sediments occurs in February, at over 74 micrograms of bifenthrin per kilogram of sediment (ppb). All sediment concentrations of bifenthrin over 63 ppb occur between January and June (Figure 5.8;

Appendix D). Due to the absence of TWG sediment bound pyrethroid toxicity metrics, thresholds for sediment concentration reporting were selected to show overall periodicity in peak concentrations. The concentrations of sediment sorbed bifenthrin is dependent on the organic carbon factor. Some of the drainages into Ormond Lagoon have organic carbon factors over 3 times higher than the lagoon itself, which would lead to a corresponding increase in sediment-bound bifenthrin concentrations (Appendix A).

Figure 5.8. Daily Peak Bifenthrin Exceedances in the Sediments above 63 ppb in OLW over 30 years.

In addition to direct toxic effects, the major food source of TWG are benthic invertebrates, which are orders of magnitude more sensitive to pyrethroids and bifenthrin specifically. The LC_{50} of bifenthrin for *H. azteca* is 4.55 nanograms per liter of water (ng/L). This threshold is expected to be exceeded in the benthic region daily on 99.96% of each day simulated over 30 years and can exceed 30 ppb in the benthic zone.

5.2.2 Permethrin

Over the course of a 30-year model simulation the expected environmental daily peak aqueous concentration in the water column for permethrin exceeds 86 times the BS fry 96-hr LC_{50} (0.9 ug/L) and 39 times the BS fry 48-hr LC_{50} (1.8 ug/L; Figure 5.9; Appendix D). Of the 86 estimated exceedances over 0.9 ug/L, 61% occur between November and February while January is the most frequent month of simulated exceedances, again coinciding with the months of the most precipitation. Unlike the major source of environmental bifenthrin, for permethrin in the 86 daily peak water concentrations over 0.9 ug/L, 70% or more originate from professional impervious applications.

Like bifenthrin and all pyrethroids, permethrin is hydrophobic, adsorbing to organic carbon readily. The EPA has determined an average Koc for permethrin of 81,600. The sediment bound concentrations of permethrin peak in April, with all recorded values in excess of 30 ppb occurring between January and June (Figure 5.10). PWC predicts that peak sediment concentrations of permethrin and bifenthrin occur mid- spring, when peak TWG spawning occurs and the egg and larval TWG are thought to be at their most sensitive (USFWS, 2014).

The LC_{50} of permethrin for *H. azteca* is 48.9 ng/L (ECOTOX database; EPA, 2018). The indirect effects of permethrin to the TWG is less than that of bifenthrin, with the *H. azteca* LC_{50} exceeded for 0.4% of the days simulated.

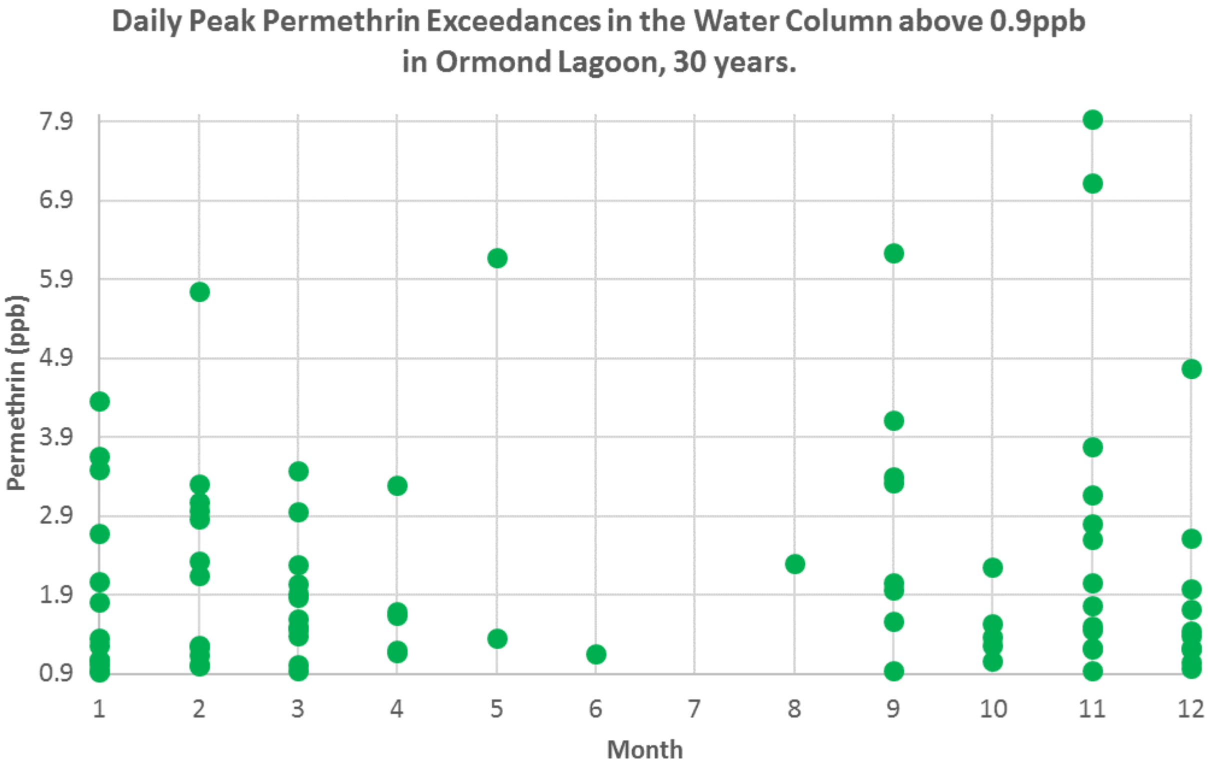


Figure 5.9. *Daily peak permethrin exceedances in the water column above 0.9 ug/L in OLW over 30 years.*

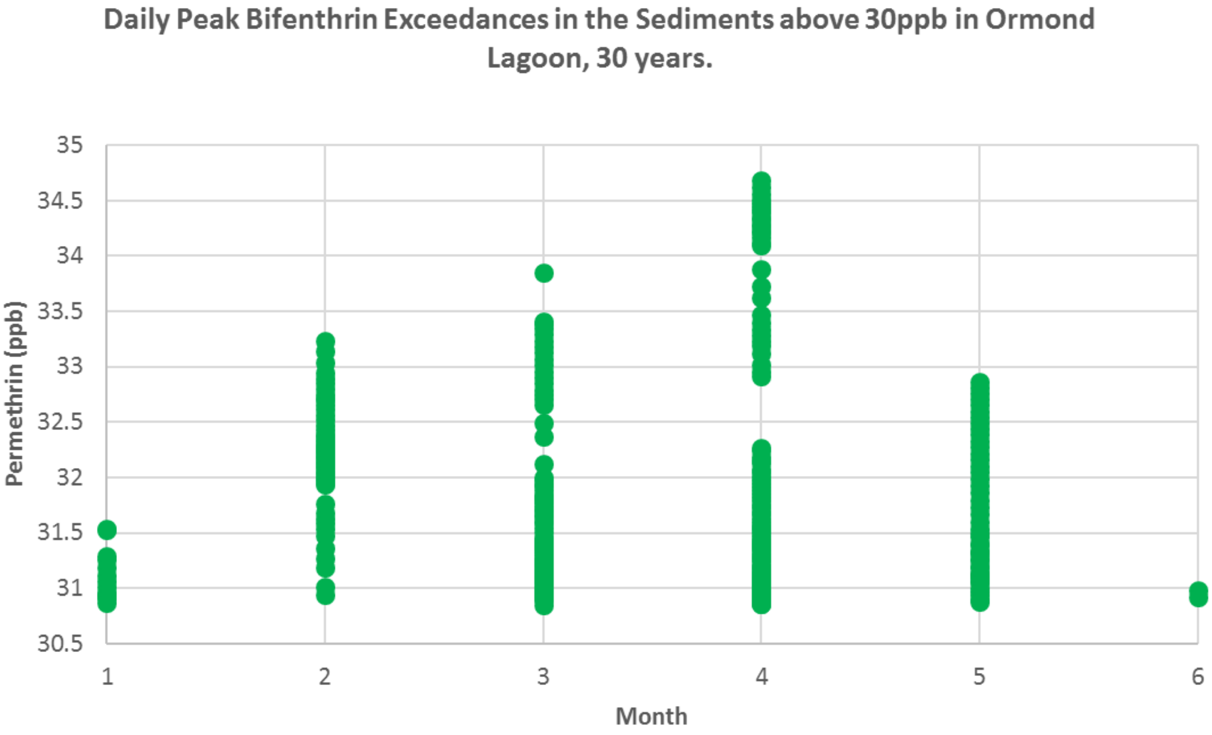


Figure 5.10. Daily peak permethrin exceedances in the sediments above 30 ppb in OLW over 30 years.

5.2.3 Fenpropathrin

The total loadings of fenpropathrin are less than that of the other two pyrethroids modelled, resulting in lower environmental concentrations. Over the course of the 30 year model simulation the expected environmental daily peak aqueous concentration in the water column for fenpropathrin exceeds 4 times the BS fry 96-hr LC_{50} (2.2 ug/L). There is no reported 48-hr LC_{50} for BS fry (Appendix D). Three of the 4 exceedances coincide with wet months, as observed for bifenthrin and permethrin peaks. In all 4 daily peak water concentrations over 2.2 ug/L, 98% or more of fenpropathrin originates from strawberry applications.

As mentioned previously, there is a lack of sediment-bound pyrethroid toxicity data for TWG or other related fish species, so the cut off thresholds reported are most useful to understand timing of peak concentrations. The generally low values of fenpropathrin in the water column resulted in correspondingly low concentrations in the sediments (Appendix D). Sediment bound fenpropathrin is unlikely to exceed 17 ppb, with the highest concentrations occurring later in the year than the other two pyrethroids modeled, in August and September.

5.3 Sampling

Results of water quality parameters are summarized in Appendix F. Data from a California Environmental Data Exchange Network (CEDEN) monitoring site were used to compare to our results on DOC and TSS (CEDEN, 2017). Results showed the Ormond Lagoon had similar DOC and chlorophyll levels for the J-street Drain as CEDEN sampling results. In the future, more samples should be taken to determine TSS, as its values differed dramatically across different locations. No pyrethroids were found above detection limits in all water samples during the October 2017 sampling event (dry season) while fenpropathrin was widely found across sampling points during the January 2018 sampling event (after precipitation). Significant concentrations of lambda-cyhalothrin were also found in samples from the Oxnard Industrial Drain and Ormond Lagoon (Table 5.2).

Table 5.2. *Pyrethroid concentrations in water samples from January 2018 sampling event.*

Location	ID	Fenpropathrin (ppb)	Lambda-Cyhalothrin (ppb)
Oxnard Industrial Drain	**SO1**	0.0145	2.6478
	SO2	0.0149	0.7341
Hueneme Drain	**SH1**	0.0858	0
	SH2	0.0505	0
J-street Drain	**SJ1**	0.0263	0
	SJ2	0	0
Ormond Lagoon	**SOL1**	0.0262	4.0055
	SOL2	0	2.6111

Results of bulk density, porosity, water content and organic factor in the sediment samples are summarized in Appendix F. Compared to its three drains, sediments in the Ormond Lagoon were found to have the least water content and organic factor. The highest values for water content and organic factor were found in the Hueneme Drain and Oxnard Industrial Drain, respectively. During the October 2017 sampling event, only two samples were reported to have pyrethroids present. Bifenthrin was found in 7 of 8 sampling points, while cis-permethrin was found only in one samples at the Oxnard Industrial Drain (Table 5.3). During the January 2018 sampling event, a general increase in concentrations of bifenthrin and cis-permethrin was observed for most of the sampling locations Also, many more types of pyrethroids were found in samples, including fenpropathrin, lambda-cyhalothrin, cypermethrin, anthraquinone, tau-fluvalinate, and trans-permethrin. Complete results on pyrethroids can be found in Appendix F.

Table 5.3. Pyrethroids detected in sediment samples during sampling events.

		October 27, 2017		January 26, 2018			
Location	**ID**	**Cis-permethrin (ppb)**	**Bifenthrin (ppb)**	**Tau-Fluvalinate (ppb)**	**Trans-permethrin (ppb)**	**Cis-permethrin (ppb)**	**Bifenthrin (ppb)**
Oxnard Industrial Drain	**SO1**	0	0.23	0.32	0.86	0.51	2.54
	SO2	0.165	1.09	1.39	1.62	1.02	4.65
Hueneme Drain	**SH1**	0	0	0.14	0	0	0.02
	SH2	0	0.07	0	0	0	0
J-street Drain	**SJ1**	0	0.08	0	0.08	0.07	0.77
	SJ2	0	0	0.15	0.07	0	0.16
Ormond Lagoon	**SOL1**	0	0.22	0.14	0	0	0.22
	SOL2	0	0.075	0.14	0	0	0.09

5.4 Best Management Practices

After conducting a literature review and speaking to relevant stakeholders, we formulated a list of structural and behavioral BMPs for pyrethroids users in coastal California (Table 5.4). While most of the background information and recommendations are specifically written for Ventura County and the OLW, the BMPs we recommend could be successfully implemented in any part of coastal California that experiences water quality and heightened toxicity levels due to pyrethroids. Below are brief explanations highlighting the BMPs we recommend, followed by a summary of our literature review that justifies our recommendations. Full, detailed BMP literature review and model results can be found in Appendix G.

__Table 5.4.__ Recommended BMPs for coastal California pyrethroid users.

	Urban	Agricultural
Behavioral	Implement a network or communication system that informs applicators of rain events	Implement Integrated Pest Management, using the most relevant forms of control for field (e.g., growing flowering plants in fields adjacent to strawberry fields)
	Apply peak pyrethroid loads earlier in dry season	Use polyacrylamide to reduce runoff
	Apply pyrethroids in granules instead of in liquid form on impervious surfaces	Apply pesticides that are less toxic to fish (i.e., insecticidal soap, acetamiprid, naled 8E)
	Apply pesticides that are less toxic to fish such as boric acid	
Structural	Urban vegetative filter strips	Vegetative Filter Strips
	Bioswales	Sediment Basin and Water/Pond

5.4.1 Agricultural

5.4.1.1 Behavioral

Implement Integrated Pest Management

IPM is an ecosystem-based strategy that focuses on long-term prevention of pests by using different forms of control including biological, habitat manipulation, cultural, and use resistant variants. IPM is growing in use and has been extremely helpful in reducing the amount of pyrethroids applied across California. IPM training programs may be offered through local organizations or free online training programs.

Use polyacrylamide to reduce runoff

Polyacrylamide (PAM) is a chemical used to minimize erosion. Application of PAM with pyrethroids, can be useful in reducing soil erosion, and thus minimize the transport of sediment-bound pyrethroids.

Apply pesticides that are less toxic to fish

Chemicals such as insecticidal soap, acetamiprid, and naled 8E are less toxic to fish species and can be used in lieu of pyrethroids.

Agricultural BMPs in coastal California have been developed over the past few decades and are well-regulated. Our recommendations for agricultural BMPs include IPM, PAM to reduce erosion, and pyrethroid substitutes that are less toxic to fish species.

IPM is a widely used BMP that uses both chemical and nonchemical forms of control. According to VCAILG's Water Quality Management Plan, 99% of all Ventura County agricultural producers are implementing an IPM program; however, the specifics of these programs can vary across farms (VCAILG, 2017b). Within an IPM, several forms of control are used including biological, pest monitoring, cultural, and pesticide selection. Biological control was only used on 26% of the acres in agricultural production in 2015 and mechanical control was only used at one site in the county (Ventura County Farm Bureau, 2015).

Since Ventura County is a large producer of strawberries and the PWC results indicate this as a significant source of pyrethroids to TWG habitat, the IPM program for strawberries is a great example of crop-specific IPM program that can be followed by other counties. Cultural control, as a part of the IPM program, could be expanded by growing more plants in adjacent fields or on the border of strawberry fields to attract adult lygus bugs, the primary pest controlled by bifenthrin application in strawberry production, away from strawberry plants. Another effective chemical approach has been indirectly limiting application rates of bifenthrin and fenpropathrin, in strawberry fields to two times a year to avoid lygus bug resistance to these pyrethroids.

Other ways pyrethroid applications could be reduced is through pyrethroid substitutes that are less toxic to TWG. Naled (Dibrom 8E), insecticidal soap, and acetamprid can be used in lieu of pyrethroids and have a lower runoff risk (Appendix G). They degrade in the environment rapidly and weakly bind to SS. When possible, using these alternatives to pyrethroids that are less toxic to the environment can reduce harm to the TWG.

Another effective BMP that can reduce more than 80% of pyrethroid runoff is PAM, a highly soluble chemical polymer commonly used to prevent soil erosion and stabilize soil (Carol, 2007). In OLW, 39 lbs of PAM were applied across the watershed, primarily in May, although it is unclear whether PAM is used directly to mitigate impacts of pyrethroid to water quality. Therefore, we recommend the use of PAM as a form of BMP in Ventura County, as studies have shown successful reduction rates, especially for furrow systems (Carol, 2007).

Based on current behavioral BMPs being implemented and studies that have shown pyrethroid reduction, our recommendations for behavioral BMPs include chemical and nonchemical practices. Implementation and improvement of IPM programs, less toxic alternative to pyrethroids, and the use of PAM are the BMPs our team recommends for reducing pyrethroid toxicity to TWG in coastal California.

5.4.1.2 Structural

Vegetative Filter Strips

Vegetative filter strips can remove up to 75% of TSS. Construction costs can often be supplemented through government-supported program, while maintenance costs are generally very low. The cost of VFS is estimated to cost $62.40/ acre, but is highly variable based on location (EPA, 2015).

Sediment Basins

Sediment basins can reduce up to 90% of TSS. The costs for sediment basins range from $600-$1,200 per drainage acre treated. The maintenance cost is expected to be about $3,000 per year per acre treated.

In agricultural regions of coastal California, our team recommends implementing VFS and sediment basins as structural BMPs. STEPL revealed that for OLW specifically, VFS can remove 75-100% of sediments, and are estimated to cost $0-$50,000 for construction and $100-$1400 per acre (BF Environmental). Maintenance costs may be coupled with other maintenance costs and reduce costs directly aimed for pyrethroid runoff reduction.

The NTT simulations that were run for an 83.2-acre plot located in OLW revealed that if an entire VFS can remove up to 70% of TSS for a blueberry field, while it can remove up to 76% of TSS in a dry bean field. For the simulations run for treating only 25% of the plot, VFS was still effective in removing at least 48% of TSS. Both STEPL and NTT agreed in the magnitude of pyrethroids that VFS can remove from a plot.

Currently, it appears no VFS have been implemented in OLW. VCAILG informed us that VFS have not been implemented due the extensive use of tile drains in Ventura County (personal communication, Nancy Broschart). However, VFS can be used in conjunction with tile drains that are often flooded.

In addition to VFS, sediment basins have been effective in removing 85-90% of TSS in past studies (Fiener et al., 2005; Markle, 2009; McCaleb and McLaughlin, 2008). NTT revealed that sediment basins were effective in removing up to 90% of TSS, which is consistent with the studies from our literature review. Sediment basins are also a cost effective solution and range in cost from $600-$1200 per drainage acre treated (California Stormwater BMP Handbook, 2003).

5.4.2 Urban

5.4.2.1 Behavioral

Implement a network/ communication system that informs applicators of rain events

A network or communication system can be implemented to inform applicators about expected rain events or probability of rain events, to be better prepared to adjust application scheduling.

Apply peak pyrethroid application earlier in dry season

Shift peak application period earlier in dry season. By applying pyrethroids earlier in the dry season, there is more time for pyrethroids to degrade and thus lowers concentrations in runoff off during rain events.

Apply pyrethroids in granules instead of in liquid form in impervious surfaces

When pyrethroids are applied on impervious surfaces, applying them in granular form can reduce runoff concentration. If possible, apply granular pyrethroids on impervious surface and transition to granular form.

Apply alternative to pyrethroids that are less toxic to fish.

Many household products are commonly used to remove persistent insects such as Argentine ants in California. Alternatives, such as boric acid, have been effective in removing Argentine ants and are not toxic to fish species.

Since most of the pyrethroids in runoff occur during large storm events, targeting behavioral changes around these times should be a higher priority. A communication-based BMP could target commercial applicators to make them aware of upcoming weather events and facilitate compliance with CDPR regulations. Regulations passed in 2012 forbid spraying pyrethroids before it rains, or when there is standing water present from recent rain (Section 11456, Food and Agricultural Code). The regulations do not define time periods before rain that would be considered appropriate to spray, and it is unclear how strictly these regulations are followed. Creating an information network, potentially through existing professional applicator groups, could increase awareness of impending wet weather events, and could improve the likelihood that applicators can adhere to these existing regulations.

Another behavioral BMP related to the threat rain events pose in transporting pyrethroids into sensitive water bodies could try to regulate more strongly pyrethroid use during months leading up to the wet season. The results of our geospatial model show that many areas have a peak in non-agricultural pyrethroid application in October-November. These months coincide with the beginning of California’s wet season making these pyrethroids available for runoff during the months with the highest average precipitation. Pyrethroids have an extended period of persistence on hard, concrete surfaces that would make them available for runoff during those wet months and be a significant source of pollution (Jiang et al., 2012). Research in Sacramento showed a single intense wet weather event was capable of transporting as much bifenthrin in a 3-hour period as would typically occur over 6 months with normal irrigation occurring (Weston et al., 2009). With the current rate of pyrethroid application peaking before the wet season starts, receiving water bodies are vulnerable to large pulses of pollution after the first storms in the year. Working with pesticide applicators to shift the height of pyrethroid application earlier in the dry season could reduce the risk of runoff during rain events and decrease the likelihood of large pulses of pollution in water bodies, which may have caused the fish kills that inspired this project.

Most of the urban pyrethroid application is applied by professional pesticide application, with over 95% of applications in liquid form (Environmental Solutions Group, 2010). When applied on wet surfaces, particularly impervious surfaces, pyrethroids in all forms have a higher runoff potential than on mulch or grass. In addition, a recent study showed that 91% of the annual load of tested pollutants were transported during storm events, justifying the strong relationship between pyrethroid runoff and storm events (Gilbreath and McKee, 2015). To improve upon current pyrethroid management plans, regulators should target the seasonal patterns in application and the form of application to reduce the runoff potential of pyrethroids. These techniques could be approached through additional regulation, training, and improved communication networks around existing regulations.

Along with practices regarding the time of application, the form in which pyrethroids are applied could reduce their runoff potential. As discussed earlier, pyrethroids are predominantly applied in the liquid form. Current regulations have tried to reduce the threat that spray form of pyrethroids pose by regulating use to pin-stream or spot treatment. However, studies have shown that when bifenthrin is applied in granular form, concentrations in runoff water are significantly decreased. While sprayed liquid application of bifenthrin led to runoff concentrations after 8 weeks that were toxic to aquatic organisms, bifenthrin applied in granular form reduced concentrations below detection levels after 8 weeks (Greenberg et al., 2010). This dramatic reduction in runoff potential after 8 weeks could inform regulations regarding pyrethroid application before the rainy season starts. If a shift from spray to granular application could be made, the threat that early season storms and pulses in pollution pose could be reduced.

In addition, alternatives to pyrethroids, such as boric acid, have been effective in removing insects that are treated with pyrethroid products. The Argentine ant has increasingly become an issue across California (Holway, 1995). In order to decrease the use of pyrethroids to treat persistent Argentine ants, boric acid could be used an effective alternative. Several studies show that boric acid is effective in removing Argentine ants from households if continuously applied at specified concentrations. Promoting the use of boric acid to Argentine ant eradicators can be a least-cost, easy transition from pyrethroid products to a product that does not pose the same harm as pyrethroids to fish species.

5.4.2.2 Structural

Urban Vegetative Filter Strips

VFS in urban areas, such as on the side of highways or parking lots have been effective in reducing 85% of pyrethroids from runoff. Urban VFS can be an effective BMP in urban areas where bifenthrin is heavily used, such as in Los Angeles and San Diego counties (CDPR, 2015).

Bioswales

Bioswales can remove up to 85% of pyrethroids in stormwater runoff. Bioswales can be effective in capturing pyrethroids in urban setting that have large parking lots. Although they can be costly, support from government programs, such as the Proposition 84 Stormwater Grant Program can be used to fund a portion of the costs.

In coastal California, structural BMPs that can be successful in removing pyrethroids from entering waterbodies include urban VFS and bioswales. While there are no urban VFS studies directly on its effectiveness on pyrethroids, VFS on the side of highways were effective in removing up to 85% of TSS (Han, 2005). In addition, bioswales can absorb low flows or carry runoff from heavy rain events. The only study found on bioswale effectiveness on pyrethroid removal was conducted in Salinas, California. Bioswales were tested for treating the runoff from parking lots, and on average removed 84% of pyrethroids from urban runoff (Anderson et al., 2016). Bioswales are effective in treating stormwater runoff for other chemicals as well and have been constructed in several coastal California counties including Ventura and Los Angeles (City of Santa Monica).

6 Discussion and Conclusions

With the increase of pyrethroid use across coastal California, it is important to understand and find solutions to mitigate their impacts on the sensitive species like the TWG. Through results of our project, it is clear that pyrethroid application and the type of pyrethroid varies substantially across coastal California and that it is mostly likely found in toxic levels to the TWG during certain times of the year at a number of important habitat locations. While California has one, if not the most, progressive pesticide use reporting and managing program in the world, statistics on pesticide use is only readily available at large time scales.

Effective pyrethroid management is difficult due to the sheer magnitude of products containing pyrethroids, and the differences in type of use for these products. For example, application in the Salinas watershed is almost entirely agricultural (93%), while in watersheds surrounding Los Angeles application is almost exclusively structural pest control (>99%). Other watersheds, such as Calleguas, apply pyrethroids between these extremes (35.7% non-agricultural), but experience peaks in agricultural and non-agricultural use at different times of year. Due to this variation in application period, each sector needs to be managed and treated with their own respective BMPs.

The geo-spatial model for pyrethroid use identified regions of heavy use of pyrethroids which have a higher risk of pyrethroid contamination. Using the OLW as a case study, the geo-spatial model narrowed down pyrethroid use to the smaller watershed level. Using this knowledge, the PWC model was then applied to estimate the EEC for the most-used pyrethroids in the OLW. Because of scarcity of active pyrethroid monitoring data, the PWC model provides an approach for predicting the risk to the TWG from pyrethroids.

With the limitation of data sources and studies specifically on pyrethroids, our project sought to provide a framework for the narrowing in on specific TWG critical habitat that are at-risk for pyrethroid contamination. With the products of our study, our team aims to inform and educate coastal California on the risks from pyrethroid contamination and possible solutions.

6.1 GeoSpatial Model

Risk Management Implications of Spatial and Temporal Variability in Pyrethroid Application at the Watershed Level

Watersheds containing TWG critical habitat experienced considerable differences in the levels of pyrethroids applied. The Salinas watershed, with 464 acres of TWG habitat, had over 42,000 pounds of pyrethroids applied, the greatest amount by far. Other watersheds like Santa Monica, Parajo, and Santa Maria also have TWG critical habitat and high rates of application. Some watersheds, such as the Smith, have large areas of critical habitat but very low rates of pyrethroid use. These differences across watersheds with critical TWG habitat highlight the importance of considering risk to the TWG at the watershed level. Focusing management efforts based on the amount of critical habitat for TWG and other species does not take into account that specific watersheds have considerably higher rates of use, and associated risk of toxicity.

The substantial temporal differences in application suggest that TWG, and other species with critical habitat through coastal California watersheds, may be at particularly high risk to pyrethroid toxicity during certain months. These risks should be thought about in the context of weather patterns around specific watersheds, as well as times of particular vulnerability for the TWG. In regions without much rain during the winter and early spring, the application of pyrethroids during spring and summer months increases the amount of pyrethroids resident in soil or in urban areas. This loading makes a watershed susceptible to large pulse of toxicity from a single large wet weather event that causes serious runoff. Continued loading and the threat of a pulse of pyrethroid runoff during these spring months coincides with peak TWG breeding during late April and early May. A wet weather event during TWG breeding has the potential to significantly impact a local population of TWG, as their nests burrow into the sediment that pyrethroids sorb to. The differences across watersheds in peak application time suggests that regulations aiming to reduce the risk to critical habitat should be tailored to specific watersheds, or times of year where application rates are highest in many watersheds.

Along with variation in when pyrethroids are applied, the distinction in type of uses (non-agricultural and agricultural) is an important factor to consider for managing risk. Certain watersheds considered experienced almost uniform use of either non-agricultural or agricultural applications. These extreme differences at individual watersheds could lead to different risk levels, depending on environmental factors in that watershed. For instance, a watershed with predominantly urban use may be more at risk after recent application to smaller storms with flashy conditions over areas covered by impervious surfaces. While watersheds that are predominantly agricultural could be at risk from large storms causing considerable sediment runoff, with high levels of pyrethroids built up in the sediment. Any BMPs that aim to mitigate the risk of pyrethroids within a watershed should be tailored to the predominant type of pyrethroid use and local conditions.

The importance of looking at pyrethroid use at the watershed level is highlighted with Ventura County statistics compared to the watersheds that make up the county. Pyrethroid use at a county resolution shows two main peaks in pyrethroid use in Ventura, the first in May driven by agricultural and the second, in October by non-agriculture. However, the three main watersheds that comprise Ventura County (Calleguas, Santa Clara, and Ventura River) have their own unique seasonality patterns and magnitudes (Figure 6.1). The

Calleguas watershed has the majority of pyrethroids application during the two peak periods. By only relying on county data, pyrethroid use in the Santa Clara and Ventura watershed is overestimated. These differences at watershed level resolution have important implications for managers, as they highlight the trends that are lost when looking solely at the county level CDPR data. Pyrethroid management strategies may be more likely to achieve goals of reducing toxicity and risk to critical habitat if management is applied at the watershed and not county level.

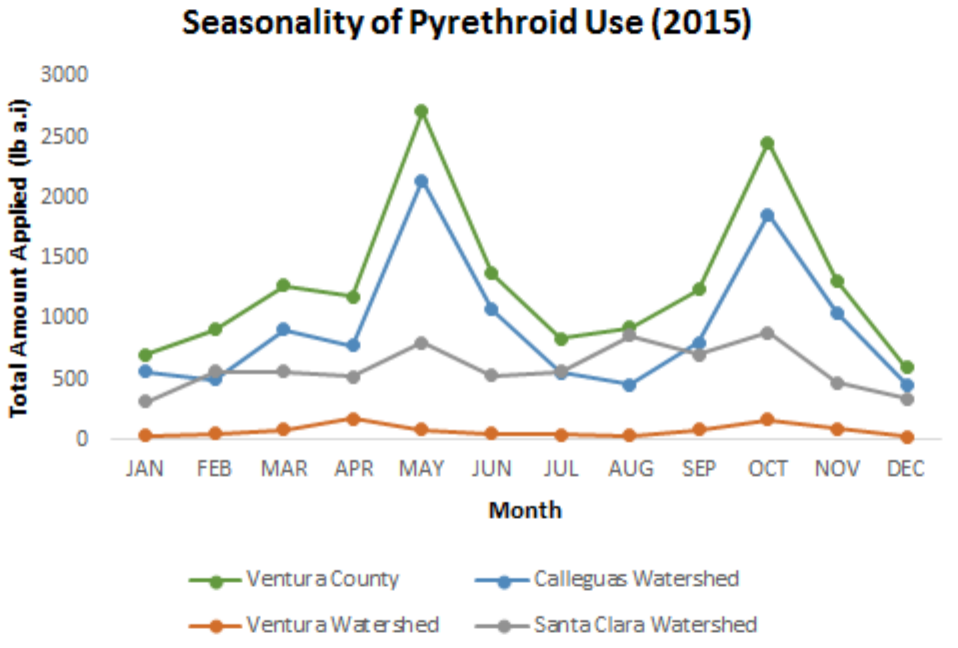


Figure 6.1. *Comparing Seasonality of Total Pyrethroid Use between Ventura County and its three watersheds: Calleguas, Ventura, and Santa Clara.*

Bifenthrin has its own unique use patterns compared to pyrethroids in general.

Bifenthrin was focused on throughout this project because of its heavy use near the OLW and its widespread detection throughout California. Bifenthrin's chemical properties allows for slow degradation in the environment and this has led to the compound being the largest source of toxicity in urban waters in California (Spot, 2015). Our analysis confirms that bifenthrin is applied heavily for non-agricultural uses and has its own spatial heterogeneity compared to total pyrethroids. Watersheds with the highest rates of bifenthrin use contained predominantly urban areas, with the exception of the Salinas watershed. Additionally, in nearly every watershed the percentage of non-agricultural bifenthrin use is greater than the non-agricultural pyrethroid use. These bifenthrin specific patterns lead to different temporal and spatial hotspots that can pose unique risks the TWG compared to pyrethroids in general. With 68% of Californians living in coastal counties as of the 2010 census, non-agricultural bifenthrin use that is concentrated in these urban centers puts

TWG critical habitat nearby at risk. Similar variation in patterns of use observed for bifenthrin likely occur for other pyrethroids as well and will be an important area of future research and management strategies.

Finer resolution mapping of sub-watersheds shows application concentrated near the coast.

By quantifying pyrethroid applications at the HUC12 level of Ventura County, we were able to further distinguish the temporal and spatial trends of pyrethroid use in regard to the TWG.

Importantly 3 main conclusions can be drawn:

- Only a few sub-watersheds that range from boarding TWG critical habitat out to around 5 miles away are responsible for the majority of pyrethroid use in the Calleguas watershed. These sub-watersheds also are highly channelized and therefore will transport water and sediments quickly during wet weather events with high levels of erosion. This combination puts the TWG in the Calleguas watershed at very high risk. This highlights that even within each large watershed, there can be high spatial variability in pyrethroid use.
- Bifenthrin use was specifically highly concentrated in a single HUC12 watershed that covers Oxnard's urban area. This use was almost entirely non-agricultural and overlaps with Ormond Lagoon. Bifenthrin use concentrated near the coast mirrors statewide trends and is likely driven by the more densely populated coastal areas where bifenthrin is predominantly used for structural pest control purposes and would potentially put aquatic species with critical habitat near urban centers at risk.
- In the case of Ormond Lagoon where use is concentrated in fairly small areas, BMPs could be concentrated over a small area by focusing on the three main sub-watersheds responsible for the majority of pyrethroid use. Additionally, these catchments will have their own agriculture versus non-agriculture use patterns that can be addressed at this resolution.

The OLW case study provides some important conclusions in regards to the state of pyrethroid contamination to the TWG throughout the state. The Calleguas watershed ranks as 2nd in bifenthrin use and 7th in total pyrethroid use for all watersheds containing TWG critical habitat.

Therefore, the TWG in other places (Los Angeles, San Francisco, Central Coast) may be at even greater risk. Further studies that examine use at smaller sub-watershed level resolution for these specific watersheds could help identify specific areas of high risk, and direct management strategies to maximize impacts.

Limitations

Some limitations pertaining to actual runoff risk and availability of pesticide data persist in the geo-spatial model. First, these models do not take into account actual runoff risk associated with the pyrethroid applications. As identified in the PWC model, different application types have a higher risk of pyrethroid runoff. Since our geo-spatial representation only takes into account actual pyrethroid applications, each watershed might have different runoff potential based on weather, type of use, soil properties and local hydrological conditions. Future projects could use a use-weighted analysis to estimate runoff potential since the use type is available in the PUR reports. Second, in order to estimate non-agricultural use by watershed we assumed homogeneous use throughout the county. While this is useful for estimating at a rough scale, and the only possible approach based on the format of the data provided by CDPR, other conditions such as wealth, pest presence, and infrastructure will likely highly affect non-agricultural use. For example, a residential area with a lower population density will most likely experience heavier users of pyrethroids than urban areas where many residents reside in high-rise buildings. Data on the locations of non-agricultural applications similar to the reporting for agricultural use would help improve the geo-spatial model.

Personal use of pyrethroids is another area that could be improved in the geo-spatial model with additional data. Personal use of pyrethroids is driven by people applying products commonly available at home improvement stores. Records of these sales are typically privately held information, but personal use has been estimated to account for 20% of total non-agricultural use in California (TDC, 2010). In this model the homogeneous per capita use calculations consistently overestimated non-agricultural use, within the range of this estimated percent that personal use accounts for in total non-agricultural use. However, these estimates are based on sales data from 2008 and aggregated for urban use statewide. Additionally, sales data does not necessarily mean that the product was used during that year. This estimate almost certainly varies at the county and watershed levels, and improved personal sales data would allow the geo-spatial model to better account for the impact of personal non-agricultural use.

6.2 PWC Model

Current pyrethroid applications in the OLW are contributing to environmental concentrations that are likely adversely affecting TWG both directly and indirectly.

The PWC demonstrated that under current use scenarios, bifenthrin, permethrin, and fenpropathrin are all likely contributing to TWG mortality directly and adversely affecting them indirectly. Using the BS fry toxicity threshold was born out of necessity, there is currently no definitive pyrethroid toxicity data for TWG. Without these specific data, monitored and EECs cannot be used definitively to understand the risk to TWG populations. Using BS fry as a surrogate, LC of pyrethroids killing at least 50% of the TWG population are predicted to be exceeded multiple times a year on average. Additionally, the combined effect of pyrethroid toxicity in the environment is poorly understood, but the effects are likely to be greater when toxic thresholds are surpassed for multiple pyrethroids simultaneously, which is likely to occur in the OLW.

The predicted timing of LC of pyrethroids in the water column were highly correlated with the southern California coastal rainy season. As assumed based on their strong hydrophobicity, it appears pyrethroids are mobilized off of their application environment and into Ormond Lagoon via precipitation events. The fish kill that occurred in 2015 that began USFWS' interest in the toxicity of pyrethroids to fish occurred following an unusual summer rain that occurred during peak pyrethroid applications to strawberries.

The sediment concentrations of pyrethroids in Ormond Lagoon are predicted to follow a similar cycle, but a few months delayed, generally peaking in late winter and early spring. This directly coincides with TWG peak spawning and the most sensitive stages of the TWG life cycle, egg and larval stages. Although they are capable of breeding year-round in the warmest reaches of their distribution, in more temperate climates breeding is relegated to spring (USFWS, 2014). Because of the short life span of TWG, usually a single year, if spawning occurs with high environmental concentrations of pyrethroids in the sediments and/or water column, the results could quickly lead to local extirpation.

The seasonally lethal direct effects of pyrethroid toxicity are complemented by exceedingly common and lethal indirect effects on the TWG food source. The LC_{50} of bifenthrin for *H. Azteca* was exceeded in more than 99% of the days modelled. This indicates sizeable reductions in the availability of prey species, which may limit the growth and general viability of TWG populations.

It is important to note that the peak water column concentrations, as well the peak sediment concentrations for bifenthrin and permethrin occur during the same season (Figure 6.2). The combined toxic effect of bifenthrin and permethrin are not well understood, but it can be assumed that when LC occur in tandem, the effects are cumulative. With multiple stressors on the population occurring in tandem, TWG populations are threatened more severely.

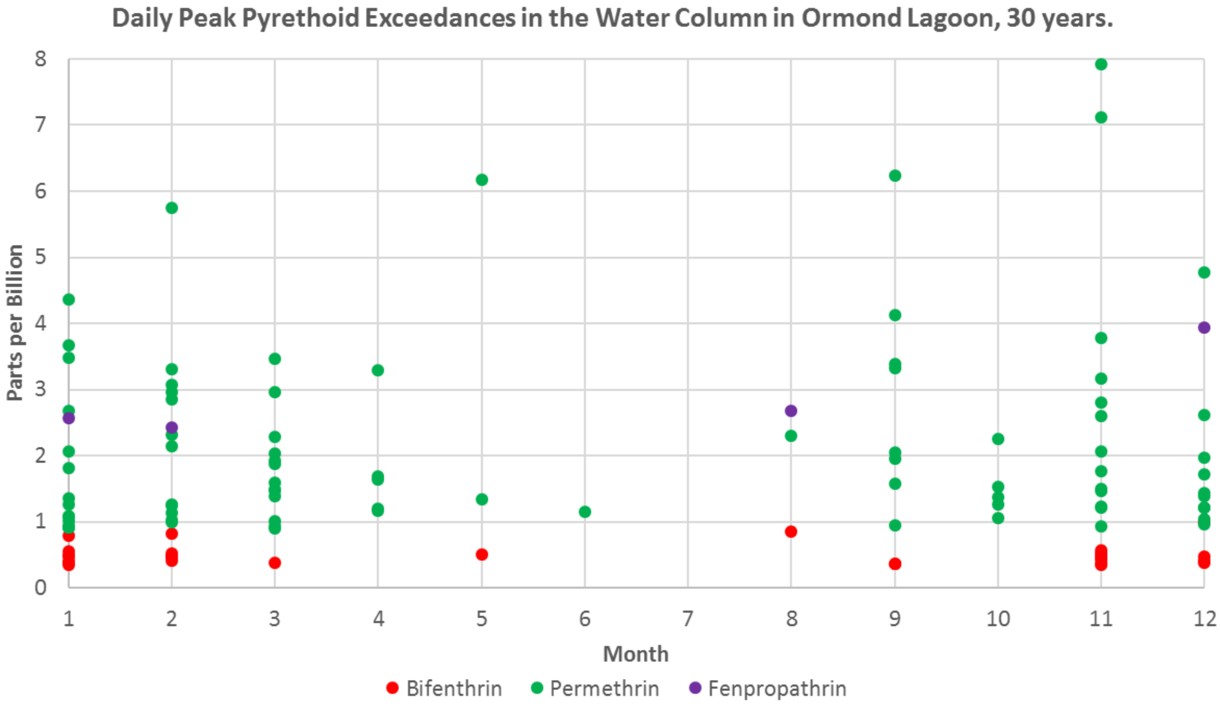


Figure 6.2. *Daily peak pyrethroid exceedances in the water column in OLW over 30 years.*

Strawberry and professional applications on impervious surfaces are the most significant sources of pyrethroids in the Ormond Lagoon.

The expected sources of pyrethroids in the Ormond Lagoon are dependent on the specific compounds, but strawberry production and professional applications on impervious surfaces supply the vast majority of bifenthrin, permethrin, and fenpropathrin to Ormond Lagoon. Strawberry production contributes over 80% of bifenthrin and over 98% of fenpropathrin during daily peak water columns exceedances. Professional applications on impervious surfaces contributed over 70% permethrin in Ormond Lagoon in daily peak water column exceedances.

The model results indicate the broader effects pyrethroids have on aquatic ecosystems.

Besides direct or indirect toxicity to TWG, pyrethroids have broader effects on diverse aquatic species, including salmonids, Japanese rice fish, fathead minnows, mysids, and water fleas. Based on LC_{50} database collected by EPA protocols (ECOTOX database; US-EPA, 2018), 0.35 µg/L (a 96-hr LC_{50} to BS fry) of bifenthrin would also be acutely toxic to around 25% of overall aquatic species. The predicted peak concentration of bifenthrin (1 ug/L) would impact around 35% of aquatic species. In the case of permethrin, a dose of 0.9 µg/L (a 96-hr LC_{50} to BS fry) would be even more toxic to influence over 30% of aquatic species. Fenpropathrin is the least toxic of the three, but it would still influence 20% of aquatic species with a concentration of 2.2 µg/L (a 96-hr LC_{50} to BS juveniles). If linked to predicted values in the PWC for peaks of permethrin (8 µg/L) and fenpropathrin (4 µg/L), ecological wide effects would be 60% and 35% respectively. Generally, salmonids, mysids, and water fleas are the most vulnerable species to pyrethroids.

Summary

The combined effects of peak aqueous concentration toxicity, peak sediment bound concentration toxicity, and peak benthic zone aqueous concentration indirect toxicity, inform our determination of current pyrethroid use to be likely adversely affecting the TWG population of Ormond Lagoon (Figure 6.3). Ormond Lagoon was selected as a case study because of historical bifenthrin related fish kills and close proximity to the research team, but there are other USFWS regulated critical habitats for TWG whose watersheds receive much larger loadings of pyrethroids. The ecological risk associated with pyrethroids, specifically bifenthrin and permethrin are likely to be frequent across the TWG range and higher for other critical populations, like those in the Salinas Watershed.

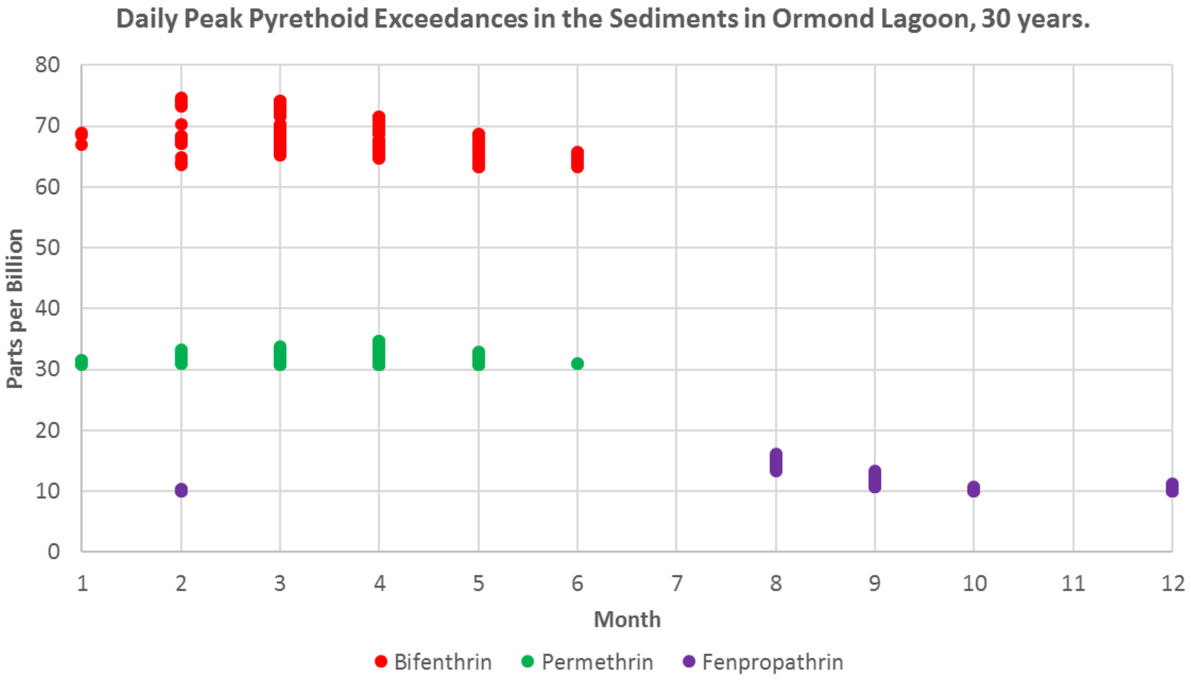


Figure 6.3. *Daily peak pyrethroid exceedances in the sediments in OLW over 30 years.*

6.3 Sampling

Overall, sampling results validate various aspects of the PWC model. First, the sampling events confirm that more types of pyrethroids were found at higher concentrations in both water and sediment samples after rainfalls. Additionally, the PWC model indicated that strawberry production was a significant contributor of pyrethroids to Ormond lagoon. This is confirmed by the sampling result in two ways:

- During the January 2018 sampling event, fenpropathrin was found in most water samples. Our analysis of the CDPR data indicates that fenpropathrin is only used for strawberry production.
- Among all sites, higher pyrethroid concentrations were always observed at the two sampling sites in the Oxnard Industrial Drain. The Oxnard Industrial drain primarily drains the agricultural areas within OLW.

Notably, low concentrations of lambda-cyhalothrin has been applied in the watershed according to the PUR report. However, high concentrations were found in water samples. Possible reasons for finding high concentrations are that sources of lambda-cyhalothrin were applied by homeowners in lawns and gardens or users have dramatically increased their use since 2015. These results highlight the dynamic nature of pesticide use, and more research should be done to detect the influence of unreported application of pyrethroids on OLW.

In order to close the knowledge gap on the dynamics of pyrethroid concentrations, more pyrethroid sampling events must take place. The results from our sampling events were much lower than the values predicted from the PWC model. As we took samples over two weeks after a rainfall, we did not capture the peak concentration of pyrethroids from a flush. More sampling events should be designed before and after rain seasons to understand long-term and peak concentrations of pyrethroids in OLW.

In addition, we can improve on our PWC model inputs by collecting more data. Whereas we used the results from our water or sediment samples to inform more site-specific values, such as organic factors, other parameters we used to populate the model were from CEDEN's dataset. Because of artificial errors, we had to use values from published research instead.

6.4 Best Management Practices

Through the literature review and model outputs, there are several feasible BMPs that can be further implemented in coastal California. For the agricultural sector, especially in Ventura County, there are many behavioral BMPs that are strictly and successfully implemented and have proven to be the cause of pyrethroid reduction. Because of organizations, such as VCAILG and UC IPM, funding, and education for behavioral BMPs has reached a majority of pyrethroid users in Ventura County.

By combining the results of our project with the BMP results, we can more effectively implement BMPs in the following ways:

- The characterization of pyrethroid use in California highlights the most intensive urban and agricultural pyrethroid use. By utilizing this information, appropriate

BMPs for each region can be recommended more specifically. Particularly, since bifenthrin is the most widely used pyrethroid, areas with highest bifenthrin use should be targeted as priority areas for BMP implementation.

- While IPM programs have been well-developed over the years, they can be tailored to reduce effects on coastal species. Specifically, BMPs can be implemented in watersheds that are both heavy users of pyrethroids and within TWG habitats.
- For both the urban and agriculture sector, the most feasible BMP is VFS, however they are often not used as a form of BMP. For example, although both STEPL and NTT informed our team of the effectiveness of VFS, there are no farms in Ventura County that implement VFS as a BMP in OLW. Although there is concern about the use of VFS with tile drains, there are ways to use both structures at the same time. In addition, tile drains are not effective in trapping pyrethroids, and therefore key structural alternatives must be implemented for pyrethroids.
- Investments in costlier BMPs can benefit heavy pyrethroid using communities in the long run. Especially for urban areas, where sources of pyrethroids are less known, investments in large scale structural BMPs, such as bioswales, that treat a larger area would be worthwhile investments.
- Lack of studies and BMPs targeted specifically for pyrethroids have guided our BMP recommendation on the basis of effectiveness for removing TSS. However, more studies on BMP effectiveness directly on pyrethroids could be helpful to recommend more specific BMPs for pyrethroid users.
- The key behavioral change in the urban sector is awareness of rain events and their impacts on pyrethroid transport. Since data on urban application is limited, putting in efforts such as communicating can be cost-effective and reach many people.

In addition to making BMP recommendations, our team created a flyer to inform the OLW community about TWG and pyrethroid toxicity. The flyer briefly explains the current situation and inspiration for our project and ways to reduce pyrethroid impacts as a member of the OLW. Using the flyer as a form of outreach, our team hopes that OLW community members will decide to make small changes and collectively improve the environment for fish and wildlife.

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8 Appendices

Appendix A: Pyrethroid Properties

Table 8.1. *Chemical and physical properties of the pyrethroids. All data provided by CDPR unless otherwise indicated.*

	MW	Water Solubility (mg/L 25°C)[a]	Kh (atm m³ mol)	Log Kow	BCF (bluegill sunfish)[b]	Soil Adsorption Koc
Bifenthrin	422.9	0.1	7.20E-03	6	6090	5.37
Cyfluthrin	434.3	0.002	3.70E-06	5.74	719	4.8
Cypermethrin	416.3	0.004	3.40E-07	6.6	597	5.49
Esfenvalerate	419.9	0.006	1.40E-07	4	2390	4
Fenpropathrin	349.4	0.014	6.30E-07	6	359	4.63
Cyhalothrin	449.9	0.003	1.90E-07	6.9	2240	5.51
Permethrin	391.3	0.006	1.40E-06	6.1	558	5.44
Pyrethrin	372.4	125.6	7.40E-10	3.56	300	3.31
Flauvalinate	502.9	0.002	3.05E-05	4.3	14000	6.04

a. USDHHS 2003

b. Laskowski 2002

Table 8.2. *Use and persistence data for pyrethroids in study area in 2015. All data provided by CDPR.*

	Lbs Applied 2015	Primary Use	Hydrolysis Half-Life, days		Photoylsis, days		Half-Life, days		
			pH 7	*pH 9*	*Water*	*Soil*	*Aerobic soil*	*Anaerobic Soil*	*Aquatic*
Bifenthrin	6048.4	Structural Pest Control	Stable	Stable	408	97	96	Stable	276
Cyfluthrin	608.8	Structural Pest Control	183	1.8	0.67	5	12	34	3
Cypermethrin	169.8	Structural Pest Control	274	1.9	30	165	28	55	7.4
Esfenvalerate	196.92	Cabbage	Stable	Stable	17	10	39	90	72
Fenpropathrin	2131.6	Strawberry	555	14	603	4.5	22	276	-
Lambda Cyhalothrin	195	Cabbage	Stable	8.7	25	54	43	-	-
Permethrin	3222.3	Nursery	Stable	242	110	104	40	197	38.2
Tau Fluvalinate	179.4	Nursery	22.5		4	-	4	-	22.5
Pyrethrin	714	Celery	Stable	Stable	<1	<1	9.5	86	10.5

Appendix B: Regulations

California Code of Regulations, Title 3, Division 6, Chapter 4, Subchapter 5, Article 1, Section 6970

6970. Surface Water Protection in Outdoor Nonagricultural Settings.

The provisions of this section apply to any person performing pest control for hire, including landscape maintenance gardeners, when any of the following pesticides is applied outdoors to structural, residential, industrial, and institutional sites:

bifenthrin
bioallethrin
S-bioallethrin
cyfluthrin
beta-cyfluthrin
gamma-cyhalothrin
lambda-cyhalothrin
cypermethrin
deltamethrin
esfenvalerate
fenpropathrin
tau-fluvalinate
permethrin
phenothrin

prallethrin
resmethrin
tetramethrin

(a) Except when prohibited in (e), applications to the soil surface, mulch, gravel, lawn, turf, or groundcover must be made using only the methods described below:

(1) Spot treatment
(2) Pin stream treatment of one-inch wide or less
(3) Perimeter band treatment of three feet wide or less from the base of a building outward
(4) Broadcast treatment but not within two feet from any horizontal impervious surface. Pin stream treatment of one-inch wide or less may be made within the two-foot area.
(5) For broadcast treatment of termiticides to preconstruction sites, prior to precipitation, the treatment site must be covered with a waterproof covering, such as a polyethylene sheet, or a concrete slab must be poured over the treated soil.

(b) Except when prohibited in (e), applications to windows and doors, and horizontal impervious surfaces must be made using only the methods described below:

(1) Spot treatment
(2) Crack and crevice treatment
(3) Pin stream treatment of one-inch wide or less

(c) Except when prohibited in (e), applications to vertical structural surfaces, such as walls, foundations, and fencing, must be made using only the methods described below:

(1) Spot treatment
(2) Crack and crevice treatment
(3) Pin stream treatment of one-inch wide or less
(4) Perimeter band treatment up to a maximum height of two feet above the grade level.

(d) Except when prohibited in (e), for applications using granules to the soil surface, mulch, gravel, lawn, turf, or groundcover, the applicator shall sweep any granules that land on horizontal impervious surfaces onto the treatment site.
(e) The following applications are prohibited:

(1) To any site during precipitation, except for applications made to the underside of eaves;
(2) To the soil surface, mulch, gravel, lawn, turf, groundcover, or horizontal impervious surfaces with standing water, including puddles;
(3) To a sewer or storm drain, or curbside gutter;
(4) To the following components of a constructed drainage system that drains to a sewer or storm drain, curbside gutter, or aquatic habitat:

(A) Visible drainage grate connected to a drain pipe; or

(B) Visible french drain, or a landscaped dry river bed, swale or trench filled with gravel or rock;
(5) To the soil surface, including preconstruction termiticide sites, mulch, gravel, lawn, turf, groundcover, or horizontal impervious surfaces within 25 feet of aquatic habitat located downgradient from the application. The applicator shall measure the distance from the high water mark or intermittent streams that are dry from the top of the near bank; or
(6) To the preconstruction termiticide site within 10 feet of a storm drain located downgradient from the application.

(f) Application to plants, shrubs, or trees where there is standing water in the dripline or perimeter of the plants, shrubs, or trees is prohibited.
NOTE: Authority cited: Section 11456, Food and Agricultural Code.
Reference: Sections 11456 and 11501, Food and Agricultural Code.

Appendix C: Toxicity Tables

Table 8.3. *LC_{50} of bifenthrin on potential surrogates for TWG.*

Order	Species	Duration (Hours)	LC_{50} (µg/L)	Reference
Perciformes	Bluegill sunfish (*Lepomis macrochirus*)	96	0.35	USDA Forest Service, 2015
Clupeiformes	Gizzard shad (*Dorosoma cepedianum*)	8 days	0.21	Drenner et al. 1993
Cypriniformes	Fathead minnow (*Pimephales promelas*)	96	0.78	Fojut et al. 2012
	Sheephead minnow (*Cyprinodon variegatus*)	96	18.65	USDA Forest Service, 2015; Harper et al. 2008
	Zebra fish (*Danio rerio*)(fry)	96	2.1	Zhang et al. 2010
	Zebra fish (embryo)	6 days	190	DeMicco et al. 2010
	Common carp (*Cyprinus carpio*)	96	5.8	Velisek et al. 2009

Table 8.4. *LC_{50} of permethrin on potential surrogates for TWG.*

Order	Species	Duration (Hours)	LC_{50} (µg/L)	Reference
Perciformes	Bluegill sunfish (*Lepomis macrochirus*)	48	1.8	Başer et al, 2003
Salmoniformes	Rainbow trout (Salmo gairdneri)	96	6.43	Kumaraguru and Besmish (1981)
		48	14	Glickman et al. (1981)
		24	25.8	Holcombe et al. (1982)
	Atlantic salmon (Salmo salar)	96	8.8	Zitko et al. (1977)
		96	12	McLeese et al. 1980
Cypriniformes	Common bleak (Alburnus alburnus)	96	4 to 8	Linden et al. 1979
	Sheepshead minnow (*Cyprinodon variegatus*)	96	7.8	Schimmel et al. 1983
Atheriniformes	Atlantic silverside (*Menidia menidia*)	96	2.2	Schimmel et al. 1983
Mugiliformes	Flathead grey mullet (*Mugil cephalus*)	96	5.5	Schimmel et al. 1983

Table 8.5. *LC$_{50}$ of fenpropathrin on potential surrogates for TWG.*

Order	Species	Duration (Hours)	LC$_{50}$ (µg/L)	Reference
Perciformes	Bluegill sunfish (Lepomis macrochirus)	96	2.3	Kegley et al. 2012
Salmoniformes	Rainbow trout (*Salmo gairdneri*)	96	2.3	Kegley et al. 2012
Cypriniformes	Grass Carp (*Ctenopharyngodon idellus*)	48	3.59	USDA Forest Service 2015
	Sheepshead minnow (*Cyprinodon variegatus*)	96	3.1	USDA Forest Service 2015
	Western Mosquitofish (*Gambusia affinis*)	48	1.3	USDA Forest Service 2015

Table 8.6. *LC$_{50}$ and EC$_{50}$ for bifenthrin on aquatic invertebrates (Source: USDA Forest Service, 2015)*

Class	Order	Species	Duration (Hours)	LC$_{50}$ (ng/L)	EC$_{50}$ (ng/L)	Endpoint for EC$_{50}$
Malacostraca	Amphipoda	*Hyalella azteca*	96	4.55	2.91	Swimming
		Gammarus pulex	48	ND	110	ND
	Mysida	*Americamysis bahia*	96	3.97	ND	ND
	Decapoda	*Palaemonetes pugio*	96	20	ND	ND
			24	42.7	ND	ND
Insecta	Trichoptera	*Hydropsyche sp*	96	ND	12.8	Movement
		Nectopsyche sp.	96	ND	186	Swimming
		Helicopsyche sp.	96	ND	251	Movement
		Hydropsyche and Cheumatopsyche sp.	24	7200	ND	ND
	Ephemeroptera	*Hexagenia sp.*	96	ND	15.3	Swimming
			96	ND	390	NOS
		Diphetor hageni	48	50.9	18.7	Swimming
		Baetis tricaudatus	48	ND	35.5	Swimming
		Serratella micheneri	48	97.4	79.4	Swimming
		Fallceon quille	48	443	183	Swimming
		Heptageniidae sp.	24	2300	ND	ND
	Plecoptera	*Isoperla quinquepunctata*	96	28.5	16.3	Clinging
		Taenionema sp.	96	ND	36.5	Swimming
	Diptera	*Chironomus tentans*	96	ND	51	Growth
		Simulium vitallium	24	1300	ND	ND
	Odonata	*Enellagma and Ishnura spp.*	24	1100	ND	ND
	Coleoptera	*Hydrophilus sp.*	24	5400	ND	ND
Branchiopoda	Cladocera	*Ceriodaphnia dubia*	24	ND	310	NOS
			48	70	ND	ND
			96	106.7	ND	ND
		Daphnia magna	48	546.3	1600	Immobility
			24	ND	3340	Hyperactivity
	Anostraca	*Thamnocephales platyurus*	24	5700	ND	ND
Bivalvia	Ostreoida	*Crassostrea virginica*	48	ND	285000	Growth

Table 8.7. LC$_{50}$ of pyrethroids for *H. Azteca. (Source: ECOTOX database, US-EPA, 2018; Ding et al., 2011; Amweg et al. 2006)*

Duration	Bifenthrin (µg/L)	Permethrin (µg/L)	Fenpropathrin (µg/L)
Water Column			
96 h	4.55 ng/L	20 ng/L	ND
10 d	1.30 ng/L	48.9 ng/L	ND
Sediment			
10 d	4.5 ng/g dry weight	90.3 ng/g dry weight	24.3 ng/g dry weight
10 d	0.18 µg/g OC	4.88 µg/g OC	1.57 µg/g OC

Table 8.8. *Toxicity of pyrethroids for TWG invertebrate prey. (Source: ECOTOX database, US-EPA, 2018)*

Pyrethroids	Species	Duration	LC$_{50}$ (µg /L)
Bifenthrin	*Americamysis bahia*	96 h	0.00397
	Chironomus tentans	10 d	0.4
Permethrin	*Cyria sp.*	48 h	5
	Chironomus decorus	24 h	4.5
	Chironomus riparius	24 h	16.6
	Chironomus tentans	96 h	10.4
Fenpropathrin	*Chironomus tentans*	10 d	0.02

Table 8.9. *Chronic effects of bifenthrin on aquatic invertebrates (Source:USDA Forest Service, 2015).*

Class	Order	Species	NOAEC (ng/L)	LOAEC (ng/L)
Malacostraca	Amphipoda	*Hyalella azteca*	0.17	0.34
		Leptocheirus plumulosus	5	13
	Mysida	*Mysidopsis bahia*	1.2	1.3
Branchiopoda	Cladocera	*Daphnia magna*	1.3	2.9
			4	20
			10	20
			20	40

Appendix D: PWC Model

Model Parameters

Chemical

Source levels:

1 Preliminary Comparative Environmental Fate and Ecological Risk Assessment for the Registration Review of Eight Synthetic Pyrethroids and Pyrethrins, Part II. Assessing Outdoor Urban Uses of Pyrethroids. U.S. EPA (2016)
2 Risks of Bifenthrin Use….Tidewater Goby (*Eucyclogobious newberryi*). U.S. EPA (2012)
3 Environmental Fate of Permethrin. California Department of Pesticide Regulation. (2003)
4 Fenpropathrin. National Center of Biotechnology, PubChem Open Chemistry Database.
5 Fenpropathrin, Risk Characterization Document. California Environmental Protection Agency. (1994)
6 Fenpropathrin. University of Hertfordshire Pesticide Properties Database (1999)

Table 8.10. Physicochemical properties of bifenthrin, used as inputs for the PWC.

Physicochemical Inputs for PWC, Bifenthrin

Property	Value and Units	Source
Sorption Coefficient (Kd)	3,104 L/kg	1
Water Column Metabolism Half-life	466.2 Days	1
Water Reference Temperature	20 Degree° Celsius	1
Benthic Metabolism Half-life	650.2 Days	1
Benthic Reference Temperature	20 Degree° Celsius	1
Aqueous Photolysis Half-life	49 Days	1
Photolysis Reference Latitude	40° North	1
Hydrolysis Half-life	0 Days	1
Soil Half-life	169.2 Days	1
Soil Reference Temperature	25 Degree° Celsius	1
Foliar Half-life	35 Days	1
Molecular Weight	422.9 g/mol	1
Vapor Pressure	0.000000181 Torr	1
Solubility	0.000014 mg/L	1
Henry's Constant	0.0072	2

Table 8.11. Physicochemical properties of permethrin, used as inputs for the PWC.

Physicochemical Inputs for PWC, Permethrin

Property	Value and Units	Source
Sorption Coefficient (Koc)	81,600 L/kgoc	3
Water Column Metabolism Half-life	56.7 Days	1
Water Reference Temperature	25 Degree° Celsius	1
Benthic Metabolism Half-life	193 Days	1
Benthic Reference Temperature	25 Degree° Celsius	1
Aqueous Photolysis Half-life	94 Days	1
Photolysis Reference Latitude	40 ° North	1
Hydrolysis Half-life	242 Days	3
Soil Half-life	39.5 Days	3
Soil Reference Temperature	25 Degree° Celsius	3
Foliar Half-life	35 Days	1
Molecular Weight	391.28 g/mol	3
Vapor Pressure	0.000000015 Torr	3
Solubility	0.0055 mg/L	3
Henry's Constant	0.0000001	3

Table 8.12. Physicochemical properties of bifenthrin, used as inputs for the PWC.

Physicochemical Inputs for PWC, Fenpropathrin

Property	Value and Units	Source
Sorption Coefficient (Koc)	5,000 L/kgoc	6
Water Column Metabolism Half-life	1,168 Days	1
Water Reference Temperature	20 Degree° Celsius	1
Benthic Metabolism Half-life	674 Days	1
Benthic Reference Temperature	25 Degree° Celsius	1
Aqueous Photolysis Half-life	0.125 Days	1
Photolysis Reference Latitude	40 ° North	1
Hydrolysis Half-life	0 Days	1
Soil Half-life	497 Days	1
Soil Reference Temperature	25 Degree° Celsius	1
Foliar Half-life	35 Days	1
Molecular Weight	349.4 g/mol	4
Vapor Pressure	0.0000000139 Torr	5
Solubility	0.33 mg/L	5
Henry's Constant	0.00018	4

Application Extents- Non-agricultural

Table 8.13. *Residential plot measurements used in calculations to determine non-agricultural, residential pyrethroid application extents for the PWC.*

OLW Residential Plot Measurements

Parameter	Value and Unit
Total Plot Area	10,890 ft^2
Houseprint Area	4,241 ft^2
Houseprint Side Length	65.1 ft
House Perimeter, Impervious	245.4 ft
House Perimeter, Pervious	15 ft
Patio Total Area	957 ft^2
Patio Side Length	30.9 ft
Driveway/Sidewalk Area	1,632 ft^2
Driveway/Sidewalk Side Length	40.3 ft

Application Extent Calculations

Impervious pin streamhouse perimeter / wall treatments

-Treatment area ground = (65.1ft * 4 sides - 15ft over grass) * 1 inch = 20.45ft^2

-Treatment area wall = (65.1ft * 4 sides - 15ft over grass) * 1 inch = 20.45ft^2

-Total treatment area per plot= 40.9 ft^2 (0.37% of the plot), 0.21% of the watershed

Pervious house perimeter and wall treatments

-Treatment area ground = 15 ft * 3 ft = 45ft^2

-Treatment area wall = 15ft * 2ft = 30ft^2

-Total treatment area per plot=75ft^2 (0.68% of the plot), 0.40% of the watershed

Impervious patio surface perimeter

-Treatment area ground = (30.9ft* 4 sides) * 1 inch = 10.29ft^2

-Total treatment area per plot=10.29ft^2 (0.09% of the plot), 0.056% of the watershed

Impervious sidewalk and driveway

Treatment area ground = (40.3ft* 4 sides) * 1 inch= 13.43ft^2

-Total treatment area per plot=13.43 ft^2 (0.12% of the plot), 0.073% of the watershed

Impervious perimeter and wall treatments and doors

Treatment area ground = (188.5ft *4 sides) * 1 inch = 62.83ft^2
Treatment area wall = (188.5fr *4 sides - 75 ft of doors) * 1 inch= 62.83ft^2
-Total treatment area per plot=125.66 ft^2 (0.11% of the plot), 0.028% of the watershed)

Table 8.14. *Watershed wide extents of structural pest control, non-agricultural, pyrethroid applications used for the PWC.*

OLW Actual Residential + Commercial Application Extents

Area	Value and Unit	Percent of Watershed Area
Professional Impervious Applications	10.76 Hectares	0.332%
Professional Pervious Applications	2.65 Hectares	0.082%
Personal Impervious Applications	10.76 Hectares	0.332%
Personal Pervious Applications	2.65 Hectares	0.082%

Application Extents- Agricultural

Table 8.15. *The MTRSs of the Ormond Lagoon Watershed and the crop extents therein receiving bifenthrin applications.*

MTRS	Celery	Raspberry	Strawberry	Total
S01N22W02	-	-	322	322
S01N22W11	-	-	87	87
S01N22W14	59	105	50	214
S01N22W22	-	15	53	68
S02N22W35	-	-	-	0
Total	**59**	**120**	**512**	**691**
Total Percent	**9%**	**17%**	**74%**	**100%**

Table 8.16. *The MTRSs of the Ormond Lagoon Watershed and the crop extents therein receiving permethrin applications.*

MTRS	Flowers	Celery	Lettuce	Total
S01N22W02	-	-	-	0
S01N22W11	85	88	-	173
S01N22W14	-	58	-	58
S01N22W22	-	-	110	110
S02N22W35	-	-	-	0
Total	**85**	**146**	**110**	**341**
Total Percent	**25%**	**43%**	**32%**	**100%**

Table 8.17. *The MTRSs of the Ormond Lagoon Watershed and the crop extents therein receiving fenpropathrin applications.*

MTRS	**Strawberry**	**Raspberry**	**Total**
S01N22W02	227	-	227
S01N22W11	52	-	52
S01N22W14	50	-	50
S01N22W22	15	53	68
S02N22W35	-	-	0
Total	344	53	**397**
Total Percent	87%	13%	100%

Application Loads- Non-Agricultural

Table 8.18. *Bifenthrin loads and schedules for non-agricultural applications used in the PWC.*

Month	**Professional Total (lbs)**	**Personal Total (lbs)**	**Professional Impervious (kg/ha)**	**Professional Pervious (kg/ha)**	**Personal Impervious (kg/ha)**	**Personal Pervious (kg/ha)**
JAN	6.905	1.726	0.413	0.102	0.046	0.004
FEB	12.962	3.240	0.775	0.191	0.086	0.007
MAR	29.160	7.290	1.744	0.430	0.193	0.016
APR	8.976	2.244	0.537	0.132	0.059	0.005
MAY	28.507	7.127	1.705	0.421	0.189	0.016
JUN	4.929	1.232	0.295	0.073	0.033	0.003
JUL	11.031	2.758	0.660	0.163	0.073	0.006
AUG	6.237	1.559	0.373	0.092	0.041	0.003
SEP	10.391	2.598	0.622	0.153	0.069	0.006
OCT	55.882	13.970	3.342	0.825	0.370	0.030
NOV	29.684	7.421	1.775	0.438	0.196	0.016
DEC	5.217	1.304	0.312	0.077	0.035	0.003
TOTAL	**209.881**	**52.470**	**12.553**	**3.098**	**1.389**	**0.114**

Table 8.19. *Permethrin loads and schedules for non-agricultural applications used in the PWC.*

Kilograms of Active Ingredient Permethrin Non-Ag Use in OLW

Month	Professional Total (lbs)	Personal Total (lbs)	Professional Impervious (kg/ha)	Professional Pervious (kg/ha)	Personal Impervious (kg/ha)	Personal Pervious (kg/ha)
JAN	3.894	0.973	0.215	0.053	0.026	0.002
FEB	3.199	0.800	0.177	0.044	0.021	0.002
MAR	3.273	0.818	0.181	0.045	0.022	0.002
APR	4.176	1.044	0.231	0.057	0.028	0.002
MAY	2.929	0.732	0.162	0.040	0.019	0.002
JUN	3.526	0.881	0.195	0.048	0.023	0.002
JUL	3.487	0.872	0.192	0.047	0.023	0.002
AUG	3.690	0.923	0.204	0.050	0.024	0.002
SEP	4.479	1.120	0.247	0.061	0.030	0.002
OCT	4.466	1.116	0.247	0.061	0.030	0.002
NOV	3.503	0.876	0.193	0.048	0.023	0.002
DEC	3.055	0.764	0.169	0.042	0.020	0.002
TOTAL	**43.676**	**10.919**	**2.411**	**0.595**	**0.289**	**0.024**

Agricultural Loads- Bifenthrin

Table 8.20. *Strawberry bifenthrin loads for agricultural applications used in the PWC.*

Day	Month	Commodity	Planted_Units	Prod_name	Quantity_Used	Quantity_Units	Treated_Amount	Treated_Units	Appl_Meth	MTRS	Bifenlbs_app	kg	kg/ha
9	2	STRAWBERRY	ACRES	BRIGADE WSB	38	Pounds	38	ACRES	Ground	S01N22W02	3.8	1.7236496	0.008318812
11	4	STRAWBERRY	ACRES	BRIGADE WSB INSECTICIDE/MITICIDE	32.3	Pounds	32.3	ACRES	Ground	S01N22W11	3.23	1.46510216	0.00707099
21	4	STRAWBERRY	ACRES	BRIGADE WSB INSECTICIDE/MITICIDE	63.99	Pounds	63.99	ACRES	Ground	S01N22W02	6.399	2.902535208	0.014008442
2	5	STRAWBERRY	ACRES	BRIGADE WSB INSECTICIDE/MITICIDE	44	Pounds	44	ACRES	Ground	S01N22W14	4.4	1.9958048	0.009632309
4	5	STRAWBERRY	ACRES	BRIGADE WSB INSECTICIDE/MITICIDE	52.5	Pounds	52.5	ACRES	Ground	S01N22W22	5.25	2.381358	0.011493096
5	5	STRAWBERRY	ACRES	BRIGADE WSB INSECTICIDE/MITICIDE	52.5	Pounds	52.5	ACRES	Ground	S01N22W22	5.25	2.381358	0.011493096
8	5	STRAWBERRY	ACRES	BRIGADE WSB	120	Pounds	120	ACRES	Ground	S01N22W02	12	5.443104	0.026269934
9	5	STRAWBERRY	ACRES	BRIGADE WSB INSECTICIDE/MITICIDE	32.3	Pounds	32.3	ACRES	Ground	S01N22W11	3.23	1.46510216	0.00707099
14	5	STRAWBERRY	ACRES	BRIGADE WSB	420	Ounce	26.25	ACRES	Ground	S01N22W11	2.625	1.190679	0.005746548
15	5	STRAWBERRY	ACRES	BRIGADE WSB	205.28	Ounce	12.83	ACRES	Ground	S01N22W11	1.283	0.581958536	0.002808694
15	5	STRAWBERRY	ACRES	BRIGADE WSB INSECTICIDE/MITICIDE	52.5	Pounds	52.5	ACRES	Ground	S01N22W22	5.25	2.381358	0.011493096
16	5	STRAWBERRY	ACRES	BRIGADE WSB	85	Pounds	85	ACRES	Ground	S02N22W35	8.5	3.855532	0.01860787
16	5	STRAWBERRY	ACRES	BRIGADE WSB	336	Ounce	21	ACRES	Ground	S01N22W02	2.1	0.9525432	0.004597238
19	5	STRAWBERRY	ACRES	BRIGADE WSB	37	Pounds	37	ACRES	Ground	S01N22W02	3.7	1.6782904	0.008099896
21	5	STRAWBERRY	ACRES	BRIGADE WSB	85	Pounds	85	ACRES	Ground	S02N22W35	8.5	3.855532	0.01860787
22	5	STRAWBERRY	ACRES	BRIGADE WSB INSECTICIDE/MITICIDE	55.5	Pounds	55.5	ACRES	Ground	S01N22W22	5.55	2.5174356	0.012149844
23	5	STRAWBERRY	ACRES	BRIGADE WSB INSECTICIDE/MITICIDE	53	Pounds	53	ACRES	Ground	S01N22W22	5.3	2.4040376	0.011602554
23	5	STRAWBERRY	ACRES	BRIGADE WSB INSECTICIDE/MITICIDE	39.35	Pounds	39.35	ACRES	Ground	S01N22W02	3.935	1.78488452	0.008614349
24	5	STRAWBERRY	ACRES	BRIGADE WSB	45	Pounds	45	ACRES	Ground	S01N22W02	4.5	2.041164	0.009851225
27	5	STRAWBERRY	ACRES	BRIGADE WSB	205.76	Ounce	12.86	ACRES	Ground	S01N22W11	1.286	0.583319312	0.002815261
28	5	STRAWBERRY	ACRES	BRIGADE WSB	44	Pounds	44	ACRES	Ground	S01N22W14	4.4	1.9958048	0.009632309
31	5	STRAWBERRY	ACRES	BRIGADE WSB INSECTICIDE/MITICIDE	32.3	Pounds	32.3	ACRES	Ground	S01N22W11	3.23	1.46510216	0.00707099
3	6	STRAWBERRY	ACRES	BIFENTURE 10DF	16	Pounds	16	ACRES	Ground	S01N22W11	1.6	0.7257472	0.003502658
4	6	STRAWBERRY	ACRES	BIFENTURE 10DF INSECTICIDE/MITICIDE	31.76	Ounce	31.76	ACRES	Ground	S01N22W02	0.1985	0.090038012	0.000434548
4	6	STRAWBERRY	ACRES	BIFENTURE 10DF	30	Pounds	15	ACRES	Ground	S01N22W02	3	1.360776	0.006567483
4	6	STRAWBERRY	ACRES	BIFENTURE 10DF INSECTICIDE/MITICIDE	60.64	Pounds	60.64	ACRES	Ground	S01N22W02	6.064	2.750581888	0.013275073
5	6	STRAWBERRY	ACRES	BIFENTURE 10DF	30	Pounds	15	ACRES	Ground	S01N22W02	3	1.360776	0.006567483
6	6	STRAWBERRY	ACRES	BIFENTURE 10DF INSECTICIDE/MITICIDE	12.77	Pounds	12.77	ACRES	Ground	S01N22W02	1.277	0.579236984	0.002795559
9	6	STRAWBERRY	ACRES	BIFENTURE 10DF INSECTICIDE/MITICIDE	9.84	Pounds	9.84	ACRES	Ground	S01N22W02	0.984	0.446334528	0.002154135
9	6	STRAWBERRY	ACRES	BIFENTURE 10DF INSECTICIDE/MITICIDE	6.09	Pounds	6.09	ACRES	Ground	S01N22W02	0.609	0.276237528	0.001333199
10	6	STRAWBERRY	ACRES	BIFENTURE 10DF	20	Pounds	10	ACRES	Ground	S01N22W02	2	0.907184	0.004378322
11	6	STRAWBERRY	ACRES	BIFENTURE 10DF INSECTICIDE/MITICIDE	21.95	Pounds	21.95	ACRES	Ground	S01N22W02	2.195	0.99563444	0.004805209
12	6	STRAWBERRY	ACRES	BIFENTURE 10DF INSECTICIDE/MITICIDE	18.28	Pounds	18.28	ACRES	Ground	S01N22W02	1.828	0.829166176	0.004001787
12	6	STRAWBERRY	ACRES	BIFENTURE 10DF INSECTICIDE/MITICIDE	14.46	Pounds	14.46	ACRES	Ground	S01N22W02	1.446	0.655894032	0.003165527
13	6	STRAWBERRY	ACRES	BIFENTURE 10DF INSECTICIDE/MITICIDE	6.09	Pounds	6.09	ACRES	Ground	S01N22W02	0.609	0.276237528	0.001333199
26	6	STRAWBERRY	ACRES	BIFENTURE 10DF INSECTICIDE/MITICIDE	12.77	Pounds	12.77	ACRES	Ground	S01N22W02	1.277	0.579236984	0.002795559
2	7	STRAWBERRY	ACRES	BIFENTURE 10DF INSECTICIDE/MITICIDE	22.1	Pounds	22.1	ACRES	Ground	S01N22W02	2.21	1.00243832	0.004838046
11	9	STRAWBERRY	ACRES	BIFENTURE 10DF INSECTICIDE/MITICIDE	14.46	Pounds	14.46	ACRES	Ground	S01N22W02	1.446	0.655894032	0.003165527
14	9	STRAWBERRY	ACRES	BIFENTURE 10DF	16	Pounds	16	ACRES	Ground	S01N22W11	1.6	0.7257472	0.003502658
16	10	STRAWBERRY	ACRES	BIFENTURE 10DF INSECTICIDE/MITICIDE	1	Pounds	11.29	ACRES	Ground	S01N22W02	0.1	0.0453592	0.000218916
2	11	STRAWBERRY	ACRES	BIFENTURE 10DF INSECTICIDE/MITICIDE	20.55	Pounds	20.55	ACRES	Ground	S01N22W02	2.055	0.93213156	0.004498726
											137.2165	62.24030667	0.30038903

Table 8.21. *Raspberry bifenthrin loads for agricultural applications used in the PWC.*

Month	Day	Commodity	Planted_Units	Prod_name	Quantity_Used	Quantity_Units	Treated_Amount	Treated_Units	Appl_Meth	MTRS	Bifenlbs_app	kg	kg/ha
5	30	RASPBERRY	ACRES	BIFENTURE EC	0.66	Gallon	14.07	ACRES	Ground	S01N22W14	1.324053122	0.60058	0.012367205
5	27	RASPBERRY	ACRES	BIFENTURE EC (CA & N	0.71	Gallon	14.26	ACRES	Ground	S01N22W14	1.424360177	0.646078	0.013304114
6	7	RASPBERRY	ACRES	BIFENTURE EC (CA & N	0.17	Gallon	3.46	ACRES	Ground	S01N22W14	0.341043986	0.154695	0.003185492
6	13	RASPBERRY	ACRES	BIFENTURE EC	0.71	Gallon	14.26	ACRES	Ground	S01N22W14	1.424360177	0.646078	0.013304114
6	15	RASPBERRY	ACRES	BIFENTURE EC (CA & N	0.25	Gallon	4.96	ACRES	Ground	S01N22W22	0.501535274	0.227492	0.004684547
6	5	RASPBERRY	ACRES	BIFENTURE EC (CA & N	0.42	Gallon	8.5	ACRES	Ground	S01N22W22	0.842579259	0.382187	0.007870039
												2.657111	0.054715512

Table 8.22. *Celery bifenthrin loads for agricultural applications used in the PWC.*

Month	Day	Commodity	Planted_Units	Prod_name	Quantity_Used	uantity_Un	Treated_Amount	Treated_Units	Appl_Meth	MTRS	Bifenlbs_app	kg	kg/ha
5	29	CELERY	ACRES	SNIPER (CA)	0.31	Gallon	6.1	ACRES	Ground	S01N22W14	0.615417224	0.279148329	0.011691
5	30	CELERY	ACRES	SNIPER (CA)	0.7	Gallon	14	ACRES	Ground	S01N22W14	1.389651795	0.630334937	0.0264
5	30	CELERY	ACRES	SNIPER	0.4	Gallon	8	ACRES	Ground	S01N22W14	0.79408674	0.360191393	0.015086
												1.269674659	0.053177

Agricultural Loads - Permethrin

Table 8.23. *Cut flowers permethrin loads for agricultural applications used in the PWC.*

MTRS	Month	Day	Commodity	Permlbs_applied	kg	kg/ha
S01N22W11	2	27	N-OUTDR FLOWERS	1.955	0.88677236	0.02577954
S01N22W11	4	15	N-OUTDR FLOWERS	1.84	0.83460928	0.024263097
S01N22W11	5	28	N-OUTDR FLOWERS	0.92	0.41730464	0.012131548
S01N22W11	11	20	N-OUTDR FLOWERS	5.06	2.29517552	0.066723516
					4.4338618	0.128897701

Table 8.24. *Celery permethrin loads for agricultural applications used in the PWC.*

MTRS	Month	Day	Commodity	Permlbs_applied	kg	kg/ha
S01N22W11	1	28	CELERY	14.37693792	6.521264027	0.110372571
S01N22W14	3	30	CELERY	1.405745042	0.637634705	0.010791985
S01N22W14	4	4	CELERY	0.990411279	0.449242633	0.007603444
S01N22W14	4	6	CELERY	1.884976306	0.855010172	0.01447107
S01N22W14	4	11	CELERY	1.214052536	0.550684518	0.00932035
S01N22W14	4	11	CELERY	1.405745042	0.637634705	0.010791985
S01N22W14	4	18	CELERY	0.990411279	0.449242633	0.007603444
S01N22W14	4	18	CELERY	0.798718774	0.362292446	0.00613181
S01N22W14	4	30	CELERY	1.405745042	0.637634705	0.010791985
S01N22W14	5	16	CELERY	1.565488796	0.710093194	0.012018347
S01N22W14	5	20	CELERY	1.789130053	0.811535079	0.013735253
					12.62226882	0.213632243

Table 8.25. *Lettuce permethrin loads for agricultural applications used in the PWC.*

MTRS	Month	Day	Commodity	Permlbs_applied	kg	kg/ha
S01N22W22	3	26	LETTUCE LEAF	2.012771309	0.912976964	0.020509239
S01N22W22	4	9	LETTUCE LEAF	1.214052536	0.550684518	0.012370652
					1.463661482	0.032879891

Agricultural Loads- Fenpropathrin

Table 8.26. *Strawberry fenpropathrin loads agricultural applications used in the PWC.*

MTRS	Month	Day	Commodity	Fenlbs_applied	kg	kg/ha
S01N22W14	5	8	STRAWBERRY	9.198190588	4.172226	0.023869
S02N22W35	5	8	STRAWBERRY	17.76980144	8.06024	0.046111
S01N22W02	5	12	STRAWBERRY	4.327351875	1.962852	0.011229
S01N22W02	5	13	STRAWBERRY	20.05055169	9.09477	0.05203
S01N22W02	5	17	STRAWBERRY	12.33108929	5.593283	0.031998
S01N22W22	5	24	STRAWBERRY	16.44145239	7.457711	0.042664
S01N22W11	6	10	STRAWBERRY	0.827085257	0.375159	0.002146
S01N22W02	6	10	STRAWBERRY	12.53159481	5.684231	0.032518
S01N22W11	6	11	STRAWBERRY	1.654170515	0.750319	0.004292
S01N22W11	6	12	STRAWBERRY	0.827085257	0.375159	0.002146
S01N22W14	6	13	STRAWBERRY	6.265797404	2.842116	0.016259
S01N22W22	6	13	STRAWBERRY	16.44145239	7.457711	0.042664
S01N22W02	6	16	STRAWBERRY	7.7813925	3.529577	0.020192
S01N22W11	6	17	STRAWBERRY	3.533909736	1.602953	0.00917
S01N22W11	6	18	STRAWBERRY	1.779486463	0.807161	0.004618
S01N22W02	6	19	STRAWBERRY	2.584785	1.172438	0.006707
S01N22W11	6	19	STRAWBERRY	1.879739221	0.852635	0.004878
					61.79054	0.353493

Table 8.27. *Raspberry fenpropathrin loads agricultural applications used in the PWC.*

MTRS	Month	Day	Commodity	Fenlbs_applied	kg	kg/ha
S01N22W22	10	24	RASPBERRY	1.553917756	0.704845	0.116119

Table 8.28. *Surface areas of Ormond Lagoon used to estimate average surface area used in the PWC.*

YEAR	MONTH	Surface Area (square meters)	Yearly Averaged Surface Area (square meters)
1994	9	91,687	91,687
2003	7	95,714	-
2003	12	95,714	95,714
2004	10	90,142	90,142
2005	6	90,396	-
2005	12	63,421	76,909
2006	8	104,588	104,588
2007	9	107,531	107,531
2009	6	107,531	107,531
2011	4	114,338	114,338
2013	12	101,040	101,040
2014	8	86,701	86,701
2015	5	84,802	84,802
2016	2	87,236	-
2016	10	75,063	81,150
Average			**95,177.67**

Table 8.29*. J-street Drain stream depth at the mouth of Ormond Lagoon used to estimate average lagoon depth in PWC.*

Month- Year	Feet above MSL (VD 1929)
Nov-12	6.84
Dec-12	4.84
Jan-13	5.23
Feb-12	4.82
Mar-13	4.56
Apr-13	4.64
May-13	5.35
Jun-13	5.62
Jul-13	5.67
Aug-13	5.37
Sep-13	5.26
Oct-13	5.88
Nov-13	6.36
Dec-13	6.03
Jan-14	5.57
Feb-14	5.64
Jul-15	5.65
Aug-15	4.66
Sep-15	4.64
Oct-15	5.79
Nov-15	5.25
Dec-15	5.37
Jan-16	3.18
Feb-16	4.85
Mar-16	3.27
Apr-16	4.54
May-16	4.45
Jun-16	4.67
Jul-16	4.62
Aug-16	3.83
Sep-16	3.52
Oct-16	4.06
Nov-16	5.35
Dec-16	3.68
Jan-17	2.86
Feb-17	2.58
Mar-17	3.69
Apr-17	5.41
May-17	5.61
Jun-17	5.03
Jul-17	4.95

Model Results

Spreadsheets will be included that detail the exact model outputs for the multiple simulations necessary to estimate total EECs.

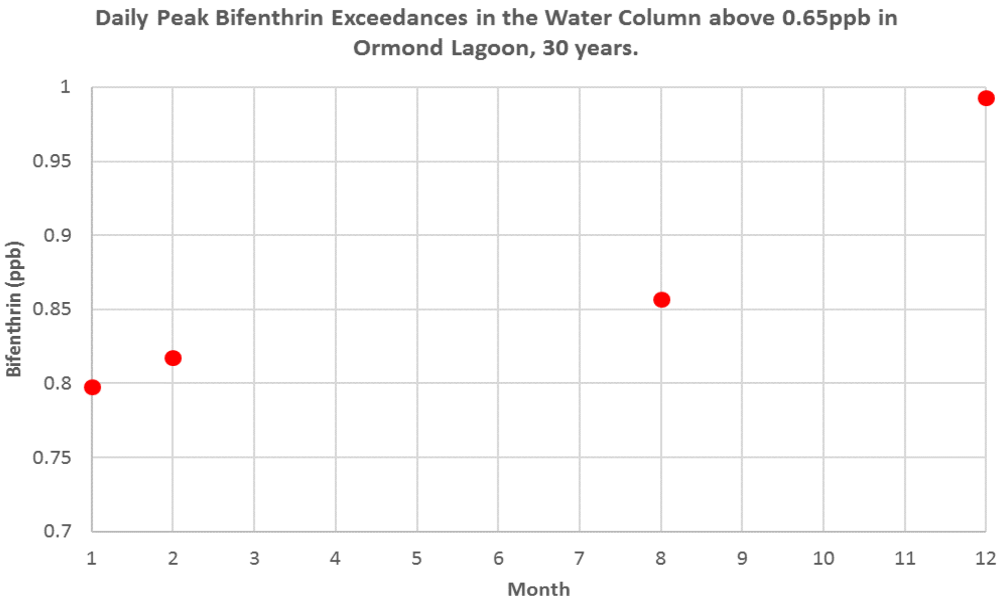


Figure 8.1. *Daily peak bifenthrin exceedances in the water column above 0.65ppb in OLW over 30 years.*

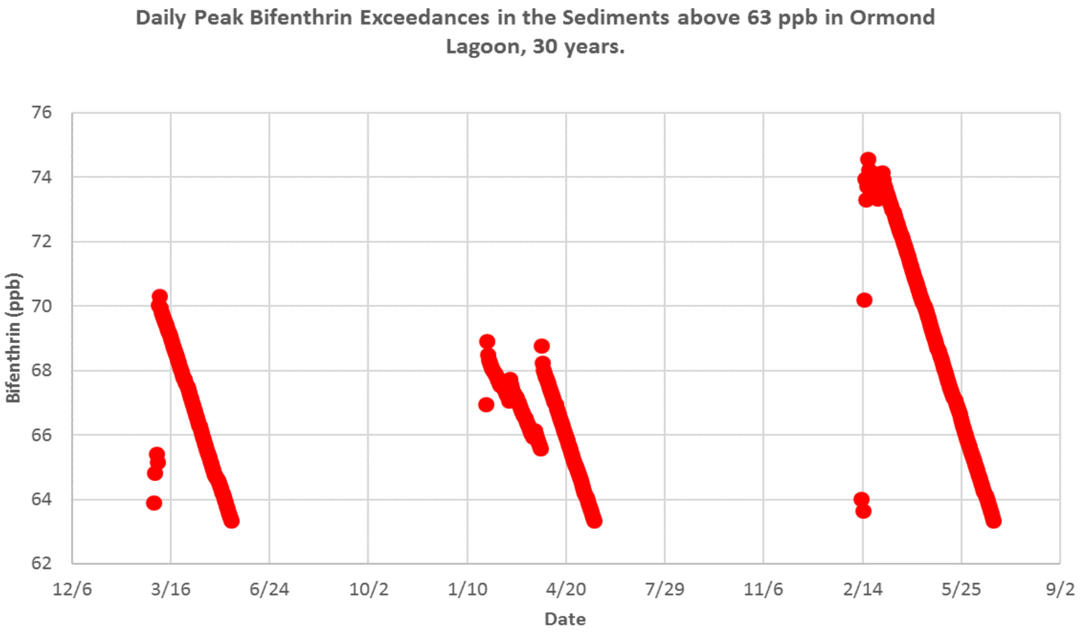


Figure 8.2*. Daily peak bifenthrin exceedances in the sediments above 63 ppb in OLW over 30 years, chronological.*

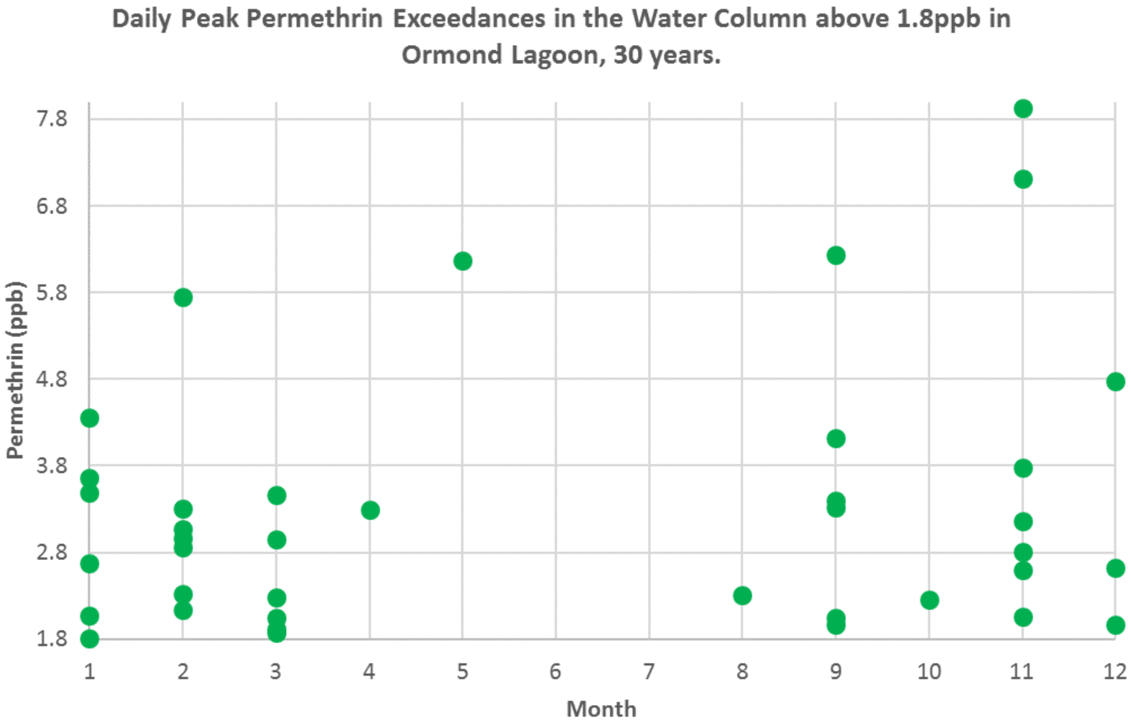


__Figure 8.3.__ Daily peak permethrin exceedances in the water column above 1.8ppb in OLW over 30 years.

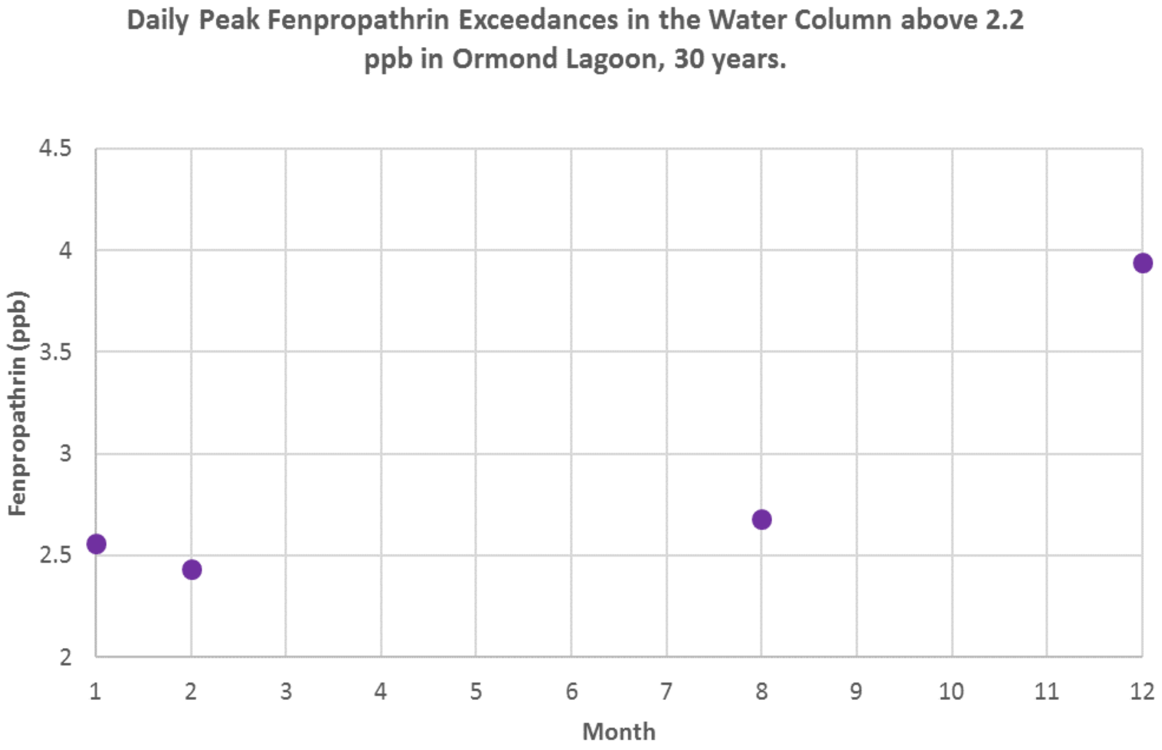


Figure 8.4. Daily peak fenpropathrin exceedances in the water column above 2.2ppb in OLW over 30 years.

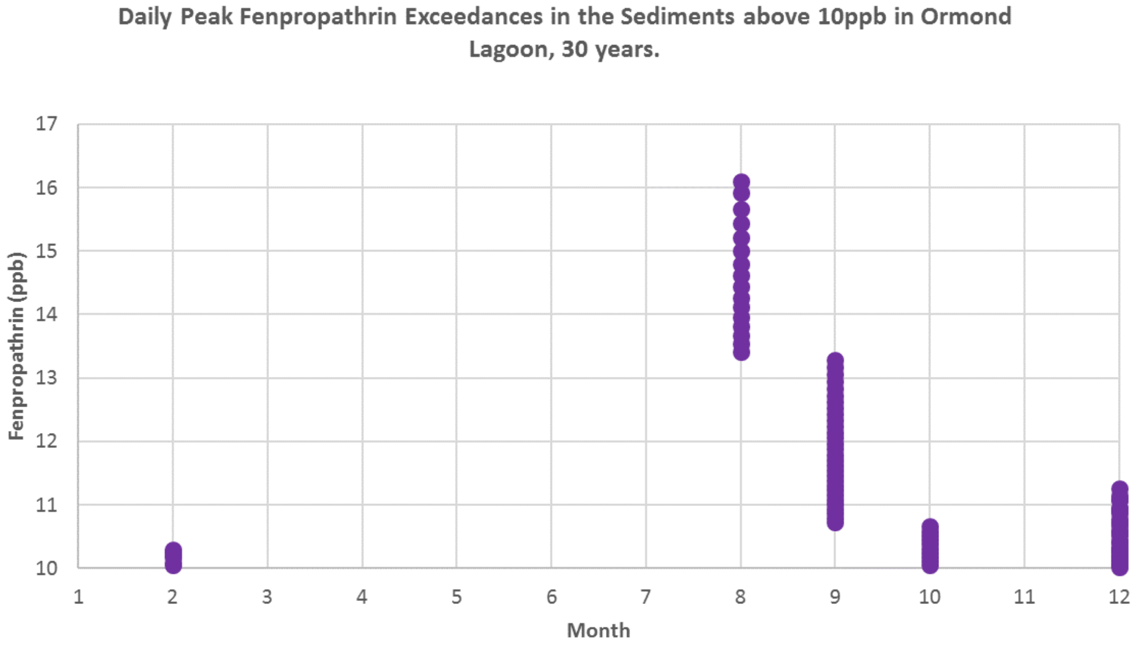


Figure 8.5. Daily peak fenpropathrin exceedances in the sediments above 10 ppb in OLW over 30 years.

Appendix E: Sampling Design

Calendar of planned field trips

Two major sampling events are scheduled. The first sampling event took place in Fall 2017 and the second event took place in Winter 2018. The sampling dates are flexible but one of the events should happen after a major rain event during the wet season.

Table 8.30. *Planned sampling dates.*

Sampling Type	Sampling Date
1. Sediment samples (three drainages) 2. Surface Water samples Three drainages and Ormond Lagoon)	Fall: In October (any dry weather)
Same as above	Winter: In January or February (After a Rainfall)

For each sampling event, record rainfalls during the previous several months. Record the level of the rainfall within a 48h period if there is a major rain event. Rainfall is an input of pyrethroids, though runoff from landscape irrigation may also an important source (Weston et al., 2011).

Presampling activities

Sampling map

Ten sampling points are located near the Ormond Lagoon (Figure 8.12), with two at each of main three drainages (Hueneme drain, J-street drain, and Oxnard industrial drain) and four at the lagoon. For water samples, we choose sampling points near bridges as taking samples from bridges can avoid disturbances of human activities, compared to wading. Also, we avoid locations where there is mixing between drainages or waterbodies (e.g., the mouth at which drainages enter Ormond Lagoon).

Figure 8.12. *Distribution of sampling points at Ormond Lagoon. Label: SH (Hueneme Drain) in red; SJ (J-Street Drain) in yellow; SO (Oxnard Industrial Drain); SOL (Sampling points in Ormond Lagoon) in black. SOL points are sorted by near the Superfund Site (SOL 1) or not (SOL 2-4). SOL 4 is away from all three main drainages.*

Checklist of equipment and supplies

A checklist is made to guarantee that all the equipment and supplies are available to use before samplings (Table 8.31). Examples of some devices are shown in Figures 8.13-16. The volume of the container and the number of supplies may change based on the actual conditions.

__Table 8.31.__ Equipment and supplies for sampling event.

Name	Number	Comment
Stainless steel scoop	1-2	Long-handled scoops preferred
Sediment sample container: Solvent-clean glass jar (16 oz)	20	20 sub-samples, 2 at each sampling point; 10 samples per sampling event; Mix 2 sub-samples thoroughly for analysis
Water sample container:	30-Oct	10 samples per sampling event; 1-2 repeated samples at each sampling point; May use empty plastic bottle instead (water containers should be made by polyethlene)
Solvent-clean plastic jar (about 500 ml)		
Box and Ice bag	3-Jan	Water samples need to be held at 25 oF (-4 oC). Sediment samples need to be stored at -4 oF (-20 oC)
Disposable gloves	several	In case we need them
GPS	1	
a string or a long-handled water sampling dipper	1	Hold plastic bottles to take surface water samples if the creek is not wadable
HQ40D meter or YSI analyzer	1	Parameters: Salinity, temperature, turbidity, pH

(a) (b)

__Figure 8.13__. Sample containers. (a) solvent-clean glass jar; (b) plastic jars used for sampling.

Figure 8.14. *YSI 556-02 Multiparameter Meter with Barometer.*

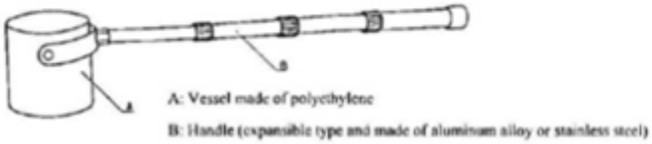


Figure 8.15. *Long handle water sampler.*

Figure 8.16. *Field sampling with a water sampling dipper.*

Sampling methods

Water sampling-surface water

All water samples are grab samples* of the surface water at 10 sampling points. More sampling events will be needed if the environmental conditions change (such as large

rainfalls). “Surface water samples will typically be collected either by directly filling the container from the surface water body being sampled or by decanting the water from a collection device such as a stainless-steel scoop or other device,” although direct dipping of the sample container into the water body is preferred.
(*Grab sample: a grab sample is a discrete sample which is collected at a specific location at a certain point in time. If the environmental medium varies spatially or temporally, then a single grab is not representative, and more samples need to be collected).

Operation: A sample may be collected directly into the sample container when the surface water source is accessible by wading or other means. The sampler should face upstream if there is a current and collect the sample without disturbing the bottom sediment. The surface water sample should always be collected prior to the collection of a sediment sample at the same location. Before taking the sample, rinse the sampling vessel with water on site 3-4 times. Submerge the sampling vessel gently (about 0.3-0.6 feet under the water), fill it with water sample and close it tightly (Figure 8.17). When the water body is not wadable, use the instrument illustrated in Figure 8.15 or Figure 8.18.

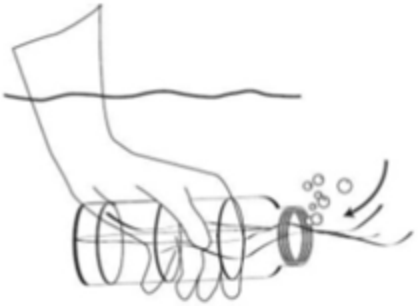


Figure 8.17. *Surface water is collected by directly filling the container.*

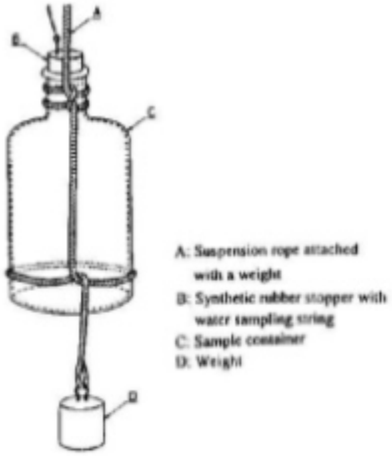


Figure 8.18. *Simple water sampler when the water is not accessible by wading; the container is fixed by the rope, attached with a weight.*

Sediment sampling

The acceptable volume for single sample should be around 1 liter (33.8 oz). Sediment samples can be collected by 10 amber glass jars (950 ml) or 20 clear glass jars (16 oz). When using 16-oz jars, 2 sub-samples should be taken at each sampling point. Sub-samples should be mixed thoroughly according to section 2.4 “Sample Homogenization” in EPA protocols (USEPA, 2014).

Since pyrethroids are strongly hydrophobic (log Koc 4.6-5.8; Laskowski, 2002), water in the sediment samples does not need to be completely removed. The finest-grained material (muddy sand or mud) is preferentially sampled.

Scoop Sampling Procedure. “When wading to the location, approach the sampling point from the downstream direction. When sampling from the edge of the water body, use caution to avoid knocking soils from the bank into the water column”. Advance scoop into the sediment, retrieve a sample and place into the glass jar. Repeat the process until a sufficient volume of soil is collected. Remove water from the jar after sampling is complete.

Notice

YSI analyzer is used at every sampling point to acquire instant data of environmental parameters, including temperature, pH, turbidity, etc. For each point, GPS location should be recorded to draw the sampling map.

Water sampling notes

1. Special care must be taken not to contaminate samples (USEPA, 2013).
2. If possible, one member of the field sampling team should take all the notes and photographs, fill out tags, etc., while the other members collect the samples (to reduce errors).
3. Sample collection activities shall proceed progressively from the least suspected contaminated area to the most suspected contaminated area (USEPA, 2013).
4. Place the sample into appropriate, labeled containers. Samples collected for VOC analysis must not have any headspace.

Parameter Detection

All water samples are held at 25 ^{o}F (-4 ^{o}C) before measurement. The temperature should not be too low to avoid freezing. All sediment samples are held at -4 ^{o}F (-20 ^{o}C).

Surface water samples

Suspended sediment

Take a measured volume (about 10~50 ml) of surface water from plastic jar. Measure the volume with a graduated cylinder. Use filter paper (0.45- micron pore size; Cicek et al., 2003) to separate the suspended and soluble materials of the water samples. The filter paper should be desiccated and weighed previously (USEPA, 1979). The difference of the weight of filter paper between before and after filtering is the TSS (Chan, 2010).

Pyrethroids

Targeted pyrethroids include bifenthrin, cyfluthrin, cypermethrin, esfenvalerate, fenpropathrin, cyhalothrin, permethrin, pyrethrin, and flauvalinate were measured using LC-MS. Chosen pyrethroids were bought to detect the threshold and sensitivity of the instrument. Yuxiong Huang, a post-doctoral student at Arturo Keller's lab (Bren School, UCSB) will assisted with manual operation of LC-MS.

Dissolved Organic Carbon

Take about 1~3 ml of surface water sample to a cuvette. Measure the absorbance under a wavelength of 254 nm using UV-vis spectroscopy (Peacock et al., 2014). Calculate DOC concentrations using the calibration curve, based on literature review (Edzwald et al., 1985).

Chlorophyll

Take a measured volume (about 10 ml) of water sample from plastic jar and take about 1-3 ml of water sample to a cuvette. Measure the absorbance under a wavelength of 653 nm and 666 nm, respectively, using UV-vis spectroscopy (Lichtenhaler et al., 1983).

Sediment samples

Bulk density and porosity

Take a measured volume (about 10-50 ml) of wet sediment from glass jar and measure the volume and wet weight. The sediment bulk density is then defined as the ratio between the weight of the wet sediment and the known volume. Desiccate the known volume of sediment at 60 ^{o}C (140 ^{o}F) for 24 hours to remove all the interstitial water. Dry weight is measured, and weight loss is assumed to include all the water loss, which is equal to the interstitial volume of the known-volume sediment sample. Sediment porosity (n) is then calculated as the ratio between the interstitial volume and the known total volume of the sediment (Danovaro, 2009).

Pyrethroids

Use LC-MS to detect the same pyrethroids with water samples except pre-treatment maybe slightly different.

Organic factor

Homogenize a wet sediment sample corresponding to 50-100 mg dry weight and put it in an aluminum cup. The cup should be weighed before. Dry the sample in a desiccator at 60 ^{o}C (140 ^{o}F) for 24 hours or until it reaches its constant weight (dry weight). Weigh the cup containing the dry sediment. Place the cup with sediment in muffle furnace at 450 ^{o}C for 4h. Weigh the cups containing the calcinated sediment. The difference between the dry and calcinated sediment weight is the weight of organic matter in each sample. The ratio (calcinated/dry) is the organic factor (Danovaro, 2009).

Appendix F: Sampling Report

There were 8 sampling sites in total, with two sites at each of three drains and Ormond Lagoon. We compared our sampling results to sampling results from CEDEN (CEDEN, 2017).

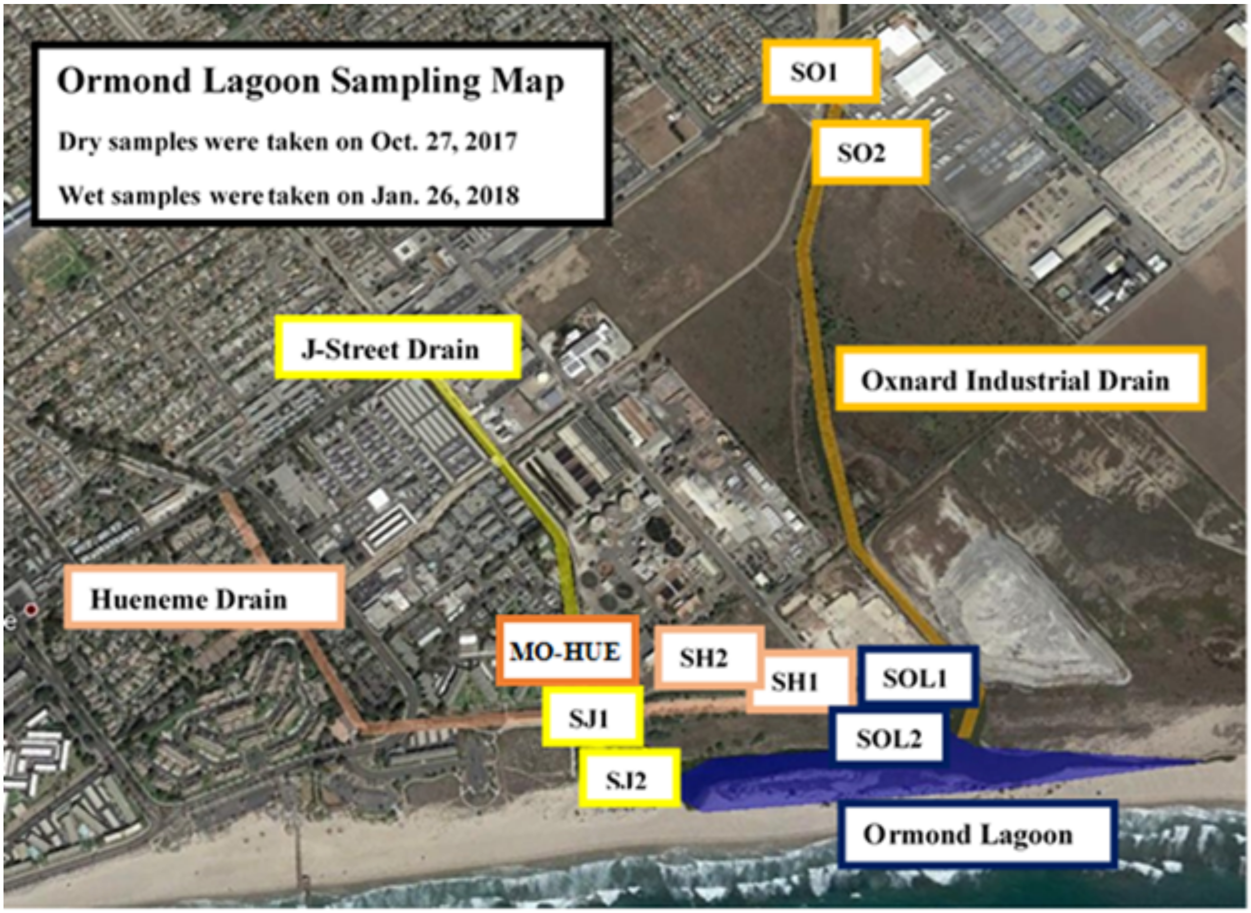


Figure 8.19. *Sampling map for OLW. Sampling sites at the Oxnard Industrial Drain; SJ1&SJ2: Sampling sites at J-street Drain; SO1&SO2: Sampling sites at Oxnard Industrial Drain; SH1&SH2: Sampling sites at Hueneme Drain; SOL1&SOL2: Sampling sites in Ormond Lagoon; A CEDEN monitoring site (MO-HUE) was also labeled on the map. (Source: CEDEN, 2017)*

Field parameters

We used a HQ40D meter to detect *in situ* temperature, conductivity, pH and DO. Conductivity data (Table 8.32) were in the range from 341 to 12000 µs/cm, which was retrieved from MO-HUE sites. Both temperatures and dissolved levels were higher than the average at MO-HUE site (DO: 5.71 mg/L, Temp: 14.6). The main disagreement was the lower pH and weak alkalinity at MO-HUE site (pH: 7.49).

Table 8.32. *Field parameters for sampling sites.*

Location	ID	Conductivity (µs/cm)	Temp	pH	DO (mg/L)
Oxnard Industrial Drain	**SO1**	3120	21.9	4.23	6.45
	SO2	3510	22	4.15	6.59
Hueneme Drain	**SH1**	6760	23.4	4.26	8.93
	SH2	7900	21.5	4.37	11.6
J-street Drain	**SJ1**	9790	21.2	4.74	17.97
	SJ2	9800	20.7	4.81	18.27
Ormond Lagoon	**SOL1**	6060	22.8	5.21	20.34
	SOL2	6930	22.1	5.18	18.38

Water parameters

Compared to TSS at MO-HUE which ranged from 44 to 220 mg/L, TSS in our samples were low. Some of results were under the suggested detection limit in an EPA protocol (10 mg/L). DOC levels were also lower than DOC at MO-HUE (4.6 mg/L).

Table 8.33. *Dissolved organic carbon, chlorophyll, and total suspended sediment TSS results of water samples.*

Location	DOC (mg/L)	Chl a (mg/L)	Chl b (mg/L)	TSS (mg/L)
Oxnard Industrial Drain	2.66	0.12	0.29	7~102
Hueneme Drain	4.21	0.35	0.52	2~27
J-street Drain	3.62	0.29	0.49	<10
Ormond Lagoon	3.54	0.31	0.59	<10
CEDEN site (MO-HUE)	4.6	NA	NA	44~220

Sediment Parameters

Table 8.34. *Bulk density, porosity, water content and organic factor of sediment samples.*

Location	Bulk density (g/cm3)	Porosity	Water content (%)	Organic factor (%)
Oxnard Industrial Drain	1.23	0.49	39.84	3.26
Hueneme Drain	1.21	0.51	42.36	1.75
J-street Drain	1.38	0.44	32.13	1.17
Ormond Lagoon	1.36	0.4	29.56	0.83

Pyrethroids

Table 8.35. *Pyrethroid concentrations in water samples (January 2018 sampling event).*

Location	ID	Fenpropathrin (ppb)	Lambda-Cyhalothrin (ppb)
Oxnard Industrial Drain	**SO1**	0.0145	2.6478
	SO2	0.0149	0.7341
Hueneme Drain	**SH1**	0.0858	0
	SH2	0.0505	0
J-street Drain	**SJ1**	0.0263	0
	SJ2	0	0
Ormond Lagoon	**SOL1**	0.0262	4.0055
	SOL2	0	2.6111

Table 8.36. *Pyrethroid concentration in sediment samples for (a) October 2017 sampling event and (b) January 2018 sampling event.*

(a)

Location	ID	Cis-permethrin (ppb)	Bifenthrin (ppb)
Oxnard Industrial Drain	SO1	0	0.23
	SO2	0.165	1.09
Hueneme Drain	SH1	0	0
	SH2	0	0.07
J-street Drain	SJ1	0	0.08
	SJ2	0	0
Ormond Lagoon	SOL1	0	0.22
	SOL2	0	0.075

(b)

Location	ID	Fenpropathrin (ppb)	Lambda-Cyhalothrin (ppb)	Cypermethrin (ppb)	Anthraquinone (ppb)	Tau-Fluvalinate (ppb)	Trans-permethrin (ppb)	Cis-permethrin (ppb)	Bifenthrin (ppb)
Oxnard Industrial Drain	SO1	0.11	0	0.4	0.3	0.32	0.86	0.51	2.54
	SO2	0.25	0	1.4	1.22	1.39	1.62	1.02	4.65
Hueneme Drain	SH1	0	0.01	0	0	0.14	0	0	0.02
	SH2	0	1.99	0	0	0	0	0	0
J-street Drain	SJ1	0	0	0	0	0	0.08	0.07	0.77
	SJ2	0	0	0	0	0.15	0.07	0	0.16
Ormond Lagoon	SOL1	0	0	0	0	0.14	0	0	0.22
	SOL2	0	0	0	0	0.14	0	0	0.09

Appendix G: Best Management Practices Literature Review and Modeling

Ventura County's Current State

VCAILG formed in 2006 in response to the Los Angeles Regional Water Quality Control Board (LARWQCB), *Conditional Waiver of Waste Discharge Requirements for Discharges from Irrigated Lands within the Los Angeles Region* (Order No. R4-2016-0143; VCAILG, 2017a). To support growers in complying with regional water quality objectives, VCAILG designed a WQMP addressing three main goals: increase farmer and landowner understanding of local agricultural water quality issues; identify gaps or deficiencies in current management practices in agricultural operations; and reduce the contribution of nutrients, pesticides, and other pollutants to impaired water bodies (Merhaut et al., 2013). The VCAILG coalesced non-point source (NPS) discharges into "responsibility areas" (RAs) according to sub-watersheds, drainage areas, crop similarities, and additional TMDL requirements, which allowed for better coordination and resulted in BMPs being implemented in all high priority drainages within the first study year in 2009 (Merhaut et al., 2013).

OLW comprises a significant part of the Oxnard Central RA, which among other water quality issues, is degraded by pyrethroid pesticides (VCAILG, 2017b). Members of RA are required to document implementation of BMPs and participate in an education program (VCAILG, 2017b).

In addition, VCAILG has implemented programs to reduce agricultural TMDLs in the Calleguas Creek and Santa Clara River watersheds. In 2009, VCAILG conducted 469 surveys of agricultural water quality management practices to assess the existing BMPs and their effectiveness. The survey included over 160 growers who farm more than 14,000 acres of land that drain into Calleguas Creek and 7,000 acres that drains into the Santa Clara River watershed (Merhaut et al., 2013). Through this study, two educational programs were developed, including class lectures and demonstration of farms showcasing successful BMP implementation. VCAILG has been successful at better understanding effective BMPs and reducing agricultural runoff over the past decade.

The conditional waiver implemented by LARWQCB set a benchmark value of 0.0006 ug/L of bifenthrin for the OLW, with an achievement timeline, noting June 30, 2021 as the date of compliance (VCAILG, 2017a). Although the VCAILG has been successful in enrolling members to reach their water quality goals, with 87.8% of all agriculture parcels within the RA belonging to VCAILG members, all wet weather bifenthrin concentrations at the RA monitoring site have exceeded the benchmark (VCAILG, 2017). It is important to note these consistent exceedances in the aqueous phase, particularly because it is likely bifenthrin has rapid temporal changes due to precipitation events and agricultural practices at any given time. One monitoring event per year is not enough to understand peak accurate concentrations or chronic concentrations. Additionally, although no specific sediment concentration benchmark has been set, concentrations indicating highly lethal doses to fish and invertebrates have been found directly in Ormond Lagoon. Sediment evaluations from the Ormond Lagoon reveal bifenthrin concentrations of 37.1µg/kg and 11.9µg/kg (EPA, 2015). The 2017 VCAILG report suggests the following for additional BMP implementations to meet bifenthrin targets: reducing bare soil within production area with cover crops or mulch, contour farming, IPM, and VFS (VCAILG, 2017b).

Of the surveyed units of the Oxnard Center RA, 0% currently use VFS and VCAILG notes that additional implementation is needed to reach compliance (VCAILG, 2017b). In surface runoff, VFSs have been shown to remove up to 25% of lamda cyhalothrin, a comparable pyrethroid to bifenthrin. The Ventura County Technical Guidance Manual for Stormwater Quality Control Measures 2011 estimates the cost of VFS construction between $0.00 and $1.30 per cubic foot with annual maintenance costs of about $0.01 per square foot per year (Geosyntec Consultants and Larry Walker Associates, 2011). The EPA claims that VFSs provide a benefit cost ratio of over 4:1 (Helmers, 2008). VFS are a low cost, low maintenance, and low technology solution to sediment sorbed pollutant transport.

Agricultural BMPs

Behavioral

Integrated Pest Management

The strategy of reducing both agricultural and urban pesticide use by implementing a variety of ecosystem-based strategies where pesticides are used to the minimal extent possible is known as IPM. Overall, pest control strategies are chosen and applied in a manner that “minimizes risks to human health, beneficial and nontarget organisms, and the environment” (UC IPM). IPM relies on a combination of five different control mechanisms including biological control, extensive pest monitoring, cultural control, mechanical and physical control, and chemical control. There are several IPM programs implemented by the UC Cooperative Extension (UCCE). For example, the UCCE that operates in Ventura county offers free online training for retail nurseries garden centers and home gardeners (UCCE, 2011). There are a wide variety of IPM strategies that are developed for specific crops, pests and locations. The University of California Riverside IPM program provides comprehensive pest management strategies that are available to for a wide variety of crops and pests for the state of California.

Below, each of the five control mechanisms of IPM are described.

Biological Control

Biological control is defined as the utilization of the actions of parasites, pathogens, and predators in managing pests in agriculture, and therefore reducing the need for chemical pesticides. There are multiple forms of biological control. Conservation of natural enemies can be accomplished by selective pesticide selection or by providing natural enemy refuge sites. Pesticide use has been heavily documented in decreasing the abundance and efficiency of beneficial natural enemies (Desneux et al., 2004).

Biopesticides, another class of biological control, are produced from or by living things are considered to be safer for the environment compared to chemical pesticides, such as microorganisms that infect and kill pests. In the case that resident natural enemies are insufficient, the augmentation of commercially available beneficial species is often used as a form of biological control. The most notable example of this type of augmentation is found in ladybugs to control aphids. However, augmentation of natural predators is not often used because it is economically not feasible.

Pest Monitoring

Pest monitoring not only identifies natural enemies, but also allows for more efficiently timed pesticide applications, in order to reduce the amount of pesticide used. The degree day (DD) models, or phenology models, is a tool that times pesticide applications and relies on pest monitoring information. This model is very useful in pest monitoring, as it predicts when pests will be present on crops based on that days over a certain temperature that fosters pest development.

Cultural Control

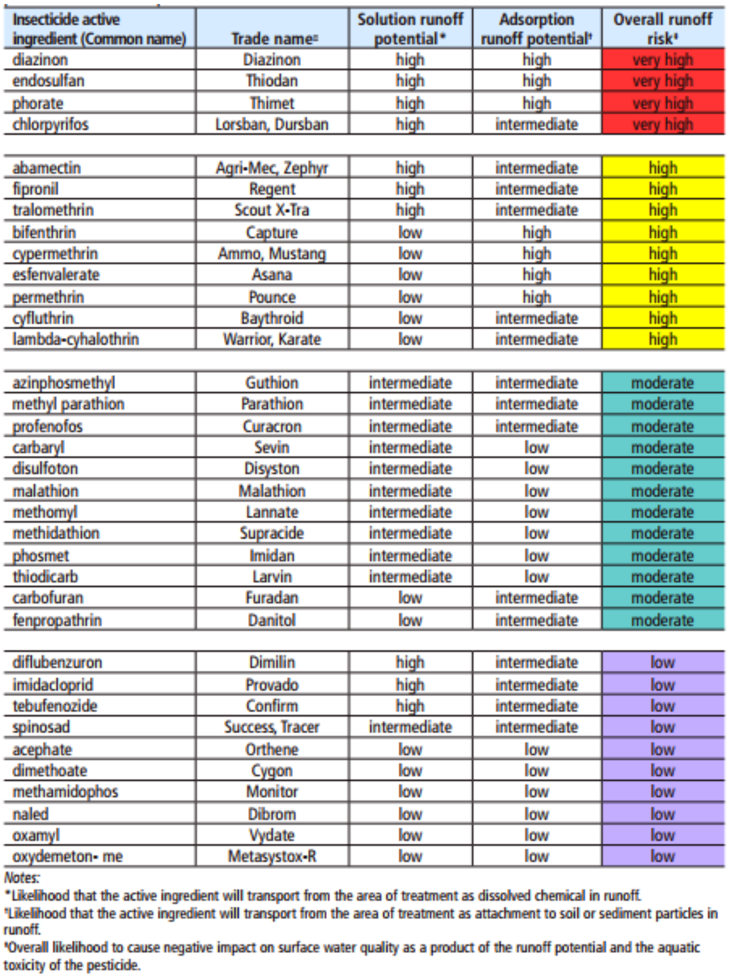
Cultural controls are practices that reduce pest establishment, reproduction, dispersal, and survival. The main purpose of cultural control is to make a crop environment less suitable for pests, and it is most often used as a preventative measure. The main strategies used for cultural control are reducing and disrupting pest habitat within or around crops, adjusting crop planting to disrupt pest habitat and nutrition requirement, diverting pest population away from crop, and reducing yield loss from insect injury.

Mechanical and Physical Control

Mechanical and physical controls are methods used to kill pests directly or create an unsuitable environment. Examples of mechanical and physical controls include traps, mulches, and steam sterilization, and barriers.

Pesticide Selection

The decision on which pesticide and how it is applied can greatly affect the amount of pesticide released into the downstream environment. Pesticides effect on downstream surface waters and sediments is largely determined by the pesticide's field dissipation half-life, adsorption coefficient, solubility and its aquatic toxicity (Figure 8.20). Bifenthrin is characterized as having high risk of runoff and there are various alternatives that will have less of an effect on downstream organisms.



Insecticide active ingredient (Common name)	Trade name=	Solution runoff potential[*]	Adsorption runoff potential[†]	Overall runoff risk[‡]
diazinon	Diazinon	high	high	very high
endosulfan	Thiodan	high	high	very high
phorate	Thimet	high	high	very high
chlorpyrifos	Lorsban, Dursban	high	intermediate	very high
abamectin	Agri-Mec, Zephyr	high	intermediate	high
fipronil	Regent	high	intermediate	high
tralomethrin	Scout X-Tra	high	intermediate	high
bifenthrin	Capture	low	high	high
cypermethrin	Ammo, Mustang	low	high	high
esfenvalerate	Asana	low	high	high
permethrin	Pounce	low	high	high
cyfluthrin	Baythroid	low	intermediate	high
lambda-cyhalothrin	Warrior, Karate	low	intermediate	high
azinphosmethyl	Guthion	intermediate	intermediate	moderate
methyl parathion	Parathion	intermediate	intermediate	moderate
profenofos	Curacron	intermediate	intermediate	moderate
carbaryl	Sevin	intermediate	low	moderate
disulfoton	Disyston	intermediate	low	moderate
malathion	Malathion	intermediate	low	moderate
methomyl	Lannate	intermediate	low	moderate
methidathion	Supracide	intermediate	low	moderate
phosmet	Imidan	intermediate	low	moderate
thiodicarb	Larvin	intermediate	low	moderate
carbofuran	Furadan	low	intermediate	moderate
fenpropathrin	Danitol	low	intermediate	moderate
diflubenzuron	Dimilin	high	intermediate	low
imidacloprid	Provado	high	intermediate	low
tebufenozide	Confirm	high	intermediate	low
spinosad	Success, Tracer	intermediate	intermediate	low
acephate	Orthene	low	low	low
dimethoate	Cygon	low	low	low
methamidophos	Monitor	low	low	low
naled	Dibrom	low	low	low
oxamyl	Vydate	low	low	low
oxydemeton- me	Metasystox-R	low	low	low

Notes:

[*] Likelihood that the active ingredient will transport from the area of treatment as dissolved chemical in runoff.

[†] Likelihood that the active ingredient will transport from the area of treatment as attachment to soil or sediment particles in runoff.

[‡] Overall likelihood to cause negative impact on surface water quality as a product of the runoff potential and the aquatic toxicity of the pesticide.

Figure 8.20. *Overall runoff risk for various insecticides.*

IPM for Lygus Bugs in Strawberry Production

Since bifenthrin is one of the most potent insecticides, it is primarily used for a number of arthropods, including strawberry pests. The most common arthropod responsible for strawberry yield losses, lygus bugs (*Lygus hesperus),* two spotted spider mites (*Tetranychus urticae*), greenhouse whiteflies (*Trialeurodes vaporariorum*), and western flower thrips (*Frankliniella occidentalis*; UC IPM). Lygus bugs have become well established in summer-planted off-cycle strawberry systems found in Ventura County (Zalom et al., 2011). However, they pose a serious risk in Oxnard strawberry growing areas because of the late growing season of the crop after May. Lygus bug populations cycle throughout the year, with adults moving between strawberries and alternate hosts such as flowering ornamental plants, beans, and weeds. Adult lygus bugs often feed on developing strawberry seeds which lead to irregularly shaped mature strawberries.

In Ventura County, an IPM plan for lygus bug management is implemented. The IPM plan includes both non-chemical and chemical management. Biological control, cultural control, and mechanical control are used as non-chemical management methods. For biological control, parasitic wasps are used to attack lygus bug eggs in commercial setting. However, this method is often avoided as it is both economically infeasible and it does not entirely control the pests, as they move back in to strawberry plants from other areas. For cultural control, the most effective strategy is to prevent spring building of eggs by controlling weeds along roadways, ditches, and field borders. Another cultural control approach is to grow flowering plants in adjacent fields or on the border of strawberry fields to attract adult lygus bugs. Through personal observation, this appears to be used in some capacity in the Oxnard Area. However, riparian areas, floodplains, and fallow fields nearby strawberry fields with large stands of common plant species such as mustards, pepperweed, lupines, filaree, lambsquarters, and common groundsel are especially problematic as a source of lygus adults when they are present throughout the season. As a form of mechanical control, bug vacuums have been effective in reducing lygus population by 75%. However, bug vacuums can result in powdery mildew or remove predator population and are also ineffective for heavier pest populations.

As for chemical management, effective monitoring and DD modelling are paramount. In order to establish the initial parameters of the DD model, monitoring for baseline values are necessary. The lygus bug DD model is designed to predict when lygus nymphs will be present in strawberries and therefore more accurately time pest management (Walsh et al., 2015). Primarily, the model looks for when days are above a threshold temperature that produces lygus eggs and allows for nymph development. While the DD model is an extremely useful tool, it does not consider potential water quality impacts and only considers efficacy and impact on natural enemies and honey bees. Another chemical management approach is limiting application of synthetic pyrethroids, especially bifenthrin and fenpropathrin, which are used for strawberry pests, to 2 applications per year, or 2.66 pint per acre. Limiting application rates to two times a year can avoid the resistance of strawberry pests to applied pyrethroids. Other effective chemicals for pest management include naled (Dibrom 8E), insecticidal soap, and acetamiprid. Naled is a short-term organophosphate chemical used to control agricultural pests on ornamental plants, kennels, and processing plants (Extension Toxicology Network, 2003). Naled adsorbs only weakly to soil particles, and it is nearly insoluble in water. However, it is not persistent in soils, as it is broken down quickly if soil is wet. Also, because naled is an organophosphate, it is readily taken up and metabolized by plants, and have short half-lives in soil. Both insecticidal soap and acetamiprid are classified as having low potential for overall runoff risk due to their rapid degradation rates. Insecticidal soap is organic and therefore has no risk of runoff. Similarly, acetamiprid is a neonicotinoid, an insecticide chemically similar to nicotine, that also has no known potential pesticide runoff potential. Acetamiprid degrade rapidly in soil and has low toxicity compared to most other insecticides and is rated as having a low absorbed runoff toxicity to fish (UC IPM WaterTox Database).

Polyacrylamide

PAM is a synthetic water-soluble polymer made from the acrylamide monomer. PAM is used in agricultural settings for stabilizing soil and preventing erosion. There have been several independent studies that have showed that technologies that remove sediment from the edge of field tail waters, such as sediment basis are also effective in reducing pyrethroid transport with reduction of up to 80% (Jones and Markle, 2011). In addition, there are no studies that show that PAM is toxic to aquatic species when applied at levels to prevent soil erosion. Anionic PAM has very low toxicity to fish.

A study conducted on a 185-ha commercial tomato farm in Patterson, California located within the San Joaquin Valley, studied the effectiveness of PAM and sediment basins on removal of pyrethroid runoff. Lambda- cyhalothrin is typically applied to tomatoes several times a year to control chewing insects. A total of 590 g a.i. of lambds-cyhalothrin was applied to a 26-ha block. Lambda-cyhalothrin residue levels in the runoff samples from the study conducted without adding PAM to the irrigation runoff ranged from 2.005 to 0.191 µg/L at the field exit (prior to entering the sediment basin) and 0.135 to 0.102 µg/L at the exit of the sediment basin. The use of PAM resulted in lower pyrethroid concentrations in irrigation runoff samples and ranged from 1.32 to 0.106 µg/L at the entrance to the sediment basin and 0.144 to 0.0416 µg/L at the exit of the sediment basin. The maximum concentrations in the inlet and outlet streams were significantly lower for pyrethroids, including reductions in concentration during the time that the sediment basin was discharging. In the study with only the sediment basin, 75 and 84 percent of the TSS and pyrethroid, respectively, were retained in the sediment pond. In the second study, concentrations of pyrethroids were lower in the outflow than the inflow and approximately 80-85% of pyrethroids were retained in the sediment basin (Jones and Markle, 2011).

Another study by a group of from the University of California, tested the effectiveness of PAM for removing pyrethroid using agricultural land with known pyrethroid levels (Carol, 2007). The structure used runoff ditches and PAM, which included three ditch designs with a simple dirt ditch, a sediment trap, and a vegetative ditch. The simple ditch was found overall ineffective to stopping the movement of pyrethroid movement. Even though the sediment trap is intended to allow sediments to settle out before the water continues through the system, 20-60% of pyrethroids were removed. However, after applying PAM, a majority of pyrethroids were removed, since pyrethroids are highly particle-associate. Therefore, stopping the movement of the sediments stop the movement of pyrethroids. The overall effectiveness of adding PAM to the irrigation ditch ranged 80-100%, varying at each site.

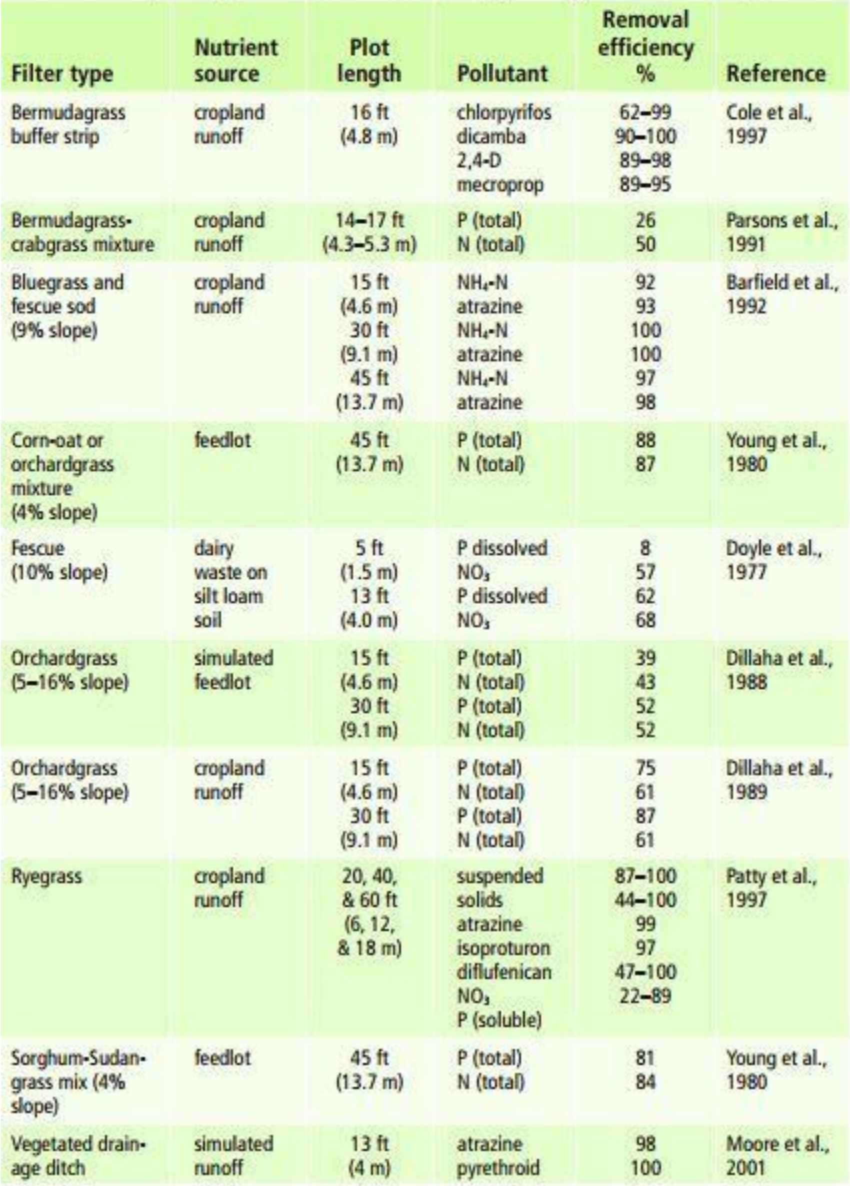
In addition, PAM is very effective in reducing other pollutants, including total SS, phosphorus, and nitrogen. Research on the Central Coast demonstrated that PAM applied initially to furrows at a concentration of 10 ppm followed by water without PAM, significantly reduced the concentration of sediment, phosphorus, and nitrogen in the run-off water across a range of soil types (Cahn). On average, suspended sediments were reduced by 86%.

Structural

Vegetated Filter Strips

VFSs are areas of land, hosting native or well adapted plant species, designed in a way to accept surface water runoff and intercept sediment transport. They can reduce the downstream concentrations of sediments by as much as 75% to 100% and biotransform and physically accumulate soluble nutrients and pollutants (Gismer et al., 2006).

VFSs are a relatively common NPS BMP, however they are particularly well suited the geography, hydrology, and water quality needs of OLW. In addition to aforementioned services VSPs can provide, they can also increase groundwater recharge and infiltration rates, reducing additional water needs of crops. This may be of particular importance and benefit to the farmer's operating within the Oxnard Plain, a major groundwater basin noted by the Department of Water Resources as subject to critical overdraft (Warne et al., 1965). Salt water intrusion into coastal groundwater has been problematic in the past, particular the middle-to-late 20th century, but recent sizeable storage allowances have halted intrusion and proved the positive contribution of groundwater recharge (Calleguas Municipal, 2017). The functions of a VFS can be maximized with an area of slope of less than 5% that carries sheetwash rather than concentrated flows (Helmers et al., 2005). This requirement suits the topography of the flat coastal margins of OWL. A systematic breakdown of pollutant removal services and efficiencies is provided by the University of California Division of Agriculture and Natural Resources (Gismer et al., 2006; Figure 8.21).



Filter type	Nutrient source	Plot length	Pollutant	Removal efficiency %	Reference
Bermudagrass buffer strip	cropland runoff	16 ft (4.8 m)	chlorpyrifos dicamba 2,4-D mecroprop	62–99 90–100 89–98 89–95	Cole et al., 1997
Bermudagrass-crabgrass mixture	cropland runoff	14–17 ft (4.3–5.3 m)	P (total) N (total)	26 50	Parsons et al., 1991
Bluegrass and fescue sod (9% slope)	cropland runoff	15 ft (4.6 m) 30 ft (9.1 m) 45 ft (13.7 m)	NH_4-N atrazine NH_4-N atrazine NH_4-N atrazine	92 93 100 100 97 98	Barfield et al., 1992
Corn-oat or orchardgrass mixture (4% slope)	feedlot	45 ft (13.7 m)	P (total) N (total)	88 87	Young et al., 1980
Fescue (10% slope)	dairy waste on silt loam soil	5 ft (1.5 m) 13 ft (4.0 m)	P dissolved NO_3 P dissolved NO_3	8 57 62 68	Doyle et al., 1977
Orchardgrass (5–16% slope)	simulated feedlot	15 ft (4.6 m) 30 ft (9.1 m)	P (total) N (total) P (total) N (total)	39 43 52 52	Dillaha et al., 1988
Orchardgrass (5–16% slope)	cropland runoff	15 ft (4.6 m) 30 ft (9.1 m)	P (total) N (total) P (total) N (total)	75 61 87 61	Dillaha et al., 1989
Ryegrass	cropland runoff	20, 40, & 60 ft (6, 12, & 18 m)	suspended solids atrazine isoproturon diflufenican NO_3 P (soluble)	87–100 44–100 99 97 47–100 22–89	Patty et al., 1997
Sorghum-Sudan-grass mix (4% slope)	feedlot	45 ft (13.7 m)	P (total) N (total)	81 84	Young et al., 1980
Vegetated drainage ditch	simulated runoff	13 ft (4 m)	atrazine pyrethroid	98 100	Moore et al., 2001

Figure 8.21. *Efficiencies of pollutant removal services by filter type. (Source: Gismer et al., 2006)*

Sediment Basins

A sediment basin is a temporary pond with control structures to capture eroded and disturbed soil that is washed off during a storm event (MDEQ, 2014). Some sediment basins can be converted into permanent storm water control practices. Sediment basins can be extremely effective in reducing pyrethroid runoff into waterbodies, and most pyrethroids are transported with TSS. Sediment basins cost $1,200 per drainage acre for basins less than 500,000 ft^2 and $600 per drainage acre for basins greater than 50,000 ft^2 (California Stormwater BMP Handbook, 2003).

A study in Central California evaluated the effectiveness of removing pyrethroids with sediment basins. The results showed that there were significant decreases of pyrethroids in sediment basins. There was a decrease of 85%, 99%, 100%, 60%, and 98% for bifenthrin, cyhalothrin, cypermethrin, esfenvalerate, and permethrin, respectively (Budd et al., 2009). Several other studies showed 80-84% removal of sediments by sediment ponds (Fiener et al., 2005; Markle, 2009; McCaleb and McLaughlin, 2008). In addition, another study conducted in the Central Valley of California showed that chlorpyrifos were more effectively removed than diazinon, likely due to the different sorption properties of these chemicals (Zhang and Zhang, 2011). This result suggests that sediments ponds can be more effective in removing hydrophobic pesticides than those with low Koc. The pond used for this study removed about 27-44% of the adsorbed pesticides, while it only removed 2-10% of dissolved chemicals. Using the results of these various studies and extending it to pyrethroids, which have high Koc, sediment basins can effectively remove pyrethroids.

STEPL WEB

STEPL WEB, an online annual runoff model integrated with the Purdue Web-based Load Duration Curve Tool which "identifies least cost BMPs for each land use and optimizes BMP selection to identify the most cost-effective BMP implementations", allows users to form targeted management of nonpoint source pollution (STEPL WEB, 2015).

> "Purdue STEPL WEB estimates BMP implementation cost based on establishment, maintenance, and opportunity costs using a cost function (equation 5.12; Arabi et al., 2006). The model computes the costs per unit of pollutant mass reduction for BMPs and establishes a priority list of BMPs to apply based on the cost per unit mass of pollutant reduction.
>
> $ct = c0 \cdot (1 + s)td + c0 \cdot rm \cdot [\sum Ni=2\ (1 + s)(i - 1)]$
> Where, ct is BMP implementation cost, c0 is establishment cost, rm is ratio of annual maintenance cost to establishment cost, s is interest rate, and td is BMP design life."

STEPL allows for users to rapidly quantify the economic costs, geographic coverage, and environmental benefits of BMP implementation schemes. STEPL estimates annual sediment load of 21,522 tons per year for the Oxnard Coastal-McGrath Lake Subwatershed the Southern lobe of the Oxnard Central RA (Figure 8.22).

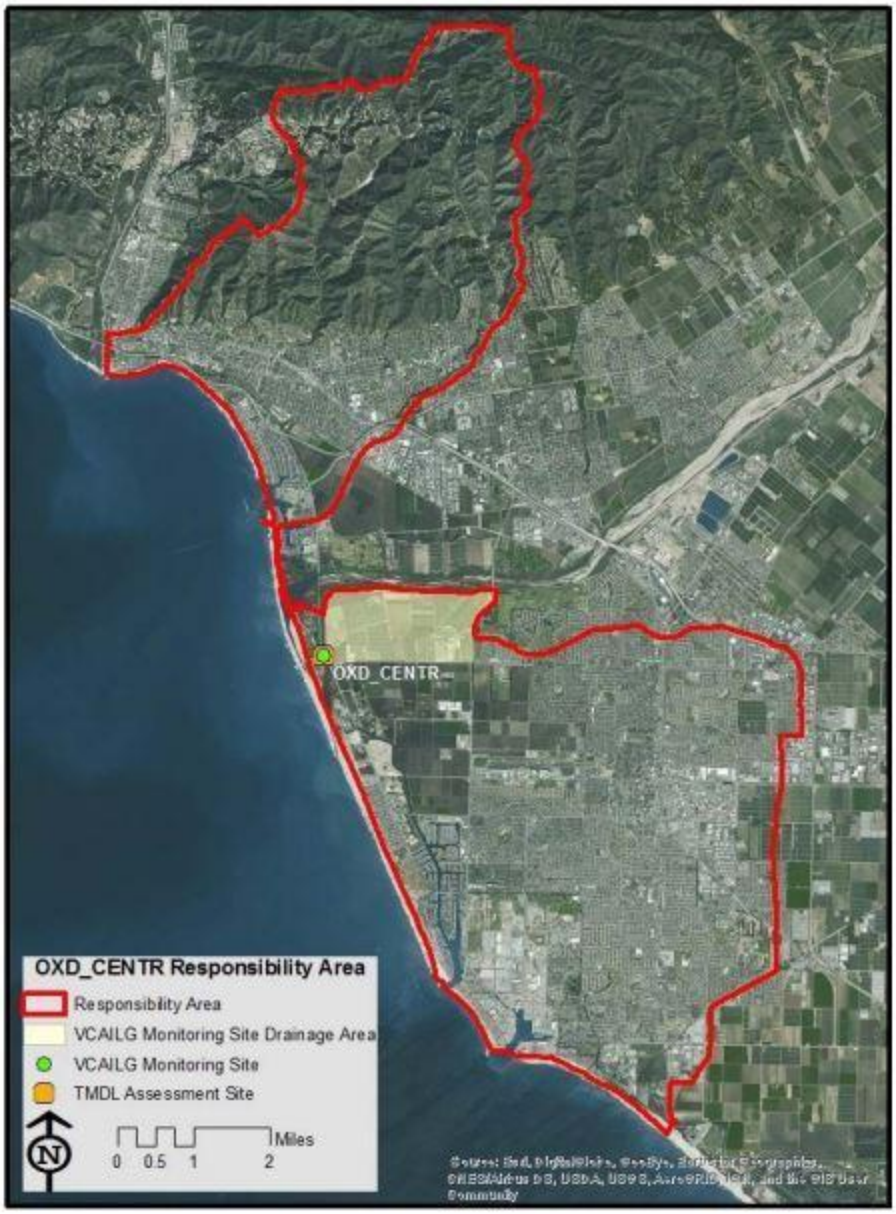
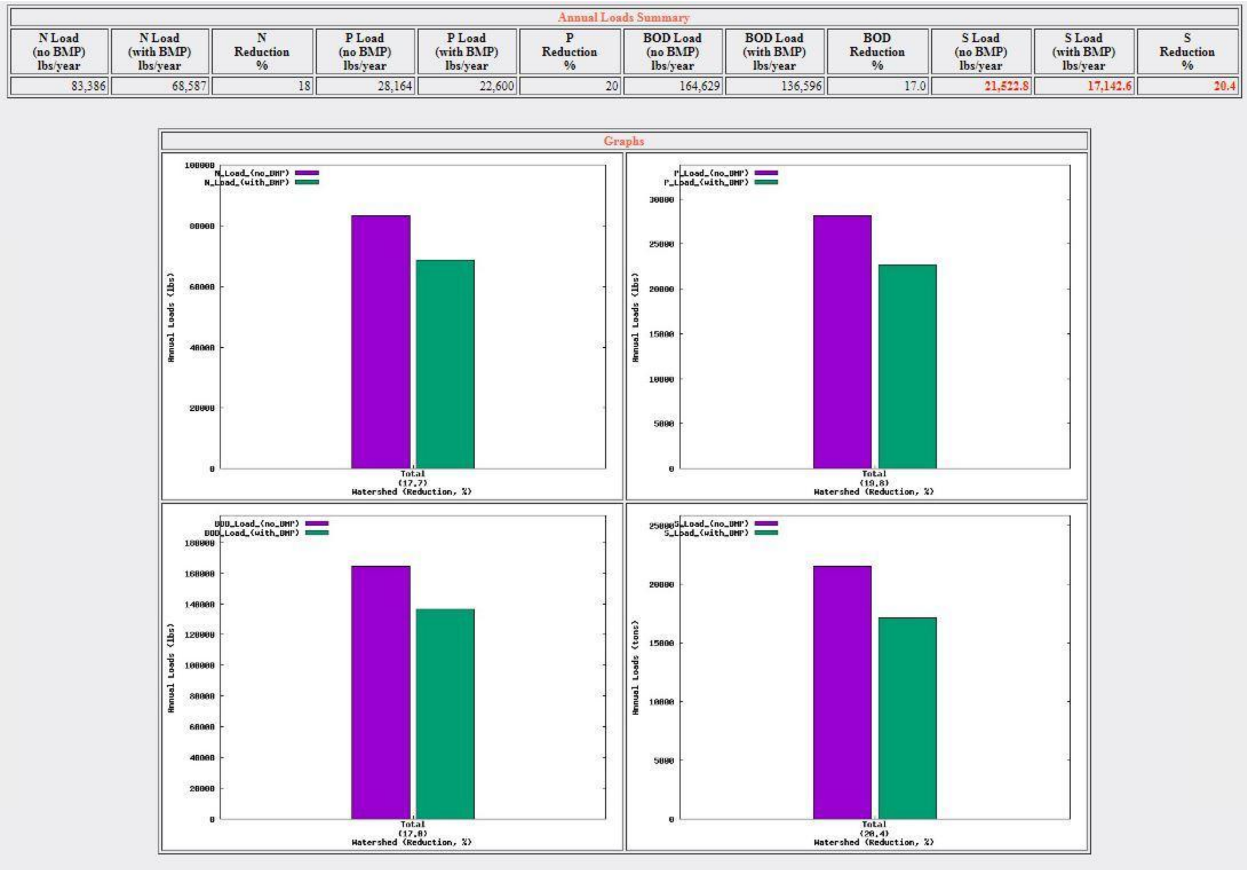


Figure 8.22. *Oxnard Center responsibility area. (Source: VCAILG, 2017)*

With a target goal of a 20% annual reduction in suspended sediment concentrations, STEPL revealed that VFS alone could be used to reach this goal.

Model assumptions include an interest rate of 3%, homogeneous soil type C, and 5% of the watershed area as maximum possible area (MPA) for BMPs: 925 acres. An optimized assessment of BMPs revealed that only 305.25 total acres of filter strips would be necessary to provide 18% nitrogen reduction, 20% phosphorus reduction, 17% BOD reduction, and 20.4% sediment reduction at just $1,850 total per year (Figure 8.23).


Annual Loads Summary

N Load (no BMP) lbs/year	N Load (with BMP) lbs/year	N Reduction %	P Load (no BMP) lbs/year	P Load (with BMP) lbs/year	P Reduction %	BOD Load (no BMP) lbs/year	BOD Load (with BMP) lbs/year	BOD Reduction %	S Load (no BMP) lbs/year	S Load (with BMP) lbs/year	S Reduction %
83,386	68,587	18	28,164	22,600	20	164,629	136,596	17.0	21,522.8	17,142.6	20.4

Graphs

Figure 8.23. *Quantitative Output of BMP Optimization Model Run. (Source: STEPL WEB, 2015)*

Scaling these results to OLW, 43% of the Oxnard McGrath subwatershed, results in $795.5 per year for 131.25 acres of VFSs, less that 2% of the entire OLW. Costs of construction and maintenance may be further reduced by USDA's Natural Resource Conservation Services Program (NRCS). This program provides funding opportunities for agricultural producers to implement VFSs to improve environmental health (NRCS, 2017). Through agricultural management assistance (AMA) the program can cover up to 75% of installation costs for conservation practices, and even greater cost-shares for historically underserved producers (NRCS, 2017).

To maximize efficiency of sediment and pollutant removal, VFSs must be designed to suit the hydrology and topography of each individual site. The agriculture in OLW lies in the east, draining into the Oxnard Industrial Drain, which lies to the west of these agricultural parcels, before entering Ormond Lagoon. VFSs should catch surface runoff and erosion before leaving the parcel and/or before entering the drainage. This would indicate southern and western VFSs would be most efficient, but using the equations included below and knowledge of local hydrology will ensure maximum efficiency potential. Manning's equation can be used to easily calculate the minimum filter strip width (Wmin), filter strip length (Lf), and maximum discharge per foot of filter strip width (q).

$$L_f = \frac{(T_t)^{1.25}(P_{2-24})^{0.625}(S)^{0.5}}{3.34 \times n}$$

$$q = \frac{0.023}{n} Y^{\frac{5}{3}} S^{\frac{1}{2}}$$

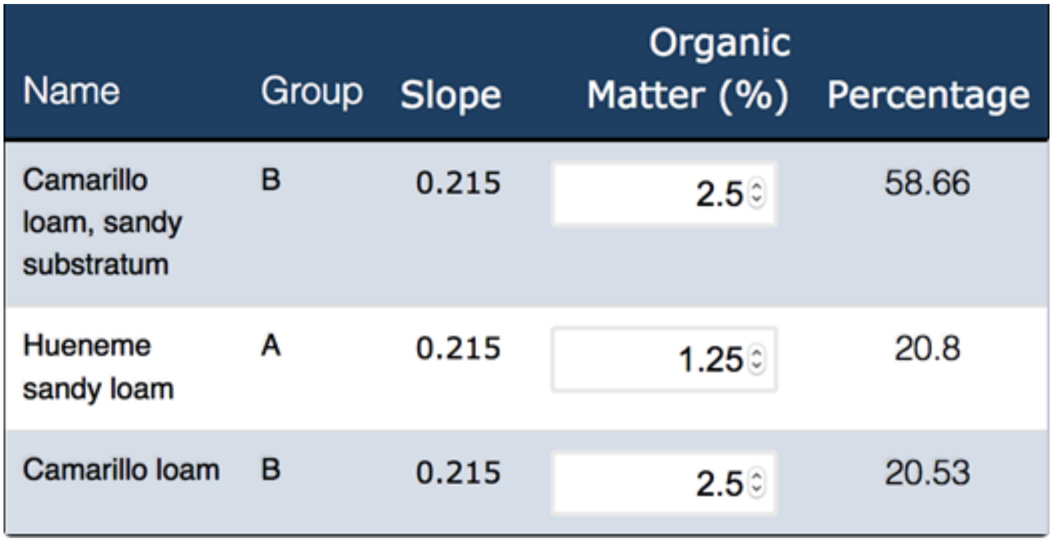
$$W_{f\min} = \frac{Q_{wq}}{q}$$

The vegetation used in the VFS is also important to the necessary filter strip length due to Manning’s “roughness coefficient” (n), which is dictated by the density of vegetation. Native perennial grasses that can tolerate dry and wet conditions with no need for additional water or nutrient provisions make very good candidates for VFSs. Calflora, a non-profit providing a searchable database of California Flora information and photos, lists over 150 grass and grass like herbs native to Ventura County (Calflora, 2017).

Nutrient Tracking Tool

NTT compares agricultural management systems to calculate a change in nitrogen phosphorus, sediment loss potential, and crop yield (Tarleton, 2018). NTT was used to determine the most suitable BMPs, using a sample 83.2-acre plot in the OLW (Figure 8.24). The Bray-1 P soil p-test was selected (Figure 8.25).

Figure 8.24. *Plot in Ventura, California off Arnold Road.*



Name	Group	Slope	Organic Matter (%)	Percentage
Camarillo loam, sandy substratum	B	0.215	2.5	58.66
Hueneme sandy loam	A	0.215	1.25	20.8
Camarillo loam	B	0.215	2.5	20.53

Figure 8.25. *Soil parameters for NTT simulation.*

In order to determine which BMPs are most suitable for this sample plot of land, simulations for both blueberries and dry beans were used. These crops were selected because NTT does not provide crop model nutrients for the crops used in OLW. Therefore, blueberries and dry beans were used instead, as they were evaluated as the most similar crops to those found in OLW farms. For each crop, several simulations were run with variation in tilling and proportion of farm treated by selected BMP (Tables 8.26-31).

Table 8.26. *Percent decrease in erosion by BMP for blueberries with no tillage.*

BMP	Fraction Treated	Surface Erosion (t/ac)	Percent Decrease in Erosion
None	-	0.53	-
VFS- orchard grass buffer	1	0.10	70%
	0.75	0.10	69%
	0.5	0.11	68%
	0.25	0.12	66%
VFS- bermuda grass buffer	1	0.16	52%
	0.75	0.16	52%
	0.5	0.17	50%
	0.25	0.18	48%
Sediment Basin	1	0.08	84%
	0.75	0.19	60%
	0.5	0.30	36%
	0.25	0.42	13%

__Table 8.27.__ Percent decrease in erosion by BMP for blueberries with low-tillage.

BMP	Fraction Treated	Surface Erosion (t/ac)	Percent Decrease in Erosion
None	-	0.48	-
VFS- orchard grass buffer	1	0.14	71%
	0.75	0.14	70%
	0.5	0.15	69%
	0.25	0.15	68%
VFS- bermuda grass buffer	1	0.14	70%
	0.75	0.15	69%
	0.5	0.17	65%
	0.25	0.16	67%
Sediment Basin	1	0.07	86%
	0.75	0.17	64%
	0.5	0.27	43%
	0.25	0.38	22%

__Table 8.28.__ Percent decrease in erosion by BMP for blueberries with high-tillage.

BMP	Fraction Treated	Surface Erosion (t/ac)	Percent Decrease in Erosion
None	-	0.34	-
VFS- orchard grass buffer	1	0.10	70%
	0.75	0.10	69%
	0.5	0.11	68%
	0.25	0.12	66%
VFS- bermuda grass buffer	1	0.10	69%
	0.75	0.11	69%
	0.5	0.17	50%
	0.25	0.12	65%
Sediment Basin	1	0.05	90%
	0.75	0.12	75%
	0.5	0.19	60%
	0.25	0.27	45%

Table 8.29. *Percent decrease in erosion by BMP for dry beans with no tillage.*

BMP	Fraction Treated	Surface Erosion (t/ac)	Percent Decrease in Erosion
None	-	0.21	-
VFS- orchard grass buffer	1	0.08	65%
	0.75	0.08	63%
	0.5	0.09	60%
	0.25	0.10	54%
VFS- bermuda grass buffer	1	0.07	65%
	0.75	0.08	64%
	0.5	0.09	60%
	0.25	0.10	55%
Sediment Basin	1	0.04	79%
	0.75	0.09	60%
	0.5	0.13	40%
	0.25	0.17	20%

Table 8.30. *Percent decrease in erosion by BMP for dry beans with low-tillage.*

BMP	Fraction Treated	Surface Erosion (t/ac)	Percent Decrease in Erosion
None	-	0.25	-
VFS- orchard grass buffer	1	0.08	67%
	0.75	0.08	66%
	0.5	0.09	63%
	0.25	0.10	59%
VFS- bermuda grass buffer	1	0.08	67%
	0.75	0.08	66%
	0.5	0.09	62%
	0.25	0.10	58%
Sediment Basin	1	0.05	80%
	0.75	0.10	60%
	0.5	0.15	40%
	0.25	0.20	20%

Table 8.31. Percent decrease in erosion by BMP for dry beans with high-tillage.

BMP	Fraction Treated	Surface Erosion (t/ac)	Percent Decrease in Erosion
None	-	0.18	-
VFS- orchard grass buffer	1	0.04	76%
	0.75	0.05	74%
	0.5	0.05	70%
	0.25	0.06	64%
VFS- bermuda grass buffer	1	0.04	75%
	0.75	0.05	73%
	0.5	0.06	69%
	0.25	0.07	63%
Sediment Basin	1	0.03	82%
	0.75	0.05	70%
	0.5	0.07	58%
	0.25	0.10	46%

Urban BMPs

Behavioral

In urban environments, pyrethroids are the most commonly used pesticides (Moran, 2010). The majority of urban pyrethroid use in California is by professional applicators (Yuzhou, 2017). The widespread use of pyrethroids has led to regular detection in urban waterways, or receiving bodies that drain urban areas. In Northern California, a study found pyrethroids in 32 of 33 urban runoff samples, with bifenthrin being the most commonly detected pyrethroid (Weston and Lydy, 2010). Bifenthrin, along with other pyrethroids, are predominantly used for structural pest control, and usage has been increasing significantly since 2000 (Yuzhou, 2017).

While structural pest control accounts for the majority of pyrethroid use, there is variation in how the pesticides are applied. In 2009, a survey of professional pesticide applicators showed that 95% of the pesticides they applied were in liquid form, with granules only accounting for 3% of the pounds of chemicals applied (Environmental Solutions Group, 2010). Pyrethroids accounted for 93% of the liquid chemicals applied and bifenthrin alone accounted for 93% of the granules applied. While these trends may have changed in recent years, it is likely there is still a strong preference for liquid forms of chemicals for their ease of application, especially for vertical surfaces.

The different forms that pyrethroids are applied in present varying levels of risk for environmental contamination. Liquid pyrethroids applied to hard surfaces have a high probability of running off into waterways. After application there is an initial level of high transferability from nonporous surface application, which suggests pyrethroids should not be applied to wet surfaces, near water, or in advance of irrigation or storm events (Jiang et al., 2012). While liquid application was shown to have high runoff from application on hard surfaces, solid, powder, and granular application of pyrethroid on the same types of hard surfaces had consistently higher runoff potential (Jiang et al., 2010). These findings informed CDPR in passing regulations to limit the amount of pyrethroids sprayed on impervious surfaces, prohibit spray application on horizontal impervious surfaces other than pinstreams or spot treatments, and ensure that granular application is only applied on pervious surfaces like grass and mulch (C.C.R.tit. 3, §6970, 2012).

The relationship between pyrethroid runoff and storm events is another important consideration in an urban setting. Urban areas with a greater concentration of impervious surfaces have significant impacts on stormwater runoff. In an urban environment rapid runoff and flashy discharge is typical for storm events in systems that cannot hold onto water as well as rural and agricultural settings can. Pyrethroids are particularly susceptible to storms washing them into waterways as they are hydrophobic and bind to sediment that can be swept away during intense flows of runoff. In San Francisco, researchers found that hydrophobic chemicals and pesticides were at greater risk to runoff during storm flows. In the same study it was shown that 91% of the annual load of tested pollutants were transported during storm events (Gilbreath and McKee, 2015). Storms acting as the main mechanism by which pyrethroids enter waterways is an important factor when considering BMPs.

Another contributing factor to pyrethroid users in California is for the removal of the Argentine ant. Argentine ants are not native to California and are difficult to eradicate and each colony has a few queen ants that are even more difficult to eradicate than the worker ants of the colonies (Holway, 1995). Because this is a widespread issue across California, alternative to pyrethroids used for Argentine ants can significantly reduce pyrethroid application rates. In a study conducted in Riverside California, 24-hr and 14-day dose results were used to determine mortality rates of worker and queen Argentine ants (Hooper and Rust, 2000). Boric acid solutions were tested at concentrations of 0.25-1%. For the 24-hr results, the 0.5% boric acid solution was toxic to worker ants but was not effective in eradicating queen ants. Other concentrations were not as effective as the 0.5% solution. For the 14-day results, 0.5% boric acid solution was toxic to both worker and queen ants. In addition, the study found that 0.5% boric acid needs to be provided continuously in order to be effective for the long-term. In addition, this study concluded that low concentrations of boric acid resulted in a slower killer to ants compared to boric acid at higher concentrations and most efficient against queens when they are continuously applied. Another study conducted in Huntington Beach, California showed that a 0.5% boric acid solution was effective in reducing 80% of Argentine ants over a 10-week period (Klotz et al., 1998). Several other studies on the impact of Argentine ants including Klotz et al. 1996, Rust et al. 2004, Ulloa-Chacón and Jaramaillio 2003, and several others found similar effects of boric acid on Argentine ant populations.

Structural

Bioswales have been evaluated for their effectiveness in removing pyrethroids. Bioswales are stormwater runoff conveyance systems that can absorb low flows or carry runoff from heavy rain events. Bioswales improve water quality by infiltrating storm water runoff and filtering the storm flows they convey (NRCS, 2005). A project in Salinas, California in 2006 determined the effectiveness of bioswales for removing pyrethroids in three different parking lots with asphalt (Anderson et al., 2016). One of the parking lots received runoff from approximately 34,900 square feet of impervious surface, swales with slopes that did not exceed 50% and 1% longitudinal slopes. The swales were planted with native bunch grasses in 6 inches of topsoil, which overlays approximately 2.5 feet of compacted subgrade. The other two parking lots had similar dimensions and capacities. The bioswales were monitored for their effectiveness based on a minimum rainfall of 0.5 inches for three different rain events. Samples were collected at the beginning, middle, and end of each storm. During the study, seven pyrethroids were detected and all were effectively removed, except for in one case. The average reduction of bifenthrin by all the bioswales was 84%. The case study of Salinas can be directly applied to Ventura County or other heavy pyrethroid using counties, with the adjustment of the bioswale parameters. It is estimated that the cost of construction for a bioswale, infiltration trench, and vegetative strip to capture 25.4 mm or 1 inch rainfall per 30 m highway is $16,291, $4,379, and $207, respectively (Osouli et al., 2017). The maintenance costs with bioswales primarily consist of mowing and cleanup tasks. Mowing is estimated to cost $187/km, while cleanup tasks are estimated at $284 per 30 m for bioswales up to 2.4 m and $426 for bioswales between 2.7m-4.8m. The annual maintenance cost of infiltration filters costs approximately $37/km which approximated to about $290 per 30 m of highway. The maintenance of VFS is estimated at a cost of $137/ hectare. The performance and cost of bioswales are dependent of the magnitude of rainfall.

Bioswales are a form of low-impact development and have been implemented in several urban settings, including Ventura County. The County of Ventura in partnership with the Ojai Valley Land Conservancy constructed a bioswale to reduce urban runoff pollutants draining to Happy Valley Drain, a tributary of the Ventura county, subject to a TMDL for algae, eutrophic conditions, and nutrients. The bioswales are 2-3 ft wide, 100 feet long, and 6-12 inches deep. The swale treats runoff from 37 acres of urban area for an estimated 1.6 million cubic feet of annual runoff. The construction of these swales, known as Happy Valley Bioswale, cost $400,000 to construct and was primarily funded by the Proposition 84 Stormwater Grant Program (Public Works Agency County of Ventura California, 2015).

In addition to bioswales, VFS, as mentioned in more detail in the agricultural BMP section, are a structural BMPs that can slow or prevent pyrethroids from entering the waterbodies. While VFS are more commonly used for the agricultural sector, there have been several studies done using VFS in urban areas that have been effective in removing more than 85% of TSS. For example, TSS were collected from a VFS treating highway runoff in eastern North Carolina (Han, 2005). The VFS on the side of the highway was effective in removing 85% of

TSS. The results of this study concluded that a 10-m or longer filter strip can retain most medium or large size (> 8 µ m) particles. Another study conducted by the Urban Stormwater Working Group of the Chesapeake Bay Program on the effectiveness of BMPs in Chesapeake Bay concluded that urban VFSs can removed about 56% of TSS from urban runoff (Law, 2014).

BMPs for Unreported Urban Use

Background

In California, both agricultural and urban pyrethroids uses are regulated at the state level by CDPR. Applicators of all commercial pyrethroids, permitted by CDPR, need to report their application details to CDPR (Budd, 2009), which are recorded in PUR databases. Most applications of pyrethroid from agriculture are included in the databases while all applications by homeowners or gardening services in urban areas are excluded (Weston et al., 2005). Those unreported urban use are evidenced by the difference between reported pyrethroid sales and reported uses. There have been some efforts on estimating unreported urban use by comparison of total sales and reported use. However, uncertainties in PUR, sales data, and other errors in the datasets prevent researchers from obtaining any meaningful results (Xuyang and Frank, 2010).

Pyrethroids are among active ingredients in most insecticides used by homeowners in landscape maintenance, structural pest control and public health pest control. Studies found that even small amount of pyrethroids used by homeowners could cause an adverse impact on aquatic species in nearby waterways. Unfortunately, this source of pyrethroid is poorly regulated. Most current management practices largely rely on public outreach and education efforts.

Previous and current efforts in California or Ventura County

Table 8.32 lists major types of BMPs on pesticide control in California (Riverside County Flood Control and Water Conservation District, 2015). Current efforts on managing unreported commercial use of pyrethroid are mainly source control BMPs, including amendments on policies, public outreach efforts, and IPM for home gardens and landscapes. Among those efforts, most well-established are public outreach efforts required by a program called Ventura Countywide Stormwater Quality Management Program (VCSQMP).

DPR 11-004-Prevention of Surface Water Contamination by Pesticides

In 2011, DPR made a proposal to amend section 6000 and adopt sections 6970 and 6972 of Title 3 California Code of Regulations (Department of Pesticide Regulation, 2012). It was approved later in 2012 and effective date was July 19, 2012. In order to protect surface water, the policy aims to restrict the pyrethroid use in outdoor nonagricultural settings. Seventeen pyrethroids are regulated under this policy. Details on application methods are listed in section 6970 while exceptions are in 6972.

Table 8.32. Major types of BMPs in use. (Source: Riverside County Flood Control and Water Conservation District, 2015)

Type of BMPS	
Source control	Regulatory
	Integrated Pest Management (IPM)
	Low Impact Development (LID)
	Public Outreach and Education
Treatment control	Infiltration Basin
	Infiltration Trench
	Media Filter
	Pervious Pavement

*This article also provides a literature review matrix on BMPs with sources and a brief description, which may inspire BMPs research on agricultural and urban use.

Ventura Countywide Stormwater Quality Management Program

The prog ram was established in 1992. Ten Cities, the County, and District have worked together since then to ensure compliance with the countywide NPDES permit through various management programs. Each year, some practices in the Public Outreach Program Element section of VCSQMP are targeting homeowners to improve their watershed awareness and application methods of pyrethroid. A framework of public outreach program is shown in Table 8.33.

Table 8.33. *Control Measures for the Public Outreach Program Element.*

PO	Control Measure	Content
PO1	Public Reporting	Identify Staff to Serve as Contact Persons for Public Reporting.
		Maintain Public Reporting Hotline Numbers
		Promote/Publicize Public Reporting Hotline Numbers/Contact Information
PO2 & PO3	Public Outreach Implementation & Youth Outreach Education	Educate Ethnic Communities
		Make Five (5) Million Stormwater Quality Impressions per Year
		Maintain and Update the Countywide Stormwater Website
		Permittee Individual Efforts
		Work with Existing Local Watershed Groups
		Storm Drain Inlet Markers and Signage Discouraging Illegal Dumping
		Educational Materials
		Community Events
		Pollutant-Specific Outreach
PO4	Business Outreach	Corporate Outreach
		Business Assistance Program
PO5	Effectiveness Assessment	Behavioral Change Assessment Strategy
		Outreach Program Annual Effectiveness Assessment
		Public Outreach Program Element Modifications

A framework to estimate unreported use of pyrethroid pesticides

A research (Xuyang and Frank, 2010) was done by Department of Pesticide Regulation Environmental Monitoring Branch in Sacramento to estimate unreported use of group III pyrethroid pesticides by comparison of use and sales reported in CDPR. Besides homeowners, employees who incidentally apply to business building, institutional and industrial facilities are also considered into unreported use. Four types of disagreement prevent researchers from making reliable conclusion. For example, one disagreement is the reported use is larger than reported sales.

A potential equation to estimate unreported uses:
Unreported urban use ≈ unreported use = reported sales - reported use + εtotal
where εtotal includes contributions from both εsales and εuse.

Appendix H: Pyrethroid & Bifenthrin Applications in Coastal California Watersheds

Table 8.34. *Pyrethroid and bifenthrin applications in coastal California watersheds.*

Watershed	Area of Goby Critical Habitat (acres)	Total Pyrethroid (lbs)	Peak Pyrethroid Application Month	% Non-Agriculture Pyrethroid Use	Total Bifenthrin (lbs)	% Non-Agriculture Bifenthrin Use
Santa Ana	-	52254	July	98.00%	14650	99.50%
Salinas	464	42487	August	7.00%	5460	43.10%
Los Angeles	-	42353	August	99.70%	9363	99.90%
San Gabriel	-	35131	August	99.70%	7533	99.60%
Coyote	-	30384	August	99.20%	1435	96.50%
San Diego	-	29643	December	99.20%	10671	99.90%
San Francisco Bay	-	25600	April	99.90%	2046	99.90%
San Jacinto	-	20284	May	93.30%	6975	93.70%
Santa Monica Bay	75.1	19253	August	100.00%	4445	100.00%
Santa Maria	456	15085	July	27.50%	3066	38.70%
Pajaro	191	14906	August	25.00%	2779	47.40%
Monterey Bay	245	13607	August	15.50%	2761	15.30%
San Luis Rey-Escondido	58	13323	May	79.90%	4385	87.90%
San Pablo Bay	-	11515	June	99.40%	2109	99.90%
Calleguas	168.5	11221	May	35.70%	4574	57.80%
Santa Margarita	-	9976	August	94.40%	3390	96.50%
Newport Bay	-	8882	April	99.40%	1682	99.10%
Seal Beach	-	8851	April	99.70%	1671	99.60%
Central Coastal	405.7	8698	July	57.60%	4872	90.00%
Aliso-San Onofre	14.3	7427	April	99.00%	1651	98.00%
Santa Clara	269	7187	October	55.90%	2228	67.00%
San Francisco Coastal South	510	5968	January	97.30%	135	92.00%
Santa Ynez	-	5650	April	42.90%	730	53.00%
Suisun Bay	-	5431	September	99.70%	2756	100.00%
Santa Barbara Coastal	224	5191	April	92.30%	778	98.00%
Russian	-	3720	June	95.50%	479	100.00%
Big-Navarro-Garcia	122.8	1677	May	99.60%	324	100.00%
San Antonio	3	1154	April	62.10%	145	78.00%
Upper Eel	-	1060	August	100.00%	191	92.00%
Ventura	54.5	938	April	85.00%	491	90.00%
Tomales-Drake Bays	3022	936	June	98.50%	26	100.00%

Mad-Redwood	3019.9	749	September	100.00%	321	100.00%
Cuyama	-	726	May	53.40%	302	98.00%
San Felipe Creek	-	542	February	45.60%	145	60.00%
Lower Eel	39.1	508	September	99.60%	170	100.00%
Mattole	-	244	September	100.00%	76	100.00%
South Fork Eel	-	240	September	100.00%	74	100.00%
Gualala-Salmon	108.1	206	June	100.00%	31	100.00%
Carrizo Creek	-	180	December	100.00%	65	100.00%
Smith	2704	136	May	28.70%	20	100.00%
Lower Klamath	-	107	November	100.00%	47	100.00%