Department of Pesticide Regulation
Environmental Monitoring Branch
1001 I Street
Sacramento, California 95812

Modeling bifenthrin outdoor uses in residential areas of California

Yuzhou Luo, Ph.D.

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1 Introduction

Bifenthrin is considered to be the leading cause of pyrethroid-related toxicity in urban areas. According to the review of pyrethroids and fipronil monitoring data during 2003–2012 by the California Stormwater Quality Association (Ruby, 2013), bifenthrin was detected most frequently of all pesticides evaluated, 69% in sediment samples and 64% in water samples. The most recent monitoring data by the California Department of Pesticide Regulation (CDPR) (July 2015 to June 2016) also show that bifenthrin was associated with the highest benchmark exceedance frequency in water compared to USEPA aquatic life benchmark and the largest contributor to pyrethroids-related toxicity units in sediment (Budd, 2016; Ensminger, 2016).

To reduce the exposure of aquatic organisms from residential uses of pyrethroids products, a series of mitigation efforts were developed by the U.S. Environmental Protection Agency (USEPA), CDPR, and registrants. Those include [1] USEPA recommended label statements in 2009 and its 2013 revision (USEPA, 2013) for all products intended for professional uses, [2] "Bifenthrin label memorandum of agreement" (Bifenthrin MOA) between bifenthrin manufacturers and CDPR in 2011 (CDPR, 2011) for selected bifenthrin products for professional uses, and [3] surface water regulations adopted by CDPR in 2012 (CDPR, 2012) for professional applications.

This study aims to simulate the use, runoff, and environmental concentrations of bifenthrin in California residential areas, with the historical application methods and revised methods by both label changes and surface water regulations. Residential outdoor uses of bifenthrin products including lawn/vegetation applications and outdoor surface treatments are considered here. Applications not subject to surface runoff (e.g., subterranean or surfaces protected from rainfall and irrigation) are not included. Both professional and homeowner uses are modeled so that the predicted concentrations can be compared with monitoring data and water quality criteria in urban receiving water. The core assumption is that a "hypothetical label" of bifenthrin products can be derived from the major products for professional and homeowner uses in California, and used to conservatively represent total bifenthrin applications in residential areas.

To be consistent with toxicity values considered in the development of water quality criteria for bifenthrin, aqueous (freely dissolved) concentrations in *porewater* and associated concentrations in sediment particles at equilibrium are used in this study for monitoring data and model predictions. A reference model (i.e., baseline simulation) is first developed based on the historical use information of bifenthrin products before any of the abovementioned mitigation actions. The results of baseline simulation will be validated by comparing them to monitoring data of bifenthrin in urban receiving water of California. Then recommended label changes and surface water regulations are implemented as modeling scenarios for their effects in reducing total applied mass and runoff of pesticides from residential areas. Additional scenarios of bifenthrin applications are proposed and tested with more restrictions on treated surface areas, application interval, and application time window.

Major findings and implications of this study are summarized here:

- A baseline simulation ("3-ft up, 10-ft out," monthly applications, 4 times per year) generates reasonable and conservative prediction of the worst-case condition of bifenthrin observed in California urban receiving water.
- The current USEPA acute benchmark (75 ng/L) is higher than the water solubility of bifenthrin used in this model, i.e., no action is needed to achieve this criterion.
- Based on the label changes and surface water regulations, applied mass will be reduced by 60.2% and concentration by 80.6%. However, the predicted concentrations are still higher than all water quality criteria (except for USEPA acute benchmark).

2 Background

2.1 Urban uses

Only professional uses of pesticides in urban/residential areas of California are reported to the PUR database. There is a general increasing trend of annual use amounts of bifenthrin by professional applicators for landscape maintenance and structural pest control in California since 2000, especially after 2010 (Figure 1). Bifenthrin uses decreased over two years (2013 and 2014) after the surface water regulation, but increased again in 2015.

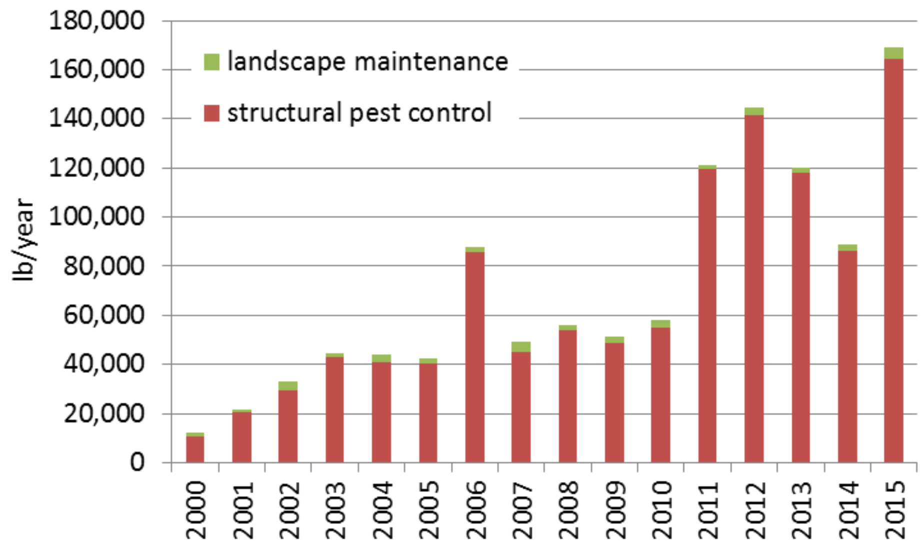


Figure 1. Annual urban professional uses (structural pest control and landscape maintenance) of bifenthrin in California during 2000–2015. Data source: CDPR internal database of pesticide use reporting, accessed 4/21/2017.

PUR data are not directly used in model simulations in this study, but used to identify the primary products in California containing bifenthrin for professional uses. Based on the recent 3-year PUR data (2013–2015), the top-5 products by use are:

- Masterline Bifenthrin 7.9 Termiticide/Insecticide
- Bifen I/T Insecticide/Termiticide
- Talstar Termiticide/Insecticide
- Wisdom TC Flowable
- Talstar Professional Insecticide

The five products account for 89% of total urban/residential uses in California during 2013–2015. They are all registered for subterranean, lawn and garden, outdoor surface and perimeter, and indoor uses.

A number of use/usage surveys were conducted in order to further characterize residential uses of bifenthrin in California. Survey results are reviewed and incorporated in the modeling efforts of this study:

Homeowner uses

Pesticide uses by homeowners are not documented in the PUR. Percentage of homeowner uses of bifenthrin in total urban/residential uses was estimated to be 20% (TDC, 2010). In 2010, CDPR conducted surveys of pesticide products sold in retail stores in Northern and Southern California (Osienski et al., 2010). Results showed that six bifenthrin products (available in one or more formulations of granular, liquid concentrate, and ready-to-spray) for outdoor uses are available to California homeowners, and some of the products are labeled for outside surface treatment including foundation and impervious horizontal surfaces (Table 1). These products, especially those for outdoor surface treatment, are further reviewed in this study.

Table 1. Pesticide products containing bifenthrin and available in California retail stores

Product name	Subterranean	Indoor	Lawn & garden	Outside surfaces
Bug-B-Gon Max Insect Killer for Lawns (Granular)			x	
Total Kill Lawn and Garden Insect Killer (Granular)			x	
Home Defense Max: Outdoor Perimeter Insect Killer (RTS)				x
Home Defense Max: Perimeter and Indoor Insect Killer (Granular or RTS)		x		x
Home Defense Max: Termite and Destructive Bug Killer (Concentrate or RTS)	x			x
Bug-B-Gon Max Lawn and Garden Insect Killer (Concentrate and RTS)			x	

Notes: [1] RTS = ready-to-spray; [2] according to the PUR database, Bug-B-Gon Max Insect Killer for Lawns was also used by professional applicators.

House fraction treated with pesticides

Pyrethroids Working Group (PWG) survey results suggested that 75.9% of households in California use outdoor pest control products, including applications by professional applicators, homeowners, or both (Winchell, 2013). This value is considered as a conservative estimate compared to other survey results and has been incorporated in the Pesticide Registration Evaluation Model (PREM) by CDPR’s Surface Water Protection Program (SWPP) for evaluating insecticide uses in residential area.

Application frequency and interval

A PWG survey in 2009 suggested that the frequency of professional applications was most commonly monthly or every other month for residential customers in California (PWG, 2010).

Application with bifenthrin

Based on the PWG survey results in 2009, Winchell (2013) calculated the fraction of use sites treated by each active ingredient. It concluded that the fraction of outdoor insecticide application represented by bifenthrin use is 27.1%.

2.2 Monitoring data

The purpose of monitoring data analysis in this study is to determine *one* value of bifenthrin concentration to represent the “worst-case” condition observed in urban receiving water of

California. This value will be compared to simulation results for model validation and compared to water quality criteria to estimate the reductions required to achieve a certain criterion.

Monitoring data of *sediment* samples are considered for this purpose, since both the modeling results and water quality criteria are presented in the form of aqueous (freely dissolved) concentration in porewater. Data were retrieved from DPR's Surface Water Database (SURF) (CDPR, 2017), California Environmental Data Exchange Network (CEDEN, http://www.ceden.org/), and the data compiled for California Stormwater Quality Association (CASQA) (Ruby, 2013). Only samples from urban *receiving water* are considered.

The average value of the top-3 concentrations in sediment (Table 2) is 570.7 µg/kg[dw]. The use of top-3 observations is consistent with the approach in SWPP's urban model development (Luo, 2014a) and risk assessments for fipronil (Budd and Luo, 2016). This value is higher than most of the measurements in receiving water, but it's still significantly less than those measured at stormdrain outfalls, which were considered in USEPA's preliminary ecological risk assessment (ERA) (USEPA, 2016).

Table 2. The top-3 concentrations of bifenthrin measured in sediment of urban receiving water bodies in California

Date	Site	Value, µg/kg[dw]	Reference
6/9/2011	Bouquet Canyon Creek	846	SWAMP Stream Pollution Trends
9/24/2004	Kaseberg Creek	436.6	(Weston et al., 2005)
Aug 2004~ Mar 2005	Curry Creek	429.5	(Amweg et al., 2006)

An alternative method to characterize the worst-case condition is also tested, by calculating the 1-in-10-year concentration from monitoring data before and including 2012. This approach is consistent with the calculation of the estimated environmental concentration (EEC) for acute risk assessment used by USEPA and SWPP. Data are available for less than 10 years (9 years from 2001–2009), so "inclusive percentile" is used in the calculation and the result is 518.8 µg/kg[dw]. This is lower than the previously determined value (570.7), but note that the standard procedure for calculating the 1-in-10-year concentration is based on exclusive percentile, which may generate higher values. In conclusion, the value (570.7 µg/kg[dw]) determined from top-3 measurements is used in this study to represent the worst-case condition.

The concentration of bifenthrin in porewater (C_{pore}, µg/L) is estimated from the measured total concentration in sediment (C_{sed}, µg/kg[dw]) based on the equilibrium assumption between porewater and sediment particles:

$$C_{pore} = \frac{C_{sed}}{f_{TOC} * KOC} \quad (1)$$

where f_{TOC} (dimensionless) is the fraction of total organic carbon (TOC) in sediment, and KOC (L/kg[OC]) is the organic carbon (OC)-normalized partitioning coefficient. A complete form of Eq. (1) should also include parameters of sediment bulk density and biomass concentration in the denominator. But for bifenthrin, due to its high KOC values (236,750 L/kg[OC], see the later section for environmental fate data used in this study), those parameters have only minor effects on the results. In this study, f_{TOC} is set as 4.0%, the default value in the modeling scenario of USEPA standard pond. Based on CDPR's monitoring results, the average f_{TOC} in sediment of urban receiving water is 4.4% (Michael Ensminger, 2016, personal communication). Therefore, the use of a lower f_{TOC} generates conservative estimation of porewater concentration with Eq. (1). Finally, the worst-case condition according to observed concentration in sediment, 570.7 µg/kg[dw], is converted to porewater concentration of 0.0603 µg/L (or 60.3 ng/L). This value is higher than the water solubility of bifenthrin, so it cannot be used for risk assessments. In this study, it's only used for comparing with water quality criteria to estimate required reductions to achieve a certain criterion (Section 3.3), or with simulation results for model validation (Section 4.1).

2.3 Previous modeling efforts

In 2007, USEPA's Environmental Fate and Effects Division (EFED) developed Tier-2 modeling scenarios for pesticide uses in nationwide suburban residential settings (USEPA, 2007), including scenarios for impervious surfaces and residential turf in California. In 2012, those suburban residential scenarios were used by USEPA to evaluate risks of bifenthrin use to federally threatened and endangered species in California (USEPA, 2012). Historical bifenthrin labels for residential uses, such as "10-ft perimeter treatment," were modeled and modeling results showed that the EEC in porewater, calculated as 1-in-10-year concentration, was 4.28 ng/L.

Jorgenson et al. (2013) estimated the use reduction of pyrethroid insecticides according to the Bifenthrin MOA and surface water regulations, and predicted the corresponding changes of pyrethroid concentrations in the lower American River watershed based on a simple screening-level model. They concluded that the mitigation actions will reduce predicted total toxic unit by 84%. The predicted concentrations would continue to exceed proposed water quality criteria in the lower American River, which is associated with comparatively higher dilution capacity compared to other urban receiving water such as an urban creek.

In 2014, CDPR's Surface Water Protection Program (SWPP) developed California-specific residential modeling scenario for pesticides (Luo, 2014a) and incorporated into SWPP's Pesticide Registration Evaluation Model (PREM). Compared to the EFED model, SWPP model reflects higher residential density, higher impervious surface coverage, and the consideration of dry-weather runoff. This SWPP model was initially developed for registration evaluation of new pesticide products. It was recently updated and used for post-use risk assessments and generated satisfactory results for residential uses of fipronil products (Budd and Luo, 2016).

In the preliminary ecological risk assessment (ERA) for pyrethroids by USEPA (2016), bifenthrin products with revised labels were modeled for their uses in residential areas of California. The modeling settings were similar to the 2007 suburban residential scenarios, and resulted in an EEC of 0.326 ng/L in porewater (Table 37 in the preliminary ERA). However, the results were based on a *single* application on June 1. The 2016 preliminary ERA also discussed SWPP model for urban pesticide uses as an "alternative exposure model," and concluded that

EFED's national based model may not be suitable to represent urban areas in California because its residential lot scenario does not represent California-specific pesticide use and transport.

3 Methods and materials

3.1 Simulation design

SWPP's PREM with California-specific urban scenarios is used in this study. The model uses the same simulation engines as those in EFED's Pesticide in Water Calculator (PWC), i.e., Pesticide Root-Zone Model (PRZM) and Variable Volume Water Model (VVWM). Required data for model simulations are summarized below, and data preparation processes will be elaborated in later sections:

- Environmental fate data (Table 3, Section 3.2)
- Water quality criteria (Table 4, Section 3.3)
- Single application rate (0.254 kg[bifenthrin]/ha[treated area], Section 3.4)
- Multiple applications (application interval = 30 days, number of applications = 4/year, Section 3.5)
- Application methods (Section 3.6)

Application methods, mathematically represented as treated surface areas for modeling, are the primary parameters to be affected by the recommended label changes and surface water regulations. Therefore, they are incorporated as the key variables in the development of modeling scenarios (Section 3.7). In addition, changes on other application information (application rate, interval, time window, and number of applications) are also considered in modeling scenarios with more restrictions.

PREM reports aqueous (freely dissolved) concentrations in bulk water and in porewater of the receiving water body at daily time step for the 30-year simulation period of 1961–1990. In this study, predicted concentrations of bifenthrin in *porewater* and associated concentrations in sediment are used for model validation and risk assessments. Concentrations in porewater are considered bio-available to sediment-dwelling organisms such as *Hyalella azteca*, from which water quality criteria for bifenthrin are usually developed. CVRWQCB (2015) suggested that the compliance determination of water quality objective should be based on dissolved concentrations of bifenthrin in porewater, e.g., those measured by solid-phase microextraction (SPME) and sediment filtration, or calculated based on chemical equilibrium.

A "baseline simulation" is developed with the treated surface areas according to the historical labels of major bifenthrin products for urban/residential uses in California. Results of the baseline simulation are compared with monitoring data for model validation. Specifically, the EEC for model validation is calculated as the predicted 1-in-10-year daily concentration of bifenthrin in porewater, and compared to the worst-case condition (60.3 ng/L) determined in Section 2.2. It's expected that the EEC will overestimate the observation within one magnitude, i.e., the ratio of prediction/observation within 1~10X.

After validation, the model is used for "scenarios analysis" with modeling scenarios developed with treated surface areas according to recommended label changes and surface water regulations. Scenario analyses are conducted for two purposes. First, the results are used to quantitatively evaluate the effects of label changes and surface water regulations on applied amounts and environmental concentrations of bifenthrin. For this purpose, the EEC's (in water and in sediment) are calculated by the PREM default algorithm (i.e., 1-in-10-year daily concentration), and compared to those reported from the baseline simulation. Relative changes in applied mass and EEC to the baseline simulation results are reported for each scenario. The second purpose of the scenario analysis is to conduct risk assessments. Results of the scenario analysis are compared with water quality criteria to determine if the scenario is sufficient to meet the criteria.

3.2 Physiochemical properties

In this study, model inputs of physiochemical properties (Table 3) are mainly taken from the preliminary ERA (USEPA, 2016). KOC (organic carbon-normalized partitioning coefficient) is retrieved from a previous modeling study (USEPA, 2012), equivalent to Kd (partitioning coefficient) =9470 L/kg in receiving water (OC=4%), while the 2016 preliminary ERA used a lower value (Kd=3104 L/kg) (USEPA, 2016). In addition, SPHOT (soil photolysis half-life) is based on DPR-accepted studies and derived in (Luo, 2014b). This variable is not used in USEPA modeling.

Table 3. Model inputs for physiochemical properties of bifenthrin

Variable	Description	Value
MWT (g/mole)	Molecular weight	422.9
VP (torr)	Vapor pressure	1.8e-7
SOL (mg/L)	Water solubility	1.4e-5
AERO (day)	Aerobic soil metabolism half-life (HL)	169.2
SPHOT (day)	Soil photolysis HL	104
AQPHOT (day)	Aqueous photolysis HL	49
HYDRO (day)	Hydrolysis HL	Stable
AERO_W (day)	Aerobic aquatic metabolism HL	466.2
ANAER_W (day)	Anaerobic aquatic metabolism HL	650.2
KOC (L/kg[OC])	Organic carbon (OC)-normalized partitioning coefficient	236,750

3.3 Water quality criteria

Water quality criteria are taken from three data sources and summarized in Table 4.

- USEPA aquatic life benchmarks (USEPA, 2017), accessed 3/1/2017. The lowest benchmarks for bifenthrin are 75 (acute) and 1.3 (chronic) ng/L. Note that the acute benchmark (75 ng/L) is above the water solubility.
- Benchmark equivalents, generated based on the toxicity studies used in the preliminary ERA (USEPA, 2016). Two toxicity values: 0.493 ng/L (acute, *Hyalella azteca*, 96-hr EC50, MRID 49552201) and 0.05 ng/L (chronic, *Hyalella azteca*, 10-d NOAEC, MRID 48593601), were used in the ERA for calculating invertebrates risk quotients. The two values are not yet included in the current version of the USEPA benchmarks but used in

this study for benchmark equivalents. The same method was previously used to prepare water quality criteria for pesticides not covered by USEPA benchmarks (Luo et al., 2013).

- Water quality objectives developed by California Central Valley Regional Water Quality Control Board (Fojut et al., 2012; CVRWQCB, 2015). Criteria calculated at the 5th percentile are used in this study.

Table 4. Water quality criteria of bifenthrin (ng/L) considered in this study

Source	Acute	Chronic
USEPA benchmarks	75 (>SOL)	1.3
Benchmark equivalents	0.2465	0.05
CVRWQCB water quality objectives (the 5^{th} percentile)	0.8	0.1

Notes: the acute toxicity value (0.493 ng/L) is divided by two to derive the acute benchmark equivalent, while the chronic toxicity value (0.05 ng/L) is used as the chronic benchmark equivalent.

The water quality criteria are compared to the worst-case condition of bifenthrin concentrations in porewater derived from observed concentrations (60.3 ng/L, Section 2.2), in order to calculate the required relative changes of concentration to achieve a certain criterion (Table 5).

Table 5. Required relative changes of concentration for the selected water quality criteria

Source	Acute	Chronic
USEPA benchmarks	0	-97.8%
Benchmark equivalents	-99.6%	-99.9%
CVRWQCB water quality objectives (the 5^{th} percentile)	-98.7%	-99.8%

EEC calculations for risk assessments vary by water quality criteria (Table 6). Due to the high persistence of bifenthrin in sediment, the concentration values in porewater presented as daily peaks, 4-day moving averages, or 21-day moving averages are very similar.

Table 6. EEC calculation for various water quality criteria considered in this study

Water quality criteria		EEC calculation
USEPA benchmarks, or benchmark equivalents	Acute	PREM default algorithm (i.e., 1-in-10-year daily concentration)
	Chronic	1-in-10-year 21-d daily moving-average concentration
CVRWQCB water quality objectives	Acute	1-in-3-year peak concentration
	Chronic	1-in-3-year 4-d daily moving average concentration

Notes: [1] 21-d moving average for chronic risk assessments for bifenthrin is suggested by USEPA (2016). [2] EEC calculations for the CVRWQCB water quality objectives are based on their specific criteria statements: "*Aquatic life in the Sacramento River and San Joaquin River basins should not be affected unacceptably if the four-day average concentration of bifenthrin does not exceed [the chronic criterion] more than once every three years, on the average, and if the one-hour average concentration of bifenthrin does not exceed [the acute criterion] more than once every three years on the average*" (CVRWQCB, 2015).

3.4 Single application rate

The single application rate is usually not explicitly displayed on pesticide labels for urban uses, but can be derived from the AI percentage, product density, dilution chart, and application volume. PREM provides a rate calculator for this purpose. Section 2.1 summarized major bifenthrin products for both professional uses and homeowner uses in California. Their single application rates are estimated in this section (Table 7). Recommended label changes (by USEPA or Bifenthrin MOA) and CDPR surface water regulations have no effects on application rates of bifenthrin uses in residential areas.

The five major products for professional uses (Masterline bifenthrin 7.9 T/I, Wisdom TC Flowable, and Talstar T/I, Talstar Professional insecticide, and Bifen I/T) have the same AI content (7.9%), and very similar mixing ratio and application volume for lawn applications and pest control on outdoor surfaces and around buildings. For all residential applications, the application volume is up to 1.0 fluid oz. of product per 1000 ft^2. Therefore, the maximum permissible label rate is determined to be 0.254 kg[bifenthrin]/ha in this study. This rate is consistent with those derived in the previous USEPA modeling: 0.258 (USEPA, 2012), or 0.247 kg/ha (USEPA, 2016). Similarly, application rates for homeowner-use products labeled for outdoor surface treatment are calculated (Table 7). Products for professional uses have higher application rates compared to those for homeowner uses. Therefore, model simulations with the application rate of 0.254 kg/ha (derived for professional uses) provide a conservative estimation for homeowner uses.

Table 7. Single application rates calculated for major bifenthrin products for professional applicators and homeowners

Product(s)	Dilution and volume	Application rate (kg/ha)
Major products for professional uses (Masterline bifenthrin 7.9 T/I, Wisdom TC Flowable, and Talstar T/I, Talstar Professional insecticide, and Bifen I/T)	1 fl oz per gallon of water to be sprayed over 1000 ft^2 (AI concentration in the final spray = 0.06%)	0.254
Home Defense Max: Outdoor Perimeter Insect Killer	(Ready-to-spray AI concentration = 0.3%) A package (32 oz) will treat 360*4 ft2	0.203
Home Defense Max: Termite and Destructive Bug Killer	0.5 fl oz per gallon of water to be sprayed over 167 ft^2 (AI concentration in the final spray = 0.0094%)	0.219
Home Defense Max: Perimeter and Indoor Insect Killer	(Ready-to-spray AI concentration = 0.05%) No information for application volume in the label, assumed the same as the professional use products (1000ft^2/gallon) due to similar AI concentration.	0.195

Note: There are 6 bifenthrin products available in California retail stores (Section 2.1). The three labeled for outdoor surface treatment are reviewed here.

3.5 Multiple applications

Multiple applications are allowed for bifenthrin products, but the application frequency and the maximum number of applications are not well defined. A minimum interval of 7 days are mentioned in the products for professional uses, while in some products for homeowner uses, the labels suggested that one application keeps listed bugs/insects out for up to 1 month. For a more realistic characterization of multiple applications, this study considers the following results of use/usage survey (see Section 2.1 for more information):

- Monthly applications of outdoor pest control products (all insecticides including bifenthrin); and
- 27.1% of the applications are associated with the use of bifenthrin.

Therefore, the maximum number of bifenthrin applications per year is estimated as 365/30*27.1%=3.3 (where 365/30 is the potential number of monthly applications of *any* insecticide for outdoor pest control per year), and conservatively set as 4 for modeling. In addition, this study assumes bifenthrin treatment on a *monthly* cycle for conservative estimation.

This study does not specify the date of the first application, but conducted multiple model runs by varying the date monthly from Jan 1st to Dec 1st (or the first days of months within the proposed application window, if applications are prohibited for some months in a modeling scenario). The date with the highest predicted environmental concentrations will be used for model validation and risk assessments. Previous studies showed that applications during California's winter rainfall seasons may generate higher EEC, and thus should be considered for conservative estimation. For example, the date of the first application was set as Oct 15th for bifenthrin uses in California residential areas in the 2012 USEPA study (USEPA, 2012). In that study, multiple applications of bifenthrin were evaluated with the following two settings: [1] 2 applications on a 7-day cycle, and [2] 6 applications on a 56-day cycle. Those scenarios will also be tested in this study to ensure the simulation won't miss worst-case conditions. In the preliminary ERA, multiple applications were not modeled (USEPA, 2016).

3.6 Application methods

Professional uses

Table 8 summarizes the application methods of bifenthrin uses for lawn application and outdoor surface treatment in historical labels, and according to the recommended label changes and surface water regulations. There are many aspects in the label changes and regulations, but this study only reviewed those related to the determination of potential treated areas of lawns and outdoor surfaces which are not protected from rainfall and irrigation.

Table 8. Summary of label changes and surface water regulations for professional application methods of bifenthrin products

Surfaces	Historical labels	Bifenthrin MOA	SW regulations	USEPA2013
Vertical surface connected to an impervious surface that could result in runoff into storm drain	Perimeter band treatment: 2~3 ft	Not allowed	Pinstream	Not allowed
Other vertical surface		≤3ft	≤2ft	≤3ft
Impervious horizontal surfaces	[1] Perimeter band treatment: 6~10 ft, or [2] broadcast for mosquito control	crack and crevice, spot	crack and crevice, spot, pinstream	crack and crevice, spot, pinstream (pest entry points only)
Pervious surfaces		No change to historical labels	[1] perimeter treatment: ≤3ft, or [2] broadcast with 2ft buffer to impervious surfaces (where pinstream treatment may be made)	No change to historical labels

Homeowner uses

The revised label statements with USEPA 2013 language are also proposed for products primarily used by homeowners, but with less application restrictions. Table 9 compares the application restrictions recommended by the bifenthrin MOA and USEPA 2013 language, and those observed in the bifenthrin products for homeowner uses. The major difference is that the restriction of application to vertical surfaces connected to an impervious surface that could result in runoff into storm drains is *not* included in the labels of some products for homeowner uses. These surfaces are associated with high runoff potentials. Therefore, this study will evaluate homeowner treatment on these surfaces in addition to the application methods allowed for both professional and homeowner uses.

Table 9. Application methods of bifenthrin products for homeowner uses in California

(a) Application methods

	Home Defense Max: Outdoor Perimeter Insect Killer	Home Defense Max: Termite and Destructive Bug Killer	Home Defense Max: Perimeter and Indoor Insect Killer
Application methods	Perimeter treatment (4-foot band)	Perimeter treatment (band width not mentioned)	Perimeter treatment (12-inch band)

(b) Comparison to the bifenthrin MOA and USEPA 2013 label language

	Home Defense Max: Outdoor Perimeter Insect Killer	Home Defense Max: Termite and Destructive Bug Killer	Home Defense Max: Perimeter and Indoor Insect Killer
Do not apply directly to impervious horizontal surfaces except as a spot or crack and crevice treatment	x	x	x
Applications to the side of a building, up to a maximum height of 3 feet above grade	Total band of 4 feet on the soil and up the side of the house	x	x
Do not apply to vertical surfaces connected to an impervious surface that could result in runoff into storm drains			x

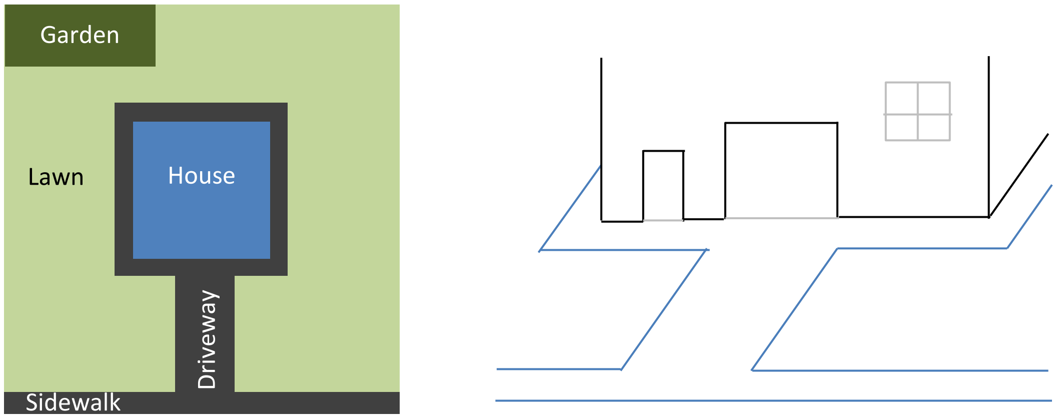
Notes: [1] There are 6 bifenthrin products available in California retail stores (Section 2.1). The three labeled for outdoor surface treatment are reviewed here. [2] Only application methods and label languages related to outdoor impervious surfaces are reviewed in the above tables. [3] Refer to Table 7 for application volumes and rates.

Treated surface area

In PREM, application methods are mathematically represented by areas of the surfaces potentially to be treated by a pesticide product. SWPP's urban conceptual model (Figure 2) is used to determine the area fractions for each scenario. Details for the conceptual model development and associated parameters are documented in the PREM technical report (Luo, 2014a). For example, the treated area of 3-ft perimeter application on vertical surfaces can be estimated as:

$$\text{Treated area} = 38.73\ \text{ft/side} * 4\ \text{sides} * 3\ \text{ft} = 464.76\ \text{ft}^2$$
$$\text{Or, converted to area fraction} = 464.76\ \text{ft}^2/5337\ \text{ft}^2 = 8.71\%$$

where 38.73 ft is the length of the house, and 5337 ft^2 is the total area of the residential lot. To simplify the simulation, spot treatment and crack and crevice directed spray are combined and characterized by treated area fractions of 2.5% on pervious surfaces and 2.5% on impervious surfaces (USEPA, 2012). In SWPP's conceptual model, this results in a treated area of 133 ft^2 (=2.5%*5337 ft^2), or about 10% of the total treatable, impervious horizontal surfaces (Figure 2).



(a) Modeled components of residential landscape

(b) Surfaces in the front of a house subject to bifenthrin treatments

Figure 2. SWPP's conceptual model for a typical single family home

3.7 Modeling scenarios

Three sets of modeling scenarios are developed in this study: baseline simulation (*historical* labels), scenarios for recommended label changes and surface water regulations (*current* labels), and scenarios with more restrictions suggested in other studies (*proposed* labels) (Table 10). Label reviews in Sections 3.4–3.6 suggest that a "hypothetical label" of bifenthrin products can be summarized from the major products for professional and homeowner uses in California, and used to conservatively represent total bifenthrin applications in residential areas. Specific considerations in the scenario development are summarized as follows:

- For historical labels of bifenthrin products for both professional and homeowner uses, the hypothetical label is described as "*monthly applications for 4 times per year, with 10-ft perimeter treatment at rate of 0.254 kg/ha*". This application method (both the application rate and treated areas) is considered as conservative representation of homeowner-use products (Table 7).
- For current amended labels, the hypothetical label is similar to that for historical labels, except for application methods which are interpreted according to the label changes recommended by USEPA and CDPR surface water regulations (Table 8). Label review suggests that the recommended statements have been incorporated into the majority of product labels for professional uses. In addition, as discussion in Section 3.5, some of the recommended label changes for professional products, especially those related to treatment on impervious surfaces, also have been placed on the new labels of homeowner-use products. The only major difference is that the applications to vertical surfaces connected to an impervious surface that could result in runoff into storm drains are not prohibited in some of the latest labels for homeowner uses. Therefore, for the modeling scenarios with current amended labels:

- Homeowner uses *without* treatment on these particular surfaces (vertical surfaces connected to an impervious surface that could result in runoff into storm drains) are combined together with professional uses in the modeling, and
- Homeowner uses *with* treatment on these particular surfaces are modeled as additional sources. It's assumed that 20% of treated households are treated by homeowners, according to the fraction of homeowner uses over total urban/residential uses of bifenthrin reported in the literature (TDC, 2010), and half of them (i.e., 10% of treated households) will be treated by homeowners on these particular surfaces in addition to other permissible methods.

- For potential application methods with more restrictions, this study tests the USEPA modeling scenario by limiting applications to impervious surfaces to pinstream perimeter treatment (USEPA, 2016).

Table 10. Modeling scenarios for bifenthrin uses in residential areas of California

Modeling scenario	Notes
[0] Baseline simulation (i.e., scenario for "historical labels")	This is similar to the modeling scenarios previously used to evaluate the historical bifenthrin labels (USEPA, 2012; Jorgenson et al., 2013). Although estimated from perimeter treatment, the treated areas on pervious surfaces are expected to cover all potential applications on pervious surfaces (soil, lawn, mulch, or other vegetation)
Perimeter treatment of 7 ft on horizontal surfaces and 3 ft on vertical surfaces.	
[0A] *Application methods same to [0], but 2 applications on a 7-day interval*	Multiple applications evaluated in USEPA (2012), with the first date of application on Oct 15th for both scenarios.
[0B] *Application methods same to [0], but 6 applications on a 56-day interval*	
[1] Scenario for label changes recommended by the Bifenthrin MOA and USEPA 2013 language	This scenario is mostly likely observed with the amended labels of bifenthrin products for professional and homeowner uses.
▪ 3 ft on vertical surface *not* connected to an impervious surface that could result in runoff into storm drain. ▪ 10% of households also receive 3-ft treatment on vertical surfaces connected to an impervious surface that could result in runoff into storm drains. ▪ Crack and crevice, spot treatment on impervious horizontal surfaces.	
[2] Scenario for label changes and surface water regulations	This scenario reflects CDPR's expectation on professional applications of bifenthrin products with both label changes and the regulations.
Similar to the scenario [1], but reduce the band from 3 to 2 ft on vertical surfaces; and reduce treated areas of pervious surface with the 2-ft	

buffer to adjacent impervious surfaces	
[3] Scenario for more restrictions on impervious surfaces	This is actually the scenario modeled in the preliminary ERA (USEPA, 2016). Perimeter pinstream treatment on impervious surfaces was also recommended in the PWG Pathway ID study as a "revised practice" (Davidson et al., 2014), and tested with cypermethrin on the expansion joint between garage door and driveway.
Similar to the scenario [1], but assume: ▪ Products for homeowner uses will follow the same label changes recommended for professional uses, i.e., no more treatment on vertical surfaces connected to an impervious surface that could result in runoff into storm drains. ▪ Applications to impervious horizontal surfaces are limited to perimeter treatment with *pinstream* (which is currently recommended in the USEPA 2013 language for "pest entry points" for products intended for professional uses)	

Note: single application rate of 0.254 kg/ha, 4 applications per year, a 30-d interval are applied for all scenarios, unless otherwise stated (as in the scenarios [0A] and [0B])

4 Modeling results and discussion

4.1 Baseline simulation

Results of the baseline simulation (the scenario [0], Table 10) and its alternatives ([0A] and [0B]) are reported as 1-in-10-year daily concentrations in porewater:

- 94.0 ng/L, the scenario [0] with 4 applications at a 30-day interval
- 45.3 ng/L, the scenario [0A] with 2 applications at a 7-day interval (USEPA, 2012)
- 88.0 ng/L, the scenario [0B] with 6 applications at a 56-day interval (USEPA, 2012)

Compared to the USEPA scenarios, the baseline simulation developed in this study generates more conservative estimates. The predicted EEC of 94.0 ng/L overestimates the predefined concentration for model validation derived from monitoring results (60.3 ng/L, Section 2.2) by 1.6X. As mentioned before, conservative estimates from 1~10X are expected in model validation. Therefore, the model configuration is valid for scenario analysis. Homeowner uses explain 20% of the applied mass and 20% of the predicted concentration in the total values, the same fraction as assumed in the model configuration.

4.2 Scenario analysis

Modeling scenarios in Table 10 are tested with the validated model. Results are presented as applied mass and environmental concentrations and compared to the results of baseline simulation or to the water quality criteria (Table 11).

Table 11. Modeling results for scenario analysis

(a) Summary (as relative changes to baseline simulation)

	Scenario [1]	[2]	[3]
Applied mass	-34.6%	-60.2%	-41.5%
EEC (1-in-10-year daily concentration)	-80.5%	-80.6%	-97.9%

(b) EEC values (calculated according to water quality criteria)

Water quality criteria (ng/L)			Scenario [1]	[2]	[3]
USEPA benchmarks	acute	75	**18.3**	**18.2**	**2.0**
	chronic	1.3	17.2	17.1	2.0
Benchmark equivalents	acute	0.2465	18.3	18.2	2.0
	chronic	0.05	17.2	17.1	2.0
CVRWQCB water quality objectives (the 5th percentile)	acute	0.8	13.7	13.6	1.4
	chronic	0.1	13.7	13.6	1.4

Notes: Methods for EEC calculations are defined in Table 6. EEC values in **bold** are lower than the corresponding water quality criterion.

Scenario [1] simulates the label changes recommended by the Bifenthrin MOA and USEPA 2013 language, and similar changes observed in the products for homeowner uses. This scenario results in a reduction of 34.6% on applied mass and 80.5% on EEC. The reduction in applied mass is a result of the prohibition of applications to vertical surfaces connected to an impervious surface that could result in runoff into storm drain, and the limitation of applications to impervious horizontal surfaces as crack and crevice and spot treatment. Impervious surfaces are associated higher runoff potential and identified as major transport pathways for pyrethroids (Davidson et al., 2014). Therefore, the resulting concentration reduction is significantly higher than the mass reduction. In scenario [1], homeowner uses contribute 21.2% applied mass and 36.7% predicted concentration, due to the potential applications to vertical surfaces connected to an impervious surface that could result in runoff into storm drains. Homeowner uses by themselves generate a (1-in-10-year daily average) EEC of 6.73 ng/L, exceeding water quality criteria except for the USEPA acute benchmark.

Scenario [2] simulates professional applications by following surface water regulations, in addition to the restrictions already addressed in the label changes. The regulations further reduce bifenthrin applications on vertical surfaces (from 3-ft to 2-ft band) and pervious surfaces. The predicted reduction of applied mass is 60.2%, much higher than that in scenario [1]. Specifically, the model predicts 49% reduction of applied mass on pervious surfaces and 76% on impervious surfaces, consistent with the results of a previous study where estimated use reductions with the Bifenthrin MOA and surface water regulations on pervious surface and impervious surfaces are

50% and 80%, respectively (Jorgenson et al., 2013). For concentration, the predicted reduction is 80.6%. Note that scenario [2] does not predict additional EEC reduction compared to the scenario [1]. This may be explained by the fact that, in scenario [1], the applications are mainly reduced from impervious horizontal surfaces or vertical surfaces connected to an impervious surface that could result in runoff into storm drain, while in scenario [2], the further reduced treated surfaces are either pervious surfaces or vertical surfaces not directly draining to impervious surfaces.

Scenario [3] is similar to [1] but further reduces bifenthrin applications to impervious horizontal surfaces by allowing only perimeter pinstream treatment. This scenario results in a reduction of 41.5% on applied mass and 98.0% on EEC. This scenario also assumes that label changes recommended for products for professional uses will also be placed on homeowner-use product, so there is no more treatment on vertical surfaces connected to an impervious surface that could result in runoff into storm drain. In this case, the contribution of homeowner uses for both applied mass and predicted concentrations go down to 20%. By following the model parameterization in the preliminary ERA (USEPA, 2016), the application rate of pinstream treatment is assumed the same as the label rate (0.254 kg/ha). However, actual application rates of pinstream treatment could be significantly higher than the label rate and associated with great variability.

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