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Methodology for Evaluating Pesticides for Surface Water Protection: Urban pesticide uses

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Executive summary

This report presents a modeling approach to evaluate urban pesticide uses for surface water protection. The approach will be incorporated into the main program of registration evaluation used by the Surface Water Protection Program (SWPP) (Luo and Deng, 2012b, a). Urban pesticides evaluation by the SWPP are previously conducted by following the USEPA approaches with California urban scenarios, predefined urban landscapes, and post-processing procedures (USEPA, 2013c). The new development in this report is generally based on the same models and modeling scenarios. Improvements and modifications are mainly on simulation design and landscape design so that the modeling results are more representative of California urban conditions. Improvements of the proposed modeling approach relative to the USEPA approach are summarized as follows:

- Introduction of four types of surfaces by permeability and water sources,
- Consideration of pesticide transport induced by dry-weather runoff from impervious surfaces,
- Separation of impervious and pervious portions in the modeling scenarios,
- Use of prescheduled lawn irritation,
- Characterization of residential and commercial/industrial areas to reflect California urban conditions, and
- Aggregation of water, sediment, and pesticide yields for the urban watershed.

Registration evaluation with the newly developed urban model will be required for outdoor pesticide applications when the treated surface is in a drainage area with significant portion of impervious surfaces. Examples are residential areas, commercial/industrial facilities, and highway and road rights-of-way applications. The model is inappropriate to simulate use patterns which are not associated with irrigation or precipitation induced hydrologic processes or not characterized with an area-based application rate.

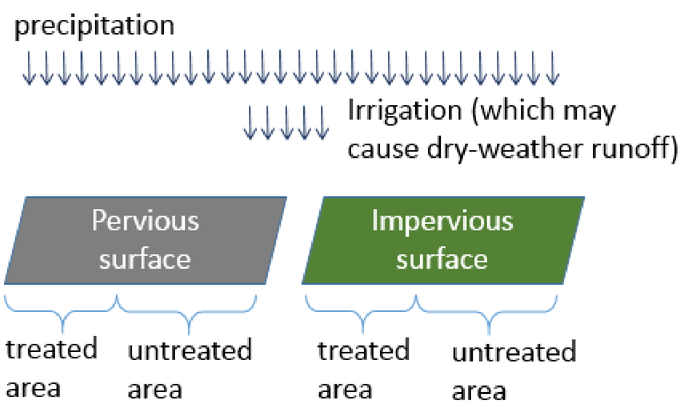
Terminology

- Runoff curve number (CN): an empirical parameter for predicting surface runoff from rainfall, developed by the Soil Conservation Service (SCS) (USDA, 1986). CN can be defined for single homogeneous surfaces, or calculated as a composite value for a complex landscape (such as an urban watershed). PRZM uses CN for surface runoff simulation.
- Dry-weather runoff: water runoff resulting from non-precipitation outdoor water uses, also called "urban drool". Only runoff due to lawn irrigation by sprinklers is considered here. Other sources such as hose irrigation and car wash are not simulated.
- Urban watershed and receiving water body: two components of DPR's conceptual model for urban pesticide evaluation; includes a 10-ha urban watershed that drains into a USEPA standard farm pond of 1 ha*2 m. The same conceptual model is used by USEPA for both registration evaluation and post-use risk assessment.
- Modeled surfaces: for modeling, the urban watershed is divided into different types of surfaces according to permeability and hydrologic characteristics. Four types of surfaces are considered in this study:
  - 1 - pervious surfaces not subject to dry-weather runoff (e.g., native vegetation, gardens with drip irrigation),
  - 2 - impervious surfaces not subject to dry-weather runoff (e.g., roof, roads),
  - 3 - pervious surfaces with dry-weather runoff (lawns), and
  - 4 - impervious surfaces with dry-weather runoff (paved areas adjacent to lawns).
- Effective application rate: (defined for each modeled surface) the total mass of pesticide active ingredient (AI) applied to the surface divided by the total area of the surface.
- "f" factors (dimensionless): the total area (in fraction of the 10-ha watershed) of each modeled surface. The "f" factors are determined by the representative landuse in an urban watershed (residential, commercial/industrial, or rights-of-way).
- "ft" factors (dimensionless): the treated area (in fraction of the 10-ha watershed) of each modeled surfaces.
- Impervious surface coefficient (ISC, dimensionless): the fractional area of impervious surface over a given landscape. Two ISC's are used in this report: the overall ISC (impervious surface fraction over the entire 10 ha urban watershed), and residential ISC (impervious surface fraction of the urban watershed's residential landuse).
- House size: reported square footage for "inhabitable" areas of a house unit according to ANSI standards. Data for house size is available in the American Housing Survey (AHS).
- House footprint size: projected area of a house. The difference between house size and footprint size may be related to the house design and the areas (e.g., garage) not accounted into the reported footage. No data is available for footprint size, and it's assumed in this study as the same value of the house size.
- Landscape unit: to simplify landscape characterizations, an urban watershed is assumed to be completely covered by identical landscape units. For example, in the USEPA settings for commercial/industrial applications, it's assumed that there are 9 facilities in a 10-ha urban watershed. Each unit (1.1 ha) includes a commercial/industrial lot and surrounding areas (modeled as impervious surface of roads by USEPA).
- Landscape design: in each landscape unit, representative sizes and dimensions of landscape components (building, paved areas around a building, driveway, sidewalk, lawns, etc.) are required to be determined for modeling purposes.

1 Introduction

Compared to agricultural uses, pesticide applications to urban environment are associated with greater spatial variability with respect to landscape characteristics and pesticide use patterns and rates. An urban watershed consists of different types of landscape surfaces according to their hydrologic responses, for example, classified by permeability and water sources for runoff generation (Figure 1). Pesticides could be applied to one or multiple surfaces, and usually only a small portion of each surface is actually treated. The proposed label rates by themselves are inadequate to calculate the total amount of pesticide applied to the urban watershed.

(a)



(b)

Precipitation							
Areas not subject to dry-weather runoff				Areas subject to dry-weather runoff			
[1] Pervious surface (f_1)		[2] Impervious surface (f_2)		[3] Pervious surface (f_3)		[4] Impervious surface (f_4)	
Treated area (ft_1)	Untreated area	Treated area (ft_2)	Untreated area	Treated area (ft_3)	Untreated area	Treated area (ft_4)	Untreated area

Figure 1. (a) Conceptual model and (b) representation of urban landscape with pesticide applications. f's are fractional areas over the urban watershed ($f_1+f_2+f_3+f_4=100\%$), and ft's are fractional treated areas over the urban watershed

USEPA evaluates proposed *agricultural* pesticide registrations using PE5 (PRZM-EXAMS version 5) and Tier 2 modeling scenarios under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) modeling framework. However, USEPA does not have a consistent modeling approach for the registration evaluation of *urban* pesticide uses. The major difficulty in modeling urban pesticide runoff especially from impervious surfaces is associated with data limitation. For terrestrial pesticide fate processes, only soil-related fate data (aerobic/anaerobic soil metabolism, field dissipation, soil photolysis) are required to be submitted, and may not be applicable to impervious surfaces. In addition, data is only required for the active ingredient, while washoff potentials of pesticides from impervious surfaces could be significantly associated with their product formulations (Jorgenson and Young, 2010). According to the model review by Cheplick et al. (2006), in addition, adequate urban pesticide runoff models do not exist. For example, USEPA Storm Water Management Model (SWMM) is primarily developed to predict non-point source loads of suspended solids, heavy metals, chlorides, nutrients, and hydrocarbons with natural, continuous accumulation as sources. PRZM was originally developed for pervious surfaces, but extended to use for urban environmental settings. Typically, equations designed for pervious surfaces have been applied with parameter extrapolation, attempting to simulate pesticide runoff from impervious surfaces.

For post-use risk assessments, USEPA developed “nonstandard” modeling scenarios (USEPA, 2007a) and post-processing of PE5 results for urban environmental settings in the effects determinations for endangered species (USEPA, 2013a, b). The details of the USEPA modeling approach for urban pesticides are provided in Appendix 1, and can be summarized as:

- Model: PE5
- Modeling scenario: two types of surfaces, pervious and impervious, are considered. Tier 2 modeling scenarios were developed for each of the surfaces.
- Simulation design: separate simulations for the two modeled surfaces are conducted in the PE5 for estimated environmental concentrations (EEC) in a USEPA standard farm pond from pervious surfaces and from impervious surfaces. Overall concentrations in the receiving water of the urban watershed are calculated as area-weighted averages of predicted concentrations from the two simulations.
- Landscape design: standard lots were developed for suburban residential, commercial/industrial, and rights-of-way applications in the 10-ha urban watershed, with representative sizes and dimensions of buildings, lawns, sidewalks, driveways, parking lots, and roads. For example, the suburban residential watershed is comprised of ¼-acre residential lots, each with a house footprint of 1000 ft^2 surrounded by lawns (USEPA, 2010).

The USEPA Offices of Pesticide Programs (OPP) concluded that the CA impervious scenario is the most suitable available modeling approach for impervious runoff (USEPA, 2012a, 2013d). Known limitations are mainly reported for the simulation design and landscape design (CASQA, 2011, 2013). Reviewers suggested that the EEC’s of pesticide reported in USEPA urban risk assessment may have been underestimated relative to California conditions. Low concentration estimates are due to non-representative landscape design of residential lots, use of an average of EEC’s from pervious and impervious surface for watershed-wide EEC, and the exclusion of some important processes (e.g., dry-weather runoff from impervious surfaces). For example, the majority of urban runoff in California and the southwest originates from impervious surfaces, so simple averaging of pervious and impervious EECs does not represent actual watershed EECs. In addition, the USEPA residential lot scenario, based on national suburban data, is not representative of pesticide use and transport in California urban areas where the landscapes are commonly associated with smaller lot size, higher fraction of impervious surfaces (especially impervious areas immediately next to buildings), and highly compacted soil.

Here we propose a modeling approach for urban pesticides in the registration evaluation. The approach will generally follow the PRZM-EXAMS simulations and associated USEPA urban modeling scenarios, and address the known limitations in the USEPA risk assessments for urban modeling pesticides according to California conditions. The new modeling approach is summarized as follows:

- Model: PRZM and EXAMS (used separately without the PE5 interface).
- Modeling scenario: For PRZM, four types of surfaces (Figure 1) are considered. Minor changes are made on the USEPA urban scenarios for California. The modified scenarios better characterize the pervious and impervious portions of an urban watershed. For EXAMS, the scenario for USEPA standard farm pond is used with no changes.
- Simulation design: A new modeling approach is developed. PRZM simulations are separately conducted for the four modeled surfaces, and area-weighted averages of PRZM outputs are routed into a USEPA standard farm pond for EXAMS simulation.
- Landscape design: For residential applications and commercial/industrial applications, USEPA landscape designs are significantly modified to better represent the actual conditions in California. For rights-of-way applications, 50% pervious and 50% impervious surfaces are assumed (as by the USEPA).

2 Modeling approaches

2.1 Overview of the modeling approach

In the proposed SWPP modeling approach, PRZM is used for pesticide runoff simulation from a conceptual urban drainage area of 10 ha, and EXAMS is used for pesticide fate simulation in the 1-ha USEPA standard farm pond as receiving water body. Those are consistent to the USEPA registration evaluation for agricultural uses. USEPA tier 2 modeling scenarios for California urban areas are used with minor changes on the pervious surface scenarios (i.e., CA residential scenario and CA right-of-way scenario). Simulation design and landscape design for the urban simulation were significantly changed in the SWPP approach. All changes in the SWPP modeling approach are aimed for a better description of California urban environment and associated pesticide fate processes. Some of them also give more conservative estimations of aquatic exposures to urban pesticide uses. Table 1 lists the differences between the USEPA and SWPP modeling approaches for urban pesticide evaluation.

Table 1. Differences between USEPA and SWPP modeling approaches

Modeling components	**USEPA**	**SWPP**
Modeled surfaces	Pervious and impervious surfaces	Surface 1, 2, 3, and 4 (Figure 1)
Dry-weather runoff from impervious surface	Not considered	Considered, on the modeled surface 4 (Figure 1)
Pervious modeling scenarios	Based on composite CN for urban watershed with hydrologic soil group of C (Table 2, Appendix 1.2)	Based on CN for pervious surface only. Hydrology soil group of D is assumed to reflect highly compacted soil, and to be consistent with representative soil properties used in the USEPA urban scenarios (Table 5, Appendix 2.2)
Lawn irrigation	Automatically irrigation	Prescheduled irrigation (Appendix 2.2)
Residential landscape design	Based on national suburban survey data (1/4 acre lot). Equal portion (50%) of pervious and impervious surfaces	Based on survey and GIS data for urban areas of California, with smaller lot size (1/12 acre) and higher ISC (83%) (Appendix 2.3).
EXAMS results	PRZM-EXAMS is conducted for each modeled surface, and EXAMS results are average as overall outputs	PRZM is conducted for each modeled surface, and combined results for the watershed are routed into the EXAMS simulation (Sections 2.2 and 2.3).

The urban model will be incorporated as the second stage in the two-stage registration evaluation procedure developed for general pesticide products (Luo and Deng, 2012a, b), with the first stage of initial screening identical to that used for other non-urban pesticides. For example, if the urban pesticide is associated with low aquatic acute toxicity, the second stage evaluation will not be conducted. Aquatic exposure risk is characterized by risk quotients which compare the EXAMS predicted EEC's to the acute aquatic toxicity to the most sensitive species. This is consistent to the USEPA registration evaluation and risk assessment with tier 2 modeling approaches.

Registration evaluation for urban pesticide uses will be required for outdoor pesticide applications when the treated surface is in a drainage area with significant portion of impervious surface. Examples are residential areas, commercial/industrial facilities, and highway and road rights-of-way applications. In addition, PRZM is a model for transport and fate simulations over landscape, and requires area-based application rates (i.e., mass applied/area). Consequently, the model is inappropriate to simulate use patterns which are not associated with irrigation or precipitation induced hydrologic processes or not characterized with an area-based application rate. For example, swimming pool additives and cooling water system additives should not be evaluated with the proposed procedures.

2.2 Effective application rate

According to the environmental configurations in Figure 1, the drainage area is conceptually divided into 4 types of surfaces for modeling purpose based on the sources of rainfall (precipitation only or precipitation and dry-weather runoff) and the surface permeability (pervious or impervious). The 4 modeled surfaces are defined by their fractional areas over the 10-ha urban watershed ("f" factors of f_1, f_2, f_3, and f_4), with indices of "1" for pervious surface with no dry-weather runoff, "2" for impervious surface with no dry-weather runoff, "3" for pervious surface with dry-weather runoff, and "4" for impervious surface with dry-weather runoff (Figure 1). Each modeled surface type is further characterized by the actual treated area, in fraction of the 10-ha urban watershed: "ft" factors of ft_1, ft_2, ft_3, and ft_4 for the respective modeled surface.

Effective application rate is defined for each modeled surface, as the total applied mass of pesticide AI on the surface divided by the total area of the surface,

$$RATE_i = \frac{MASS_i}{f_i \times 10\text{ha}} \quad (1)$$

where *i* is a running index for the modeled surfaces (*i*=1,2,3,4), $RATE_i$ (kg[AI]/ha) and $MASS_i$ (kg[AI]) are the effective application rate and total applied mass of pesticide AI, respectively, on the surface *i*, and 10ha is the total urban drainage area. Applied mass could be from *intentional application* or *incidental application*. For intentional applications, MASS is calculated based on the label rate (LABEL) and treated area (ft_i),

$$RATE_i = \frac{MASS_i}{f_i \times 10\text{ha}} = \frac{LABEL \times (ft_i \times 10\text{ha})}{f_i \times 10\text{ha}}\text{,or} \quad (2)$$

$$RATE_i = LABEL\frac{ft_i}{f_i} \quad (3)$$

In this case (intentional applications), "ft" factors are determined from proposed application method and landscape design. In a 10-ha residential watershed with 201.6 lots, for example, broadcast application to lawns of 653 ft^2 per lot suggesting a ft_3 of $653ft^2 * 201.6/(10ha * 107{,}639ft^2/ha) = 0.12$.

Incidental application is simulated as overspray of pesticide applied to the adjacent target surface. In order to use Eq. (3) for incidental applications, a factor (f_{over}) is introduced to estimate the incidental applications to the non-target surface (i) by overspray from the intentional application on the target surface (j),

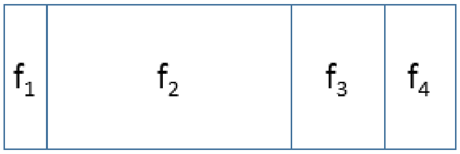
$$ft_i = ft_j \cdot f_{over}\text{,or} \quad (4)$$

$$MASS_i = MASS_j \cdot f_{over} \quad (5)$$

For conservative estimation, we assume that pesticide application to lawns (j=3) will generate incidental application to adjacent paved area (i=4), and applications to paved areas (j=2 or j=4) will result in incidental application to lawns (i=3). For granular application, f_{over} is set to be 0 (USEPA, 2012a). For other application methods, USEPA suggested a f_{over} of 5.68% for residential lawn application, by assuming 3-ft overspray on driveway, sidewalk, and road (out of the lot) (USEPA, 2007d, 2012d). This value is accepted in this study for residential and commercial/industrial application. For rights-of-way applications, f_{over} of 1% suggested by USEPA (USEPA, 2007d, 2012a) is used in this study. "f" and "ft" factors are summarized in the Appendix 2.4. Figure 2 demonstrates the calculation of effective application rates.

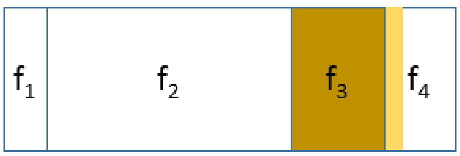
Calculation of effective application rates, with an example of broadcast application to lawns and overspray to adjacent paved area in a residential watershed

[1] "f" factors taken from Table 8 for residential watershed



f_1=0.05, f_2=0.74, f_3=0.12 (lawns), and f_4=0.09 (paved area adjacent to lawns and subject to dry-weather runoff).

[2] broadcast application to lawns (surface 3) with LABEL rate, and conservatively assume that all overspray are received by the surface 4



Calculation of effective application rate for each surface (i=1,2,3,4):

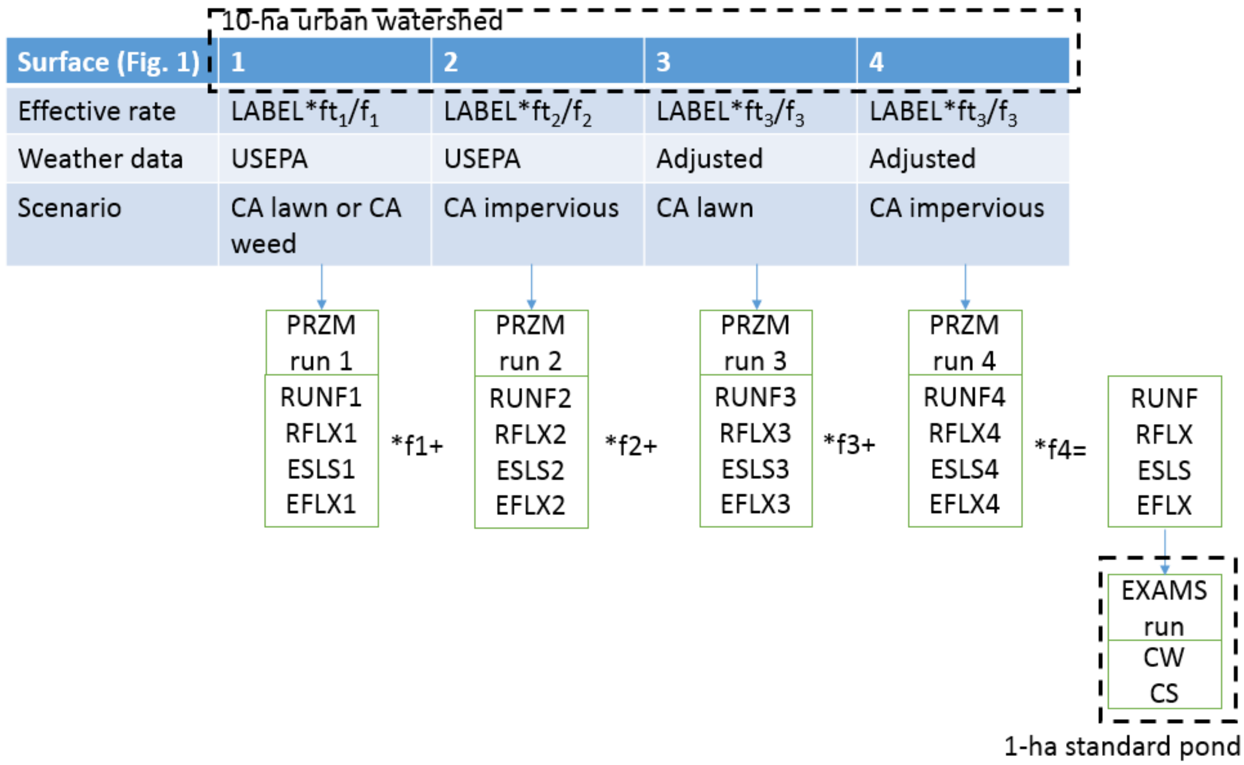
Modeled surface (i)	Surface area ("f")	Treated area ("ft")	Effective application rate, $RATE_i$=LABEL*ft_i/f_i, Eq. (3)
1	f_1=0.05	ft_1=0	0
2	f_2=0.74	ft_1=0	0
3	f_3=0.12	ft_3=f_3, broadcast application	LABEL
4	f_4=0.09	ft_4= ft_3*f_{over}, Eq. (4)	LABEL*(ft_3*f_{over})/f_4=0.0133*LABEL, by assuming f_{over}=1%

Figure 2. Demonstration of effective application rate calculation for urban pesticide evaluation

2.3 Simulation design

Transport processes of water and pesticide over the 4 modeled surfaces are simulated separately by PRZM (Figure 3), with the pervious (for the modeled surfaces 1 and 3) and impervious (for the modeled surfaces 2 and 4) modeling scenarios (Table 5). Label rate ("LABEL", Figure 3) is adjusted by the "f" and "ft" factors for effective application rates in PRZM simulations as in Eq. (3). For the surfaces 1 and 2 which receive only precipitation, USEPA formatted meteorological data during 1961-1990 for exposure assessment models (USEPA, 2006b) is used as weather inputs. For the surfaces 3 and 4, precipitation in the USEPA meteorological data will be adjusted by adding the lawn irrigation with user-defined rate, frequency, and season.

PRZM reports daily runoff depth ("RUNF", Figure 3), soil erosion flux ("ESLS"), and pesticide dissolved and sediment-bound fluxes ("RFLX" and "EFLX", respectively) for each of the modeled surface. The aggregated PRZM "edge-of-watershed" daily water, erosion and pesticide outputs are then calculated as the area-weighted averages of the four surface outputs where the f factors are the weighting coefficients. The combined PRZM results are routed to EXAMS for daily pesticide concentrations in the water column ("CW") and in the sediment ("CS") in the USEPA standard farm pond.



Notes: Weather data: USEPA = USEPA meteorological data (USEPA, 2006b); "Adjusted" = USEPA data adjusted by adding irrigation water into precipitation. LABEL = label rate (kg/ha); PRZM and EXAMS outputs (all output variables are in daily time series for the simulation period of 1961-1990): RUNF = water runoff depth (cm/day); RFLX = pesticide runoff flux (g/cm2/day); ESLS = soil erosion (ton/ha/day); EFLX = pesticide erosion flux (g/cm^2/day); and CW and CS are EXAMS predicted pesticide concentrations in water (µg/L) and in sediment (µg/kg[dry sediment]) of the USEPA standard farm pond, respectively.

Figure 3. Conceptual model for registration evaluation for urban pesticide uses. See the text for the modeled surfaces and their "f" and "ft" factors.

As suggested by USEPA, 1-in-10-year peaks of predicted concentrations (i.e., the 90th percentile of annual peaks) are used in the acute aquatic exposure analysis:

$$RQ = \frac{EEC_{peak}}{LC_{50}} \tag{6}$$

where RQ (dimensionless) is the risk quotient, EEC_{peak} (µg/L in water or µg/kg[dry sediment]) in sediment) is the 1-in-10-year peaks determined from the EXAMS predictions (CW and CS, Figure 3), and LC50 (or LC50SED for sediment analysis) is the corresponding acute toxicity values. If the resulting RQ is larger than a level of concern (LOC) of 0.5, the pesticide product is considered with a "high" risk quotient, and the pesticide product is not supported for registration. Otherwise, the product is designed to have a "low" risk quotient and the product is supported for registration.

3 Evaluation procedures

3.1 Input data acquisition

- The physicochemical properties and toxicity data for the AI of concern are prepared by following the guideline for SWPP registration evaluation (Luo, 2013).
- The product formulation, use pattern, and application method are retrieved for the proposed label.
- The maximum label rate (kg/ha) of single application, the maximum number of applications per year/season, and the minimal application interval are retrieved from the proposed label. If the number and interval of applications are not specified, 12 applications with 30-day interval are assumed as suggested by USEPA: PCOs apply pesticides to residential sites more often on a monthly or bimonthly basis (80% for the total), while the commercial facilities are treated monthly (83%) (USEPA, 2013d).
- Additional chemical properties and environmental fate data required by the EXAMS, including molecular weight (MWT, g/mol), aqueous photolysis half-life (AQPHOT, day), vapor pressure (VP, torr), and HENRY's law constant (HENRY, atm*m^3/mol). If not available in the registrant-submitted data, HENRY can be calculated according to the following equation (USEPA, 1996):

  $$HENRY = \frac{MWT \cdot VP/760}{SOL} \quad (7)$$

  where 760 (torr/atm) is a factor to convert VP from unit torr to atm, and SOL (mg/L) is water solubility.

- "f" and "ft" factors, estimated based on use pattern, application method, and overspray fraction. Recommended values (or methods for estimation) are shown in Table 8 and Table 9 (Appendix 2.4). If user-defined values are in use, justifications are required.
- Weather data is based on the USEPA formatted meteorological data for exposure assessment models (USEPA, 2006b) as used in the USEPA registration evaluation. The meteorological data files contain measurements at 237 weather stations located throughout the United States for a period extending from 1961-1990. The station at San Francisco ("w23234.dvf") was used as the default data. The same data is used in the USEPA urban modeling scenarios for California (USEPA, 2007a).
- User-defined data for lawn irrigation: rate (applied water depth for an irrigation day, cm/day), interval (day), and season. Default values are set as irrigation at a rate of 0.33 inch (0.85 cm) every other day (i.e., 1.16 inch/week) during March to November, as suggested in the previous PRZM modeling in California urban areas (Hoogeweg et al., 2011). Irrigation may be occasionally scheduled on a rainy day, which represents a worst-case condition for residential lawn management by homeowners. In terms of total water use, the modeled irrigation rate is in agreement with the suggested values by University of California Agricultural and Natural Resources (UCANR) (Hartin et al., 1993) for cold-season turfgrasses (e.g., tall fescue in the USEPA residential scenario, Table 2) over California urban areas (0.9~1.3 inch/week). Monthly comparisons indicated that the modeled rate (1.16 inch/week) may underestimate UCANR suggested rates during May to September, and overestimate other months.

3.2 Modeling procedures

The modeling procedures for evaluating urban pesticide uses have been incorporated in the SWPP methodology for registration evaluation. Manual evaluation is also possible by following the same procedures.

1. Prepare input data as specified in section 3.1.
2. (For residential and commercial/industrial applications only) prepare adjusted weather data by adding irrigation water into daily precipitation of the USEPA weather data.
3. Write PRZM execution supervisor file (*.RUN) for each modeled surface (1~4, Figure 1). USEPA weather data will be used for surfaces 1 and 2, while the adjusted weather data will be used for the surfaces 3 and 4.
4. (For each modeled surface) calculate effective application rate with “f” and “ft” factors in Eq. (3), write PRZM input files (*.INP) with the respective modeling scenarios (Table 5), and run PRZM.
5. (For each modeled surface) read the PRZM output file (*.ZTS) for the daily results of RUNF (water runoff depth, cm/day), RFLX (pesticide runoff flux, g/cm2/day), ESLS (soil erosion, ton/ha/day), and EFLX (pesticide erosion flux, g/cm2/day) during the simulation period of 1961-1990.
6. Combine the PRZM outputs, by calculating area-weighted averages (by “f” factors) of each output variable (Figure 3). The combined results are considered as the edge-of-watershed fluxes of water, sediment, and pesticides from the entire urban watershed.
7. Write the combined results of PRZM into EXAMS transfer files (*.D[YY], YY for two-digit year from “61” to “90”).
8. Write EXAMS command file (*.EXA), and run EXAMS with the USEPA standard farm pond scenario.
9. Read the EXAMS output file (“fgetsexp.xms”) for daily results of CW (pesticide aqueous concentration), and CS (pesticide concentrations in benthos) during 1961-1990.
10. Calculate the 1-in-10-year peak concentrations from CW and CS, and return their risk quotients by Eq. (6) for registration recommendations. If RQ>0.5, the pesticide product under evaluation is not supported for registration. Otherwise, the product is supported for registration.

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Appendix

1 Summary of USEPA risk assessments for urban pesticide uses

1.1 Models: PRZM and EXAMS

In registration evaluation for agricultural uses and risk assessment for urban uses, PRZM and EXAMS are used by USEPA for simulating landscape and in-water fate processes of pesticides. Pesticide reductions between the edge of the drainage area and the receiving water body is not considered. This approach is expected to generate conservative estimates of pesticide loadings and exposures. PE5 was developed as a graphical interface (shell) that facilitates placing chemical- and use-specific input values into the proper positions in PRZM input files and EXAMS chemical files (USEPA, 2006a).

1.2 USEPA modeling scenarios

Modeling scenarios provide representative input data of hydrologic characteristics on the landscape or in the receiving water body, including the parameters for farming calendar, plant growth curve, erosion, irrigation, soil properties, and water-sediment interaction. In regulatory settings, modeling results are expected to provide generic and conservative evaluations on pesticide fate and exposure based on limited data. The USEPA Tier-2 modeling scenarios are specially designed for registration evaluation and post-use risk assessment of pesticides (USEPA, 2016a). For PRZM, "standard" scenarios (which are used by USEPA in the registration evaluation) are developed for agricultural uses organized by crops and by states. In 2007, "nonstandard" scenarios (used by USEPA in the post-use risk assessments only) were developed for non-agricultural uses in California (studies for California Red-legged frog) and in Texas (studies for Barton Springs Salamander) (USEPA, 2013a, b, 2016a). For EXAMS, two modeling scenarios are available: the USEPA standard farm pond for aquatic ecosystem risk assessment and the index reservoir for drinking water exposure assessment.

Three urban scenarios were developed for California, including CA residential, CA right-of-way, and CA impervious scenarios. In the scenarios modeling parameters are formatted for the PE5 (USEPA, 2016a) with detailed descriptions and justifications in the "nonstandard scenario metadata" (USEPA, 2007a).

Table 2. Summary of USEPA modeling scenarios for urban pesticide uses in California

Name	Impervious scenario "CAimperviousRLF"	Residential scenario "CAresidentialRLF"	Right-of-way scenario "CArightofwayRLF_v2"
Represented surface	Impervious surfaces, San Francisco, CA	Urban/suburban home and residential uses in the San Francisco Bay area	Rights-of-way areas including roads, power lines, and railroads in Central/Coastal California.
Curve number (CN)	98, the highest CN value for the fully developed urban areas, according to the Table 2-2a of TR-55 (USDA, 1986)	83, a composite CN based on the TR-55 (USDA, 1986), by assuming 38% of impervious surface (CN=98) and 62% of pervious surface (CN=74). 74 is for lawn for hydrologic group C, and 38% is suggested for the lot size of ¼ acre (Table 2-2a, TR-55).	92, a composite CN for paved streets and roads, and open ditches, including right-of-way for hydrologic group C (USDA, 1986). Based on CN=98 for impervious surface and 74 for weeds, the composite CN of 92 suggests an impervious fraction of 75%.
Crop	None	Tall fescue, with year-round automatic irrigation	Representative parameters for European weeds, mustard, and thistles
Soil	Parameters are manipulated to simulate impervious surface with high bulk density, low field capacity, and zero organic carbon content	Tierra soils. Parameters for the first horizon was adjusted to represent amended soil for residential lawn according to USEPA guidance on development of turf scenarios	Gaviota series

Note: The right-of-way scenario is conceptually different to other USEPA modeling scenarios. It represents a linear surface that drains into an adjacent water body (drainage ditch). For the consistency in modeling, however, the right-of-way scenario was developed in a similar manner as a standard scenario that assumes a 10-hectare field draining into a 1-hectare static pond (USEPA, 2007a).

For pesticide application to vertical walls, no modeling scenario has been specifically developed. In USEPA studies, wall treatment is simulated with the modeling scenario for impervious surfaces (USEPA, 2012a, 2013d). It's assumed that pesticide application on walls is mathematically equivalent to application to horizontal impervious surfaces with the same rate and treated area.

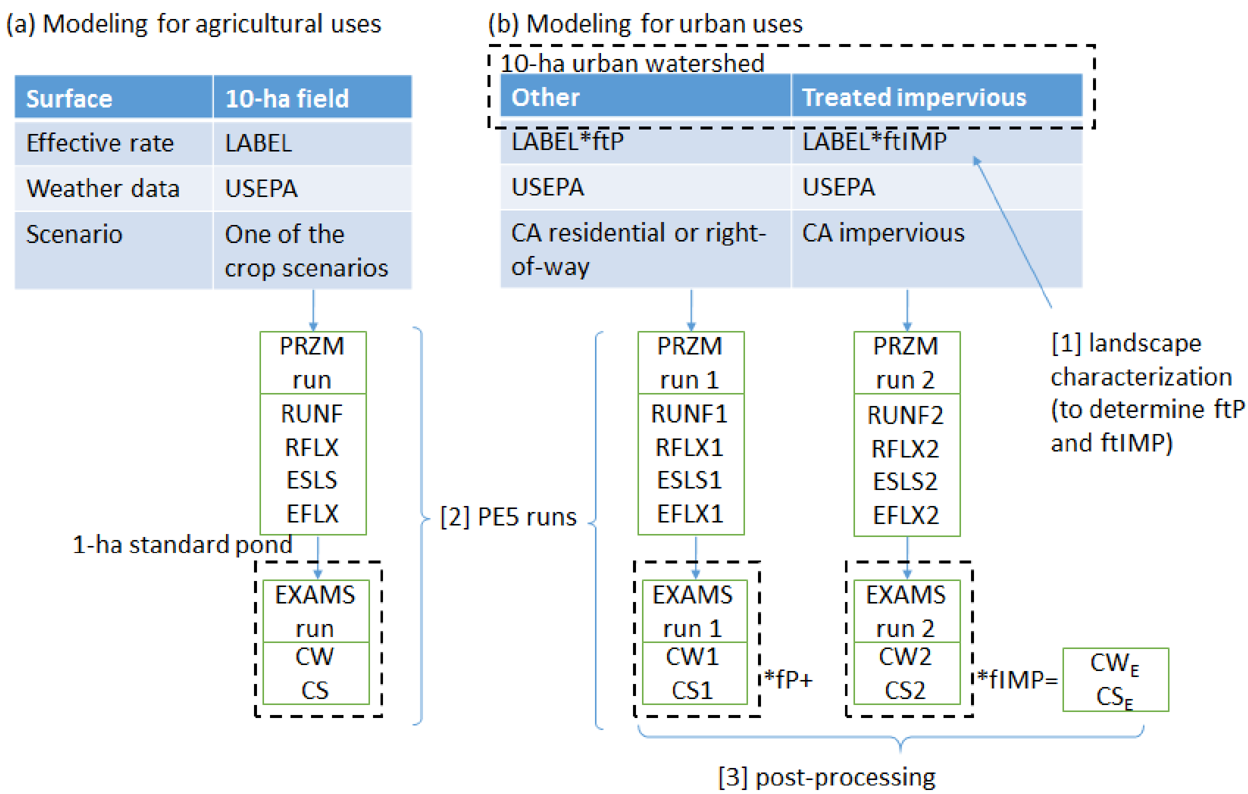
The scenario for USEPA standard farm pond presents a static pond with surface area of 1 ha (100 m by 100 m) and a depth of 2 m. A full list of predefined pond parameters is documented in the scenario available as EXAMS environmental input file (USEPA, 2016b).

1.3 USEPA simulation design for exposure assessment

USEPA Tier-2 modeling scenarios are originally based on a 10-ha agricultural field that drains into an adjacent 1-hectare static water body (USEPA standard farm pond) that is 2 meters deep (2×10^4 m^3 volume) with no outlet (Figure 4a). PRZM simulates pesticide application, movement and transformation on an agricultural field and reports resultant pesticide loadings to a receiving water body via runoff, erosion, and spray drift. EXAMS simulates the fate of the pesticide in the water body and reports concentrations in water volume and in sediment. Aerial drift (not shown in the figure) is simulated in the PRZM-EXAMS by considering a fraction (defined by the PRZM parameter "DRFT": 0.01 for ground spray and 0.05 for aerial spray) of applied mass as direct inputs to the USEPA standard farm pond. The measure of exposure for aquatic risk assessment is the 1-in-10-year peak or rolling mean concentration. The 1-in-10-year peak is used for estimating acute exposures of direct effects to aquatic organisms. The 1-in-10-year 60-day mean is used for assessing the effects to fish and aquatic-phase amphibians from chronic exposure. The 1-in-10-year 21-day mean is used for assessing the effects on aquatic invertebrates from chronic exposure.

For consistency with agricultural scenarios, a 10-ha urban watershed and the USEPA standard farm pond are assumed in the risk assessment for urban pesticides. Two sets of PRZM-EXAMS simulations are conducted independently, one for pervious surfaces and one for impervious surfaces of the urban watershed. The area-weighted averages of EXAMS-predicted EEC's from the two simulations are reported as overall outputs for the watershed (Figure 4b), as documented in the USEPA risk assessments:

- For right-of-way and residential areas: the final EEC is calculated as [impervious EEC]*50%+[pervious EEC]*50%. In this approach, it is assumed that a right-of-way and a residential area are composed of equal parts pervious and impervious surfaces (USEPA, 2007d).
- For commercial/industrial areas: The outputs from the California pervious and impervious scenarios were combined according to their area percentages to estimate the aquatic exposure from this use (USEPA, 2011).



Weather data: USEPA formatted meteorological data for exposure assessment models (USEPA, 2006b). fP = fraction of pervious surface over the 10-ha watershed, fIMP=fraction of impervious surface over the 10-ha watershed (i.e., the overall ISC), g/ha); Other variables have been defined in Figure 4.

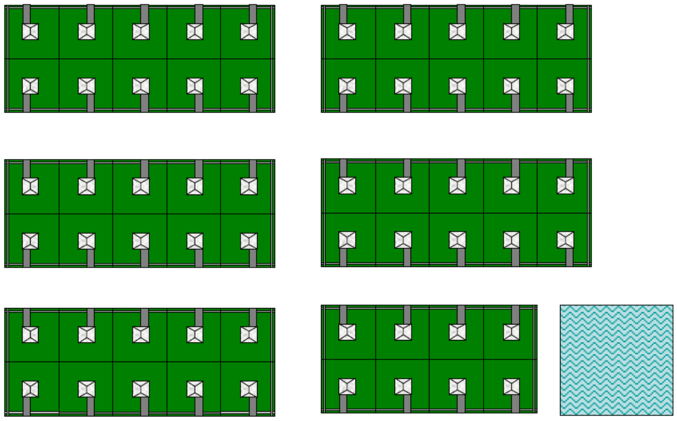
Figure 4. USEPA modeling approach in the effects determinations for the California Red-legged frog and other California listed species with (a) agricultural and (b) urban uses. Modeling components for urban uses [1] landscape characterization, [2] PE5 simulations with urban modeling scenarios, and [3] post-processing

1.4 USEPA landscape design

1.4.1 Residential areas

Residential applications of pesticides are evaluated with a conceptual residential watershed of 10 ha. The watershed is segmented into identical landscape units, and each unit includes one residential lot and surrounded roads. USEPA considered 58 residential lots of ¼ acre each in the 10-ha (Figure 5). Detailed size and dimension of the enclosed components (house, lawn, driveway, and sidewalk) are summarized in Table 3.

(a)



(b)

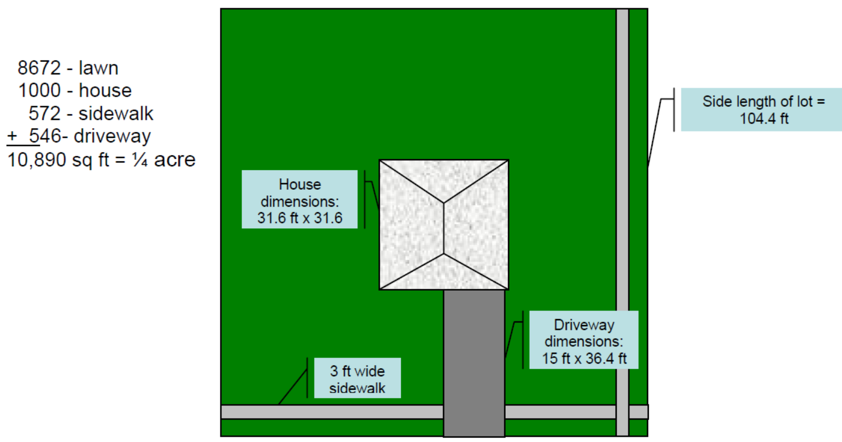


Figure 5. (a) A standard residential watershed, and (b) landscape design for residential lot, taken from USEPA effects determination for carbaryl (USEPA, 2007d), Appendix E. The schematic represents a corner lot, while a mid-block lot has small size of walkway.

Table 3. Components in a residential lot characterized for urban pesticide evaluation (USEPA, 2007d)

Components (Figure 5)	**Size and dimension**
Lot size	10,890 ft^2 (1/4 acre) = 104.4 * 104.4
House footprint	1000 ft^2 = 31.6*31.6
Driveway	546 ft^2 = 36.4*15
Sidewalk	268 ft^2 = 89.4*3 (mid-block lots)
Lawn	9075 ft^2 (mid-block lots)

The assumption of ¼ acre lot was justified by the 2003 American Housing Survey (AHS) data for suburban homes (USEPA, 2007d). The same data suggested that a typical suburban home is 2000 ft^2, and USEPA divided this value by 2 (2-story house) and set the size of house footprint to be 1000 ft^2 (USEPA, 2007d). This may underestimate the footprint size for the 2000-ft^2 house.

The driveway is designed by assuming the house is placed in the center of the lot, thus driveway will be 36.4 ft long. In addition, the driveway is assumed to be 15 ft wide. The length of the sidewalk is the width of the lot (104.4 ft) minus the width of the driveway (15 ft), and it's assumed that the sidewalk is 3 ft wide. The total impervious surface (house + driveway + sidewalk) is 1814.5 ft^2 for the mid-block lot, which leaves 9075 ft^2 (or 83% of the lot) as lawns.

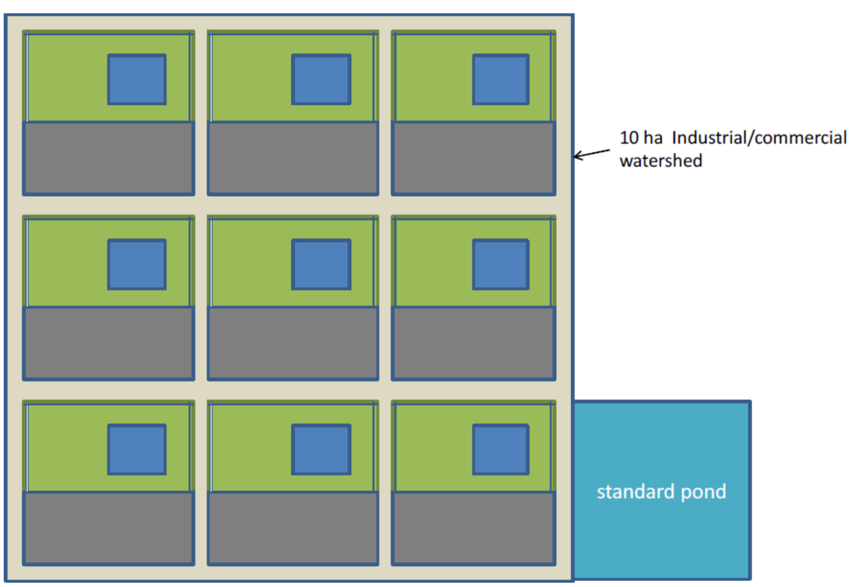
The residential ISC is 0.17 (total impervious surface, 1814.5 ft^2, divided by the lot size) by following the USEPA design for standard lot. To match the predefined overall ISC of 0.5 in the watershed, the number of houses in the watershed is estimated as 58 (USEPA, 2007d).

In the recent studies (USEPA, 2012a, 2013d), USEPA made some adjustments to the standard lot design. A garage of 900 ft^2 was introduced to the lot and the total building footprint size (for the house size of 2000 ft^2) was increased to 1900 ft^2. The size of lawn to be treated was significantly reduced to 2000 ft^2, about 18% of the size of the residential lot. Those changes in the recent USEPA studies have been considered in the development of SWPP modeling approaches.

1.4.2 Commercial/industrial facilities

To evaluate the commercial/industrial lawn uses of acephate (USEPA, 2011), USEPA develop a standard 10-ha watershed with buildings, sidewalk, parking lots, and roads. There are 9 facilities in the standard commercial/industrial watershed (Figure 6), each with a building of 1000 m^2 (10,764 ft^2). The total area of a commercial/industrial lot (building, lawn, sidewalk, and parking lot) is 8725 m^2, with half of the area taken by parking lot. The sidewalk was assumed to take up half of each lot and the half of the lot that had lawn. Sidewalks were assumed to be 1 m wide (USEPA, 2011) (Figure 6). By considering the lot and surround road areas, the overall ISC is 0.72. For pesticide application to lawns, the incidentally treated areas were assumed to be include a 1 m swath along the edge of each parking lot, a 1 m swath along each road frontage, and the whole sidewalk on each lot (USEPA, 2011).

(a)



(b)

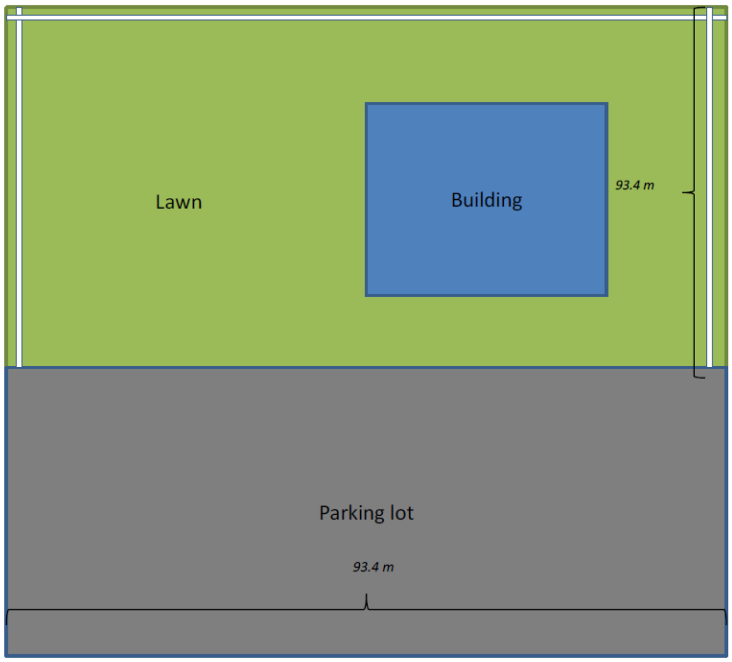


Figure 6. (a) A standard commercial/industrial watershed and (b) landscape design (the lot size: 8725 m^2; the building size: 1000 m^2), taken from USEPA effects determination for acephate (USEPA, 2011), Appendix L, figure 2. The length of the sidewalk measured in the figure should be 46.7 m (labeled as 93.4 m in the USEPA report)

In the recent risk assessment for bifenthrin and deltamethrin (USEPA, 2012a, 2013b), USEPA introduced a watershed for urban and rural structures and buildings with larger building size (35,880 ft^2) and higher lot density (15 lots in a 10-ha watershed). However, detailed information on the landscape design and overall ISC is not provided. SWPP registration evaluation on commercial/industrial uses is mainly based on the 9-lot scenarios in Figure 6 with modifications according to California conditions.

1.4.3 Rights-of-way applications

The drainage area with rights-of-way applications is conceptually modeled as a 10-ha watershed with 50% pervious surface (weed) and 50% impervious surface. USEPA suggested that the assumption of equal parts of pervious and impervious surfaces is more likely to be representative of a highway or road right-of-way (USEPA, 2007d). Different ratios of the two surfaces could be observed, but may not significantly affect the risk assessment results. For example, larger fraction of impervious surface increases runoff volume in the right-of-way watershed, but at the same time tends to reduce the area to be treated (i.e., weeds) thus the total applied mass and overspray. The pervious and impervious portions of the watershed are simulated with USEPA right-of-way and impervious modeling scenarios for California (Table 2), respectively.

1.5 PRZM-EXAMS results vs. surface water monitoring data

Table 4. Observed and predicted maximum concentrations (in water column, ppb) for urban pesticide uses in the USEPA risk assessments

Pesticide	The maximum EEC among urban uses by USEPA (the corresponding use patterns in parentheses)	Top 3 concentrations in the CDPR database (sampling site in parentheses) (CDPR, 2019)
acephate	2456 (commercial lawns)	13.5 (Alisal Creek) 11.3 (Chualar Creek) 3.44 (Alisal Creek)
alachlor	6.3 (residential wood ornamentals)	2.7 (Walsal Slough) 0.86 (Orestimba Creek) 0.52 (Del Puerto Creek)
bensulide	>SOL (56 ppb used in the modeling)	19.6 (Alisal Creek) 8.57 (Quail Creek) 7.75 (Chualar Creek)
bifenthrin	>SOL (0.014 ppb)	5.209 (Storm drain) 2.3 (Central Irvine Channel) 1.95 (Marshburn Slough)
carbaryl	14.6 (residential lawns)	8.4 (Ingram/Hospital Creek) 5.2 (Merced River) 3.95 (Merced River)
cyfluthrin and beta-cyfluthrin	>SOL (2.32 ppb)	0.498 (Storm drain) 0.022 (New River) 0.0189 (Storm drain)
deltamethrin	>SOL (0.2 ppb)	0.231 (Storm drain) 0.004 (New River)
diflubenzuron	34.13 (commercial/industrial)	No detections
lambda-cyhalothrin	>SOL (5 ppb)	0.14 (Del Puerto Creek) 0.13 (Sand Creek) 0.106 (Orestimba Creek)
malathion	24.0 (rights-of-way)	22 (Alisal Creek) 12.9616 (Main Street Ditch at Highway 166) 6 (Colusa Basin Drain #5)
methomyl	42.9 (scatter bait)	55.3 (Chualar Creek) 32.8 (Alisal Creek) 25.043 (Alisal Creek)

Notes:

[1] References of USEPA risk assessments: acephate (USEPA, 2011), alachlor (USEPA, 2009a), bensulide (USEPA, 2007b, 2012b), bifenthrin (USEPA, 2012a), carbaryl (USEPA, 2007d, 2010), cyfluthrin and beta-cyfluthrin (USEPA, 2013c), deltamethrin (USEPA, 2013d), diflubenzuron (USEPA, 2009b), lambda-cyhalothrin (USEPA, 2012d), malathion (USEPA, 2007c), and methomyl (USEPA, 2012c).

[2] In the above risk assessments, USEPA evaluated both agricultural and urban uses. Here only simulation results for *urban use patterns* are considered, and the maximum values of EEC's are reported. The maximum EEC by agricultural uses could be higher than that by urban uses.

[3] The top 3 concentrations are based on from all available data in the CDPR surface water database, representing California statewide maximum values from agricultural, urban, and mixed drainage areas.

[4] The monitoring data was retrieved in November 2013, while the EEC's were only based on urban use patterns registered before the time of USEPA assessments (see publication years in the references).

[5] In the aquatic exposure modeling, "*beta-cyfluthrin was used as surrogate of cyfluthrin because beta-cyfluthrin contains similar isomers as cyfluthrin [beta-cyfluthrin consists of four of the eight possible isomers of cyfluthrin, which are the more potent isomers (to target organisms) of cyfluthrin]. More importantly, the application rate and aquatic toxicity endpoints for cyfluthrin are similar to beta-cyfluthrin when they are expressed in beta-cyfluthrin equivalents.*" (USEPA, 2013c)

[5] "…monitoring programs only provide occurrence data for cyfluthrin. Because cyfluthrin contains the 4 isomers in beta-cyfluthrin, it is assumed the monitoring data for cyfluthrin will be representative of occurrence data for beta-cyfluthrin."

Model performance of PRZM-EXAMS for urban pesticide evaluation is evaluated by comparing modeling results of urban uses and surface water monitoring data in urban watersheds. Both model predictions and monitoring data are taken from USEPA reports for "Effects determinations for the California red-legged frog and other California listed species" (USEPA, 2013a). As of November 2013, 11 of the evaluated pesticide AI's are associated with urban use patterns, and simulated with USEPA urban modeling scenarios for California. The maximum of predicted concentrations (as 1-in-10-year peaks in the USEPA standard farm pond) over evaluated *urban* use patterns are compared to the top 3 (highest) concentration reported in the CDPR surface water database (CDPR, 2019) (Table 4).

The maximum concentration by PRZM-EXAMS with USEPA urban modeling scenarios were generally higher than the maximum concentrations from surface water monitoring (Figure 7). For bifenthrin and deltamethrin, the monitoring data exceed their solubility used in the modeling (0.014 and 0.2 ppb, respectively). According to the uncertainty analysis by USEPA (USEPA, 2012a), this may suggest presence of dissolved organic matter or suspended matter in the water that could sorb the chemical and cause it to be present at higher concentrations, although it would not be bioavailable. For methomyl, one water sample in an agricultural creek (the Chualar Creek in Monterey County) was with higher concentration (55.3 ppb) than the modeled results based on urban use patterns.

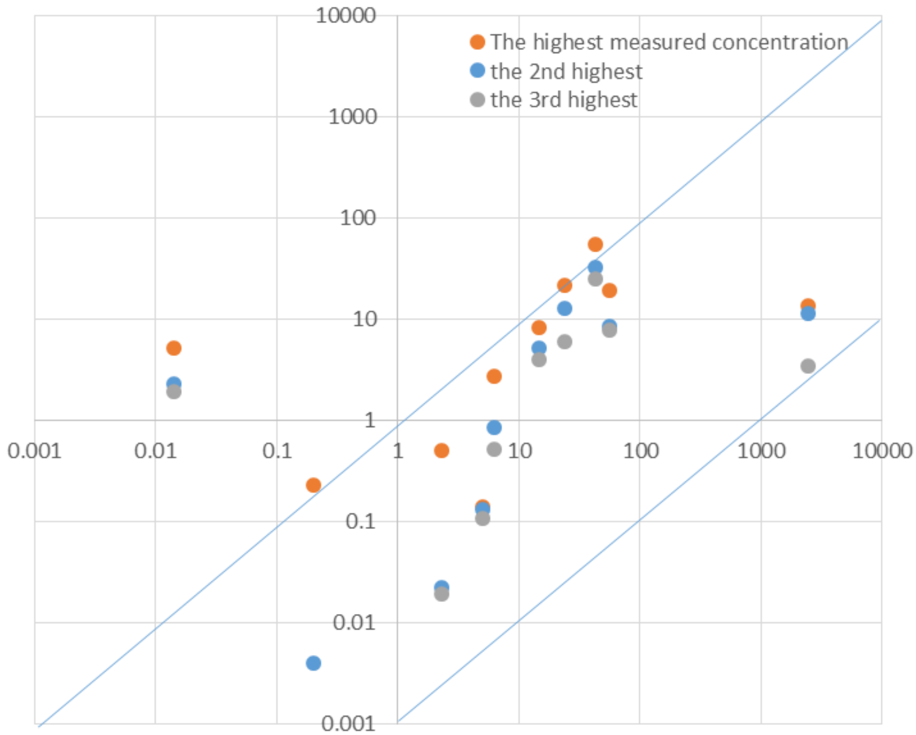


Figure 7. Maximum EEC's predicted in USEPA risk assessments for urban pesticides uses (x-axis) vs. the top 3 concentrations in the CDPR surface water database (y-axis), based on the data in Table 4. All concentrations are for water column with unit ppb. Blue lines indicated 1:1 and 1:1000 ratios of y:x (or observed:predicted). EEC's exceeding water solubility in the modeling processes are circled and discussed in the text.

1.6 Limitations and issues on the USEPA modeling approach for urban pesticide assessments and its applications

- Lawn irrigation: [1] lawn irrigation is usually pre-scheduled in California, and not really reflects soil moisture conditions as modeled in the PRZM automatic irrigation. [2] irrigation-induced runoff on impervious surfaces adjacent to lawns are not considered, which could be an important source of urban pesticide runoff during the dry season of California.
- In the USEPA landscape design for standard residential and commercial/industrial lots, buildings are surround by lawns. In California, however, urban areas commonly include paved surfaces immediately next to buildings. The inclusion of the impervious surfaces may increase pesticide runoff especially with perimeter treatments.
- The USEPA standard residential lot is designed based on suburban survey data on a national basis. Large lot size (or lower residential density) results in lower fraction of impervious surfaces and thus underestimates pesticide runoff from the urban watershed.
- The USEPA residential and rights-of-way scenarios for California actually simulate hydrology processes over the entire urban watershed. This is indicated by the composite curve numbers used in the scenarios (Table 2) according to the USDA TR-55 for small urban watershed (USDA, 1986). Therefore, those scenarios are expected to predict surface runoff from the entire watershed (not only from the pervious portion of the watershed), thus overestimate pesticide runoff from treated pervious surfaces.
- Inconsistent assumptions of hydrologic soil groups were used. Soils with group D were selected for both residential and right-of-way scenario according to their metadata (USEPA, 2007a). However, their CN's are assigned based on the group C according to TR-55 (Table 2).
- Inconsistent assumptions of ISC were used. It's assumed that a watershed for residential or for rights-of-way applications is represented by equal portions of pervious and impervious surfaces. In the modeling scenarios, however, the composite CN's were assigned based on different ISC's (38% for residential area, Table 2).
- In some USEPA studies, the ¼-acre standard lot was used in an inappropriate way: effective application rate was calculated for residential lots, not for the watershed (which includes residential lots, 59% of the watershed; and roads, 41%).
- In some USEPA studies, an incorrect conversion of "1 acre = 435,600 ft^2" was used in the calculation of effective application rates. This decreases the rates by 10 times.
    - An example for the above two issues: in the risk assessment for bifenthrin application to residential lawn with the label rate of 0.4 lb[AI]/A to a lawn of 2000 ft^2, the effective application rate was calculated as (Table 3-1, note #25, page 97) (USEPA, 2012a),
    - 0.4 lb[AI]/A * 2000 ft^2 * **4 homes per acre** / **435,600 ft^2/A**= **0.00735** lb[AI]/A
    - This should be corrected as: 0.4 lb[AI]/A * 2000 ft^2 * **58 homes per a 10-ha watershed** / **1.08×10^6 ft^2/10-ha**= **0.043** lb[AI]/A
- In recent assessments on bifenthrin and deltamethrin (USEPA, 2012a, 2013d), effective application rates were calculated based on a house footprint size of 2000 ft^2 although it's documented as 1000 ft^2.

2 Supplementary materials for SWPP modeling approach for the registration evaluation of urban pesticide uses

2.1 The use of PRZM

PRZM is selected in this study based on the following considerations:

- PRZM is widely accepted by USEPA, European Commission, and registrants for registration evaluation and risk assessments of pesticides.
- PRZM urban modeling scenarios have been specifically developed for California.
- USEPA maintains an active PE5-based project of risk assessments for the red-legged frog and other California listed species. Some of the pesticides under consideration are associated with urban uses. The methodology and results provide references for model development and validation.
- PRZM is one of the few models with modeling capability for pesticides in both dissolved and adsorbed phases.
- The PRZM input parameters are designed by following the USEPA data requirement for pesticide registration. In addition, USEPA provides a guidance for selecting PRZM input parameters in modeling the environmental fate and transport of pesticides (USEPA, 2009c).
- USEPA continuously supports and improves the PRZM. New versions of PRZM, such as the one proposed in the USEPA Surface Water Calculator (Fry et al., 2013), can be easily incorporated into the modeling approach.

2.2 Adjustments on the USEPA modeling scenarios

The USEPA impervious scenario for California and USEPA standard farm pond are used in the proposed modeling approach with no changes. The residential and right-of-way applications scenarios for California are adjusted to better simulate water and pesticide runoff from the pervious portion of an urban watershed (Table 5).

The USEPA residential and right-of-way scenarios for California are revised in this study by replacing the "composite" CN's by the "pervious" CN's. The pervious CN is set as 80 for both scenarios, as suggested for the open space with grass cover > 75% for hydrologic soil group D (USDA, 1986), reflecting highly compacted soil in California urban areas and consistent to the selection of soils in developing the original modeling scenarios (USEPA, 2007a). In specific, changes are made in the records 9 and 9B of the PRZM input file (*.INC). The revised scenarios, in this study called "SWPP lawn" and "SWPP weed" scenarios according to the vegetation actually considered in the scenarios, only represent the pervious portion in the watershed of residential, commercial/industrial, or right-of-way areas. Unlike the USEPA scenarios, therefore, fraction of impervious surfaces has no effects on the CN's in the revised scenarios.

In the USEPA residential scenario for California, year-round over-canopy irrigation to lawns is triggered automatically when the soil moisture is lower than 50% of soil capacity. In California, irrigation timing and rate are usually prescheduled, and not significantly related to soil moisture. Therefore, automatic irrigation is not used in the SWPP lawn scenario, while irrigations to lawns (and to the adjacent areas) are simulated by adding irrigation water into precipitation. In this case, lawn irrigation will be characterized by rate (water depth applied during an irrigation day), frequency, and season. The changes are made by switching off automatic irrigation (IRFLAG =

0, in the recode 20 of the PRZM input file) and removing related parameters (IRTYP, FLEACH, PCDEPL, and RATEAP, in the recode 27).

Table 5. Modeling scenarios used in the SWPP registration evaluation for urban pesticides

Scenario	**Adjustments to USEPA scenarios**	**Residential**	**Commercial and industrial**	**Rights-of-way**
USEPA impervious	No changes	x	x	x
SWPP lawn	Based on USEPA residential, by setting CN=80, and disabling automatic irrigation	x	x	
SWPP weed	Based on USEPA right-of-way, by setting CN=80			x

Notes: "x" indicates the scenario will be applied in the registration evaluation for pesticide uses in the corresponding urban watershed. Details for the original USEPA scenarios can be found in Table 2 of 0.

2.3 Landscape design for California urban areas

2.3.1 Overall impervious surface coefficient

The overall ISC in California urban areas is conservatively determined as the 90th percentile of the overall ISC in the San Francisco – Oakland urban area. Two datasets are used: [1] 100-meter resolution impervious surface of the United States in the USGS Land Cover Characterization Program, compiled by the National Atlas (NAUS, 2013), and [2] the Adjusted Urban Boundaries of California, developed by California Department of Transportation (Caltrans, 2010). Based on the data analysis (Figure 8), overall ISC of 0.83 is used in the modeling approach for registration evaluation.

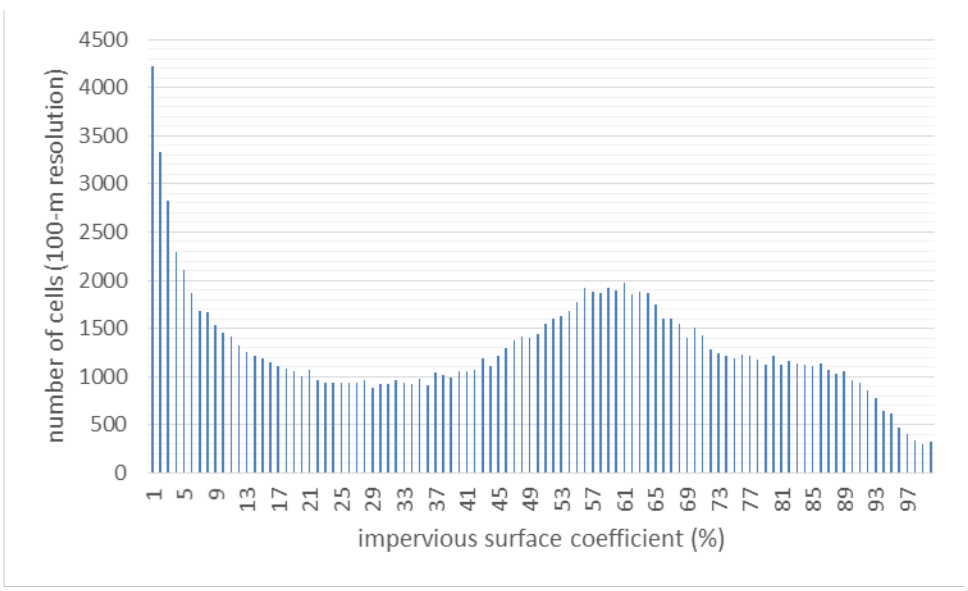


Figure 8. Histogram of the impervious surface coefficients over San Francisco – Oakland urban area. ISC=83% reflects a cumulative distribution probability of 90%.

2.3.2 Residential density

The residential density in California urban areas is conservatively determined as the 90th percentile of the residential density in the surveyed urban areas of California (Sacramento, Irvine, and Santa Cruz). Survey results are taken from California Office of Environmental Health Hazard Assessment (Washburn et al., 2010). Based on the data analysis, residential density of 12 houses per acre is used in the modeling approach for registration evaluation.

2.3.3 Size of residential house footprint

Two sizes are involved in this analysis:

- House size: reported square footage ("inhabitable" areas of a house unit according to ANSI standards);
- Footprint size: projected area of a house, by considering the multiple stores in a house and the areas (e.g., garage) not accounted into the reported footage.

House square footage is estimated based on the publicly available data from the United States Census 2011 American Housing Survey (AHS). Data for San Francisco Metropolitan areas is considered in this study. It's assumed that the house footage is associated with its residential lot size: larger houses are most likely to be observed in larger lots. Therefore, the cumulative probability of 90% (for which the residential density of 12 dwelling unit per acre is determined) is used to estimate the corresponding house size range of 1000-1500 ft^2 (Figure 9). The house size of 1500 ft^2 is selected in this study for residential landscape design.

To simplify the parameterization in this study, the house footprint size is set as the house size (1500 ft^2) for the standardization of a residential lot. This assumption is generally consistent to the USEPA settings for suburban areas: based on the data analysis on the national data of AHS for single detached homes in suburban area, USEPA concluded that "*a typical home is 2000 square feet*" (USEPA, 2010). In the early studies (USEPA, 2007d), the size of house footprint was set as 1000 ft^2, and in recent studies (USEPA, 2012a, 2013d) it's increased by introducing a garage of 900 ft^2 so that the total footprint size (1900 ft^2) is similar to the representative house square footage of 2000 ft^2.

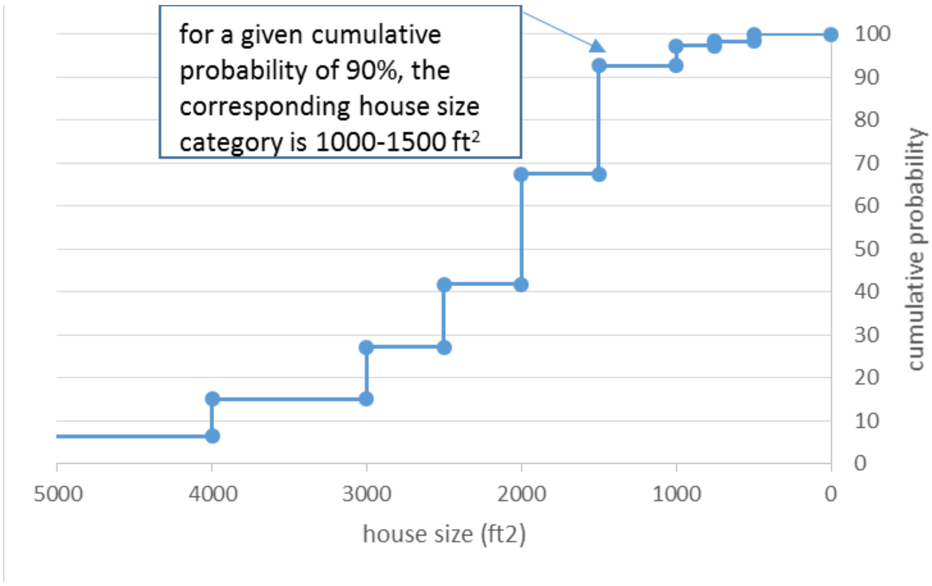


Figure 9. Cumulative probability distribution for residential houses with various footage, based on the 2011 American Housing Survey (AHS) data for San Francisco Metropolitan areas

2.3.4 Residential areas

The landscape design for residential areas of California can be summarized as: The average lot size is 1/12 acre. Overall and residential ISC's are 0.83 and 0.75, respectively, suggesting that 68% of the 10-ha residential watershed is occupied by residential lots, and the other 32% by roads. The following considerations have been incorporated in the landscape design:

- Residential lot size: based on the landscape surveys in Sacramento, Irvine, and Santa Cruz by California Office of Environmental Health Hazard Assessment (OEHHA) (Washburn et al., 2010), <u>the 90^{th} percentile of residential density is 12 dwelling units per acre</u>, suggestion a lot size of 3630 ft^2 for conservative exposure assessment
- Size of house footprint: based on American Housing Survey (AHS) 2011 data for San Francisco Metropolitan areas, the 90^{th} percentile of house square footage is 1500 ft^2. The same value is assumed as the size of house footprint.
- California urban watersheds commonly include impervious area immediately next to buildings. Therefore, a 3-ft paved area around a house is introduced in addition to the landscape structure already presented in USEPA settings.
- Assumptions in the USEPA residential settings in determining the sizes of drive way, sidewalk, and lawns, are accepted in landscape design of this study (Table 6).
- Table 6 listed the size and dimension for each component in a residential lot, and the resultant <u>residential ISC is 0.75</u>. This value is higher than that derived from the OEHHA survey (Washburn et al., 2010), in which the representative residential ISC is 0.62 under the density of 12 dwelling units per acre (Table 2 in the OEHHA report), suggesting a conservative estimation for exposure assessment.
- Overall ISC of California urban area used in this study is 0.83. We estimated the number of residential lots in the watershed by adjusting the fraction of residential lot surface so that the weighted mean of residential lot and road ISCs (0.75 and 1.0, respectively) matched the overall California urban area ISC of 0.83. Assuming the watershed area

fraction of residential lots is X, then: 0.75X+1.0*(1-X)=0.83. The solution is X = 0.68, yielding (12 house/acre * 1 acre/.4047 ha* 10 ha * 0.68 =) 201.6 house in the watershed

Table 6. Landscape design for a standard residential lot (similar to the USEPA standard lot, Figure 5b, but with a smaller lot side)

Components	**Size and dimension in the SWPP evaluation**	**Justification (and comparison to the USEPA settings in Table 3)**
Size of the landscape unit	5337 ft^2	201.6 lots in the 10-ha watershed
Lot size	3630 ft^2	Based on the density of 12 houses per acre
House footprint	38.7*38.7=1500 ft^2	Based on the American Housing Survey
Driveway	15*36.4 =546 ft^2	USEPA settings
Sidewalk	45.2*3=135 ft^2 (including the lower 3-ft portion of driveway)	USEPA settings
Lawn	653 ft^2	18% of the lot area as suggested by USEPA settings, indicating a fraction of 12% over the watershed (f_3)
Paved area around the house	501 ft^2 (including the upper 3-ft portion of driveway)	3 ft wide
Other landuse (pervious surfaces not subject to dry-weather runoff, f_1)	295 ft^2	Area balance

2.3.5 Commercial/industrial areas

USEPA landscape design for commercial/industrial watershed (0) is adjusted in this study. The first change is to increase the overall ISC from 0.72 (USEPA settings) to 0.83 (the 90th percentile of ISC in San Francisco – Oakland urban area). The ISC for commercial/industrial areas is comparable to the values in the category of retail (0.86), retail/office (0.80), urban office (0.85), light industrial (0.81), and mixed use (0.80), according to the OEHHA survey (Washburn et al., 2010). In addition, it's assumed that a paved area of at least 3-ft width is developed around each facility building.

In summary, the 10-ha commercial/industrial watershed is completely covered by 9 identical landscape units, each with a facility building of 1000 m^2 (10,764 ft^2, or 104 ft*104 ft) (Table 7). Size of parking lot is adjusted to match the newly assigned overall ISC of 0.83. All the pervious area (1.0-ISC=17% of the watershed) is considered as lawns.

Table 7. Landscape design for a standard commercial/industrial facility

Description	**Size and dimension in the SWPP evaluation**	**Justification**
Size of the landscape unit	120,000 ft^2	USEPA settings
Facility building	10,764 ft^2 (104*104)	USEPA settings
Paved area around the building	1281 ft^2	3 ft wide, not considered by USEPA
Sidewalk	2011 ft^2	USEPA settings
Parking lot	59,432 ft^2	To conserve the overall ISC of 0.83
Lawn	20,400 ft^2	17% of the watershed (f_3=1-ISC), evenly assigned to the 9 facilities per watershed.

2.3.6 Rights-of-way applications

The USEPA settings for rights-of-way applications are used in this study with no changes.

2.4 Summary for the "f" and "ft" factors

Table 8 summarizes the "f" and "ft" factors for urban watersheds with residential, commercial/industrial, and rights-of-way applications based on the landscape design and in study and accepted USEPA assumptions in urban pesticide risk assessments.

Table 8. Summary for the "f" and "ft" factors. Except for the overspray coefficient f_{over}, all factors (f_{IMP}, f_1, f_2, f_3, f_4, ft_1, ft_2, ft_3, and ft_4) are expressed as area in fraction over the 10-ha watershed

Factors	**Residential; Commercial and industrial**	**Right-of-way**
f_{IMP} (overall ISC)	83% (1)	50% (2)
Number of landscape units	201.6; 15	1
f_3 (lawns)	12% (2); 17%	0
f_4 (impervious surface adjacent to lawns and receive irrigation water)	9% (3); 10% (4)	0
f_2 (impervious surface not subject to dry-weather runoff)	f_{IMP}-f_4	same
f_1 (pervious surface not subject to dry-weather runoff)	1-f_2-f_3-f_4	same
ft_1 (treated previous area with no dry-weather runoff)	Defined by the treated areas in perimeter treatment, application to lawns, and crack & crevice treatment	0.1 (5)
ft_2 (treated impervious area with no dry-weather runoff)	Defined by the treated areas in wall treatment, perimeter treatment, application to paved areas, crack & crevice treatment, and overspray from application to lawns	ft_1* f_{over} (overspray from application to weeds)
ft_3 (treated pervious area with dry-weather runoff)	Same to ft_1	0
ft_4 (treated impervious area subject to dry-weather runoff)	Same to ft_2	0

Notes: (1) the 90th percentile of impervious surface fraction over the San Francisco – Oakland urban areas. (2) USEPA settings used in this study. (3) It's conservatively estimated based on the paved areas around the house with a width of 3 ft: 501 ft^2 * 201.6 homes per a 10-ha watershed / [10-ha]. This is similar to the USEPA method in estimating overspray of lawn applications to impervious surfaces (USEPA, 2007d). (4) It's assumed to be the same area as estimated for overspray by lawn irrigation: 1026 m^2 for the edge of parking lot, swath along road frontage, and the whole sidewalk on each lot, according to the USEPA settings (USEPA, 2011), and 119 m^2 (1281 ft^2, Table 7) for the whole paved area around the building. The total area is 12,325 ft^2 per lot, or 10.3% of the watershed. (5) It's assumed that no more than 10% of the watershed is covered in rights-of-way (USEPA, 2012a).

As shown in Table 8, treated area factors ft_3 and ft_4 for residential applications and for commercial/industrial applications will be determined based on the application method and the landscape design. Estimation of the two factors for common urban pesticide uses are demonstrated in Table 9. Please note that, with the presence of pervious surfaces (e.g., lawn or soil) adjacent to paved area and walls treated with pesticides, the off-site movement of pesticide may be significantly reduced before entering storm drains. Therefore, the application of impervious scenario to pesticide treatments on walls and on paved areas around buildings represents a conservative estimation.

Table 9. Treated area fractions ("ft" factors) for common use patterns of urban pesticides (target surfaces: P for pervious and IMP for impervious)

Use pattern	**Target surface**	**"ft" factors**
Broadcast spray (lawn and general outdoor)	P	$ft_3=f_3$ $ft_4=ft_3*f_{over}$
Wall treatment	IMP	$ft_4=L*W*N/[10\text{-ha}]$ $ft_3=ft_4*f_{over}$
Perimeter treatment	P and IMP	▪ $W \leq 3$ ft, applied to the paved area: $ft_4= L*W*N/[10\text{-ha}]$ $ft_3=ft_4*f_{over}$ ▪ $W>3$ ft, applied to the paved area and lawn: $ft_4=L*3*N/[10\text{-ha}]$ $ft_3=L*(W-3)*N/[10\text{-ha}]$
Crack & crevice treatment	P and IMP	$ft_3=ft_4=2.5\%$

Notes: L=perimeter of the building (155 ft for a residential house, 416 ft for a commercial/industrial facility), W=width of application (ft), and N=number of buildings in the 10-ha watershed (201.6 for residential house, 9 for commercial/industrial facility)