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Modeling for evaluating occupational bystander cancer risk from 1,3-Dichloropropene

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1 Introduction

1,3-Dichloropropene (1,3-D) is a fumigant used to control nematodes, insects, and disease organisms in the soil. It is commonly used as a pre-plant treatment that is injected into soil. It may also be applied through drip irrigation. Regardless of the application method, the possibility of offsite transport of this fumigant due to volatilization may subsequently result in human exposure through inhalation. To mitigate lifetime cancer risk to non-occupational bystanders (including infants and children), California Department of Pesticide Regulation (DPR) limits the use of 1,3-D on a regional basis (township cap) to achieve a regulatory target concentration of no more than 0.56 ppb as a 70-year average as specified by the 2016 risk management directive (Marks, 2016). To address acute exposures to non-occupational bystanders from 1,3-D, DPR issued a second risk management directive that established a regulatory target concentration of 55 ppb averaged over a 72-hour period (Henderson, 2021). In 2023, DPR proposed regulations to mitigate 1,3-D acute exposures to non-occupational bystanders that include setbacks from occupied structures, application rate limits, application block size limits, and fumigation method changes (DPR, 2023). The proposed acute mitigation measures will also mitigate the cancer risk to non-occupational bystanders without township caps. Therefore, the proposed regulations will replace the current township cap requirements.

DPR's 2017 revision to the 2015 risk characterization document (RCD) (Rubin, 2017) estimated that the cancer risk for occupational bystanders ranged from 1.4 to 4.8 excess cancers per 1,000,000 people depending on whether the mode of action is portal of entry or systemic. This cancer risk meets DPR's goal of no more than 10 excess cancers per 1,000,000 people (or one excess cancer per 100,000 people) specified in DPR's 2016 risk management directive (Marks, 2016). To meet this goal, DPR's risk management directive specifies a regulatory target concentration of no more than 0.56 ppb as a 70-year average. The RCD estimated a lifetime exposure of 0.33 ppb for occupational bystanders (with a 40-year work exposure) (DPR, 2015). Therefore, the RCD indicates that mitigation measures to address cancer risk to occupational bystanders are not needed. However, the RCD relied on different methodology to estimate air concentrations than DPR is using to estimate air concentrations for the acute mitigation measures.

Recently, California Office of Environmental Health Hazard Assessment (OEHHA, 2024) estimated that an occupational bystander exposed five days a week, eight hours per day, for 40 years to 0.21 ppb has a risk of cancer of 1 in 100,000. OEHHA assumed a potency value of 0.057 ppm^{-1}, equivalent to an inhalation cancer slope of factor of 0.19 $(mg/kg\text{-}day)^{-1}$.

In this study, air dispersion modeling approach is used to estimate the average air concentrations of 1,3-D for occupational bystanders during the OEHHA-recommended working days and hours (Monday to Friday, 08:00 to 16:00) to hypothetical 1,3-D applications. The concentrations are predicted under various field conditions in terms of region, season, fumigation method, buffer zone settings (distance and duration), and application block size. The modeling results, together with other OEHHA (2024) recommendations, will be used to calculate the lifetime occupational exposure adjacent to the fields treated by 1,3-D.

2 Methods and materials

2.1 Air dispersion modeling

Air concentrations of 1,3-D are simulated by AERFUM, an integrated air dispersion modeling system for soil fumigants developed by DPR (Luo, 2019). The current version of AERFUM uses the 64-bit AERMOD v23132 (USEPA, 2023) as the simulation engine for predicting hourly concentrations of 1,3-D in the air. AERFUM includes two modeling approaches: “unit simulation” which simulates a hypothetical pesticide application event on one field for air concentrations around the treated area, and “regional simulation” which simulates reported pesticide uses for concentration distribution at a regional scale. In this study, the unit simulations of AERFUM are utilized for the modeling of single 1,3-D applications.

To be consistent with the previous modeling for township cap (Luo, 2022a) and non-occupational bystander acute exposure (Luo, 2022b, 2023), a 5-year simulation period during 2013-2017 is used in this study. Meteorological data are taken from the NWS (National Weather Service) weather stations with the ASOS (Automated Surface Observing System) program. The MetProc program (Luo, 2017) is utilized to retrieve and process hourly meteorological input data in the AERMOD required format for the simulation period. Meteorological data are retrieved from Parlier and Watsonville for the inland and coastal regions, respectively. More information on the selection of meteorological data has been documented previously (Luo, 2023). Inland and coastal county designations follow the definition used for the buffer zones of chloropicrin (DPR, 2017) (Table 1).

Table 1. County designations for inland and coastal regions in California

Inland	Coastal
Alameda, Amador, Alpine, Butte, Calaveras, Colusa, Contra Costa, El Dorado, Fresno, Glenn, Imperial, Inyo, Kern, Kings, Lake, Lassen, Madera, Mariposa, Merced, Modoc, Mono, Napa, Nevada, Placer, Plumas, Riverside, Sacramento, San Benito, San Bernardino, San Joaquin, Santa Clara, Shasta, Sierra, Siskiyou, Solano, Stanislaus, Sutter, Tehama, Trinity, Tulare, Tuolumne, Yolo, Yuba	Del Norte, Humboldt, Los Angeles, Marin, Mendocino, Monterey, Orange, San Diego, San Francisco, San Luis Obispo, San Mateo, Santa Barbara, Santa Cruz, Sonoma, Ventura

2.2 Field fumigation methods and flux time series

According to the updated 1,3-D regulation, 24 field fumigation methods (FFMs) are allowed in California (Appendix I), including 18 FFMs currently registered and 6 FFMs newly proposed (24-inch injection and 40% TIF methods). Their flux time series with hourly flux rates (μg/m^2/s) were generated by HYDRUS model (Brown, 2022, 2023) with 21 distinct sets of soil conditions sampled in previous fumigant field studies. The flux time series were generated with a reference application rate of 100 lb/ac. HYDRUS assumes the completion of each application at 8AM on the day of application, and predicts flux rates for the next 500 hours. The field conditions and management practices following the minimum requirements of 1,3-D field fumigations in the proposed 1,3-D regulation, such as soil moisture and tarp cutting time (if applicable), have been reflected in the modeling of flux time series.

The 24 FFMs are categorized into 8 groups according to injection method/depth and tarpaulin type (Table 2). In each group, a representative FFM is selected by considering the emission ratios, peak fluxes, and historical uses (Luo, 2022b, 2023). The HYDRUS-generated flux time series for a representative method are used for modeling the corresponding group of FFMs.

Table 2. Groups of field fumigation methods (FFMs) and the representative method for each group. Highlighted is the representative FFM for the group. TIF = Totally Impermeable Film.

Group of FFMs	FFMs in the group
1-Standard nontarp and non-TIF tarp shallow (12 inch) methods	**1201**, 1202, 1203, 1204, 1205
2-Standard nontarp and non-TIF tarp deep (18 inch) methods	**1206**, 1207, 1208, 1210, 1211
3-Chemigation (drip)/non-TIF tarp method	**1209**
4-24-inch injection methods	**1224**, 1225, 1226, 1227
5-TIF methods – broadcast and strip	**1242**, 1247, 1249
6-TIF methods – bed and drip	**1243**, 1245, 1248, 1259
7-40% TIF with 18-inch injection depth method	**1250**
8-40% TIF with 24-inch injection depth method	**1264**

2.3 Simulation design

AERFUM unit simulations are configured (Table 3) to estimate the average 1,3-D concentrations at a given set of buffer zone settings (distance and duration) to the source area (i.e., treated field) over the working hours (08:00-16:00, Monday to Friday, Figure 1) during the 500-hr flux duration after one application. Model configurations are similar to those previously used for modeling application factors (Luo and Brown, 2022) and setback distances for 1,3-D (Luo, 2022b, 2023).

Table 3. Model settings for occupational bystander exposure assessment from one application of 1,3-D

Input variable	Input data/value
FFMs	8 representative FFMs (Table 2)
Flux time series	21 series for each representative FFM, 168 in total
Application block size	1 to 80 ac
Application rate	332 lb/ac
Buffer zone distances	0 (edge of field), 25, 60, and 100 ft
Buffer zone durations	48, 120, 168, and 500 hours from the end of application
Potential field working hours	8 hours per day (08:00-16:00), 5 days per week (Monday to Friday) (OEHHA, 2024)
Receptor height	1.0 m
Meteorological data	Parlier (WBAN93193) and Watsonville (WBAN23277), 2013-2017. WBAN = Weather-Bureau-Army-Navy, a five-digit identifier for weather stations operated by National Weather Service.

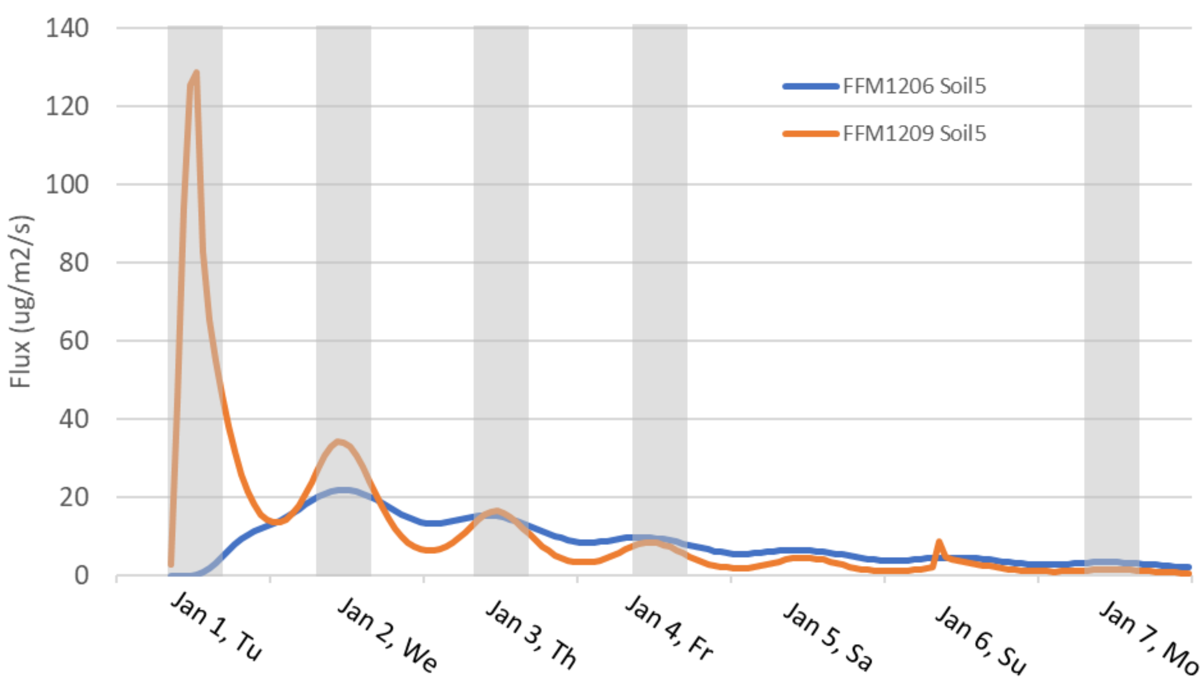

Figure 1. Demonstration of 8-hour working periods (08:00-16:00, Monday to Friday) aligned with a time series of 1,3-D emission flux (application completed at 8AM 1/1/2013 as examples). In total there are 15 workdays during the 500-hour flux duration; only 5 of them in the first week after application are shown here.

There are 15 workdays or 120 (= 15×8) working hours for potential occupational bystander exposure following one application of 1,3-D (Figure 1). The application is first modeled as the worst-case condition of 332 lb/ac and 80 ac, treated by each of the representative FFMs (Table 2) and the associated flux time series. In addition, applications with block sizes < 80 ac are also modeled. In summary, the modeling results for the worst-case applications (332 lb/ac and 80 ac) provide reference concentrations of 1,3-D for occupational bystander exposure, which could be further adjusted by actual application rates (linear relationship) and application block sizes (relationship to be established in this study) to reflect the realistic field conditions.

The buffer zone distances for occupational bystanders are set as 0 (i.e., the edge of field), 25, 60, or 100 ft, by following the minimum buffer zone distances for chloropicrin varying by application methods and application block size (DPR, 2017), i.e., 25 ft for TIF applications, 60 ft for non-TIF applications ≤ 6 ac, 100 ft for non-TIF applications > 6 ac and all untarped applications. Buffer zone distances consistent with chloropicrin will make compliance and enforcement easier for applications using products containing both 1,3-D and chloropicrin. A maximum 100-ft distance is also consistent with the minimum 1,3-D setback distance for occupied structures. A larger buffer zone would likely require revisions to the setback requirements. The buffer zone durations are modeled as 48 hours, 120 hours (5 days), 168 hours (7 days), and 500 hours (21 days) from the end of application. These buffer zone durations were also selected to make compliance and enforcement easier. Forty-eight hours is consistent with the chloropicrin buffer zone duration. Five days and seven days are consistent with the field reentry period and setback duration for 1,3-D, respectively. Air concentrations are predicted at a receptor height of 1.0 m, representing the average breathing height of 0.5 to 1.5 m for occupational bystanders who might be harvesting or other tasks that require a low height. More details on the receptor configuration were documented in the technical report for AERFUM (Luo, 2019).

For each input dataset (Table 3) as a unique combination of flux time series (specified by FFM and soil), buffer zone distance, buffer zone duration, and region (represented by meteorological data), the following modeling procedures are implemented in AERFUM to determine the air concentration of 1,3-D for occupational bystander exposure:

1) Setup the source area (i.e., the treated field) according to the application block size.
2) Generate two rings of receptors: [1] at the edge of the treated field, and [2] at a given buffer zone distance (25, 60, or 100 ft) from the field.
3) Started on 1/1/2013, a 1,3-D application event on the source area is assumed to be completed at 8AM. The hourly flux rates from the HYDRUS-generated flux time series are adjusted by the application rate (332 lb/ac) and assigned to the subsequent hours after application.
4) For each receptor, predict hourly concentrations over the duration of flux time series (500 hours in this study).

5) Select the potential working hours (8AM to 5PM, Monday to Friday, Figure 1) from the 500 hours. For the hours within the buffer zone duration from the end of application, extract predicted concentrations from the receptors located at the buffer zone distance. For the hours after the buffer zone duration, extract predicted concentrations from the receptors located at the edge of field.
6) Calculate the average over the above retrieved concentrations, and assign the result to the date of application.
7) Move to the next day in the simulation period (2013 to 2017), and repeat above processes (Note: according to the flux duration of 500 hours, applications on the last 21 days of 2017 will not be modeled, i.e., 12/11/2017-12/31/2017).
8) AERFUM will generate 1805 concentration values (1805 = days of the 5-year simulation period minus the 21-day flux duration), indexed by date and corresponding season.

AERFUM continuously models all days and months in the simulation period. To be consistent with the previous modeling for application factors (Luo and Brown, 2022) and setback distances (Luo, 2022b, 2023), the predicted concentrations for occupational bystander exposure analysis are reported for the two seasons of nonwinter (March to October) and winter (November to February). For each application method, its 21 flux time series (for 21 soil conditions) are modeled by following the above procedure. The median value of the modeling results is assigned to the corresponding method. For the worst-case applications (332 lb/ac and 80 ac), for example, AERFUM finally reports 512 average concentration values for the 8 representative FFMs, 4 buffer zone distances, 4 buffer zone durations, 2 seasons, and 2 regions.

The modeling approach for occupational bystander exposure is similar to that for non-occupational bystander exposure but with different input parameters and post-processing of model outputs (Table 4).

Table 4. Modeling approaches for occupational bystander vs. non-occupational bystander exposures to 1,3-D

Parameter	Occupational bystanders, this study	Non-occupational bystanders (Luo, 2023)
Risk evaluated	Cancer	Acute
Emission estimates	HYDRUS modeling for 500 hours	Same
Air concentration estimates	AERFUM modeling	Same
Fumigation methods	24 methods in 8 groups	Same
Regions	Inland and coastal counties	Same
Weather data	Parlier and Watsonville, 2013-2017	Same
Seasons	Winter (November-February) and non-winter (March-October)	Same
Maximum application rate	332 lbs/ac	Same
Maximum acreage	80 ac	Same
Time of exposure	8 hours/day, 08:00-16:00	24 hours/day
Days of exposure	5 days/week, Monday-Friday	7 days/week
Receptor height	1.0 m	1.5 m
Receptor distances to field	Buffer zone distance (0, 25, 60, or 100 ft)	Setback distance (100, 200, 300, 400, or 500 ft)

Estimated concentration at each receptor	Average 8-hr concentrations (08:00-16:00), Monday-Friday, in the 500-hour emission period	Maximum 72-hr moving average concentrations in the emission period
Output from each simulation	Average of all receptors	Maximum
Number of model simulations	1805 for each region (Section 2.2)	Same
Air concentration statistics	50th percentile (i.e., median) of the 1805 outputs	95th percentile of the 1805 outputs

3 Modeling results

3.1 The worst-case applications (332 lb/ac and 80 ac)

The model-predicted average 1,3-D concentrations during the 120 potential working hours (Figure 1) after a worst-case application are summarized in Tables 4 to 7. Each table presents the model predictions with a modeled buffer zone duration: 48 hours (Table 5), 120 hours (Table 6), 168 hours (Table 7), and 500 hours (Table 8) from the end of application. Concentrations are predicted for each unique combination of FFM (8 groups), region (inland or coastal counties), season (March to October or November to February), and buffer zone distances (0, 25, 60, and 100 ft). The concentrations at field edge (buffer zone distance = 0 and buffer zone duration = 0) represent the condition without a buffer zone. Therefore, the predicted edge-of-field concentrations (as shown in the first two columns of each table) are independent to the modeled buffer zone duration, and only related to FFM, region, and season.

Table 5 (48-hour buffer zone duration). Predicted average 1,3-D concentrations (ppb) for the occupational bystander exposure after a single application (332 lb/ac and 80 ac)

(a) Inland counties

FFM	0 ft		25 ft		60 ft		100 ft	
	Nov-Feb	Mar-Oct	Nov-Feb	Mar-Oct	Nov-Feb	Mar-Oct	Nov-Feb	Mar-Oct
1201	15.3	10.8	13.2	9.2	11.8	8.2	11.1	7.7
1206	9.8	6.8	9.4	6.5	9.1	6.3	8.9	6.1
1209	25.0	18.6	19.2	14.1	15.3	10.9	12.8	9.1
1224	5.6	3.9	5.6	3.8	5.5	3.8	5.5	3.8
1242	4.9	3.5	4.7	3.3	4.6	3.2	4.5	3.2
1243	6.2	4.3	5.8	4.1	5.6	4.0	5.5	3.8
1250	7.3	4.9	6.7	4.7	6.6	4.6	6.5	4.5
1264	4.2	2.9	4.2	2.9	4.2	2.9	4.2	2.9

(b) Coastal counties

FFM	0 ft		25 ft		60 ft		100 ft	
	Nov-Feb	Mar-Oct	Nov-Feb	Mar-Oct	Nov-Feb	Mar-Oct	Nov-Feb	Mar-Oct
1201	14.8	10.3	12.8	8.9	11.6	8.1	10.7	7.6
1206	9.6	6.6	9.2	6.4	8.9	6.1	8.8	6.0
1209	23.5	17.3	18.3	13.5	14.6	10.8	12.2	9.1
1224	5.5	3.8	5.5	3.8	5.5	3.8	5.5	3.8
1242	4.7	3.3	4.6	3.2	4.5	3.1	4.4	3.1
1243	6.1	4.2	5.8	4.0	5.5	3.8	5.4	3.7
1250	7.0	4.8	6.8	4.6	6.6	4.5	6.5	4.4
1264	4.3	2.9	4.3	2.9	4.3	2.9	4.3	2.9

Table 6 (120-hour buffer zone duration). Predicted average 1,3-D concentrations (ppb) for the occupational bystander exposure after a single application (332 lb/ac and 80 ac)

(a) Inland counties

FFM	0 ft		25 ft		60 ft		100 ft	
	Nov-Feb	Mar-Oct	Nov-Feb	Mar-Oct	Nov-Feb	Mar-Oct	Nov-Feb	Mar-Oct
1201	15.3	10.8	11.6	8.2	9.0	6.4	7.4	5.3
1206	9.8	6.8	8.0	5.5	6.7	4.6	5.9	4.1
1209	25.0	18.6	18.5	13.6	13.8	10.1	10.8	8.0
1224	5.6	3.9	5.0	3.4	4.6	3.2	4.4	3.0
1242	4.9	3.5	4.1	2.9	3.5	2.5	3.2	2.3
1243	6.2	4.3	5.0	3.4	4.0	2.8	3.5	2.4
1250	7.3	5.0	5.8	4.0	5.0	3.4	4.5	3.1
1264	4.2	2.9	3.8	2.6	3.6	2.4	3.4	2.3

(b) Coastal counties

FFM	0 ft		25 ft		60 ft		100 ft	
	Nov-Feb	Mar-Oct	Nov-Feb	Mar-Oct	Nov-Feb	Mar-Oct	Nov-Feb	Mar-Oct
1201	14.8	10.3	11.4	8.0	8.9	6.2	7.3	5.2
1206	9.6	6.6	7.9	5.5	6.7	4.7	5.9	4.1
1209	23.5	17.4	17.6	13.0	13.2	9.9	10.4	7.8
1224	5.5	3.8	5.0	3.5	4.6	3.2	4.3	3.0
1242	4.7	3.3	4.0	2.8	3.5	2.5	3.2	2.3
1243	6.1	4.2	4.9	3.4	4.0	2.8	3.5	2.5
1250	7.0	4.8	5.9	4.0	5.0	3.5	4.5	3.2
1264	4.3	2.9	3.9	2.7	3.6	2.5	3.5	2.4

Table 7 (168-hour buffer zone duration). Predicted average 1,3-D concentrations (ppb) for the occupational bystander exposure after a single application (332 lb/ac and 80 ac)

(a) Inland counties

FFM	0 ft		25 ft		60 ft		100 ft	
	Nov-Feb	Mar-Oct	Nov-Feb	Mar-Oct	Nov-Feb	Mar-Oct	Nov-Feb	Mar-Oct
1201	15.3	10.8	11.3	8.0	8.5	6.0	6.7	4.8
1206	9.8	6.8	7.5	5.2	5.9	4.1	5.0	3.4
1209	25.0	18.6	18.2	13.4	13.3	9.8	10.2	7.6
1224	5.6	3.9	4.6	3.2	4.0	2.7	3.6	2.4
1242	4.9	3.5	3.9	2.7	3.2	2.3	2.8	2.0
1243	6.2	4.3	4.7	3.3	3.7	2.5	3.0	2.1
1250	7.3	4.9	5.6	3.8	4.5	3.1	3.8	2.7
1264	4.2	2.9	3.6	2.5	3.2	2.2	2.9	2.0

(b) Coastal counties

FFM	0 ft		25 ft		60 ft		100 ft	
	Nov-Feb	Mar-Oct	Nov-Feb	Mar-Oct	Nov-Feb	Mar-Oct	Nov-Feb	Mar-Oct
1201	14.8	10.3	11.1	7.8	8.4	5.9	6.7	4.7
1206	9.6	6.6	7.5	5.2	6.0	4.1	5.0	3.5
1209	23.5	17.3	17.2	12.9	12.6	9.5	9.7	7.3
1224	5.5	3.8	4.6	3.2	4.0	2.8	3.6	2.5
1242	4.7	3.3	3.8	2.7	3.2	2.3	2.8	2.0
1243	6.1	4.2	4.6	3.2	3.6	2.5	3.0	2.1
1250	7.0	4.8	5.5	3.8	4.5	3.1	3.9	2.7
1264	4.3	2.9	3.7	2.5	3.2	2.2	2.9	2.0

Table 8 (500-hour buffer zone duration). Predicted average 1,3-D concentrations (ppb) for the occupational bystander exposure after a single application (332 lb/ac and 80 ac)

(a) Inland counties

FFM	0 ft		25 ft		60 ft		100 ft	
	Nov-Feb	Mar-Oct	Nov-Feb	Mar-Oct	Nov-Feb	Mar-Oct	Nov-Feb	Mar-Oct
1201	15.3	10.8	10.9	7.7	7.9	5.6	6.0	4.3
1206	9.8	6.8	7.0	4.9	5.0	3.5	3.8	2.7
1209	25.0	18.6	18.1	13.3	13.1	9.6	9.8	7.3
1224	5.6	3.9	4.0	2.7	2.9	2.0	2.2	1.5
1242	4.9	3.4	3.5	2.4	2.5	1.8	1.9	1.3
1243	6.2	4.3	4.5	3.1	3.2	2.2	2.5	1.7
1250	7.0	4.9	5.0	3.5	3.6	2.5	2.8	1.9
1264	4.2	2.9	3.1	2.1	2.2	1.5	1.7	1.1

(b) Coastal counties

FFM	0 ft		25 ft		60 ft		100 ft	
	Nov-Feb	Mar-Oct	Nov-Feb	Mar-Oct	Nov-Feb	Mar-Oct	Nov-Feb	Mar-Oct
1201	14.8	10.3	10.8	7.5	7.7	5.5	5.9	4.2
1206	9.6	6.6	6.9	4.8	5.0	3.5	3.8	2.7
1209	23.5	17.3	17.1	12.8	12.3	9.3	9.4	7.1
1224	5.5	3.8	4.0	2.8	2.9	2.0	2.2	1.5
1242	4.7	3.3	3.4	2.4	2.5	1.8	1.9	1.4
1243	6.1	4.2	4.4	3.0	3.2	2.2	2.4	1.7
1250	7.0	4.8	5.0	3.5	3.6	2.5	2.8	1.9
1264	4.3	2.9	3.1	2.1	2.2	1.5	1.7	1.2

3.2 Other application block sizes

The application block sizes of 1, 5, 10, 20, and 40 ac are modeled with the maximum rate of 332 lb/ac (Table 9 for the results at the edge of field, and Table 10 for those with a 100-ft and 48-hour buffer zone). The modeling results are presented as relative values to the concentrations modeled for an 80-ac field. In Table 9, for example, the first value of 0.93 indicates an 7% (=1-0.93) reduction of the predicted edge-of-field concentration by reducing the application block size from 80 to 40 ac.

Table 9. Predicted average 1,3-D concentrations (as relative values to the concentrations modeled for an 80-ac field) at the edge of field for the occupational bystander exposure after a single application (332 lb/ac and various block sizes)

(a) Inland counties

FFM	Nov-Feb					Mar-Oct				
	40ac	20ac	10ac	5ac	1ac	40ac	20ac	10ac	5ac	1ac
1201	0.93	0.83	0.77	0.69	0.50	0.94	0.84	0.78	0.71	0.52
1206	0.94	0.84	0.78	0.70	0.51	0.93	0.84	0.78	0.71	0.53
1209	0.93	0.84	0.78	0.70	0.51	0.94	0.84	0.78	0.70	0.52
1224	0.93	0.84	0.78	0.70	0.52	0.94	0.84	0.78	0.71	0.53
1242	0.94	0.84	0.78	0.70	0.52	0.94	0.84	0.79	0.71	0.53
1243	0.93	0.83	0.77	0.69	0.52	0.94	0.84	0.79	0.71	0.53
1250	0.89	0.80	0.74	0.66	0.49	0.91	0.82	0.77	0.69	0.51
1264	0.93	0.84	0.78	0.70	0.52	0.94	0.84	0.78	0.71	0.53

(b) Coastal counties

FFM	Nov-Feb					Mar-Oct				
	40ac	20ac	10ac	5ac	1ac	40ac	20ac	10ac	5ac	1ac
1201	0.93	0.83	0.77	0.69	0.50	0.93	0.83	0.77	0.69	0.50
1206	0.93	0.83	0.77	0.69	0.50	0.93	0.83	0.77	0.69	0.50
1209	0.93	0.83	0.77	0.69	0.50	0.93	0.83	0.76	0.68	0.49
1224	0.93	0.83	0.77	0.69	0.51	0.93	0.83	0.77	0.69	0.51
1242	0.93	0.84	0.78	0.70	0.51	0.93	0.83	0.77	0.69	0.50
1243	0.93	0.83	0.77	0.69	0.50	0.93	0.83	0.77	0.70	0.51
1250	0.93	0.83	0.77	0.69	0.50	0.93	0.83	0.77	0.69	0.51
1264	0.92	0.83	0.77	0.69	0.50	0.93	0.83	0.77	0.70	0.51

Table 10. Predicted average 1,3-D concentrations (as relative values to the concentrations modeled for an 80-ac field) with a 100-ft buffer zone and 48-hour buffer zone duration for the occupational bystander exposure after a single application (332 lb/ac and various block sizes).

(a) Inland counties

FFM	Nov-Feb					Mar-Oct				
	40ac	20ac	10ac	5ac	1ac	40ac	20ac	10ac	5ac	1ac
1201	0.91	0.80	0.72	0.64	0.44	0.92	0.81	0.74	0.66	0.46
1206	0.92	0.82	0.76	0.68	0.49	0.93	0.83	0.77	0.69	0.51
1209	0.89	0.76	0.66	0.56	0.36	0.89	0.75	0.66	0.56	0.36
1224	0.93	0.84	0.78	0.70	0.52	0.93	0.84	0.78	0.71	0.53
1242	0.93	0.83	0.77	0.69	0.50	0.93	0.84	0.78	0.70	0.52
1243	0.92	0.82	0.76	0.68	0.48	0.93	0.83	0.77	0.69	0.50
1250	0.93	0.83	0.77	0.69	0.50	0.93	0.84	0.78	0.70	0.51
1264	0.93	0.84	0.78	0.70	0.52	0.96	0.87	0.80	0.73	0.54

(b) Coastal counties

FFM	Nov-Feb					Mar-Oct				
	40ac	20ac	10ac	5ac	1ac	40ac	20ac	10ac	5ac	1ac
1201	0.92	0.81	0.74	0.64	0.44	0.91	0.80	0.72	0.64	0.44
1206	0.92	0.82	0.75	0.67	0.48	0.93	0.82	0.76	0.68	0.49
1209	0.90	0.77	0.68	0.58	0.36	0.88	0.75	0.65	0.55	0.34
1224	0.93	0.83	0.77	0.69	0.50	0.93	0.83	0.77	0.69	0.51
1242	0.93	0.83	0.76	0.68	0.50	0.92	0.82	0.76	0.68	0.49
1243	0.92	0.82	0.76	0.67	0.48	0.92	0.82	0.75	0.67	0.48
1250	0.92	0.82	0.76	0.68	0.49	0.93	0.83	0.76	0.68	0.49
1264	0.93	0.83	0.77	0.69	0.50	0.93	0.83	0.77	0.70	0.51

Based on the modeling results, the concentration for any block size could be determined by either interpolation or curve fitting. For a given set of FFM and buffer zone settings, for example, there is a general log-linear relationship between concentration and block size.

3.3 Additional modeling with recent meteorological data (2019-2023)

In the primary model simulations (Section 2.3), the meteorological data for a 5-year period of 2013-2017 is used for consistency with the previous modeling studies for non-occupational bystander exposure assessments (Luo, 2022a, b; Luo and Brown, 2022; Luo, 2023). Additional model simulations are conducted with the recent 5-year meteorological data from 2019-2023. Except for the meteorological inputs, all other modeling parameters and configurations follow the same settings in Table 4. Presented in Table 11 are the modeling results for two scenarios (edge of field and a 100-ft buffer for 48 hours) with the worst-case application (332 lb/ac and 80 ac). Predicted concentrations with 2019-2013 meteorological data are similar to those with 2013-2017 data (Section 3.1). The relative changes range from -0.05 to 0.11, with a median of zero.

Table 11. Predicted average 1,3-D concentrations (ppb) with 2019-2023 meteorological data for the occupational bystander exposure after a single application (332 lb/ac and 80 ac)

(a) edge of the field

FFM	Inland	Inland	Coastal	Coastal
	Nov-Feb	Mar-Oct	Nov-Feb	Mar-Oct
1201	13.8	10.6	14.8	10.7
1206	9.1	6.7	9.7	6.8
1209	22.9	18.0	24.4	17.9
1224	5.3	3.8	5.5	3.9
1242	4.5	3.4	4.8	3.4
1243	6.3	4.5	6.1	4.3
1250	6.5	4.8	7.0	4.9
1264	4.0	2.9	4.3	3.0

(b) 100-ft and 48-hr buffer zone

FFM	Inland	Inland	Coastal	Coastal
	Nov-Feb	Mar-Oct	Nov-Feb	Mar-Oct
1201	10.2	7.5	10.9	7.8
1206	8.2	6.1	8.7	6.2
1209	11.9	8.9	12.7	9.3
1224	5.3	3.8	5.5	3.9
1242	4.2	3.2	4.4	3.2
1243	5.0	3.8	5.4	3.9
1250	6.0	4.4	6.5	4.6
1264	3.9	2.9	4.2	3.0

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Appendix I. 1,3-Dichloropropene field fumigation methods

Table 12. 1,3-Dichloropropene field fumigation methods in California

Method Group	Method Name	Field Fumigation Method (FFM) Code
1	Nontarp/shallow/broadcast or bed	1201
1	Tarp/shallow/broadcast	1202
1	Tarp/shallow/bed	1203
1	Nontarp/shallow/broadcast or bed/3 water treatments	1204
1	Tarp/shallow/bed/3 water treatments	1205
2	Nontarp/18 inches deep/broadcast or bed	1206
2	Tarp/18 inches deep/broadcast	1207
2	Tarp/18 inches deep/bed	1208
3	Chemigation (drip system)/tarp	1209
2	Nontarp/18 inches deep/strip	1210
2	Nontarp/18 inches deep/GPS targeted	1211
4	Nontarp/24 inches deep/broadcast	1224
4	Tarp/24 inches deep/broadcast	1225
4	Nontarp/24 inches deep/strip	1226
4	Nontarp/24 inches deep/GPS targeted	1227
5	Totally Impermeable Film (TIF) tarp/shallow/broadcast	1242
6	TIF tarp/shallow/bed	1243
6	TIF tarp/shallow/bed/3 water treatments	1245
5	TIF tarp/deep/broadcast	1247
6	TIF tarp/deep/bed	1248
5	TIF tarp/deep/strip	1249
7	40% TIF tarp/18 inches deep/broadcast	1250
6	Chemigation (drip)/ TIF tarp	1259
8	40% TIF tarp/24 inches deep/broadcast	1264