OFFICE OF ENVIRONMENTAL HEALTH HAZARD ASSESSMENT

Invasive Species Program

Exposure Assessment

Imidacloprid: Soil Application to Non-Commercial Citrus Trees for Asian Citrus Psyllid Control

June 2015

Pesticide and Environmental Toxicology Branch
Office of Environmental Health Hazard Assessment
California Environmental Protection Agency

CONTRIBUTIONS AND ACKNOWLEDGEMENT

This document was prepared by the Pesticide and Environmental Toxicology Branch of the California Office of Environmental Health Hazard Assessment.

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Acknowledgements

We thank the California Department of Pesticide Regulation and the California Department of Food and Agriculture for their review of a draft of this document.

This assessment was informed by members of the public who brought concerns forward at informational public meetings hosted by the California Department of Food and Agriculture (CDFA) and by CDFA staff members who provided helpful information to OEHHA staff.

List of Abbreviations and Acronyms

ACP	Asian Citrus Psyllid
atm m^3/mole	atmospheres cubic meter per mole
Cal/EPA	California Environmental Protection Agency
CDFA	California Department of Food and Agriculture
C_A	concentration of imidacloprid in fruit – acute exposure
Csc	concentration of imidacloprid in fruit – subchronic exposure
CR_A	citrus fruit consumption rate - acute exposure
CRsc	citrus fruit consumption rate - subchronic exposure
CYP450	cytochrome P450
D_A	dose - acute exposure
Dsc	dose - subchronic exposure
DPR	California Department of Pesticide Regulation (within Cal/EPA)
FAO	Food and Agriculture Organization (of the United Nations)
g/mol	grams per mole
HLB	Huanglongbing
K_d	dissociation constant
K_{oc}	soil organic carbon-water partition coefficient
K_{ow}	octanol-water partition coefficient
L	fraction of total citrus fruit consumption that is home grown
mg/L	milligram per liter
mg/kg	milligram per kilogram of body weight
mm Hg	millimeter mercury
ND	non-detectable
ng	nanogram (one millionth of a milligram)
NHANES	National Health and Nutrition Examination Survey
OEHHA	Office of Environmental Health Hazard Assessment (within Cal/EPA)
ppb	parts per billion (e.g., µg/kg)
ppm	parts per million (e.g., mg/kg)
RfD	Reference Dose
µg/kg	microgram per kilogram of body weight
USDA	United States Department of Agriculture
US EPA	United States Environmental Protection Agency
WHO	World Health Organization

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Exposure Assessment: Soil Application of Imidacloprid to Non-Commercial Citrus Trees for Asian Citrus Psyllid Control

Summary

In this exposure assessment, the Office of Environmental Health Hazard Assessment (OEHHA) evaluated human exposure to imidacloprid which may occur from the treatment by the California Department of Food and Agriculture (CDFA) of non-commercial citrus trees for the control of Asian Citrus Psyllid (ACP) in Southern California. Imidacloprid's ecological exposures and effects, including possible effects on bees, were not evaluated.

Imidacloprid use to control ACP

The ACP, *Diaphorina citri*, is a tiny mottled brown insect, about the size of an aphid. It feeds on citrus plants and can transmit a bacterium, *Candidatus Liberibacto,* which is associated with the disease huanglongbing (HLB). The bacterium is harmless to humans but is a serious threat to citrus. HLB-infected trees produce yellow leaves and inedible fruit, and usually die within a few years. Presently, there is no cure for HLB. The only way to prevent HLB spread is to control the ACP population and remove and destroy infected trees.

ACP is considered an invasive species in North America and was first detected in California in 2008. Shortly thereafter, CDFA, citrus growers, and related parties developed plans to control and manage ACP and thus prevent the infestation and spread of HLB. Recognizing that ACP can infest non-commercial as well as commercial citrus trees, CDFA began a non-commercial citrus ACP control program, which includes application of two insecticide formulations to non-commercial citrus trees in or near areas where ACP has been detected (hereafter referred to as "ACP treatments."). These treatments primarily involve residential properties, with a few community parks and schools within treatment zones. Only properties with citrus trees, and only citrus trees (and a very few other plants on which ACP can live) are treated.

One of the ACP-treatment insecticide formulations, Merit 2F®, contains imidacloprid as its active ingredient. Imidacloprid belongs to the neonicotinoid insecticide family and has a chemical structure similar to that of nicotine. It binds to specific receptors on neurons of the central nervous system of insects and at sufficiently high concentrations causes neurotoxicity, paralysis, and death. Similar receptors also exist on mammalian cells, but they have a lower affinity towards imidacloprid and are found on many different cell types besides neurons of the central nervous system. It is believed that these differences account for the higher toxicity observed in insects compared to mammals.

When Merit 2F® is used by CDFA for ACP treatment, it is diluted with water and applied directly to the soil within 6-24 inches of the base of the targeted tree. Imidacloprid is subsequently absorbed by the root system and distributed into all parts of the tree.

In a collaborative effort with CDFA, the California Department of Pesticide Regulation (DPR) monitored imidacloprid residues in fruit of orange and lemon trees following ACP treatment. Low levels of imidacloprid were detected in approximately one third of the fruit samples. The primary focus of this assessment is to address health concerns related to the consumption of home-grown citrus fruit from trees treated in the ACP control program.

Residents' exposure from fruit consumption

In this exposure assessment, OEHHA used the fruit monitoring data of DPR (2011) and evaluated acute and subchronic exposures to imidacloprid through the consumption of home-grown citrus fruit. Because ACP detections can be sporadic in localized geographic areas, it is unlikely that a given residence will receive more than 3-4 consecutive yearly treatments. Chronic exposures (generally defined as greater than 7-8 years) to imidacloprid are not likely and are not evaluated in the assessment.

This assessment modeled three residential groups: (1) the general population, (2) women of child-bearing age as a surrogate for the developing and susceptible fetus, and (3) small children, representing highly exposed individuals. Central-tendency and high-end dose estimates are calculated for each group. The high-end dose estimates are presented below.

The estimated acute high-end doses are:

Adults:	2.1 µg/kg body weight
Women of child-bearing age:	2.5 µg/kg body weight
Small children:	12 µg/kg body weight

The estimated subchronic high-end doses are:

Adults:	0.025 µg/kg body weight - day
Women of child-bearing age:	0.029 µg/kg body weight - day
Small children:	0.18 µg/kg body weight - day

In order to put the estimated doses in perspective, acute, acute developmental, and subchronic Reference Doses (RfDs) (dose values below which adverse health effects are not expected) developed by DPR (2006a) and the US Environmental Protection Agency (US EPA) (2013) are provided below (after converting doses in units of mg/kg-day to µg/kg-day):

DPR

- Acute RfD 90 µg/kg body weight
- Acute developmental RfD 60 µg/kg body weight
- Subchronic RfD 70 µg/kg body weight - day

US EPA

- Acute RfD 140 µg/kg body weight
- Incidental/intermediate RfD 100 µg/kg body weight - day

*Incidental and Intermediate term is defined as 1 day to 6 months exposure

A comparison of the high-end dose estimates determined in this assessment with the corresponding RfDs developed by DPR and US EPA shows that exposure to imidacloprid residue from consumption of home-grown citrus fruit from ACP-treated trees is not likely to pose a health hazard to the residents.

Residents' exposure from pathways other than fruit consumption

In addition to the consumption of citrus fruit, OEHHA also performed screening-level evaluations on the consumption of citrus leaves and flowers, ground water intake, and dermal exposure. Screening-level doses are high-end estimates intended to represent a very high possible dose, however unlikely it may be ("worst-case").

Because imidacloprid is distributed to all parts of a plant, it is possible that residents may be exposed if they use citrus leaves or flowers in their cooking or in making beverages. Residents may also be exposed if imidacloprid were to leach into groundwater used for drinking water or by dermal contact with soil or fruit juice.

OEHHA used imidacloprid citrus leaf residue data from ACP-treated trees and estimated acute exposure to imidacloprid through the consumption of citrus leaves. This estimated acute dose is less than two percent of that estimated for the consumption of citrus fruit and is thus considered insignificant.

There are no data on imidacloprid residues in citrus flowers that are specific to the ACP program. OEHHA used surrogate data from a published study that measured imidacloprid in citrus flowers following soil application to provide a rough estimate of screening-level exposure dose. The estimate is 1/1000 that of citrus fruit consumption and therefore is considered insignificant.

Based on the treatment method, physical properties of imidacloprid and groundwater monitoring data, OEHHA determined that dermal contact with soil and consumption of ground water are not likely to cause significant exposure to imidacloprid following ACP

treatment. Nevertheless, OEHHA used groundwater monitoring and soil data to confirm that in the unlikely event that exposures via these pathways were to occur, the exposures would not pose a health hazard to residents.

OEHHA considers inhalation exposure to imidacloprid from ACP treatments to be unlikely and insignificant based on imidacloprid's low volatility, imidacloprid application methods, and the lack of detection of imidacloprid in air samples following ACP treatments.

Conclusion

OEHHA considered potential exposure to imidacloprid following soil application by CDFA for residential control of ACP and found that consumption of citrus fruit is the only significant pathway. This pathway is quantitatively evaluated using citrus fruit residue data provided by DPR that is specific to the ACP treatment. The results show that imidacloprid doses associated with this pathway are relatively low and are not likely to pose a health hazard to residents whose yards are treated by CDFA for ACP.

Introduction

The purpose of this report is to evaluate potential human exposure to imidacloprid used in the California Department of Food and Agriculture's (CDFA's) Asian Citrus Psyllid (ACP) control and management program. The report does not evaluate imidacloprid's potential ecological exposures and effects, including possible effects on bees.

ACP in California

The ACP, *Diaphorina citri*, is a tiny mottled brown insect, about the size of an aphid. It feeds on all varieties of citrus (e.g., oranges, grapefruit, lemons, and mandarins) and a few very closely related ornamental plants in the family Rutaceae (e.g., calamondin, box orange, Indian curry leaf, and orange jessamine or orange jasmine) (Grafton-Cardwell and Daugherty, 2013). ACP feeds on young leaves and can transmit a bacterium called *Candidatus Liberibacter* from an infected plant to a healthy plant through its feeding. The bacterium is associated with the citrus disease Huanglongbing (HLB), also known as citrus greening disease.

Candidatus Liberibacter blocks the flow of nutrients within the infected tree, and kills the tree within a few years. Symptoms of HLB include yellow shoots with mottling and chlorosis of the leaves, misshapen fruit, fruit that does not fully color, and fruit that has a very bitter taste making it unfit for human consumption. HLB was first detected In the United States in Florida in 2005. While HLB does not infect humans, it is fatal to citrus trees and is probably the most serious disease to sweet orange, mandarin and grapefruit trees (NRC, 2010). As there is no cure for HLB, the best way to prevent its spread is to remove and destroy the infected plant and control ACP populations (CDFA, 2012a).

The first, and so far only, detection of HLB in California occurred during March 2012 in Los Angeles County. The bacterium was detected in samples collected from a single tree and from the ACP found on that tree. It is thought that this was the result of an HLB-infected branch brought in from Asia and grafted to the tree (CDFA, 2012b).

HLB has the potential to devastate the citrus industry. It has been estimated that between 2006 and 2011, HLB cost Florida $4.5 billion in revenue and over 8,200 jobs (Hodges and Spreen, 2012). If HLB were to infect citrus trees in California, the economic losses due to inedible fruit and juice, shortened tree life span, and damage to citrus trees in residential and public property could be significant.

In order to lessen the possibility of HLB in California, CDFA declared ACP a grave threat to California's $2 billion a year citrus industry and has made emergency proclamations for treatment in the counties where it has been detected. ACP was first detected in California in San Diego County along the United States-Mexico border in

2008. Since that time it has spread to or entered 13 other counties as far north as Santa Clara and San Joaquin counties. CDFA's ACP control program includes the treatment of non-commercial citrus (e.g., citrus in public parks and city properties as well as on residential properties). The ACP control program uses two insecticide formulations. The first, Tempo SC Ultra®, contains beta-cyfluthrin as its active ingredient and is applied to the foliage of targeted trees and plants from the ground level. This provides quick-kill to the ACP on the tree. The second formulation, Merit 2F®, contains imidacloprid as its active ingredient and is applied as a soil drench followed by irrigation. It is applied to the soil directly under the target tree. Merit 2F® provides long term systemic protection to the plants.

Use of Imidacloprid to Control ACP

Imidacloprid was first registered by the US Environmental Protection Agency (US EPA) in 1994 (Hovda and Hooser, 2002) for an insecticide product called Merit® with label use on turf and ornamentals. Subsequently, imidacloprid has been registered for use on various food and feed crops, tobacco plants, buildings for termite control, on cats and dogs for flea control, and in residential buildings for bed bug and other insect control. Currently, imidacloprid is classified as a General Use Pesticide, meaning that it is available to the general public and can be used without supervision or special training.

Over the years, imidacloprid has gradually replaced many insecticides, such as organophosphates and methylcarbamates, due to its high insecticidal potency, low mammalian toxicity, and relatively low insect resistance. It can be applied by foliage spraying or soil drench.

When used in the ACP program, Merit 2F® is diluted with water and applied to the soil around the base (label states within 6-24 inches) of the target tree. Imidacloprid is slowly taken up by the tree roots and translocated through the tree's xylem to the leaves and other vegetative plant parts. Insects that feed or suck on the leaves ingest the imidacloprid and subsequently die. A very small amount of imidacloprid may also be distributed to the fruit and flowers via the phloem (Sur and Stork, 2003; Krischik et al., 2007; Serikawa et al., 2012) or through another yet unidentified mechanism.

Chemical and Physical Properties and Environmental Fate

The chemical name for imidacloprid is N-(6-chloropyridin-3-ylmethyl)-2-nitroiminoimidazolidine. It belongs to a class of chemicals known as neonicotinoids, which are synthetic analogs of nicotine.

Chemical and physical properties

Imidacloprid is relatively soluble in water and is not volatile at ambient temperature. Some of its physical and chemical properties are listed in Table 1.

Table 1. Chemical and Physical Properties of Imidacloprid

Property	Value
Molecular weight	255.7 g/mol
Water solubility	514 mg/L (20ºC, at pH 7)
Vapor pressure	1.00×10^{-7} mm Hg (20ºC)
Hydrolysis half-life	>30 days (25ºC, at pH 7)
Aqueous photolysis half-life	<1-3 hours (24ºC, at pH 7)
Anaerobic soil degradation half-life	27 days
Aerobic soil degradation half-life	997 days
Soil surface photolysis half-life	39 days
Field dissipation half-life	26 – 229 days
Henry's Law constant	6.5×10^{-11} atm m^3/mole (20ºC)
Octanol-water coefficient (K_{ow})	3.7
Soil sorption coefficient (K_{oc}) (mean values)	249[b] – 336[c]
Dissociation constant in water (K_d)	6.7[d]
Soil organic carbon-water partition coefficient (K_{oc})	132–310

[a] All data are from DPR, 2006b, except as noted ; [b] From Oi, 1999; [c] From Oliver et al., 2005; [d] From US EPA, 2007

Environmental degradation

In the environment, the principal routes of dissipation for imidacloprid are aqueous photolysis, microbial degradation and uptake by plants. In water, imidacloprid degradation is highly dependent on exposure to sunlight. The half-life of imidacloprid in water with sunlight is 1-3 hours and in water without sunlight is 33 to 44 days (Sarkar et al., 1999).

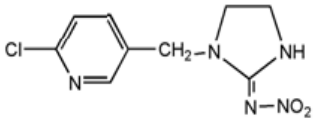
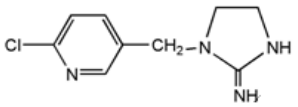
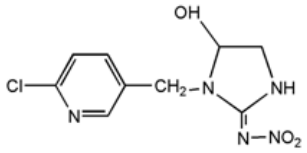
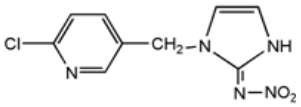
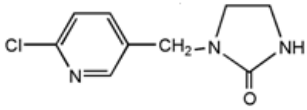
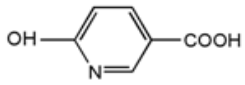
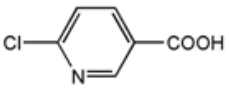
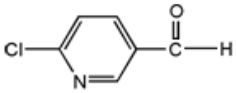
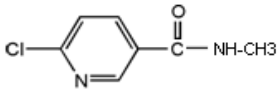
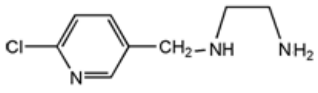
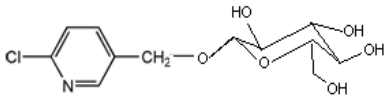
Literature reports of the half-life of imidacloprid in soil vary considerably. The half-life for the photolysis of imidacloprid on soil surface is reported by Cox et al. (2004) as 90 hours while DPR (2006b) reports a value of 39 days. For imidacloprid which has been encapsulated by soil, half-lives were reported as 26-229 days by DPR (2006b) and values falling within that range from laboratory studies were reported by Cox et al. (2004), Oi (1999), Sammani et al. (2013), and Scholz and Spiteller (1992), and from field studies were reported by Rouchard et al. (1994) and Rouchard et al. (1996). McGaughey et al. (2013) and the Canadian Council of Ministers of the Environment (CCME, 2007) report values from registrant studies ranging from 83-174 days. Based

on the aforementioned half-lives, it is suggested that there is little potential for accumulation of imidacloprid in soil following repeated annual application (CCME, 2007). However, CCME (2007) also notes that longer half-lives have been determined from field studies, in particular a half-life of 2 years from imidacloprid applied to seed potatoes. Additionally, the time for 90% of imidacloprid to dissipate from soil can be much greater than one year (CCME, 2007), suggesting that accumulation with annual treatments could occur in a minority of applications. It is noted that the Merit 2F® label specifies a maximum total level that can be applied over a year period.

In soil, imidacloprid's mobility depends for the most part on soil adsorption, which in turn is primarily influenced by soil organic matter and clay particle content (Cox et al., 1998; Cox et al., 2004; Fernandez-Perez et al., 1998; Papiernik et al., 2006). However, studies on the depth and rate of movement of imidacloprid found that mobility varied greatly between studies and depended on soil properties, irrigation/precipitation, and the imidacloprid formulation used (Knoepp et al., 2012). The laboratory study of Gupta et al. (2002) reported that more than 60% of applied imidacloprid was adsorbed to soil, while 29 to 40% moved 25 centimeters through the soil column into leachate. The study also found that imidacloprid in formulated form had a higher tendency to be absorbed than technical-grade imidacloprid. Field studies of Felsot et al. (1998), Junior et al. (2004), and Knoepp et al. (2012) found rapid and relatively deep leaching of imidacloprid which they attributed to preferential flow pathways (macro-pores in the top soil layers). Papiernik et al. (2006) found that imidacloprid degradation products, imidacloprid-guanidine, imidacloprid-guanidine-olefin, and imidacloprid-urea, likewise adsorbed to soil. Knoepp et al. concluded that due to variability in organic content of soil and the existence of preferential flow pathways, it is difficult to make generalizations about the movement and concentrations of imidacloprid in soil.

Table 2 lists environmental degradation products of imidacloprid (i.e., in soil, water, and plants). Exposure to degradation products are not evaluated in this assessment because all except one (desnitro-imidacloprid) are considered to be less toxic than the parent compound and there is little or no information regarding levels of any of the degradation products in citrus plant parts (e.g., fruit). Additionally, desnitro-imidacloprid was a "minor metabolite of citrus" at about 0.12% of radioactivity of parent compound (Koester, 1990).

Table 2. Degradation Products of Imidacloprid in the Environment

Parent & Degradation Product	Chemical Name	Structure[a]	Degradation location
Imidacloprid CAS 105827-78-9	1-[(6-chloro-3-pyridinyl)methyl]-N-nitro-2-imidazolidinimine 1-[(6-chloropridin-3-yl)methyl]-N-nitro-4,5-dihydroimidazol-2-amine		not applicable
Desnitro-imidacloprid (Imidacloprid guanidine) NTN 33823	1-[(6-chloro-3-pyridinyl)methyl]-4,5-dihydro-1H-imidazol-2-amine		plants
5-hydroxy-imidacloprid 5-OH-imidacloprid (monohydroxy metabolite) WAK 4103	1-[(6-chloro-3-pyridinyl)methyl]-5-hydroxy-4,5-dihydro-N-nitro-1H-imidazol-2-amine		plants
Olefinic-imidacloprid Imidacloprid olefin NTN 35884	1[(6-chloro-3-pyridinyl)methyl]-N-nitro-1H-imidazol-2-amine		plants
Imidacloprid-urea	1-[(6-chloro-3-pyridinyl)methyl]-2-imidazolidinone		soil water
6-hyroxynicotinic acid CAS 5006-66-6	6-hydroxypyridine-3-carboxylic acid		soil
6-chloronicotinic acid WAK 3583 CAS 5326-23-8	6-chloro-3-pyridinecarboxylic acid 2-chloropyridine-5-carboxylic acid		soil
6-chloronicotinic aldehyde CAS 23100-12-1	6-chloro-3-pyridinecarboxaldehyde		water
6-chloro-N-methylnicotinamide CAS 54189-82-1	6-chloro-N-methyl-3-pyridinecarboxamide		water
6-chloro-3-pyridyl-methylethylenediamine CAS 101990-44-7	N1-[(6-chloro-3-pyridinyl)methyl]-1,2-ethanediamine		water
monoglucoside of 6-chloropicolyl alcohol			plants

[a] Structure of chemicals adapted from DPR (2006b)

Exposure Assessment

CDFA applies imidacloprid as a soil drench to non-commercial citrus trees for the control and treatment of ACP. In this assessment, OEHHA assesses potential residential exposure to imidacloprid as a result of the treatment. The assessment consists of two steps. The first step is to identify the significant exposure pathways that are associated with the ACP treatment. This includes calculation of screening-level exposure dose estimates, which are high-end estimates intended to protect individuals who could potentially be exposed to such doses. The second step is to estimate more refined doses associated with the identified significant exposure pathways.

Oral Route

Consumption of fruit, leaves, or flowers

Imidacloprid applied to soil is taken up by the tree's root system and translocated by the xylem into the vegetative parts of the plant. A very small amount may travel through the phloem (the "vascular" system which moves nutrients throughout the tree) into fruit and other developing parts (Sur and Stork, 2003; Krischik et al., 2007; Serikawa et al., 2012). As part of DPR's environmental monitoring program, fruit and leaf samples were collected from ACP-treated citrus trees. Imidacloprid residues were found at low levels in about one-third of the fruit samples and at much higher levels in all the leaf samples tested. Human exposure to imidacloprid could occur through consumption of food products made from fruit (e.g., fresh juice, marmalade); leaves (e.g., tea, savory dishes); or flowers (e.g., tea, jam). Human consumption of citrus fruit and juice is common, supported by the listing of three types of citrus fruit on FDA's list of the 20 most frequently consumed foods (US FDA, 2014). Some individuals consume large amounts of citrus fruit and juice. The consumption of citrus fruit and juice is determined to be a plausible and potentially significant exposure pathway which is further evaluated in this exposure assessment.

Consumption of ground or surface water

This assessment also considered the significance of exposure to imidacloprid via consumption of surface water or groundwater. For surface water, aerosol deposition of imidacloprid onto surface water following ACP treatment is not expected since the chemical is applied as a liquid (not as a spray) directly into a shallow trench in the soil around the base of the tree. In the ACP treatment program, only a small amount of imidacloprid is used and the site of application is generally not close to surface water bodies (e.g., rivers or lakes) that might be used for drinking water. Even if some imidacloprid did remain in the top layer of soil, lateral movement is expected to be very

limited based on a field study of Knoepp et al (2012). The study measured imidacloprid at various depths and lateral distances from the sites of soil application and found that imidacloprid was detectable only in locations less than 0.5 meters lateral from the application site.

Imidacloprid contamination of surface water from commercial agricultural use has been observed in monitoring surveys in California by DPR (Starner and Goh, 2012). However, these measurements are from large-scale commercial (agricultural) use areas where foliar application, treatment in close proximity to surface water bodies, and water runoff are likely to have contributed to the surface water contamination. The surface water exposure pathway is considered insignificant for ACP treatments and is not further evaluated.

Groundwater is determined to be an unlikely or very rare exposure pathway. The ACP treatments have taken place mostly in Southern California where the vast majority of the 542 Southern California Basin Network wells are over 100 feet deep and only three wells are as shallow as 25 feet (USGS, 2013). Some of these wells provide water for domestic use, including drinking water, and suggest that private wells in southern California used for domestic use are at least 25 feet deep. Field and laboratory tests indicate that imidacloprid generally does not leach to a soil depth of more than four feet, suggesting that groundwater contamination from imidacloprid of any significant amount is unlikely. However, it is acknowledged that conduits and cracks in the soil column may allow imidacloprid to reach depths greater than four feet.

DPR has a groundwater monitoring program that collects samples from wells for selected pesticides, including imidacloprid, in California. Between 2005 and 2011, DPR analyzed 817 samples collected from 37 agricultural counties and found only one detection of imidacloprid at a very low concentration (0.005 ppb) (DPR, 2013). The application rate and the area covered in an agricultural setting are likely to be much greater than those in the ACP treatment program, and yet imidacloprid has been detected only once in groundwater. Although ground water contamination from ACP treatments is considered unlikely and very rare, a calculation can be made using the DPR groundwater level (0.005 ppb) and the high-end water intake rate for children of 196 ml/kg body weight - day (OEHHA, 2012).

$$\text{Dose}_{\text{groundwater}} = 0.005 \text{ ng/ml} \times 196 \text{ ml/kg body weight - day}$$
$$= 0.98 \text{ ng/kg body weight - day}$$

The calculation confirms that in the unlikely event that exposure did occur, it would be to an inconsequential amount (ng/kg body weight - day relative to mg/kg body weight - day for reference exposure levels identified on page 26). Based on the exposure calculation using the groundwater monitoring data and the relatively deep level of wells in Southern California, it is concluded that consumption of groundwater is not a significant exposure pathway and is not further evaluated.

Dermal Route

Dermal exposure to imidacloprid could occur through skin contact with citrus pulp or juice, or with fluid from leaves. The extent of exposure is likely to be insignificant because imidacloprid levels in fruit are low (in the ppb range) and only a small part of the body (i.e., hands) would come into contact with a small amount of juice or pulp.

Dermal exposure could also occur through skin contact with contaminated soil soon after application by soil drench. However, imidacloprid is highly diluted when applied and the product label recommends saturation of the soil to an extent which will pull the imidacloprid to the absorptive root level (6" depth). This leaves little imidacloprid near the soil surface. Exposure to residents through soil contact is expected to be low.

It has been estimated by DPR (2006a) that the dermal absorption efficiency (the percent of a chemical which is transferred through the skin) of imidacloprid is approximately 8%. The low dermal absorption efficiency would limit the potential health hazard of this route if dermal exposure were to occur.

A screening-level dose is estimated for dermal exposure via contact with contaminated soil for children 2 to 8 years of age. It represents a worst case for the dermal exposure to soil pathway because children 2 to 8 years of age have an exposed body surface area adjusted for body weight that is higher than that of other ages including adults. Further, children of this age group are more likely to play in soil and be exposed through dermal contact.

Using the high-end total body surface area of 0.046 m^2/kg body weight for a 2 to 8 year old child who has 34% of unclothed body surface area (OEHHA, 2012), a high-end soil adherence value of 5.9 g soil per kg body weight (OEHHA, 2012), a maximum imidacloprid soil level of 4250 µg/kg soil (following soil application) (Knoepp et al., 2012), and a dermal absorption of 8% (DPR, 2006a), a screening-level dermal exposure dose is estimated as:

Absorbed $Dose_{dermal}$

$= 0.046\ m^2/kg\ body\ weight \times 0.34 \times 5.9\ g/m^2 \times 4250\ \mu g/kg \times 0.08$
$= 0.031\ \mu g/kg\ body\ weight$

Converting to nanograms (ng), the calculated dose can be expressed as 31 ng/kg body weight - day.

This dose is much less than established RfD values identified on page 26. It should be noted that the imidacloprid level in soil is taken from a study not related to the ACP control treatment. The value from the Knoepp et al. study is a surrogate to confirm that

the dermal exposure pathway is not significant. Dermal exposure to contaminated soil is not further evaluated in this assessment.

Inhalation Route

Inhalation exposure to the vapor phase of imidacloprid is not expected to occur for two main reasons. The first is that Merit 2F® is applied as a diluted solution (not a spray) to a shallow trench in the soil at the base of the tree, a process which will not generate aerosols. The second is that imidacloprid will not volatilize from soil or water as it has a low vapor pressure (1.00×10^{-7} mm Hg at 20 ºC) and Henry's Law Constant (6.5×10^{-11} atm m^3/mole at 20°C) (Table 1).

Exposure to imidacloprid particles is not expected to occur because the label of the imidacloprid formulation used in the ACP treatment states that the soil should be saturated sufficiently to move the imidacloprid to the absorptive root level (6" soil depth). If there is residual imidacloprid on the soil surface, it is likely to be degraded within several hours if sunlight is present.

DPR collected more than 20 air samples near the treatment area following ACP treatments and did not detect imidacloprid (A. Arcus-Arth, OEHHA: personal communication with D. Kim, June 2014). For these reasons, inhalation is not considered significant exposure pathway and is not further evaluated in this assessment.

Dose Estimation for Consumption of Citrus Fruit, Leaves and Flowers

In this section, we identify exposure durations and subpopulations relevant to this exposure assessment. We estimate the extent of exposure associated with the significant exposure pathways identified in the previous section. These pathways are the consumption of citrus leaves, citrus flowers, and citrus fruit. We use the following general model to estimate dose from food consumption:

$$\text{Dose} = C \times CR \times L \qquad \text{Equation 1}$$

Where:

Dose = imidacloprid dose from food consumption (µg/kg body weight for acute exposure and µg/kg body weight - day for subchronic exposure)
C = concentration of imidacloprid in the food (µg/g or µg/ml)
CR = consumption rate of the food item (g/kg body weight - day)
L = percent of consumed food item which is home grown (unitless)

The subscripts $_A$ and $_{SC}$ are used to denote acute and subchronic exposures, respectively.

Exposure durations modeled

Both acute and subchronic exposures are evaluated in this exposure assessment. Acute exposure is defined as an exposure that lasts less than 24 hours while subchronic exposure is defined as an exposure with a duration that ranges from more than one day to several years. Chronic exposure is not evaluated in this assessment. Chronic exposure is generally described as greater than 7-8 years (US EPA, 1989; OEHHA, 2008). It is very unlikely that a particular property would be treated for the control of ACP for more than 7-8 consecutive years. Imidacloprid levels in citrus fruit can remain above the detection limit for more than one year after soil application (Joint FAO/WHO, 2002), but decrease over time after the last application.

Evaluation of the citrus fruit consumption pathway

In a number of field studies, imidacloprid residues have been detected in citrus fruit following soil applications (Joint FAO/WHO, 2002; Blasco et al., 2005; Castle et al., 2005). Low levels of imidacloprid were found in approximately a third of the fruit samples collected from citrus trees following treatment in the ACP program (DPR, 2011). Based on the DPR monitoring results and the fairly large serving sizes of citrus fruit (e.g., orange juice), it is determined that the consumption of fresh citrus fruit and of food and beverages made from citrus fruit are likely exposure pathways.

Resident groups modeled

In order to ensure the evaluation is health protective, exposures to three different groups are independently evaluated for this pathway. The three groups are defined as follows:

- Adults: 19 years of age and older
- Women of child-bearing age: females 13 to 49 years old
- Young children: 1 and 2 year olds

The “adults” group represents the general population. The other two groups represent sensitive or susceptible individuals. A developmental neurotoxicity study (DPR, 2006a) suggests that the developing fetus may be more susceptible to imidacloprid than adults. Since fetuses are exposed to environmental chemicals through their mothers, women of child-bearing age are used as a surrogate to represent this group.

Young children have higher food and fluid consumption rates on a per body weight basis (grams consumed per kg body weight) than older children and adults, with one and two year-olds having the highest rates. For this reason, children one and two years-old are identified as a sensitive group. Exposures to children and teenagers not specifically estimated in this evaluation and are expected to be lower than that determined for the one- and two-year-old children.

Variates used in the exposure models of fruit consumption

This section describes the method used in estimating the variate values which will be used in the exposure model (Equation 1) for acute and subchronic exposures.

Imidacloprid residues in fruit from ACP-treated trees (C_A and C_{SC})

DPR monitored imidacloprid residue levels in citrus fruit as part of CDFA's treatment program (DPR, 2011). Only mature fruit from orange and lemon trees were sampled. Each sample was a composite of several fruit from a single tree or from the same type of tree (i.e., either orange or lemon) at one residential site. Monitoring results provided by DPR show there are a total of 53 orange and lemon samples, which were collected from 31 residential sites in Southern California. The whole fruit (i.e., rind, pulp, and juice) was analyzed in the study.

Samples that were labeled as "0 weeks after treatment" were collected up to one week post-application (A. Arcus-Arth, OEHHA; personal communication with D. Kim, DPR, 2012) and had no detectable imidacloprid levels. Because it takes time for imidacloprid to migrate from soil to roots and then be distributed throughout the tree, one week is likely insufficient for imidacloprid to be transported into fruit. For this reason, samples labeled as "0 weeks after treatment" are considered background and are not included in analyses for this exposure assessment. Only "post-application" samples are analyzed.

Table 3. Number of Fruit Samples Collected from ACP Treated Trees

Sample type	Lemon	Orange	Lemon + Orange
Background	4	5	9
Post-application	27	17	44
Total	31	22	53

*Data from DPR, 2011

In laboratory analyses for chemical residues, there can be uncertainty as to whether a chemical is absent or if the chemical level is too low to be detected by laboratory instruments. Each laboratory develops a reporting limit level for each chemical depending on the chemical's specific sample preparation and analytical methods. The citrus fruit samples were analyzed by more than one laboratory resulting in multiple reporting limits for the dataset. DPR reported measurements that are below the

reporting limit as “non-detectable” (ND) and reported detectable levels as the value that was measured. Table B2 in Appendix B lists the raw data reported by DPR from the post-application samples.

Of the post-application samples, 29 (66%) are non-detects (ND) and 15 (34%) have quantifiable levels of imidacloprid (see Table 4, below).

Table 4. Post-Application Samples Above or Below the Reporting Limit

Range of Detection	Lemon	Orange	Total
Below reporting limit (ND)	16 (59%)	13 (76%)	29 (66%)
Above reporting limit	11 (41%)	4 (24%)	15 (34%)
Total	27	17	44

*Data from DPR, 2011

A software program (ProUCL) developed by US EPA (US EPA, 2011b) is used to analyze the citrus fruit imidacloprid residue data and estimate the summary statistics (e.g., mean and 95th percentile values). Rather than assuming that all NDs represent zero levels of the chemical, the program considers the possibility that some NDs represent the presence of a chemical that cannot be quantitatively measured. It uses information from the dataset to estimate the extent to which values may represent the absence or the very low level presence of a chemical.

The specific methods used in ProUCL depend on the dataset being analyzed. The fruit sample data do not fit the normal or lognormal distribution and are best analyzed using an approach that does not use a specific distribution (i.e., a nonparametric approach). Because the samples were analyzed by multiple laboratories which have different reporting limits, the reporting limit of some samples is different from others. In ProUCL, the approach which is nonparametric and can handle multiple reporting limits (cutoff values) is the Kaplan Meier approach. This approach is selected to analyze the fruit sample data and the results are provided in Table 5, below. Additional details of the analysis are provided in Appendix B.

Table 5. Summary Statistics of Imidacloprid Residues in Citrus Fruit

Parameter	Imidacloprid (µg/g)
Mean	0.023
Standard Deviation	0.038
Standard Error of the Mean	0.006
90th percentile	0.071
95th percentile	0.085
Maximum	0.226

*analyzed using Kaplan Meier methodology in US EPA (2011b, ProUCL 4.1; see Appendix B)
*data from DPR, 2011

For this assessment, the mean residue level values are used for estimating the central tendency doses for acute and subchronic exposures. The maximum residue level is

used to estimate the high-end dose for acute exposure. This is a health-protective approach as it assumes all citrus food consumed by an individual in one day has the highest imidacloprid level measured by the monitoring program. The same approach is not used for estimating the high-end dose for subchronic exposure as it is unlikely that an individual would be exposed to the maximum residue level over many weeks or months. Instead, the mean residue level is used to estimate high-end subchronic exposure dose. A similar approach is used by California's Air Toxics Hot Spots program (OEHHA, 2012).

Table 6. Imidacloprid Concentrations (C) Used to Estimate Dose

Exposure	Dose Estimate	Statistic	Concentration (µg/g) [1]
Acute	Central tendency	Mean	0.023
	High-end	Maximum	0.226
Subchronic	Central tendency	Mean	0.023
	High-end	Mean	0.023

[1] Some residue values were reported to two significant digits, while the maximum value (0.226 µg/g) was reported to three significant digits.

The DPR imidacloprid analyses were conducted on the whole fruit. There is uncertainty as to the uniformity of imidacloprid levels among different parts of citrus fruit (e.g., pulp and peel). For the purpose of this assessment, it is assumed that imidacloprid is uniformly distributed throughout the fruit.

Citrus fruit consumption rates (CR_A and CR_{SC})

National Health and Nutrition Examination Survey (NHANES) data collected between 1999 and 2004 (CDC, 1999-2004) were used to estimate citrus fruit consumption rate (CR_A and CR_{SC}), that is, the grams of citrus fruit and foods made from citrus fruit that are consumed, normalized by body weight in kilograms. OEHHA chose this dataset for several reasons. The survey is nation-wide and is designed to provide estimates which are representative of the U.S. population. It is fairly recent and thus reflective of current eating trends. In addition, the sample sizes for most subpopulations are sufficiently large to provide relatively robust estimates, and the accuracy of the collection methodology has been validated. It contains detailed 24-hour dietary intake and serving information (e.g., one-half medium grapefruit, one slice of toast with one tablespoon orange marmalade)**,** body weight measurements, and other relevant data in two-year survey cycles. Several kinds of citrus fruit are recognized in the survey: grapefruit, kumquat, tangerine, orange, lemon, and lime. NHANES analyzed the collected information then converted the intake data into consumption data (e.g., grams of orange - day). The consumption data applies only to the edible portion of the food.

While an individual can consume a dish, food product, or beverage that contains citrus fruit as one of the many ingredients (e.g., fruit salad with tangerine segments, fruit juice blend), NHANES data do not specify the exact proportion of citrus in these mixtures.

Instead of arbitrarily assigning proportions of citrus to a mixture, this assessment limits the analyses to citrus-only food items plus two fruit juice blends which are likely to contain at least 50% citrus. For these two fruit juice blends, the amount of citrus consumed is assumed to be one-half of the reported consumption of the juice blend. Thus, the estimated consumption rate includes citrus fruit (e.g., whole kumquats, tangerine segments), citrus fruit juice (orange, lemon, lime, tangerine, and grapefruit), and two citrus fruit juice blends.

In order to calculate citrus consumption rates (g citrus per kg body weight - day), this assessment first summed the amount of citrus consumed by each participant in the day chosen for the survey. Then, each individual's daily consumption of citrus is divided by his/her body weight (also provided by NHANES) to derive grams of citrus fruit consumed per kg body weight - day. The compiled data set includes all participants who reported at least some citrus consumption and for whom body weight measurements are available.

The estimated CR_A values for the three age-gender groups are shown in Table 7.

Table 7. One Day Citrus Fruit Consumption Rates

CR_A (g/kg body weight - day)			
Subpopulation	**Sample Size**	**Central tendency (mean)**	**High-end (95^{th} percentile)**
1<3 years	240	17.4	51.0
Female 13<50 years	1528	4.03	10.8
Adult >18 years	3861	3.53	9.20

Analyzed by OEHHA (2012), based on NHANES 1999-2004 (CDC, 1999-2004)

One limitation of the NHANES 1999-2004 data is that it did not collect longitudinal consumption data, i.e., data collected over long periods of time on each individual. Instead only one or two days of consumption are recorded. This limitation is especially important for foods not consumed on a daily basis, such as some types of citrus, for which long term consumption rates are needed. To estimate daily citrus fruit consumption averaged over a long period (subchronic, one year (CR_{SC})), the amount consumed on a consumption day (g/kg body weight - day) by an individual can be used together with that person's frequency of consumption (days/year). Consumption frequency data are only available in NHANES 2003-2004; therefore only NHANES 2003-2004 was used.

For subchronic exposure dose calculations in this assessment, the mean and the 95^{th}-percentile of CR_{SC} data are used. The estimated CR_{SC} values for the three resident groups are shown in Table 8.

Table 8. Daily Citrus Fruit Consumption Rate Averaged Over One Year

CR_{SC} (g fruit / kg body weight – day)			
Subpopulation	**Sample size**	**Mean**	**95th-percentile**
1<3years	66	12.0	50.4
Female 13<50 years	393	2.26	8.0
Adult >18 years	984	2.25	6.9

Fraction of citrus fruit consumed from trees treated for ACP

This risk assessment evaluates risk from exposure to imidacloprid via the consumption of citrus fruit from trees in residential yards, community gardens and parks that have been treated for the control of ACP. However, individuals may also consume citrus fruit from commercial sources such as supermarkets, grocery stores and farmers markets. The variate L is defined as the ratio of the amount of citrus fruit consumed that is from ACP-treated trees to the total amount of citrus fruit consumed. For acute oral exposures, L is assumed to be 1.0 (100 percent). For acute exposures, all of the citrus fruit an individual consumes during one day may come from ACP treated trees.

For subchronic exposures, it is not appropriate to assume that all the citrus fruit consumed by an individual over months or years (the subchronic time period) is from ACP-treated trees. OEHHA (2012) developed an L of 0.16 (16 percent) for the consumption of all fruit by households that farm which is home grown. The value 0.16 is used for subchronic exposure assessments.

Calculation of imidacloprid dose from citrus fruit consumption

Acute exposure from citrus fruit consumption is determined by using Equation 1 and the variate values presented in Table 9. The resulting dose estimates are presented in Table 10.

Table 9. Variate Values Used for Acute Exposure Imidacloprid Doses

	Central tendency estimate[1]	**High-end estimate**[2]
CR_A (g/kg body weight)		
1<3 years	17.4	51.0
Female 13-49 years	4.03	10.8
Adult > 18 years	3.53	9.20
L_A (unitless)	1.0	1.0
C_A (µg imidacloprid / g fruit)	0.023	0.226

[1] central tendency estimates are the mean values for CR_A and C_A

[2] high-end estimates are the 95th-percentile for CR_A and the maximum value for C_A

Table 10. Calculated Acute Exposure Imidacloprid Doses

D_A (µg/kg body weight -- day)		
Subpopulation	**Central tendency**	**High-end**
1<3 years	0.400	11.5
Female 13-49 years	0.093	2.45
Adult > 18 years	0.081	2.07

Subchronic exposure from citrus fruit consumption is determined by using Equation 3 and the variate values presented in Table 11. The resulting dose estimates are presented in Table 12.

Table 11. Variate Values Used for Subchronic Exposure Imidacloprid Doses

Variate	**Central tendency estimate[1]**	**High-end estimate[2]**
CR_{SC} (g/kg body weight - day averaged over a year)		
1<3 years	12.0	50.4
Female 13-49 years	2.26	8.0
Adults >18 years	2.25	6.9
L (unitless)	0.16	0.16
C (µg imidacloprid / gram fruit)	0.023	0.023

[1] central tendency estimates are the mean values for CR_{SC} and C_{SC}

[2] high-end estimates are the 95th-percentile for CR_{SC} and the mean value for C_{SC}

Table 12. Calculated Subchronic Exposure Imidacloprid Doses

D_{sc} (µg/kg body weight - day)		
Subpopulation	**Central tendency**	**High-end**
1<3 years	0.044	0.185
Females 13-49 years	0.008	0.029
Adults > 18 years	0.008	0.025

*daily doses averaged over one year

In order to put the estimated doses in perspective, acute, acute developmental, and subchronic RfDs developed by DPR (DPR, 2006a) and US EPA (US EPA, 2013) are provided below:

DPR

- Acute RfD 90 µg/kg body weight
- Acute developmental RfD 60 µg/kg body weight
- Subchronic RfD 70 µg/kg body weight - day

US EPA

- Acute RfD 140 µg/kg body weight
- Incidental and intermediate term (1 day – 6 months) RfD 100 µg/kg body weight - day

A comparison of the acute and subchronic high-end dose estimates of the three resident groups calculated above with the corresponding acute and subchronic (or intermediate) RfDs developed by DPR and US EPA shows that exposure to imidacloprid residues in home grown citrus fruit from trees treated in the ACP program is not likely to pose a health hazard to residents.

Evaluation of the citrus leaf consumption pathway

As noted above, imidacloprid residues have been detected in citrus leaves following soil application of imidacloprid (Tattar et al., 1998; Setamou et al., 2010). Imidacloprid exposure via consumption of food and beverages made from the contaminated leaves could occur. Only acute exposure is considered for this consumption pathway. Model variate values in an acute exposure calculation are often higher than those in a subchronic exposure calculation. Furthermore, it is unlikely that an individual would consume citrus leaves on a daily basis for an extended period of time. For these reasons, subchronic exposure dose to citrus leaf consumption is not estimated in this assessment.

CDFA collected leaf samples from ACP-treated citrus trees in 2010. The imidacloprid citrus leaf residue data were shared with OEHHA (A. Arcus-Arth, OEHHA: personal communication with F. Byrne, University of California, Riverside, April 2011). The leaf residue data set has a total of 237 samples with mean, 95th-percentile, and maximum values of 2.0, 6.1, and 7.7 ppm (µg/g), respectively. For this screening-level evaluation, the maximum leaf residue level is used in the estimation of acute exposure ($C_{A\text{-}Leaf}$).

In order to estimate leaf CR for acute exposures ($CR_{A\text{-}Leaf}$), online recipes were searched for food dishes that use citrus leaf as an ingredient. Though it is not common, citrus leaves are used in food and beverages, particularly by certain ethnic and cultural groups. Among the recipes, Thai fish cake (also known as Tod Mun) seems to use the highest number of citrus leaves per serving (approximately one leaf per serving, which is equivalent to one leaf per 110 grams or ¼ pound of fish cake).

Very young children (toddlers) generally have higher food consumption rates on a body weight basis than older children and adults so this age group is often used in risk assessment to represent a highly exposed subpopulation. However, since children this young tend to consume bland or sweet food items, they are less likely to consume spicy, tangy foods such as Thai fish cakes. The 6-10 year old age group is chosen as an age group likely to consume Thai fish cakes at high consumption rates. The dose on a body weight basis of this group is expected to be higher than that of other age groups (e.g., teenagers and adults).

It is assumed that a child 6-10 years of age with an average body weight of 32 kg (US EPA, 2011a) could consume as much as two servings of fish cakes (about ¼ pound each) in one day. Assuming a citrus leaf weighs approximately 0.55 grams (Martin et al., 1966), $CR_{A\text{-}Leaf}$ can be calculated as follows:

$CR_{A\text{-}Leaf}$ = [(2 servings x 0.55 g/serving)/32 kg]
= 0.034 g of leaves/kg body weight

Since, in one day, all consumed citrus leaves can be home grown, $L_{A\text{-}Leaf}$ is assumed to be 1.0 (equivalent to 100 percent).

Using Equation 1, the maximal leaf imidacloprid level, and assumptions described above, a high-end acute oral dose of 0.26 µg/kg is estimated for a 6-10 year old child:

$Dose_{A\text{-}Leaf}$ = $C_{A\text{-}Leaf}$ x $CR_{A\text{-}Leaf}$ x $L_{A\text{-}Leaf}$
= 7.7 µg/g x 0.034 g/kg x 1.0
= 0.26 µg/kg body weight

As calculated above, a high-end dose estimate of 11.5 µg/kg body weight is determined for an acute exposure by a young child (1-2 years old) consuming fruit. This dose from fruit is roughly 44 times higher than the estimated acute dose for citrus leaf consumption (0.26 µg/kg body weight). This comparison shows that the citrus leaf consumption pathway is a minor exposure pathway and would not make a significant contribution to the overall dose.

Evaluation of the citrus flower consumption pathway

Citrus flowers are sometimes used in foods, such as salads, and for making beverages or jams. To evaluate the significance of the citrus flower consumption pathway, similar to citrus leaf consumption, an acute exposure assessment is conducted to provide a screening level dose. There are no flower residue data specific to the ACP program. However, flower residue levels from soil application to citrus trees are available in the open literature with a high-end value of 90 ng imidacloprid/ml nectar (Byrnes, 2014).

This estimate of imidacloprid residue in citrus flowers is used in this screening-level evaluation.

It is further assumed that there is 22.8 µl of nectar in a citrus flower (Albrigo et al., 2012) and a citrus flower weighs 0.5 g (Castillo et al., 1991). The concentration of imidacloprid in citrus flowers is calculated as:

$$C_{A\text{-flower}} = 90 \text{ ng/ml} \times 22.8 \text{ µl/flower} \times \text{flower}/0.5 \text{ g} \times \text{ml}/1000\text{µl}$$
$$= 4.1 \text{ ng imidacloprid/g flower}$$

As a rough estimate of flower consumption rates, two online recipes for orange blossom jam provide information from which 37 and 42 grams of orange flower consumption are derived (Helou, 2013; and Masoudansari, 2014). These rates are for adults; no data on citrus flower consumption rates for children were found. The adult consumption rate of 42 grams of citrus flowers consumed in one day are normalized by the mean adult (16<70 years of age) body weight of 80 kg (OEHHA, 2012) to derive 0.525 g flowers/kg body weight - day.

Dose is derived as:

$$\text{Dose}_{A\text{-flower}} = C_{A\text{-flower}} \times CR_{A\text{-flower}} \times L_{A\text{-flower}}$$
$$= 4.2 \text{ ng/g flower} \times 0.525 \text{ g flowers/kg body weight - day} \times 1.0$$
$$= 2.21 \text{ ng/kg body weight - day}$$

The calculated $\text{Dose}_{A\text{-flower}}$ is much lower than the dose from acute citrus fruit consumption. This exposure pathway is considered minor and not likely to contribute significantly to overall dose.

Uncertainties

A number of uncertainties have been identified in this evaluation and they are discussed below:

1. The sample size of the imidacloprid levels in citrus fruit dataset is relatively small (44 samples) and many samples (over 60%) are below detection limits. This might lead to an over-estimate or under-estimate of true imidacloprid levels in citrus fruit.

2. Most of the samples with detectable levels are from lemon trees; only four orange samples have detectable levels. Also, the four highest contaminant levels (0.08 ppm - 0.226 ppm) are found in lemons. By contrast, the highest contaminant level found in the orange samples is 0.03 ppm. In order to reduce the uncertainty associated with small sample sizes, the orange and lemon samples are combined in this assessment. By doing so, it is assumed that the absorption, distribution,

metabolism, and accumulation of imidacloprid in lemon and orange trees are similar. Consumption rate of oranges is generally higher than that of lemons. If this assumption is not correct, calculated imidacloprid doses may not be accurate.

3. The imidacloprid residue levels reported by DPR are based on the whole fruit. Studies have shown that imidacloprid applied to soil may distribute itself differently in peel and pulp. This assessment assumes imidacloprid is uniformly distributed throughout the fruit. This assumption may lead to over- or under-estimation of exposure.

Conclusion

OEHHA considered potential exposure to imidacloprid following soil application by CDFA for residential control of ACP and found that consumption of citrus fruit is the only significant pathway. This pathway is quantitatively evaluated using citrus fruit residue data provided by DPR that is specific to the ACP treatment. The results show that imidacloprid doses associated with this pathway are relatively low and are not likely to pose a health hazard to residents whose yards are treated by CDFA for ACP.

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Appendix A

Effects on imidacloprid levels of fruit processing, freezing, and storage

Several studies have shown that freezing, cooking, processing, and other storage methods have only slight effects on imidacloprid levels in citrus fruit. Some of the studies are discussed below:

A hydrolysis study was conducted to determine the effects of processing on imidacloprid residues. Radioactively labeled imidacloprid was subjected to 90-120 °C for 20-120 minutes at pH levels of 4-6. The results showed that imidacloprid was stable after simulated pasteurization, baking/boiling and sterilization. The Joint Meeting on Pesticide Residues (FAO/WHO, 2002) concluded that "considering the hydrolytic stability under the conditions tested, it is not expected that hydrolysis will contribute to the degradation of imidacloprid or affect the nature of imidacloprid residues during processing."

Freezer stability studies on imidacloprid and its metabolites were conducted on whole lemons fortified with approximately 1 mg/kg imidacloprid and stored at an average of -19.2°C for various periods of time. Residues of imidacloprid and its metabolites ranged from 91-96% of initial radiolabeling for up to two years (FAO/WHO, 2002). Though our concern is for residues in citrus, this study supports the potential for exposure to imidacloprid over subchronic periods from stored produce treated with imidacloprid.

There is a study which investigated the effects of processing of citrus fruit into edible products on imidacloprid levels (reported in FAO/WHO, 2002). Raw citrus fruit with residue levels of 0.12, 0.20, and 0.19 mg/kg for oranges and 0.26 mg/kg for lemons were processed into juice, marmalade, and dried pulp. The juice and dried pulp were both processed using commercial methods and the results are not applicable to this assessment regarding home grown citrus. For marmalade, the study attempted to simulate "typical household production" of orange marmalade. This involved slicing the peel into small strips and combining it with the pulp in a ratio of one part pulp to 0.8 parts peel. The peel/pulp mixture was combined with sugar and a gelling agent and cooked for 5 minutes. A processing factor was then calculated by dividing the mg/kg residue in the processed product by the mg/kg residue in the raw whole fruit. The processing factor incorporates changes in residue levels from dilution or dehydration as well as effects from heating, freezing, chemical reactions, etc. The processing factor for marmalade is 0.625, which is interpreted as the final product having approximately 62.5% of the original raw whole fruit. This suggests that imidacloprid levels were still fairly high even after dilution from the addition of other ingredients and following "cooking" for five minutes (no specific temperature given but candies tend to "cook" at temperatures of 210-250°F).

A study was conducted to evaluate the stability of imidacloprid in frozen citrus. Whole lemons were fortified with ^{14}C-labelled imidacloprid and associated metabolites at 6.414 ppm and stored in a freezer at an average of -19.2°C (range -4.7° to -23.9° C). At 0, 3, 6, 9, and 12 months, the percent remaining of total residue was 92, 93, 95, 96, and 91 percent, respectively (Morishima, 1992a,b;1994, as cited in FAO/WHO, 2002). The result shows imidacloprid levels are essentially the same at month 0 as at month 12. A similar study was conducted with oranges which were fortified with both imidacloprid and four metabolites and then frozen. Samples were analyzed several times from 0-21 months post-fortification. Recovery rates ranged from 84-128% after analytic corrections (FAO/WHO, 2002). Imidacloprid appears to be relatively stable during frozen storage, with possible slight reductions in levels.

Appendix B

Imidacloprid levels in fruit from ACP treated citrus trees

This appendix describes the type and number of citrus fruit samples collected and analyzed by DPR (2011) as part of the environmental monitoring of the ACP treatment program. Certain characteristics of the samples and approach used in the data evaluation are also discussed.

Fruit from lemon and orange trees treated for ACP at 31 residential sites in Southern California were sampled between 2009 and 2010. There were a total of 53 samples. Each samples was labeled as "background", "0 weeks after treatment" or at specified times post-application.

All the "0 weeks after treatment" samples were below detection limits. Because it takes time for imidacloprid in soil to be taken up by the treated tree and distributed to the fruit, it is unlikely that a significant amount of imidacloprid would have reached the fruit in less than one week. For the purpose of this assessment, the "0 weeks after treatment" samples are considered as background samples.

The sampling program only collected mature fruit, and each analytical sample was a composite of several fruit from a single tree or from the same type of tree (i.e., either orange or lemon) at one residential site. The analyses were conducted on the whole fruit (i.e., rind, juice, pulp, albedo). Table B1, below, summarizes sample sizes of the collected citrus fruit.

Table B1. Sample Sizes of Fruit Collected from ACP Treated Trees

Treatment period	Lemon	Orange	Total (lemon + orange)
Pre-treatment	1	3	4
"0 wks after treatment"	3	2	5
Total background	**4**	**5**	**9**
Total post-application	**27**	**17**	**44**
Total	**31**	**22**	**53**

*Data from DPR, 2011 (memo)

The raw data of post-application samples from ACP treated trees is presented in Table B2.

Table B2. Post-Application Imidacloprid Residues in ACP Treated Tree Fruit

Post-Application Interval (weeks)	Reside level (ppm)	Reporting limit (ppm)	Citrus Type
1	ND	0.01	Lemon
3	ND	0.01	Lemon
3	ND	0.01	Orange
3	ND	0.01	Orange
5	ND	0.05	Lemon
6	ND	0.01	Lemon
6	ND	0.01	Orange
6	ND	0.01	Orange
10	ND	0.01	Lemon
13	ND	0.02	Orange
13	ND	0.02	Orange
15	0.013	0.01	Lemon
15	0.025	0.01	Lemon
15	ND	0.01	Orange
16	0.02	0.02	Lemon
16	ND	0.02	Lemon
16	ND	0.02	Orange
19	ND	0.01	Orange
21	ND	0.02	Lemon
24	0.09	0.02	Lemon
28	0.11	0.02	Lemon
28	ND	0.02	Lemon
29	0.226	0.01	Lemon
30	0.03	0.02	Orange
35	0.022	0.01	Orange
42	0.012	0.01	Orange
42	0.015	0.01	Orange
42	ND	0.01	Lemon
46	0.015	0.01	Lemon
46	0.024	0.01	Lemon
50	ND	0.01	Lemon
53	0.08	0.01	Lemon
72	0.02	0.02	Lemon
81	ND	0.01	Lemon
88	ND	0.01	Orange
89	ND	0.05	Lemon
89	ND	0.02	Lemon
93	ND	0.02	Lemon
94	0.01	0.01	Lemon
95	ND	0.01	Orange
95	ND	0.01	Orange
95	ND	0.01	Orange
98	ND	0.01	Lemon
98	ND	0.01	Lemon

*A sample was considered non-detectable (ND) if the level was below the appropriate reporting limit (RL).

When analyzing for chemicals, laboratories establish detection limits (DLs) for each analytical method and targeted compound. There can be several DL values for one chemical if more than one method has been developed for that chemical's analysis.

The DL is the lowest concentration of the substance that can be differentiated from a blank sample with 99% confidence, assuming the absence of interference from substances other than the analyte in the sample (CDPH, 2005; Corl, 2002). To help interpret the analytical results, a reporting limit (RL) is defined for each method for each chemical. The RL can be defined as the lowest concentration of the substance that has been corrected for deviations from the DL (e.g., adjustments for sample dilution, weight and moisture) (Corl, 2002). The RL is always greater in value than its corresponding DL.

The imidacloprid residues from the ACP treated tree fruit were analyzed by multiple laboratory groups, which resulted in multiple RLs. The RLs were 0.01, 0.02 and 0.05 ppm. If the level was below the RL the residues were classified as non-detectable (ND), while levels above the RL were reported as the quantified value obtained from the analysis. All methods analyzed samples for imidacloprid alone; imidacloprid metabolites were not measured (DPR, 2011).

All background samples of imidacloprid residues (including "0 weeks after treatment") were reported as ND. Of the post-treatment sample residues, 29 (66%) were ND and 15 (34%) had quantified levels (see Table B3, below). Hereafter, citrus fruit residues refer to the post-application samples only.

Table B3. Summary of Post-Application Samples

	Lemon	Orange	Total
Non-detects	16 (59%)	13 (76%)	29 (66%)
Above reporting limit	11 (41%)	4 (24%)	15 (34%)
Total	**27**	**17**	**44**

*Data from DPR, 2011

The true numerical value of a result classified as ND is either equal to zero, equal to the RL, or equal to some unidentifiable value between zero and the RL. Because the exact numerical value of a ND is unknown, it cannot be included in a statistical analysis in the same way that quantified values can. Several approaches have been developed for including NDs in statistical analyses. These approaches have been incorporated into software developed by the US EPA (2011b) (ProUCL 4.1: Statistical Software for Environmental Applications for Data Sets with and without Nondetect Observations). The analyst must select the approaches in ProUCL 4.1 which are the most appropriate for their data in order to obtain the most reliable results with the least error. ProUCL 4.1 is used to analyze the imidacloprid residue data reported by DPR.

The imidacloprid fruit residue data do not fit the normal, lognormal or gamma distributions based on goodness-of-fit tests run in ProUCL 4.1 (with an alpha value of 0.05). The data are highly skewed to the right based on visual inspection, and the dataset has a skewness value of 2.352.

Therefore, an approach which does not assume a distributional fit (i.e., nonparametric approach) was used to incorporate the NDs in the statistical analysis. Kaplan Meier estimates using the Chebyshev inequality were used to analyze the data as it can be used on datasets that have multiple cutoff values, as is the case for the imidacloprid residue dataset. Results of the Kaplan-Meier (Chebyshev) analysis are provided in Table B4, below.

Table B4. Imidacloprid Residues from ACP Treated Tree Fruit (ppm)

Summary Statistic	Imidacloprid level
Max	0.226
Mean	0.023
Standard Deviation (SD)	0.038
Standard Error of the Mean (SEM)	0.006
90th percentile	0.071
95th percentile	0.085

*analyzed using Kaplan Meier methodology in ProUCL 4.1
**data from DPR, 2011 (memo)

For long term exposures, it is likely that over time a person would be exposed to both low and high level residues. Therefore, for long term exposures of imidacloprid from citrus fruit, the mean residue level is used in the evaluation.