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STONE ENVIRONMENTAL

REFINED EFFECTS DETERMINATION FOR DELTA SMELT POTENTIALLY EXPOSED TO MALATHION

FINAL REPORT

Prepared by: Roger L. Breton[1], Gillian E. Manning[1], Yvonne H. Clemow[1], Sara I. Rodney[1], Dwayne R.J. Moore[2], Colleen D. Greer[2], John P. Hanzas[3], Michael F. Winchell[3], Tammy L. Estes[3], Brent Toth[3], Katherine Budreski[3], and Lauren Padilla[3]

[1]Intrinsik Environmental Sciences, Inc.
1125 Colonel By Dr., CTTC – Suite 3600, Ottawa, ON,
Canada K1S 5R1

[2]Intrinsik Environmental Sciences (US), Inc.
41 Campus Dr., Suite 202, New Gloucester, ME,
USA 04260

[3]Stone Environmental Inc.,
535 Stone Cutters Way, Montpelier, VT
USA 05602

Prepared for: Cheminova (EPA Company No.: 4787),
1600 Wilson Boulevard, Suite 700, Arlington, VA
USA 22209

Date: June 10, 2016

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[Signature]: Paul Whatling

Paul Whatling
Senior Registration Manager
FMC Corporation
EPA Agent for Cheminova A/S

June 10, 2016

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Author and Title	Company	Signature	Date
Roger L. Breton Senior Scientist and Project Manager	Intrinsik Environmental Sciences, Inc.		June 10, 2016
Gillian E. Manning Risk Analyst II	Intrinsik Environmental Sciences, Inc.		June 10, 2016
Yvonne H. Clemow Risk Analyst II	Intrinsik Environmental Sciences, Inc.		June 10, 2016
Sara I. Rodney Scientist	Intrinsik Environmental Sciences, Inc.		June 10, 2016
Dr. Dwayne R.J. Moore, Vice President and Senior Scientist	Intrinsik Environmental Sciences (US), Inc.		June 10, 2016
Colleen D. Greer Risk Analyst II	Intrinsik Environmental Sciences (US), Inc.		June 10, 2016
John P. Hanzas Senior Geoscientist	Stone Environmental, Inc.		June 10, 2016
Michael F. Winchell Senior Environmental Modeler / GIS Specialist	Stone Environmental, Inc.		June 10, 2016
Tammy L. Estes Senior Research Scientist	Stone Environmental, Inc.		June 10, 2016
Brent Toth	Stone Environmental, Inc.		June 10, 2016
Katherine Budreski Senior GIS Specialist	Stone Environmental, Inc.		June 10, 2016
Lauren Padilla Senior Environmental Modeler	Stone Environmental, Inc.		June 10, 2016

Sponsor/Submitter and Title	Signature	Date
Paul Whatling Senior Registration Manager, FMC Corporation, EPA Agent for Cheminova A/S.		June 10, 2016

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Refined Effects Determination for Delta Smelt Potentially Exposed to Malathion

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EXECUTIVE SUMMARY

The delta smelt (DS; *Hypomesus transpacificus*) is an annual fish endemic to the Sacramento-San Joaquin Estuary. DS are federally listed species. That is, they are considered imperiled, and as such are subject to protection under the *Endangered Species Act* (ESA). The species was listed as threatened on March 5, 1993 by the United States Fish and Wildlife Service (FWS, 2012).

Under the Federal Insecticide, Fungicide and Rodenticide Act, the United States Environmental Protection Agency (EPA) registers pesticides for use in the United States (US). Registration of a pesticide is the authorization of an "action" under section 7(a)(2) of the ESA. As such, EPA is required to ensure that pesticide registrations are unlikely to jeopardize threatened and endangered species or the critical habitat on which they depend.

In 2010, EPA issued their malathion effects determinations for DS and all three distinct population segments (DPSs) of the California tiger salamander (CTS) in a document entitled: Risks of Malathion Use to the Federally Threatened Delta Smelt (*Hypomesus transpacificus*) and California Tiger Salamander (*Ambystoma californiense*), Central California Distinct Population Segment, and the Federally Endangered California Tiger Salamander, Santa Barbara County and Sonoma County Distinct Population Segments (EPA, 2010a). EPA's effects determinations for the DS and CTS and subsequent request for consultation with the FWS were made pursuant to the October 20, 2006 Settlement Agreement in Center for Biological Diversity (Center for Biological Diversity vs. EPA et al., Case No. 072794-JCS). Based on their assessment, EPA made a Likely to Adversely Affect (LAA) determination for the DS and for all three DPSs of the CTS (CTS-CC, CTS-SB, and CTS-SC). Additionally, the Agency concluded that malathion may modify the designated critical habitat of these species. Cheminova provided EPA with comments on their DS and CTS effects determinations (Teed et al., 2015 [MRID 49692201]). Our major concerns are listed below:

- **EPA inappropriately relied on conclusions from outdated risk assessments in their DS and CTS effects determinations.** EPA's previous risk assessments were conducted prior to issuance of the final Re-registration Eligibility Decision (RED) for malathion (EPA, 2009a), and are therefore not consistent with the changes in use patterns or other restrictions that have been imposed as a result of that RED.
- **EPA did not consider all available toxicity data.** The list of ecotoxicology studies used in conducting EPA's effects determination was incomplete as many of the studies submitted by Cheminova in the last decade are not included.
- **EPA did not explain how effects metrics were selected.** Rationale was not provided for the selection of the effects metrics used in EPA's DS and CTS effects determination. Cheminova noted a lack of transparency in the classification and selection of toxicity data used, as well as questionable derivations of acute-to-chronic ratios (ACR).
- **EPA assessed incorrect use patterns.** We noted many discrepancies between the use patterns listed by EPA in their effects determination and those supported by Cheminova.

- **EPA inappropriately considered risk of malaoxon.** Cheminova strongly believes that it is unnecessary to assess the oxon metabolite of malathion, malaoxon, for reasons provided in Cheminova's comments on EPA's DS and CTS effects determinations (Teed et al., 2015 [MRID 49692201]) and presented again in Appendix B.
- **EPA did not estimate risk in their DS and CTS effects determinations.** In their effects determination, EPA (2010a) compared RQs to their LOCs to determine whether there is potential for risk to DS or CTS through either direct or indirect effects. NAS (2013) advised against the use of RQs and uncertainty factors in risk assessments for listed species. The RQ approach used by EPA does not estimate risk, but instead uses conservative assumptions, including the use of uncertainty factors, or stringent and possibly implausible exposure scenarios, to avoid making a type II error (i.e., concluding that a pesticide is unlikely to cause effects when it does yield such effects; NAS, 2013). Risk is the product of the probability of an adverse effect and its magnitude. If an exposure scenario is predicted to potentially cause a risk to biota in a screening-level ecological risk assessment (SLERA), based on a risk quotient exceeding a level of concern (LOC) as carried out at the time by EPA, then refined risk assessments are needed to appropriately characterize risk. Refined assessments should estimate the probability of effects of different magnitudes using concentration-response curves and probabilistic exposure modeling (Suter, 1993; EPA, 2004a; NAS, 2013).

Due to inconsistencies in their risk assessment approaches, the EPA, FWS, National Marine Fisheries Service (NMFS) and US Department of Agriculture (USDA) invited the National Academy of Sciences (NAS) to examine a number of scientific and technical issues related to assessing risk of species listed under the ESA to pesticides registered under FIFRA. In 2013, NAS published the report entitled "Assessing Risks to Endangered and Threatened Species from Pesticides" (NAS, 2013). This report provides a common approach that EPA, FWS and NMFS can use to conduct risk assessments and also provides guidance on a number of important topics, including use of best available data, exposure and effects modeling, consideration of chemical mixtures, uncertainty analysis and propagation, and risk characterization methods.

After the release of the NAS panel report (NAS, 2013), the EPA, FWS, NMFS and USDA adopted the Interagency "Interim Approaches for National-Level Pesticide Endangered Species Assessment" (Agencies, 2013) (hereafter referred to as the "Interagency Interim Approaches") for conducting endangered species assessments for pesticides. The Interagency Interim Approaches consist of three steps: (1) a conservative analysis to determine which listed species could be exposed, (2) refined analyses to determine risks to individuals, and (3) population modeling to determine if species are in "jeopardy" from pesticide use (Agencies, 2013). Currently, the three-step interim approach is being applied to two "beta" cases: one involving three organophosphate insecticides (chlorpyrifos, diazinon, and malathion), and one involving two carbamate insecticides (carbaryl and methomyl). The experience with these beta cases will then be used to modify the interim approach, as appropriate. In light of the current interagency approach and the need for improved risk estimation, Cheminova requested that Intrinsik undertake a revised effects determination focusing on direct and indirect effects to DS. This

effects determination follows a structure similar to that used for previous EPA effects determinations (EPA, 2007; 2010a) but employs the new Step 1 and Step 2 effects metrics presented in the Interagency Interim Approaches (Agencies, 2013). The revised effects determination follows a tiered approach and includes a screening-level and a refined assessment with a weight-of-evidence risk characterization.

To ensure the best available data were used, as required by the ESA, Cheminova developed study evaluation criteria for aquatic species (Breton et al., 2014 [MRID 49333901]; Breton et al. 2015 [MRID 49692301]) that were applied uniformly, in a transparent manner to GLP studies conducted using standard guidelines, open-literature studies and other reports. These criteria give precedence to the relevance of the test substance, among other important considerations. When these criteria are applied, most of the studies relied upon by EPA to derive its proposed effects metrics are found to be unacceptable. In fact, these studies would also be found unacceptable if EPA's own data quality guidance for peer reviewed literature (EPA, 2011) were applied.

In the aquatic screening-level effects determination, estimated environmental concentrations (EECs) in EPA's standard pond scenario were predicted using the Pesticide Root Zone Model/Exposure Analysis Modeling System (PRZM/EXAMS) and Pesticides in Flooded Applications Model (PFAM), both of which are very conservative. Conservative effects metrics prescribed by the Interagency Interim Approaches for endangered species assessments (Agencies, 2013) were also applied (Table 1).

Table E-1 Prescribed endpoints as per the Interagency Interim Approaches (Agencies, 2013)

Taxon	*Mortality*		*Sublethal Effects*	
	Direct Effects	*Indirect Effects*	*Direct Effects*	*Indirect Effects*
Fish	Concentration that would result in a 1 in a million chance of causing mortality to an individual[a]	Concentration that would result in a 10% decrease of individuals[a]	The lowest available NOEC or other scientifically defensible effect threshold (ECx)[b]	Lowest available LOEC for growth or reproduction
Aquatic Invertebrates				

[a] Calculated using the HC5 of an SSD of LC50/EC50 values and a representative slope. If an SSD cannot be derived, the most sensitive LC50 or EC50 is used.

[b] Endpoints will generally be a) from *in vivo* studies that are conducted with whole organisms and b) linked to environmentally relevant exposures.

The results of the screening-level risk characterization suggest that there is the potential for acute risk to DS and for acute and chronic risk to the aquatic invertebrate prey of DS. Although chronic RQs for DS were greater than one for malathion use on rice, wildrice and watercress, it is not expected that these uses will result in unacceptable risk to DS for several reasons:

- rice and watercress account for minor portions of malathion applied in California (0.418% and 0.0807% by weight, and 0.502% and 0.115% by area, respectively);
- the PFAM model incorporates a number of conservative assumptions (farm pond placed next to a rice or watercress paddy without any buffer, weir level set equal to fill level, use at the maximum application rates and minimum application intervals);

- actual water concentrations measured immediately after malathion applications to flooded rice fields were up to 35 times lower than concentrations estimated using the PFAM model (Judy et al., 1991a,b [MRID 42058401, 42058402]);
- amphipod survival was affected in small watercress beds applied with malathion, but not in large beds or in settling pools (Crane et al., 1995); and
- spatial analyses suggest that DS critical habitat rarely coincides with California rice paddies or watercress operations.

A refined probabilistic exposure analysis was conducted for flowing water bodies to assess risk of DS and their aquatic invertebrate prey to malathion. The Soil and Water Assessment Tool (SWAT) was used to predict aquatic EECs in the water bodies within DS critical habitat. The application of the SWAT model considered all uses of malathion within the watershed draining into the California Delta, including the Sacramento and San Joaquin drainages. Dose-response curves and species sensitivity distributions were used as the effects metrics for DS and aquatic invertebrates, respectively. The EEC distributions obtained from SWAT modeling were integrated with the aquatic invertebrate SSD to derive risk curves, which indicate the probability of exceeding effects of differing magnitude. Other lines of evidence, including aquatic field studies, mesocosm studies, surface water monitoring data, and incident reports, were also considered in the weight-of-evidence risk characterization.

In the refined effects determination, acute risk to DS was categorized as *de minimis* for the ten worst-case reaches of the DS SWAT model. Acute and chronic risk to aquatic invertebrate communities was categorized as *de minimis* to low for all but one of the worst-case SWAT scenarios (reach 209), where chronic risk was categorized as intermediate. However, the chronic AUC for this reach (10.7%) just barely exceeded the low-intermediate risk boundary of 9.82%. Furthermore, there is little overlap between this reach and DS critical habitat. Chronic effects of malathion to aquatic species are highly unlikely because malathion degrades almost instantly in aquatic environments, particularly in marine environments. Several aquatic studies have had difficulty maintaining chronic exposures of malathion (Claude et al., 2012 [MRID 48752901]; Palmer et al., 2011a,b [MRID 48617501, 48617506]; Rhodes and Leak, 1997). Estimated half-lives for malathion in GLP studies testing aerobic aquatic systems range from 0.3 to 3.3 days (Blumhorst, 1991a [MRID 42271601]; Knoch, 2001 [MRID 46769502]; Hiler and Mannella, 2012 [MRID 48906401]). The use of extended malathion exposures over several weeks to months in chronic toxicity tests is, therefore, inconsistent with exposure in the environment. Exposures are expected to peak with applications, and quickly dissipate in the environment within a matter of days. In a worst-case scenario, receptors may be exposed to pulse exposures when multiple applications are allowed during the growing season. But even under these conditions, receptors can metabolize and recover from malathion exposures. In addition, the results of field, mesocosm and monitoring studies indicate that malathion is unlikely to affect DS or their aquatic invertebrate prey. Five field studies evaluated the effects of malathion applied at rates ranging from 0.051 to 1 lb/A on aquatic ecosystems (Giles, 1970 [MRID 00058820]; Jensen et al., 1999; Tagatz et al., 1974; Kuhajda et al., 1996 [MRID 47587601]; Crane et al., 1995) but did not observe any persistent effects on the abundance and survival of fish or aquatic invertebrate communities. In mesocosm studies, effects on cladoceran

abundance were observed following acute exposures ≥5.8 µg/L (Ebke, 2002 [MRID 46525901]; Relyea, 2005, 2009 [MRID 48261129]; Hua and Relyea, 2012, 2014; Halstead et al., 2014; Brogan and Relyea, 2015; Shrestha et al., 1987) and repeated pulse exposures ≥3.1 µg/L (Groner and Relyea, 2011). However, populations recovered from acute exposures of up to 40 µg/L within seven weeks (Hua and Relyea, 2014). Furthermore, several other invertebrate taxa consumed by DS (i.e., copepods, amphipods, and insects) were far less sensitive than cladocerans and abundance was only affected at exposures ≥40 µg/L (Relyea, 2005; Hua and Relyea, 2014; Shrestha et al., 1987). Maximum peak concentrations modeled in SWAT were below 30 µg/L for all but one reach (203), and measured malathion concentrations in California surface water samples collected between 2001 and 2015 were also below 30 µg/L. In addition, a surface water monitoring study targeted to the areas and times at which early life stages of DS are observed did not detect malathion (LOD = 0.015 and 0.017 µg/L) in any samples collected between 1998 and 2000 (Kuivila and Moon, 2004).

Considering all lines of evidence, malathion use under the current label is not expected to cause direct effects to DS. Furthermore, malathion uses would rarely be associated with acute and chronic effects to the aquatic invertebrate prey of DS, and in the instances where adverse effects are observed, recovery is expected to occur once exposures have ceased.

Refined Effects Determination for Delta Smelt Potentially Exposed to Malathion

1.0 INTRODUCTION

The delta smelt (*Hypomesus transpacificus*; hereafter referred to as DS) is an annual fish endemic to the Sacramento-San Joaquin Estuary (Miller et al., 2012). DS are federally listed species. That is, they are considered imperiled, and as such are subject to protection under the *Endangered Species Act* (ESA). The species was listed as threatened on March 5, 1993 by the United States Fish and Wildlife Service (FWS, 2012).

Under the *Federal Insecticide, Fungicide and Rodenticide Act*, the United States Environmental Protection Agency (EPA) registers pesticides for use in the United States (US). Registration of a pesticide is the authorization of an "action" under section 7(a)(2) of the ESA. As such, EPA is required to ensure that pesticide registrations are unlikely to jeopardize threatened and endangered species or the critical habitat on which they depend.

In 2010, EPA issued their malathion effects determinations for DS and all three distinct population segments (DPSs) of the California tiger salamander (CTS) in a document entitled: Risks of Malathion Use to the Federally Threatened Delta Smelt (*Hypomesus transpacificus*) and California Tiger Salamander (*Ambystoma californiense*), Central California Distinct Population Segment, and the Federally Endangered California Tiger Salamander, Santa Barbara County and Sonoma County Distinct Population Segments (EPA, 2010a). EPA's effects determinations for the DS and CTS and subsequent request for consultation with the FWS were made pursuant to the October 20, 2006 Settlement Agreement in Center for Biological Diversity (Center for Biological Diversity vs. EPA et al., Case No. 072794-JCS). Based on their assessment, EPA made a Likely to Adversely Affect (LAA) determination for the DS and for all three DPSs of the CTS (CTS-CC, CTS-SB, and CTS-SC). Additionally, the Agency concluded that malathion may modify the designated critical habitat of these species.

Cheminova A/S (hereafter referred to as "Cheminova") is the sole manufacturer and primary registrant in the United States for the technical form of malathion (CAS Registry Number 121-75-5). All other registrants of technical malathion obtain their material from Cheminova and all end-use products registered in the United States are produced from Cheminova's technical malathion. For purposes of the consultation process for malathion under Section 7 of the ESA, Cheminova is considered an "applicant" entitled to fully participate in the consultation process. In 2015, Cheminova A/S and Cheminova, Inc., were acquired by FMC Corporation ("FMC"). Cheminova Inc.'s end-use product registrations are in the process of being transferred to FMC. The registrations currently held by Cheminova A/S will be transferred to FMC in the near future. When these transfers are accomplished, FMC will supplant Cheminova as the "applicant".

Due to inconsistencies in their risk assessment approaches, the EPA, FWS, National Marine Fisheries Service (NMFS) and US Department of Agriculture (USDA), collectively referred to as the Agencies, recently invited the National Academy of Sciences (NAS) to examine a number of

scientific and technical issues related to assessing risk of species listed under the ESA to pesticides registered under FIFRA. In 2013, NAS published the report entitled "Assessing Risks to Endangered and Threatened Species from Pesticides" (NAS, 2013). This report provides a common approach that EPA, FWS and NMFS can use to conduct risk assessments and also includes discussion on a number of scientific issues, including use of best available data, exposure and effects modeling, consideration of chemical mixtures, uncertainty analysis and propagation, and risk characterization methods. Cheminova agrees with many of the NAS (2013) recommendations and generally believes that they should be implemented in the effects determinations where appropriate.

Cheminova has a number of concerns with regard to EPA's malathion effects determinations for DS and CTS (EPA, 2010a), which were discussed in detail in Teed et al. (2015 [MRID 49692201]). These concerns focus mainly on incorrect use patterns, use of conclusions from previous assessments that are now outdated, inappropriate selection of effect metrics, inappropriate consideration of malathion degradates, flaws in exposure modeling, and the identification of data gaps. Moreover, EPA's DS and CTS EDs need revision in light of the Interagency Interim Approaches (Agencies, 2013) being proposed by the Agencies in response to the NAS (2013) recommendations. The Interagency Interim Approaches are currently being applied to two "beta" cases, one involving three organophosphate insecticides (chlorpyrifos, diazinon and malathion), and one involving two carbamate insecticides (carbaryl and methomyl). The experience with these beta cases will then be used to modify the Interagency Interim Approaches, as appropriate.

In response to the concerns outlined in Cheminova's response document Teed et al. (2015 [MRID 49692201]), changes to the ESA assessment process, and availability of many new studies for malathion, Cheminova has developed a revised effects determination (ED) for DS that follows a structure similar to that used for previous EPA effects determinations (EPA, 2007; 2010a) but employs the approach to developing Step 1 and Step 2 effects metrics presented in the Interagency Interim Approaches (Agencies, 2013). This revised effects determination makes use of the best available data for malathion (Breton et al., 2014 [MRID 49333901]; 2015 [MRID 49692301]). The report is organized into six major sections, not including appendices: Introduction (Section 1.0), Problem Formulation (Section 2.0), Screening-Level Effects Determination (Section 3.0), Refined Effects Determination (Section 4.0), Final Conclusion of the DS Effects Determination (Section 5.0), and References (Section 6.0). The effects determination for CTS is presented in a separate document (Breton et al., 2016).

2.0 PROBLEM FORMULATION

The objective of this problem formulation is to review information on the properties of malathion and the biology of DS to: 1) identify exposure scenarios that will be assessed, and 2) develop an analysis plan outlining the assessment approach for evaluating potential risk to DS. The problem formulation includes descriptions of DS distribution, habitat and life history, malathion use patterns, physical and chemical properties, environmental fate and transport, routes of exposure, mode of action and ecological effects. This information will be used to generate a conceptual model, determine the measures of exposure and effects, and develop an analysis plan for this effects determination.

2.1 Delta Smelt (*Hypomesus transpacificus*)

DS are slender-bodied bony fishes that generally reach a standard length (tip of snout to origin of caudal fin) of 60 to 70 mm (2.4 to 2.8 inches; FWS, 1995; see Figure 2-1), although they may reach lengths of up to 120 mm (FWS, 2010). This species is different from other smelts in the genus *Hypomesus* because it is confined to a limited geographical area and larvae are pelagic (Bennett, 2005). Also, DS have relatively low fecundity and most individuals only live for one year (Bennett, 2005). These attributes make DS a useful indicator of the overall ecosystem health of the Delta (IEPSFB, 2015).

DS were at first considered to be a population of the pond smelt, *Hypomesus olidus* (FWS, 1995). In the early 1960s, DS were recognized as a distinct species (Hamada, 1961). Subsequently, DS were described as one of two subspecies of *Hypomesus transpacificus*, the other being the Japanese wakasagi (*Hypomesus nipponensis*; McAllister, 1963). However, these taxa have since been found to be genetically distinct species presumably derived from different marine ancestors (Moyle, 1976; 1980; Stanley et al., 1993). Electrophoretic and field studies have shown that hybridization has taken place between DS and wakasagi (FWS, 1995).

2.1.1 Species Listing Status

The US Fish and Wildlife Service (FWS) listed DS as a threatened species on March 5th, 1993 (FWS, 2012). The FWS has given DS a recovery priority number of 2C (FWS, 2009). This code identifies the species as having a high degree of threat but a high potential for recovery (FWS, 1995). Potential threats to DS include the destruction, modification or curtailment of habitat or range, as well as introduced species that modify habitat (e.g., *Egeria densa*), compete for food (e.g., *Corbula amurensis*), or prey upon DS (*Micropterus salmoides*, *Morone saxatilis* and *Menidia beryllina*). Entrainment, environmental contaminants, and small population effects may also pose threats to the species (FWS, 2009; 2010).

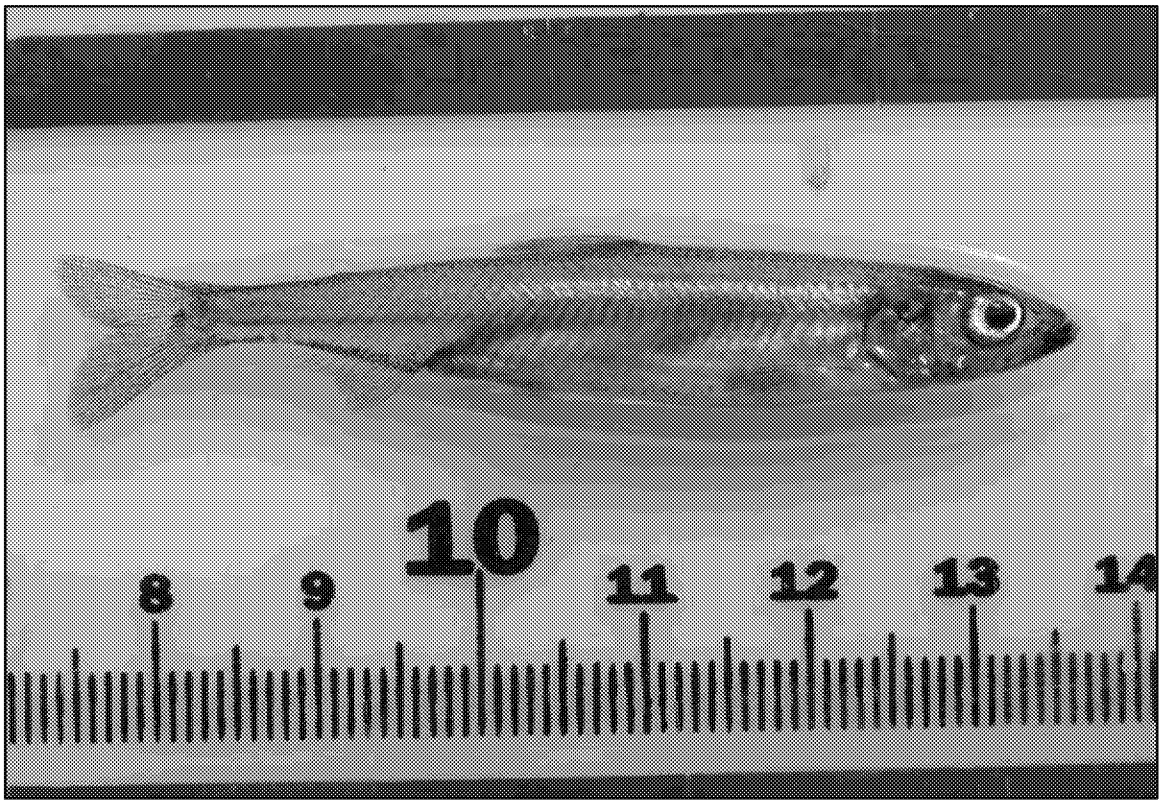

Figure 2-1 Photo of young adult delta smelt

2.1.2 Distribution

DS are endemic to the San Francisco Bay and Sacramento-San Joaquin Delta Estuary (Delta) in California (FWS, 2010). Historically, DS could be found from San Pablo Bay upstream to Sacramento on the Sacramento River and to Mossdale on the San Joaquin River (FWS, 2010). Currently, it is only found from San Pablo Bay upstream through Contra Costa, Sacramento, San Joaquin, Solano, and Yolo Counties (FWS, 2010). DS is a euryhaline and migratory species, moving from freshwater to brackish waters and back to freshwater to spawn within one year (FWS, 2010). Critical habitat has been designated in Suisun Bay, in Goodyear, Suisun, Cutoff, First Mallard, and Montezuma Sloughs, and in the existing contiguous waters of the Delta (EPA, 2010a; see Figure 2-2).

Abundance throughout its range has fluctuated greatly from year to year and accurate population size estimates are impossible (FWS, 2004; 2010). Declines began in 1981 and the population has remained at extremely low levels since (FWS, 2004). DS abundance indices have trended to record lows from 2002 through 2008, and the DS index is now estimated at the lowest level ever measured (1.5% of the 1980 index level) (FWS, 2010). In fact, tow net surveys have shown that juvenile DS have almost completely disappeared from the southern Delta (FWS, 2004). Throughout its range, most DS are caught in shallow waters of low salinity (FWS, 2004).

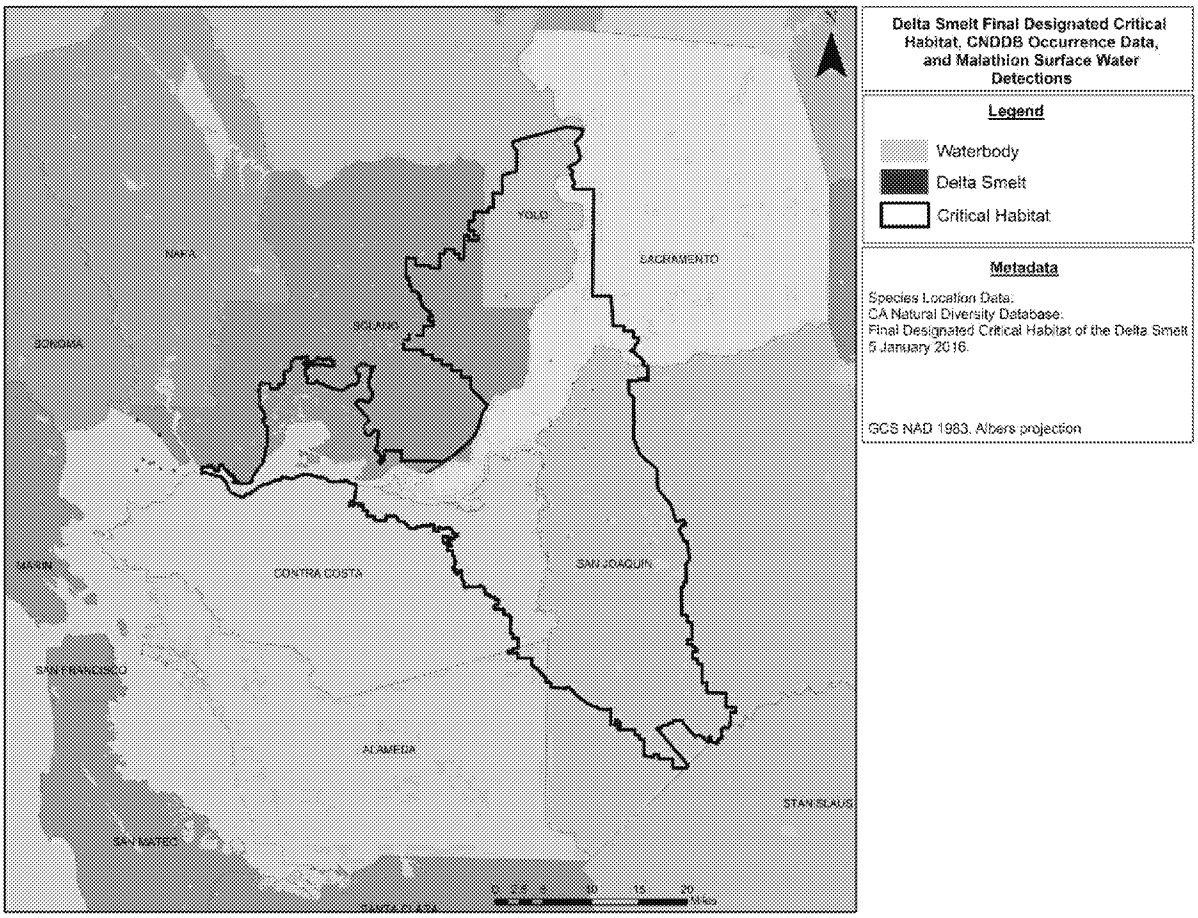

Figure 2-2 Final critical habitat and current CNDDB occurrence records of delta smelt

2.1.3 Habitat

DS are found in waters ranging in salinity from 0 to 12 g/L, while rarely occurring in water with more than 10-12 g/L salinity (FWS, 1995). Most catches have occurred in 0.2 to 2.0 g/L salinity (Bennett, 2005). They prefer shallow (< 3 m; The Bay Institute, 2007) and naturally turbid waters that are laden with silt and particulates (FWS, 1995).

Spawning occurs in tidally-influenced freshwater ranging from 7 to 22°C (Wang, 1986; FWS, 1995; Moyle, 2002; Bennett, 2005). Adult DS prefer to spawn in areas of high freshwater discharge (Bennett, 2005), where there is adequate substrate to attach their eggs (FWS, 1995). Precise spawning areas and microhabitats are unknown (Bennett, 2005). However spawning locations have been inferred from the collection of larvae in sloughs and shallow edge-waters of channels in the upper Delta and in Montezuma Slough near Suisun Bay (FWS, 2010). Barker, Lindsey, Cache, Prospect, Georgiana, Beaver, Hog, and Sycamore sloughs, the Sacramento River, and tributaries of northern Suisun Bay were also identified as important DS spawning habitat by the FWS (1994). In a laboratory study described by Bennett (2005), DS were found to deposit 54-84% of their eggs on gravel in areas of high water flow when offered six potential

substrata in high (8.8 cm/s) and low (1.4 cm/s) velocity flows. After several weeks of development, DS larvae move downstream to their nursery habitat in the "low salinity zone" (LSZ), where salinity ranges from 2 to 7 g/L (FWS, 2010). The LSZ occurs at the inland edge of estuarine habitat and moves depending on San Francisco Bay-Delta water outflow (Herbold and Vendlinski, 2012). Reduced outflow causes the LSZ to move upstream. Since 2000, the LSZ has been fixed in the western Delta during the summer and fall (Herbold and Vendlinski, 2012). Nursery and dispersal habitats encompass the area extending eastwards from Carquinez Straight, including Suisun Bay, Grizzly Bay, Honker Bay, Montezuma Slough and its tributary sloughs up to the Sacramento River and its confluence with Three Mile Slough, and south along the San Joaquin River, including Big Break (FWS, 1994). Post-larval DS have been caught in the western Delta and Suisun Bay, at the landward margin of the LSZ (Bennett, 2005). Juvenile DS may be found as far downstream as San Pablo Bay and Carquinez Strait (Wang, 2007).

2.1.4 Life History

DS are a semi-anadromous, annual species (Bennett, 2005) and spend a large part of their life in the freshwater edge of the "mixing zone", where the salinity is approximately 2 g/L (FWS, 1994; 1995). The mixing zone of an estuary is defined as the area where freshwater and saltwater meet (FWS, 1995). Prior to spawning, DS migrate inland to freshwater sloughs and shallow edge-waters of channels in the upper Delta (FWS, 1995; EPA, 2010a). Gravid adults have been collected from December to April but were most common in February and March (FWS, 1994). Spawning has been observed from January to July (FWS, 1995), but generally occurs from late March through mid-May (EPA, 2010a). Although never observed in the wild, spawning is believed to occur at night, with females broadcasting their eggs a few centimeters above the substratum (FWS, 1995; 2010; Bennett, 2005). Eggs are demersal and adhesive, remaining in place until hatch (Moyle, 1976; Wang, 1986). Spawning is also believed to be closely associated with the lunar phase and to occur during neap tidal periods (Bennett, 2005). Females typically produce around 1900 eggs. However, fecundity can range from 1200 to 2600 eggs per female (Moyle et al., 1992). Most adults die following their first spawning (Radtke, 1966), but some individuals (<10%) have been observed in the lab to spawn twice in one season or in two sequential seasons (Bennett, 2005; Brown and Kimmerer, 2001).

Embryos hatch at 4.5 to 6 mm total length after 10 to 14 days and feed on their yolk sacs for 4 to six days following hatch (Mager, 1996; FWS, 1994). Exogenous feeding begins once the yolk sac has been almost fully absorbed (Bennett, 2005). At 25 to 40 days post-hatch and when larvae are 14 to 20 mm in length, the swim bladder and fin-folds have almost completely developed (Bennett, 2005).

Larvae remain in the freshwater spawning grounds until their swim bladders develop, after which they move downstream to the mixing zone (FWS, 1994; 1995). Larvae are generally most abundant in the Delta from mid-April through May, while juveniles are especially abundant at this location during May and June (FWS, 1994; 2010; Wang, 2007). At the end of June or early July, juveniles leave the South Delta and move towards Suisun Bay, where they can be found as far downstream as San Pablo Bay and Carquinez Strait (Wang, 2007).

Growth during the post-larval period occurs at a rate of about 0.5 mm per day until juveniles reach a total length of 20 to 40 mm in length, after which growth slows to approximately 0.35 mm per day until September when they have reached 40 to 50 mm (Bennett, 2005).

In September or October, young of the year return upstream to spawn through the winter and spring (Bennett, 2005; FWS, 2010). Pre-spawning DS have been observed in the vicinity of Decker Island and the confluence of the Sacramento and San Joaquin Rivers from September to November. A summary of DS life history depicting their approximate life stage and location over the course of a year is provided in Figure 2-3.

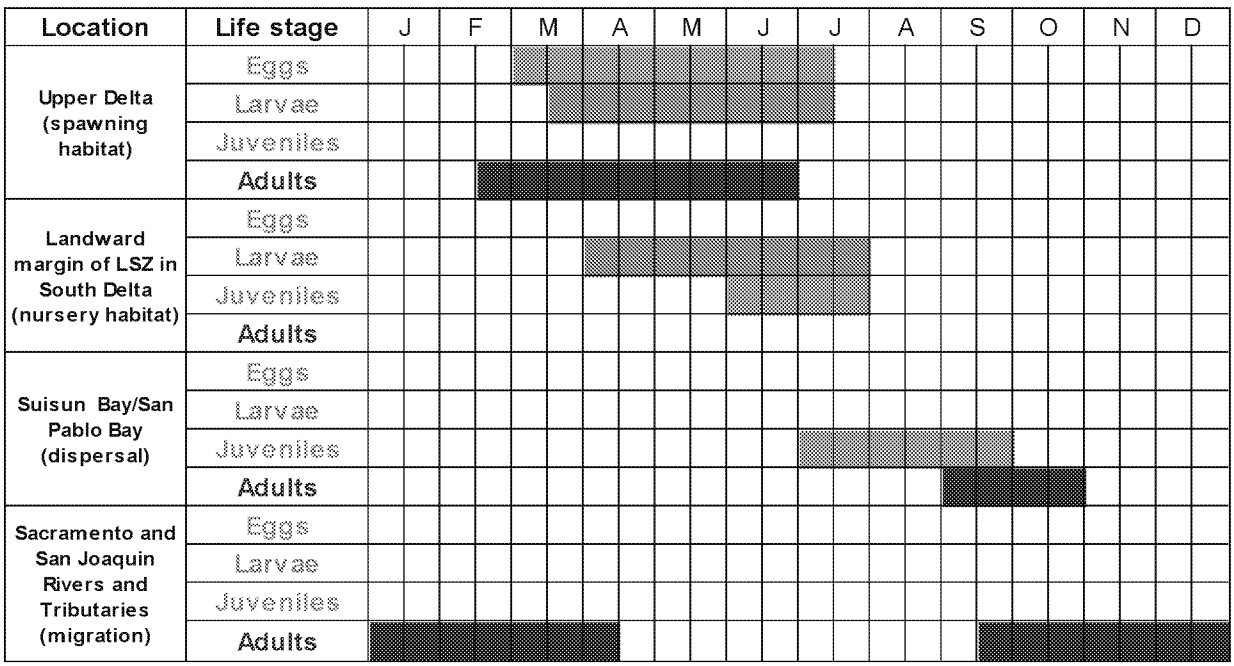

Figure 2-3 Delta smelt life stages and locations, by month

2.1.5 Diet

The diet of the DS is composed almost entirely of copepods (Bennett, 2005). Stomach content analyses of 1475 smelt larvae revealed that they feed almost entirely (>85% by number) on sub-adult cyclopoid and calanoid copepods (Nobriga, 2002). Small portions of rotifers and cladocerans were also consumed (Nobriga, 2002). Historically, the copepod *Eurytemora affinis* and the mysid shrimp *Neomysis mercedis* were the main prey items for DS. However, *Pseudodiaptomus forbesi* has replaced *Eurytemora affinisis* as a major prey source since its introduction into the San Francisco Bay-Delta (FWS, 2010). DS larvae were reported to feed on phytoplankton until four days post-hatch, after which they fed on rotifers and *Artemia* nauplii (FWS, 1995). First-feeding larvae consumed only algae and rotifers in aquaculture. However, gut contents analysis of young DS indicate that DS larvae mainly consume larval copepods in the field (Nobriga, 2002; Bennett, 2005). Juvenile and adult DS consume adult copepods

(Nobriga, 2002; Bennett, 2005). Prey selection is proportional to prey abundance (Nobriga, 2002). FWS (1995) suggests that, in addition to copepods, cladocerans, amphipods, insect larvae, and *Neomysis mercedis* may make up small portions of the diet.

2.2 Malathion Use Patterns

2.2.1 Malathion Use in California

Malathion was first registered in 1956 and is classified as a general use non-systemic insecticide and acaricide. Malathion is used to control aphids, citrus thrips, grasshoppers, leafminers, mites, whiteflies, beetles, weevils, midges, scale, fruitworms, moths, leafrollers, rootworms, mealybugs, leafhoppers, lygus bugs, and maggots. It is widely used in agriculture, ornamental nurseries, pastures, and rangelands and is also applied for residential outdoor use, for building perimeters, regional pest eradication/suppression programs and to control adult mosquitoes, biting midges and flies of public health and veterinary importance. Malathion is currently formulated as emulsifiable concentrates and ready to use liquids. It can be applied by fixed wing and rotary aircraft, truck-mounted fogger, ground boom, chemigation and hand-held sprayer.

The California Pesticide Use Reporting database (CA PUR) is one of the most extensive pesticide use databases available (see http://www.cdpr.ca.gov/docs/pur/purmain.htm; CDPR, 2000, 2009; FWS, 2006; CNDDB, 2009). Since 1995, all agricultural pesticide use in California has been reported monthly to the county agricultural commissioner who, in turn, reported the data to the California Department of Pesticide Regulation (CDPR). These reports include the date and location (section, township, and range) where the pesticide was applied, the kind and amount of pesticides used, the crops to which the pesticide was applied, the type of commodity, identification numbers (IDs) for the site and the pesticide user ("operator"), and the number of planted and treated acres (CDPR, 2000, 2009). Before buying or using pesticides, every operator is required to obtain a unique operator ID from the county where the pest control work will be performed. Growers obtain a site ID from the county agricultural commissioner for each location and crop or commodity where pest control work is anticipated. The information is then recorded on the restricted material permit or other approved form. California has a broad definition of "agricultural use". Thus, reporting requirements include pesticide applications to parks, golf courses, cemeteries, rangeland, pastures, and along roadside and railroad rights-of-way. In addition, post-harvest pesticide treatments of agricultural commodities must be reported, along with pesticide treatments in poultry and fish production, and some livestock applications. Exceptions to the full use reporting requirements are home and garden use and most industrial and institutional uses (CDPR, 2009).

Malathion use data were downloaded from the CAPUR database and imported into MS-Access 2003. Pesticide use data from 2000 to 2013 were then queried to determine the total amount of malathion applied, as active ingredient and formulated product. The agricultural and non-agricultural use pattern information for malathion is presented in Table 2-1. The dominant use for malathion in California from 2000-2013 was for alfalfa (1,588,157 lb active ingredient). The

next highest uses were for strawberries (1,299,525 lb active ingredient), lettuce (749,977 lb active ingredient) and walnuts and chestnuts (337,167 lb active ingredient). It is important to note that the use of malathion in the last 12 years is likely an over representation of future use because reductions in maximum application rates described in the RED (EPA, 2009a) were not implemented until 2011.

Table 2-1 Malathion use in California from 2000 to 2013

Crop or Use	*Formulated Product Applied (lb)*	*Active Ingredient Applied (lb)*	*Acres Treated (A)*[a]
Agricultural			
Alfalfa	2,009,621	1,588,157	1,300,190
Apricot	233	186	60.0
Asparagus, carrots[b]	42,668	34,608	22,281
Avocado	16,457	8,607	78,630
Barley	16,576	13,043	11,669
Beans[c]	59,817	45,278	35,788
Beets[d]	2,590	2,039	1,876
Blueberries	6,046	5,194	4,059
Broccoli[e]	209,128	168,226	96,564
Brussels sprouts, Dandelion	11,970	9,772	5,788
Cabbage[f]	74,593	59,904	34,779
Caneberries, Gooseberry, Blackberry, Boysenberry, Dewberry, Loganberry, Raspberry	100,380	80,119	40,350
Celery	238,580	192,881	133,968
Cherry	144,189	128,579	87,610
Chinese greens (Chinese cabbage)[g]	50,540	40,433	22,435
Citrus, Grapefruit, Lemon, Lime, Orange, Tangelo, Tangerines[h]	418,827	331,669	241,022
Clover, Lespedeza, Trefoil, Vetch	577	467	255
Collards[i]	22,005	17,785	12,127
Corn (Sweet and Pop)	26,915	19,687	20,550
Cotton	85,785	55,263	51,022
Cucumber, chayote fruit	4,146	3,284	2,079
Date	1,478,282	74,214	28,165
Eggplant, Oriental eggplant	611	451	284
Endive (Escarole)	5,462	4,441	2,862
Field corn	8,834	6,924	6,757
Figs	16,441	13,010	5,757
Flax[j]	4,839	3,874	2,363
Garlic	17,938	14,284	7,655
Grapes (Raisin, table, wine)	133,806	89,562	45,635
Grasses (Bermuda, Forage, Hay)[k]	82,759	66,119	56,334
Guava	4.86	3.70	21.3
Kale, Mustard	21,678	17,662	9,722
Leek[l]	1,539	1,249	837
Lettuce[m]	927,393	749,977	456,689
Macadamia nut[n]	1,279	998	924
Mango[o]	73.0	50.0	167
Melon (not Watermelon), Pumpkin[p]	21,165	16,721	14,267
Mint[q]	3,000	2,430	2,523
Mushrooms	5.00	3.00	1.00
Nectarine	1,195	968	111
Okra	3,683	2,980	1,841
Onion, Shallot	98,806	79,688	51,348
Parsley	834	656	474

Table 2-1 Malathion use in California from 2000 to 2013			
Crop or Use	***Formulated Product Applied (lb)***	***Active Ingredient Applied (lb)***	***Acres Treated (A)[a]***
Peaches[r]	990	782	923
Pear[s]	2,189	1,687	407
Peas	21,747	16,646	21,109
Pecan[t]	912	734	124
Peppers	12,559	10,122	8,595
Potato, Sweet potato, Yams	4,524	3,683	2,274
Radish[u]	1,765	1,411	1,035
Rice, Wild rice	39,428	28,796	19,926
Rye	48.0	38.0	33.0
Safflower	1,892	1,504	1,429
Sorghum	5,433	4,383	3,096
Sorghum, Oats, Wheat[v]	4,405	3,375	3,177
Squash (Summer)[w]	5,607	4,485	2,783
Squash (Winter)[x]	6,067	4,821	2,894
Strawberry	1,607,247	1,299,525	677,324
Swiss chard	2,660	2,160	1,387
Tomato, Tomatillo	57,140	41,947	42,918
Turf (Bermuda grass)[y]	5.00	1.00	7.00
Turnips, Rutabaga, Parsnips	1,956	1,591	941
Walnut, Chestnut	420,099	337,167	93,099
Watercress	6,819	5,565	4,564
Watermelon	4,966	3,593	1,804
Wheat	121,916	95,669	87,736
Non-Agricultural			
Agricultural uncultivated areas[z]	8,043	4,641	11,441
Christmas tree plantations, Pine seed orchards	1,005	813	262
Fence rows/hedge rows[aa]	226,410	167,955	178
Grains, stored[bb]	53.0	39.0	1.00
Household/domestic dwellings (perimeter)/ refuse/ solid waste sites/ containers[cc]	554,149	296,012	49.0
Intermittently flooded areas[dd]	5,647	4,315	1,940
Mosquito control/public health, medfly control[ee]	538,140	511,759	19,133
Ornamentals[ff]	123,444	90,005	64,494

Source: CDPR, 2015a, downloaded (http://calpip.cdpr.ca.gov/main.cfm) August 2012 (Years 2000 – 2010), June 2013 (Year 2011), and January 2016 (Years 2012 and 2013).

[a] Where "acres treated" represent data reported in units of acres (A) in the CaPUR database. Data for "acres treated" for some non-agricultural uses are not reported in the CaPUR database in acres and, therefore, were not included in this summary table. As such, the total acres treated for non-agricultural uses may be under represented in Table 2-1.

[b] Includes vegetables (all or unspec)

[c] Beans = beans, broad (Fava, Horse bean; all/unspec), beans (all or unspec), beans, dried type, beans, succulent (other than Lima) .

[d] Includes Sugarbeet, general.

[e] Includes Broccoli raab (Rapa, Italian turnip, Rapini).

[f] Includes cabbage (Savoy), Cauliflower, Cole crops (all or unspec), and Radicchio.

[g] Includes Amaranth, Bok choy (Wong bok), Chinese broccoli (white flowering) (Gai lon), Chinese cabbage (Nappa, Won bok, Celery cabbage), Gai choy (Loose leaf), Gai lon, Kohlrabi, and Mizuna.

[h] Includes Kumquat (all or unspec) and Pomelo.

[i] Includes spinach.

[j] Includes Chicory (all or unspec), Fennel (all or unspec), flavoring and spice crops (all or unspec), Rape (all or unspec), and Sunflower, general.

[k] Includes forage - fodder grasses (all or unspec; Hay), grasses grown for seed (all or unspec), pastures (all or unspec), rangeland (all or unspec), Sudangrass (forage - fodder (Sorghum Sudanese)), Timothy (forage - fodder), and orchardgrass (forage - fodder).

[l] Includes Chive (Sibericum).

[m] Includes Arugula (Roquette, Rocket salad) and leafy vegetables (all or unspec).

[n] Includes Almond and Olive (all or unspec).

[o] Includes Cherimoya, Kiwi fruit, Pomegranate (miscellaneous fruit), and subtropical and tropical fruit (all or unspec)

[p] Includes Cantaloupe.

[q] Includes Peppermint, Basil (bush, garden, sweet) and Chervil (salad chervil).
[r] Includes Plum (includes wild plums for human consumption) and Prune
[s] Includes Apple, pome fruits (all or unspec), and Quince.
[t] Includes nut crops, nut trees (all or unspec).
[u] Includes Chinese radish/Daikon (Lobok, Japanese radish).
[v] Includes grain crops (all or unspec).
[w] Includes Squash (zucchini).
[x] Includes Squash (all or unspec).
[y] Includes ornamental turf (all or unspec).
[z] Includes animal husbandry premises, Chickens (all or unspec), county ag. comm. sales, farm animals (all or unspec; livestock), greenhouses (empty; environs, benches, etc.), poultry (all or unspec), and soil application, preplant-outdoor (seedbeds, etc.)
[aa] Includes landscape maintenance, rights of way
[bb] Includes feed/food storage areas (unspecified)
[cc] Includes buildings and structures (non-ag outdoors), commodity fumigation, and structural pest control
[dd] Includes research commodity, site unknown, uncultivated non-ag areas (all or unspec)
[ee] Includes fumigation, other, public health pest control, regulatory pest control, vertebrate pest control
[ff] Includes non-greenhouse grown cut flowers or greens, non-greenhouse grown plants in containers, non-greenhouse grown transplant/propagative material, non-outdoor container/field grown plants, non-outdoor grown cut flowers or greens, non-outdoor grown transplant/propagative material, and Chrysanthemum, garland (crown daisy).

2.2.2 *Malathion Use and Delta Smelt Habitat by County*

For those counties containing DS critical habitat and/or where DS have been observed (1919 to 2015), malathion use by county from 2000 to 2013 is summarized in Table 2-2.

Table 2-2 Malathion use (2000 to 2013) and presence of DS critical habitat and DS observations (1919 to 2015) by California county

County	*DS Critical Habitat Present[a]*	*DS Observations[b]*	*Formulated Product Applied (lb)*	*Active Ingredient Applied (lb)*	*Acres Treated (A)[c]*
Alameda	No	No	12,270	6,378	163
Alpine	No	No	4.00	3.00	0
Amador	No	No	1,374	885	649
Butte	No	No	48,907	40,061	8230
Calaveras	No	No	4,554	3,239	2815
Colusa	No	No	92,967	81,110	34639
Contra Costa	Yes	Yes	15,569	11,578	4247
El Dorado	No	No	9,049	5,129	407
Fresno	No	No	625,637	518,272	200813
Glenn	No	No	125,583	103,576	55240
Humboldt	No	No	31.0	24.0	7.00
Imperial	No	No	1,018,351	786,159	608407
Inyo	No	No	109	86.0	20.0
Kern	No	No	593,451	480,233	242134
Kings	No	No	281,917	221,832	103354
Lake	No	No	4,899	3,315	2822
Lassen	No	No	4,279	3,416	2466
Los Angeles	No	No	55,958	31,454	8113
Madera	No	No	86,725	66,657	53750
Marin	No	No	9.04	4.85	0
Mariposa	No	No	509	256	10.0
Mendocino	No	No	229	166	52.0
Merced	No	No	425,236	339,641	251391
Modoc	No	No	19,518	15,907	15233
Mono	No	No	559	454	330
Monterey	No	No	1,273,643	1,031,369	562770
Napa	No	No	9,683	7,149	2244

Table 2-2 Malathion use (2000 to 2013) and presence of DS critical habitat and DS observations (1919 to 2015) by California county

County	*DS Critical Habitat Present*[a]	*DS Observations*[b]	*Formulated Product Applied (lb)*	*Active Ingredient Applied (lb)*	*Acres Treated (A)*[c]
Nevada	No	No	225	87.4	15.3
Orange	No	No	107,249	75,334	34076
Placer	No	No	10,770	5,781	424
Plumas	No	No	0	0	1.00
Riverside	No	No	1,762,597	266,643	129880
Sacramento	Yes	Yes	58,142	36,813	12141
San Benito	No	No	13,580	11,010	6800
San Bernardino	No	No	116,461	75,756	20859
San Diego	No	No	72,400	47,485	108256
San Francisco	No	No	220	152	0
San Joaquin	Yes	Yes	327,717	262,495	160996
San Luis Obispo	No	No	413,448	333,193	200616
San Mateo	No	No	11,584	7,524	2801
Santa Barbara	No	No	1,053,791	847,996	502207
Santa Clara	No	No	43,228	30,257	12515
Santa Cruz	No	No	250,511	201,750	104516
Shasta	No	No	52,266	40,875	24896
Siskiyou	No	No	39,603	32,103	28384
Solano	Yes	Yes	33,063	22,559	19718
Sonoma	No	No	3,120	2,330	1475
Stanislaus	No	No	139,804	107,798	62154
Sutter	No	No	93,202	75,975	19162
Tehama	No	No	49,086	39,444	16451
Trinity	No	No	0.105	0.0523	0
Tulare	No	No	343,187	258,605	126155
Tuolumne	No	No	3,512	1,756	3.00
Ventura	No	No	319,798	255,732	147266
Yolo	Yes	Yes	131,067	102,146	81728
Yuba	No	No	62,270	50,748	9901

Source: CDPR, 2015a, downloaded (http://calpip.cdpr.ca.gov/main.cfm) August 2012 (Years 2000 – 2010), June 2013 (Year 2011), and January 2016 (Years 2012 and 2013); CNDDB, 2016; FWS, 2010.

[a] Indicates presence of DS Critical Habitat as defined by US Fish and Wildlife Service, March 2010 (FWS, 2010).

[b] Indicates observations of DS from 1919 to 2015 (CNDDB, 2016).

[c] Data provided in the Pesticide Use Reporting database in units of acres or square feet are included in the summary table. Data provided in units of cubic feet, thousand cubic feet, pounds, tons, or miscellaneous, are not included as they cannot be converted accurately to acres. As such, the acres treated data in this table may under-represent the actual acres treated with malathion between 2000 and 2013.

2.2.3 Label Application Rates

As of March 14, 2016 there are 15 malathion-containing products registered for use in California. These products are listed in Table 2-3 along with the percent active ingredient in each product.

Table 2-3 Malathion-containing insecticides registered in California[a]

California Registration Name	*% Active ingredient*	*CA Registration #*	*EPA Registration #*[b]
Max kill dusta-cide 6	6	1015-69-AA	1015-69
Gowan malathion 8	79.5	10163-21-ZA	10163-21
Gowan malathion 8 flowable	79.5	10163-21-ZB	10163-21

Table 2-3 Malathion-containing insecticides registered in California[a]			
California Registration Name	***% Active ingredient***	***CA Registration #***	***EPA Registration #[b]***
Drexel malathion 5EC	57	19713-217-AA	19713-217
Ortho max malathion insect spray concentrate	50	239-739-ZN	239-739
Gordon's malathion 50% spray	50	33955-394-ZB	33955-394
Malathion 8-e insecticide	79.5	34704-452-ZA	34704-452
Malathion 8 aquamul	81.8	34704-474-ZA	34704-474
Spectracide malathion insect spray concentrate	50	46515-19-AA-8845	46515-19
Ace dilutable concentrate malathion 50 insect spray	50	46515-19-AA-988	46515-19
Fyfanon technical	96.5	4787-5-AA	4787-5
Fyfanon 8 lb. Emulsion	81.8	5905-250-ZA	5905-250
Fyfanon ULV mosquito	96.5	67760-34-ZA	279-3539
Fyfanon ULV AG	96.5	67760-35-AA	279-3540
Cheminova malathion 57%	57	67760-40-ZA	279-3587

[a] Registration name and number as per CDPR product/label database (CDPR, 2016. March 14, 2016). (www.cdpr.ca.gov/docs/label/labelque.htm).

[b] As per EPA's PPLS database (www.epa.gov/pesticides/PPLS). EPA registration names are based on the primary brand name of a product which can be sold and renamed by various distributors. However, in CA, all distributors/subregistrants must register individual products sold in CA. As such, the names of products for particular registration numbers may be different between the CDPR and EPA.

The maximum allowable single application rates for malathion-containing insecticides in California, as specified on the labels, range from 0.175 to 10.62 lb a.i./A[1]. The minimum application interval is typically three to 14 days depending on the crop, but can be as much as 30 days for avocado and citrus fruits (i.e., grapefruit, lemon, lime, orange, tangelo, and tangerines). The label-permitted application rates and retreatment intervals for non-ULV and ULV use patterns to be modeled in our assessment of malathion can be found in Appendix A. Non-ULV applications are those in which formulated malathion (end-use products) is applied via aerial, ground or airblast methods to agricultural or non-agricultural use sites. ULV applications are those in which technical (end-use products) malathion is applied via aerial and/or airblast methods. ULV applications typically refer to a total volume of <0.5 gal/A (<1.89L/ha) applied, as such ULV applications have lower applications rates compared to non-ULV applications (EPA, 1998a). Further, dissipation rates on foliage are lower for ULV applications. Both non-ULV and ULV applications are considered in this effects determination.

2.3 Malathion Physical and Chemical Properties

Malathion (diethyl (dimethoxyphosphinothioylthio) succinate; CAS 121-75-5) is an organophosphorous insecticide (Figure 2-4). It has a relatively low vapor pressure at 30°C and a low Henry's law constant (Table 2-4) suggesting low to intermediate volatility. Malathion is highly water soluble and its estimated log K_{ow} (2.75) indicates that malathion will not significantly

[1] The rate of 10.62 lb a.i./A corresponds to a non-agricultural use on fence rows/hedge rows of 0.2439 lb a.i./1000 ft2 that was extrapolated to lbs ai/A. The highest application rate on agricultural use sites is the 7.5 lb a.i./A rate for citrus in California (EPA, 2009a).

bioaccumulate in aquatic organisms. This was confirmed in a fish bioaccumulation study (Forbis and Leak, 1994a,b [MRID 43106401, 43106402]; Kammerer and Robinson, 1994 [MRID 43340301]). Malathion is not expected to absorb light at wavelengths greater than 202.8 nm (Friis, 1992 [MRID 42265301]; Murrell et al., 2010 [MRID 47963501]), suggesting that it is unlikely to be degraded by photolysis.

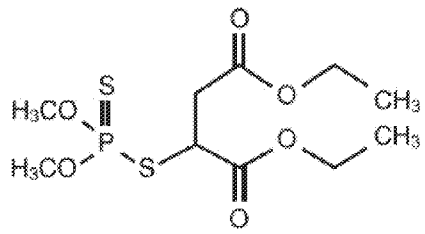

Figure 2-4 Chemical structure of malathion

The physical and chemical properties of malathion relevant to the environmental fate and behavior of the chemical are summarized in Table 2-4.

Table 2-4 Physical and chemical properties of malathion

Property	*Value*	*Comments*	*References [MRID]*
Chemical formula	$C_{10}H_{19}O_6PS_2$	—	—
Molecular weight	330.36 g/mol	—	—
Solubility in water	145 mg/L at 20-23°C	Very soluble	Cheminova A/S, 1988 [40966603]
Vapor pressure	4×10^{-5} mm Hg at 30°C	Low to intermediate volatility	Cheminova A/S, 1988 [40966603]
Henry's Law Constant (K)	1.2×10^{-7} atm m^3/mol (based on vapor pressure of 4×10^{-5} mm Hg and water solubility of 145 mg/L)	Low potential to volatilize from water or moist soil	Cheminova A/S, 1988 [40966603]
Log octanol/water partition coefficient (log K_{ow})	2.75	Low potential for bioaccumulation	Mangels, 1987 [40944108]
Soil-water partition coefficient (K_d - L/kg-soil) (% organic carbon)	Sandy loam (CA): 0.83 (0.55% OC) Sand: 1.23 (0.4% OC) Loam: 1.76 (1% OC) Silt loam: 2.47 (1.35% OC) Sandy loam (AR): 1.6 (0.6% OC)	Low potential for soil leaching	Blumhorst, 1989 [41345201]

2.4 Malathion Environmental Fate and Behavior

In this section, we discuss the transport and fate of malathion in the environment after application in California. When applied via ground, aerial and airblast application methods, malathion may be transported by spray drift and runoff from fields into the Sacramento-San Joaquin Estuary, which is habitat for DS and their prey. As a result, DS can be exposed to

malathion in different environmental compartments (e.g., water and sediment, soil, air, plants and animals). The following is a description of the fate and behavior of malathion in these media using best available data (i.e., data obtained through Good Laboratory Practice (GLP) guideline studies).

2.4.1 Fate and Behavior in Water and Sediment

2.4.1.1 Hydrolysis

Hydrolysis is an important route of malathion degradation in water. In a GLP study following the EPA Pesticide Assessment Guidelines, Subdivision N, Section 161-1, Teeter (1988 [MRID 40941201]) reported that in sterile solutions (25°C) of decreasing pH (pH 9, 7 and 5), malathion had increasing half-lives (DT50) of 0.49, 6.21 and 107 days, respectively. After 28 days, parent radiolabeled malathion accounted for 80.3% of the applied compound at pH 5, but only 3.7% in pH 7. Only 3.6% of applied malathion was present in water at pH 9 two days after application.

Malathion (95% purity) transformation in estuarine water and sediment was investigated in an open-literature study conducted by Walker (1976). To assess abiotic transformation in an estuarine environment, water (approximately 10 g/L salinity; pH 7.4) and sediments (pH 7.8; 49% moisture) were collected from a salt marsh estuary and sterilized. They were then treated with 6,400 and 10,000 µg malathion/L, respectively. Treatments were incubated in the dark at 25°C. Percent loss was determined directly after treatment on day zero, and then on days 1, 3, 5, 11, 18, 25 and 40. One day after treatment, 19% of the malathion in sterile solution had degraded, and by the third day, 62% had degraded. These results suggest that the hydrolysis half-life of malathion in neutral saline (10 g/L; pH 7.4) water is between one and three days. By day 25, 100% of the malathion had degraded. Similar results were obtained in parallel treated non-sterile water, suggesting that hydrolysis is the dominant route of malathion degradation in saline water. Degradation was initially more rapid in the sterile sediments, with 30% degradation occurring on the first day. However, by day three, only 46% of the applied malathion had degraded. By day five, 47% of applied malathion could be recovered from treated sterile sediments, implying a half-life in near neutral sterile saline sediments (pH 7.8; 10 g/L salinity in water phase) of three to five days.

The effect of salinity on the degradation of malathion in estuarine water was determined by incubating 0.17 µg/L malathion in the dark in sterilized seawater varying in salinity from 0 to 25 g/L at 25°C (Walker, 1976). As salinity increased, the rate at which malathion chemically degraded also increased. To illustrate, at 0 g/L salinity, the half-life of malathion in the experiment was between five and seven days (pH 6.9), whereas at 14 g/L salinity, the half-life was between one and three days (pH 8.0). At 25 g/L salinity (pH 8.1), the half-life was approximately one day (Walker, 1976).

In the aquatic environment, malathion is quickly degraded by bacteria and hydrolysis. Hydrolysis half-lives ranged from 0.49 to 107 days at pHs ranging from five to nine in freshwater environments (Teeter, 1988 [MRID 40941201]). In saline environments, hydrolysis half-lives are

one to three days at pH 7.4 (10 g/L salinity) and pH 8.0 (14 g/L salinity), and one day at pH 8.1 (25 g/L salinity) (Walker, 1976).

2.4.1.2 Aqueous Photolysis

In an aqueous photolysis study carried out at 25 ± 1°C for 30 days (Carpenter, 1990 [MRID 41673001]), radiolabeled malathion (9.49 and 9.73 mg/L) degraded in a sterile pH 4 solution. This study was conducted under GLP in accordance with the EPA Pesticide Assessment Guidelines, Subdivision N, Section 161-2. Photolytic half-lives of 94 and 156 days (corrected for dark controls) in photo-sensitized (1% acetone) and non-sensitized buffer solutions were reported, respectively. Malathion degraded with half-lives of 264 to 299 days in the dark controls. Malaoxon was not reported to be detected. The photoproducts were O,O-dimethyl phosphorodithoic acid and the half esters (Carpenter, 1990 [MRID 41673001]). The results suggest that photodegradation in water is not a major route of malathion degradation.

2.4.1.3 Aerobic Aquatic Metabolism.

In a 120 day GLP study conducted according to the SETAC Guideline "Procedures for assessing the environmental fate and ecotoxicity of pesticides", part 1, 8.2 of March 1995, radiolabeled malathion was added to two natural water/sediment systems kept in the dark at 22 ± 2°C (Knoch, 2001a [MRID 46769502]). The sediments were classified (USDA classification) as sand and loam with pH values of 7.5 and 8.0, respectively. The organic carbon content was 1.3 and 4%, respectively. Water in both systems was at pH 8.0 at sampling. Malathion was applied at a nominal rate of 1 mg/kg water, which was estimated to be equivalent to an application rate of 3,000 g a.i./ha (2.68 lb a.i./A). The radioactivity in the water phases of both test systems had declined to 1% of applied radioactivity by day 120. Sediment values ranged from 26 to 37% of applied radioactivity on day 120. Most of the residual radioactivity was found in the non-extractable residues of the humic fraction after 90 days (23 to 31%). Malathion was degraded to malathion monocarboxylic acid (MMCA) and malathion dicarboxylic acid (MDCA). These compounds degraded to $^{14}CO_2$ as 58 to 69% of applied radioactivity after 120 days. Malaoxon was not detected in this study. The half-life for malathion in the loam test system was 10 hours. In the sand test system, the estimated half-life was eight hours.

In another GLP aerobic aquatic metabolism study by Blumhorst (1991a [MRID 42271601]) conducted in accordance with the EPA Pesticide Assessment Guidelines, Subdivision N, Section 162-4, pond water (pH 8.5 and 138 mg $CaCO_3$/L hardness) and sediment (sand at pH 7.8 and 0.74 %OC) were maintained in the dark at 22 ± 1°C. Samples were fortified with 1,080 µg/L malathion. Half-life values of 1.09 and 2.55 days in the water and sediment phases were reported, respectively. The initial degradation product was malathion monocarboxylic acid (α and ß isomers), which further degraded to the desmethyl MMCA, MDCA and desmethyl dicarboxylic acid metabolites. Malaoxon was not detected in this study.

Walker (1976) investigated malathion (95% purity) transformation in estuarine water and sediment. To assess biotic transformation, water (approximately 10 g/L salinity; pH 7.4) and sediments (pH 7.8; 49% moisture) were collected from a salt marsh estuary and treated with 6.4

and 10,000 µg malathion/L, respectively. Treatments were incubated in the dark at 25°C. Percent loss of applied malathion was determined directly after treatment on day zero, and then on days 1, 3, 5, 11, 18, 25, and 40. One day after treatment, 20% of the malathion in solution had reportedly degraded, and by the third day 60% had degraded (implying an aqueous half-life of less than three days, for the study). By day 25, 100% of the applied malathion had degraded. Similar results were obtained in parallel treated sterile water, suggesting that biotic degradation in saline water may be minor compared to hydrolysis as a route of malathion transformation. However, degradation was notably more rapid in the non-sterile sediments, with 85% degradation occurring in the first day, suggesting that biotic processes are an important route of malathion degradation in sediment (Walker, 1976).

Cheminova recently commissioned a GLP aerobic aquatic metabolism study that was conducted according to OCSPP 835.4300 and OECD 308 guidelines at low and neutral pH (Hiler and Mannella, 2012 [MRID 48906401]). [^{14}C] malathion (100.0% radio purity) was applied at a dose rate of 0.35 mg/L to sediment/water systems collected from Maryland (pH 7.0) and North Carolina (pH 5.4), USA, and from Calwich (pH 7.2) and Chatsworth (pH 6.4), England. This dose rate was estimated from an application rate of 6.25 lb a.i./A malathion applied to a pond that is 1 hectare in size and 2 m in depth. The samples were stored in the dark at 20 ± 2°C and aerated throughout the test. The Maryland samples were analyzed at time 0, 3 and 6 hours, and 1, 3, 7, 14, and 30 days after dosing; the North Carolina samples were analyzed at time 0, 3 and 6 hours, and 1, 3, 7, 14, 30, and 72 days; the Calwich samples were analyzed at time 0, 5.5 and 12 hours, and 1, 2, 3, 6, and 10 days; and the Chatsworth samples were analyzed at time 0, 5.5 hours, and 1, 3, 6, 10, 17, and 30 days.

Malathion was quantified by high-performance (or pressure) liquid chromatography (HPLC) at each sampling time. Average radiocarbon recoveries ranged from 88.7 to 93.9% of applied. The main degradates observed in the neutral test systems were MMCA and MDCA, and represented 22.3 to 62.7% of the applied malathion. The main degradates in the acidic systems were also MMCA and MDCA, and represented 16.9 to 40.0% of the applied malathion. Minor degradates in all systems included fumaric acid and succinic acid. Up to 7% of the applied malathion was detected as the degradate hydroxy-MDCA in all water/sediment systems. O,O-desmethyl hydroxyl-MDCA was detected (up to 7.6% of applied malathion) in all but the Maryland samples, and an unknown polar metabolite was detected (up to 5.7% of applied malathion) in the Maryland and North Carolina samples. Malaoxon was not detected in any samples.

Half-lives were calculated with respect to the total water-sediment system and dissipation rates were also calculated separately for the water and sediment layers. All half-lives were calculated using a Single-First Order model, except for a select few that were calculated using a First-Order Multi-Compartment Model (FOMC) or a Double First-Order in Parallel Model (DFOP), as indicated. The total system half-lives for the Maryland, North Carolina, Calwich, and Chatsworth samples were 1.1, 3.3, 0.3 (DFOP), and 2.7 days, respectively. The DT90 values were ≤ 11.1 days for all systems. The water layer half-lives for the Maryland, North Carolina, Calwich, and Chatsworth samples were 1.0, 3.4, 0.2 (DFOP), and 2.8 days, respectively, and the sediment layer half-lives were 0.9, 0.7 (FOMC), 0.3 (DFOP), and 0.6 (DFOP) days, respectively.

Malathion is quickly degraded by aerobic processes in the aquatic environment. Reported aerobic aquatic metabolism half-lives for freshwater environments ranged from 0.3 to 3.3 days at pH conditions ranging from 5.4 to 8.5 (Hiler and Mannella, 2012 [MRID 48906401]; Knoch, 2001a [MRID 46769502]; Blumhorst, 1991a [MRID 42271601]). In marine environments, the results of Walker (1976) indicate that the aerobic aquatic half-life for malathion is less than three days at a salinity of 10 g/L.

2.4.1.4 Anaerobic Aquatic Metabolism

A GLP study conducted in accordance with the EPA Pesticide Assessment Guidelines, Subdivision N, Section 162-3 reported half-lives of 2.49 and 2.45 days in the water and sediment phases, respectively, of an anaerobic pond water-sediment system (22 ± 2°C in the dark) (Blumhorst, 1991b [MRID 42216301]). The sediment was classified (USDA classification) as sandy loam with 0.71% organic content (OC) and a pH of 7.8. The associated water had a pH of 8.7. The primary degradation product was malathion monocarboxylic acid, which further degraded to demethyl MMCA, MDCA, and demethyl dicarboxylic acid. Less than 2% of the applied malathion remained two weeks after application.

In a GLP mesocosm study with stainless steel pond enclosures (1060 L, 150 cm depth) containing freshwater assemblages of pelagic and benthic organisms, malathion (440 g/L EW formulation) was applied to achieve nominal concentrations of 1.2, 5.0 and 30 µg a.i./L. The pH in all enclosures following treatment was >8.0. The estimated water column DT50s for treatment concentrations were 2.3, 0.9 and 0.8 days, respectively (Ebke, 2002 [MRID 46525901]). Malathion concentrations in the sediment were below the limit of detection in all samples collected.

In summary, the anaerobic aquatic metabolism half-life is 2.5 days at pH 8.7 and 22°C (Blumhorst, 1991 [MRID 42216301]). Aquatic dissipation half-lives of 0.8 to 2.3 days were reported by Ebke (2002 [MRID 46525901]).

2.4.2 Fate and Behavior in Soil

2.4.2.1 Soil Photolysis

Photo-transformation in soil is a negligible route of malathion degradation. In a 30-day GLP photo-transformation study conducted in accordance with the EPA Pesticide Assessment Guidelines, Subdivision N, Section 161-3, 10 mg malathion/kg was applied to sandy loam and no transformation products comprised greater than 5.5% of the recovered radioactivity (Dykes et al., 1990 [MRID 41695501]). After 30 days of irradiation (12-hour light/12-hour dark cycle, 25±1°C), 85.4% of the recovered radioactivity was unaltered malathion. Total $^{14}CO_2$ was <6% of the applied radioactivity. The extrapolated photolytic half-life from the study was 173 days. The limited photolytic degradation for malathion from the two surface studies is expected, given that malathion likely only adsorbs wavelengths less than 202.8 nm (Friis, 1992 [MRID 42265301]; Murrell et al., 2010 [MRID 47963501]).

2.4.2.2 Aerobic Soil Metabolism

Aerobic soil biotransformation is the primary route of malathion degradation in the field. The following summarizes the results of studies that measured the degradation rate of malathion under various aerobic soil conditions. The studies were conducted in the dark at 20 to 25°C ± 2°C for 92 to 162 days.

A GLP study following the EPA Pesticide Assessment Guidelines, Subdivision N, Section 162-1 was conducted by Saxena (1988 [MRID 47834301]) and reported on the aerobic soil metabolism of malathion in sandy loam soil (0.5% OC, pH 6.5). MDCA and $^{14}CO_2$ were the only transformation products observed at greater than 10% of applied radioactivity (malaoxon was not detected as a metabolite). $^{14}CO_2$ was the principal degradation product, accounting for close to 60% of the applied radioactivity by the end of the study (162 days). The reported half-life for malathion in the test soil was 1.05 days. Saxena (1988 [MRID 47834301]) was determined to be unacceptable by EPA (2011) for reasons including a lack of maintenance of soil moisture, inadequate description of soil collection procedures, and no reported level of detection. However, the study still provides evidence of quick dissipation of malathion.

A GLP aerobic soil biotransformation study following the EPA Pesticide Assessment Guidelines, Subdivision N, Section 162-1 was conducted in loam soil with 1.2-1.6% OC, pH 6.1, and 75% bulk water content (Blumhorst, 1990 [MRID 41721701]). The application rate was 6.88 mg malathion/kg soil, which corresponds to 6.25 lb a.i./A. After seven days, 0.4% of the original radioactivity was detected as malathion. All primary transformation products had further degraded to less than 0.1% of the initial applied radioactivity (Blumhorst, 1990 [MRID 41721701]). Only MDCA, malathion and $^{14}CO_2$ occurred at more than 10% of applied radioactivity at any point in the study. Malaoxon was detected in this study at 1.0% of applied radioactivity on the day of application, but had declined to 0.1% by the third day. The fact that malaoxon was detected immediately after application indicates that it was present as an impurity in the spray mix. Based on the results obtained from sterile soil in the same study, the author concluded that aerobic metabolism was the primary route of malathion degradation in soil under aerobic conditions. The reported half-lives for malathion in aerobic non-sterile soil from this study were 0.212 and 0.203 days in two separate experiments (Blumhorst, 1990 [MRID 41721701]).

More recently, a GLP study conducted by Knoch (2001b [MRID 46769501]) reported the rates and routes of aerobic biotransformation of malathion in four soils (i.e., sand, silty clay and two silty loams). Soil organic carbon ranged from 0.5 to 2.7%. Soil pHs in water were 6.3, 6.7, 6.8 and 8.1 in silty loam, sand, a second silty loam and silty clay soils, respectively. The application rate was 2,000 g a.i./ha (1.79 lb a.i./A). Malathion was degraded in all four soils forming MMCA and MDCA. Both transformation products exceeded 10% of applied radioactivity in soil, reaching combined peak levels of 25% after eight hours and 61.7% after 24 hours. After 29 days, these transformation products degraded to less than 3.2% of applied radioactivity (malaoxon was not detected as a metabolite). $^{14}CO_2$ accounted for most of the applied radioactivity at the end of the study. Reported half-lives were 0.17, 0.18, 0.25 and 0.25 days for

silty clay, sand and the two silty loams, respectively. This study was conducted in accordance with the SETAC guideline "Procedures for assessing the environmental fate and ecotoxicity of pesticides", part 1, 1.1 of March 25 and with the OECD Draft Guideline for Aerobic and Anaerobic Transformation in Soil of July 1999.

As part of a GLP soil leaching study following the EPA Pesticide Assessment Guidelines, Subdivision N, Section 163-1, Nixon (1995 [MRID 43868601]) conducted pilot studies to determine the half-lives of malathion in sand (pH 7.6; 0.25% OC), sandy loam (pH 6.8; 1% OC), loam (pH 7.6; 1.71% OC), and silty clay (pH 5.9; 1.36% OC). The soils were brought to 75% of field capacity with deionized water and dosed with approximately 5 mg a.i./kg dw of radiolabeled malathion. Flasks were capped and incubated in the dark at 25°C. Aerobic conditions were not sustained in this study. Flasks were sampled at 0, 6, 24, 48, and 72 hours. The estimated half-lives from the experiment were as follows: sand, 0.6 days; sandy loam, 0.09 days hours; loam 0.5 hours (0.02 days); and silty clay, 0.9 hours (0.04 days) (Nixon, 1995 [MRID 43868601]). Malaoxon was not detected in soil samples measured by Nixon (1995 [MRID 43868601]).

These studies point to microbial metabolism as the major route of malathion degradation in aerobic soils. In all six soils tested, the rates of aerobic metabolism of malathion were similar (<one day) regardless of soil type, % organic carbon or pH. Malathion is degraded rapidly in soil via biotransformation and reliable GLP studies have reported aerobic soil half-lives ranging from 0.5 to 14.3 hours (0.02 to 0.60 days) at soil pHs ranging from 5.9 to 8.1 (Blumhorst, 1990 [MRID 41721701]; Knoch, 2001b [MRID 46769501]; Nixon, 1995 [MRID 43868601]).

2.4.2.3 Anaerobic Soil Metabolism

In a GLP aerobic/anaerobic soil metabolism experiment following the EPA Pesticide Assessment Guidelines, Subdivision N, Sections 162-1 and 162-2 (Saxena, 1988 [MRID 47834301]), degradation of radiolabeled malathion (3.12 mg/kg-soil) was observed in soil samples (loamy sand, pH 6.5, 0.5% OC) flooded with water after 1.08 days of aerobic incubation at 25 ± 2°C in the dark. Following flooding, the soils were maintained under anaerobic conditions (also 25 ± 2°C in the dark). At the time of flooding, radiolabeled malathion had already declined to 43.2% of applied radioactivity. Malathion degraded to 1% of applied radioactivity under anaerobic conditions 30 days following flooding (first measurement following flooding). At 62 days post flooding (second and final measurement), malathion accounted for 0.7% of the applied radioactivity. The half-life of malathion under these anaerobic conditions was much less than 30 days, but could not be determined exactly with only two sample dates. The major metabolites identified were $^{14}CO_2$, soil-bound residues and MDCA. As mentioned above, Saxena (1988 [MRID 47834301]) was determined to be unacceptable by EPA (2011).

The relatively rapid degradation of malathion under anaerobic soil conditions in the laboratory is consistent with the results of two comprehensive dissipation studies carried out in US rice paddies (Judy et al., 1991a,b [MRID 42058401, MRID 42058402]; see Section 2.4.2.8) in which no malathion was detected in soil samples taken immediately after each of three weekly applications of 650 g a.i./ha (0.58 lb a.i./A).

2.4.2.4 Adsorption/Desorption

Malathion is moderately adsorbed by soil. In a batch equilibrium (slurry) GLP study conducted in accordance with the EPA Pesticide Assessment Guidelines, Subdivision N, Section 163-1, Blumhorst (1989 [MRID 41345201]) applied radiolabeled malathion to two sandy loams (pH 6.9 and 4.5; 0.55% OC and 0.6% OC), sand (pH 6.2; 0.4% OC), loam (pH 6.1; 1.0% OC), and silt loam (pH 7.4; 1.4% OC). Initial nominal concentrations were 100, 10, 1.0, and 0.1 mg/L malathion, and the solution:soil ratio was 5:1. The equilibration time was two hours. Regression analysis of the data showed that adsorption and desorption isotherms were well described by the empirical Freundlich equation. Adsorption generally increased as soil organic matter, clay content and cation exchange capacity increased. K_{ads} values ranged from 0.828 in sandy loam to 2.47 in silt loam. Adsorption K_{oc} values ranged from 151 in sandy loam to 308 in sand (Table 2-5). The only metabolite detected in the study was MDCA. These results suggest that malathion is somewhat mobile in soil.

Table 2-5 Adsorption coefficients (K_{ads} and K_{oc}) for malathion in different soils from Blumhorst (1989 [MRID 41345201])

Soil Type	*Organic Carbon (%)*	*Clay Content (%)*	*Cation Exchange Capacity (meq/100 g)*	K_{ads}	K_{oc}
Sandy loam (SARS-01)	0.55	8	5.6	0.83	151
Sand (SARS-02)	0.4	4	1.9	1.23	308
Loam (SARS-03)	1.0	18	10.6	1.76	176
Silt loam (SARS-04)	1.35	26	15.7	2.47	183
Sandy loam (SARS-05)	0.6	10	5.6	1.60	267
Summary Statistics					
Mean	—	—	—	1.58	217
Standard deviation	—	—	—	0.614	67.0
Coefficient of variation	—	—	—	0.39	0.31

2.4.2.5 Leaching

A GLP study conducted by Nixon (1995 [MRID 43868601]) was carried out following the US EPA Pesticide Assessment Guidelines, Subdivision N, Series 163-1. The purpose of the study was to evaluate the soil leaching potential of malathion and its degradation products by column leaching in four soil types (sand, pH 7.6, 0.25% OC; sandy loam, pH 6.8, 1% OC; loam, pH 7.6, 1.71% OC; silty clay, pH 5.9, 1.36% OC). Soils were treated with approximately 5 mg a.i./kg dw soil. Following aging of approximately one half-life in each soil type, the soils were mixed thoroughly and added to the top of replicate columns containing untreated soil of each respective type. Saturated flow experiments were carried out on all four soils, while unsaturated flow leaching was assessed only in sandy loam. Saturated flow columns were eluted with a volume of 0.01M $CaCl_2$ equivalent to 50.8 cm (20 inches) of rainfall, while unsaturated flow columns containing sandy loam were eluted with the equivalent of 1 cm/day (0.4 inches/day) for

45 days. In the saturated flow leaching study (following aerobic aging), malathion and its degradation products exhibited moderate mobility. The percentages of applied radiocarbon (4.7-5.1 mg malathion/kg dw soil) passing through the columns in leachate were 5, 48.4, 61.8, and 74.4% for silty clay, sand, loam, and sandy loam, respectively. The parent malathion was only detected in the leachate of the sand column (2% of applied radiocarbon). MDCA was the predominant component of leachate fractions, followed by MMCA. No malaoxon was detected in either leachates or soil extracts (<0.12% of applied radiocarbon, <0.6 mg/kg). MDCA was the only degradation product identified in the leachate of the unsaturated flow experiment with sandy loam (11.8% of applied radiocarbon). Of the applied radiocarbon that remained in the soils, most stayed in the top 0 to 8 cm layer, with smaller percentages found in lower layers (8 to 32 cm). Reported distribution coefficients, K_d, for total radiocarbon under saturated flow conditions were 0.87, 0.50, 0.82, and 14.2 for sand, sandy loam, loam and silty clay, respectively. In unsaturated flow columns (sandy loam), the distribution coefficient for total radiocarbon was 3.8. Degradation of malathion is so rapid that the composition of total radiocarbon changed significantly during the leaching process, with malathion accounting for less than 40% of the applied radiocarbon found in leachate and extracted from soils. Thus, the reported K_d values are of limited utility for predicting the mobility of malathion (Nixon, 1995 [MRID 43868601]).

2.4.2.6 Volatilization

The Henry's Law Constant (K) for malathion of 1.2 $x10^{-7}$ atm m^3/mol indicates that the compound has a low potential to volatilize from moist soil or water (Cheminova A/S, 1988 [MRID 40966603]). In a GLP laboratory volatility study conducted in accordance with the EPA Pesticide Assessment Guidelines, Subdivision N, Section 163-2, less than 5.1% of malathion, in either emulsifiable concentrate (EC), ultra-low-volume (ULV), or ready-to-use (RTU) end-use products, was volatilized from soil surfaces (silt loam; pH 6.5, 2.2% OM, 16% clay, 25°C) over a 16-day study period (Spare and Cutchin, 1991 [MRID 42015201]).

A GLP aerobic soil biotransformation study following the EPA Pesticide Assessment Guidelines, Subdivision N, Section 162-1 was conducted in loam (1.2-1.6% OC, pH 6.1) and found that volatilization of ^{14}C-compounds did not occur (Blumhorst, 1990 [MRID 41721701]). The application rate was 6.88 mg malathion/kg soil (6.25 lb a.i./A). Similarly, Knoch (2001b [MRID 46769501]) investigated aerobic biotransformation of malathion in four soils (sand, silty clay, and two silty loams). Soil organic carbon ranged from 0.5 to 2.7%, and pH ranged from 5.1 to 7.3. The application rate was 2,000 g a.i./ha (1.79 lb a.i./A). Less than 0.1% of applied radioactivity was observed as volatile degradation products (excluding $^{14}CO_2$) during the experiment. Moreover, malaoxon was not detected. Knoch (2001b [MRID 46769501]) is a GLP study and was conducted in accordance with the SETAC guideline "Procedures for assessing the environmental fate and ecotoxicity of pesticides", part 1, 1.1 of March 1995 and with the OECD Draft Guideline for Aerobic and Anaerobic Transformation in Soil of July 1999.

In a GLP ^{14}C-malathion column leaching study with four soil types (sand, pH 7.6, 0.25% OC; sandy loam, pH 6.8, 1% OC; loam, pH 7.6, 1.71% OC; silty clay, pH 5.9, 1.36% OC), Nixon

(1995 [MRID 43868601]) reported ≤0.1% of applied radiocarbon was recovered in the volatile traps of saturated flow experiments for all four soil types. Similarly, in a concurrent unsaturated flow experiment with sandy loam, less than 0.1% of applied radiocarbon was recovered in the volatile trap. This study was carried out following the EPA Pesticide Assessment Guidelines, Subdivision N, Section 163-1.

The results of these studies indicate that volatilization is not an important aspect of malathion mobility in the environment.

2.4.2.7 Field Dissipation

Rice et al. (1990a [MRID 41748901]) performed a GLP terrestrial field soil dissipation study following the EPA Pesticide Assessment Guidelines, Subdivision N, Section 164-1 in Dooly County, Georgia using the Cythion ULV end-use product (91% purity). The test site was comprised of a treated cotton plot, a treated bare ground plot and an untreated plot. Six applications of malathion were at a rate of 1,300 g a.i./ha (1.16 lb a.i./A). The soil was loamy sand (pH 6.6, 0.42% OC). Dissipation of malathion was too rapid to determine a half-life but it was clearly less than one day. In all treated plots, malathion degraded to MDCA. Concentrations of MCDA measured in the top 6 inches of soil immediately following the last application were 0.010 and 0.028 ppm (mg a.i./kg dw) for bare ground and crop plots, respectively. Residues of MDCA dissipated to below the LOQ (0.010 mg a.i./kg dw) by day one following the final application of both bare ground and crop plots (Jacobson and Lochhaas, 1992a [MRID 43042401]).

Another GLP study conducted in accordance with the EPA Pesticide Assessment Guidelines, Subdivision N, Section 164-1 was carried out in Madera County, California that consisted of three treated replicate cotton plots, three treated bare ground plots and one untreated plot (Rice et al., 1990b [MRID 41727701]). The soil was a sandy loam (pH 6.1, 0.35% OC). Malathion (91% purity) was applied once a week for six weeks at a rate of 1,300 g a.i./ha (1.16 lb a.i./A). In all treated plots, malathion degraded to MDCA. Dissipation of malathion was too rapid to permit determination of a half-life but it was clearly less than one day. In this study, malathion was not detected below 30.5 cm (12 inches) (Rice et al., 1990b [MRID 41727701]). In all treated plots, malathion degraded to MCDA. In the crop plots, the MDCA concentrations were 0.052 and 0.044 ppm (mg a.i./kg dw) within the top six inches and between six and 12 inches of soil, respectively, immediately following the final application of malathion. MDCA in the top six inches of soil dissipated to below the LOQ (0.010 mg/kg dw) by 7 days after application. When all residues from all depths were summed, the MDCA half-life was estimated to be 1.7 days (Jacobson and Lochhaas, 1992b [MRID 43042402]).

Judy et al. (1991a,b [MRID 42058401, MRID 42058402]) also reported half-lives of less than one day (pH 5.5 to 7.4) for dissipation of malathion from studies of flooded rice paddies in California and Missouri. In these studies, malathion was applied weekly for three weeks at a rate of 650 g a.i./ha (0.58 lb a.i./A). Both studies are GLP and were conducted in accordance with the EPA Pesticide Assessment Guidelines, Subdivision N, Sections 164-2 and 165-3.

Therefore, the half-life for field dissipation of malathion on soil is expected to be less than one day (Rice et al., 1990a,b [MRIDs 41748901, 41727701]; Judy et al., 1991a,b [MRIDs 42058401, 42058402]).

2.4.2.8 Semi-Aquatic Field Dissipation and Irrigated Crop Accumulation

In a GLP study following the EPA Pesticide Assessment Guidelines, Subdivision N, Sections 164-2 and 165-3, three weekly applications of 650 g a.i./ha (0.58 lb a.i./A) malathion concentrate were made to a rice paddy (loamy sand and sandy loam, pH 7.3-7.7, 0.3-0.4% OC) in California (Judy et al. 1991a [MRID 42058401]). Soil cores and water samples were taken from the rice paddy before and after each application. Soil cores were then taken periodically for a year after the final application. Water samples were collected weekly in the first month after the final application. In addition, plots of lettuce, carrots, barley, grain sorghum, and tomatoes were irrigated from the treated rice paddy starting one day after the first application. Soil core samples were taken from each crop plot following irrigation, and periodically after the final application. During irrigation, water samples were taken from the irrigation system following each application. Also, vegetation samples were taken of the irrigated crops at immature growth stages and at crop maturity.

No malathion residues were detected in any soil samples from the treated rice plot (detection limit of 0.01 mg/kg dw soil; Judy et al., 1991a [MRID 42058401]). A mean malathion concentration of 21 µg/L in water was determined in samples collected from the treated irrigated crop plot immediately following the first application. No malathion residues were detected in any other water samples. Malaoxon was not detected in any water samples collected from the rice plot or the irrigation system (detection limit 10 µg/L). Malaoxon was only detected in two soil samples two days after the final application (16 days after the initial application). Concentrations in the two samples were 0.014 to 0.22 mg/kg dw in the 0-10 cm (0-4 ") layer sample, and 0.01 to 0.02 mg/kg dw in the ~45-60 cm (18-24") layer sample.

In another GLP study in Missouri that followed the same protocol as Judy et al. (1991a [MRID 42058401]), Judy et al. (1991b [MRID 42058402]) made three weekly applications of 650 g a.i./ha (0.58 lb a.i./A) (8 oz Cythion®) to a rice paddy (clay, pH 5.5-6.1, 0.7-1.3% OC). Following each application, malathion residues were detected in water samples collected from the rice plot. However, immediately prior to the second and third applications, malathion had dissipated to below the limit of detection in rice paddy water samples. The mean malathion residue concentration in rice paddy water following the final application was 160 µg/L. Malathion residues were found in only one water sample taken from the irrigation system following the first watering (13 µg/L). Malaoxon was not detected in any water samples from either the rice plot of the irrigation system (limit of detection 10 µg/L). No malathion residues were detected in soil samples (detection limit 0.01 mg/kg dw soil) or in any plant samples from the irrigated crop plots. Based on results presented above, malathion does not persist in semi-aquatic environments for long periods.

2.4.3 Fate and Behavior in Air

Phototransformation in air is a negligible route of malathion degradation. In an air photolysis study following the EPA Pesticide Assessment Guidelines, Subdivision N, Section 161-4 (Miller, 1988 [MRID 40969301]), less than 10% of the radiolabeled-malathion contained in 100 L Tedlar bags degraded over four days of irradiation, and no transformation products were observed (Miller, 1988 [MRID 40969301]). The UV-Vis absorption characteristics of malathion have been documented (Murrell et al., 2010 [MRID 47963501]). Under acidic conditions, the mean molar absorption coefficient and mean bandwidth of the peak at 201.5 nm was 3857 L/mol-cm and 23.3 nm (±0.3 nm), respectively. For neutral conditions, the mean molar absorption coefficient and mean bandwidth of the peak at 202.3 nm (± 0.3 nm) was 3227 L/mol-cm and 25.8 nm (±0.3 nm), respectively. For basic conditions the mean molar absorption coefficient and mean bandwidth of the peak at 202.8 nm (± 0.3 nm) was 12471 L/mol-cm and 24.5 nm (±0.3 nm), respectively.

2.4.4 Fate and Behavior in Plants

Malathion is not a systemic insecticide. However, two studies suggest that malathion and/or its metabolites are taken up by plants at very low levels. These studies applied radiolabeled malathion and measured radioactivity in plant tissues. In a GLP rotational crop study following the EPA Pesticide Assessment Guidelines, Subdivision N, Section 165-1 and conducted with turnip, lettuce and wheat plants by Wootton and Johnson (1993 [MRID 42785501]), radiolabeled malathion (^{14}C-malathion; 57% EC) was applied to sandy loam soil at a rate of 8,848 g a.i./ha (7.9 lb a.i./A). The applied malathion was manually incorporated into the soil (4 inches deep). Turnips, lettuce and wheat were planted at 30, 120 and 365 days after soil treatment. At each rotational interval, crops were sampled at immature and mature stages. Soil samples were collected prior to and after treatment, and at each planting and harvest. By 30 days after treatment, malathion concentrations in soil were approximately 0.07 mg/kg ww or 2.6% of total radioactive residue (TRR). Malaoxon was not detected (LOQ <0.01 mg/kg). By 365 days after treatment, malathion was only 0.5% TRR (0.01 mg/kg).

Radiocarbon residues of malathion in crop samples were at least one order of magnitude lower than in soil samples and decreased over the study period. Only the 30 days after treatment plot had crop samples with measurable residues. Malathion was found at 0.03 mg/kg ww in immature turnips, and was detected at 0.02 mg/kg in immature lettuce and immature wheat. Malaoxon was not detected (LOQ <0.01 mg/kg). The rapid degradation of malathion in soil left little malathion for uptake by rotational crops even within 30 days of application (Wootton and Johnson, 1993 [MRID 42785501]).

In parallel GLP field studies carried out in Missouri and California in accordance with the EPA Pesticide Assessment Guidelines, Subdivision N, Sections 164-2 and 165-3, several field crops were irrigated with water from malathion-treated rice paddies within 24 hours of three weekly applications of 649.6 g a.i./ha (0.58 lb a.i./A; Judy et al., 1991a,b [MRID 42058401, 42058402]). Plant samples were taken at immature growth stages and maturity. Malathion and malaoxon were not detected in barley, carrots, corn, grain, sorghum, soybeans, sweet potatoes, lettuce or

tomatoes irrigated with water from treated rice paddies. However, malathion was detected in irrigated crop water in one sample collected the day after the first application (13 µg/L) in Missouri and in two samples collected the day after the first application (22 µg/L for both measurements) in California.

In a recent GLP study following BBA guidelines part IV, 3-3, part IV, 3-6 and part IV, 3-8, an EW formulation containing 440 g/L malathion was applied to an apple orchard in the Kraichgau-Stromberg region of southwest Germany (Knäbe, 2004 [MRID 46525902]). The test substance was applied once in mid-May with a calibrated airblast sprayer at a rate of 1,800 g a.i./ha (1.6 lb a.i./A). Grasses and weeds growing between the trees were sampled seven days before the application (malathion was not detected) and then 0, 1, 2, 4, 8, 16, and 27 days after application. By day 27, malathion was below the limit of quantification of 0.01 mg/kg ww in sampled weeds and grasses. The maximum concentration of 45.0 mg/kg ww was observed on day 0. During the study, a total of 28.5 mm of precipitation was recorded. The first rainfall event occurred approximately 13 days after the application, at which point concentrations in grasses and weeds had already fallen to less than half the maximum observed concentration. The orchard received approximately eight hours of sun per day. The average monthly temperatures from the nearest weather station were 12.4 and 17.2°C, for May and June, respectively. Knäbe (2004 [MRID 46525902]) reported a dissipation half-life on grasses and weeds of 18.5 hours, and a corresponding DT90 of 2.6 days.

Cheminova has compiled an extensive database of GLP foliar dissipation study data (Moore et al., 2014a [MRID 49389301]). The database contains different studies conducted on various field, row and orchard crops in which malathion was applied via non-ULV and/or ULV application (Moore et al., 2014a [MRID 49389301]). These residue trials include both residue decline studies and preharvest interval studies and have been conducted on a wide variety of fruits, vegetables, cereals, and forage items for non-ULV and ULV malathion end use products. Studies were conducted in accordance with the Commission Directive 96/68/EC amending Council Directive 91/414/EC and/or EPA Pesticide Assessment Guidelines, Subdivision N, Section 171-4. Using the data feed item (crop type) specific half-lives and RUDs were estimated that are specific to malathion (Moore et al., 2014a [MRID 49389301]). Cheminova estimated mean DT50 (in days) for long/tall grass (ULV: 5.18; non-ULV: 4.51), forage/leafy crops (ULV: 3.9; non-ULV: 1.86), small fruit (ULV: 6.01; non-ULV: 5.06) and large fruit (ULV: 6.14; non-ULV: 3.31). A detailed description of the data and methodology can be found in Moore et al. (2014a [MRID 49389301]).

2.4.5 Fate and Behavior in Fish

A GLP flow-through bioaccumulation study for bluegill (*Lepomis macrochirus*) exposed to technical grade malathion was conducted in accordance with the EPA Pesticide Assessment Guidelines, Subdivision N, Section 165-4 and described in three reports (Forbis and Leak, 1994a,b [MRID 43106401, 43106402]; Kammerer and Robinson, 1994 [MRID 43340301]). Fish were exposed to radiolabeled malathion at a nominal water concentration of 1 µg/L for 28 days. Fish and water samples were analyzed at time zero, four hours after initial exposure and again 1, 3, 7, 14, 21, and 28 days after initial exposure. On day 28, the remaining fish were transferred to untreated water and sampled on days 1, 3, 7, 10, and 14 of depuration. Samples were also collected on days 21 and 28 for metabolite identification. Total radioactive residues were determined in water and in fish tissue (edible and inedible) at each sampling interval. Radioactive residues in whole fish ranged from 21 to 130 µg/kg at all sampling intervals. The uptake rate was estimated to be 104 ± 13 µg/kg of fish per µg/L of water per day. The depuration rate constant was determined to be 1.01 ± 0.09 per day, and the time to reach 50% depuration was estimated to be 0.69 ± 0.06 day. The whole fish BCF for bluegill was estimated to be 103 ± 16. MMCA was the major metabolite found in both fish tissues and water. Thus, malathion is not expected to bioaccumulate in fish.

2.4.6 Summary of Fate and Behavior in the Environment

The fate and behavior properties of malathion reported above are presented in Table 2-6.

Table 2-6 Summary of fate characteristics of malathion

Chemical Property	*Half-life (d)*	*Conditions*	*References [MRID]*
Degradation			
Hydrolysis	0.49 – 107	Water pH 5-9	Teeter, 1988 [MRID 40941201]
Hydrolysis (saline)	1 – 3 1 – 3 1	pH 7.4, 10 g/L salinity pH 8.0, 14 g/L salinity pH 8.1, 25 g/L salinity	Walker, 1976
Photolysis in water	94 – 156	pH 4, 25°C	Carpenter, 1990 [41673001]
Aerobic aquatic metabolism	0.3 – 3.3	Water pH 8.2-8.5	Blumhorst, 1991a [41721601]; Knoch, 2001a [46769502]; Hiler and Mannella, 2012 [48906401]
Aerobic aquatic metabolism (saline)	<3	Water pH 7.4, 10 g/L salinity, 25°C	Walker, 1976
Anaerobic aquatic metabolism	2.5	pH 8.7, 22±2°C	Blumhorst, 1991b [42216301]
Photolysis on soil	173	pH 6.5, 23.5°C, 10 mg a.i./kg ww	Dykes et al., 1990 [41695501]
Aerobic soil metabolism	0.02 – 0.60	pH 5.9-8.1, 20-27°C	Blumhorst, 1990 [41721701]; Knoch, 2001b [46769501]; Nixon, 1995 [MRID 43868601]
Dissipation			
Field soil dissipation	<1	pH 5.5-7.4	Rice et al., 1990a,b [41748901; 41727701]; Judy et al., 1991a,b [42058401; 42058402]
Foliage dissipation	3.9-6.14	ULV	Range of mean DT50 for long/tall grass, forage/leafy crops and small and large fruits calculated by Moore et al. (2014a [MRID 49389301])
	1.85 – 5.06	Non-ULV	

Table 2-6 Summary of fate characteristics of malathion			
Chemical Property	***Half-life (d)***	***Conditions***	***References [MRID]***
Aquatic dissipation	0.8 – 2.3	pH>8.0	Ebke, 2002 [46525901]

2.5 Mode of Action

Malathion is a contact organophosphorus pesticide, with stomach and respiratory action, and is used to kill a broad range of insects and mites. Malathion is metabolically activated to its oxygen analog, malaoxon, and the rate of formation and detoxification of malaoxon in organisms influences the degree of toxicity (EPA, 2016a). The toxicity of organophosphate chemicals, such as malathion, is based on inhibition of acetylcholinesterase (AChE) in the central and peripheral nervous systems. The inhibition of AChE results in a temporary effect, but over-exposure can lead to the build-up of the neurotransmitter acetylcholine (ACh) at cholinergic nerve endings, causing continual nerve stimulation (Namba, 1971; EPA, 2009a). ACh build-up and continual nerve stimulation can lead to very specific, but temporary, clinical signs of toxicity in fish including reduction in spontaneous swimming and feeding rates, swimming stamina, predator detection and homing behavior (Risher et al., 1987; WHO, 1991; Moore and Waring, 1996; Van Dolah et al., 1997; Scholz et al., 2000; Sandahl et al., 2005; Labenia et al., 2007). A variety of studies with estuarine fish have suggested that brain AChE inhibition of >50% is associated with mortality and some species of fish appear capable of tolerating much higher (>90%) brain AChE inhibition (Fulton and Key, 2001; Sandahl et al., 2005).

2.6 Malaoxon and Other Degradates

In plants and animals, malathion is metabolically converted to malaoxon (the oxygen analog to malathion). Malaoxon also inhibits the functionality of AChE. Malaoxon was identified by EPA as being the primary degradate of concern for ecological risk (EPA, 2010a). In several instances, EPA (2010a) asserts that malaoxon exposure would increase risk estimates above those predicted from exposure to malathion alone. Cheminova disagrees with this position because data suggest that degradates of malathion (i.e., malaoxon, MMCA and MDCA) are not expected to contribute significantly to ecological exposure and risk of organisms compared to the parent compound. As such, based on weight of evidence, Cheminova believes that degradates of malathion should not be assessed. See Appendix B for a detailed discussion on the occurrence and toxicity of malathion degradates. In brief, though malaoxon has been demonstrated to be slightly more toxic than malathion to some aquatic species, the fate and behavior of malaoxon suggests that it is likely not produced in the aquatic environment. Moreover, malaoxon degrades rapidly in water, sediment and soil samples. On the rare occasions when it is detected, malaoxon is found only at small percentages of applied malathion. As such, malaoxon is unlikely to be transported at environmentally relevant concentrations in which exposure would cause significant effects on growth, reproduction and survival. Thus, the effects of exposure to malathion degradates in the environment will not be considered in this effects determination.

2.7 Toxicity of Malathion

The following section provides an overview of the toxicity of malathion to receptors considered to be at risk in EPA's effects determination for the DS (EPA, 2010a). These taxa will be the focus of this refined effects determination and include both direct and indirect effects to the DS. Direct effects would result from a reduction in survival, growth and reproduction of the DS, while indirect effects would result from a reduction in survival, growth and reproduction of prey species (freshwater, marine and estuarine invertebrates). The effects metrics recommended for use in this effects determination are presented in Section 2.11 (Analysis Plan).

EPA is responsible for evaluating the quality of studies that are considered for use in their pesticide risk assessments. Moreover, the *Endangered Species Act* underscores and reinforces this duty, by requiring use of the "best available scientific data" (EPA, 2016b). In its recent review and guidance document entitled: "Assessing Risks to Endangered and Threatened Species from Pesticides", the National Academy of Sciences (NAS) noted the lack of a formal, consistent approach in defining "best data available" among EPA, US Fish and Wildlife Service and the National Marine Fisheries Service (NAS, 2013). It was suggested that the strengths and weaknesses of key studies be properly documented to ensure the relevance of each study.

NAS (2013) advised, with respect to the quality of data used in ecological risk assessment, that enough information should be provided by the author(s) for adequate scientific evaluation and reproducibility of the results. Cheminova is in agreement with this recommendation. If adequate information on study quality is not provided in a source document, the quality of the study is unknown (NAS, 2013). Data of lower quality should not be used to drive risk assessments when higher quality studies are available (NAS, 2013). Accordingly, all relevant data should be evaluated for quality before it is used in risk assessment.

A Pellston Workshop on improving the usability of ecotoxicology in regulatory decision-making was organized by the Society of Environmental Toxicology and Chemistry (SETAC) and held on August 30th to September 4th, 2015. SETAC Pellston Workshops provide a platform for discussions and collaborations between academia, business, government and NGOs. Topics addressed by workshop attendees included:

1. improving the reliability and reproducibility of ecotoxicity studies;
2. improving the use of peer-reviewed studies in regulatory risk assessment of chemicals; and
3. improving the methods used to evaluate single pieces of evidence or lines of evidence in risk assessment.

Experts at the Pellston Workshop acknowledged that there has been a steady convergence in peer reviewed journals of data transparency and reporting aspects (Stavely et al., 2016; McCarty et al., 2012; Ågerstrand et al., 2011), but that improvements are still needed. Most peer-reviewed journal articles today are not sufficiently technically sound to support risk assessment decisions. Although the peer-review process lends credibility to the information

contained in journal articles, this does not necessarily mean a study is high quality or appropriate for application in regulatory decision-making (Hall et al., 2012). Reviewers do not typically re-analyze data and will tend to accept that the authors' analysis is properly conceived (The Economist, 2013). In addition, academic research is seldom conducted for the specific purpose of risk assessment in a regulatory setting (Beronius et al., 2014). Studies in the peer-reviewed scientific literature seldom follow Good Laboratory Practice (GLP), and may or may not follow an acceptable guideline. The information reported in journal articles may be adequate to meet the research objective, but is often insufficient for risk assessment. Reasons for this include unawareness of information needed for regulatory use, and lack of space available in scientific journals (Beronius et al., 2014). Finally, peer-reviewed journal articles are typically selected for publication due to their stimulation of scientific debate (McCarty et al., 2012). With this in mind, it is well recognized that there is a publication bias, i.e., that insignificant or negative results (e.g., no effects) are less likely to be submitted and published in peer reviewed journals, and this bias may be growing (Harris et al., 2014; The Economist, 2013). For similar reasons, studies repeating previously published work to contradict or confirm results are less likely to be accepted for publication in scientific journals (Stavely et al., 2016; Harris et al., 2014; Nature, 2013).

Information about the toxic effects of malathion can be found in various sources, including registrant-submitted studies, many of which were conducted pursuant to GLP requirements. Studies submitted to satisfy EPA requirements follow widely accepted protocols and generally provide the best available data (McCarty et al., 2012). Protocols are based on current and well-tested analytical methods and have been through rigorous scientific review. Good Laboratory Practice Standards require thorough documentation and verification of study conduct. EPA's GLPs specifically state that "The identity, strength, purity, and composition, or other characteristics that will appropriately define the test, control, or reference substance shall be determined for each batch and shall be documented before use in a study" (40 CFR Part 160.105(a), 2013). It is Cheminova's contention that all sources of information should be evaluated using common criteria. For this effects determination, available toxicity studies from all sources were evaluated for quality and acceptability using the criteria developed by Cheminova (Breton et al., 2014 [MRID 49333901]). Cheminova's approach to evaluating studies builds upon the Breton et al. (2009), Klimisch et al. (1997), California Department of Fish and Game (CDFG), EPA ECOTOXicology database (ECOTOX) and Office of Pesticide Programs (OPP) (EPA, 2011) schemes. The detailed study evaluation criteria as well as completed study evaluations for malathion toxicity studies can be found in Breton et al. (2014 [MRID 49333901]; 2015 [MRID 49692301]). Those studies scored as acceptable or, in their absence, those scored as supplemental were considered for use as effect metrics for this effects determination. A summary of the results from acceptable and supplemental studies considered in this effects determination is provided below. When author-reported endpoints were in terms of test substance (i.e., not corrected for % active ingredient), Intrinsik converted the endpoint to active ingredient using the reported purity, assuming w/w. Endpoints not clearly reported in terms of active ingredient or test substance were noted within the text and tables.

Registrant GLP toxicity studies commissioned by Cheminova have been conducted using Cheminova's registered technical malathion and its registered formulated products. Some impurities are known to potentiate, or have synergistic or antagonistic effects on toxicity. Levels of these impurities vary based on manufacturing process employed by different manufacturers and handling conditions (Breton et al., 2014 [MRID 49333901]; Hillwalker and Reiss, 2014 [MRID 49316501]). Data presented in Hillwalker and Reiss, (2014 [MRID 49316501]) also show that the impurity content of isomalathion and malaoxon in malathion significantly increases toxicity in a number of organisms. Therefore, it is important to know the impurity profile of technical material and the composition of inerts within a formulation when assessing the effects of the parent compound on non-target organisms. Because the inert profiles of end-use products are considered to be "confidential business information", it is not possible for Cheminova to evaluate the relevance of toxicity data that may be available for end-use products registered in the US by other companies. However, almost all of the regulatory ecological effects data submitted to EPA were conducted using end-use products manufactured by either Cheminova or American Cyanamid and these data have been conducted according to EPA guidelines and GLPs. Because Cheminova is familiar with the inert profiles of the end-use products tested in these studies, they are generally considered acceptable for use in risk assessment if they otherwise meet our acceptance criteria.

A comparison of the effect concentrations from acceptable and supplemental studies shows that technical malathion is equally or slightly more toxic to aquatic organisms than are malathion formulations (Table 2-7). As a result, studies conducted using technical malathion will be the focus of the assessment of malathion toxicity to aquatic receptors. See Breton et al. (2014 [MRID 49333901]; 2015 [MRID 49692301]) for more details on evaluation of studies conducted with technical malathion and formulations.

Table 2-7 Comparison of toxicity of technical malathion and formulated product to aquatic biota									
Product Tested	***Purity (% a.i.)***	***Common Name***	***Scientific Name***	***Exposure Duration***	***Endpoint***	***Measure of Effect***	***Concentration (µg a.i./L)***	***Reference [MRID]***	***Cheminova's Study Rating***
Aquatic Invertebrates									
Technical	96.9	Water flea	*Daphnia magna*	48 h	EC50	Immobilization	0.70	Gries and Purghart, 2001a [47540303]	Acceptable
Formulation	40.6	Water flea	*Daphnia magna*	48 h	EC50	Immobilization	1.8	Gries and Purghart, 2001b [49086401]	Acceptable
Formulation	57	Water flea	*Daphnia magna*	48 h	LC50	Survival	1.3	Burgess, 1989 [41029701]	Supplemental
Fish									
Technical	96	Rainbow trout	*Oncorhynchus mykiss*	96 h	LC50	Survival	174	Gries and Purghart, 2001c [47540302]	Acceptable
Formulation	40.6	Rainbow trout	*Oncorhynchus mykiss*	96 h	LC50	Survival	300	Gries and Purghart, 2001d [47540308, 49051203]	Acceptable
Technical	96.9	Bluegill	*Lepomis macrochirus*	96 h	LC50	Survival	52	Gries and Purghart, 2001e [47540304]	Acceptable
Formulation	40.6	Bluegill	*Lepomis macrochirus*	96 h	LC50	Survival	53	Gries and Purghart, 2001f [49051202]	Acceptable

2.7.1 Fish

Study evaluations for freshwater and marine fish toxicity studies are presented in Breton et al. (2014 [MRID 49333901], 2015 [MRID 49692301]).

Freshwater acute

Ten acceptable acute studies were available for freshwater fish exposed to technical malathion, all of which were conducted under GLP (Table 2-8). Typically to assess effects to fish, 96-hour LC50s are used in screening-level assessments because they are often the most sensitive time point assessed in acute tests (EPA, 2004a). Of the acceptable studies, the bluegill sunfish (*Lepomis macrochirus*) and green sunfish (*Lepomis cyanellus*) appear to be the most sensitive species with 96-hour LC50s of 52 and 130 µg a.i./L, respectively (Gries and Purghart, 2001e [MRID 47540304]; Brougher et al., 2014a [MRID 49364101]). The fathead minnow (*Pimephales promelas*) and common carp (*Cyprinus carpio*) appear to be considerably less sensitive, with 96-hour LC50s of 28,000 and >9,600 µg a.i./L, respectively (Claude et al., 2013a [MRID 49252802]; Gries and Van der Kolk, 2002 [MRID 48998005]). There are no supplemental studies available that assess acute effects to freshwater fish.

Freshwater chronic

There was one acceptable chronic fish study and one supplemental chronic fish study (Table 2-9). Palmer et al. (2011a [MRID 48617506]) conducted the acceptable 21-day study using the fathead minnow. The LOEL for reproductive effects (reduction in eggs laid) was 820 µg a.i./L and the associated NOEL was 250 µg a.i./L. The study rated as supplemental was conducted by Cohle (1989 [MRID 41422401]). The 97-day study was conducted using a flow-through system and rainbow trout (*Oncorhynchus mykiss*). The LOEL for fry survival and growth was 44 µg a.i./L and the associated NOEL was 21 µg a.i./L.

Marine acute

Two acceptable acute marine fish studies (Table 2-10) were available. From these studies, the 96-hour LC50s were 20.8 and 47.4 µg a.i./L for the three-spined stickleback (*Gasterosteus aculeatus*) and sheepshead minnow (*Cyprinodon variegatus*), respectively (Gries et al. 2002a [MRID 48998006]; Burke, 2011 [MRID 49055701]). A supplemental acute study was also available for the sheepshead minnow (*Cyprinodon variegatus*) in which the reported 96-hour LC50 was 38 µg a.i./L (Bowman, 1989 [MRID 41174301]).

Marine chronic

One acceptable chronic study was available for marine fish (Table 2-11). The sheepshead minnow was exposed to malathion for 34 days and effects to survival, hatch, length, and weight were assessed. The most sensitive effect was survival, for which the NOEL and LOEL were 8.2 and 16 µg a.i./L, respectively (Hurd and Sharpe, 2011 [MRID 48705301]).

Table 2-8 Acceptable toxicity studies conducted with technical malathion: acute endpoints for freshwater fish[a]								
Common Name	***Scientific Name***	***Purity (% a.i.)***	***Exposure Duration***	***Endpoint***	***Measure of Effects***	***Concentration in µg test substance/L (brackets indicate µg a.i./L)***	***Reference***	***MRID***
Bluegill sunfish	*Lepomis macrochirus*	96.9	24 h	LC50	Survival	120 (116)[b]	Gries and Purghart, 2001e	47540304
Bluegill sunfish	*Lepomis macrochirus*	96.9	48 h	LC50	Survival	120 (116)[b]	Gries and Purghart, 2001e	47540304
Bluegill sunfish	*Lepomis macrochirus*	96.9	72 h	LC50	Survival	76 (74)[b]	Gries and Purghart, 2001e	47540304
Bluegill sunfish	*Lepomis macrochirus*	96.9	96 h	LC50	Survival	54 (52)[b]	Gries and Purghart, 2001e	47540304
Bluegill sunfish	*Lepomis macrochirus*	96.9	96 h	LOEL	Survival	64 (62)[b]	Gries and Purghart, 2001e	47540304
Bluegill sunfish	*Lepomis macrochirus*	96.9	96 h	NOEL	Survival	32 (31)[b]	Gries and Purghart, 2001e	47540304
Coho salmon	*Oncorhynchus kisutch*	96.8	24 h	LC50	Survival	(800)	Brougher et al., 2014b	49479003
Coho salmon	*Oncorhynchus kisutch*	96.8	48 h	LC50	Survival	(770)	Brougher et al., 2014b	49479003
Coho salmon	*Oncorhynchus kisutch*	96.8	72 h	LC50	Survival	(740)	Brougher et al., 2014b	49479003
Coho salmon	*Oncorhynchus kisutch*	96.8	96 h	LC50	Survival	(720)	Brougher et al., 2014b	49479003
Common carp	*Cyprinus carpio*	96	24 h	LC50	Survival	>10000 (>9600)[b]	Gries and Van der Kolk, 2002	48998005
Common carp	*Cyprinus carpio*	96	48 h	LC50	Survival	>10000 (>9600)[b]	Gries and Van der Kolk, 2002	48998005
Common carp	*Cyprinus carpio*	96	72 h	LC50	Survival	>10000 (>9600)[b]	Gries and Van der Kolk, 2002	48998005
Common carp	*Cyprinus carpio*	96	96 h	LC50	Survival	>10000 (>9600)[b]	Gries and Van der Kolk, 2002	48998005
Common carp	*Cyprinus carpio*	96	96 h	NOEL	Survival	≥10000 (≥9600)[b]	Gries and Van der Kolk, 2002	48998005
Fathead minnow	*Pimephales promelas*	99.4	24 h	LC50	Survival	(38000)	Claude et al., 2013a	49252802
Fathead minnow	*Pimephales promelas*	99.4	48 h	LC50	Survival	(35000)	Claude et al., 2013a	49252802
Fathead minnow	*Pimephales promelas*	99.4	72 h	LC50	Survival	(28000)	Claude et al., 2013a	49252802
Fathead minnow	*Pimephales promelas*	99.4	96 h	LC50	Survival	(28000)	Claude et al., 2013a	49252802

Table 2-8 Acceptable toxicity studies conducted with technical malathion: acute endpoints for freshwater fish[a]								
Common Name	***Scientific Name***	***Purity (% a.i.)***	***Exposure Duration***	***Endpoint***	***Measure of Effects***	***Concentration in µg test substance/L (brackets indicate µg a.i./L)***	***Reference***	***MRID***
Fathead minnow	*Pimephales promelas*	98.6	24 h	LC50	Survival	(28000)	Claude et al., 2013b	49252801
Fathead minnow	*Pimephales promelas*	98.6	48 h	LC50	Survival	(27000)	Claude et al., 2013b	49252801
Fathead minnow	*Pimephales promelas*	98.6	72 h	LC50	Survival	(27000)	Claude et al., 2013b	49252801
Fathead minnow	*Pimephales promelas*	98.6	96 h	LC50	Survival	(27000)	Claude et al., 2013b	49252801
Fathead minnow	*Pimephales promelas*	96	24 h	LC50	Survival	>7980 (>7660)	Gries et al., 2002b	48998004
Fathead minnow	*Pimephales promelas*	96	48 h	LC50	Survival	>7980 (>7660)	Gries et al., 2002b	48998004
Fathead minnow	*Pimephales promelas*	96	72 h	LC50	Survival	>7980 (>7660)	Gries et al., 2002b	48998004
Fathead minnow	*Pimephales promelas*	96	96 h	LC50	Survival	>7980 (>7660)	Gries et al., 2002b	48998004
Fathead minnow	*Pimephales promelas*	96	96 h	LOEL	Survival	7980 (7660)	Gries et al., 2002b	48998004
Fathead minnow	*Pimephales promelas*	96	96 h	NOEL	Survival	946 (909)	Gries et al., 2002a	48998004
Green sunfish	*Lepomis cyanellus*	96.8	24 h	LC50	Survival	(>270)	Brougher et al., 2014a	49364101
Green sunfish	*Lepomis cyanellus*	96.8	48 h	LC50	Survival	(200)	Brougher et al., 2014a	49364101
Green sunfish	*Lepomis cyanellus*	96.8	72 h	LC50	Survival	(150)	Brougher et al., 2014a	49364101
Green sunfish	*Lepomis cyanellus*	96.8	96 h	LC50	Survival	(130)	Brougher et al., 2014a	49364101
Medaka	*Oryzias latipes*	96.8	24 h	LC50	Survival	(>2700)	Brougher et al., 2014c	49364102
Medaka	*Oryzias latipes*	96.8	48 h	LC50	Survival	(2600)	Brougher et al., 2014c	49364102
Medaka	*Oryzias latipes*	96.8	72 h	LC50	Survival	(1800)	Brougher et al., 2014c	49364102
Medaka	*Oryzias latipes*	96.8	96 h	LC50	Survival	(1500)	Brougher et al., 2014c	49364102
Rainbow trout	*Oncorhynchus mykiss*	96.9	2 h	LC50	Survival	1100 (1066)[b]	Gries and Purghart, 2001c	47540302

Table 2-8 Acceptable toxicity studies conducted with technical malathion: acute endpoints for freshwater fish[a]								
Common Name	***Scientific Name***	***Purity (% a.i.)***	***Exposure Duration***	***Endpoint***	***Measure of Effects***	***Concentration in µg test substance/L (brackets indicate µg a.i./L)***	***Reference***	***MRID***
Rainbow trout	*Oncorhynchus mykiss*	96	4 h	LC50	Survival	690 (669)[b]	Gries and Purghart, 2001c	47540302
Rainbow trout	*Oncorhynchus mykiss*	96	24 h	LC50	Survival	410 (397)[b]	Gries and Purghart, 2001c	47540302
Rainbow trout	*Oncorhynchus mykiss*	96	48 h	LC50	Survival	370 (359)[b]	Gries and Purghart, 2001c	47540302
Rainbow trout	*Oncorhynchus mykiss*	96	72 h	LC50	Survival	270 (261)[b]	Gries and Purghart, 2001c	47540302
Rainbow trout	*Oncorhynchus mykiss*	96	96 h	LC50	Survival	180 (174)[b]	Gries and Purghart, 2001c	47540302
Rainbow trout	*Oncorhynchus mykiss*	96	96 h	LOEL	Survival	197 (191)	Gries and Purghart, 2001c	47540302
Rainbow trout	*Oncorhynchus mykiss*	96	96 h	NOEL	Survival	91 (89)	Gries and Purghart, 2001c	47540302
Western mosquitofish	*Gambusia affinis*	96.8	24 h	LC50	Survival	(5600)	Brougher et al., 2014d	49422801
Western mosquitofish	*Gambusia affinis*	96.8	48 h	LC50	Survival	(4500)	Brougher et al., 2014d	49422801
Western mosquitofish	*Gambusia affinis*	96.8	72 h	LC50	Survival	(3400)	Brougher et al., 2014d	49422801
Western mosquitofish	*Gambusia affinis*	96.8	96 h	LC50	Survival	(2900)	Brougher et al., 2014d	49422801

[a] No supplemental acute toxicity studies conducted with technical malathion on freshwater fish were available.
[b] Authors did not correct for purity. Intrinsik converted these endpoints using the reported purity, assuming w/w.

Table 2-9 Acceptable and supplemental toxicity studies conducted with technical malathion: chronic endpoints for freshwater fish[a]

Common Name	Scientific Name	Purity (% a.i.)	Exposure Duration	Endpoint	Measure of Effects	Concentration µg/L (µg a.i./L)	Reference	MRID	Cheminova's Study Rating
Fathead minnow	*Pimephales promelas*	96	21 d	LOEL	Reproduction	(820)	Palmer et al., 2011a	48617506	Acceptable
Fathead minnow	*Pimephales promelas*	96	21 d	NOEL	Reproduction (cumulative number of eggs produced and eggs per female per reproductive day; tubercle score for males)	(250)	Palmer et al., 2011a	48617506	Acceptable
Rainbow trout	*Oncorhynchus mykiss*	94	97 d	LOEL	Fry survival and growth	44[b]	Cohle, 1989	41422401	Supplemental
Rainbow trout	*Oncorhynchus mykiss*	94	97 d	NOEL	Fry survival and growth	21[b]	Cohle, 1989	41422401	Supplemental

[a] Study was deemed supplemental. Study met generic, chemical-specific and additional acceptability criteria. However, as per the National Academy of Sciences (NAS, 2013), the test material must be determined to be relevant to the United States. For malathion, the relevance of the study can only be determined by knowing the composition of the product and demonstrating that the composition is similar to a currently registered product. For these reasons, a study is classified as acceptable when the composition of the impurities and/or inerts is known and is verifiable as being relevant to the United States, and meets all other generic and acceptable criteria. Studies conducted by American Cyanamid can be classified as supplemental if the batch number is available.

[b] It is unclear whether endpoints are reported in terms of test substance or active ingredient.

Table 2-10 Acceptable and supplemental toxicity studies conducted with technical malathion: acute endpoints for marine fish[a]

Common Name	Scientific Name	Purity (% a.i.)	Exposure Duration	Endpoint	Measure of Effects	Concentration µg test substance/L (µg a.i./L)	Reference	MRID	Cheminova's Study Rating
Sheepshead minnow	Cyprinodon variegatus	98.8	24 h	LC50	Survival	(181.8)	Burke, 2011	49055701	Acceptable
Sheepshead minnow	Cyprinodon variegatus	98.8	48 h	LC50	Survival	(122)	Burke, 2011	49055701	Acceptable
Sheepshead minnow	Cyprinodon variegatus	98.8	72 h	LC50	Survival	(113.5)	Burke, 2011	49055701	Acceptable
Sheepshead minnow	Cyprinodon variegatus	98.8	96 h	LC50	Survival	(47.4)	Burke, 2011	49055701	Acceptable

Table 2-10 Acceptable and supplemental toxicity studies conducted with technical malathion: acute endpoints for marine fish[a]

Common Name	*Scientific Name*	*Purity (% a.i.)*	*Exposure Duration*	*Endpoint*	*Measure of Effects*	*Concentration µg test substance/L (µg a.i./L)*	*Reference*	*MRID*	*Cheminova's Study Rating*
Sheepshead minnow	Cyprinodon variegatus	98.8	24 h	LOEL	Survival	(89.6)	Burke, 2011	49055701	Acceptable
Sheepshead minnow	Cyprinodon variegatus	98.8	48 h	LOEL	Survival	(46.9)	Burke, 2011	49055701	Acceptable
Sheepshead minnow	Cyprinodon variegatus	98.8	72 h	LOEL	Survival	(46.9)	Burke, 2011	49055701	Acceptable
Sheepshead minnow	Cyprinodon variegatus	98.8	96 h	LOEL	Survival	(28.5)	Burke, 2011	49055701	Acceptable
Sheepshead minnow	Cyprinodon variegatus	98.8	24 h	NOEL	Survival	(68.5)	Burke, 2011	49055701	Acceptable
Sheepshead minnow	Cyprinodon variegatus	98.8	48 h	NOEL	Survival	(28.5)	Burke, 2011	49055701	Acceptable
Sheepshead minnow	Cyprinodon variegatus	98.8	72 h	NOEL	Survival	(28.5)	Burke, 2011	49055701	Acceptable
Sheepshead minnow	Cyprinodon variegatus	98.8	96 h	NOEL	Survival	(28.5)	Burke, 2011	49055701	Acceptable
Sheepshead minnow	Cyprinodon variegatus	94	24 h	LC50	Survival	43 (40)[b]	Bowman, 1989	41174301	Supplemental
Sheepshead minnow	Cyprinodon variegatus	94	48 h	LC50	Survival	43 (40)[b]	Bowman, 1989	41174301	Supplemental
Sheepshead minnow	Cyprinodon variegatus	94	72 h	LC50	Survival	40 (38)[b]	Bowman, 1989	41174301	Supplemental
Sheepshead minnow	Cyprinodon variegatus	94	96 h	LC50	Survival	40 (38)[b]	Bowman, 1989	41174301	Supplemental
Sheepshead minnow	Cyprinodon variegatus	94	96 h	LOEL	Survival	35 (33)[b]	Bowman, 1989	41174301	Supplemental
Sheepshead minnow	Cyprinodon variegatus	94	96 h	NOEL	Survival	18 (17)[b]	Bowman, 1989	41174301	Supplemental
Three-spined stickleback	Gasterosteus aculeatus	96	2 h	LC50	Survival	>81.4 (>78.1)	Gries et al., 2002a	48998006	Acceptable
Three-spined stickleback	Gasterosteus aculeatus	96	24 h	LC50	Survival	21.7 (20.8)	Gries et al., 2002a	48998006	Acceptable
Three-spined stickleback	Gasterosteus aculeatus	96	4 h	LC50	Survival	>52.7 (>50.6)	Gries et al., 2002a	48998006	Acceptable
Three-spined stickleback	Gasterosteus aculeatus	96	48 h	LC50	Survival	21.7 (20.8)	Gries et al., 2002a	48998006	Acceptable

Table 2-10 Acceptable and supplemental toxicity studies conducted with technical malathion: acute endpoints for marine fish[a]

Common Name	Scientific Name	Purity (% a.i.)	Exposure Duration	Endpoint	Measure of Effects	Concentration µg test substance/L (µg a.i./L)	Reference	MRID	Cheminova's Study Rating
Three-spined stickleback	Gasterosteus aculeatus	96	72 h	LC50	Survival	21.7 (20.8)	Gries et al., 2002a	48998006	Acceptable
Three-spined stickleback	Gasterosteus aculeatus	96	96 h	LC50	Survival	21.7 (20.8)	Gries et al., 2002a	48998006	Acceptable
Three-spined stickleback	Gasterosteus aculeatus	96	96 h	LOEL	Survival	11.1 (10.7)	Gries et al., 2002a	48998006	Acceptable
Three-spined stickleback	Gasterosteus aculeatus	96	96 h	NOEL	Survival	5.01 (4.81)	Gries et al., 2002a	48998006	Acceptable

[a] Study was deemed supplemental. Study met generic, chemical-specific and additional acceptability criteria. However, as per the National Academy of Sciences (NAS, 2013), the test material must be determined to be relevant to the United States. For malathion, the relevance of the study can only be determined by knowing the composition of the product and demonstrating that the composition is similar to a currently registered product. For these reasons, a study is classified as acceptable when the composition of the impurities and/or inerts is known and is verifiable as being relevant to the United States, and meets all other generic and acceptable criteria. Studies conducted by American Cyanamid can be classified as supplemental if the batch number is available.

[b] Author did not correct for purity. Intrinsik converted these endpoints using the reported purity assuming w/w.

Table 2-11 Acceptable toxicity studies conducted with technical malathion: chronic endpoints for marine fish[a]

Common Name	Scientific Name	Purity (% a.i.)	Exposure Duration	Endpoint	Measure of Effects	Concentration (µg a.i./L)	Reference	MRID
Sheepshead minnow	*Cyprinodon variegatus*	96	34 d	LOEL	Dry weight	>33	Hurd and Sharpe, 2011	48998006
Sheepshead minnow	*Cyprinodon variegatus*	96	34 d	NOEL	Dry weight	33	Hurd and Sharpe, 2011	48998006
Sheepshead minnow	*Cyprinodon variegatus*	96	34 d	LOEL	Hatch	>33	Hurd and Sharpe, 2011	48998006
Sheepshead minnow	*Cyprinodon variegatus*	96	34 d	NOEL	Hatch	33	Hurd and Sharpe, 2011	48998006
Sheepshead minnow	*Cyprinodon variegatus*	96	34 d	LOEL	Standard length	>33	Hurd and Sharpe, 2011	48998006
Sheepshead minnow	*Cyprinodon variegatus*	96	34 d	NOEL	Standard length	33	Hurd and Sharpe, 2011	48998006
Sheepshead minnow	*Cyprinodon variegatus*	96	34 d	LOEL	Survival	16	Hurd and Sharpe, 2011	48998006
Sheepshead minnow	*Cyprinodon variegatus*	96	34 d	NOEL	Survival	8.2	Hurd and Sharpe, 2011	48998006

[a] No supplemental chronic toxicity studies conducted with technical malathion on marine fish were available.

2.7.2 *Aquatic Invertebrates*

Study evaluations for aquatic invertebrates can be found in Breton et al. (2014 [MRID 49333901], 2015 [MRID 49692301]).

Freshwater acute

There were five acceptable studies and one supplemental study available for the acute toxicity of malathion to freshwater invertebrates (Table 2-12). In the five acceptable studies, Gries and Purghart (2001a [MRID 4754303]) reported a 48-hour EC50 (immobilization) of 0.70 µg a.i/L for the water flea (*Daphnia magna*) and Brougher et al. (2014e-h [MRID 49479002, 49389402, 49479001, 49534901]) reported 48-hour LC50s of 3.5, 4.8, 23, and >35,000 µg a.i/L for the midge (*Chironomus dilutus*), freshwater amphipod (*Gammarus pseudolimnaeus*), mayfly (*Centroptilum triangulifer*), and red swamp crayfish (*Procambarus clarkii*), respectively. From the only supplemental study, an acute 48-hour EC50 for immobility of 2.1 µg a.i./L was reported by Mattock (2002 [MRID 41718401]).

Freshwater chronic

There were no acceptable studies for chronic effects of malathion to aquatic freshwater invertebrates. There was, however, one supplemental study that was conducted by Blakemore and Burgess (1990 [MRID 41718401]) (Table 2-13). The study was conducted over a 21-day period using a flow-through system and *Daphnia magna*. The LOEL and NOEL for survival and reproduction were 0.1 and 0.06 µg a.i./L, respectively (Table 2-13).

Marine acute

For acute toxicity to marine invertebrates, there were three acceptable toxicity studies and one supplemental toxicity study available (Table 2-14). Brougher et al. (2014i-k [MRIDs 49389401, 49534902, 49389403]) reported a 48-hour LC50 of 7.8 µg a.i./L for the mysid shrimp (*Americamysis bahia*), a 48-hour LC50 of >162 µg a.i./L for the daggerblade grass shrimp (*Palaemonetes pugio*), and a 96-hour EC50 (shell deposition) of 2700 µg a.i./L for the Eastern oyster (*Crassostrea virginica*). Forbis (1990 [MRID 41474501]) found 24, 48, 72, and 96-hour LC50s of >6.8, 3.6, 2.3, and 2.2 µg a.i./L, respectively for the mysid shrimp (*Mysidopsis bahia,* which is now known as *Americamysis bahia*).

Marine chronic

For marine invertebrates, one acceptable chronic study is available (Table 2-15). Claude et al. (2012 [MRID 48752901]) exposed adult mysid shrimp (*Americamysis bahia*) to malathion for 39 days and measured effects to survival, growth and reproduction. The reported NOEL and LOEL (survival and growth) were 0.58 and 1.2 µg a.i./L, respectively. The NOEL and LOEL for reproduction were 0.29 and 0.58 µg a.i./L, respectively. In addition, Claude et al. (2012 [MRID 48752901]) reported a 14-day NOEL of 1.2 µg a.i./L for survival of juvenile mysids.

Table 2-12 Acceptable and supplemental toxicity studies conducted with technical malathion: acute endpoints for freshwater invertebrates

Common Name	Scientific Name	Purity (% a.i.)	Exposure Duration	Endpoint	Measure of Effects	Concentration in µg test substance/L (brackets indicate µg a.i./L)	Reference	MRID	Cheminova's Study Rating[a]
Freshwater amphipod	*Gammarus pseudolimnaeus*	96.8	24 h	LC50	Survival	(>8.8)	Brougher et al., 2014f	49389402	Acceptable
Freshwater amphipod	*Gammarus pseudolimnaeus*	96.8	48 h	LC50	Survival	(4.8)	Brougher et al., 2014f	49389402	Acceptable
Freshwater amphipod	*Gammarus pseudolimnaeus*	96.8	72 h	LC50	Survival	(3.1)	Brougher et al., 2014f	49389402	Acceptable
Freshwater amphipod	*Gammarus pseudolimnaeus*	96.8	96 h	LC50	Survival	(2.1)	Brougher et al., 2014f	49389402	Acceptable
Mayfly	*Centroptilum triangulifer*	96.8	24 h	LC50	Survival	(53)	Brougher et al., 2014g	49479001	Acceptable
Mayfly	*Centroptilum triangulifer*	96.8	48 h	LC50	Survival	(23)	Brougher et al., 2014g	49479001	Acceptable
Midge	*Chironomus dilutus*	96.8	24 h	LC50	Survival	(54)	Brougher et al., 2014e	49479002	Acceptable
Midge	*Chironomus dilutus*	96.8	48 h	LC50	Survival	(3.5)	Brougher et al., 2014e	49479002	Acceptable
Red swamp crayfish	*Procambarus clarkii*	96.8	24 h	LC50	Survival	>(35000)	Brougher et al., 2014h	49534901	Acceptable
Red swamp crayfish	*Procambarus clarkii*	96.8	48 h	LC50	Survival	>(35000)	Brougher et al., 2014h	49534901	Acceptable
Red swamp crayfish	*Procambarus clarkii*	96.8	72 h	LC50	Survival	(33000)	Brougher et al., 2014h	49534901	Acceptable
Red swamp crayfish	*Procambarus clarkii*	96.8	96 h	LC50	Survival	(21000)	Brougher et al., 2014h	49534901	Acceptable
Water flea	*Daphnia magna*	96.9	24 h	EC50	Immobilization	>1.3 (1.3)[b]	Gries and Purghart, 2001a	47540303	Acceptable
Water flea	*Daphnia magna*	96.9	48 h	EC50	Immobilization	0.72 (0.70)[b]	Gries and Purghart, 2001a	47540303	Acceptable
Water flea	*Daphnia magna*	99.4	24 h	EC50	Immobilization	(5.1)	Mattock, 2002	47540301	Supplemental
Water flea	*Daphnia magna*	99.4	48 h	EC50	Immobilization	(2.1)	Mattock, 2002	47540301	Supplemental

[a] Study was deemed supplemental because it met generic and chemical-specific criteria, but did not meet additional acceptability criteria.
[b] Authors did not correct for purity. Intrinsik converted these endpoints to µg a.i./L using the reported chemical purity assuming w/w.

Table 2-13 Supplemental toxicity studies conducted with technical malathion: chronic endpoints for freshwater invertebrates[a]

Common Name	Scientific Name	Purity (% a.i.)	Exposure Duration	Endpoint	Measure of Effects	Concentration (µg a.i./L)	Reference	MRID
Water flea	*Daphnia magna*	94	21 d	EC50	Immobilization	0.52	Blakemore and Burgess, 1990	41718401
Water flea	*Daphnia magna*	94	21 d	LOEL	Growth (adult mean length)	0.1	Blakemore and Burgess, 1990	41718401
Water flea	*Daphnia magna*	94	21 d	NOEL	Growth (adult mean length)	0.06	Blakemore and Burgess, 1990	41718401
Water flea	*Daphnia magna*	94	21 d	LOEL	Reproduction (mean time to first brood and reproduction day)	0.1	Blakemore and Burgess, 1990	41718401
Water flea	*Daphnia magna*	94	21 d	NOEL	Reproduction (mean time to first brood and reproduction day)	0.06	Blakemore and Burgess, 1990	41718401
Water flea	*Daphnia magna*	94	21 d	LOEL	Survival	0.1	Blakemore and Burgess, 1990	41718401
Water flea	*Daphnia magna*	94	21 d	NOEL	Survival	0.06	Blakemore and Burgess, 1990	41718401

[a] Study was deemed supplemental. Study met generic, chemical-specific and additional acceptability criteria. However, as per the National Academy of Sciences (NAS, 2013), the test material must be determined to be relevant to the United States. For malathion, the relevance of the study can only be determined by knowing the composition of the product and demonstrating that the composition is similar to a currently registered product. For these reasons, a study is classified as acceptable when the composition of the impurities and/or inerts is known and is verifiable as being relevant to the United States, and meets all other generic and acceptable criteria. Studies conducted by American Cyanamid can be classified as supplemental if the batch number is available. No acceptable chronic toxicity studies conducted with technical malathion on freshwater invertebrates were available.

Table 2-14 Acceptable and supplemental toxicity studies conducted with technical malathion: acute endpoints for marine/estuarine invertebrates

Common Name	Scientific Name	Purity (% a.i.)	Exposure Duration	Endpoint	Measure of Effects	Concentration (µg a.i./L)	Reference	MRID	Cheminova's Study Rating[a]
Daggerblade grass shrimp	*Palaemonetes pugio*	96.8	24 h	LC50	Survival	>162	Brougher et al., 2014j	49534902	Acceptable
Daggerblade grass shrimp	*Palaemonetes pugio*	96.8	48 h	LC50	Survival	>162	Brougher et al., 2014j	49534902	Acceptable
Daggerblade grass shrimp	*Palaemonetes pugio*	96.8	72 h	LC50	Survival	121	Brougher et al., 2014j	49534902	Acceptable
Daggerblade grass shrimp	*Palaemonetes pugio*	96.8	96 h	LC50	Survival	67	Brougher et al., 2014j	49534902	Acceptable
Eastern oyster	*Crassostrea virginica*	96.8	96 h	EC50	Shell deposition	2700	Brougher et al., 2014k	49389403	Acceptable
Eastern oyster	*Crassostrea virginica*	96.8	96 h	NOEL	Shell deposition	530	Brougher et al., 2014k	49389403	Acceptable
Mysid	*Americamysis bahia*	96.8	24 h	LC50	Survival	>8.4	Brougher et al., 2014i	49389401	Acceptable
Mysid	*Americamysis bahia*	96.8	48 h	LC50	Survival	7.8	Brougher et al., 2014i	49389401	Acceptable
Mysid	*Americamysis bahia*	96.8	72 h	LC50	Survival	6.5	Brougher et al., 2014i	49389401	Acceptable
Mysid	*Americamysis bahia*	96.8	96 h	LC50	Survival	4.8	Brougher et al., 2014i	49389401	Acceptable
Mysid	*Americamysis bahia*	94	24 h	LC50	Survival	>6.8	Forbis, 1990	41474501	Supplemental
Mysid	*Americamysis bahia*	94	48 h	LC50	Survival	3.6	Forbis, 1990	41474501	Supplemental
Mysid	*Americamysis bahia*	94	72 h	LC50	Survival	2.3	Forbis, 1990	41474501	Supplemental
Mysid	*Americamysis bahia*	94	96 h	LC50	Survival	2.2	Forbis, 1990	41474501	Supplemental
Mysid	*Americamysis bahia*	94	96 h	LOEL	Survival	2.6	Forbis, 1990	41474501	Supplemental
Mysid	*Americamysis bahia*	94	96 h	NOEL	Survival	1.5	Forbis, 1990	41474501	Supplemental

[a] Study was deemed supplemental. Study met generic, chemical-specific and additional acceptability criteria. However, as per the National Academy of Sciences (NAS, 2013), the test material must be determined to be relevant to the United States. For malathion, the relevance of the study can only be determined by knowing the composition of the product and demonstrating that the composition is similar to a currently registered product. For these reasons, a study is classified as acceptable when the composition of the impurities and/or inerts is known and is verifiable as being relevant to the United States, and meets all other generic and acceptable criteria. Studies conducted by American Cyanamid can be classified as supplemental if the batch number is available. No acceptable acute toxicity studies conducted with technical malathion on marine invertebrates were available.

Table 2-15 Acceptable toxicity studies conducted with technical malathion: chronic endpoints for marine invertebrates[a]

Common Name	Scientific Name	Purity (% a.i.)	Exposure Duration	Endpoint	Measure of Effects	Concentration (µg a.i./L)	Reference	MRID
Mysid	*Americamysis bahia*	96	39 d	LOEL	Adult survival	1.2	Claude et al., 2012	48752901
Mysid	*Americamysis bahia*	96	39 d	NOEL	Adult survival	0.58	Claude et al., 2012	48752901
Mysid	*Americamysis bahia*	96	39 d	LOEL	Growth	1.2	Claude et al., 2012	48752901
Mysid	*Americamysis bahia*	96	39 d	NOEL	Growth	0.58	Claude et al., 2012	48752901
Mysid	*Americamysis bahia*	96	14 d	NOEL	Juvenile survival	≥1.2	Claude et al., 2012	48752901
Mysid	*Americamysis bahia*	96	39 d	LOEL	Reproduction	0.58	Claude et al., 2012	48752901
Mysid	*Americamysis bahia*	96	39 d	NOEL	Reproduction	0.29	Claude et al., 2012	48752901

[a] No supplemental chronic toxicity studies conducted with technical malathion on marine invertebrates were available.

2.8 Routes of Exposure

Although labels state that the pesticide cannot be directly applied to aquatic habitats, malathion may be transported to DS habitats via spray drift during application and run-off from fields into soils or aquatic systems. The most important route of exposure of the DS to malathion is via direct exposure to their gills and integument in surface water and sediment. DS may also be exposed indirectly from consumption of aquatic prey items (e.g., invertebrates) that have been exposed to malathion in the water column, sediment, or diet.

Indirect effects to DS could potentially occur as a result of effects to the aquatic habitat components and prey abundance. Algae, aquatic plants and aquatic invertebrates may come into direct contact with malathion in the water column, sediment or diet, and negative effects on prey abundance or habitat would indirectly hinder the survival, growth and reproduction of DS.

2.9 Protection Goals

Protection goals describe the overall aim of risk-based decision making and are used as the basis for defining assessment endpoints. In turn, assessment endpoints are ecological characteristics that are deemed important to evaluate and protect (e.g., survival of DS). They guide the assessment by providing a basis for assessing potential risks to receptors. Factors considered in selecting assessment endpoints include mode of action, potential exposure pathways, and sensitivity of ecological receptors. Assessment endpoints can be general (e.g., maintenance of fish populations) or specific (e.g., survival of estuarine fish), but must be relevant to the ecosystem they represent and susceptible to the stressors of concern (EPA, 1998b; Suter et al., 1993).

For direct effects to the DS, the assessment endpoint is the survival, reproduction and growth of individuals of this species. Protection at the organism level will ensure the continued existence of DS populations.

For indirect effects to the DS, the assessment endpoint is the productivity of prey communities, including aquatic invertebrates. This assessment endpoint is at the community level of organization because the DS is a generalist feeder (Section 2.1.5) and modification of the availability of only a few sensitive species is unlikely to impact the overall availability of food for the DS.

2.10 Risk Hypotheses and Conceptual Model

All chemicals have the potential to cause toxicological effects. The likelihood of adverse ecological effects depends on the receptors being exposed, the route and duration of exposure, and the inherent toxicity of the chemical. If all three components (i.e., a receptor, a route of exposure, and any level of toxicity) are present, the possibility of a toxicological risk exists. Risk hypotheses are specific assumptions about potential adverse effects and are based on what is known about the chemical, receptors and environment. Risk hypotheses are derived using

professional judgement and information available on the sources of exposure, characteristics of the stressor (e.g., chemistry, fate and transport), the ecosystems at risk, and anticipated effects to ecological receptors. A conceptual model provides a written and visual description of the possible exposure routes between ecological receptors and a stressor. The model includes risk hypotheses for how a stressor might come into contact with, and affect, receptors. This section derives risk hypotheses and a conceptual model for DS potentially exposed to malathion.

2.10.1 Exclusions from the Effects Determination

Based on the results of the EPA (2010a) effects determination for the DS, and the information presented in Sections 2.1 to 2.8, taxa not at risk, and factors not contributing to risk to DS have been removed from consideration in this effects determination. These exclusions are presented below.

2.10.1.1 Taxa Not at Risk

EPA derived risk quotients (RQs) to estimate potential risk to the DS from the use of malathion (EPA, 2010a). The RQs were then compared to the Agency's level of concern (LOC) to determine whether malathion had the potential to cause adverse effects to the DS, their prey and/or their habitat.

The Agency relied on a conservative approach by using the most sensitive toxicity endpoint values for fish, aquatic invertebrates, and plants, the maximum labeled application rates, and upperbound estimates of concentrations on prey items or in the environment. Birds, mammals and terrestrial invertebrates were not evaluated because they do not coexist with DS.

Based on the results of EPA's effects determination, the following receptors and endpoints were determined to not be at risk from exposure to malathion:

- Indirect effects to DS via reduction in terrestrial plants (habitat) for all use patterns; and
- Indirect effects to DS via reduction in aquatic plants (food/habitat) for all use patterns

Throughout their assessment, EPA (2010a) is inconsistent in describing which DS prey items are being considered. For example, on page 158 of their assessment, EPA (2010a) concluded "that the use of malathion has a high potential to cause indirect effects on the DS through reduction of fish and invertebrate prey". However, in the final effects determination on page 187, no mention of the indirect effects to DS based on reduction in fish prey is made. Furthermore, in their description of DS life history, EPA (2010a, Attachment 2) does not list fish species as potential prey items of the DS. A literature review also found no evidence that DS prey on other fish. For these reasons, indirect effects to DS via reductions in fish prey will not be considered in this assessment.

2.10.1.2 Metabolites

The malathion degradate, malaoxon, will not be assessed in this refined effects determination for the reasons listed below:

- There are numerous laboratory and field studies indicating that malaoxon is rarely found in soil, soil leachates and water;
- on the rare occasions when malaoxon has been found, it was only at very small percentages of applied malathion; and
- during water monitoring in aquatic environments, malaoxon has rarely been detected.

A more detailed description of the points listed above can be found in Appendix B.

2.10.1.3 Formulations

As mentioned in Section 2.7, registrant GLP toxicity studies have been conducted for aquatic organisms (fish and invertebrates) using technical malathion and formulated products. A comparison of the effect concentrations from these studies shows that technical malathion is more toxic to aquatic organisms than malathion formulations (Table 2-7). As a result, this effects determination will focus only on the active ingredient and effects metrics will be obtained from studies conducted using technical malathion.

2.10.1.4 Routes of Exposure

DS is most likely to be exposed to malathion through absorption of water-borne malathion by the integument and gills, and by consumption of prey that have absorbed or ingested malathion.

DS could also be exposed through incidental ingestion of sediment, soil and sand while foraging in water or consuming prey. However, incidental soil and sediment ingestion are not considered important routes of exposure because the rates of ingestion are far slower than the food ingestion rate (EPA, 2004a). EPA (2004a) showed that ingestion of soil at an incidental rate of up to 15% of the diet would not significantly increase dietary exposure. In fact, inclusion of sediment in the diet for the majority of food items would effectively reduce total exposure because pesticide concentrations are lower in soil than they are in dietary items (EPA, 2004a; Fletcher et al., 1994). Direct contact of malathion via sediment is an unlikely route of exposure for DS because malathion is not directly applied to sediments and the DS is not found in the terrestrial environment where malathion is directly applied. Moreover, malathion does not readily bind to sediment from the water column due to its low log K_{ow} (Table 2-4). In a field mesocosm study, malathion was not detected in sediment within 99 days following malathion application to the water column (Ebke, 2002 [MRID 46525901]). For reasons described above, it is unlikely that DS and their prey will be exposed to malathion via sediment. Therefore, exposure to malathion via sediment will not be considered further in this effects determination.

2.10.1.5 Use Patterns

The use patterns that will be assessed in this refined effects determination are based on the most recent Registration Eligibility Decision (RED) (EPA, 2009a) with a few exceptions, which are described below.

Malathion use patterns for cull piles and turf will not be assessed in this effects determination because these uses have been cancelled.

Mushrooms are typically grown indoors in compost material called "casing". Malathion is applied to the casing material, which does not result in a direct exposure to environmental receptors (EPA, 2010a). Although the left over casing material can be applied to agricultural fields subsequent to its use with mushrooms, much of the malathion would likely be hydrolyzed or metabolized by bacteria present in the casing before it is applied to land (EPA, 2010a). For these reasons, the use of malathion on mushrooms will not be assessed in this effects determination. Malathion use patterns for grains (stored) and grains/cereal/flour bins/ flour elevators will also be excluded from this effects determination because they are indoor uses and are not relevant to ecological risk.

Malathion uses in intermittently flooded areas, swamps, marshes and stagnant waters are related to the public health mosquito control and are not considered in this effects determination. Although we are supporting the use of malathion as an adulticide for public health mosquito control as well as for outdoor homeowner uses, the focus of this assessment was on agricultural uses of malathion. Medfly control falls under section 18 local need uses and will also not be considered in this effects determination.

2.10.2 Risk Hypotheses for this Effects Determination

Based on the habitat and ecology of the DS and the results of the EPA effects determination (EPA, 2010a), the risk hypotheses tested in this refined effects determination are presented below.

Potential Direct Effects to DS

- Acute and chronic effects to survival, growth and reproduction of DS may result from exposure to malathion in surface water due to spray drift and runoff.

Potential Indirect Effects to DS

- Malathion in surface water due to spray drift and/or runoff may come into direct contact with aquatic invertebrate prey of the DS. Exposure to malathion in the water column could have significant acute and/or chronic effects on the survival, growth and reproduction of aquatic invertebrate prey, which could adversely affect the DS.

2.10.3 Conceptual Model

For this effects determination, the stressor is the release of malathion into the environment. The conceptual model for evaluating risks to DS from the use of malathion is shown in Figure 2-5. Only those pathways assessed in this refined effects determination are illustrated.

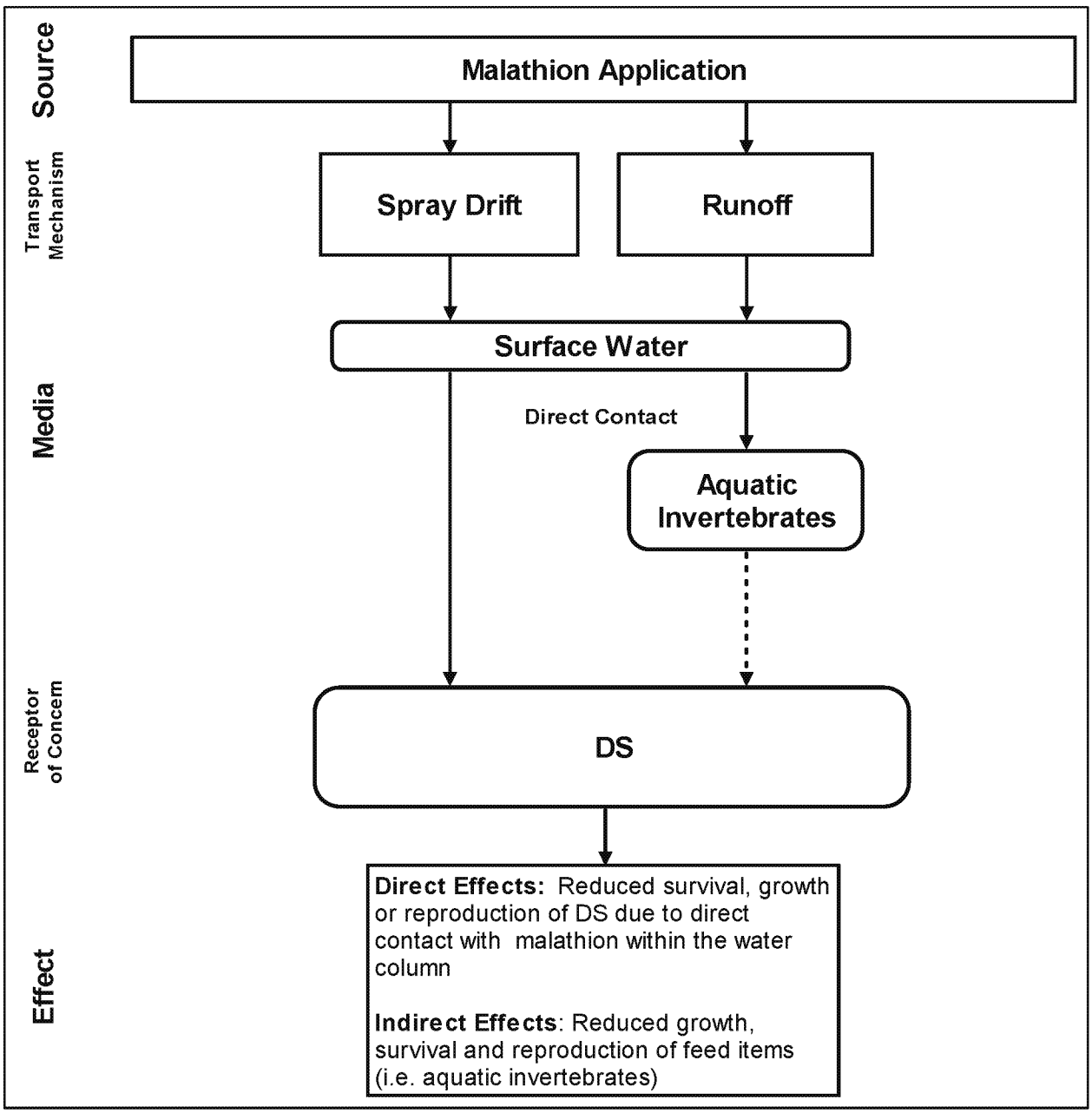

Figure 2-5 Conceptual model for the application of malathion in California leading to the exposure of delta smelt (DS) and their prey

ED_002284_00026674-00065

2.11 Analysis Plan

The analysis plan outlines the rationale and approach for the effects determination.

A tiered approach was used to assess the effects to DS and their prey (Figure 2-6). This approach is conceptually similar to the tiered approach that EPA uses for ecological risk assessment (EPA, 1998b) in that increasingly refined analyses are only conducted for exposure scenarios for which concern was not eliminated in a previous tier. Thus, only those exposure scenarios for which a presumed risk remains proceed to the next tier.

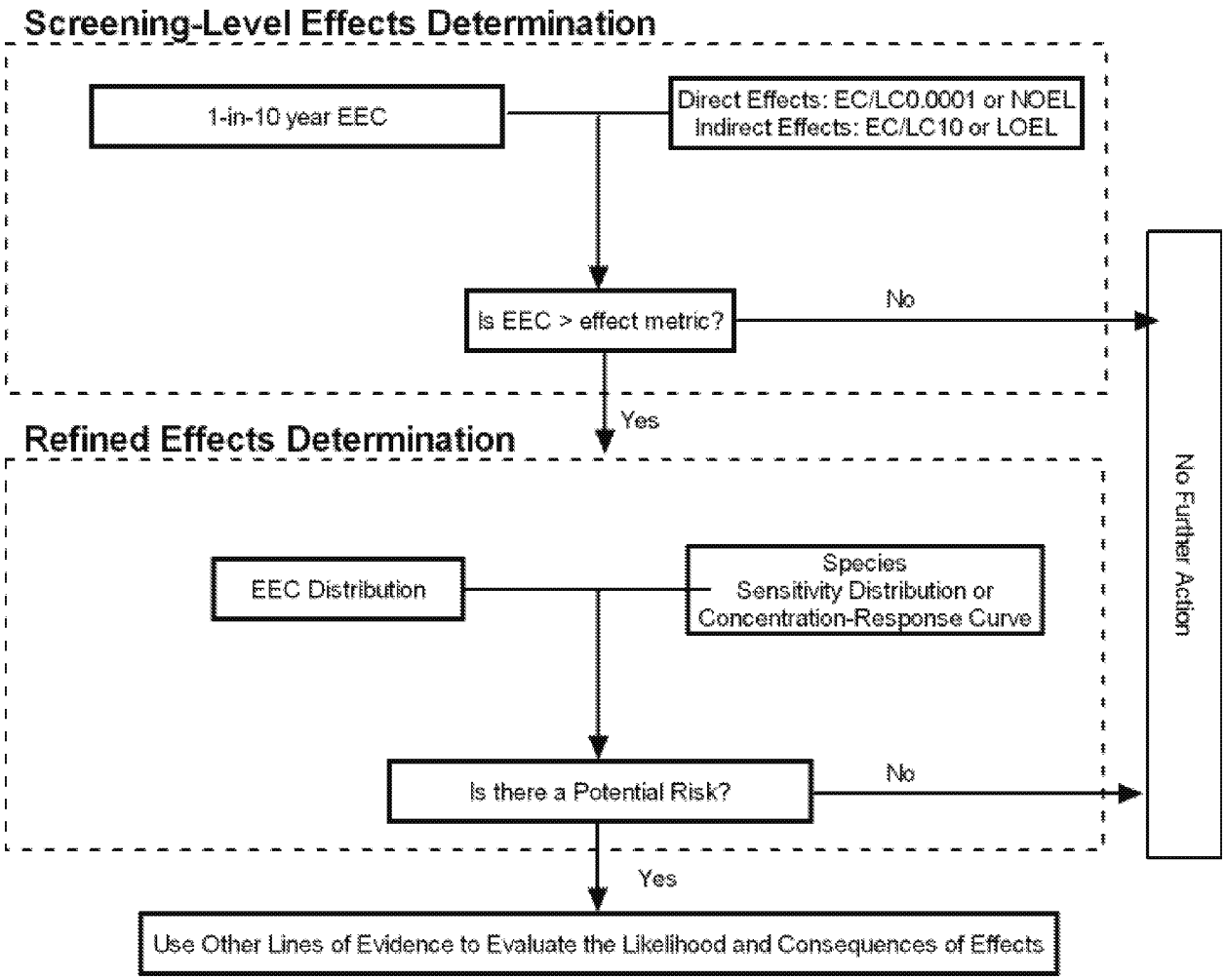

Figure 2-6 Tiered approach for assessing effects to DS and aquatic invertebrates exposed to malathion

Measures of exposure and effect are the metrics used to quantify potential risks to a receptor (i.e., taxon of concern). EPA (1998b) groups measures into one of three categories:

ED_002284_00026674-00066

1. Measures of effect are measureable changes in an attribute of the receptor, or a surrogate, in response to the stressor;
2. Measures of exposure account for the presence and movement of the stressor in the environment and co-occurrence with the assessment endpoint; and
3. Measures of ecosystem and receptor characteristics consider the influence that the environment, organism behavior and life history will have on exposure and response to the stressor.

Measures of exposure were compared to measures of effect in the process of risk characterization for each receptor and exposure scenario. The measures of exposure and effects considered in this effects determination are presented below. Field studies, monitoring data, and chemical-specific incident reports were also considered as part of a weight-of-evidence approach for this effects determination.

The tiers in this effects determination span from calculation of simple and conservative RQs, to the use of probabilistic methods. The screening-level effects determination focused on determining if the use patterns presented in Appendix A pose significant risk to DS and their prey. The use patterns of potential concern were then assessed using refined methods to determine probabilities of effects of differing magnitude to DS and their prey. The screening-level and refined measures of effects and exposure are described below.

2.11.1 Screening-level Measures of Effect and Exposure

The screening-level effects determination focused on direct effects to DS, as well as indirect effects to DS via the reduction in aquatic invertebrate prey. The following effects were considered:

- Direct acute and chronic effects to the survival, growth and reproduction of DS; and
- Acute and chronic effects to the survival, growth and reproduction of aquatic invertebrate prey.

In response to the NAS (2013) recommendations, EPA, FWS, NMFS and USDA developed their Interim Approaches for National-Level Pesticide Endangered Species Act Assessments Based on the Recommendations of the National Academy of Sciences April 2013 Report (Agencies, 2013). The Interagency Interim Approaches recommends that the following endpoints be used to assess the potential for direct and indirect effects to endangered species (see Table 2-16).

Table 2-16 Prescribed endpoints as per the Interagency Interim Approaches (Agencies, 2013)

Taxon	*Mortality*		*Sublethal Effects*	
	Direct Effects	*Indirect Effects*	*Direct Effects*	*Indirect Effects*
Fish Aquatic Invertebrates Aquatic-phase amphibians	Concentration that would result in a 1 in a million chance of causing mortality to an individual[a]	Concentration that would result in a 10% decrease of individuals[a]	The lowest available NOEC or other scientifically defensible effect threshold (ECx)[b]	Lowest available LOEC for growth or reproduction
Aquatic plants - vascular Aquatic plants - non-vascular	None	None	Concentration equal to the lowest value among the available NOAEC and EC5 values.	Concentrations equal to the lowest available LOAEC and EC25 values
Birds Mammals Reptiles Terrestrial-phase amphibians Terrestrial invertebrates	Dose that would result in a 1 in a million chance of causing mortality to an individual[a]	Dose that would result in a 10% decrease of individuals[a]	The lowest available NOEL or other scientifically defensible effect threshold (EDx)[b]	Lowest available LOEL for growth or reproduction
Terrestrial plants - monocots Terrestrial plants - dicots Terrestrial plants - non-angiosperm	None	None	Concentration equal to the lowest value among the NOAEC and EC5 values from the available seedling emergence and vegetative vigor studies	Concentrations equal to the lowest available LOAEC and EC25 values from the available seedling emergence and vegetative vigor studies

[a] Calculated using the HC5 of an SSD of LC50/EC50 values and a representative slope. If an SSD cannot be derived, the most sensitive LC50 or EC50 is used.

[b] Endpoints will generally be a) from *in vivo* studies that are conducted with whole organisms and b) linked to environmentally relevant exposures.

The most sensitive and relevant measures of effect were selected for each taxon in the screening-level effects determination (Table 2-17). An evaluation of available studies was conducted to ensure that the best available data were used in this effects determination (Breton et al., 2014 [MRID 49333901], 2015 [MRID 49692301]). Toxicity study reports were screened using study evaluation criteria designed to ensure that only high quality data were used. Study evaluation criteria for aquatic invertebrate and fish toxicity studies distinguished these studies as acceptable (i.e., best available data), supplemental or unacceptable. Each study rating was based on an evaluation of study design and execution, adherence to toxicity testing protocols, statistical analyses, and other key aspects of the study (Breton et al., 2014 [MRID 49333901], 2015 [MRID 49692301]). The results of the data screening criteria process for these studies are available in Breton et al. (2014 [MRID 49333901], 2015 [MRID 49692301]).

The most important route of exposure for DS and their aquatic invertebrate prey is direct exposure to malathion within the water column. Therefore, to characterize exposure of aquatic biota to malathion it is necessary to predict estimated environmental concentrations (EECs) of malathion in surface water bodies.

Notwithstanding Cheminova's concerns with the following models (see Teed et al., 2015 [MRID 49692201]), in this assessments, screening-level EECs were initially calculated using standard conservative exposure models (e.g., PRZM/EXAMS and PFAM). The use patterns considered for aquatic exposure scenarios are described in Appendix A. If these highly conservative models showed that receptors might be at risk, higher tier refinements were used when possible and appropriate to calculate more realistic and detailed exposure estimates.

With the exception of rice, wildrice and watercress use patterns, screening-level malathion aquatic EECs over various durations (i.e., annual peak, 21-day, and 60-day) were estimated using the EPA Pesticide Root Zone Model (PRZM 3.12.2) (executable date May 12, 2005) and Exposure Analysis Modeling System (EXAMS 2.98.04) (executable date April 25, 2005) for the use patterns shown in Table A-1 and Table A-2 of Appendix A. These models were run using the EPA/OPP/EFED shell PE Version 5 (November 15, 2006) with EPA standard PRZM crop scenarios and an EPA standard static pond water body.

PRZM predicts pesticide transport and transformation in the soil profile and is capable of simulating pesticide runoff, erosion, plant uptake, leaching, transformation, foliar washoff, and volatilization. Daily edge-of-field loadings of pesticides dissolved in runoff waters and sorbed to sediment are discharged into a standard water body ("standard pond") simulated by the EXAMS model. Input data are required for soil characteristics, hydrology, pesticide chemistry, meteorology, use pattern, and the crop of interest. For each malathion use pattern considered in this assessment, the most appropriate EPA standard crop scenario were chosen to represent that use (Appendix A). For each scenario, 30 years (1961-90) of site-specific climate data were used in PRZM. The PRZM results were used as inputs into EXAMS to estimate exposure concentrations of malathion in surface waters of a standard pond. The standard pond scenario assumes a hypothetical treated field of 10 ha draining into a 1 ha pond that is 2 m deep. The pond is assumed to have no in- or out-flows. PRZM/EXAMS estimates exposure for this static water body, and thus produces far more conservative estimates than would be the case for flowing water bodies.

Each exposure scenario was simulated for a range of application dates. Malathion may be applied between emergence and harvest of a crop. Because rainfall patterns and other climatic variables vary temporally, off-field transport of malathion via runoff will also vary temporally. As a result, choice of application date can affect the estimated concentrations of malathion in the standard pond. For each possible application date, EXAMS determines a distribution of annual peak, 21-day and 60-day average EECs based on the 30-year simulation (i.e., 30 data points). The 1-in-10 year EECs will be calculated for each possible application date. For example, if an exposure scenario has 60 possible application dates, sixty 90th percentile peak and 21-day and 60-day averages will be derived. The maxima of these 90th percentile concentrations will be used for determining risk to DS and their aquatic invertebrate prey. Use of maximum 90th percentile values is highly conservative because the approach assumes the worst possible application date for the period of time between emergence and harvest of a crop in a year.

For rice, wild rice and watercress scenarios, EPA's Pesticides in Flooded Application Model (PFAM prerelease version 1.0, executable date 1/23/2013) was used to estimate malathion concentrations for the EPA standard pond resulting from outflow from a flooded rice or watercress paddy adjacent to the EPA standard pond (Young, 2013). Pesticides are typically applied directly onto paddy water and uncontrolled drainage or overflow from the paddies may result in pesticide residues being released to downstream waters (Luo et al., 2011). For this reason, the usual procedure for estimating surface water EECs using PRZM/EXAMS is not appropriate for rice, wildrice and watercress. Results from these simulations more realistically represent malathion concentrations under vulnerable but "real world" conditions compared to EECs calculated from the very conservative EPA Tier I Rice model equation. However, PFAM results still represent a worst-case exposure scenario in which a farm pond is immediately adjacent to a rice or watercress paddy without any buffer between the paddy and the water body. The environmental fate parameters used in PFAM to simulate malathion behavior in a rice, wildrice or watercress paddy were the same as used in the PRZM EXAMS modeling, the only exception being that PFAM uses Heat of Henry (J/mol) instead of Henry's Law Constant (atm-m^3/mol).

For certain non-agricultural uses of malathion, EECs were derived using guidance from the EPA assessment (2010). EPA provides specific guidance for modeling certain non-agricultural scenarios in PE5 (PRZM/EXAMS linkage program). The modeling approach described in EPA (2010a) includes a process for creating surrogate scenarios for the following use patterns, and end-use products:

- Agricultural uncultivated areas, non-agricultural uncultivated areas, non-ULV (aerial, groundspray and airblast applications)
- Fence rows/hedge rows, non-ULV (aerial, groundspray and airblast applications)
- Household/domestic dwellings (perimeter/refuse/solid waste sites/containers, non-ULV (groundspray; residential)

More details on the approach taken to estimate EECs for these use patterns are presented in Section 3.2.3.

Using the Agencies (2013) approach (Table 2-16), the following measures of exposure and effect were used in the screening-level effects determination for DS and their prey (Table 2-17).

Table 2-17 Summary of assessment endpoints and measures of exposure and effect for the screening-level effects determination			
Assessment Endpoint	***Exposure Duration***	***Measure of Exposure***	***Measure of Ecological Effect[a]***
Direct Effects to Delta Smelt			
Survival, growth and reproduction of delta smelt	Acute freshwater and estuarine/ marine fish	Estimated 1-in-10 year annual peak concentrations of malathion based on a 30-year simulation in a standard-sized pond located adjacent to treated agricultural and non-agricultural use sites	Concentration that would result in a chance of 1 in a million of causing mortality to DS calculated using the HC5 of a fish SSD and a representative slope
	Chronic freshwater fish	Estimated 1-in-10 year annual peak 60-day averaged concentrations of malathion based on a 30-year simulation in standard-sized ponds located adjacent to treated agricultural and non-agricultural use sites	97-d NOEL of 21 µg a.i./L for rainbow trout (*Oncorhynchus mykiss*) survival (Cohle, 1989 [MRID 41422401])
	Chronic estuarine/ marine fish		34-d NOEL of 8.2 µg a.i./L for sheepshead minnow (*Cyprinodon variegatus*) (Hurd and Sharpe, 2011 [MRID 48705301])
Indirect Effects to Delta Smelt via Reduced Aquatic Invertebrate Prey			
Survival, growth and reproduction of aquatic invertebrates	Acute freshwater and estuarine/ marine invertebrates	Estimated 1-in-10 year annual peak concentrations of malathion based on a 30-year simulation in a standard-sized pond located adjacent to treated agricultural and non-agricultural use sites	Concentration that would result in a decrease of 10% of individuals calculated using the HC5 from an aquatic invertebrate SSD and a representative slope
	Chronic freshwater invertebrates	Estimated 1-in-10 year annual peak 21-day averaged concentrations of malathion based on a 30-year simulation in standard-sized ponds located adjacent to treated agricultural and non-agricultural use sites	21-d LOEL of 0.1 µg a.i./L for *Daphnia magna* reproduction (Blakemore and Burgess, 1990 [MRID 41718401])
	Chronic estuarine/ marine invertebrates		39-d LOEL of 0.58 µg a.i./L for the saltwater mysid (*Americamysis bahia*) (Claude et al., 2012 [MRID 48752901])

[a] Cheminova's study evaluation criteria and all study evaluations are presented in Breton et al. (2014 [MRID 49333901]; 2015 [MRID 49692301]).

2.11.2 *Refined Measures of Effect and Exposure*

The purpose of the refined effects determination is to apply less conservative and more realistic exposure scenarios than were used in the screening-level effects determination. Refined measures of effect and exposure are outlined in Table 2-18. For species found to be at risk in the screening-level effects determination, a probabilistic approach was taken to assess risk to taxa and exposure scenarios that screened through from the previous tier.

Table 2-18 Summary of assessment endpoints and measures of exposure and effect for the aquatic refined effects determination			
Assessment Endpoint	***Exposure Duration***	***Measure of Exposure***	***Measure of Ecological Effect***
Direct Effects to Delta Smelt			
Survival, growth and reproduction of delta smelt	Acute	Distribution of 96-h concentrations of malathion in DS habitats adjacent to treated agricultural and non-agricultural use sites	Acute concentration-response curve for fish
	Chronic	Distribution of 60-d average concentrations of malathion in DS habitats adjacent to treated agricultural and non-agricultural use sites	Chronic concentration-response curve for fish
Indirect Effects to Delta Smelt via Reduced Aquatic Invertebrate Prey			
Survival, growth and reproduction of aquatic invertebrates	Acute	Distribution of 48-h concentrations of malathion in DS habitats adjacent to treated agricultural and non-agricultural use sites	Acute community-level species sensitivity distribution for invertebrates
	Chronic	Distribution of 21-d average concentrations of malathion in DS habitats adjacent to treated agricultural and non-agricultural use sites	Chronic community-level species sensitivity distribution for invertebrates

Most probabilistic risk assessments estimate the probability that exposure exceeds a specified NOEC/NOEL (no observed effects concentration/dose) or LOEC/LOEL (lowest observed effects concentration/dose). An alternative approach is to estimate the probabilities of effects of varying magnitude. Because DS are generalist feeders, this effects determination was not restricted to the most sensitive prey species. As long as overall productivity of prey species is protected, indirect effects to DS are not expected. To determine overall effects on prey productivity, the preferred measure of effect is at the community level of organization. A species sensitivity distribution (SSD) was used as an effects metric for community structure of aquatic invertebrates, and a fish concentration-response curve was developed to assess effects to DS.

A Soil and Water Assessment Tool (SWAT) model was developed and used to predict aquatic EECs in the water bodies within the DS critical habitat. Only drainage areas below reservoirs draining the Sierra Nevada and coastal mountain rages were included in the modeled watershed area. This area was associated with 97.9% of malathion use within the Delta watershed. The Delta watershed was divided up into 344 subbasins, each of which had an associated stream/river reach where daily malathion concentration predictions would be made. The subbasin boundaries were designed to align with standard HUC12 boundaries, and capture the main stem rivers entering the Delta (i.e., the Sacramento and the San Joaquin Rivers), major tributaries, as well as smaller backwater sloughs within the DS critical habitat. The primary datasets used in the development and parameterization of the DS SWAT model were NHDPlus for hydrologically-corrected topography, SSURGO for soils, Cropland Data Layer (CDL) for agricultural land cover, National Climactic Data Center (NCDC) for weather, and CDPR PUR for malathion use. The structure of the model allows for the prediction of flow, sediment, and pesticide outputs at multiple scales and locations throughout a watershed. The hydrology of the model was calibrated to observed historical flow data and malathion

concentration predictions were compared against available monitoring data. The resulting model produced 29-year time series of daily malathion concentrations within multiple flowing water bodies throughout the DS critical habitat. To account for the uncertainty in malathion application patterns, the SWAT model was run probabilistically (through Monte Carlo simulation) to assess a broad range of possible application scenarios. The frequency distribution of these daily time series was used to determine annual maximum EECs for various durations (e.g., 48-hour, 96-hour, 21-day) for comparison with effects metrics and determination of risk.

The SWAT modeling approach represents a significant improvement over the PRZM/EXAMS approach to modeling aquatic EECs pertinent to the DS. The primary deficiency in the PRZM/EXAMS approach is that it simulates pesticide EECs in a one ha pond with inflow from a 10 ha field. This aquatic environment and "watershed" description is far different from the water bodies inhabited by the DS and the watershed that drains into the habitat. The DS SWAT model captures the appropriate hydrology and the actual malathion use patterns that are relevant to estimating potential exposure of the DS to malathion.

2.11.3 Risk Characterization

The purpose of the risk characterization is to combine information about toxicity and exposure to make informed statements about the possibility of adverse effects for each use pattern for both direct and indirect effects to the DS. A tiered approach that includes a conservative and deterministic screening-level effects determination leading to the computation of RQs, and a refined probabilistic-based effects determination with a weight-of-evidence analysis was followed. This approach is conceptually similar to the tiered approach used by EPA for ERAs (EPA, 2004a), in that increasingly refined analyses are conducted for exposure scenarios for which concern to non-target taxa was not eliminated in a previous tier.

2.11.3.1 Screening-Level Risk Characterization

In the screening-level effects determination, potential for risk was quantified using a deterministic risk quotient (RQ) approach that consists of dividing estimated exposure concentrations by acute and chronic effect metrics. If RQs were below 1 (i.e., EEC is less than the corresponding effects metric), the exposure scenarios were eliminated from further consideration. Exposure scenarios with a RQ>1 (i.e. EEC exceeds the corresponding effects metric) proceeded to the refined effects determination (Figure 2-6).

NAS (2013) advised against the use of RQs and uncertainty factors in risk assessments for listed species. The RQ approach used by EPA does not estimate risk, but instead uses conservative assumptions, including the use of uncertainty factors, or stringent and possibly implausible exposure scenarios, to avoid making a type II error (i.e. concluding that a pesticide is unlikely to cause effects when it does yield such effects; NAS, 2013). RQs provide no information on the probability of an adverse effect to a listed species. Instead, the use of probabilistic approaches for risk characterization, which have the ability to propagate uncertainties in exposure and effect through to a risk estimate for individuals and populations, was recommended (NAS, 2013).

The endpoints used to assess the potential for direct and indirect effects to endangered species were modified by the Interagency Interim Approaches (Agencies, 2013) in response to the NAS (2013) criticisms on the use of RQs and LOCs (see Table 2-16). However, for their Step 1 and Step 2 analyses, EPA indicates that modeled EECs will be compared directly to the endpoints listed in Table 2-16 to determine the use sites and taxa that proceed to the next step of the ERA process. As such, this risk characterization approach is still deterministic and does not address the NAS (2013) recommendation to include the use of probabilistic methods. As recommended by NAS (2013), probabilistic approaches were used in the refined assessment to further characterize the risk of scenarios with RQs>1.

2.11.3.2 Refined Risk Characterization

For exposure scenarios screening through to the refined effects determination, risk curves were used to quantify risk. Each exposure distribution was integrated with an effects distribution (e.g., SSD or concentration-response curve) to derive a risk curve that indicates the probability of exceeding effects of differing magnitude. The risk curve was then used to categorize risk as *de minimis*, low, intermediate, or high. Risk categories are intended to be qualitative descriptors of risks to DS and their prey.

The Ecological Committee on FIFRA Risk Assessment Methods (ECOFRAM, 1999) referred to risk curves as "joint probability curves" (Giddings et al., 2005) while others use the term "risk curves" (e.g., EPA, 2004b; Moore et al., 2010a,b; 2014b). This approach has been used in ecological risk assessments performed for EPA at the Calcasieu Estuary, LA, the Housatonic River, MA (EPA, 2002, 2004b), and by others in ecological risk assessments of pesticides (Giesy et al., 1999; Giddings et al., 2005; Moore et al., 2006; Moore et al., 2010a,b; 2014b; 2016; Whitfield Aslund et al., 2016; Clemow et al., in prep.; Manning et al., in prep.). In this refined effects determination, area under the risk curve (AUC) was estimated for each exposure scenario. AUC is the area under the curve divided by the sum of the AUC and the area above the curve, with the result multiplied by 100. The AUC was used to categorize risk as follows:

- If the *area under the risk curve (AUC)* is less than the AUC associated with a risk product (risk product = exceedance probability x magnitude of effect) of 0.25% (e.g., 5% exceedance probability of 5% or greater effect = 0.25%), then the risk is categorized as *de minimis*. The AUC for risk products of 0.25% is 1.75%;
- If the *AUC* is equal to or greater than 1.75% but less than 9.82% (i.e., the AUC for risk products of 2%), then the risk is categorized as low;
- If the *AUC* is equal to or greater than 9.82% but less than 33% (i.e., the AUC for risk products of 10%), then the risk is categorized as intermediate; and
- If the *AUC* is equal to or greater than 33%, then the risk is categorized as high.

The risk curves defined by risk products of 0.25%, 2%, and 10% are shown graphically in Figure 2-7. The risk categories are based on a rationale described previously (Moore et al., 2010a; 2014b) and included the following considerations.

- Losses of small numbers of individuals from a local population should not adversely affect the population (Giddings et al., 2005; Moore, 1998). One of the foundations of hierarchy theory (Allen and Starr, 1982) is that effects at lower levels of ecological organization (e.g., organism level) are not necessarily transmitted to higher levels of ecological organization (e.g., population level).
- Although there are exceptions, an adverse effect level of 10% is unlikely to be ecologically significant to a local population. Such an effect generally cannot be reliably confirmed by field studies (Moore, 1998; Suter et al., 2000).
- Controlled exposure–response experiments with microcosms and mesocosms have demonstrated that, at some level of exposure, temporary changes occur in the abundance of a few, sensitive species. At a higher level of exposure, more severe and longer lasting effects occur that may have pronounced ramifications for community structure and function. The transition from minor to major effects usually occurs at concentrations greater than the 10th percentile of the SSD (Giddings et al., 1996, 1997; Solomon et al., 1996; Versteeg et al., 1999).
- Based on an analysis of EPA regulatory practice, Suter et al. (2000) concluded that decreases in an ecological assessment endpoint of less than 20% are generally acceptable. For example, the approximate detection limit of field measurement techniques used in regulating contaminants based on bioassessment of aquatic ecosystems is 20%. The community metrics for an exposed benthic invertebrate community must be reduced by >20% compared with pristine reference sites to be considered even slightly impaired in the EPA rapid bioassessment procedure (Plafkin et al., 1989).
- The curve corresponding to a risk product of 2% passes through the points corresponding to a very low probability (i.e., 10%) of 20% or greater effect, and a low probability (i.e., 20%) of 10% or greater effect. Thus, based on the considerations described above, if risk products are generally less than the 2% boundary for an exposure scenario, then it can almost certainly be considered a low risk scenario.
- The curve corresponding to a risk product of 10% passes through the points corresponding to a median probability (i.e., 50%) of 20% or greater effect and a 20% probability of 50% or greater effect. In this assessment, exposure scenarios with risk products generally above the 10% boundary were considered to be high risk scenarios because there was a low to median probability of detectable and possibly major impacts on local bird populations. Scenarios with risk curves generally between the low and high boundaries were judged to be intermediate risk scenarios.
- When there is a very low likelihood of a scenario affecting receptors, risk will be categorized as *de minimis*. A 5% probability of exceeding 5% adverse effect lies on the curve defined by the risk product equal to 0.25%. The AUC associated with the risk curve defined by risk products of 0.25% (AUC = 1.75%) was thus used as the upper boundary for the category of *de minimis* risk.

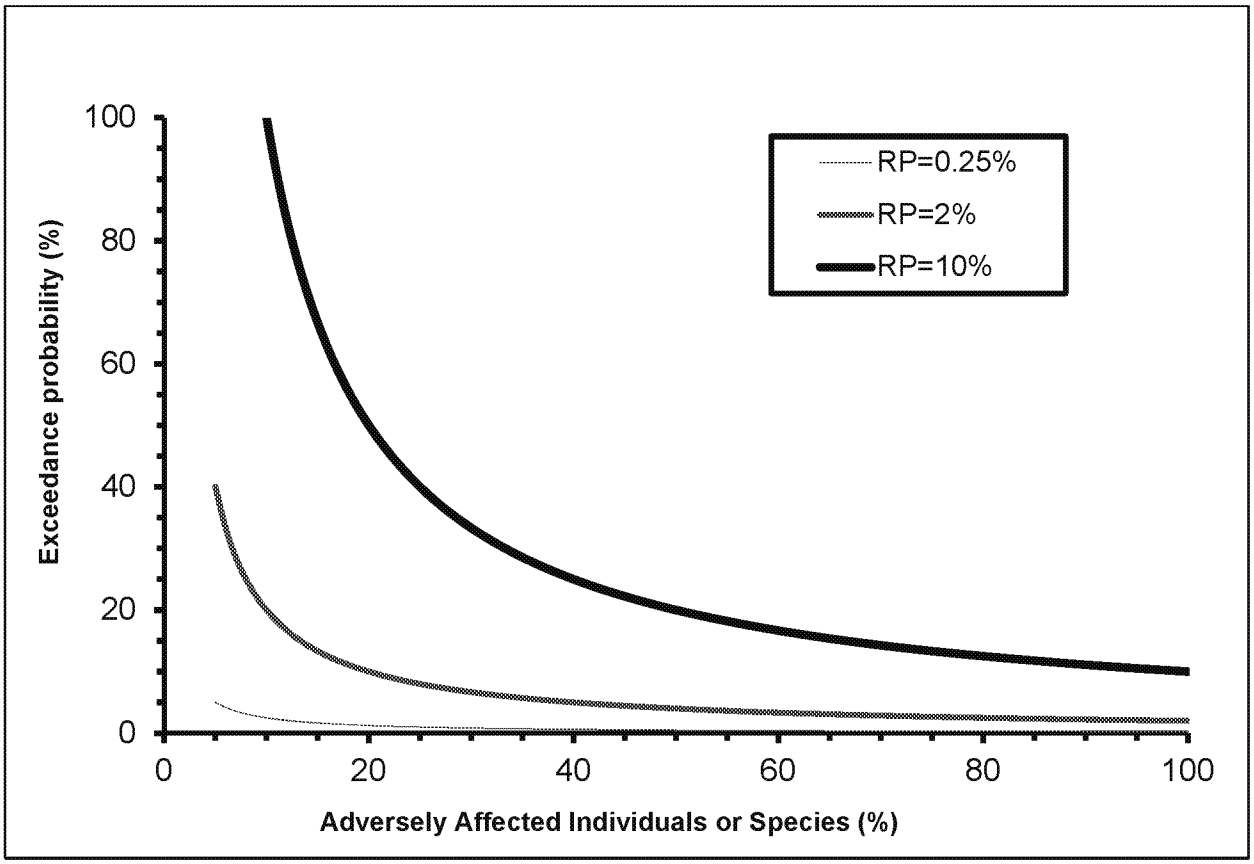

Figure 2-7 Risk curves defined by risk products (RP) of 0.25%, 2% and 10%

DS are opportunistic predators. Therefore, effects limited to a few sensitive populations of prey species are unlikely to lead to adverse effects to DS via reduction in food availability. Additionally, the high reproductive potential of most aquatic invertebrate species allows them to recover in a relatively short time after experiencing low-to-moderate adverse effects (van den Brink et al., 1996; Sherratt et al., 1999; Suter et al., 2000; Barnthouse, 2004). However, Liess and Schulz (1999) demonstrated that recovery can take a very long time (months to years) for some aquatic organisms (e.g., aquatic invertebrates) with reduced ability to recolonize (e.g., local populations are extirpated, and connections to new migrating or upstream populations are limited). Thus, exposure scenarios in the high risk category would be of concern because of the long periods of time potentially required for recovery.

Aquatic ecosystems generally exhibit "functional redundancy" in the temperate zone (Baskin, 1994; Moore, 1998). This means that multiple species are generally present to perform each critical function (Rosenfeld, 2002). Agricultural ecosystems are, to some degree, already affected because of changes brought by the presence of humans, crop fields, livestock, infrastructure, and so on. Systems in relatively unstable environments (the case for most agro-ecosystems) are more likely to recover from new disturbances (e.g., a pesticide application), especially those that mimic historical disturbance events (e.g., previous pesticide applications; Denslow, 1985; Rapport et al., 1985; Moore, 1998). Some studies have shown that a large number of species could be lost before the disappearance of a functional group (e.g., nitrogen-

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fixing microorganisms) in a specific community (Fonseca and Ganade, 2001). Walker et al. (1999) showed that even minor species in an ecosystem (those present in low numbers) serve an important role by maintaining ecosystem function when functionally similar dominant species undergo a decline. Similarly, the high reproductive potential of many ecosystems allows them to rebound in a relatively short time after experiencing low-to-moderate adverse effects (van den Brink et al., 1996; Sherratt et al., 1999; Suter et al., 2000; Barnthouse, 2004).

2.11.4 Other Lines of Evidence

In addition to the results of the screening and refined effects determinations, other lines of evidence were considered in the risk characterization, including:

- mesocosm and field studies, whereby data from actual experiments in the field were used to parameterize the models (e.g., soil degradation half-life, foliar residues, time spent on field) and refine risk;
- monitoring data were used to estimate environmental concentrations and to determine if exposure estimates are ecologically relevant; and
- incident reports were used as evidence to support the justification of ruling out risk to certain taxa.

2.11.5 Uncertainties, Strengths and Limitations of the Assessment

Uncertainties are inherent in almost every aspect of the risk assessment process. The extent of the uncertainty is determined by the availability and quality of the data, as well as the variability associated with many of the processes and factors being considered. Generally, these uncertainties were addressed by incorporating conservative assumptions into the analysis. As a result, the risk characterizations, particularly the screening-level risk characterization, will greatly overstate risk.

One component of an effects determination involves assigning numerical values to various input parameters in models to obtain estimates of exposure and risk. Numerical values are typically required to describe chemical concentrations in environmental media, their fate and transport, wildlife exposure and receptor parameters, and toxicity. The conclusions of any effects determination are dependent on the data and assumptions that are used within it, and are greatly influenced by the variability and uncertainty that is associated with these data and assumptions. Therefore, the key areas of variability and uncertainty, and any major limitations of the effects determination were characterized in the screening-level and refined effects determination.

3.0 SCREENING-LEVEL EFFECTS DETERMINATION

The purpose of this chapter is to characterize the risks of malathion to DS and their aquatic invertebrate prey. As described in Section 2.10.1.1, EPA concluded in their effects determination that terrestrial and aquatic plants are not at risk from malathion. Therefore, these taxa are not assessed in this effects determination.

This screening-level effects determination used a conservative RQ approach to determine if there was potential risk to the DS and their prey from exposure to malathion. The phases of the screening-level effects determination include: effects assessment (Section 3.1), exposure assessment (Section 3.2) and risk characterization (Section 3.3). Each of these phases is described below.

3.1 Screening-Level Effects Assessment

Based on the critical evaluation of aquatic toxicity studies, effect metrics protective of survival, growth and reproduction for DS and their aquatic invertebrate prey were selected for this screening-level effects determination (Table 3-1) (Breton et al., 2014 [MRID 49333901]; 2015 [MRID 49692301]; Teed et al., 2015 [MRID 49692201]). These effects metrics are further described in Sections 3.1.1 and 3.1.2 below.

Table 3-1 Measures of ecological effects selected for the screening-level effects determination for malathion							
Species	***Freshwater/ Marine***	***Exposure Duration***	***Endpoint***	***Effect Concentration (µg a.i./L)***	***Probit Slope***	***Effect Metric (µg a.i./L)***	***Reference [MRID]***
Direct Effects to Delta Smelt							
Fish SSD	Freshwater/ Marine	Acute	96-h HC5	12.3	2.81	0.250[a]	Gries and Purghart, 2001e [47540304]
Rainbow trout (*Oncorhynchus mykiss*)	Freshwater	Chronic	97-d NOEL (fry survival between day 37 and 97)	21	NA	21	Cohle, 1989 [41422401]
Sheepshead minnow (*Cyprinodon variegatus*)	Marine	Chronic	34-d NOEL (fry survival)	8.2	NA	8.2	Hurd and Sharpe, 2011 [48705301]
Indirect Effects to Delta Smelt via Reduction in Aquatic Invertebrate Prey							
Aquatic invertebrate SSD	Freshwater/ Marine	Acute	48-h HC5	0.476	2.99	0.177[b]	Gries and Purghart, 2001a [47540303]
Daphnia magna	Freshwater	Chronic	21-d LOEL (reproduction)	0.1	NA	0.1	Blakemore and Burgess, 1990 [4178401]
Mysid shrimp (*Americamysis bahia*)	Marine	Chronic	39-d LOEL (reproduction)	0.58	NA	0.58	Claude et al. 2012 [48752901]

[a] One in a million chance of mortality for direct effects to DS.
[b] 10% chance of mortality for effects on aquatic invertebrate prey of DS.

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3.1.1 Direct Effects to DS

3.1.1.1 Acute

As per the Interagency Interim Approaches (Agencies, 2013), direct effects to listed fish species are to be assessed using the concentration that would result in a chance of one in a million of causing mortality to an individual, calculated using the HC5 from an SSD of LC50 or EC50 values. An SSD is a statistical distribution that captures the variation in toxicological sensitivity among a given set of species to a contaminant. The SSD is expressed as a cumulative distribution function (CDF) and is comprised of effect concentrations or doses (e.g., 96-hour LC50) on the x axis and cumulative probability (p) on the y axis (Posthuma et al., 2002). The number of data points used to construct the SSD depends on the number of species tested for the endpoint of interest.

Sufficient acceptable toxicity data were available to derive an acute SSD for freshwater and estuarine/marine fish. Toxicity studies were screened using criteria designed to ensure that only high quality data were used in deriving the SSD (Breton et al., 2014a [MRID 49333901], 2015 [MRID 49692301]). To develop the fish SSD, acute freshwater and estuarine/marine fish LC50s from nine acceptable studies conducted with technical malathion were used (Table 3-2). The exposure period for all endpoints was 96 hours. The sensitivity ranges of freshwater and estuarine/marine fish species overlaps (Breton et al. (2014a [MRID 49333901], 2015 [MRID 49692301]). The range of acceptable and supplemental LC50 data for freshwater species is 52 to 38,000 µg a.i./L, whereas the range for estuarine/marine species is 20.8 to 181.8 µg a.i./L. Furthermore, DS inhabit both freshwater and estuarine environments. Therefore, it is reasonable to combine freshwater and marine fish species to derive the acute SSD. Study evaluations for all data included in the acute fish SSD can be found in Breton et al. (2014a [MRID 49333901], 2015 [MRID 49692301]).

Table 3-2 Acceptable 96-hour LC50 data for technical malathion used to develop the acute SSD for fish

Freshwater or Estuarine/ Marine Fish	*Common Name*	*Scientific Name*	*96-h LC50 (µg a.i./L)*	*Probit Slope[a]*	*Reference [MRID]*
Freshwater	Bluegill sunfish	*Lepomis macrochirus*	52	26.0	Gries and Purghart, 2001e [47540304]
Freshwater	Coho salmon	*Oncorhynchus kisutch*	720	27.2[b]	Brougher et al., 2014a [49479003]
Freshwater	Fathead minnow	*Pimephales promelas*	28,000	64.8[c]	Claude et al., 2013 [49252802]
Freshwater	Green sunfish	*Lepomis cyanellus*	130	7.60	Brougher et al., 2014b [49364101]
Freshwater	Medaka	*Oryzias latipes*	1500	4.24	Brougher et al., 2014c [49364102]
Freshwater	Rainbow trout	*Oncorhynchus mykiss*	174	21.9	Gries and Purghart, 2001c [47540302]
Freshwater	Western mosquitofish	*Gambusia affinis*	2900	5.00	Brougher et al., 2014d [49422801]
Estuarine/Marine	Sheepshead minnow	*Cyprinodon variegatus*	47.4	2.81	Burke, 2011 [49055701]

Table 3-2 Acceptable 96-hour LC50 data for technical malathion used to develop the acute SSD for fish					
Freshwater or Estuarine/ Marine Fish	***Common Name***	***Scientific Name***	***96-h LC50 (µg a.i./L)***	***Probit Slope[a]***	***Reference [MRID]***
Estuarine/Marine	Three-spined stickleback	*Gasterosteus aculeatus*	20.8	3.04	Gries et al., 2002a [48998006]

[a] Probit slopes calculated in SAS Version 9.3, SAS/STAT 12.1 unless otherwise indicated.
[b] Partial mortality was only observed for one test concentration in the coho salmon dataset. European commission guidance recommends that at least two partial mortalities be observed in order to use Probit analysis for the calculation of an EC/LC50 (EC, 2003).
[c] No partial mortalities were observed in the fathead minnow dataset. European commission guidance recommends that at least two partial mortalities be observed in order to use Probit analysis for the calculation of an EC/LC50 (EC, 2003).

The acute SSD was generated using SSD Master v3.0 (Rodney et al., 2013), an Excel-based tool that fits five different cumulative distribution functions (normal, logistic, extreme value, Gumbel) in both log and arithmetic space. This software allows for testing of model fit. The Gumbel model using log LC50 and EC50 values was the best-fitting model according to the Anderson-Darling (AD) goodness-of-fit test statistic ($A^2 = 0.170$) and various graphical plots of model residuals (e.g., p-p and q-q plots). The Gumbel model equation is shown below.

$$f(x) = e^{-e^{\frac{(L-x)}{s}}}$$ **Equation 3-1**

Where,

x is the concentration metameter;
$f(x)$ is the proportion of taxa affected; and
L and s are the location and scale parameters of the model.

The fitted model parameters were: $L = 2.068$ and $s = 0.890$ (Figure 3-1) for acute toxicity data reported in µg a.i./L. The HC5 (concentration that will affect 5% of species in the SSD) from the acute SSD is 12.3 µg a.i./L.

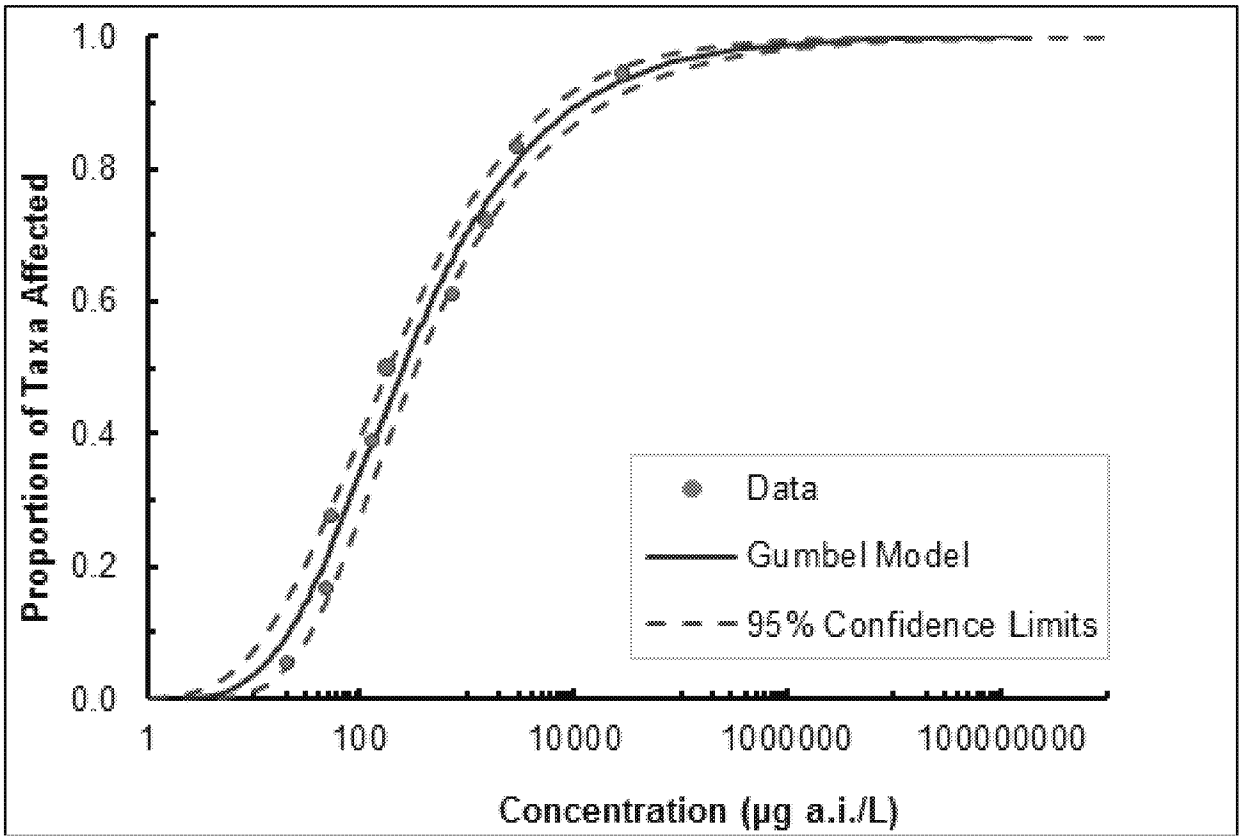


Figure 3-1 Acute SSD with approximate 95% confidence limits for fish species exposed to malathion

Probit slopes for all 96-hour LC50s included in the fish SSD were calculated in SAS Software® (SAS Version 9.3, SAS/STAT 12.1) and are presented in Table 3-2. Using the most conservative slope of 2.81 for the sheepshead minnow and the HC5 of 12.3 µg a.i./L, the concentration that would result in a chance of one in a million (0.0001%) of causing mortality to fish was estimated to be 0.250 µg a.i./L (Table 3-1).

3.1.1.2 Chronic

In accordance with the Interagency Interim Approaches (Agencies, 2013), direct effects to DS were assessed using the lowest available NOEL or other scientifically defensible effect threshold. The rainbow trout 97-day early life stage NOEL for fry survival of 21 µg a.i./L for rainbow trout (*Oncorhynchus mykiss*) reported by Cohle (1989 [MRID 41422401]) was the only NOEL from an acceptable or supplemental early life stage toxicity test in freshwater fish and was, therefore, used as the screening-level effects metric to assess chronic risk to DS in freshwater environments (Table 3-1).

The 34-day NOEL (fry survival) of 8.2 µg a.i./L for sheepshead minnow (*Cyprinodon variegatus*) (Hurd and Sharpe, 2011 [MRID 48705301]) was the most sensitive NOEL for marine/estuarine fish and was, therefore, used as the screening-level effects metric for assessing chronic risk to DS in marine/estuarine environments (Table 3-1).

3.1.2 *Indirect Effects to DS via Reduction in Aquatic Invertebrate Prey*

3.1.2.1 Acute

As per the Interagency Interim Approaches (Agencies, 2013), effects to aquatic invertebrates upon which a listed species depends are to be assessed using the concentration that would result in a 10% decrease of individuals, calculated using the HC5 from an SSD of LC50 or EC50 values. The number of acute toxicity studies available for freshwater invertebrates was limited. As a result, acute toxicity studies for estuarine/marine invertebrates (i.e., 48- or 96-hour EC50s for eastern oyster, grass shrimp and mysid shrimp) were included in the acute SSD dataset. In the case of malathion, there is no reason to believe that freshwater invertebrates are more sensitive than estuarine/marine invertebrates as the sensitivity ranges of freshwater and estuarine/marine invertebrate species overlaps. The LC/EC50 range for freshwater species from acceptable studies conducted with technical malathion is 0.70 µg a.i./L to >35,000 µg a.i./L, whereas the range for estuarine/marine species is 7.8 to >7500 µg a.i./L. Therefore, it is reasonable to combine freshwater and estuarine/marine aquatic invertebrate species to derive the acute SSD. Study evaluations for all data included in the acute aquatic invertebrate SSD can be found in Breton et al. (2014 [MRID 49333901]; 2015 [MRID 49692301]).

The acceptable acute toxicity data used to derive the acute SSD are presented in Table 3-3.

Table 3-3 Acceptable toxicity data for technical malathion used to develop the acute SSD for aquatic invertebrates

Freshwater or Estuarine/ Marine Invertebrate	*Common Name*	*Scientific Name*	*Endpoint*	*Value (µg a.i./L)*	*Probit Slope* [a]	*Reference [MRID]*
Freshwater	Amphipod	*Gammarus pseudolimnaeus*	48-h LC50	4.8	21.1[b]	Brougher et al., 2014f [49389402]
Freshwater	Crayfish	*Procambarus clarkia*	48-h LC50	>35,000	NC	Brougher et al., 2014h [49534901]
Freshwater	Grass shrimp	*Palaemonetes pugio*	48-h LC50	>162	3.56	Brougher et al., 2014j [49534902]
Freshwater	Mayfly	*Centroptilum triangulifer*	48-h LC50	23	10[c]	Brougher et al., 2014g [49479001]
Freshwater	Midge	*Chironomus dilutus*	48-h LC50	3.5	8.4[c]	Brougher et al., 2014e [49479002]
Freshwater	Water flea	*Daphnia magna*	48-h EC50 (immobilization)	0.70	2.99	Gries and Purghart, 2001a [47540303]
Estuarine/ Marine	Eastern oyster	*Crassostrea virginica*	96-h LC50	>7500[d]	NC	Brougher et al., 2014k [49389403]
Estuarine/ Marine	Mysid	*Americamysis bahia*	48-h LC50	7.8	40.5[b]	Brougher et al., 2014i [49389401]

NC: not calculated.

[a] Probit slopes calculated in SAS Version 9.3, SAS/STAT 12.1 unless otherwise indicated.

[b] Partial mortality was only observed for one test concentration in the amphipod and mysid datasets. European commission guidance recommends that at least two partial mortalities be observed in order to use Probit analysis for the calculation of an EC/LC50 (EC, 2003).

[c] Author-reported probit slope.

[d] No effects on mortality were observed at the highest test concentration of 7500 µg a.i./L in the eastern oyster shell deposition study (Brougher et al., 2014k [MRID 49389403]).

The acute SSD was generated using SSD Master v3.0 (Rodney et al., 2013). The crayfish was the most tolerant species tested and had a qualified 48-hour LC50 of > 35,000 µg a.i./L (Brougher et al., 2014h [MRID 49534901]). Furthermore, only 30% mortality was observed at the highest concentration tested. The eastern oyster was the second most tolerant species (Brougher et al., 2014k [MRID 49389403]) and a different endpoint (shell deposition) was examined in this study than in all other acceptable aquatic invertebrate studies. There is uncertainty in the LC50 estimates for the crayfish and eastern oyster, therefore, the truncation option in SSD Master was used to exclude the crayfish and eastern oyster endpoints from the model fit. This option allows for the exclusion of tolerant taxa when fitting the models, while the observed proportion of taxa affected remains true to the full dataset (Rodney et al., 2013). A qualified 48-hour LC50 of >162 µg a.i./L was also obtained for the grass shrimp (*Palaemonetes pugio*) (Brougher et al., 2014j [MRID 49534902]). However, 50% mortality was observed at the highest test concentration. The probit analysis performed by Brougher et al. (2014j [MRID 49534902]) on the grass shrimp data was replicated by Intrinsik and an LC50 of 174 µg a.i./L was obtained. However, since this value is extrapolated beyond the tested concentrations, the more conservative 48-hour LC50 reported by Brougher et al. (2014j [MRID 49534902]) was included in the SSD.

The Gumbel model using log LC50 and EC50 values was the best-fitting model according to the Anderson-Darling (AD) goodness-of-fit test statistic (A^2 = 0.340) and various graphical plots of model residuals (e.g., p-p and q-q plots). The gumbel model equation is shown above (Equation 3-1). The fitted model parameters were: s = 1.09 and L = 0.877 (Figure 3-2) for acute toxicity data reported in µg/L. The HC5 (concentration that will affect 5% of species in the SSD) from the acute SSD is 0.476 µg/L.

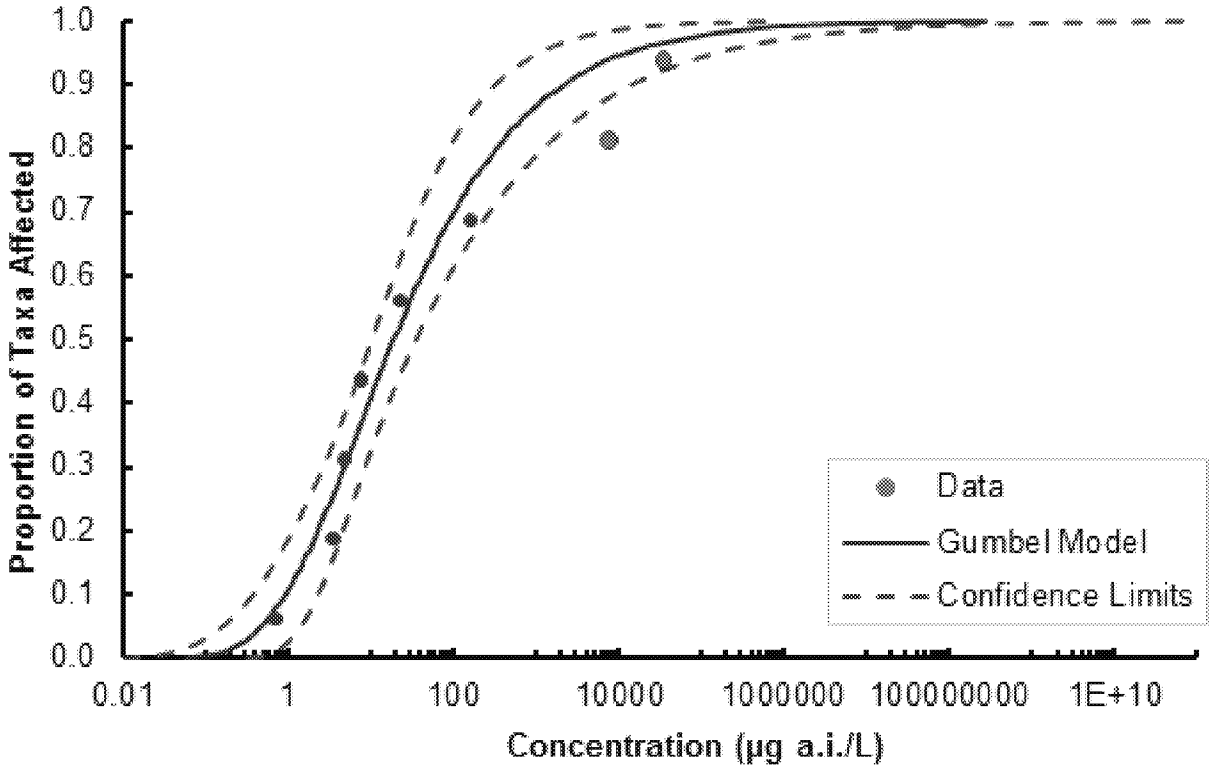


Figure 3-2 Acute SSD with approximate 95% confidence limits for aquatic invertebrate species exposed to malathion

Probit slopes for the 48-hour EC50/LC50s included in the aquatic invertebrate SSD are presented in Table 3-3. Brougher et al. (2014g,e [MRID 49479001, 49479002]) reported probit slopes for 48-hour mayfly and midge toxicity data reported in units of µg a.i./L. All other probit slopes were calculated using SAS Software® (SAS Version 9.3, SAS/STAT 12.1). Probit slopes were not calculated for the crayfish and Eastern oyster since these endpoints were truncated from the SSD. Using the HC5 of 0.476 µg a.i./L and the most conservative probit slope of 2.99 for *Daphnia magna*, the concentration resulting in 10% mortality freshwater invertebrates was estimated to be 0.177 µg a.i./L (Table 3-1).

3.1.2.2 Chronic

As per the Interagency Interim Approaches (Agencies, 2013), a LOEL for growth and reproduction should be used as the chronic effects metric for indirect effects. Since acceptable chronic studies were not available for freshwater invertebrates, the 21-day LOEL (survival, growth and reproduction) of 0.10 µg a.i./L for the water flea (*Daphnia magna*) reported by Blakemore and Burgess (1990 [MRID 41718401]) was used as the screening-level effects metric for assessing chronic risk to freshwater invertebrates (Table 3-1).

The 39-day LOEL (reproduction) of 0.58 µg a.i./L for mysid (*Americamysis bahia*) (Claude et al., 2012 [MRID 48752901]) was the most sensitive chronic LOEL for marine/estuarine invertebrates and was, therefore, used as the screening-level effects metric for assessing chronic risk to marine/estuarine invertebrates (Table 3-1).

3.2 Screening-Level Exposure Assessment

3.2.1 PRZM/EXAMS Modeling

The EPA simulation models, PRZM (3.12.2) and EXAMS (2.98.04), were used to estimate malathion concentrations in surface water. PRZM predicts pesticide transport in the soil profile and is capable of simulating pesticide runoff, erosion, plant uptake, leaching, transformation, foliar wash off, and volatilization. Daily edge-of-field loadings of pesticides dissolved in runoff waters and sorbed to sediment are discharged into a standard water body ("standard pond") simulated by the EXAMS model. Input data are required for soil characteristics, hydrology, pesticide chemistry, meteorology, use pattern, and the crop of interest. For each exposure scenario (Appendix A; Table A-1 and Table A-2), 30 years of site-specific climate data were used in PRZM. The PRZM results were used as inputs into EXAMS to estimate concentrations of malathion in surface waters of a standard pond. The standard pond scenario assumes a hypothetical treated field of 10 ha draining into a 1 ha pond that is 2 m deep, and is assumed to have no in- or out-flows. PRZM/EXAMS estimates exposure for this static water body, and thus produces far more conservative estimates than would be the case for flowing water bodies.

Each exposure scenario was simulated for a range of application dates, as malathion can be applied at various times between pre-emergence and harvest of a crop. Because rainfall patterns and other climatic variables vary temporally, off-field transport of malathion via runoff also varies temporally. As a result, choice of application date affects the EECs of malathion in the standard pond. For each possible application date, EXAMS determines a distribution of annual peak, 21-day and 60-day average EECs based on the 30-year simulation.

The 1-in-10 year EECs were calculated for each possible application date. For example, if an exposure scenario had 60 possible application dates, 60 90th percentile peak, 21-day and 60-day averages were derived. The maxima of these 90th percentile concentrations were used for determining risk to DS and their aquatic invertebrate prey. Use of maximum 90th percentile values is a highly conservative because the approach assumes the worst possible application date for the period of time between emergence and harvest of a crop in a year. Additional discussion of the conservative assumptions made in PRZM/EXAMS is provided in Teed et al. (2015 [MRID 49692201]) and in Section 3.4.2.1, below.

Exposure scenarios with multiple applications were run using the multi-application date option in the PE5 shell. For most of the exposure scenarios, the date range was selected to cover the entire range of dates recorded in the CA PUR database for 2004- 2008. This database is maintained by the CDPR and can be accessed at http://calpip.cdpr.ca.gov/main.cfm. For those crop scenarios with no information in the CA PUR database, the date range selected covered the time from the emergence date to the harvest date as listed in the Environmental Fate and

Effects Division (EFED) standard scenario description. For multiple applications, some date ranges were shortened to allow for the last annual application to occur on December 31 because PE5 does not allow annual application patterns to cross calendar years.

Worst-case scenarios according to the pesticide labels (i.e., maximum application rates, maximum frequency, shortest interval between applications) for each crop application were assumed for malathion. When crop scenario data for specific use patterns were not available in PRZM/EXAMS, a surrogate scenario was assigned. For example, crop data were not available for the eggplant use pattern. As a result, a tomato scenario was used as a surrogate. The exposure scenarios modeled with PRZM/EXAMS are shown in Table A-1 and Table A-2 (Appendix A).

3.2.1.1 Input Parameters for PRZM and EXAMS

The most recent EPA guidance was followed for deriving input parameters for PRZM/EXAMS (EPA, 2009b). The input parameters for PRZM/EXAMS are presented in Table 3-4. The aerobic aquatic, benthic, soil, and foliar dissipation half-lives were calculated from data provided from a number of studies and used as inputs for PRZM/EXAMS. Details on the calculation of these half-lives are presented in Reiss (2013 [MRID 49211704]) and Moore et al. (2014a [MRID 49389301]). Half-lives were calculated prior to the release of EPA's Standard Operating Procedure for Using the NAFTA Guidance to Calculate Representative Half-Life Values and Characterizing Pesticide Degradation" (EPA, 2015a) and, therefore, were not estimated using this approach.

Table 3-4 Input parameters used in PRZM and EXAMS to estimate concentrations of malathion in a standard pond at the edge of a treated field.

Parameter	*Input Value*	*Reference [MRID]*
Application type	Ground spray, airblast and aerial	
Runoff flow	None	
Incorporation depth	0	
Spray drift fraction	0.01 (ground) 0.03 (airblast) 0.05 (aerial)	
Application efficiency	0.99 (ground spray and airblast) 0.95 (aerial)	
Molecular weight	330.36 g/mol	Product Chemistry
Vapor pressure	4×10^{-5} mmHg	Cheminova A/S, 1988 [40966603]
Henry's Law constant	1.2×10^{-7} atm m^3 mol^{-1}	Cheminova A/S, 1988 [40966603]
K_{OC} (mL/g)	217	Blumhorst, 1989 [41345201]
Aqueous solubility (mg/L @ 30°C)	145 mg/L	Cheminova A/S, 1988 [40966603]
Aqueous photolysis half-life (d)	156	Carpenter, 1990 [41673001]
Aerobic aquatic biolysis half-life (d)	3.4	T90 calculated from: Knoch, 2001a [46769502] and Hiler and Mannella [48906401]
Benthic half-life (d)	7.5	Half-life of 2.5 d from Blumhorst (1991b [42216301]) multiplied by 3 as per EPA, (2009b)

Table 3-4 Input parameters used in PRZM and EXAMS to estimate concentrations of malathion in a standard pond at the edge of a treated field.		
Parameter	***Input Value***	***Reference [MRID]***
Soil half-life (d)	0.24	T90 calculated from: Blumhorst, 1990b [41721701] and Knoch, 2001b [46769501]
Foliar dissipation half-life (d)	4.10 (non-ULV); 5.73 (ULV)	Pooled 90th percentile of estimated t-distribution calculated by Moore et al. (2014a [MRID 49389301])
Hydrolysis half-life at pH 7 (d)	6.21	Teeter, 1988 [40941201]

To calculate an aerobic aquatic half-life, model input guidance from EPA (2009b) states that the rate of hydrolysis should be subtracted from the rate of aerobic aquatic metabolism when both aquatic metabolism and hydrolysis rate data are included as PRZM/EXAMS inputs. Seven half-lives for total aerobic aquatic metabolism, ranging from 0.3 to 3.3 days were available (Blumhorst, 1991a [MRID 42271601]; Knoch, 2001a [MRID 46769502]; Hiler and Mannella, 2012 [MRID 48906401]). However, hydrolysis testing at the pH used in the aerobic aquatic metabolism studies has not been conducted. Also, model estimates indicated stability that was not demonstrated in test systems investigated by Knoch (2001a [MRID 46769502]) and Hiler and Mannella (2012 [MRID 48906401]). Thus, linear regression analyses between pH and hydrolysis half-lives were conducted using data from Teeter (1988 [MRID 40941201]) to estimate pH-specific hydrolysis half-lives for malathion. These were then subtracted from the total system degradation rates, resulting in an estimated aerobic aquatic biolysis rate for each pH. The linear regression of pH-specific hydrolysis data from Teeter (1998 [MRID 40941201]), as calculated by Reiss (2013 [MRID 49211704]) is:

$$\log_{10}(Hydrolysis\ half-life\ in\ days) = -0.585 \times pH + 4.93 \qquad \textbf{Equation 3-2}$$

For example, using Equation 3-2, the hydrolysis half-life at pH 8.1 is 1.55 days, which corresponds to a rate of hydrolysis at pH 8.1 of 0.44 d^{-1}. This rate of hydrolysis was subtracted from the corresponding rate of aerobic aquatic metabolism at pH 8.1 (2.10 d^{-1}, Knoch, 2001a [MRID 46769502]). Therefore, the resulting biolysis rate at pH 8.1 is 1.66 d^{-1}. This represents an aerobic aquatic biolysis half-life of 0.42 days.

The same procedure was applied to the remaining aerobic metabolism half-lives. The aerobic aquatic biolysis half-lives adjusted for hydrolysis were 0.42 and 0.61 days from Knoch (2001a [MRID 46769502]), and 1.3, 4.2, 0.33, and 5.6 days from Hiler and Mannella (2012 [MRID 48906401]). The value for Blumhorst (1991a [MRID 42271601]) was negative, indicating that the hydrolysis rate predicted from the Teeter (1988 [MRID 40941201]) study was larger than the total dissipation rate observed by Blumhorst (1991a [MRID 42271601]). This could have resulted from several factors, such as variability across the Blumhorst (1991a [MRID 42271601]) and Teeter (1988 [MRID 40941201]) studies, inaccurate pH measurement in the Blumhorst (1991a [MRID 42271601]), or uncertainty in extrapolating the hydrolysis rates to unmeasured pHs (Reiss, 2013 [MRID 49211704]). Therefore, the Blumhorst (1991a [MRID

42271601]) half-life was omitted from the analysis. The mean value for the remaining six adjusted estimates is 2.06 days with a standard deviation of 2.24.

The upper 90 percent confidence limits on the mean (T90) aerobic aquatic biolysis half-life, soil half-life, and foliar dissipation half-lives were calculated using Equation 3-3. The derivation of this value can be found in Reiss (2013 [MRID 49211704]) and Moore et al. (2014a) [MRID 49389301].

$$t90 = sample\ mean + \frac{t_{0.9,n-1}s}{\sqrt{n}}$$ **Equation 3-3**

Where,

s is the sample standard deviation;

n is the sample size; and

$t_{0.9,n-1}$ is the value from the t-distribution defined by degrees of freedom *n-1*, such that the estimated probability of a lower mean first order half-life value is 0.9.

The resulting aerobic aquatic biolysis half-life used as an input parameter in PRZM/EXAMS is 3.4 days.

To calculate the soil half-life, a mean half-life was calculated from five half-life estimates from the two acceptable aerobic soil GLP studies (0.21 days from Blumhorst (1990 [MRID 41721701]); and, 0.17, 0.18, 0.25 and 0.25 days from Knoch (2001b [MRID 46769501])). Using Equation 3-3, the estimated T90 on the mean soil half-life was calculated to be 0.24 days (Table 3-4).

Cheminova has assembled an extensive database of foliar dissipation half-lives for malathion. Moore et al. (2014a [MRID 49389301]) presents the available data, and the approach taken to calculate the foliar dissipation half-lives. The estimated 90th percentile upper confidence bound on the mean half-life values are 4.10 days (non-ULV) and 5.73 days (ULV).

Other inputs included a foliar extraction coefficient for pesticide wash off per centimeter of rainfall, which was set to 0.5. There was no simulation of volatilization from the foliage or plant uptake of malathion. However, malathion decay on the plant surface was simulated automatically by PRZM.

3.2.1.2 PRZM/EXAMS Modeling Results

The peak, 21-day, and 60-day 90th percentile EECs are presented in Appendix C. For non-ULV agricultural uses, the lowest EECs resulting from PRZM/EXAMS were for groundspray applications to hops (0.63 lb a.i./A, three applications, seven day re-treatment interval) and melon (not watermelon), pumpkin and cantaloupe (1.00 lb a.i./A, two applications, seven day re-treatment interval) and the highest were for aerial applications to strawberry (2.00 lb a.i./A, four applications, seven day re-treatment interval) and guava (1.25 lb a.i./A, 13 applications, three day re-treatment interval). For ULV agricultural uses, the lowest EECs resulting from

PRZM/EXAMS were for groundspray application to citrus and kumquats (0.175 lb a.i./A, two applications, seven day re-treatment interval) and the highest were for aerial applications to cotton (1.22 lb a.i./A, three applications, seven day re-treatment interval) and cherry (1.22 lb a.i./A, four applications, seven day re-treatment interval).

For non-ULV non-agricultural uses modeled in PRZM/EXAMS, the lowest EECs were for groundspray and aerial applications to Christmas tree plantations and pine tree orchards (3.20 lb a.i./A, two applications, seven day re-treatment interval) and ornamentals (4.00 lb a.i./A, two applications, 10 day re-treatment interval) and the highest were for aerial application to Christmas tree plantations and pine tree orchards (3.20 lb a.i./A, two applications, 10 day re-treatment interval).

3.2.2 Pesticides in Flooded Applications Model (PFAM)

Rice, wildrice and watercress crops are grown in unique environments where paddies are flooded shortly after planting. Pesticides are typically applied directly onto paddy water. Uncontrolled drainage or overflow from the paddies may result in pesticide residues being released to downstream waters (Luo et al., 2011). For this reason, the usual procedure for estimating surface water EECs using PRZM/EXAMS is not appropriate for rice and watercress. Rather, the EPA Pesticides in Flooded Applications Model (PFAM prerelease version 1.0, executable date 1/23/2013) was used to estimate malathion concentrations for the EPA standard pond resulting from outflow from a flooded rice or watercress paddy adjacent to the EPA standard pond (Young, 2013). Results from these simulations are intended to represent more advanced and realistic estimation of malathion concentrations compared to EECs calculated from the EPA Tier I Rice model equation (EPA, 2015b).

PFAM is a two compartment model (water column compartment on top of a benthic compartment where the water column compartment represents the water level in the paddy) developed to simulate flooded and unflooded conditions in a paddy. Assumptions in PFAM include (as reproduced from Luo et al., 2011):

- suspended matter in the water column has negligible volume;
- hydrolysis, photolysis, and volatilization act only on dissolved species;
- within a single region (water column or benthic), the rate coefficient for biological metabolism is the same for both dissolved and sorbed forms of pesticide;
- the hydrolysis rate coefficient in the soil pore water of the benthic layer is the same as that in the water column; and
- linear equilibrium partitioning exists within each region among all sorbed species.

EPA has evaluated PFAM and compared it to results from both observed data and the Tier I Rice model. Both peak and chronic PFAM estimates in the water column and released water were substantially lower than estimates from the Tier I Rice model (Young, 2013).

Stone Environmental conducted a separate analysis in which PFAM estimates were compared to the results of two rice paddy field studies (Judy et al., 1991a,b [MRID 42058401, 42058402]).

PFAM over-estimated malathion concentrations in the rice paddy over time compared to observed concentrations from the Judy et al. (1991a,b [MRID 42058401, 42058402]) studies. Investigation revealed that this over-estimation occurred because in the Judy et al. (1991a,b [MRID 42058401, 42058402]) studies, malathion degraded faster in paddy water than the total water half-life of 2.2 days (based on combined hydrolysis and aerobic aquatic degradation) estimated by Cheminova for regulatory water modeling purposes (Reiss, 2013 [MRID 49211704]). Using both of the rice paddy studies, Stone estimated that the calibrated water half-life was less than 1 day when no changes were made to other modeling parameters for each site. This analysis is described below.

Currently, there are no regulatory standard crop scenarios that have been developed for PFAM by EPA. However, three standard scenarios are available for another rice model, RICEWQ that requires similar environmental parameters to PFAM (Williams et al., 2011). Each of these standard scenarios uses 30 years of continuous NOAA SAMSON weather data from a nearby weather station. The scenarios are: Arkansas rice (Little Rock, AR weather file), California rice (Sacramento, CA weather file) and Gulf rice (Port Arthur, TX weather file). Each weather file contains 30 years of observed daily rainfall, evaporation, temperature, solar radiation and wind speed data for 1961 – 1990.

Some of the AR, Gulf and CA standard scenario parameter values from RICEWQ were converted into PFAM units for simulating the application of malathion to rice, wild rice and watercress. Table 3-5 outlines the scenario input values that were used in the PFAM simulations along with the RICEWQ parameters from which the PFAM parameters were derived.

Table 3-5 PFAM modeling input weather, paddy and benthic parameters[a].

PFAM Parameter	*Parameter Source from RICEWQ*	*Arkansas Scenario*	*California Scenario*	*Gulf Scenario*
Weather File	Weather Data	W13963.dvf (Little Rock, AR)	W23232.dvf (Sacramento, CA)	W12917.dvf (Port Arthur, TX)
Latitude	N/A	35°	39°	30°
Zero height reference (mm/dd)	Crop emergence date	05/11	05/16	04/26
Days from zero height to full height	Crop maturity date	114 (9/2/2014)	138 (10/1/2014)	82 (7/17/2014)
Days from zero height to removal	Crop harvest date	125 (9/13/2014)	145 (10/8/2014)	103 (8/7/2014)
Maximum fractional areal coverage	Maximum aerial coverage of crop (fraction)	0.8	0.8	0.8
Date for flood event 1 then number of days after event 1 for subsequent flooding events	Dates to irrigate paddy (mm/dd)	4/26 then 36, 121, and 126 days thereafter representing 6/1, 8/25 and 8/30	5/1 then 4, 18, 141, and 146 days thereafter representing 5/5, 5/19, 9/19, and 9/24	4/11 then 5, 7, 14, 99 and 104 days thereafter representing 4/16, 4/18, 4/25, 7/19, and 7/24
Min. level (m) for each flood event	Depth of water to initiate irrigation	0.05 for all 4 flood events	0.05 for all 5 flood events	0.05, 0.025, 0.025, 0.05, 0.05, and 0.05

Table 3-5 PFAM modeling input weather, paddy and benthic parameters[a].

PFAM Parameter	*Parameter Source from RICEWQ*	*Arkansas Scenario*	*California Scenario*	*Gulf Scenario*
Weather File	Weather Data	W13963.dvf (Little Rock, AR)	W23232.dvf (Sacramento, CA)	W12917.dvf (Port Arthur, TX)
				for flood events 1 - 6, respectively
Fill level (m)	Depth of paddy outlet	0.2	0.15	0.15
Weir level (m) - set equal to fill level (m)	N/A	0.2	0.15	0.15
Mass transfer coefficient (m/s) - default value from PFAM guidance document	N/A	1.0×10^{-8}	1.0×10^{-8}	1.0×10^{-8}
Leakage (m/d)	Seepage rate	0.002	0.002	0.002
Reference depth (m)	Depth of paddy outlet or berm height	0.20	0.15	0.15
Benthic depth (m)	Depth of active sediment layer	0.05	0.05	0.05
Benthic porosity - set equal to benthic porosity in standard pond scenario in EXAMS2.98.04 model	N/A	0.50	0.50	0.50
Dry bulk density (g/cm^3)	Bulk density of bed sediment	1.35	1.43	1.35
F_{OC} water column on SS	Organic carbon	0.01305	0.01116	0.0058
F_{OC} benthic	Organic carbon	0.01305	0.01116	0.0058
Suspended sediment, SS (mg/L)	Suspended sediment concentration	50	20	100
Water column DOC (mg/L) - set equal to DOC from standard pond scenario in EXAMS2.98.04 model	N/A	5.0	5.0	5.0
Chlorophyll, CHL (mg/L) - set equal to CHL from standard pond scenario in EXAMS2.98.04 model	N/A	0.005	0.005	0.005
EXAMS-defined distribution factor default value, Dfac- set equal to Dfac from standard pond scenario in EXAMS2.98.04 model	N/A	1.19	1.19	1.19
Factor by which degradation increases for a 10°C temperature rise, Q10 - set equal to Q10 from standard pond scenario in EXAMS2.98.04 model	N/A	2	2	2

[a] Information in brackets represents RICEWQ inputs.

3.2.2.1 Input Parameters for PFAM

The environmental fate parameters used in PFAM to simulate malathion behavior in a rice, wildrice or watercress paddy were set to be the same as used in PRZM/EXAMS (Table 3-6). The only exception is that PFAM uses Heat of Henry (J/mol) instead of Henry's Law Constant (atm-m^3/mol). The Heat of Henry of 54,041 J/mol for malathion was obtained from the EPA EPI Suite tool (EPA, 2013a).

Table 3-6 Environmental fate parameters used in PFAM.

Parameter	*Input value*	*Reference [MRID]*
Water column half-life (d @ 25°C)	3.4	Reiss, 2013 [49211704]
Benthic compartment half-life (d @ 25°C)	7.5	Reiss, 2013 [49211704]
Unflooded soil half-life (d @ 25°C)	0.24	Reiss, 2013 [49211704]
Aqueous near-surface photolysis half-life (d @ 25°C)	156	Carpenter, 1990 [41673001]
Hydrolysis half-life (d)	6.21	Reiss, 2013 [49211704]
Koc (mL/g)	217	Reiss, 2013 [49211704]
Molecular weight (g/mol)	330.36	Product Chemistry
Vapor pressure (Torr)	4.00×10^{-5}	Cheminova A/S, 1988 [40966603]
Solubility (mg/L)	145	Cheminova A/S, 1988 [40966603]
Heat of Henry (J/mol)	54,041	EPI Suite value for Malathion
Henry reference temperature (°C)	25	

The maximum application rate of malathion to rice, wild rice and watercress is 1.25 lb a.i./A (or equivalently, 1.40 kg a.i./ha) as specified in the most recent malathion RED (EPA, 2009a). For the Arkansas and Louisiana Gulf scenarios for rice and wild rice, the most recent malathion RED (EPA, 2009a) specifies a maximum of two applications per year with a minimum re-application interval of seven days. For the California watercress scenario, a maximum of five applications per year with a minimum re-application interval of three days is specified in the most recent malathion RED (EPA, 2009a). As was done for PRZM/EXAMS modeling, 90th percentile EECs were calculated for each possible application date. The maxima of these 90th percentile concentrations was used for determining risk to aquatic organisms.

3.2.2.2 PFAM Modeling Results

For PFAM simulations used for standard ecological aquatic modeling, the paddy is assumed to be adjacent to the EPA standard pond. The paddy is assumed to release water and overflow into the EPA standard pond. The EECs for the EPA standard pond from this modeling are detailed below in Table 3-7.

Table 3-7 Screening Level Regulatory EECs for EPA standard pond with regulatory 2.2 day water half-life.					
Crop	*State*	*EECs (µg/L)*			
		Peak	*4-d*	*21-d*	*60-d*
Rice, wildrice	AR	145	117	68.2	24.8
Rice, wildrice	LA	185	141	67.3	24.1
Watercress	CA	127	107	69.0	31.3

To examine the realism of the screening-level regulatory EECs, PFAM was parameterized to simulate environmental conditions for each of two combined aquatic sediment field dissipation and irrigated crop accumulation studies in rice paddies with malathion (Judy et al., 1991a,b [MRID 42058401, 42058402]). For both of these field study simulations, the water half-life in PFAM was adjusted until predicted paddy water concentrations of malathion adequately fit to measured malathion concentrations in the rice paddies. Adjustment to the water half-life was the only input parameter changed in the field study simulations for this calibration exercise. Once this water half-life calibration step was completed, the longer of the two calibrated water half-lives from the two field study simulations was used to refine the screening-level EECs for the three standard PFAM scenarios to reflect more realistic malathion behavior in rice paddies.

The first rice paddy study was conducted in the Madera area of California in 1989 (Judy et al., 1991a [MRID 42058401]). The site had rice planted on July 21, 1989 and had three weekly applications of malathion at 0.58 lb a.i./A beginning on August 14, 1989. The elevation at the study site was 280 feet and the water level in the paddy was set to 6 inches. The soil type in the sediment of the paddy at the site was a Hanford sandy loam. The soil profile simulated in PFAM is detailed in Table 3-8.

Table 3-8 California Hanford sandy loam soil profile simulated in PFAM.									
Horizon	*Depth (cm)*	*Texture*	*Bulk Density (g/cc)*	*% Sand*	*% Silt*	*% Clay*	*Field Capacity*	*Wilting Point*	*% Organic Matter*
1	30	Loamy Sand	1.25	83	11	6	0.0929	0.0519	0.4
2	30	Sandy Loam	1.38	67	23	10	0.0957	0.0547	0.4
3	30	Sandy Loam	1.32	63	25	12	0.1196	0.0786	0.3
4	30	Sandy Loam	1.40	63	27	10	0.1168	0.0758	0.4

PFAM was set-up to simulate the above conditions in a rice paddy. The water half-life of 2.2 days was initially used to predict EECs, and then adjusted downward until there was good agreement between the measured EECs in the rice paddies of the Judy et al. (1991a [MRID 42058401]) study and those predicted by PFAM. For this study site, the calibrated water half-life (with no separate hydrolysis simulated) was 2 hours (i.e., 0.083 days). Results from this calibration modeling are detailed in Figure 3-3.

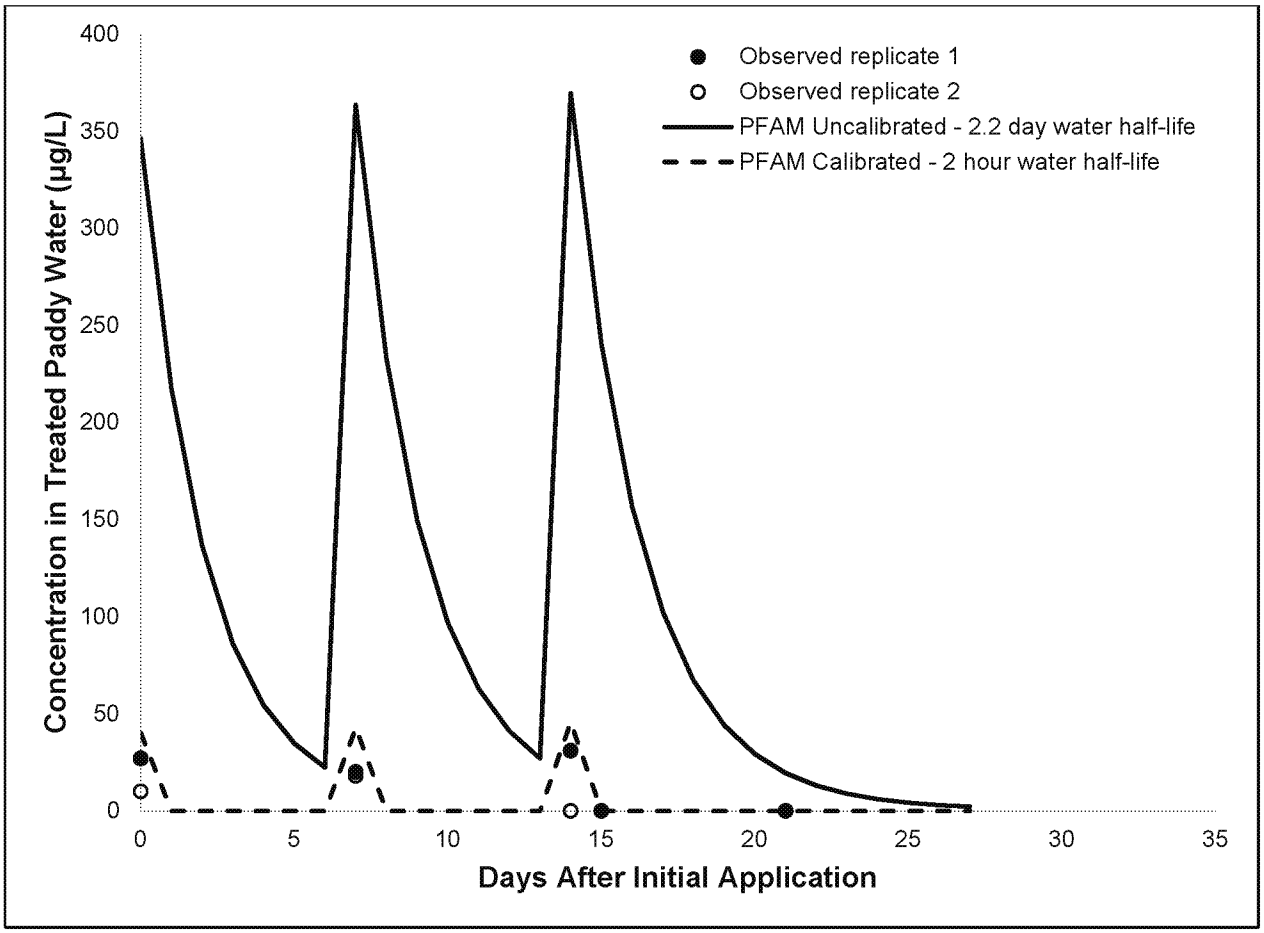


Figure 3-3 Comparison of malathion paddy water concentrations observed at the California study site (Judy et al., 1991a [MRID 42058401]), modeled in PFAM with the screening-level water half-life of 2.2 days, and modeled in PFAM with calibrated water half-life of 2 hours.

The second paddy study was conducted in the Steele area of Missouri in 1989 (Judy et al., 1991b [MRID 42058402]). The site had rice planted on June 6, 1990 and had three weekly applications of malathion applied at 0.58 lb a.i./A beginning on July 31, 1990. The elevation at the study site was 287 feet and the water level in the paddy was set to four inches. The soil type in the paddy sediment at the site was a Dundee silt loam. The soil profile simulated in PFAM is detailed in Table 3-9.

Table 3-9 Missouri Dundee Silt Loam Soil Profile Simulated in PFAM.

Horizon	*Depth (cm)*	*Texture*	*Bulk Density (g/cc)*	*% Sand*	*% Silt*	*% Clay*	*Field Capacity*	*Wilting Point*	*% Organic Matter*
1	30	Clay	1.01	19.3	34	46.7	0.396	0.272	1.3
2	30	Clay	0.99	17.3	38	44.7	0.396	0.272	0.7

PFAM was set-up to simulate the above conditions in a rice paddy. The water half-life of 2.2 days was initially used to predict EECs, and then adjusted downward until there was good agreement between measured EECs in the rice paddies of the Judy et al. (1991b [MRID 42058402]) study and those predicted by PFAM. For this study site, the calibrated water half-life (with no separate hydrolysis simulated) was one day. Results from this calibration modeling are detailed in Figure 3-4.

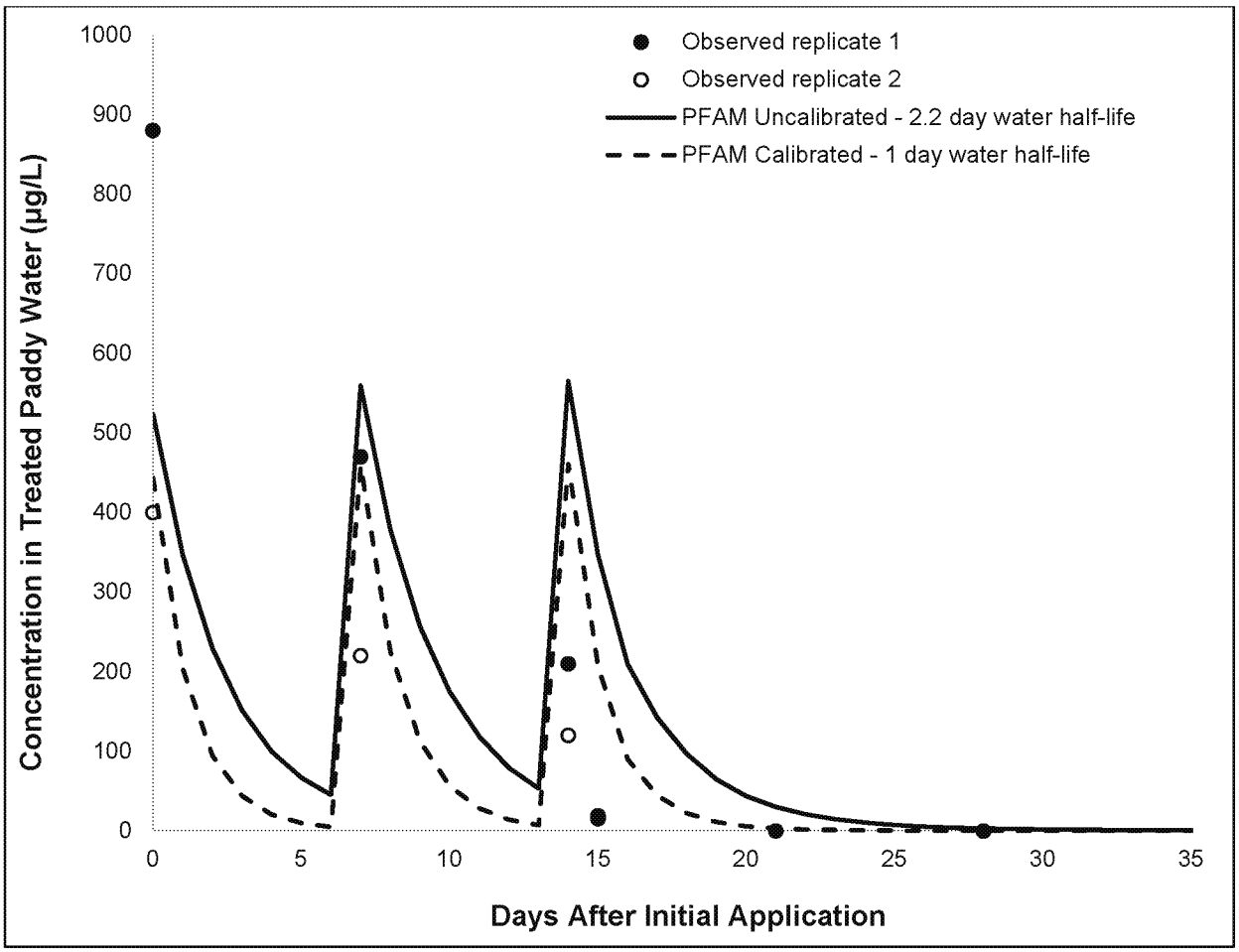


Figure 3-4 Comparison of malathion paddy water concentrations observed at the Missouri study site (Judy et al., 1991b [MRID 42058402]), modeled in PFAM with the screening-level water half-life of 2.2 days, and modeled in PFAM with calibrated water half-life of 1 day.

The above graph shows that on the date of the first application, one of the two observed replicate values had a measured paddy water concentration of 880 µg/L, which is impossible with the applied application rate in 4 inch water depth, even with no degradation simulated. Thus, the data were considered an outlier. The second replicate had a measured value of 400 µg/L, which is quite reasonable for this study site conditions.

To examine the effect of reduced water half-life for the three standard PFAM environmental scenarios on the EPA standard pond predicted EECs, each of the scenarios were re-run with a

one day water half-life (with no separate hydrolysis simulated). These refined EECs are detailed in Table 3-10 below.

Table 3-10 Refined EECs for EPA standard pond with calibrated 1.00 day water half-life.

Crop	*State*	*EECs (µg/L)*			
		Peak	*4-d*	*21-d*	*60-d*
Rice, wildrice	AR	98.0	55.4	26.1	9.20
Rice, wildrice	LA	121	67.0	24.6	8.60
Watercress	CA	85.9	67.1	38.2	15.7

Using the more realistic half-life of one day, the refined EECs were reduced by over 30% relative to the screening-level regulatory EECs for the EPA standard pond simulated to receive overflow and release water from an adjacent rice paddy.

3.2.3 EPA Modeling Approach for Non-Agricultural Uses of Malathion

The EPA document, *Risks of Malathion Use to the Federally Threatened Delta Smelt (Hypomesus transpacificus) and California Tiger Salamander (Ambystoma californiense), Central California Distinct Population Segment, and the Federally Endangered California Tiger Salamander, Santa Barbara County and Sonoma County Distinct Population Segments* (EPA, 2010a) gives specific guidance for modeling certain non-agricultural scenarios in PRZM/EXAMS. Section 3.2.1 of EPA (2010a) describes the process for creating surrogate (reference) scenarios for the uses listed below:

- agricultural uncultivated areas, non-agricultural uncultivated areas, non-ULV (aerial, groundspray and airblast applications);
- fence rows/hedge rows, non-ULV (groundspray applications); and
- household/domestic dwellings (perimeter/refuse/solid waste sites/containers, non-ULV (groundspray; impervious and residential).

Because none of the uses listed above would be expected to occur on an entire 10 hectare PE5 model area, a model was created following EPA guidance (EPA, 2010a) to estimate the EECs for a 1,000 square foot application area within the 10 hectare model area. For the purpose of estimating RQs, EPA (2010a) assumed that each hectare within the 10 hectare modeled area contained a 100 square foot area of treatment. The surrogate scenarios modeled an application rate of 1 lb a.i./A (1.12 kg a.i./ha) per application rather than the labeled application rate because there was a concern that the solubility limit of malathion would be exceeded (a physical impossibility) if the full application rate was applied. Model runs using 1 lb a.i./A, 2 lb a.i./A, and 4 lb a.i./A (for 4 applications each) indicated that a linear relationship existed between application rate and EEC for all three model scenarios. This allowed the EEC of the 1 lb a.i./A run to be scaled to the labeled application rate.

Stone identified two errors in the equation used by EPA to adjust the application area from 10 hectares to 1000 ft^2:

1. the EPA equation assumes a 10 acre PRZM watershed. The equation was corrected to reflect the actual 10 hectare PRZM watershed; and
2. application units of lb/A were converted to kg/ha.

Accordingly, Equation 3-4, as shown below (where the PRZM/EXAMS EEC of 3.63 µg a.i./L was used to estimate the EEC_{peak} for fence rows/hedge rows following EPA guidance (EPA, 2010a)), incorporates these changes and corrections and was used to estimate the EECs in the screening-level effects determination for the uses listed above.

$$EEC_{peak} = \frac{\frac{3.63\ \mu g\ a.i./L}{1.121\ kg\ a.i./ha} \times 11.91\ kg\ a.i./ha \times 1000 ft^2}{43{,}560\ ft^2/A \times 10 ha \times 2.471\ A/ha} = 0.0358\ \mu g\ a.i./L \qquad \textbf{Equation 3-4}$$

3.2.3.1 Non-Agricultural Use Approach Modeling Results

The peak, 21-day, and 60-day 90th percentile EECs are presented in Appendix C. For non-ULV non-agricultural uses, the lowest and highest EECs using EPA guidance (EPA, 2010a) for non-ULV uses were for groundspray application to agricultural uncultivated and non-agricultural uncultivated areas (1.00 lb a.i./A, one application) and groundspray application to fence rows/hedge rows (10.62 lb a.i./A, four applications, seven day re-treatment interval), respectively.

3.3 Screening-Level Risk Characterization

Risk characterization integrates the exposure and effects assessments to determine the potential risk of exposure scenarios for both direct and indirect effects to the DS. The screening-level effects determination evaluated risk using RQs calculated by dividing EECs by acute and chronic effect metrics. Acute effects metrics were compared to peak EECs and chronic effects metrics were compared to 60-day EECs for DS and to 21-day EECs for aquatic invertebrates. RQs greater than one indicated possible risk to receptors.

Results of the risk characterization for aquatic taxa are summarized in Appendix C. Acute and chronic RQs for non-ULV malathion for DS and aquatic invertebrates are shown in Table C-1 and Table C-3, respectively, while the respective ULV RQs are shown in Table C-2 and Table C-4. RQs greater than one are bolded throughout.

Results of the risk characterization for acute and chronic exposures to ULV and non-ULV uses of malathion (scenarios modeled in PRZM/EXAMS) are as follows:

- **Direct effects to DS:** All non-ULV uses (139 scenarios), and all ULV uses except for citrus, grapefruit, lemon, lime, orange, tangelo, tangerines and citrus and kumquats

(28/30 scenarios) had acute RQs greater than one. However, no chronic RQs were greater than one for either freshwater or marine/estuarine fish.

- **Direct effects to aquatic invertebrate prey of DS:** All non-ULV uses (139 scenarios) and all ULV uses except for citrus and kumquats (29/30 scenarios) had acute RQs greater than one. Using the LOEL for freshwater invertebrates, all non-ULV uses and all ULV uses except for citrus, grapefruit, lemon, lime, orange, tangelo, tangerines and citrus and kumquats (28/30 scenarios) had chronic RQs greater than one. Using the marine/estuarine invertebrates LOEL, 110 of 139 non-ULV scenarios and 14 of 30 ULV scenarios had chronic RQs greater than one.

Results of the risk characterization for acute and chronic exposures to non-ULV uses of malathion on rice, wildrice and watercress (scenarios modeled in PFAM) are as follows:

- **Direct effects to DS:** All uses had acute RQs greater than one. Using the marine/estuarine fish NOEL, all uses had chronic RQs greater than one. Using the freshwater fish NOEL, three of six scenarios had chronic RQs greater. The EECs calculated using the adjusted water half-life did not exceed the chronic effect metric for freshwater fish.
- **Direct effects to aquatic invertebrate prey of DS:** All uses had acute and chronic RQs greater than one.

Results of the risk characterization for acute and chronic exposures to non-ULV uses of malathion (scenarios modeled using EPA's modeling approach for non-agricultural use patterns) are as follows:

- **Direct effects to DS:** Only one of six scenarios (ground application to household/domestic dwellings (perimeter)/ refuse/ solid waste sites/ containers using the impervious scenario) had an acute RQ greater than one. No uses had chronic RQs greater than one.
- **Direct effects to aquatic invertebrate prey of DS:** Only one of six scenarios (ground application to household/domestic dwellings (perimeter)/ refuse/ solid waste sites/ containers using the impervious scenario) had an acute RQ greater than one. No uses had chronic RQs greater than one.

3.3.1 Summary

The results of the screening-level risk characterization suggest that there is the potential for acute risk to DS and for acute and chronic risk to the aquatic invertebrate prey of DS. Although chronic RQs for DS were greater than one for malathion use on rice, wildrice and watercress, it is not expected that these uses will result in unacceptable risk to DS for several reasons.

Firstly, rice and watercress account for a minor portions of malathion applied in California. Malathion applications to rice and watercress in California from 2000 to 2013 account for only 0.418% and 0.0807%, respectively, of total malathion use by weight, and 0.502% and 0.115% by area covered (Table 2-1). Secondly, even with the adjustments made to the PFAM model to

incorporate site-specific data, there are several limitations that result in highly conservative estimates of exposure (as described above in Section 3.2.2). The additional analysis conducted using a half-life from a rice field study provides more realistic estimates of exposure. However, the slower rate of the two available studies (one day rather than two hours) was used as a conservative measure (Judy et al., 1991a,b [MRID 42058401, 42058402]). Looking into the literature, a rice paddy field monitoring study and subsequent fate modeling exercise conducted by Anyusheva et al. (2012) and La et al. (2014) were identified, which involved the application of dimethoate and fenitrothion (both organophosphate pesticides) to rice paddies in Vietnam. These studies identified two key components that influence fate: solubility (positively correlated with wash-off fraction), and the water decay rate (a function of the aquatic half-life). Malathion is both highly soluble and has a short aquatic half-life, indicating rapid dissipation and degradation if exposed to natural waterbodies. A third study was also identified, which examined the effects of Malathion 60 applied on watercress crops to the amphipod *Gammarus pulex* living below the crop beds (Crane et al., 1995). Amphipods were placed in cages below either a large watercress bed, a small watercress bed, or the settling pools that receive water from the beds. The authors observed no significant mortality pre- or post-spray with the exception of the small watercress bed, indicating that survival of amphipods present within the watercress beds may be affected, but that this is not the case in the settling pools.

Furthermore, spatial analyses suggest that DS habitat rarely coincides with California rice paddies or watercress operations (See Appendix D). Stone compared the areas where malathion has been applied to rice and watercress (CA PUR data collected between 2003 and 2012), as well as land classified as rice paddies (National Agricultural Statistics Service (NASS) Crop Data Layer (CDL)), with DS critical habitat, as designated by FWS, and occurrence data reported in the FESTF Multi-Jurisdictional Database (MJD) and the California Natural Diversity Database (CNDDB). Data from the CA PUR database collected between 2003 and 2012 indicated that two applications to rice sites amounting to 412 lb a.i. malathion and four applications to wild rice sites amounting to 937 lb a.i. malathion occurred within DS critical habitat in the ten-year period examined. However, no malathion applications for rice or wildrice overlapped with elemental occurrences (EOs) from the CNDDB and MJD. The minimum distance between a DS EO and malathion application on rice and wild rice between 2003 and 2012 was 23.4 km. Between 2003 and 2012, no malathion applications to watercress overlapped with DS critical habitat or EOs, and the minimum distance between DS critical habitat and/or elemental occurrences and malathion applications to watercress was 62.9 km. Based on NASS CDL data for 2009 to 2013, only 1.8% of DS critical habitat was classed as a rice producing area (Appendix D). Taken together, these results indicate that exposure of DS and their aquatic invertebrate prey to malathion via applications made to rice, wild rice and watercress would rarely occur since malathion is infrequently applied to these crops within DS habitat and land classified as a rice producing area by the NASS CDL represents a very small percentage of DS habitat. As such, risk to DS and their aquatic invertebrate prey from application of malathion to rice, wild rice and watercress will not be assessed further in the refined effects determination.

Based on the results from the screening-level effects determination, the refined aquatic effects determination will focus on: 1) acute risk to DS and 2) acute and chronic risk to aquatic invertebrates.

3.4 Uncertainty in the Screening-level Effects Determination

3.4.1 Effects Assessment

The National Academy of Sciences (NAS, 2013) suggests that toxicological data be evaluated prior to use in risk assessment, and that test material must be determined to be relevant to the United States. Moreover, EPA (2011) prescribes that studies used for risk assessment be evaluated for quality, and that, as required by the ESA, best available data only be used for risk assessment. In their consideration of the assessment of risk to endangered species, the National Academy of Sciences (NAS, 2013) noted that there is little guidance that defines "best available data". It was suggested that the strengths and weaknesses of key studies be properly documented to ensure the relevance of each study. Moreover, NAS (2013) notes the importance of the utility of studies. For example, they note that studies found in databases may not be suitable for risk assessment if the data and methods are not transparent to reproduce results.

In the screening-level aquatic effects assessment, the most sensitive and relevant endpoints were selected as effects metrics. Studies were reviewed to determine the best available data (as required by the ESA, and recommended by NAS (2013)). There is some uncertainty associated with these endpoints, including the number of acceptable and supplemental studies available to derive effects metrics and the relevance of the studied species to the target organisms being assessed in this effects determination. The level of certainty associated with the effects metric selection for DS and their aquatic invertebrate prey is discussed in the sections below.

3.4.1.1 DS

Acute

There are acceptable and supplemental toxicity studies for eight freshwater and two estuarine/marine species, representing seven families, six orders and a wide range of sensitivities to malathion toxicity. The 96-hour LC50s for technical malathion ranged from 21.7 to 28,000 µg a.i./L (Breton et al., 2014 [MRID 49333901]; 2015 [MRID 49692301]). The screening-level effects metric for DS in this effects determination was the estimated concentration resulting in a chance of one in a million (or 0.0001%) of causing mortality to an individual, calculated using the HC5 of 12.3 µg a.i./L and from a fish SSD and the most conservative probit slope of 2.81 (see Section 3.1.1.1). The resulting concentration of 0.250 µg a.i./L is 19 times lower than the lowest acute NOEL of 4.81 µg a.i./L (for threespined stickleback) from all acceptable, supplemental and unacceptable studies for fish (Breton et al., 2014 [MRID 49333901]; 2015 [MRID 49692301]). Furthermore, in their Draft Biological

Evaluation, EPA (2016a) derived a mortality threshold for fish of 3.39 µg/L based on an HC5 of 38.6 µg/L and a standard probit slope of 4.5.

There is very little known about the sensitivity of DS to pesticides, relative to standard test species (USDI, 2008). None of the species used in malathion toxicity studies belong to the same order as DS and it is therefore uncertain how sensitive DS is to malathion toxicity compared to the different test species. However, two studies have recently reported acute LC50s for DS exposed to esfenvalerate and permethrin (Connon et al., 2009; Jeffries et al., 2015). Jeffries et al. (2015) reported a 96-hour LC50 of 4.07 µg/L for permethrin in larval DS and compared this value to acute LC50s for 23 other fish species (including both listed and standard test species). Based on 96-hour LC50 data for larval and juvenile fish, DS was approximately two to four times more sensitive to permethrin toxicity relative to the bluegill sunfish, fathead minnow and sheepshead minnow, but either had equal sensitivity or was less sensitive than Atlantic silverside (*Menidia menidia*), brook trout (*Salvelinus fontinalis*), rainbow trout and zebrafish (*Danio rerio*; Jeffries et al., 2015). Connon et al. (2009) reported 24-hour LC50s of 0.19 and 0.25 µg/L for 10-day old and 52-day old DS exposed to esfenvalerate. An advanced query of EPA's ECOTOX database (http://cfpub.epa.gov/ecotox/advanced_query.htm) was performed on November 5, 2015 to obtain acute LC50 data for esfenvalerate in other fish species. Acute LC50s for larval and juvenile fish ranged from 0.07 µg/L for the rainbow trout to 16.7 µg/L for chinook salmon. Again, DS was less sensitive to esfenvalerate toxicity compared to the rainbow but, on average, was 1.8 and 5.66 times more sensitive than the fathead minnow and bluegill sunfish, respectively. Although the relative sensitivity of fish species to these pyrethroid pesticides differs from that observed for malathion, the results of Jeffries et al. (2015) and Connon et al. (2009) indicate that acute toxicity of pesticides to DS is not outside the range observed for standard test species. Therefore, because of the abundance of acute fish toxicity data available for malathion and the conservative nature of the effects metric used in this assessment, we have high confidence that the acute screening-level effects metric of 0.250 µg a.i./L is protective of DS.

Chronic

Acceptable and/or supplemental toxicity studies are available for two freshwater species (rainbow trout and fathead minnow) and for one estuarine/marine fish species (sheepshead minnow). The 97-day rainbow trout NOEL of 21 µg a.i./L for fry survival and growth (Cohle, 1989 [MRID 41422401]) and the 34-day sheepshead minnow NOEL of 8.2 µg a.i./L for survival (Hurd and Sharpe, 2011 [MRID 48705301]) were selected as the screening-level effects metrics for DS in freshwater and estuarine/marine environments, respectively. Only a 10-month survival NOEL of 7.4 µg/L for the bluegill sunfish (Eaton, 1970) was lower than the most sensitive chronic effect metric for fish of 8.2 µg a.i./L (Hurd and Sharpe, 2011 [MRID 48705301]). However, Eaton (1970) was rated unacceptable because it did not include any information on controls, did not conduct any statistical analyses in the calculation of the NOEL, and did not report the source of the test substance (Breton et al., 2014 [MRID 49333901]). In chronic toxicity tests, malathion concentrations are maintained in test systems over extended durations of weeks to months. This approach, particularly for chronic exposure to malathion, is inconsistent

with exposure in the environment. Exposures are expected to peak with applications, and quickly dissipate in the environment within a matter of days. Estimated half-lives for malathion in GLP studies testing aerobic aquatic systems range from 0.3 to 3.3 days (Blumhorst, 1991a [MRID 42271601]; Knoch, 2001 [MRID 46769502]; Hiler and Mannella, 2012 [MRID 48906401]). In a worst-case scenario, receptors may be exposed to pulse exposures when multiple applications are allowed during the growing season. But even under these conditions, receptors can metabolize and recover from malathion exposures (See Sections 2.4.5 and 4.3.3). As such, it is virtually impossible that DS would be continuously exposed to 7.4 µg/L malathion (or higher) over a ten month period, since the maximum 90-day and annual 90th percentile EECs calculated in PRZM/XAMS and PFAM were 2.93 and 0.721 µg a.i./L, respectively. Therefore, we have a high degree of confidence that the chronic screening-level effects metrics selected are protective of DS.

3.4.1.2 Aquatic Invertebrate Prey of DS

Acute

Acceptable and supplemental toxicity studies were available for five freshwater and three estuarine/marine invertebrate species. The 48-hour EC50/LC50 data for technical malathion from acceptable and supplemental studies ranged from 0.70 to >35,000 µg a.i./L. The screening-level effects metric for aquatic invertebrate prey of DS in this effects determination was the estimated concentration resulting in a 10% decrease of individuals, calculated using the HC5 of 0.476 µg a.i./L from an aquatic invertebrate SSD and the most conservative probit slope of 2.99 (see Section 3.1.2.1). The estimated concentration of 0.177 µg a.i./L was similar to the lowest acute NOEL of 0.11 µg a.i./L from all acceptable, supplemental and unacceptable studies for aquatic invertebrates (Breton et al., 2014 [MRID 49333901]; 2015 [MRID 49692301]). The selected effect metric is also very similar and slightly lower than EPA's indirect effects threshold for aquatic invertebrates of 0.22 µg/L (based on an HC5 value of 0.356 and probit slope of 5.14; EPA, 2016a).

As described in Section 2.1.5, DS primarily feed on calanoid and cyclopoid copepods. Although rated unacceptable, Naqvi and Hawkins (1989) reported 48-hour LC50s of 1.12 and 0.561 µg a.i./L for the calanoid copepod (*Diaptomus sp.*) and the cyclopoid copepod (*Eucyclops sp.*), which are both above the HC5 of 0.476 µg a.i./L. In addition, DS consume a wide variety of prey items, including phytoplankton, cladocerans, rotifers, amphipods, brine shrimp, insect larvae, and mysids. Acute LC50 and EC50 data for these taxa are summarized in Table 3-11. The geometric mean of 48-hour LC50 data for only one of 23 prey species (*Chironomus ramosus*) was below the HC5 of 0.476 µg a.i./L. In addition, this LC50 was reported in a study rated unacceptable according to Cheminova's study evaluation criteria (Breton et al., 2014 [MRID 49333901]). The fact that only one in 23 species (4%) had an LC50 below the HC5 supports our assumption that the aquatic invertebrate SSD is representative of aquatic invertebrate prey of DS.

Acute toxicity data for aquatic invertebrates are widely available for malathion, and a number of studies have focused on taxa that are representative of DS prey items. Furthermore, the vast

majority of acute LC50 and EC50 data were well above the HC5 of 0.476 µg a.i./L from the aquatic invertebrate SSD. Therefore, we have a high degree of confidence that the acute screening-level effect metric of 0.177 µg a.i./L is protective of the aquatic invertebrate prey of DS. However, it is very likely that this effect metric will over predict risk to DS aquatic invertebrate prey since some prey items of the DS (e.g., amphipods and rotifers) have LC50 values that are approximately 10,000 and150,000 times higher than the HC5 of 0.476 µg a.i./L.

Chronic

Acceptable and/or supplemental toxicity studies are available for one freshwater and one estuarine/marine species. The 21-day LOEL of 0.1 µg a.i./L for growth, reproduction and survival of the water flea (*Daphnia magna*; Blakemore and Burgess, 1990 [MRID 41718401]) and the 39-day LOEL of 0.58 µg a.i./L for reproduction in mysid shrimp (*Americamysis bahia*; Claude et al., 2012 [MRID 48752901]) were selected as the screening-level effects metrics for freshwater and estuarine/marine invertebrate prey of DS, respectively. Only one other chronic NOEL was available for technical malathion from a study rated unacceptable according to Cheminova's study evaluation criteria (Dortland, 1980; Breton et al., 2014 [MRID 49333901]). Dortland (1980) reported a 21-day NOEL of 0.15 µg/L for immobilization *Daphnia magna*, which is higher than the selected effects metric for freshwater invertebrates. Although few chronic toxicity studies were available for aquatic invertebrates, the available 48-hour LC50 data for technical malathion indicate that the water flea and mysid shrimp are among the most sensitive freshwater and estuarine/marine invertebrate species to malathion toxicity. As such, we have high confidence that the acute and chronic effects metrics for aquatic invertebrates are protective of DS prey items.

As described above (Section 3.4.1.1), the use of extended malathion exposures over several weeks to months in chronic toxicity tests is inconsistent with exposure in the environment. Exposures are expected to peak with applications, and quickly dissipate in the environment within a matter of days. In a worst-case scenario, receptors may be exposed to pulse exposures when multiple applications are allowed during the growing season. But even under these conditions, receptors can recover from malathion exposures (See Section 4.3.3).

Table 3-11	Acceptable, supplemental and unacceptable 48-hour toxicity data for malathion and DS aquatic invertebrate prey items.						
DS prey item	***Freshwater or Estuarine/ Marine Invertebrate***	***Scientific Name***	***Endpoint***	***Value µg test substance/L (µg a.i./L)***	***Geomean µg test substance/L (µg a.i./L)***	***Reference [MRID]***	***Cheminova's Study Rating***
Amphipods	Freshwater	*Gammarus fasciatus*	48-h LC50	0.5	1.00	Sanders, 1972 [05017538]	Unacceptable
	Freshwater	*Gammarus fasciatus*	48-h LC50	2			
	Freshwater	*Gammarus lacustris*	48-h LC50	1.8	1.8	Sanders, 1969 [05009242]	Unacceptable
	Freshwater	*Gammarus pseudolimnaeus*	48-h LC50	(4.8)	(4.8)	Brougher et al., 2014f [49389402]	Acceptable
	Marine	*Gammarus palustris*	48-h LC50	1200	5590	Leight and Van Dolah, 1999	Unacceptable
	Marine	*Gammarus palustris*	48-h LC50	26000			
Cladocerans	Freshwater	*Alonella sp.*	48-h LC50	2 (1.12)	2 (1.12)	Naqvi and Hawkins, 1989	Unacceptable
	Freshwater	*Ceriodaphnia dubia*	48-h LC50	2.12	2.25	Ankley et al., 1991	Unacceptable
	Freshwater	*Ceriodaphnia dubia*	48-h LC50	3.35		Maul et al., 2006	Unacceptable
	Freshwater	*Ceriodaphnia dubia*	48-h LC50	1.14		Nelson and Roline, 1998	Unacceptable
	Freshwater	*Daphnia carinata*	48-h LC50	100	100	Santharam et al., 1976	Unacceptable
	Freshwater	*Daphnia magna*	48-h LC50	4.09	3.19	Barata et al., 2004	Unacceptable
	Freshwater	*Daphnia magna*	48-h LC50	2.2 (1.3)		Burgess, 1989 [41029701]	Supplemental
	Freshwater	*Daphnia magna*	48-h EC50 (immobilization)	2.2		Dortland, 1980	Unacceptable
	Freshwater	*Daphnia magna*	48-h EC50 (immobilization)	(0.70)		Gries and Purghart, 2001a [47540303]	Acceptable
	Freshwater	*Daphnia magna*	48-h EC50 (immobilization)	4.4 (1.8)		Gries and Purghart, 2001b [49086401]	Acceptable
	Freshwater	*Daphnia magna*	48-h LC50	33		Hermens et al., 1984	Unacceptable
	Freshwater	*Daphnia magna*	48-h EC50 (immobilization)	1.8		Kikuchi et al., 2000	Unacceptable

Table 3-11 Acceptable, supplemental and unacceptable 48-hour toxicity data for malathion and DS aquatic invertebrate prey items.

DS prey item	*Freshwater or Estuarine/ Marine Invertebrate*	*Scientific Name*	*Endpoint*	*Value µg test substance/L (µg a.i./L)*	*Geomean µg test substance/L (µg a.i./L)*	*Reference [MRID]*	*Cheminova's Study Rating*
	Freshwater	*Daphnia magna*	48-h EC50 (immobilization)	1		Mayer and Ellersieck, 1986 [40098001]	Unacceptable
	Freshwater	*Daphnia magna*	48-h EC50 (immobilization)	(2.1)		Mattock, 2002 [47540301]	Supplemental
	Freshwater	*Daphnia magna*	48-h EC50 (immobilization)	5.13 (2.08)			
	Freshwater	*Daphnia magna*	48-h LC50	6.94		Zhang et al., 2011	Unacceptable
	Freshwater	*Daphnia magna*	48-h LC50	11.32			
	Freshwater	*Daphnia magna*	48-h LC50	11.62			
	Freshwater	*Daphnia pulex*	48-h EC50	2	1.90	Cope, 1966	Unacceptable
	Freshwater	*Daphnia pulex*	48-h EC50 (immobilization)	1.8		Mayer and Ellersieck, 1986 [40098001]	Unacceptable
	Freshwater	*Simocephalus serrulatus*	48-h EC50	3	1.33	Cope, 1966	Unacceptable
	Freshwater	*Simocephalus serrulatus*	48-h EC50 (immobilization)	0.59-6.2		Mayer and Ellersieck, 1986 [40098001]	Unacceptable
Copepods	Freshwater	*Diaptomus sp.*	48-h LC50	2 (1.12)	2 (1.12)	Naqvi and Hawkins, 1989	Unacceptable
	Freshwater	*Eucyclops sp.*	48-h LC50	1 (0.561)	1 (0.561)		
Insect larvae	Freshwater	*Notonecta undulata*	48-h LC50	110	110	Federle and Collins, 1976	Unacceptable
	Freshwater	*Simulium vittatum*	48-h LC50	(54.2)	(54.2)	Overmyer et al., 2003	Unacceptable
	Freshwater	*Centroptilum triangulifer*	48-h LC50	(23)	(23)	Brougher et al., 2014g [49479001]	Acceptable
	Freshwater	*Chironomus dilutus*	48-h LC50	(3.5)	(3.5)	Brougher et al., 2014e [49479002]	Acceptable
	Freshwater	*Chironomus ramosus*	48-h LC50	0.00054	0.00054	Majumdar and Gupta, 2009	Unacceptable
	Freshwater	*Acroneuria pacifica*	48-h LC50	16	16	Jensen and Gaufin, 1964 [00065497]	Unacceptable
	Freshwater	*Pteronarcys californica*	48-h LC50	180	180	Jensen and Gaufin, 1964 [00065497]	Unacceptable
Mysids	Estuarine/ Marine	*Americamysis bahia*	48-h LC50	(3.6)	(5.30)	Forbis, 1990 [41474501]	Supplemental
	Estuarine/ Marine	*Americamysis bahia*	48-h LC50	(7.8)		Brougher et al., 2014i [49389401]	Acceptable

Table 3-11 Acceptable, supplemental and unacceptable 48-hour toxicity data for malathion and DS aquatic invertebrate prey items.

DS prey item	*Freshwater or Estuarine/ Marine Invertebrate*	*Scientific Name*	*Endpoint*	*Value µg test substance/L (µg a.i./L)*	*Geomean µg test substance/L (µg a.i./L)*	*Reference [MRID]*	*Cheminova's Study Rating*
Rotifers[a]	Freshwater	*Brachionus calyciflorus*	24-h LC50	33720	33720	Fernandez-Casalderry et al., 1992	Unacceptable
	Freshwater	*Brachionus rubens*	24-h LC50	35300 (17650)	35300 (17650)	Snell and Persoone, 1989	Unacceptable
	Estuarine/ Marine	*Brachionus plicatilis*	24-h EC50 (immobilization)	74000	74000	Guzzella et al., 1997	Unacceptable

[a] 48-hour LC50/EC50 data were not available for rotifers. As such, 24-hour endpoints are reported.

3.4.2 Exposure Assessment

3.4.2.1 PRZM/EXAMS

The EPA standard pond scenario in PRZM/EXAMS assumes that a pesticide applied to a 10 hectare field drains via runoff and erosion into a one hectare pond that is two meters deep. Spray drift is also assumed to be in the direction of the standard pond. No flow to or from the pond is assumed over the course of the 30-year model simulation. The use of the farm pond scenario is thus highly conservative and unrealistic for nearly all aquatic species, and particularly so for estuarine species like DS. Also, EPA often describes PRZM/EXAMS outputs as 1-in-10 year estimated environmental concentrations and "90th percentiles" values, a designation that is very misleading. The following lists some of the main concerns that Cheminova has with the use of PRZM/EXAMS to assess exposure of aquatic organisms to malathion:

- Before estimating a "90th percentile", the PRZM/EXAMS model first determines the peak daily pesticide concentration (or longer-term concentrations for non-acute exposures) for each year in a 30-year simulation. The model then calculates the 90th percentile from these 30 values. For a 30-year period, EPA's "90th percentile" is actually a concentration that would only be exceeded on three days in 30 years (or a 1-in-10 year event). On a daily basis, this estimate would actually be a 99.97th percentile. In other words, the daily peak concentrations estimated by EPA using PRZM/EXAMS would be lower than the 1-in-10 year daily peak for 99.97 percent of days in the pond, assuming that the other components of the modeling were accurate and unbiased (which they are not).
- To derive valid probabilistic exposure estimates (e.g., a 90th percentile), all key input variables must be modeled as distributions that reflect the range of plausible values for each variable. However, the only probabilistic variable in PRZM/EXAMS is the meteorology (most importantly, rainfall). Conservative assumptions are made for almost all other key variables (e.g., 90th percentile estimates for rates of dissipation in the environment, extreme slope, zero interception by vegetative barriers, etc.). The compounding effect of these multiple conservative assumptions is implausibly high exposure estimates.
- EPA/EFED uses an expert judgment procedure for identifying the soil series and geographical conditions that are supposed to represent 90th percentile worst-case scenarios in the Tier II exposure concentration estimation process. It is not possible to determine whether these scenarios actually represent a 90th percentile vulnerability. This expert judgment procedure is used in lieu of a quantitative process that would examine the entire set of available soil and geographical data and then rank vulnerability based upon predicted exposure.
- As discussed in Jones and Russell (2001), there is limited consideration of hydrology in PRZM. The farm pond is assumed to be static, meaning that there are no inflows or outflows of water that would remove or dilute pesticide concentrations. In streams and rivers, any pesticide runoff would disperse downstream and be diluted. In flowing water bodies, pesticides would only be expected to occur during short pulses rather than over

extended durations. In addition, the runoff water or sediment assumed to be carrying the pesticide to the water body has an associated volume that is not considered as an addition to the standard pond. In some scenarios used by EPA, the amount of soil assumed to enter the farm pond would be enough to fill it in.

- The current EPA/EFED PRZM 3.12.2 model excludes several soil processes that can affect runoff. Jones and Russell (2001) notes that one of the most influential factors related to runoff modeling is evapotranspiration, which is inaccurately represented and generally underestimated. The evapotranspiration extraction depth in the topsoil does not consider upward water movement and is somewhat arbitrary. This results in the incorrect simulation of runoff and leads to the overestimation of recharge. As well, seasonal variations in soil condition and texture are not accounted for in PRZM 3.12.2. Soil processes involving potential pathways can include preferential flow, freezing and thawing of soil, and soil crusting (Jones and Russell, 2001).
- The subjectivity of selecting physiochemical properties creates uncertainty when using PRZM 3.12.2. As noted by Jones and Russell (2001), parameters such as compartment size can substantially affect results. EPA acknowledges compartment size as a deficiency and states that pesticide associated with eroded solids is only removed from the top-most compartment and that changing compartment size may dramatically change pesticide mass removed by erosion (EPA, 2013a).
- EPA/EFED standard scenarios have not been calibrated with hydrology-predicted results and have not been compared to actual "real-world" runoff and eroded sediment results. Rather, soil selection and input parameters are based upon recommendations from local crop experts (EPA, 2003). Thus, there is no way to assess whether off-field runoff and eroded sediment are over-estimated or under-estimated. Furthermore, there is no consideration of seasonal variation in runoff due to differences in crop growth stages (Jones and Russell, 2001). Because off-field runoff and eroded sediment are primary mechanisms for off-field movement of pesticides (in addition to off-field drift), inaccurate estimates of runoff and off-field erosion will result in inaccurate estimates of off-field pesticide mass.
- The assumption that all runoff from the 10 hectare field drains into the standard pond is an unrealistic assumption in many situations. Many farms would have runoff draining in several directions.
- The wind is assumed to always be blowing in the direction of the pond, an unrealistic assumption given that wind direction is variable. Also, malathion labels must state for agricultural uses, "Do not apply when weather conditions favor drift from target area." (EPA, 2009a).
- For foliar applications, the current EPA/EFED PRZM 3.12.2 crop standard scenarios set foliar wash-off from plant leaves to 50%, which for many products is quite high (EPA, 2003). This is another significant factor when predicting soil loading (Jones and Russell, 2001).
- The current EPA/EFED PRZM 3.12.2 crop scenarios ignore the fact that farmers are unlikely to apply pesticide during rainy conditions. Pursuant to the RED (EPA, 2009a), malathion product labels are required to contain the following text: "applying this product in calm weather when rain is not predicted for the next 24 hours will help to ensure that

wind or rain does not blow or wash pesticide off the treatment area." Rainy conditions increase the quantity of off-field pesticide residues in runoff because the other loss functions (e.g., degradation in soil, infiltration into soil, volatilization, etc.) have not yet had a chance to take place (EPA, 2003).

- In the absence of a mandatory buffer, the standard pond is assumed to be at the edge of the treatment area. In most cases, there would be a natural buffering distance between the application area and a water body that would mitigate some portion of spray drift and runoff.
- Time and extent of maximum canopy cover may vary by crop. However, these parameters are not specified for each crop standard scenario in PRZM 3.12.2. Because canopy cover affects interception and therefore pesticide losses through runoff and sediments, this generalization is likely to affect the accuracy of model results (Jones and Russell, 2001). In addition, canopy interception is a critical factor in determining soil loading for compounds applied to foliage.
- Leaching is sensitive to degradation rate, and predictions of pesticide concentrations by PRZM 3.12.2 become increasingly conservative with increasing rate of pesticide degradation (Jones and Russell, 2001). Hydrolysis of malathion is rapid under neutral alkaline conditions (half-lives for 6.21 and 0.49 days at pH 7 and 9, respectively; Teeter, 1988 [MRID 40941201]). Furthermore, biodegradation will contribute substantively to the dissipation of malathion in water. Aerobic and anaerobic aquatic metabolism half-lives for malathion range from 0.3 to 3.3 days (Blumhorst, 1991a [MRID 41721601]; Blumhorst, 1991b [MRID 42216301]; Knoch, 2001a [MRID 46769502]; Hiler and Mannella, 2012 [MRID 48906401]; Walker, 1976). Also important when measuring leaching is to properly define soil hydraulic properties. However, PRZM 3.12.2 makes use of disturbed soil cores rather than undisturbed, which Jones and Russell (2001) found do not provide accurate hydraulic measurements.
- Many parameters in the Tier II standard scenarios are estimated individually without consideration of whether they coexist in reality. For example, comparison of the runoff curve numbers of antecedent moisture condition II listed in Table 5.10 of the PRZM 3.12.2 User's Manual to the values in EPA/EFED California PRZM 3.12.2 standard crop scenarios indicates that many scenarios are parameterized to generate conservative estimates of off-field runoff from a malathion-treated field. The runoff curve numbers of antecedent moisture condition II control the interaction of hydrologic groups and land use treatments on off-field runoff estimation (EPA, 1998b). Additionally, the PRZM 3.12.2 parameters that impact prediction of off-field eroded sediment are also set to generate conservative estimates of eroded sediment when values from the PRZM 3.12.2 User's Manual, Tables 5.5 – 5.7 are compared to the input values in the California PRZM 3.12.2 standard crop scenarios (EPA, 1998b). Each of these independently derived conservative parameterizations is combined with slopes set to be steep and have fine soil textures. The net result is that the estimated off-field runoff, erosion, and pesticide loadings are highly conservative. Per EPA guidance, each input parameter is supposed to represent a 90th percentile vulnerability for that parameter (EPA, 2003). Collectively, however, combining these parameter values creates a vulnerability scenario much higher than the 90th percentile. Thus, the resulting predicted EECs are actually far

greater than what a true 90th percentile EEC would be due to the effect of compounding conservatism.

In addition to these concerns, stagnant ponds are not reflective of DS's natural spawning habitat that must have sufficient flow to transport larvae to shallow nursery habitat in Suisun Bay, CA (EPA, 2010b). In actuality, the California Delta receives water inflows from approximately 40% of the land area in California, representing about 50% of the state's streamflow. Attempting to base EECs of malathion in the Delta waterways based on simulation of a one hectare farm pond has no scientific basis.

Concentrations of malathion in flowing water bodies as well as ponds and lakes with in- and out-flows are likely to be substantially lower than those estimated by PRZM/EXAMS for stagnant ponds. Immediately upon entering the water body, malathion will begin to disperse from the turbulence of the river flow or within pond and lake flows. Therefore, a SWAT (Soil and Water Assessment Tool) model was developed for the refined ERA to evaluate malathion exposure in flowing water bodies throughout DS critical habitat. The model simulates pesticide runoff and drift from use sites and routes those residues downstream through the major Sacramento and San Joaquin rivers, eastern tributaries, and many of the more minor streams and sloughs of the Sacramento-San Joaquin River Delta (Appendix E). The EECs predicted by the SWAT model will be used to assess risk to DS and aquatic invertebrates in the refined effects determination.

3.4.2.2 PFAM

There are many assumptions and uncertainties associated with the PFAM modeling approach to estimating EECs. For this SLERA, the following sources of uncertainty are of particular note.

- There are no standard scenarios available for PFAM. The three built-in scenarios available for RICEWQ were used as templates for similar scenarios in PFAM. The RICEWQ documentation does not discuss the sources of the input values for the three scenarios and whether these scenarios were designed to represent a 90th percentile vulnerability for rice or watercress paddies.
- The PFAM results represent a situation with a farm pond immediately adjacent to a rice or watercress paddy without any distance or buffer between the paddy and the water body. This is a worst-case scenario that may not represent the actual situation where malathion is applied in the DS critical habitat.
- To generate conservative EECs, the weir level in the three PFAM standard scenarios was set equal to fill level. In the real world, the weir level may be higher than the fill level. Thus, overflow with malathion residues is less likely, which would result in lower concentrations in the adjacent pond.
- The current PFAM scenarios ignore the likelihood that farmers are unlikely to apply pesticide during rainy conditions. Rainy conditions increase the quantity of off-paddy pesticide residues in outflow since the overflow out of the paddy is likely to be higher. Moreover, loss functions such as degradation in the paddy water have not yet had time to have any effect before the malathion residues leave the paddy via overflow.

- The exposure assessment assumed that malathion formulations were used at the maximum application rates with minimum time intervals between applications and applied using methods that would result in the highest EECs. In practice, lower application rates with longer time periods between applications are more commonly used. Thus, the assumptions made in the PFAM modeling biased the EECs in a conservative direction.

3.4.3 Risk Characterization

Potential for risk from exposure to malathion was assessed using a RQ approach, where aquatic EECs were divided by the selected acute and chronic effects metrics for each taxon. As stated by NAS (2013), the RQ approach does not estimate risk, but instead uses conservative assumptions, or stringent and possibly implausible exposure scenarios, to avoid making a type II error (i.e., concluding that a pesticide is unlikely to cause effects when it does yield such effects). RQs provide no information on the probability of an adverse effect to an organism. Rather, the use of the worst-case assumptions allows one to assume that a sufficiently large margin exists between the exposure and effects thresholds, and consequently, that an RQ below one indicates negligible risk. The use of probabilistic approaches for risk characterization, which have the ability to propagate uncertainties in exposure and effect through to a risk estimate for individuals and populations is, therefore, recommended for refined assessments (NAS, 2013).

4.0 REFINED EFFECTS DETERMINATION

As described in Section 3.3, although chronic RQs for DS were greater than one for malathion use on rice, wildrice and watercress, it is not expected that these uses will result in unacceptable risk to DS. Therefore, the refined assessment will focus on the potential for acute risk to DS and for acute and chronic risk to the aquatic invertebrate prey of DS. Several lines of evidence, including refined exposure and effects modeling, surface water monitoring data, incident reports, and field and mesocosm studies, are also used to characterize risk to DS and their aquatic invertebrate prey.

4.1 Refined Effects Assessment

4.1.1 Direct Effects to DS

Since the sensitivity of DS to malathion is unknown, a concentration-response curve representative of the 5th percentile of the fish SSD (See Section 3.1.1.1) was derived as a conservative effect metric. A probit concentration-response curve was derived using the HC5 of 12.3 µg a.i./L as the LC50 and the most conservative slope of 2.81 for the sheepshead minnow (Table 3-2).

The fitted model is presented in Figure 4-1 and the model parameters are $\mu = 1.09$ and $\sigma = 0.356$.

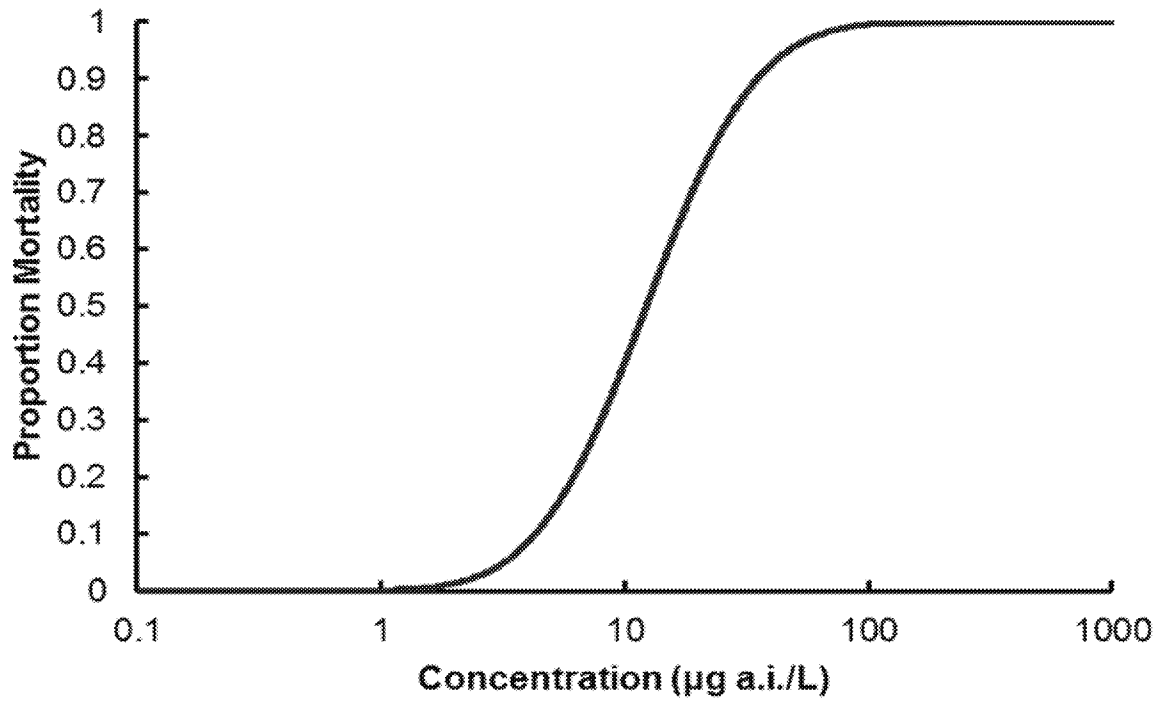


Figure 4-1 Log probit model for species representative of the 5th percentile of the acute fish SSD.

4.1.2 *Indirect Effects to DS via Reduction in Aquatic Invertebrate Prey*

Because DS are generalist feeders, this effects determination was not restricted to the most sensitive prey species. As long as overall productivity of prey species is protected, indirect effects to DS are not expected. To determine overall effects on aquatic invertebrate prey productivity, the preferred measure of effect is at the community level of organization (e.g., community structure). The aquatic invertebrate SSD described in Section 3.1.2.1 was used as the acute effects metric for community structure.

For the refined chronic effects determination, the acute SSD was converted to a chronic SSD using an acute-to-chronic ratio (ACR). Two ACRs for aquatic invertebrates were calculated using acceptable and/or supplemental toxicity data (Breton et al., 2014 [MRID 49333901], 2015 [MRID 49692301]). An ACR of 7.95 was obtained by dividing the acute 48-hour EC50 for *Daphnia magna* (0.70 µg a.i./L; Gries and Purghart, 2001a [MRID 47540303]) by a 21-day EC10 for *Daphnia magna* (0.0881 µg a.i./L; Blakemore and Burgess, 1990 [MRID 41718401]), and an ACR of 19.0 was obtained by dividing the acute 48-hour LC50 for *Americamysis bahia* (7.8 µg a.i./L; Brougher et al., 2014i [MRID 49389401]) by a 39-day EC10 for *Americamysis bahia* (0.266 µg a.i./L; Claude et al., 2012 [MRID 48752901]). Appendix G provides the details on the calculation of the EC10 from the Blakemore and Burgess (1990 [MRID 41718401]) and Claude et al. (2012 [MRID 48752901]) studies. Using the approach for ACR calculation described in EPA's guidelines for deriving water quality criteria (Stephan et al., 1985), the geometric mean of the water flea and saltwater mysid ACRs was calculated to be 15.3. The acute SSD was divided by this ACR of 15.3 to derive the corresponding chronic SSD.

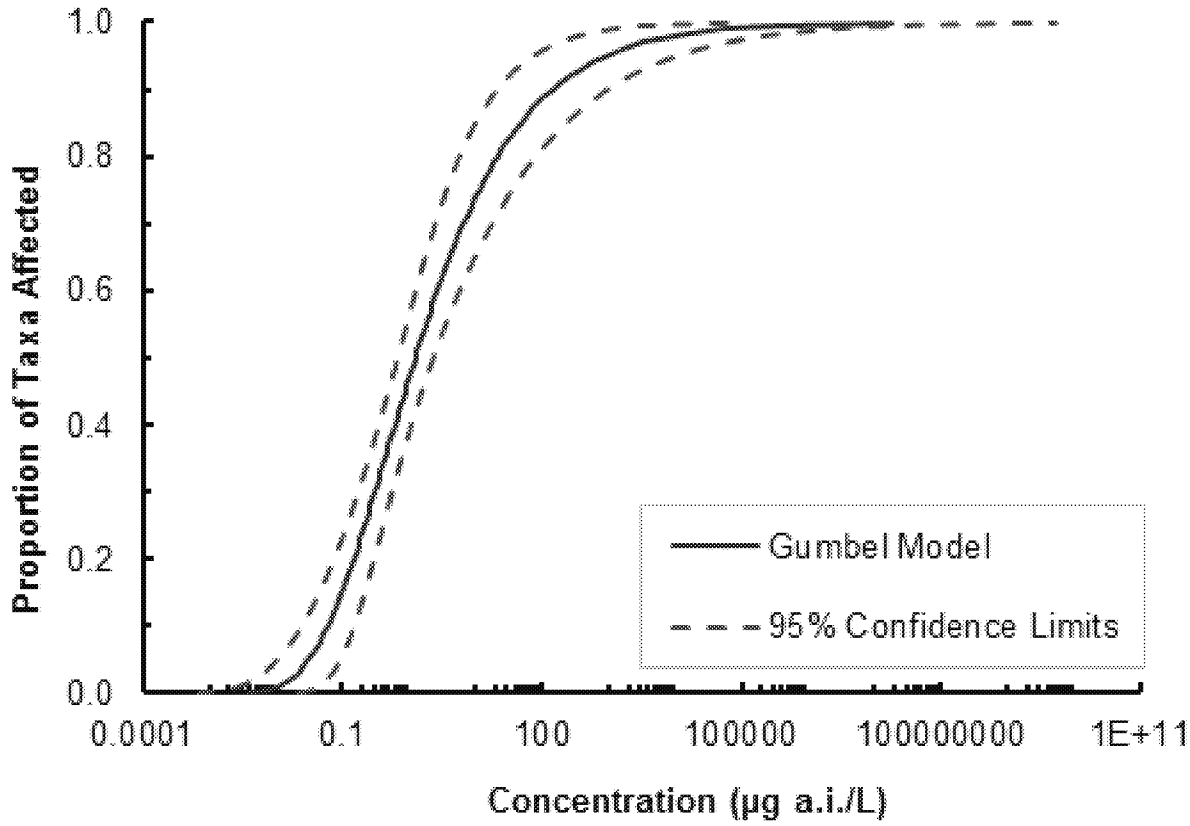


Figure 4-2 Chronic SSD with approximate 95% confidence limits for aquatic invertebrate species exposed to malathion.

4.2 Refined Exposure Assessment

The Soil and Water Assessment Tool (SWAT) was selected to evaluate malathion exposure in flowing water bodies throughout the DS critical habitat. The DS critical habitat, which overlaps with the Sacramento-San Joaquin River Delta, is shown in Figure 4-3 along with its associated watershed. Application of SWAT to the region located upstream of DS critical habitat led to the development of a watershed-scale model capable of capturing the majority of malathion use in the large, agriculturally intensive Central Valley region of California. The model simulates the fate and transport of pesticide moving off use sites via spray drift and runoff and routes those residues downstream through the major Sacramento and San Joaquin rivers, eastern tributaries, and many of the more minor streams and sloughs of the Delta.

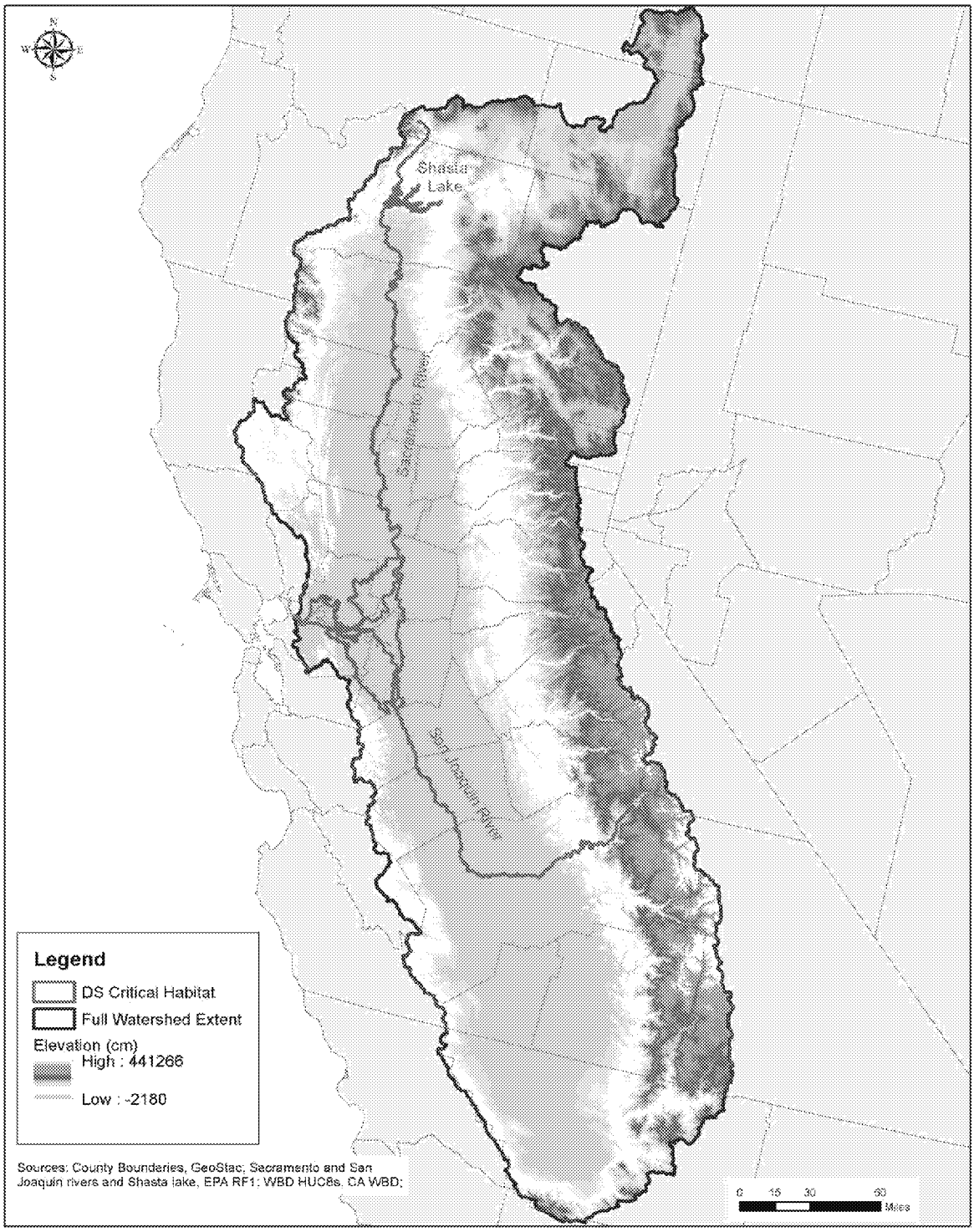


Figure 4-3 Watershed overview.

ED_002284_00026674-00116

4.2.1 Soil and Water Assessment Tool (SWAT)

SWAT is a continuous-simulation, physically-based, semi-distributed watershed model that has been used in a broad range of hydrologic and water quality applications (Gassman et al., 2007; Breton et al., 2013 [MRID 49211702]; Whitfield Aslund et. al., 2015). It was developed at the Grassland, Soil and Water Research Laboratory of the United States Department of Agriculture's Agricultural Research Service (USDA-ARS) (Arnold et al., 1998). SWAT has been used to model pesticide transport at the watershed scale in the literature since at least 2005. It was recently selected from a pool of 36 models as one of three that were most appropriate for watershed-scale simulation of pesticides (Quilbe et al., 2006). Pesticide transport modeling with SWAT has been conducted in both static and flowing water bodies. Ramanarayanan et al. (2005) looked at potential accumulation of the pesticide isoxaflutole and a metabolite in semi-static water bodies in the midwestern United States. Their study showed that SWAT was capable of adequately characterizing pesticide fate and transport in both flowing and semi-static water bodies (reservoirs). Most other pesticide applications with SWAT have focused on flowing water bodies, including Kannan et al. (2006), Holvoet et al. (2008), Larose et al. (2007), Parker et al. (2007), Luo and Zhang (2010), Breton et al. (2013 [MRID 49211702]), Fohrer et al. (2014), Boithias et al. (2014), and Whitfield Aslund et al. (2015).

The structure of the SWAT model allows for the prediction of flow, sediment, and pesticide outputs at multiple scales and locations throughout a watershed. A full SWAT watershed is divided up into multiple subbasins. Subbasin delineation is based on the size of the complete watershed being modeled and the order of the stream segments within the model. Nodes are created in the subbasins at each point where model predictions are required. Outputs from the model are then generated for every subbasin. A subbasin is divided into multiple hydrologic response units (HRUs), which are representative of unique combinations of land, soils, and slope within a subbasin. Each HRU is considered an independent land unit within SWAT, and each HRU can have different parameterizations and agronomic practices. Within a subbasin, the HRU outputs of runoff, sediment, and pesticide fluxes are aggregated and provided as input to a single stream "reach" that transports the flows, sediment and pesticides downstream to the next subbasin. These fluxes enter a reach at the upstream end and are routed to the downstream end, during which in-stream processes such as deposition, re-suspension, and degradation take place.

Similar to the Pesticide Root Zone Model (PRZM) and Exposure Analysis Modeling System (EXAMS) regulatory models, a SWAT simulation can be run for an extended number of years to predict the expected hydro-chemical behavior based on a wide range of weather conditions. The annual maximum concentrations for various exposure durations of interest (i.e., 24-hour, 21-day, and 60-day) can be calculated from the daily pesticide concentrations output by the SWAT model and compared against the ecotoxicological effects metrics for the species under consideration. The selection of the watershed chosen for the flowing water body exposure assessment, the development of model inputs and parameterization, and the simulation results of the model are discussed in the following sections.

4.2.2 Watershed Identification

Watershed identification was intended to balance the need to encompass the historic malathion use areas upstream of critical habitat with the need to keep the model's complexity at a practical level. According to the California Pesticide Use Report (PUR), historic malathion use was reported throughout agricultural and urban regions within the Central Valley including both the Sacramento River Basin to the north and the San Joaquin River Basin to the south (CDPR, 2011). The California PUR database is a comprehensive collection of nearly all agricultural pesticide use and some non-agricultural use in the state since 1990. Average error estimates for spatial attributes in the PUR have been reported as less than 5% (Wilhoit et al. 2001). To constrain model complexity, only drainage areas below reservoirs draining the Sierra Nevada and coastal mountain ranges were included in the modeled watershed area. This area was associated with 97.9% of the malathion use within the Delta watershed (additional use outside the modeled watershed was still accounted for). Outflow from major reservoirs below mountain headwaters was accounted for by specifying point source freshwater inlets using United States Geological Survey (USGS) daily streamflow gage data (USGS, 2013a). Additional details concerning the identification of the watershed can be found in Appendix E.

4.2.3 Model Development, Parameterization, and Calibration

The main steps in the development of the malathion DS SWAT model included delineating the watershed and subbasins, accounting for engineering modifications to hydrology, compiling relevant weather data, defining the HRUs based on land use and soils, developing schedules of crop management practices like irrigation, fertilization, and tillage, and characterizing malathion applications. Development of application characteristics included selection of use site, application rate, method, timing and drift fraction. The initial parameterization of the model (prior to calibration) was also an important step that defined the values adopted for the majority of the model inputs. A summary of the model development and input datasets is provided here, with further details available in Appendix E.

The primary datasets used in the development and parameterization of the DS SWAT model are summarized in Table 4-1. The NHDPlus, SSURGO, Cropland Data Layer (CDL), NCDC, and the PUR represent the best available datasets for hydrologically corrected topography, soils, agricultural land cover, weather, and malathion use respectively.

Table 4-1 SWAT model input data sources.			
Dataset	***Usage***	***Dataset Source***	***Source Link***
NHDPlus V2 DEM	Delineation of watershed boundaries, stream channels, and calculation of topographic parameters.	Horizon Systems / United States Geological Survey	http://www.horizon-systems.com/NHDPlus/NHDPlusV2_home.php
SSURGO soil	Spatial extent of soil unit boundaries and their physical/chemical characteristics.	Natural Resource Conservation Service	http://soildatamart.nrcs.usda.gov/
Cropland Data Layer	Spatial extent of crop and land cover classes.	National Agricultural Statistics Service	http://www.nass.usda.gov/research/Cropland/SARS1a.htm
Weather	Derivation of daily precipitation and temperature time series for the SWAT model.	National Climatic Data Center	http://www.ncdc.noaa.gov/cdo-web/
Malathion use	Determination of the spatial and temporal pattern of malathion applications within the watershed.	California Department of Pesticide Regulation	http://cdpr.ca.gov/docs/pur/purmain.htm

4.2.3.1 Model Development

The Delta watershed was divided up into 344 subbasins, each of which had an associated stream/river reach where daily malathion concentration predictions would be made. The outlets of the subbasin were designed to correspond to the locations of USGS streamflow gages and water quality monitoring sites for use in model calibration. The subbasin boundaries were designed to align with standard HUC12 boundaries, and capture the main stem rivers entering the Delta (i.e., the Sacramento and the San Joaquin Rivers), major tributaries, as well as smaller backwater sloughs within the DS critical habitat. Freshwater inflows from the mountainous headwaters were accounted for by 24 inlets at the edge of the simulated watershed. These inlets were important SWAT model inputs influencing the water volume in many reaches of the Delta. These 24 inlets, mapped in Figure 4-4, drain 26,300 square miles or about 40% of the 60,700 square-mile Delta watershed. Thirty-year-long time series of daily-average stream flow were developed for each of these locations from USGS gage data. In addition to the inlets, numerous water exports, diversions, and flood control structures were incorporated into the model. Accounting for these structures in the model was critical to accurately simulate the flows and malathion loads throughout the watershed and within the DS critical habitat. For additional details on the modeling of the structures, refer to Appendix E.

The geographic extent of the DS SWAT model required the compilation of an extensive climate dataset that captured the spatial heterogeneity of precipitation and temperature across the Delta watershed. A 30-year time series of daily temperature (minimum and maximum) and precipitation was developed from January 1st, 1981 through to December 31st, 2010. Complete 30-year precipitation and maximum/minimum temperature time series were created for 48 and 51 stations for precipitation and temperature, respectively. A map showing the spatial distribution of the precipitation and temperature stations relative to the malathion DS SWAT model watershed is shown in Figure 4-5. The methods and data sources used to compile these weather time series are discussed in Appendix E.

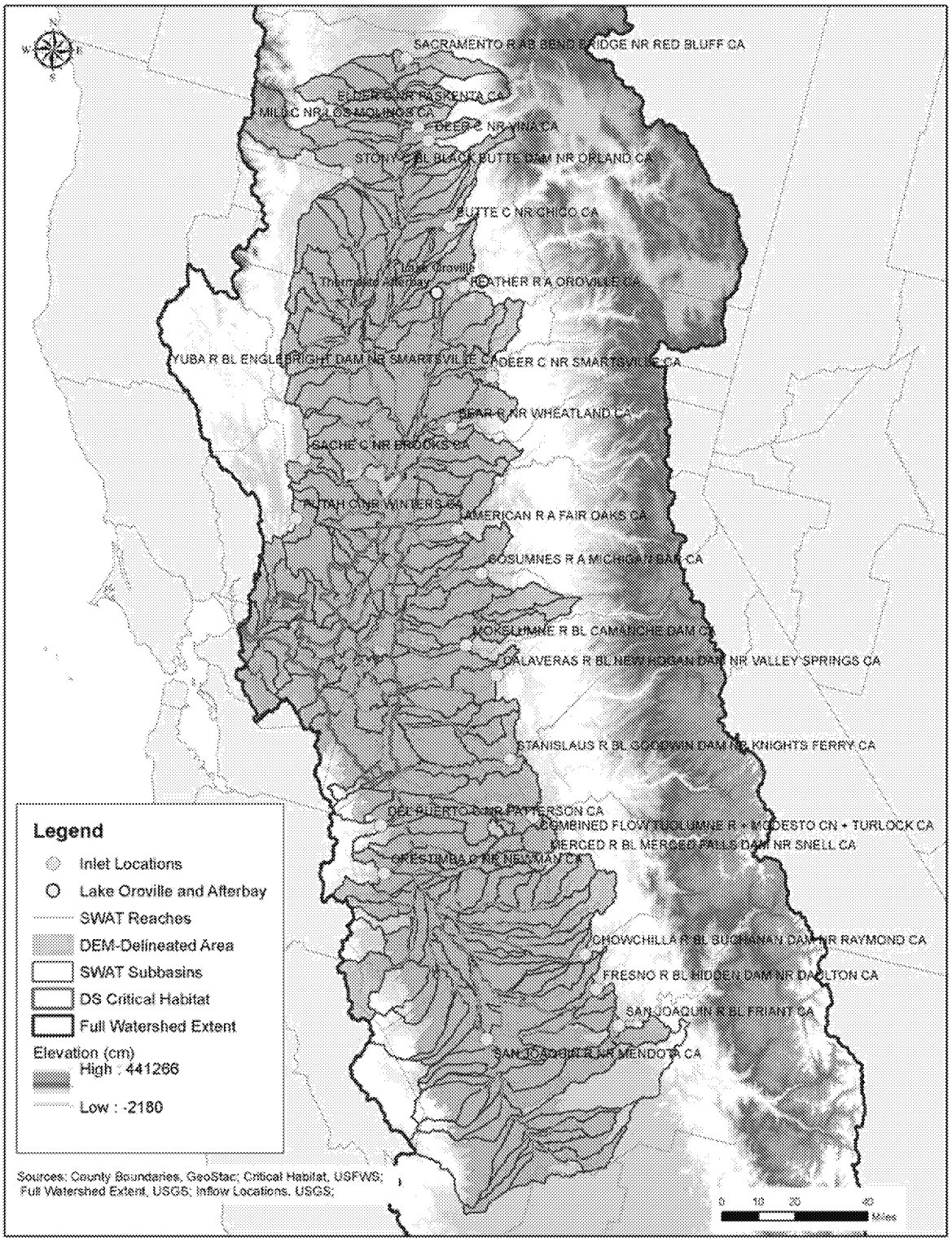


Figure 4-4 Watershed subbasins and inlet locations.

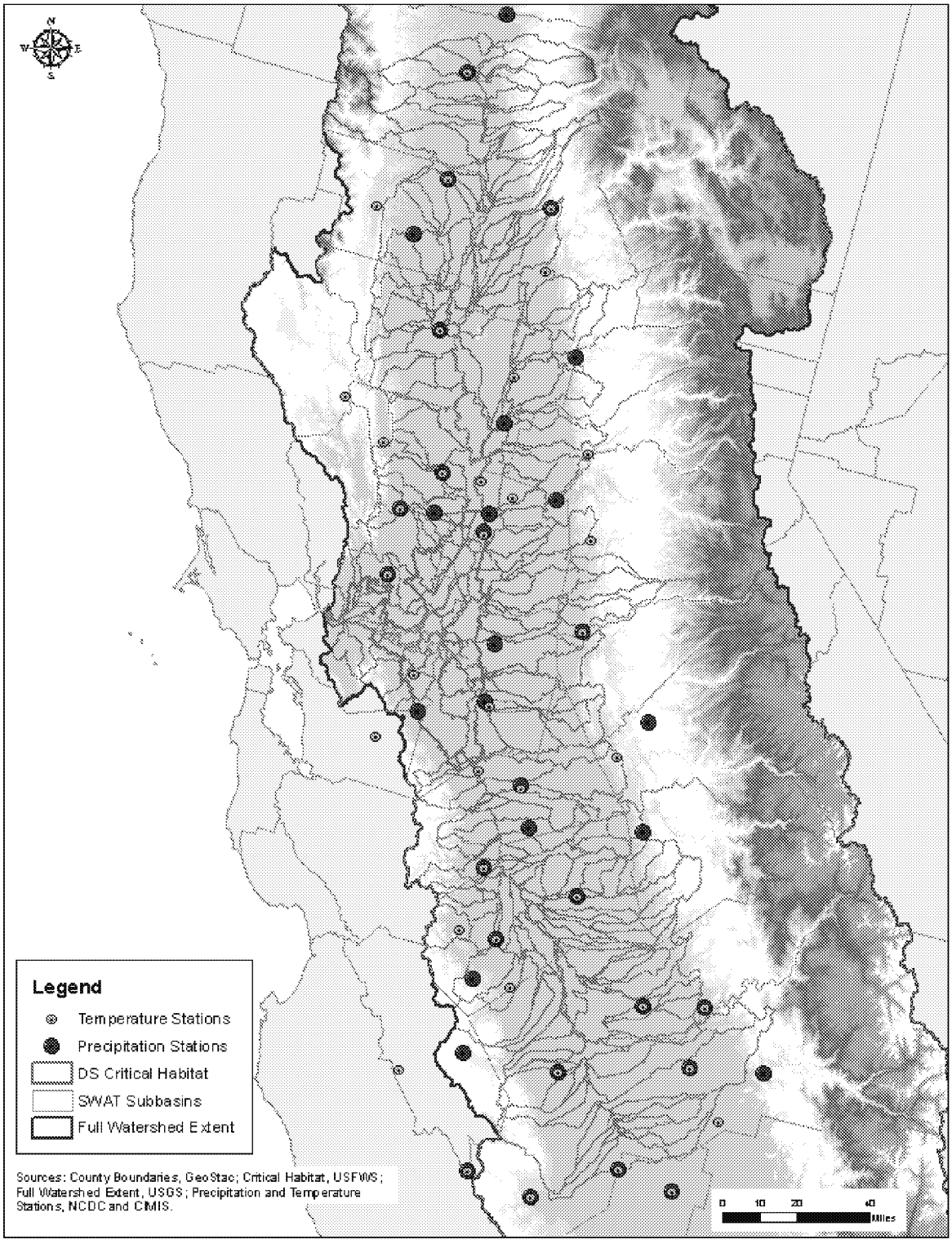


Figure 4-5 Distribution of SWAT model weather stations.

The delineation of each subbasin into hydrologic response units (HRUs) determines the level of spatial heterogeneity within the model. The goal in HRU delineation was to capture the variability in land use, soils, and slope, while maintaining a practical level of complexity. HRU delineation for the DS SWAT model used multiple years of the CDL to represent the land use, the SSURGO database to represent the soils, and slopes derived from the NHDPlus V2 dataset. In total, 37,041 HRUs were delineated within the boundaries of the DS SWAT model, of which 15,909 had land use types that could potentially receive malathion applications. Each HRU was simulated independently in SWAT, with fluxes of runoff, erosion, and pesticides that were subsequently aggregated up to the subbasin level. Additional details regarding the land use and soils analysis, and the HRU delineation are provided in Appendix E.

4.2.3.2 Model Parameterization

The SWAT model allows for detailed agronomic/land use management schedules to be defined for each crop or land cover class. Management schedules include planting, harvest, tillage, fertilization, irrigation, and pesticide application operations. These agronomic practices affect crop growth/land cover, soil moisture, and pesticide mass, all of which are important for determining the magnitude and timing of off-target movement of pesticide via runoff. Dominant crops/land covers within each subbasin of the DS SWAT model were identified and agronomic management schedules were developed for each. In total, 37 different crop management schedules were developed based on information obtained through local agricultural extension publications and personal contacts. A complete discussion and presentation of the agricultural management schedules can be found in Appendix E. Additional summary information on the pesticide applications follows.

Predictions of malathion concentrations in the DS critical habitat are sensitive to the spatial and temporal variation in simulated pesticide applications. Variable application timing and location may occur as a result of differences in cropping practices between growers as well as differences in field treatment among fields of a single grower. These variations were accounted for in the malathion DS SWAT model by choosing application dates and locations according to analysis of historical PUR data from 2006-2010. Applications of malathion to all agricultural and non-agricultural use sites were simulated concurrently in the DS SWAT model.

Application timing was determined based on historical PUR data between 2006 and 2010. Probability distributions by month were developed for each subbasin and SWAT land use group combination based on total malathion mass applied in each month. For example, a month with no malathion applied within the five year period had a probability of zero. A month with 25% of the applied mass of malathion within the five year period was assigned a probability of 25%. The application month was drawn from the PUR-based distributions and then the application day was chosen from a uniform distribution of days within the month. The percentage of total applied malathion mass by month and land use group is provided in Table 4-2. The majority of applications (86-100% of annual applications between 2006-2010) reported in the modeled watershed area were non ultra-low-volume (ULV) product formulations. Therefore, application parameters such as rate, number of applications and application interval, were determined according to the non-ULV Cheminova Malathion 57% EC product label (EPA Reg. No.: 67760-

40), also specified by the malathion RED. The maximum labeled rate, maximum number of malathion applications and minimum re-treatment interval were selected for each use site.

Table 4-2 Percentage of annual malathion applications (by mass) occurring each month

SWAT Land Use Group	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Total*
Corn/soybeans			14.4	2.6	0.6	23.0	22.6	36.9					100
Cotton						1.3	10.9	34.1	17.0	36.8			100
Hay/forage/silage		0.3	66.7	9.5	1.3	1.2	12.3	6.2	2.5	0.0			100
Orchards and grapes	0.2	0.1	0.0	0.6	8.4	9.0	16.8	45.4	17.9	1.2	0.3		100
Other crops		0.1				1.8	94.5	3.6					100
Other grains	0.6		16.1	61.7	21.6		0.0		0.0		0.0	0.0	100
Other row crops							85.2	14.8					100
Rice				12.9	23.1	55.0	8.9						100
Sorghum							81.2		18.8				100
Urban Med/High Density	9.0	8.9	9.8	12.0	9.9	8.5	8.4	8.3	7.6	6.2	6.2	5.4	100
Urban Open/Low Density	0.2	0.7	1.6	29.0	10.0	5.7	6.3	17.9	14.9	12.4	0.8	0.5	100
Vegetables and ground fruit	1.2	0.0	0.5	2.8	21.5	18.0	25.4	18.5	7.2	4.9	0.0	0.0	100
Wheat		1.3	43.8	52.1	2.4	0.4							100

Determination of the application type as aerial or ground was also based on the historic probability of malathion applications occurring within the Delta watershed (2006 – 2010) found in the PUR database. The fractions of ground and aerial applications by mass were computed for each SWAT land use grouping (combining malathion use sites associated with a common land use group), and are reported in Table 4-3. Averaging over all SWAT land use groups, malathion was more likely to be applied aerially than via groundspray, with 61.4% aerial applications and 38.6% ground.

Table 4-3 Aerial and ground malathion application probability

SWAT Land Use Code	*SWAT Land Use Group*	*Ground Probability*	*Aerial Probability*
AGRL	Other crops	0.021	0.979
AGRR	Other row crops	0.139	0.861
CORN	Corn/soybeans	0.216	0.784
COTS	Cotton	0.543	0.457
GRSG	Sorghum	0.020	0.980
HAY	Hay/forage/silage	0.339	0.661
ORCD	Orchards and grapes	0.868	0.132
RICE	Rice	0.025	0.975
STRW	Vegetables and ground fruit	0.474	0.526
URLD/URMD	Urban Open/Low and Med/High density	0.991	0.009
WBAR	Other grains	0.104	0.896
WWHT	Wheat	0.010	0.990

The spatial locations and annual amount of malathion use were determined from the PUR database for each year from 2006 to 2010. Annual malathion use was aggregated at the subbasin level by land use, resulting in a "target" amount of malathion for each subbasin/land use combination applied within the watershed for each of the five years assessed (Table 4-4). A Monte Carlo approach was used to randomly choose one of the five years of malathion use to serve as the target year from which individual applications to specific HRUs were derived for each land use group. The subset of HRUs receiving applications were also selected randomly from all HRUs belonging to the same land use group in each subbasin. A unique sequence of applications, with timing based on PUR probability described above, was designed for each HRU at the maximum rate, maximum number of repetitions, and minimum interval for a given use site to sum to the annual total mass targeted. This sequence was repeated for every year of the 30-year model simulation. Through random sampling of the target year, randomized HRUs receiving applications, random selection of the first application date in a sequence, and by making many simulations, historical malathion use from each of the five years assessed was incorporated into the prediction of malathion EECs. A complete discussion of the parameterization of malathion applications is provided in Appendix E.

Table 4-4 Summary of malathion application by mass (kg) by year

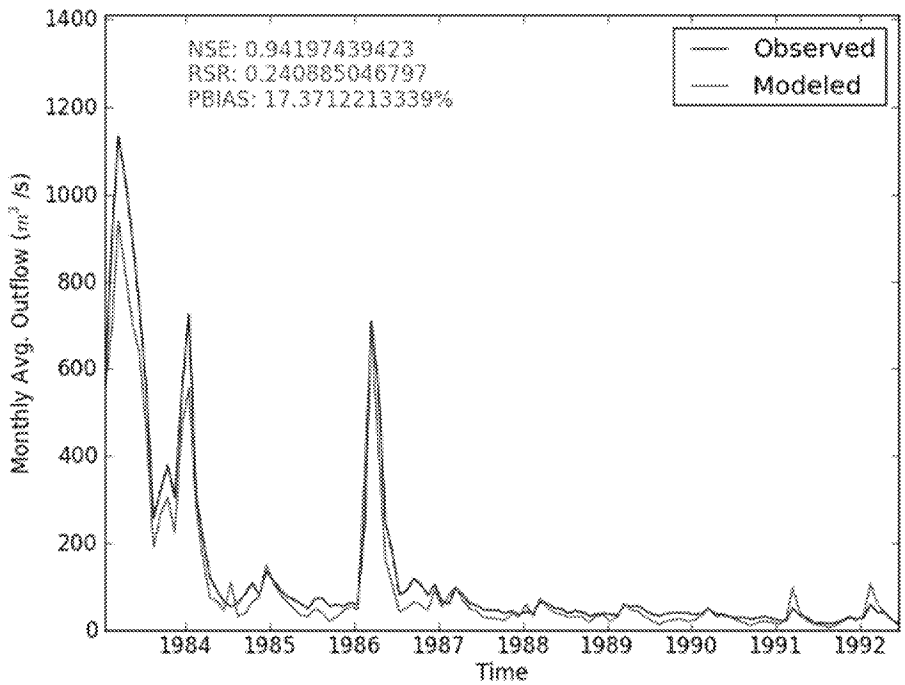
SWAT Land Use Group	*SWAT Land Use Code*	*2006*	*2007*	*2008*	*2009*	*2010*
Other crops	AGRL	763	1866	447		204
Other row crops	AGRR	7	7	7		7
Corn/soybeans	CORN	78	44	84	71	150
Cotton	COTS	440	7	33	117	608
Sorghum	GRSG	78	57	57		44
Hay/forage/silage	HAY	17419	23906	23629	23578	35844
Orchards and grapes	ORCD	14807	17747	11019	11696	22579
Rice	RICE	687	1283	1900	255	
Vegetables and ground fruit	STRW	1686	3373	1946	1021	3097
Urban Open/Low density	URLD	8213	6322	3207	8253	9503
Urban Med/High density	URMD		278	356	304	
Other grains	WBAR	48	57	315	612	98
Wheat	WWHT	500	544	1583	840	881
Total		44726	55491	44583	46748	73016

To account for spray drift, the SWAT model was customized to allow a fraction of each malathion application to enter a subbasin reach directly as a drift input. The fraction of an application entering a subbasin reach as drift varied for each HRU and was a function of the spatial relationship between the HRU and the receiving water body. The determination of spray drift as a function of distance was calculated using the AgDRIFT model version 2.1.1. The aerial drift curves were calculated using the Tier III Aerial (Agricultural) option, and the ground curves were calculated using the Tier I Ground (Agricultural) option within AgDRIFT. The details of the spray drift modeling and the methodology for calculating HRU-specific drift fractions is provided in Appendix E.

4.2.3.3 Model Calibration

Watershed-scale water quality models, including SWAT, can be calibrated for streamflow, sediment yield, or water quality parameters, including pesticides. Calibration of the DS SWAT model hydrology was conducted to improve model-predicted streamflow compared to observations. Calibration focused on hydrologic aspects of the model because of the importance of flow rates/volumes to prediction of pesticide concentrations and the availability of observed data. Explicit calibration to pesticide monitoring station data was not conducted due to insufficient observations. There are several long-term USGS flow gages within the Delta watershed that were used for hydrologic calibration. Additionally, streamflow for two SWAT reaches was calibrated to data from the DAYFLOW model, an empirical model of Delta hydrology developed and maintained by California Department of Water Resources (CDWR, 2013). The period selected for calibration of the DS watershed was January 1983 – December 1992, with a validation period of January 2001 – December 2010. The model was calibrated and validated at a monthly time step. An example plot of flow simulation calibration and validation for a main stem location, the San Joaquin River near Vernalis, is provided in Figure 4-6. Additional calibration and validation plots and statistics are provided in Appendix E.

(A)



(B)

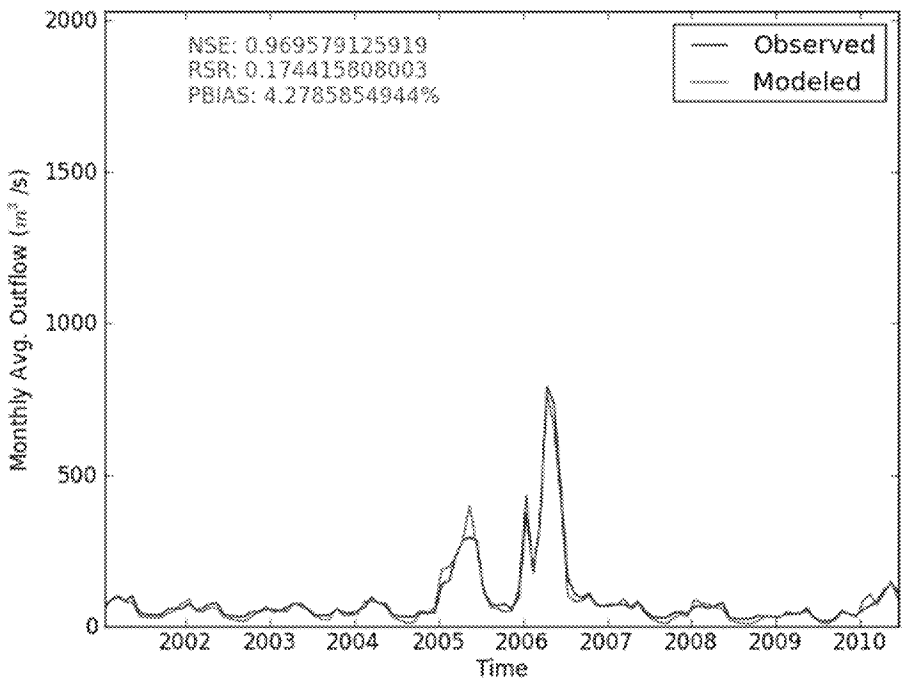


Figure 4-6 Monthly flow calibration (A) and validation (B) at subbasin 219 (San Joaquin River near Vernalis)

4.2.4 Model Simulation Results and Discussion

Simulations of the calibrated malathion DS SWAT model were run for the 30-year period from 1981-2010. This period was selected to provide a comprehensive range in weather conditions from which malathion EECs would be predicted. In addition, uncertainty in the spatial and temporal variability in pesticide applications was accounted for through Monte Carlo simulations of the SWAT model. The Monte Carlo approach is outlined in this section followed by a summary of the probabilistic results generated.

The spatially and temporally varying patterns of historic malathion use reported in the PUR were sampled at random to generate an ensemble of 100 unique application scenarios. This number of application scenarios was chosen based on a convergence analysis that showed 90th-percentile peak EECs calculated from at least 60 random simulations varied less than 5%. Each scenario was based on a different randomly selected target malathion use year between 2006 and 2010 with application dates and the method of application (i.e., aerial or ground spray) drawn randomly according to historic PUR probability and malathion application mass distributed over a random combination of eligible HRUs. The model was run for a 30-year period for each of the unique, randomly generated application scenarios. Application scenarios remained the same for all simulation years within a single 30-year run. The first simulation year

was not evaluated as part of the results data set and was not included in the calculation of EECs to remove the effect of initial conditions on the numerical solution of the model. From the EECs resulting from the most recent 29 years of the 100 unique simulations, probability distributions were computed for the concentrations in every modeled reach within the DS critical habitat.

Observed and model-simulated concentrations were compared throughout the critical habitat to validate model performance. A formal statistical validation was not possible due to the limited number of monitoring data points and the limited spatial and temporal resolution of the model. A qualitative comparison of observed maximum concentrations and modeled 90th percentile 24-hour-average, stream-average EECs, supported that the model captures observed variation in location and magnitude of malathion concentrations throughout the DS critical habitat. A complete discussion of the comparison of modeled and observed malathion concentrations within and surrounding the DS critical habitat is provided in Appendix E.

The 90th percentiles of annual maximum EECs were calculated for exposure periods of 24 hours, 48 hours, 4 days, 21 days, and 60 days for each of the 59 model reaches within the critical habitat (see Table 4-5). Reaches 197 and 155 had the highest 90th percentile EECs while reaches 197 and 159 had the highest median EECs. These reaches were modeled as smaller headwaters with the potential for low flow rates based on runoff inputs alone. However, in reality, as seen by satellite imagery (Figure 4-7), reaches 159 and 197 are connected to a network of larger channels, not fully represented in SWAT that provide a continual source of flow and stabilize the water volumes in those segments making them behave more like semi-static reservoirs than headwaters. As such, the concentrations for reaches 159 and 197 were likely biased high for these actual reaches because the modeled water volumes were underestimated. Additional refinements were, therefore, made to the SWAT model for reaches 159 and 197 to more accurately account for the water volumes in those reaches. For those reaches, the refined EECs were calculated for the 48-hour and 21-day durations. The 90th percentile 48-hour-average and 21-day-average annual maximum concentrations were 0.012 and 0.005 µg/L, respectively, for reach 197, and were 0.011 and 0.005 µg/L, respectively for reach 159. In comparison, the initial modeled 90th percentile annual maximum concentrations for these durations were 4.92 and 0.96 µg/L for reach 197, and 1.02 and 0.23 µg/L for reach 159. Additional details concerning the refinement approach and results for these subbasins can be found in Appendix E.

Aside from the small headwater reaches that were refined, the other critical habitat reaches had 48-hour EECs ranging from 0 to 1.65 µg/L. Concentrations in the higher end of the range generally occurred in reaches corresponding to the subbasins with the greatest malathion use and in headwater reaches with the smallest drainage areas and thus the lowest flow volumes, making them particularly susceptible to spray drift deposition. The 21-day 90th percentile EECs were 0.96 and 0.49 µg/L in the highest two reaches, reach 197 and 155, respectively. For the 57 other critical habitat reaches, 21-day EECs ranged from 0 to 0.28 µg/L. Many of the reaches with higher annual maximum 21-day averages were the same as those having the higher 48-hour averages for the same reasons of high annual malathion use and smaller flow volumes.

Table 4-5 90th and 50th percentile EECs in DS critical habitat reaches[a]

Subbasin	24-hour (µg/L)		48-hour (µg/L)		96-hour (µg/L)		21-day (µg/L)		60-day (µg/L)	
	90th %ile	50th %ile	90th %ile	50th %ile	90th %ile	50th %ile	90th %ile	50th %ile	90th %ile	50th %ile
197	7.52	0.618	4.92	0.390	2.71	0.213	0.957	0.0458	0.341	0.0163
197[b]	0.0127	0.00137	0.0122	0.00133	0.00991	0.00109	0.00469	3.19E-04	0.00169	1.12E-04
203	2.74	0.0948	1.51	0.0521	0.766	0.0266	0.160	0.00735	0.0582	0.00261
155	2.53	0.102	1.65	0.0647	0.912	0.0347	0.491	0.00961	0.173	0.00364
159	2.01	0.677	1.02	0.342	0.529	0.174	0.232	0.0677	0.0867	0.0258
159[b]	0.0133	0.00538	0.0111	0.00451	0.00815	0.00327	0.00511	0.00158	0.00183	6.44E-04
169	1.89	0.0227	1.36	0.0162	0.812	0.00950	0.161	0.00195	0.0565	6.84E-04
209	1.81	0.258	1.18	0.166	0.644	0.0925	0.283	0.0362	0.116	0.0144
204	1.12	0.0244	0.688	0.0150	0.553	0.00868	0.201	0.00188	0.0721	6.59E-04
210	0.953	0.191	0.638	0.123	0.375	0.0693	0.167	0.0302	0.0784	0.0133
144	0.912	0.126	0.744	0.0878	0.467	0.0524	0.216	0.0224	0.0794	0.00992
153	0.848	0.0605	0.547	0.0386	0.297	0.0211	0.0796	0.00660	0.0299	0.00256
191	0.812	0.00135	0.519	9.62E-04	0.284	5.96E-04	0.0881	1.45E-04	0.0314	5.16E-05
201	0.776	0.0944	0.537	0.0639	0.334	0.0456	0.128	0.0178	0.0487	0.00714
207	0.597	0.123	0.399	0.0788	0.235	0.0454	0.110	0.0200	0.0552	0.00932
146	0.547	0.0710	0.418	0.0489	0.260	0.0282	0.114	0.0112	0.0417	0.00505
158	0.486	0.0342	0.315	0.0221	0.170	0.0120	0.0448	0.00385	0.0165	0.00150
164	0.464	0.0238	0.354	0.0172	0.212	0.00991	0.118	0.00263	0.0422	9.84E-04
194	0.361	0.0248	0.232	0.0159	0.205	0.00885	0.0898	0.00192	0.0321	7.26E-04
196	0.344	0.0440	0.247	0.0315	0.145	0.0194	0.0600	0.00800	0.0223	0.00291
161	0.328	0.0243	0.210	0.0156	0.114	0.00850	0.0293	0.00277	0.0109	0.00106
173	0.248	0.0711	0.137	0.0458	0.0787	0.0252	0.0308	0.00677	0.0119	0.00301
221	0.241	0.0386	0.168	0.0272	0.0967	0.0159	0.0430	0.00732	0.0168	0.00289
184	0.236	0.0416	0.172	0.0285	0.101	0.0160	0.0435	0.00688	0.0177	0.00283
176	0.219	0.00980	0.154	0.00752	0.0938	0.00508	0.0442	0.00235	0.0183	0.00105
168	0.203	0.0109	0.157	0.00806	0.0957	0.00472	0.0535	0.00125	0.0188	4.85E-04
157	0.190	0	0.134	0	0.0790	0	0.0176	0	0.00617	0
220	0.168	0.0271	0.118	0.0192	0.0678	0.0112	0.0304	0.00515	0.0118	0.00205
162	0.144	0.0192	0.132	0.0166	0.101	0.0117	0.0490	0.00502	0.0183	0.00231
143	0.120	0.0170	0.0801	0.0110	0.0483	0.00614	0.0221	0.00169	0.00791	7.58E-04
216	0.0957	0.00963	0.0670	0.00680	0.0383	0.00396	0.0142	0.00144	0.00520	5.67E-04
149	0.0901	0.0242	0.0516	0.0144	0.0269	0.00800	0.00632	0.00182	0.00231	6.76E-04
154	0.0897	0.00228	0.0563	0.00140	0.0297	7.37E-04	0.00674	2.56E-04	0.00236	8.94E-05

Table 4-5 90th and 50th percentile EECs in DS critical habitat reaches[a]

Subbasin	24-hour (µg/L)		48-hour (µg/L)		96-hour (µg/L)		21-day (µg/L)		60-day (µg/L)	
	90th %ile	50th %ile	90th %ile	50th %ile	90th %ile	50th %ile	90th %ile	50th %ile	90th %ile	50th %ile
170	0.0751	0.00991	0.0492	0.00626	0.0289	0.00359	0.0121	0.00109	0.00492	4.63E-04
186	0.0684	0.0216	0.0346	0.0109	0.0175	0.00551	0.00438	0.00119	0.00166	4.74E-04
218	0.0663	0.00437	0.0483	0.00355	0.0308	0.00240	0.0112	0.00104	0.00409	4.64E-04
200	0.0660	0.0127	0.0499	0.00883	0.0323	0.00595	0.0118	0.00238	0.00492	0.00106
205	0.0463	0.00582	0.0348	0.00447	0.0214	0.00291	0.00800	0.00127	0.00313	6.28E-04
219	0.0408	0.00879	0.0269	0.00577	0.0152	0.00334	0.00600	0.00135	0.00241	6.33E-04
177	0.0360	0.00112	0.0262	8.05E-04	0.0147	4.96E-04	0.00345	1.18E-04	0.00125	4.85E-05
208	0.0338	0.00467	0.0227	0.00301	0.0131	0.00170	0.00475	4.52E-04	0.00193	2.06E-04
202	0.0289	0.00762	0.0147	0.00399	0.00828	0.00213	0.00306	5.66E-04	0.00123	2.59E-04
187	0.0277	0.00817	0.0143	0.00437	0.00748	0.00232	0.00251	6.43E-04	0.00101	2.72E-04
193	0.0277	0.00613	0.0167	0.00406	0.0105	0.00262	0.00404	0.00108	0.00168	4.90E-04
192	0.0267	0.00564	0.0165	0.00357	0.00982	0.00217	0.00384	8.29E-04	0.00155	3.76E-04
171	0.0256	0.00666	0.0169	0.00443	0.00958	0.00252	0.00253	6.95E-04	9.46E-04	2.66E-04
195	0.0211	0.00555	0.0108	0.00292	0.00607	0.00156	0.00224	4.16E-04	9.09E-04	1.89E-04
189	0.0196	0.00575	0.0104	0.00313	0.00543	0.00167	0.00181	4.64E-04	7.32E-04	1.95E-04
190	0.0140	0.00330	0.00736	0.00185	0.00390	9.87E-04	0.00127	2.88E-04	5.27E-04	1.20E-04
181	0.0127	0.00284	0.00675	0.00188	0.00367	0.00108	0.00137	2.84E-04	5.13E-04	1.31E-04
163	0.0118	0.00327	0.00869	0.00238	0.00529	0.00146	0.00106	3.02E-04	3.73E-04	1.06E-04
183	0.0115	0.00268	0.00770	0.00198	0.00430	0.00124	0.00109	3.74E-04	4.93E-04	1.84E-04
160	0.00822	0.00465	0.00546	0.00302	0.00304	0.00166	6.45E-04	3.70E-04	2.78E-04	1.63E-04
174	0.00724	0.00375	0.00441	0.00240	0.00246	0.00134	6.91E-04	3.17E-04	3.00E-04	1.46E-04
185	0.00658	0.00146	0.00530	0.00117	0.00362	8.29E-04	0.00158	3.73E-04	6.86E-04	1.76E-04
182	0.00390	0.00118	0.00328	9.69E-04	0.00213	6.64E-04	5.84E-04	2.23E-04	2.66E-04	1.10E-04
156	0.00288	9.01E-06	0.00191	5.23E-06	0.00107	2.71E-06	2.19E-04	5.46E-07	7.68E-05	1.93E-07
178	0.00283	8.59E-04	0.00237	7.03E-04	0.00154	4.82E-04	4.22E-04	1.62E-04	1.93E-04	7.95E-05
179	0.00162	6.29E-04	0.00139	4.96E-04	9.96E-04	3.49E-04	2.84E-04	1.17E-04	1.31E-04	5.56E-05
148	0.00157	6.03E-04	0.00108	4.15E-04	6.57E-04	2.64E-04	3.76E-04	1.45E-04	1.92E-04	8.26E-05
145	2.34E-05	3.20E-07	1.30E-05	1.65E-07	6.83E-06	8.39E-08	1.40E-06	1.90E-08	5.14E-07	7.05E-09

[a] Shaded rows indicate reaches considered in the refined risk characterization (Section 4.3). Reaches with the highest 90th and 50th percentile EECs were selected for risk curve analysis.

[b] 90th and 50th percentiles of EECs after refining the SWAT model for reaches 197 and 159.

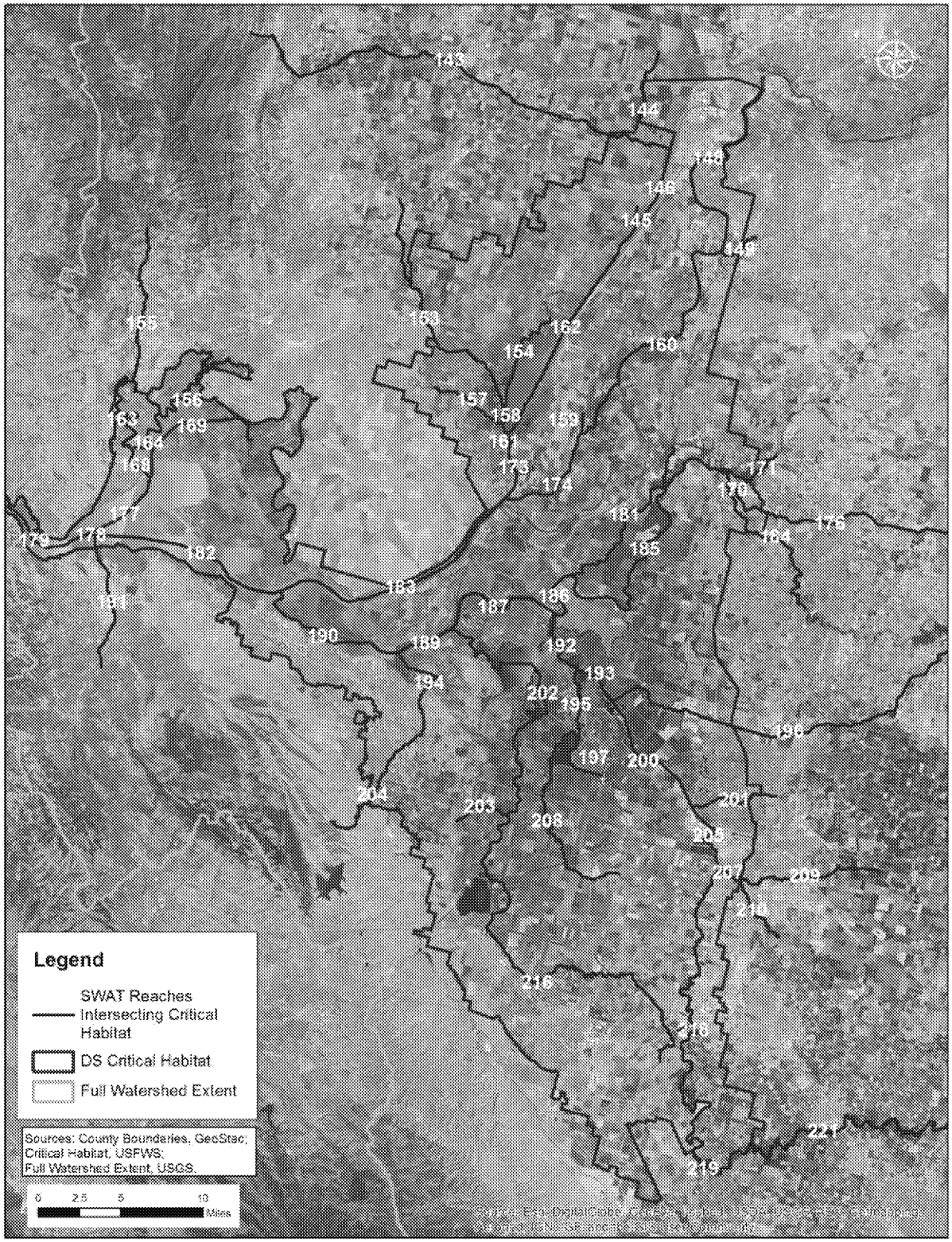


Figure 4-7 SWAT Reaches in Critical Habitat

4.3 Refined Risk Characterization

As mentioned in Section 4.2, a SWAT model was developed to evaluate malathion exposure in flowing water bodies throughout the DS critical habitat. The model simulates the fate and transport of malathion moving off use sites via spray drift and runoff, and routes those residues downstream through the major Sacramento and San Joaquin rivers, eastern tributaries, and minor streams and sloughs of the California Delta. One hundred unique application scenarios were randomly generated based on the spatially and temporally varying patterns of historic malathion use. Each model simulation predicted 29 years of daily malathion concentrations within each watershed reach, which were then used to calculate annual maximum EECs for various exposure durations (e.g., 48-hours, 96-hours, 21-days).

Risk curves were derived for the ten worst-case reaches of the DS SWAT model (see Table 4-5), which were identified by ranking the 50th and 90th percentiles of EECs for the 59 modeled reaches. As described in 2.11.3.2, exposure distributions were integrated with an effects distribution (i.e., SSD or concentration-response curve) to derive a risk curve that indicates the probabilities of exceeding effects of differing magnitude. Each risk curve was then used to categorize risk as *de minimis*, low, intermediate, or high.

In this assessment, the probability of an exposure concentration exceeding a level of effect is quantified as the area under a risk curve (risk curve AUC). The AUC will be used to categorize risk (see Section 2.11.3.2). The AUCs and associated risk categories for each of the worst-case reaches are presented in Table 4-6.

Table 4-6 Refined risk characterization results for SWAT modeling of the Sacramento-San Joaquin River Delta							
Location ID	*Taxa*	*Exposure Duration*	*Exposure Distribution*	*Effects Distribution*	*Risk Result*		
					Max Risk Product	*AUC (%)*	*Risk Category*
Rch 144	Fish	Acute	96-h	96-h conc response	0.00276	0.0118	*De minimis*
Rch 153	Fish	Acute	96-h	96-h conc response	0.00538	0.0141	*De minimis*
Rch 155	Fish	Acute	96-h	96-h conc response	0.0768	0.218	*De minimis*
Rch 159	Fish	Acute	96-h	96-h conc response	0	5.00×10^{-8}	*De minimis*
Rch 197	Fish	Acute	96-h	96-h conc response	0	5.00×10^{-8}	*De minimis*
Rch 201	Fish	Acute	96-h	96-h conc response	0.00193	0.00601	*De minimis*
Rch 203	Fish	Acute	96-h	96-h conc response	0.0546	0.170	*De minimis*
Rch 207	Fish	Acute	96-h	96-h conc response	0.00241	0.00554	*De minimis*
Rch 209	Fish	Acute	96-h	96-h conc response	0.0138	0.0473	*De minimis*
Rch 210	Fish	Acute	96-h	96-h conc response	0.0141	0.0349	*De minimis*
Rch 144	Aquatic invertebrates	Acute	48-h	48-h SSD	0.860	2.09	Low
Rch 153	Aquatic invertebrates	Acute	48-h	48-h SSD	0.622	1.79	Low
Rch 155	Aquatic invertebrates	Acute	48-h	48-h SSD	1.64	3.63	Low
Rch 159	Aquatic invertebrates	Acute	48-h	48-h SSD	4.00×10^{-5}	2.69×10^{-4}	*De minimis*
Rch 197	Aquatic invertebrates	Acute	48-h	48-h SSD	4.59×10^{-4}	0.00263	*De minimis*
Rch 201	Aquatic invertebrates	Acute	48-h	48-h SSD	0.725	1.73	*De minimis*
Rch 203	Aquatic invertebrates	Acute	48-h	48-h SSD	1.85	4.37	Low
Rch 207	Aquatic invertebrates	Acute	48-h	48-h SSD	0.437	1.40	*De minimis*
Rch 209	Aquatic invertebrates	Acute	48-h	48-h SSD	1.54	3.95	Low
Rch 210	Aquatic invertebrates	Acute	48-h	48-h SSD	0.820	2.47	Low
Rch 144	Aquatic invertebrates	Chronic	21-d	48-h SSD/ACR	3.34	8.01	Low
Rch 153	Aquatic invertebrates	Chronic	21-d	48-h SSD/ACR	1.37	3.98	Low
Rch 155	Aquatic invertebrates	Chronic	21-d	48-h SSD/ACR	3.86	8.10	Low
Rch 159	Aquatic invertebrates	Chronic	21-d	48-h SSD/ACR	0.0267	0.0825	*De minimis*
Rch 197	Aquatic invertebrates	Chronic	21-d	48-h SSD/ACR	0.0500	0.0978	*De minimis*
Rch 201	Aquatic invertebrates	Chronic	21-d	48-h SSD/ACR	2.58	6.13	Low
Rch 203	Aquatic invertebrates	Chronic	21-d	48-h SSD/ACR	2.94	6.54	Low
Rch 207	Aquatic invertebrates	Chronic	21-d	48-h SSD/ACR	2.48	6.06	Low
Rch 209	Aquatic invertebrates	Chronic	21-d	48-h SSD/ACR	4.92	10.7	Intermediate
Rch 210	Aquatic invertebrates	Chronic	21-d	48-h SSD/ACR	3.59	8.43	Low

4.3.1 Direct Effects to DS

There was *de minimis* risk of acute effects to fish residing in the ten worst-case reaches of the Delta. As shown in Table 4-6, AUCs ranged from 0.00000005% for reaches 159 and 197 to 0.218% for reach 155 (Table 4-6, Figure 4-8). A sample risk curve for acute exposure of fish in reach 155 of the Delta is shown in Figure 4-9. The probability that SWAT EECs exceeded concentrations associated with 1% mortality to freshwater and marine fish was less than 4% for all reaches, and there was less than a 1% probability of observing a 5% effect on mortality.

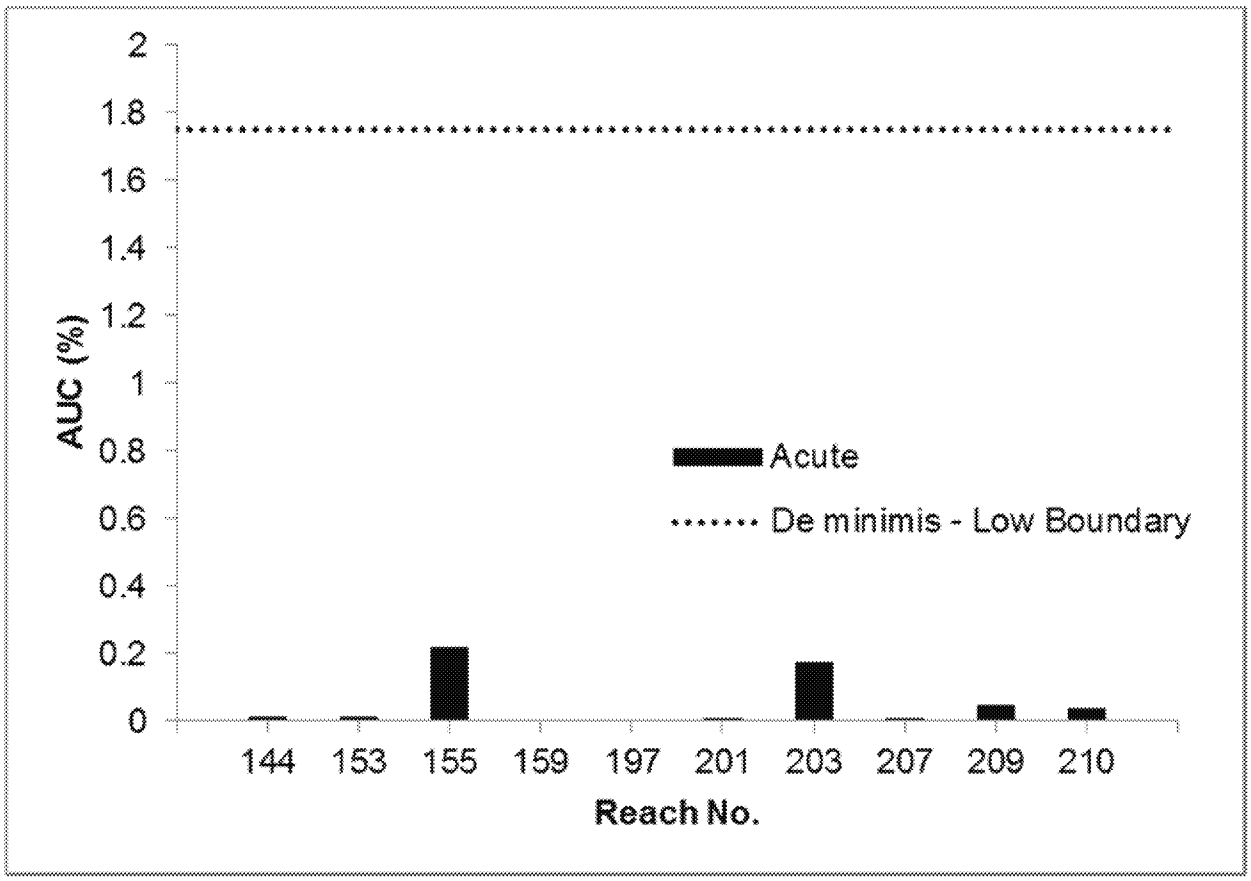
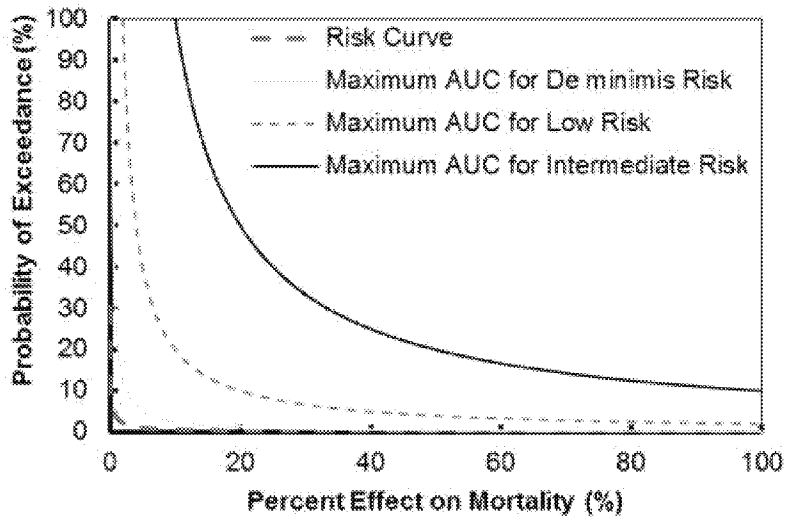


Figure 4-8 Acute risk curve AUCs for fish exposed to malathion in the Sacramento-San Joaquin River Delta



Percent Effect on Mortality (%)	*Probability of Exceeding Effect (%)*
1	3.83
5	0.966
10	0.552
50	<0.0345
90	<0.0345
95	<0.0345
99	<0.0345

Risk Summary	
AUC	0.218
Risk Category	*De minimis*

Figure 4-9 Risk curve for acute exposure of marine fish to malathion in reach 155 of the Sacramento-San Joaquin River Delta

4.3.2 Indirect Effects to DS via Reduction in Aquatic Invertebrate Prey

For four of the ten worst-case reaches, there was *de minimis* risk of acute effects to aquatic invertebrates (AUCs of 0.000269 to 1.73%). Low risk of acute effects (AUCs of 1.79 to 4.37%) was observed for the remaining reaches (Table 4-6, Figure 4-10). A sample risk curve for acute exposure of aquatic invertebrates in reach 203 of the Delta is shown in Figure 4-11.

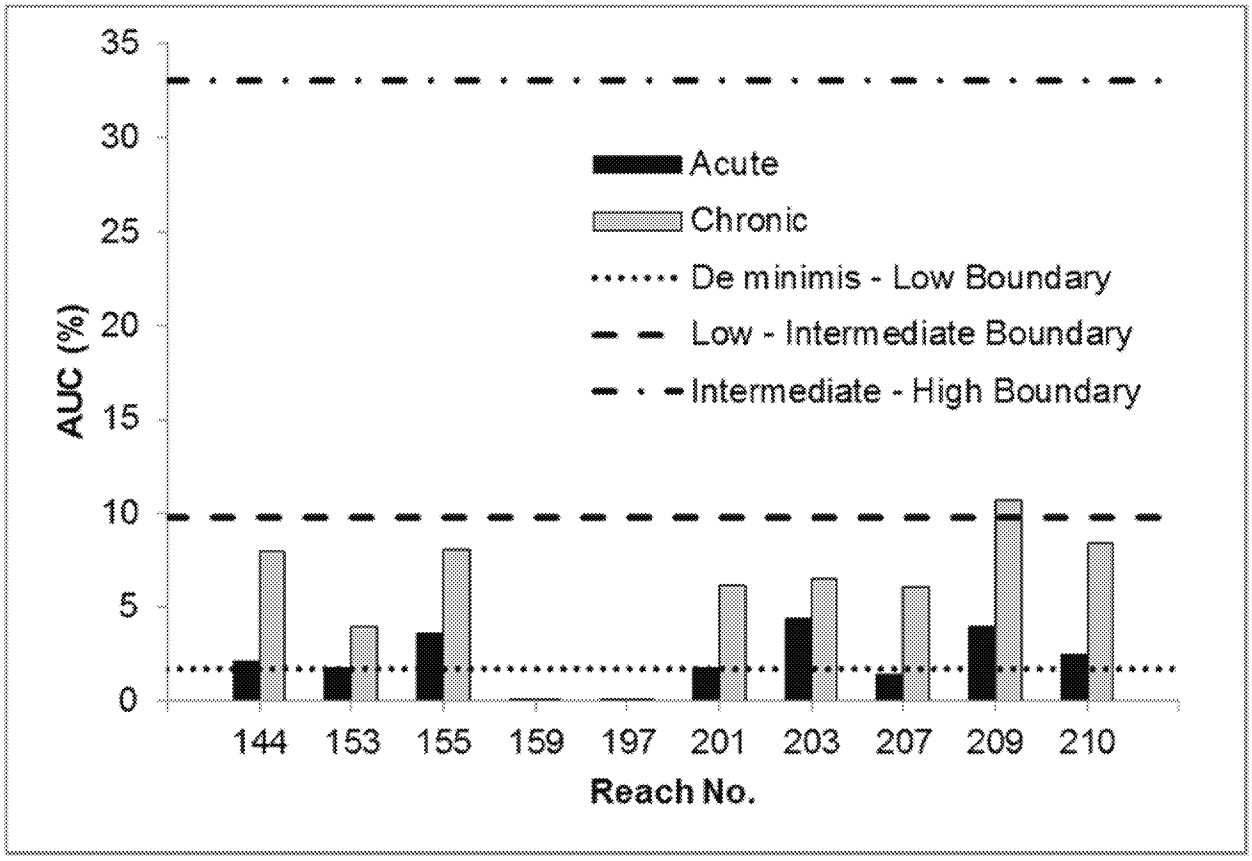
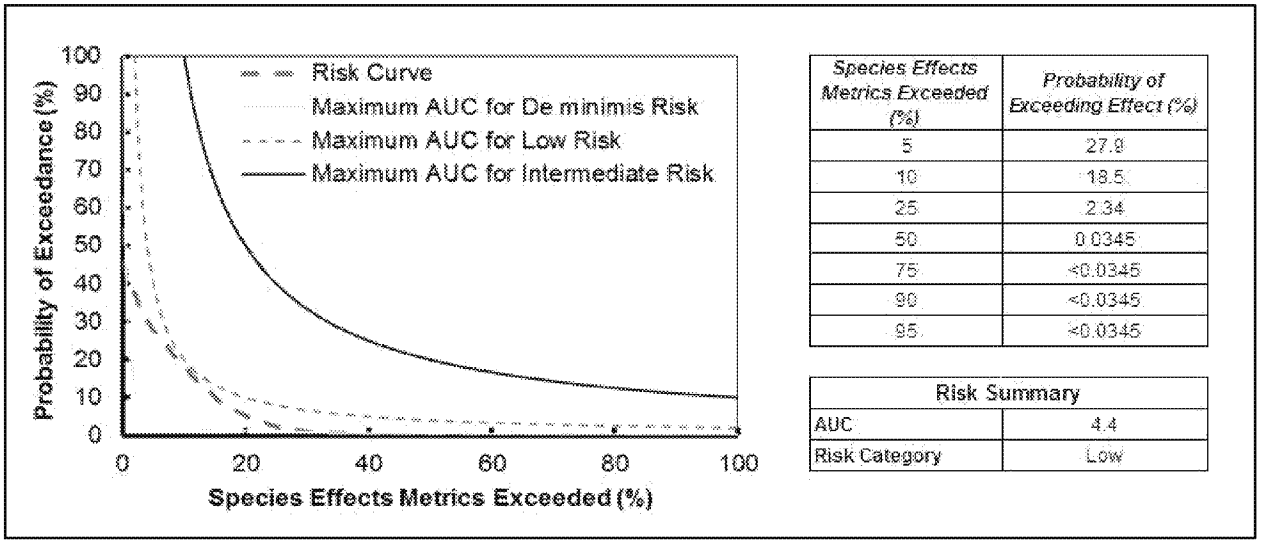


Figure 4-10 Acute and chronic risk curve AUCs for aquatic invertebrates exposed to malathion in the Sacramento-San Joaquin River Delta

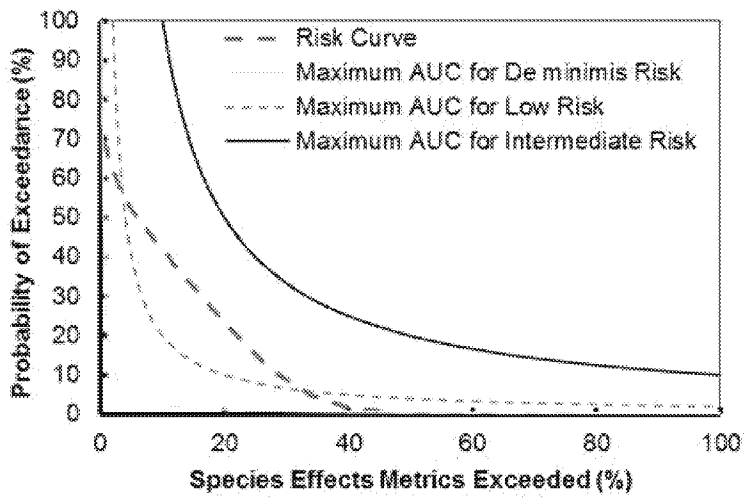


Species Effects Metrics Exceeded (%)	Probability of Exceeding Effect (%)
5	27.9
10	18.5
25	2.34
50	0.0345
75	<0.0345
90	<0.0345
95	<0.0345

Risk Summary	
AUC	4.4
Risk Category	Low

Figure 4-11 Risk curve for acute exposure of aquatic invertebrates to malathion in reach 203 of the Sacramento-San Joaquin River Delta

As described in Section 4.2.4, reaches 155, 159, and 197 were modeled as smaller headwaters with the potential for low flow rates based on runoff inputs alone. However, in reality, reaches 159 and 197 are connected to a network of larger channels, not fully represented in SWAT that provide a continual source of flow and stabilize the water volumes in those segments making them behave more like semi-static reservoirs than headwaters. As such, the concentrations for reaches 159 and 197 were likely biased high for these actual reaches because the modeled water volumes were underestimated. Additional refinements were, therefore, made to the SWAT model for reaches 159 and 197 to more accurately account for the water volumes in those reaches. After refinements to the SWAT model were made, there was *de minimis* risk of chronic effects to aquatic invertebrates for reaches 159 and 197 (AUCs of 0.0825 and 0.0978%, respectively). Seven of the ten worst-case reaches had low risk and AUCs ranged from 3.98% (reach 153) to 8.43% (reach 210). Intermediate risk of chronic effects to aquatic invertebrates was observed for reach 209 (Figure 4-12). However, the chronic AUC for reach 209 (10.7%) is only slightly higher than the low-intermediate risk boundary (9.82%). Furthermore, there is limited overlap between reaches 209 and 210 and DS critical habitat as shown in Figure 4-7.



Species Effects Metrics Exceeded (%)	*Probability of Exceeding Effect (%)*
5	52.2
10	42.2
25	15.2
50	0.172
75	<0.0345
90	<0.0345
95	<0.0345

Risk Summary	
AUC	10.7
Risk Category	Intermediate

Figure 4-12 Risk curve for chronic exposure of aquatic invertebrates to malathion in reach 209 of the Sacramento-San Joaquin River Delta.

4.3.3 Other Lines of Evidence

4.3.3.1 Field Studies

Kuhajda et al. (1996 [MRID 47587601]) investigated effects to fish and aquatic invertebrates in Stewart Creek, Fayette County, Alabama following malathion application to adjacent cotton fields. Applications to cotton fields surrounding Stewart Creek were considered a worst-case scenario because there were no buffers between the Creek and treated fields and the banks of the Creek lacked riparian vegetation to intercept runoff or spray drift. The field study was carried out over a three-year period, with malathion being applied only in the first two years. There were three sampling locations along Stewart Creek: a malathion spray location ("Spray"), a site downstream of the spray location ("Downstream") and a site upstream of the spray location ("Control"). The Spray and Downstream locations were channelized habitats, whereas the Control location was a more natural and stable habitat for aquatic biota. During the course of the study, measurements of species diversity, quantity of species, quantity of individuals, brain acetylcholinesterase (AChE) activity in two fish species and malathion concentrations in water were taken.

Kuhajda et al. (1996 [MRID 47587601]) applied malathion to cotton fields via ground and aerial spraying at a rate of 1 lb/A (1.12 kg/ha). Although the test substance was not provided by study authors, Fyfanon ULV (96.6% malathion) was used as part of the BWEP during this time frame. Over the course of the study, malathion applications to two cotton fields within 25 feet of Stewart Creek were made eight times in 1993 and fifteen times in 1994 as part of a boll weevil eradication effort. Multiple malathion applications were applied to both cotton fields adjacent to Stewart Creek. Application intervals ranged from four to 39-day interval between applications but were typically between five and eight days. This use pattern is representative of many worst-case scenarios on current malathion labels, such as application to strawberries (2 lb a.i./A applied four times per season with a seven-day retreatment interval), papaya (1.25 lb a.i./A applied eight times per season with a three-day retreatment interval), and guava (1.25 lb a.i./A applied 13 times per season with a three day retreatment interval; EPA, 2009a). During the course of the study, an 11 acre cotton field located upstream of the spray location was also treated with 1 lb/A malathion nine times in 1993 and 14 times in 1994. Many other pesticides were applied in addition to malathion within the Stewart Creek area between 1993 and 1994. Collection of water samples to determine malathion concentrations in Stewart Creek were taken every 15 minutes, from one hour before to four hours following malathion application. To evaluate differences between the sample sites and changes between the sampling periods, biological samples were grouped into spray and no-spray periods and counts of individuals, numbers of species and diversity were determined. Two species of fish were analyzed for brain AChE activity, *Notropis baileyi* (rough shiner) and *Etheostoma rupestre* (rock darter).

Malathion concentrations in Stewart Creek ranged from below the detection limit (detection limit not reported) to a maximum of 31.1 µg/L in 1993 and 1994 (Kuhajda et al., 1996 [MRID 47587601]). The highest concentrations were observed at the spray location shortly after application of malathion in nearby fields. Aerial applications produced higher concentrations of

malathion than ground applications. Concentrations of malathion also declined rapidly following application, as four-hour average concentrations were approximately six- to nine-fold lower than peak concentrations, indicating that malathion dispersed rapidly in the flowing-water system. Malathion application to cotton fields bordering Stewart Creek significantly affected the brain AChE activity in one of the two species examined, *N. baileyi*. Percent reductions in brain AChE activity relative to *N. baileyi* from the control site were up to 26.0% in fish sampled at the spray site and up to 36.3% in fish sampled downstream of the spray site. A number of estuarine fish studies have suggested that brain AChE inhibition of >50% is associated with mortality and some species of fish appear capable of tolerating much higher (>90%) brain AChE inhibition (Fulton and Key, 2001; Sandahl et al., 2005). Furthermore, based upon the abundance data for this species over the course of the study, *N. baileyi* populations at the spray and downstream locations were not adversely affected by malathion application in nearby cotton fields. In conclusion, Kuhajda et al (1996 [MRID 47587601]) concluded that no adverse or long-term effects in the fish and aquatic invertebrates were apparent based on the number of individuals, number of taxa or diversity indices.

A field study conducted by Jensen et al. (1999) tested the effects of ultra-low volume malathion (Cythion™; emulsifiable concentrate) on wetland communities in the Central Valley of California. Two sets of paired treatment and control sites were studied, with malathion applied over seasonally impounded wetlands in the Colusa National Wildlife Refuge. Control wetlands were placed upwind from treated sites to prevent spray drift. Malathion was applied at dusk on September 30, 1996 at a rate of 0.236 L/min and using a truck speed of 16 km/h. The applications were identical to operational pest control in the area. Water samples were taken before and after application. Approximately 6 µg/L malathion was detected in post-treatment water samples from both treated wetlands, but not detected in control wetlands or pre-treatment samples. Adult female mosquitoes (*Aedes melanimon*), larval mosquitoes (*Culex tarsalis*) and mosquitofish (*Gambusia affinis*) were pre-counted and placed into separate appropriate enclosures to monitor survivorship in control and treatment wetlands after malathion exposure. Aquatic macroinvertebrates were collected using D-ring aquatic sweep nets from each wetland before and after application of malathion and analyzed for effects on abundance and biomass. Flying insect abundance was also monitored before and after malathion application in each wetland using ultraviolet light traps. Results found no detectable effects of malathion on survival of mosquito larvae or on the abundance or biomass of any other aquatic macroinvertebrates or on mosquitofish. However, all adult mosquitoes died in treated wetlands. Adult mosquitos did survive in control wetlands, indicating that drift did not occur. Flying insect abundance decreased on the day of malathion application in both treated and control wetlands, but within 24 hours abundance rebounded to pre-treatment levels. This suggests that flying insect populations are resilient to malathion exposure due to renewed activity or immigration and continued emergence of adults. The authors concluded that ultra-low volume applications of malathion used to control adult mosquitoes are unlikely to substantially affect aquatic invertebrate or fish populations in seasonal wetlands.

Tagatz et al. (1974) applied malathion as an ULV aerosol spray to a salt-marsh wetland in northwestern Florida. Three applications of 57 g/ha (0.051 lb/A) ULV malathion (Cythion

Technical, 95% purity) were made at low tide to maximize settling and retention and at sunset, when mosquito activity was greatest. Grass shrimp (*Palaemonetes vulgaris*), blue crabs (*Callinectes sapidus*) and sheepshead minnow (*Cyprinodon variegatus*) were placed in containers of water throughout the treated and untreated marshes. No negative effects on the shrimp, crabs and minnows were observed and no organisms contained detectable levels of malathion. The highest water concentrations, up to 0.34 µg/L, were measured in the containers within three days of application.

Giles (1970 [MRID 00058820]) studied the effects of malathion on aquatic organisms in a small forested watershed over a two-year period. In 1961, tracer plot studies were conducted to develop techniques for use of the radionuclide tracer method. Malathion-S^{35} was applied using a backpack ground sprayer to two 0.04 ha (0.1 A) plots on August 29th, 1961 at a rate of 0.81 kg/ha (0.73 lb/A) and two other plots were included as carrier and untreated controls. In 1962, malathion-S^{35} was aerially applied (0.81 kg/ha or 0.73 lb/A) to one of two adjoining eight hectare (roughly 20 acres) forested watersheds. On May 15th, 1962 the plane crashed at the end of the first swath and most of the malathion in the tank was confined to the airplane and the crash site. A second flight occurred on May 25th, 1962 and malathion application was applied as planned.

In 1962, crayfish (*Cambarus bartoni sciotensis*) were caught from 500 m below the watersheds and placed in ponds within the treated and untreated areas. Crayfish were observed daily before and after malathion was applied. Concentrations of malathion in the pond on the day of malathion application (May 25th, 1962) ranged from 1500 to 8500 µg/L. The stream in the treated area was strained for three hours after spraying to collect dead and moribund animals. A large amount of dead organisms was collected within the first hour after spraying (n=1274), but this number was reduced to 640 organisms in the second hour and 598 organisms in the third hour. The majority of collected organisms belonged to the Chironomidae, Ceratopogonidae, Sciaridae and Empididae families. Measured malathion concentrations in the stream were not reported for the May 25th, 1962 application and effects on aquatic invertebrate abundance and diversity were not characterized in this study. Thus, the reported effects to aquatic invertebrates in the stream are of little use for assessing malathion risk to aquatic invertebrate populations and communities.

In the 1961 tracer plot studies, fish captured from streams were placed in buckets of water on each of the plot areas. Twenty four hours after malathion application, all but one of the brook sticklebacks (*Eucalia inconstans*) on the treated plots were dead. However, brook sticklebacks on untreated plots all survived. All blacknose dace (*Rhinichthys atratulus meleagris*) and a mud minnow (*Umbra limi*) survived and appeared to be healthy. Measurements for the buckets used to house fish in the tracer plot study were not reported, nor were the malathion concentrations measured following application. As such, the results of the tracer plot study are not useful for characterizing risk to fish. In the 1962 watershed study, four southern red-bellied dace (*Chrosomus erythrogaster*) were held in cages within the treated pond and observed for four days before and seven days after the malathion application. Blacknose dace were also observed in the ponds for two weeks after treatment. Concentrations of malathion in the pond on the day of malathion application (May 25th, 1962) ranged from 1500 to 8500 µg/L. No effects

to fish were observed and above-background radiation was not detected in either fish species in the treated and untreated ponds. Thus, southern red-bellied dace, blacknose dace and crayfish in the treated pond were not adversely affected by malathion (Giles, 1970 [MRID 00058820]).

Crane et al. (1995) examined the effects of Malathion 60 applied on watercress crops to amphipods, *Gammarus pulex*, living below the watercress beds. Two watercress beds were chosen; one large bed that required spray applications on two consecutive days to ensure coverage of the entire crop and one small bed that only required one application. Wild-caught amphipods were placed in cages below the watercress crops before (control) and after spraying. Additional cages with amphipods were placed below settling pools that received water from the watercress beds and were used to minimize the release of suspended sediment to the adjacent chalk streams. Cages were collected two hours to seven days after deployment. Malathion 60 was applied at a rate of 10 mL Malathion 60/ha. Heavy rain and a high water table resulted in an additional application being made to the large watercress bed; applications occurred on days one, three and four. No significant mortality was observed pre- or post-spray except for below the small bed, where mortality was significantly higher than the corresponding settling pond at both sampling times. There were no significant decreases in feeding rates at any of the sampling times or locations. The field observations indicate that Malathion 60 applied to watercress beds may affect survival of amphipods below the beds, but not in the settling pools.

The American lobster (*Homarus americanus*) population in Long Island Sound suffered a significant mortality event in the fall of 1999, which was followed by two years of smaller, more localized die-offs (Pearce and Balcom, 2005). In comparison to the previous year, lobster landings in western Long Island Sound declined by 99% and landings in the eastern portion of Long Island Sound decreased by 64 to 91% (CTDEP, 2000). To investigate the potential causes of these die-offs (e.g., disease, anthropogenic contaminants and other environmental stressors), the Long Island Sound Lobster Research Initiative (LRI) was put in place and managed by the Steering Committee for Lobster Disease Research (SCLDR), a subcommittee of the Atlantic States Marine Fisheries Commission (ASMFC). Under this initiative, researchers were asked to submit proposals related to the physical/chemical environment, disease, pesticides and immunological responses to stress (Pearce and Balcom, 2005) and 17 projects were selected by the SCLDR (Balcom and Clemetson, 2006). Pearce and Balcom (2005) summarized the collective results of the LRI that were presented and discussed during the Fourth Long Island Sound Lobster Health Symposium, held in Stony Brook, NY in October, 2004.

A number of potential causes of the lobster die-offs, including increased water temperature, low dissolved oxygen levels, exposure to sulfides and ammonia, infection by parasitic amoebae (*Neoparamoeba pemaquidensis*) and exposure to pesticides were investigated under the LRI. Mosquito control programs were undertaken in New York and Connecticut in response to the appearance of mosquito-borne West Nile Virus in the summer and fall of 1999 and there was a belief among lobstermen that the lobster die-off was linked to pesticide applications used to control mosquitoes (Balcom and Clemetson, 2006). Malathion, resmethrin, sumithrin and methoprene were applied in New York and/or Connecticut between August and October of 1999

and application data for these pesticides were collected from the New York State Department of Environmental Conservation and the Connecticut Department of Environmental Protection (Miller et al., 2005; Wilson et al., 2005).

Laboratory toxicity studies investigating the lethal and immunotoxic effects of malathion, resmethrin and methoprene to lobsters were conducted under the research initiative (Pearce and Balcom, 2005). In addition, two independent modeling efforts were conducted using hydrodynamic models and the aforementioned pesticide application data to determine whether individual pesticides applied for mosquito control could have been responsible for the lobster mortalities (Miller et al., 2005; Wilson et al., 2005). Miller et al. (2005) modeled two extremely conservative exposure scenarios. The first scenario assumed that the entire amount of a pesticide applied within the Long Island Sound drainage area between June and November 1999 reached Long Island Sound and did not degrade over time. The second scenario assumed that all of the applied pesticide reached Long Island Sound and then degraded. The maximum malathion concentration calculated in the first scenario was 10.3 µg/L. This concentration exceeds the most sensitive malathion LC50 of 3.7 µg/L for effects to larvae (Zulkosky et al., 2005), but is well below the adult lobster LC50 of 38 µg/L (De Guise et al., 2004). Assuming a decay rate of 0.88 d^{-1} (or a half-life of approximately 19 h), the highest malathion concentration predicted in the second scenario was 5.4 µg/L and occurred in the surface waters of Flushing Bay (Miller et al., 2005). However, the predicted concentrations of malathion near bottom waters (areas inhabited by lobsters) did not exceed 1.6 µ/L. Thus, Miller et al. (2005) concluded that malathion should not be considered a causative agent of the lobster die-off.

Wilson et al. (2005) modeled a less conservative exposure scenario, which only considered New York pesticide application data within two zip codes of the coast, applied weekly loadings of pesticides and accounted for degradation. However, the approach used was still very conservative in assuming that all the pesticide applied on land reached Long Island Sound. Wilson et al. (2005) concluded that there is little evidence for bottom concentrations exceeding 0.001 µg/L for any of the pesticides considered. The results of both modeling exercises indicated that malathion concentrations, alone, in the water column of western Long Island Sound could not have been high enough to cause adult lobster mortality in 1999. In their final report, Pearce and Balcom (2005) concluded that the mortality of adult lobsters observed in 1999 was likely compounded by above average water temperatures, low dissolved oxygen concentrations and an infection. Moreover, recent studies have failed to demonstrate a link between malathion exposure and the decline in lobster populations. Those populations have continued to decline in the absence of detectable concentrations of pesticides, which bolsters the belief that warming temperatures are the main culprit (CDEEP, 2012; Collins, 2016; Middletown Press, 2016).

Summary

Five field studies evaluated the effects of malathion applied at rates ranging from 0.051 to 1 lb/A on aquatic ecosystems, particularly wetlands and watercress beds (Giles, 1970 [MRID 00058820]; Jensen et al., 1999; Tagatz et al., 1974; Kuhajda et al., 1996 [MRID 47587601];

Crane et al., 1995). These studies reported peak concentrations ranging from 0.34 to 8500 µg/L following malathion spraying (concentrations exceeding the EECs predicted by PRZM/EXAMS and PFAM in the screening-level assessment). Although Giles (1970 [MRID 00058820]) reported effects to fish and aquatic invertebrates, measured malathion concentrations associated with these effects were not reported and the results are therefore not useful for characterizing risk to fish and aquatic invertebrates. All other studies observed no persistent effects on the abundance and survival of fish or aquatic invertebrate communities. In particular, Kuhajda et al. (1996 [MRID 47587601]) measured peak malathion concentrations ranging from <LOD to 10.89 µg/L in 1993 and from 4.34 to 31.10 µg/L in 1994, but did not observe any significant effects on species abundance, number of taxa or diversity for fish or aquatic invertebrate communities over the three-year study. Although Kuhajda et al. (1996 [MRID 47587601]) observed a significant reduction in brain AChE in rough shiners (*Notropis baileyi*), the biochemical change did not have a significant effect on the survival of the shiners.

The reduction of lobsters in Long Island Sound was evaluated through two independent modeling exercises (Miller et al., 2005; Wilson et al., 2005). In both cases, estimated exposure concentrations of malathion in the Sound were lower than the lowest toxicity value available for adult lobsters. Pearce and Balcom (2005) concluded that the mortality of adult lobsters observed in 1999 was likely compounded by above average water temperatures, low dissolved oxygen concentrations and an infection. Moreover, recent studies have failed to demonstrate a link between malathion exposure and the decline in lobster populations. Those populations have continued to decline in the absence of detectable concentrations of pesticides, which bolsters the belief that warming temperatures are the main culprit (CDEEP, 2012; Collins, 2016; Middletown Press, 2016). Finally, all available lobster toxicity studies were rated as unacceptable by Cheminova because they did not follow standard testing guidelines and did not provide enough details to fully replicate the studies.

Most of these field studies presented above were conducted prior to 1992, when Cheminova submitted their confidential statement of formula based on a highly refined manufacturing process that produces technical malathion with higher active ingredient content and reduces impurity content compared to previous manufacturers (Hillwalker and Reiss, 2014 [MRID 49316501]). Thus, the field studies conducted prior to 1992 likely used malathion products containing higher impurity levels, which could cause higher levels of effect than the malathion products currently registered in the US.

4.3.3.2 Mesocosm Studies

Outdoor Mesocosm Studies

Ebke (2002 [MRID 46525901]) conducted a GLP mesocosm study to investigate acute and chronic effects of malathion directly applied as a formulation (Malathion 440 g/L EW; Cheminova A/S, Lemvig, Denmark; 40.6% w/w purity) to aquatic communities in outdoor pond mesocosms (1,060 L each). The study involved a single and direct application of malathion to 16 stainless steel enclosures containing freshwater assemblages of pelagic and benthic organisms. There were six control enclosures. The study involved six treatment concentrations

with three replicates each for the 0.6, 1.2, 2.5 and 5.0 µg a.i./L treatments and two replicates each for the 10 and 30 µg a.i./L treatments. Biological sampling for zooplankton, macrozoobenthos, emerging insects, phytoplankton, periphyton and macrophytes occurred on a weekly or bi-weekly basis for 99 days. Concentrations in treatment enclosures declined rapidly with half-life values ranging from 0.8 to 2.3 days. Sediment concentrations never exceeded the detection limit (DL = 0.3 µg/kg ww).

In the highest malathion treatment (30 µg a.i./L), there were no effects on periphyton, phytoplankton, productivity (determined via chlorophyll a levels), macrophytes, macroinvertebrates, emergent insects and functional endpoints (e.g., redox potential) (Ebke, 2002 [MRID 46525901]). There were transient effects in certain zooplankton species (*Daphniidae*, *Chydoridae*), but complete recovery occurred within 28 days. No species were eliminated from either of the 30 µg a.i./L enclosures. Similar results were observed in the 10 µg a.i./L treatment, except that only *Daphniidae* species were transiently affected in this treatment. No effects were observed in any of the remaining malathion treatments. The results confirm that cladoceran species are the most sensitive species to malathion exposure. However, in natural systems where malathion dissipation and degradation are expected to be rapid following application, recovery of cladocerans will also be rapid.

Relyea (2005) used outdoor mesocosms to examine the impact of malathion on the biodiversity of aquatic communities containing algae and 25 species of animals. Zooplankton and phytoplankton assemblages from six local ponds were added to polyethylene tanks containing 1000 L of well water, 300 g dry leaves and 25 g rabbit chow (initial nutrient source). Anuran larvae (*Rana sylvatica*, *Rana pipiens*, *Bufo americanus*, *Hyla versicolor* and *Pseudacris crucifer*), spotted salamander larvae (*Ambystoma maculatum*), snails (*Physa integra*, *Helisoma trivolvis* and *Stagnicola elodes*), damselfly larvae (*Lestes* sp.), dragonfly larvae (*Anax junius* and *Tramea* sp.), diving beetle larvae (*Dytiscus* sp. and *Acilius semisulcatus*) and hemipterans (*Notonecta undulata* and *Belastoma flumineum*) were added to mesocosms 22 to 24 days after the addition of zooplankton and phytoplankton communities. Either a negative control (250 mL of water) or 320 µg/L of commercial-grade malathion (50.6% purity; 162 µg a.i./L based on malathion purity) was applied to mesocosms and abundance and survival measurements were taken 12 days after the initial exposure. The effects of malathion treatment on (1) total species richness of the aquatic community, (2) species richness and biomass of four major functional groups in the community (i.e., predators (insects and salamanders), large herbivores (snails and tadpoles), zooplankton and periphyton algae) and (3) individual species abundance were examined.

Malathion exposures of 162 µg a.i./L reduced overall species richness by 30% compared to controls. There were significant decreases in predator richness and biomass and in zooplankton species richness, but no effects on large herbivore richness or biomass, zooplankton abundance, or periphyton biomass. This exposure level significantly reduced *Tramea* dragonfly survival and eliminated *Dytiscus* beetle and backswimmer (*Neonecta undulata*) populations. However, other insect predators (i.e., *Anax junius*, *Belostoma flumineum* and *Lestes* sp.) were unaffected. *Daphnia pulex* and *Daphnia ambigua* were effectively absent from malathion-treated

mesocosms. However, only effects on *Daphnia pulex* were significant. Aside from an increase in *Eurytemora* abundance, no effects of malathion exposure on other zooplankton species (i.e., *Daphnia longiremis*, *Ceriodaphnia* sp., *Scapholebris* sp., *Eurycyclops agilis*, *Mesocyclops edax*, or *Leptochaptumorus* sp.) were observed. Exposure to 162 µg a.i./L malathion did not adversely affect the survival of snails or amphibian tadpoles. In fact, a 28 to 43% increase in leopard frog (*Rana pipiens*) survival and a 50 to 67% increase in wood frog (*Rana sylvatica*) survival in the malathion treatment group were observed compared to control. However, these effects were not statistically significant.

In summary, malathion exposures of 162 µg a.i./L eliminated or significantly reduced the abundance of a limited number of cladoceran and insect species, but had indirect positive effects on copepod (i.e., *Eurytemora*) and anuran tadpoles, which were likely due to malathion effects on predators. Relyea (2005) notes that this study observed the effects of malathion within a short time frame (~two weeks) and that many taxa have the potential to recover over longer periods of time if pesticide exposure is not a recurring event.

Relyea (2009 [MRID 48261129]) studied the effects of malathion on aquatic communities using outdoor mesocosms over a 57-day period. Water was supplied from nearby ponds and contained zooplankton, phytoplankton and periphyton. Algal and zooplankton communities were allowed to develop in the mesocosm prior to addition of leopard frog (*Rana pipiens*) and gray tree frog (*Hyla versicolor*) tadpoles. Technical-grade malathion (99% purity) was added to the water at a nominal concentration of 10 µg/L. However, the actual concentration achieved was 5.8 µg/L. Survival of tadpoles in the control mesocosms was 96% and survival in the malathion mesocosms was also near 100% for both species. Mass at metamorphosis was comparable to control values. Average zooplankton abundance was significantly decreased compared to control levels for *Ceriodaphnia* sp., but not for *Leptodiaptomus minutus*, *Skistodiaptomus oregonensis* or *Daphnia pulex*. Likewise, the abundances of phytoplankton and periphyton were not significantly different from control. Thus, only the biomass of cladocerans was significantly reduced following exposure to 5.8 µg/L malathion. However, since *Ceriodaphnia* sp. abundance was averaged for the two sampling times (days 16 and 36), it is unknown when significant effects occurred and if the *Ceriodaphnia* sp. population was recovering following the initial exposure.

Hua and Relyea (2012) compared the effects of a malathion formulation (50% purity, Malathion Plus, Ortho Corporation, Marysville, OH) on two aquatic communities with geographically distinct amphibian assemblages from Pennsylvania and Oregon. Mesocosm studies were conducted with a factorial experimental design. Each mesocosm included (1) either wood frog (*Rana sylvatica*) or Cascades frog (*Rana cascadae*) larvae for the Pennsylvania and Oregon assemblages, respectively, (2) either a presence or absence of a zooplankton predator (larval north western salamanders (*Ambystoma gracile*) for the Pennsylvania assemblage or spotted salamanders (*Ambystoma laterale*) for the Oregon assemblage) and (3) one of three nominal malathion concentrations (0, 5, or 50 µg a.i./L). Originally, Malathion Plus (Ortho Corporation, Marysville, OH, 50% purity) was added to mesocosms at concentrations of 1 or 10 µg a.i./L. However, concentrations measured in samples collected four hours after dosing were an order

of magnitude less than the nominal concentration. Thus, applied concentrations were increased to 5 and 50 µg a.i./L. Measured concentrations were 6 and 40 µg a.i./L in samples collected three hours after dosing. Abiotic response variables (temperature, pH, DO and light attenuation), zooplankton, phytoplankton and periphyton abundance were measured on day 22. Emergence of wood frogs and Cascades frogs was monitored from day 16 until day 40 and mass at metamorphosis was measured.

Copepod abundance increased in the 6 µg a.i./L treatment compared to controls, but did not differ from controls for the 40 µg a.i./L treatment. Cladoceran abundance was practically reduced to zero individuals in the 6 and 40 µg a.i./L treatment groups in all amphibian assemblages. Thus, the increase in copepod abundance at the 6 µg a.i./L treatment was likely due to reduced competition with cladocerans. However, at the 40 µg a.i./L treatment, the toxic effects of malathion on copepods appeared to offset the positive effects of reduced competition.

Phytoplankton abundance was greater in both malathion treatments compared to controls. This increase was likely due to overall reductions in zooplankton, which are the major consumers of phytoplankton. Malathion-related increases in phytoplankton also had effects on abiotic variables associated with increased photosynthesis, such as pH and DO. Conversely, periphyton biomass was significantly lower at the 40 µg a.i./L treatment compared to controls. The reduction in periphyton biomass is likely an indirect effect of malathion treatment. Periphyton competes with phytoplankton for light and nutrients, thus the malathion-related increase in phytoplankton is likely associated with the reduction in periphyton.

Anuran and salamander survival was high across all treatments and ranged from 97.1% to 99.4%. Anuran mass at metamorphosis was increased in the malathion treatments relative to the control and Cascades frog metamorphs were larger than the wood frog metamorphs. The positive effect of malathion on anuran mass at metamorphosis may be due to a brief initial increase in periphyton abundance after insecticide application, which has been observed by Boone and Semlitsch (2002), Boone et al., (2005), Boone and Bridges-Britton (2006), Relyea and Diecks (2008) and Mackey and Boone (2009). Because wood frogs and cascade frogs have relatively short larval periods, they may be able to complete metamorphosis before declines in periphyton occur (Hua and Relyea, 2012). Salamander mass was significantly different between malathion treatments and amphibian assemblages. Salamander mass decreased significantly with increasing malathion concentrations and was likely due to the reduction in zooplankton prey.

Overall, Hua and Relyea (2012) found that malathion concentrations ranging from 6 to 40 µg a.i./L had direct lethal effects of cladoceran populations and indirect effects on abiotic variables, phytoplankton, periphyton and copepod abundance and amphibian mass at metamorphosis. However, these taxa were only sampled once and recovery could not be measured. Although mass at metamorphosis for both anurans and salamander was affected by malathion exposure, significant effects on amphibian survival were not observed. Amphibian survival is not affected likely because, even if prey base composition changes, overall abundance of the prey base is sufficient to not affect survival of the amphibian larvae.

Hua and Relyea (2014) conducted a mesocosm study to measure the direct and indirect effects of malathion on aquatic population and community-level variables. Technical-grade malathion (Chem Service, West Chester, PA) was applied at nominal concentrations of 10 or 40 µg/L to outdoor mesocosms containing algae, zooplankton, amphipods (*Crangonyx pseudocracilis*), isopods (*Asellus aquaticus*), snails (*Physa acuta*, *Helisoma trivolvis* and *Stagnacola elodes*) and spring-breeding tadpoles (wood frogs (*Rana sylvatica*), leopard frogs (*R. pipiens*), American toads (*Anaxyrus* [*Bufo*] *americanus*) and spring peepers (*Pseudacris crucifer*)). Tadpoles of two summer-breeding amphibians species (gray treefrogs (*Hyla versicolor*) and green frogs (*R. clamitans*)) were added approximately three weeks after insecticide application. All tanks were covered with 60% shade cloth to prevent organisms from entering or leaving the systems (Hua and Relyea, 2014). Water samples were taken four hours after dosing and after the addition of summer-breeding amphibian species to measure insecticide concentrations. Trace amounts of malathion (0.2 µg/L) were detected in the controls and measured concentrations of malathion in treatments were 2.8 (10 µg/L nominal concentration) and 12 µg/L (40 µg/L nominal concentration) after four hours. Malathion was not detected in water after addition of the summer-breeding amphibian species. The authors stated that because the first and second set of samples were processed two and five weeks after collection, respectively, storage degradation likely occurred (Hua and Relyea, 2014). Abiotic variables (temperature, pH, DO and light attenuation), zooplankton, phytoplankton and periphyton abundance were measured two, four, nine and 18 weeks after malathion application. Snail abundance was assessed six and 18 weeks after dosing, detritivore (amphipods and isopods) abundance was measured 13 weeks after dosing and amphibian metamorphosis was recorded daily from four weeks after dosing. Survival to metamorphosis and mass at metamorphosis were measured. Mass of green frog tadpoles was measured at week 18 since they are an overwintering species and did not undergo metamorphosis over the course of the study.

Direct effects on cladoceran and copepod abundance were not observed at any time point following exposure to 10 µg/L malathion. However for the 40 µg/L treatment, significant reductions in zooplankton abundance relative to controls were observed at the two and four week sampling times for cladocerans and at the two week sampling time for copepods. Recovery of cladoceran abundance was observed by the nine week sampling time and copepod populations recovered by week four. The relatively rapid recoveries of cladoceran and copepod populations were likely due to the complete degradation of malathion by week three of the study. Malathion had no significant effects on amphipod abundance at the 10 µg/L concentration and no effects on isopod abundance at either concentration. However, the 40 µg/L malathion treatment severely reduced amphipod abundance. Detritivore abundance was only sampled once, therefore, recovery was not assessed. No significant effects of malathion on abiotic variables, phytoplankton, periphyton or snail abundance were observed.

Neither of the malathion treatments affected the survival to metamorphosis nor the mass at metamorphosis of spring-breeding amphibians. The 40 µg/L treatment reduced gray treefrog survival to less than 50%, but mass at metamorphosis was not affected by malathion. The mass of green frog tadpoles was not affected by either malathion treatment.

In summary, the 40 µg/L nominal malathion treatment (measured 12 µg/L) was associated with significant reductions in zooplankton and amphipod abundance, and gray treefrog survival (Hua and Relyea, 2014). However, recovery of zooplankton abundance was observed within nine weeks. Recovery was not measured for amphipods. The observed reduction in gray treefrog survival is likely due to indirect effects of malathion treatment since malathion had completely degraded at the time the summer-breeding tadpoles were added to the mesocosm (Hua and Relyea, 2014). Instead, the authors attribute gray treefrog mortality to possible formation of the malathion degradate, malaoxon. However, the authors do not report whether malaoxon was actually measured. In addition, formation of malaoxon in this mesocosm study is unlikely since, as described in Appendix B, no malaoxon was detected in hydrolysis and photolysis studies (Teeter, 1988 [MRID 40941201]; Miller, 1988 [MRID 40969301]; Carpenter, 1990 [MRID 41673001]; Sanders, 1988 [MRID 41039001]; Dykes et al., 1990 [MRID 41695501]; Spare and Cutchin, 1991 [MRID 42015201]); soil and water samples from two aquatic dissipation studies and two soil dissipation studies (Rice et al., 1990a,b [MRID 41748901, 41727701]; Jacobson and Lochhaas, 1992a,b [MRID 43042401, 43042402]; Judy et al., 1991a,b [MRID 42058401, 42058402]); and water-sediment systems treated with malathion (Knoch, 2001a [MRID 46769502]; Hiler and Mannella, 2012 [MRID 48906401]; Blumhorst, 1991a,b [MRID 42271601; 42216301]).

Halstead et al. (2014) conducted a freshwater mesocosm study to examine the effects of malathion on species- and ecosystem-level responses. The authors hypothesized that malathion would reduce zooplankton and arthropod abundance, leading to increases in non-arthropod herbivores and phytoplankton. Outdoor mesocosms covered with 60% shade cloth and containing zooplankton (Copepod nauplii, Calanoidea spp., Cyclopoidea spp., *Ceriodaphnia* sp. and *Diaphanosoma* sp.), periphyton, phytoplankton, macrophytes (*Hydrilla verticillata* and *Utricularia macrorhiza*), amphibian larvae (*Osteopilus septentrionalis* and *Rana sphenocephala*), snails (*Melanoides tuberculate*, *Planorbella scalaris*, *P. trivolvis* and *Viviparus georgianus*) and macroarthropods (*Anax junius*, *Belostoma flumineum*, Corixidae sp., *Procambarus alleni* and *Ranatra* sp.) were exposed to 102 or 204 µg/L technical-grade malathion (98.4% purity, Chem Service, West Chester, PA; 100 and 200 µg a.i./L based on malathion purity) dissolved in acetone. Negative and solvent controls were also included. Weekly measurements of phytoplankton abundance, light availability and water temperature were taken and periphyton and zooplankton abundance, DO and pH were measured biweekly. Amphibian, snail and macroarthropod abundances were measured at the end of the 4-week experiment. The Bray-Curtis similarity index was used as the dissimilarity measure for the whole ecosystem.

No significant effects to amphibians, macroarthropods, snails, copepod nauplii, Calanoidea spp., Cyclopoidea spp., *Diaphanosoma* sp., periphyton or phytoplankton were observed in response to malathion exposure. *Ceriodaphnia* sp. abundance was significantly reduced compared to controls throughout the experiment (Halstead et al., 2014), but appeared to be increasing between weeks two and four. As such, recovery of *Ceriodaphnia* sp. could have been observed had the experiment been of longer duration. *Diaphanosoma* sp. abundance

increased between weeks two and four of the experiment and was likely a result of reduced competition for nutrients with *Ceriodaphnia* sp. Bray-Curtis similarity was significantly different between control mesocosms and malathion-treated mesocosms. However, there was no evidence of a community-level dose response to the two malathion treatments.

Brogan and Relyea (2015) performed a factorial mesocosm to examine the mitigating effects of macrophytes on malathion toxicity to aquatic communities. Mesocosms contained one of four macrophyte treatments (0, 10, 50 or 100 *Elodea canadensis* shoots planted) and one of three malathion exposure scenarios was administered (no exposure, single pulse and repeated pulse). Microbial, algal and zooplankton communities were established in 1200 L mesocosms and on day 0 of the experiment, 20 gray treefrog (*Hyla versicolor*) tadpoles, 15 pond snails (*Physa acuta* and *Physa gyrina*), and seven ram snails (*Helisoma trivolis*) were added. Mesocosms were left undisturbed for 10 days prior to exposure. Technical-grade malathion (99% purity; Chem Service Inc., West Chester, PA) was applied at a target concentration of 18 µg/L to all treated mesocosms on day 19. However, since this application did not significantly reduce cladoceran populations, an additional application of 36 µg/L malathion was made on day 37 for the single pulse treatment and on days 37, 55 and 73 for the repeated-pulse treatment. Water samples were collected one hour after application and sent for analysis of malathion concentrations. However, results were unreliable and concentrations could not be verified.

The response variables sampled by Brogan and Relyea (2015) and sampling times are listed below:

- *Elodea* density on day 47 (qualitative measurement) and on day 320 (quantitative measurement)
- abiotic water quality variables (pH, dissolved oxygen (DO), light decay rate, temperature) on days 26, 47, 68 and 100
- cladoceran, copepod and rotifer densities on days 26, 47, 68 and 100
- phytoplankton abundance (measured as chlorophyll *a*) on days 26, 47, 68 and 100
- periphyton mass on days 26, 47, 68 and 100
- pond and ram horn snail abundance and mass on day 68
- gray tree frog survival and mass at metamorphosis checked daily after emergence of first metamorph on day 30 until the final gray treefrog emergence on day 94

Where included, *Elodea* density increased in all mesocosms over the course of the experiment. By the end of the experiment (day 320), there were no significant differences in biomass density between the 10 and 50 macrophyte treatments, but both groups contained 50% less biomass than the 100 macrophyte treatment. As expected based on the results of Brogan and Relyea (2013a,b; 2014), mesocosm pH values increased with increasing macrophyte treatments. *Elodea*-treated mesocosms had pH value at least 1.17 units higher than mesocosms without *Elodea*. In addition, inclusion of *Elodea* had no effect on temperature, but increased DO and reduced light decay rates.

Cladocerans were marginally affected by the initial 18 µg/L malathion treatment ($p = 0.061$), but there were no effects of *Elodea* or the *Elodea* x malathion interaction on cladoceran densities.

After the 36 µg/L malathion treatment was applied, the single pulse exposure resulted in reduced cladoceran density by 76% in mesocosms without *Elodea*, but populations returned to control levels within 21 days. However, for the repeated pulse exposures, mesocosms without *Elodea* had cladoceran densities that were 97% lower than controls on days 47, 68 and 100. In contrast, no adverse effects of malathion treatment were observed on cladoceran densities for mesocosms that contained *Elodea*. Copepods and rotifers are much more resistant to malathion toxicity compared to cladocerans. Accordingly, no direct effects of malathion treatment on these taxa were observed by Brogan and Relyea (2015).

The reduction in cladocerans observed in mesocosms without *Elodea* did not result in phytoplankton blooms for the single pulse exposure, likely due to the rapid recovery of populations. However, phytoplankton blooms in the repeated pulse exposure were observed from day 68 to day 100. Phytoplankton blooms were not observed in any of the mesocosms containing *Elodea*, which indicates that macrophytes mitigated both the direct effect of malathion on cladoceran populations and the indirect effects on phytoplankton.

Ram horn snails may have been affected by malathion-induced phytoplankton blooms since reduced abundance of these organisms relative to controls were observed in the repeated pulse treatment mesocosms without *Elodea*. It is unlikely that this effect resulted from direct toxicity of malathion based on a 48-hour LC50 of 228,840 µg/L for the ramhorn snail (Tchounwou et al., 1991). Rather, ramhorn snails may have been affected by reduced production or quality of periphyton, resulting from phytoplankton blooms (Brogan and Relyea, 2015). Malathion exposures of 18 to 36 µg/L were not associated with any effects on gray treefrog survival or mass at metamorphosis, and survival was high across all mesocosms (86 ± 2%).

Groner and Relyea (2011) conducted a freshwater mesocosm study to examine the effects of malathion on common pond species. The authors hypothesized a trophic cascade of effects wherein zooplankton would be reduced, causing an increase in phytoplankton, which would in turn shade and reduce periphyton, thereby decreasing the growth and development of tadpoles. Additionally, they hypothesized that these effects would be greater in smaller weekly applications then they would in larger single applications. Aliquots of pond water were collected from local ponds, screened for predators, and added to 1200 L mesocosms. All tanks were covered with 60% shade cloth to prevent organisms from entering or leaving the systems. Leopard frog eggs (*R. pipiens*) were collected from one egg mass and hatched in laboratory conditions. Forty tadpoles were then added to each mesocosm and allowed to acclimate for six days before malathion was added into the experiment. Three exposure concentrations were selected and subsequently measured to be 3.1 µg a.i./L added once a week for four weeks and 34 and 384 µg a.i./L added once. However, the 34 µg/L concentration had to be estimated due to damage to the sample. Periphyton, phytoplankton, and zooplankton abundance was measured at seven and 21 days by measuring mass, chlorophyll a, and density, respectively. Zooplankton was identified to group of cladoceran or copepod. Amphibian endpoints were selected to be survival to metamorphosis, mass after metamorphosis, time to metamorphosis. After metamorphs reached Gosner stage 42 (Gosner, 1960), they were removed from experimental chambers. To simulate the potential for pond drying, 225 L of water were removed

from each mesocosm every three days beginning on day 88. However, few tadpoles exposed to malathion remained in the experiment after the ponds were dried, so this method did not ultimately alter survival. Abiotic experimental conditions including DO, temperature, pH, and light extinction were measured on days seven and 21.

Malathion exposure was determined to significantly alter the structure of pond communities and tadpole survival. At seven days, cladoceran density in the two highest exposure concentrations was reduced by at least 93% compared to the control. At 21 days, cladoceran density was significantly reduced for all exposure concentrations when compared to the controls. At that time, copepod density was also significantly increased relative to the controls in the weekly treatment and the lowest single-application treatment, but not in the high single-application. Phytoplankton productivity was also significantly greater at this time point when compared to the controls. Additionally, periphyton mass was reduced in the low single-exposure treatment. Tadpole survival was significantly decreased by all exposure treatments, by at least 8%. Single-exposure treatments did not significantly alter the time to metamorphosis but exposure to multiple treatments significantly increased the time to metamorphosis of tadpoles. Mass at emergence was significantly decreased by multiple exposures but significantly increased in the single-exposure treatments.

In summary, Groner and Relyea (2011) found that malathion exposure can significantly alter the makeup of freshwater pond communities and that the observed differences can be different if exposure happens more than once, even at lower concentrations. They observed significant direct results for amphibians exposed to concentrations greater than 3.1 µg/L and differences in all measured factors of community structure 21 days after exposure to malathion. They hypothesized that the results indicating significant differences in amphibian growth were due to alterations in community structure, thereby changing food availability and competition with mesocosms.

Indoor Mesocosm Studies

Shrestha et al. (1987) conducted a laboratory and nursery pond study to assess the effects of malathion on zooplankton and fish populations in the context of fish aquaculture. Cladocerans and copepods prey on fish hatchlings, thus reducing fish harvests in aquaculture. However, other aquatic invertebrate taxa, such as rotifers, represent an important food source for early life stage fish (Shrestha et al. 1987). In the laboratory experiment, zooplankton and grass shrimp larvae were exposed to 0, 1000 and 1500 µg/L of a malathion emulsion (50% purity; 500 and 750 µg a.i./L based on malathion purity) for 48 hours before adding fish hatchlings to the test system. The zooplankton population was observed daily. Crustaceans and copepods died within a few hours of malathion treatment (500 and 750 µg a.i./L). However, neither treatment level affected fish fry or rotifer populations. The fish species used in the laboratory experiments were not specified and although the authors indicate that fish fry and rotifer mortality occurred in controls, survival rates for each taxon included in the experiment were not reported.

In the nursery pond experiments, 1000 and 1500 µg/L of malathion emulsion (50% purity; 500 and 750 µg a.i./L) were each applied to three ponds (Shrestha et al., 1987). The study did not report whether indoor or outdoor nursery ponds were tested. Copepod and cladoceran populations were significantly reduced following malathion application, but recovered to their initial population stage within eight to nine days. Thus, even at the high exposure concentrations tested, aquatic invertebrate populations rebounded rapidly. An increase in rotifer populations was observed following malathion application, likely as a result of reduced competition with copepods and cladocerans. Malathion applications in nursery ponds were made 48 hours before fish were added. Ponds were then stocked with either four to five day-old silver carp (*Hypophthalmichthys molitrix*) or two to three day-old Indian carp (mrigal carp (*Cirrhina mrigala*) and rohu (*Labeo rohita*) at a density of 300 per square meter. Fish survival for all species was significantly higher in nursery ponds where malathion was applied (56.6% survival for rohu in 750 µg a.i./L malathion treatment to 95.0% for silver carp in 750 µg a.i./L malathion treatment) compared to untreated ponds (26.0% survival for silver carp to 32.0% for rohu).

Sweilum (2006) investigated the effects of sub-lethal exposures of malathion on the growth rate, hematological properties, and production of juvenile Nile tilapia (*Oreochromis niloticus*). Glass ponds (3 m^2) were filled with freshwater and exposed to 0, 500, 1000, or 2000 µg/L malathion for the 24-week duration of the experiment. Water was aerated, changed weekly in order to maintain pesticide concentrations, and filtered daily to remove fecal matter and detritus. Sixty fish were placed in each pond and fed six days per week. Abiotic conditions measured were temperature and DO (twice daily); pH (daily); and alkalinity, ammonia, nitrate, and phosphate (estimated monthly). Biweekly, plankton was collected, identified, and counted, and tilapia length and body weight was measured. Blood samples were collected from 15 fish from each pond and erythrocytes, hematocrit, hemoglobin, proteins, and serum glucose and lipids were measured. Proteins, glycogen, and lipids were measured in fish muscles. Malathion concentrations were determined in the liver, gills, and muscles of fish upon the termination of the study. Production was determined as a factor of mass per fish.

The number of phytoplankton and zooplankton organisms were significantly less in all exposed treatments when compared to the control. Tilapia growth rate was also significantly decreased by exposure to all levels of malathion used in this study. Additionally, the authors claim that malathion caused a decrease in survival and feeding rate of all exposed tilapia in this study but do not report statistics to support this result. Significant alterations in hematological and muscle composition were observed for all endpoints measured in this study at all concentrations except for muscle glycogen and blood glucose, for which significant results were only observed at concentrations above 1000 µg/L, and blood lipids, for which no significant differences were observed. All significant results observed were decreased relative to the control except for blood glucose and muscle glycogen, wherein exposure to malathion increased these parameters compared to the control. The authors also reported a trend of increased malathion residue in tilapia organs with increasing exposure concentration. Statistical analysis was not completed for the endpoint of production but the authors reported decreased production, net returns, and probability with increasing dose of the chemical.

In summary, Sweilum (2006) determined that exposure to malathion at a concentration of at least 500 µg/L can have significant effects on the growth and the makeup of the muscle and blood of Nile tilapia. The results for growth and survival of the fish may be in part due to the reduction in plankton caused by pesticide exposure. However, the author did not report the source or active ingredient of the chemical used, nor did he measure the actual experimental chemical concentration. Furthermore, many of the abiotic factors measured in this study were significantly different in exposure treatments when compared to the control. Additionally, the experimental design only utilized a single replicate for each exposure concentration.

Summary

Ten mesocosm studies are available that studied the effects of malathion on aquatic communities (Ebke, 2002 [MRID 46525901]; Relyea, 2005, 2009 [MRID 48261129]; Sweilum, 2006; Groner and Relyea, 2011; Hua and Relyea, 2012, 2014; Halstead et al., 2014; Brogan and Relyea, 2015; Shrestha et al., 1987). Studies attempted to quantify effects to fish, aquatic-phase amphibians, periphyton, phytoplankton, macrophytes, zooplankton and macroarthropods. Test concentrations ranged from 0.6 to 750 µg a.i./L. Effects on cladocerans, the most sensitive taxon tested, were observed at concentrations ≥5.8 µg/L for single pulse exposures (Ebke, 2002 [MRID 46525901]; Relyea, 2005, 2009 [MRID 48261129]; Sweilum, 2006; Hua and Relyea, 2012, 2014; Halstead et al., 2014; Shrestha et al., 1987) and ≥3.1 µg/L for repeated pulse exposures (Groner and Relyea, 2011). The effects observed on cladocerans are not unexpected, given that the acceptable 48-h LC50 for the water flea (*Daphnia magna*) is 0.70 µg a.i./L (Gries and Purghart, 2001a [MRID 47540303]). However, when measured, recovery of cladoceran populations occurred within eight days to seven weeks of when effects were originally observed (Ebke, 2002 [MRID 46525901]; Hua and Relyea, 2014; Brogan and Relyea, 2015; Shrestha et al., 1987). Other aquatic invertebrate taxa (e.g., copepods, rotifers, snails, amphipods, isopods, and insects) were considerably less sensitive to malathion. Reductions in copepod, amphipod and insect abundance were only observed in response to malathion exposures ≥40 µg/L (Relyea, 2005; Groner and Relyea, 2011; Hua and Relyea, 2014; Shrestha et al., 1987). Copepod populations recovered within two weeks of the original effects being observed (Hua and Relyea, 2014; Shrestha et al., 1987). The study designs did not allow for measurement of recovery in amphipod and insect populations (Relyea, 2005; Hua and Relyea, 2014). Overall, aquatic-phase amphibians, fish, snails, rotifers, isopods, periphyton, phytoplankton and macrophytes were resistant to malathion toxicity.

4.3.3.3 Effects of Macrophytes on Malathion Toxicity

Brogan and Relyea (2013a) measured the effects of the macrophyte *Elodea canadensis* on malathion toxicity to *Daphnia magna*. Daphnia were exposed to measured malathion concentrations of 0, 3.2, 4.7, 17.7 and 29.6 µg/L in the presence of different densities of *Elodea* (0, 344, 612, 899 and 1,102 g dry wt/m^3) for 48 hours. The 48-hour LC50 values for malathion decreased with increasing *Elodea* density, and an order of magnitude difference was observed between the 48-hour LC50 with no *Elodea* added (2.8 µg/L) and the LC50 at the highest *Elodea* density (25.2 µg/L). The effect of *Elodea* on the rate at which malathion toxicity decreases over time was also measured. Water samples were collected from each experimental container 2, 6,

10, and 48 hours after malathion had been applied, and new *Daphnia* were exposed to these samples. Malathion toxicity at a given concentration decreased at a faster rate with increasing *Elodea* density. With no *Elodea*, the 4.7, 17.7, and 29.6 µg/L malathion concentrations caused greater than 50% mortality at all time points, but at the 1,102 g dry wt/m^3 *Elodea* density, *Daphnia* mortality for all malathion concentrations and time points did not differ significantly from controls. Similar results were observed with three additional macrophyte species: *Myriophyllum spicatum*, *Ceratophyllum demersum*, and *Vallisneria americana*. The presence of all macrophytes species decreased malathion toxicity to *Daphnia magna* and increased the rate at which toxicity decreases over time (Brogan and Relyea, 2013b).

Brogan and Relyea (2013a) observed an increase in pH from 8 with no added *Elodea* to 10 with 1,102 g dry wt/m^3 *Elodea*. Each unit increase in pH is associated with an order of magnitude decrease in the malathion half-life (Brogan and Relyea, 2013a). The authors, therefore, hypothesized that the effects of macrophyte density on malathion toxicity were due to their effects on water pH. During photosynthesis, submerged plants remove carbon dioxide and increase dissolved oxygen in water, leading to an increase in pH (Brogan and Relyea, 2013b). Thus, the presence of macrophytes may reduce malathion toxicity by increasing the rate at which it is degraded.

Brogan and Relyea (2014) tested this hypothesis by comparing malathion toxicity to *Daphnia magna* under different pH conditions in the absence of macrophytes or in the presence of macrophytes with varying photosynthetic activity. Using a factorial experimental design, *Daphnia* were exposed to five nominal concentrations of technical-grade malathion (0, 1, 5, 10, 50 µg/L; 99.1% purity) under four environmental conditions: (1) presence of *Elodea canadensis* in full sunlight, (2) presence of *Elodea* in complete shade, (3) addition of 1 M hydrochloric acid to maintain low pH conditions (~7.5), and (4) addition of 1 M sodium carbonate to maintain high pH conditions(~9.5). Malathion concentrations of 0, 1, 4, 36, and 36 µg/L were measured in water samples. The effects of malathion on *Daphnia* neonates were observed over a 48-hour period.

Water pH levels measured one hour before malathion application, and 24 and 48 hours after malathion application were significantly higher in the no-plant/high pH and unshaded-plant conditions compared to the no-plant/low pH and shaded plant conditions. In addition, no significant effects of malathion treatment or the interaction between malathion treatment and plant-pH conditions on water pH were observed. The no-plant/low-pH and shaded plant conditions had pH values within 0.1 standard units of each other, and the no-plant/high pH and unshaded-plant conditions were within 0.32 units of each other.

Survival of *Daphnia* neonates was significantly affected by plant-pH condition, malathion treatment and their interaction. For malathion concentrations of 4 and 6 µg/L, *Daphnia* survival after 48 hours was 62-78% higher in the no-plant/high-pH and unshaded plant conditions compared to the no-plant/low-pH and shaded plant conditions. In addition, no significant differences in survival were observed between the no-plant/high-pH and unshaded plant conditions or between the no-plant/low-pH and shaded plant conditions. Although no statistically

significant differences in *Daphnia* survival were observed between any of the four conditions when *Daphnia* were exposed to 36 µg/L malathion, higher survival was still observed in the no-plant/high-pH and unshaded plant conditions compared to the no-plant/low-pH and shaded plant conditions. These results strongly support the hypothesis that macrophytes mitigate malathion toxicity to *Daphnia* through increases in pH since reductions in pH through the addition of sodium carbonate had the same mitigating effect as including photosynthetically active submerged plants in the test system.

Brogan and Relyea (2013a) had also proposed that sorption of malathion to the surface of macrophytes could be another mechanism for mitigation of malathion toxicity (Brogan and Relyea, 2013a). However, Brogan and Relyea (2014) demonstrated that "the mitigating effect of submerged plants on malathion toxicity could be predicted entirely based on the pH of the water and that sorption played no role in mitigation". This finding is consistent with malathion's low binding affinity to organic substrates (log K_{ow} = 2.75) and the results of Gao et al. (2000), which showed weak sorption of malathion and other organophosphate pesticides to aquatic plants. Based on average daily pH values from the USGS real-time surface water quality monitoring data, surface water pH values exceeding 8 are common, suggesting that pH-mediated insecticide mitigation may be a widespread phenomenon (Brogan and Relyea, 2014).

As described in Section 4.3.3.2, Brogan and Relyea (2015) performed a factorial mesocosm to examine the mitigating effects of macrophytes on malathion toxicity to aquatic communities. Mesocosms contained one of four macrophyte treatments (0, 10, 50 or 100 *Elodea canadensis* shoots planted) and one of three malathion exposure scenarios was administered (no exposure, single pulse and repeated pulse). Technical-grade malathion (99% purity; Chem Service Inc., West Chester, PA) was applied at a target concentration of 18 µg/L to all treated mesocosms on day 19. However, since this application did not significantly reduce cladoceran populations, an additional application of 36 µg/L malathion was made on day 37 for the single pulse treatment and on days 37, 55 and 73 for the repeated-pulse treatment. Effects on abiotic variables (pH, DO, temperature, light decay rate), macrophyte density, zooplankton (cladoceran, copepod and rotifer) density, phytoplankton abundance, periphyton mass, pond snail (*Physa acuta* and *Physa gyrina*) and ram snail (*Helisoma trivolis*) abundance and mass, and gray treefrog survival and mass at metamorphosis were recorded.

As expected based on the results of Brogan and Relyea (2013a,b; 2014), mesocosm pH values increased with increasing macrophyte treatments. *Elodea*-treated mesocosms had pH value at least 1.17 units higher than mesocosms without *Elodea*. The single pulse exposure resulted in reduced cladoceran density in mesocosms without *Elodea*, but populations recovered within 21 days. The repeated pulse exposures in mesocosms without *Elodea* reduced cladoceran densities by 97% relative to controls, resulting in phytoplankton blooms and reduced abundance of ramhorn snails. However, no adverse effects of malathion treatment were observed on cladocerans or any other taxa for mesocosms that contained *Elodea.*

Malathion exposures of 18 to 36 µg/L were not associated with any effects on gray treefrog survival or mass at metamorphosis. However, the 50 and 100 macrophyte treatments reduced

mass at metamorphosis by 25% relative to the 0 and 10 macrophyte treatments. *Elodea* treatment also had an effect on pond snail and ramhorn snail abundance, which was likely a result of observed reductions in periphyton with increasing macrophyte density. Thus, the direct effects of the single and repeated pulse exposures of malathion to cladoceran populations and indirect effects to phytoplankton abundance were successfully mitigated by all macrophyte treatments.

Summary

Brogan and Relyea (2013a,b; 2014; 2015) demonstrated that malathion toxicity to cladocerans is substantially reduced in the presence of macrophytes. This reduction in toxicity was confirmed to be due to the photosynthetic activity of macrophytes, which increases the pH of the test system, leading to increased degradation of malathion. Furthermore, the initial findings of the microcosm studies (Brogan and Relyea, 2013a,b; 2014) were supported by a recent outdoor mesocosm study (Brogan and Relyea, 2015). Wildlife do not live in the inert environments used in standard toxicity tests, and factors such as pH, temperature, presence of organic matter and shading of water bodies, can influence the degree to which organisms are exposed to and affected by pesticides.

The pH of dilution water used in acceptable toxicity tests ranged from 7.46 to 8.5 for aquatic invertebrates, 6.84 to 8.6 for fish, and 8.0 to 8.2 for aquatic-phase amphibians (Breton et al., 2014 [MRID 49333901]). Although these pH values are representative of aquatic ecosystems in the US, pH values exceeding eight are common (Brogan and Relyea, 2014; 2015). San Francisco Bay waters have typical pH values ranging from 7.8 to 8.2 (ACE, 1998), but can range from 6.5 to 8.5 (CRWQCB, 2007). As such, the pH values maintained during toxicity testing are representative of those observed in DS habitat.

4.3.3.4 Comparative Toxicity of Organophosphates and Pyrethroids to Aquatic Invertebrates

Halstead et al. (2015) conducted a study with the goals of determining whether insecticides within a given chemical class pose similar threats to aquatic macroarthropods, and which insecticides or insecticide classes pose the lowest risk to these species. Acute toxicity tests with the crayfish (*Procambarus alleni*) and water bug (*Belostoma flumineum*) was conducted for three organophosphate (chlorpyrifos, malathion and terbufos) and three pyrethroid (esfenvalerate, λ-cyhalothrin, and permethrin) pesticides. Thirty annual peak EECs for pesticide use on corn in five US states (Illinois, Mississippi, North Carolina, Ohio and Pennsylvania) were calculated in EPA's Surface Water Contamination Calculator (SWCC) using manufacturer's recommended application rates, pesticide physicochemical properties, local abiotic conditions from SWCC, and standard EPA scenarios for corn production. The 150 peak EECs predicted for each pesticide were divided by 96-hour and 10-day LC50s derived from toxicity tests, and the resulting RQs were compared to EPA's LOC of 0.5 for non-listed aquatic invertebrates.

The 96-hour LC50s for crayfish and water bug exposed to malathion were 48,936 and 2695 µg/L, respectively, and represented the lowest LC50s of all pesticides tested. The 96-hour

LC50s for the five other pesticides tested ranged from 0.21 (λ-cyhalothrin) to 29.3 µg/L (chlorpyrifos), and from 0.25 (λ-cyhalothrin) to 74.3 µg/L (terbufos) for the crayfish and water bug, respectively. Since the crayfish and water bugs used in toxicity testing were collected from an area in which malathion is used heavily for adult mosquito control, it is possible that the organisms collected have undergone selection for malathion resistance. However, the 96-hour LC50 calculated for *Procambarus alleni* was similar to data reported for other *Procambarus* species in EPA's ECOTOX database (96-hour LC50 = 49,170 - 50,000 µg/L; Halstead et al., 2015). Malathion's toxicity relative to other pesticides is further described in Appendix H. Overall, malathion had intermediate toxicity to fish and aquatic invertebrates relative to other organophosphates. Fish and aquatic invertebrates were most sensitive to azinphos-methyl, chlorpyrifos and chlorethoxyphos, and least sensitive to dimethoate and dicrotophos. However, malathion was approximately 9 to 260,000 times less toxic to fish compared to carbamate and pyrethroid pesticides.

Both the crayfish and water bug RQs for organophosphates (based on the 96-hour LC50s) rarely exceeded the LOCs (0-22% of scenarios). Crayfish RQs for pyrethroids exceeded the non-listed species LOC of 0.5 for 97 to 100% of scenarios. However, only λ-cyhalothrin had RQs consistently exceeding the LOC (99% of scenarios). Malathion was the only insecticide where no RQs exceeded the non-listed species LOC for aquatic invertebrates. Halstead et al. (2015) conducted survival analyses using Cox mixed-effects models and found that insecticide class accounted for 55.7% and 91.1% of variation in mortality data for the crayfish and water bug, respectively. Although the crayfish model indicated that differences among individual pesticides accounted for 44.3% of variance, the authors suggest that this is largely due to the extremely low toxicity of malathion to crayfish.

Overall, these analyses indicate that risk of insecticides to aquatic invertebrates can be predicted based on chemical class and/or mode of action. The organophosphate LC50s for the crayfish and water bug are one to five orders of magnitude higher than pyrethroid LC50s, and aquatic exposure modeling indicates that use of organophosphate pesticides poses significantly less risk to aquatic invertebrates than comparable uses of pyrethroids. Furthermore, amongst the organophosphate pesticides tested, malathion had the highest LC50s and the lowest predicted EECs. Thus, malathion poses lower risk to aquatic invertebrates compared to pyrethroids and other organophosphates (e.g., chlorpyrifos and terbufos).

4.3.3.5 Monitoring Data

This section summarizes the available California surface water and groundwater data for malathion and malaoxon obtained from a number of federal and state monitoring programs in the US. The following data sources were included in the review of monitoring data:

Federal Monitoring Programs:

- EPA Storage and Retrieval (STORET) Data Warehouse (2001-2015; EPA, 2013b; EPA/USGS/NWQMC, 2016)

- US Department of Agriculture (USDA) Pesticide Data Program (PDP) (2004-2013; USDA, 2016)
- US Geological Survey (USGS) National Water Quality Assessment (NAWQA) Program (2001-2013; USGS, 2013a)
- USGS National Water Information System (NWIS) (2001-2015; USGS, 2013b,c; EPA/USGS/NWQMC, 2016)

California Monitoring Programs:

- California Department of Pesticide Regulation (CDPR) Surface Water Database (SWD) (2001-2014; CDPR, 2014; 2015b)
- California Environmental Data Exchange Network (CEDEN) (2001-2014; CEDEN, 2013; 2016)

A brief description of each of these data sources, how the data were isolated, and a summary of the data from each program is provided in Appendix I.

Malathion and malaoxon data from all sources were imported into MS-Access 2010© and duplicate samples with the same sample type, sampling procedure, collection date, time, location (i.e., same latitude/longitude coordinates, station ID, and depth) and sample ID (if available) were removed. To be conservative, the entry with the highest reported concentration or, if no malathion was detected, the lowest limit of detection (LOD), limit of quantitation (LOQ), or reporting limit (RL) was retained for analysis and the other duplicate entries were removed. Only data from 2001 to 2015 were included in the analyses to reflect more recent changes in product labels and use patterns. Combined results from these programs are discussed below.

The monitoring data sources use different terminology. To simplify the reporting of results, LOD, LOQ, and sample medium will be used to represent the following terms:

- LOD: limit of detection, method detection limit, detection limit
- LOQ: limit of quantitation, practical quantitation limit
- Sample medium: sample medium, sample matrix

Summaries of malathion and malaoxon water quality data for all databases and sample media are provided in Table 4-7 to Table.

Table 4-7 Summary of California groundwater monitoring data for malathion (2001-2015)

Source (date range)	*Sample Medium*	*# Samples*	*# Detects*	*Detects (%)*	*Range of Detected Values (µg/L)*[a]	*90th Percentile of Detected Values (µg/L)*[b]	*90th Percentile of All Values (µg/L)*[c]	*Range of LOD/ LOQ/ RLs (µg/L)*
USDA PDP (2007-2013)	Groundwater	60	0	0.00	ND	NA	0.0150	0.01 – 0.03[d]
USGS NAWQA (2001-2012)	Groundwater	728	0	0.00	ND	NA	0.0135	0.016 – 0.027[d]
USGS NWIS (2001-2015)	Groundwater	1019	0	0.00	ND	NA	0.0135	0.006 – 0.027[d]

[a] ND = Not detected.
[b] NA = Not applicable.
[c] In the 90th percentile calculation for all samples, malathion concentrations for non-detects were estimated as half the limit of detection (LOD), limit of quantitation (LOQ) or reporting limit (RL).
[d] LOD.

Table 4-8 Summary of California surface water monitoring data for malathion (2001-2015)

Source (date range)	*Sample Medium*	*# Samples*	*# Detects*	*Detects (%)*	*Range of Detected Values (µg/L)*[a]	*90th Percentile of Detected Values (µg/L)*[b]	*90th Percentile of All Values (µg/L)*[c]	*Range of LOD/ LOQ/ RLs (µg/L)*
EPA STORET (2001-2015)	Water	593	18	3.04	0.06 – 0.36	0.248	0.005	NR[d,e]
USDA PDP (2005-2012)	Untreated water	87	0	0.00	ND	NA	0.0150	0.01 – 0.03[e]
USGS NAWQA (2001-2012)	Surface water	1435	198	13.80	0.0015 – 0.4	0.0635	0.0135	0.016 – 0.15[e]
USGS NWIS (2001-2015)	Surface water	2366	268	11.33	0.0013 – 5.46	0.111	0.0135	0.0037 – 0.3[e]
CDPR SWD (2001-2014)	Surface water	8317	314	3.78	0.0086 – 22.5	0.898	0.05	0 – 4[f,g]
CEDEN (2001-2014)	Sample water	751	34	4.53	0.0086 – 0.556	0.317	0.015	0.0021 – 0.05[e]; 0.006 –0.1[h]

[a] ND = Not detected.
[b] NA = Not applicable.
[c] In the 90th percentile calculation for all samples, malathion concentrations for non-detects were estimated as half the limit of detection (LOD), limit of quantitation (LOQ) or reporting limit (RL).
[d] 97% of California water samples for malathion from EPA STORET were reported as "non-detect" or "present below quantification limit" with no associated LOD or LOQ. In the 90th percentile calculation, non-detects were estimated to be half the maximum LOD of 0.01 µg/L reported for California monitoring data in STORET and samples where malathion was detected but not quantifiable were estimated to be equal to the LOD of 0.01 µg/L.
[e] LOD.
[f] LOQ.
[g] One entry in the CDPR SWD reported an LOQ as 0 µg/L. The next lowest LOQ was 0.0037 µg/L.
[h] RL.

Table 4-9 Summary of nation-wide groundwater monitoring data for malaoxon (2001-2015)

Source (date range)	*Sample Medium*	*# Samples*	*# Detects*	*Detects (%)*	*Range of Detected Values (µg/L)*[a]	*90th Percentile of Detected Values (µg/L)*[b]	*90th Percentile of All Values (µg/L)*[c]	*Range of LOD/ LOQ/ RLs (µg/L)*
USDA PDP (2007-2013)	Groundwater	54	0	0.00	ND	NA	0.300	0.3 – 0.6[d]
USGS NAWQA (2001-2012)	Groundwater	569	0	0.00	ND	NA	0.0400	0.008 – 0.08[d]
USGS NWIS (2001-2015)	Groundwater	846	0	0.00	ND	NA	0.0400	0.003 – 0.08[d,e]

[a] ND = Not detected.
[b] NA = Not applicable.
[c] In the 90th percentile calculation for all samples, malathion concentrations for non-detects were estimated as half the limit of detection (LOD), limit of quantitation (LOQ) or reporting limit (RL).
[d] LOD.
[e] RL.

Table 4-10 Summary of nation-wide surface water monitoring data for malaoxon (2001-2015)

Source (date range)	*Sample Medium*	*# Samples*	*# Detects*	*Detects (%)*	*Range of Detected Values (µg/L)*[a]	*90h Percentile of Detected Values (µg/L)*[b]	*90th Percentile of All Values (µg/L)*[c]	*Range of LOD/ LOQ/ RLs (µg/L)*
USDA PDP (2012)	Untreated water	26	0	0.00	ND	NA	0.300	0.00037 – 0.6[d]
USGS NAWQA (2001-2012)	Surface water	657	1	0.15	0.0209	NA	0.0400	0.008 – 0.09[d]
USGS NWIS (2001-2015)	Surface water	958	2	0.21	0.0002 – 0.021	0.0189	0.0400	0.003 – 0.09[d]
CDPR SWD (2005-2012)	Surface water	429	0	0.00	ND	NA	0.0400	0.02 – 0.08[e]

[a] ND = Not detected.
[b] NA = Not applicable.
[c] In the 90th percentile calculation for all samples, malathion concentrations for non-detects were estimated as half the limit of detection (LOD), limit of quantitation (LOQ) or reporting limit (RL).
[d] LOD.
[e] LOQ.

Surface water samples were collected in regions of heavy agricultural use across the US and analyzed for pesticides. More than a decade's worth of water sample data is available from some monitoring stations. For example, the USGS NAWQA program has monitored water quality within 42 study units located across the US between 1991 and 2012. These study units were designed to "cover a variety of important hydrologic and ecological resources, critical sources of contaminants, including agriculture, urban and natural sources; and a high percentage of population served by municipal water supply and irrigated agriculture" (USGS, 2014). Furthermore, the NAWQA study units are representative of a wide range of agricultural practices (e.g., crops, tillage, irrigation, drainage and chemical use) and landscapes (e.g., geology, soil type, topography, climate and hydrology) (USGS, 2013d). The CDPR also designs their studies based on the locations and time of year where and when pesticides are applied (Bennett, 1997).

Malathion was infrequently detected. The vast majority of water samples from all databases had malathion concentrations below the LOD or LOQ with 0 to 13.8% of samples having detected concentrations of malathion. Malathion concentrations were below the LOD (0.006 to 0.03 µg/L) in all California groundwater samples. Between 2001 and 2015, malathion concentrations in surface water samples collected in the California ranged from 0.0013 to 22.5 µg/L, and LODs/LOQs ranged from 0.0021 to 4 µg/L (the CDPR reported LOQs of 0 µg/L, but these values are not included in the range presented). The highest malathion concentration (22.5 µg/L) was observed at a reclamation ditch in Monterey county. Given that many of the monitoring program data were targeted to agricultural areas during periods of intense pesticide use (i.e., during growing season), they are considered a reliable information source in the risk characterization process. The USGS NAWQA program provides information on the dominant land use surrounding each of the monitoring stations (Gilliom and Thelin, 1997). The majority of malathion detects from the NAWQA program were associated with mixed land uses (52.0%), which may contain urban, forest, agriculture or mining land use. Urban uses accounted for 25.8% of malathion detects, followed by agricultural/crop (21.7%), and 'other' uses (0.5%).

Malaoxon was not detected in groundwater and was rarely detected in surface water samples. In surface water, malaoxon was detected in 0.00 to 0.21% of surface water samples collected in California between 2001 and 2015. Detected malaoxon concentrations ranged from 0.0002 to 0.0209 µg/L and LODs and LOQs ranged from 0.00037 to 0.6 µg/L. Estimated 90th percentiles of malaoxon concentration based on all sampled values ranged from 0.0400 to 0.300 µg/L. However, due to the large number of non-detects, these estimates were largely dependent on the LODs available for malaoxon. Detected malaoxon concentrations in surface water did not exceed any acute EC50s or LC50s obtained from acceptable aquatic invertebrate or fish studies conducted with malaoxon (Breton et al. 2014 [MRID 49333901]). See Appendix B for additional discussion of malathion degradates.

Malathion Surface Water Data vs. Modeled EECs

Peak PRZM/EXAMS and PFAM EECs ranged from 0.00107 to 15.7 µg/L and from 85.9 to 185 µg/L, respectively. The majority of peak PRZM/EXAMS (85.7%) and PFAM EECs (100%) exceeded the highest 90th percentile for surface water monitoring data (0.898 µg/L from the CDPR SWD). In addition, 97.1% of peak PRXM/EXAMS EECs exceeded the highest 90th percentile for surface water data based on all samples collected (0.05 µg/L from the CDPR SWD). These results indicate that the 90th percentile EECs obtained from PRZM/EXAMS are much higher than malathion concentrations typically observed in surface water. In contrast, the 24-hour 90th percentile and maximum EECs obtained from SWAT modeling ranged from 0.0000234 to 2.74 µg/L and from 0.00498 to 55.2 µg/L, respectively. Although still conservative, SWAT EECs are much more representative of actual malathion concentrations observed in the environment compared to screening-level EECs from PRZM/EXAMS and PFAM (Table 4-11).

Table 4-11 Comparison of modeled EECs to malathion surface water monitoring data

Source	*Scenario*	*Range of peak 90th percentile concentrations (µg /L)*
Screening-level PRZM/EXAMS	All scenarios	0.00107 – 15.7
PFAM	All scenarios	85.9 – 185
SWAT	All reaches	2.34×10^{-5} – 2.74[a]
Surface water monitoring data	Detections only	0.0635 – 0.898
	All samples	0.00500 – 0.0500

[a] Range of 90th percentile SWAT EECs after refinement of reaches 197 and 159.

Winchell and Snyder (2014) compared estimated drinking water concentrations (EDWCs) modeled in PRZM/EXAMS to surface water monitoring data in order to evaluate the accuracy of EPA's regulatory modeling approach for drinking water. Seven studies that compared PRZM/EXAMS modeling results and monitoring data were identified from a literature review and included in this analysis. Sampling frequencies for monitoring data ranged from once every three days to once every two weeks during the high runoff season, which were determined to be sufficient for estimating 95th percentile annual maximum concentrations and median annual concentrations, respectively. Acute and chronic EDWCs modeled in PRZM/EXAMS exceeded maximum/95th percentile monitoring concentrations by a factor of 1.5 to 85,041, and a median of 229. Modeled concentrations were at least an order of magnitude greater than monitoring data estimates in over 90% of comparisons and were over three orders of magnitude greater than monitoring data estimates in a third of comparisons (Winchell and Snyder, 2014). These factors are comparable to those observed for malathion, where the maximum peak PRZM/EXAMS and PFAM estimates were 17 and 206 times greater than the highest 90th percentile based on malathion detections.

Malathion Concentrations in DS Critical Habitat

Malathion surface water samples collected within and surrounding DS critical habitat are presented in Figure 4-13. Malathion concentrations were estimated as half the LOD/LOQ for samples with non-detectable levels of malathion. Malathion samples were taken from several sites within and surrounding DS critical habitat. Malathion detections in DS critical habitat ranged from 0.0013 to 0.07 µg/L and did not exceed any of the screening-level effects metrics for DS or aquatic invertebrates. Estimated malathion concentrations at only one site (CDPR site no. 03_2) within DS critical habitat exceeded the lowest screening-level effect metric (i.e., freshwater invertebrate chronic LOEL of 0.1 µg/L). Malathion levels were below the LOQ of 0.5 µg/L in all surface water samples collected from site no. 03_2 (Drain 11 at the Walsal Slough) in 2004 and 2005.

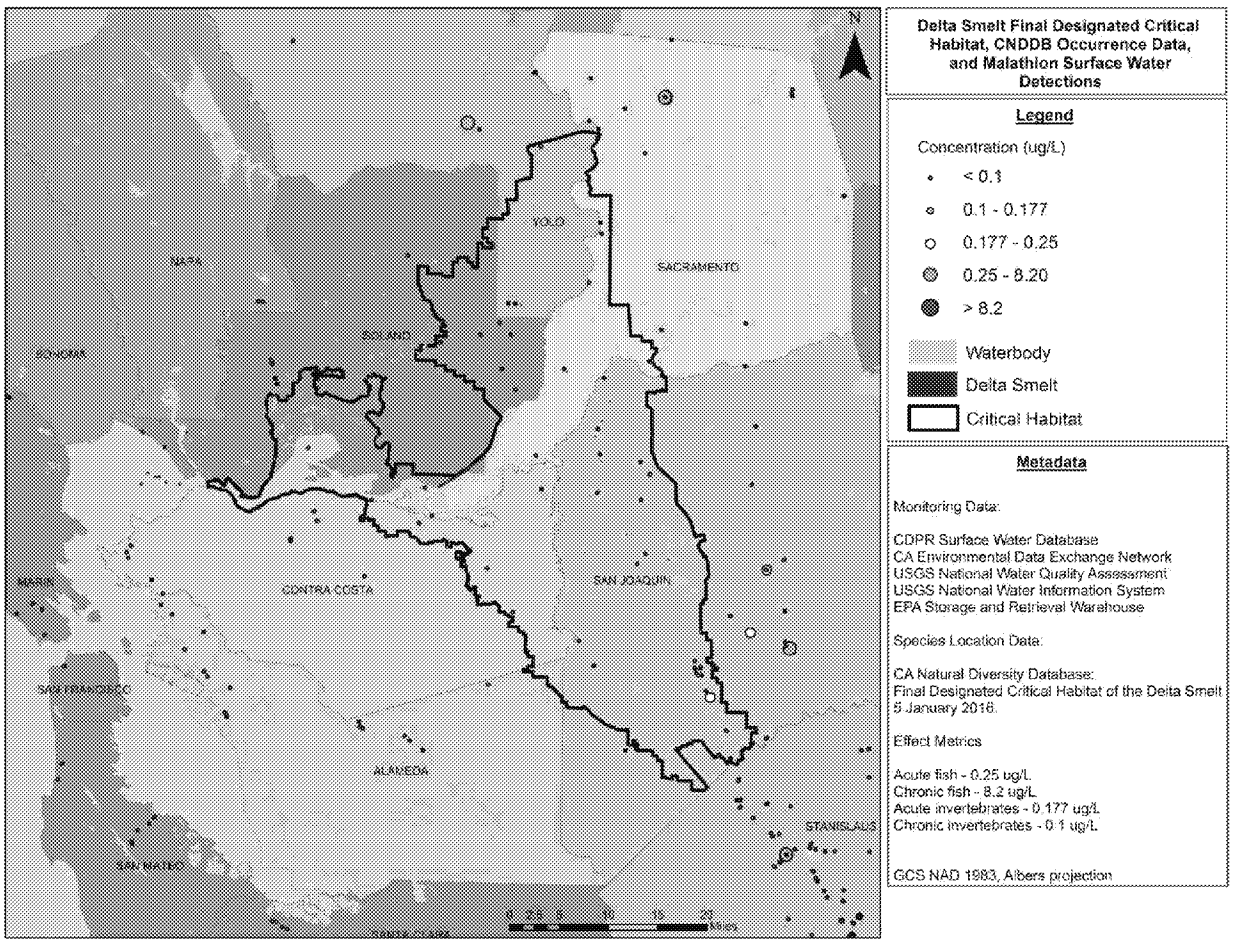


Figure 4-13 Map of malathion detections observed in DS critical habitat between 2001 and 2015

A three-year survey of pesticide concentrations in DS critical habitat was also conducted by Kuivila and Moon (2004) from 1998 to 2000. To estimate the potential pesticide exposures of

early life stage DS, water samples from the Sacramento-San Joaquin Delta were collected from April to June, in co-ordination with the CDFG's DS early life stage monitoring program. Pesticide sampling sites were selected to include known spawning areas of the DS, congregation areas of juvenile DS, and source inputs of pesticides to the Delta (Kuivila and Moon, 2004). Sites within the Delta were sampled on a weekly to bi-weekly basis, and one site in Suisun Bay (used to characterize juvenile DS exposures) was sampled on a daily to weekly basis. Kuivila and Moon (2004) collected 202 water samples over the three-year study period, but malathion was not detected in any samples. LODs for malathion were 0.015 and 0.017 µg/L in Sacramento-San Joaquin Delta and Suisun Bay water, respectively (Crepeau et al., 2000). These results suggest that early life stage DS are unlikely to be exposed to malathion concentrations that would result in adverse effects.

Malathion Surface Water Data vs. Screening-level Effects Metrics

The highest malathion concentration detected in California surface water between 2001 and 2015 (22.5 µg/L) exceeded all the screening-level effects metrics for DS and their aquatic invertebrate prey. However, the conservative nature of these effects metrics (particularly the acute effects metrics) is discussed in Section 3.4.1. Furthermore, as discussed above, malathion was only detected at concentrations ranging from 0.003 to 0.56 µg/L in counties co-occurring with DS critical habitat (i.e., Contra Costa, Sacramento, San Joaquin, Solano and Yolo).

Although malathion concentrations detected in and around DS critical habitat exceeded or approached the chronic effects metric of 0.1 and 0.58 µg/L for freshwater and marine invertebrates, respectively, these concentrations are not likely to be sustained over the extended periods of time necessary to observe chronic effects due to the rapid dissipation of malathion in aquatic systems. Based on GLP studies testing aerobic aquatic systems, estimated half-lives for malathion in water range from 0.2 to 3.4 days (Blumhorst, 1991a [MRID 42271601]; Knoch, 2001 [MRID 46769502]; Hiler and Mannella, 2012 [MRID 48906401]). In addition, malathion degrades more quickly in marine environments compared to freshwater. Bourquin (1975) found that the rate of hydrolytic degradation of malathion increased with increasing salinity and Walker (1976) reported an aerobic aquatic metabolism half-life of less than three days in water with 10‰ salinity. Based on the typical pH values observed in the San Francisco Bay (7.8 to 8.2; ACE, 1998), malathion half-lives in DS habitat would be less than one day (Blumhorst, 1991a [MRID 42271601]; Knoch, 2001 [MRID 46769502]).

The 90th percentiles of malathion detections in surface water throughout California (0.0635 to 0.898 µg/L) exceeded the acute DS and acute/chronic aquatic invertebrate effects metrics. However, these concentrations are more representative of peak malathion exposures than of chronic exposures. When factoring in samples with non-detects (with estimated concentrations of half the LOD or LOQ), 90th percentiles ranged from 0.005 to 0.05 µg/L and a very small percentage of samples (0 to 2.66%) had malathion levels exceeding the screening-level effects metrics for DS and aquatic invertebrates (Table 4-12).

Table 4-12 Percentage of surface water samples with malathion concentrations exceeding screening-level effects metrics for DS and aquatic invertebrates[a]

Source (date range)	Delta Smelt			Aquatic Invertebrates		
	Concentration associated with 0.0001% probability of mortality (0.250 µg a.i./L)[b]	97-d NOEL for rainbow trout (21 µg a.i./L)[c]	34-d NOEL for sheepshead minnow (8.2 µg a.i./L)[d]	Concentration associated with 10% probability of mortality (0.177 µg a.i./L)[e]	21-d LOEL for Daphnia magna (0.10 µg a.i./L)[f]	39-d LOEL for Americamysis bahia (0.58 µg a.i./L)[g]
EPA STORET (2001-2009)	0.169%	0%	0%	0.169%	0.169%	0%
USDA PDP (2005-2012)	0%	0%	0%	0%	0%	0%
USGS NAWQA (2001-2012)	0.139%	0%	0%	0.418%	0.697%	0%
USGS NWIS (2001-2015)	0.380%	0%	0%	0.761%	1.31%	0.169%
CDPR SWD (2001-2014)	1.83%	0.0120%	0.0481%	2.15%	2.66%	1.06%
CEDEN (2001-2014)	0.533%	0%	0%	0.666%	1.60%	0%

[a] Malathion concentrations for non-detects were estimated as half the LOD or LOQ.
[b] See Section 3.1.1.1.
[c] Cohle et al. (1989 [MRID 41422401]).
[d] Hurd and Sharpe (2011 [MRID 48705301]).
[e] See Section 3.1.2.1.
[f] Blakemore and Burgess (1990 [MRID 41718401]).
[g] Claude et al. (2012 [MRID 48752901]).

Summary

The surface water and groundwater monitoring data provide a strong line of evidence for this effects determination. A variety of data sources that focused on regions with heavy agricultural use and collected samples over several years were available for California. Sampling times were also targeted for the timing of pesticide application, which provided a reasonable estimate of peak concentrations. Overall, there was a low frequency of detection for malathion and malaoxon in surface water and groundwater samples.

Aquatic monitoring data for malathion in California and the results of Kuivila and Moon (2004) support the findings of the refined-level effects determination that malathion poses negligible risk to DS. Very few samples (0 to 1.83%) were estimated to exceed the acute and chronic effects metrics for fish, and although malathion concentrations above the acute and chronic effects metrics for DS and their aquatic invertebrate prey were observed in California, none of these detections occurred within DS critical habitat. In addition, detections above the lowest acute and chronic effects metrics for aquatic invertebrates were only observed in a maximum of 2.15% and 2.66% of water samples, respectively, collected between 2001 and 2015.

4.3.3.6 Incident Reports

The US Ecological Incident Information System (EIIS) contains information on reported ecological incidents involving pesticides. EIIS data were received on May 7th, 2015 in response to a *Freedom of Information Act* (FOIA) request dated April 20th, 2015. There have been 31 incidents involving aquatic species and malathion from 1970 to 2007, and only two aquatic incidents have been reported since 2000 (Appendix J). The EIIS report provides general information on the incident location, date, certainty, legality, end-use product, application method and total magnitude. Certainty is ranked on a scale from 0 to 4 where 0 is considered unrelated to application of malathion and 4 is considered highly probable. Of the 31 aquatic incidents reported, five were considered highly probable, 11 were probable, 13 were possible, and two were unlikely to be related to malathion application. The legality code indicates whether the incident was due to a registered use, misuse (not applied as per label), accidental misuse (e.g., spill), intentional misuse (e.g., baiting) or unknown. Of the 31 aquatic incidents reported, 10 were classified as occurring with registered uses of malathion, 14 were unknown, and seven were due to misuse. Incidents involving the misuse of malathion (accidental or intentional) are not considered further in this effects determination. In some incident reports, information is also available that describes the affected species, responses observed (e.g., mortality, behavioral), and the identified route of exposure. Additional information on application rate and type, and local meteorological conditions was not provided. There is also a significant amount of descriptive information missing for many of the reported incidents, making it difficult to interpret the information in some cases.

As stated above, five of the 31 aquatic incidents had a high probability (Certainty Code = 4) of being associated with malathion use (Appendix J). Of these five incidents, two were associated with a registered use, while the remainder were either unknown or the result of misuse. The most recent reported aquatic incidents, which occurred in 2003 and 2007, were both the result

of spills. All of the remaining incidents occurred prior to 2000. The majority of all aquatic incidents involved fish kills. Both drift and runoff were the commonly reported routes of transport to aquatic environments. There was insufficient detail for many of the reported aquatic incidents to determine the end-use product or application methods most commonly (Appendix J).

Incident reports suspected of being related to malathion use on cotton fields associated with Boll Weevil Eradication Program (BWEP) operations were also obtained from the USDA on October 6th, 2015 in response to a FOIA request submitted on September 17th, 2014 (USDA, 2015). There were 18 aquatic incidents reported, and 12 of these were either unrelated or unlikely to be related to malathion use (Appendix J). All reported aquatic incidents involved effects to fish.

In three incidents, malathion exposures in combination with other stressors (e.g. low oxygen levels, application of another chemical) could have contributed to fish kills of one to hundreds of individuals. Mullet and perch mortalities were also reported in a pond with a measured malathion concentration of 4.2 µg/L, however the findings of this report were inconclusive due the late reporting of the incident. Only one incident near site 302091501 in Arkansas was likely related to malathion exposure. The affected pond was located 50 feet from the treated cotton field and 22 to 29 µg/L malathion was measured in the pond four days after application. Based on the size of the pond and distance from the cotton field, malathion concentrations immediately after application were estimated to be 38 to 68 µg/L (Appendix J). Based on reported LC50 data for sensitive fish species, the USDA determined that malathion could have been a factor in the observed bream mortalities (USDA, 2015).

Summary

Overall, the EIIS data suggest that incidents resulting from the legal, registered uses of malathion are infrequent, particularly given the widespread use of malathion over the 37-year reporting period. The majority of the incidents resulted from misuse of malathion or had insufficient information provided to determine whether malathion was the cause of the observed effects. Very few incidents have occurred since 2000 and all aquatic incidents occurred prior to the last re-registration of malathion, which involved amendments to labeled use patterns (EPA, 2009a). The lack of recent incidents suggests that the current malathion labels are protective of aquatic biota.

Most of the recently observed malathion incidents were related to applications made under the BWEP. However, as of 2013, the boll weevil has been eradicated from all cotton-producing states except for Texas' Lower Rio Grande Valley area (USDA, 2013). As such, USDA Animal and Plant Health Inspection Services (APHIS) projects that during the post eradication phase, the program will apply malathion for boll weevil control only where outbreaks occur (USDA, 2009).

Furthermore, Cheminova has improved its manufacturing process for malathion to reduce toxicologically significant impurities (Hillwalker and Reiss, 2014 [MRID 49316501]), label rates

have been adjusted in recent years and other mitigations have been put in place (EPA, 2009a). These factors will continue to reduce the likelihood of incidents occurring.

4.4 Uncertainty in the Refined Effects Determination

4.4.1 Effects Assessment

4.4.1.1 Fish Concentration-response Curves

A concentration-response curve representative of the 5th percentile of the fish SSD was selected as the effects metric for DS in the refined effects determination. This conservative effects metric was chosen due to uncertainty in the sensitivity of DS to malathion relative to other test species (Section 3.4.1.1). In contrast, the 96-hour LC50s for the three most sensitive test species (three-spined stickleback, sheepshead minnow and bluegill sunfish) correspond to approximately the HC10, HC21 and HC23 of the fish SSD. As shown in Figure 4-14, the concentration-response curve used in the refined effects more determination was much more conservative than those derived for the three-spined stickleback, bluegill sunfish and sheepshead minnow (See Appendix G for further details). Since data from Connon et al. (2009) and Jeffries et al. (2015) indicates that DS sensitivity to pesticides is within the range of sensitivity observed for other standard test species, the use of the HC5 concentration-response curve is expected to overestimate malathion effects to DS.

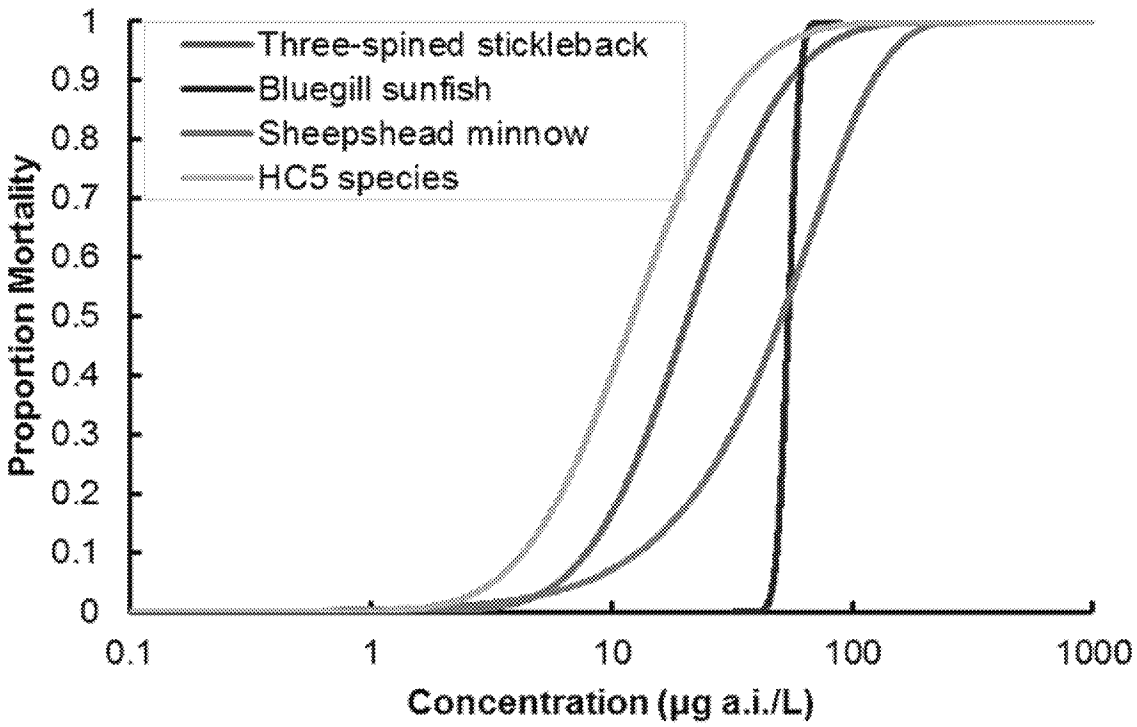


Figure 4-14 Comparison of acute fish concentration-response curves

4.4.1.2 Aquatic Invertebrate SSDs

Acute

In the refined aquatic assessment, the acute and chronic SSDs for aquatic invertebrates were based upon limited toxicity data. The acute SSD for aquatic invertebrates had eight (five freshwater and three marine) taxa represented. There is uncertainty in the LC50 estimates for the crayfish and eastern oyster because they are qualified values. To address this uncertainty, the truncation option in SSD Master was used to exclude the crayfish and eastern oyster endpoints from the model fit. This option allows for the exclusion of tolerant taxa when fitting the models, while the observed proportion of taxa affected remains true to the full dataset (Rodney et al., 2013). To assess the impact of removing the crayfish and eastern oyster endpoints from the model fit, the final SSD was compared to a second SSDs that included all acceptable toxicity data without truncation (Figure 4-15). The SSD without truncation was very similar to the final SSD used in the refined effects determination, indicating that the decision to truncate the crayfish and Eastern oyster values is unlikely to affect the risk findings for aquatic invertebrates.

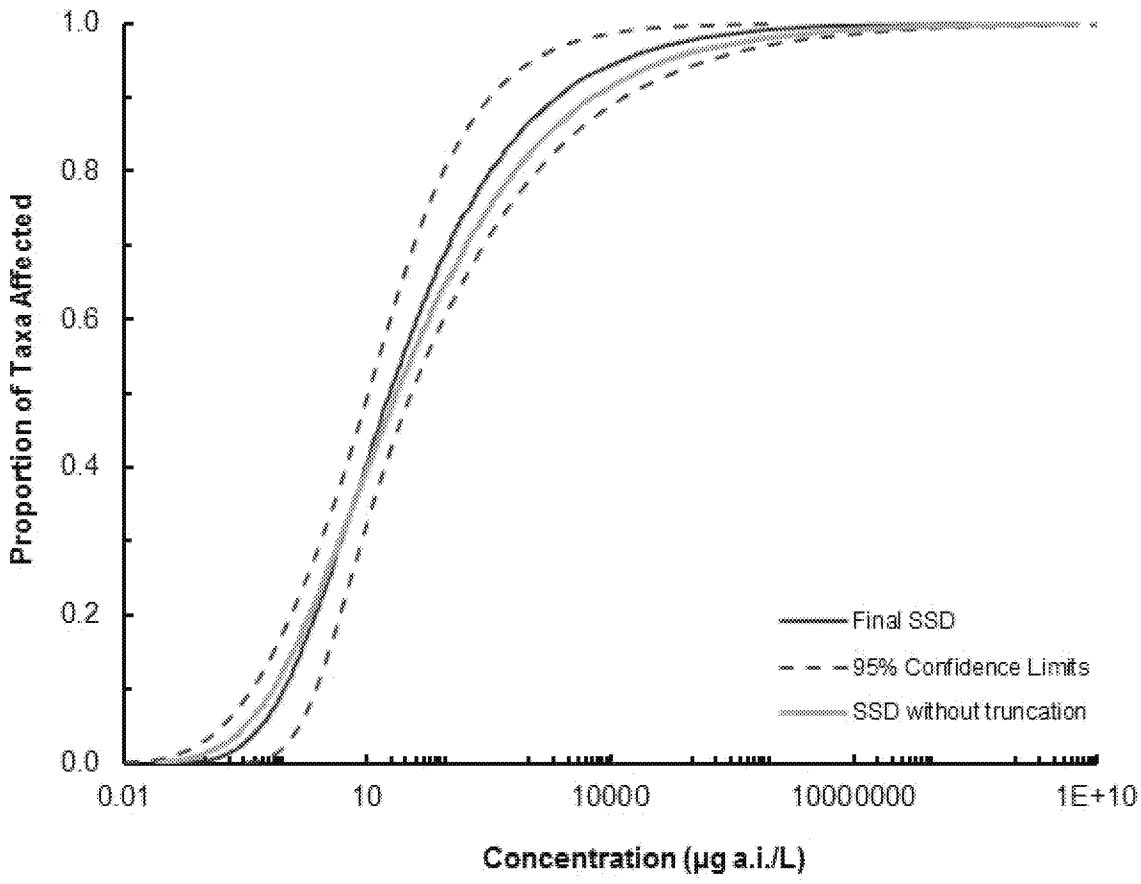


Figure 4-15 Comparison of acute aquatic invertebrate SSDs. The final SSD used in the refined effects determination and 95% confidence limits are compared to an SSD that included all acceptable data without any truncation

To determine the effect of the choice of SSD to the final risk conclusions, risk curves were run using both aquatic invertebrate SSDs. In all cases, acute risk to aquatic invertebrates ranged from *de minimis* to low. Chronic risk was categorized as intermediate for Reach 210 in addition to Reach 209 when using the SSD without truncation, but was *de minimis* or low for all other reaches. However, as shown in Figure 4-7, there is limited overlap between reaches 209 and 210 and DS critical habitat. As such, the choice of aquatic invertebrate SSD had no impact on the findings of this assessment.

Although model fit was excellent for the acute aquatic invertebrate SSD, uncertainty could be reduced further by conducting acute GLP toxicity tests on additional aquatic invertebrate species consumed as prey by DS (e.g., copepods). In their Draft Biological Evaluation of malathion, EPA developed an aquatic invertebrate SSD that included endpoints for 60 freshwater and 11 estuarine/marine invertebrate species (EPA, 2016a). As shown in Table 4-13, the HC5 values derived by Cheminova and EPA (2016a) were very similar. However, Cheminova's SSD was more conservative than EPA's at the HC10 level and above. As a result, using Cheminova's SSD produces more conservative risk estimates than using EPA's SSD.

Table 4-13 Comparison of Cheminova and EPA SSDs for aquatic invertebrates

Percentile	*Cheminova HCx values (µg/L)*	*EPA HCx values (µg/L)*
5	0.476	0.386
10	0.923	1.18
50	19.0	137.2
90	2175	15846
95	13321	48822

Chronic

The chronic SSD was derived by shifting the acute SSDs by an acute-to-chronic ratio (ACR). As described in Section 4.1.2, the chronic SSD for aquatic invertebrates relied on a ACRs calculated for *Daphnia magna* and *Americamysis bahia*, which are the most sensitive freshwater and estuarine/marine invertebrate species, respectively. EPA's Office of Pesticide Programs' (OPP) and Office of Water's (OW) considerations for developing ACRs are described in Hoff et al. (2010) and summarized below:

Office of Pesticide Programs

- Acute and chronic data used to derive ACRs must be from scientifically valid guideline or open literature studies classified as "acceptable", "supplemental" or "quantitative".
- When possible, acute and chronic toxicity data from the same species should be used to derive ACRs.
- When possible, acute and chronic toxicity values should be from studies conducted under similar test conditions (e.g. flow, dilutional water quality, temperature, hardness, etc.). If differences in test conditions between two studies could affect the bioavailability/toxicity of a pesticide, data from these studies should not be used to derive an ACR.

- Mollusk shell deposition data is not recommended for deriving ACRs.
- Acute toxicity data expressed as a ">" value should not be used to derive an ACR.
- ACRs below 1 should not be used. This may occur when acute and chronic data are (1) from studies conducted with different species, (2) from studies that used different forms of the pesticide (e.g., technical vs. formulated products), or (3) from studies that used different protocols or test conditions.
- The mode of action of the pesticide should be considered before applying an ACR from one species to another within the same broad taxonomic group.

Office of Water

- Chronic data used to derive ACRs must be from acceptable studies, as specified in Stephan et al. (1985).
- Acute and chronic data derived as part of the same study are preferred for calculating ACRs. If unavailable, acute and chronic studies conducted in the same laboratory or studies conducted in different laboratories but with similar test conditions are acceptable.
- Water quality characteristics known to be related to toxicity (e.g. dissolved organic carbon > 5 mg/L, hardness, pH) should be accounted for.
- Chronic toxicity data must be from flow-through toxicity tests (or static renewal for daphnids) and appropriate endpoints and exposure durations for the species should be used, as specified in the Stephan et al. (1985; summarized for Cladocerans and Mysids in Table 4-14).
- Control groups must have acceptable survival, growth and reproduction.
- Acute and chronic data must be from the same species to generate an ACR.

Table 4-14 Acceptable chronic toxicity tests (Stephan et al., 1985).

Species	*Chronic Toxicity Test Characteristics*
Cladocerans	Life cycle toxicity test >=2 test concentrations organisms <24 h old 21-day exposure endpoints: survival, young/female
Mysid	Life cycle toxicity test >=2 test concentrations organisms <24 h old exposure until 7 d past median time of first brood release in controls endpoints: survival, growth and young per female

The *Daphnia magna* and *Americamysis bahia* ACRs were evaluated against the OPP and OW best practices from Hoff et al. (2010). As shown in Table 4-15, the ACRs derived for both species were in accordance with EPA's recommendations. Furthermore, the chronic toxicity tests used to derive the ACRs (Blakemore and Burgess, 1990 [MRID 41718401]; Claude et al., 2012 [MRID 48752901]) also met the Stephan et al. (1985) requirements for chronic toxicity tests. Thus, although there is uncertainty associated with the use of an ACR in predicting the chronic toxicity of malathion to aquatic invertebrates, the high quality of the data used to derive the ACR reduces the level of uncertainty.

Table 4-15 Evaluation of aquatic invertebrate ACRs according to EPA best practices (Hoff et al., 2010).		
EPA Best Practices	***Daphnia magna***	***Americamysis bahia***
Validity of toxicity studies	Gries and Purghart (2001a [MRID 47540303]) was rated acceptable and Blakemore and Burgess, (1990 [MRID 41718401]) was rated supplemental based on Cheminova's study evaluation criteria (Breton et al., 2014 [MRID 49333901]).	Brougher et al. (2014i [MRID 49389401]) and Claude et al. (2012 [MRID 48752901]) were both rated acceptable based on Cheminova's study evaluation criteria (Breton et al., 2014 [MRID 49333901]).
Acute and chronic toxicity data from the same species? (Y/N)	Y	Y
Acute and chronic data obtained from: (1) same study, (2) different studies conducted by same laboratory using same dilution water, or (3) different studies with similar test conditions?	(3) different studies with similar test conditions	(2) same laboratory, same dilution water
Unusual test conditions or significant difference in test conditions between studies? (Y/N)	N	N
Chronic toxicity study conducted under flow-through or static-renewal conditions?	Flow-through	Flow-through
Acceptable endpoints and exposure durations used in acute and chronic studies?	Acute: 48-h EC50 (immobilization) = 0.7 µg a.i./L Chronic: 21-day EC10 (number of young) = 0.0881 µg a.i./L	Acute: 48-h LC50 = 7.8 µg a.i./L Chronic: 39-day EC10 (number of young) = 0.266 µg a.i./L
Mollusk shell deposition data used in ACR calculation? (Y/N)	N	N
Acute ">" values used in ACR calculation? (Y/N)	N	N
Resulting ACR <1? (Y/N)	N	N
Pesticide mode of action generally applicable aquatic invertebrates? (Y/N)	Y (acetylcholinesterase inhibition)	Y (acetylcholinesterase inhibition)

4.4.2 Exposure Assessment

The SWAT model was selected for simulating the hydrology and pesticide transport processes in the California Delta watershed. There are several sources of uncertainty associated with the modeling that are described below.

- Agronomic practices throughout the entire CA Central Valley were estimated based upon local agricultural extension publications and personal contacts. While the practices were representative of typical operations, actual practices are likely to vary from farm to farm. This variability in practices may have some impact in malathion pesticide transport processes, primarily at the local level.
- The malathion use information, including application amounts and timing for each crop, was based upon a sampling of five recent years (2006 – 2010) and aggregated at the subbasin level. Assumptions were that applications were made at the maximum

application rate and minimum retreatment interval. The actual practices, particularly the retreatment interval, may differ from the worst case assumptions made in this modeling.

- A new approach to modeling spray drift within the SWAT model was developed for this application. The approach accounts for the spatial relationship between HRUs and receiving waters within each subbasin. While this is a spatially realistic and rigorous approach to estimating spray drift at the watershed scale, there remain significant uncertainties in quantifying spray drift contributions. This modeling application assumed that applications were always made with a 10 mph wind blowing in the direction from the treated area to a receiving water body. This is a very conservative assumption. In addition, barriers to drift, such as buildings, other infrastructure, or vegetation, were not accounted for in the drift calculations. This also represents a conservative assumption.
- The effects of tidal action within some water bodies within the critical habitat were not directly accounted for. The SWAT model does not simulate tidal mixing. All modeled flows within the Delta represent net outflow independent of tidal phase. We consider this assumption conservative for the purposes of pesticide exposure predictions because the mixing with tidal ocean waters would have both diluting and dissipating effects on pesticide concentrations in the Delta: dilution with the influx of water at high tide, flushing with the ebb tide.
- The DS SWAT model was calibrated with flow data from 13 long term flow stations. While this represents a substantial sampling of flow conditions throughout the study area, data for some types of water bodies, such as small headwater drainages within the Central Valley, were not available for calibration. Therefore, flows in these portions of the model have greater uncertainty than the larger rivers and tributaries.
- The engineered water system within the California Central Valley is very complex. The DS SWAT model accounts for many of the major transfers, diversions, and flood control structures, but cannot account for all of them. The uncertainties in the water movement and transfers throughout the Central Valley have the greatest impact on the smaller drainages within the Central Valley, and less so on the larger streams and rivers near the Delta.
- The SWAT model is a complex, process-based model of the hydrologic, biological, and chemical processes within a watershed. Although SWAT is one of the most widely used, peer-reviewed watershed models of the past decade, it is not a perfect representation of the natural system. Model structural uncertainty is difficult to quantify in terms of the impacts on the model predictions. However, the SWAT modeling approach represents a significant improvement over the PRZM/EXAMS approach to modeling aquatic EECs because it captures the appropriate hydrology and the actual malathion use patterns that are relevant to estimating potential exposure of the DS to malathion. Ultimately, models such as SWAT represent one of the best tools for understanding environmental quality in systems where limited or no monitoring data are available (Santhi et al., 2006; McCutcheon, 1989).

4.4.3 Risk Characterization

4.4.3.1 Field Studies

In the aquatic field studies summarized in Section 4.3.3.1, the malathion use patterns ranged from a single application of 0.051 lb/A (Tagatz et al., 1974) to multiple applications (9-15) of 1 lb/A with a five to eight day retreatment interval (Kuhajda et al., 1996 [MRID 47587601]). However, there are a number of agricultural use patterns of malathion registered in the US with higher seasonal application rates and/or shorter retreatment intervals (e.g., nectarine, guava and papaya; Appendix A). Although the use patterns examined in Kuhajda et al., 1996 [MRID 47587601] are similar to some worst-case scenarios on malathion labels, the authors identified several limitations of their study. Multiple chemicals were applied to the study area prior to and over the course of the study; malathion applications were made to a nearby cotton field the day of pre-spray invertebrate sample collection and the day before pre-spray fish sample collection; only one sample was collected at each sampling location before malathion applications, which provided little information regarding pre-spray biological variation within the study area; and moderate differences in stream characteristics existed between the control location and spray/downstream locations (Kuhajda et al., 1996 [MRID 47587601]). Many of these limitations would have resulted in overstating the risks attributed to malathion exposure. Furthermore, the study authors state that the reported results "cannot be directly extrapolated to any other concentrations, application methods, or duration of exposure of aquatic communities to this substance" (Kuhajda et al., 1996 [MRID 47587601]).

Jensen et al. (1999) and Tagatz et al. (1974) examined the effects of aquatic invertebrate communities following malathion applications for mosquito control. However, these uses are not within the scope of the current assessment and the rates of malathion applied in these studies, either in units L/min or at low applications of 0.051 lb/A, make it difficult to use the results of these studies to characterize the risk of other malathion uses to aquatic communities. Most studies reported peak surface water concentrations of malathion following applications that could be compared to modeled exposure estimates for other uses, but this information was not provided by Crane et al. (1995) or for the tracer plot studies in Giles (1970 [MRID 00058820]). The application rate of 0.81 kg/ha reported by Giles (1970 [MRID 00058820]) may also have been erroneous, as this application rate was also reported as 2 lb/A in parentheses. Furthermore this study applied malathion directly to a forested watershed, which is not a labeled use of malathion. Studies were fifteen to 45 years old and may not have used currently registered products or accepted agricultural practices. Based on these factors, studies could potentially be overstating the risks of current malathion products and use patterns. Cheminova's confidential statement of formula was submitted by Cheminova in 1992 based on a highly refined manufacturing process that produces technical malathion with higher active ingredient content and reduces impurity content compared to previous manufacturers (Hillwalker and Reiss, 2014 [MRID 49316501]). Thus, the field studies conducted prior to 1992 likely used malathion products containing higher impurity levels, making the relevance of the data suspect. As such, there are a number of uncertainties associated with the results of the aquatic field studies in terms of their relevance to current label uses of malathion.

4.4.3.2 Mesocosm Studies

Laboratory studies are often performed under static conditions using a single species and are designed to reduce confounding interactions in order to provide a better link between exposure and effect. However, laboratory-based single species tests do not consider the interactions between species and do not include realistic environmental conditions that allow for interactions of abiotic and biotic factors. Conversely, higher tier studies, such as field and mesocosm studies, are designed to more closely resemble natural conditions and likely exposure scenarios for registered use patterns, and can bridge the gap between controlled laboratory studies and the natural environment. They can help elucidate the ecological relevance of effects identified in laboratory studies, including community- and ecosystem-level effects, potential indirect effects, and the potential for recovery. Higher tier studies may include varying exposure concentrations over time due to single or multiple applications, varying application intervals, temporal decline following application, natural weather conditions, and community interactions, as expected in the natural environment.

By extending the observation period beyond the final application or exposure event, higher tier studies are also able to determine the potential recovery of the aquatic community. Recovery is an important process by which sensitive species are able to persist in an environment following exposure to stressors. Recovery may occur if the toxic substance disappears and/or its biological availability decreases below the critical threshold for the exposed community, other relevant test conditions (e.g., food supply, nutrients, temperature) meet the needs of aquatic invertebrates, the generation times of affected species are shorter than the study duration, and/or recolonization from outside the test system is possible. A recovery period of 8 weeks is often used as the maximum allowable time to determine whether the test system could effectively rebound following exposure (Brock et al., 2000; De Jong et al., 2008). However, the duration of an ecologically-relevant recovery period depends upon the ecosystem, population and taxonomic group involved, and is a risk management decision unique to each test system (De Jong et al., 2008).

A number of aquatic mesocosms studies conducted within the past fifteen years were available for malathion. However, only one of the available mesocosm studies was performed under GLP conditions (Ebke, 2002 [MRID 46525901]). The literature studies summarized above often did not report on recovery of aquatic species due to inadequate study duration, sampling, or data analysis (e.g., Relyea, 2005; Relyea, 2009; Hua and Relyea, 2012; Halstead et al., 2014), did not indicate which malathion product was tested (Shrestha et al., 1987; Relyea, 2005; Relyea 2009 [MRID 48261129]; Sweilum, 2006), did not measure malathion concentrations after the initial application (Shrestha et al., Relyea, 2005; Halstead et al., 2014; Brogan and Relyea, 2015; Sweilum, 2006) and used unrealistically high exposure concentrations (i.e., Shrestha et al., 1987; Halstead et al., 2014). The covering of outdoor mesocosms tanks conducted in Hua and Relyea (2014), Halstead et al. (2014) and Groner and Relyea (2011) likely affected the recovery of species in these studies since the introduction of organisms from non-affected areas is an important contributor to recovery. However, such covers are recommended "to prevent disturbance of test systems by large birds such as herons or ducks "(OECD, 2006). Finally,

older studies, such as Shrestha et al. (1987), were likely performed with products and formulations no longer produced and containing higher impurity levels.

As shown in Table 4-16, the majority of studies focused on effects to aquatic invertebrates, aquatic plants and aquatic-phase amphibians. Only Sweilum (2006) and Shrestha et al. (1987) investigated effects to fish, and there were a number of issues with these studies, including missing details regarding the product tested and the use of realistically high exposure concentrations. In addition, the fish species tested included three carp species (silver carp (*Hypophthalmichthys molitrix*), mrigal carp (*Cirrhina mrigala*) and rohu (*Labeo rohita*)) and nile tilapia, which tend to be insensitive to malathion toxicity. Although rated unacceptable by Cheminova's study evaluation criteria (Breton et al., 2014 [MRID 49333901]), acute LC50s for the mrigal carp, rohu and nile tilapia ranged from 2200 to 5397 µg/L (Arora et al., 1971; Pathiratne and George, 1998; Roy and Munshi, 1988; Shao-Nan and De-Fang, 1996; Sreenivasan and Swaminathan, 1967). An acceptable study conducted with the common carp (*Cyprinus carpio*) did not observe any mortalities at concentrations up to 9600 µg a.i./L (Gries and van der Kolk, 2002 [MRID 48998005]), further indicating that carp species are very tolerant to malathion exposures. Because the sensitivity of DS relative to other test species is unknown, the lack of effects to carp observed in Shrestha et al. (1987) and the growth effects of malathion to nile tilapia observed at 500 µg/L (Sweilum, 2006) are not helpful in assessing the likelihood of effects to DS.

Table 4-16 Taxa included in aquatic mesocosm studies

Study	*Aquatic-phase amphibians*	*Fish*	*Aquatic invertebrates*	*Macrophytes*	*Algae*
Ebke, 2002 [MRID 46525901]	N	N	Y	Y	Y
Relyea, 2005	Y	N	Y	N	Y
Sweilum, 2006	N	Y	Y	N	Y
Relyea, 2009	Y	N	Y	N	Y
Groner and Relyea, 2011	Y	N	Y	N	Y
Hua and Relyea, 2012	Y	N	Y	N	Y
Hua and Relyea, 2014	Y	N	Y	N	Y
Halstead et al., 2014	Y	N	Y	Y	Y
Brogan and Relyea, 2015	Y	N	Y	Y	Y
Shrestha et al., 1987	N	Y	Y	N	N

There are varying degrees of uncertainty associated with each of the aquatic mesocosm studies. GLP studies and those that reported sufficient details on the malathion products tested, experimental conditions, and recovery of taxa (i.e., Ebke, 2002 [MRID 46525901]; Hua and Relyea, 2014; Brogan and Relyea, 2015) have the lowest uncertainty, whereas studies that did not report this information have higher uncertainty. Based on the number of mesocosm studies available for aquatic-phase amphibians, aquatic invertebrates and aquatic plants, there is a higher level of certainty associated with the findings for these taxa compared to the findings for fish.

4.4.3.3 Monitoring Data

Monitoring data is an important line of evidence to consider in ecological risk assessments for aquatic biota as it incorporates environmental realism and complexities that cannot be captured in exposure models (e.g., multiple applications that vary over space and time, variable crops, field sizes, slopes, soils, microclimates, receiving environments, etc.) and it can be used to corroborate the effectiveness of past management decisions. Shortcomings of this line of evidence are that it may miss exposure peaks if sampling is not targeted to the times and locations of pesticide applications, and that monitoring data cannot be used to forecast changes in exposure given specific changes to a label.

The OPP recently released guidance on the use of monitoring data in pesticide risk assessments (EPA, 2014a,b). The most important elements required for OPP to use monitoring data in a risk assessment are:

- study objective, including purpose and design of the study;
- location description (latitude and longitude, if possible);
- water body type (stream, river or other flowing body; lake, reservoir, or other static body; groundwater; nature of aquifer, e.g., surficial or confined);
- date sampled;
- sample media (e.g., water, filtered water, bed sediment, tissue);
- chemical analyzed and reported concentration;
- analytical method and detection limit (LOD) or limit of quantitation (LOQ);
- depth to water level for groundwater;
- well characteristics, such as well depth, screened interval, and aquifer type if known (e.g., confined vs. unconfined); and
- well purpose (e.g., ambient vs. drinking water).

In addition, the following points should be considered in the interpretation of available monitoring data:

- Quality assurance (QA)/quality control (QC) for sample collection and analytical methods, including a discussion of any limitations of the data
- Time of sample [e.g., date, time; duration (if a composite), timing to stream hydrograph (if flow-weighted sample)]. Were samples collected at a time when runoff/spray drift were likely?
- Sample collection method (e.g., grab or composite)
- Time frame and duration of monitoring sampling. Were samples collected frequently enough to estimate the desired duration of exposure (acute vs. chronic)? Land use, including cropping pattern, agriculture/urban, etc. preferably in immediate vicinity of sample site though general information on specific pesticide use sites would be useful. Were samples collected from sites where the pesticide was used (agricultural areas), sites receiving surface water runoff via storm water conveyances (urban areas), or is there a pathway between the use site and the aquifer sampled (groundwater)?

- Pesticide usage that could affect water quality at sampling location
- How does runoff, leaching vulnerability at the sampling sites compare to the overall pesticide use area?
- Was the water body sampled relevant to the habitats of concern in the assessment?
- Did the sampling methodology and analytical methods go through a formal QA process? If so, is this process documented (e.g., in a report or on a website address)?
- For pesticides that adsorb to sediments: percent organic carbon, bulk density, etc.
- For some chemicals, environmental conditions (e.g., temperature, pH, hardness, turbidity) may affect mobility and persistence. If this is known to occur, information on the parameter would be helpful in interpreting the data. What were the rainfall patterns before, during and after the pesticide application?

OPP is most likely to use monitoring data quantitatively in a risk assessment (1) if sampling is frequent enough to adequately estimate exposures for the endpoints of concern, (2) if sampling occurs in areas and at a time where pesticides are expected to be used, and (3) if monitoring sites reflect areas that have a likelihood of pesticide occurrence based on pesticide use, local runoff or leaching vulnerability (EPA, 2014b). Monitoring data that has information for some but not all of the elements presented above may still be useful in providing a lower bound of exposure or for qualitative comparisons to model results. EPA (2014b) has stated that monitoring data lacking study objectives, context on where samples were taken, analytical methods, and LODs can be described but should not be used as quantitative or qualitative measures of exposure.

To identify the highest quality sources included in the analysis of monitoring data, each source was evaluated based on the most important elements identified by OPP (Table 4-17 and Table 4-18). OPP's list of important data elements was modified slightly to include analytical method and LOD/LOQ as separate elements. For surface water monitoring data sources, the depth to well surface, well characteristics and well purpose elements were not considered.

Table 4-17 Evaluation of groundwater monitoring data sources using most important elements specified by OPP (EPA, 2014a).

Element	*USDA PDP*	*USGS NAWQA*	*USGS NWIS*
Study objective	Y	Y	Y
Location description	Y	Y	Y
Water body type	Y	Y	Y
Date sampled	Y	Y	Y
Sample media	Y	Y	Y
Chemical analyzed and reported concentration	Y	Y	Y
Analytical method	Y	N	N
LOD/LOQ	Y	Y/N[a]	Y/N[a]
Depth to water level	N	Y	Y
Well characteristics	N	Y	Y
Well purpose	N	Y	N
Total	**8/11**	**9.5/11**	**8.5/11**

Shaded rows indicate OPP's minimum requirements for qualitative use in an assessment.

[a] LOD only reported for non-detects.

Table 4-18 Evaluation of surface water monitoring data sources using most important elements specified by OPP (EPA, 2014a).

Element	*EPA STORET*	*USDA PDP*	*USGS NAWQA*	*USGS NWIS*	*CDPR SWD*	*CEDEN*
Study objective	Y[a]	Y	Y	Y	Y[a]	N
Location description	Y	Y	Y	Y	Y	Y
Water body type	N	N[b]	Y[c]	Y	Y	Y
Date sampled	Y	Y	Y	Y	Y	Y
Sample media	Y	Y	Y	Y	Y	Y
Chemical analyzed and reported concentration	Y	Y	Y	Y	Y	Y
Analytical method	Y[c]	Y	N	N	Y/N[d]	Y
LOD/LOQ	N	Y	Y/N[e]	Y/N[e]	Y	Y
Total	**6/8**	**7/8**	**6.5/8**	**6.5/8**	**7.5/8**	**7/8**

Shaded rows indicate OPP's minimum requirements for qualitative use in an assessment.

[a] Available from metadata.

[b] Location description sometimes indicates sampled water body was sampled.

[c] Database includes this information, however it is not reported for the majority of samples.

[d] CDPR study reports include the analytical methods used.

[e] LOD only reported for non-detects.

Only the USDA PDP reported the minimum data requirements for use in a qualitative assessment (i.e., study objective, sampling location, analytical method and LOD/LOQ). However, the majority of water quality sources surveyed in this assessment reported at least three of the four requirements. Study objectives and analytical methods were not always included within the database, but would most likely be available from the original monitoring study reports. Furthermore, a description of the QA procedures was available for all data sources.

In general, monitoring programs focus on areas where chemical contaminants are likely to be present, and focus temporally on when the contamination is likely to occur. The spatial extent of the data also captures the variability in environmental factors (e.g., low/high precipitation years) that may have an impact on chemical concentrations in the monitored water bodies. Since older monitoring data may not reflect changes in application rates and use restrictions (i.e., label changes) that currently impact malathion use, only data from water samples collected in 2001 or later were included in the monitoring data analyses. The monitoring programs summarized meet nearly all of OPP's minimum requirements for qualitative use in an ecological risk assessment and the majority of the data presented have undergone some form of QA. Therefore, we have high confidence that the monitoring data represent reasonable surrogates for use in exposure characterization and for comparison to modeled exposure estimates.

4.4.3.4 Incident Reports

Incident reports have a large degree of uncertainty associated with them. Tissue testing is not often performed, and exact cause of death is rarely established. Incident reports often present findings involving multiple pesticides, making the contribution of the individual pesticides to the reported effects uncertain. The majority of incidents reported for malathion have low certainty associated with them, were due to misuse or are not representative of current labels. Thus, incident reports are not a very reliable source of information in the risk characterization process.

4.5 Weight of Evidence Risk Characterization

The screening-level effects determination indicated that DS and their aquatic invertebrate prey were potentially at risk from acute malathion exposures. In addition, aquatic invertebrates were also potentially at risk from chronic malathion exposures. In the refined effects determination, acute risk to DS was categorized as *de minimis* for the ten worst-case reaches of the DS SWAT model. Acute and chronic risk to aquatic invertebrate communities was categorized as *de minimis* to low for all but one of the worst-case SWAT scenarios (reach 209), where chronic risk was categorized as intermediate. However, the chronic AUC for this reach (10.7%) just barely exceeded the low-intermediate risk boundary of 9.82%. Furthermore, there is little overlap between this reach and DS critical habitat.

Chronic effects of malathion to aquatic species are highly unlikely because malathion degrades almost instantly in aquatic environments, particularly in marine environments. Claude et al. (2012 [MRID 48752901]) had difficulty maintaining malathion concentrations in a flow-through

life cycle test for the mysid. Mean measured concentrations ranged from 70.2 to 80% of nominal. Palmer et al. (2011a,b [MRID 48617501, 48617506]) also reported measured concentrations ranging from 75 to 85% and 70 to 88% in chronic freshwater studies for the African clawed frog and fathead minnow, respectively. An investigation of malathion concentrations in chronic life cycle tests supports this phenomenon. Rhodes and Leak (1997) investigated the decline of malathion concentrations in a flow through system during a chronic life-cycle test on fathead minnows (*Pimephales promelas*). The study was developed because in a past flow-through experiment, measured concentrations of malathion fell well below nominal concentrations after approximately three weeks of exposure (Rhodes and Leak, 1997). Multiple attempts were made to determine the cause of malathion decline in these chronic experiments: maintenance of neutral pH, increased flow rate, and increased tank cleaning regimen. It was hypothesized that all of these factors could have led to increased malathion degradation and dissipation within the tanks. All attempts were unsuccessful at maintaining malathion concentration over the entire study (156 days). Rhodes and Leak (1997) concluded that the disappearance of malathion in the chronic study is consistent with results seen in environmental fate studies for malathion. Estimated half-lives for malathion in GLP studies testing aerobic aquatic systems range from 0.3 to 3.3 days (Blumhorst, 1991a [MRID 42271601]; Knoch, 2001 [MRID 46769502]; Hiler and Mannella, 2012 [MRID 48906401]). The use of extended malathion exposures over several weeks to months in chronic toxicity tests is inconsistent with exposure in the environment. Exposures are expected to peak with applications, and quickly dissipate in the environment within a matter of days. In a worst-case scenario, receptors may be exposed to pulse exposures when multiple applications are allowed during the growing season. But even under these conditions, receptors can metabolize and recover from malathion exposures (See Sections 2.4.5 and 4.3.3).

The results of aquatic field and mesocosm studies supported those of the screening-level assessment, in that malathion exposure (at concentrations ranging from 0.6 to 8500 µg/L) was rarely associated with adverse effects to aquatic-phase amphibians, fish and aquatic plants. No treatment-related effects to aquatic invertebrate communities were reported by Jensen et al. (1999), Kuhajda et al. (1996 [MRID 47547601]), or Tagatz et al. (1974), who measured peak malathion concentrations ranging from 0.34 to 31.1 µg/L. Effects on cladocerans, the most sensitive aquatic invertebrate taxon tested, were observed following acute exposures ≥5.8 µg/L (Ebke, 2002 [MRID 46525901]; Relyea, 2005, 2009 [MRID 48261129]; Hua and Relyea, 2012, 2014; Halstead et al., 2014; Brogan and Relyea, 2015; Shrestha et al., 1987). In addition, weekly pulse exposures of 3.1 µg/L malathion had effects on cladoceran populations after 21 days of exposure (Groner and Relyea, 2011). However, cladoceran abundance recovered from single exposures of 10 µg/L and 30 µg/L within two and four weeks, respectively (Ebke, 2002 [MRID 46525901]) and from single exposures of 40 µg/L within seven weeks of when effects were originally observed (Hua and Relyea, 2014). Brogan and Relyea (2015) also observed recovery of cladoceran density from pulse exposures of 18 and 36 µg/L within three weeks. In addition, other aquatic invertebrate taxa (e.g., copepods, rotifers, snails, amphipods, isopods, and insects) were considerably less sensitive to malathion. Reductions in copepod, amphipod and insect abundance were only observed in response to malathion exposures ≥40 µg/L (Relyea, 2005; Groner and Relyea, 2011; Hua and Relyea, 2014; Shrestha et al., 1987).

Copepod populations exposed to 40, 500 and 750 µg/L malathion recovered within two weeks of the original effects being observed (Hua and Relyea, 2014; Shrestha et al., 1987). The 90th percentile peak and 21-day EECs predicted from the DS SWAT model were all below the lowest concentration at which effects to cladoceran abundance were observed in mesocosm studies with single pulse and repeated pulse exposures, respectively (5.8 and 3.1 µg/L; Relyea, 2009; Groner and Relyea, 2011). Furthermore, the maximum peak EECs predicted by SWAT modeling for all but one reach (reach 203) were below 30 µg/L, the concentration at which Ebke (2002 [MRID 46525901]) observed recovery of cladoceran populations within four weeks. Measured malathion concentrations in California surface water samples collected between 2001 and 2015 were also below 30 µg/L. Thus, malathion exposures would rarely be associated with effects to aquatic invertebrate communities. However, in those rare instances when effects do occur, recovery of aquatic invertebrate populations would be expected.

The surface water monitoring results of malathion also support the findings of the refined aquatic risk assessment. California monitoring data for 2001 to 2015 was collected from six programs that reported malathion concentrations for 87 to 8317 surface water samples. Reported concentrations of malathion in California surface water ranged from 0.0013 to 22.5 µg/L. However, malathion concentrations within DS critical habitat were estimated to be below 0.1 µg/L at all but one site, where malathion concentrations were below the LOQ of 0.5 µg/L. Furthermore, Kuivila and Moon (2004) targeted surface water monitoring to the areas and times at which early life stages of DS are observed did not detect malathion (LOD = 0.015 and 0.017 µg/L) in any samples collected between 1998 and 2000. These results indicate that SWAT modeling of malathion exposures within DS critical habitat was sufficiently conservative.

The majority of malathion incidents reported by the EIIS (29 of 31) and BWEP (18 of 18) reported adverse effects on fish. Two incidents occurring in 1979 and 1981 reported effects to aquatic invertebrates (*Decapoda* and *Callinectes sapidus*), and two other incidents occurring in 1988 and 2003 reported effects to reptiles (*Alligator mississipiensis*, *Testudines*, and unknown snake). In all cases reported in the EIIS, the incident either resulted from misuse or unknown use of malathion. Only two aquatic incidents have been reported in the EIIS since 2000, and both were associated with misuse of malathion (Appendix J). Malathion concentrations of 0.12 to 29 µg/L were measured in ponds following applications to nearby cotton fields as part of the BWEP. There was only one incident where malathion was detected at concentrations high enough to cause the observed fish mortalities, and two incidents where malathion exposure or other factors (e.g., low oxygen levels and exposure to other chemicals) could have resulted in the observed mortalities. Nearly all fish kill incidents reported in the BWEP were observed in static ponds on homeowner properties, and are not representative of DS habitat. Although incident reports represent a weak line of evidence because not all effects to wildlife are reported and there is often insufficient information provided to determine whether malathion was the cause of the observed effects, the lack of recent incidents reported in the EIIS and the few malathion-related incidents for the BWEP suggest that the current malathion labels are protective of aquatic biota.

5.0 FINAL CONCLUSION OF THE DS EFFECTS DETERMINATION

Considering all lines of evidence, malathion use under the current label is not expected to cause direct effects to DS. Screening-level modeling eliminated the potential for chronic risk to DS, and using a SWAT model that predicted malathion concentrations throughout the Sacramento and San Joaquin rivers, eastern tributaries, and many of the more minor streams and sloughs of the Delta, acute risk was categorized as *de minimis* for DS exposed to malathion. Furthermore, based on the results of SWAT modeling, monitoring data analyses and mesocosm studies discussed above, malathion uses would rarely be associated with acute and chronic effects to the aquatic invertebrate prey of DS, and in the instances where adverse effects are observed, recovery is expected to occur once exposures have ceased.

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Appendix A
Malathion Use Patterns and Exposure Scenarios

Table A-1 Use patterns and PRZM/EXAMS exposure scenarios for non-ULV uses of malathion						
Crop	***PRZM Scenario***	***State***	***PRZM Category[a]***	***Application Method***	***Model Run Dates***	***Max. App. Rate (lb ai/A)/ No. App. per Season/ Retreatment Interval (d)***
Agricultural Uses						
Alfalfa, Clover, Lespedeza, Trefoil, Vetch	Alfalfa	CA	OP	Groundspray	January 16 – December 31	1.25/6/14-16
Alfalfa, Clover, Lespedeza, Trefoil, Vetch	Alfalfa	CA	OP	Aerial	January 16 – December 31	1.25/6/14-16
Apricot	Fruit	CA	std	Groundspray	May 1 – June 30	1.5/2/7
Apricot	Fruit	CA	std	Airblast	May 1 – June 30	1.5/2/7
Apricot	Fruit	CA	std	Aerial	January 16 – August 1	1.5/2/7
Asparagus, Carrots	Row Crop	CA	rlf	Groundspray	March 1 – April 8	1.25/2/7
Asparagus, Carrots	Row Crop	CA	rlf	Aerial	March 1 – April 8	1.25/2/7
Avocado	Avocado	CA	rlf	Groundspray	January 1 – December 31	4.7/2/30
Avocado	Avocado	CA	rlf	Airblast	January 1 – December 31	4.7/2/30
Barley	Wheat	CA	rlf	Groundspray	March 1 – June 15	1.25/2/7
Barley	Wheat	CA	rlf	Aerial	March 1 – June 15	1.25/2/7
Beet	Row Crop	CA	rlf	Groundspray	January 1 – April 8	1.25/3/7
Beet	Row Crop	CA	rlf	Aerial	January 1 – April 8	1.25/3/7
Blueberries	Wine Grapes	CA	rlf	Groundspray	May 1 – August 1	1.25/3/5
Blueberries	Wine Grapes	CA	rlf	Aerial	March 1 – August 1	1.25/3/5
Broccoli, Chinese broccoli, Broccoli raab, Cauliflower	Cole	CA	rlf	Groundspray	January 1 – March 1	1.25/2/7
Broccoli, Chinese broccoli, Broccoli raab, Cauliflower	Cole	CA	rlf	Aerial	January 1 – March 1	1.25/2/7
Brussels sprouts, Dandelion	Lettuce	CA	std	Groundspray	February 16 – May 12	1.25/2/7
Brussels sprouts, Dandelion	Lettuce	CA	std	Aerial	February 16 – May 12	1.25/2/7
Cabbage, Horseradish, Kohlrabi	Cole	CA	rlf	Groundspray	January 1 – March 1	1.25/6/7
Cabbage, Horseradish, Kohlrabi	Cole	CA	rlf	Aerial	January 1 – March 1	1.25/6/7
Caneberries (Gooseberry, Blackberry, Boysenberry, Dewberry, Loganberry, Raspberry, Currant)	Wine Grapes	CA	rlf	Groundspray	March 1 – August 1	2/3/7

Table A-1 Use patterns and PRZM/EXAMS exposure scenarios for non-ULV uses of malathion						
Crop	*PRZM Scenario*	*State*	*PRZM Category[a]*	*Application Method*	*Model Run Dates*	*Max. App. Rate (lb ai/A)/ No. App. per Season/ Retreatment Interval (d)*
Caneberries (Gooseberry, Blackberry, Boysenberry, Dewberry, Loganberry, Raspberry, Currant)	Wine Grapes	CA	rlf	Airblast	March 1 – August 1	2/3/7
Caneberries (Gooseberry, Blackberry, Boysenberry, Dewberry, Loganberry, Raspberry, Currant)	Wine Grapes	CA	rlf	Aerial	March 1 – August 1	2/3/7
Celery	Row Crop	CA	rlf	Groundspray	January 1 – April 8	1.5/2/7
Celery	Row Crop	CA	rlf	Aerial	January 1 – April 8	1.5/2/7
Cherry	Fruit	CA	std	Groundspray	February 1 – August 1	1.75/4/3
Cherry	Fruit	CA	std	Airblast	February 1 – August 1	1.75/4/3
Cherry	Fruit	CA	std	Aerial	February 1 – August 1	1.75/4/3
Chinese greens (Chinese cabbage)	Row Crop	CA	rlf	Groundspray	January 1 – April 8	1.25/2/7
Chinese greens (Chinese cabbage)	Row Crop	CA	rlf	Aerial	January 1 – April 8	1.25/2/7
Citrus, Grapefruit, Lemon, Lime, Orange, Tangelo, Tangerine	Citrus	CA	std	Groundspray	January 1 – December 31	1.5/3/30
Citrus, Grapefruit, Lemon, Lime, Orange, Tangelo, Tangerine	Citrus	CA	std	Airblast	January 1 – December 31	1.5/3/30
Citrus, Grapefruit, Lemon, Lime, Orange, Tangelo, Tangerine	Citrus	CA	std	Aerial	January 1 – December 31	1.5/3/30
Citrus, Grapefruit, Lemon, Lime, Orange, Tangelo, Tangerine, Kumquat	Citrus	CA	std	Airblast	January 1 – December 31	7.5/1/-
Collards	Cole	CA	rlf	Groundspray	January 1 – March 1	1.0/3/7
Collards	Cole	CA	rlf	Aerial	January 1 – March 1	1.0/3/7
Corn (Field)	Corn	CA	OP	Groundspray	April 1 – September 8	1/2/7
Corn (Field)	Corn	CA	OP	Aerial	April 1 – September 8	1/2/7
Corn (Sweet and Pop)	Corn	CA	OP	Groundspray	April 1 – September 8	1/2/5
Corn (Sweet and Pop)	Corn	CA	OP	Aerial	April 1 – September 8	1/2/5

Table A-1 Use patterns and PRZM/EXAMS exposure scenarios for non-ULV uses of malathion

Crop	*PRZM Scenario*	*State*	*PRZM Category*[a]	*Application Method*	*Model Run Dates*	*Max. App. Rate (lb ai/A)/ No. App. per Season/ Retreatment Interval (d)*
Cotton	Cotton w/irrigation	CA	std	Groundspray	May 1 – November 11	2.5/3/7
Cotton	Cotton w/irrigation	CA	std	Aerial	May 1 – November 11	2.5/3/7
Cotton	Cotton	CA	std	Groundspray	May 5 – November 11	2.5/3/7
Cotton	Cotton	CA	std	Aerial	May 5 – November 11	2.5/3/7
Cucumber, Chayote fruit	Melon	CA	rlf	Groundspray	May 16 – August 2	1.75/2/7
Cucumber, Chayote fruit	Melon	CA	rlf	Aerial	May 16 – August 2	1.75/2/7
Eggplant (4 apps), Oriental eggplant (5 apps)	Tomato	CA	std	Groundspray	May 1 – September 1	1.56/5/5
Eggplant (4 apps), Oriental eggplant (5 apps)	Tomato	CA	std	Aerial	May 1 – September 1	1.56/5/5
Figs	Fruit	CA	std	Groundspray	March 1 – August 1	2.0/2/5
Figs	Fruit	CA	std	Airblast	March 1 – August 1	2.0/2/5
Figs	Fruit	CA	std	Aerial	January 16 – August 1	2.0/2/5
Flax	Cotton with irrigation	CA	std	Groundspray	May 1 – November 11	0.5/3/7
Flax	Cotton with irrigation	CA	std	Aerial	May 1 – November 11	0.5/3/7
Garlic	Garlic	CA	rlf	Groundspray	April 1 – July 30	1.56/3/7
Garlic	Garlic	CA	rlf	Aerial	April 1 – July 30	1.56/3/7
Grapes (Raisin, table, wine)	Grapes	CA	std	Groundspray	April 1 – August 31	1.88/2/14
Grapes (Raisin, table, wine)	Grapes	CA	std	Airblast	April 1 – August 31	1.88/2/14
Grapes (Raisin, table, wine)	Grapes	CA	std	Aerial	February 1 – August 31	1.88/2/14
Grass, Forage, Hay, Pasture, Rangeland	Rangeland hay	CA	rlf	Groundspray	November 1 – December 31; January 1 – May 1	1.25/1/-
Grass, Forage, Hay, Pasture, Rangeland	Rangeland hay	CA	rlf	Aerial	November 1 – December 31; January 1 – May 1	1.25/1/-
Guava	Fruit	CA	std	Groundspray	January 16 – August 1	1.25/13/3
Guava	Fruit	CA	std	Airblast	January 16 – August 1	1.25/13/3
Guava	Fruit	CA	std	Aerial	January 16 – August 1	1.25/13/3
Hops	Hops	OR	std	Groundspray	April 1 – September 1	0.63/3/7
Hops	Hops	OR	std	Aerial	April 1 – September 1	0.63/3/7
Kale, Mustard	Cole	CA	rlf	Groundspray	January 1 – March 1	1.0/3/5

Table A-1 Use patterns and PRZM/EXAMS exposure scenarios for non-ULV uses of malathion

Crop	*PRZM Scenario*	*State*	*PRZM Category*[a]	*Application Method*	*Model Run Dates*	*Max. App. Rate (lb ai/A)/ No. App. per Season/ Retreatment Interval (d)*
Kale, Mustard	Cole	CA	rlf	Aerial	January 1 – March 1	1.0/3/5
Leek	Garlic	CA	rlf	Groundspray	April 1 – July 30	1.56/2/7
Leek	Garlic	CA	rlf	Aerial	April 1 – July 30	1.56/2/7
Lettuce, Endive, Spinach, Swiss chard	Lettuce	CA	std	Groundspray	February 16 – May 12	1.88/2/5
Lettuce, Endive, Spinach, Swiss chard	Lettuce	CA	std	Aerial	February 16 – May 12	1.88/2/5
Macadamia nut	Almonds	CA	std	Groundspray	May 1 – September 13	0.94/6/7
Macadamia nut	Almonds	CA	std	Airblast	May 1 – September 13	0.94/6/7
Macadamia nut	Almonds	CA	std	Aerial	January 16 – September 13	0.94/6/7
Mango	Fruit	CA	std	Groundspray	March 1 – August 1	0.94/10/7
Mango	Fruit	CA	std	Airblast	March 1 – August 1	0.94/10/7
Mango	Fruit	CA	std	Aerial	January 16 – August 1	0.94/10/7
Melon (not Watermelon), Pumpkin, Cantaloupe	Melon	CA	rlf	Groundspray	May 16 – August 2	1.0/2/7
Melon (not Watermelon), Pumpkin, Cantaloupe	Melon	CA	rlf	Aerial	May 16 – August 2	1.0/2/7
Mint	Mint	OR	std	Groundspray	April 15 – August 1	0.94/3/7
Mint	Mint	OR	std	Aerial	April 15 – August 1	0.94/3/7
Nectarine	Fruit	CA	std	Groundspray	March 1 – July 31	3.0/3/7
Nectarine	Fruit	CA	std	Airblast	March 1 – July 31	3.0/3/7
Okra	Tomato	CA	std	Groundspray	June 1 – July 31	1.2/5/7
Okra	Tomato	CA	std	Aerial	June 1 – July 31	1.2/5/7
Onion, Shallot	Onion	CA	std	Groundspray	January 16 – June 15	1.56/2/7
Onion, Shallot	Onion	CA	std	Aerial	January 16 – June 15	1.56/2/7
Papaya	Fruit	CA	std	Groundspray	January 16 – August 1	1.25/8/3
Papaya	Fruit	CA	std	Airblast	January 16 – August 1	1.25/8/3
Papaya	Fruit	CA	std	Aerial	January 16 – August 1	1.25/8/3
Parsley	Lettuce	CA	std	Groundspray	February 16 – May 12	1.5/2/7
Parsley	Lettuce	CA	std	Aerial	February 16 – May 12	1.5/2/7
Passion fruit	Wine Grapes	CA	rlf	Groundspray	March 1 – August 1	1.0/8/7

Table A-1 Use patterns and PRZM/EXAMS exposure scenarios for non-ULV uses of malathion

Crop	*PRZM Scenario*	*State*	*PRZM Category*[a]	*Application Method*	*Model Run Dates*	*Max. App. Rate (lb ai/A)/ No. App. per Season/ Retreatment Interval (d)*
Passion fruit	Wine Grapes	CA	rlf	Aerial	March 1 – August 1	1.0/8/7
Peaches	Fruit	CA	std	Groundspray	January 16 – July 31	3/3/11
Peaches	Fruit	CA	std	Airblast	January 16 – July 31	3/3/11
Peaches	Fruit	CA	std	Aerial	January 16 – July 31	3/3/11
Pear, Apple	Fruit	CA	std	Groundspray	April 1 – August 1	1.25/2/7
Pear, Apple	Fruit	CA	std	Airblast	April 1 – August 1	1.25/2/7
Pear, Apple	Fruit	CA	std	Aerial	January 16 – August 1	1.25/2/7
Peas	Row Crop	CA	rlf	Groundspray	January 1 – April 8	1.0/2/7
Peas	Row Crop	CA	rlf	Aerial	January 1 – April 8	1.0/2/7
Pecans	Almonds	CA	std	Groundspray	May 1 – September 13	2.5/2/7
Pecans	Almonds	CA	std	Airblast	May 1 – September 13	2.5/2/7
Pecans	Almonds	CA	std	Aerial	January 16 – September 13	2.5/2/7
Peppers	Row Crop	CA	rlf	Groundspray	April 1 – April 8	1.56/2/5
Peppers	Row Crop	CA	rlf	Aerial	April 1 – April 8	1.56/2/5
Pineapple	Fruit	CA	std	Groundspray	April 1 – August 1	2.0/3/7
Pineapple	Fruit	CA	std	Aerial	January 16 – August 1	2.0/3/7
Potato, Sweet potato, Yam	Potato	CA	rlf	Groundspray	February 16 – June 15	1.56/2/7
Potato, Sweet potato, Yam	Potato	CA	rlf	Aerial	February 16 – June 15	1.56/2/7
Radish	Onion	CA	std	Groundspray	January 16 – June 15	1.0/3/7
Radish	Onion	CA	std	Aerial	January 16 – June 15	1.0/3/7
Rice, Wild rice[b]	PFAM - 2.2 day water half-life	AR	—	Direct	May 11 – September 2	1.25/2/7
Rice, Wild rice[b]	PFAM - 1 day water half-life	AR	—	Direct	May 11 – September 2	1.25/2/7
Rice, Wild rice[b]	PFAM - 2.2 day water half-life	LA, Gulf	—	Direct	April 26 – July 17	1.25/2/7
Rice, Wild rice[b]	PFAM - 1 day water half-life	LA, Gulf	—	Direct	April 26 – July 17	1.25/2/7
Rye	Wheat	CA	rlf	Groundspray	February 1 – June 15	1.0/3/7
Rye	Wheat	CA	rlf	Aerial	February 1 – June 15	1.0/3/7
Salsify	Lettuce	CA	std	Groundspray	February 16 – May 12	1.25/3/7
Salsify	Lettuce	CA	std	Aerial	February 16 – May 12	1.25/3/7

Table A-1 Use patterns and PRZM/EXAMS exposure scenarios for non-ULV uses of malathion						
Crop	***PRZM Scenario***	***State***	***PRZM Category[a]***	***Application Method***	***Model Run Dates***	***Max. App. Rate (lb ai/A)/ No. App. per Season/ Retreatment Interval (d)***
Sorghum, Oats, Wheat	Wheat	CA	rlf	Groundspray	February 1 – June 15	1/2/7
Sorghum, Oats, Wheat	Wheat	CA	rlf	Aerial	February 1 – June 15	1/2/7
Squash (Summer)	Melon	CA	rlf	Groundspray	May 16 – August 2	1.75/3/7
Squash (Summer)	Melon	CA	rlf	Aerial	May 16 – August 2	1.75/3/7
Squash (Winter)	Melon	CA	rlf	Groundspray	May 16 – August 2	1.0/3/7
Squash (Winter)	Melon	CA	rlf	Aerial	May 16 – August 2	1.0/3/7
Strawberry	Strawberry (non plastic)	CA	rlf	Groundspray	January 1 – July 1	2.0/4/7
Strawberry	Strawberry (non plastic)	CA	rlf	Aerial	January 1 – July 1	2.0/4/7
Tomato, Tomatillo	Tomato	CA	std	Groundspray	May 1 – September 1	1.56/4/5
Tomato, Tomatillo	Tomato	CA	std	Aerial	May 1 – September 1	1.56/4/5
Turnips, Rutabaga, Parsnips	Potato	CA	rlf	Groundspray	February 16 – June 15	1.25/3/5
Turnips, Rutabaga, Parsnips	Potato	CA	rlf	Aerial	February 16 – June 15	1.25/3/5
Walnut, Chestnut	Almonds	CA	std	Groundspray	May 1 – September 13	2.5/3/7
Walnut, Chestnut	Almonds	CA	std	Airblast	May 1 – September 13	2.5/3/7
Walnut, Chestnut	Almonds	CA	std	Aerial	January 16 – September 13	2.5/3/7
Watercress[b]	PFAM - 2.2 day water half-life	CA	—	Direct	May 16 – September 13	1.25/5/3
Watercress[b]	PFAM - 1 day water half-life	CA	—	Direct	May 16 – September 13	1.25/5/3
Watermelon	Melon	CA	rlf	Groundspray	May 16 – August 2	1.5/4/7
Watermelon	Melon	CA	rlf	Aerial	May 16 – August 2	1.5/4/7
Non-Agricultural Uses						
Agricultural uncultivated areas, non-agricultural uncultivated areas[c]	Right of way	CA	rlf	Groundspray	September 1 – November 2	1/1/-
Agricultural uncultivated areas, non-agricultural uncultivated areas[c]	Right of way	CA	rlf	Airblast	September 1 – November 2	1/1/-
Agricultural uncultivated areas, non-agricultural uncultivated areas[c]	Right of way	CA	rlf	Aerial	September 1 – November 2	1/1/-

Table A-1 Use patterns and PRZM/EXAMS exposure scenarios for non-ULV uses of malathion

Crop	*PRZM Scenario*	*State*	*PRZM Category*[a]	*Application Method*	*Model Run Dates*	*Max. App. Rate (lb ai/A)/ No. App. per Season/ Retreatment Interval (d)*
Christmas tree plantations, Pine seed orchards	Forestry	CA	rlf	Groundspray	March 1 – November 30	3.2/2/7
Christmas tree plantations, Pine seed orchards	Forestry	CA	rlf	Airblast	March 1 – November 30	3.2/2/7
Christmas tree plantations, Pine seed orchards	Forestry	CA	rlf	Aerial	March 1 – November 30	3.2/2/7
Fence rows/ hedge rows[c]	Right of way	CA	rlf	Groundspray	September 1 – November 2	10.62/4/7[d]
Household/domestic dwellings (perimeter)/ refuse/ solid waste sites/ containers[c]	Impervious	CA	rlf	Groundspray	January 1 – December 31	10.62/4/7[d]
Household/domestic dwellings (perimeter)/ refuse/ solid waste sites/ containers[c]	Residential	CA	rlf	Groundspray	January 1 – December 31	10.62/4/7[d]
Ornamentals	Nursery	CA	std	Groundspray	January 1 – December 31	4/2/10

[a] OP: organophosphate pesticide scenario; std: standard crop scenario; rlf: California red-legged frog scenario.
[b] EECs calculated using the Pesticides in Flooded Applications Model (PFAM pre-release version 1.0)
[c] EECs calculated using EPA's modeling approach for some non-agricultural uses (EPA, 2010).
[d] Labeled rate specified as 0.2439 lb/1000 ft^2.

Table A-2 Use patterns and PRZM/EXAMS exposure scenarios for ULV uses of malathion						
Crop	*PRZM Scenario*	*State*	*PRZM Category[a]*	*Application method*	*Model Run Dates*	*Max. App. Rate (lb ai/A)/No. App. per Season/Retreatment Interval (d)*
Agricultural Uses						
Alfalfa, Clover, Lespedeza, Trefoil, Vetch	Alfalfa	CA	OP	Groundspray	January 16 - December 31	0.61/6/14-16
Alfalfa, Clover, Lespedeza, Trefoil, Vetch	Alfalfa	CA	OP	Aerial	January 16 - December 31	0.61/6/14-16
Barley	Wheat	CA	rlf	Groundspray	March 1 – June 15	0.61/2/7
Barley	Wheat	CA	rlf	Aerial	March 1 – June 15	0.61/2/7
Beans	Row Crop	CA	rlf	Groundspray	January 1 – April 8	0.61/2/7
Beans	Row Crop	CA	rlf	Aerial	January 1 – April 8	0.61/2/7
Blueberries	Wine Grapes	CA	rlf	Groundspray	May 1 – August 1	0.77/3/10
Cherry	Fruit	CA	std	Groundspray	Feb. 1 - August 1	1.22/4/7
Cherry	Fruit	CA	std	Airblast	Feb. 1 - August 1	1.22/4/7
Cherry	Fruit	CA	std	Aerial	Feb. 1 - August 1	1.22/4/7
Citrus, Grapefruit, Lemon, Lime, Orange, Tangelo, Tangerines	Citrus	CA	std	Groundspray	January 1 - December 31	0.175/3/7
Citrus, Grapefruit, Lemon, Lime, Orange, Tangelo, Tangerines	Citrus	CA	std	Airblast	January 1 - December 31	0.175/3/7
Citrus, Grapefruit, Lemon, Lime, Orange, Tangelo, Tangerines	Citrus	CA	std	Aerial	January 1 - December 31	0.175/3/7
Citrus, Kumquats	Citrus	CA	std	Groundspray	January 1 - December 31	0.175/2/7
Citrus, Kumquats	Citrus	CA	std	Airblast	January 1 - December 31	0.175/2/7
Citrus, Kumquats	Citrus	CA	std	Aerial	January 1 - December 31	0.175/2/7
Corn (sweet and pop)	Corn	CA	OP	Groundspray	April 1 – September 8	0.61/2/5

Table A-2 Use patterns and PRZM/EXAMS exposure scenarios for ULV uses of malathion						
Crop	*PRZM Scenario*	*State*	*PRZM Category*[a]	*Application method*	*Model Run Dates*	*Max. App. Rate (lb ai/A)/No. App. per Season/Retreatment Interval (d)*
Corn (Sweet and Pop)	Corn	CA	OP	Aerial	April 1 – September 8	0.61/2/5
Cotton	Cotton	CA	std	Groundspray	May 5 - November 11	1.22/3/7
Cotton	Cotton w/irrigation	CA	std	Aerial	May 1 - November 11	1.22/3/7
Cotton	Cotton w/irrigation	CA	std	Groundspray	May 1 - November 11	1.22/3/7
Grass, Forage, Hay, Pasture, Rangeland	Rangeland hay	CA	rlf	Groundspray	November 1 – December 31; January 1 – May 1	0.92/1/-
Grass, Forage, Hay, Pasture, Rangeland	Rangeland hay	CA	rlf	Aerial	November 1 – December 31; January 1 – May 1	0.92/1/-
Lupine	Alfalfa	CA	OP	Groundspray	January 16 - December 31	0.61/1/-
Lupine	Alfalfa	CA	OP	Aerial	January 16 - December 31	0.61/1/-
Rye	Wheat	CA	rlf	Groundspray	February 1 – June 15	0.61/1/-
Rye	Wheat	CA	rlf	Aerial	February 1 – June 15	0.61/1/-
Sorghum, Oats, Wheat t	Wheat	CA	rlf	Groundspray	February 1 – June 15	0.61/2/7
Sorghum, Oats, Wheat	Wheat	CA	rlf	Aerial	February 1 – June 15	0.61/2/7

OP: organophosphate pesticide scenario; std: standard crop scenario; rlf: California red-legged frog scenario.

Appendix B
Rationale for not Assessing Malathion Degradation Products

According to EPA's Guidance for Residues of Concern in Ecological Risk Assessment (EPA, 2012), when evaluating the potential ecological concern of a degradation product it is important to consider the physical-chemical properties, environmental fate, and ecotoxicity. Major residues are defined as degradates that form 10% or greater of the applied parent compound in laboratory studies, whereas those that form <10% are labeled minor residues. Minor residues are generally not considered to be of concern, unless they show no sign of degradation or if they are known or expected to have similar or greater ecotoxicity to the parent compound (EPA, 2012). Major residues should be characterized based on mechanism of action (similar or different from parent compound) and level of toxicity (less toxic, similar in toxicity, more toxic than the parent compound). In the absence of available fate and ecotoxicological data for each specific residue of potential concern, EPA (2012) notes that "best professional judgment" may be used to classify assumed mechanism(s) of action. For organophosphates, the potential for and extent of oxon formation should be determined (i.e., malaoxon formation in the case of malathion). If the oxon is expected to form, ecotoxicological studies should be conducted to determine the level of toxicity (EPA, 2009; 2012).

Malathion degradation in the environment is dependent on the media and surrounding environmental conditions. In aerobic and anaerobic soil and aquatic degradation studies, the primary degradates of malathion have been identified as malathion monocarboxylic acid (MMCA) and malathion dicarboxylic acid (MDCA). Malaoxon has been identified as a minor degradation product on plants and dry/inert surfaces.

Of these three degradates, malaoxon is the only one to have greater toxicity than its parent under some instances. In some instances, malaoxon is less toxic than malathion to some species (i.e., bluegill), has similar toxicity for others (i.e., water flea, rainbow trout, ring-necked pheasant, northern bobwhite) and is more toxic for others yet (i.e., mallard duck, yellow canary, rats). Although malaoxon has higher toxicity for some species compared to malathion, it is not expected to be produced in amounts in the natural environment that would cause harm to animals. Studies show that malaoxon is either not formed, or formed in very small amounts that degrade and dissipate rapidly. Thus, Cheminova, believes that a quantitative assessment of the risk of malathion degradates is not warranted. Evidence to support this assertion is provided below.

Non-malaoxon Degradate Toxicity to Non-Target Organisms

The toxicity of MMCA and MDCA has been studied in four species: water flea, (*Daphnia magna*), bluegill (*Lepomis machrochirus*), Sprague-Dawley rat and earthworms (*Eisenia fetida*) (Table B-1 and Table B-2). Both of these degradates are considerably less toxic than the parent compound in all four species tested.

Gries and Purghart (2001a [MRID 47540310]) exposed neonate (<24 hours old) *Daphnia magna* to five nominal concentrations of MMCA (α + β mixture) ranging from 0.5 to 8.0 mg test substance/L. After 48 hours of exposure, there was no immobility (mortality) observed in the control groups. However, there was 65 and 100% immobilization observed in the 4.0 and 8.0

mg test substance/L test groups respectively. As such, the calculated EC50 for MMCA reported by the authors was 3.5 mg test substance/L (3.2 mg a.i./L). This concentration is 4571 times higher than the malathion acute effects metric for freshwater aquatic invertebrates (48-hour EC50 of 0.70 µg a.i./L for *Daphnia magna*; Gries and Purghart, 2001b [MRID 47540303]).

The toxicity of MDCA to *Daphnia magna* was investigated by Gries and Purghart (2001c [MRID 47540305]). *Daphnia magna* were exposed under flow-through conditions to nominal test concentrations of 6.25, 12.5, 25, 50 and 100 mg test substance/L for 48 hours. The 48-hour EC50 (immobilization) reported from this study was 71 mg test substance/L (70 mg a.i./L). This concentration is 100,000 times higher than the malathion acute effects metric for freshwater aquatic invertebrates (48-hour EC50 of 0.70 µg a.i./L for *Daphnia magna*; Gries and Purghart, 2001b [MRID 47540303]).

The toxicity of MMCA (α + β mixture) to bluegill sunfish (*Lepomis machrochirus*) was studied by Gries and Purghart (2001d [MRID 47540309]). Bluegill sunfish were exposed under flow-through conditions to nominal test concentrations of 0 (control), 1.56, 3.13, 6.25, 12.5, 25, 50 and 100 mg test substance/L. There were seven fish per test concentration that were observed for mortality. After 96 hours of exposure, mortality was recorded. There was no mortality in the controls or test groups, except for the 50 and 100 mg test substance/L test groups that had 14 and 71% mortality, respectively. The 96-hour LC50 was calculated to be >79 mg test substance/L (>72.8 mg a.i./L) from this study. This qualified LC50 is 1,400 times higher than the malathion acute effects metric for freshwater fish (96-hour LC50 of 52 µg a.i./L for *Lepomis macrochirus*; Gries and Purghart (2001e [MRID 47540304]).

A 96-hour LC50 of >100 mg test substance/L (98.8 mg a.i./L) was reported for bluegill sunfish (*Lepomis machrochirus*) exposed to MDCA (Gries and Purghart, 2001f [MRID 47540306]). No mortality was observed after 96 hours in the controls or the one tested concentration of 100 mg test substance/L (98.8 mg a.i./L). These results indicate that MDCA is much less toxic than malathion.

MMCA toxicity to rats (Sprague-Dawley) was studied by Sanders (2008a [MRID 49252804]) following the OECD (2001) guideline 420 “Acute Oral Toxicity – Fixed Dose Procedure”. In this study, no mortality was observed up to 2,000 mg test substance/kg bw (1,840 mg a.i./kg bw) and there were no treatment related effects on body weight or necropsy findings. Thus, the estimated oral LD50 for this degradate was estimated to be >2,000 mg test substance/kg bw (>1,840 mg a.i./kg bw) for the rat. In addition, the NOEL is >2,000 mg test substance/kg bw (>1,840 mg a.i./kg bw). This result indicates that MMCA is less toxic to rats than malathion since the mammalian acute oral LD50 is 2,010 mg a.i./kg bw for malathion (Moore, 2003 [MRID 48153112]).

Sanders (2008b [MRID 4925803]) exposed Sprague-Dawley rats to MDCA using the OECD (2001) guideline 420 “Acute Oral Toxicity – Fixed Dose Procedure”. There were no mortalities after oral exposure to 2,000 mg test substance/kg bw (1,980 mg a.i./kg bw). As such, the reported LD50 from the study was >2,000 mg/kg bw (>1,980 mg a.i./kg bw).

The toxicity of MMCA (α + β mixture) to the earthworm (*Eisenia fetida*, subspecies *andrei*), was investigated following OECD (1984) guideline 207 for earthworm acute toxicity tests (Friedrich, 2012a [MRID 49086404]). Adult earthworms (approx. three months old) were exposed to MMCA (α + β mixture) via alimentary and dermal uptake. The worms were exposed in groups of ten to MMCA (α + β mixture), obtained by the study sponsor (Cheminova A/S; 89.4% ww purity), in one liter glass containers filled in artificial soil. Test concentrations (n = 7) ranged from 15.63 to 1000 mg a.i./kg soil dw. Worms were monitored for mortality after seven and 14 days, while fresh weight was measured at day 14. Other behavioral (i.e., reaction to light and touch) and pathological symptoms (i.e., ulcers, blisters, twisted segments) were also noted if observed. After 14 days, there was no observed abnormal behavior noted in any treatment groups or control. Mortality in the control group was ≤10%, thereby meeting control mortality validity criteria. There was also no mortality after 14 days of exposure in the 15.63, 31.25, 62.5, 125, 250 and 500 mg a.i./kg dw test concentrations. Mortality of 2.5% was observed in the 250 and 1,000 mg a.i./kg dw test groups. However, the effects were not significantly different from controls. As such, the estimate 14-day LC50 is >1,000 mg a.i./kg dw and the corresponding NOEL (mortality) is 1, 000 mg a.i./kg dw. There were significant decreases in fresh weight biomass measured in worms exposed to 62.5, 125, 250, 500 and 1,000 mg a.i./kg dw. Therefore, the NOEL and LOEL for biomass are 31.25 and 62.5 mg a.i./kg dw, respectively. Wüthrich (1991 [MRID 49086403]) assessed the acute toxicity of malathion to earthworms (*Eisenia foetida foetida*) and obtained a 14-day LC50 of 590 mg a.i./kg dw. Thus, malathion is at least 1.7 times more toxic to earthworms than MMCA.

Friedrich (2012b [MRID 49086405]) investigated the toxicity of MDCA via alimentary and dermal exposure to earthworms (*Eisenia fetida*, subspecies *andrei*) following the OECD (1984) guideline 207 for earthworm acute toxicity tests. Adults worms were exposed to seven test concentrations (15.63, 31.25, 62.5, 125, 250, 500 and 1,000 mg a.i./kg dw) of MDCA (Cheminova A/S, 98.8% ww purity) in one liter glass containers filled with artificial soil. Mortality was monitored after seven and 14 days of exposure and fresh weight was measured after 14 days only. Mortality in the control group after 14 days was ≤10% which met the validity criteria required according to test guidelines (OECD, 1984). There was 2.5% mortality in the 62.5 mg a.i./kg dw test group. However, this effect was not significant compared to controls. Therefore, the 14 day LC50 is >1000 mg a.i./kg dw and the NOEL is 1000 mg a.i./kg dw. There were significant decreases in fresh weight biomass measured in worms exposed to 250, 500 and 1000 mg a.i./kg dw. Therefore, the NOEL and LOEL for biomass are 125 and 250 mg a.i./kg dw, respectively. Based on the 14-day malathion LC50 of 590 mg a.i./kg dw in earthworms (*Eisenia foetida foetida*) obtained by Wüthrich (1991 [MRID 49086403]), malathion is at least 1.7 times more toxic to earthworms than MDCA.

Table B-1	Potency ratios for malathion/non-malaoxon degradate toxicity derived using acceptable and supplemental studies for aquatic species				
Group	***Species***	***Chemical***	***Effect Metric***	***Reference [MRID]***	***Parent/ Degradate Ratio***
Freshwater Invertebrates (Acute)	Waterflea (*Daphnia magna*)	Malathion	48-h EC50 (Immobilization), 0.70 µg a.i./L	Gries and Purghart, 2001b [47540303]	NA
		Malathion dicarboxylic acid	48- h EC50 (Immobilization), 70,000 µg a.i./L	Gries and Purghart, 2001c [47540305]	0.00001
		Malathion monocarboxylic acid	48-h EC50 (Immobilization), 3,200 µg a.i./L	Gries and Purghart, 2001a [47540310]	0.000219
Freshwater fish (Acute)	Bluegill sunfish (*Lepomis macrochirus*)	Malathion	96-h LC50, 52 µg a.i./L	Gries and Purghart, 2001e [47540304]	NA
		Malathion dicarboxylic acid	96-h LC50, >98,800 µg a.i./L	Gries and Purghart, 2001f [47540306]	<0.000526
		Malathion monocarboxylic acid	96-h LC50, >72,800 µg a.i./L	Gries and Purghart, 2001d [47540309]	<0.000714

Table B-2	Potency ratios for malathion/non-malaoxon degradate toxicity derived using acceptable and supplemental studies for terrestrial species				
Group	***Species***	***Chemical***	***Effect Metric***	***Reference [MRID]***	***Parent/ Degradate Ratio***
Mammals (Acute)	Rat (Sprague-Dawley)	Malathion	Female, 1 dose (14-d observation) oral LD50, 2010 mg a.i./kg bw	Moore, 2003 [48153112]	NA
		Malathion dicarboxylic acid	Female, 1 dose (14-d observation) oral LD50, >1980 mg a.i./kg bw	Sanders, 2008b [49252803]	<1.02
		Malathion monocarboxylic acid	Female, 1 dose (14-d observation) oral LD50, >1840 mg a.i./kg bw	Sanders, 2008a [49252804]	<1.09
Terrestrial invertebrates (Acute)	Earthworm (*Eisenia fetida*)	Malathion	14-d LC50, 590 mg a.i./kg dw	Wüthrich, 1991 [49086403]	NA
		Malathion dicarboxylic acid	14-d LC50, >1000 mg a.i./kg dw	Friedrich, 2012a [49086404]	<0.59
		Malathion monocarboxylic acid	14-d LC50, >1000 mg a.i./kg dw	Friedrich, 2012a [49086404]	<0.59

Malaoxon Toxicity

In its DS and CTS ED, EPA used the potency ratio of 89.9 to qualitatively assess risk of malaoxon to all aquatic organisms. The evidence supporting this potency ratio is based on a single open literature study with the yellow-legged frog (*Rana boylii*) (Sparling and Fellers, 2007). This study was deemed unacceptable based on Cheminova's study evaluation criteria (Breton et al., 2014 [MRID 49333901]). The study did not follow a standard test method. The authors did not report control mortality, measured test concentrations, characteristics of test species and test conditions. In addition, a concentration-response relationship was not demonstrated and the authors acknowledged that confidence limits could not be calculated because the proportion of individuals dying in the lower concentrations of malathion was relatively constant. This study is, therefore, inappropriate for deriving a potency ratio in the risk assessment.

The sensitivity of species exposed to stressors can be quite variable and is influenced by biological (toxicokinetics and toxicodynamic characteristics) and physical characteristics. It is, therefore, not scientifically appropriate to apply a potency ratio derived for one species to species from widely disparate taxonomic groups (e.g., aquatic invertebrates and fish), particularly when data are available to derive taxon-specific potency ratios. Moreover, the use of potency ratios is not warranted when acceptable and relevant toxicity data are available for malaoxon itself. Cheminova has conducted and submitted a variety of GLP toxicity studies for malaoxon. For comparison purposes, Cheminova has derived malathion/malaoxon potency ratios for aquatic and terrestrial species using acceptable guideline GLP studies (Table B-3 and Table B-4) to illustrate the differences between a generic ratio of 89.9 and taxon specific ratios. As can be seen, taxon specific acute ratios range from 0.83 to 41 (aquatic and terrestrial species), which are much lower than the ratio of 89.9 for aquatic species applied by EPA using the unacceptable literature study.

Table B-3 Potency ratios for malathion/malaoxon toxicity derived using acceptable studies for aquatic species

Group	*Species*	*Chemical*	*Effects Metric*	*Reference [MRID]*	*Parent/Oxon Ratio*
Freshwater Invertebrates (Acute)	Water flea (*Daphnia magna*)	Malathion	48-h EC50 (Immobilization), 0.70 a.i./L	Gries and Purghart, 2001b [47540303]	2.4
		Malaoxon	48-h EC50 (Immobilization), 0.294 µg a.i./L	Bergfield, 2011 [48571803]	
Freshwater Fish (Acute)	Rainbow trout (*Oncorhynchus mykiss*)	Malathion	96-h LC50, 174 µg a.i./L	Gries and Purghart, 2001g [47540302]	2.58
		Malaoxon	96-h LC50, 67.4 µg a.i./L	Gerke, 2011a [48571802]	
	Bluegill (*Lepomis macrochirus*)	Malathion	96-h LC50, 52 µg a.i./L	Gries and Purghart, 2001e [47540304]	0.83
		Malaoxon	96-h LC50, 62.6 µg a.i./L	Gerke, 2011b [48571801]	

Table B-4 Potency ratios for malathion/malaoxon toxicity derived using acceptable studies for terrestrial species

Group	*Species*	*Chemical*	*Effects Metric*	*Reference [MRID]*	*Parent/Oxon Ratio*
Birds (Acute)	Northern bobwhite (*Colinus virginianus*)	Malathion	1 dose (14-d observation) oral LD50, 345 mg a.i./kg bw	Rodgers, 2002 [48153114]	8.0
		Malaoxon	1 dose (14-d observation) oral LD50, 43 mg a.i./kg bw	Gallagher et al., 2002a [48153104]	
	Yellow canary (*Serinus canaria*)	Malathion	1 dose (14-d observation) oral LD50, >2,400 mg a.i./kg bw	Stafford, 2011a [48571805]	>36.9
		Malaoxon	1 dose (14-d observation) oral LD50, 65 mg a.i./kg bw	Stafford, 2011b [48571806]	
	Mallard duck (*Anas platyrhynchos*)	Malathion	1 dose (14-d observation) oral LD50, >2,250 mg a.i./kg bw	Hubbard and Beavers, 2012a [48963307]	>25.9
		Malaoxon	1 dose (14-d observation) oral LD50, 87 mg a.i./kg bw	Hubbard and Beavers, 2012b [48963306]	
	Ring-necked pheasant (*Phasianus colchicus*)	Malathion	1 dose (14-d observation) oral LD50, 136 mg a.i./kg bw	Hubbard and Beavers, 2012c [48963305]	6.48
		Malaoxon	1 dose (14-d observation) oral LD50, 21 mg a.i./kg bw	Hubbard et al, 2012a [49024601]	
	Ring-necked pheasant (*Phasianus colchicus*)	Malathion	5-d (3-d) dietary LC50, 2,514 mg a.i./kg diet	Hubbard et al., 2012b [48963301]	1.37
		Malaoxon	5-d (3-d) dietary LC50, 1,832 mg a.i./kg diet	Hubbard et al., 2012c [48963302]	
	Northern bobwhite (*Colinus virginianus*)	Malathion	5-d (3-d) dietary LC50, 2,022 mg a.i./kg diet	Gallagher et al., 2002b [48153106]	2.38
		Malaoxon	5-d (3-d) dietary LC50, 848 mg a.i./kg diet	Gallagher et al., 2002c [48153105]	
	Mallard duck (*Anas platyrhynchos*)	Malathion	5-d (3-d) dietary LC50, >5,620 mg a.i./kg diet	Hubbard et al., 2012d [48963303]	NA
		Malaoxon	5-d (3-d) dietary LC50, >3,000 mg a.i./kg diet	Hubbard et al., 2012e [48963304]	
Mammals (Acute)	Rat (Sprague-Dawley)	Malathion	Female, 1 dose (14-d observation) oral LD50, 2,010 mg a.i./kg bw	Moore, 2003 [48153112]	41
		Malaoxon	Female, 1 dose (14-d observation) oral LD50, 49 mg a.i./kg bw	Lowe, 2011 [48571808]	

Despite the fact that calculated potency ratios indicate that malaoxon is more toxic than malathion to some non-target organisms, multiple lab and field studies have shown that malaoxon degrades quickly and is not persistent in the environment at levels that would cause toxicity. Further, it has been infrequently detected in multiple field monitoring programs. See below for more details of the identification and persistence of malaoxon in the environment.

Non-Target Organism Exposure to Malathion and Malaoxon

As stated above, evidence suggests that although malaoxon may be more toxic than malathion for some species, significant exposure of non-target organisms to malaoxon is unlikely. Malaoxon is generally not produced or measured in soil, soil leachates or water. It is also infrequently detected in aquatic environments. Moreover, malaoxon degrades quickly and when it is detected under environmental conditions, concentrations are typically small percentages or applied malathion. Further details are provided below.

Malaoxon has not been detected in laboratory adsorption and desorption studies (Nixon, 1995 [MRID 43868601]), aerobic and anaerobic soil metabolism studies (Knoch, 2001a [MRID 46769501]), except in one study where the applied product was contaminated (Blumhorst, 1990 [MRID 41721701]); hydrolysis and photolysis studies (Teeter, 1988 [MRID 40941201]; Miller, 1988 [MRID 40969301]; Carpenter, 1990 [MRID 41673001]; Sanders, 1988 [MRID 41039001]; Dykes et al., 1990 [MRID 41695501]; Spare and Cutchin, 1991 [MRID 42015201]); soil and water samples from two aquatic dissipation studies and two soil dissipation studies (Rice et al., 1990a,b [MRID 41748901, 41727701]; Jacobson and Lochhaas, 1992a,b [MRID 43042402, 43042401]; Judy et al., 1991a,b [MRID 42058402, 42058401]); and water-sediment systems treated with malathion (Knoch, 2001b [MRID 46769502]; Hiler and Mannella, 2012a [MRID 48906401]; Blumhorst, 1991a,b [MRID 42271601; 42216301]).

Malaoxon is infrequently detected in aquatic environments. Malaoxon surface water, untreated water and groundwater monitoring data from the EPA Storage and Retrieval (STORET) Data Warehouse, U.S. Department of Agriculture (USDA) Pesticide Data Program (PDP), U.S. Geological Survey (USGS) Nation Water Quality Assessment (NAWQA) Program, USGS National Water Information System (NWIS), California Department of Pesticide Regulation (CDPR) Surface Water Database (SWD), Quality-Assessed Agrichemical Contaminant Database for Nebraska Ground Water (QACD), Oregon Department of Environmental Quality (ODEQ) Laboratory Analytical Storage and Retrieval (LASAR) database ,Texas Commission on Environmental Quality (TCEQ) Interagency Pesticide Database, Washington State Department of Ecology (WSDE) Environmental Information Management (EIM) database, and Gulka et al. (2015) collected between 2001 and 2015 were examined. The monitoring programs targeted areas expected to be contaminated with pesticides. No malaoxon detections were reported in the EPA STORET, CDPR, QACD, or TCEQ IPD databases. In surface water data collected from USGS NAWQA, USGS NWIS, ODEQ LASAR, WSDE EIM and Gulka et al. (2015), malaoxon was detected at concentrations ranging from 0.0002 to 0.204 µg/L (limits of detection (LODs) = 0.001 – 2.4 µg/L). Overall, malaoxon was detected in 0 to 5.20% of surface water samples (Table B-5). Malaoxon was detected in 0.04 to 0.05% of groundwater samples from NAWQA and NWIS at concentrations ranging from 0.01 to 0.097 µg/L (LODs = 0.0025 – 0.24 µg/L). Malaoxon was detected in one untreated water sample from the USDA PDP at a concentration of 0.0012 µg/L. The most sensitive aquatic endpoint for malaoxon was a 48-hour NOEL of 0.130 µg a.i./L for immobilization in *Daphnia magna* (Bergfield, 2011 [MRID 48571803]). Only 0.023% and 0.024% of malaoxon surface water samples from the NAWQA and NWIS databases had detected concentrations exceeding this NOEL and no malaoxon

detections from the ODEQ LASAR database exceeded the NOEL. Furthermore, no malaoxon concentrations in surface water samples exceeded the 48-hour EC50 of 0.294 µg a.i./L for immobilization in *Daphnia magna* (Bergfield, 2011 [MRID 48571803]). The levels of malaoxon detected in groundwater samples did not exceed any aquatic endpoints for malaoxon. These results indicate that malaoxon is rarely observed in surface water, untreated water and groundwater and when detected, is reported at very low concentrations that are not likely to significantly affect aquatic organisms.

Table B-5 Summary of groundwater and surface water monitoring data for malaoxon from 2001 to 2015

Database	*Date Range*	*Sample Medium*	*No. Samples*	*No. Detects*	*% Detects*	*Range of Detected Values (µg/L)*[a]	*Range of LOD/ LOQ/ RLs (µg/L)*
EPA STORET	2013-2015	Surface water	54	0	0.00	ND	NR
	2015	Water	39	0	0.00	ND	NR
USDA PDP	2007-2013	Groundwater	1485	0	0.00	ND	0.00037 – 0.6[a]
	2004-2013	Untreated water	1221	1	0.08	0.0012	0.00037 – 0.6[a]
USGS NAWQA	2001-2012	Groundwater	5261	2	0.04%	0.0148 – 0.0336	0.0025 – 0.24[a]
	2001-2012	Surface water	8729	9	0.10%	0.0209 – 0.204	0 – 0.7[a,b]
USGS NWIS	2001-2015	Groundwater	8381	4	0.05	0.01 – 0.097	0.003 – 0.24[a]
	2001-2015	Surface water	16801	25	0.15	0.0002 – 0.204	0 – 0.7[a,c]
	2011-2013	Untreated water	2	0	0.00	ND	0.022[a]
CDPR SWD	2005-2012	Surface water	481	0	0.00	ND	0.02 – 0.08[d]
ODEQ LASAR	2004	Groundwater	3	0	0.00	ND	0.51 – 1[d]
	2003-2008	Surface water	1541	4	0.26	0.06 – 0.126	0.02 – 2.4[a]; 0.025[d]
QACD	2003-2011	Groundwater	372	0	0.00	ND	0.008 – 0.08[a,d]
TCEQ IPD	2010-2011	Spring	2	0	0.00	ND	0.022 – 0.08[a,d]
Gulka et al., 2015	2013	Surface water	491	25	5.09	0.002 – 0.01	0.001[a]

ND = Not detected
NR = Not reported
[a] Limit of detection (LOD)
[b] One entry in NAWQA was reported as less than 0 µg/L. The next lowest LOD was 0.0025 µg/L.
[c] One entry in NWIS was reported as less than 0 µg/L. The next lowest LOD was 0.003 µg/L.
[d] Limit of quantitation (LOQ)
[e] Reporting limit (RL)

Malaoxon degrades quickly in soil and aquatic environments. Malaoxon degradation was investigated in a recent aerobic soil metabolism study (Hiler, 2012 [MRID 48903601]). The study was conducted with radio-labeled malaoxon (99.2% purity) and four acidic soils (pH 5.8 to 6.3): sandy loam with low organic content (Hanford), sandy loam with high organic content (Vacaville), loamy sand (Speyer, Germany) and loam (Iowa). In addition to determining the

degradation rate of the four soils, the Vacaville sandy loam was used to determine the degradation pathway of malaoxon. A dose rate of 1.02 ppm malaoxon was used, assuming the highest possible application rate of malathion (citrus, 4.5 lbs a.i./A) and a conservative rate of conversion of malathion to malaoxon (5%). This dose rate represented an application rate of 1.0 µg/g of dry soil. Malaoxon was applied to 50 g (dry weight) samples of each soil and the samples were stored in amber glass bottles and aerated for 120 days. A field moisture capacity of pF 2.0 to 2.5 and temperature of 20 ± 2°C were maintained throughout the testing period. Duplicate soil samples were analyzed for malaoxon three and six hours and 1, 2, 3, 7, 13, 30, 62, 90 (92 for Iowa soil) and 120 days after dosing. High-performance liquid chromatography (HPLC) was used to quantify malaoxon in the soil samples. Average radiocarbon recoveries ranged from 92.6 to 93.9%. Malaoxon had degraded to ≤2.0% of the applied rate in all soils by the end of the study period (120 days). The major degradate was a polar product that consisted of the α/β monoacid and a dehydrogenated form of the diacid. Monoethyl maleate, diethyl maleate and diethylmethylthiosuccinate were minor degradation products. The half-lives were calculated using a Single First-Order (SFO) model. The half-lives for the Hanford, Speyer, Vacaville and Iowa soils were 0.3, 0.2, 0.6 and 0.5 days, respectively. Their respective degradation rate constants were 2.1947, 3.9121, 1.1428 and 1.4848 d^{-1}. The DT90 values were ≤2.0 days for all soils. This study suggests that even if malaoxon is present in very small amounts after application of malathion (either formed after application of malathion or released as an impurity) it would degrade quickly in the environment. Shepler (2004 [MRID 46396601]) studied the rate of hydrolysis and hydrolytic products of [^{14}C]malaoxon. Concentrations of [^{14}C]malaoxon at varying pHs (5, 7 and 9) were maintained in the dark at 25°C throughout the study period (31 days). Radioactive malaoxon and its degradates were quantified by high performance liquid chromatography (HPLC). Radiocarbon recoveries ranged between 92.1 and 110.5% of the applied dose for all samples. Half-life hydrolysis of malaoxon in aqueous buffer samples were 32.5, 8.8 and 0.18 days for pH 5, 7 and 9 respectively. DT90s were 108.1, 29.3 and 0.61 days for pHs 5, 7 and 9, respectively. Malaoxon is most stable under acidic conditions, which are less likely to occur in nature. At neutral or slightly basic conditions, those representative of ecologically relevant conditions, malaoxon degrades quickly.

As noted above, when malaoxon is found in the environment, it is only at very small percentages of applied malathion. This is further supported by Hiler (2011 [MRID 48508601]) who conducted an aerobic aquatic metabolism study using [^{14}C]malaoxon applied to sediment/water samples from two sites in the U.S. The samples were inoculated and incubated in the dark under aerobic conditions at 20°C for 14 days (North Dakota sample) to one month (Georgia sample) to determine the breakdown and radiocarbon distribution of [^{14}C]malaoxon. The site in Georgia had sandy sediment with a 1:1 sediment/water ratio at pH of 4.7. The test system had a pH of 6.1. The North Dakota site had a more loamy sediment (greater humic and fulvic acid component) with a 1:1 sediment/water ratio at pH of 8.1. The test system had a pH of 8.4. Hiler (2011 [MRID 48508601]) calculated DT50s and DT90s for malaoxon using sediment/water samples from both sites. In sandy sediment (Georgia sample), the DT50 and DT90 of malaoxon were 5.1 and 17.1 days, respectively and in the water, more than 90% of the malaoxon had degraded by day 14. In loamy sediment (North Dakota), the DT50 and DT90 of malaoxon were one and 3.3 days, respectively. Malaoxon in the North Dakota test system had

degraded by more than 90% in the water layer within four days. These studies also suggest that even if malaoxon would be present in very small amounts after application of malathion (either formed after application of malathion or released as an impurity) it would degrade quickly in the environment.

Malaoxon is found at small percentages of applied malathion under dry and microbially inactive environmental conditions. In a study conducted by CaEPA (1993), malathion was applied in diluted slurry with a ratio of 10,000: 1 bait to malathion. Bait and malathion are typically mixed in a ratio of 4:1. According CaEPA (1993), all matrices were covered with a film of bait mixture following application, as opposed to the discrete droplets that would be expected with a field application. As indicated by the authors, the influence of this extreme mixture on malathion degradation is unknown and requires further study. The conditions in the CaEPA (1993) study have no relevance to public health spraying programs or agricultural uses involving malathion. Cheminova submitted a study that was conducted in EPA Region 10 (California) and measured the formation of malathion degradates in soil and sand samples treated with malathion alone (target rate of 1.22 lb a.i./A) or in combination with NuLure® insect bait (ratios of 4:1 and 10,000:1 bait to malathion) (Rice, 2011 [MRID 48626701]). Malaoxon concentrations did not exceed 6% and 10% of the corresponding malathion levels in sand and soil, respectively (Rice, 2011 [MRID 48626701]). A similar study quantifying degradation products in sand and soil treated with an equivalent rate of 1.22 lb [^{14}C]malathion/A observed maximum malaoxon levels of 2% and 4% applied radiocarbon (AR) for sand and soil, respectively (Hiler and Mannella, 2012b [MRID 48986601]). By the end of the 30-day study period, malaoxon levels had declined to below 2% AR in both sand and soil.

Several GLP field residue and dissipation studies commissioned by Cheminova were reviewed and analyzed by Habig (2011 [MRID 48409301]). Malathion and malaoxon residues were measured in a variety of field crops, fruit and long grasses at numerous time points after application of malathion (i.e., 0, 1, 3, 4, 7, 10, 11, 14 and 21 days). Residue data were separated into categories to represent particular feed item groups (i.e., long/tall grass, forage and leafy crops, large fruit and small fruit/seeds). Malathion residues peaked on the day of application for all feed item categories. The highest mean residue concentration of 43.8 mg/kg ww was measured on forage and leafy crops. Similarly, malaoxon residues peaked on the day of application on forage and leafy crops, long/tall grass and small fruit. However, on large fruit malaoxon peaked on the day after application. The highest mean measured malaoxon residue concentration from all feed item classes was 0.2 mg/kg ww, measured on long/tall grass (Habig, 2011 [MRID 48409301]).

In a field study conducted in southwest Germany, Knäbe (2004 [MRID 46525902]) investigated malathion and malaoxon residues on plant material and arthropods in an apple orchard after airblast application of EW formulation containing 440 g/L malathion. The application rate was 1.61 lb a.i./A (1.81 kg a.i./ha). Ground vegetation between the apple trees was collected (weeds and grass) as well as canopy-dwelling (using inventory sampling) and ground-dwelling arthropods (using pitfall traps and D-vac sampling). Samples were collected using inventory sampling seven days before application and then 0, 2, 4, 8, 16 and 27 days after application.

Pitfall traps were collected six days prior to application and then 1, 2, 3, 4, 8, 16 and 24 days after application. D-vac sampling was carried out on days 0, 1, 2 and 8 days after application.

Procedural recoveries for malathion and malaoxon measured on arthropod samples were 94% and 84%, respectively. The LOQ was 0.01 mg/kg ww. In canopy-dwelling arthropods the author reports dissipation half-lives of 11.69 hours and 0.13 hours, for malathion and malaoxon, respectively. On these arthropods, measured malaoxon residues peaked on the day of application (Day 0), at 0.09 mg/kg ww. Malathion residues were highest on the day of application and peaked at 9.4 mg/kg ww. By mass, the highest measured malaoxon residues on canopy-dwelling arthropods was ~0.96% of peak measured malathion (Knäbe, 2004 [MRID 46525902]).

Recoveries for short vegetation (grass and weeds) were 95% and 94%, respectively, for malathion and malaoxon. The LOQ was 0.01 mg/kg ww. The author reported dissipation half-lives for malathion and malaoxon were 18.48 hours and 0.19 hours respectively. Malathion and malaoxon both peaked on the day of application (45.0 mg/kg ww and 0.09 mg/kg ww, respectively). By mass, the highest measured malaoxon residues on short vegetation was ~0.2% of peak measured malathion (Knäbe, 2004 [MRID 46525902]).

Discussion and Conclusion

Non-oxon degradates of malathion show negligible toxicity to aquatic and terrestrial species and as such are not of ecotoxicological concern (EPA, 2012). Though malaoxon has been demonstrated to more toxic than malathion to some species, the fate and behavior of malaoxon suggests that it is likely not produced in the aquatic environment. Moreover, malaoxon degrades rapidly in water, sediment and soil samples. On the rare occasion when it is detected, malaoxon is found only at small percentages of applied malathion or at small concentrations in aquatic environments. As such, malaoxon is unlikely to be transported at environmentally relevant concentrations in which exposure would cause significant effects on growth, reproduction and survival.

In the terrestrial environment, malaoxon has half-lives shorter then one day, indicating that malaoxon degrades quickly on arthropods and short vegetation, which are important feed items for terrestrial organisms. Given the above, risk associated with malaoxon exposure is likely negligible for birds and mammals.

Previous ecological risk assessments produced by EPA determined that it was unnecessary to consider potential malaoxon exposure. EPA (2006) concluded that malaoxon was not expected to be a “significant component of the ecological hazard of malathion to non-target organisms”. EPA (2007) considered exposure to malaoxon in its California Red-legged frog effects determination for malathion and found that “the conclusions reached for malathion alone are adequate to cover the potential effects associated with maloxon”.

Cheminova believes that an ecological risk assessment of malathion only is warranted and would be sufficiently conservative to be protective of combined malathion and malaoxon exposure to declining malathion residues and their degradates in the environment.

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Appendix C
Screening-level Estimated Environmental Concentrations (EECs) and Risk Quotients (RQs) for Delta Smelt and Their Aquatic Invertebrate Prey

Table C-1 Estimated environmental concentrations (EECs) and risk quotients (RQs) for DS exposed to non-ULV uses of malathion[a]

Crop	*State*	*Application Method*	*Max. Application Rate (lb ai/A)/No. Applications per Season/ Retreatment Interval (d)*	*EECs (µg/L)*		*Freshwater/ Marine Fish*	*Freshwater Fish*	*Marine Fish*
				Peak	*60-day*	*Acute[b]*	*Chronic[c]*	*Chronic[d]*
Agricultural Uses								
Alfalfa, Clover, Lespedeza, Trefoil, Vetch	CA	Groundspray	1.25/6/14-16	1.71	0.319	**6.84**	0.0152	0.0389
Alfalfa, Clover, Lespedeza, Trefoil, Vetch	CA	Aerial	1.25/6/14-16	4.48	1.32	**17.9**	0.0628	0.161
Apricot	CA	Groundspray	1.50/2/7	0.999	0.118	**4.00**	0.00562	0.0144
Apricot	CA	Airblast	1.50/2/7	3.00	0.354	**12.0**	0.0169	0.0432
Apricot	CA	Aerial	1.5/2/7	6.04	0.838	**24.2**	0.0399	0.102
Asparagus, Carrots	CA	Groundspray	1.25/2/7	1.11	0.159	**4.46**	0.00758	0.0194
Asparagus, Carrots	CA	Aerial	1.25/2/7	4.60	0.644	**18.4**	0.0307	0.0786
Avocado	CA	Groundspray	4.70/2/30	11.8	1.11	**47.1**	0.0526	0.135
Avocado	CA	Airblast	4.70/2/30	15.3	1.91	**61.4**	0.0910	0.233
Barley	CA	Groundspray	1.25/2/7	2.02	0.249	**8.06**	0.0118	0.0303
Barley	CA	Aerial	1.25/2/7	5.38	0.692	**21.5**	0.0330	0.0844
Beets	CA	Groundspray	1.25/3/7	2.11	0.305	**8.44**	0.0145	0.0372
Beets	CA	Aerial	1.25/3/7	5.58	1.03	**22.3**	0.0490	0.125
Blueberries	CA	Groundspray	1.25/3/5	1.05	0.174	**4.20**	0.00830	0.0213
Blueberries	CA	Aerial	1.25/3/5	5.57	0.954	**22.3**	0.0454	0.116
Broccoli, Chinese broccoli, Broccoli raab, Cauliflower	CA	Groundspray	1.25/2/7	2.57	0.316	**10.3**	0.0151	0.0385
Broccoli, Chinese broccoli, Broccoli raab, Cauliflower	CA	Aerial	1.25/2/7	5.41	0.800	**21.6**	0.0381	0.0975
Brussels sprouts, Dandelion	CA	Groundspray	1.25/2/7	1.88	0.208	**7.54**	0.00991	0.0254
Brussels sprouts, Dandelion	CA	Aerial	1.25/2/7	5.36	0.688	**21.5**	0.0328	0.0839
Cabbage, Horseradish, Kohlrabi	CA	Groundspray	1.25/6/7	2.78	0.579	**11.1**	0.0276	0.0706

Table C-1 Estimated environmental concentrations (EECs) and risk quotients (RQs) for DS exposed to non-ULV uses of malathion[a]

Crop	*State*	*Application Method*	*Max. Application Rate (lb ai/A)/No. Applications per Season/ Retreatment Interval (d)*	*EECs (µg/L)*		*Freshwater/ Marine Fish*	*Freshwater Fish*	*Marine Fish*
				Peak	*60-day*	*Acute[b]*	*Chronic[c]*	*Chronic[d]*
Cabbage, Horseradish, Kohlrabi	CA	Aerial	1.25/6/7	6.26	2.08	**25.0**	0.0991	0.254
Caneberries (Gooseberry, Blackberry, Boysenberry, Dewberry, Loganberry, Raspberry, Currents)	CA	Groundspray	2.00/3/7	1.84	0.340	**7.35**	0.0162	0.0415
Caneberries (Gooseberry, Blackberry, Boysenberry, Dewberry, Loganberry, Raspberry, Currents)	CA	Airblast	2.00/3/7	4.82	0.925	**19.3**	0.0440	0.113
Caneberries (Gooseberry, Blackberry, Boysenberry, Dewberry, Loganberry, Raspberry, Currents)	CA	Aerial	2.00/3/7	7.78	1.51	**31.1**	0.0718	0.184
Celery	CA	Groundspray	1.50/2/7	2.31	0.293	**9.25**	0.0140	0.0358
Celery	CA	Aerial	1.50/2/7	5.95	0.868	**23.8**	0.0413	0.106
Cherry	CA	Groundspray	1.75/4/3	3.57	0.512	**14.3**	0.0244	0.0625
Cherry	CA	Airblast	1.75/4/3	7.25	1.19	**29.0**	0.0566	0.145
Cherry	CA	Aerial	1.75/4/3	11.2	1.86	**44.9**	0.0887	0.227
Chinese greens (Chinese cabbage)	CA	Groundspray	1.25/2/7	1.93	0.245	**7.70**	0.0116	0.0298
Chinese greens (Chinese cabbage)	CA	Aerial	1.25/2/7	4.96	0.723	**19.8**	0.0344	0.0882
Citrus, Grapefruit, Lemon, Lime, Orange, Tangelo, Tangerines	CA	Groundspray	1.50/3/30	1.10	0.174	**4.38**	0.00830	0.0212
Citrus, Grapefruit, Lemon, Lime, Orange, Tangelo, Tangerines	CA	Airblast	1.50/3/30	2.73	0.485	**10.9**	0.0231	0.0592

Table C-1 Estimated environmental concentrations (EECs) and risk quotients (RQs) for DS exposed to non-ULV uses of malathion[a]

Crop	*State*	*Application Method*	*Max. Application Rate (lb ai/A)/No. Applications per Season/ Retreatment Interval (d)*	*EECs (µg/L)*		*Freshwater/ Marine Fish*	*Freshwater Fish*	*Marine Fish*
				Peak	*60-day*	*Acute[b]*	*Chronic[c]*	*Chronic[d]*
Citrus, Grapefruit, Lemon, Lime, Orange, Tangelo, Tangerines	CA	Aerial	1.50/3/30	4.37	0.791	**17.5**	0.0377	0.0965
Citrus, Grapefruit, Lemon, Lime, Orange, Tangelo, Tangerines, Kumquats	CA	Airblast	7.50/1/-	13.4	1.26	**53.6**	0.0599	0.153
Collards	CA	Groundspray	1.00/3/7	2.21	0.310	**8.85**	0.0148	0.0379
Collards	CA	Aerial	1.00/3/7	4.96	0.884	**19.9**	0.0421	0.108
Corn (Field)	CA	Groundspray	1.00/2/7	0.749	0.105	**3.00**	0.00498	0.0128
Corn (Field)	CA	Aerial	1.00/2/7	3.60	0.490	**14.4**	0.0234	0.0598
Corn (Sweet and Pop)	CA	Groundspray	1.00/2/5	0.886	0.126	**3.54**	0.00601	0.0154
Corn (Sweet and pop)	CA	Aerial	1.00/2/5	3.96	0.509	**15.9**	0.0242	0.0621
Cotton	CA	Groundspray	2.50/3/7	3.54	0.534	**14.1**	0.0254	0.0651
Cotton	CA	Groundspray	2.50/3/7	3.95	0.586	**15.8**	0.0279	0.0715
Cotton	CA	Aerial	2.50/3/7	10.2	1.97	**40.8**	0.0938	0.240
Cotton	CA	Aerial	2.50/3/7	10.1	2.04	**40.4**	0.0971	0.249
Cucumber, Chayote fruit	CA	Groundspray	1.75/2/7	1.17	0.135	**4.66**	0.00641	0.0164
Cucumber, Chayote fruit	CA	Aerial	1.75/2/7	5.83	0.674	**23.3**	0.0321	0.0822
Eggplant (4 apps), Oriental eggplant (5 apps)	CA	Groundspray	1.56/5/5	1.31	0.306	**5.25**	0.0146	0.0373
Eggplant (4 apps), Oriental eggplant (5 apps)	CA	Aerial	1.56/5/5	6.27	1.53	**25.1**	0.0728	0.186
Figs	CA	Groundspray	2.00/2/5	1.82	0.232	**7.29**	0.0110	0.0283
Figs	CA	Airblast	2.00/2/5	4.88	0.604	**19.5**	0.0288	0.0737
Figs	CA	Aerial	2.00/2/5	8.77	1.12	**35.1**	0.0534	0.137
Flax	CA	Groundspray	0.50/3/7	0.707	0.107	**2.83**	0.00508	0.0130
Flax	CA	Aerial	0.50/3/7	2.04	0.394	**8.15**	0.0188	0.0480
Garlic	CA	Groundspray	1.56/3/7	1.51	0.262	**6.06**	0.0125	0.0319
Garlic	CA	Aerial	1.56/3/7	5.79	1.10	**23.2**	0.0523	0.134

Table C-1 Estimated environmental concentrations (EECs) and risk quotients (RQs) for DS exposed to non-ULV uses of malathion[a]

Crop	*State*	*Application Method*	*Max. Application Rate (lb ai/A)/No. Applications per Season/ Retreatment Interval (d)*	*EECs (µg/L)*		*Freshwater/ Marine Fish*	*Freshwater Fish*	*Marine Fish*
				Peak	*60-day*	*Acute[b]*	*Chronic[c]*	*Chronic[d]*
Grapes (Raisin, table, wine)	CA	Groundspray	1.88/2/14	1.16	0.183	**4.65**	0.00871	0.0223
Grapes (Raisin, table, wine)	CA	Airblast	1.88/2/14	3.41	0.525	**13.6**	0.0250	0.0640
Grapes (Raisin, table, wine)	CA	Aerial	1.88/2/14	5.93	1.01	**23.7**	0.0482	0.124
Grass, Forage, Hay, Pasture, Rangeland	CA	Groundspray	1.25/1/-	1.66	0.164	**6.66**	0.00780	0.0200
Grass, Forage, Hay, Pasture, Rangeland	CA	Aerial	1.25/1/-	4.42	0.427	**17.7**	0.0203	0.0521
Guava	CA	Groundspray	1.25/13/3	3.44	1.03	**13.8**	0.0489	0.125
Guava	CA	Airblast	1.25/13/3	6.51	2.66	**26.0**	0.127	0.325
Guava	CA	Aerial	1.25/13/3	9.52	4.38	**38.1**	0.209	0.534
Hops	OR	Groundspray	0.63/3/7	0.488	0.101	**1.95**	0.00483	0.0124
Hops	OR	Aerial	0.63/3/7	2.43	0.502	**9.72**	0.0239	0.0612
Kale, Mustard	CA	Groundspray	1.00/3/5	2.42	0.300	**9.67**	0.0143	0.0366
Kale, Mustard	CA	Aerial	1.00/3/5	5.76	0.899	**23.0**	0.0428	0.110
Leek	CA	Groundspray	1.56/2/7	1.24	0.176	**4.95**	0.00837	0.0214
Leek	CA	Aerial	1.56/2/7	5.52	0.743	**22.1**	0.0354	0.0906
Lettuce, Endive, Spinach, Swiss chard	CA	Groundspray	1.88/2/5	4.84	0.477	**19.4**	0.0227	0.0582
Lettuce, Endive, Spinach, Swiss chard	CA	Aerial	1.88/2/5	10.5	1.18	**41.9**	0.0562	0.144
Macadamia nut	CA	Groundspray	0.94/6/7	0.738	0.231	**2.95**	0.0110	0.0282
Macadamia nut	CA	Airblast	0.94/6/7	2.07	0.680	**8.27**	0.0324	0.0830
Macadamia nut	CA	Aerial	0.94/6/7	4.60	1.56	**18.4**	0.0743	0.190
Mango	CA	Groundspray	0.94/10/7	0.985	0.402	**3.94**	0.0192	0.0491
Mango	CA	Airblast	0.94/10/7	2.30	1.15	**9.21**	0.0548	0.140
Mango	CA	Aerial	0.94/10/7	4.52	2.12	**18.1**	0.101	0.258
Melon (not Watermelon), Pumpkin, Cantaloupe	CA	Groundspray	1.00/2/7	0.666	0.0770	**2.66**	0.00367	0.00939
Melon (not Watermelon), Pumpkin, Cantaloupe	CA	Aerial	1.00/2/7	3.33	0.385	**13.3**	0.0183	0.0469
Mint	OR	Groundspray	0.94/3/7	0.728	0.144	**2.91**	0.00686	0.0176
Mint	OR	Aerial	0.94/3/7	3.62	0.715	**14.5**	0.0341	0.0872

Table C-1 Estimated environmental concentrations (EECs) and risk quotients (RQs) for DS exposed to non-ULV uses of malathion[a]

Crop	*State*	*Application Method*	*Max. Application Rate (lb ai/A)/No. Applications per Season/ Retreatment Interval (d)*	*EECs (µg/L)*		*Freshwater/ Marine Fish*	*Freshwater Fish*	*Marine Fish*
				Peak	*60-day*	*Acute[b]*	*Chronic[c]*	*Chronic[d]*
Nectarine	CA	Groundspray	3.00/3/7	2.95	0.484	**11.8**	0.0230	0.0590
Nectarine	CA	Airblast	3.00/3/7	6.93	1.34	**27.7**	0.0639	0.164
Okra	CA	Groundspray	1.20/5/7	0.776	0.191	**3.10**	0.00911	0.0233
Okra	CA	Aerial	1.20/5/7	3.87	0.955	**15.5**	0.0455	0.117
Onion, Shallot	CA	Groundspray	1.56/2/7	1.35	0.169	**5.39**	0.00806	0.0207
Onion, Shallot	CA	Aerial	1.56/2/7	5.71	0.845	**22.9**	0.0403	0.103
Papaya	CA	Groundspray	1.25/8/3	3.42	0.710	**13.7**	0.0338	0.0865
Papaya	CA	Airblast	1.25/8/3	6.48	1.73	**25.9**	0.0822	0.210
Papaya	CA	Aerial	1.25/8/3	9.11	2.75	**36.4**	0.131	0.336
Parsley	CA	Groundspray	1.50/2/7	2.26	0.250	**9.05**	0.0119	0.0305
Parsley	CA	Aerial	1.50/2/7	6.44	0.826	**25.7**	0.0393	0.101
Passion fruit	CA	Groundspray	1.00/8/7	1.03	0.418	**4.11**	0.0199	0.0510
Passion fruit	CA	Aerial	1.00/8/7	4.01	1.94	**16.0**	0.0924	0.237
Peaches	CA	Groundspray	3.00/3/11	3.56	0.608	**14.3**	0.0289	0.0741
Peaches	CA	Airblast	3.00/3/11	7.45	1.57	**29.8**	0.0749	0.192
Peaches	CA	Aerial	3.00/3/11	11.2	2.47	**44.8**	0.118	0.301
Pears, Apple	CA	Groundspray	1.25/2/7	0.954	0.132	**3.81**	0.00629	0.0161
Pears, Apple	CA	Airblast	1.25/2/7	2.67	0.354	**10.7**	0.0168	0.0431
Pears, Apple	CA	Aerial	1.25/2/7	5.03	0.698	**20.1**	0.0333	0.0852
Peas	CA	Groundspray	1.00/2/7	1.54	0.196	**6.16**	0.00932	0.0239
Peas	CA	Aerial	1.00/2/7	3.97	0.579	**15.9**	0.0275	0.0706
Pecan	CA	Groundspray	2.50/2/7	1.82	0.218	**7.29**	0.0104	0.0266
Pecan	CA	Airblast	2.50/2/7	5.24	0.634	**21.0**	0.0302	0.0774
Pecan	CA	Aerial	2.50/2/7	10.6	1.43	**42.6**	0.0683	0.175
Peppers	CA	Groundspray	1.56/2/5	1.64	0.188	**6.56**	0.00894	0.0229
Peppers	CA	Aerial	1.56/2/5	6.29	0.798	**25.2**	0.0380	0.0973
Pineapple	CA	Groundspray	2.00/3/7	1.77	0.303	**7.07**	0.0144	0.0370
Pineapple	CA	Aerial	2.00/3/7	8.48	1.65	**33.9**	0.0784	0.201
Potato, Sweet potato, yams	CA	Groundspray	1.56/2/7	1.77	0.195	**7.09**	0.00929	0.0238
Potato, Sweet potato, yams	CA	Aerial	1.56/2/7	5.77	0.774	**23.1**	0.0369	0.0944
Radish	CA	Groundspray	1.00/3/7	1.01	0.184	**4.05**	0.00878	0.0225
Radish	CA	Aerial	1.00/3/7	3.91	0.794	**15.6**	0.0378	0.0969

Table C-1 Estimated environmental concentrations (EECs) and risk quotients (RQs) for DS exposed to non-ULV uses of malathion[a]

Crop	*State*	*Application Method*	*Max. Application Rate (lb ai/A)/No. Applications per Season/ Retreatment Interval (d)*	*EECs (µg/L)*		*Freshwater/ Marine Fish*	*Freshwater Fish*	*Marine Fish*
				Peak	*60-day*	*Acute[b]*	*Chronic[c]*	*Chronic[d]*
Rice, Wildrice[e]	AR	Direct	1.25/2/7	98.0	9.20	**392**	0.438	**1.12**
Rice, Wildrice[f]	AR	Direct	1.25/2/7	145	24.8	**580**	**1.18**	**3.02**
Rice, Wildrice[e]	LA, Gulf	Direct	1.25/2/7	121	8.60	**484**	0.410	**1.05**
Rice, Wildrice[f]	LA, Gulf	Direct	1.25/2/7	185	24.1	**740**	**1.15**	**2.94**
Rye	CA	Groundspray	1.00/3/7	2.61	0.364	**10.4**	0.0173	0.0444
Rye	CA	Aerial	1.00/3/7	5.09	0.949	**20.3**	0.0452	0.116
Salsify	CA	Groundspray	1.25/3/7	1.96	0.311	**7.84**	0.0148	0.0379
Salsify	CA	Aerial	1.25/3/7	5.61	1.01	**22.4**	0.0480	0.123
Sorghum, Oats, Wheat	CA	Groundspray	1.00/2/7	2.40	0.263	**9.61**	0.0125	0.0321
Sorghum, Oats, Wheat	CA	Aerial	1.00/2/7	5.08	0.668	**20.3**	0.0318	0.0814
Squash (Summer)	CA	Groundspray	1.75/3/7	1.20	0.192	**4.80**	0.00915	0.0234
Squash (Summer)	CA	Aerial	1.75/3/7	6.00	0.961	**24.0**	0.0457	0.117
Squash (Winter)	CA	Groundspray	1.00/3/7	0.686	0.110	**2.75**	0.00523	0.0134
Squash (Winter)	CA	Aerial	1.00/3/7	3.43	0.549	**13.7**	0.0261	0.0669
Strawberry	CA	Groundspray	2.00/4/7	10.2	1.26	**40.7**	0.0599	0.153
Strawberry	CA	Aerial	2.00/4/7	15.4	2.86	**61.8**	0.136	0.349
Tomato, Tomatillo	CA	Groundspray	1.56/4/5	1.30	0.248	**5.20**	0.0118	0.0302
Tomato, Tomatillo	CA	Aerial	1.56/4/5	6.23	1.23	**24.9**	0.0584	0.150
Turnips, Rutabaga, Parsnips	CA	Groundspray	1.25/3/5	2.17	0.213	**8.69**	0.0101	0.0260
Turnips, Rutabaga, Parsnips	CA	Aerial	1.25/3/5	5.70	0.919	**22.8**	0.0438	0.112
Walnut, Chestnut	CA	Groundspray	2.50/3/7	1.94	0.326	**7.76**	0.0155	0.0397
Walnut, Chestnut	CA	Airblast	2.50/3/7	5.43	0.950	**21.7**	0.0452	0.116
Walnut, Chestnut	CA	Aerial	2.50/3/7	11.1	2.10	**44.5**	0.100	0.256
Watercress[e]	CA	Direct	1.25/5/3	85.9	15.7	**344**	0.748	**1.91**
Watercress[f]	CA	Direct	1.25/5/3	127	31.3	**508**	**1.49**	**3.82**
Watermelon	CA	Groundspray	1.50/4/7	1.03	0.210	**4.13**	0.0100	0.0256
Watermelon	CA	Aerial	1.50/4/7	5.14	1.05	**20.6**	0.0500	0.128
Non-Agricultural Uses								
Agricultural uncultivated areas, non-agricultural uncultivated areas[g]	CA	Groundspray	1.00/1/-	0.00107	8.75E-05	0.00427	4.17E-06	1.07E-05

Table C-1 Estimated environmental concentrations (EECs) and risk quotients (RQs) for DS exposed to non-ULV uses of malathion[a]

Crop	*State*	*Application Method*	*Max. Application Rate (lb ai/A)/No. Applications per Season/ Retreatment Interval (d)*	*EECs (µg/L)*		*Freshwater/ Marine Fish*	*Freshwater Fish*	*Marine Fish*
				Peak	*60-day*	*Acute[b]*	*Chronic[c]*	*Chronic[d]*
Agricultural uncultivated areas, non-agricultural uncultivated areas[g]	CA	Airblast	1.00/1/-	0.00194	1.68E-04	0.00776	7.99E-06	2.05E-05
Agricultural uncultivated areas, non-agricultural uncultivated areas[g]	CA	Aerial	1.00/1/-	0.00289	2.49E-04	0.0116	1.18E-05	3.03E-05
Christmas tree plantations, pine seed orchards	CA	Groundspray	3.20/2/7	6.84	0.804	**27.4**	0.0383	0.0980
Christmas tree plantations, pine seed orchards	CA	Airblast	3.20/2/7	11.3	1.46	**45.3**	0.0696	0.178
Christmas tree plantations, pine seed orchards	CA	Aerial	3.20/2/7	15.7	2.10	**62.8**	0.100	0.256
Fence rows/ hedge rows[g]	CA	Groundspray	10.62/4/7	0.0358	0.00396	0.143	1.89E-04	4.83E-04
Household/ domestic dwellings (perimeter)/ refuse/ solid waste sites/ containers[g]	CA	Groundspray	10.62/4/7	0.00934	0.00216	0.0374	1.03E-04	2.64E-04
Household/domestic dwellings (perimeter)/ refuse/ solid waste sites/ containers[g]	CA	Groundspray	10.62/4/7	0.401	0.0467	**1.60**	0.00222	0.00569
Ornamentals	CA	Groundspray	4.00/2/10	7.02	0.714	**28.1**	0.0340	0.0870

[a] RQs greater than 1 are bolded.
[b] RQs calculated using the concentration of 0.250 µg a.i./L associated with a chance of 1 in a million of causing mortality to DS (calculated using an HC5 of 12.3 µg a.i./L and a slope of 2.81).
[c] RQs calculated using 97-d NOEL (fry survival between day 37 and 97) of 21 µg a.i./L for *Oncorhynchus mykiss* (Cohle, 1989 [MRID 41422401]).
[d] RQs calculated using 34-d NOEL (fry survival) of 8.2 µg a.i./L for *Cyprinodon variegates* (Hurd and Sharpe, 2011 [MRID 48705301]).
[e] EECs calculated using the Pesticides in Flooded Applications Model (PFAM pre-release version 1.0) and calibrated half-life of 1 day.
[f] EECs calculated using the Pesticides in Flooded Applications Model (PFAM pre-release version 1.0) and screening-level half-life of 2.2 days.
[g] EECs calculated using EPA's modeling approach for some non-agricultural uses (EPA, 2010).

Table C-2 Estimated environmental concentrations (EECs) and risk quotients (RQs) for DS exposed to ULV uses of malathion[a]

Crop	*State*	*Application Method*	*Max. Application Rate (lb ai/A)/No. Applications per Season/Retreatment Interval (d)*	*EECs (µg/L)*		*Freshwater/ Marine Fish*	*Freshwater Fish*	*Marine Fish*
				Peak	*60-day*	*Acute[b]*	*Chronic[c]*	*Chronic[d]*
Alfalfa, Clover, Lespedeza, Trefoil, Vetch	CA	Groundspray	0.61/6/14-16	0.835	0.156	**3.34**	0.00743	0.0190
Alfalfa, Clover, Lespedeza, Trefoil, Vetch	CA	Aerial	0.61/6/14-16	2.19	0.644	**8.75**	0.0306	0.0785
Barley	CA	Groundspray	0.61/2/7	1.00	0.127	**4.02**	0.00602	0.0154
Barley	CA	Aerial	0.61/2/7	2.65	0.341	**10.6**	0.0162	0.0416
Beans	CA	Groundspray	0.61/2/7	0.940	0.119	**3.76**	0.00568	0.0146
Beans	CA	Aerial	0.61/2/7	2.43	0.353	**9.70**	0.0168	0.0430
Blueberries	CA	Groundspray	0.77/3/10	0.497	0.107	**1.99**	0.00510	0.0131
Cherry	CA	Groundspray	1.22/4/7	1.60	0.330	**6.41**	0.0157	0.0403
Cherry	CA	Airblast	1.22/4/7	3.28	0.812	**13.1**	0.0387	0.0990
Cherry	CA	Aerial	1.22/4/7	5.04	1.31	**20.2**	0.0623	0.160
Citrus, Grapefruit, Lemon, Lime, Orange, Tangelo, Tangerines	CA	Groundspray	0.175/3/7	0.193	0.0321	0.770	0.00153	0.00391
Citrus, Grapefruit, Lemon, Lime, Orange, Tangelo, Tangerines	CA	Airblast	0.175/3/7	0.417	0.0877	**1.67**	0.00418	0.0107
Citrus, Grapefruit, Lemon, Lime, Orange, Tangelo, Tangerines	CA	Aerial	0.175/3/7	0.689	0.146	**2.76**	0.00695	0.0178
Citrus, kumquats	CA	Groundspray	0.175/2/7	0.145	0.0217	0.580	0.00103	0.00265
Citrus, kumquats	CA	Airblast	0.175/2/7	0.388	0.0586	**1.55**	0.00279	0.00715
Citrus, kumquats	CA	Aerial	0.175/2/7	0.642	0.0975	**2.57**	0.00464	0.0119
Corn (sweet and pop)	CA	Groundspray	0.61/2/5	0.541	0.0774	**2.16**	0.00369	0.00944
Corn (sweet and pop)	CA	Aerial	0.61/2/5	2.42	0.311	**9.67**	0.0148	0.0379
Cotton	CA	Groundspray	1.22/3/7	1.85	0.260	**7.39**	0.0124	0.0317

Table C-2 Estimated environmental concentrations (EECs) and risk quotients (RQs) for DS exposed to ULV uses of malathion[a]

Crop	*State*	*Application Method*	*Max. Application Rate (lb ai/A)/No. Applications per Season/Retreatment Interval (d)*	*EECs (µg/L)*		*Freshwater/ Marine Fish*	*Freshwater Fish*	*Marine Fish*
				Peak	*60-day*	*Acute[b]*	*Chronic[c]*	*Chronic[d]*
Cotton	CA	Groundspray	1.22/3/7	2.08	0.303	**8.33**	0.0144	0.0369
Cotton	CA	Aerial	1.22/3/7	4.98	0.962	**19.9**	0.0458	0.117
Cotton	CA	Aerial	1.22/3/7	5.07	1.00	**20.3**	0.0478	0.122
Grass, Forage, Hay, Pasture, Rangeland	CA	Groundspray	0.92/1/-	1.39	0.194	**5.56**	0.00924	0.0237
Grass, Forage, Hay, Pasture, Rangeland	CA	Aerial	0.92/1/-	3.37	0.569	**13.5**	0.0271	0.0694
Lupine	CA	Groundspray	0.61/1/-	0.592	0.0498	**2.37**	0.00237	0.00607
Lupine	CA	Aerial	0.61/1/-	1.95	0.173	**7.79**	0.00824	0.0211
Rye	CA	Groundspray	0.61/1/-	1.29	0.124	**5.15**	0.00590	0.0151
Rye	CA	Aerial	0.61/1/-	2.59	0.246	**10.4**	0.0117	0.0300
Sorghum, Oats, Wheat	CA	Groundspray	0.61/2/7	1.51	0.164	**6.02**	0.00782	0.0200
Sorghum, Oats, Wheat	CA	Aerial	0.61/2/7	3.14	0.411	**12.6**	0.0196	0.0501

[a] RQs greater than 1 are bolded.
[b] RQs calculated using the concentration of 0.250 µg a.i./L associated with a chance of 1 in a million of causing mortality to DS (calculated using an HC5 of 12.3 µg a.i./L and a slope of 2.81).
[c] RQs calculated using 97-d NOEL (fry survival between day 37 and 97) of 21 µg a.i./L for *Oncorhynchus mykiss* (Cohle, 1989 [MRID 41422401]).
[d] RQs calculated using 34-d NOEL (fry survival) of 8.2 µg a.i./L for *Cyprinodon variegates* (Hurd and Sharpe, 2011 [MRID 48705301]).

Table C-3 Estimated environmental concentrations (EECs) and risk quotients (RQs) for aquatic invertebrates exposed to non-ULV uses of malathion[a]

Crop	*State*	*Application Method*	*Max. Application Rate (lb ai/A)/No. Applications per Season/ Retreatment Interval (d)*	*EECs (µg/L)*		*Freshwater/ Marine Invertebrates*	*Freshwater Invertebrates*	*Marine Invertebrates*
				Peak	*21-day*	*Acute[b]*	*Chronic[c]*	*Chronic[d]*
Agricultural Uses								
Alfalfa, Clover, Lespedeza, Trefoil, Vetch	CA	Groundspray	1.25/6/14-16	1.71	0.529	**9.66**	**5.29**	0.911
Alfalfa, Clover, Lespedeza, Trefoil, Vetch	CA	Aerial	1.25/6/14-16	4.48	1.74	**25.3**	**17.4**	**3.00**
Apricot	CA	Groundspray	1.50/2/7	0.999	0.330	**5.65**	**3.30**	0.569
Apricot	CA	Airblast	1.50/2/7	3.00	0.989	**16.9**	**9.89**	**1.71**
Apricot	CA	Aerial	1.5/2/7	6.04	2.27	**34.1**	**22.7**	**3.91**
Asparagus, Carrots	CA	Groundspray	1.25/2/7	1.11	0.432	**6.30**	**4.32**	0.744
Asparagus, Carrots	CA	Aerial	1.25/2/7	4.60	1.75	**26.0**	**17.5**	**3.02**
Avocado	CA	Groundspray	4.70/2/30	11.8	2.53	**66.5**	**25.3**	**4.37**
Avocado	CA	Airblast	4.70/2/30	15.3	3.66	**86.7**	**36.6**	**6.31**
Barley	CA	Groundspray	1.25/2/7	2.02	0.689	**11.4**	**6.89**	**1.19**
Barley	CA	Aerial	1.25/2/7	5.38	1.90	**30.4**	**19.0**	**3.27**
Beets	CA	Groundspray	1.25/3/7	2.11	0.802	**11.9**	**8.02**	**1.38**
Beets	CA	Aerial	1.25/3/7	5.58	2.62	**31.5**	**26.2**	**4.53**
Blueberries	CA	Groundspray	1.25/3/5	1.05	0.470	**5.93**	**4.70**	0.811
Blueberries	CA	Aerial	1.25/3/5	5.57	2.55	**31.5**	**25.5**	**4.40**
Broccoli, Chinese Broccoli, Broccoli raab, Cauliflower	CA	Groundspray	1.25/2/7	2.57	0.868	**14.5**	**8.68**	**1.50**
Broccoli, Chinese Broccoli, Broccoli raab, Cauliflower	CA	Aerial	1.25/2/7	5.41	2.19	**30.6**	**21.9**	**3.78**
Brussels Sprouts, Dandelion	CA	Groundspray	1.25/2/7	1.88	0.568	**10.6**	**5.68**	0.979
Brussels Sprouts, Dandelion	CA	Aerial	1.25/2/7	5.36	1.87	**30.3**	**18.7**	**3.23**
Cabbage, Horseradish, Kohlrabi	CA	Groundspray	1.25/6/7	2.78	1.08	**15.7**	**10.8**	**1.86**
Cabbage, Horseradish, Kohlrabi	CA	Aerial	1.25/6/7	6.26	3.08	**35.4**	**30.8**	**5.31**
Caneberries (Gooseberry, Blackberry, Boysenberry,	CA	Groundspray	2.00/3/7	1.84	0.864	**10.4**	**8.64**	**1.49**

Table C-3 Estimated environmental concentrations (EECs) and risk quotients (RQs) for aquatic invertebrates exposed to non-ULV uses of malathion[a]

Crop	*State*	*Application Method*	*Max. Application Rate (lb ai/A)/No. Applications per Season/ Retreatment Interval (d)*	*EECs (µg/L)*		*Freshwater/ Marine Invertebrates*	*Freshwater Invertebrates*	*Marine Invertebrates*
				Peak	*21-day*	*Acute[b]*	*Chronic[c]*	*Chronic[d]*
Dewberry, Loganberry, Raspberry, Currents)								
Caneberries (Gooseberry, Blackberry, Boysenberry, Dewberry, Loganberry, Raspberry, Currents)	CA	Airblast	2.00/3/7	4.82	2.34	**27.2**	**23.4**	**4.04**
Caneberries (Gooseberry, Blackberry, Boysenberry, Dewberry, Loganberry, Raspberry, Currents)	CA	Aerial	2.00/3/7	7.78	3.81	**44.0**	**38.1**	**6.57**
Celery	CA	Groundspray	1.50/2/7	2.31	0.810	**13.1**	**8.10**	**1.40**
Celery	CA	Aerial	1.50/2/7	5.95	2.38	**33.6**	**23.8**	**4.10**
Cherry	CA	Groundspray	1.75/4/3	3.57	1.39	**20.1**	**13.9**	**2.39**
Cherry	CA	Airblast	1.75/4/3	7.25	3.22	**40.9**	**32.2**	**5.55**
Cherry	CA	Aerial	1.75/4/3	11.2	5.06	**63.4**	**50.6**	**8.72**
Chinese greens (Chinese cabbage)	CA	Groundspray	1.25/2/7	1.93	0.675	**10.9**	**6.75**	**1.16**
Chinese greens (Chinese cabbage)	CA	Aerial	1.25/2/7	4.96	1.98	**28.0**	**19.8**	**3.42**
Citrus, Grapefruit, Lemon, Lime, Orange, Tangelo, Tangerines	CA	Groundspray	1.50/3/30	1.10	0.265	**6.19**	**2.65**	0.457
Citrus, Grapefruit, Lemon, Lime, Orange, Tangelo, Tangerines	CA	Airblast	1.50/3/30	2.73	0.705	**15.4**	**7.05**	**1.22**
Citrus, Grapefruit, Lemon, Lime, Orange, Tangelo, Tangerines	CA	Aerial	1.50/3/30	4.37	1.17	**24.7**	**11.7**	**2.01**
Citrus, Grapefruit, Lemon, Lime, Orange, Tangelo, Tangerines, Kumquats	CA	Airblast	7.50/1/-	13.4	3.47	**75.7**	**34.7**	**5.99**
Collards	CA	Groundspray	1.00/3/7	2.21	0.806	**12.5**	**8.06**	**1.39**
Collards	CA	Aerial	1.00/3/7	4.96	2.27	**28.0**	**22.7**	**3.92**
Corn (field)	CA	Groundspray	1.00/2/7	0.749	0.285	**4.23**	**2.85**	0.492

Table C-3 Estimated environmental concentrations (EECs) and risk quotients (RQs) for aquatic invertebrates exposed to non-ULV uses of malathion[a]

Crop	*State*	*Application Method*	*Max. Application Rate (lb ai/A)/No. Applications per Season/ Retreatment Interval (d)*	*EECs (µg/L)*		*Freshwater/ Marine Invertebrates*	*Freshwater Invertebrates*	*Marine Invertebrates*
				Peak	*21-day*	*Acute[b]*	*Chronic[c]*	*Chronic[d]*
Corn (Field)	CA	Aerial	1.00/2/7	3.60	1.34	**20.3**	**13.4**	**2.31**
Corn (Sweet and Pop)	CA	Groundspray	1.00/2/5	0.886	0.350	**5.00**	**3.50**	0.603
Corn (Sweet and Pop)	CA	Aerial	1.00/2/5	3.96	1.41	**22.4**	**14.1**	**2.43**
Cotton	CA	Groundspray	2.50/3/7	3.54	1.27	**20.0**	**12.7**	**2.19**
Cotton	CA	Groundspray	2.50/3/7	3.95	1.49	**22.3**	**14.9**	**2.56**
Cotton	CA	Aerial	2.50/3/7	10.2	4.94	**57.6**	**49.4**	**8.52**
Cotton	CA	Aerial	2.50/3/7	10.1	5.15	**57.0**	**51.5**	**8.87**
Cucumber, Chayote Fruit	CA	Groundspray	1.75/2/7	1.17	0.381	**6.59**	**3.81**	0.657
Cucumber, Chayote Fruit	CA	Aerial	1.75/2/7	5.83	1.91	**32.9**	**19.1**	**3.29**
Eggplant (4 apps), Oriental eggplant (5 apps)	CA	Groundspray	1.56/5/5	1.31	0.705	**7.41**	**7.05**	**1.22**
Eggplant (4 apps), Oriental eggplant (5 apps)	CA	Aerial	1.56/5/5	6.27	3.48	**35.4**	**34.8**	**6.00**
Figs	CA	Groundspray	2.00/2/5	1.82	0.646	**10.3**	**6.46**	**1.11**
Figs	CA	Airblast	2.00/2/5	4.88	1.67	**27.5**	**16.7**	**2.89**
Figs	CA	Aerial	2.00/2/5	8.77	3.07	**49.5**	**30.7**	**5.29**
Flax	CA	Groundspray	0.50/3/7	0.707	0.255	**4.00**	**2.55**	0.439
Flax	CA	Aerial	0.50/3/7	2.04	0.988	**11.5**	**9.88**	**1.70**
Garlic	CA	Groundspray	1.56/3/7	1.51	0.675	**8.56**	**6.75**	**1.16**
Garlic	CA	Aerial	1.56/3/7	5.79	2.83	**32.7**	**28.3**	**4.88**
Grapes (Raisin, table, wine)	CA	Groundspray	1.88/2/14	1.16	0.466	**6.57**	**4.66**	0.803
Grapes (Raisin, table, wine)	CA	Airblast	1.88/2/14	3.41	1.31	**19.3**	**13.1**	**2.26**
Grapes (Raisin, table, wine)	CA	Aerial	1.88/2/14	5.93	2.52	**33.5**	**25.2**	**4.34**
Grass, Forage, Hay, Pasture, Rangeland	CA	Groundspray	1.25/1/-	1.66	0.455	**9.41**	**4.55**	0.785
Grass, Forage, Hay, Pasture, Rangeland	CA	Aerial	1.25/1/-	4.42	1.19	**25.0**	**11.9**	**2.05**
Guava	CA	Groundspray	1.25/13/3	3.44	1.77	**19.5**	**17.7**	**3.06**
Guava	CA	Airblast	1.25/13/3	6.51	4.18	**36.8**	**41.8**	**7.21**
Guava	CA	Aerial	1.25/13/3	9.52	6.71	**53.8**	**67.1**	**11.6**
Hops	OR	Groundspray	0.63/3/7	0.488	0.251	**2.76**	**2.51**	0.432
Hops	OR	Aerial	0.63/3/7	2.43	1.24	**13.7**	**12.4**	**2.14**
Kale, Mustard	CA	Groundspray	1.00/3/5	2.42	0.783	**13.7**	**7.83**	**1.35**

Table C-3 Estimated environmental concentrations (EECs) and risk quotients (RQs) for aquatic invertebrates exposed to non-ULV uses of malathion[a]

Crop	*State*	*Application Method*	*Max. Application Rate (lb ai/A)/No. Applications per Season/ Retreatment Interval (d)*	*EECs (µg/L)*		*Freshwater/ Marine Invertebrates*	*Freshwater Invertebrates*	*Marine Invertebrates*
				Peak	*21-day*	*Acute[b]*	*Chronic[c]*	*Chronic[d]*
Kale, Mustard	CA	Aerial	1.00/3/5	5.76	2.40	**32.5**	**24.0**	**4.14**
Leek	CA	Groundspray	1.56/2/7	1.24	0.489	**6.99**	**4.89**	0.843
Leek	CA	Aerial	1.56/2/7	5.52	2.05	**31.2**	**20.5**	**3.53**
Lettuce, Endive, Spinach, Swiss chard	CA	Groundspray	1.88/2/5	4.84	1.31	**27.3**	**13.1**	**2.25**
Lettuce, Endive, Spinach, Swiss chard	CA	Aerial	1.88/2/5	10.5	3.25	**59.2**	**32.5**	**5.61**
Macadamia nut	CA	Groundspray	0.94/6/7	0.738	0.350	**4.17**	**3.50**	0.603
Macadamia nut	CA	Airblast	0.94/6/7	2.07	1.01	**11.7**	**10.1**	**1.74**
Macadamia nut	CA	Aerial	0.94/6/7	4.60	2.35	**26.0**	**23.5**	**4.04**
Mango	CA	Groundspray	0.94/10/7	0.985	0.453	**5.57**	**4.53**	0.781
Mango	CA	Airblast	0.94/10/7	2.30	1.21	**13.0**	**12.1**	**2.08**
Mango	CA	Aerial	0.94/10/7	4.52	2.21	**25.5**	**22.1**	**3.81**
Melon (not Watermelon), Pumpkin, Cantaloupe	CA	Groundspray	1.00/2/7	0.666	0.218	**3.76**	**2.18**	0.376
Melon (not Watermelon), Pumpkin, Cantaloupe	CA	Aerial	1.00/2/7	3.33	1.09	**18.8**	**10.9**	**1.88**
Mint	OR	Groundspray	0.94/3/7	0.728	0.365	**4.11**	**3.65**	0.630
Mint	OR	Aerial	0.94/3/7	3.62	1.83	**20.5**	**18.3**	**3.15**
Nectarine	CA	Groundspray	3.00/3/7	2.95	1.25	**16.6**	**12.5**	**2.16**
Nectarine	CA	Airblast	3.00/3/7	6.93	3.39	**39.2**	**33.9**	**5.84**
Okra	CA	Groundspray	1.20/5/7	0.776	0.333	**4.39**	**3.33**	0.574
Okra	CA	Aerial	1.20/5/7	3.87	1.66	**21.9**	**16.6**	**2.87**
Onion, Shallot	CA	Groundspray	1.56/2/7	1.35	0.461	**7.62**	**4.61**	0.796
Onion, Shallot	CA	Aerial	1.56/2/7	5.71	2.30	**32.3**	**23.0**	**3.97**
Papaya	CA	Groundspray	1.25/8/3	3.42	1.58	**19.3**	**15.8**	**2.72**
Papaya	CA	Airblast	1.25/8/3	6.48	3.81	**36.6**	**38.1**	**6.58**
Papaya	CA	Aerial	1.25/8/3	9.11	6.10	**51.5**	**61.0**	**10.5**
Parsley	CA	Groundspray	1.50/2/7	2.26	0.681	**12.8**	**6.81**	**1.17**
Parsley	CA	Aerial	1.50/2/7	6.44	2.25	**36.4**	**22.5**	**3.88**
Passion fruit	CA	Groundspray	1.00/8/7	1.03	0.488	**5.80**	**4.88**	0.841
Passion fruit	CA	Aerial	1.00/8/7	4.01	2.16	**22.6**	**21.6**	**3.72**
Peaches	CA	Groundspray	3.00/3/11	3.56	1.23	**20.1**	**12.3**	**2.13**

Table C-3 Estimated environmental concentrations (EECs) and risk quotients (RQs) for aquatic invertebrates exposed to non-ULV uses of malathion[a]

Crop	*State*	*Application Method*	*Max. Application Rate (lb ai/A)/No. Applications per Season/ Retreatment Interval (d)*	*EECs (µg/L)*		*Freshwater/ Marine Invertebrates*	*Freshwater Invertebrates*	*Marine Invertebrates*
				Peak	*21-day*	*Acute[b]*	*Chronic[c]*	*Chronic[d]*
Peaches	CA	Airblast	3.00/3/11	7.45	2.99	**42.1**	**29.9**	**5.16**
Peaches	CA	Aerial	3.00/3/11	11.2	4.69	**63.3**	**46.9**	**8.08**
Pears, Apple	CA	Groundspray	1.25/2/7	0.954	0.362	**5.39**	**3.62**	0.625
Pears, Apple	CA	Airblast	1.25/2/7	2.67	0.976	**15.1**	**9.76**	**1.68**
Pears, Apple	CA	Aerial	1.25/2/7	5.03	1.89	**28.4**	**18.9**	**3.25**
Peas	CA	Groundspray	1.00/2/7	1.54	0.540	**8.70**	**5.40**	0.931
Peas	CA	Aerial	1.00/2/7	3.97	1.59	**22.4**	**15.9**	**2.73**
Pecan	CA	Groundspray	2.50/2/7	1.82	0.609	**10.3**	**6.09**	**1.05**
Pecan	CA	Airblast	2.50/2/7	5.24	1.77	**29.6**	**17.7**	**3.05**
Pecan	CA	Aerial	2.50/2/7	10.6	3.88	**60.1**	**38.8**	**6.69**
Peppers	CA	Groundspray	1.56/2/5	1.64	0.517	**9.26**	**5.17**	0.892
Peppers	CA	Aerial	1.56/2/5	6.29	2.20	**35.6**	**22.0**	**3.79**
Pineapple	CA	Groundspray	2.00/3/7	1.77	0.798	**9.98**	**7.98**	**1.38**
Pineapple	CA	Aerial	2.00/3/7	8.48	4.12	**47.9**	**41.2**	**7.11**
Potato, Sweet potato, Yams	CA	Groundspray	1.56/2/7	1.77	0.547	**10.0**	**5.47**	0.943
Potato, Sweet potato, Yams	CA	Aerial	1.56/2/7	5.77	2.13	**32.6**	**21.3**	**3.67**
Radish	CA	Groundspray	1.00/3/7	1.01	0.479	**5.72**	**4.79**	0.825
Radish	CA	Aerial	1.00/3/7	3.91	2.00	**22.1**	**20.0**	**3.45**
Rice, wildrice[e]	AR	Direct	1.25/2/7	98.0	26.1	**554**	**261**	**45.0**
Rice, wildrice[f]	AR	Direct	1.25/2/7	145	68.2	**819**	**682**	**118**
Rice, Wildrice[e]	LA, Gulf	Direct	1.25/2/7	121	24.6	**684**	**246**	**42.4**
Rice, Wildrice[f]	LA, Gulf	Direct	1.25/2/7	185	67.3	**1045**	**673**	**116**
Rye	CA	Groundspray	1.00/3/7	2.61	0.882	**14.7**	**8.82**	**1.52**
Rye	CA	Aerial	1.00/3/7	5.09	2.37	**28.7**	**23.7**	**4.08**
Salsify	CA	Groundspray	1.25/3/7	1.96	0.772	**11.1**	**7.72**	**1.33**
Salsify	CA	Aerial	1.25/3/7	5.61	2.54	**31.7**	**25.4**	**4.38**
Sorghum, Oats, Wheat	CA	Groundspray	1.00/2/7	2.40	0.700	**13.6**	**7.00**	**1.21**
Sorghum, Oats, Wheat	CA	Aerial	1.00/2/7	5.08	1.80	**28.7**	**18.0**	**3.10**
Squash (Summer)	CA	Groundspray	1.75/3/7	1.20	0.526	**6.78**	**5.26**	0.907
Squash (Summer)	CA	Aerial	1.75/3/7	6.00	2.63	**33.9**	**26.3**	**4.53**
Squash (Winter)	CA	Groundspray	1.00/3/7	0.686	0.300	**3.88**	**3.00**	0.518

Table C-3 Estimated environmental concentrations (EECs) and risk quotients (RQs) for aquatic invertebrates exposed to non-ULV uses of malathion[a]

Crop	*State*	*Application Method*	*Max. Application Rate (lb ai/A)/No. Applications per Season/ Retreatment Interval (d)*	*EECs (µg/L)*		*Freshwater/ Marine Invertebrates*	*Freshwater Invertebrates*	*Marine Invertebrates*
				Peak	*21-day*	*Acute[b]*	*Chronic[c]*	*Chronic[d]*
Squash (Winter)	CA	Aerial	1.00/3/7	3.43	1.50	**19.4**	**15.0**	**2.59**
Strawberry	CA	Groundspray	2.00/4/7	10.2	3.15	**57.5**	**31.5**	**5.42**
Strawberry	CA	Aerial	2.00/4/7	15.4	6.45	**87.2**	**64.5**	**11.1**
Tomato, Tomatillo	CA	Groundspray	1.56/4/5	1.30	0.653	**7.35**	**6.53**	**1.13**
Tomato, Tomatillo	CA	Aerial	1.56/4/5	6.23	3.21	**35.2**	**32.1**	**5.54**
Turnips, Rutabaga, Parsnips	CA	Groundspray	1.25/3/5	2.17	0.599	**12.3**	**5.99**	**1.03**
Turnips, Rutabaga, Parsnips	CA	Aerial	1.25/3/5	5.70	2.49	**32.2**	**24.9**	**4.29**
Walnut, Chestnut	CA	Groundspray	2.50/3/7	1.94	0.861	**11.0**	**8.61**	**1.48**
Walnut, Chestnut	CA	Airblast	2.50/3/7	5.43	2.49	**30.7**	**24.9**	**4.29**
Walnut, Chestnut	CA	Aerial	2.50/3/7	11.1	5.27	**62.8**	**52.7**	**9.08**
Watercress[e]	CA	Direct	1.25/5/3	85.9	38.2	**485**	**382**	**65.9**
Watercress[f]	CA	Direct	1.25/5/3	127	69.0	**718**	**690**	**119**
Watermelon	CA	Groundspray	1.50/4/7	1.03	0.456	**5.84**	**4.56**	0.785
Watermelon	CA	Aerial	1.50/4/7	5.14	2.28	**29.0**	**22.8**	**3.93**
Non-Agricultural Uses								
Agricultural uncultivated areas, non-agricultural uncultivated areas[g]	CA	Groundspray	1.00/1/-	0.00107	2.47E-04	0.00603	0.00247	4.25E-04
Agricultural uncultivated areas, non-agricultural uncultivated areas[g]	CA	Airblast	1.00/1/-	0.00194	4.72E-04	0.0110	0.00472	8.14E-04
Agricultural uncultivated areas, non-agricultural uncultivated areas[g]	CA	Aerial	1.00/1/-	0.00289	7.00E-04	0.0163	0.00700	0.00121
Christmas tree plantations, pine seed orchards	CA	Groundspray	3.20/2/7	6.84	2.15	**38.6**	**21.5**	**3.70**
Christmas tree plantations, pine seed orchards	CA	Airblast	3.20/2/7	11.3	3.93	**64.0**	**39.3**	**6.78**
Christmas tree plantations, pine seed orchards	CA	Aerial	3.20/2/7	15.7	5.68	**88.7**	**56.8**	**9.79**
Fence rows/ hedge rows[g]	CA	Groundspray	10.62/4/7	0.0358	0.00954	0.202	0.0954	0.0164

Table C-3 Estimated environmental concentrations (EECs) and risk quotients (RQs) for aquatic invertebrates exposed to non-ULV uses of malathion[a]

Crop	*State*	*Application Method*	*Max. Application Rate (lb ai/A)/No. Applications per Season/ Retreatment Interval (d)*	*EECs (µg/L)*		*Freshwater/ Marine Invertebrates*	*Freshwater Invertebrates*	*Marine Invertebrates*
				Peak	*21-day*	*Acute[b]*	*Chronic[c]*	*Chronic[d]*
Household/domestic dwellings (perimeter)/ refuse/ solid waste sites/ containers[g]	CA	Groundspray	10.62/4/7	0.00934	0.00455	0.0528	0.0455	0.00785
Household/domestic dwellings (perimeter)/ refuse/ solid waste sites/ containers[g]	CA	Groundspray	10.62/4/7	0.401	0.122	**2.27**	**1.22**	0.211
Ornamentals	CA	Groundspray	4.00/2/10	7.02	1.95	**39.7**	**19.5**	**3.36**

[a] RQs greater than 1 are bolded.
[b] RQs calculated using the concentration of 0.177 µg a.i./L associated with a 10% probability of mortality to aquatic invertebrates (calculated using an HC5 of 0.476 µg a.i./L and a slope of 2.99).
[c] RQs calculated using 21 d LOEL 0.1 µg a.i./L (survival growth and reproduction) for waterflea *(Daphnia magna*) (Blakemore and Burgess, 1990 [MRID 41718401]).
[d] RQs calculated using 39 d LOEL (reproduction) 0.58 µg a.i./L for saltwater mysid (*Americamysis bahia*) (Claude et al., 2012 [MRID 48752901]).
[e] EECs calculated using the Pesticides in Flooded Applications Model (PFAM pre-release version 1.0) and calibrated half-life of 1 day.
[f] EECs calculated using the Pesticides in Flooded Applications Model (PFAM pre-release version 1.0) and screening-level half-life of 2.2 days.
[g] EECs calculated using EPA's modeling approach for some non-agricultural uses (EPA, 2010).

Table C-4 Estimated environmental concentrations (EECs) and risk quotients (RQs) for aquatic invertebrates exposed to ULV uses of malathion[a]

Crop	*State*	*Application Method*	*Max. Application Rate (lb ai/A)/No. Applications per Season/ Retreatment Interval (d)*	*EECs (µg/L)*		*Freshwater/ Marine Invertebrates*	*Freshwater Invertebrates*	*Marine Invertebrates*
				Peak	*21-day*	*Acute[b]*	*Chronic[c]*	*Chronic[d]*
Alfalfa, Clover, Lespedeza, Trefoil, Vetch	CA	Groundspray	0.61/6/14-16	0.835	0.259	**4.72**	**2.59**	0.447
Alfalfa, Clover, Lespedeza, Trefoil, Vetch	CA	Aerial	0.61/6/14-16	2.19	0.852	**12.4**	**8.52**	**1.47**
Barley	CA	Groundspray	0.61/2/7	1.00	0.349	**5.67**	**3.49**	0.602
Barley	CA	Aerial	0.61/2/7	2.65	0.937	**15.0**	**9.37**	**1.62**
Beans	CA	Groundspray	0.61/2/7	0.940	0.329	**5.31**	**3.29**	0.568
Beans	CA	Aerial	0.61/2/7	2.43	0.968	**13.7**	**9.68**	**1.67**
Blueberries	CA	Groundspray	0.77/3/10	0.497	0.211	**2.81**	**2.11**	0.364
Cherry	CA	Groundspray	1.22/4/7	1.60	0.718	**9.05**	**7.18**	**1.24**
Cherry	CA	Airblast	1.22/4/7	3.28	1.73	**18.5**	**17.3**	**2.99**
Cherry	CA	Aerial	1.22/4/7	5.04	2.76	**28.5**	**27.6**	**4.76**
Citrus, Grapefruit, Lemon, Lime, Orange, Tangelo, Tangerines	CA	Groundspray	0.175/3/7	0.193	0.0827	**1.09**	0.827	0.143
Citrus, Grapefruit, Lemon, Lime, Orange, Tangelo, Tangerines	CA	Airblast	0.175/3/7	0.417	0.215	**2.36**	**2.15**	0.371
Citrus, Grapefruit, Lemon, Lime, Orange, Tangelo, Tangerines	CA	Aerial	0.175/3/7	0.689	0.357	**3.89**	**3.57**	0.615
Citrus, Kumquats	CA	Groundspray	0.175/2/7	0.145	0.0571	0.819	0.571	0.0984
Citrus, Kumquats	CA	Airblast	0.175/2/7	0.388	0.157	**2.19**	**1.57**	0.270
Citrus, Kumquats	CA	Aerial	0.175/2/7	0.642	0.261	**3.63**	**2.61**	0.449
Corn (Sweet and Pop)	CA	Groundspray	0.61/2/5	0.541	0.215	**3.05**	**2.15**	0.370
Corn (Sweet and Pop)	CA	Aerial	0.61/2/5	2.42	0.862	**13.7**	**8.62**	**1.49**
Cotton	CA	Groundspray	1.22/3/7	1.85	0.637	**10.4**	**6.37**	**1.10**
Cotton	CA	Groundspray	1.22/3/7	2.08	0.752	**11.8**	**7.52**	**1.30**
Cotton	CA	Aerial	1.22/3/7	4.98	2.43	**28.1**	**24.3**	**4.18**
Cotton	CA	Aerial	1.22/3/7	5.07	2.54	**28.6**	**25.4**	**4.37**
Grass, Forage, Hay, Pasture, Rangeland	CA	Groundspray	0.92/1/-	1.39	0.396	**7.85**	**3.96**	0.682

Table C-4 Estimated environmental concentrations (EECs) and risk quotients (RQs) for aquatic invertebrates exposed to ULV uses of malathion[a]

Crop	*State*	*Application Method*	*Max. Application Rate (lb ai/A)/No. Applications per Season/ Retreatment Interval (d)*	*EECs (µg/L)*		*Freshwater/ Marine Invertebrates*	*Freshwater Invertebrates*	*Marine Invertebrates*
				Peak	*21-day*	*Acute[b]*	*Chronic[c]*	*Chronic[d]*
Grass, Forage, Hay, Pasture, Rangeland	CA	Aerial	0.92/1/-	3.37	0.935	**19.0**	**9.35**	**1.61**
Lupine	CA	Groundspray	0.61/1/-	0.592	0.140	**3.35**	**1.40**	0.241
Lupine	CA	Aerial	0.61/1/-	1.95	0.483	**11.0**	**4.83**	0.832
Rye	CA	Groundspray	0.61/1/-	1.29	0.345	**7.27**	**3.45**	0.594
Rye	CA	Aerial	0.61/1/-	2.59	0.684	**14.7**	**6.84**	**1.18**
Sorghum, Oats, Wheat	CA	Groundspray	0.61/2/7	1.51	0.434	**8.51**	**4.34**	0.749
Sorghum, Oats, Wheat	CA	Aerial	0.61/2/7	3.14	1.10	**17.7**	**11.0**	**1.90**

[a] RQs greater than 1 are bolded.
[b] RQs calculated using the concentration of 0.177 µg a.i./L associated with a 10% probability of mortality to aquatic invertebrates (calculated using an HC5 of 0.476 µg a.i./L and a slope of 2.99).
[c] RQs calculated using 21 d LOEL 0.1 µg a.i./L (survival growth and reproduction) for waterflea *(Daphnia magna*) (Blakemore and Burgess, 1990 [MRID 41718401]).
[d] RQs calculated using 39 d LOEL (reproduction) 0.58 µg a.i./L for saltwater mysid (*Americamysis bahia*) (Claude et al., 2012 [MRID 48752901]).

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Appendix D
Spatial Analysis of Malathion Application to Rice and Watercress Relative to Delta Smelt Occurrence and Critical Habitat

An assessment of pesticide use on rice, wild rice, and watercress crops was completed by Stone Environmental to determine the spatial extent of the crops within delta smelt (DS) critical habitat and elemental occurrences (EOs) (Budreski and Winchell, 2014). The following text summarizes the results from Budreski and Winchell (2014). An assessment of the California Department of Pesticide Regulation (CDPR) Pesticide Use Reporting (PUR) was conducted to determine the spatial extent of historic pesticide applications on rice, wild rice and watercress from 2003 to 2012. This was followed by an analysis of National Agricultural Statistics Service (NASS) Cropland Data Layer (CDL) coverage of rice within the DS habitat.

2003 to 2012 PUR Pesticide Use in DS Habitat

Section-level PUR data from 2003 to 2012 were summarized for all pesticide applications on rice, wild rice and watercress crops. The overlap of section-reported applications over the 10 year time period and the DS critical habitat and elemental occurrences (EOs) was summarized. DS critical habitat and EO habitat areas from the DS Multi-Jurisdictional Database (MJD) and California Natural Diversity Database (CNDDB) were evaluated.

Table D-1 summarize the section-reported PUR applications and total pounds of active ingredient of those applications, respectively, within DS habitats for rice, wild rice, and watercress. There were 2,172 pesticide applications on rice sites within DS critical habitat, which amounted to 167,518 pounds of active ingredient over the 10 year period. However, only two of these pesticide applications within the DS critical habitat on rice were malathion applications. A total of 412 pounds of active ingredient of malathion was applied to rice within DS critical habitat over the 10 year period. There were 14 total pesticide applications on rice within a single CNDDB/MJD EO, amounting to 199 pounds of active ingredient Table D-2). This EO is within the DS critical habitat and, therefore, also included in the application totals for all pesticides within DS critical habitat in Table D-1 and Table D-2. However, there were no malathion applications on rice sites over the 10 year period within CNDDB or MJD EOs. The nearest malathion application on rice sites to CNDDB or MJD EOs from 2003 to 2012 was 23.4 km. Figure D-1 illustrates the extent of historic rice pesticide use in relation to DS habitat.

There were 40 pesticide applications on wild rice from 2003 to 2012 that were within DS critical habitat (Figure D-1) and applications within DS critical habitat amounted to 10,608 pounds of active ingredient (Table D-2). There were four malathion applications in the DS critical habitat on wild rice, which amounted to 937 pounds of active ingredient applied within DS critical habitat between 2003 and 2012. There were no pesticide applications to wild rice within CNDDB or MJD EOs over the 10 year period examined, with the closest malathion application being 23.4 km away. Figure D-2 illustrates the extent of historic wild rice pesticide use in relation to DS habitat.

There were no pesticide applications to watercress sites within DS critical habitat or EOs (Table D-1 and D-2). The nearest malathion application to DS habitat was 62.9 km away. Figure D-3 illustrates the extent of historic watercress pesticide use in relation to DS habitat.

Table D-1	Section-reported PUR summary of the number of applications and pesticide use from 2003 to 2012 on rice, wild rice, and watercress sites					
Crop	*Number of Applications*					
	All Pesticides			*Malathion*		
	Statewide	*DS Critical Habitat[a]*	*CNDDB/MJD EOs[a]*	*Statewide*	*DS Critical Habitat[a]*	*CNDDB/MJD EOs[a]*
Rice	253,707	2,172 (0.9%)	14 (<0.1%)	16	2 (12.5%)	0 (0.0%)
Wild rice	1,077	40 (3.7%)	0 (0.0%)	101	4 (4.0%)	0 (0.0%)
Watercress	2,329	0 (0.0%)	0 (0.0%)	891	0 (0.0%)	0 (0.0%)

[a] The percent of statewide section-reported applications are provided in parentheses for each category.

Table D-2	Section-reported PUR summary of the pounds of pesticide applied from 2003 to 2012 on rice, wild rice, and watercress sites					
Crop	*Lbs. of Active Ingredient*					
	All Pesticides			*Malathion*		
	Statewide	*DS Critical Habitat[a]*	*CNDDB/MJD EOs[a]*	*Statewide*	*DS Critical Habitat[a]*	*CNDDB/MJD EOs[a]*
Rice	44,824,024	167,517 (0.4%)	199 (<0.1%)	2,173	412 (19.0%)	0 (0.0%)
Wild rice	490,689	10,608 (2.2%)	0 (0.0%)	17,324	937 (5.4%)	0 (0.0%)
Watercress	5,164	0 (0.0%)	0 (0.0%)	4,330	0 (0.0%)	0 (0.0%)

[a] The percent of statewide section-reported applications are provided in parentheses for each category.

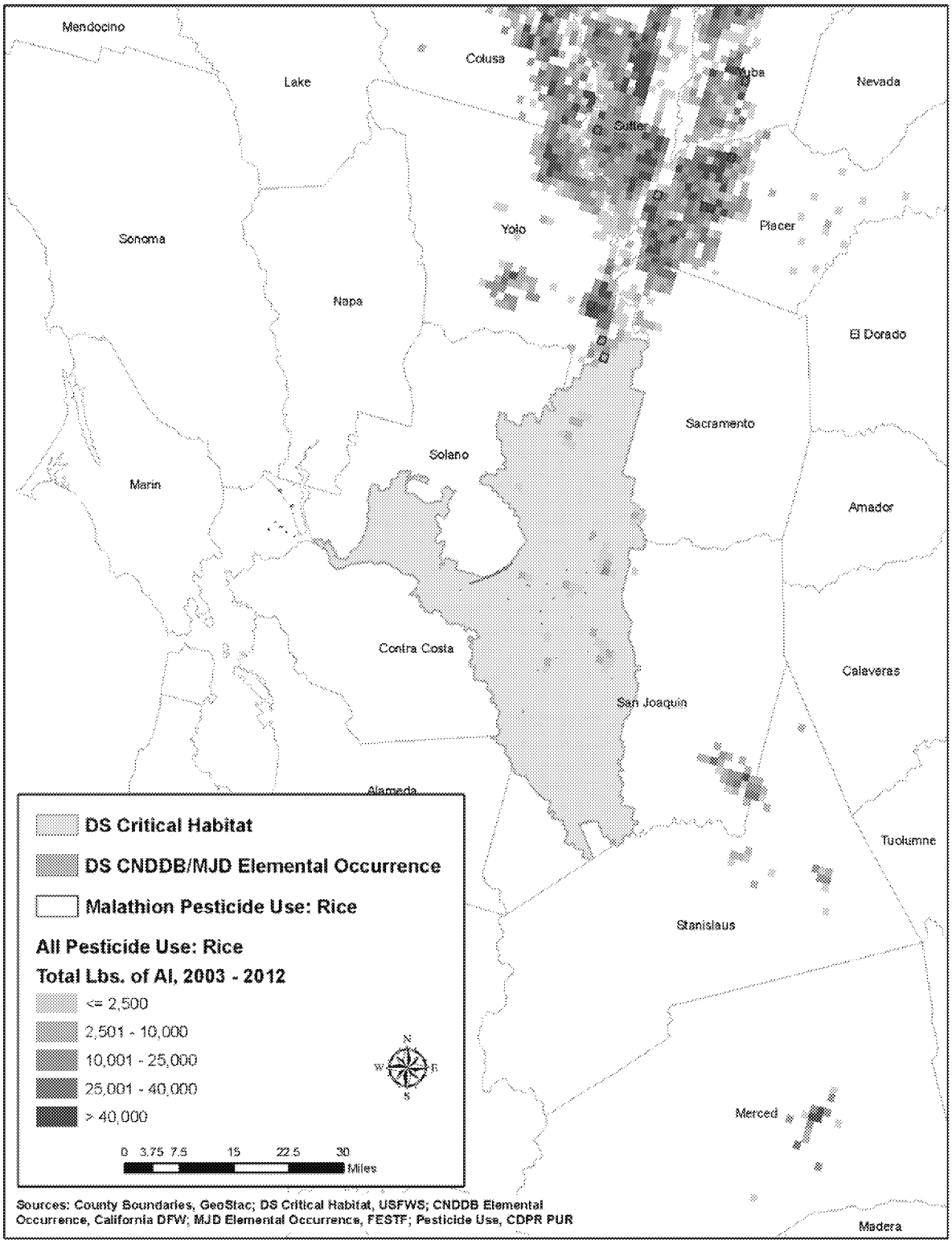

Figure D-1 **Extent of pesticide use on rice reported at the PLSS section level from 2003 to 2012 in proximity to DS habitat**

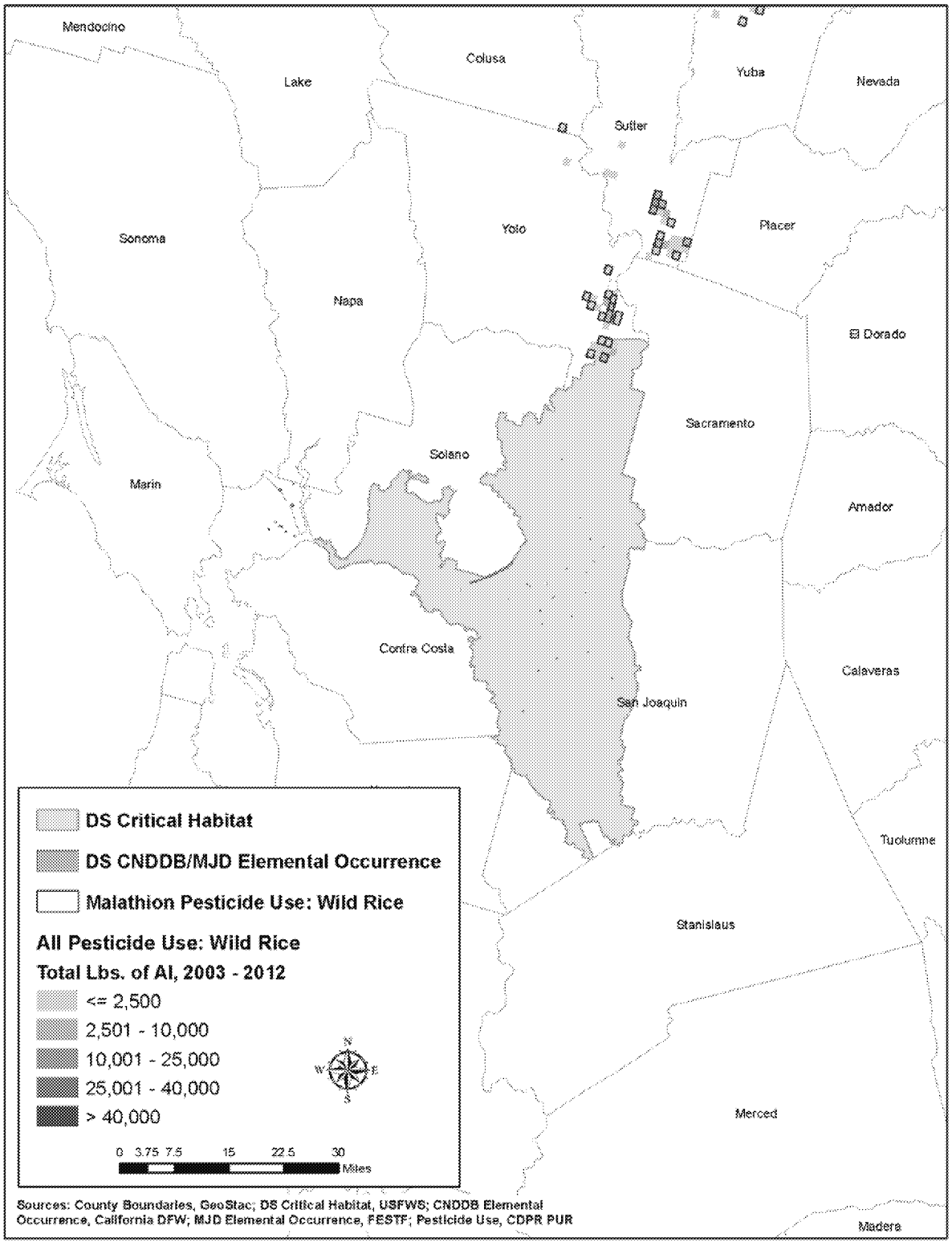

Figure D-2 **Extent of pesticide use on wild rice reported at the PLSS section level from 2003 to 2012 in proximity to DS habitat**

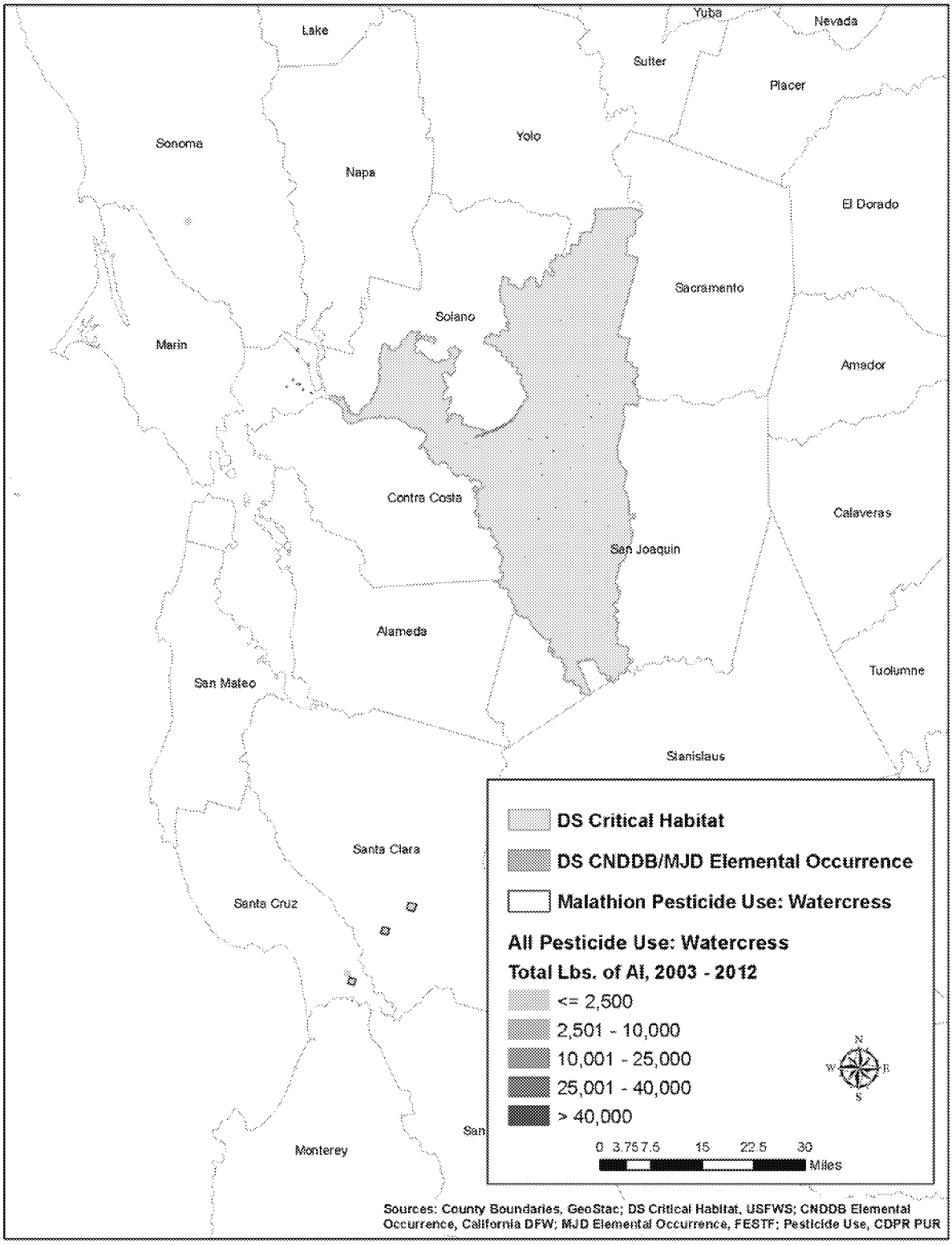

Figure D-3 **Extent of pesticide use on watercress reported at the PLSS section level from 2003 to 2012 in proximity to DS habitat**

NASS CDL Rice Overlap with DS Habitat

To further understand the extent of rice within DS habitat and the potential for pesticide applications, the most recent five years of NASS CDL (2009 to 2013) were evaluated to determine current rice growing sites within California. The NASS CDL database is the best available crop-level land cover database nationwide and has been published on a yearly basis since 2008. The NASS CDL rice class (class three) was extracted for each of the five years and then all years were combined to create the five-year CDL rice crop footprint. If a pixel was classified as rice in any one of the five years, it was preserved as a rice pixel in the final crop footprint. The area of rice growing areas within DS habitats was summarized.

DS critical habitat consists of 819,295 acres in California and EOs sum to approximately 1,240 acres based on the MJD and CNDDB (Table D-3). The 5-year CDL rice crop footprint indicates that there are 739,261 acres of land in rice production in California for at least one year from 2009 to 2013. Of that, 14,946 acres overlap with DS critical habitat (1.8% of total DS critical habitat area) and only two acres overlap with a CNDDB/MJD EO (0.2% of total DS EO area) (Table D-3). Figure D-4 illustrates the extent of the 5-year CDL rice crop footprint in relation to DS habitat.

Table D-3 5-Year CDL rice crop footprint overlap DS habitat

Habitat	*Total Habitat Area (Acres)*	*CDL (2009 to 2013) Rice Area (Acres)*	*Percent of Total Habitat Area*
DS Critical Habitat	819,295	14,946	1.8%
DS CNDDB/MJD EOs	1,240	2	0.2%

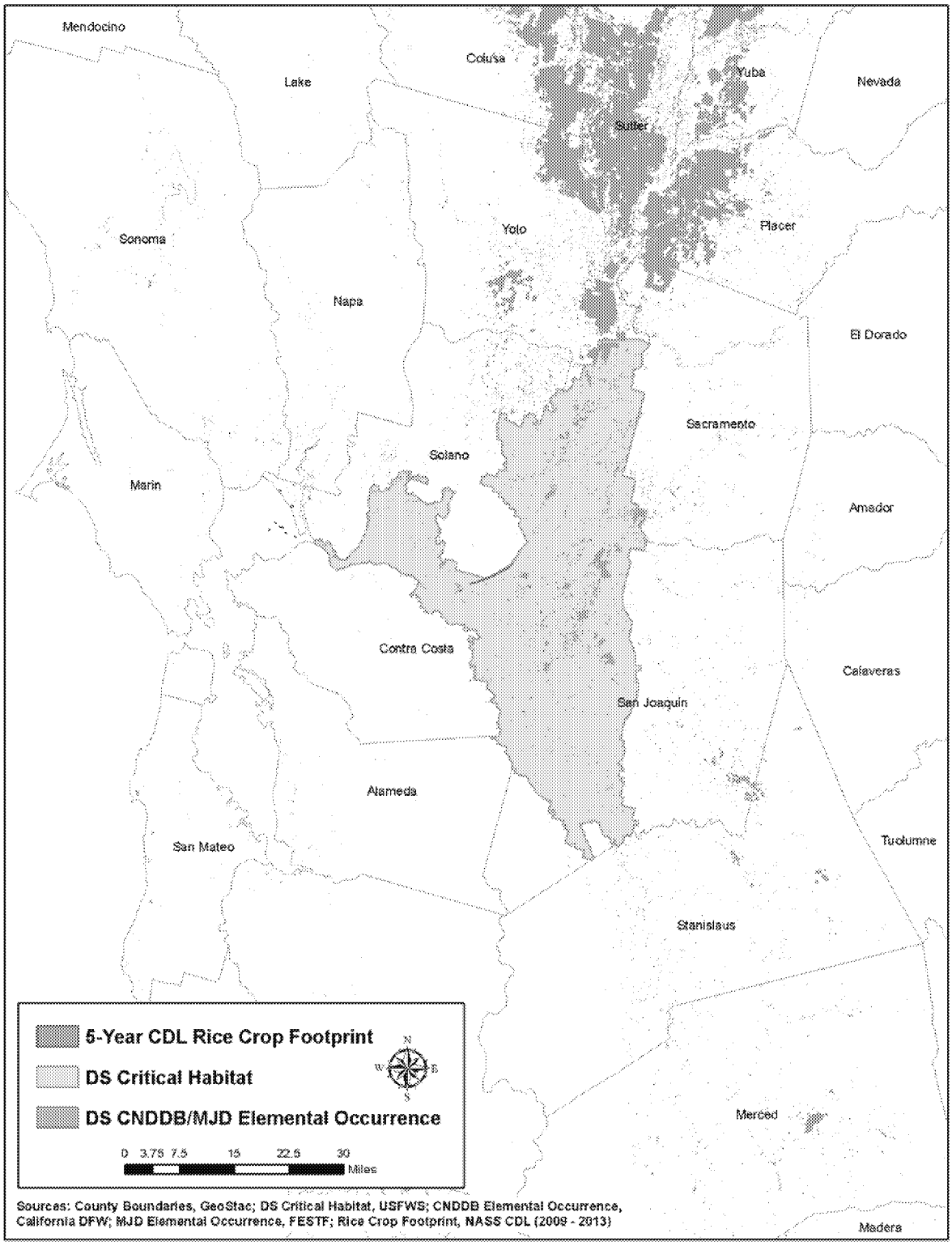

Figure D-4 **Extent of 5-year CDL rice crop footprint from 2009 to 2013 and overlap with DS habitats**

References

Budreski, K and Winchell, M. 2014. Memo to Roger Breton of Intrinsik Environmental Sciences, Inc., Ottawa, ON. December 19, 2014, from Stone Environmental, Inc., Montpelier, VT. Re: Rice, Watercress in DS Habitat.

Appendix E
Watershed-Scale Flowing Water Body Modeling of Malathion for the Delta Smelt

INTRODUCTION

The Soil and Water Assessment Tool (SWAT) was selected to evaluate malathion exposure in flowing water bodies throughout the Delta smelt (*Hypomesus transpacificus*)(DS) critical habitat. The DS critical habitat, which overlaps with the Sacramento-San Joaquin River Delta, is shown in Figure E-1 along with its associated watershed. Application of SWAT to the region located upstream of DS critical habitat led to the development of a watershed-scale model capable of capturing the majority of malathion use in the large, agriculturally intensive Central Valley region of California. The model simulates the fate and transport of pesticide moving off use sites via spray drift and runoff and routes those residues downstream through the major Sacramento and San Joaquin rivers, eastern tributaries, and many of the more minor streams and sloughs of the Delta.

SWAT is a continuous-simulation, physically-based, semi-distributed watershed model that has been used in a broad range of hydrologic and water quality applications (Gassman et al., (2007), Breton et al. (2013)). It was developed at the Grassland, Soil and Water Research Laboratory of the United States Department of Agriculture's Agricultural Research Service (USDA-ARS) (Arnold et al., 1998), SWAT has been used to model pesticide transport at the watershed scale in the literature since at least 2005. It was recently selected from a pool of 36 models as one of three that were most appropriate for watershed-scale simulation of pesticides (Quilbe et al., 2006). Pesticide transport modeling with SWAT has been conducted in both static and flowing water bodies. Ramanarayanan et al. (2005) looked at potential accumulation of the pesticide isoxaflutole and a metabolite in semi-static water bodies in the midwestern United States. Their study showed that SWAT was capable of adequately characterizing pesticide fate and transport in both flowing and semi-static water bodies (reservoirs). Most other pesticide applications with SWAT have focused on flowing water bodies, including Kannan et al. (2006), Holvoet et al. (2008), Larose et al. (2007), Parker et al. (2007), Luo and Zhang (2010) and Breton et al. (2013).

The structure of the SWAT model allows for the prediction of flow, sediment, and pesticide outputs at multiple scales and locations throughout a watershed. A full SWAT watershed is divided up into multiple subbasins. Subbasin delineation is based on the size of the complete watershed being modeled and the order of the stream segments within the model. Nodes are created in the subbasins at each point where model predictions are required. Outputs from the model are then generated for every subbasin. A subbasin is divided into multiple hydrologic response units (HRUs), which are representative of unique combinations of land, soils, and slope within a subbasin. Each HRU is considered an independent land unit within SWAT, and each HRU can have different parameterizations and agronomic practices. Within a subbasin, the HRU outputs of runoff, sediment, and pesticide fluxes are aggregated and provided as input to a single stream "reach" that transports the flows, sediment and pesticides downstream to the next subbasin. These fluxes enter a reach at the upstream end and are routed to the downstream end, during which in-stream processes such as deposition, re-suspension, and degradation take place.

Similar to the Pesticide Root Zone Model (PRZM) and Exposure Analysis Modeling System (EXAMS) regulatory models, a SWAT simulation can be run for an extended number of years to predict the expected hydro-chemical behavior based on a wide range of weather conditions. The annual maximum concentrations for various exposure durations of interest (i.e., 24-hour, 21-day, and 60-day) can be calculated from the daily pesticide concentrations calculated from the SWAT model output and compared against the ecotoxicological effects metrics for the species under consideration. The selection of the watershed chosen for the flowing water body exposure assessment, the development of model inputs and parameterization, and the simulation results of the model are discussed in the sections that follow.

WATERSHED IDENTIFICATION

Watershed identification was intended to balance the need to encompass the historic malathion use areas upstream of critical habitat with the need to keep the model's complexity at a practical level. According to the California Pesticide Use Report (PUR), historic malathion use was reported throughout agricultural and urban regions within the Central Valley including both the Sacramento River Basin to the north and the San Joaquin River Basin to the south (CDPR, 2011). The California PUR database is a comprehensive collection of nearly all production agricultural pesticide use and some nonagricultural use in the state since 1990. Average error estimates for spatial attributes in the PUR have been reported as less than 5% (Wilhoit et al. 2001). To constrain model complexity, only drainage areas below reservoirs draining the Sierra Nevada and coastal mountain ranges were included in the modeled watershed area. This area also corresponded with 97.9% of the malathion use within the Delta watershed (additional use outside the modeled watershed was still accounted for). Outflow from major reservoirs below mountain headwaters was accounted for by specifying point source freshwater inlets using United States Geological Survey (USGS) daily streamflow gage data (USGS, 2013).

The southern extent of the watershed was restricted using California Watershed Boundary Dataset 8-digit hydrologic unit code (CA WBD HUC8) boundaries as shown in Figure E-17. According to the HUC8s, except for periodic flood water from the North Fork Kings River, the San Joaquin and Kings River watersheds are otherwise not considered hydrologically connected. It is assumed that the North Fork Kings River contains negligible malathion residues due to its origination point upstream of agricultural sites in undeveloped land. Therefore, the modeled watershed area included the Upper Dry Basin that drains to Mendota Pool on the San Joaquin River but excluded the Upper King and Tulare Lake Bed Basins that drain to Tulare County. Periodic releases of water through the Mendota Pool control gates were represented in the SWAT model as freshwater inflows with flow rates specified according to USGS stream flow gage data.

MODEL DEVELOPMENT

The main steps in the development of the malathion DS SWAT model included delineating the watershed and subbasins, accounting for engineering modifications to hydrology, compiling relevant weather data, defining the HRUs based on land use and soils, developing schedules of crop management practices like irrigation, fertilization, and tillage, and characterizing malathion applications. Development of application characteristics included selection of use site, application rate, method, timing and drift fraction. The initial parameterization of the model (prior to calibration) was also an important step that defined the values adopted for the majority of the model inputs. The following sections describe each of the model development steps in detail.

Input Datasets

Several publically available databases served as the foundation for developing the malathion DS SWAT model. These datasets, their use, and their sources are summarized inTable E-1. Many of these input datasets are described in greater detail in the sections that follow.

Subbasin Delineation

The SWAT model allows a watershed and its subbasin boundaries to be delineated via one of two methods: (1) Automatically delineated using a digital elevation model (DEM) or (2) Input directly from a delineation provided by the user. For the malathion DS SWAT model watershed subbasin delineation, a hybrid of the two options was chosen.

The DEM used for the initial automatic delineation was the hydrologically conditioned "HydroDEM" from the latest version of NHDPlus (NHDPlus version 2). Hydrologic conditioning involves burning the NHD streamlines with defined flow direction into the DEM and building HUC-12 watershed boundaries up as walls into the DEM. The complete process is described in the NHDPlus 2 user's manual (McKay et al., 2012).

The initial DS subbasin delineation required that a stream drainage area threshold be defined. The drainage area threshold represents the upstream area where a stream will begin. The size of this threshold affects both stream length and the number of subbasins in a watershed. The upstream area threshold is chosen to balance the size of the watershed being modeled and the desired details in the stream network. The threshold determines the number of subbasins in the model watershed and, therefore, the level of watershed heterogeneity. For the DS watershed, the stream drainage area threshold was set at 10,000 hectares. This threshold resulted in a set of subbasins that captured both Sacramento and San Joaquin rivers and major tributaries, as well as several representative smaller backwater sloughs in the critical habitat. This threshold also ensured that reaches extended all the way to the location of inlets associated with observed flows located at the watershed edge.

The subbasins defined by the drainage threshold were further refined with the placement of additional subbasin outlets. Several subbasin outlets were added in the model to coincide with

the locations of actual USGS flow gages and National Water Quality Assessment (NAWQA) Program, California Department of Pesticide Regulation (CDPR), and California Environmental Data Exchange Network (CEDEN) sampling stations that monitor pesticide concentrations including malathion. Inside the DS critical habitat, additional subbasin outlets were placed to coincide with important DS spawning areas. The final watershed had 344 subbasins. A map of the watershed and the 344 subbasins is provided in Figure E-18.

This watershed boundary and associated subbasins were then expanded manually to include additional potential drainage areas according to the connectivity defined by hydrologic unit codes. These areas were originally discounted by the DEM-based delineation due to “breaks” in the flow accumulation network. Inspection of aerial imagery, as well as the connectivity in HUC-12 watersheds, provided support for including these areas as being “hydrologically connected” to the Delta outlet. The overall result was a watershed with subbasin boundaries aligned with HUC-12 boundaries that included a slightly broader drainage area than that of the automated approach alone.

Watershed Inlets

Freshwater inlets at the edge of the watershed were important SWAT model inputs influencing the water volume in the majority of reaches in the Delta. Altogether the 24 inlets mapped in Figure E-18 (excluding San Joaquin River near Mendota Pool) drain 26,300 square miles or about 40% of the 60,700 square-mile Delta watershed. Thirty-year-long time series of daily-average stream flow were developed for each of these locations from USGS gage data. In cases of short periods of missing data, the time-series were linearly interpolated.

Two inlet time-series required some calculation beyond minor interpolation. To capture the total outflow from Lake Oroville to the Feather River, the data were summed from two streamflow gage stations: Thermalito Afterbay relative to Feather River (USGS Station ID 11406920) and Feather River at Oroville (USGS Station ID 11407000). To include inflows to the San Joaquin River due to releases from Mendota Pool, the average difference in flow by month was computed between downstream and upstream gages: San Joaquin River near Mendota (11254000) and San Joaquin River at San Mateo Rd near Mendota (USGS Station ID 11253130). Metadata for the inlets are provided in Table E-20.

Exports, Diversions, and Flood Control

The watershed of the DS critical habitat contains a large, complex network of engineered structures for flood control, irrigation, and drinking water which may result in the transport of surface water to destinations hundreds of miles away. These diversions are substantial in magnitude, may be highly variable in time, and lack monthly or seasonal patterns according to stream flow data recorded at USGS gage stations upstream and downstream of diversions.

Accurately modeling the temporal variability and spatial extent of surface water diversions, including the ways in which they redistribute pesticide mass, was critical for predicting malathion concentrations in the DS habitat. Daily time series of flow diversions were computed in SWAT from daily- or monthly-averaged flow rates recorded by the California Department of Water Resources and USGS streamflow gages. Along with the flow, malathion mass, suspended or dissolved in the reaches due to runoff, eroded sediment, or spray drift from field applications, could also be diverted to other parts of the watershed beside the reach immediately downstream. Diverted malathion mass was computed for each reach based on the ratio of diverted to overall flow rate. The current version of the SWAT model (SWAT 2012, Rev589) did not include the option of diverting/transferring flows and chemical mass based on a time series. To accomplish this, the SWAT model code was modified to add a new type of transfer operation that read in daily or monthly time series of flow transfers/diversions, and then distributed flow and pesticide mass as described above. The details of the transfer code modification and operation are described in Padilla et al. 2013.

There were three main kinds of diversions addressed in the DS SWAT model: 1) spillage over flood control structures or weirs along the Sacramento River between Colusa and Sacramento, 2) water exports to federal and state pumping facilities from Mokelumne, Old and Middle rivers channels inside the Delta, and 3) irrigation diversions from major reaches throughout the watershed via canals and ditches. There were 33 diversions in total with 9 from daily-averaged gage data and 24 from monthly-averaged data.

To model the effects of Sacramento River flood control structures, daily gaged flow over the Colusa, Moulton and Tisdale weirs was transferred from the Sacramento River to Sutter Bypass and routed down the bypass until it re-joined the Sacramento River near Fremont. Spillage at Fremont and Sacramento weirs was transferred to Yolo Bypass. All transferred water (and any pesticide or other masses carried by it) re-joined the main-stem Sacramento River by the time it reached Rio Vista. Weir locations are shown in Figure E-19.

To model the export water leaving the Delta at the State Water Project and Central Valley Project facilities, water was drawn from the Sacramento River and San Joaquin River on a daily time-step at a ratio of three to one for best fit to observations at gage stations. The Sacramento export water was transferred and routed down the Mokelumne River at the Delta Cross-Channel. When the water joined the San Joaquin River, it was transferred again and routed in reverse through the Old and Middle Rivers, ultimately exiting the watershed to simulate removal at the pumps. The Middle River received 50% of the total export flow rate and 40% of the export rate moved up the Old River. The remaining 10% of the Delta export rate was withdrawn from the San Joaquin River near the entrance to the Contra Costa Canal. Points through which exports were routed are also shown in Figure E-19.

A complete listing of the daily transfers related to flood control and Delta exports, including the source and destination subbasin number (where applicable), is provided in Table E-3. All other monthly diversions, primarily related to irrigation, are listed in Table E-22 and located on the

map in Figure E-20. The amount of surface water that moved around the basin by engineering controls (e.g., flood control gates, weirs, canals and ditches) highlights the importance of accounting for transfers accurately in the malathion DS SWAT model.

Tides

Many water bodies within the DS critical habitat are strongly influenced by tides. The SWAT model does not simulate tidal mixing. All modeled flows within the Delta represent net outflow independent of tidal phase. We consider this assumption conservative for the purposes of pesticide exposure predictions because the mixing with tidal ocean waters would have both diluting and dissipating effects on pesticide concentrations in the delta: dilution with the influx of water at high tide, flushing with the ebb tide. Because the concentrations of pesticides predicted with the malathion DS SWAT model are conservative (higher than would be expected given additional dilution and mixing), it was determined that these predictions would result in pesticide EECs protective of the DS within the critical habitat water bodies. For this reason, incorporation of an additional model to represent the tidal mixing was not adopted.

Weather

The geographic extent of the SWAT model used to model pesticide transport into the Delta extends approximately 300 miles from north to south and 100 miles from east to west. This required the development of an extensive climate dataset to be used as a primary input to the SWAT model. The objective in the development of this weather dataset was to compile long-term historical daily weather time series for the Central Valley of California capturing the spatial heterogeneity of precipitation and temperature across the Delta watershed. A 30-year time series of daily temperature (minimum and maximum) and precipitation was developed for 1/1/1981 through 12/31/2010. An important component to the development of this dataset was to construct a complete time series with no days of missing data over the 30 year period. This required the identification of “base stations” that had the most complete records and resulted in an even spatial distribution over the watershed. Next, secondary “estimator” stations were identified to estimate the values for precipitation and temperature of the base stations for the missing days. These estimator stations were selected using Euclidean distance and elevation constraints to keep the estimations as representative of the base stations as possible. Details of the data sources and processes followed in the construction of this dataset are provided in the sections that follow.

Weather Data Sources

Three primary data sources were used to construct the weather database for the malathion DS SWAT model. The first data source was acquired from the Global Historical Climatology Network (GHCN)-Daily. This is a collection of global historical daily climate records from numerous sources. The database archive includes over 40 meteorological elements including snowfall, snow depth, evaporation, wind movement, wind maximums, soil temperature, cloudiness, maximum/minimum temperature, and precipitation. Daily GHCN data covering the

CA Central Valley and surrounding area was attained using National Climatic Data Center's (NCDC) Climate Data Online web mapping application (NCDC, 2012a).

The second data source acquired through NCDC was the Integrated Surface Database (ISD) consisting of global observations compiled from over 100 data sources into a single format. The database comprises over 20,000 stations worldwide. Currently there are over 11,000 "active" stations updated daily in the database. ISD contains numerous parameters such as wind speed and direction, wind gust, maximum/minimum temperature, dew point, cloud data, sea level pressure, altimeter setting, station pressure, present weather, visibility, snow depth, and precipitation. An inventory of all ISD stations was used to identify stations of interest (NCDC, 2012b). For these stations, daily data were collected using the Interactive Selection/Graphing tool (http://www.ncdc.noaa.gov/oa/climate/isd/index.php, accessed 11/8/2012).

The third data source used in the development of the model's climate time series was the State of California's Irrigation Management Information System. The California Irrigation Management Information System (CIMIS) is a program of the Office of Water Use Efficiency (OWUE), California Department of Water Resources (DWR). Its purpose is to manage a network of over 120 automated weather stations in the state of California which collect weather data on a minute-by-minute basis to calculate hourly and daily values. The list of all CIMIS stations, active and inactive, was used to identify stations of interest in and surrounding the Central Valley. For these stations, daily records of maximum/minimum temperature and precipitation were collected (CIMIS, 2012).

Weather Data Processing

Weather data, minimum/maximum temperature and precipitation, were compiled from the sources listed in the previous section (i.e., GHCN, ISD, CIMIS) to create a master list of all weather stations, respective elevation, and their available data within the Central Valley during the time period of interest. Spatial datasets of all stations were merged and elevations represented in consistent units (e.g., meters).

Base stations for precipitation and temperature were selected independently, as SWAT simulations do not require identical stations for each weather input. Base stations were selected by an iterative process to ensure complete coverage of the Central Valley region. The first selection of base stations used the following criteria:

- 365 days or fewer missing days over the 30-year time series
- Not within 10 miles (Euclidean distance) of another station with better data
- Include stations just outside of the valley in the lower foothills, but not the mountains (the model uses observed inflow data from the mountainous areas)

To account for areas with poor coverage, the second selection iteration chose stations within the relevant area according to the following criteria:

- Fewest missing days over the 30-year time series
- Minimizes radius of no coverage (e.g., central location within gap for substantial coverage)
- Not within 10 miles (Euclidean distance) of another station with better data
- Include stations just outside of the valley in the lower foothills, but not the mountains
- Had a suitable number of nearby "secondary" stations that could be used to estimate any missing days

Complete 30-year precipitation and maximum/minimum temperature time series were created for each base station (51 and 54 stations for precipitation and temperature, respectively). Missing base station data were resolved initially with secondary station data and then with other base station data. In cases of missing data at the base stations, data from the nearest secondary stations were substituted. Secondary stations were identified for each base station as the nearest additional stations within a 30-mile radius of the base station and with an elevation within 350 meters of the base station. Substitution began with the nearest secondary station and expanded to the next nearest secondary station until all of the missing data were resolved. In some cases, after extracting data from available secondary stations, if periods of missing data still remained, data were substituted from the next nearest base station with an elevation within 350 meters of the base station with missing data.

As a final consistency check, base stations were grouped into five regions from north to south and cumulative precipitation, minimum temperature, and maximum temperature over the 30-year time series were plotted. Base stations with inconsistencies (i.e., sharp increases, irregular slopes) in comparison to the surrounding base stations in their group were discarded from further consideration. Inconsistency in long term records is often indicative of a movement of the station's location or a change in equipment, and can introduce bias into the climate records. This last step reduced the base stations to 48 and 51 for precipitation and temperature, respectively. A map showing the spatial distribution of the precipitation and temperature stations relative to the malathion DS SWAT model watershed is shown in Figure E-21.

Land Use

The land use/crop class dataset is a critical component to the delineation of HRUs in a SWAT model. Land use classification has a significant influence on the hydrologic response of the HRU and also defines the locations of potential pesticide applications for a given use. The approach followed in developing the land use dataset sought to capture the variability in crop rotations by considering multiple years of land use data. The approach also simplifies the crop/land use categories by aggregating crop/land use classes into broader "land use groups". The NASS Cropland Data Layer (CDL) for the years from 2007 – 2011 served as the primary dataset for the development of the malathion DS SWAT model land use layer. The CDL represents explicit crop and land use classifications (over 100 different classifications in most years) and it attempts to capture year-to-year variability by basing classifications on remote sensing and ground truth training data annually. While this highly specific level of land

classification can be useful, it is not practical to use a land use dataset with such a high degree of discretization for a SWAT model covering a geographic extent the size of the Delta watershed. For this reason, the explicit CDL crop/land use classes were aggregated into generalized land use groups.

The Environmental Fate and Effects Division (EFED) of the EPA (EPA, 2012) recently proposed an approach for aggregating the crop groups based on crop associations. This approach was more recently refined by CropLife America (CLA, 2012). The generalized crop groups included corn/soybeans, cotton, hay/forage/silage, orchards/grapes, sorghum, vegetables and ground fruit, wheat, other row crops, other grains, and other crops. Additional non-agricultural classes were also included. Table E-5 provides a complete listing of the CDL land use/crop classifications and their associated crop/land use group. The *SWAT Land Group* represents the crop or land use group associated with the CDL class in the development of the SWAT land use dataset. The SWAT land use group was the same as the primary CLA crop group, except that the SWAT land use group broke out the urban class into lower and higher density classes.

To identify the most likely crop/land use group for each pixel in the land use dataset, each of the 5 years of CDL data (2007 – 2011) were re-classified into crop/land use groups. The five years of crop/land use groups were then combined such that for each pixel, the crop/land use group could be assessed temporally. Next, the grouped classification that was present for the majority of years was assigned to the pixel. If there was no majority crop/land use group for the pixel, then the group from the most recent year (2011) was assigned to the pixel. A map showing the grouped land use classes over the extent of the DS watershed is shown in Figure E-7. Table E-6 summarizes the land use area and percent of the total watershed area for each of the land use classes within the modeled portion of the DS watershed.

Soils

The SWAT model uses soils data for the simulation of many processes, including evapotranspiration, infiltration, runoff, plant growth, and chemical transport. Some of the primary soil parameters required by the SWAT model include hydrologic soil group, soil horizon depth, water holding capacity, hydraulic conductivity, bulk density, and organic carbon content. The Soil Survey Geographic (SSURGO) database (NRCS, 2012) was used to characterize the soil properties of the Delta watershed. SSURGO is the highest spatial resolution (1:24,000 scale) most detailed and widely available dataset within the United States. Each soil mapping unit within the watershed can contain multiple soil series (typically around 3). In developing the soils input to the SWAT model, the most prevalent soil series in each mapping unit was selected to represent the entire mapping unit in SWAT. For some soils, attributes required by SWAT were missing for one or more layers. In these situations, the missing soil attributes were estimated based on similarity to other soils in terms of depth, saturated hydraulic conductivity, and hydrologic soil group. For a small area of the watershed where SSURGO data were not available, State Soil Geographic (STATSGO) data were substituted. STATSGO is a medium resolution (1:250,000 scale) more generalized soils database. For hydrologic modeling

application requiring a detailed description of soil heterogeneity, STATSGO should only be used in cases when SSURGO data are unavailable.

Figure E-8 shows the boundaries of the SSURGO/STATSGO mapping units symbolized according to the hydrologic soil group. Hydrologic group "D" soils, which are the least pervious, are the most susceptible to runoff, while group "A" soils, which are the most pervious, are the least susceptible to runoff. A wide range of soil hydrologic group conditions exist across the Delta watershed.

HRU Delineation

In the malathion DS SWAT model, HRUs were delineated based on unique combinations of land use, soils, and slope characteristics. As is standard practice when delineating HRUs in SWAT, thresholds for lumping minor land uses, soils and slopes were applied. The thresholds chosen were 0% for land use area (i.e., no lumping of land uses), 5% soils area over a given land use within a subbasin, and 5% slope class area for a given soil within a land use and subbasin. This means that for a given soil within a subbasin, if the soil covers less than 5% of that land use, then it will be lumped in with the more prevalent soils that make up greater than 5% of the land use area. Similarly, for a slope class within a subbasin, if the slope covers less than 5% of that soil for a given land use, then it will be lumped in with the more prevalent slope classes that make up greater than 5% of the soils area for a given land use.

In addition, all HRUs for land use classes that were potential pesticide application areas were split into treated and non-treated sub-HRUs. The ratio of the treated to non-treated sub-HRU areas was scaled up or down to achieve a target malathion mass on the treated area while conserving the total HRU area. Scaling the treated to non-treated ratio allowed applications to meet specific targets for land uses within each subbasin while maintaining applications at the maximum labeled rates. Target amounts of pesticide to apply to the different land uses were derived from PUR data for each subbasin. The process for this derivation is described in detail in Section 0. After splitting the HRUs into a pesticide treated and non-treated fraction, a total of 37,041 HRUs were created, of which 15,909 had land use types that could receive malathion applications. Figure E-24 shows a close-up of the un-divided HRUs within the DS critical habitat area. In Figure E-24, each color represents a different HRU, showing the significant heterogeneity that exists even in the relatively small area shown.

Agronomic Practices

An agronomic management schedule was developed for each of the generalized crop/land use groups introduced in the Land Use Section. An agronomic management schedule specifies the timing and relevant parameters to be used by the SWAT model for agronomic practices such as planting, harvesting, irrigating, tilling, fertilizing, and treatment with pesticide. A management schedule may define a crop rotation and include different practices in each year of the rotation. Definition of agronomic practices within the model is important to the prediction of pesticide concentrations in the DS habitat because the practices determine the magnitude and timing of

crop growth which effects the soil moisture for runoff and the fraction of malathion applications intercepted by foliage or soil (which have different degradation rates). Also, the tillage determines the extent that malathion is incorporated into the soil. Deeper tillage leads to less availability of malathion at the soil surface for runoff. This section discusses the selection of dates and other parameters for each of the practices in a management schedule except for treatment with pesticide which is discussed in more detail in the Malathion Applications Section.

In the SWAT model, it is possible to define a unique management schedule for each HRU. With 37,041 HRUs, it was necessary to simplify the number of different schedules. To reduce model complexity, management schedules were developed around specific crops that were most representative of each land use group. CDL data from 2007 to 2011 was used to identify the dominant crops according to maximum acreage within each of the land use groups (defined in the Land Use Section) that were agricultural for 28 HUC8 regions. Maximum-acreage crops were identified independently for different HUC8 regions to account for some spatial variation throughout the watershed. In total, there were 27 crops that emerged as the area-maximum dominant crop in at least one HUC8/agricultural land use group combination within the Central Valley (Table E-7). Management schedules were assigned to HRUs based on the HRU's HUC8 location and land use group.

The 27 dominant crops determined using CDL data included most of the labeled uses for malathion on the Cheminova malathion 57% product label. However, there were a few crops on the malathion label that had minor representation according to the CDL at the HUC8 level but were the dominant malathion use site for a given subbasin/land use group as determined by the malathion mass applied in the period 2006-2010 recorded in the PUR database. To provide more accuracy in agronomic practices in locations receiving malathion applications, nine additional agronomic management schedules were developed for malathion use sites that were not originally captured by the CDL dominant crop analysis. These management schedules are listed in Table E-26, and with the schedules from Table E-7, a total of 36 possible unique management schedules were developed. And used by the model to simulate the different crops grown in the watershed. Each HRU was initially assigned one of the dominant 27 management schedules based on the dominant crop analysis. However, for HRUs randomly selected for malathion applications (see the Malathion Applications section), the initial management schedule could be changed to one of the additional nine schedules to better represent the dominant use sites associated with the HRU's land use group. This approach ensured that malathion applications were made to HRUs with land cover characteristics most representative of historic crop conditions. Malathion use sites and their associated agronomic management schedules are shown in Table E-27. Agronomic management schedules were determined for each HRU before running the SWAT model and remained the same throughout the entire 30-year simulation duration.

Agronomic information, such as tillage, irrigation, and planting/harvest dates, was collected through literature and written communication with extension agents or field experts for the dominant crops and use sites described above (36 schedules in total). Although there is greater heterogeneity in crops and agronomic practices within the Central Valley than modeled by the

management schedules described in this section, the dominant crops and their agronomy are assumed to be representative of the region and provide the proper land cover characteristics to represent the hydrologic conditions at the watershed scale. Due to the scale of area covered, agronomic practices were based primarily on practices and schedules for San Joaquin and Sacramento counties.

For irrigation and fertilization, the SWAT model operations of "auto-irrigation" and "auto-fertilization" were applied to all of the 36 agronomic management schedules. Irrigation methods vary by crop and location according to California's Department of Water Resources (DWR) state-wide irrigation methods survey. However, the auto-irrigation practice was considered appropriate due to the dominance of low volume irrigation within the crop groups of interest (Aegerter, 2011a, b, 2012; Cahn, 2011; Dara, 2011; Daugovish, 2011; CA DWR, 2011; Fulton, 2011; Hill, 2012; Holtz, 2012; Lobo, 2011; Miyao, 2012; Orang, 2011; Verdegaal, 2012). Auto-irrigation provides enough water to the crops to ensure that the soil water deficit does not exceed a threshold of 30 mm. When the deficit reaches 30 mm, water is automatically applied to the soil until it reaches field capacity. With this type of irrigation, surface runoff from irrigation will not occur. The auto-fertilization management operation was chosen and parameterized to provide enough fertilizer to ensure that the crops were not nutrient stressed. Other agronomic practices included in the management schedules varied by crop. Specific aspects of agronomic schedules for each of the crop groups are described in **Error! Reference source not found.**F.

Environmental Fate and Application Parameters

The environmental fate parameters of malathion in soil, water, and sediment specific to the SWAT model simulation of flowing water bodies are presented in Table E-10. The channel sediment organic carbon fraction of 4% used to derive the CHPST_KOC value was adopted from the same assumptions used in EPA's guidance for the pond sediment organic carbon in the standard pond (http://www.epa.gov/oppefed1/models/water/input_parameter_guidance.htm verified on 9/13/13). The application efficiency values of 0.99 for ground applications and 0.95 for aerial applications were chosen following current EPA guidance.

Determination of the application type as aerial or ground was made according to the historic probability of malathion applications occurring within the Delta watershed (2006 – 2010) found in the PUR database. The fraction of ground and aerial applications by mass were computed for each SWAT land use grouping (lumping together malathion use sites associated with a common land use group), and are reported in Table E-11. Averaging overall SWAT land use groups, malathion was more likely to be applied aerially than via groundspray, with 61.4% aerial applications and 38.6% ground.

The majority of applications (86-100% of annual applications between 2006-2010) reported in the modeled watershed area were non ultra-low-volume (ULV) product formulations. Therefore, application parameters such as rate, number of applications and application interval, were determined according to the non-ULV Cheminova Malathion 57% EC product label. More detail on the specification of these parameters is provided in the next section.

Malathion Applications

Predictions of malathion concentrations in the DS critical habitat are sensitive to the spatial and temporal variation in simulated pesticide applications. Variable application timing and location may occur as a result of differences in cropping practices between growers as well as differences in field treatment among fields of a single grower. These variations were accounted for in the malathion DS SWAT model by choosing application dates and locations according to analysis of historical PUR data from 2006-2010.

Application Timing

Application timing was determined based on historical PUR data between 2006 and 2010. Probability distributions by month were developed for each subbasin and SWAT land use group combination based on total malathion mass applied in each month. For example, a month with no application mass in the five year period had a probability of zero. A month with 25% of the application mass in the five year period was assigned a probability of 25%. The application month was drawn from the PUR-based distributions and then the application day was chosen from a uniform distribution of days within the month. The percentage of total applied malathion mass by month and crop group is provided in Table E-12.

The number of malathion applications and the interval between them were selected as the maximum number and minimum interval specified by the malathion RED and the Cheminova malathion 57% product label for each use site. Application rates were always the maximum label rate.

Application Spatial Extent

Malathion applications were based on the locations of use sites reported in the PUR database. For each year in the 2006-2010 period, the PUR malathion application locations were mapped to SWAT subbasins according to their PLSS section number. This was accomplished by intersecting the PLSS section boundaries with the Delta watershed subbasin boundaries to calculate the fraction of each section with historical malathion use that fell within each subbasin. 97.9% of the total mass applied in the Delta watershed was located in one of the SWAT subbasins. The remaining 2.1% of applications outside the model domain but within the Delta watershed were mapped to the nearest upstream subbasin to ensure 100% of historic use was modeled. Applications reported at the county level without specific PLSS section numbers were also mapped and distributed over the nearest subbasins. The spatial distribution of annual malathion mass, applied by subbasin, is shown for each year (2006 to 2010) in Figure E-25 E-10 to E-14.

Within a subbasin, the annual total mass applied was summed over all use site names that were related to each SWAT crop group. The relationship between crop groups and site names was primarily based on relating site names to like CDL classes. These relationships are provided in

Table E-13. The result was a total annual mass target to apply to each subbasin and land use pair for each of the five years. The annual total malathion mass applied to each SWAT land use group, summed for all subbasins, is presented in Table E-14.

For each subbasin/land use group combination, the PUR use site name with the most applied mass in the five year period was designated the dominant site and therefore the most representative site for defining application characteristics. The malathion RED information for this dominant site determined the application rate, number of applications, and interval at which to apply the target mass. Dominant use sites also determined which set of crop management practices (described in the Agronomic Practices section) to apply. The 2010 targets, dominant sites, rates, repetitions, and intervals are provided as an example in Table E-15. Note that to reduce complexity, unique combinations of subbasin/landuse with total annual targets of less than 1 kg malathion were distributed equally among the other subbasin/landuse targets. This amounted to spatial redistribution of between 37 kg (2007) and 62 kg (2009), which represented at most 0.1% of the total simulated mass in the watershed annually. For similar reasons, applications made outside of the SWAT model watershed but within the greater Delta watershed were mapped to the most upstream subbasin within the same HUC8 boundary as the application site. This was the case for 0.03% to no more than 1.0% of annual malathion mass applied.

A particular year's target malathion mass was distributed as individual applications with unique application dates to a subset of the subbasin/landuse pair's HRUs. Generally, more than one combination of HRUs could meet the mass targets. Thus, HRUs were drawn at random with uniform probability. For applications to developed land uses, the pervious area of the HRU was assumed to receive the application at the dominant use site rate. HRUs were continually selected at random until the sum of their applied mass met or exceeded the target. If the target mass was exceeded, rather than making an application to the entire HRU area, the fraction of the HRU receiving the application was reduced to meet the target mass for the subbasin/landuse pair.

In some rare cases, there were not enough HRUs with area sufficient to receive the targeted malathion mass for a particular subbasin and land use. To ensure application of the full malathion target mass, HRUs in the same subbasin with alternate land use of a similar type were chosen at random to receive the application. Two alternate generalized land use groups, "agricultural" and "developed," were designed for this purpose. The following land uses were considered agricultural: corn/soybeans, cotton, hay/forage/silage, orchards and grapes, other crops, other grains, other row crops, rice, sorghum, vegetables and ground fruit, and wheat. The low density urban and medium density urban land uses were considered developed. In the event the desired agricultural HRUs did not have sufficient application area, any HRUs belonging to the agricultural alternate land use group in the same subbasin were used as substitutes. The same was true for developed HRUs. A few selected agricultural land uses had a very close match with just one other land use. For example, corn and sorghum have similar crop growth and surface roughness characteristics and management practices. In these cases, the closest matching HRU type would be chosen as a substitute for the application first, before

opening up the selection to the rest of the HRUs belonging to the agricultural and developed alternate land use groups. The land uses with preferential alternate HRUs are shown in Table E-16. Whenever an HRU substitution was made, the management practices, curve number, and impervious fraction of the alternate were updated to reflect the characteristics of the desired land use. The overall alternate application strategy described above was implemented to preserve as close as possible the targeted amount, location, and physical characteristics pertaining to the historic applications.

Of the five target years between 2006 and 2010, the year to simulate was selected at random with uniform probability. Once the target year was established for a simulation, the location, timing, method, and rate of applications designed to meet the subbasin/land use target masses remained constant for the duration of the 30-year SWAT simulation.

Spray Drift

Direct deposition of spray drift onto flowing water bodies is an important exposure pathway to capture in the malathion DS SWAT model. Prediction of malathion EECs may be sensitive to drift deposition because this pathway does not involve any dilution from runoff or degradation on the crops or soil. This section describes the methodology used to account for spray drift. The steps included defining the drift fraction of the application rate as a function of distance from the applied field edge, and defining water body areas within drift proximity of every HRU.

Drift Curves

Theoretical aerial and ground spray drift curves were computed from the AgDRIFT model version 2.1.1. AgDRIFT is a dynamic model that makes predictions of distances traveled by chemical particles after application to a standardized field given parameters that describe the aircraft (for aerial applications), meteorology, nozzle setup, and application. (Teske et al 2001; Teske et al, 2002).

For the aerial spray drift curve, AgDRIFT was run using the Tier III Aerial (Agricultural) option to generate two aerial drift curves: one based on orchard crop parameters and the other based on row crop parameters. The malathion 57% product RED constraints on windspeed, droplet size, aircraft, weather conditions, and tank mix were applied for the modeling. All drift curves were derived assuming the AgDRIFT default 20-swath field depth. The windspeed was set to 10 mph for modeling based on the label recommended range of 3-10 mph for reduction of spray drift. The atmosphere was assumed to be moderately stable because application during atmospheric inversions is not recommended by the label. The product was modeled with the minimum dilution of five gallons of water per acre as specified in the label. A medium droplet size distribution was assumed, also in accordance with the product RED.

The ground drift-distance curve was calculated using the AgDRIFT Tier I Ground (Agricultural) option and was the same for all crops that received ground applications. Input parameters were based on product label specifications for ground applications or were chosen as the most

conservative of the default values. The malathion 57% product RED requires nozzle height of no more than four feet above the crop canopy. Therefore, the high boom option was selected for modeling. The labels also require using only medium or coarse spray nozzles according to the ASAE (S572) definition for standard nozzles, so the ASAE Fine to Medium/Coarse drop size distribution was used in modeling. Other model inputs were 90th data percentile and 20 swaths.

For both aerial and ground drift curves, the Terrestrial Assessment tool was used to determine area-average drift fractions in seven discrete distance zones from the field edge: 0 to 7.62 meters, 7.62 to 20 meters, 20 to 40 meters, 40 to 60 meters, 60 to 120 meters, 120 to 200 meters, and 200 to 400 meters. The upper bound of 400 meters was chosen as the distance at which the drift fraction became negligible given the decrease in drift fraction with distance based on the drift model predictions.

Aerial drift fractions were generally higher than the ground drift fractions. Drift fractions modeled for orchard crops were lower than for row crops because the increased surface roughness of the orchard crops intercepted more spray droplets preventing drift away from the field.

Both the aerial and the ground spray drift model assumptions are summarized in Table E-17Table E-35. The model results are summarized in Table E-18 which provides the average drift fraction of the application rate in the seven distinct distance zones from the field edge.

Water Body Areas

The water bodies with the potential to receive drift deposition were defined as the CA high resolution (1:24,000 scale) NHD Area features throughout the Central Valley in the following categories: Bay Inlet, Canal/Ditch, Foreshore, Sea/Ocean, and Stream/River. The 'Areas of Complex Channels' category was also considered but ultimately excluded because the features covered wide non-water-body areas as verified by satellite imagery. The California Aqueduct and the Delta- Mendota Canal were also excluded as potential drift areas because these channels flow away from the DS critical habitat. Additional water bodies in the NHD dataset that were not explicitly modeled were also removed from the set of water bodies included in the drift calculations. Conversely, water bodies that were included in the model but not found in NHD Area were added to the set of water bodies evaluated for drift. Both of these steps ensured that the ratio of drift depositional area to water body volume in the model would be close to the actual ratio in the real world. In cases where water bodies were added to the data set, the surface area was assumed to be a 1 or 2 meter buffer around the modeled stream segment. Buffers of 2 meters were used when the modeled stream segment connected to perennial streams or canals. Buffers of 1 meter were used when the modeled stream segment connected to intermittent streams. A map of the final set of all water bodies included in the drift calculation is shown in Figure E-30 (inset) with a zoom view of the water bodies in the critical habitat.

From the potential drift recipient water bodies described above, areas falling within a designated proximity to the borders of each HRU were computed as that HRU's drift deposition water body area. Proximity alone determined the water body area that received drift; no assumptions were

made about wind direction. This is the equivalent of assuming that all nearby water bodies located in any direction around the HRU are downwind of the applied area which results in conservative estimates of spray drift deposition rates. The proximity to an HRU was defined depending on the malathion label requirements for a particular application type. For aerial applications, malathion must be applied with a setback of 25 feet from water as prescribed by the Cheminova 57% RED. Therefore, to compute the water body areas that could intercept aerial spray drift, sections of HRU borders that were less than 25 feet from water body edges were clipped back to 25 feet before conducting proximity analysis. Ground applications did not have a labeled setback distance requirement. Water body area was calculated within seven discrete proximity bands from HRU borders: 0 to 7.62 meters, 7.62 to 20 meters, 20 to 40 meters, 40 to 60 meters, 60 to 120 meters, 120 to 200 meters, and 200 to 400 meters. The average drift fractions were computed for each distance band from the curves described in the previous section. A schematic example of the calculation of water body area within the first three distance zones for a hypothetical HRU and surrounding water body is shown in Figure E-16.

Drift Fraction and Mass Calculation for HRUs

The overall drift mass deposited on water bodies originating from each HRU is the product of: (drift fraction of application rate)* (application rate)*(water area). To account for the decreasing drift fractions with increasing distance from the applied field, the drift mass was computed in each proximity band described in the preceding section and summed over all bands.

For example, drift mass for the idealized, hypothetical HRU in the simplified schematic of Figure E-17 would be $c_1 \cdot rate \cdot A_1^w + c_2 \cdot rate \cdot A_2^w$. Here, c_i = drift fraction of applied rate in zone i, A^w_i = water surface area in zone *i*, and rate = application rate.

Mathematically, this can be re-arranged to find an effective drift fraction, *c*, that is actually the average fraction, weighted by the water area in each distance zone,

$$Drift = \frac{c_1 \cdot A_1^w + c_2 \cdot A_2^w}{A_1^w + A_2^w} \cdot rate \cdot (A_1^w + A_2^w) = c \cdot rate \cdot A^w$$

Where,

Drift is the total drift mass applied to water body, and
A^w is total water body area over all drift zones.

Generalizing for the jth HRU with distance zones, *i*, the effective drift fraction over all zones is,

$$c_j = \frac{\sum_i A_{ij}^w c_i}{\sum_i A_{ij}^w},$$

Where,

c_j is the overall drift fraction for HRU *j*,
c_i is the average drift fraction for the ith distance range, and
A^w_{ij} is the water body area in distance range *i* for HRU *j*. The c_j may be thought of as the centroid of the segments of the drift curve that correspond to water body locations.

Using the above drift fraction calculation, the drift mass directly deposited onto water bodies in the vicinity of HRU *j* was defined as $D_j = c_j \cdot rate \cdot A_j^w$. Here *rate* is the application rate and $A_j^w = \sum_i A_{ij}^w$ is the total water body area that received drift from HRU *j*. The drift expression above accounts for drift on all water bodies in close proximity to the HRU. This represents a worst case scenario for wind direction as all water body areas are always downwind of the application area and therefore in the path of drift.

One additional modification was made to the drift mass expression. The drift-receiving water body area is scaled by the ratio of the modeled HRU application area, A^{app}, to the 'spatial' HRU area, A^{spa}, on which the water body area computation was based. This ratio scales the water body areas linearly to account for the actual application area of the HRU in the model as shown in the following equation:

$$D_j = c_j \cdot rate \cdot A_j^w \cdot \frac{A_j^{app}}{A_j^{spa}}.$$

Where,

D_j is drift mass on nearby water bodies generated by HRU *j* (kg)
c_j is effective drift fraction accounting for varying distances between water bodies and field edge
A^w_j *is* sum of water body areas within 400m of HRU j (ha)
A_j^{app} isapplication area for HRU j (ha)
A_j^{spa} is area of the spatial HRU j before any lumping of minor soil and slope classes (ha)
rate isapplication rate (kg/ha).

This spatial HRU area is the HRU area before the minor soil and slope classes were lumped to reduce model complexity. The water body area, A^w_j, was computed based on proximity to the spatial HRU area but the actual applied area could have more or less nearby water areas. For example, if an application is made to only a fraction of the HRU area, the scale factor would have a value less than one, thereby reducing the drift-receiving water body area. If an application is made to the full HRU area and that area was the result of lumping several minor soil areas, the scale factor would increase the drift-receiving water body area.

In some cases, the above drift calculation led to unrealistically high drift mass predictions. For example, for very small HRUs surrounded by relatively large water areas, it was possible for the drift deposition on water to be greater than the amount of drift that could be generated by the mass applied to the HRU. In these cases, the drift amount was capped so as not to exceed the

mass that could be generated by the applied area with a maximum drift fraction. The maximum drift fraction, c_{max}, was based on the maximum amount of drift that could be generated by the worst case water body configuration: a long HRU with minimum width (minimum width is one pixel width of 30 meters) completely surrounded by receiving water areas. This represents a worst case because it assumes that 1) all of the drift is generated at the near edge-of-field rate – the highest rate, and 2) all of this drift is intercepted by water. The maximum drift for aerial applications was calculated assuming adherence to the 25 ft setback. Values for cmax are provided in Table E-18.

Applying the maximum drift rate, the final expression for the simulated drift mass deposited directly onto water bodies for HRU j is:

$$D_j = min\left\{c_j \cdot rate \cdot A_j^w \cdot \frac{A_j^{app}}{A_j^{spa}}, c_{max} \cdot rate \cdot A_j^{app}\right\}$$

Where,

definitions are as above and

c_{max} is maximum drift fraction, corresponds to water bodies in the closest distance band of a narrow field.

Drift, D_j, was calculated for all HRUs in the SWAT model before simulation and was provided as a set of drift input parameters to the model. Every time the model simulated an application, this amount of chemical was added directly to the pesticide mass balance of the corresponding reaches.

Model Parameterization

The ArcSWAT interface to the SWAT model (Winchell et al., 2013) provides a streamlined method for developing an initial set of parameters and input files required to run the SWAT model. These "default" inputs are based on databases of land use, crop, and agronomic practices (tillage and fertilizer) that are provided with the interface. While SWAT simulations can be conducted based on the model default parameters, adjustment of some default parameters is often beneficial. This section will discuss the adjustments made to the default hydrologic parameters provided in the ArcSWAT database. These were modified to be more consistent with published sources of parameter values, and to incorporate additional data that allows for better parameter estimation.

Precipitation and Temperature Parameterization

In regions such as the California Central Valley and surrounding foothills, climate conditions can vary significantly over changes in elevation generally with precipitation increasing and temperature decreasing with increasing elevation. Because of this, precipitation and

temperature values were corrected for differences between the climate station elevation and subbasin-average elevation using temperature lapse rates and a precipitation scaling factor. A temperature lapse rate of -3.56 ºC/km was assigned to subbasins in the north of the Delta and a value of -4.00 ºC/km was assigned to subbasins south of the Delta. These values were computed based on the Parameter-elevation Regressions on Independent Slopes Model (PRISM) average temperature data from 1971 to 2000 (PRISM, 2010). The daily time series of minimum and maximum temperature in the climate database are then adjusted by multiplying the change in elevation between temperature gage and subbasin by the lapse rate and then adding that value to the climate station temperature.

Precipitation scaling factors varied for each subbasin based on the ratio of the subbasin-average mean annual precipitation from 1981-2010 PRISM data to the subbasin's nearest NCDC station's mean annual precipitation. The dimensionless scale-factors ranged between 1.94 and 0.42. The daily precipitation time series in the climate database are then adjusted by multiplying the scaling factor by the daily precipitation value from the climate station assigned to the subbasin. The use of the temperature lapse rates and precipitation scaling factors was critical in the simulation of several of the higher elevation subbasins.

SCS Curve Numbers

One of the most important parameters to define in the SWAT model is the Soil Conservation Service (SCS) curve number value. The curve number has significant influence on the total water yield from an HRU and the allocation of streamflow between surface runoff, interflow, and baseflow. The baseline antecedent soil moisture condition II (CN2) values for different land uses within the watershed for each hydrologic soil group (A – D) are provided in Table E-37. The source for each set of curve numbers is also provided in the table. A wide range of curve numbers for row crops are published in standard curve number tables (SCS, 1986), which vary depending on residue cover, hydrologic condition, and row orientation (straight row versus contoured). In Table E-19, the curve numbers chosen for row crops assume straight rows, no residue cover, and good hydrologic condition. These are the same conditions assumed in the derivation of the CN2 value for many of the US EPA's PRZM/EXAMS standard crop scenarios. For some land uses and crops, the default curve numbers from the SWAT crop database were used without modification (e.g., forest and wetlands). In addition, the standard CN2 values are assumed to be appropriate for a land slope of 5%. The SWAT model Theoretical Documentation (Neitsch et. al, 2011) provides equations to adjust CN2 values for slopes other than 5% based on work by Williams (1995). These slope-based adjustments to the CN2 value were made to all land cover classes within the SWAT model.

Additional SWAT parameters, different from the ArcSWAT interface default values, were set based on expert judgement and experience with the model. These adjustments have been found to result in reasonable hydrologic simulations across a range of watersheds. These parameter adjustments are summarized Table E-20. Some of these parameters were modified during calibration to better match observed streamflow.

Model Calibration

All models can benefit from calibration to observed data. Watershed-scale water quality models, including SWAT, can be calibrated for streamflow, sediment yield, or water quality parameters, including pesticides. There are several long-term USGS flow gages within the Delta watershed that were used for hydrologic calibration (see Figure E-33). Additionally, streamflow for two SWAT reaches was calibrated to data from the DAYFLOW model, an empirical model of Delta hydrology developed and maintained by California Department of Water Resources (CA DWR 2013).

The period selected for calibration of the DS watershed was January 1983 – December 1992, with a validation period of January 2001 – December 2010. The model was calibrated and validated at a monthly time step. The calibration and validation of the simulated hydrology was evaluated using statistical performance measures following the guidelines of Moriasi et al. (2007) as follows:

1. The Nash Sutcliffe Efficiency (NSE): The NSE (Nash and Sutcliffe, 1970) is an indicator of how well the simulated versus observed data fall on the 1:1 line. NSE can vary from a value of negative infinity to 1. Values above 0 are considered acceptable, with a value of 1 indicating a perfect match between the model and the observed data.
2. The Percent Bias (PBIAS): PBIAS measures the tendency for simulated values to be larger or smaller than the observed values (Gupta et al., 1999). Values of PBIAS < 0 indicate that the model tends to over predict the observations, while values > 0 indicate that the model tends to under predict the observations. The optimal value for PBIAS is a value of 0.
3. The ratio of the root mean square error to the standard deviation of measured data (RSR): The RSR provides a way of normalizing the often measured root mean squared error (RMSE) based on the standard deviation of the observations (Moriasi et al., 2007). RSR varies from a minimum value of 0 (indicating an RMSE of 0) up to a large number greater than 1. The optimal value for RSR is 0.

Moriasi et al. (2007) also provides guidance for acceptable levels of model performance based on these statistical values for simulation on a monthly time step. These values have been replicated here in Table E-21. These performance metrics are not directly applicable to calibration on a daily time step which is subject to greater variability and uncertainty.

The calibration strategy focused on achieving an accurate simulation of the movement of water and pesticide mass within the Central Valley and into the California Delta. This required appropriate accounting for the numerous diversions and water transfers throughout the watershed. Achieving an accurate representation of the water transfers required constructing monthly and sometimes daily time series of these flow movements. In addition, calibration of the headwater subbasins within the watershed were used to make generally global adjustments to parameters controlling the partitioning of runoff between surface water, lateral flow, and base flow. Several headwater subbasins had flow data available for calibration. However,

identification of subbasin-specific parameter adjustments was not an approach that was followed. Instead, a common set of parameter adjustments that could be applied across all subbasins in the watershed were identified (in some cases based on basic subbasin or HRU characteristics). The result of this approach is that parameter calibrations have not been tuned to individual headwater subbasins or downstream locations. Thus, calibration performance is not as high as it could have been at some locations. However, the simple, more generalized calibration is reasonably suitable for all areas of the watershed based on validation of streamflow observations, and results in fewer difficult-to-justify local parameter adjustments.

Graphs of the monthly streamflow for both the validation and calibration periods are provided in Figure E-19 through Figure E-31. For some subbasins, only one of the calibration or validation time periods were available due to the length of the observed flow record. Overall, the timing and magnitude of streamflow simulated by the SWAT model agrees well with the observed flows. A summary of the monthly RSR, NSE, and PBIAS calibration statistics is provided in Table E-22.

Most of the monthly statistics for the mainstem reaches in the DS model fall in the very good range defined by Moriasi et al. (2007). For the headwater subbasins, most of the statistics fall within the satisfactory to very good range (e.g., subbasin 25 and subbasin 198). However, some fall in the unsatisfactory range (e.g., subbasin 204 and 236). This was determined to be acceptable given the calibration strategy of not focussing on identifying subbasin-specific calibration parameters. In addition, subbasin 204 contains a flood control reservoir that controls approximately 60% of the subbasin, making simulation of the flow at that location particularly difficult without local calibration and knowledge of the reservoir behavior. A summary of the adjusted SWAT model parameters are provided in Table E-23. These same adjustments were applied to all subbasins and HRUs within the watershed unless otherwise noted.

MODEL SIMULATION RESULTS AND DISCUSSION

Simulations of the calibrated malathion DS SWAT model were run for the 30-year period from 1981-2010. This period was selected to provide a comprehensive range in weather conditions from which malathion EECs would be predicted. In addition, uncertainty in the spatial and temporal variability in pesticide applications was accounted for through Monte Carlo simulations of the SWAT model. The Monte Carlo approach is outlined in the next section followed by a summary of the probabilistic results generated. The SWAT model concentrations are compared to observed concentrations. Lastly, EECs are discussed for different exposure durations.

Monte Carlo Simulation Approach

The spatially and temporally varying patterns of historic malathion use reported in the PUR were sampled at random to generate an ensemble of 100 application scenarios. This number of application scenarios was chosen based on convergence analysis that showed 90th-percentile peak EECs calculated from at least 60 random simulations varied less than 5%. Each scenario was based on a different randomly selected target malathion use year between 2006-2010 with

application dates and aerial or ground spray method drawn randomly according to historic PUR probability and malathion application mass distributed over a random combination of eligible HRUs. The model was run for a 30 year period for each of the unique, randomly generated application scenarios. Application scenarios remained the same for all simulation years within a single 30-year run. The first simulation year was not evaluated as part of the results data set and was not included in the calculation of EECs to eliminate initial transients in the numerical solution of the model. From the EECs resulting from the most recent 29 years of the 100 unique simulations, probability distributions were computed for the concentrations in every reach within the DS critical habitat.

Results and Discussion

Observed and model simulated concentrations were compared throughout the critical habitat to validate model performance. A formal statistical validation was not possible due to the limited number of monitoring data points and the limited spatial and temporal resolution of the model. In contrast to the model, in which concentrations are estimated daily, the sparsely sampled observations are unlikely to capture all of the peak concentrations. On the other hand, observations represent instantaneous concentrations at specific points in time and space while the true peak concentrations in the model are smoothed by daily and stream-segment averaging. Acknowledging that the observations and the reported 24-hour model concentrations reflect slightly different estimates of exposure, a comparison of observed maximum concentrations and modeled 90th percentile 24-hour-average, stream-average EECs, shown in Figure E-32, supports that the model captures observed variation in location and magnitude of malathion concentrations. The observed data points shown in Figure E-32 are the maximum concentrations detected in the reaches near the critical habitat both modeled by SWAT and in smaller water bodies and at island drains not modeled by SWAT. The monitoring program data sources queried included EPA's Storage and Retrieval (STORET) Data Warehouse (1986-2012) (EPA, 2013), the US Department of Agriculture (USDA) Pesticide Data Program (PDP; 1992-2011) (USDA, 2013), the US Geological Survey (USGS) National Water Quality Assessment (NAWQA) Program (1992-2012) (USGS, 2013b), the USGS National Water Information System (NWIS; 1925-2013) (USGS, 2013a), the California Department of Pesticide Regulation (CDPR) Surface Water Database (1991-2010) (CDPR, 2013), and the California Environmental Data Exchange Network (CEDEN; 2001-2011) (CEDEN, 2013). An analysis of the California malathion surface water data from each program is provided in Breton et al., 2016. For the majority of reaches, the model predicted EECs were greater than the observed maxima. One exception was the maximum detection in the Calaveras River at Pezzi Road (see Figure E-33 for location map) with a concentration of 1.38 µg/L while the SWAT prediction of the 90th-percentile 24-hour EEC for the corresponding Calaveras River reach segment was 0.59 µg/L. The maximum SWAT predicted concentration in this segment during the same time period as the observations was 1.79 µg/L. The point shown in the figure was the only detection at this location out of 24 samples taken between January 16, 1996 and November 28, 2007. This detection was observed before changes were made to label uses of malathion (EPA, 2009a) in 2009. Since then, all reported surface water concentrations state-wide in California have been equal to or below 0.426 µg/L. The SWAT-predicted concentrations are reach averages, in some

cases over long reach segments, and so do not necessarily capture all of the maximum observed concentrations at localized points in time and space. That the reach-average, 24-hour-average, modeled EECs and maximum concentrations most often exceeded the observed localized samples is evidence of the conservatism built into the model assumptions.

For five of the monitoring locations in and around the critical habitat with the greatest number of samples, distributions of model predicted concentrations were developed and compared to the range of observed values. Unfortunately, the small observed sample sizes and the limited number of quantifiable observations did not allow for creation of observed probability distributions. The five locations selected for comparison to model distributions, in addition to having the largest sample sizes, were located around the border of the critical habitat to give confidence that the chemical concentrations flowing into the habitat were of the correct order of magnitude. Two of the locations were just inside the habitat area at the major north and south inflows: the Sacramento River at Freeport and the San Joaquin River near Vernalis. Three of the locations were just outside the habitat on the eastern tributaries: the Stanislaus River at Ripon and Caswell State Park, the Calaveras River at Sutter Street, West Lane and Pezzi Road, and the Mokelumne River at Bruella Road. The monitoring stations included in each of these locations were from CEDEN, CDPR, and NAWQA databases and are shown on the map in Figure E-33.

For each monitoring location, the samples from all data sources were combined and samples with identical date, concentration, and level of quantitation were assumed to be duplicates and removed. Data summarizing the comparison of modeled and observed concentrations is provided in Table E-24 for the five locations. For all locations the number of non-quantifiable observations was large, between 86% and 100% of observations. Therefore, it was not possible to resolve complete distributions for the observed data; only the range of observations above and below quantitation limits could be compared to model distributions. Given the high percentage of non-quantifiable observations, the few observations that were in fact quantifiable are expected to represent the tails of the observed distribution, although the exact percentiles cannot be estimated. Compared to modeled concentrations, the quantifiable observations generally fall in the upper 5th percentile of the model distribution. Additionally, for all locations except Sacramento Freeport, the modeled maximum concentration was greater than the maximum quantifiable concentration or the maximum LOQ. For San Joaquin at Vernalis there were 59 quantifiable observations representing 5% of samples ranging from 0.003 to 0.12 µg/L which overlaps with the upper 5th percentile of the model distribution. For Mokelumne at Bruella Road, there were no observations above quantitation limits. The range of LOQs at Mokelumne falls between the 99th and 100th percentiles in the model distribution. For Stanislaus, the 16 quantifiable observations (14% of samples) ranging between 0.0042 and 0.0159 µg/L fall between the 95th and 100th percentile of the model distribution. The one quantifiable observation out of 24 samples (4%) at the Calaveras River of 1.38 µg/L falls in the upper 1% of the model distribution. Only for the Sacramento at Freeport do observed concentrations exceed maximum 24-hour average model predicted values. The lower end of the observed range falls in the upper 1% of the model distribution while the upper end of the observed range exceeds but remains within one order of magnitude of the modeled maximum. The above analysis confirms that the

model is consistent with the available observations and a reasonable tool for the prediction of malathion concentrations in a variety of flowing water bodies.

The 90th percentile annual maximum EECs were calculated for exposure periods of 24 hours, 48 hours, 4 days, 21 days, and 60 days for every model reach within the critical habitat. The complete list of EECs is provided in Table E-43 E-25. The locations of 90th percentile EECs are mapped for the acute and chronic exposure durations of 48 hours and 21 days, respectively, in Figure E-34 and Figure E-35.

For the five critical habitat reaches that had the highest peak 90th-percentile EECs, the complete EEC distributions are shown in Figure E-36. All five of these reaches were modeled as smaller headwaters with the potential for low flow rates based on runoff inputs alone. The predicted concentrations would be representative of small backwater reaches or sloughs with similar nearby cropped area if they existed elsewhere within the critical habitat. However, in reality, as seen by satellite imagery, these reaches (with the exception of reach 155) are connected to a network of larger channels, not fully represented in SWAT, that provides a continual source of flow and stabilizes the water volumes in those segments making them behave more like semi-static reservoirs than headwaters. The concentrations are likely biased high for these actual reaches because the modeled water volumes were underestimated. For these reaches, more refined modeling was required for more accurate predictions of exposure. The objective of the refined modeling was to develop a more detailed local SWAT model that more accurately represented the receiving water body. The approach was applied to subbasin 197, which had the highest overall EEC distribution, and subbasin 159, which had the next highest concentrations for the largest portion of the distribution (shown as blue and orange curves in Figure E-36).

The revised modeling approach represented main channel segments in the Sacramento-San Joaquin River Delta in each of the refined subbasins as a semi-static reservoir with uncontrolled outflow. The modeled reservoirs were parameterized to more closely match the surface area of the actual water bodies and represent a shallow estimate of actual depth. Depths were estimated based on depth observations from the NOAA Nautical Chart map service (NOAA, 2011). For subbasin 197, depths in the relevant channels, including Latham Slough, Empire Cut, Whiskey Slough, and Turner Cut, ranged from 1 to 12 meters. The 25th percentile depth of 3.7 meters was assumed for the principal spillway (representing the target volume) and the average depth of 4.6 meters was assumed for the emergency spillway depth (representing the maximum volume). For subbasin 159, the associated channels with depth information, which included Sutter and Elk sloughs, ranged from 1.8 to 6 meters deep. The 25th percentile depth used to model the principal spillway was 3.4 meters and the average depth used for modeling the emergency spillway was 3.9 meters. In both subbasins, outflow from the water body was kept nearly constant to maintain a generally steady volume of water receiving malathion inputs. Malathion was allowed to accumulate over time in the receiving water which was likely a more conservative scenario than reality.

The resulting predictions of annual maximum 48-hour- and 21-day-average concentrations in the channels ranged from 0.0 to 0.043 µg/L for subbasin 197 and 2.9e-5 to 0.026 µg/L for subbasin 159. The 90th percentile 48-hour-average/21-day-average annual maximum concentrations were 0.012/0.005 µg/L and 0.011/0.005 µg/L for the two subbasins, 197 and 159, respectively. In comparison, the initial modeled 90th percentile annual maximum concentrations for these durations were 4.92/0.96 µg/L and 1.02/0.23 µg/L, respectively. EEC distributions from the refined modeling are shown for the two subbasins in Figure E-37.

Besides the small headwater reaches mentioned above, the other critical habitat reaches had 48-hour (acute effects metric) EECs ranging between 0 and 1.65 µg/L. Concentrations in the higher end of the range generally occurred in reaches corresponding to the subbasins with the greatest malathion use and in headwater reaches with the smallest drainage areas and thus the lowest flow volumes, making them particularly susceptible to spray drift deposition. The 21-day EECs used for chronic effects assessment were 0.96 and 0.49 µg/L in the highest two reaches mentioned above, reach 197 and 155, respectively. For the 57 other critical habitat reaches, 21-day EECs ranged between 0 and 0.28 µg/L. Many of the reaches with higher annual maximum 21-day averages were the same as those having the higher 48-hour averages for the same reasons of high annual malathion use and smaller flow volumes.

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TABLES

Table E-48 SWAT Model Input Data Sources			
Dataset	***Usage***	***Dataset Source***	***Source Link***
NHDPlus V2 DEM	Delineation of watershed boundaries, stream channels, and calculation of topographic parameters.	Horizon Systems / United States Geological Survey	http://www.horizon-systems.com/NHDPlus/NHDPlusV2_home.php
SSURGO soil	Spatial extent of soil unit boundaries and their physical/chemical characteristics.	Natural Resource Conservation Service	http://soildatamart.nrcs.usda.gov/
Cropland Data Layer	Spatial extent of crop and land cover classes.	National Agricultural Statistics Service	http://www.nass.usda.gov/research/Cropland/SARS1a.htm
Weather	Derivation of daily precipitation and temperature time series for the SWAT model.	National Climatic Data Center	http://www.ncdc.noaa.gov/cdo-web/
Malathion use	Determination of the spatial and temporal pattern of malathion applications within the watershed.	California Department of Pesticide Regulation	http://cdpr.ca.gov/docs/pur/purmain.htm

Table E-20 Inlet Gage Locations and Drainage Area					
USGS Site Number	***Station Name***	***Latitude***	***Longitude***	***HUC8 Code***	***Drainage Area (mi^2)***
11251000	SAN JOAQUIN R BL FRIANT CA	36.984	-119.724	18040001	1676
11258000	FRESNO R BL HIDDEN DAM NR DAULTON CA	37.097	-119.890	18040007	258
11259000	CHOWCHILLA R BL BUCHANAN DAM NR RAYMOND CA	37.216	-119.991	18040007	236
11270900	MERCED R BL MERCED FALLS DAM NR SNELL CA	37.522	-120.332	18040002	1061
11274500	ORESTIMBA C NR NEWMAN CA	37.315	-121.125	18040002	134
11274630	DEL PUERTO C NR PATTERSON CA	37.487	-121.209	18040002	72.6
11302000	STANISLAUS R BL GOODWIN DAM NR KNIGHTS FERRY CA	37.852	-120.638	18040010	986
11308900	CALAVERAS R BL NEW HOGAN DAM NR VALLEY SPRINGS CA	38.148	-120.825	18040011	363
11323500	MOKELUMNE R BL CAMANCHE DAM CA	38.226	-121.023	18040005	621
11335000	COSUMNES R A MICHIGAN BAR CA	38.500	-121.045	18040013	536
11377100	SACRAMENTO R AB BEND BRIDGE NR RED BLUFF CA	40.288	-122.187	18020103	8900
11379500	ELDER C NR PASKENTA CA	40.024	-122.512	18020103	92.4
11381500	MILL C NR LOS MOLINOS CA	40.055	-122.024	18020103	131

Table E-20 Inlet Gage Locations and Drainage Area					
USGS Site Number	***Station Name***	***Latitude***	***Longitude***	***HUC8 Code***	***Drainage Area (mi^2)***
11383500	DEER C NR VINA CA	40.014	-121.948	18020103	208
11388000	STONY C BL BLACK BUTTE DAM NR ORLAND CA	39.818	-122.325	18020103	738
11390000	BUTTE C NR CHICO CA	39.726	-121.709	18020105	147
11407000	FEATHER R A OROVILLE CA	39.522	-121.548	18020106	3624
11418000	YUBA R BL ENGLEBRIGHT DAM NR SMARTSVILLE CA	39.235	-121.274	18020125	1108
11418500	DEER C NR SMARTSVILLE CA	39.224	-121.269	18020125	84.6
11424000	BEAR R NR WHEATLAND CA	39.000	-121.407	18020108	292
11446500	AMERICAN R A FAIR OAKS CA	38.635	-121.228	18020111	1888
11451950	CACHE C NR BROOKS CA	38.737	-122.124	18020110	1041
11454000	PUTAH C NR WINTERS CA	38.515	-122.082	18020109	574
11289651	COMBINED FLOW TUOLUMNE R + MODESTO CN + TURLOCK CA	37.666	-120.442	18040002	1538
11254000	SAN JOAQUIN R NR MENDOTA CA	36.811	-120.378	18040001	2117*

*drainage area difference between 11254000 and 11253131

Table E-50 Flood Control Transfers and Delta Exports		
Description	***Source Subbasin***	***Destination Subbasin***
Flood Control transfers to Sutter Bypass	97	107
Fremont Weir spillage to Yolo Bypass	122	144
Sacramento Weir spillage to Yolo Bypass	138	146
Delta Cross Channel transfer from Sacramento to North Branch Mokelumne	174	181
Delta Cross Channel to South Mokelumne	181	185
South Mokelumne through Little Ootato Slough to San Joaquin River	185	193
CVP/SWP pumping from San Joaquin after Mokelumne	187	202
Contra-Costa Canal (CCC) exports	190	out of watershed
CVP/SWP pumping down Middle River	202	195

Table E-22 Diversion Flow Rates by Subbasin			
Subbasin	***Average (m3/s)1***	***Maximum (m3/s)1***	***Minimum (m3/s)1***
14	-11	-39	0
42	-4	-13	0
35	-28	-88	0
97	-4	-15	0

Table E-22 Diversion Flow Rates by Subbasin			
Subbasin	*Average (m3/s)1*	*Maximum (m3/s)1*	*Minimum (m3/s)1*
104	-9	-27	0
103	-4	-12	0
127	-6	-23	0
114	-6	-29	0
125	-21	-79	0
118	-36	-98	0
143	-8	-20	-1
142	0	-1	0
148	-9	-26	-1
165	0	-2	0
188	-3	-11	0
201	-1	-3	0
219	-6	-19	0
221	-8	-19	0
233	-35	-86	0
227	-1	-2	0
244	-19	-56	0
248	-3	-8	0
286	-1	-10	0
304	-2	-18	0
315	-6	-19	0
333	-2	-14	0
183	-44	-149	0

Table E-52 Cropland Data Layer to SWAT Land Use Group Classification		
CDL ID	*CDL Class Name*	*SWAT Land Use Group*
1	Corn	Corn/soybeans
2	Cotton	Cotton
3	Rice	Rice
4	Sorghum	Sorghum
5	Soybeans	Corn/soybeans
6	Sunflower	Other row crops
10	Peanuts	Other row crops
11	Tobacco	Other row crops
12	Sweet Corn	Corn/soybeans
13	Pop or Orn Corn	Corn/soybeans

Table E-52 Cropland Data Layer to SWAT Land Use Group Classification		
CDL ID	***CDL Class Name***	***SWAT Land Use Group***
14	Mint	Other row crops
21	Barley	Other grains
22	Durum Wheat	Wheat
23	Spring Wheat	Wheat
24	Winter Wheat	Wheat
25	Other Small Grains	Other grains
26	Dbl Crop WinWht/Soybeans	Wheat
27	Rye	Other grains
28	Oats	Other grains
29	Millet	Other grains
30	Speltz	Other grains
31	Canola	Other grains
32	Flaxseed	Other grains
33	Safflower	Other grains
34	Rape Seed	Other grains
35	Mustard	Other grains
36	Alfalfa	Hay/forage/silage
37	Other Hay/Non Alfalfa	Hay/forage/silage
38	Camelina	Hay/forage/silage
39	Buckwheat	Other grains
41	Sugarbeets	Other row crops
42	Dry Beans	Veg./ground fruit
43	Potatoes	Veg./ground fruit
44	Other Crops	Other crops
45	Sugarcane	Other row crops
46	Sweet Potatoes	Veg./ground fruit
47	Misc Vegs & Fruits	Veg./ground fruit
48	Watermelons	Veg./ground fruit
49	Onions	Veg./ground fruit
50	Pickles	Veg./ground fruit
51	Chick Peas	Veg./ground fruit
52	Lentils	Veg./ground fruit
53	Peas	Veg./ground fruit
54	Tomatoes	Veg./ground fruit
55	Caneberries	Veg./ground fruit
56	Hops	Other crops

Table E-52 Cropland Data Layer to SWAT Land Use Group Classification		
CDL ID	***CDL Class Name***	***SWAT Land Use Group***
57	Herbs	Other crops
58	Clover/Wildflowers	Hay/forage/silage
59	Sod/Grass Seed	Other crops
60	Switchgrass	Hay/forage/silage
61	Fallow/Idle Cropland	Other crops
62	Pasture/Grass	Grassland
63	Forest	Forest
64	Shrubland	Shrubland
65	Barren	Barren
66	Cherries	Orchards and grapes
67	Peaches	Orchards and grapes
68	Apples	Orchards and grapes
69	Grapes	Orchards and grapes
70	Christmas Trees	Other crops
71	Other Tree Crops	Orchards and grapes
72	Citrus	Orchards and grapes
73	Other Tree Fruits	Orchards and grapes
74	Pecans	Orchards and grapes
75	Almonds	Orchards and grapes
76	Walnuts	Orchards and grapes
77	Pears	Orchards and grapes
80	Other Non-Tree Fruit	Veg./ground fruit
82	Developed	Urban Med/High
83	Water	Water
87	Wetlands	Wetlands
92	Aquaculture	Water
111	Open Water	Water
112	Perennial Ice/Snow	Perennial ice/snow
121	Developed/Open Space	Urban Open/Low
122	Developed/Low Intensity	Urban Open/Low
123	Developed/Med Intensity	Urban Med/High
124	Developed/High Intensity	Urban Med/High
131	Barren	Barren
141	Deciduous Forest	Forest
142	Evergreen Forest	Forest
143	Mixed Forest	Forest

Table E-52 Cropland Data Layer to SWAT Land Use Group Classification		
CDL ID	***CDL Class Name***	***SWAT Land Use Group***
152	Shrubland	Shrubland
171	Grassland Herbaceous	Grassland
181	Pasture/Hay	Hay/forage/silage
182	Cultivated Crop	Other crops
190	Woody Wetlands	Wetlands
195	Herbaceous Wetlands	Wetlands
201	Almonds (2007 CA Only)	Orchards and grapes
202	Tomatoes (2007 AZ, CA only)	Veg./ground fruit
203	Walnuts (2007 CA Only)	Orchards and grapes
204	Pistachios	Orchards and grapes
205	Triticale	Other grains
206	Carrots	Veg./ground fruit
207	Asparagus	Veg./ground fruit
208	Garlic	Veg./ground fruit
209	Cantaloupes	Veg./ground fruit
210	Prunes	Orchards and grapes
211	Olives	Orchards and grapes
212	Oranges	Orchards and grapes
213	Honeydew Melons	Veg./ground fruit
214	Broccoli	Veg./ground fruit
215	Cherry Orchards (2007 CA Only)	Orchards and grapes
216	Peppers	Veg./ground fruit
217	Pomegranates	Orchards and grapes
218	Nectarines	Orchards and grapes
219	Greens	Veg./ground fruit
220	Plums	Orchards and grapes
221	Strawberries	Veg./ground fruit
222	Squash	Veg./ground fruit
223	Apricots	Orchards and grapes
224	Vetch	Hay/forage/silage
225	Dbl Crop WinWht/Corn	Corn/soybeans
226	Dbl Crop Oats/Corn	Corn/soybeans
227	Lettuce	Veg./ground fruit
228	Cucumber	Veg./ground fruit
229	Pumpkins	Veg./ground fruit

Table E-52 Cropland Data Layer to SWAT Land Use Group Classification		
CDL ID	***CDL Class Name***	***SWAT Land Use Group***
230	Dbl Crop Lettuce/Durum Wht	Wheat
231	Dbl Crop Lettuce/Cantaloupe	Veg./ground fruit
232	Dbl Crop Lettuce/Cotton	Cotton
233	Dbl Crop Lettuce/Barley	Other grains
234	Dbl Crop Durum Wht/Sorghum	Sorghum
235	Dbl Crop Barley/Sorghum	Sorghum
236	Dbl Crop WinWht/Sorghum	Sorghum
237	Dbl Crop Barley/Corn	Corn/soybeans
238	Dbl Crop WinWht/Cotton	Cotton
239	Dbl Crop Soybeans/Cotton	Corn/soybeans
240	Dbl Crop Soybeans/Oats	Corn/soybeans
241	Dbl Crop Corn/Soybeans	Corn/soybeans
242	Blueberries	Veg./ground fruit
243	Cabbage	Veg./ground fruit
244	Cauliflower	Veg./ground fruit
245	Celery	Veg./ground fruit
246	Radishes	Veg./ground fruit
247	Turnips	Veg./ground fruit
248	Eggplants	Veg./ground fruit
249	Gourds	Veg./ground fruit
250	Cranberries	Veg./ground fruit
254	Dbl Crop Barley/Soybeans	Corn/soybeans

Table E-53 SWAT Model Land Use Areas		
Crop/Land Use Class	***Modeled Area (Ha)***	***Percent of Modeled Area (%)***
Barren	26,471	0.55
Corn/soybeans	147,638	3.05
Cotton	74,142	1.53
Forest	265,911	5.49
Grassland	1,700,466	35.09
Hay/forage/silage	369,259	7.62
Orchards and grapes	668,209	13.79
Other crops	172,783	3.57
Other grains	59,516	1.23
Other row crops	7,214	0.15

Table E-53 SWAT Model Land Use Areas		
Crop/Land Use Class	***Modeled Area (Ha)***	***Percent of Modeled Area (%)***
Rice	253,616	5.23
Shrubland	230,054	4.75
Sorghum	358	0.01
Urban Open/Low Density	357,536	7.38
Vegetables and ground fruit	77,285	1.59
Water	61,358	1.27
Wetlands	119,520	2.47
Wheat	113,337	2.34
Urban Med/High Density	140,896	2.91
TOTAL	4,845,570	100.00

Table E-54 Dominant Crops for Agronomic Management Schedules Based on CDL		
SWAT Land Use Group	***Dominant Crop (Management Schedule Name)***	***Years in Rotation***
Corn/soybeans	Corn	4
Corn/soybeans	Dbl Crop Oats/Corn	1
Corn/soybeans	Dbl Crop WinWht/Corn	1
Cotton	Cotton	3
Hay/forage/silage	Alfalfa	4
Hay/forage/silage	Clover/Wildflowers	3
Hay/forage/silage	Pasture/Hay	4
Orchards and grapes	Almonds	1
Orchards and grapes	Olives	1
Orchards and grapes	Pistachios	1
Orchards and grapes	Pomegranates	1
Orchards and grapes	Prunes	1
Orchards and grapes	Walnuts	1
Orchards and grapes	WineGrape	1
Other grains	Oats	1
Other grains	Safflower	1
Other grains	Triticale	1
Other row crops	Sugarbeets	1
Other row crops	Sunflower	1
Rice	Rice	1
Sorghum	Dbl Crop WinWht/Sorghum	1
Sorghum	Sorghum	1
Vegetables and ground fruit	Blueberries	5
Vegetables and ground fruit	DryBeans	1
Vegetables and ground fruit	Strawberries	1

Table E-54 Dominant Crops for Agronomic Management Schedules Based on CDL		
SWAT Land Use Group	***Dominant Crop (Management Schedule Name)***	***Years in Rotation***
Vegetables and ground fruit	Tomatoes	1
Wheat	WinterWheat	2

Table E-26 Dominant Crops for Agronomic Management Schedules Based on Malathion Use		
SWAT Land Use Group	***Dominant Crop (Management Schedule Name)***	***Years in Rotation***
Orchards and grapes	Cherries	1
Orchards and grapes	Tangerines/Oranges	1
Other crops	Christmas Trees	6
Other crops	Parsley	1
Other row crops	Mint	5
Vegetables and ground fruit	Asparagus	1
Vegetables and ground fruit	Lettuce	1
Vegetables and ground fruit	Melon	1
Vegetables and ground fruit	Onion	1

Table E-27 Agronomic Management Schedules for Malathion Use Sites	
PUR Use Site Name	***Agronomic Management Schedule Name***
ALFALFA	Alfalfa
ALMOND	Walnut
ANIMAL PREMISE	Pasture/Hay
APPLE	Walnut
ASPARAGUS	Asparagus
BARLEY	Triticale
BEAN, DRIED	DryBeans
BEAN, SUCCULENT	DryBeans
BOYSENBERRY	Blueberries
CANTALOUPE	Melon
CHERRY	Cherry
CORN (FORAGE - FODDER)	Corn
CORN, HUMAN CONSUMPTION	Corn
COTTON	Cotton
CUCUMBER	Melon
EGGPLANT	Melon
FIG	Prunes
GARLIC	Onion
GRAPE	WineGrape

Table E-27 Agronomic Management Schedules for Malathion Use Sites	
PUR Use Site Name	***Agronomic Management Schedule Name***
GRAPE, WINE	WineGrape
LETTUCE, HEAD	Lettuce
MELON	Melon
MINT	Mint
OAT	Oats
OAT (FORAGE - FODDER)	Oats
OKRA	Asparagus
ONION, DRY	Onion
ORANGE	Orange
PARSLEY	Cilantro
PASTURELAND	Pasture/Hay
PEACH	Cherry
PEPPER, FRUITING	Asparagus
PUMPKIN	Melon
RANGELAND	Pasture/Hay
RESEARCH COMMODITY	Strawberries
RICE	Rice
RICE, WILD	Rice
RYEGRASS	Triticale
SOIL FUMIGATION/PREPLANT	Uncultivated
SORGHUM (FORAGE - FODDER)	Sorghum
SORGHUM/MILO	Sorghum
SQUASH	Melon
SQUASH, ZUCCHINI	Melon
STRAWBERRY	Strawberries
SUDANGRASS	Sorghum
SWEET POTATO	Asparagus
TANGERINE	Orange
TOMATO	Tomatoes
TOMATO, PROCESSING	Tomatoes
UNCULTIVATED AG	Uncultivated
WALNUT	Walnut
WATERMELON	Melon
WHEAT	Winter Wheat
WHEAT (FORAGE - FODDER)	Winter Wheat

Table E-57 Malathion Envrionmental Fate Parameters for SWAT Model			
Parameter	***Description***	***Value***	***Notes***
SKOC	Soil adsorption coefficient (mg/kg)/(mg/L)	217	Reiss (2013)
WOF	Foliar Wash-off fraction	0.5	SWAT Database
HLIFE_F	Foliar half-life (days)	4.1	Moore et al. (2014)
HLIFE_S	Soil half-Life (days)	0.24	Reiss (2013)
AP_EF	Application efficiency	1	
WSOL	Water solubility (mg/L)	145	Cheminova A/S (1988)
CHPST_REA	Pesticide reaction coefficient in reach (1/day)	0.31548	Based on aquatic half-life of 2.2 (hydrolysis+biolysis) days (Reiss, 2013)
SEDPST_REA	Pesticide reaction coefficient in reach bed sediment (1/day)	0.09242	Equivalent to benthic half-life of 7.5 days, Reiss (2013) Table 13 (3 times mean half-life from Blumhorst (1991))
CHPST_KOC	Pesticide partition coefficient between water and sediment in reach (m^3/g)	0.00000868	Based on 217 Koc, fraction of organic carbon of 0.04 (EPA assumption for standard pond)
CHPST_VOL	Pesticide volatilization coefficient (m/d)	0.001804	Following the method in Chapra (1997) , pages 727 - 731

Table E-58 Aerial and Ground Application Probability			
SWAT Land Use Code	***SWAT Land Use Group***	***Ground Probability***	***Aerial Probability***
AGRL	Other crops	0.021	0.979
AGRR	Other row crops	0.139	0.861
CORN	Corn/soybeans	0.216	0.784
COTS	Cotton	0.543	0.457
GRSG	Sorghum	0.020	0.980
HAY	Hay/forage/silage	0.339	0.661
ORCD	Orchards and grapes	0.868	0.132
RICE	Rice	0.025	0.975
STRW	Vegetables and ground fruit	0.474	0.526
URLD/URMD	Urban Open/Low and Med/High density	0.991	0.009
WBAR	Other grains	0.104	0.896
WWHT	Wheat	0.010	0.990

Table E-59 Percentage of Annual Applications Occurring Each Month													
SWAT Land Use Group	***Jan***	***Feb***	***Mar***	***Apr***	***May***	***Jun***	***Jul***	***Aug***	***Sep***	***Oct***	***Nov***	***Dec***	***Total***
Corn/soybeans			14.4	2.6	0.6	23.0	22.6	36.9					100
Cotton						1.3	10.9	34.1	17.0	36.8			100
Hay/forage/silage		0.3	66.7	9.5	1.3	1.2	12.3	6.2	2.5	0.0			100
Orchards and grapes	0.2	0.1	0.0	0.6	8.4	9.0	16.8	45.4	17.9	1.2	0.3		100
Other crops		0.1				1.8	94.5	3.6					100
Other grains	0.6		16.1	61.7	21.6		0.0		0.0		0.0	0.0	100
Other row crops							85.2	14.8					100
Rice				12.9	23.1	55.0	8.9						100
Sorghum							81.2		18.8				100
Urban Med/High Density	9.0	8.9	9.8	12.0	9.9	8.5	8.4	8.3	7.6	6.2	6.2	5.4	100
Urban Open/Low Density	0.2	0.7	1.6	29.0	10.0	5.7	6.3	17.9	14.9	12.4	0.8	0.5	100
Vegetables and ground fruit	1.2	0.0	0.5	2.8	21.5	18.0	25.4	18.5	7.2	4.9	0.0	0.0	100
Wheat		1.3	43.8	52.1	2.4	0.4							100

Table E-60 SWAT Land Use, CDL Class and PUR Site Names		
SWAT Land Use Group	***CDL Class Name***	***PUR Site Name***
Corn/soybeans	Corn	CORN (FORAGE - FODDER)
Corn/soybeans	Corn	CORN, HUMAN CONSUMPTION
Cotton	Cotton	COTTON
Hay/forage/silage	Alfalfa	ALFALFA
Hay/forage/silage	Pasture/Hay	ANIMAL PREMISE
Hay/forage/silage	Pasture/Hay	BERMUDAGRASS
Hay/forage/silage	Pasture/Hay	FORAGE HAY/SILAGE
Hay/forage/silage	Pasture/Hay	PASTURELAND
Hay/forage/silage	Pasture/Hay	RANGELAND
Hay/forage/silage	Pasture/Hay	TIMOTHY
Orchards and grapes	Almonds	ALMOND
Orchards and grapes	Apples	APPLE
Orchards and grapes	Apricots	APRICOT
Orchards and grapes	Cherries	CHERRY
Orchards and grapes	Citrus	CITRUS
Orchards and grapes	Citrus	GRAPEFRUIT
Orchards and grapes	Citrus	KIWI
Orchards and grapes	Citrus	KUMQUAT
Orchards and grapes	Citrus	LEMON
Orchards and grapes	Citrus	LIME
Orchards and grapes	Citrus	POMELO
Orchards and grapes	Citrus	TANGELO
Orchards and grapes	Citrus	TANGERINE
Orchards and grapes	Citrus	TROPICAL/SUBTROPICAL FRUIT
Orchards and grapes	Grapes	GRAPE

Table E-60 SWAT Land Use, CDL Class and PUR Site Names		
SWAT Land Use Group	***CDL Class Name***	***PUR Site Name***
Orchards and grapes	Grapes	GRAPE, WINE
Orchards and grapes	Nectarines	NECTARINE
Orchards and grapes	Oranges	ORANGE
Orchards and grapes	other orchard	AVOCADO
Orchards and grapes	other orchard	DATE
Orchards and grapes	other orchard	FIG
Orchards and grapes	other orchard	GUAVA
Orchards and grapes	Peaches	PEACH
Orchards and grapes	Pears	PEAR
Orchards and grapes	Pecans	PECAN
Orchards and grapes	Plums	PLUM
Orchards and grapes	Pomegranates	POMEGRANATE
Orchards and grapes	Walnuts	WALNUT
Other crops	Christmas Trees	CHRISTMAS TREE
Other crops	general ag	COMMODITY FUMIGATION
Other crops	general ag	GRANARY
Other crops	general ag	UNCULTIVATED AG
Other crops	general ag	UNKNOWN
Other crops	Herbs	CHERVIL
Other crops	Herbs	CHIVE
Other crops	Herbs	FENNEL
Other crops	Herbs	HERB, SPICE
Other crops	Herbs	PARSLEY
Other grains	Barley	BARLEY
Other grains	Barley	BARLEY (FORAGE - FODDER)
Other grains	Mustard	MUSTARD
Other grains	Oats	OAT
Other grains	Oats	OAT (FORAGE - FODDER)
Other grains	other grain	GRAIN
Other grains	Rye	RYEGRASS
Other grains	Safflower	SAFFLOWER
Other row crops	Mint	MINT
Other row crops	Sunflower	SUNFLOWER
Rice	Rice	RICE
Rice	Rice	RICE, WILD
Sorghum	Sorghum	SORGHUM (FORAGE - FODDER)
Sorghum	Sorghum	SORGHUM/MILO
Sorghum	Sorghum	SUDANGRASS
Urban Med/High Density	Developed/Med Intensity	COUNTY AG COMM
Urban Med/High Density	Developed/Med Intensity	FUMIGATION, OTHER
Urban Open/Low Density	Developed/Low Intensity	LANDSCAPE MAINTENANCE

Table E-60 SWAT Land Use, CDL Class and PUR Site Names		
SWAT Land Use Group	***CDL Class Name***	***PUR Site Name***
Urban Open/Low Density	Developed/Low Intensity	N-OUTDR FLOWER
Urban Open/Low Density	Developed/Low Intensity	N-OUTDR PLANTS IN CONTAINERS
Urban Open/Low Density	Developed/Low Intensity	N-OUTDR TRANSPLANTS
Urban Open/Low Density	Developed/Low Intensity	POULTRY
Urban Open/Low Density	Developed/Low Intensity	PUBLIC HEALTH
Urban Open/Low Density	Developed/Low Intensity	REGULATORY PEST CONTROL
Urban Open/Low Density	Developed/Low Intensity	RIGHTS OF WAY
Urban Open/Low Density	Developed/Low Intensity	STRUCTURAL PEST CONTROL
Urban Open/Low Density	Developed/Low Intensity	UNCULTIVATED NON-AG
Urban Open/Low Density	Developed/Low Intensity	VERTEBRATE CONTROL
Vegetables and ground fruit	Asparagus	ASPARAGUS
Vegetables and ground fruit	Blueberries	BLUEBERRY
Vegetables and ground fruit	Broccoli	BROCCOLI
Vegetables and ground fruit	Cabbage	CABBAGE
Vegetables and ground fruit	Cantaloupes	CANTALOUPE
Vegetables and ground fruit	Carrots	CARROT
Vegetables and ground fruit	Cauliflower	CAULIFLOWER
Vegetables and ground fruit	Celery	CELERY
Vegetables and ground fruit	Cucumber	CUCUMBER
Vegetables and ground fruit	Dry Beans	BEAN, DRIED
Vegetables and ground fruit	Dry Beans	BEAN, UNSPECIFIED
Vegetables and ground fruit	Dry Beans	FAVA BEAN
Vegetables and ground fruit	Eggplants	EGGPLANT
Vegetables and ground fruit	Garlic	GARLIC
Vegetables and ground fruit	Greens	AMARANTH, EDIBLE (CHINESE SPINACH)
Vegetables and ground fruit	Greens	ARRUGULA
Vegetables and ground fruit	Greens	BOK CHOY
Vegetables and ground fruit	Greens	CHINESE CABBAGE (NAPPA)
Vegetables and ground fruit	Greens	COLLARD
Vegetables and ground fruit	Greens	DANDELION GREEN
Vegetables and ground fruit	Greens	ENDIVE (ESCAROLE)
Vegetables and ground fruit	Greens	GAI CHOY
Vegetables and ground fruit	Greens	GAI LON
Vegetables and ground fruit	Greens	KALE
Vegetables and ground fruit	Greens	MIZUNA
Vegetables and ground fruit	Greens	SPINACH
Vegetables and ground fruit	Greens	SWISS CHARD
Vegetables and ground fruit	Greens	VEGETABLES, LEAFY
Vegetables and ground fruit	Greens	WATERCRESS
Vegetables and ground fruit	Honeydew Melons	MELON
Vegetables and ground fruit	Lettuce	LETTUCE, HEAD

Table E-60 SWAT Land Use, CDL Class and PUR Site Names		
SWAT Land Use Group	***CDL Class Name***	***PUR Site Name***
Vegetables and ground fruit	Lettuce	LETTUCE, LEAF
Vegetables and ground fruit	Onions	ONION, DRY
Vegetables and ground fruit	Onions	ONION, GREEN
Vegetables and ground fruit	other ground	BEET
Vegetables and ground fruit	other ground	BLACKBERRY
Vegetables and ground fruit	other ground	BOYSENBERRY
Vegetables and ground fruit	other ground	BRUSSELS SPROUT
Vegetables and ground fruit	other ground	KOHLRABI
Vegetables and ground fruit	other ground	LEEK
Vegetables and ground fruit	other ground	OKRA
Vegetables and ground fruit	other ground	PARSNIP
Vegetables and ground fruit	other ground	RAPPINI
Vegetables and ground fruit	other ground	RASPBERRY
Vegetables and ground fruit	other ground	RESEARCH COMMODITY
Vegetables and ground fruit	other ground	SOIL FUMIGATION/PREPLANT
Vegetables and ground fruit	Peas	BEAN, SUCCULENT
Vegetables and ground fruit	Peas	PEAS
Vegetables and ground fruit	Peppers	PEPPER, FRUITING
Vegetables and ground fruit	Peppers	PEPPER, SPICE
Vegetables and ground fruit	Potatoes	POTATO
Vegetables and ground fruit	Pumpkins	PUMPKIN
Vegetables and ground fruit	Radishes	RADISH
Vegetables and ground fruit	Squash	SQUASH
Vegetables and ground fruit	Squash	SQUASH, SUMMER
Vegetables and ground fruit	Squash	SQUASH, WINTER
Vegetables and ground fruit	Squash	SQUASH, ZUCCHINI
Vegetables and ground fruit	Strawberries	STRAWBERRY
Vegetables and ground fruit	Sweet Potatoes	SWEET POTATO
Vegetables and ground fruit	Tomatoes	TOMATILLO
Vegetables and ground fruit	Tomatoes	TOMATO
Vegetables and ground fruit	Tomatoes	TOMATO, PROCESSING
Vegetables and ground fruit	Turnips	TURNIP
Vegetables and ground fruit	Watermelons	WATERMELON
Wheat	Winter Wheat	WHEAT
Wheat	Winter Wheat	WHEAT (FORAGE - FODDER)

Table E-61 Summary of Malathion Application Mass (kg) by Year						
SWAT Land Use Group	***SWAT Land Use Code***	***2006***	***2007***	***2008***	***2009***	***2010***
Other crops	AGRL	763	1866	447		204
Other row crops	AGRR	7	7	7		7
Corn/soybeans	CORN	78	44	84	71	150
Cotton	COTS	440	7	33	117	608
Sorghum	GRSG	78	57	57		44
Hay/forage/silage	HAY	17419	23906	23629	23578	35844
Orchards and grapes	ORCD	14807	17747	11019	11696	22579
Rice	RICE	687	1283	1900	255	
Vegetables and ground fruit	STRW	1686	3373	1946	1021	3097
Urban Open/Low density	URLD	8213	6322	3207	8253	9503
Urban Med/High density	URMD		278	356	304	
Other grains	WBAR	48	57	315	612	98
Wheat	WWHT	500	544	1583	840	881
Total		44726	55491	44583	46748	73016

Table E-62 Summary of 2010 Modeled Applications						
Subbasin	***SWAT Land Use Group***	***Target Mass (kg)***	***Representative Use Site***	***Rate (kg/ha)***	***# of Applications***	***Interval (d)***
1	AGRR	7	MINT	3.162	3	7
1	URLD	68	N-OUTDR TRANSPLANTS	5.604	2	10
2	STRW	4	STRAWBERRY	8.968	4	7
2	ORCD	11	WALNUT	8.406	3	7
2	URLD	59	PUBLIC HEALTH	0.5692	1	0
3	URLD	1	N-OUTDR TRANSPLANTS	5.604	2	10
3	AGRL	118	MINT	3.162	3	7
13	HAY	152	ALFALFA	2.802	2	14
21	HAY	201	ALFALFA	2.802	2	14
24	HAY	48	ALFALFA	2.802	2	14
27	ORCD	2	WALNUT	8.406	3	7
32	HAY	2	ALFALFA	2.802	2	14
33	HAY	14	ALFALFA	2.802	2	14
35	HAY	25	ALFALFA	2.802	2	14

Table E-62 Summary of 2010 Modeled Applications						
Subbasin	*SWAT Land Use Group*	*Target Mass (kg)*	*Representative Use Site*	*Rate (kg/ha)*	*# of Applications*	*Interval (d)*
37	ORCD	7	WALNUT	8.406	3	7
39	ORCD	2	WALNUT	8.406	3	7
42	HAY	78	ALFALFA	2.802	2	14
44	HAY	6	ALFALFA	2.802	2	14
45	HAY	90	ALFALFA	2.802	2	14
45	URLD	2	PUBLIC HEALTH	0.5692	1	0
46	HAY	225	ALFALFA	2.802	2	14
47	HAY	1050	ALFALFA	2.802	2	14
47	ORCD	462	WALNUT	8.406	3	7
48	HAY	13	ALFALFA	2.802	2	14
50	ORCD	29	WALNUT	8.406	3	7
51	ORCD	17	WALNUT	8.406	3	7
53	STRW	2	STRAWBERRY	8.968	4	7
54	HAY	228	ALFALFA	2.802	2	14
55	URLD	60	PUBLIC HEALTH	0.5692	1	0
55	HAY	500	ALFALFA	2.802	2	14
55	COTS	77	COTTON	8.406	3	7
56	HAY	30	ALFALFA	2.802	2	14
56	URLD	15	PUBLIC HEALTH	0.5692	1	0
56	COTS	103	COTTON	8.406	3	7
57	URLD	13	PUBLIC HEALTH	0.5692	1	0
57	HAY	20	ALFALFA	2.802	2	14
58	URLD	25	PUBLIC HEALTH	0.5692	1	0
58	HAY	178	ALFALFA	2.802	2	14
59	URLD	8	PUBLIC HEALTH	0.5692	1	0
60	URLD	10	PUBLIC HEALTH	0.5692	1	0
63	HAY	46	ALFALFA	2.802	2	14
63	URLD	115	PUBLIC HEALTH	0.5692	1	0
63	ORCD	4	WALNUT	8.406	3	7
64	HAY	78	ALFALFA	2.802	2	14
64	URLD	115	PUBLIC HEALTH	0.5692	1	0
65	HAY	46	ALFALFA	2.802	2	14
65	URLD	5	PUBLIC HEALTH	0.5692	1	0
66	URLD	4	PUBLIC HEALTH	0.5692	1	0
68	STRW	14	SOIL FUMIGATION/PREPLANT	8.968	4	7
68	ORCD	13	WALNUT	8.406	3	7
69	HAY	3	ALFALFA	2.802	2	14
69	URLD	35	PUBLIC HEALTH	0.5692	1	0
70	URLD	55	PUBLIC HEALTH	0.5692	1	0

Table E-62 Summary of 2010 Modeled Applications						
Subbasin	*SWAT Land Use Group*	*Target Mass (kg)*	*Representative Use Site*	*Rate (kg/ha)*	*# of Applications*	*Interval (d)*
70	HAY	5	ALFALFA	2.802	2	14
71	HAY	307	ALFALFA	2.802	2	14
71	URLD	63	PUBLIC HEALTH	0.5692	1	0
71	STRW	60	BEAN, DRIED	1.368	2	7
72	URLD	2	PUBLIC HEALTH	0.5692	1	0
73	URLD	178	PUBLIC HEALTH	0.5692	1	0
74	URLD	15	PUBLIC HEALTH	0.5692	1	0
75	URLD	1	PUBLIC HEALTH	0.5692	1	0
76	URLD	19	PUBLIC HEALTH	0.5692	1	0
77	STRW	10	BEAN, DRIED	1.368	2	7
77	URLD	41	PUBLIC HEALTH	0.5692	1	0
77	HAY	9	ALFALFA	2.802	2	14
78	ORCD	36	ORANGE	5.043	3	30
79	URLD	6	PUBLIC HEALTH	0.5692	1	0
80	ORCD	65	WALNUT	8.406	3	7
82	URLD	103	PUBLIC HEALTH	0.5692	1	0
83	URLD	2	PUBLIC HEALTH	0.5692	1	0
84	URLD	140	PUBLIC HEALTH	0.5692	1	0
85	URLD	142	PUBLIC HEALTH	0.5692	1	0
86	HAY	321	ALFALFA	2.802	2	14
86	URLD	209	PUBLIC HEALTH	0.5692	1	0
87	URLD	4	PUBLIC HEALTH	0.5692	1	0
89	ORCD	589	WALNUT	8.406	3	7
89	URLD	2	PUBLIC HEALTH	0.5692	1	0
91	URLD	2	PUBLIC HEALTH	0.5692	1	0
91	ORCD	132	WALNUT	8.406	3	7
94	ORCD	408	WALNUT	8.406	3	7
95	URLD	213	PUBLIC HEALTH	0.5692	1	0
95	HAY	446	ALFALFA	2.802	2	14
96	URLD	123	PUBLIC HEALTH	0.5692	1	0
96	STRW	90	BEAN, DRIED	1.368	2	7
96	HAY	373	ALFALFA	2.802	2	14
97	HAY	15	ALFALFA	2.802	2	14
97	STRW	30	BEAN, DRIED	1.368	2	7
97	URLD	49	PUBLIC HEALTH	0.5692	1	0
98	URLD	2	STRUCTURAL PEST CONTROL	0.5692	1	0
98	ORCD	11	WALNUT	8.406	3	7
99	STRW	43	BEAN, DRIED	1.368	2	7
99	URLD	152	PUBLIC HEALTH	0.5692	1	0

Table E-62 Summary of 2010 Modeled Applications						
Subbasin	*SWAT Land Use Group*	*Target Mass (kg)*	*Representative Use Site*	*Rate (kg/ha)*	*# of Applications*	*Interval (d)*
99	HAY	259	ALFALFA	2.802	2	14
99	ORCD	82	WALNUT	8.406	3	7
100	ORCD	1323	WALNUT	8.406	3	7
100	URLD	3	PUBLIC HEALTH	0.5692	1	0
101	URLD	5	PUBLIC HEALTH	0.5692	1	0
101	ORCD	444	WALNUT	8.406	3	7
102	ORCD	103	WALNUT	8.406	3	7
103	ORCD	26	WALNUT	8.406	3	7
104	ORCD	660	WALNUT	8.406	3	7
104	URLD	1	PUBLIC HEALTH	0.5692	1	0
105	URLD	12	STRUCTURAL PEST CONTROL	0.5692	1	0
105	ORCD	630	WALNUT	8.406	3	7
106	URLD	33	PUBLIC HEALTH	0.5692	1	0
106	ORCD	1170	WALNUT	8.406	3	7
106	COTS	115	COTTON	8.406	3	7
107	ORCD	7	WALNUT	8.406	3	7
107	URLD	12	PUBLIC HEALTH	0.5692	1	0
107	COTS	44	COTTON	8.406	3	7
108	URLD	2	PUBLIC HEALTH	0.5692	1	0
108	ORCD	165	WALNUT	8.406	3	7
109	ORCD	5	WALNUT	8.406	3	7
110	URLD	53	STRUCTURAL PEST CONTROL	0.5692	1	0
111	ORCD	2	WALNUT	8.406	3	7
111	URLD	2	PUBLIC HEALTH	0.5692	1	0
113	URLD	6	STRUCTURAL PEST CONTROL	0.5692	1	0
113	HAY	176	ALFALFA	2.802	2	14
114	HAY	380	ALFALFA	2.802	2	14
114	URLD	8	STRUCTURAL PEST CONTROL	0.5692	1	0
115	URLD	4	STRUCTURAL PEST CONTROL	0.5692	1	0
116	URLD	25	STRUCTURAL PEST CONTROL	0.5692	1	0
119	ORCD	209	WALNUT	8.406	3	7
119	URLD	6	PUBLIC HEALTH	0.5692	1	0
121	ORCD	16	WALNUT	8.406	3	7
121	URLD	16	PUBLIC HEALTH	0.5692	1	0
124	URLD	25	STRUCTURAL PEST CONTROL	0.5692	1	0
126	URLD	2	STRUCTURAL PEST CONTROL	0.5692	1	0

Table E-62 Summary of 2010 Modeled Applications						
Subbasin	*SWAT Land Use Group*	*Target Mass (kg)*	*Representative Use Site*	*Rate (kg/ha)*	*# of Applications*	*Interval (d)*
126	HAY	86	ALFALFA	2.802	2	14
127	URLD	3	STRUCTURAL PEST CONTROL	0.5692	1	0
127	HAY	169	ALFALFA	2.802	2	14
127	ORCD	87	WALNUT	8.406	3	7
128	URLD	32	STRUCTURAL PEST CONTROL	0.5692	1	0
128	ORCD	4	PEACH	10.089	3	11
129	HAY	184	ALFALFA	2.802	2	14
129	URLD	2	STRUCTURAL PEST CONTROL	0.5692	1	0
129	ORCD	502	WALNUT	8.406	3	7
130	URLD	6	STRUCTURAL PEST CONTROL	0.5692	1	0
130	HAY	1647	ALFALFA	2.802	2	14
130	ORCD	14	WALNUT	8.406	3	7
131	HAY	174	ALFALFA	2.802	2	14
132	ORCD	11	WALNUT	8.406	3	7
132	HAY	26	ALFALFA	2.802	2	14
132	URLD	3	STRUCTURAL PEST CONTROL	0.5692	1	0
133	URLD	2	STRUCTURAL PEST CONTROL	0.5692	1	0
133	HAY	657	ALFALFA	2.802	2	14
134	HAY	79	ALFALFA	2.802	2	14
135	URLD	32	STRUCTURAL PEST CONTROL	0.5692	1	0
136	URLD	19	STRUCTURAL PEST CONTROL	0.5692	1	0
136	STRW	2	STRAWBERRY	8.968	4	7
137	URLD	30	STRUCTURAL PEST CONTROL	0.5692	1	0
137	STRW	2	MELON	2.242	2	7
138	ORCD	19	WALNUT	8.406	3	7
138	URLD	1	STRUCTURAL PEST CONTROL	0.5692	1	0
141	URLD	1	STRUCTURAL PEST CONTROL	0.5692	1	0
142	URLD	29	STRUCTURAL PEST CONTROL	0.5692	1	0
143	ORCD	159	WALNUT	8.406	3	7
143	URLD	6	STRUCTURAL PEST CONTROL	0.5692	1	0
143	HAY	7	ALFALFA	2.802	2	14
144	HAY	530	ALFALFA	2.802	2	14
144	ORCD	213	WALNUT	8.406	3	7

Table E-62 Summary of 2010 Modeled Applications						
Subbasin	*SWAT Land Use Group*	*Target Mass (kg)*	*Representative Use Site*	*Rate (kg/ha)*	*# of Applications*	*Interval (d)*
144	URLD	6	STRUCTURAL PEST CONTROL	0.5692	1	0
145	HAY	498	ALFALFA	2.802	2	14
145	ORCD	28	WALNUT	8.406	3	7
145	URLD	4	STRUCTURAL PEST CONTROL	0.5692	1	0
147	URLD	37	STRUCTURAL PEST CONTROL	0.5692	1	0
148	URLD	27	STRUCTURAL PEST CONTROL	0.5692	1	0
149	URLD	14	STRUCTURAL PEST CONTROL	0.5692	1	0
150	URLD	23	STRUCTURAL PEST CONTROL	0.5692	1	0
151	URLD	147	STRUCTURAL PEST CONTROL	0.5692	1	0
151	STRW	4	BOYSENBERRY	8.968	4	7
152	URLD	27	STRUCTURAL PEST CONTROL	0.5692	1	0
153	ORCD	211	WALNUT	8.406	3	7
153	HAY	173	ALFALFA	2.802	2	14
153	URLD	52	N-OUTDR PLANTS IN CONTAINERS	5.604	2	10
154	HAY	4	ALFALFA	2.802	2	14
154	ORCD	21	WALNUT	8.406	3	7
154	URLD	5	STRUCTURAL PEST CONTROL	0.5692	1	0
155	STRW	1	STRAWBERRY	8.968	4	7
155	URLD	10	STRUCTURAL PEST CONTROL	0.5692	1	0
155	ORCD	122	WALNUT	8.406	3	7
156	ORCD	9	WALNUT	8.406	3	7
156	URLD	9	STRUCTURAL PEST CONTROL	0.5692	1	0
157	URLD	7	STRUCTURAL PEST CONTROL	0.5692	1	0
159	ORCD	48	WALNUT	8.406	3	7
159	URLD	3	STRUCTURAL PEST CONTROL	0.5692	1	0
160	URLD	14	STRUCTURAL PEST CONTROL	0.5692	1	0
160	HAY	696	ALFALFA	2.802	2	14
160	ORCD	8	WALNUT	8.406	3	7
162	HAY	75	ALFALFA	2.802	2	14
162	URLD	5	STRUCTURAL PEST CONTROL	0.5692	1	0
163	URLD	7	STRUCTURAL PEST CONTROL	0.5692	1	0
165	URLD	23	STRUCTURAL PEST CONTROL	0.5692	1	0

Table E-62 Summary of 2010 Modeled Applications						
Subbasin	*SWAT Land Use Group*	*Target Mass (kg)*	*Representative Use Site*	*Rate (kg/ha)*	*# of Applications*	*Interval (d)*
165	HAY	7	ALFALFA	2.802	2	14
167	HAY	210	ALFALFA	2.802	2	14
167	URLD	63	STRUCTURAL PEST CONTROL	0.5692	1	0
169	URLD	7	STRUCTURAL PEST CONTROL	0.5692	1	0
170	HAY	240	ALFALFA	2.802	2	14
170	URLD	3	STRUCTURAL PEST CONTROL	0.5692	1	0
171	URLD	64	N-OUTDR PLANTS IN CONTAINERS	5.604	2	10
172	ORCD	7	WALNUT	8.406	3	7
173	URLD	6	STRUCTURAL PEST CONTROL	0.5692	1	0
174	HAY	15	ALFALFA	2.802	2	14
176	HAY	24	ALFALFA	2.802	2	14
176	URLD	22	STRUCTURAL PEST CONTROL	0.5692	1	0
176	STRW	90	BEAN, DRIED	1.368	2	7
176	ORCD	97	WALNUT	8.406	3	7
179	URLD	4	STRUCTURAL PEST CONTROL	0.5692	1	0
181	HAY	472	ALFALFA	2.802	2	14
181	URLD	29	STRUCTURAL PEST CONTROL	0.5692	1	0
182	URLD	4	STRUCTURAL PEST CONTROL	0.5692	1	0
183	URLD	16	STRUCTURAL PEST CONTROL	0.5692	1	0
184	HAY	76	ALFALFA	2.802	2	14
184	URLD	5	STRUCTURAL PEST CONTROL	0.5692	1	0
184	STRW	5	PUMPKIN	2.242	2	7
184	ORCD	159	WALNUT	8.406	3	7
185	HAY	281	ALFALFA	2.802	2	14
185	URLD	8	STRUCTURAL PEST CONTROL	0.5692	1	0
185	ORCD	281	CHERRY	7.844	4	3
186	URLD	16	STRUCTURAL PEST CONTROL	0.5692	1	0
186	HAY	241	ALFALFA	2.802	2	14
187	URLD	12	STRUCTURAL PEST CONTROL	0.5692	1	0
188	ORCD	396	WALNUT	8.406	3	7
188	HAY	144	ALFALFA	2.802	2	14
188	URLD	3	STRUCTURAL PEST CONTROL	0.5692	1	0
188	STRW	15	ONION, DRY	3.498	2	7

Table E-62 Summary of 2010 Modeled Applications						
Subbasin	*SWAT Land Use Group*	*Target Mass (kg)*	*Representative Use Site*	*Rate (kg/ha)*	*# of Applications*	*Interval (d)*
190	URLD	3	STRUCTURAL PEST CONTROL	0.5692	1	0
191	URLD	2	STRUCTURAL PEST CONTROL	0.5692	1	0
192	URLD	1	STRUCTURAL PEST CONTROL	0.5692	1	0
192	HAY	29	ALFALFA	2.802	2	14
193	URLD	1	STRUCTURAL PEST CONTROL	0.5692	1	0
193	HAY	45	ALFALFA	2.802	2	14
194	ORCD	45	CHERRY	7.844	4	3
196	URLD	24	STRUCTURAL PEST CONTROL	0.5692	1	0
196	HAY	131	ALFALFA	2.802	2	14
196	STRW	6	CUCUMBER	3.922	2	7
196	ORCD	1933	WALNUT	8.406	3	7
197	STRW	42	ASPARAGUS	2.802	2	7
197	HAY	385	ALFALFA	2.802	2	14
197	URLD	5	STRUCTURAL PEST CONTROL	0.5692	1	0
198	URLD	3	STRUCTURAL PEST CONTROL	0.5692	1	0
199	ORCD	1990	CHERRY	7.844	4	3
199	URLD	5	STRUCTURAL PEST CONTROL	0.5692	1	0
200	URLD	2	STRUCTURAL PEST CONTROL	0.5692	1	0
201	ORCD	15	CHERRY	7.844	4	3
202	HAY	69	ALFALFA	2.802	2	14
202	URLD	2	STRUCTURAL PEST CONTROL	0.5692	1	0
202	ORCD	31	CHERRY	7.844	4	3
203	ORCD	414	CHERRY	7.844	4	3
203	HAY	142	ALFALFA	2.802	2	14
203	URLD	3	STRUCTURAL PEST CONTROL	0.5692	1	0
204	ORCD	186	CHERRY	7.844	4	3
204	URLD	3	STRUCTURAL PEST CONTROL	0.5692	1	0
205	ORCD	18	WALNUT	8.406	3	7
205	URLD	2	STRUCTURAL PEST CONTROL	0.5692	1	0
206	ORCD	4103	WALNUT	8.406	3	7
206	STRW	35	SQUASH	5.883	3	7
206	URLD	1251	N-OUTDR PLANTS IN CONTAINERS	5.604	2	10
208	HAY	241	ALFALFA	2.802	2	14

Table E-62 Summary of 2010 Modeled Applications						
Subbasin	*SWAT Land Use Group*	*Target Mass (kg)*	*Representative Use Site*	*Rate (kg/ha)*	*# of Applications*	*Interval (d)*
208	STRW	37	ASPARAGUS	2.802	2	7
208	URLD	5	STRUCTURAL PEST CONTROL	0.5692	1	0
209	ORCD	770	WALNUT	8.406	3	7
209	STRW	115	ONION, DRY	3.498	2	7
209	URLD	4	STRUCTURAL PEST CONTROL	0.5692	1	0
210	ORCD	38	WALNUT	8.406	3	7
210	URLD	2	STRUCTURAL PEST CONTROL	0.5692	1	0
210	STRW	222	ONION, DRY	3.498	2	7
211	ORCD	92	WALNUT	8.406	3	7
211	STRW	232	ONION, DRY	3.498	2	7
212	URLD	1	STRUCTURAL PEST CONTROL	0.5692	1	0
215	URLD	12	STRUCTURAL PEST CONTROL	0.5692	1	0
215	ORCD	192	WALNUT	8.406	3	7
215	HAY	169	ALFALFA	2.802	2	14
215	STRW	361	PUMPKIN	2.242	2	7
216	HAY	1458	ALFALFA	2.802	2	14
216	URLD	29	STRUCTURAL PEST CONTROL	0.5692	1	0
216	CORN	27	CORN, HUMAN CONSUMPTION	2.242	2	5
216	STRW	447	ASPARAGUS	2.802	2	7
217	URLD	3	STRUCTURAL PEST CONTROL	0.5692	1	0
217	HAY	3	ALFALFA	2.802	2	14
218	ORCD	29	WALNUT	8.406	3	7
218	URLD	13	STRUCTURAL PEST CONTROL	0.5692	1	0
218	HAY	345	ALFALFA	2.802	2	14
218	STRW	6	ONION, DRY	3.498	2	7
219	STRW	136	ONION, DRY	3.498	2	7
219	URLD	1	STRUCTURAL PEST CONTROL	0.5692	1	0
221	HAY	41	ALFALFA	2.802	2	14
221	ORCD	626	WALNUT	8.406	3	7
221	STRW	9	ONION, DRY	3.498	2	7
221	URLD	9	N-OUTDR TRANSPLANTS	5.604	2	10
222	HAY	59	ALFALFA	2.802	2	14
222	URLD	4	STRUCTURAL PEST CONTROL	0.5692	1	0
222	ORCD	28	WALNUT	8.406	3	7

Table E-62 Summary of 2010 Modeled Applications						
Subbasin	*SWAT Land Use Group*	*Target Mass (kg)*	*Representative Use Site*	*Rate (kg/ha)*	*# of Applications*	*Interval (d)*
224	ORCD	389	CHERRY	7.844	4	3
224	URLD	4	STRUCTURAL PEST CONTROL	0.5692	1	0
224	STRW	46	BEAN, DRIED	1.368	2	7
226	ORCD	11	WALNUT	8.406	3	7
226	URLD	7	N-OUTDR TRANSPLANTS	5.604	2	10
226	HAY	3	ALFALFA	2.802	2	14
227	HAY	57	ALFALFA	2.802	2	14
227	ORCD	36	WALNUT	8.406	3	7
228	HAY	41	ALFALFA	2.802	2	14
228	URLD	1	STRUCTURAL PEST CONTROL	0.5692	1	0
228	ORCD	26	CHERRY	7.844	4	3
228	STRW	296	BEAN, DRIED	1.368	2	7
229	STRW	59	BEAN, DRIED	1.368	2	7
229	ORCD	11	WALNUT	8.406	3	7
230	STRW	6	BEAN, DRIED	1.368	2	7
230	URLD	4	STRUCTURAL PEST CONTROL	0.5692	1	0
230	HAY	93	ALFALFA	2.802	2	14
230	ORCD	189	WALNUT	8.406	3	7
231	HAY	16	ALFALFA	2.802	2	14
231	STRW	111	BEAN, DRIED	1.368	2	7
231	ORCD	22	CHERRY	7.844	4	3
232	STRW	38	BEAN, DRIED	1.368	2	7
232	ORCD	22	WALNUT	8.406	3	7
233	ORCD	105	WALNUT	8.406	3	7
233	URLD	3	STRUCTURAL PEST CONTROL	0.5692	1	0
234	URLD	2	STRUCTURAL PEST CONTROL	0.5692	1	0
234	HAY	418	ALFALFA	2.802	2	14
234	ORCD	30	WALNUT	8.406	3	7
234	CORN	14	CORN (FORAGE - FODDER)	2.242	2	5
235	URLD	2	STRUCTURAL PEST CONTROL	0.5692	1	0
235	ORCD	49	CHERRY	7.844	4	3
235	STRW	23	BEAN, DRIED	1.368	2	7
236	URLD	2	STRUCTURAL PEST CONTROL	0.5692	1	0
237	STRW	198	TOMATO	6.996	4	5
237	URLD	2	STRUCTURAL PEST CONTROL	0.5692	1	0

Table E-62 Summary of 2010 Modeled Applications						
Subbasin	*SWAT Land Use Group*	*Target Mass (kg)*	*Representative Use Site*	*Rate (kg/ha)*	*# of Applications*	*Interval (d)*
237	ORCD	12	CHERRY	7.844	4	3
238	STRW	19	ONION, DRY	3.498	2	7
238	HAY	451	ALFALFA	2.802	2	14
238	ORCD	15	WALNUT	8.406	3	7
238	URLD	5	STRUCTURAL PEST CONTROL	0.5692	1	0
239	HAY	26	ALFALFA	2.802	2	14
239	ORCD	19	WALNUT	8.406	3	7
239	URLD	2	STRUCTURAL PEST CONTROL	0.5692	1	0
239	CORN	102	CORN (FORAGE - FODDER)	2.242	2	5
240	STRW	81	BEAN, DRIED	1.368	2	7
241	ORCD	20	CHERRY	7.844	4	3
241	STRW	42	BEAN, DRIED	1.368	2	7
241	URLD	1	STRUCTURAL PEST CONTROL	0.5692	1	0
242	STRW	27	BEAN, DRIED	1.368	2	7
243	URLD	3	PUBLIC HEALTH	0.5692	1	0
244	URLD	4	PUBLIC HEALTH	0.5692	1	0
245	STRW	9	BEAN, DRIED	1.368	2	7
245	URLD	2	STRUCTURAL PEST CONTROL	0.5692	1	0
245	CORN	6	CORN (FORAGE - FODDER)	2.242	2	5
245	HAY	40	ALFALFA	2.802	2	14
246	ORCD	8	CHERRY	7.844	4	3
248	URLD	3	PUBLIC HEALTH	0.5692	1	0
248	ORCD	9	WALNUT	8.406	3	7
249	URLD	2	STRUCTURAL PEST CONTROL	0.5692	1	0
253	URLD	2	PUBLIC HEALTH	0.5692	1	0
255	HAY	30	ALFALFA	2.802	2	14
255	URLD	2	STRUCTURAL PEST CONTROL	0.5692	1	0
256	HAY	51	ALFALFA	2.802	2	14
256	URLD	3	PUBLIC HEALTH	0.5692	1	0
257	HAY	26	ALFALFA	2.802	2	14
257	ORCD	1	CHERRY	7.844	4	3
257	URLD	3	STRUCTURAL PEST CONTROL	0.5692	1	0
258	HAY	102	ALFALFA	2.802	2	14
258	URLD	1	PUBLIC HEALTH	0.5692	1	0
259	HAY	27	ALFALFA	2.802	2	14

Table E-62 Summary of 2010 Modeled Applications						
Subbasin	*SWAT Land Use Group*	*Target Mass (kg)*	*Representative Use Site*	*Rate (kg/ha)*	*# of Applications*	*Interval (d)*
260	URLD	5	N-OUTDR TRANSPLANTS	5.604	2	10
260	ORCD	24	WALNUT	8.406	3	7
261	URLD	2	STRUCTURAL PEST CONTROL	0.5692	1	0
263	HAY	503	ALFALFA	2.802	2	14
263	URLD	4	PUBLIC HEALTH	0.5692	1	0
264	ORCD	12	WALNUT	8.406	3	7
264	URLD	4	PUBLIC HEALTH	0.5692	1	0
265	HAY	31	ALFALFA	2.802	2	14
265	URLD	2	N-OUTDR TRANSPLANTS	5.604	2	10
268	URLD	4	PUBLIC HEALTH	0.5692	1	0
268	HAY	42	ALFALFA	2.802	2	14
269	URLD	1	PUBLIC HEALTH	0.5692	1	0
270	ORCD	228	CHERRY	7.844	4	3
270	URLD	4	PUBLIC HEALTH	0.5692	1	0
270	HAY	222	ALFALFA	2.802	2	14
273	HAY	279	ALFALFA	2.802	2	14
273	WBAR	43	BARLEY	2.802	2	7
273	WWHT	37	WHEAT	3.363	3	7
273	URLD	7	PUBLIC HEALTH	0.5692	1	0
275	URLD	4	PUBLIC HEALTH	0.5692	1	0
275	ORCD	37	CHERRY	7.844	4	3
275	HAY	314	ALFALFA	2.802	2	14
276	URLD	2	PUBLIC HEALTH	0.5692	1	0
277	HAY	295	ALFALFA	2.802	2	14
277	URLD	3	PUBLIC HEALTH	0.5692	1	0
279	URLD	18	REGULATORY PEST CONTROL	0.5692	1	0
279	HAY	1011	ALFALFA	2.802	2	14
279	WWHT	206	WHEAT	3.363	3	7
279	COTS	129	COTTON	8.406	3	7
280	URLD	3	STRUCTURAL PEST CONTROL	0.5692	1	0
280	WBAR	6	BARLEY	2.802	2	7
280	WWHT	67	WHEAT	3.363	3	7
280	HAY	325	ALFALFA	2.802	2	14
281	HAY	41	ALFALFA	2.802	2	14
281	URLD	2	PUBLIC HEALTH	0.5692	1	0
282	HAY	91	ALFALFA	2.802	2	14
282	URLD	2	PUBLIC HEALTH	0.5692	1	0

Table E-62 Summary of 2010 Modeled Applications						
Subbasin	*SWAT Land Use Group*	*Target Mass (kg)*	*Representative Use Site*	*Rate (kg/ha)*	*# of Applications*	*Interval (d)*
283	URLD	3	PUBLIC HEALTH	0.5692	1	0
283	ORCD	89	FIG	4.484	2	5
283	HAY	40	ALFALFA	2.802	2	14
284	URLD	4	PUBLIC HEALTH	0.5692	1	0
284	HAY	1319	ALFALFA	2.802	2	14
284	WWHT	40	WHEAT	3.363	3	7
285	HAY	262	ALFALFA	2.802	2	14
285	WWHT	4	WHEAT	3.363	3	7
286	URLD	3	STRUCTURAL PEST CONTROL	0.5692	1	0
286	HAY	286	ALFALFA	2.802	2	14
287	HAY	330	ALFALFA	2.802	2	14
287	URLD	2	PUBLIC HEALTH	0.5692	1	0
288	URLD	2	PUBLIC HEALTH	0.5692	1	0
288	HAY	312	ALFALFA	2.802	2	14
289	HAY	565	ALFALFA	2.802	2	14
289	URLD	10	PUBLIC HEALTH	0.5692	1	0
290	HAY	80	ALFALFA	2.802	2	14
290	URLD	47	REGULATORY PEST CONTROL	0.5692	1	0
291	WWHT	2	WHEAT	3.363	3	7
291	HAY	59	ALFALFA	2.802	2	14
291	URLD	23	REGULATORY PEST CONTROL	0.5692	1	0
292	URLD	10	PUBLIC HEALTH	0.5692	1	0
292	HAY	256	ALFALFA	2.802	2	14
293	URLD	4	STRUCTURAL PEST CONTROL	0.5692	1	0
293	HAY	580	ALFALFA	2.802	2	14
295	ORCD	2	ORANGE	5.043	3	30
295	URLD	2	STRUCTURAL PEST CONTROL	0.5692	1	0
297	URLD	3	STRUCTURAL PEST CONTROL	0.5692	1	0
297	ORCD	15	ORANGE	5.043	3	30
298	URLD	112	REGULATORY PEST CONTROL	0.5692	1	0
298	HAY	231	ALFALFA	2.802	2	14
298	STRW	59	ONION, DRY	3.498	2	7
299	URLD	3	STRUCTURAL PEST CONTROL	0.5692	1	0
299	HAY	1322	ALFALFA	2.802	2	14
299	WBAR	49	BARLEY	2.802	2	7

Table E-62 Summary of 2010 Modeled Applications						
Subbasin	*SWAT Land Use Group*	*Target Mass (kg)*	*Representative Use Site*	*Rate (kg/ha)*	*# of Applications*	*Interval (d)*
300	GRSG	7	SORGHUM (FORAGE - FODDER)	2.242	2	7
301	ORCD	18	FIG	4.484	2	5
301	URLD	5	STRUCTURAL PEST CONTROL	0.5692	1	0
302	URLD	321	REGULATORY PEST CONTROL	0.5692	1	0
302	ORCD	54	GRAPE, WINE	4.214	2	14
302	HAY	118	ALFALFA	2.802	2	14
303	URLD	141	REGULATORY PEST CONTROL	0.5692	1	0
303	WWHT	2	WHEAT	3.363	3	7
303	HAY	1322	ALFALFA	2.802	2	14
304	URLD	2	STRUCTURAL PEST CONTROL	0.5692	1	0
305	URLD	8	REGULATORY PEST CONTROL	0.5692	1	0
305	WWHT	27	WHEAT	3.363	3	7
305	HAY	86	ALFALFA	2.802	2	14
306	URLD	2	STRUCTURAL PEST CONTROL	0.5692	1	0
307	HAY	296	ALFALFA	2.802	2	14
307	URLD	157	REGULATORY PEST CONTROL	0.5692	1	0
308	URLD	2	STRUCTURAL PEST CONTROL	0.5692	1	0
309	ORCD	17	GRAPE	4.214	2	14
309	URLD	2	STRUCTURAL PEST CONTROL	0.5692	1	0
310	GRSG	37	SORGHUM (FORAGE - FODDER)	2.242	2	7
310	ORCD	37	GRAPE, WINE	4.214	2	14
310	URLD	6	STRUCTURAL PEST CONTROL	0.5692	1	0
311	URLD	8	STRUCTURAL PEST CONTROL	0.5692	1	0
311	ORCD	60	GRAPE	4.214	2	14
312	URLD	9	REGULATORY PEST CONTROL	0.5692	1	0
313	URLD	131	REGULATORY PEST CONTROL	0.5692	1	0
314	URLD	4	REGULATORY PEST CONTROL	0.5692	1	0
314	HAY	18	ALFALFA	2.802	2	14
315	ORCD	94	WALNUT	8.406	3	7
315	URLD	70	REGULATORY PEST CONTROL	0.5692	1	0
316	HAY	220	ALFALFA	2.802	2	14
316	URLD	122	REGULATORY PEST CONTROL	0.5692	1	0

Table E-62 Summary of 2010 Modeled Applications						
Subbasin	*SWAT Land Use Group*	*Target Mass (kg)*	*Representative Use Site*	*Rate (kg/ha)*	*# of Applications*	*Interval (d)*
317	URLD	86	REGULATORY PEST CONTROL	0.5692	1	0
318	URLD	81	REGULATORY PEST CONTROL	0.5692	1	0
319	URLD	54	REGULATORY PEST CONTROL	0.5692	1	0
320	HAY	805	ALFALFA	2.802	2	14
320	URLD	40	REGULATORY PEST CONTROL	0.5692	1	0
321	HAY	44	ALFALFA	2.802	2	14
322	ORCD	169	GRAPE	4.214	2	14
322	STRW	31	SQUASH, ZUCCHINI	5.883	3	7
322	HAY	70	ALFALFA	2.802	2	14
322	URLD	179	REGULATORY PEST CONTROL	0.5692	1	0
323	WWHT	30	WHEAT	3.363	3	7
323	URLD	93	REGULATORY PEST CONTROL	0.5692	1	0
323	HAY	689	ALFALFA	2.802	2	14
324	URLD	227	REGULATORY PEST CONTROL	0.5692	1	0
324	WWHT	98	WHEAT	3.363	3	7
325	URLD	143	REGULATORY PEST CONTROL	0.5692	1	0
325	HAY	1333	ALFALFA	2.802	2	14
325	AGRL	57	PARSLEY	3.362	2	7
325	WWHT	54	WHEAT	3.363	3	7
326	URLD	5	REGULATORY PEST CONTROL	0.5692	1	0
326	HAY	309	ALFALFA	2.802	2	14
327	URLD	334	REGULATORY PEST CONTROL	0.5692	1	0
327	STRW	9	BEAN, SUCCULENT	1.368	2	7
327	ORCD	6	WALNUT	8.406	3	7
327	HAY	1110	ALFALFA	2.802	2	14
328	WWHT	137	WHEAT	3.363	3	7
328	AGRL	29	PARSLEY	3.362	2	7
328	URLD	108	REGULATORY PEST CONTROL	0.5692	1	0
328	HAY	2340	ALFALFA	2.802	2	14
329	URLD	2	REGULATORY PEST CONTROL	0.5692	1	0
330	URLD	713	REGULATORY PEST CONTROL	0.5692	1	0
330	ORCD	1095	GRAPE	4.214	2	14
330	HAY	172	ALFALFA	2.802	2	14
330	STRW	23	EGGPLANT	8.745	5	5

Table E-62 Summary of 2010 Modeled Applications						
Subbasin	*SWAT Land Use Group*	*Target Mass (kg)*	*Representative Use Site*	*Rate (kg/ha)*	*# of Applications*	*Interval (d)*
331	HAY	513	ALFALFA	2.802	2	14
331	URLD	99	REGULATORY PEST CONTROL	0.5692	1	0
332	URLD	102	REGULATORY PEST CONTROL	0.5692	1	0
332	ORCD	37	GRAPE	4.214	2	14
332	STRW	2	TOMATO	6.996	4	5
333	URLD	19	REGULATORY PEST CONTROL	0.5692	1	0
335	ORCD	35	GRAPE	4.214	2	14
335	URLD	135	REGULATORY PEST CONTROL	0.5692	1	0
336	WWHT	178	WHEAT	3.363	3	7
336	COTS	100	COTTON	8.406	3	7
336	HAY	1058	ALFALFA	2.802	2	14
336	URLD	490	REGULATORY PEST CONTROL	0.5692	1	0
337	URLD	78	REGULATORY PEST CONTROL	0.5692	1	0
338	HAY	6	ALFALFA	2.802	2	14
338	URLD	80	REGULATORY PEST CONTROL	0.5692	1	0
339	URLD	4	REGULATORY PEST CONTROL	0.5692	1	0
341	URLD	170	REGULATORY PEST CONTROL	0.5692	1	0
341	ORCD	29	TANGERINE	5.043	3	30
342	URLD	101	REGULATORY PEST CONTROL	0.5692	1	0
343	URLD	180	REGULATORY PEST CONTROL	0.5692	1	0
343	COTS	40	COTTON	8.406	3	7
344	URLD	126	REGULATORY PEST CONTROL	0.5692	1	0
344	ORCD	13	GRAPE	4.214	2	14

Table E-63 Land Uses with a Preferred Alternate	
Land Use	First Alternate Land Use
Other crops[a]	Other row crops, Rice
Corn/soybeans	Sorghum
Sorghum	Corn/soybeans
Hay/forage/silage	Wheat
Vegetables and ground fruit	Other row crops
Urban Open/Low	Urban Med/High Density
Urban Med/High Density	Urban Open/Low
Other grains	Wheat
Wheat	Other grains

[a] Other row crops or rice was substituted for other crops depending on location within the watershed

Table E-35 Drift Modeling Assumptions

Parameter	*Aerial Row Crops*	*Aerial Orchard Crops*	*Ground All Crops*	*Justification*
Aircraft	Basic (Air Tractor AT-401)	Basic (Air Tractor AT-401)		Label requires boom length 75% of wing span or less
Wind Speed	10 mph	10 mph (label max)		Label recommends application in 3-10 mph wind speeds
Nozzle	Basic BCPC medium	Basic BCPC medium	ASAE Fine to Medium/Coarse	Label recommends ASAE medium/coarse nozzle or median droplet size of 300 um
Droplet Size	26.05 to 1403.04 µm (medium)	26 .05 to 1403.04 µm (medium)	341 µm median	Label recommends ASAE medium/coarse nozzle or median droplet size of 300 um
Boom Height	10 ft	10 ft	High boom (50 in)	Label recommends applications 10 ft or less (aerial) and 4 ft or less (ground) above crop canopy
Swaths	20 swaths, 60 ft width	20 swaths, 60 ft width	20, 45 ft width	AgDRIFT default
Swath Displacement	0.3722	0.3722		AgDRIFT default
Surface roughness	0.13 ft (0.04 m)	1.64 ft (0.5 m)		Minimum value for orchard and non-orchard crops in AgDRIFT Manual
Atmosphere	Moderately Stable	Moderately Stable		Label recommends not applying during atmospheric inversions
Dilution	5 gallons water per acre	5 gallons water per acre		Labeled minimum water in tank mix for each crop
A.I. %/Inert %	57%/43%	57%/43%		Product formulation
Application Rate	2.5 lbs/acre	7.5 lbs/acre		Maximum single application rate for row crop (cotton) and orchard crop (citrus)

Table E-35 Drift Modeling Assumptions				
Parameter	***Aerial Row Crops***	***Aerial Orchard Crops***	***Ground All Crops***	***Justification***
A.I./product ratio	5 lbs/gallon	5 lbs/gallon		Product formulation
Total Tank mix Vol	5.5 gallons/acre	6.5 gallons/acre		Calculated from application rate and tank water volume
Specific Gravity	1.07	1.07		Specified by product Material Safety Data Sheet
A.I %. + Inerts in Tank %	5.182 % + 3.909%	13.154 % + 9.922%		Calculated from tank mix and product formulation
Nonvolatile Fraction	1.0/1.0	1.0/1.0		Based on non-volatility described in Reiss
Tank water %	90.91%	76.92%		Calculated using above inputs in AgDRIFT tank mix calculator
Temperature	86 F	86 F		AgDRIFT default
Relative Humidity	50%	50%		AgDRIFT default

Table E-65 Fraction of Application Rate Deposited as Drift			
Distance from field edge (m)	***Row Crop Aerial Drift Fraction***	***Orchard Aerial Drift Fraction***	***Ground Aerial Drift Fraction***
0-7.62	0.2403	0.1666	0.0823
7.62 -20	0.1187	0.0833	0.0136
20-40	0.0607	0.0437	0.0073
40-60	0.0293	0.024	0.0047
60-120	0.0151	0.013	0.0029
120-200	0.0091	0.0064	0.0016
200-400	0.0063	0.0034	0.0009
Theoretical Maximum	0.0645	0.0429	0.0238

Table E-37 SCS Curve Numbers for Modeled Land Uses					
Crop	***CN2A***	***CN2B***	***CN2C***	***CN2D***	***SCS TR55 Class or SWAT Default***
Agricultural Land-Generic	67	78	85	89	RC/SR/Good
Alfalfa	30	58	71	78	Meadow for hay
Barren	77	86	91	94	Fallow/SR
Spring Canola-Argentine	63	75	83	87	Close Grown/SR/Good
Red Clover	30	58	71	78	Meadow for hay
Corn	67	78	85	89	RC/SR/Good
Upland Cotton-harvested with	67	78	85	89	RC/SR/Good
Corn Silage	67	78	85	89	RC/SR/Good
Forest-Mixed	36	60	73	79	SWAT Default

Table E-37 SCS Curve Numbers for Modeled Land Uses					
Crop	*CN2A*	*CN2B*	*CN2C*	*CN2D*	*SCS TR55 Class or SWAT Default*
Vineyard	43	65	76	82	Woods/Orchard/Fair
Grain Sorghum	67	78	85	89	RC/SR/Good
Hay	30	58	71	78	Meadow for hay
Lima Beans	67	77	83	87	SWAT Default
Oats	63	75	83	87	Close Grown/SR/Good
Rice	63	75	83	87	Close Grown/SR/Good
Range-Brush	35	56	70	77	Brush/Fair
Range-Grasses	49	69	79	84	Pasture/Grass/Fair
Rye	63	75	83	87	Close Grown/SR/Good
Sugarbeet	67	78	85	89	RC/SR/Good
Strawberry	67	78	85	89	RC/SR/Good
Sunflower	67	78	85	89	RC/SR/Good
Tomato	67	78	85	89	RC/SR/Good
Wetlands-Mixed	49	69	79	84	SWAT Default
Winter Wheat	63	75	83	87	Close Grown/SR/Good
Urban low density (pervious)	49	69	79	84	Open spaces, fair hydro condition
Urban medium density (pervious)	49	69	79	84	Open spaces, fair hydro condition

Table E-67 Initial Values for SWAT Model Parameters		
SWAT Parameter	*Parameter Description*	*Initial Value*
CH_N1	Tributary channel Manning's N	0.075
CN_N2	Main channel Manning's N	0.035
ALPHA_BF	Baseflow recession constant	0.01
IPET	PET Method	Hargreaves
SURLAG	Surface runoff lag time	1.50
ICN	Daily curve number adjustment method	Plant ET
CNCOEF	Curve number coefficient	0.5

Table E-68 Model Performance Ratings for Statistics on a Monthly Time Step (from Moriasi et al., 2007)			
Performance Rating	*RSR*[a]	*NSE*[b]	*PBIAS*[c] *(%)*
Very Good	0.00 < RSR < 0.50	0.75 < NSE < 1.00	PBIAS < ±10
Good	0.50 < RSR < 0.60	0.65 < NSE < 0.75	±10 < PBIAS < ±15
Satisfactory	0.60 < RSR < 0.70	0.50 < NSE < 0.65	±15 < PBIAS < ±25
Unsatisfactory	RSR > 0.70	NSE < 0.50	PBIAS > ±25

[a] RSR = The ratio of the root mean square error to the standard deviation of measured data
[b] NSE = The Nash Sutcliffe Efficiency
[c] PBIAS = The percent bias

Table E-69 Monthly Calibration Statistics								
Subbasin	***USGS Gage ID***	***USGS Name***	***1983-1992***			***2001-2010***		
			RSR[a]	***NSE[b]***	***PBIASc[3]***	***RSR[a]***	***NSE[2b]***	***PBIAS[c]***
25	11382000	Thomes C A Paskenta CA	0.58	0.66	-3.06			
54	11389000	Sacramento R A Butte City CA	0.13	0.98	-8.24			
97	11390500	Sacramento R BL Wilkins Slough Nr Grimes CA	0.29	0.91	-2.44	0.41	0.83	-6.22
128	11447293	Dry C A Vernon St Bridge A Roseville CA				0.89	0.21	28.94
138	11425500	Sacramento R A Verona CA	0.27	0.93	-3.06	0.42	0.82	-5.11
188	11325500	Mokelumne R A Woodbridge CA	0.12	0.98	-17.7	0.12	0.99	-11.38
198	11183600	Walnut C A Concord CA	0.46	0.79	4.47			
204	11337600	Marsh C A Brentwood CA				0.92	0.15	-37.39
219	11303500	San Joaquin R Nr Vernalis CA	0.24	0.94	17.37	0.17	0.97	4.28
236	11271320	Dry C Nr Snelling CA	0.31	0.9	-21.34			
245	11274000	San Joaquin R Nr Newman CA	0.23	0.95	2.06	0.29	0.92	-23.68
173 +174	DAYFLOW Rio	Sacramento R at Rio	0.18	0.97	-16.55	0.23	0.94	-10.07
183 +190	DAYFLOW Outflow	CA Delta Outflow	0.12	0.99	-9.98	0.17	0.97	-11.06

[a] RSR = The ratio of the root mean square error to the standard deviation of measured data
[b] NSE = The Nash Sutcliffe Efficiency
[c] PBIAS = The percent bias

Table E-70 SWAT Calibration Parameters			
SWAT Parameter	***Parameter Description***	***Initial Value***	***Calibrated Value***
CNCOEF	Curve number ET Coefficient	0.5	0.8
SURLAG	Surface runoff lag factor	1.5	2
RCHRG_DP	Deep aquifer percolation fraction	0.05	Northern Subs, 0.2 - 0.4; Southern Subs, 0.1 - 0.2
ALPHA_BF	Baseflow recession constant	0.01	Slope <= 5%, 0.002; Slope > 5%, 0.1
GWQMIN	Shallow aquifer threshold depth for return flow (mm)	0	250
GW_DELAY	Groundwater delay (d)	31	3
SHALLST	Initial shallow aquifer storage (mm)	0	250
SLSOIL	Slope length for lateral subsurface flow	Variable, same as surface slope length (10 m - 121 m)	Variable as a function of slope (<1% = 120; <3% = 90; <8% = 75; <12% = 60; >12% = 45)

Table E-70 SWAT Calibration Parameters			
SWAT Parameter	***Parameter Description***	***Initial Value***	***Calibrated Value***
PLAPS	Precipitation scaling factor	Based on PRISM analysis	0.75 * original value
AUTO_WSTRS	Soil water deficit below field capacity at which irrigation occurs (mm)	N/A	30
IRR_MX	Depth of auto-irrigation when triggered (mm)	N/A	25

Table E-71 Comparison of Modeled and Observed Data for Selected Reaches					
	Rch 148 (Sacramento at Freeport)	*Rch 219 (San Joaquin at Vernalis)*	*Rch 188 (Mokelumne)*	*Rch 221 (Stanislaus)*	*Rch 199 (Calaveras)*
Model Max Conc. (µg/L)	0.0032	0.2051	0.7373	1.4433	1.7879
Model 99% Conc. (µg/L)	0.0004	0.0046	0.0212	0.0265	0.0214
Model 95% Conc. (µg/L)	0.0001	0.0006	0.0003	0.0014	1.85E-05
Model 90% Conc. (µg/L)	3.82E-05	0.0002	3.26E-07	0.0001	4.20E-08
Obs[a] Max Conc. (µg/L)[b]	< 0.03	< 1	< 0.1	< 0.058	1.3800
Range of Obs above LOQs (µg/L)	0.00365-0.0221	0.003-0.12	N/A	0.0042-0.0159	1.38
Range of Obs below LOQs (µg/L)	0.005-0.03	0.005-1.0	0.05-0.1	0.00-0.058	0.03-0.1
Obs above LOQs (%)	7%	5%	0%	14%	4%
Obs below LOQs (%)	93%	95%	100%	86%	96%
Number of Obs	213	1256	52	111	24
Obs Time Period	Nov 15 1996 - Aug 7 2012	Jan 13 1991 - Sep 6 2012	May 16 2006 - Dec 13 2011	Apr 4 1991-Aug 31 2006	Jan 16 1996 - Nov 28 2007

[a] "Obs" = Observed
[b] "< value" means the maximum concentration reported was an LOQ Model data are reported for the same time period as observed.

Table E-43 90th-percentile EECs in Critical Habitat Reaches					
Subbasin	*24-hour (µg/L)*	*48-hour (µg/L)*	*4-day (µg/L)*	*21-day (µg/L)*	*60-day (µg/L)*
197	7.52	4.92	2.71	0.96	0.34
203	2.74	1.51	0.77	0.16	0.06
155	2.53	1.65	0.91	0.49	0.17
159	2.01	1.02	0.53	0.23	0.09
169	1.88	1.36	0.81	0.16	0.06
209	1.81	1.18	0.64	0.28	0.12
204	1.12	0.69	0.55	0.20	0.07
210	0.95	0.64	0.37	0.17	0.08
144	0.91	0.74	0.47	0.22	0.08
153	0.85	0.55	0.30	0.08	0.03
191	0.81	0.52	0.28	0.09	0.03
201	0.78	0.54	0.33	0.13	0.05
207	0.60	0.40	0.24	0.11	0.06
146	0.55	0.42	0.26	0.11	0.04
158	0.49	0.32	0.17	0.04	0.02
164	0.46	0.35	0.21	0.12	0.04
194	0.36	0.23	0.21	0.09	0.03
196	0.34	0.25	0.14	0.06	0.02
161	0.33	0.21	0.11	0.03	0.01
173	0.25	0.14	0.08	0.03	0.01
221	0.24	0.17	0.10	0.04	0.02
184	0.24	0.17	0.10	0.04	0.02
176	0.22	0.15	0.09	0.04	0.02
168	0.20	0.16	0.10	0.05	0.02
157	0.19	0.13	0.08	0.02	0.01
220	0.17	0.12	0.07	0.03	0.01
162	0.14	0.13	0.10	0.05	0.02
143	0.12	0.08	0.05	0.02	0.01
216	0.10	0.07	0.04	0.01	0.01
149	0.09	0.05	0.03	0.01	0.00
154	0.09	0.06	0.03	0.01	0.00
170	0.08	0.05	0.03	0.01	0.00
186	0.07	0.03	0.02	0.00	0.00
218	0.07	0.05	0.03	0.01	0.00
200	0.07	0.05	0.03	0.01	0.00
205	0.05	0.03	0.02	0.01	0.00
219	0.04	0.03	0.02	0.01	0.00
177	0.04	0.03	0.01	0.00	0.00
208	0.03	0.02	0.01	0.00	0.00

Table E-43 90th-percentile EECs in Critical Habitat Reaches					
Subbasin	***24-hour (µg/L)***	***48-hour (µg/L)***	***4-day (µg/L)***	***21-day (µg/L)***	***60-day (µg/L)***
202	0.03	0.01	0.01	0.00	0.00
187	0.03	0.01	0.01	0.00	0.00
193	0.03	0.02	0.01	0.00	0.00
192	0.03	0.02	0.01	0.00	0.00
171	0.03	0.02	0.01	0.00	0.00
195	0.02	0.01	0.01	0.00	0.00
189	0.02	0.01	0.01	0.00	0.00
190	0.01	0.01	0.00	0.00	0.00
181	0.01	0.01	0.00	0.00	0.00
163	0.01	0.01	0.01	0.00	0.00
183	0.01	0.01	0.00	0.00	0.00
160	0.01	0.01	0.00	0.00	0.00
174	0.01	0.00	0.00	0.00	0.00
185	0.01	0.01	0.00	0.00	0.00
182	0.00	0.00	0.00	0.00	0.00
156	0.00	0.00	0.00	0.00	0.00
178	0.00	0.00	0.00	0.00	0.00
179	0.00	0.00	0.00	0.00	0.00
148	0.00	0.00	0.00	0.00	0.00
145	0.00	0.00	0.00	0.00	0.00

FIGURES

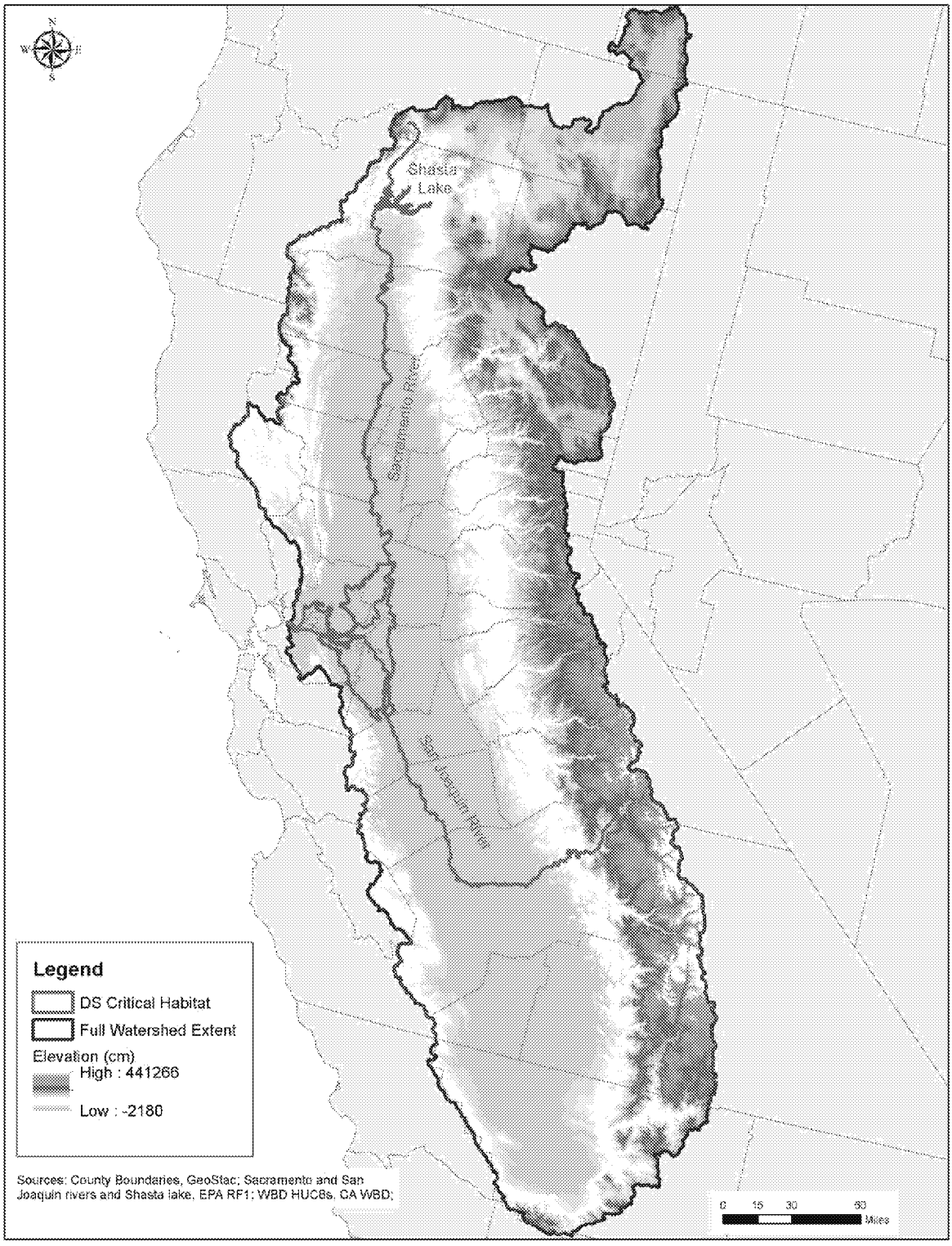


Figure E-27 Watershed Overview

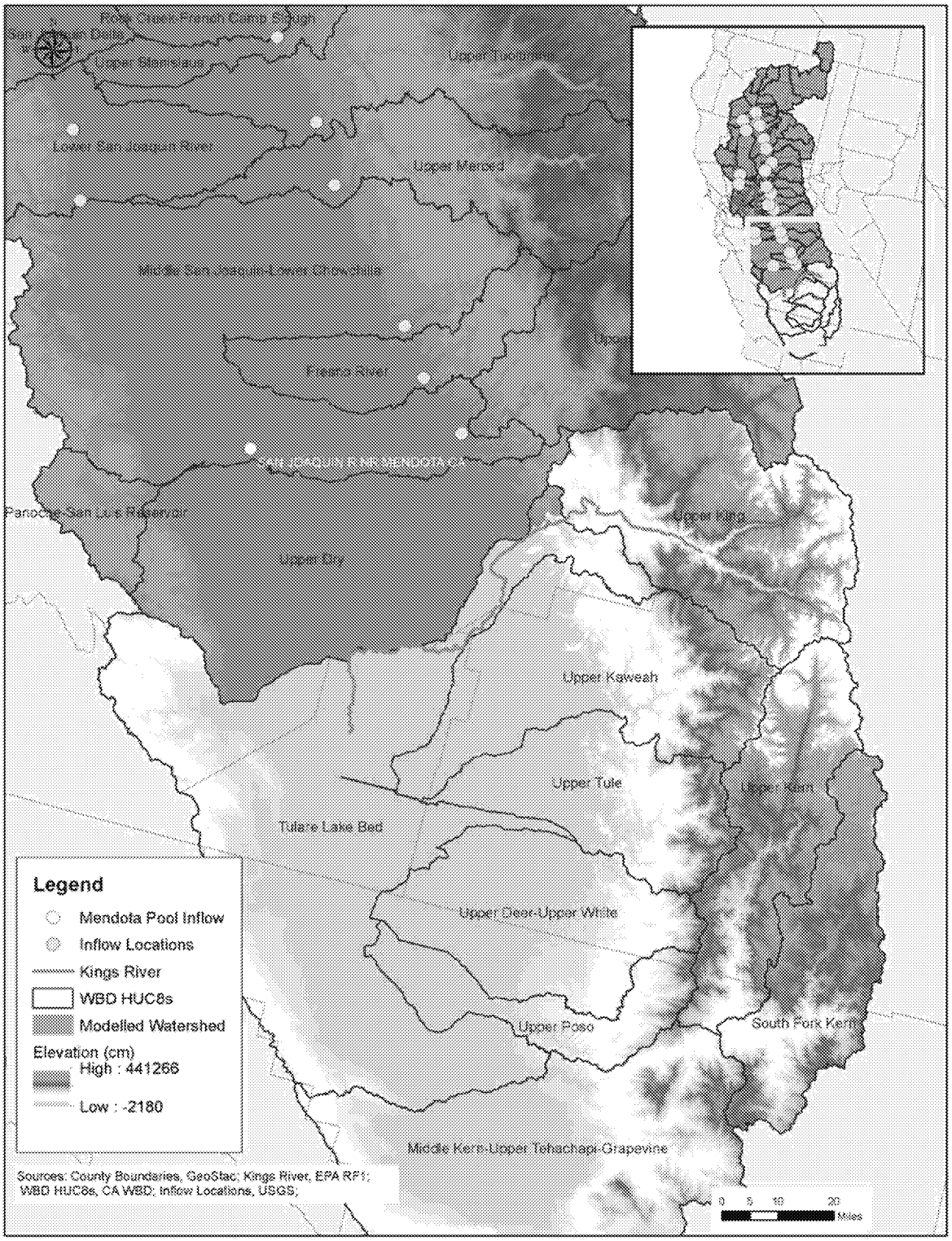


Figure E-17 Delta Watershed Identification

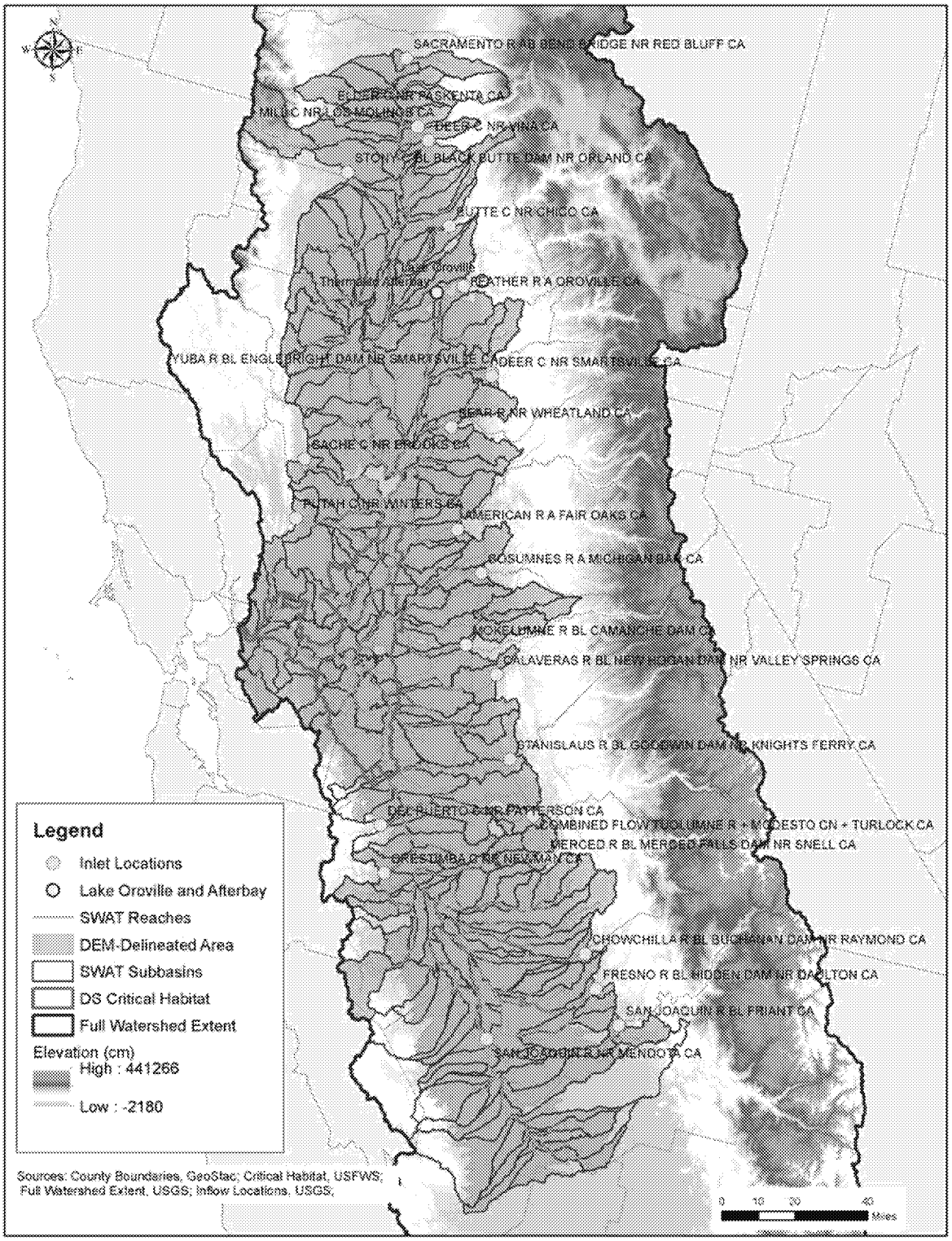


Figure E-18 Watershed Subbasins and Inlet Locations

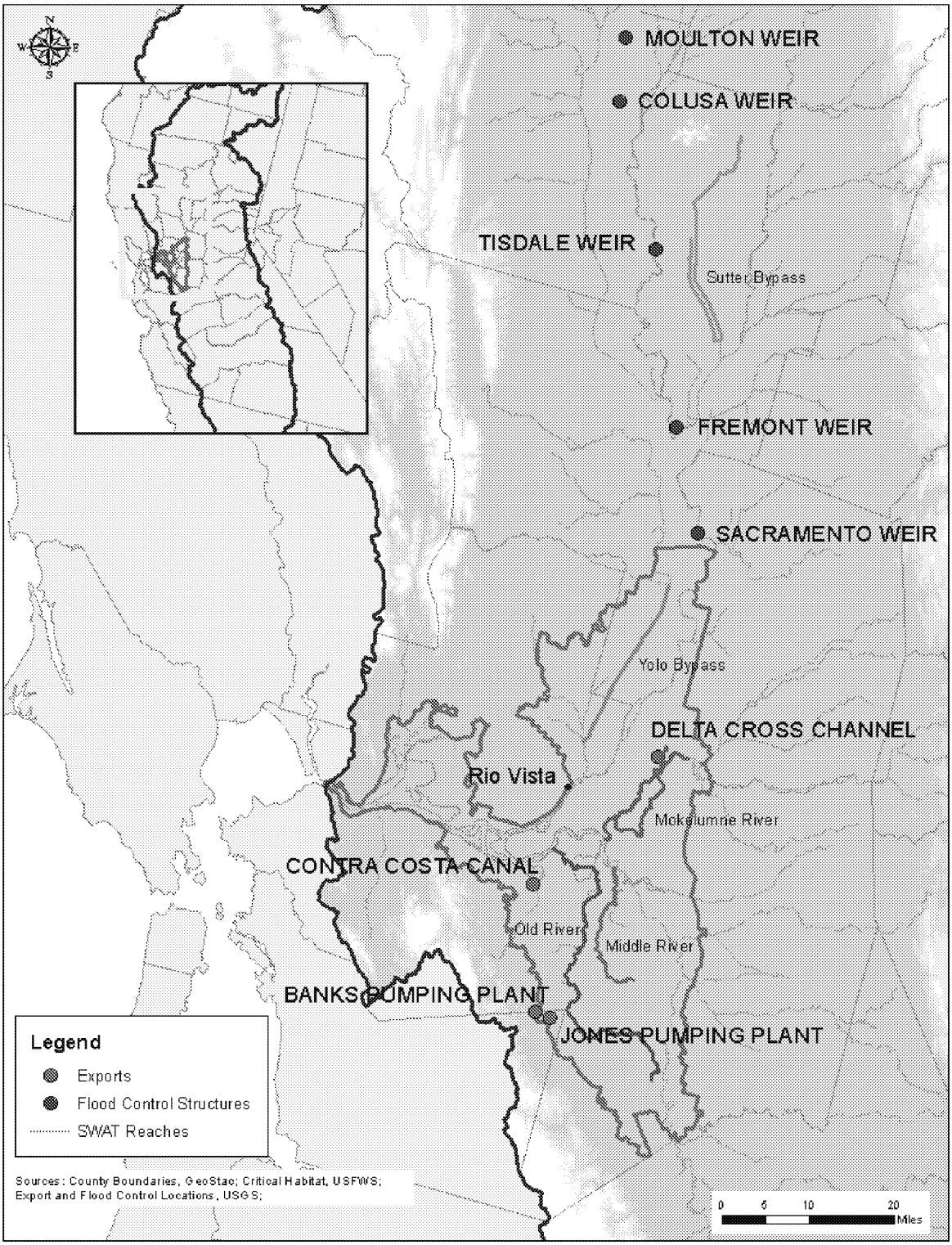


Figure E-19 Major Flood Control Diversions and Water Withdrawals

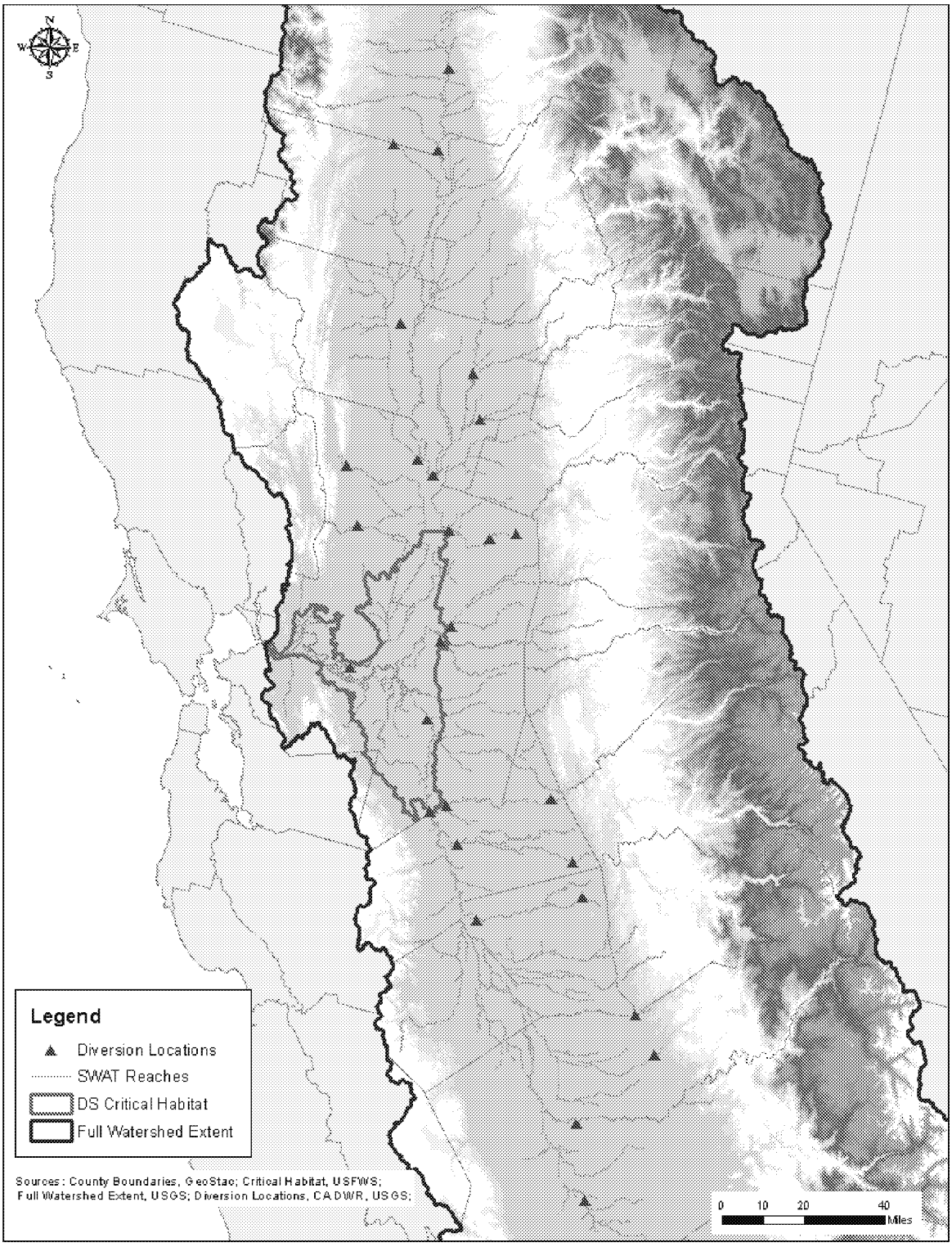


Figure E-20 Diversions (Irrigation and Other)

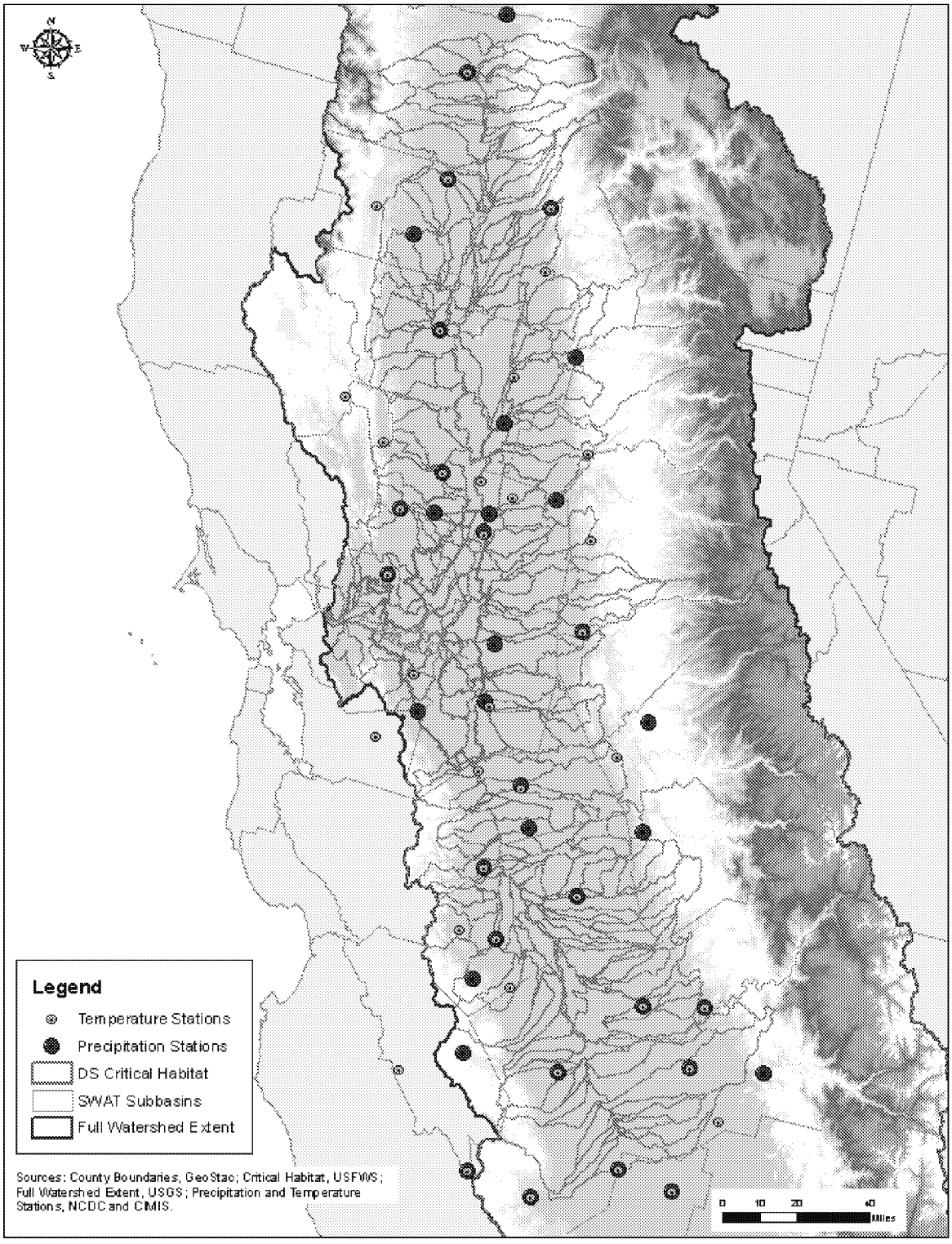


Figure E-21 Distribution of SWAT Model Weather Stations

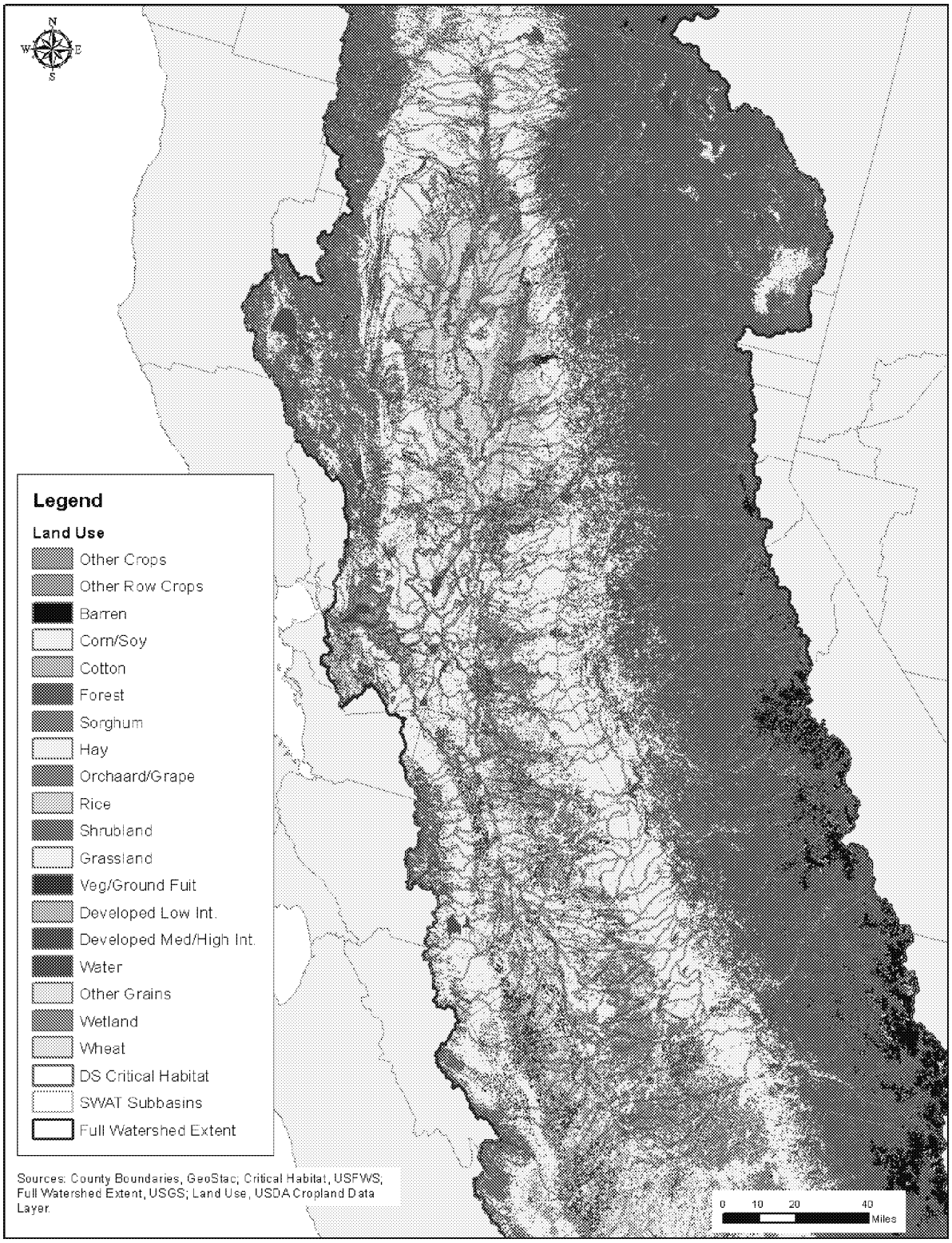


Figure E-33 SWAT Model Land Use Classification

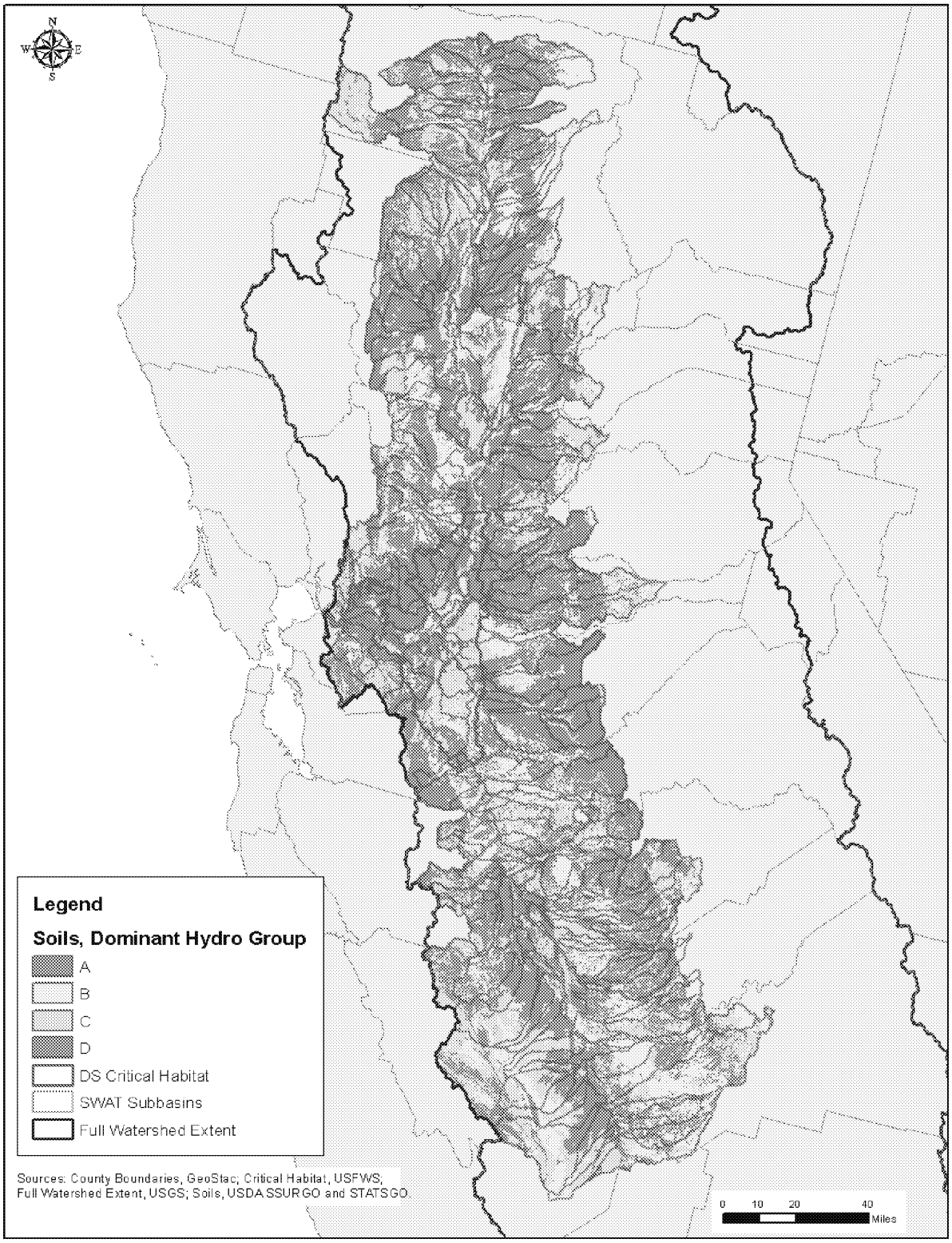


Figure E-34 Soil Hydrologic Groups in SWAT Model Area

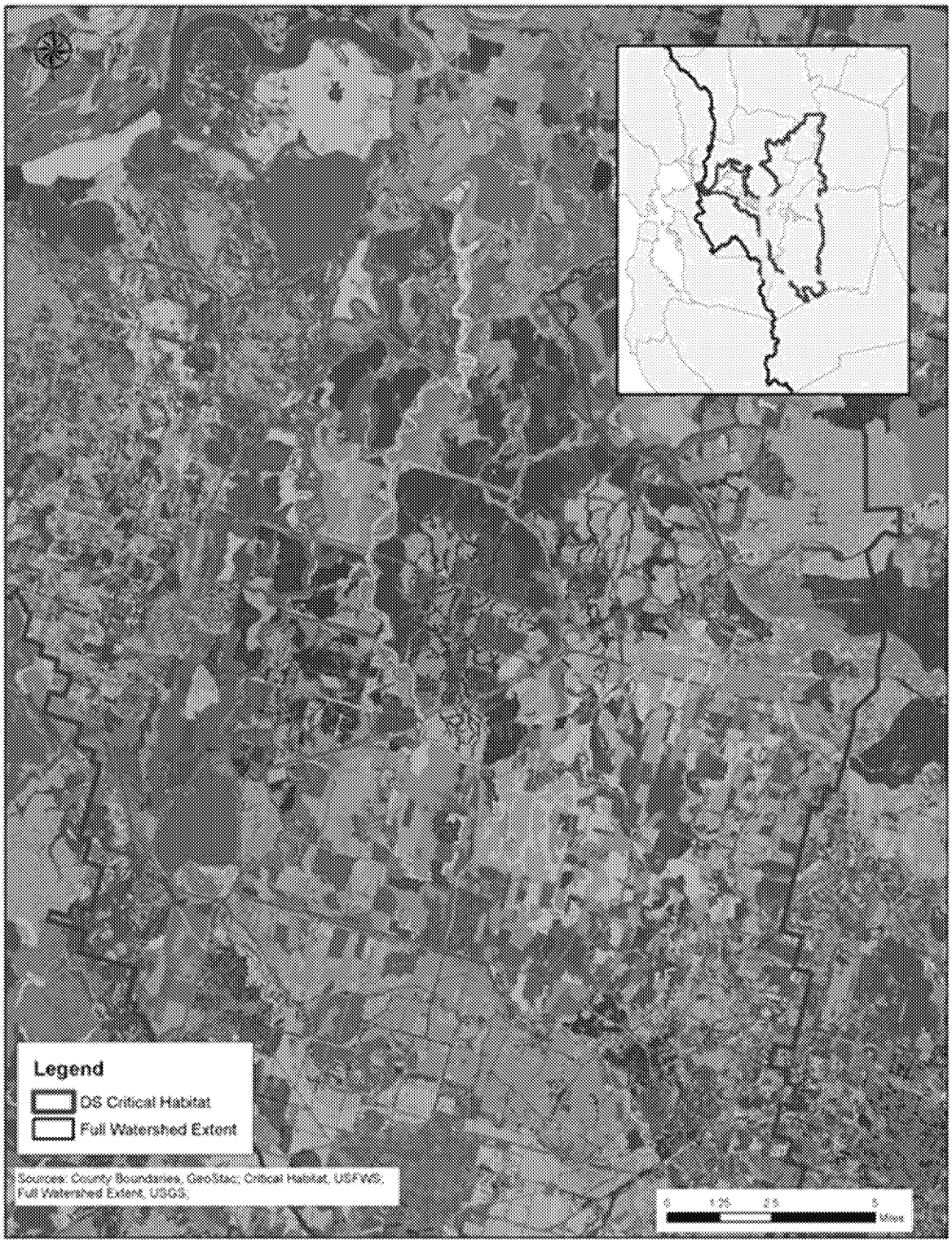


Figure E-24 **Segment of Hydrologic Response Unit Delineation in DS Critical Habitat**

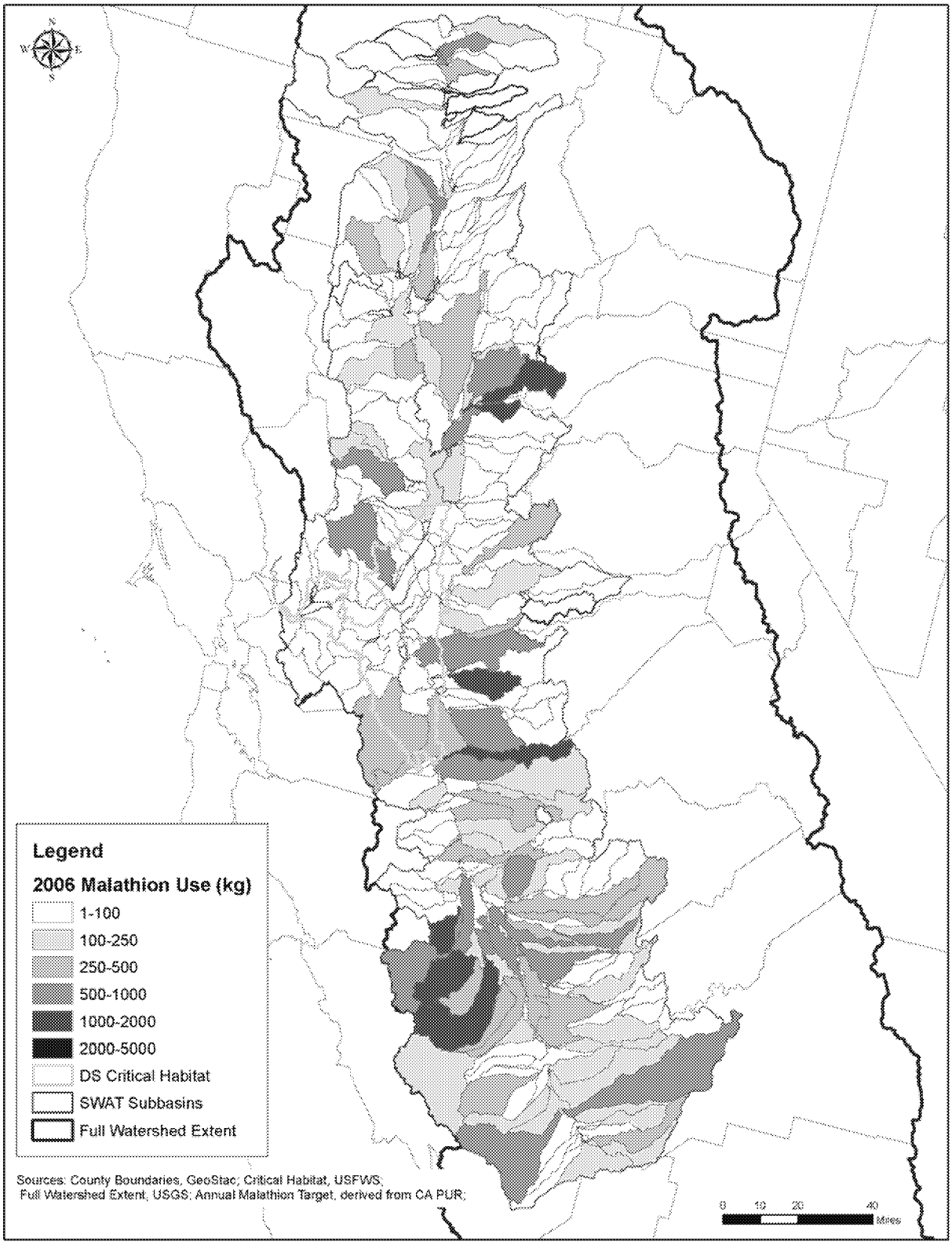


Figure E-25 Annual Malathion Application Target Mass in 2006

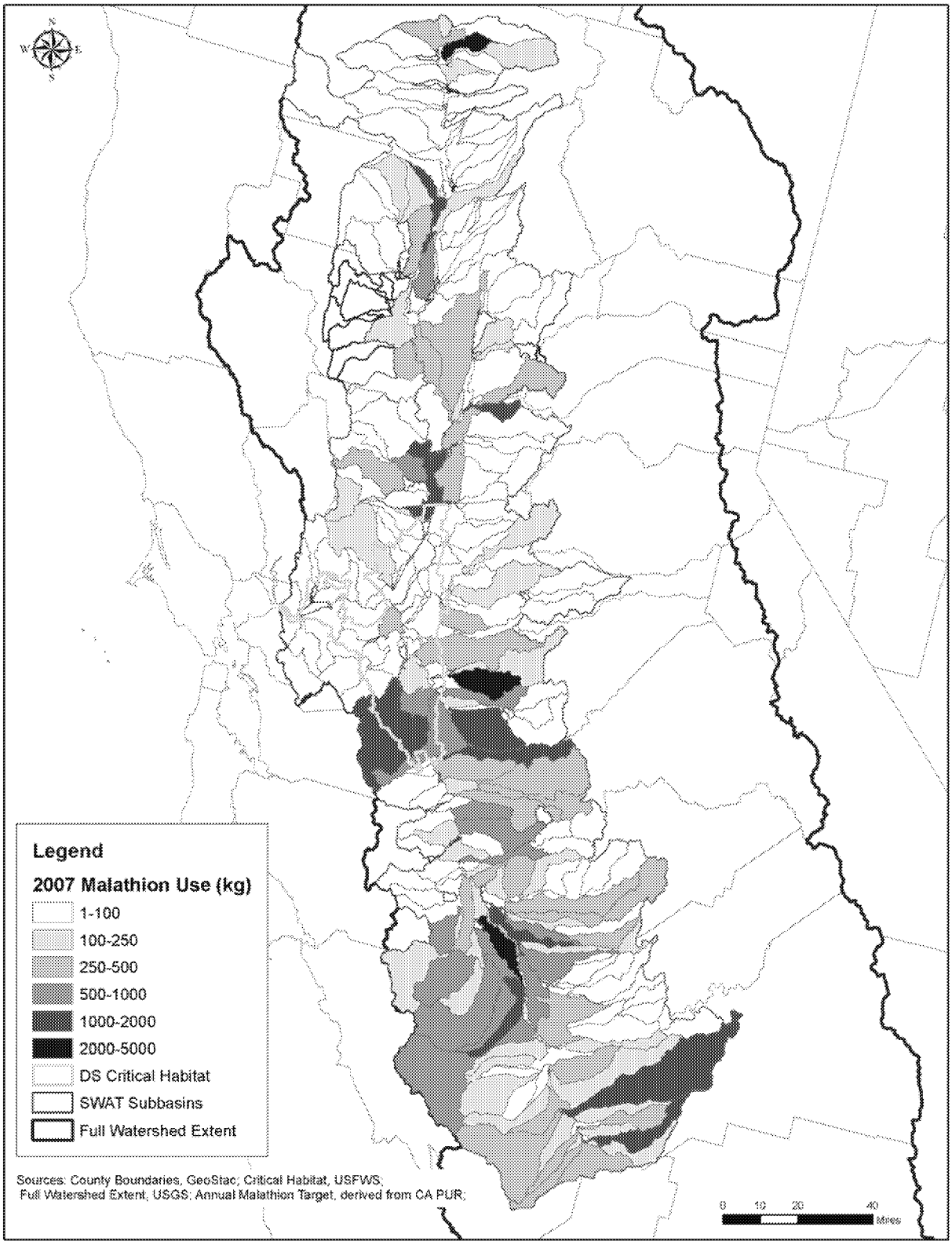


Figure E-37 Annual Malathion Application Target Mass in 2007

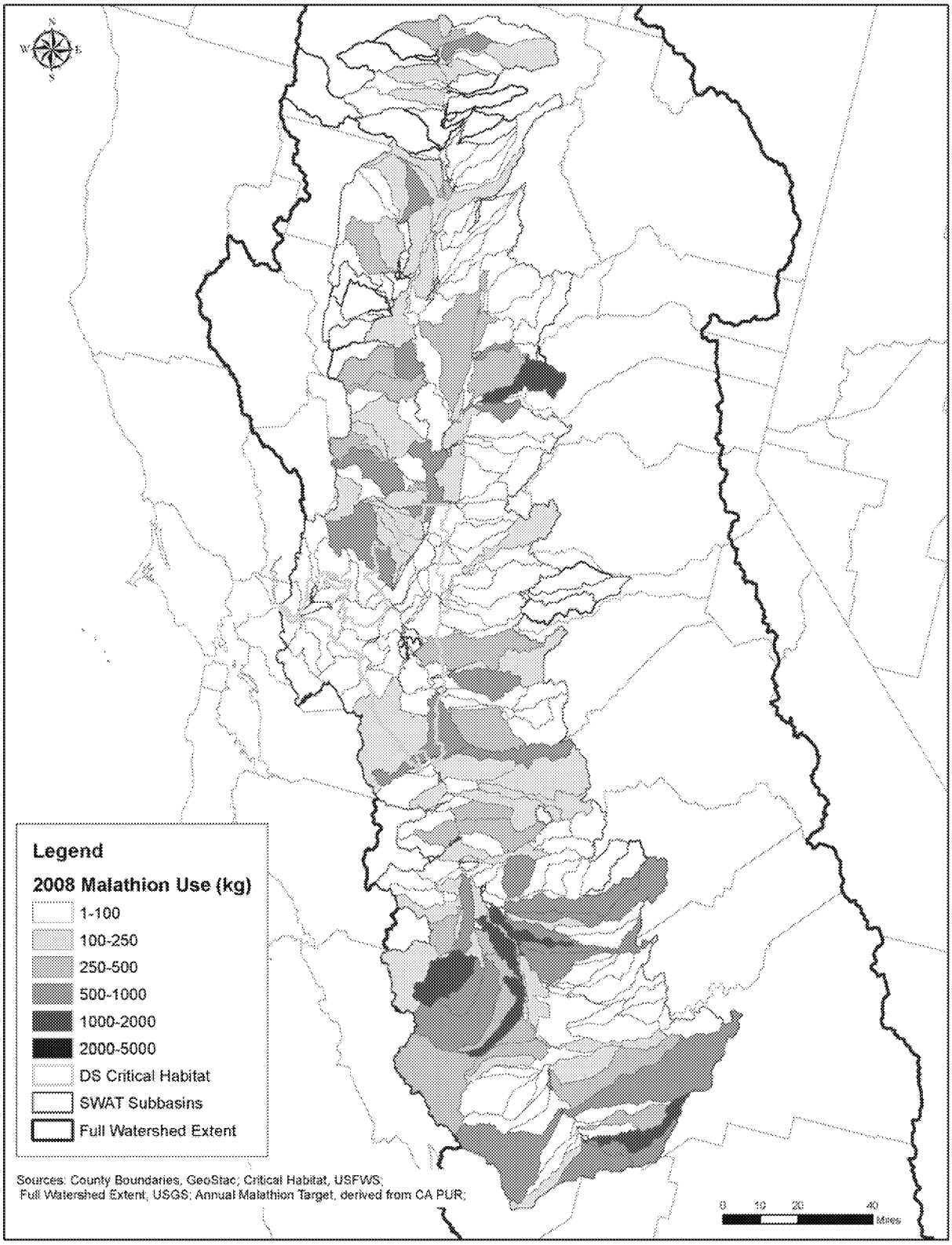


Figure E-38 Annual Malathion Application Target Mass in 2008

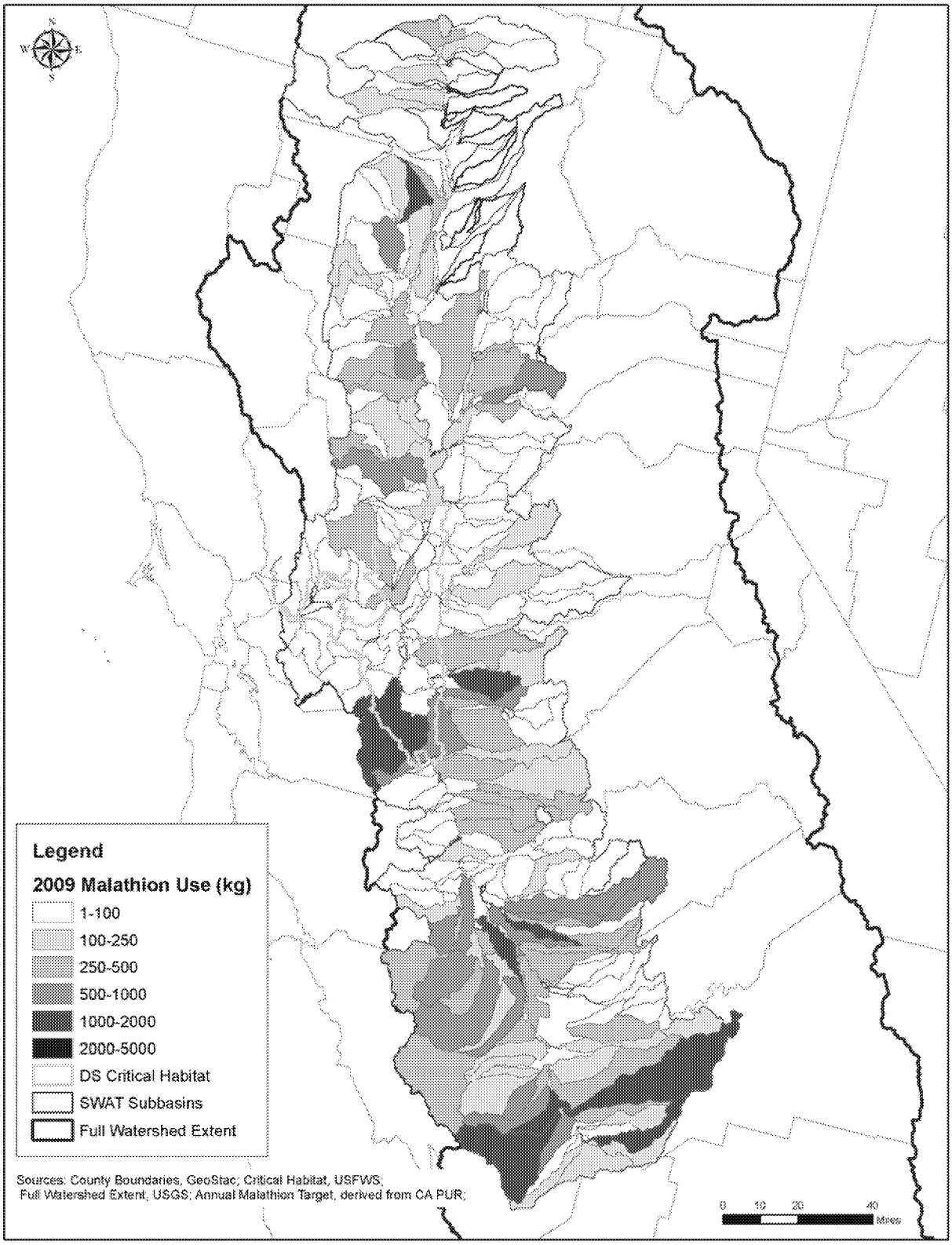


Figure E-39 Annual Malathion Application Target Mass in 2009

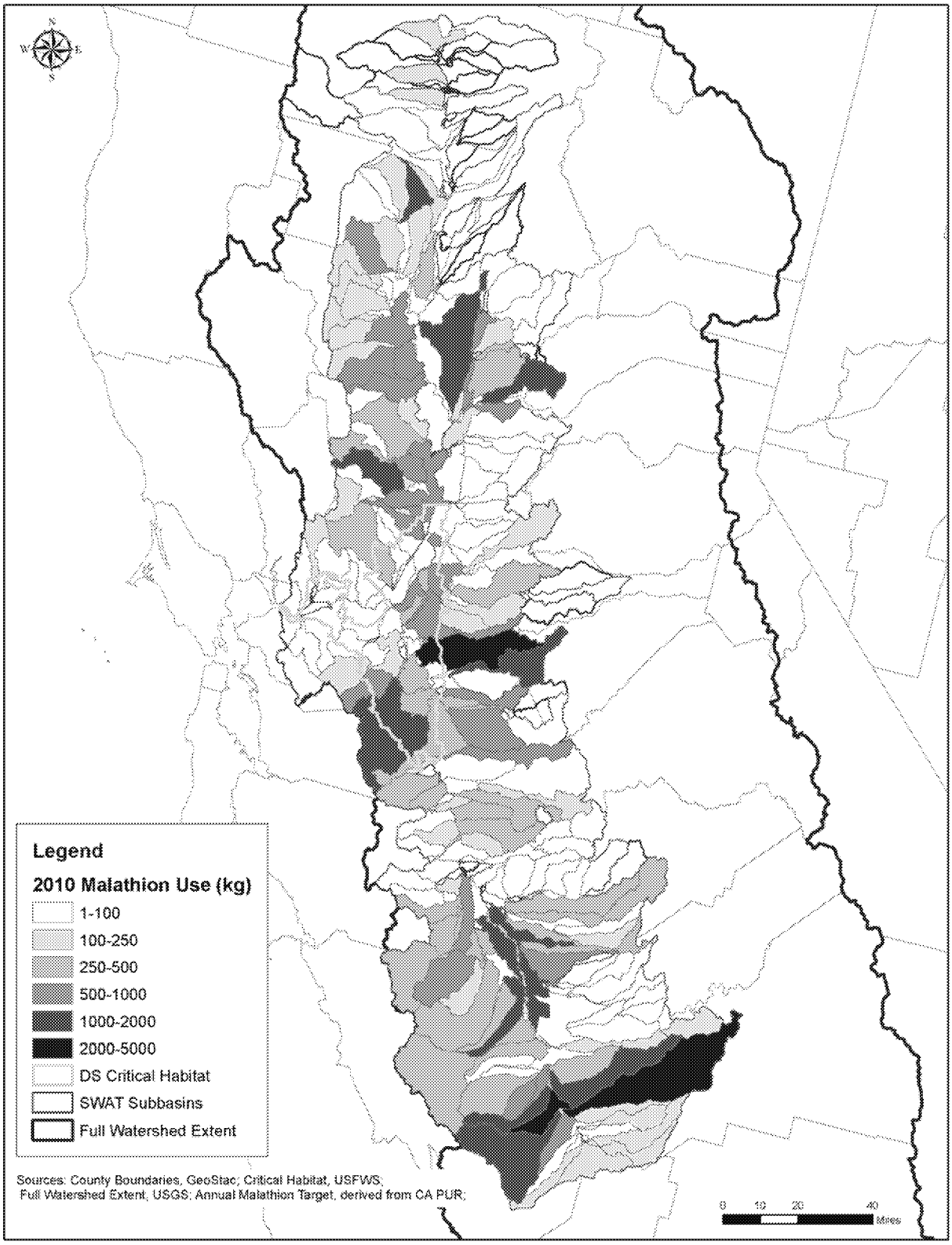


Figure E-40 Annual Malathion Application Target Mass in 2010

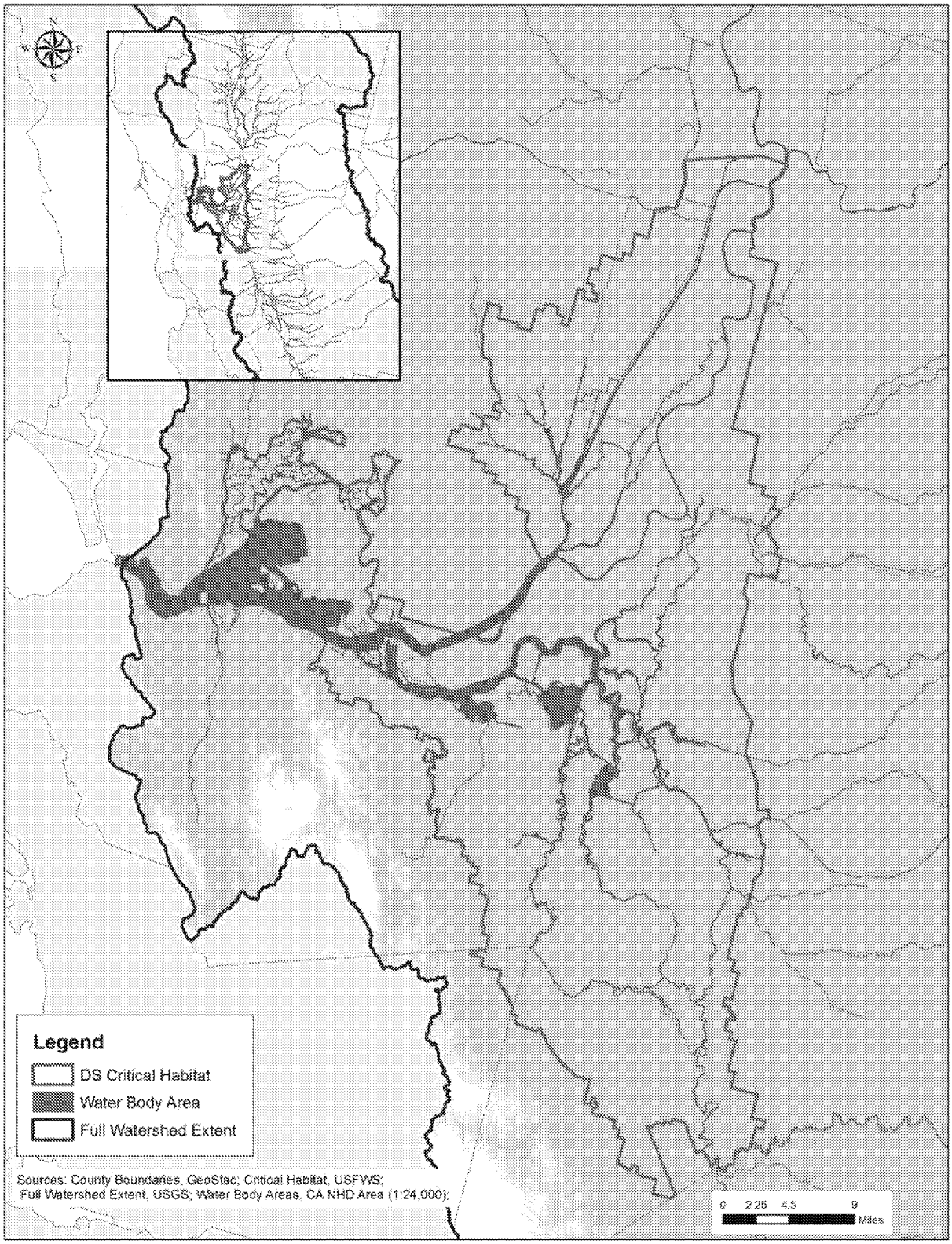
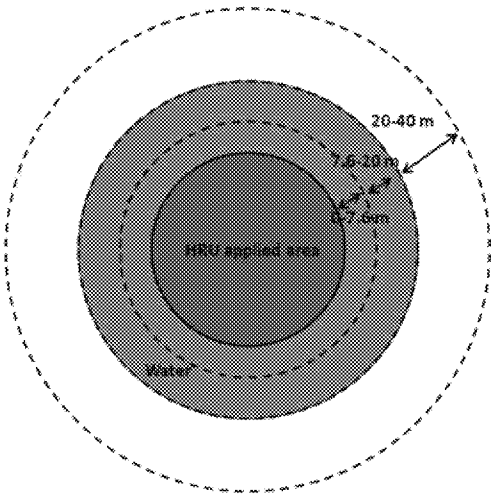


Figure E-30 Water Body Areas for Drift Calculation

A. Ground Spray Example



B. Aerial Spray Example

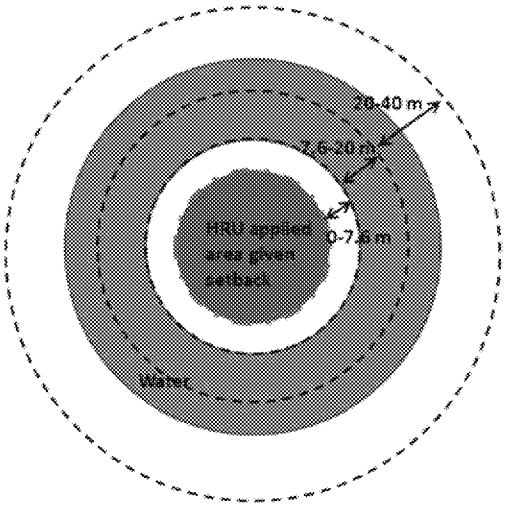


Figure E-42 Schematic of Calculation of Water Body Area Receiving Spray Drift

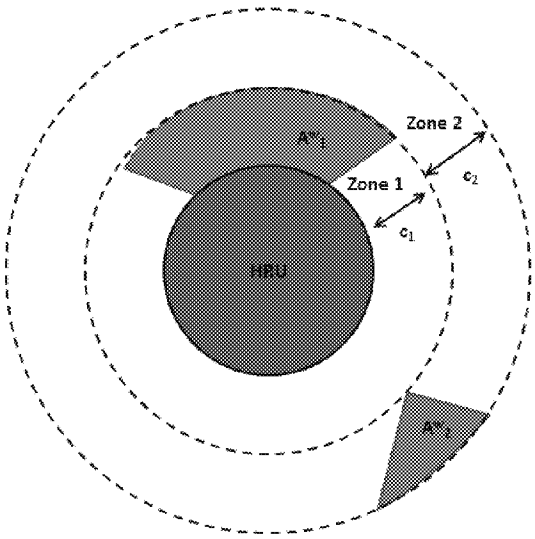


Figure E-43 Schematic Example of Spray Drift Calculation

Assumes all surrounding area is downwind

Definitions:

c_i is the average drift fraction for the ith distance zone

A^w_i is the water body area in distance zone i for the HRU

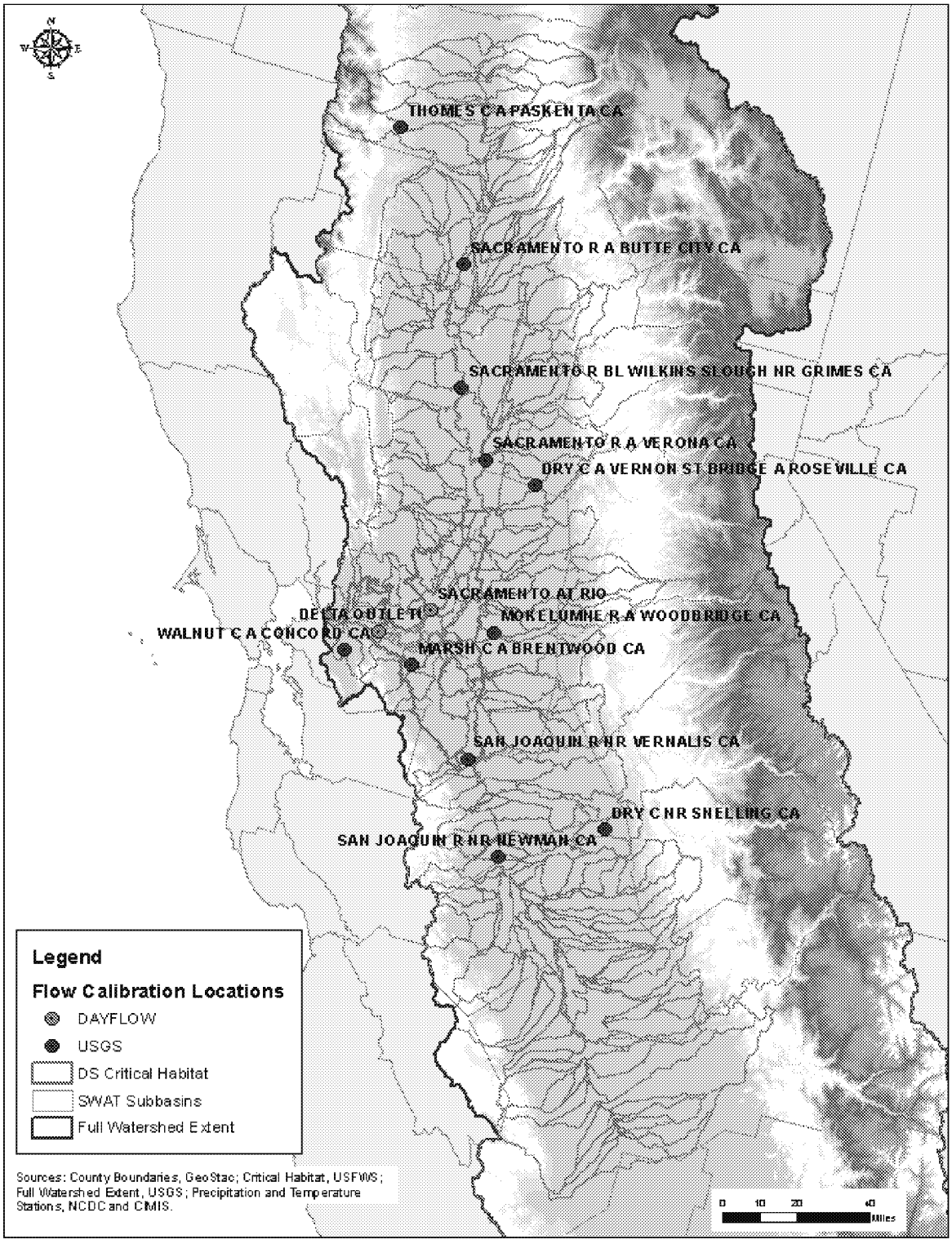


Figure E-33 Flow Calibration Sites for SWAT Model

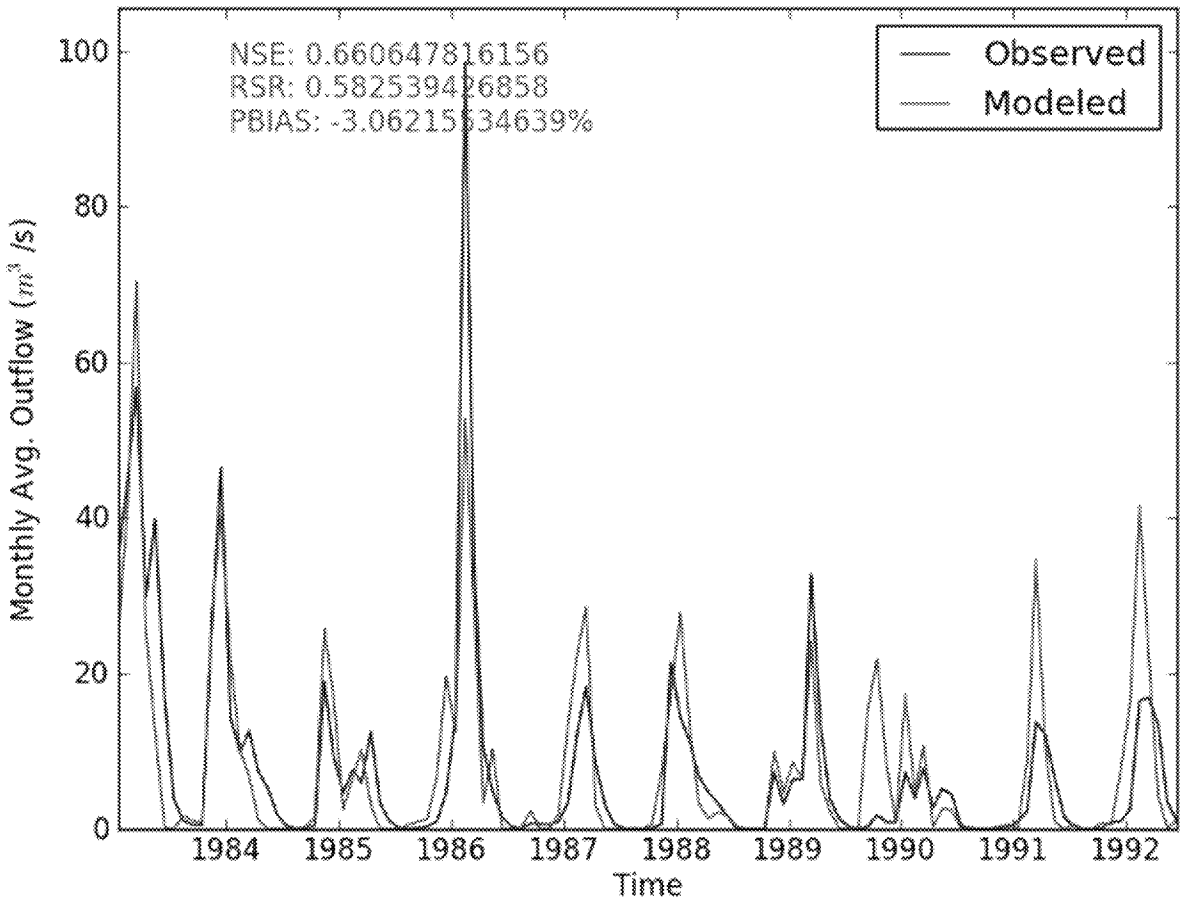


Figure E-45 **Monthly Flow Calibration at Subbasin 25 (Thomes Creek at Paskenta)**

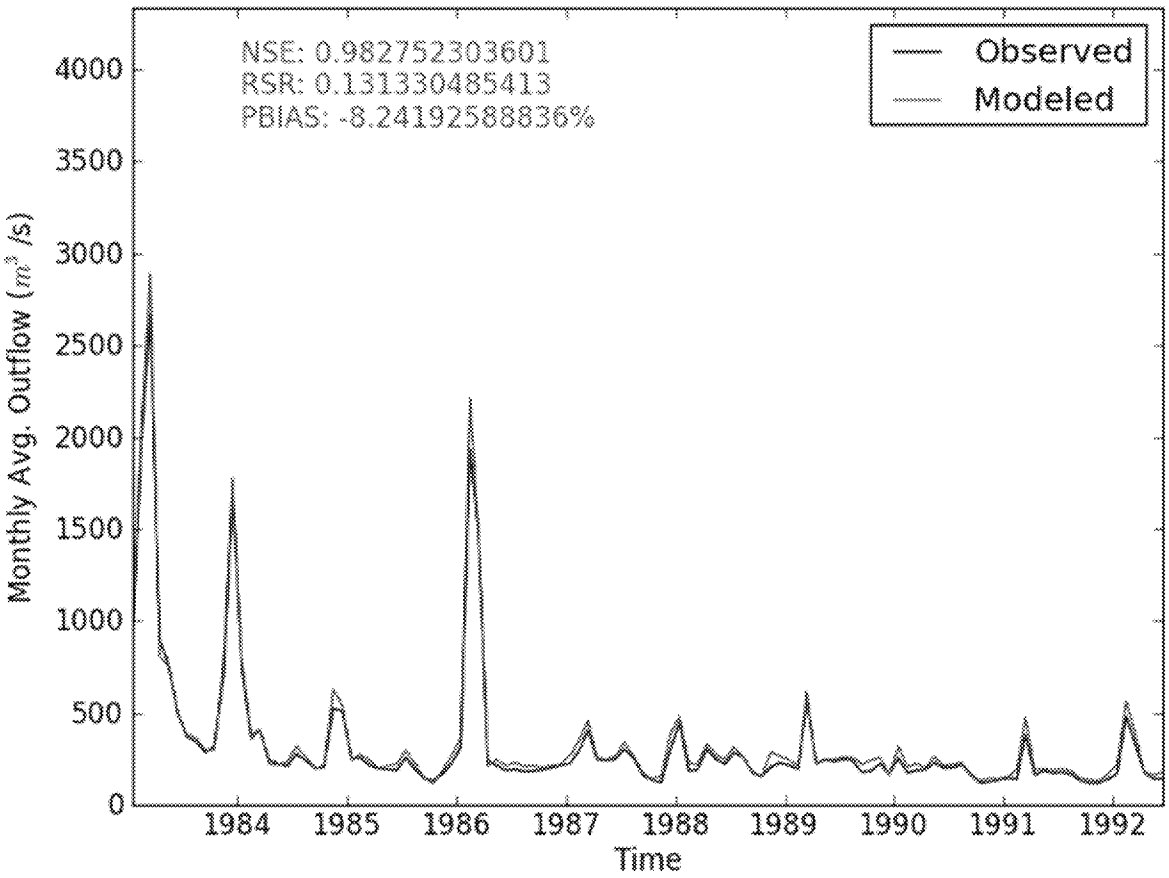
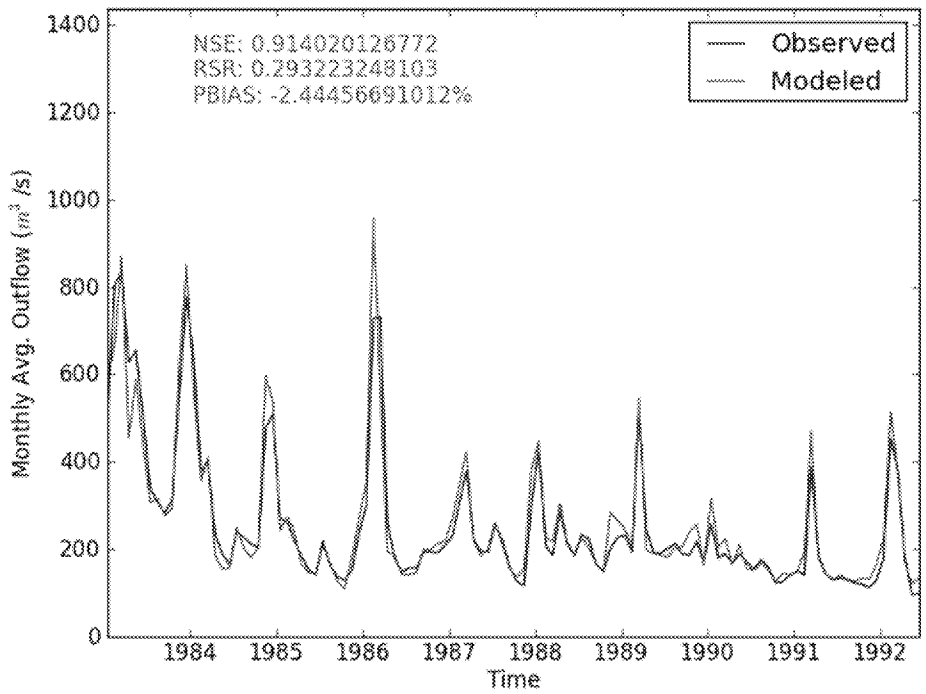


Figure E-46 **Monthly Flow Calibration at Subbasin 54 (Sacramento River at Butte City)**



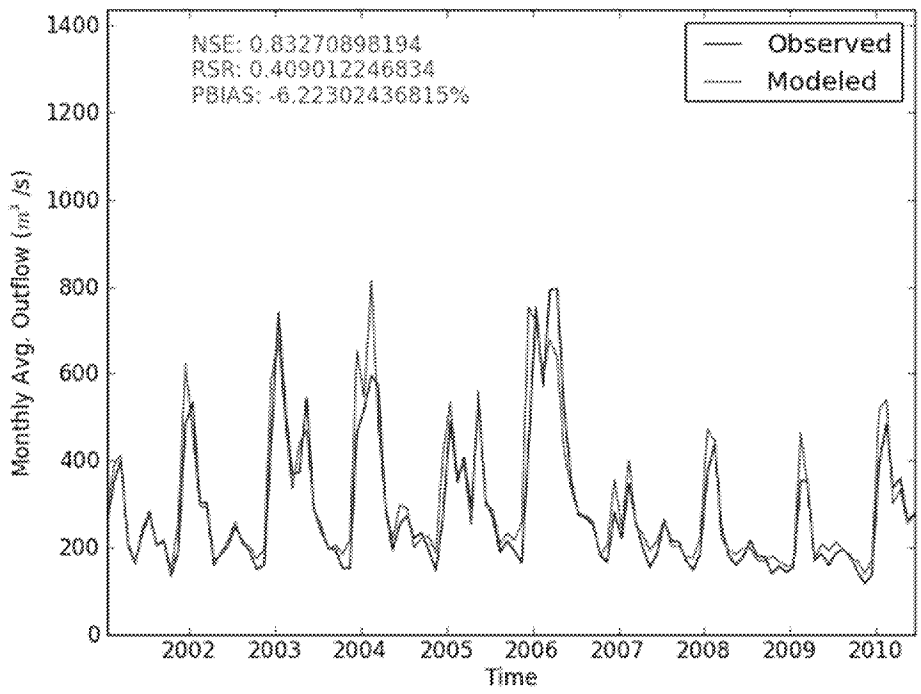


Figure E-47 **Monthly Flow Calibration (top) and Validation (bottom) at Subbasin 97 (Sacramento River below Wilkins)**

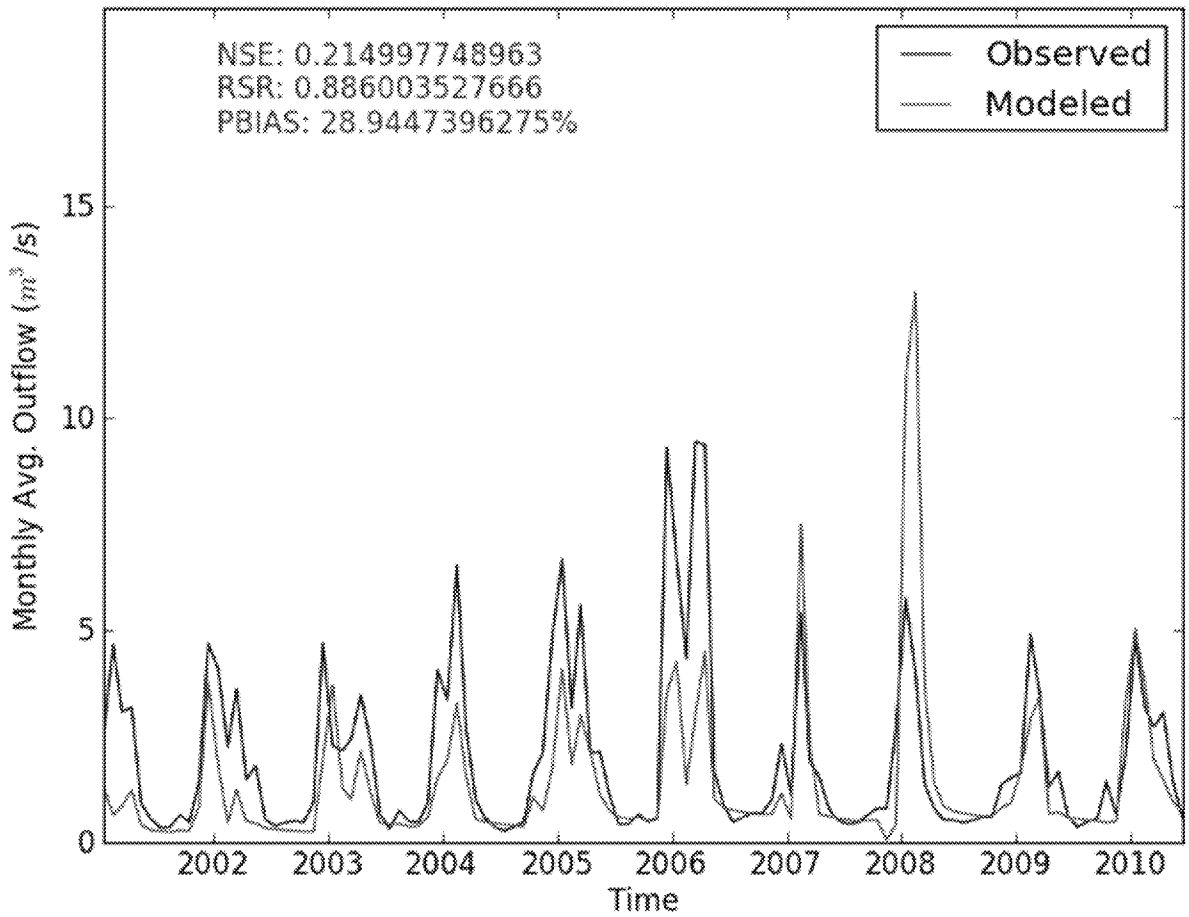
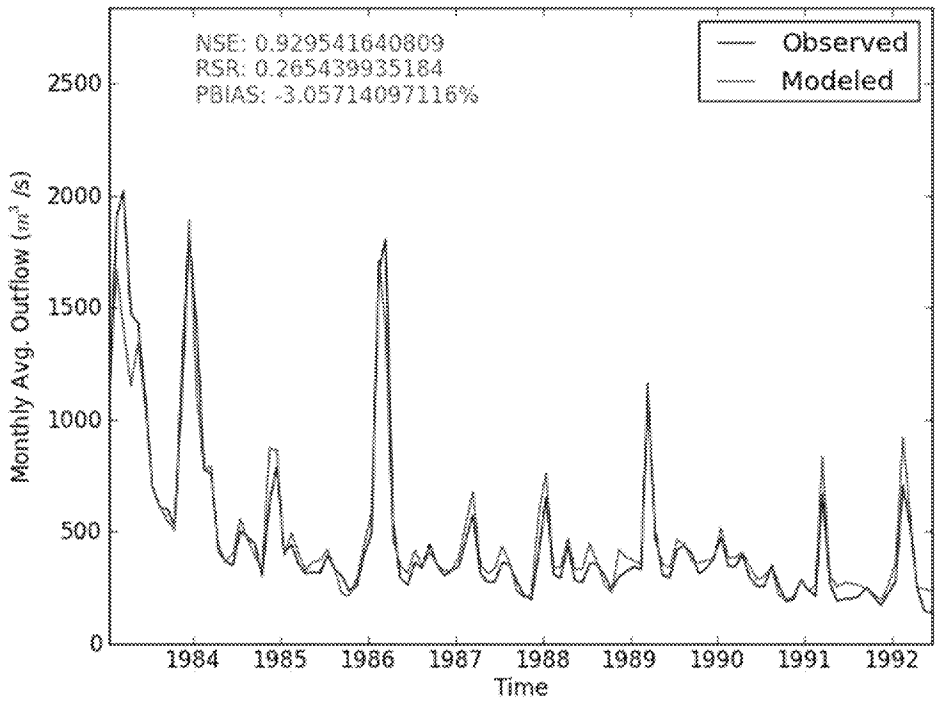


Figure E-48 **Monthly Flow Validation at Subbasin 128 (Dry Creek at Vernon)**



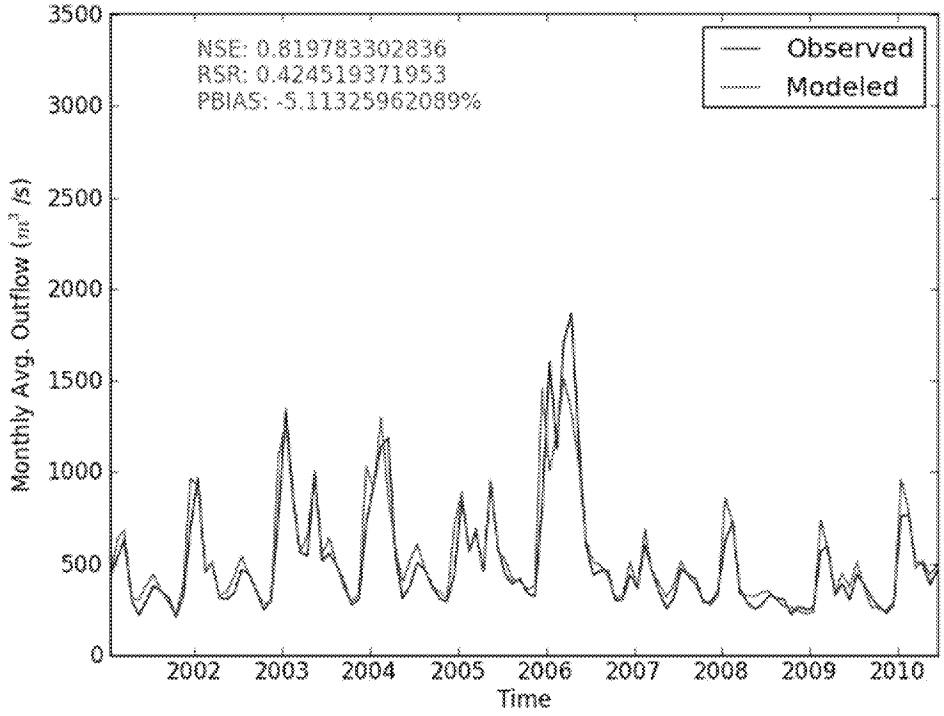
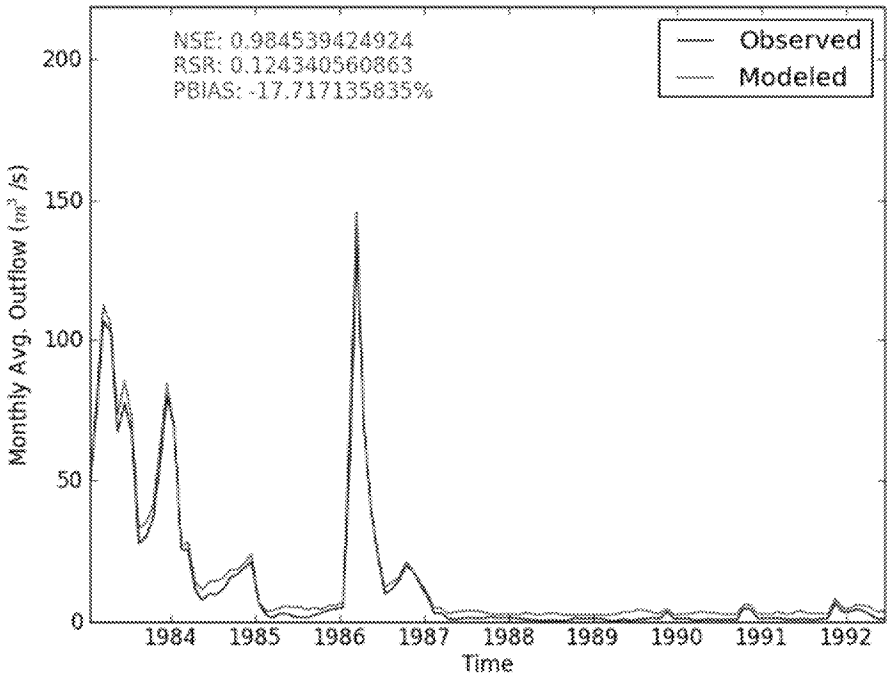


Figure E-49 **Monthly Flow Calibration (top) and Validation (bottom) at Subbasin 138 (Sacramento River at Verona)**



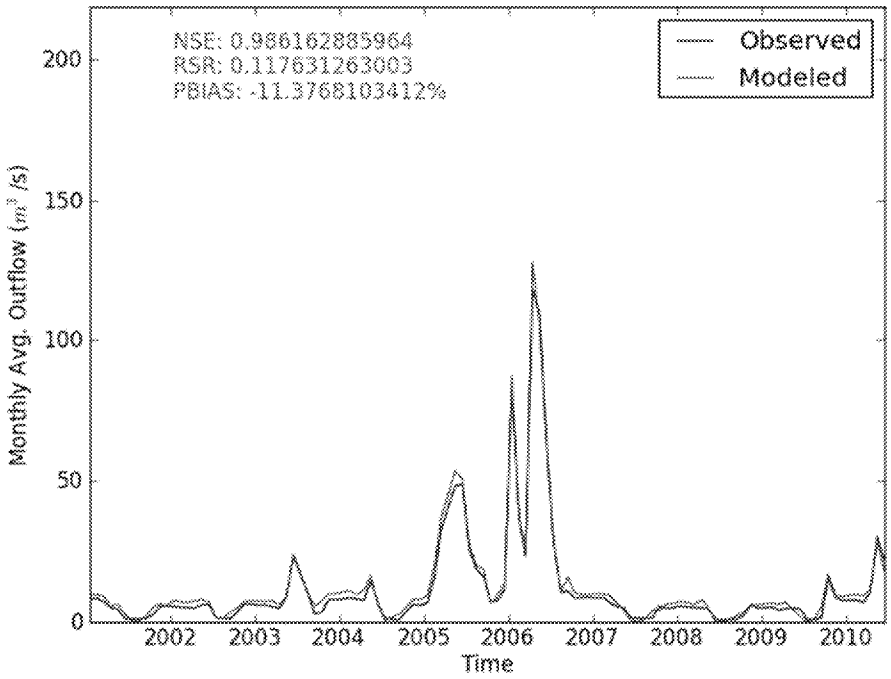


Figure E-50 **Monthly Flow Calibration (top) and Validation (bottom) at Subbasin 188 (Mokelumne River at Woodbridge)**

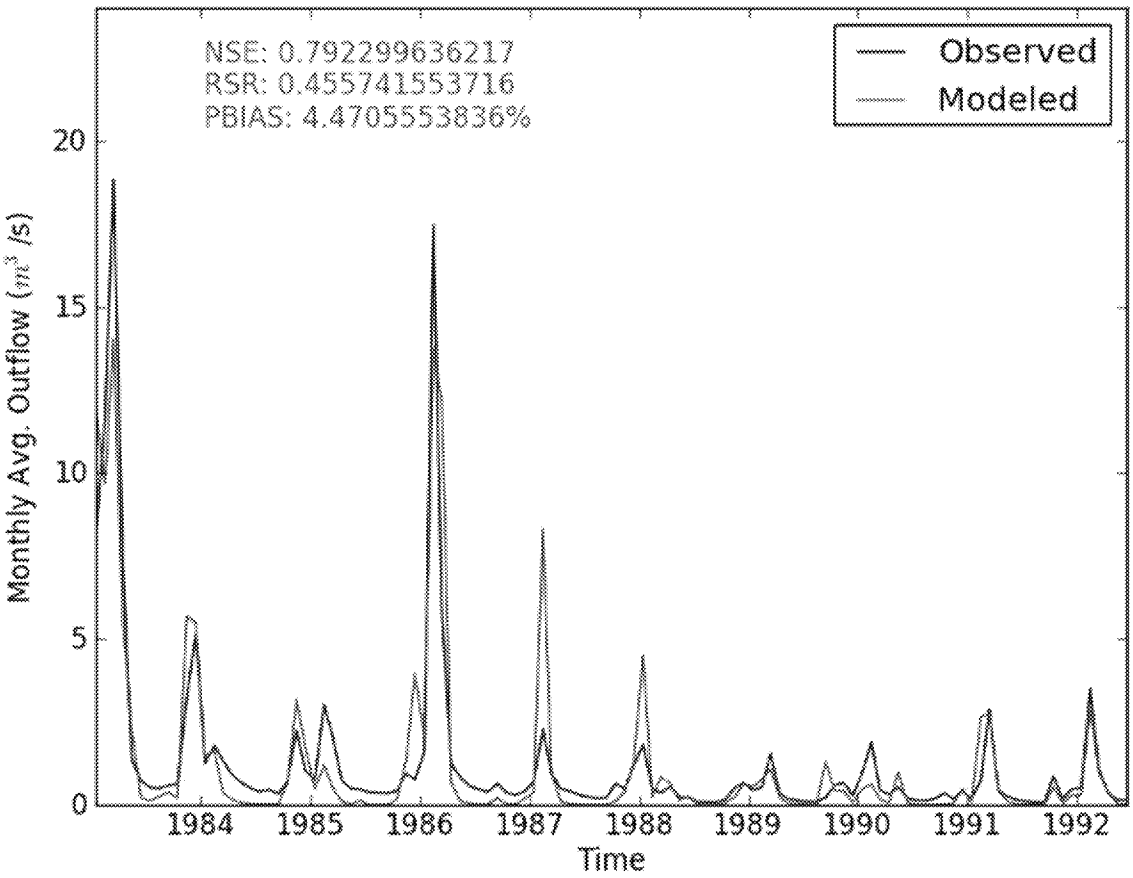


Figure E-51 Monthly Flow Calibration at Subbasin 198 (Walnut Creek at Concord)

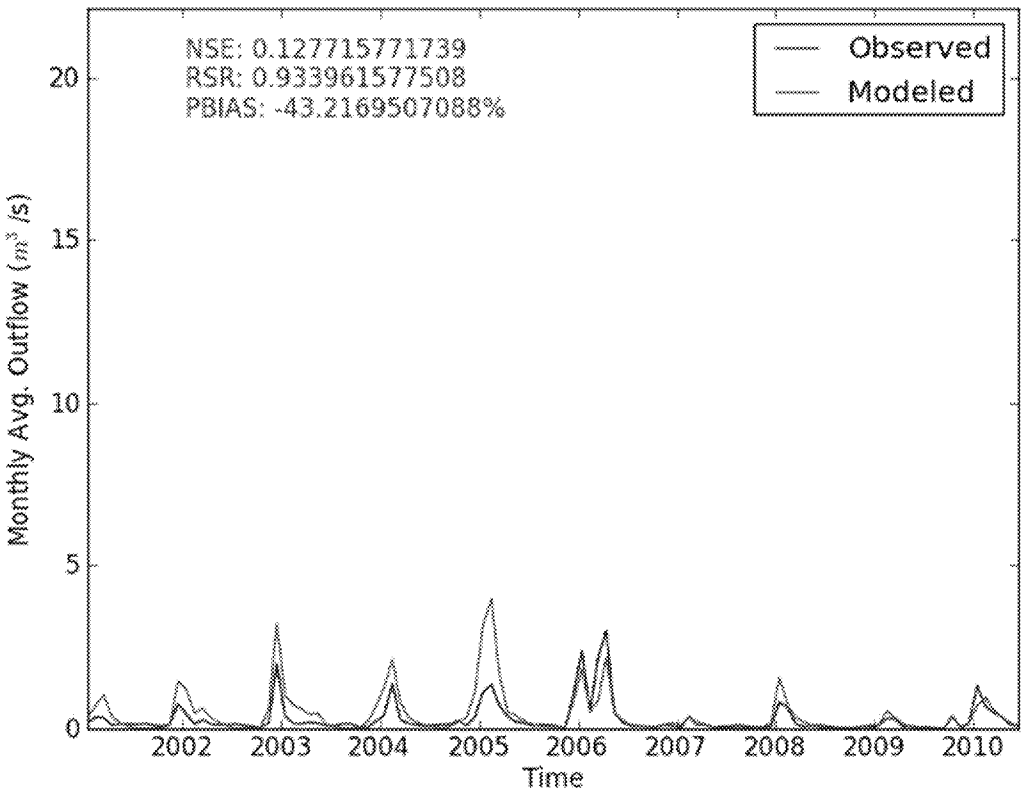
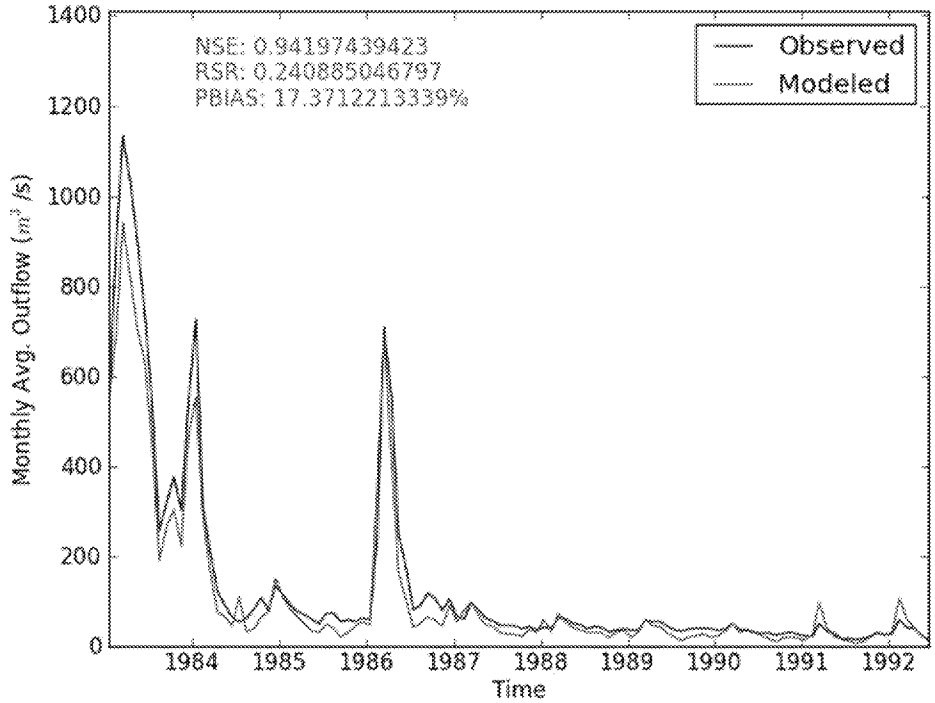


Figure E-52 **Monthly Flow Validation at Subbasin 204 (Marsh Creek at Brentwood)**



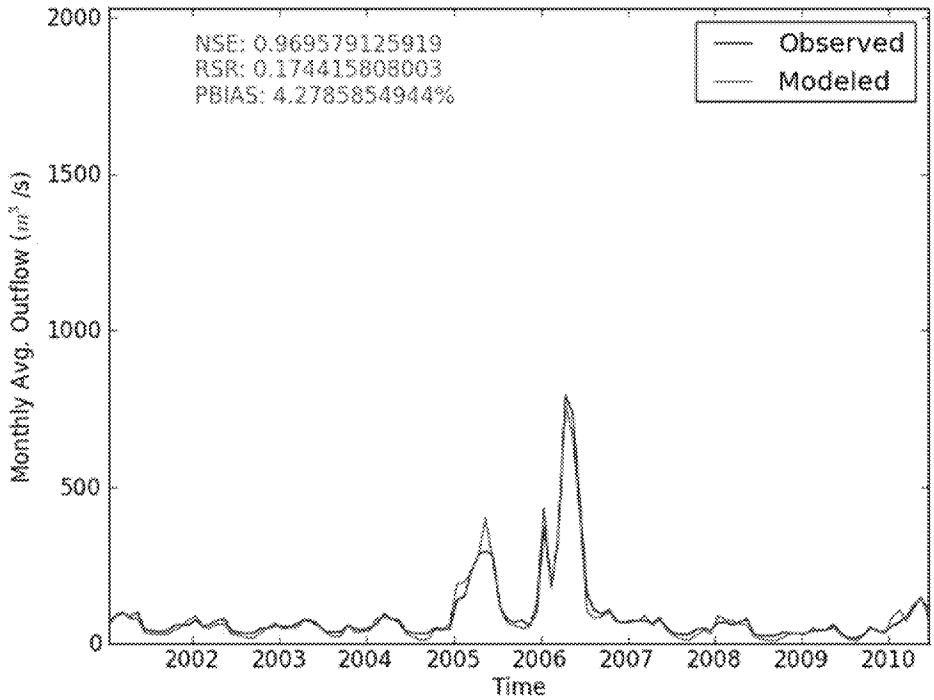


Figure E-53 **Monthly Flow Calibration (top) and Validation (bottom) at Subbasin 219 (San Joaquin River near Vernalis)**

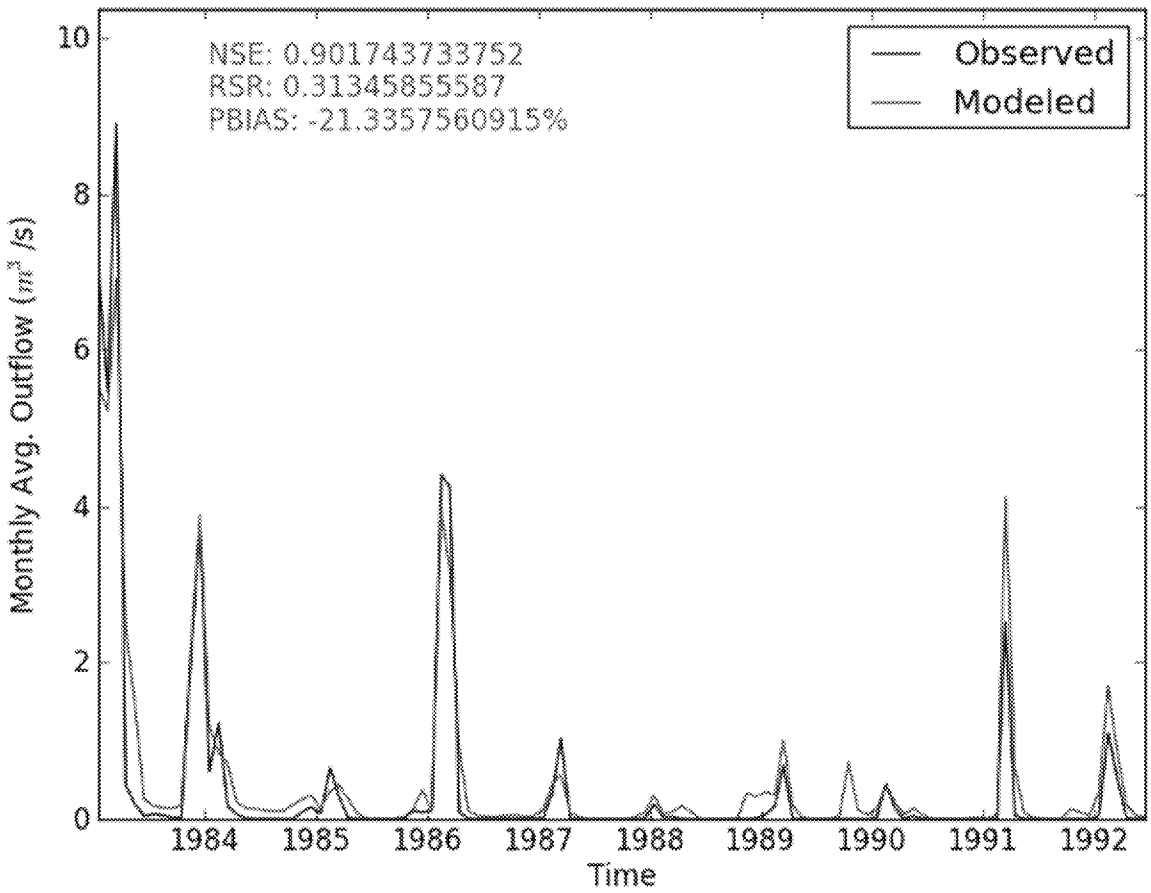
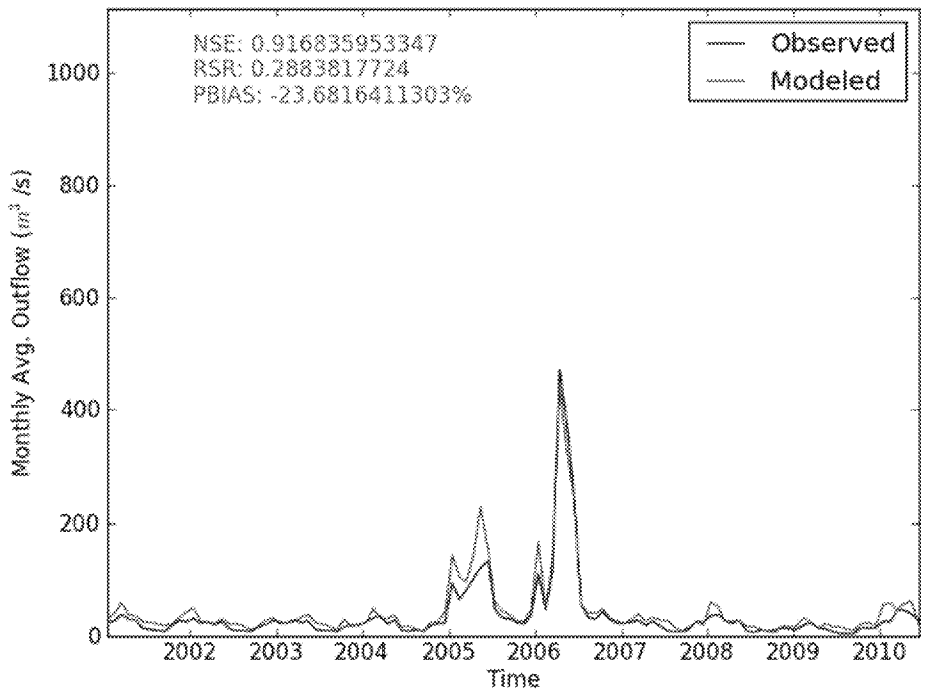


Figure E-54 **Monthly Flow Calibration at Subbasin 236 (Dry Creek near Snelling)**



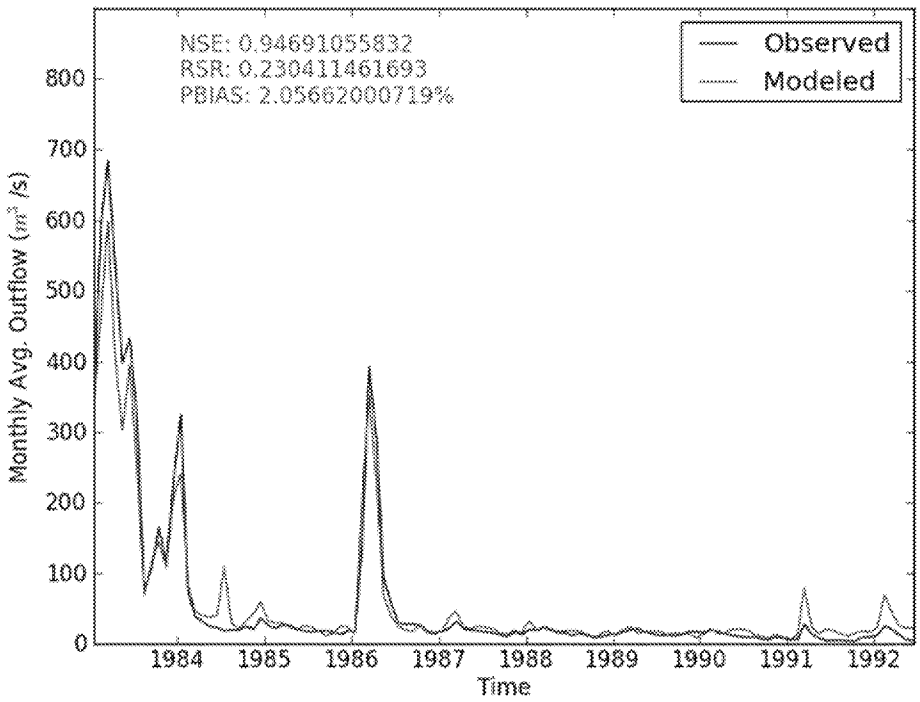
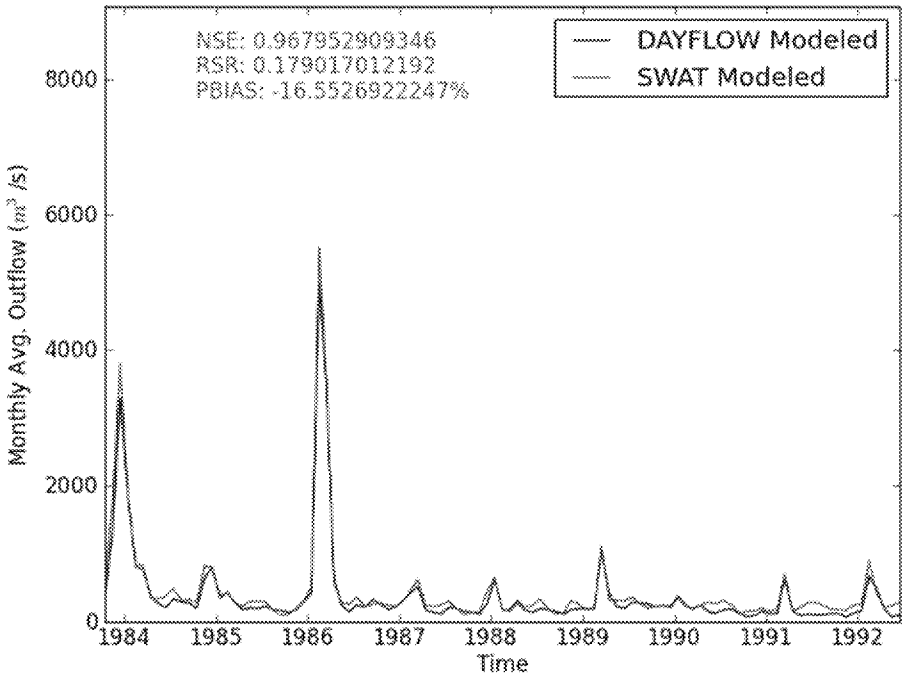


Figure E-55 **Monthly Flow Calibration (top) and Validation (bottom) at Subbasin 245 (San Joaquin River near Newman)**



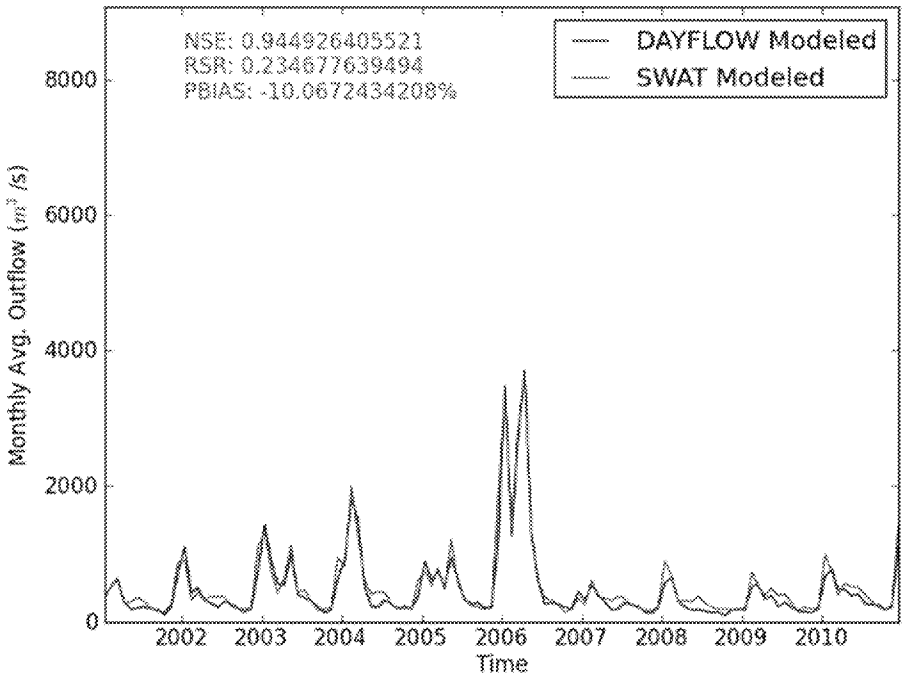
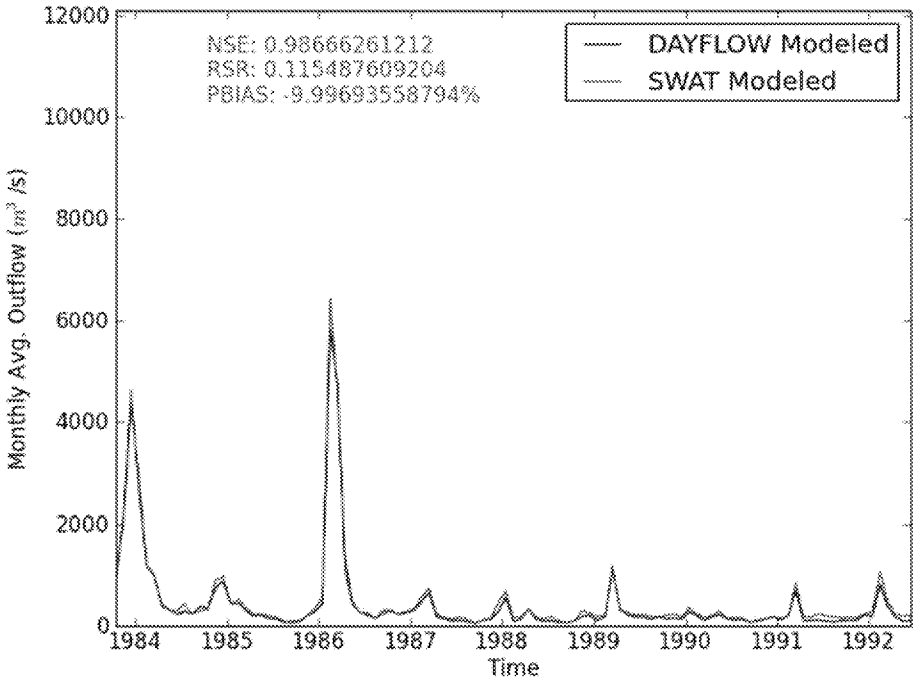


Figure E-56 **Monthly Flow Calibration (top) and Validation (bottom) for Sum of Subbasins 173, 174 (Sacramento River at Rio)**



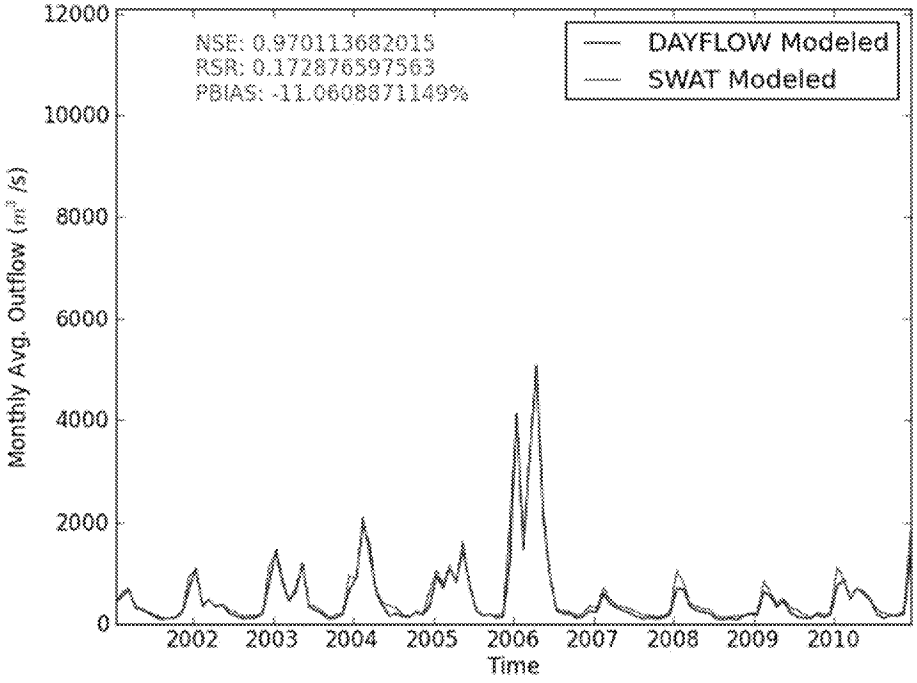


Figure E-57 **Monthly Flow Calibration (top) and Validation (bottom) for Sum of Subbasins 183, 190 (Delta Outflow)**

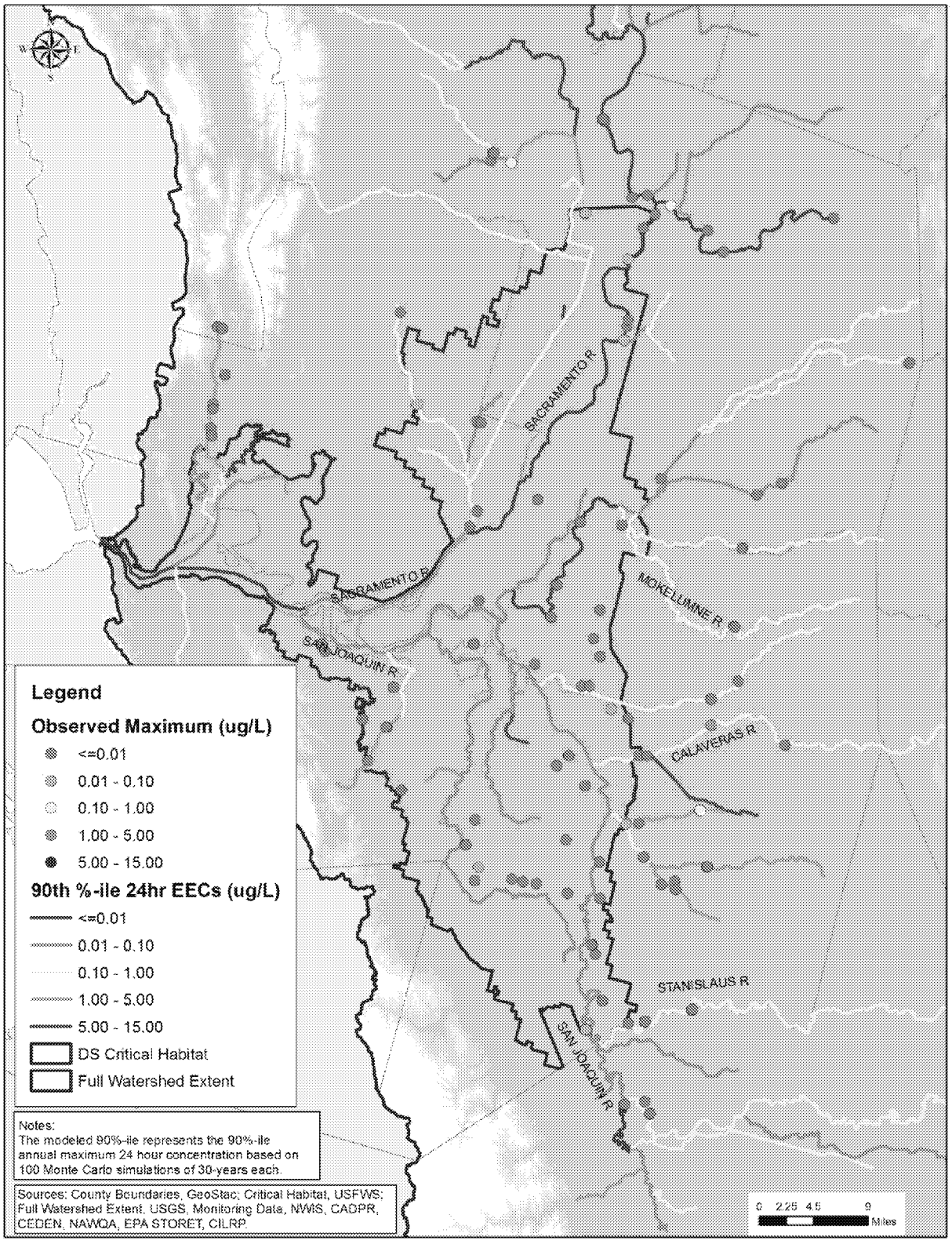


Figure E-58 Comparison of Modeled and Observed Concentrations

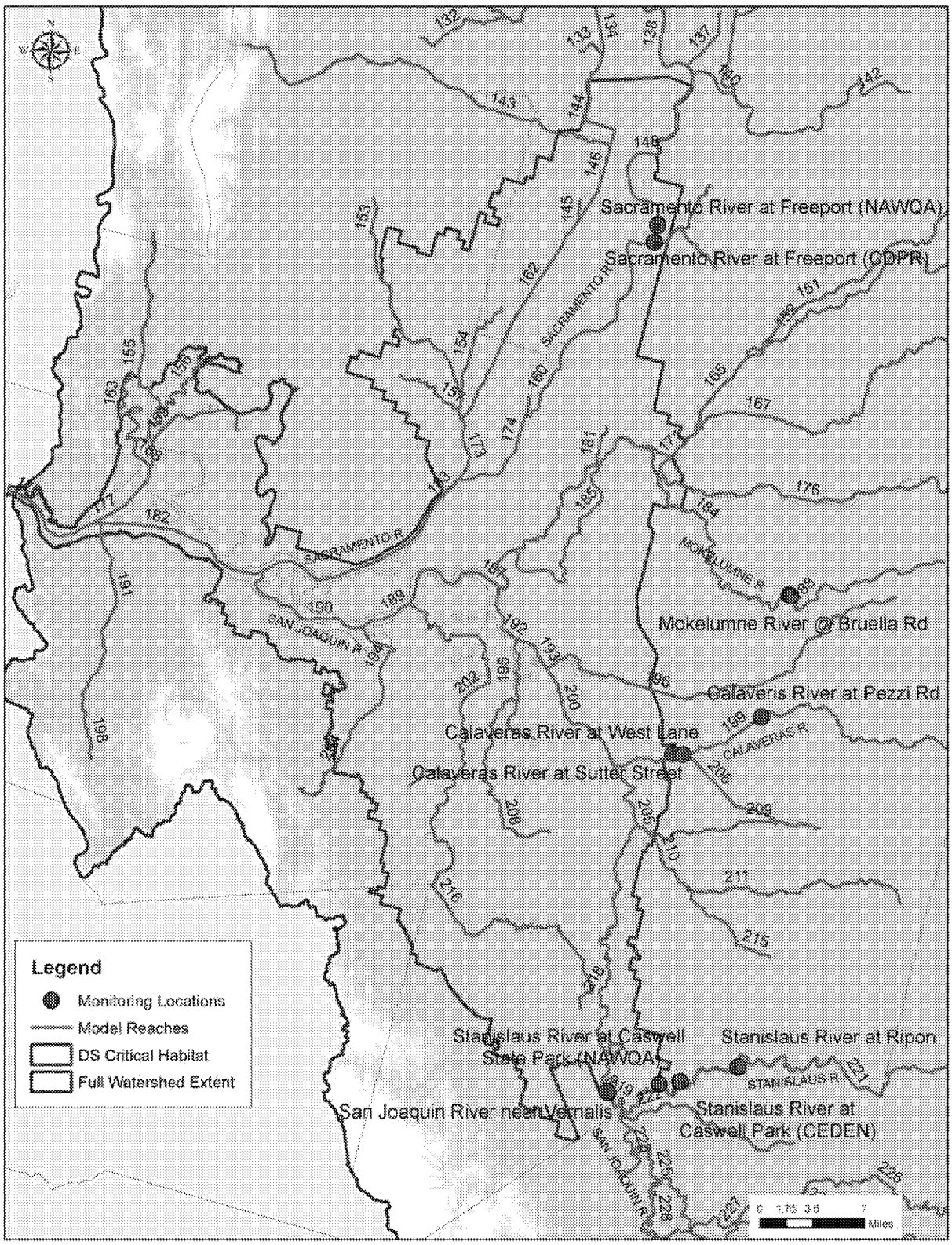


Figure E-59 Monitoring Stations with Highest Number of Samples

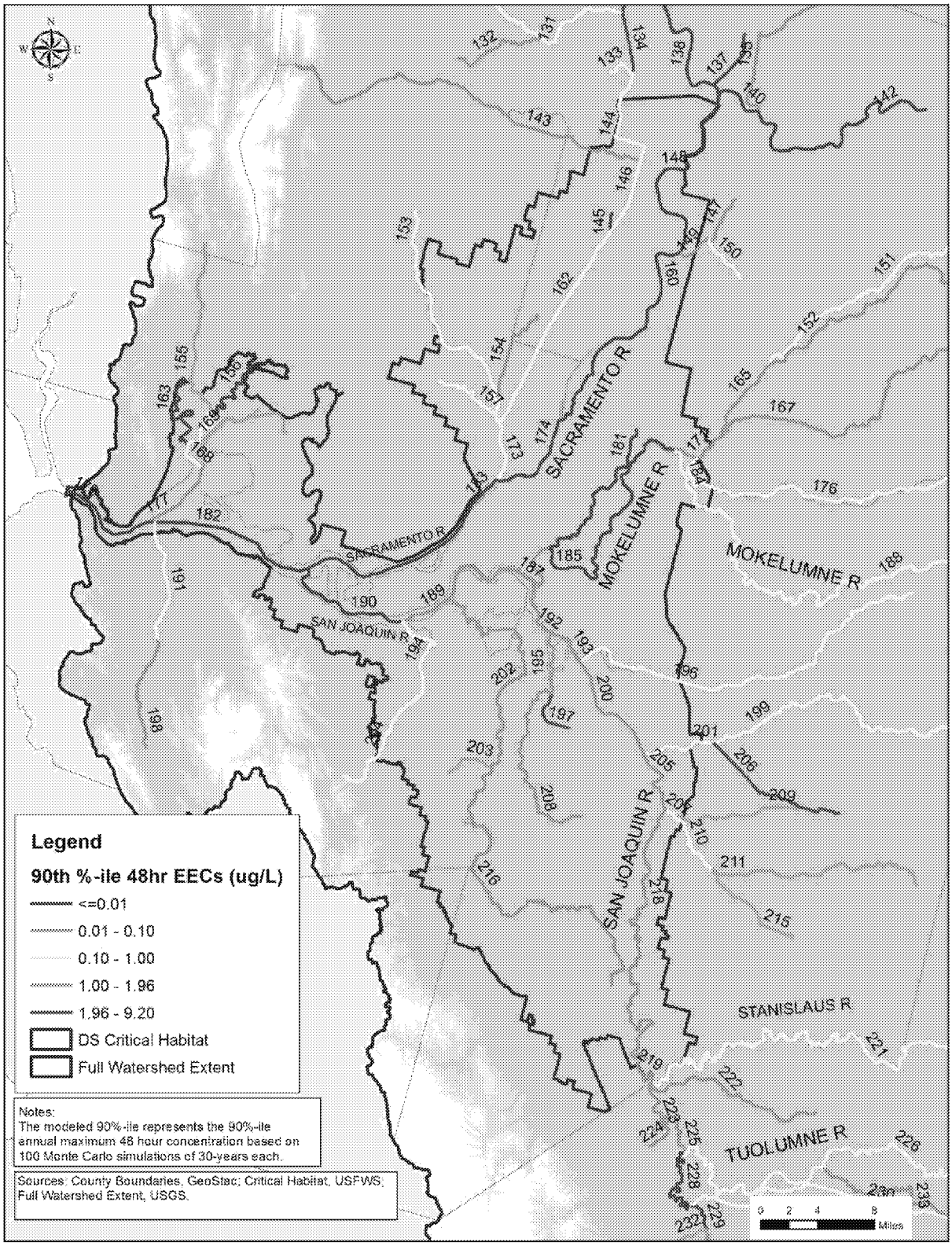


Figure E-60 odeled 90th-percentile 48-hour EECs

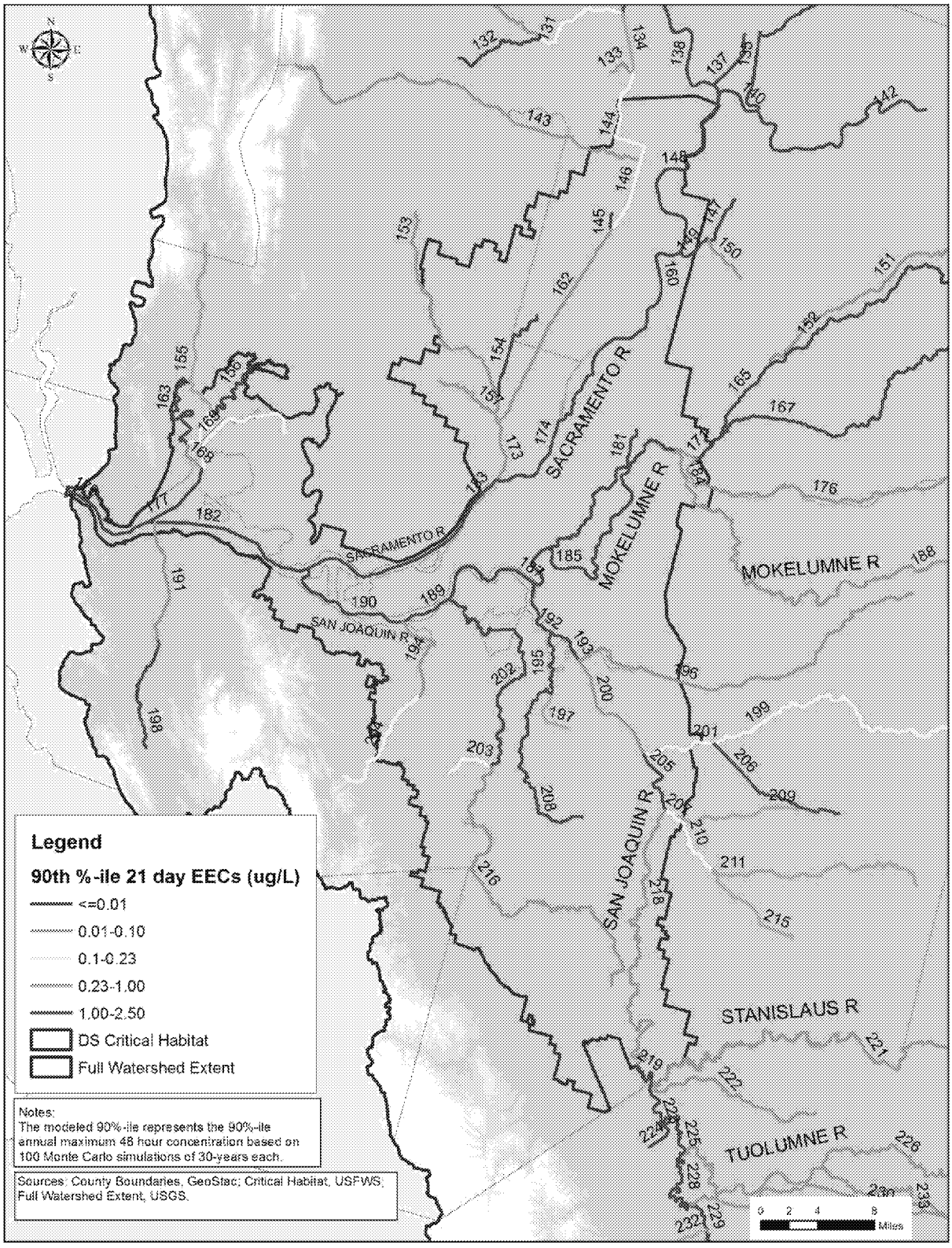


Figure E-61 Modeled 90th-percentile 21-day EECs

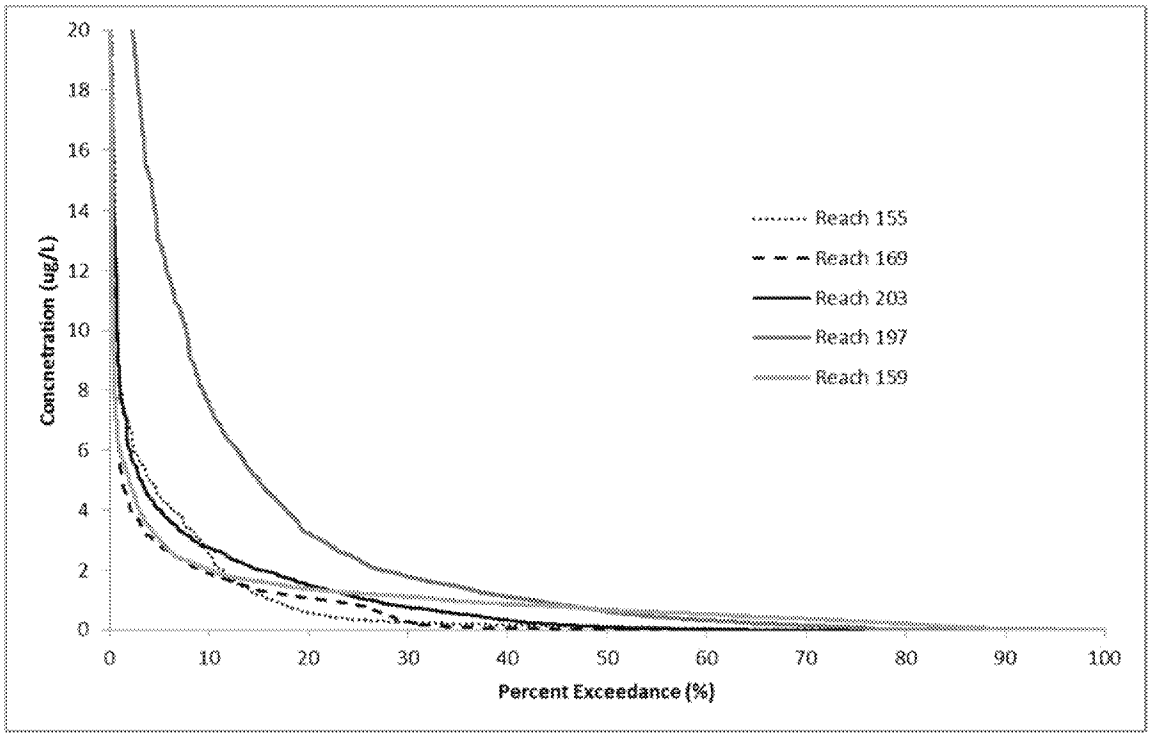


Figure E-62 **Peak EEC Distributions for Top Five Reaches with Highest Concentrations**

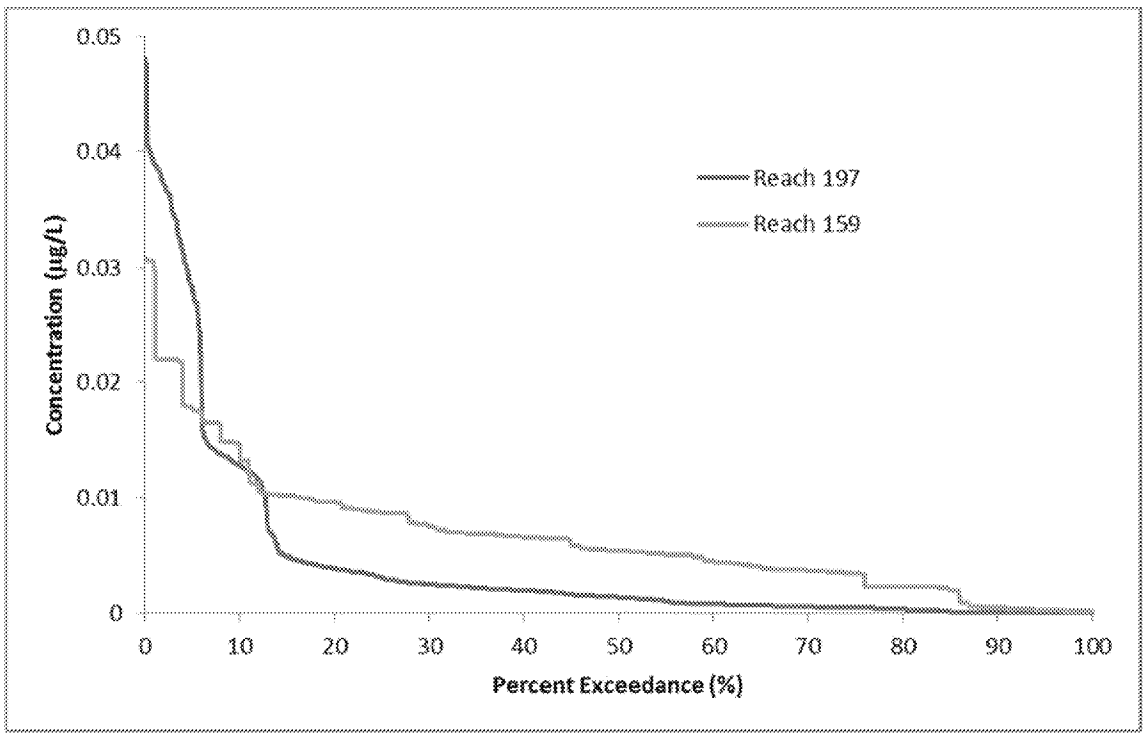


Figure E-63 **Peak EEC Distributions for Subbasins 197 and 159 after Refined Modeling**

Appendix F
Agronomic Practices Modeled by the SWAT Model

Details of the agronomic practices included in the 36 agronomic management schedules modeled by the SWAT model are provided for each crop group. Crop groups may have more than one unique agronomic management schedule representing a specific crop.

Corn/Soybean Crop Group

In the Central valley, corn may be single cropped or double cropped. Single cropped corn and corn double cropped with oats or winter wheat were identified as dominant. Single cropped corn was assumed to be field corn and double cropped corn was assumed to be for silage (UCCE, 2008c, 2012c). Single cropped corn is generally planted in April and harvested in August whereas double cropped corn is typically planted in May and harvested in September (UCCE, 2012c).

Land preparation for single cropped corn is done from October to April and two cultivations for weed control are performed, once before planting and once during the growing season. As some tillage practices for single cropped corn were done over 25% of the field, which was not translatable to SWAT simulations, single cropped corn was assumed to grow for four consecutive years with the 25% tillage practice applied over the entire acreage once during the four year period (UCCE, 2008c).

For double cropped corn, tillage begins after harvest of winter forage in April or May to prepare the land for planting; cultivation for weed control is done once during the growing season (UCCE, 2008e, 2012c). Land preparation for oats or winter wheat is done after corn harvest in September and planting occurs in November. No cultivation is done for weed control during the oat or winter wheat growing season (UCCE, 2008e, 2012c).

Agronomic management schedules were developed for all three dominant varieties of single and double cropped corn and implemented in SWAT and are detailed in Table F-1.

Cotton

Acala and pima varieties of cotton are commonly grown in the Central valley (UCCE, 2012d, e). Due to their common agronomic practices, documentation for the acala variety served as the basis for cotton's agronomic schedule. Cotton is planted in March or April according to a 5-day forecast of degree-days to avoid chilling injury to emerging seedlings (UC-IPM, 2012). To simplify this process, planting was assumed to occur in April and harvest in October or November (UCCE, 2012d). Land preparation (i.e., tillage) is done from November to March and cultivation for weed control is done three times during the growing season (UCCE, 2012d). Cotton experiences deep subsoil tillage once every three years. Cotton was assumed to grow for three consecutive years and the subsoil tillage practice was applied once over this time period. The agronomic management schedule for cotton was developed and implemented in SWAT and is detailed in Table F-2.

Hay/forage/silage

Three crops were dominant in the hay/forage/silage crop group: alfalfa, pasture/hay, and clover. Pasture/hay was represented by oat hay (UCCE, 2012f) and clover was assumed to be harvest for seed (UCCE, 1991). Due to these crop groups being planted in fall and harvested in spring, we assumed that at the start of the calendar year (January 1) all crops were growing. Thus, irrigation and fertilization were initialized on this date.

Alfalfa is planted in September and has an expected stand life of four years with seven harvests a year in April, May, June, July, August, September, and October (UCCE, 2008a). Land preparation is done from August through September (UCCE, 2008s) with no tillage for weed control during the growing season.

Clover is planted in September and has a stand life of three years with one harvest a year in August. Land preparation is done in August and the field is tilled once yearly in February (UCCE, 1991).

Oat hay is planted in October and harvested in April or May (UCCE, 2012f). Land preparation is done from September to October with no tillage during the growing season (UCCE, 2012f).

Agronomic management schedules were developed for each crop and implemented in SWAT as detailed in Table F-3.

Orchards and grapes

Seven orchard crops were found to be dominant by acreage in the Central valley: almonds, olives, pistachios, pomegranates, prunes, walnuts, and grapes. In addition, cherries and tangerines/oranges were found to be the dominant crops for malathion use. All orchards were assumed to be established with no new plantings over the 30-year simulation period; irrigation and fertilization were initialized at the start of the calendar year (January 1) to indicate growing crops. Olive orchard information was gathered from data sources on the production of table olives and grape information came from data on the production of Cabernet Sauvignon wine (UCCE, 2011a, 2012b).

Orchards, except for cherries and tangerines/oranges, are harvested once yearly from August to October (UCCE, 2008b, 2010a, 2011a, b, 2012a, b, 2013). No tillage after establishment was documented for almonds (Holtz, 2012; UCCE, 2011b; UC-IPM, 1999a), olives (UCCE, 2011a), pomegranates (UCCE, 2010a), prunes (UCCE, 2012a), and walnuts (UCCE, 2013). Pistachios are tilled four times a year for weed control in February, April, June and August (UCCE, 2008b). Wine grapes are also tilled four times a year for weed control in March, April, May and October (UCCE, 2012b; UC-IPM, 2002; Verdegaal, 2012). Cherries are harvested in May. Tangerines/oranges have three harvests per year, one in each of the months of February, April and November. Agronomic management schedules for all orchards and vineyards were developed for SWAT and are detailed in Table F-4.

Other crops

Two crops in the Other Crops land use class that represented a small fraction of the overall watershed land use were identified as dominant crops with respect to malathion use for certain subbasins: christmas trees, and parsley. Christmas tree stands were assumed to have a six year lifespan. The stand is established in the first year with tillage and planting. Harvest occurs in December of the sixth year. Limited information was available for parsley, so the management practices used for cilantro were assumed to apply. Parsley is planted and harvested three times per year with plantings in March, June and September, and harvests occurring one month after planting. Land preparation occurs between each harvest. Agronomic management schedules for Christmas trees and Parsley were developed for SWAT and are detailed in Table F-5.

Other grains

Three grain crops were identified as dominant: oats, safflower, and triticale. Safflower was assumed to be flat planted (UCCE, 2011c). Oats and triticale have similar agronomic practices; due to this and their grouping in documentation, identical agronomic schedules were developed for them (UCCE, 2008e).

Oats and triticale were assumed to be double-cropped for silage and, as they are planted in the fall (end of November) and harvested in the spring (May), they were assumed to be growing at the start of the calendar year (January 1). Irrigation and fertilization were initialized on this date. Land preparation occurs in November and a growing-season tillage was not considered (UCCE, 2008e).

Safflower is planted from March through May and harvested in August. Land preparation for flat planted production is done in October and mechanical weed control tillage is performed in May (UCCE, 2011c).

Agronomic management schedules for oats, safflower, and triticale were developed for SWAT and are detailed in Table F-7.

Other row crops

Sugarbeets and sunflower were the dominant varieties in this crop group. Mint was also determined to be a dominant malathion label use. Sugarbeets were assumed to be spring planted and fall harvested and sunflower was assumed to be harvested for seed (UCCE, 1994).

Sugarbeets are planted in January and harvested in September. Land preparation occurs from October through December. Mechanical tillagefor weed control is done during the growing season in April and May while post-harvest tillage is performed in September (UCCE, 1994).

Sunflowers are planted in April and harvested from August to September. Land preparation is done in the fall, from October to November. Mechanical tillage for weed control is performed once prior to planting in March and once during the growing season in May. To account for rotation after harvest, deep tillage practices were applied post-harvest in October. Laser leveling was recommended to occur once every 10 years but due to its infrequency it was not included in the schedule (UCCE, 2011).

Mint is assumed to be grown for peppermint oil. It is planted in April and has an expected stand life of five years with one harvest per year in August or September. After harvest in the third year, the mint stand is reconditioned by disc, ripper and rototiller for insect suppression, to break up soil compaction and to spread rootstocks.

Agronomic management schedules for sugarbeets, sunflowers, and mint were developed for SWAT and are detailed in Table F-7.

Rice

Rice agronomy was based on production in the Sacramento-San Joaquin Delta. It is planted from April to May and harvested from September to October. Land preparation is performed in the spring and there is no growing season or post-harvest tillage (Hill, 2012; UCCE, 2007). Agronomic management schedules were developed for SWAT and are detailed in Table F-8.

Sorghum

Sorghum may be single cropped or double cropped. Single cropped sorghum and double cropped sorghum with winter wheat were identified as dominant crops and both were assumed to be produced for grain (UCCE, 2008f, 2009b).

Single cropped sorghum is planted from late May to early July and harvested in September. Land preparation occurs in April and May and mechanical cultivation is performed for weed control twice during the growing season in June and July (UCCE, 2009b).

Double cropped sorghum and winter wheat are planted in the fall and harvested in the spring in June. Land preparation for winter wheat is performed after sorghum harvest; planting occurs at the end of November. No cultivation is done for weed control during the winter wheat growing season (UCCE, 2008f, 2009b).

Agronomic management operations were developed for single and double cropped sorghum and implemented in SWAT and detailed in Table F-9.

Vegetables and ground fruit

Four varieties dominated in the vegetable category: blueberries, dry beans, strawberries, and tomatoes. In addition to the crops with dominant acreage, four crops were dominant malathion

use sites: asparagus, lettuce, melon, onions. Blueberries and strawberries are planted in the fall. Irrigation and fertilization was, therefore, initialized at the start of the calendar year (January 1) to indicate growing crops (UCCE, 2009a, 2011d).

Blueberries are transplanted in October and have an assumed productive life of four years with one year of non-productivity after planting. To account for this, a stand life of five years was assigned with the first year having no harvest. For the four years of productivity (years two-five), harvest occurs over a five week period from late April/early May until the end of June. Land preparation begins early in summer and there is no tillage during or after the growing season (UCCE, 2009a).

Dry beans were assumed to be double cropped with a winter cereal or forage. They are planted in June and harvested in September. Land preparation is done in June and cultivation for weed control is done twice in July during the growing season. The recommended practice of post-harvest laser leveling once every four years was not included in the dry beans management schedule because it was a minor operation (UCCE, 2010b).

Strawberries were assumed to be in annual production (UC-IPM, 1999b). They are transplanted in October and harvested multiple times from March to August. Land preparation occurs from August to September and year-end cleanup includes post-harvest tillage (UCCE, 2011d).

Tomatoes were assumed to be for processing. They are transplanted from late March to early June and harvested from July through September. Land preparation occurs from August to early November; tillage for weed control is done twice before planting and three times during the growing season; the tillage practice of laser leveling over 4% of the acreage was not included in SWAT due to its minor contribution (Aegerter, 2011a, b, 2012; Miyao, 2012; UCCE, 2008d).

With its long stand life of 10 years or more, asparagus was assumed to already be established at the beginning of simulation and continue without replanting through the entire simulation. This considerably reduced model complexity by avoiding implementation of ten-year management schedules. Harvest occurs every year in March. Soil cultivation occurs in May, June and October.

Lettuce was assumed to be in yearly production. Lettuce is planted in January and harvested in April. The majority of land preparation by tillage occurs in October.

Melon was assumed to be produced yearly. Land preparation occurs in February and March. Planting occurs in March and harvest occurs in July.

Onions were assumed to be produced annually with land preparation just before planting in April and a single harvest in October. Land is tilled again after harvest.

Agronomic management schedules for all vegetables and ground fruit are detailed in Table F-10.

Wheat

Winter wheat was identified as the dominant variety. It is planted in the fall from late October to mid-December and harvested in the spring in June. To account for this in SWAT, wheat was assumed to be growing at the start of the calendar year (January 1) and irrigation and fertilization were initialized on this date. As some tillage practices occur over 50% of the field, winter wheat was grown for two consecutive years and the 50% tillage practices applied over the entire acreage once during the two year period. Land preparation occurs from August to October with no tillage during or after the growing season (UCCE, 2009c). The agronomic management schedule for winter wheat is detailed in Table F-11.

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Table F-1 Corn/Soybean Group Agronomic Management Schedules				
Dominant Crop	***Year***	***Month/Day***	***Operation***	***Description***
Corn	1	1-Apr	Tillage	Rolling Cultivator Ge15ft
Corn	1	7-Apr	Planting	CORN
Corn	1	8-Apr	Auto-irrigation	AUTO_WSTRS = 30
Corn	1	9-Apr	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Corn	1	1-May	Tillage	Row Cultivator Ge15ft
Corn	1	1-Sep	Harvest	Harvest & kill
Corn	1	21-Sep	Tillage	Soil Finisher
Corn	1	3-Oct	Tillage	Land Plane-leveler
Corn	1	4-Oct	Tillage	Land Plane-leveler
Corn	1	5-Oct	Tillage	Lister (middle-buster)
Corn	2	1-Apr	Tillage	Rolling Cultivator Ge15ft
Corn	2	7-Apr	Planting	CORN
Corn	2	8-Apr	Auto-irrigation	AUTO_WSTRS = 30
Corn	2	9-Apr	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Corn	2	1-May	Tillage	Row Cultivator Ge15ft
Corn	2	1-Sep	Harvest	Harvest & kill
Corn	2	21-Sep	Tillage	Soil Finisher
Corn	2	3-Oct	Tillage	Land Plane-leveler
Corn	2	4-Oct	Tillage	Land Plane-leveler
Corn	2	5-Oct	Tillage	Lister (middle-buster)
Corn	3	1-Apr	Tillage	Rolling Cultivator Ge15ft
Corn	3	7-Apr	Planting	CORN
Corn	3	8-Apr	Auto-irrigation	AUTO_WSTRS = 30
Corn	3	9-Apr	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Corn	3	1-May	Tillage	Row Cultivator Ge15ft
Corn	3	1-Sep	Harvest	Harvest & kill
Corn	3	21-Sep	Tillage	Soil Finisher
Corn	3	3-Oct	Tillage	Land Plane-leveler
Corn	3	4-Oct	Tillage	Land Plane-leveler
Corn	3	5-Oct	Tillage	Lister (middle-buster)
Corn	4	1-Apr	Tillage	Rolling Cultivator Ge15ft
Corn	4	7-Apr	Planting	CORN
Corn	4	8-Apr	Auto-irrigation	AUTO_WSTRS = 30
Corn	4	9-Apr	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Corn	4	1-May	Tillage	Row Cultivator Ge15ft
Corn	4	1-Sep	Harvest	Harvest & kill
Corn	4	21-Sep	Tillage	Soil Finisher
Corn	4	1-Oct	Tillage	Disk Plow Lt23ft
Corn	4	2-Oct	Tillage	Deep Ripper- Subsoiler
Corn	4	3-Oct	Tillage	Land Plane-leveler

Table F-1 Corn/Soybean Group Agronomic Management Schedules				
Dominant Crop	***Year***	***Month/Day***	***Operation***	***Description***
Corn	4	4-Oct	Tillage	Land Plane-leveler
Corn	4	5-Oct	Tillage	Lister (middle-buster)
Dbl Crop Oats/Corn	1	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Dbl Crop Oats/Corn	1	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Dbl Crop Oats/Corn	1	1-May	Harvest	Harvest and kill - oats
Dbl Crop Oats/Corn	1	5-May	Tillage	Disk Plow Lt23ft
Dbl Crop Oats/Corn	1	6-May	Tillage	Disk Plow Lt23ft
Dbl Crop Oats/Corn	1	7-May	Tillage	Soil Finisher
Dbl Crop Oats/Corn	1	8-May	Tillage	Soil Finisher
Dbl Crop Oats/Corn	1	14-May	Planting	CORN SILAGE
Dbl Crop Oats/Corn	1	15-May	Auto-irrigation	AUTO_WSTRS = 30
Dbl Crop Oats/Corn	1	16-May	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Dbl Crop Oats/Corn	1	21-May	Tillage	Disk Border Maker
Dbl Crop Oats/Corn	1	1-Jun	Tillage	Disk Border Maker
Dbl Crop Oats/Corn	1	14-Jun	Tillage	Row Cultivator Ge15ft
Dbl Crop Oats/Corn	1	1-Sep	Harvest	Harvest and kill - corn silage
Dbl Crop Oats/Corn	1	1-Nov	Tillage	Soil Finisher
Dbl Crop Oats/Corn	1	2-Nov	Tillage	Soil Finisher
Dbl Crop Oats/Corn	1	3-Nov	Tillage	Disk Border Maker
Dbl Crop Oats/Corn	1	21-Nov	Planting	OATS
Dbl Crop Oats/Corn	1	22-Nov	Auto-irrigation	AUTO_WSTRS = 30
Dbl Crop Oats/Corn	1	23-Nov	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Dbl Crop WinWht/Corn	1	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Dbl Crop WinWht/Corn	1	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Dbl Crop WinWht/Corn	1	1-May	Harvest	Harvest and kill - winter wheat
Dbl Crop WinWht/Corn	1	1-May	Tillage	Disk Plow Lt23ft
Dbl Crop WinWht/Corn	1	2-May	Tillage	Disk Plow Lt23ft
Dbl Crop WinWht/Corn	1	3-May	Tillage	Soil Finisher
Dbl Crop WinWht/Corn	1	4-May	Tillage	Soil Finisher
Dbl Crop WinWht/Corn	1	14-May	Planting	CORN SILAGE
Dbl Crop WinWht/Corn	2	15-May	Auto-irrigation	AUTO_WSTRS = 30
Dbl Crop WinWht/Corn	3	16-May	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Dbl Crop WinWht/Corn	1	21-May	Tillage	Disk Border Maker
Dbl Crop WinWht/Corn	1	1-Jun	Tillage	Disk Border Maker
Dbl Crop WinWht/Corn	1	14-Jun	Tillage	Row Cultivator Ge15ft
Dbl Crop WinWht/Corn	1	1-Sep	Harvest	Harvest and kill - corn silage
Dbl Crop WinWht/Corn	1	1-Nov	Tillage	Soil Finisher
Dbl Crop WinWht/Corn	1	2-Nov	Tillage	Soil Finisher
Dbl Crop WinWht/Corn	1	3-Nov	Tillage	Disk Border Maker
Dbl Crop WinWht/Corn	1	21-Nov	Planting	WINTER WHEAT

Table F-1 Corn/Soybean Group Agronomic Management Schedules				
Dominant Crop	***Year***	***Month/Day***	***Operation***	***Description***
Dbl Crop WinWht/Corn	1	22-Nov	Auto-irrigation	AUTO_WSTRS = 30
Dbl Crop WinWht/Corn	1	23-Nov	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9

Table F-2 Cotton Group Agronomic Management Schedules				
Dominant Crop	***Year***	***Month/Day***	***Operation***	***Description***
Cotton	1	1-Feb	Tillage	Row Cultivator Ge15ft
Cotton	1	1-Mar	Tillage	Offset Dis/lghtduty Ge19ft
Cotton	1	2-Mar	Tillage	Lister (middle-buster)
Cotton	1	1-Apr	Planting	COTTON
Cotton	1	2-Apr	Auto-irrigation	AUTO_WSTRS = 30
Cotton	1	3-Apr	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Cotton	1	1-May	Tillage	Rolling Cultivator Ge15ft
Cotton	1	14-May	Tillage	Rolling Cultivator Ge15ft
Cotton	1	14-Jun	Tillage	Rolling Cultivator Ge15ft
Cotton	1	7-Nov	Harvest	Harvest and Kill
Cotton	1	14-Nov	Tillage	Disk Plow Lt23ft
Cotton	1	22-Nov	Tillage	Disk Plow Lt23ft
Cotton	1	23-Nov	Tillage	Disk Plow Lt23ft
Cotton	2	1-Feb	Tillage	Row Cultivator Ge15ft
Cotton	2	1-Mar	Tillage	Offset Dis/lghtduty Ge19ft
Cotton	2	2-Mar	Tillage	Lister (middle-buster)
Cotton	2	1-Apr	Planting	COTTON
Cotton	2	2-Apr	Auto-irrigation	AUTO_WSTRS = 30
Cotton	2	3-Apr	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Cotton	2	1-May	Tillage	Rolling Cultivator Ge15ft
Cotton	2	14-May	Tillage	Rolling Cultivator Ge15ft
Cotton	2	14-Jun	Tillage	Rolling Cultivator Ge15ft
Cotton	2	7-Nov	Harvest	Harvest and Kill
Cotton	2	14-Nov	Tillage	Disk Plow Lt23ft
Cotton	2	22-Nov	Tillage	Disk Plow Lt23ft
Cotton	2	23-Nov	Tillage	Disk Plow Lt23ft
Cotton	3	1-Feb	Tillage	Row Cultivator Ge15ft
Cotton	3	1-Mar	Tillage	Offset Dis/lghtduty Ge19ft
Cotton	3	2-Mar	Tillage	Lister (middle-buster)
Cotton	3	1-Apr	Planting	COTTON
Cotton	3	2-Apr	Auto-irrigation	AUTO_WSTRS = 30
Cotton	3	3-Apr	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Cotton	3	1-May	Tillage	Rolling Cultivator Ge15ft
Cotton	3	14-May	Tillage	Rolling Cultivator Ge15ft

Table F-2 Cotton Group Agronomic Management Schedules				
Dominant Crop	***Year***	***Month/Day***	***Operation***	***Description***
Cotton	3	14-Jun	Tillage	Rolling Cultivator Ge15ft
Cotton	3	7-Nov	Harvest	Harvest and Kill
Cotton	3	14-Nov	Tillage	Disk Plow Lt23ft
Cotton	3	21-Nov	Tillage	Deep Ripper- Subsoiler
Cotton	3	22-Nov	Tillage	Disk Plow Lt23ft
Cotton	3	23-Nov	Tillage	Disk Plow Lt23ft

Table F-3 Hay/Forage/Silage Group Agronomic Management Schedules				
Dominant Crop	***Year***	***Month/Day***	***Operation***	***Description***
Alfalfa	1	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Alfalfa	1	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Alfalfa	1	1-Apr	Harvest	Harvest only
Alfalfa	1	1-May	Harvest	Harvest only
Alfalfa	1	1-Jun	Harvest	Harvest only
Alfalfa	1	1-Jul	Harvest	Harvest only
Alfalfa	1	1-Aug	Harvest	Harvest only
Alfalfa	1	1-Sep	Harvest	Harvest only
Alfalfa	1	1-Oct	Harvest	Harvest only
Alfalfa	2	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Alfalfa	2	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Alfalfa	2	1-Apr	Harvest	Harvest only
Alfalfa	2	1-May	Harvest	Harvest only
Alfalfa	2	1-Jun	Harvest	Harvest only
Alfalfa	2	1-Jul	Harvest	Harvest only
Alfalfa	2	1-Aug	Harvest	Harvest only
Alfalfa	2	1-Sep	Harvest	Harvest only
Alfalfa	2	1-Oct	Harvest	Harvest only
Alfalfa	3	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Alfalfa	3	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Alfalfa	3	1-Apr	Harvest	Harvest only
Alfalfa	3	1-May	Harvest	Harvest only
Alfalfa	3	1-Jun	Harvest	Harvest only
Alfalfa	3	1-Jul	Harvest	Harvest only
Alfalfa	3	1-Aug	Harvest	Harvest only
Alfalfa	3	1-Sep	Harvest	Harvest only
Alfalfa	3	1-Oct	Harvest	Harvest only
Alfalfa	4	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Alfalfa	4	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Alfalfa	4	1-Apr	Harvest	Harvest only

Table F-3 Hay/Forage/Silage Group Agronomic Management Schedules				
Dominant Crop	***Year***	***Month/Day***	***Operation***	***Description***
Alfalfa	4	1-May	Harvest	Harvest only
Alfalfa	4	1-Jun	Harvest	Harvest only
Alfalfa	4	1-Jul	Harvest	Harvest only
Alfalfa	4	1-Aug	Harvest	Harvest only
Alfalfa	4	1-Sep	Harvest	Harvest only
Alfalfa	4	1-Oct	Harvest	Harvest and kill
Alfalfa	4	7-Oct	Tillage	Disk Plow Ge23ft
Alfalfa	4	8-Oct	Tillage	Subsoil Chisel Plow
Alfalfa	4	9-Oct	Tillage	Laser Planer
Alfalfa	4	10-Oct	Tillage	Disk Border Maker
Alfalfa	4	14-Oct	Tillage	Soil Finisher
Alfalfa	4	15-Oct	Tillage	Harrow 10 Bar Tine 36 Ft
Alfalfa	4	16-Oct	Planting	ALFALFA
Alfalfa	4	17-Oct	Auto-irrigation	AUTO_WSTRS = 30
Alfalfa	4	18-Oct	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Clover/Wildflowers	1	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Clover/Wildflowers	1	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Clover/Wildflowers	1	1-Feb	Tillage	Roller Packer Flat Roller
Clover/Wildflowers	1	1-Aug	Harvest	Harvest
Clover/Wildflowers	2	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Clover/Wildflowers	2	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Clover/Wildflowers	2	1-Feb	Tillage	Roller Packer Flat Roller
Clover/Wildflowers	2	1-Aug	Harvest	Harvest
Clover/Wildflowers	3	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Clover/Wildflowers	3	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Clover/Wildflowers	3	1-Feb	Tillage	Roller Packer Flat Roller
Clover/Wildflowers	3	1-Aug	Harvest	Harvest and kill
Clover/Wildflowers	3	11-Aug	Tillage	Subsoil Chisel Plow
Clover/Wildflowers	3	12-Aug	Tillage	Offset Dis/lghtduty14-18ft
Clover/Wildflowers	3	13-Aug	Tillage	Offset Dis/lghtduty14-18ft
Clover/Wildflowers	3	14-Aug	Tillage	Laser Planer
Clover/Wildflowers	3	15-Aug	Tillage	Land Plane-leveler
Clover/Wildflowers	3	1-Sep	Planting	RED CLOVER
Clover/Wildflowers	3	2-Sep	Auto-irrigation	AUTO_WSTRS = 30
Clover/Wildflowers	3	3-Sep	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Pasture/Hay	1	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Pasture/Hay	1	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Pasture/Hay	1	1-Apr	Harvest	Harvest and kill
Pasture/Hay	2	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Pasture/Hay	2	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9

Table F-3 Hay/Forage/Silage Group Agronomic Management Schedules				
Dominant Crop	***Year***	***Month/Day***	***Operation***	***Description***
Pasture/Hay	2	1-Apr	Harvest	Harvest and kill
Pasture/Hay	3	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Pasture/Hay	3	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Pasture/Hay	3	1-Apr	Harvest	Harvest and kill
Pasture/Hay	4	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Pasture/Hay	4	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Pasture/Hay	4	1-Apr	Harvest	Harvest and kill
Pasture/Hay	4	1-Sep	Tillage	Disk Plow Lt23ft
Pasture/Hay	4	1-Oct	Tillage	Soil Finisher
Pasture/Hay	4	7-Oct	Planting	HAY
Pasture/Hay	4	8-Oct	Auto-irrigation	AUTO_WSTRS = 30
Pasture/Hay	4	9-Oct	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9

Table F-4 Orchard/Grape Group Agronomic Management Schedules				
Dominant Crop	***Year***	***Month/Day***	***Operation***	***Description***
Almonds	1	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Almonds	1	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Almonds	1	1-Sep	Harvest	Harvest only
Cherries	1	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Cherries	1	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Cherries	1	1-May	Harvest	Harvest only
Olives	1	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Olives	1	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Olives	1	1-Oct	Harvest	Harvest only
Pistachios	1	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Pistachios	1	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Pistachios	1	1-Feb	Tillage	Tandem Disk Reg 14-18ft
Pistachios	1	1-Apr	Tillage	Tandem Disk Reg 14-18ft
Pistachios	1	1-Jun	Tillage	Tandem Disk Reg 14-18ft
Pistachios	1	1-Aug	Tillage	Tandem Disk Reg 14-18ft
Pistachios	1	1-Sep	Harvest	Harvest Only
Pomegranates	1	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Pomegranates	1	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Pomegranates	1	1-Sep	Harvest	Harvest only
Prunes	1	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Prunes	1	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Prunes	1	1-Aug	Harvest	Harvest only
Tangerines/Oranges	1	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Tangerines/Oranges	1	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9

Table F-4 Orchard/Grape Group Agronomic Management Schedules				
Dominant Crop	***Year***	***Month/Day***	***Operation***	***Description***
Tangerines/Oranges	1	1-Feb	Harvest	Harvest only
Tangerines/Oranges	1	1-Apr	Harvest	Harvest only
Tangerines/Oranges	1	1-Nov	Harvest	Harvest only
Walnuts	1	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Walnuts	1	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Walnuts	1	1-Sep	Harvest	Harvest only
WineGrape	1	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
WineGrape	1	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
WineGrape	1	1-Mar	Tillage	Tandem Disk Reg Le13ft
WineGrape	1	1-Apr	Tillage	Tandem Disk Reg Le13ft
WineGrape	1	1-May	Tillage	Tandem Disk Reg Le13ft
WineGrape	1	1-Sep	Harvest	Harvest only
WineGrape	1	1-Oct	Tillage	Tandem Disk Reg Le13ft

Table F-5 Other Crops Group Agronomic Management Schedules				
Dominant Crop	***Year***	***Month/Day***	***Operation***	***Description***
Christmas Trees	1	1-Jan	Tillage	Ripper 10 Ft
Christmas Trees	1	2-Jan	Tillage	Offset Dis/lghtduty Ge19ft
Christmas Trees	1	1-Feb	Planting	EVERGREEN
Christmas Trees	1	2-Feb	Auto-irrigation	AUTO_WSTRS = 30
Christmas Trees	1	3-Feb	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Christmas Trees	2	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Christmas Trees	2	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Christmas Trees	3	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Christmas Trees	3	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Christmas Trees	4	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Christmas Trees	4	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Christmas Trees	5	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Christmas Trees	5	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Christmas Trees	6	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Christmas Trees	6	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Christmas Trees	6	1-Dec	Harvest	Harvest and kill
Parsley	1	1-Feb	Tillage	Offset Dis/lghtduty Ge19ft
Parsley	1	2-Feb	Tillage	Deep Ripper- Subsoiler
Parsley	1	3-Feb	Tillage	Moldboard Plow Reg 4-6b
Parsley	1	4-Feb	Tillage	Offset Dis/lghtduty Ge19ft
Parsley	1	5-Feb	Tillage	Land Plane-leveler
Parsley	1	6-Feb	Tillage	Chisel Plow Gt21ft
Parsley	1	7-Feb	Tillage	Lister (middle-buster)

Table F-5 Other Crops Group Agronomic Management Schedules				
Dominant Crop	***Year***	***Month/Day***	***Operation***	***Description***
Parsley	1	8-Feb	Tillage	Bedder Shaper
Parsley	1	1-Mar	Planting	SPINACH
Parsley	1	2-Mar	Auto-irrigation	AUTO_WSTRS = 30
Parsley	1	3-Mar	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Parsley	1	15-Mar	Tillage	Row Cultivator Ge15ft
Parsley	1	1-Apr	Harvest	Harvest and kill
Parsley	1	2-Apr	Tillage	Offset Dis/lghtduty Ge19ft
Parsley	1	1-May	Tillage	Offset Dis/lghtduty Ge19ft
Parsley	1	2-May	Tillage	Deep Ripper- Subsoiler
Parsley	1	3-May	Tillage	Moldboard Plow Reg 4-6b
Parsley	1	4-May	Tillage	Offset Dis/lghtduty Ge19ft
Parsley	1	5-May	Tillage	Land Plane-leveler
Parsley	1	6-May	Tillage	Chisel Plow Gt21ft
Parsley	1	7-May	Tillage	Lister (middle-buster)
Parsley	1	8-May	Tillage	Bedder Shaper
Parsley	1	2-Jun	Planting	SPINACH
Parsley	1	2-Jun	Auto-irrigation	AUTO_WSTRS = 30
Parsley	1	3-Jun	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Parsley	1	15-Jun	Tillage	Row Cultivator Ge15ft
Parsley	1	1-Jul	Harvest	Harvest and kill
Parsley	1	2-Jul	Tillage	Offset Dis/lghtduty Ge19ft
Parsley	1	1-Aug	Tillage	Offset Dis/lghtduty Ge19ft
Parsley	1	2-Aug	Tillage	Deep Ripper- Subsoiler
Parsley	1	3-Aug	Tillage	Moldboard Plow Reg 4-6b
Parsley	1	4-Aug	Tillage	Offset Dis/lghtduty Ge19ft
Parsley	1	5-Aug	Tillage	Land Plane-leveler
Parsley	1	6-Aug	Tillage	Chisel Plow Gt21ft
Parsley	1	7-Aug	Tillage	Lister (middle-buster)
Parsley	1	8-Aug	Tillage	Bedder Shaper
Parsley	1	1-Sep	Planting	SPINACH
Parsley	1	2-Sep	Auto-irrigation	AUTO_WSTRS = 30
Parsley	1	3-Sep	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Parsley	1	15-Sep	Tillage	Row Cultivator Ge15ft
Parsley	1	1-Oct	Harvest	Harvest and kill
Parsley	1	2-Oct	Tillage	Offset Dis/lghtduty Ge19ft

Table F-6 Other Grains Group Agronomic Management Schedules				
Dominant Crop	***Year***	***Month/Day***	***Operation***	***Description***
Oats	1	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Oats	1	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Oats	1	1-May	Harvest	Harvest and kill
Oats	1	1-Nov	Tillage	Soil Finisher
Oats	1	2-Nov	Tillage	Soil Finisher
Oats	1	3-Nov	Tillage	Disk Border Maker
Oats	1	21-Nov	Planting	OATS
Oats	1	22-Nov	Auto-irrigation	AUTO_WSTRS = 30
Oats	1	23-Nov	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Safflower	1	1-Mar	Tillage	Row Cultivator Lt15ft
Safflower	1	2-Mar	Tillage	Rolling Cultivator Lt15ft
Safflower	1	1-Apr	Planting	SPRING CANOLA-ARGENTINE
Safflower	1	2-Apr	Auto-irrigation	AUTO_WSTRS = 30
Safflower	1	3-Apr	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Safflower	1	1-May	Tilage	Rolling Cultivator Lt15ft
Safflower	1	1-Aug	Harvest	Harvest and Kill
Safflower	1	1-Oct	Tillage	Disk Plow Lt23ft
Safflower	1	2-Oct	Tillage	Soil Finisher
Triticale	1	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Triticale	1	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Triticale	1	1-May	Harvest	Harvest and kill
Triticale	1	1-Nov	Tillage	Soil Finisher
Triticale	1	2-Nov	Tillage	Soil Finisher
Triticale	1	3-Nov	Tillage	Disk Border Maker
Triticale	1	21-Nov	Planting	RYE
Triticale	1	22-Nov	Auto-irrigation	AUTO_WSTRS = 30
Triticale	1	23-Nov	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9

Table F-7 Other Row Crops Group Agronomic Management Schedules				
Dominant Crop	*Year*	*Month/Day*	*Operation*	*Description*
Mint	1	1-Apr	Tillage	Roller Packer Flat Roller
Mint	1	2-Apr	Planting	SPINACH
Mint	1	3-Apr	Auto-irrigation	AUTO_WSTRS = 30
Mint	1	4-Apr	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Mint	1	1-Sep	Harvest	Harvest only
Mint	2	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Mint	2	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Mint	2	1-Apr	Tillage	Roller Packer Flat Roller
Mint	2	1-Aug	Harvest	Harvest only
Mint	3	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Mint	3	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Mint	3	1-Apr	Tillage	Roller Packer Flat Roller
Mint	3	1-Aug	Harvest	Harvest only
Mint	3	1-Sep	Tillage	Offset Dis/lghtduty Ge19ft
Mint	3	2-Sep	Tillage	Packer 40 Ft
Mint	3	3-Sep	Tillage	Deep Ripper- Subsoiler
Mint	3	4-Sep	Tillage	Roller Packer Flat Roller
Mint	3	5-Sep	Tillage	Roto-tiller
Mint	3	6-Sep	Tillage	Roller Packer Flat Roller
Mint	4	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Mint	4	1-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Mint	4	1-Apr	Tillage	Roller Packer Flat Roller
Mint	4	1-Aug	Harvest	Harvest only
Mint	5	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Mint	5	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Mint	5	1-Apr	Tillage	Roller Packer Flat Roller
Mint	5	1-Aug	Harvest	Harvest and Kill
Sugarbeets	1	1-Jan	Planting	SUGARBEET
Sugarbeets	1	2-Jan	Auto-irrigation	AUTO_WSTRS = 30
Sugarbeets	1	3-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Sugarbeets	1	4-Jan	Tillage	Bed Roller 4 Row
Sugarbeets	1	1-Apr	Tillage	Beet Cultivator 8 Row
Sugarbeets	1	1-May	Tillage	Beet Cultivator 8 Row
Sugarbeets	1	1-Sep	Harvest	Harvest and Kill
Sugarbeets	1	7-Sep	Tillage	Disk Plow Lt23ft
Sugarbeets	1	8-Sep	Tilage	Disk Plow Lt23ft
Sugarbeets	1	1-Oct	Tillage	Offset Dis/heavduty Ge19ft
Sugarbeets	1	2-Oct	Tillage	Offset Dis/heavduty Ge19ft
Sugarbeets	1	3-Oct	Tillage	Chisel Plow Le15ft
Sugarbeets	1	4-Oct	Tillage	Offset Dis/heavduty Ge19ft

Table F-7 Other Row Crops Group Agronomic Management Schedules				
Dominant Crop	***Year***	***Month/Day***	***Operation***	***Description***
Sugarbeets	1	5-Oct	Tillage	Land Plane-leveler
Sugarbeets	1	6-Oct	Tillage	Land Plane-leveler
Sugarbeets	1	7-Oct	Tillage	Land Plane-leveler
Sugarbeets	1	8-Oct	Tillage	Lister (middle-buster)
Sunflower	1	1-Mar	Tillage	Rolling Cultivator Lt15ft
Sunflower	1	1-Apr	Planting	SUNFLOWER
Sunflower	1	2-Apr	Auto-irrigation	AUTO_WSTRS = 30
Sunflower	1	3-Apr	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Sunflower	1	1-May	Tillage	Row Cultivator Lt15ft
Sunflower	1	1-Aug	Harvest	Harvest and kill
Sunflower	1	1-Oct	Tillage	Disk Plow Lt23ft
Sunflower	1	5-Oct	Tillage	Disk Plow Lt23ft
Sunflower	1	6-Oct	Tillage	Subsoil Chisel Plow
Sunflower	1	7-Oct	Tillage	Land Plane-leveler
Sunflower	1	8-Oct	Tillage	Land Plane-leveler
Sunflower	1	9-Oct	Tillage	Laser Planer
Sunflower	1	1-Nov	Tillage	Lister (middle-buster)

Table F-8 Rice Group Agronomic Management Schedules				
Dominant Crop	***Year***	***Month/Day***	***Operation***	***Description***
Rice	1	1-Apr	Tillage	Offset Dis/heavduty Le13ft
Rice	1	2-Apr	Tillage	Offset Dis/heavduty Le13ft
Rice	1	3-Apr	Tillage	Soil Finisher
Rice	1	4-Apr	Tillage	Float
Rice	1	5-Apr	Tillage	Levee-plow-disc
Rice	1	1-May	Planting	RICE
Rice	1	2-May	Auto-irrigation	AUTO_WSTRS = 30
Rice	1	3-May	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Rice	1	25-Oct	Harvest	Harvest & kill

Table F-9 Sorghum Group Agronomic Management Schedules				
Dominant Crop	***Year***	***Month/Day***	***Operation***	***Description***
Dbl Crop WinWht/Sorghum	1	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Dbl Crop WinWht/Sorghum	1	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Dbl Crop WinWht/Sorghum	1	1-Jun	Harvest	Harvest and kill - winter wheat
Dbl Crop WinWht/Sorghum	1	7-Jun	Tillage	Disk Plow Lt23ft
Dbl Crop WinWht/Sorghum	1	8-Jun	Tillage	Disk Border Maker

Table F-9 Sorghum Group Agronomic Management Schedules				
Dominant Crop	***Year***	***Month/Day***	***Operation***	***Description***
Dbl Crop WinWht/Sorghum	1	9-Jun	Tillage	Soil Finisher
Dbl Crop WinWht/Sorghum	1	14-Jun	Planting	GRAIN SORGHUM
Dbl Crop WinWht/Sorghum	1	15-Jun	Auto-irrigation	AUTO_WSTRS = 30
Dbl Crop WinWht/Sorghum	1	16-Jun	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Dbl Crop WinWht/Sorghum	1	21-Jun	Tillage	Furrow-out Cultivator
Dbl Crop WinWht/Sorghum	1	7-Jul	Tillage	Furrow-out Cultivator
Dbl Crop WinWht/Sorghum	1	1-Sep	Harvest	Harvest and Kill - grain sorghum
Dbl Crop WinWht/Sorghum	1	1-Nov	Tillage	Soil Finisher
Dbl Crop WinWht/Sorghum	1	2-Nov	Tillage	Soil Finisher
Dbl Crop WinWht/Sorghum	1	3-Nov	Tillage	Disk Border Maker
Dbl Crop WinWht/Sorghum	1	21-Nov	Planting	WINTER WHEAT
Dbl Crop WinWht/Sorghum	1	22-Nov	Auto-irrigation	AUTO_WSTRS = 30
Dbl Crop WinWht/Sorghum	1	23-Nov	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Sorghum	1	1-May	Tillage	Disk Plow Lt23ft
Sorghum	1	2-May	Tillage	Disk Border Maker
Sorghum	1	3-May	Tillage	Soil Finisher
Sorghum	1	14-Jun	Planting	GRAIN SORGHUM
Sorghum	1	15-Jun	Auto-irrigation	AUTO_WSTRS = 30
Sorghum	1	16-Jun	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Sorghum	1	21-Jun	Tillage	Furrow-out Cultivator
Sorghum	1	7-Jul	Tillage	Furrow-out Cultivator
Sorghum	1	1-Sep	Harvest	Harvest and Kill

Table F-10 Vegetables/Ground Fruit Group Agronomic Management Schedules				
Dominant Crop	***Year***	***Month/Day***	***Operation***	***Description***
Asparagus	1	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Asparagus	1	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Asparagus	1	15-Mar	Harvest	Harvest only
Asparagus	1	1-May	Tillage	Rolling Cultivator Ge15ft
Asparagus	1	1-Jun	Tillage	Rolling Cultivator Ge15ft
Asparagus	1	1-Oct	Tillage	Disk Plow Ge23ft
Blueberries	1	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Blueberries	1	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Blueberries	2	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Blueberries	2	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9

Table F-10 Vegetables/Ground Fruit Group Agronomic Management Schedules				
Dominant Crop	*Year*	*Month/Day*	*Operation*	*Description*
Blueberries	2	1-May	Harvest	Harvest only
Blueberries	2	1-Jun	Harvest	Harvest only
Blueberries	3	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Blueberries	3	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Blueberries	3	1-May	Harvest	Harvest only
Blueberries	3	1-Jun	Harvest	Harvest only
Blueberries	4	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Blueberries	4	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Blueberries	4	1-May	Harvest	Harvest only
Blueberries	4	1-Jun	Harvest	Harvest only
Blueberries	5	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Blueberries	5	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Blueberries	5	1-May	Harvest	Harvest only
Blueberries	5	1-Jun	Harvest	Harvest and kill
Blueberries	5	1-Jul	Tillage	Chisel Plow Le15ft
Blueberries	5	2-Jul	Tillage	Disk Plow Lt23ft
Blueberries	5	3-Jul	Tillage	Disk Plow Lt23ft
Blueberries	5	4-Jul	Tillage	Disk Border Maker
Blueberries	5	5-Jul	Tillage	Roller Packer Flat Roller
Blueberries	5	1-Oct	Planting	Vineyard
Blueberries	5	2-Oct	Auto-irrigation	AUTO_WSTRS = 30
Blueberries	5	3-Oct	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
DryBeans	1	1-Jun	Tillage	Subsoil Chisel Plow
DryBeans	1	2-Jun	Tillage	Disk Plow Lt23ft
DryBeans	1	3-Jun	Tillage	Soil Finisher
DryBeans	1	4-Jun	Tillage	Soil Finisher
DryBeans	1	5-Jun	Tillage	Land Plane-leveler
DryBeans	1	6-Jun	Tillage	Lister (middle-buster)
DryBeans	1	7-Jun	Tillage	Rolling Cultivator Lt15ft
DryBeans	1	15-Jun	Planting	LIMA BEANS
DryBeans	1	16-Jun	Auto-irrigation	AUTO_WSTRS = 30
DryBeans	1	17-Jun	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
DryBeans	1	1-Jul	Tillage	Row Cultivator Lt15ft
DryBeans	1	14-Jul	Tillage	Row Cultivator Lt15ft
DryBeans	1	1-Sep	Harvest	Harvest and kill
Lettuce	1	1-Jan	Tillage	Rolling Cultivator Ge15ft
Lettuce	1	2-Jan	Tillage	Bedder Shaper
Lettuce	1	3-Jan	Planting	LETTUCE
Lettuce	1	4-Jan	Auto-irrigation	AUTO_WSTRS = 30
Lettuce	1	5-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9

Table F-10 Vegetables/Ground Fruit Group Agronomic Management Schedules				
Dominant Crop	*Year*	*Month/Day*	*Operation*	*Description*
Lettuce	1	1-Apr	Harvest	Harvest and kill
Lettuce	1	1-Oct	Tillage	Offset Dis/lghtduty Ge19ft
Lettuce	1	2-Oct	Tillage	Offset Dis/lghtduty Ge19ft
Lettuce	1	3-Oct	Tillage	Offset Dis/lghtduty Ge19ft
Lettuce	1	4-Oct	Tillage	Ripper 10 Ft
Lettuce	1	5-Oct	Tillage	Land Plane-leveler
Lettuce	1	6-Oct	Tillage	Chisel Plow Gt15ft
Melon	1	1-Feb	Tillage	Offset Dis/lghtduty Ge19ft
Melon	1	2-Feb	Tillage	Deep Ripper- Subsoiler
Melon	1	3-Feb	Tillage	Offset Dis/lghtduty Ge19ft
Melon	1	1-Mar	Tillage	Land Plane-leveler
Melon	1	2-Mar	Tillage	Lister (middle-buster)
Melon	1	3-Mar	Planting	HONEYDEW MELON
Melon	1	4-Mar	Auto-irrigation	AUTO_WSTRS = 30
Melon	1	5-Mar	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Melon	1	1-May	Tillage	Rolling Cultivator Ge15ft
Melon	1	1-Jul	Harvest	Harvest and kill
Onion	1	1-Apr	Tillage	Chisel Plow Gt21ft
Onion	1	2-Apr	Tillage	Deep Ripper- Subsoiler
Onion	1	3-Apr	Tillage	Roto-tiller
Onion	1	4-Apr	Tillage	Lister (middle-buster)
Onion	1	5-Apr	Tillage	Bedder Shaper
Onion	1	6-Apr	Planting	ONION
Onion	1	7-Apr	Auto-irrigation	AUTO_WSTRS = 30
Onion	1	8-Apr	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Onion	1	1-Jun	Tillage	Row Cultivator Ge15ft
Onion	1	1-Oct	Harvest	Harvest and kill
Onion	1	1-Nov	Tillage	Moldboard Plow Reg 4-6b
Strawberries	1	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
Strawberries	1	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Strawberries	1	14-Mar	Harvest	Harvest only
Strawberries	1	14-Apr	Harvest	Harvest only
Strawberries	1	14-May	Harvest	Harvest only
Strawberries	1	14-Jun	Harvest	Harvest only
Strawberries	1	14-Jul	Harvest	Harvest only
Strawberries	1	7-Aug	Harvest	Harvest and kill
Strawberries	1	9-Aug	Tillage	Disk Plow Lt23ft
Strawberries	1	11-Aug	Tillage	Disk Plow Lt23ft
Strawberries	1	12-Aug	Tillage	Bed Roller 4 Row
Strawberries	1	13-Aug	Tillage	Disk Plow Lt23ft

Table F-10 Vegetables/Ground Fruit Group Agronomic Management Schedules				
Dominant Crop	*Year*	*Month/Day*	*Operation*	*Description*
Strawberries	1	14-Aug	Tillage	Bed Roller 4 Row
Strawberries	1	15-Aug	Tillage	Disk Plow Lt23ft
Strawberries	1	16-Aug	Tillage	Bed Roller 4 Row
Strawberries	1	17-Aug	Tillage	Disk Plow Lt23ft
Strawberries	1	18-Aug	Tillage	Bed Roller 4 Row
Strawberries	1	19-Aug	Tillage	Disk Plow Lt23ft
Strawberries	1	20-Aug	Tillage	Bed Roller 4 Row
Strawberries	1	21-Aug	Tillage	Deep Ripper- Subsoiler
Strawberries	1	22-Aug	Tillage	Deep Ripper- Subsoiler
Strawberries	1	23-Aug	Tillage	Moldboard Plow Reg 4-6b
Strawberries	1	24-Aug	Tillage	Land Plane-leveler
Strawberries	1	25-Aug	Tillage	Land Plane-leveler
Strawberries	1	26-Aug	Tillage	Chisel Plow Le15ft
Strawberries	1	1-Sep	Tillage	Bedder Shaper
Strawberries	1	2-Sep	Tillage	Disk Plow Lt23ft
Strawberries	1	1-Oct	Planting	Transplanted
Strawberries	1	2-Oct	Auto-irrigation	AUTO_WSTRS = 30
Strawberries	1	3-Oct	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Tomatoes	1	1-Jan	Tillage	Rolling Cultivator Lt15ft
Tomatoes	1	2-Jan	Tillage	Rolling Cultivator Lt15ft
Tomatoes	1	1-Mar	Tillage	Power Mulcher
Tomatoes	1	21-Mar	Planting	TOMATOES
Tomatoes	1	22-Mar	Auto-irrigation	AUTO_WSTRS = 30
Tomatoes	1	23-Mar	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
Tomatoes	1	7-Apr	Tillage	Row Cultivator Lt15ft
Tomatoes	1	27-Apr	Tillage	Row Cultivator Lt15ft
Tomatoes	1	7-May	Tillage	Row Cultivator Lt15ft
Tomatoes	1	15-Jul	Harvest	Harvest only
Tomatoes	1	7-Aug	Harvest	Harvest only
Tomatoes	1	1-Sep	Harvest	Harvest and kill
Tomatoes	1	12-Sep	Tillage	Disk Plow Lt23ft
Tomatoes	1	13-Sep	Tillage	Rice Roller
Tomatoes	1	14-Sep	Tillage	Deep Ripper- Subsoiler
Tomatoes	1	15-Sep	Tillage	Deep Ripper- Subsoiler
Tomatoes	1	16-Sep	Tillage	Soil Finisher
Tomatoes	1	17-Sep	Tillage	Bed Roller 4 Row
Tomatoes	1	18-Sep	Tillage	Land Plane-leveler
Tomatoes	1	19-Sep	Tillage	Land Plane-leveler
Tomatoes	1	1-Oct	Tillage	Lister (middle-buster)
Tomatoes	1	2-Oct	Tillage	Bedder Shaper

Table F-11 Winter Wheat Group Agronomic Management Schedules				
Dominant Crop	***Year***	***Month/Day***	***Operation***	***Description***
WinterWheat	1	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
WinterWheat	1	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
WinterWheat	1	1-Jun	Harvest	Harvest & kill
WinterWheat	1	1-Aug	Tillage	Soil Finisher
WinterWheat	1	1-Oct	Tillage	Soil Finisher
WinterWheat	1	2-Oct	Tillage	Spike Tooth Harrow Gt25ft
WinterWheat	1	3-Oct	Tillage	Bed Roller 4 Row
WinterWheat	1	1-Nov	Planting	WINTER WHEAT
WinterWheat	1	2-Nov	Auto-irrigation	AUTO_WSTRS = 30
WinterWheat	1	3-Nov	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
WinterWheat	2	1-Jan	Auto-irrigation	AUTO_WSTRS = 30
WinterWheat	2	2-Jan	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9
WinterWheat	2	1-Jun	Harvest	Harvest & kill
WinterWheat	2	21-Jun	Tillage	Disk Plow Lt23ft
WinterWheat	2	1-Aug	Tillage	Disk Plow Lt23ft
WinterWheat	2	2-Aug	Tillage	Soil Finisher
WinterWheat	2	1-Oct	Tillage	Soil Finisher
WinterWheat	2	2-Oct	Tillage	Disk Border Maker
WinterWheat	2	3-Oct	Tillage	Lister (middle-buster)
WinterWheat	2	4-Oct	Tillage	Spike Tooth Harrow Gt25ft
WinterWheat	2	5-Oct	Tillage	Bed Roller 4 Row
WinterWheat	2	1-Nov	Planting	WINTER WHEAT
WinterWheat	2	2-Nov	Auto-irrigation	AUTO_WSTRS = 30
WinterWheat	2	3-Nov	Auto-fertilization	AFERT_ID = '15-15-15' , AUTO_NSTR = 0.9

Appendix G
Refined Effects Assessment

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Acute Effects Assessment

To assess the acute effects of malathion to delta smelt (DS) in freshwater and marine environments, three acute concentration-response curves were fit to data from an acceptable freshwater fish study (Gries and Purghart, 2001a [MRID 47540304]) and from acceptable marine fish studies (Burke, 2011 [MRID 49055701]; Gries et al. 2002 [MRID 48998006]).

Freshwater Fish

Gries and Purghart (2001a [MRID 47540304]) investigated the toxicity of malathion to bluegill sunfish (*Lepomis macrochirus*) exposed for 96 hours under flow-through conditions. The study was reviewed and evaluated by Breton et al. (2014 [MRID 49333901]). Gries and Purghart (2001a [MRID 47540304]) was scored as acceptable using Cheminova's data reliability criteria (Breton et al., 2014 [MRID 49333901]).

Table G-73 contains primary data extracted from the study used in concentration-response analyses. Five test concentrations plus a control were used in this test. Nominal test concentrations ranged from 7.75 µg a.i./L to 124 µg a.i./L. Mortality ranged from 0% in the control and the first three treatment groups, to 100% at the highest treatment level. The only partial response (i.e., some individuals surviving and some dying) occurred at the second highest treatment level in which four of seven fish survived (Table G-73).

The recovery of quality control samples ranged from 79 to 105%. Recovery from experimental units was measured at the beginning and ending of the exposure period. Recovery ranged from 22.4% in the lowest treatment at 96 hours to 100% at the middle treatment level at time zero. The recovery from the lowest treatment group at 96 hours was considered by the authors to be an outlier. On average, at 96 hours, recovery was 88.8% from the other treatment groups. Herein, analyses were done with mean measured concentrations both including and excluding the lowest treatment level.

With only one treatment level containing partial effects, comparison between binomial response models is impracticable. The standard log probit model was fit to cumulative mortality at 96 hours versus mean measured concentrations of malathion in water. The PROC PROBIT procedure in SAS Software® (SAS Version 9.3) was used. The fitted model is presented in Figure G-64. Confidence limits could not be calculated since only one partial mortality occurred.

Since the inclusion of the lowest treatment group did not change model estimates at two significant digits, we opted to exclude the dubious lower treatment level in the final modelling presented here.

The LD50 estimate from the log probit model is 54.4 µg a.i./L. The intercept and slope of the generalized linear model are -45.2 and 26.0, respectively. In terms of the tolerance distribution, the model parameters are $\mu = 1.74$ and $\sigma = 0.0384$.

Table G-73 Effects of malathion on bluegill sunfish (*Lepomis macrochirus*) exposed for 96 hours[a]								
Nominal Concentration (µg test substance/L)	*Nominal Concentration (µg a.i./L)*	*0-hour Concentration (µg a.i./L)*	*96-hour Concentration (µg a.i./L)*	*Mean Measured Concentration (µg a.i./L)*	*Number of Exposed Fish*	*Number of Dead Fish at 96 hour*	*Mortality (%)*	*Proportion Dead*
0	0	0.290[b]	0.550[b]	0.420[b]	7	0	0	0
8	7.75	6.72	1.73[c]	4.23	7	0	0	0
16	15.5	14.8	14.7	14.7	7	0	0	0
32	31.0	31.1	27.2	29.2	7	0	0	0
64	62.0	59.9	54.5	57.2	7	5	71.4	0.714
128	124	110	105	107	7	7	100	1

[a] Data from page 9 and Table 3 (page 23) of Gries and Purghart (2001a [MRID 47540304]).

[b] Peak area observed for control samples were subtracted from treatment samples, and 0 µg a.i./L was used as the mean measured concentration in the statistical analyses herein.

[c] Gries and Purghart (2001a [MRID 47540304]) recorded only 22.4% recovery of nominal at 96 hours in the lowest treatment group. This was considered an outlier by the authors. We ran analyses with and without this treatment group and found that effects on the concentration-response model estimates were negligible.

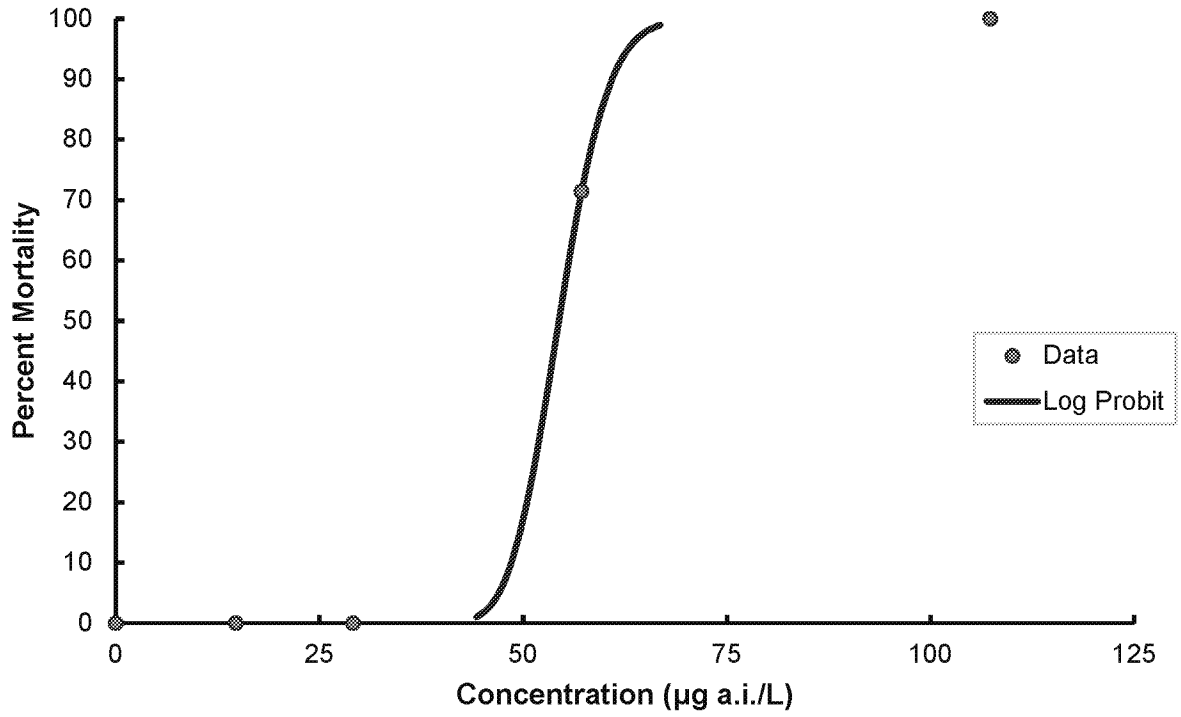

Figure G-64 **Log probit model fit to bluegill sunfish (*Lepomis macrochirus*) mortality data from Gries and Purghart (2001a [MRID 47540304])**

Marine Fish

Burke (2011 [MRID 49055701]) investigated the toxicity of malathion to sheepshead minnow (*Cyprinodon variegatus*) exposed for 96 hours under semi-static renewal conditions. The study was reviewed and evaluated by Breton et al. (2014 [MRID 49333901]). Burke (2011 [MRID 49055701]) was scored as acceptable using Cheminova's study evaluation criteria (Breton et al., 2014 [MRID 49333901]).

Table G-74 contains primary data extracted from the study used in concentration-response analyses. Six test concentrations plus controls were used in this test. Nominal test concentrations ranged from 42.6 µg a.i./L to 194 µg a.i./L. Mortality ranged from 0% in the controls to 100% at the highest and third highest treatment levels. Partial response (i.e., some individuals surviving and some dying) occurred at all other treatment levels (Table G-74).

The recovery of quality control samples ranged from 96 to 102%. Recovery from experimental units was measured throughout the exposure period. Recovery ranged from an average of 66% in the lowest treatment to 95.7% at the highest treatment level. Herein analyses were done with mean measured concentrations.

Table G-74 Effects of malathion on sheepshead minnow (*Cyprinodon variegatus*) exposed for 96 hours[a]						
Nominal Concentration (µg malathion technical/L)	*Nominal Concentration (µg a.i./L)*	*Mean Measured Concentration (µg a.i./L)*	*Number of Fish Exposed*	*Number of Dead Fish*	*Mortality (%)*	*Proportion Dead*
Control		0	7	0	0	0
Solvent Control		0	7	0	0	0
44.6	42.6	28.5	7	3	42.9	0.429
60.2	58.3	46.9	7	3	42.9	0.429
81.3	78.7	68.5	7	2	28.6	0.286
110	10.6	89.6	7	7	100	1
148	14.3	117	7	6	85.7	0.857
200	194	185	7	7	100	1

[a] Data from Table 3 of Burke (2011 [MRID 49055701]).

The PROC PROBIT procedure in SAS Software® (SAS Version 9.3) was used to fit standard models to cumulative mortality at 96 hours versus mean measured concentrations of malathion in water. The standard models available in PROC PROBIT include probit, logistic and Gompertz (extreme value). These models were fit to arithmetic and logged concentration data. Goodness of fit was assessed by Chi-Square statistics and visual inspection. All of the arithmetic models predicted effects at negative concentrations. Therefore, the best fitting model was selected from among the log models (Table G-75).

Table G-75 Summary of results of goodness-of-fit tests applied to concentration-response models fit to sheepshead minnow (*Cyprinodon variegatus*) mortality data from Burke (2011 [MRID 49055701])

Model	*Pearson Chi Square Value*	*p-value*	*Likelihood Ratio Chi Square Value*	*p-value*
Log probit	8.1507	0.0862	9.5119	0.0495
Log Gompertz/ extreme value	7.1104	0.1302	8.4484	0.0765
Log logistic	8.326	0.0803	9.7964	0.044

The log Gompertz model was selected as the best fitting model (see Equation G-1), and is presented with the data and confidence limits in Figure G-65.

$$f(x) = 1 - e^{-e^{\frac{(x-\mu)}{\sigma}}}$$ **Equation G-1**

The LD50 estimate from the log Gompertz model is 51.1 µg a.i./L. The intercept and slope of the generalized linear model are -5.78 and 3.17, respectively. In terms of the tolerance distribution, the model parameters are $\mu = 1.82$ and $\sigma = 0.316$.

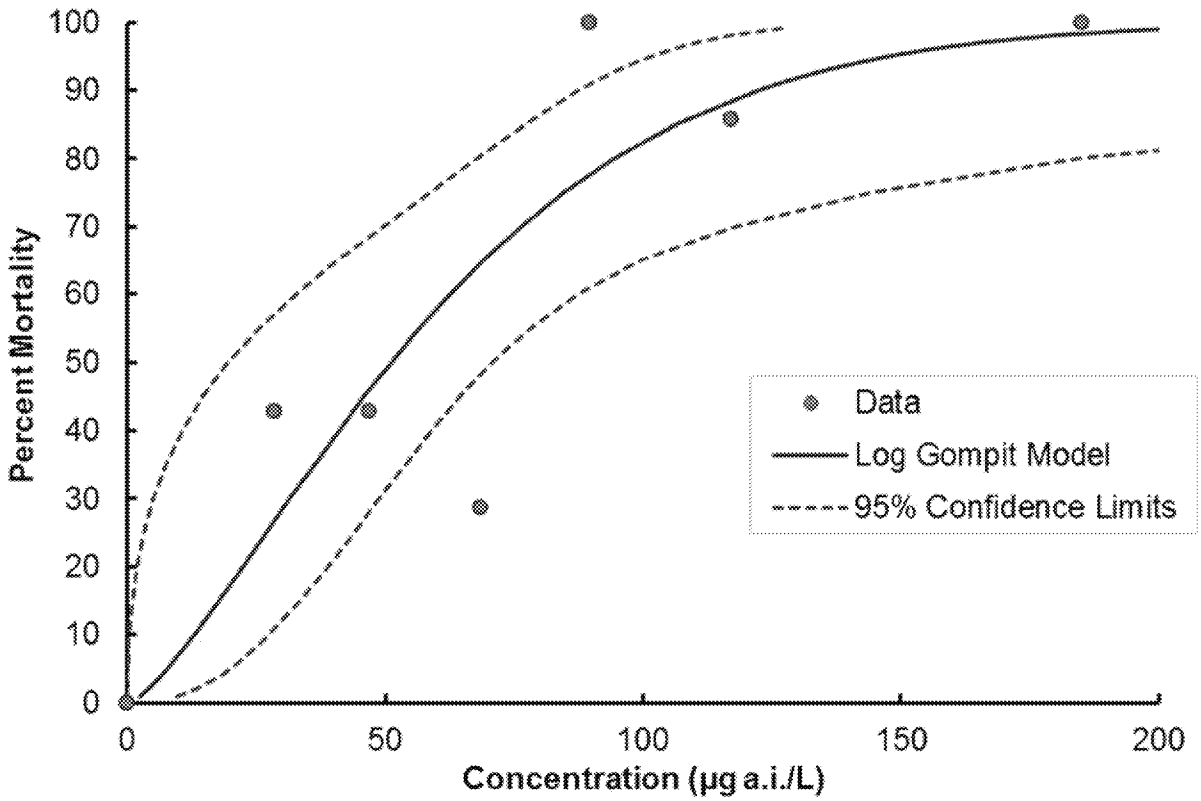

Figure G-65 **Log gompertz model fit to sheepshead minnow (Cyprinodon variegatus) mortality data from Burke (2011 [MRID 49055701])**

Gries et al. (2002 [MRID 48998006]) evaluated the effects of malathion to the three-spined stickleback (*Gasterosteus aculeatus*) under flow-through conditions. The study was reviewed and evaluated by Breton et al. (2014 [MRID 49333901]). Gries et al. (2002 [MRID 48998006]) was scored as acceptable using Cheminova's study evaluation criteria (Breton et al., 2014 [MRID 49333901]).

Table G-76 contains the primary data extracted from the study and used in concentration-response analyses. Six test concentrations plus controls were used in this test. Nominal test concentrations ranged from 2.4 µg a.i./L to 76.8 µg a.i./L. Mortality ranged from 0% in the controls to 100% at the highest treatment level. Partial response (i.e., some individuals surviving and some dying) occurred at the 9.6, 19.2, and 38.4 µg a.i./L nominal treatment levels (Table G-76).

The recovery of quality control samples ranged from 90.4 to 115%, with the exception of one outlier that showed a recovery of 44.2%. Recovery from experimental units was measured at the beginning and ending of the exposure period. The mean measured concentrations ranged from 76 to 111% of nominal concentrations. As such, analyses were done with mean measured concentrations.

Table G-76 Effects of malathion on three-spined stickleback (*Gasterosteus aculeatus*) exposed for 96 hours[a]						
Nominal Concentration (µg malathion technical/L)	*Nominal Concentration (µg a.i./L)*	*Mean Measured Concentration (µg a.i./L)*[b]	*Number of Fish Exposed*	*Number of Dead Fish*	*Mortality (%)*	*Proportion Dead*
Control	Control	<LOQ	7	0	0	0
2.5	2.4	1.82	7	0	0	0
5	4.8	4.81	7	0	0	0
10	9.6	10.7	7	2	29.0	0.290
20	19.2	19	7	3	43.0	0.430
40	38.4	40.1	7	5	71.0	0.710
80	76.8	78.2	7	7	100	1

[a] Data from Table 4 of Gries et al. (2002 [MRID 48998006]).
[b] LOQ = 0.824 and 0.832 µg a.i./L

The PROC PROBIT procedure in SAS Software® (SAS Version 9.3) was used to fit standard models to cumulative mortality at 96 hours versus mean measured concentrations of malathion in water. The standard models available in PROC PROBIT include probit, logistic and Gompertz (extreme value). These models were fit to arithmetic and logged concentration data. Goodness of fit was assessed by Chi-Square statistics and visual inspection. All of the arithmetic models predicted effects at negative concentrations. Therefore, the best fitting model was selected from among the log models (Table G-77).

Table G-77 Summary of results of goodness-of-fit tests applied to concentration-response models fit to three-spined stickleback (*Gasterosteus aculeatus*) mortality data from Gries et al. (2002 [MRID 48998006])

Model	*Pearson Chi Square Value*	*p-value*	*Likelihood Ratio Chi Square Value*	*p-value*
Log probit	1.3093	0.8598	1.6987	0.7909
Log Gompertz/ extreme value	1.415	0.8416	1.8877	0.7564
Log logistic	1.5859	0.8113	2.1211	0.7135

The log probit model was selected as the best fitting model and is presented with the data and confidence limits in Figure G-66. The LD50 estimate from the log probit model is 20.9 µg a.i./L. The intercept and slope of the generalized linear model are -4.02 and 3.04, respectively. In terms of the tolerance distribution, the model parameters are $\mu = 1.32$ and $\sigma = 0.329$.

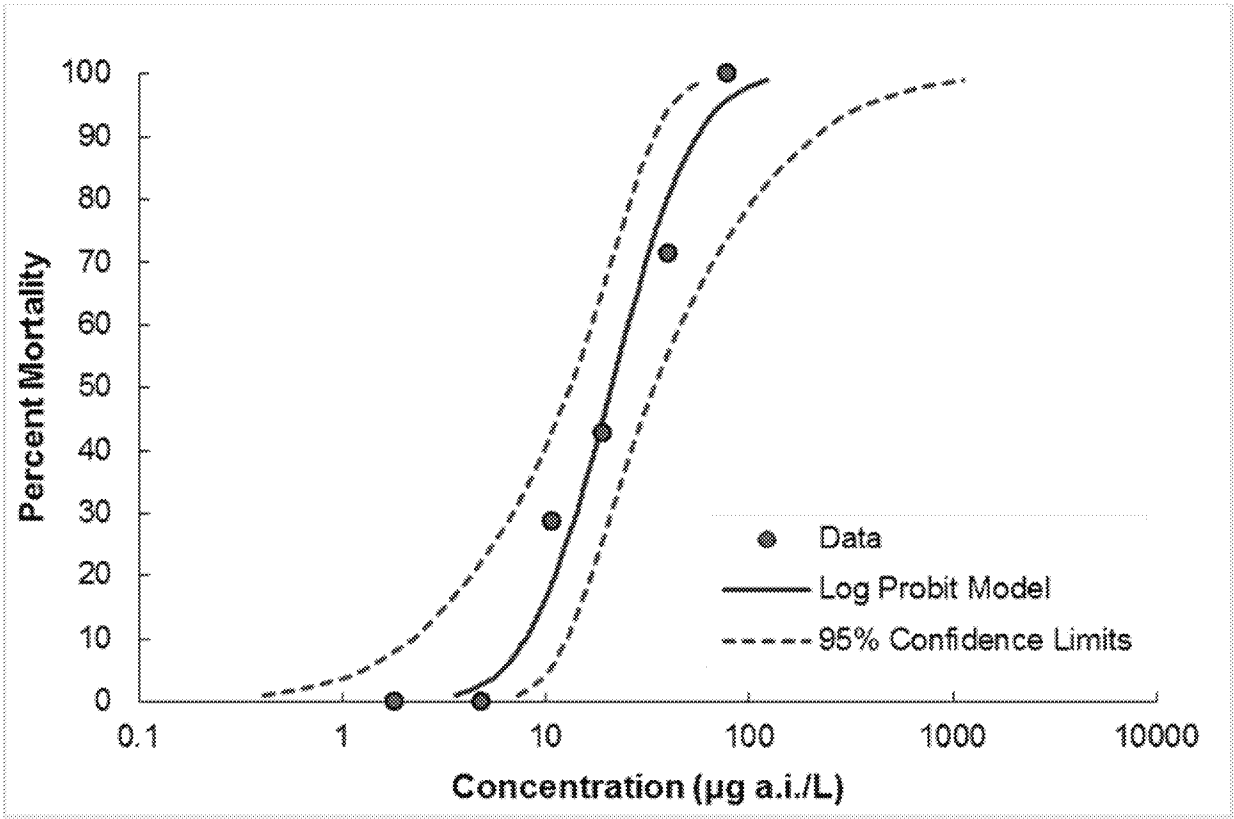

Figure G-66 **Log gompertz model fit to three-spined stickleback (*Gasterosteus aculeatus*) mortality data from Gries et al. (2002 [MRID 48998006])**

Chronic Effects Assessment

Only two chronic aquatic invertebrate studies were rated either acceptable or supplemental according to Cheminova's study evaluation criteria (Breton et al., 2014 [MRID 49333901]), which was not sufficient for the purposes of deriving a chronic aquatic invertebrate SSD. Therefore, the acute SSD described in 3.1.2 of the effects determination was converted to a chronic SSD using an acute-to-chronic ratio (ACR).

Using the acceptable and supplemental toxicity studies for aquatic invertebrates, ACRs for malathion were developed for two species: water flea (*Daphnia magna*) and mysid (*Americamysis bahia*). The ACRs were calculated using 48-hour LC50s (Gries and Purghart, 2001b [MRID 47540303]; Brougher et al., 2014 [MRID 49389401]) and chronic EC10s (Blakemore and Burgess, 1990 [MRID 41718401]; Claude et al., 2012 [MRID 48752901]). The acute effects metrics were taken from the toxicity studies directly, both of which were rated acceptable based on Cheminova's study evaluation criteria (Breton et al., 2014 [MRID 49333901]; 2015 [MRID 49692301]). For the chronic EC10s, analyses of the chronic effects data are described for water flea and mysid, respectively below.

Blakemore and Burgess (1990 [MRID 41718401]) investigated the toxicity of malathion to water flea (*Daphnia magna)* exposed in water for 21 days. The study was evaluated by Breton et al. (2014 [MRID 49333901]) and rated supplemental. Table G-78 contains key data extracted from Blakemore and Burgess (1990 [MRID 41718401]), including measures of effects to survival, growth and reproduction. Dose-response curves were modeled for survival and reproduction, with these two measures of effects being clearly more sensitive than growth.

Table G-78 Effects of malathion on *Daphnia magna* exposed for 21 days in water[a]

Mean Measured Concentration (µg a.i./L)	*Replicate*	*Initial Number Instar*	*Dead on or before Day 21*	*Mortality (%)*	*Mean Adult Length on Day 21 (mm)*	*Total Young*	*Adult Reproductive Days*	*Number of Young/Adult Reproductive Day*	*Time to First Brood (d)*
Control	A	10	0	0	4.33	1801	150	12	7
Control	B	10	1	10	4.28	1613	138	11.7	7
Control	C	10	0	0	4.36	1837	150	12.2	7
Control	D	10	0	0	4.33	1861	150	12.4	7
Solvent Control	A	10	0	0	4.29	1735	150	11.6	7
Solvent Control	B	10	0	0	4.33	1951	150	13	7
Solvent Control	C	10	0	0	4.36	1834	150	12.2	7
Solvent Control	D	10	1	10	4.24	1716	149	11.5	7
0.06	A	10	0	0	4.26	1773	150	11.8	7
0.06	B	10	0	0	4.33	1839	150	12.3	7
0.06	C	10	0	0	4.24	1720	150	11.5	7
0.06	D	10	0	0	4.23	1727	150	11.5	7
0.1	A	10	0	0	4.26	1560	150	10.4	7
0.1	B	10	1	10	4.28	1388	139	10	7
0.1	C	10	0	0	4.25	1514	150	10.1	7
0.1	D	10	0	0	4.26	1501	150	10	7
0.25	A	10	1	10	4.19	1097	139	7.9	7
0.25	B	10	0	0	4.16	1176	150	7.8	7
0.25	C	10	0	0	4.19	1269	150	8.5	7
0.25	D	10	0	0	4.17	1158	150	7.7	7
0.46	A	10	1	10	3.8	707	125	5.7	9
0.46	B	10	2	20	3.83	707	126	5.6	9
0.46	C	10	3	30	3.91	690	112	6.2	9
0.46	D	10	4	40	3.93	655	108	6.1	9
0.94	A	10	10	100	----	43	30	1.4	10
0.94	B	10	10	100	----	66	51	1.3	10
0.94	C	10	10	100	----	56	30	1.9	10
0.94	D	10	10	100	----	81	36	2.3	10

[a] Data from Tables 4 and 5 in Blakemore and Burgess (1990 [MRID 41718401]).

Dose-response modeling was carried out in SAS Software® (SAS Version 9.3, SAS/STAT 12.1). For survival, based on the plotted data (Figure G-67), normal (probit), logistic and Gompertz/extreme value models were fit to the data with a log (base 10) transformation on the independent variable (concentration). These three models are the models available for binomial dose-response modeling in the PROC PROBIT procedure in SAS/STAT 12.1. Model fit was assessed by visual inspection, and by reported goodness-of-fit statistics (Pearson Chi-Square and likelihood ratio Chi-square). The goodness-of-fit results are summarized in Table G-79 below.

Table G-79 Summary of goodness-of-fit statistics for models fit to water flea (*Daphnia magna*) mortality data from Blakemore and Burgess (1990 [MRID 41718401])

Model	*Pearson Chi-Square*	*p-value*	*Likelihood Ratio Chi-Square*	*p-value*
Probit	1286	<0.0001	29.3	0.0443
Logistic	412	<0.0001	21.5	0.255
Gompertz/extreme value	**81.3**	**<0.0001**	**13.8**	**0.742**

Bolded font indicates better fitting model by goodness-of-fit statistics

The log Gompertz/extreme value model fit the data the best by visual inspection and goodness-of-fit statistics. Accordingly, this model was selected to represent the chronic mortality dose-response for water flea (*Daphnia magna*) instars exposed to malathion. Model parameters are intercept = 1.7936, slope = 8.4484, or expressed as a tolerance distribution: μ =-0.2123038, and σ = 0.11836515, with the following equation.

$$p = 1 - e^{-e^{\frac{(x-\mu)}{\sigma}}}$$ **Equation G-2**

Where,

p is the probability of mortality; and
x is the $\log_{10}$ (concentration), where concentration is in μg a.i./L.

The estimated EC10 from this model is 0.332 μg a.i./L.

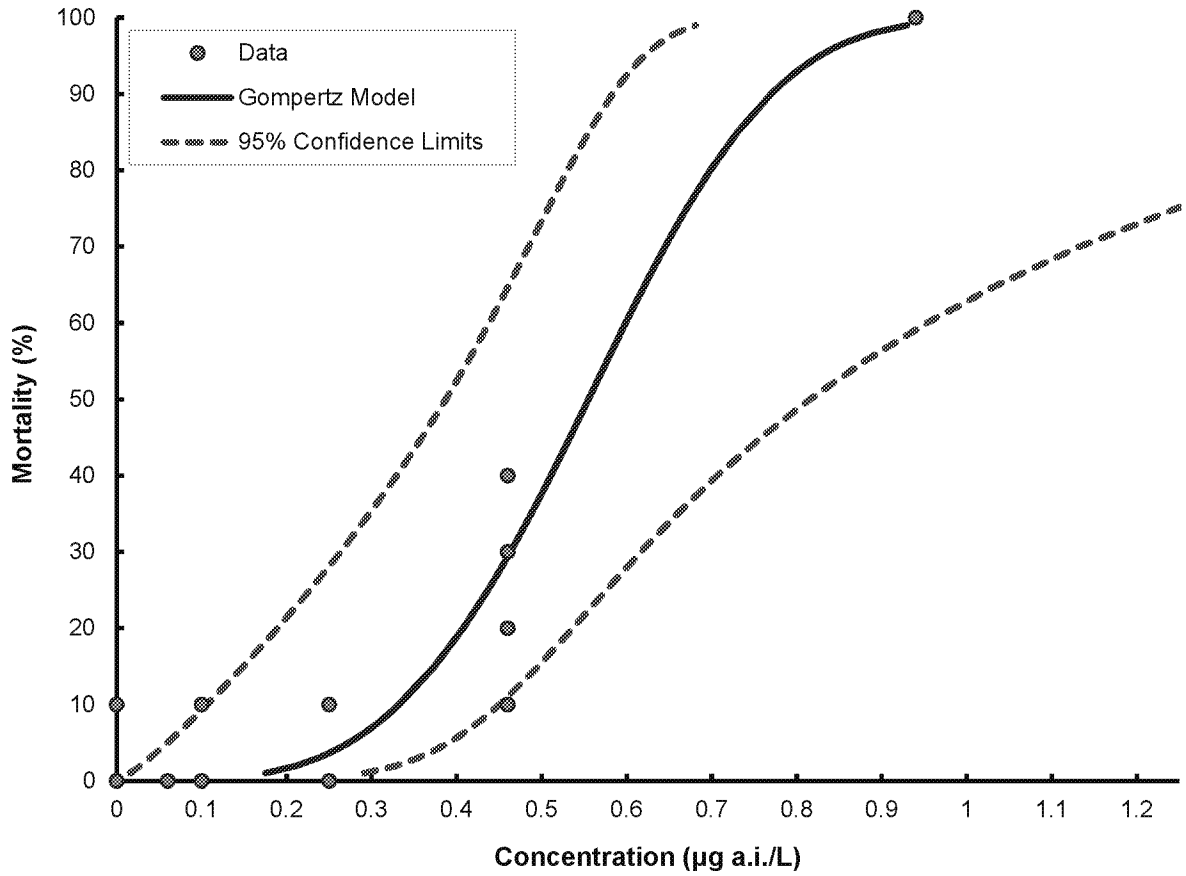

Figure G-67 **Model fit to water flea (*Daphnia magna*) mortality data from Blakemore and Burgess (1990 [MRID 41718401])**

For effects to reproduction, we considered the total number of young to be the most ecologically relevant, and also overall the more sensitive measure of reproductive effects. Given the count response variable, we fit a generalized linear models assuming a Poisson response with a log link function, following Bailer and Oris (1997). The PROC GENMOD procedure was used in SAS/STAT 12.1. To account for over-dispersion of the response variable, the variance was scaled with a dispersion parameter of the Pearson Chi-Square statistic divided by its degrees of freedom. Both a simple model and a polynomial were fit to the data, given some apparent curvature in the response variable (Figure G-68). Based on visual inspection and goodness-of-fit statistics (Table G-80), the polynomial model was selected as best-fitting. A summary of the selected model results is presented in Table G-81. The selected model fit to the data is presented in Figure G-68. The EC10 from this model is 0.0881 µg a.i./L.

Table G-80 Summary of goodness-of-fit statistics for models fit to water flea (*Daphnia magna*) total offspring data from Blakemore and Burgess (1990 [MRID 41718401])

Generalized Linear Model	*AIC*	*AICC*	*BIC*
Linear (y=a+bx)	841.3	841.9	843.7
Polynomial ($y=a+b_1x+b_2x^2$)	326.6	327.8	330.1

AIC = Akaike information criterion, AICC = Akaike information criterion corrected, Bayesian information criterion
Bolded font indicates better fitting model by goodness-of-fit statistics

Table G-81 Summary of maximum likelihood parameters for selected model fit to water flea (*Daphnia magna*) total offspring data from Blakemore and Burgess (1990 [MRID 41718401])

Parameter	*Degrees of Freedom*	*Estimate*	*Standard Error*	*Wald 95% Confidence Limits*		*Wald Chi-Square*	*p-value*
Intercept	1	7.495	0.0212	7.4534	7.5365	125222	<.0001
b_1	1	-0.9581	0.1989	-1.348	-0.5682	23.19	<.0001
b_2	1	-2.6944	0.3031	-3.2885	-2.1004	79.03	<.0001
Scale (Pearson Chi-Square estimated)	0	2.338	0	2.338	2.338		

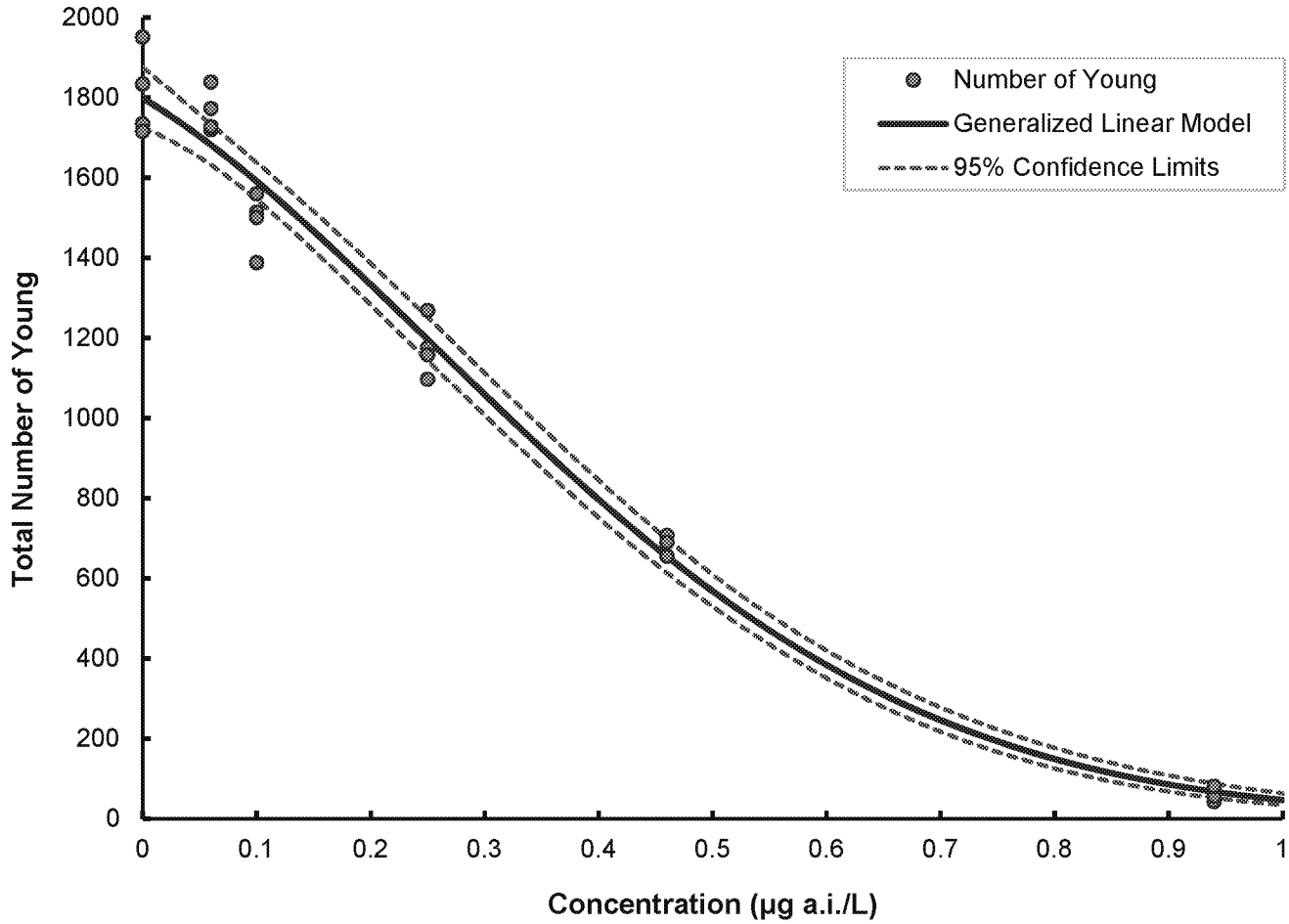

Figure G-68 Model fit to water flea (*Daphnia magna*) total offspring data from Blakemore and Burgess (1990 [MRID 41718401])

Of the two measures of effects analyzed from the Blakemore and Burgess (1990 [MRID 41718401]) chronic toxicity test with water flea (*Daphnia magna*), the reproductive measure of total young produced the lower EC10 of 0.0881 µg a.i./L. Thus, this metric was used to derive an acute-to-chronic ratio (ACR) for *Daphnia magna*.

Claude et al. (2012 [MRID 48752901]) investigated the toxicity of malathion to mysid (*Americamysis bahia)* exposed in water for 39 days. The study was evaluated by Breton et al. (2014 [MRID 49333901]) and rated acceptable. Based on the results of the study, mysids were most sensitive to effects on reproduction. Table G-82 contains key reproductive data extracted from Claude et al. (2012 [MRID 48752901]). A dose-response was modeled for the average number of young produced per replicate, with this measure being the most ecologically relevant, as well as the most sensitive of measure of effects to reproduction in the mysid.

Table G-82 Effects of malathion on *Americamysis bahia* exposed for 39 days in water[a]						
Nominal Test Concentration (µg a.i./L)	*Mean Measured Test Concentration (µg a.i./L)*	*Replicate*	*Test Compartment[b]*	*Day of First Brood Release Per Compartment[c]*	*Number of Young Produced*	*Number of Reproductive Days[d]*
0	<LOQ	A	1	31	7	24
0	<LOQ	A	2	24	12	24
0	<LOQ	A	3	38	10	24
0	<LOQ	A	4	34	11	24
0	<LOQ	A	5	33	13	24
0	<LOQ	B	1	NA	0	3
0	<LOQ	B	2	31	21	24
0	<LOQ	B	3	22	3	24
0	<LOQ	B	4	NA	0	16
0	<LOQ	B	5	NA	0	7
0	<LOQ	C	1	NA	0	8
0	<LOQ	C	2	26	3	24
0	<LOQ	C	3	26	21	24
0	<LOQ	C	4	24	10	24
0	<LOQ	C	5	NA[e]	NA[e]	NA[e]
0	<LOQ	D	1	26	3	24
0	<LOQ	D	2	31	7	24
0	<LOQ	D	3	26	2	24
0	<LOQ	D	4	32	1	24
0	<LOQ	D	5	38	13	24
0.094	0.066	A	1	NA	0	24
0.094	0.066	A	2	35	11	24
0.094	0.066	A	3	25	16	24
0.094	0.066	A	4	35	10	24
0.094	0.066	A	5	NA	0	24
0.094	0.066	B	1	25	9	24
0.094	0.066	B	2	24	9	24
0.094	0.066	B	3	31	11	24
0.094	0.066	B	4	26	2	24
0.094	0.066	B	5	NA	0	24
0.094	0.066	C	1	24	1	24
0.094	0.066	C	2	31	2	24
0.094	0.066	C	3	28	12	24
0.094	0.066	C	4	24	16	24
0.094	0.066	C	5	24	2	24
0.094	0.066	D	1	NA	0	24
0.094	0.066	D	2	39	6	24
0.094	0.066	D	3	38	10	24

Table G-82 Effects of malathion on *Americamysis bahia* exposed for 39 days in water[a]						
Nominal Test Concentration (µg a.i./L)	*Mean Measured Test Concentration (µg a.i./L)*	*Replicate*	*Test Compartment[b]*	*Day of First Brood Release Per Compartment[c]*	*Number of Young Produced*	*Number of Reproductive Days[d]*
0.094	0.066	D	4	NA	0	24
0.094	0.066	D	5	31	4	24
0.19	0.14	A	1	NA	0	24
0.19	0.14	A	2	27	18	24
0.19	0.14	A	3	38	8	24
0.19	0.14	A	4	26	19	24
0.19	0.14	A	5	NA[e]	NA[e]	NA[e]
0.19	0.14	B	1	29	4	20
0.19	0.14	B	2	NA	0	19
0.19	0.14	B	3	32	4	16
0.19	0.14	B	4	25	12	24
0.19	0.14	B	5	NA[e]	NA[e]	NA[e]
0.19	0.14	C	1	16	2	3
0.19	0.14	C	2	39	6	24
0.19	0.14	C	3	39	8	24
0.19	0.14	C	4	31	8	24
0.19	0.14	C	5	25	1	24
0.19	0.14	D	1	37	1	24
0.19	0.14	D	2	31	9	24
0.19	0.14	D	3	26	21	24
0.19	0.14	D	4	25	4	24
0.19	0.14	D	5	NA[e]	NA[e]	NA[e]
0.38	0.29	A	1	25	15	24
0.38	0.29	A	2	39	10	24
0.38	0.29	A	3	39	3	24
0.38	0.29	A	4	NA	0	24
0.38	0.29	A	5	38	1	24
0.38	0.29	B	1	NA	0	16
0.38	0.29	B	2	NA	0	0
0.38	0.29	B	3	39	3	24
0.38	0.29	B	4	33	1	24
0.38	0.29	B	5	39	3	24
0.38	0.29	C	1	25	8	20
0.38	0.29	C	2	39	4	24
0.38	0.29	C	3	30	5	24
0.38	0.29	C	4	39	6	24
0.38	0.29	C	5	30	7	24
0.38	0.29	D	1	26	9	24

Table G-82 Effects of malathion on *Americamysis bahia* exposed for 39 days in water[a]						
Nominal Test Concentration (µg a.i./L)	*Mean Measured Test Concentration (µg a.i./L)*	*Replicate*	*Test Compartment[b]*	*Day of First Brood Release Per Compartment[c]*	*Number of Young Produced*	*Number of Reproductive Days[d]*
0.38	0.29	D	2	39	8	24
0.38	0.29	D	3	39	6	24
0.38	0.29	D	4	35	18	24
0.38	0.29	D	5	NA	0	24
0.75	0.58	A	1	NA	0	24
0.75	0.58	A	2	39	9	24
0.75	0.58	A	3	22	4	24
0.75	0.58	A	4	NA	0	0
0.75	0.58	A	5	NA	0	0
0.75	0.58	B	1	28	8	24
0.75	0.58	B	2	NA	0	4
0.75	0.58	B	3	28	19	24
0.75	0.58	B	4	39	2	24
0.75	0.58	B	5	35	6	24
0.75	0.58	C	1	NA	0	24
0.75	0.58	C	2	32	4	20
0.75	0.58	C	3	NA	0	24
0.75	0.58	C	4	NA	0	24
0.75	0.58	C	5	NA	0	9
0.75	0.58	D	1	NA	0	24
0.75	0.58	D	2	NA	0	7
0.75	0.58	D	3	26	2	24
0.75	0.58	D	4	NA	0	24
0.75	0.58	D	5	NA[e]	NA[e]	NA[e]
1.5	1.2	A	1	NA	0	22
1.5	1.2	A	2	NA	0	7
1.5	1.2	A	3	NA	0	14
1.5	1.2	A	4	NA	0	24
1.5	1.2	A	5	NA[e]	NA[e]	NA[e]
1.5	1.2	B	1	NA	0	24
1.5	1.2	B	2	NA	0	24
1.5	1.2	B	3	NA	0	15
1.5	1.2	B	4	NA	0	9
1.5	1.2	B	5	25	3	24
1.5	1.2	C	1	NA	0	14
1.5	1.2	C	2	NA	0	6
1.5	1.2	C	3	NA	0	11
1.5	1.2	C	4	NA	0	24

Table G-82 Effects of malathion on *Americamysis bahia* exposed for 39 days in water[a]

Nominal Test Concentration (µg a.i./L)	*Mean Measured Test Concentration (µg a.i./L)*	*Replicate*	*Test Compartment[b]*	*Day of First Brood Release Per Compartment[c]*	*Number of Young Produced*	*Number of Reproductive Days[d]*
1.5	1.2	C	5	NA	0	9
1.5	1.2	D	1	NA	0	24
1.5	1.2	D	2	NA	0	24
1.5	1.2	D	3	NA	0	24
1.5	1.2	D	4	33	1	24
1.5	1.2	D	5	NA[e]	NA[e]	NA[e]

[a] Data extracted from Claude et al. (2012 [MRID 48752901]).
[b] Each compartment contained 1 male/female pair, with a maximum of five pairs per replicate test chamber.
[c] NA = The female in the compartment never released a brood.
[d] The number of reproductive days is the number of days that the female was alive from first brood release in the test (Day 16) to the end of the test.
[e] Insufficient number of mature males and/or females to establish a reproductive pair for this test compartment.

For the continuous response of average number of young produced per replicate we fit a reverse normal cumulative distribution function, following Bruce and Versteeg (1992; Equation G-3). This method was selected because it can accommodate responses of zero, while still accounting for declining variability in response with increasing concentration, which is visible in the plotted data. The PROC NLIN procedure in SAS/STAT 12.1 was used. See the model fit to the data in Figure G-69 below. The model results are presented in Table G-83.

$$R = \begin{cases} R_0 \cdot \Phi\left[\left(log(EC_x) - log(C)\right)/\sigma + Z_x\right] & C > 0 \\ R_0 & C = 0 \end{cases}$$ **Equation G-3**

Where,

R t	the predicted biotic response at concentration *C;*
R_0	the predicted biotic response for controls;
Φ[ ]	the cumulative area under the standard, normal distribution;
log (EC_x)	the logarithm of the predicted EC given an *x* percentage of decrease in the biological parameter versus control;
Z_x	the normal deviate above which *x* percentage of the area of the standard normal distribution lies. For EC10 this value is 1.2816; and
Σ	the standard deviation of the normal distribution.

Table G-83 Model results for average young versus malathion concentration for *Americamysis bahia* exposed for 39 days in water[a]

Parameter	*Estimate*	*Approximate Standard Error*	*Approximate 95% Confidence Limits*	
LOG_EC10	-0.5752	0.1609	-0.9098	-0.2406
SIGMA	0.2163	0.0735	0.0634	0.3692
C0	6.737	0.813	5.0463	8.4277

[a] Data extracted from Claude et al. (2012 [MRID 48752901]).

Based on the results in Table G-83, the estimated EC10 for average young of *Americamysis bahia* exposed in water for 39 days is 0.266 µg a.i./L.

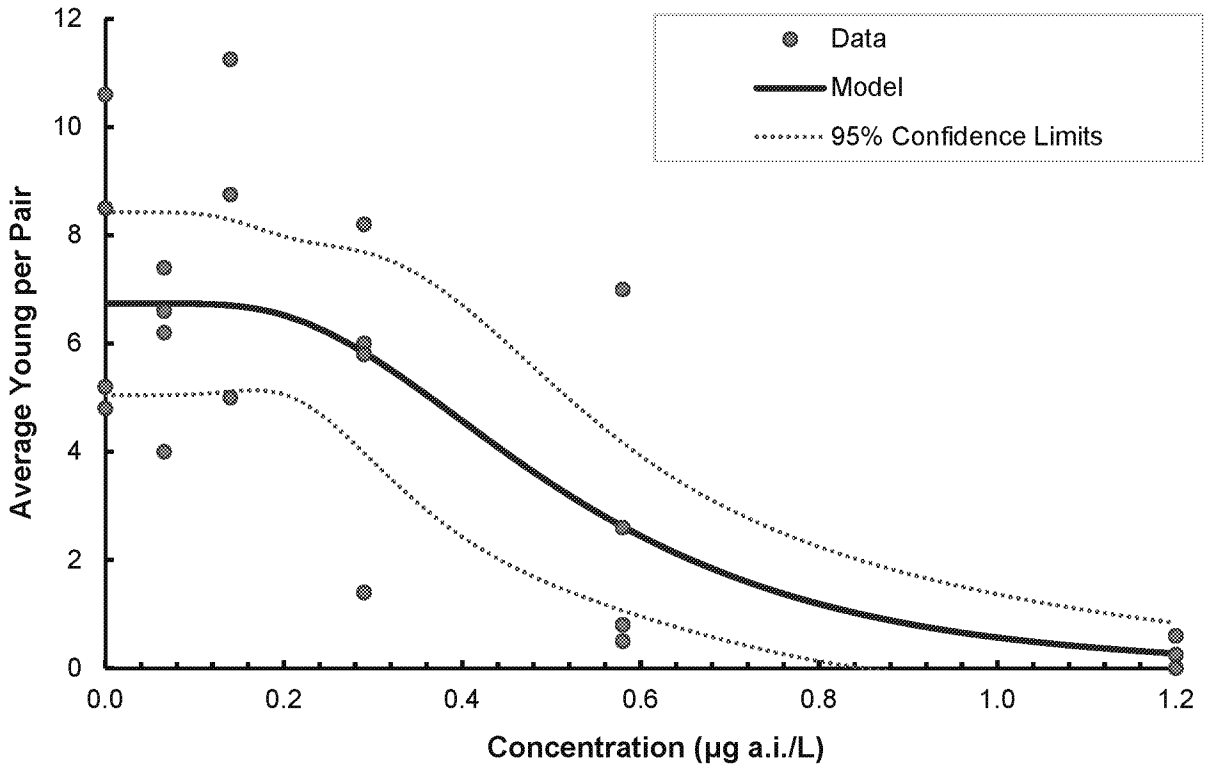

Figure G-69 **Model fit to mysid (*Americamysis bahia*) average young per pair data from Claude et al. (2012 [MRID 48752901]).**

Based on the estimated EC10s derived above, the calculated ACRs were 7.95 and 29.3 for the water flea and mysid, respectively (see Table G-84).

Table G-84 Derivation of aquatic invertebrate ACRs for malathion with acceptable and supplemental toxicity data.								
Common Name	***Scientific Name***	***LC50 (µg a.i./L)***	***Chronic Study Type***	***Chronic Measure of Effects***	***Chronic EC10 (µg a.i./L)***	***ACR (LC50/EC10)***	***Acute Reference (Cheminova Study Rating)***	***Chronic Reference (Cheminova Study Rating)***
Water flea	Daphnia magna	0.7	Life-cycle test (21 days)	Reproduction (total young)	0.0881	7.95	Gries and Purghart, 2001b [MRID 47540303] (Acceptable)	Blakemore and Burgess, 1990 [MRID 41718401] (Supplemental)
Mysid	Americamysis bahia	7.8	Life-cycle test (39 days)	Reproduction (number of young produced)	0.266	29.3	Brougher et al., 2014 [MRID 49389401] (Acceptable)	Claude et al., 2012 [MRID 48752901] (Acceptable)

Using the approach for ACR calculation described in EPA's guidelines for deriving water quality criteria (Stephan et al., 1985), the geometric mean of the water flea and mysid ACRs was calculated to be 15.3. The acute SSD was divided by this ACR of 15.3 to derive the corresponding chronic SSD (Figure G-70).

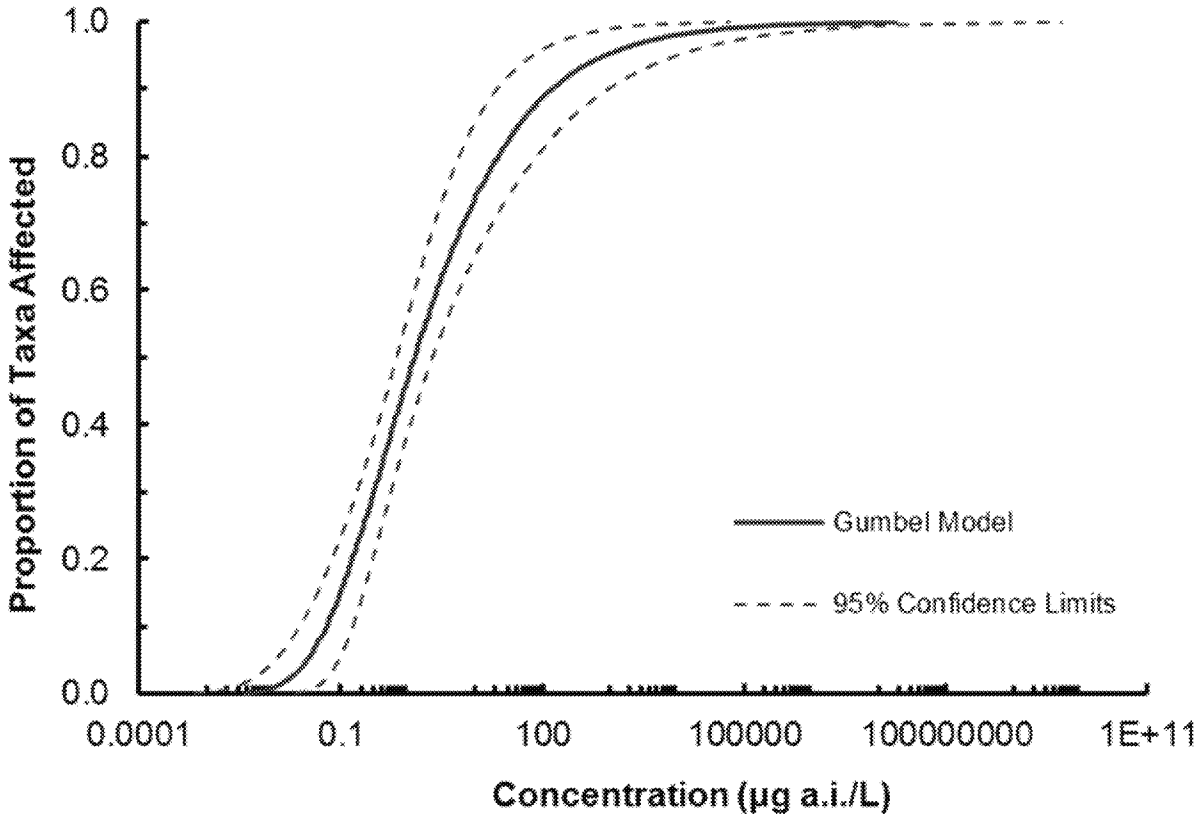

Figure G-70 **Chronic SSD with approximate 95% confidence limits for aquatic invertebrate species exposed to malathion.**

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Appendix H
Relative Toxicity of Malathion

ED_002284_00026674-00426

In light of the Conventional Reduced Risk Pesticide Comparison Program, this appendix summarizes the relative toxicity of malathion to other organophosphates and to some other common pesticide classes (e.g., pyrethroids, carbamates). The Conventional Reduced Risk Pesticide Comparison Program was developed by EPA to expedite review and registration of conventional pesticides that have been proven to pose lower risk than existing registered pesticides (EPA, 2015). The Program supports the registration of lower risk pesticides as alternatives to conventional pesticides to reduce potential human and environmental impacts. Pesticides classified as reduced risk have low impact on human health, lower toxicity to non-target organisms, low potential for groundwater contamination, low use rates, and low pest resistance potential. The purpose of this appendix is to compare the toxicities of a selection of organophosphate pesticides to non-target organisms, highlighting the lower toxicity of malathion compared to other widely used active ingredients.

Organophosphate Comparison

Toxicity data for 20 organophosphate pesticides were extracted from EPA registration review documents (EPA, 1995, 2004a, 2005a,b, 2007, 2008a-j, 2009a-i) to compare the relative toxicities of organophosphate pesticides using a series of surrogate species. Data were drawn from reregistration documents and endangered species assessments prepared and released by the EPA.

Using EPA's standard toxicity study guidelines, the review of data focused on surrogate species that EPA has highlighted as being representative of similar species in the same taxon. For example, to fulfill requirement 40 CFR Part 158 for data supporting reregistration of a pesticide, a pesticide must have acute avian toxicity data for both a passerine species and an upland game bird or waterfowl (CFR, 2015). Guideline OCSPP 850.2100 for acute oral toxicity testing in birds is a requirement of 40 CFR Part 158 and the guideline recommends using the northern bobwhite (*Colinus virginianus*) as a representative upland game bird, the mallard duck (*Anas platyrhynchos*) for waterfowl, and the house sparrow (*Passer domesticus*), zebra finch (*Taeniopygia guttata*) or red-wing blackbird (*Agelaius phoeniceus*) as a representative passerine species (EPA, 2012a). The ring-necked pheasant (*Phasianus colchicus*) was listed as an alternative upland game bird species. For fish, data to fulfill 40 CFR Part 158 are required for one coldwater and one warmwater freshwater fish species, as well as an estuarine or marine species (CFR, 2015). Guideline 850.1075 recommends using the rainbow trout (*Oncorhynchus mykiss*) and bluegill sunfish (*Lepomis macrochirus*) as the cold- and warmwater fishes, respectively, and the Atlantic silverside (*Menidia menidia*) or sheepshead minnow (*Cyprinodon variegatus*) as the saltwater species (EPA, 1996a). Similarly for chronic exposure of fish, guideline 850.1400 recommends the rainbow trout (*O. mykiss*), fathead minnow (*Pimephales promelas*), and sheepshead minnow (*C. variegatus*) (EPA, 1996b).

The extracted data are shown in Tables H-1 to H-9. Data were organized by taxon, with focus on surrogate species recommended in OCSPP Guidelines and 40 CFR Part 158. Looking at the data, it is quite clear that toxicities range by orders of magnitude for different organophosphates.

Overall, aquatic and terrestrial biota were often most sensitive to phorate, fenitrothion and dicrotophos, and least sensitive to malathion and trichlorfon.

Birds

For mallard ducks (*A. platyrhynchos*) (Table H-1), the LD50s range from 0.62 mg/kg bw for phorate (Hudson et al., 1984 [MRID 00160000]) to 2550 mg/kg bw for fenitrothion (Fletcher, 1971a [MRID 00126886]). With an LD50 of >2250 mg a.i./kg bw (Hubbard and Beavers, 2012a [MRID 48963307]), malathion is almost four orders of magnitude less toxic to mallards than phorate and within the same order of magnitude of toxicity as fenitrothion. For ring-necked pheasants (*P. colchicus*), malathion is the least toxic of the organophosphates with available toxicity data on an acute oral basis (LD50 = 136 mg/kg bw, Hubbard and Beavers, 2012b [MRID 48963305]; Table H-1) and second least toxic on an acute dietary (LC50 = 2514 mg a.i./kg diet, Hubbard et al., 2012c [MRID 48963301]; Table H-2) basis. Malathion is also of lower chronic toxicity compared to almost all organophosphates tested (Table H-3). Malathion is four orders of magnitude less toxic to mallards (NOEC = 1200 mg/kg diet, Pedersen and Fletcher, 1993 [MRID 42782101]) and northern bobwhite (*C. virginianus*) (NOEC = 110 mg/kg diet (Beavers et al., 1995 [MRID 43501501])) than dicrotophos, the most chronically toxic organophosphate studied (NOECs 0.5-1 mg/kg diet; Cameron, 1996a,b [MRID 44005501, 44005502]).

Mammals

Malathion is the least toxic of all organophosphates evaluated for rats (*Rattus norvegicus*) (Table H-4). LD50s range from 1.4 mg/kg bw for phorate (Kiplinger, 1993 [MRID 42857001]) to 2010 mg/kg bw for malathion (Moore, 2003 [MRID 48153112]), and chronic NOECs range from 0.04 mg/kg bw/day for disulfoton (MRID 00157511, as cited in EPA, 2009a) to 394 mg/kg bw/day for malathion (Schroeder, 1990 [MRID 41583401]). Based on LD50 values, malathion is four to five orders of magnitude less toxic to rats than the chemicals with the highest toxicities. In addition, EPA has determined that malathion is the least toxic of all OPs based on its potency to inhibit brain cholinesterase activity (see Figure H-1 below).

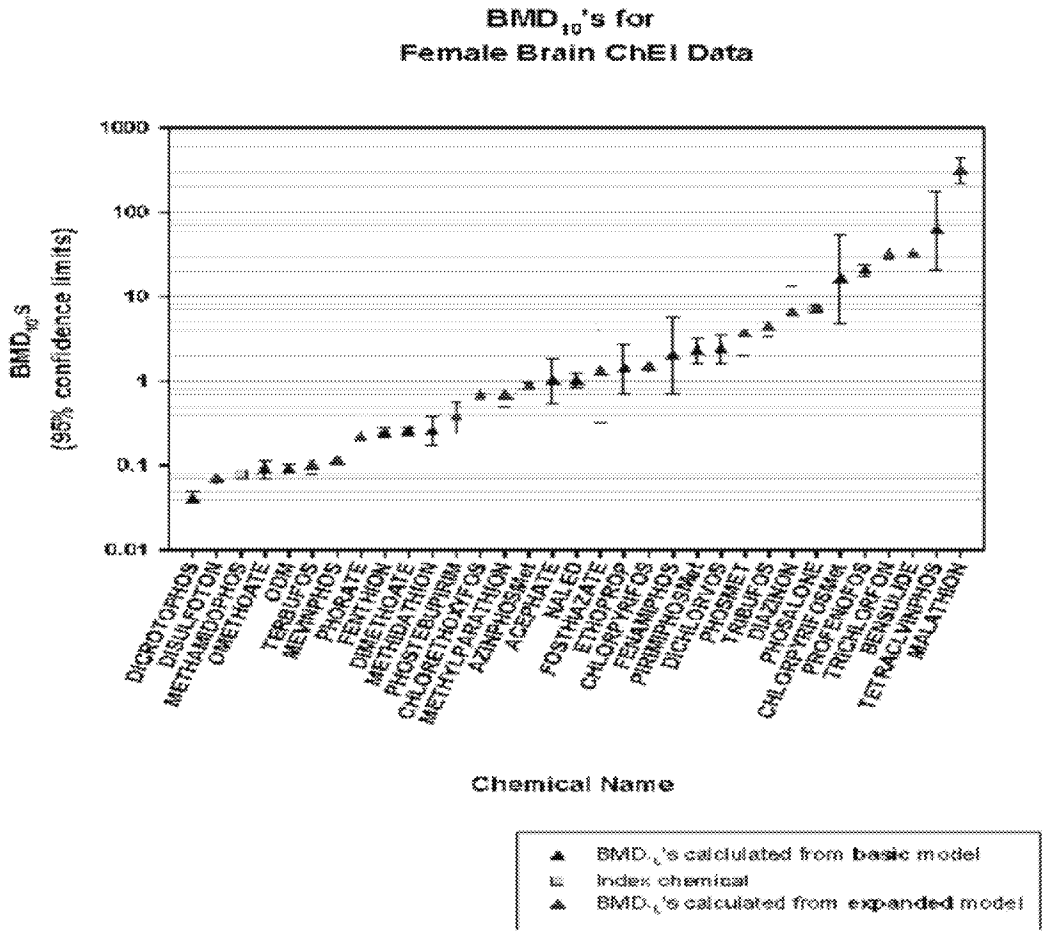

Figure H-1 Plot of BMD10s and the 95% confidence limits for female rat brain ChE inhibition for the OPs (EPA, 2006)

Terrestrial Invertebrates

For honey bees (*Apis mellifera*), LD50s for contact exposure range from 0.02 µg/bee for fenitrothion (Stevenson, 1978 [MRID 05001991]) to 59.83 µg/bee for trichlorfon (Atkins et al., 1975 [MRID 00036935]) (Table H-5). With a contact LD50 of 0.189 µg a.i./bee (Sindermann and Porch, 2013a [MRID 49270301]), malathion is one order of magnitude less toxic than fenitrothion. For oral toxicities, LD50s range from 0.11 µg/bee for methyl parathion (MRID 44038201) to 1.66 µg/bee for malathion (Sindermann and Porch, 2013b [MRID 49270302]). Again, malathion is at least an order of magnitude less toxic to honey bees than the most toxic chemical on an acute oral basis.

Fish

For bluegill (*L. macrochirus*), LC50s range from 1.8 µg/L for chlorpyrifos (Mayer and Ellersieck, 1986 [MRID 40098001]) to 24,200 µg/L for dicrotophos (Mayer and Ellersieck, 1986 [MRID 40098001]) (Table H-6). With an LC50 of 54 µg/L (Gries and Purghart, 2001a [MRID 47540304]), malathion is an order of magnitude less toxic than chlorpyrifos on an acute basis. For chronic exposure (Table H-7), NOECs for rainbow trout (*O. mykiss*) range from 0.44 µg/L for azinphos methyl (MRID 40579601) to 110 µg/L for trichlorfon (Gagliano, 1992 [MRID 42571701]). With a NOEC of 21 µg/L (Cohle, 1989 [MRID 41422401]), malathion is two orders of magnitude less toxic to rainbow trout than azinphos-methyl for chronic exposure.

Aquatic Invertebrates

For aquatic invertebrates, acute EC50s for daphnids (*Daphnia sp.*) range from 0.066 µg/L for naled (Mayer and Ellersieck, 1986 [MRID 40098001]) to 44 µg/L for ethoprop (Vilkas, 1977 [MRID 00068325]) (Table H-8). Malathion has an EC50 of 0.7 µg a.i./L (Gries and Purghart, 2001b [MRID 47540303]), indicating that daphnids are over one order of magnitude less sensitive to malathion than to naled. For chronic exposure (Table H-9), NOECs for daphnids range from 0.0057 µg/L for trichlorfon (MRID 40452601) to 800 µg/L for ethoprop (Putt, 1995 [MRID 43877401]). The NOECs for mysids (*Americamysis bahia*) range from <0.0046 µg/L for chlorpyrifos (Sved et al., 1993 [MRID 42664901]) to 5,300,000 µg/L for phorate (Overman and Wisk, 1995 [MRID 43730501].). Comparatively, the NOECs for malathion are 0.06 µg/L (Blakemore and Burgess, 1990 [MRID 41718401]) and 0.29 µg/L (Claude et al., 2012a [MRID 48752901]) for daphnids and mysids, respectively.

Table H-1 Oral toxicity of organophosphates to birds.

Birds	*Mallard (Anas platyrhynchos)*		*Northern Bobwhite (Colinus virginianus)*		*Ringed-necked Pheasant (Phasianus colchicus)*		*House Sparrow (Passer domesticus)*	
Active Ingredient	*LD50 (mg/kg bw)*	*Reference [MRID]*	*LD50 (mg/kg bw)*	*Reference [MRID]*	*LD50 (mg/kg bw)*	*Reference [MRID]*	*LD50 (mg/kg bw)*	*Reference [MRID]*
Azinphos methyl	136	Hudson et al., 1984 [00160000]	32	[40254801] As cited in EPA, 2005	74.9	Hudson et al., 1984 [00160000]	-	-
Chlorethoxyphos	-	-	28	Grimes and Jaber, 1987 [40883735]. As cited in EPA, 1995.	-	-	197	[41736839] As cited in EPA, 1995.
Chlorpyrifos	75.6	Hudson et al., 1984 [00160000]	32	[41043901] As cited in EPA 2008e.	8.41	Hudson et al., 1984 [00160000]	10	Schafer and Brunton, 1979 [40378401]
Diazinon	1.44	Fletcher and Pedersen, 1988a [40895301]	-	-	-	-	-	-
Dichlorvos	7.78	Hudson et al., 1984 [00160000]	8.8	Grimes and Jaber, 1988 [40818301]	11.3	Hudson et al., 1984 [00160000]	-	-
Dicrotophos	4.24	Hudson et al., 1984 [00160000]	-	-	3.21	Hudson et al., 1984 [00160000]	3	Hudson et al., 1984 [00160000]
Dimethoate	44	Hubbard and Beavers, 2012c [48964901]	10.2	Zok, 2001a [47769701]	14.1	Zok, 2001b [47769702]	-	-
Disulfoton	6.5	Hudson et al., 1984 [00160000]	-	-	-	-	-	-
Ethoprop	12.6	Hudson et al., 1984 [00160000]	-	-	-	-	4.21	Schafer and Brunton, 1979 [40378401]
Fenitrothion	2550	Fletcher, 1971a [00126886]	23	[40233701] As cited in EPA 2009b	34.5	Fletcher, 1971b [00126885]	-	-
Malathion	>2250	Hubbard and Beavers, 2012a [48963307]	345	Rodgers, 2002 [48153114]	136	Hubbard and Beavers, 2012b [48963305]	-	-

Table H-1 Oral toxicity of organophosphates to birds.

Birds	*Mallard (Anas platyrhynchos)*		*Northern Bobwhite (Colinus virginianus)*		*Ringed-necked Pheasant (Phasianus colchicus)*		*House Sparrow (Passer domesticus)*	
Active Ingredient	*LD50 (mg/kg bw)*	*Reference [MRID]*	*LD50 (mg/kg bw)*	*Reference [MRID]*	*LD50 (mg/kg bw)*	*Reference [MRID]*	*LD50 (mg/kg bw)*	*Reference [MRID]*
Methidathion	6.7	[00230346] As cited in EPA, 2008d	-	-	-	-	-	-
Methyl parathion	-	-	6.6	Hudson et al., 1984 [00160000]	-	-	-	-
Naled	36.9	Hudson et al., 1984 [00160000]	-	-	-	-	-	-
Phorate	0.62	Hudson et al., 1984 [00160000]	-	-	-	-	-	-
Phosmet	>2000	Fink, 1976 [00084460]	-	-	-	-	-	-
Tebupirimphos	-	-	20.3	[42005405] As cited in EPA, 2009e	-	-	3.53	Fischer, 1991 [42005415]

Table H-2 Dietary toxicity of organophosphates to birds.								
Birds	***Mallard (Anas platyrhynchos)***		***Northern Bobwhite (Colinus virginianus)***		***Ringed-necked Pheasant (Phasianus colchicus)***		***Japanese Quail (Coturnix japonica)***	
Active Ingredient	***LC50 (mg/kg diet)***	***Reference [MRID]***	***LC50 (mg/kg diet)***	***Reference [MRID]***	***LC50 (mg/kg diet)***	***Reference [MRID]***	***LC50 (mg/kg diet)***	***Reference [MRID]***
Azinphos methyl	1940	Hill et al., 1975a [00022923]	488	Hill et al., 1975a [00022923]	1821	Hill et al., 1975a [00022923]	639	Hill et al., 1975a [00022923]
Chlorethoxyfos	203	Grimes and Jaber, 1987 [40883738]. As cited in EPA, 2005.	181	Long et al., 1990 [41736841]. As cited in EPA, 2005.	-	-	-	-
Chlorpyrifos	136	Stevenson, 1965 [00095007] As sited in EPA 2008e.	423	[00046955] As sited in EPA 2008e.	553	Hill et al., 1975a [00022923]	293	[00115301] As sited in EPA 2008e.
Diazinon	32	Fletcher and Pedersen, 1988b [40895302]	-	-	-	-	-	-
Dichlorvos	1317	Hill et al., 1975a [00022923]	-	-	568	Hill et al., 1975a [00022923]	-	-
Dimethoate	1066	Hubbard et al., 2009 [47744401]	154	Zok, 2001c [47769705]	396	Zok, 2001d [47769706]	-	-
Disulfoton	-	-	544	Lamb and Jones, 1973 [0094233]	-	-	333	Hill et al., 1975b [00034769]
Ethoprop	-	-	33	Hill et al., 1975a [00022923]	-	-	-	-
Fenitrothion	2482	Hill et al., 1975a [00022923]	157	Hill et al., 1975a [00022923]	-	-	-	-
Malathion	>5620	Hubbard et al., 2012a [48963303]	2022	Gallagher et al., 2003 [48153106]	2514	Hubbard et al., 2012b [48963301]	-	-
Methidathion	-	-	224	Beavers, 1979 [42081701]	-	-	-	-

Table H-2 Dietary toxicity of organophosphates to birds.								
Birds	***Mallard (Anas platyrhynchos)***		***Northern Bobwhite (Colinus virginianus)***		***Ringed-necked Pheasant (Phasianus colchicus)***		***Japanese Quail (Coturnix japonica)***	
Active Ingredient	***LC50 (mg/kg diet)***	***Reference [MRID]***	***LC50 (mg/kg diet)***	***Reference [MRID]***	***LC50 (mg/kg diet)***	***Reference [MRID]***	***LC50 (mg/kg diet)***	***Reference [MRID]***
Methyl parathion	-	-	28.2	Pennwalt Corp., 1972 [00102329]	-	-	-	-
Naled	2724	Hill et al., 1975a [00022923] As cited in EPA, 2008h.	2117	Hill et al., 1975a [00022923] As cited in EPA, 2008h.	2538	Hill et al., 1975a [00022923] As cited in EPA, 2008h.	1327	Hill et al., 1975a [00022923]
Oxydemeton methyl	-	-	434	Hill et al., 1975a [00022923]				
Phorate	240	Hill et al., 1975a [00022923]	-	-	-	-	-	-
Phosmet	-	-	501	Hill et al., 1975a [00022923]	-	-	-	-
Tebupirimphos	577	[42005410] As cited in EPA, 2009e.	191	[42005409] As cited in EPA, 2009e.	-	-	-	-

Table H-3 Chronic toxicity of organophosphates to birds.						
Birds	***Mallard (Anas platyrhynchos)***			***Northern Bobwhite (Colinus virginianus)***		
Active Ingredient	***NOEC (mg/kg diet)***	***LOEC (mg/kg diet)***	***Reference [MRID]***	***NOEC (mg/kg diet)***	***LOEC (mg/kg diet)***	***Reference [MRID]***
Azinphos methyl	10.5	32.5	[40844201] As cited in EPA, 2005a.	36.5	87.4	[41056101] As cited in EPA, 2005a.
Chlorethoxyfos	5	25	Beavers et al., 1988 [40883740] As cited in EPA, 1995	25	-	Beavers et al., 1988 [40883739] As cited in EPA, 1995
Chlorpyrifos	25	60	Fink and Beavers, 1978 [00046952] As cited in EPA, 2008e.	25	>125	[00046951] As cited in EPA, 2008e.
Diazinon	8.3	16.33	[41322901] As cited in EPA, 2004a.	-	-	-
Dichlorvos	5	15	Redgrave, 1997 [44233401]	30	100	Cameron, 1996a [43981701]
Dicrotophos	1	3	Cameron, 1996b [44005501]	0.5	1.5	Cameron, 1996c [44005502]
Dimethoate	35.4	152	Gallagher et al., 1996a [43967101]	10.1	35.4	Gallagher et al., 1996b [44049001]
Disulfoton	37	80	[43032502] As sited in EPA, 2009a.	37	74	[43032501] As cited in EPA, 2008j.
Ethoprop	-	40	Taliaferro and Miller, 1997 [44312702]	-	7.5	[44312701] As cited in EPA, 2008g.
Fenitrothion	-	-	-	13	17	[41958401] As cited in EPA, 2009b.
Malathion	1200	2400	Pedersen and Fletcher, 1993 [42782101].	110	350	Beavers et al., 1995 [43501501]
Methidathion	1	10	[44381602] As cited in EPA, 2008d.	-	-	-
Methyl parathion	-	-	-	6.3	15.5	[41179302] As cited in EPA, 2009f.

Table H-3 Chronic toxicity of organophosphates to birds.						
Birds	***Mallard (Anas platyrhynchos)***			***Northern Bobwhite (Colinus virginianus)***		
Active Ingredient	***NOEC (mg/kg diet)***	***LOEC (mg/kg diet)***	***Reference [MRID]***	***NOEC (mg/kg diet)***	***LOEC (mg/kg diet)***	***Reference [MRID]***
Naled	266	-	[44517902] As cited in EPA, 2009c.	<130	130	[44517901] As cited in EPA, 2008h.
Oxydemeton methyl	-	-	-	1.8	-	[40747202] As cited in EPA, 2008c.
Phorate	5	-	Beavers, 1979 [00029691] As cited in EPA, 2009d.	-	-	-
Phosmet	60	150	Fletcher et al., 1982a,b [00105999, 00125786]	60	-	[001059-99] As cited in EPA, 2008i.
Tebupirimphos	9	19	[42784501] As cited in EPA, 2009e.	8.5	26	[42005413] As cited in EPA, 2009e.
Trichlorfon	-	-	-	9	30	Pedersen and Thompson, 1994 [43119501]

Table H-4 Acute and chronic toxicities of organophosphates to mammals.							
Active Ingredient	*Rat (Rattus norvegicus)*						
	Acute Toxicity		*Chronic Toxicity*				
	LD50 (mg/kg bw)	*Reference [MRID]*	*NOEC (mg/kg diet)*	*LOEC (mg/kg diet)*	*NOEL (mg/kg bw/d)*	*LOEL (mg/kg bw/d)*	*Reference [MRID]*
Azinphos methyl	7.8	[40280101] As cited in EPA, 2005a.	5	15	-	-	[40332601] As cited in EPA, 2005a.
Chlorethoxyphos	1.8	[40883711] As cited in EPA, 1995.	0.1	-	-	-	[00008330] As cited in EPA, 1995.
Chlorpyrifos	118	ECOTOX 37866 As cited in EPA, 2008e.	20	100	1	-	[41730301] As cited in EPA, 2008e.
Coumaphos	17	[00110597] As cited in EPA, 2008a.	25	-	-	-	[43061701] As cited in EPA, 2008a.
Diazinon	1250	EPA, 2004a	-	-	0.67	6.69	Giknis, 1989 [41158101]
Dichlorvos	56	Gaines, 1960 [00005467]	20	-	-	-	Tyl et al., 1992 [42483901]
Dicrotophos	9	[00261098] As cited in EPA, 2008c.	0.5	1	-	-	[00263684] As cited in EPA, 2008c.
Dimethoate	358	Kynoch, 1986 [00164200]	14	63	1.2	5.5	Brooker et al., 1992 [42251501]
Disulfoton	1.9	[00072293] As cited in EPA, 2009a	0.04	1.2	-	-	[00157511] As cited in EPA, 2009a
Ethoprop	32.8	[00078035] As cited in EPA, 2008g.	30	150	-	-	[41921201] As cited in EPA, 2008g.
Fenitrothion	330	[00232483] As cited in EPA, 2009b.	20	120	2.74	8.4	[41689001, 42668801] EPA, 2009b
Malathion	2010	Moore, 2003 [48153112]	5000	7500	394	612	Schroeder, 1990 [41583401]
Methidathion	12	[00012714] As cited in EPA, 2008d.	5	25	-	-	[40079812, 40079813] As cited in EPA, 2008d.

Table H-4 Acute and chronic toxicities of organophosphates to mammals.

Active Ingredient	*Rat (Rattus norvegicus)*						
	Acute Toxicity		*Chronic Toxicity*				
	LD50 (mg/kg bw)	*Reference [MRID]*	*NOEC (mg/kg diet)*	*LOEC (mg/kg diet)*	*NOEL (mg/kg bw/d)*	*LOEL (mg/kg bw/d)*	*Reference [MRID]*
Methyl parathion	4.5	EPA, 2009f	-	-	0.44	2.3	[00119087] As cited in EPA, 2009f.
Naled	92	[00142660] As cited in EPA, 2009c.	-	-	6	-	[00146498] As cited in EPA, 2009c.
Oxydemeton methyl	48	[40779801] As cited in EPA, 2008b.	-	-	0.05	-	[00155396, 00260513, 00256926] As cited in EPA, 2008b.
Phorate	1.4	Kiplinger, 1993 [42857001]	2	-	0.2	-	Schroeder, 1991 [44422302] As cited in EPA, 2009d
Phosmet	113	[00461-89] As cited in EPA, 2008i.	-	-	1.5	6.1	[41520001] As cited in EPA, 2009g
Tebupirimphos	1.8	[42005436] As cited in EPA, 2009e.	5	-	-	-	[42005456] As cited in EPA, 2009e
Trichlorfon	136	[00256446] As cited in EPA, 2009h.	500	1750	-	-	Eigenberg, 1991 [42228301]

Table H-5 Acute contact and oral toxicity of organophosphates to honey bees.				
Active Ingredient	***Honey bee (Apis mellifera)***			
	Contact LD50 (µg a.i./bee)	***Reference [MRID]***	***Oral LC50 (µg a.i./bee)***	***Reference [MRID]***
Azinphos methyl	0.063	[05004151] As cited in EPA, 2005a.	0.15	[05004151] As cited in EPA, 2005a
Chlorethoxyphos	0.09	[40883749] As cited in EPA, 1995.	-	-
Chlorpyrifos	0.059	Stevenson, 1978 [05001991]	-	-
Diazinon	0.22	[05004151] As cited in EPA, 2004a	-	-
Dichlorvos	0.495	Atkins et al., 1975 [00036935]	-	-
Dicrotophos	0.076	Stevenson, 1978 [05001991]	-	-
Dimethoate	0.14	Zenker, 2011 [49178402]	0.111	Zenker, 2011 [49178402]
Disulfoton	4.1	[05004151] As cited in EPA, 2009a	-	-
Ethoprop	2.58	EPA, 2008g	-	-
Fenitrothion	0.02	Stevenson, 1978 [05001991]	0.38	Atkins et al., 1975 [00036935]
Malathion	0.189	Sindermann and Porch, 2013a [49270301]	1.66	Sindermann and Porch, 2013b [49270302]
Methidathion	0.236	Atkins et al., 1975 [00036935]	-	-
Methyl parathion	0.28	Ecotox E91623 As cited in EPA, 2009f	0.11	[44038201] As cited in EPA, 2009f
Naled	0.48	Atkins et al., 1975 [00036935]	-	-
Oxydemeton methyl	0.54	Stevenson, 1978 [05001991]	0.31	Stevenson, 1978 [05001991]
Phorate	0.32	Stevenson, 1978 [05001991]	-	-
Phosmet	1.1	[00066220] As cited in EPA, 2009g	-	-
Trichlorfon	59.83	Atkins et al., 1975 [00036935]	-	-

Table H-6 Acute toxicity of organophosphates to fish.

Active Ingredient	*Rainbow Trout (Oncorhynchus mykiss)*		*Bluegill (Lepomis macrochirus)*		*Sheepshead Minnow (Cyprinodon variegates)*	
	LC50 (µg/L)	*Reference [MRID]*	*LC50 (µg/L)*	*Reference [MRID]*	*LC50 (µg/L)*	*Reference [MRID]*
Azinphos methyl	2.9	Mayer and Ellersieck, 1986 [40098001]	4.1	Mayer and Ellersieck, 1986 [40098001]	2	Morton et al., 1997
Chlorethoxyphos	89	Hutton, 1990 [41334101] As cited in EPA, 1995	2.3	Hutton, 1990 [41334102] As cited in EPA, 1995	1.8	Graves and Swigert, 1992 [42559223] As cited in EPA, 1995
Chlorpyrifos	-	-	1.8	Mayer and Ellersieck, 1986 [40098001]	-	-
Coumaphos	-	-	-	-	280	Mayer, 1986 [40228401]
Diazinon	90	Johnson and Finley, 1980 [40094602]	-	-	-	-
Dichlorvos	500	Mayer and Ellersieck, 1986 [40098001]	869	Jones, 1994 [43284701]	7350	Jones and Davis, 1994a [43571403]
Dicrotophos	6300	Mayer and Ellersieck, 1986 [40098001]	24,200	Mayer and Ellersieck, 1986 [40098001]	83,800	Jones et al., 1995 [43603306] As cited in EPA, 2008c
Dimethoate	24,000	Brougher et al., 2012a [48821403]	31,000	Brougher et al., 2012b [48821401]	111,000	Graves and Swigert, 1993a [42760001]
Disulfoton	-	-	39	[00068268] As cited in EPA, 2009a	520	Mayer, 1986 [40228401]
Fenitrothion	1300	[40233703] As cited in EPA, 2009b	2500	[40233704] As cited in EPA, 2009b	>1000	Mayer and Ellersieck, 1986 [40098001]
Ethoprop	-	-	300	[00160187] As cited in EPA, 2008g	-	-
Malathion	174	Gries and Purghart, 2001c [47540302]	54	Gries and Purghart, 2001b [47540304]	47.4	Burke, 2011 [49055701]
Methidathion	-	-	2.2	[00011841] As cited in EPA, 2008d	7.8	[00015735] As cited in EPA, 2008d
Methyl parathion	-	-	-	-	3400	Surprenant, 1988 [40932103] As cited in EPA, 2009f
Naled	92	Mayer and Ellersieck, 1986 [40098001]	90	Mayer and Ellersieck, 1986 [40098001] As cited in EPA, 2008h.	-	-
Oxydemeton methyl	730	[40269001] As cited in EPA, 2008b	1220	[40269002] As cited in EPA, 2008b	-	-

Table H-6 Acute toxicity of organophosphates to fish.

Active Ingredient	*Rainbow Trout (Oncorhynchus mykiss)*		*Bluegill (Lepomis macrochirus)*		*Sheepshead Minnow (Cyprinodon variegates)*	
	LC50 (µg/L)	*Reference [MRID]*	*LC50 (µg/L)*	*Reference [MRID]*	*LC50 (µg/L)*	*Reference [MRID]*
Phorate	-	-	2.35	Mayer and Ellersieck, 1986 [40098001]	-	-
Phosmet	230	[00109135] As cited in EPA, 2008i	70	Julin and Sanders, 1977 [00063194]	170	Bowman, 1987 [40612702]
Tebupirimphos	-	-	89	[42005424] As cited in EPA, 2009e	36	[44193602] As cited in EPA, 2009e
Trichlorfon	158	Mayer and Ellersieck, 1986 [40098001]	-	-	-	-

Table H-7 Chronic toxicity of organophosphates to fish.

Active Ingredient	*Rainbow Trout (Oncorhynchus mykiss)*			*Fathead Minnow (Pimephales promelas)*			*Sheepshead Minnow (Cyprinodon variegates)*		
	NOEC (µg/L)	*LOEC (µg/L)*	*Reference [MRID]*	*NOEC (µg/L)*	*LOEC (µg/L)*	*Reference [MRID]*	*NOEC (µg/L)*	*LOEC (µg/L)*	*Reference [MRID]*
Azinphos methyl	0.44	0.98	[40579601] As cited in EPA, 2005a	-	-	-	0.17	0.34	Morton et al., 1997 As cited in EPA, 2005a
Chlorethoxyphos	-	-	-	0.84	1.6	Hutton, 1990 [40883745] As cited in EPA, 1995	-	-	-
Chlorpyrifos	-	-	-	0.57	-	Mayes et al., 1993 [42834401] As cited in EPA, 2008e	-	-	-
Coumaphos	11.7	24.6	Gagliano and Bowers, 1993 [43066301]	-	-	-	-	-	-
Dichlorvos	5.2	10.1	Davis, 1995 [43788001] As cited in EPA, 2005b	-	-	-	960	1840	Ward and Davis, 1995a [43790401]

Table H-7 Chronic toxicity of organophosphates to fish.

Active Ingredient	*Rainbow Trout (Oncorhynchus mykiss)*			*Fathead Minnow (Pimephales promelas)*			*Sheepshead Minnow (Cyprinodon variegates)*		
	NOEC (µg/L)	*LOEC (µg/L)*	*Reference [MRID]*	*NOEC (µg/L)*	*LOEC (µg/L)*	*Reference [MRID]*	*NOEC (µg/L)*	*LOEC (µg/L)*	*Reference [MRID]*
Dimethoate	1250	2490	Hicks, 2013 [49083401]	18,000	96,000	Schneider et al., 2012 [48670603]	2400	4600	Hurd and Sharpe, 2011a [48772901]
Disulfoton	220	240	[41935801] As cited in EPA, 2008j	-	-	-	0.96	-	[43960501] As cited in EPA, 2009a
Fenitrothion	46	88	Cohle, 1988, [40891201] As cited in EPA, 2009b	-	-	-	-	-	-
Ethoprop	-	-	-	24	54	Surprenant, 1987 [40650102]	5.9	11	Sousa, 1997a [44472101]
Malathion	21	44	Cohle, 1989 [41422401]	-	-	-	8.2	16	Hurd and Sharpe, 2011 [48705301]
Methidathion	-	-	-	6.3	-	[00015735] As cited in EPA, 2008d	-	-	-
Methyl parathion	<80	80	[00128791] As cited in EPA, 2009f	-	-	-	8.86	17.7	[46744201] As cited in EPA, 2009f
Naled	-	-	-	2.9	-	[42602210] As cited in EPA, 2009c	-	-	-
Phorate	-	-	-	-	-	-	9.6×10^{7}	-	Sousa, 1994 [41803806] As cited in EPA, 2009d
Phosmet	3.2	6	Cohle, 1988 [40938701]	-	-	-	-	-	-
Tebupirimphos	-	-	-	130	265	[42784502] As cited in EPA, 2009e	-	-	-
Trichlorfon	110	234	Gagliano, 1992 [42571701]	-	-	-	-	-	-

Table H-8 Acute toxicity of organophosphates to aquatic invertebrates.

Active Ingredient	*Waterflea (Daphnia sp.)*		*Scud (Gammarus sp.)*		*Eastern Oyster (Crassostrea virginica)*		*Mysid (Americamysis bahia)*	
	EC50 (µg/L)	*Reference [MRID]*	*EC50 (µg/L)*	*Reference [MRID]*	*EC50 (µg/L)*	*Reference [MRID]*	*EC50 (µg/L)*	*Reference [MRID]*
Azinphos methyl	1.13	[00068678] As cited in EPA, 2005a	0.1	Mayer and Ellersieck, 1986 [40098001]	1000	Mayer, 1986 [40228401]	0.21	[40380502] As cited in EPA, 2005a
Chlorethoxyphos	0.41	[41334103] As cited in EPA, 1995	-	-	0.13	Ward and Boeri, 1990 [41736848] As cited in EPA, 1995	0.054	Graves, 1994 [43142201] As cited in EPA, 1995
Chlorpyrifos	0.07	Pablo et al., 2008 EXCOTOX 108483	-	-	-	-	0.035	Mayer, 1986 [40228401]
Diazinon	-	-	0.2	Johnson and Finley, 1980 [40094602]	-	-	4.2	Surprenant, 1988 [40625501]
Dichlorvos	0.07	Mayer and Ellersieck, 1986 [40098001]	-	-	89,100	Jones and Davis, 1994b [43571404]	19.1	Jones and Davis, 1994b [43571404]
Dicrotophos	12.7	Davis and Cunningham, 1995 [43787901] As cited in EPA, 2008c	2600	Sanders, 1972 [05017538]	>125,000	Cunningham and Davis, 1995 [43739801] As cited in EPA, 2008c	77	Jones et al., 1995 [43603305] As cited in EPA, 2008c
Dimethoate	2000	Hertl, 2002 [48298306]	-	-	113,000	Graves and Swigert, 1993b [42760002]	22,000	Graves and Swigert, 1993c [42760003]
Disulfoton	-	-	-	-	720	Mayer, 1986 [40228401]	-	-
Ethoprop	44	Vilkas, 1977 [00068325]	-	-	3700	Dionne, 1995 [43686302]	-	-
Fenitrothion	11	Johnson and Finley, 1980 [40094602]	4.3	[00120401] As cited in EPA, 2009b	450	Mayer and Ellersieck, 1986 [40098001]	-	-
Malathion	0.70	Gries and Purghart, 2001b [47540303]	4.8	Brougher et al., 2014a [49389402]	2700	Brougher et al., 2014b [49389403]	3.6	Forbis, 1990 [41474501]
Methidathion	7.2	Vilkas, 1976, [00011350]	-	-	-	-	0.7	[00157350] As cited in EPA, 2008d
Methyl parathion	0.97	ECOTOX 56473 As cited in EPA, 2009f	-	-	12,000	Mayer, 1986 [40228401]	0.35	Surprenant, 1988 [40932104] As cited is EPA, 2009f

Table H-8 Acute toxicity of organophosphates to aquatic invertebrates.

Active Ingredient	*Waterflea (Daphnia sp.)*		*Scud (Gammarus sp.)*		*Eastern Oyster (Crassostrea virginica)*		*Mysid (Americamysis bahia)*	
	EC50 (µg/L)	*Reference [MRID]*	*EC50 (µg/L)*	*Reference [MRID]*	*EC50 (µg/L)*	*Reference [MRID]*	*EC50 (µg/L)*	*Reference [MRID]*
Naled	0.066	Mayer and Ellersieck, 1986 [40098001]	-	-	-	-	-	-
Oxydemeton methyl	-	-	190	[00097842] As cited in EPA, 2008b	-	-	-	-
Phorate	-	-	0.6	Sanders, 1972 [05017538]	-	-	-	-
Phosmet	-	-	2	[00063193] As cited in EPA, 2009g	-	-	1.6	Bowman, 1987 [40612702]
Tebupirimphos	0.078	[42005428] As cited in EPA, 2009e	-	-	958	[44193601] As cited in EPA, 2009e	6.63	[44169501] As cited in EPA, 2009e
Trichlorfon	-	-	-	-	>114,000	Drotter and Krueger, 1998a [44499201]	-	-

Table H-9 Chronic toxicity of organophosphates to aquatic invertebrates.

Active Ingredient	*Waterflea (Daphnia sp.)*			*Mysid (Americamysis bahia)*		
	NOEC (µg/L)	*LOEC (µg/L)*	*Reference [MRID]*	*NOEC (µg/L)*	*LOEC (µg/L)*	*Reference [MRID]*
Azinphos methyl	0.25	0.4	[00073606] As cited in EPA, 2005a	0.02	0.03	Morton et al., 1997
Chlorethoxyphos	0.032	0.06	Baer, 1991 [41808301]. As cited in EPA, 1995	0.00124	0.0258	Boeri et al., 1995 [43717701] As cited in EPA, 1995
Chlorpyrifos	0.025	-	Rose et al., 2002, ECOTOX 65825] As cited in EPA, 2008e	<0.0046	-	Sved et al., 1993 [42664901] As cited in EPA, 2008e
Diazinon	0.17	0.32	[40782302] As cited in EPA, 2004a	0.23	0.42	Sousa, 1997b [44244801]
Dichlorvos	0.0058	0.0122	Ward and Davis, 1995b [43890301]	1.48	3.25	Ward and Davis, 1995c [43854301]
Dicrotophos	-	-	-	3.09	6.15	Davis and Cunningham, 1996 [43893901]

Table H-9 Chronic toxicity of organophosphates to aquatic invertebrates.

Active Ingredient	*Waterflea (Daphnia sp.)*			*Mysid (Americamysis bahia)*		
	NOEC (µg/L)	*LOEC (µg/L)*	*Reference [MRID]*	*NOEC (µg/L)*	*LOEC (µg/L)*	*Reference [MRID]*
Dimethoate	40	100	Wuthrich, 1990 [42864701]	140	280	Claude et al., 2012b [48804201]
Disulfoton	0.037	0.070	Blakemore, 1999 [41935802] As cited in EPA, 2008j	2.3	-	[43610901] As cited in EPA, 2009a
Fenitrothion	0.087	0.23	[40891101] As cited in EPA, 2009b	-	-	-
Ethoprop	800	2400	Putt, 1995 [43877401]	0.36	-	Sousa, 1997c [44457501]
Malathion	0.06	0.1	Blakemore and Burgess, 1990 [41718401]	0.29	0.58	Claude et al., 2012a [48752901]
Methidathion	0.66	1.13	[42081707] As cited in EPA, 2008d	0.022	0.061	[00157351] As cited in EPA, 2008d
Methyl parathion	0.25	0.55	[00128790] As cited in EPA, 2009f	0.11	0.37	[00066341] As cited in EPA, 1981
Naled	0.045	-	[42908801] As cited in EPA, 2009c	-	-	-
Phorate	0.21	-	Yurk, 1991 [42227102]. As cited in EPA, 2009d	5,300,000	-	Overman and Wisk, 1995 [43730501]
Phosmet	0.8	1	Burgess, 1988 [40652801]	0.51	-	Burgess, 1988 [40657201]
Tebupirimphos	0.011	0.022	[42784503] As cited in EPA, 2009e	0.118	0.252	[44314901] As cited in EPA, 2009e
Trichlorfon	0.0057	0.0086	[40452601] As cited in EPA, 2009h	3.1	234	Drotter and Kreuger, 1998b [44499202]

Comparison to other Pesticide Classes

The organophosphates group, to which malathion belongs, causes phosphorylation of the acetylcholinesterase enzyme (AChE). This inhibits the AChE, resulting in excess acetylcholine at the nerve endings and overstimulation (Roberts and Reigart, 2013). Signs of toxicity include sensory and behavioral disturbances, incoordination, depressed motor function, respiratory depression, increased pulmonary secretions, coma, and death. Pyrethroids and carbamates are other common pesticide classes. Pyrethroids are synthetic insecticides that have the chemical properties of pyrethrum, a chemical extract from chrysanthemum flowers (Roberts and Reigart, 2013). Pyrethroids are neurotoxins and act by paralyzing the nervous system of insects. In mammals, signs of pyrethroid toxicity include tremors, reflex hyperexcitability, choreoathetosis, seizures, and coma. Carbamates are N-methyl carbamate esters that cause reversible carbamylation of the AChE (Roberts and Reigart, 2013). This results in accumulation of acetylcholine, which affects the muscarinic, nicotinic and central nervous systems. Signs of carbamate toxicity include muscle twitching, incoordination, seizures, paralysis, lethargy, respiratory despression, pulmonary edema, coma, and death (Roberts and Reigart, 2013).

Halstead et al. (2015) examined whether insecticides within a given chemical class pose similar threats to aquatic macroarthropods, and which insecticides or insecticide classes pose the lowest risk to these species. Acute toxicity tests with the crayfish (*Procambarus alleni*) and water bug (*Belostoma flumineum*) were conducted for three organophosphate (chlorpyrifos, malathion and terbufos) and three pyrethroid (esfenvalerate, λ-cyhalothrin and permethrin) pesticides.

The 96-hour LC50s for crayfish and water bug exposed to malathion were 48,936 and 2,695 µg/L, respectively, and represented the lowest LC50s of all pesticides tested. The 96-hour LC50s for the five other pesticides tested ranged from 0.21 (λ-cyhalothrin) to 29.3 µg/L (chlorpyrifos), and from 0.25 (λ-cyhalothrin) to 74.3 µg/L (terbufos) for the crayfish and water bug, respectively. Since the crayfish and water bugs used in toxicity testing were collected from an area in which malathion is used heavily for adult mosquito control, it is possible that the organisms collected have undergone selection for malathion resistance. However, the 96-hour LC50 calculated for *P. alleni* was similar to data reported for other *Procambarus* species in EPA's ECOTOX database (96-hour LC50 = 49,170 - 50,000 µg/L; Halstead et al., 2015).

Next, Halstead et al. (2015) calculated thirty annual peak EECs for pesticide use on corn in five US states (Illinois, Mississippi, North Carolina, Ohio, and Pennsylvania) using EPA's Surface Water Concentration Calculator (SWCC). Manufacturers' recommended application rates, pesticide physicochemical properties, local abiotic conditions from SWCC, and standard EPA scenarios for corn production were applied. The EECs predicted for each pesticide were divided by 96-hour and 10-day LC50s derived from toxicity tests, and the resulting risk quotients (RQs) were compared to EPA's level of concern (LOC) of 0.5 for non-listed aquatic invertebrates (EPA, 2004b).

The crayfish and water bug acute RQs for organophosphates (based on the 96-hour LC50s) rarely exceeded the LOC (0-22% of scenarios). However, crayfish RQs for pyrethroids exceeded the LOC for 97 to 100% of scenarios. Malathion was the only insecticide where no RQs exceeded the non-listed species LOC for aquatic invertebrates. Insecticide class accounted for 55.7% and 91.1% of variation in mortality data for the crayfish and water bug, respectively. Although the crayfish model indicated that differences among individual pesticides accounted for 44.3% of variance, the authors suggested that this is largely due to the low toxicity of malathion to crayfish.

Overall, the analyses by Halstead et al. (2015) indicated that risk of some insecticides to aquatic invertebrates can be predicted based on chemical class and/or mode of action. The organophosphate LC50s for the crayfish and water bug were one to five orders of magnitude higher than the pyrethroid LC50s, and aquatic exposure modeling indicated that use of organophosphate pesticides poses significantly less risk to aquatic invertebrates than pyrethroids. Furthermore, amongst the organophosphate pesticides tested, malathion had the highest LC50s and the lowest predicted EECs. Thus, the authors concluded that malathion poses lower risk to aquatic invertebrates compared to pyrethroids and other organophosphates (e.g., chlorpyrifos and terbufos).

A comparison of the toxicity of malathion to a selection of pyrethroids and carbamates currently registered for use in the United States for representative non-target species is shown in Table H-10. The species examined were the mallard (*Anas platyrhynchos*; bird), rat (*Rattus norvegicus*; mammal), honeybee (*Apis mellifera*; terrestrial invertebrate), and bluegill (*Lepomis macrochirus*; fish). Toxicity data were drawn from ecological risk assessments performed by EPA. Overall, malathion was the least toxic chemical. Compared to carbamates, malathion is two to three orders of magnitude less toxic to birds (approximately equal toxicity for carbaryl), one to four orders of magnitude less toxic to mammals, and one to three orders of magnitude less toxic to fish, but within the same order of toxicity to non-target terrestrial invertebrates. Compared to pyrethroids, malathion is one to two orders of magnitude less toxic to mammals and terrestrial invertebrates, and four to five orders of magnitude less toxic to fish, but of similar toxicity to birds. Therefore, it is quite clear that malathion is much less toxic to non-target organisms than other currently registered pesticides.

Table H-10 Comparison of the toxicity of malathion to carbamate and pyrethroid pesticides for representative non-target species

Chemical Class	*Chemical*	*Mallard (Anas platyrhynchos) LD50 (mg/kg bw)*	*Rat (Rattus norvegicus) LD50 (mg/kg bw)*	*Honeybee (Apis mellifera) contact LD50 (µg a.i./L)*	*Bluegill (Lepomis macrochirus) LC50 (mg/L)*	*Source [MRID]*
Organophosphate	Malathion	>2250	2010	0.189	54	Hubbard and Beavers, 2012a [48963307]; Gries and Purghart, 2001b [47540304]; Moore, 2003 [48153112]; Sindermann and Porch, 2013a [49270301]
Carbamate	Aldicarb	1	0.9	0.285	0.052	EPA, 2007b
	Carbaryl	>2000	301	1.1	-	EPA, 2007c
	Methomyl	15.9	17	<0.5	1.05	EPA, 1998
	Oxamyl	3.16	2.5	0.31	5.6	EPA, 2009j
	Propoxur	9.44	125	<11	6.2	EPA, 1997
Pyrethroids	Bifenthrin	2150	53.8	0.015	0.00035	EPA, 2012b
	Cyfluthrin	>2000[a]	16.2	0.037	0.00021[b]	EPA, 2013a
	Deltamethrin	>2250[a]	67	0.0015	0.0014	EPA, 2013b
	Esfenvalerate	381[h]	59	0.017	0.00023	EPA, 2008k
	Permetrin	>9869	152	0.024	0.00079	EPA, 2008l

[a] Data for northern bobwhite (*Colinus virginianus*)
[b] Data for rainbow trout (*Oncorhynchos mykiss*)

Conclusions

Overall, malathion has lower toxicity to EPA surrogate species compared to many other organophosphate pesticides and compared to carbamate and pyrethroid pesticides. In many cases, malathion was one to five orders of magnitude less toxic than the most toxic active ingredients evaluated. Malathion was also significantly less toxic to water bugs and crayfish than pyrethroids and the other organophosphates examined (chlorpyrifos and terbufos) in a study designed to compare toxicities within and between chemical classes. Therefore, when considering the risk and effects to the environment from the application of malathion, relative to the organophosphate class of pesticides, malathion is one of the lowest risk organophosphates available. Additionally, when effectiveness is compared, malathion is a much less toxic alternative to carbamate pesticides.

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Appendix I
Malathion and Malaoxon Monitoring Data

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Malathion and malaoxon groundwater and surface water data for California were obtained from the following sources:

Federal Monitoring Programs

- EPA Storage and Retrieval (STORET) Data Warehouse (2001-2015; EPA, 2013a; EPA/USGS/NWQMC, 2016)
- US Department of Agriculture (USDA) Pesticide Data Program (PDP) (2004-2013; USDA, 2016)
- US Geological Survey (USGS) National Water Quality Assessment (NAWQA) Program (2001-2013; USGS, 2013a)
- USGS National Water Information System (NWIS) (2001-2015; USGS, 2013b,c; EPA/USGS/NWQMC, 2016)

State Monitoring Programs:

- California Department of Pesticide Regulation (CDPR) Surface Water Database (SWD) (2001-2014; CDPR, 2014; 2015)
- California Environmental Data Exchange Network (CEDEN) (2001-2011; CEDEN, 2013; 2016)

Data from all sources were imported into MS-Access 2010© and duplicate samples with the same sample type, sampling procedure, collection date, time, location (i.e., same latitude/longitude coordinates, station ID, and depth), and sample ID (if available) were removed. To be conservative, the entry with the highest reported concentration or, if no malathion or malaoxon was detected, the lowest limit of detection (LOD), limit of quantitation (LOQ) or reporting limit (RL) was retained for analysis and the other duplicate entries were removed. Only data from 2001 to 2015 were included in the analyses to reflect more recent changes in product labels and use patterns.

EPA Storage and Retrieval (STORET) Data Warehouse

STORET is a repository for water quality, biological and physical data maintained by EPA. Data are collected by water resources management groups, including states, tribes, watershed groups, federal agencies, volunteer groups and universities, who then submit data for inclusion in the STORET Data Warehouse (EPA, 2012a). The STORET Central Warehouse http://ofmpub.epa.gov/storpubl/dw_pages.resultcriteria (accessed April 8th, 2013; EPA, 2013a) was queried for malathion and malaoxon concentrations in water samples obtained from California using STORET's default query settings. "Water" was selected as the activity medium, and "malathion" or "malaoxon" were selected as the characteristic names. No entries for malaoxon in water were present in STORET. STORET monitoring data is now available through the Water Quality Portal (EPA/USGS/NWQMC, 2016). Using this system, malathion and malaoxon monitoring data collected between 2012 and 2016 was accessed on February 4th,

2016. No malaoxon monitoring data collected in California were reported in the STORET database.

In STORET, the "activity type" code is used to distinguish between sample types. Table I-1 lists the activity type codes associated with malathion monitoring data. All sample types, excluding blanks and spiked samples, were included in data analyses.

Table I-1 Activity type codes associated with malathion data in STORET (EPA, 2012b).

Activity Type	*Description*	*Included in Analysis? (Y/N)*
Field Measurements and Observations	Measurements involve something measured in its environmental setting usually using some type of equipment. Observations are made by people, usually without the use of equipment, and are frequently qualitative.	Y
Quality Control Field Sample Equipment Rinsate Blank	A sample of analyte-free media that has been used to rinse the sampling equipment. It is collected after completion of decontamination and prior to sampling. This blank is useful in documenting adequate decontamination of sampling equipment.	N
Quality Control Sample-Field Blank	A sample of analyte-free water poured into a sample container in the field, preserved and shipped to the laboratory with field samples. The purpose of a field blank is to assess contamination from field conditions during sampling.	N
Quality Control Sample-Field Replicate	Multiple samples taken within each combination of time, location, and any other controlled variables. The purpose of collecting replicate samples is to obtain precision. For example, for a large size field it is important to break the field into homogeneous sub-areas and collect samples proportionate to the size of each sub-area.	Y
Quality Control Sample-Lab Matrix Spike	An aliquot of an environmental sample to which known quantities of analytes are added in the laboratory. The matrix spike is analyzed in an identical manner as the sample.	N
Quality Control Sample-Trip Blank	Trip blanks are test samples of analyte-free media taken from the laboratory to the sampling site and returned to the laboratory unopened. They are used to measure cross-contamination from the container and preservative during transport, field handling, and storage. Usually, at least one trip blank should be prepared for each sample type per trip.	N
Sample-Composite Without Parents	Describes a sample that is a composite of either several discrete sampling events not described elsewhere, or is a sample collected by a continuous process over some time period. No database record exists as its parent[a].	Y
Sample-Integrated Flow Proportioned	A sample integrated over an interval or space within which changes in flow are used to alter the proportion of the sampled medium contributing to the integrated sample.	Y
Sample-Integrated Horizontal Profile	A sample integrated over an interval or space within which changes in flow are used to alter the proportion of the sampled medium contributing to the integrated sample.	Y
Sample-Integrated Vertical Profile	A sample integrated over an interval or space within which changes in flow are used to alter the proportion of the sampled medium contributing to the integrated sample.	Y
Sample-Routine	A sample gathered using straightforward grab procedures for purposes of a general evaluation of the environment at the site.	Y

[a] Samples can be created from other samples, by compositing, splitting, or sub-sampling. Each new sample may be linked to its "parent(s)", so that it can be georeferenced and traced back to all the events which might influence its results (EPA, 2013b).

Table I-2 summarizes malathion water quality data obtained from STORET between 2001 and 2015. Malathion was detected in 18 of 593 samples at concentrations ranging from 0.03 to 0.36 µg/L. LODs were not reported for the majority of California water samples. In some instances, malathion was detected but not quantified, but LOQs were not reported.

Malathion detections were observed in Los Angeles, San Diego, Santa Barbara, San Joaquin and Ventura counties. Malathion concentrations in San Joaquin county ranged from 0.03 to 0.07 µg/L, and DS have not been observed in any other counties where detections occurred.

Table I-2 Summary of water monitoring data for malathion from EPA STORET (2001 to 2015).						
State	***Year***	***# Samples***	***# Detects***	***% Detects***	***Range of Detects (µg/L)[a]***	***Range of LODs (µg/L)[b,c]***
CA	2001	33	7	21.21%	0.06 – 0.081	NR
CA	2002	211	2	0.95%	0.36	NR
CA	2003	96	0	0.00%	ND	NR
CA	2004	8	0	0.00%	ND	NR
CA	2005	19	0	0.00%	ND	NR
CA	2006	24	0	0.00%	ND	NR
CA	2007	3	0	0.00%	ND	NR
CA	2008	7	0	0.00%	ND	NR
CA	2009	7	7	100.00%	BQL[d]	NR
CA	2012	49	2	4.08%	0.03 – 0.07	0.01
CA	2013	52	0	0.00%	ND	0.01
CA	2014	69	0	0.00%	ND	0.01
CA	2015	15	0	0.00%	ND	NR
CA	**All Years**	**593**	**18**	**3.04%**	**0.03 – 0.36**	**0.01**

[a] ND: not detected.
[b] NR: not reported.
[c] LOD: limit of detection.
[d] BQL: below quantitation limit.

USDA Pesticide Data Program (PDP)

The USDA PDP was established in May 1991 and manages the collection, analysis, data entry and reporting of pesticide residues on agricultural commodities as well as pesticide concentrations in municipal drinking water and well water (USDA, 2016). PDP databases and annual summary reports from 1992 to 2014 can be downloaded from http://www.ams.usda.gov/datasets/pdp/pdpdata (USDA, 2016).

Only food residue values were analyzed and recorded in the PDP database between 1992 and 2000. The PDP database (2001-2013) was queried for groundwater (WG) and untreated water (WU) samples analyzed for malathion (pesticide code = 052) and malaoxon (pesticide code = 208, reported as malathion oxygen analog).

Table I-3 to Table I-7 summarize malathion and malaoxon water quality data obtained from the USDA PDP between 2005 and 2013. No malathion or malaoxon water quality data were available in the 2014 PDP database. Between 2005 and 2013, 60 groundwater samples and 87 untreated water samples from California were analyzed for malathion. Malathion was not detected in any groundwater or untreated samples. LODs ranged from 0.01 to 0.03 µg/L.

Between 2007 and 2013, 54 California groundwater samples and 26 surface water samples were analyzed for malaoxon. As was observed for malathion, malaoxon concentrations were below the LOD (0.00037 – 0.6 µg/L) in all samples.

Table I-3 Summary of California groundwater monitoring data for malathion from the USDA PDP (2007 – 2013).							
State	*Year*	*Sample Medium*	*# Samples*	*# Detects*	*% Detects*	*Range of Detected Values (µg/L)*[a]	*Range of LODs (µg/L)*[b]
CA	2007	WG	4	0	0.00%	ND	0.03
CA	2008	WG	2	0	0.00%	ND	0.03
CA	2009	WG	13	0	0.00%	ND	0.03
CA	2010	WG	27	0	0.00%	ND	0.03
CA	2011	WG	6	0	0.00%	ND	0.01
CA	2013	WG	8	0	0.00%	ND	0.03
CA	**All Years**	**WG**	**60**	**0**	**0.00%**	**ND**	**0.01 – 0.03**

[a] ND: not detected.
[b] LOD: limit of detection.

Table I-4 Summary of California untreated water monitoring data for malathion from the USDA PDP (2005 – 2012).							
State	*Year*	*Sample Medium*	*# Samples*	*# Detects*	*% Detects*	*Range of Detected Values (µg/L)*[a]	*Range of LODs (µg/L)*[b]
CA	2005	WU	28	0	0.00%	ND	0.021
CA	2006	WU	9	0	0.00%	ND	0.021
CA	2009	WU	24	0	0.00%	ND	0.01
CA	2012	WU	26	0	0.00%	ND	0.01 – 0.03
CA	**All Years**	**WU**	**87**	**0**	**0.00%**	**ND**	**0.01 – 0.03**

[a] ND: not detected.
[b] LOD: limit of detection.

Table I-5 Summary of California groundwater monitoring data for malaoxon from the USDA PDP (2007-2013).							
State	*Year*	*Sample Medium*	*# Samples*	*# Detects*	*% Detects*	*Range of Detected Values (µg/L)*[a]	*Range of LODs (µg/L)*[b]
CA	2007	WG	4	0	0.00%	ND	0.3
CA	2008	WG	2	0	0.00%	ND	0.3
CA	2009	WG	13	0	0.00%	ND	0.6
CA	2010	WG	27	0	0.00%	ND	0.6
CA	2013	WG	8	0	0.00%	ND	0.6
All States	**All Years**	**WG**	**54**	**0**	**0.00%**	**ND**	**0.3 – 0.6**

[a] ND: not detected
[b] LOD: limit of detection

Table I-6 Summary of California surface water monitoring data for malaoxon from the USDA PDP (2012).							
State	*Year*	*Sample Medium*	*# Samples*	*# Detects*	*% Detects*	*Range of Detected Values (µg/L)*[a]	*Range of LODs (µg/L)*[b]
CA	2012	WU	26	0	0.00%	ND	0.00037 – 0.6

USGS National Water Quality Assessment (NAWQA) Program

The USGS NAWQA database was accessed on April 8th, 2013 to isolate surface water data for malathion and malaoxon over the temporal range 2001 – 2013. Malathion and malaoxon groundwater data were accessed November 8th, 2013 over the same temporal range. The NAWQA data are accessible through the web interface at the USGS NAWQA data warehouse using the following link, http://infotrek.er.usgs.gov/traverse/f?p=NAWQA:HOME:0 (USGS, 2013a). Data from the surface water/bed sediment and groundwater categories were selected and the parameter codes selected were 39530, 39531, 39532, 39533, and 65087 for malathion, and 61652, 68240, and 68242 for malaoxon. Data entries in ng/L were converted to µg/L in MS-Excel® 2010 and were subsequently imported into MS-Access© 2010 to facilitate subsequent queries and organization. The NAWQA program uses a result qualifier field code (i.e., '<', '--', 'E') to identify records that were less than ('<') the LOD, equal to a reported concentration ('--') or estimated to be the reported concentration ('E'). The analytical LOD is not specifically reported for each record. However, for those records with 'less than' qualifiers, LODs ranged from 0.008 to 0.08 µg/L for malathion and malaoxon groundwater samples, and from 0.008 to 0.15 µg/L for malathion and malaoxon surface water samples.

The NAWQA program identifies the dominant land use surrounding each of the NAWQA surface water monitoring stations as urban, mixed, agricultural/crops, or 'other'. NAWQA defines the various land uses as follows (USGS, 2013a; Gilliom et al., 2007): mixed land use may contain urban, forest, agriculture, or mining land use, but no one land use is considered dominant; agricultural land use is >50% agricultural and <5% urban; and urban is considered >25% urban and < 25% agricultural land. The 'other' land use category is for records where specific land use data are not provided.

Table I-7 to Table I-10 summarize NAWQA groundwater and surface water data for California by year (2001-2012) for malathion and malaoxon. Malathion was not detected in any groundwater samples. In surface water, malathion was detected in 198 of 1435 samples at concentrations ranging from 0.0015 to 0.4 µg/L. Of the 198 malathion detections in California surface water, 88 were from counties where DS have been observed (i.e., Sacramento and San Joaquin). The highest surface water detection from DS counties was 0.378 µg/L and was observed at Arcade Creek, near Paso Heights, Sacramento County, CA on November 20th, 2011. This detection was associated with urban land use. The majority of malathion detects in surface water were associated with mixed land uses (52.0%), followed by urban uses (25.8%), agricultural/crop uses (21.7%), and 'other' uses (0.5%). Malathion detects in surface water observed between 2001 and 2009 made up 91.4% of all detects observed between 2001 and 2012.

Malaoxon not detected in any groundwater samples. In surface water, malaoxon was detected at a concentration of 0.0209 µg/L in one sample taken on October 28th, 2008 from the San Joaquin River, near Vernalis, CA. This detection was associated with mixed land use.

NAWQA data has since been moved to the Water Quality Portal (http://waterqualitydata.us/portal/), which includes water quality data from the USGS National Water Information System (NWIS), EPA STORET, and STEWARDS. Malathion and malaoxon monitoring data obtained by the USGS between 2012 and 2016 are described in the section on NWIS, below.

Table I-7	Summary of California groundwater monitoring data for malathion from USGS NAWQA (2001 – 2012).					
State	***Year***	***# Samples***	***# Detects***	***% Detects***	***Range of Detected Values (µg/L)[a]***	***Range of LODs (µg/L)[b]***
CA	2001	79	0	0.00%	ND	0.027
CA	2002	86	0	0.00%	ND	0.027
CA	2003	59	0	0.00%	ND	0.027
CA	2004	160	0	0.00%	ND	0.027
CA	2005	18	0	0.00%	ND	0.027
CA	2006	65	0	0.00%	ND	0.027
CA	2007	15	0	0.00%	ND	0.016
CA	2008	62	0	0.00%	ND	0.016
CA	2009	80	0	0.00%	ND	0.016 – 0.02
CA	2010	39	0	0.00%	ND	0.016
CA	2011	28	0	0.00%	ND	0.016
CA	2012	37	0	0.00%	ND	0.016
All States	**All Years**	**728**	**0**	**0.00%**	**ND**	**0.016 – 0.027**

[a] ND: not detected
[b] LOD: limit of detection

Table I-8	Summary of California surface water monitoring data for malathion from USGS NAWQA (2001 – 2012).					
State	***Year***	***# Samples***	***# Detects***	***% Detects***	***Range of Detected Values (µg/L)[a]***	***Range of LODs (µg/L)[b]***
CA	2001	577	109	18.89%	0.0015 – 0.166	0.027 – 0.15
CA	2002	139	18	12.95%	0.003 – 0.218	0.027 – 0.051
CA	2003	112	14	12.50%	0.0031 – 0.172	0.027
CA	2004	117	8	6.84%	0.0134 – 0.225	0.027
CA	2005	64	10	15.63%	0.013 – 0.0776	0.027
CA	2006	45	3	6.67%	0.011 – 0.017	0.016 – 0.027
CA	2007	59	6	10.17%	0.0202 – 0.0813	0.016
CA	2008	71	11	15.49%	0.0072 – 0.4	0.016 – 0.02
CA	2009	73	2	2.74%	0.0238 – 0.0603	0.016 – 0.02
CA	2010	67	6	8.96%	0.005 – 0.0358	0.016 – 0.0201
CA	2011	60	8	13.33%	0.0086 – 0.378	0.016 – 0.0184
CA	2012	51	3	5.88%	0.0125 – 0.0648	0.016 – 0.0382
All States	**All Years**	**1435**	**198**	**13.80%**	**0.0015 – 0.4**	**0.016 – 0.15**

[a] ND: not detected
[b] LOD: limit of detection

Table I-9 Summary of California groundwater monitoring data for malaoxon from USGS NAWQA (2001 – 2012).						
State	***Year***	***# Samples***	***# Detects***	***% Detects***	***Range of Detected Values (µg/L)[a]***	***Range of LODs (µg/L)[b]***
CA	2001	60	0	0.00%	ND	0.008
CA	2002	45	0	0.00%	ND	0.008
CA	2003	34	0	0.00%	ND	0.008
CA	2004	86	0	0.00%	ND	0.008 – 0.0298
CA	2005	18	0	0.00%	ND	0.0298
CA	2006	65	0	0.00%	ND	0.039
CA	2007	15	0	0.00%	ND	0.039
CA	2008	62	0	0.00%	ND	0.02
CA	2009	80	0	0.00%	ND	0.08
CA	2010	39	0	0.00%	ND	0.08
CA	2011	28	0	0.00%	ND	0.022
CA	2012	37	0	0.00%	ND	0.022
All States	**All Years**	**569**	**0**	**0.00%**	**ND**	**0.008 – 0.08**

[a] ND: not detected
[b] LOD: limit of detection

Table I-10 Summary of surface water monitoring data for malaoxon from USGS NAWQA (2001 – 2012).						
State	***Year***	***# Samples***	***# Detects***	***% Detects***	***Range of Detected Values (µg/L)[a]***	***Range of LODs (µg/L)[b]***
CA	2001	2	0	0.00%	ND	0.008
CA	2002	40	0	0.00%	ND	0.008
CA	2003	64	0	0.00%	ND	0.008
CA	2004	61	0	0.00%	ND	0.008 – 0.045
CA	2005	64	0	0.00%	ND	0.0298 – 0.09
CA	2006	45	0	0.00%	ND	0.0298 – 0.039
CA	2007	59	0	0.00%	ND	0.02 – 0.039
CA	2008	71	1	1.41%	0.0209	0.02 – 0.08
CA	2009	73	0	0.00%	ND	0.08
CA	2010	67	0	0.00%	ND	0.022 – 0.08
CA	2011	60	0	0.00%	ND	0.022
CA	2012	51	0	0.00%	ND	0.022
All States	**All Years**	**657**	**1**	**0.15%**	**0.0209**	**0.008 – 0.09**

[a] ND: not detected
[b] LOD: limit of detection

USGS National Water Information System (NWIS)

NWIS is a distributed network of computers involved in the acquisition, processing, review and long-term storage of water data. NWIS includes information on site characteristics, stream flow, precipitation, physical and chemical properties of water, and chemical analyses for discrete water samples, sediment and biological media. Data have been obtained from all 50 states dating back to as early as 1899. "Water Data for the Nation" is the USGS public web interface through which most NWIS data can be accessed (USGS, 2011). NWIS water quality data for malathion and malaoxon were accessed on April 18th, 2013 using the "Water Quality Samples for the Nation" interface (USGS, 2013b). Parameter codes 39530, 39532, 62739 and 65087 were selected for malathion, and codes 61652 and 68240 were selected for malaoxon. Water sample site information was obtained through the "Site Inventory for the Nation" interface (USGS, 2013c). Water quality data in ng/L were converted to µg/L in MS-Excel® 2010 and were subsequently imported into MS-Access© 2010 along with sample site data. Site information was then related to the water quality entries using the site number field. NWIS uses a remark code (i.e., '<', 'E', 'M') to identify records that were less than ('<') the LOD, estimated to be the reported concentration ('E'), or verified to be present but not quantified ('M') (USGS, 2011). The analytical LOD is not specifically reported for each record. However, for those records with 'less than' qualifiers, LODs ranged from 0.003 to 1.8 µg/L for groundwater samples, 0 to 5 µg/L for surface water samples, and from 0.016 to 0.022 µg/L for untreated water samples.

Database codes describing the sampling medium and sample type associated with malathion and malaoxon water quality data retrieved from NWIS are presented in Table I-11 and Table I-12, respectively. Data entries where the medium code was listed as "untreated water supply" (WB), "groundwater" (WG) or "surface water" (WS) were included in data analysis. Data entries for all other media were removed. All sample types, excluding spiked (1,8), blank (2), reference (3,6), blind (4), not determined (A), and other QA (B) samples, were included in the analysis.

Table I-11 Medium codes associated with malathion and malaoxon data in NWIS (USGS, 2011).

Medium Code	*Description*	*Definition*	*Included in Analysis? (Y/N)*
OA	Artificial	Environmental sample - Any substance that is not part of an aquatic environment and cannot be described by the sample medium codes	N
OAQ	Artificial	Quality Control sample - Any substance that is not part of an aquatic environment and cannot be described by the sample medium codes.	N
OB	Bulk deposition	Environmental sample - A mixture of undesignated proportions of wet and dry deposition sampled by a continuously open container.	N
ON	Not determined	Environmental sample - Not determined	N
SB	Bottom material	Environmental sample - A mixture of mineral and organic matter that compose the top bed deposits (usually the first few inches) underlying a body of water.	N
SS	Suspended sediment	Environmental sample - Sediment carried in suspension by the turbulent components of the fluid or by the Brownian movement (a law of physics).	N

Table I-11 Medium codes associated with malathion and malaoxon data in NWIS (USGS, 2011).

Medium Code	*Description*	*Definition*	*Included in Analysis? (Y/N)*
WB	Untreated water supply	Environmental sample - Untreated water supply from a blend of surface and ground waters or from unknown sources.	Y
WE	Effluent	Environmental sample - Treated or untreated wastewater after use at a facility or wastewater treatment plant, or from combined sources, such as combined-sewer overflows or tile drainage systems.	N
WF	Landfill effluent	Environmental sample - A liquid material (usually water) that is drained or pumped from a landfill. It usually is a liquid that has percolated through solid landfill material to become a transport medium for materials dissolved from the landfill.	N
WG	Groundwater	Environmental sample - Water below the surface of the earth contained in the saturated zone. It does not include soil moisture or interstitial water.	Y
WGQ	Groundwater	Quality Control sample - Water below the surface of the earth contained in the saturated zone. It does not include soil moisture or interstitial water.	N
WI	Interstitial water	Environmental sample - Water occurring in the small openings, spaces, pores, and voids between particles of unconsolidated materials. Includes water found in the interstices of shallow sediments of a lake, wetland, reservoir, or stream, and in the vadose zone between the root zone and the water table. The water is held in place by entrapment, ionic attraction, and capillary or adhesive forces, rather than from pressure components of saturation.	N
WL	Leachate	Environmental sample - A solution obtained by passing a liquid (usually aqueous) through an unconsolidated solid medium, thereby dissolving materials (from the solid medium) which become a part of the solution. It also contains those precipitates that are the result of the solution process and subsequent chemical or biological reactions.	N
WS	Surface water	Environmental sample - Water on the surface of the earth stored or transported in rivers, streams, estuaries, lakes, ponds, swamps, glaciers, or other aquatic areas. It also may refer to water in urban drains and storm-sewer systems.	Y
WSQ	Surface water	Quality Control sample - Water on the surface of the earth stored or transported in rivers, streams, estuaries, lakes, ponds, swamps, glaciers, or other aquatic areas. It also may refer to water in urban drains and storm-sewer systems.	N
WT	Treated water supply	Environmental sample - Water after being processed for some particular use(s)	N
WU	Elutriation	Environmental sample - A process by which a mixture of an unconsolidated solid medium (usually soil) and a liquid medium (usually water) has been agitated for a given period of time to dissolve materials from the solid. The solid/liquid mixture is finally separated and the resulting solution is analyzed for materials dissolved during the elutriation process.	N
WW	Wet deposition	Environmental sample - Water reaching the earth's surface through precipitation as rain, snow, sleet, hail, or condensation of fog and dew. The water may contain undissolved particulate and gaseous materials acquired from the atmosphere during precipitation.	N

Table I-12 Sample type codes associated with malathion and malaoxon data in NWIS (USGS, 2011).			
Sample Type Code	***Description***	***Definition***	***Included in Analysis? (Y/N)***
A	Not determined	The sample type was not recorded.	N
B	Other QA	Other quality-assurance samples collected for specific purposes other than regular samples.	N
H	Composite (time)	Composite analyses represent samples collected over a period of time. Compositing minimizes sampling variability or analytical costs for sample group. Concentration and constituent load are assumed relatively constant over the composited time period. Or, concentrations are known to be changing and the composite sample is intended to characterize the event.	Y
1	Spike	A sample to which known quantities of specific (often organic) analytes have been added. Spiked samples are used to monitor the stability of the analytes from the time of the spike to the time of the analysis and to determine the potential bias introduced by the sample matrix. The measured and known concentrations are used to compute percent recovery for each analyte. Recovery rates are compared to potential factors, especially constituent concentrations, to discover causes of variability and (or) bias.	N
2	Blank	A blank sample is prepared from a reference material where none of the analytes of interest are present in detectable quantities. Blank samples are used to determine if environmental samples have been contaminated during the data-collection process. Detection of an analyte in a blank sample that is absent in the blank-source sample indicates bias due to contamination.	N
3	Reference	Reference samples are prepared from an aliquot of reference material. Reference samples are introduced into the data-collection process at various measurement stages to determine bias and variability of the measurement system. Individual sample results are compared to most probable values. Reference-sample results can be used to determine if an analytical process is within expected control limits and whether a project's data-quality objectives are met.	N
4	Blind	A sample submitted for analysis whose known composition is unknown to the analyst. A blind sample is prepared from a reference material. A blind sample is a particular instance of the reference sample where the identity of the sample is not revealed to the analyzing entity. Blind samples are used to measure the performance of an analytical system, results of more than one laboratory, more than one analytical method, or the consistency of the same laboratory and method over time.	N
5	Duplicate	A two-sample instance of a replicate group. The preferred terminology for this type of sample is replicate. One sample is an environmental sample. The companion sample is a quality-control sample.	Y
6	Reference material	Reference material is a general term for a homogenous substance generally prepared by laboratories or chemical suppliers where the concentration of one or more constituents is known. Reference-material samples provide the baseline analytical results for comparison to reference samples. The reference-material sample results are the generally accepted analytical most probable values (MPV). Field users will normally submit reference samples, not reference material samples.	N

Table I-12 Sample type codes associated with malathion and malaoxon data in NWIS (USGS, 2011).			
Sample Type Code	***Description***	***Definition***	***Included in Analysis? (Y/N)***
7	Replicate	A member of group of samples collected in a manner such that the samples are thought to be essentially identical. Samples where some part of the measurement process was altered (such as analysis by different laboratories or methods) are termed irreplicates. Irreplicates should not be identified as replicates. One group member is an environmental sample and the remaining group members are quality-control samples. Replicate samples are used to describe the variability measurement.	Y
8	Spike solution	A solution with one or more well established analyte concentrations. A spike solution is a specific type of a liquid reference material that is added in known quantities to a known volume of another sample to form a spiked sample. Results for spike-solution samples are stored to describe the known concentrations of the analytes in the spiking solution lot. Spike-solution results are interpreted in conjunction with spiked sample results during the computation of the percent recovery.	N
9	Regular	Sample taken from the environment collected to represent the conditions at a particular place and time.	Y

Updated malathion and malaoxon NWIS water quality data for 2012 to 2015 were obtained on February 4th, 2016 from the Water Quality Portal (EPA/USGS/NWQMC, 2016).

Table I-13 to I-15 summarize groundwater and surface water monitoring data obtained from NWIS for malathion and malaoxon. Data for California are presented by year. A total of 1019 groundwater samples collected between 2001 and 2015 were analyzed for malathion. Malathion was not detected in any samples and LODs/RLs ranged from 0.006 to 0.027 µg/L.

Of the 2366 surface water entries reported in NWIS between 2001 and 2015, 268 malathion detections were observed at concentrations ranging from 0.0013 to 5.46 µg/L (LODs/RLs = 0.0037 – 0.3 µg/L). Of these detections, 96 occurred in counties where DS have been observed (i.e., Sacramento, San Joaquin and Solano). The highest surface water detection from DS counties was 0.378 µg/L and was observed at Arcade Creek, near Paso Heights, Sacramento County, CA on November 20th, 2011. Malathion was infrequently detected above 1 µg/L (0.169% of California surface water samples) and over 88% of all malathion detects were observed between 2001 and 2009. The highest malathion detection observed in California since 2001 was 5.46 µg/L and was recorded in 2009. However, since 2009, malathion surface water concentrations reported in NWIS have not exceeded 0.378 µg/L.

Malaoxon was not detected in any of the 846 California groundwater samples from NWIS. LODs ranged from 0.003 to 0.08 µg/L. In surface water, malaoxon was detected at concentrations of 0.0002 and 0.021 µg/L in two of 958 samples from California (LODs/RLs = 0.003 – 0.09 µg/L). These samples were taken on September 5th, 2013 from Orestimba Creek near Crows Landing, CA and on October 28th, 2008 from the San Joaquin River, near Vernalis, CA, respectively.

Table I-13 Summary of California groundwater monitoring data for malathion from USGS NWIS (2001-2015).							
State	*Year*	*Medium Code*	*# Samples*	*# Detects*	*% Detects*	*Range of Detected Values (µg/L)*[a]	*Range of LODs/RLs (µg/L)*[b,c]
CA	2001	WG	80	0	0.00%	ND	0.027
CA	2002	WG	88	0	0.00%	ND	0.027
CA	2003	WG	59	0	0.00%	ND	0.027
CA	2004	WG	166	0	0.00%	ND	0.027
CA	2005	WG	29	0	0.00%	ND	0.027
CA	2006	WG	66	0	0.00%	ND	0.016 – 0.027
CA	2007	WG	20	0	0.00%	ND	0.016
CA	2008	WG	71	0	0.00%	ND	0.016
CA	2009	WG	86	0	0.00%	ND	0.016 – 0.02
CA	2010	WG	69	0	0.00%	ND	0.016
CA	2011	WG	35	0	0.00%	ND	0.016
CA	2012	WG	152	0	0.00%	ND	0.016
CA	2013	WG	80	0	0.00%	ND	0.006 – 0.016
CA	2014	WG	12	0	0.00%	ND	0.006 – 0.016
CA	2015	WG	6	0	0.00%	ND	0.006
CA	**All Years**	**WG**	**1019**	**0**	**0.00%**	**ND**	**0.006 – 0.027**

[a] ND: not detected.
[b] LOD: limit of detection.
[c] RL: reporting limit.

Table I-14 Summary of California surface water monitoring data for malathion from USGS NWIS (2001-2015).							
State	*Year*	*Medium Code*	*# Samples*	*# Detects*	*% Detects*	*Range of Detected Values (µg/L)*[a]	*Range of LODs/RLs (µg/L)*[b,c]
CA	2001	WS	703	115	16.36%	0.002 – 0.166	0.027 – 0.15
CA	2002	WS	304	21	6.91%	0.003 – 0.218	0.027 – 0.1
CA	2003	WS	195	15	7.69%	0.003 – 0.172	0.027 – 0.3
CA	2004	WS	129	10	7.75%	0.006 – 0.225	0.027 – 0.1
CA	2005	WS	68	10	14.71%	0.013 – 0.078	0.027 – 0.1
CA	2006	WS	75	4	5.33%	0.011 – 0.02	0.0037 – 0.1
CA	2007	WS	73	12	16.44%	0.0166 – 0.214	0.0037 – 0.1
CA	2008	WS	155	26	16.77%	0.007 – 1.31	0.0037 – 0.1
CA	2009	WS	149	25	16.78%	0.01 – 5.46	0.0037 – 0.1
CA	2010	WS	145	8	5.52%	0.005 – 0.085	0.0037 – 0.02
CA	2011	WS	90	9	10.00%	0.009 – 0.378	0.0037 – 0.018
CA	2012	WS	126	4	3.17%	0.0037 – 0.065	0.0037 – 0.038
CA	2013	WS	87	5	5.75%	0.0014 – 0.0255	0.0037 – 0.01
CA	2014	WS	42	4	9.52%	0.0013 – 0.0115	0.006 – 0.01

Table I-14 Summary of California surface water monitoring data for malathion from USGS NWIS (2001-2015).							
State	*Year*	*Medium Code*	*# Samples*	*# Detects*	*% Detects*	*Range of Detected Values (µg/L)*[a]	*Range of LODs/RLs (µg/L)*[b,c]
CA	2015	WS	25	0	0.00%	ND	0.0037 – 0.01
CA	**All Years**	**WS**	**2366**	**268**	**11.33%**	**0.0013 – 5.46**	**0.0037 – 0.3**

[a] ND: not detected
[b] LOD: limit of detection

Table I-15 Summary of California groundwater monitoring data for malaoxon from USGS NWIS (2001-2015).							
State	*Year*	*Sample Medium*	*# Samples*	*# Detects*	*% Detects*	*Range of Detected Values (µg/L)*[a]	*Range of LODs/RLs (µg/L)*[b]
CA	2001	WG	60	0	0.00%	ND	0.008
CA	2002	WG	45	0	0.00%	ND	0.008
CA	2003	WG	34	0	0.00%	ND	0.008
CA	2004	WG	88	0	0.00%	ND	0.008 – 0.03
CA	2005	WG	29	0	0.00%	ND	0.03
CA	2006	WG	66	0	0.00%	ND	0.039
CA	2007	WG	20	0	0.00%	ND	0.039
CA	2008	WG	71	0	0.00%	ND	0.02
CA	2009	WG	86	0	0.00%	ND	0.08
CA	2010	WG	69	0	0.00%	ND	0.022 – 0.08
CA	2011	WG	35	0	0.00%	ND	0.022
CA	2012	WG	152	0	0.00%	ND	0.022
CA	2013	WG	73	0	0.00%	ND	0.003 – 0.022
CA	2014	WG	12	0	0.00%	ND	0.003 – 0.022
CA	2015	WG	6	0	0.00%	ND	0.003
CA	**All Years**	**WG**	**846**	**0**	**0.00%**	**ND**	**0.003 – 0.08**

[a] ND: not detected.
[b] LOD: limit of detection.
[c] RL: reporting limit.

Table I-16 Summary of California surface water monitoring data for malaoxon from USGS NWIS (2001-2015).							
State	***Year***	***Sample Medium***	***# Samples***	***# Detects***	***% Detects***	***Range of Detected Values (µg/L)[a]***	***Range of LODs/RLs (µg/L)[b,c]***
CA	2001	WS	20	0	0.00%	ND	0.003 – 0.008
CA	2002	WS	43	0	0.00%	ND	0.008
CA	2003	WS	143	0	0.00%	ND	0.008
CA	2004	WS	69	0	0.00%	ND	0.008 – 0.045
CA	2005	WS	66	0	0.00%	ND	0.03 – 0.09
CA	2006	WS	61	0	0.00%	ND	0.03 – 0.039
CA	2007	WS	59	0	0.00%	ND	0.02 – 0.039
CA	2008	WS	75	1	1.33%	0.021	0.02 – 0.08
CA	2009	WS	81	0	0.00%	ND	0.005 – 0.08
CA	2010	WS	92	0	0.00%	ND	0.005 – 0.08
CA	2011	WS	60	0	0.00%	ND	0.022
CA	2012	WS	64	0	0.00%	ND	0.003 – 0.022
CA	2013	WS	58	1	1.72%	0.0002	0.003 – 0.005
CA	2014	WS	42	0	0.00%	ND	0.003 – 0.005
CA	2015	WS	25	0	0.00%	ND	0.003 – 0.005
CA	**All Years**	**WS**	**958**	**2**	**0.21%**	**0.0002 – 0.021**	**0.003 – 0.09**

[a] ND: not detected.
[b] LOD: limit of detection.
[c] RL: reporting limit.

CDPR Surface Water Database (SWD)

The CDPR SWD was developed under a 1997 agreement with the State Water Resources Control Board and includes monitoring results for pesticides in water samples taken from California rivers, creeks, urban streams, agricultural drains, the San Francisco Bay delta region, and urban storm water runoff (CDPR, 2013). The full database was downloaded on August 15th, 2014 from the following webpage: http://www.cdpr.ca.gov/docs/emon/surfwtr/surfcont.htm. Monitoring data were last updated in April 2014. Monitoring data from 2011 to 2014 were updated using the most recent version of the database from June 2015 (CDPR, 2015).

Table I-17 and Table I-18 summarize CDPR surface water data for malathion and malaoxon, respectively. Malathion was detected in 314 of 8317 surface water samples taken in California between 2001 and 2014. Measured concentrations of malathion ranged from 0.0086 to 22.5 µg/L and LOQs ranged from 0 to 2 µg/L. The highest observed concentration was reported in 2008.

Malaoxon concentrations did not exceed the LOQs (0.02 – 0.08 µg/L) in any of the 481 surface water samples presented in the CDPR SWD.

Table I-17 Summary of California surface water monitoring data for malathion from the CDPR SWD (2001 to 2014).

Year	*# Samples*	*# Detects*	*% Detects*	*Range of Detected Values (µg/L)*	*Range of LODs/LOQs (µg/L)*[a,b]
2001	839	24	2.86%	0.028 – 5.55	0.018 – 0.15
2002	581	7	1.20%	0.0282 – 0.36	0.027 – 0.1
2003	501	13	2.59%	0.0405 – 0.544	0.01 – 0.05
2004	241	6	2.49%	0.0354 – 0.225	0.027 – 2
2005	505	8	1.58%	0.0457 – 0.91	0.027 – 2
2006	443	1	0.226%	0.19	0.016 – 2
2007	732	11	1.50%	0.01 – 0.96	0.006 – 2
2008	912	46	5.04%	0.0124 – 22.5	0 – 2[d]
2009	556	27	4.86%	0.0123 – 2.80	0.006 – 2
2010	706	32	4.53%	0.017 – 13.0	0.00583 – 2
2011	901	42	4.66%	0.0086 – 11.9	0.006 – 0.1
2012	344	29	8.43%	0.0135 – 12.5	0.0037 – 4
2013	709	32	4.51%	0.021 – 3.9	0.0037 – 4
2014	347	36	10.37%	0.0139 – 3.71	0.006 – 4
All Years	**8317**	**314**	**3.78%**	**0.0086 – 22.5**	**0 – 4**[c]

[a] LOD: limit of detection.
[b] LOQ: limit of quantitation.
[c] The lowest LOQ in the CDPR SWD was reported as 0 µg/L. The next lowest LOQ was 0.0037 µg/L.

Table I-18 Summary of California surface water monitoring data for malaoxon from the CDPR SWD (2005 to 2012).					
Year	*# Samples*	*# Detects*	*% Detects*	*Range of Detected Values (µg/L)*[a]	*Range of LOQs (µg/L)*[b]
2005	14	0	0.0%	ND	0.0298
2006	45	0	0.0%	ND	0.0298 – 0.039
2007	59	0	0.00%	ND	0.02 – 0.039
2008	71	0	0.00%	ND	0.02 – 0.08
2009	71	0	0.00%	ND	0.08
2010	57	0	0.00%	ND	0.022 – 0.08
2011	112	0	0.00%	ND	0.022
2012	52	0	0.00%	ND	0.022
All Years	**481**	**0**	**0.00%**	**ND**	**0.02 – 0.08**

[a] ND: not detected.
[b] LOQ: limit of quantitation.

California Data Exchange Network (CEDEN)

CEDEN is a portal for monitoring data collected from a range of California state organizations. Current participants in the CEDEN network include several of the state water boards, Surface Water Ambient Monitoring Program (SWAMP), Southern California Coastal Water Research Project (SCCWRP), San Francisco Estuary Institute (SFEI), Marine Pollution Studies Laboratory at Moss Landing Marine Laboratories (MPSL – MLML), Central Valley Regional Data Center (CV RDC), and the EPA. These partners contribute data from their own monitoring programs to CEDEN to facilitate its dissemination to the public, and other interested parties. CEDEN data were accessed on April 9th, 2013 using the main data access page http://www.ceden.org/ceden_data.shtml (CEDEN, 2013). Using the advanced query tool, the parameter group selected was 'pesticides', the pesticide selected was 'malathion, total', and the medium selected was 'samplewater'. Malaoxon was not available as a searchable parameter within CEDEN. The available date range was from September 18th, 2001 to June 27th, 2012. The data were collected from both grab samples (at different depths) and integrated monitoring samples (samples from fixed monitoring stations). CEDEN was queried again on February 12th, 2016 to access data from 2012 to 2015 (CEDEN, 2016).

Compliance, QA and batch verification codes associated with malathion surface water data retrieved from CEDEN are presented in Table I-19, Table I-20 and Table I-21, respectively. Compliance codes indicate whether sample collection and analysis was compliant with the associated Quality Assurance Project Plan (QAPP); QA codes describe special conditions, situations or outliers that occurred before or during analysis; and batch verification codes indicate how groups of samples processed together (i.e., batches) were verified against measurement quality objectives (MQOs) and other QC standards (CEDEN, 2012). Data were excluded from the analysis if the compliance code was listed as "NR", "Qual" or "QualH; if the QA code was listed as "BRKA", "D", "FDP", "GN", "GR", "H", "IL", "LC", "NR", "PG", "PI", "VGB", "VGN", "VH", "VIL" or "VNMDL"; or if the batch verification code was listed as "VAC, VI" or "VAC, VQI". Data with the compliance code "Hist" were analyzed separately.

Table I-19 Compliance codes for malathion data in the CEDEN database (SCCWRP, 2012).		
Compliance Code	***Description***	***Included in Analysis? (Y/N)***
Com	Compliant with associated QAPP[a]	Y
Est	Data is considered to be non-quantifiable, estimated	Y
Hist	Historical; no supporting QC data	Y[b]
NR	Not recorded	N
Qual	Qualified	N
QualH	Estimated; Non-compliant with associated QAPP, analytes not covered in associated QAPP, insufficiently documented, need supplementary info for data to be used	N
Scr	Screening level analysis	Y

[a] QAPP: quality assurance project plan.
[b] Analyzed separately from compliant data.

Table I-20 QA codes for malathion data in the CEDEN database (SCCWRP, 2012).		
QA Code	***Description***	***Included in Analysis? (Y/N)***
BRKA	Sample container broken but analyzed	N
CS	QC criteria not met due to analyte concentration near RL	Y
D	EPA Flag – Analytes analyzed at a secondary dilution	N
DF	Reporting limits elevated due to matrix interferences	Y
FDP	Field duplicate Relative percent difference above QC limit	N
GN	Surrogate recovery is outside of control limits	N
GR	Internal standard recovery is outside method recovery limit	N
H	A holding time violation has occurred	N
IL	Relative percent difference exceeds laboratory control limit	N
LC	Laboratory Contamination	N
NMDL	No Method Detection Limit reported from laboratory	Y
None	None - No QA Qualifier	Y
NR	Not Recorded	Y
PG	Calibration verification outside control limits	N
PI	Primary and confirmation results varied by > than 40%	N
PJM	Result from re-extract/re-anal to confirm original result	Y
SCR	Screening level analysis	Y
UJ	Analyte was not detected above the reported sample quantitation limit. Reported quantitation limit is approximate and may not represent the actual limit of quantitation necessary to accurately and precisely measure the analyte in the sample.	Y
VC	Result was calculated by the data management team when not provided for "Does Not Qualify (DNQ)" ResQualCode, value ½ distance between MDL and RL, flagged by QA officer	N
VGB	Matrix spike recovery not within control limits, flagged by QAO	N
VGN	Surrogate recovery not within control limits, flagged by QAO	N
VH	Holding time violation occurred, flagged by QA officer	N
VIL	RPD exceeds control limit, flagged by QAO	N
VNMDL	No MDL reported from laboratory, flagged by QA officer	N

Table I-21 Batch verification codes for malathion data in the CEDEN database (SCCWRP, 2012).		
Batch Verification Code	***Description***	***Included in Analysis? (Y/N)***
NR	Not recorded	Y
VAC	Cursory verification of electronic data against MQOs including recalculation of % recoveries and RPDs for QC samples	Y
VAC, VI	Cursory verification of electronic data against MQOs including recalculation of % recoveries and RPDs for QC samples, Batch has incomplete QC; Batch Comment required	N
VAC, VMD	Cursory verification of electronic data against MQOs including recalculation of %Rs and RPDs for QC samples; Minor deviations in test conditions, batch comment required; Flagged by QAO	Y
VAC, VQI	Cursory verification of electronic data against MQOs including recalculation of %Rs and RPDs for QC samples; Batch has incomplete QC, batch comment required; Flagged by QAO	N

A summary of CEDEN data for malathion is provided in Table I-22. Malathion was detected in 34 of 751 samples obtained between 2001 and 2014 at concentrations ranging from 0.0086 to 0.556 µg/L. Method detection limits (MDLs) ranged from 0.0021 to 0.05 µg/L and RLs ranged from 0.006 to 0.1 µg/L.

Table I-22 Summary of California monitoring data for malathion from CEDEN (2001 to 2014).

Year	*# Samples*	*# Detects*	*% Detects*	*Range of Detected Values (µg/L)[a]*	*Range of MDLs (µg/L)*	*Range of RLs (µg/L)[b,c]*
2001	3	1	33.33%	0.06	0.03	0.05
2002	89	1	1.12%	0.36	0.03	0.05
2003	60	2	3.33%	0.032 – 0.069	0.03 – 0.05	0.05
2003[d]	12	6	50.00%	0.0086 – 0.142	0.0021	NR
2004	13	1	7.69%	0.033	0.03	0.05
2005	10	0	0.00%	ND	0.03	0.05
2006	14	0	0.00%	ND	0.03	0.05
2007	49	0	0.00%	ND	0.03	0.05
2008	86	5	5.81%	0.033 – 0.112	0.03	0.05
2009	84	0	0.00%	ND	0.03	0.05
2010	91	3	3.30%	0.032 – 0.085	0.03	0.05
2011	42	2	4.76%	0.166 – 0.426	0.018 – 0.03	0.05 – 0.1
2012	76	1	1.32%	0.061	0.018	0.1
2013	94	11	11.7%	0.0495 – 0.556	0.003 – 0.018	0.006 – 0.1
2014	28	1	3.57%	0.1638	0.003	0.006
All Years	**751**	**34**	**4.53%**	**0.0086 – 0.556**	**0.0021 – 0.05**	**0.006 – 0.1**

[a] ND: not detected.
[b] NR: not reported.
[c] RL: reporting limit.
[d] Historical data.

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Appendix J
Aquatic Incident Reports

Ecological Incident Information System

The US Ecological Incident Information System (EIIS) contains information on reported ecological incidences involving pesticides. EIIS data were received on May 7th, 2015 in response to a *Freedom of Information Act* (FOIA) request dated April 20th, 2015. There have been 31 incidents involving aquatic species and malathion from 1970 to 2007, and only two aquatic incidents have been reported since 2000 (Table I-1). The EIIS report provides general information on the incident location, date, certainty, legality, end-use product, application method and total magnitude. Certainty is ranked on a scale from 0 to 4 as described below (Pease, 2016):

- **Unrelated (0):** Conclusive evidence exists that a stressor other than exposure to the given pesticide caused the incident.
- **Unlikely (1):** Evidence exists that a stressor other than exposure to this pesticide caused the incident, but that evidence is not conclusive.
- **Possible (2):** The pesticide possibly could have caused the incident, but there are possible explanations that are at least as plausible. Often used when organisms were exposed to more than one pesticide.
- **Probable (3):** Circumstances of the incident and properties of the pesticide indicate that this pesticide was the cause, but confirming evidence is lacking.
- **Highly Probable (4):** Pesticide was confirmed as the cause through residue analysis or other reliable evidence, or the circumstances of the incident along with knowledge of the pesticide's toxicity or history of previous incidents give strong support that this pesticide was the cause.

Of the 31 aquatic incidents reported, five were considered highly probable, 11 were probable, 13 were possible, and two were unlikely to be related to malathion application. The legality code indicates whether the incident was due to a registered use, misuse (not applied as per label), accidental misuse (e.g., spill), intentional misuse (e.g., baiting) or unknown. Of the 31 aquatic incidents reported, 10 were classified as occurring with registered uses of malathion, 14 were unknown, and seven were due to misuse. Incidents involving the misuse of malathion (accidental or intentional) are not considered further in this effects determination. In some incident reports, information is also available that describes the affected species, responses observed (e.g., mortality, behavioural), and the identified route of exposure. Additional information on application rate and type, and local meteorological conditions was not provided. There is also a significant amount of descriptive information missing for many of the reported incidents, making it difficult to interpret the information in some cases.

As stated above, five of the 31 aquatic incidents had a high probability (Certainty Code = 4) of being associated with malathion use (Table J-1). Of these five incidents, two were associated with a registered use, while the remainder were either unknown or the result of misuse. The most recent reported aquatic incidents, which occurred in 2003 and 2007, were both the result of spills. All of the remaining incidents occurred prior to 2000. The majority of all aquatic incidents involved fish kills. Both drift and runoff were the commonly reported routes of transport

to aquatic environments. There was insufficient detail for many of the reported aquatic incidents to determine the end-use product or application methods most commonly.

There are two primary sources of incident reports in the United States. The first source is Section 6(a)(2) of FIFRA, where pesticide registrants or manufacturers are required to report to EPA any information on known adverse effects to the environment caused by registered pesticides. Before 1998, registrants were required to submit any information on all ecological incidents to their knowledge. However, registrants are now only required to submit information on "major" incidents (EPA, 2012). Incident reports submitted from other sources, such as the States, are also included in the EIIS. One of the issues with the development of the EIIS is lack of proper tracking and quality control. Within the EIIS, each incident is assigned a unique incident number. However, duplicate incidents in the malathion EIIS reports may exist (see Table J-1):

I002059-001 and I002059-002	Identical date, location, legality code and end-use product, organisms affected and exposure route. Certainty code and magnitude are different. Taxon affected and exposure route were not reported for I001059-001.

Boll Weevil Eradication Program

The Boll Weevil Eradication Program (BWEP) began in 1978 as a trial program in North Carolina and southeastern Virginia to control the cotton boll weevil (*Anthonomus grandis* Boheman), which was the top pest for cotton in the US at the time (USDA, 2013). Malathion was the main pesticide used in the BWEP and was applied at rates of 10 to 16 oz per acre (0.8-1.28 lb/A). The BWEP was later expanded to include treatment of cotton acreage in Alabama, Arizona, Arkansas, California, Florida, Georgia, Kansas, Louisiana, Mississippi, Missouri, New Mexico, Oklahoma, South Carolina, Tennessee and Texas (USDA, 2013).

Environmental monitoring for BWEP activities located near areas of human health and ecological concern, which included the investigation of incidents suspected of being related to BWEP operations, was conducted by the USDA (USDA, 2006; 2007; 2008; 2009a; 2010). Malathion incident reports collected by the Environmental Compliance Team, Riverdale, MD in relation to the BWEP were requested on September 17th, 2014 under the *Freedom of Information Act* (FOIA) and were received on October 6th, 2015 (USDA, 2015). There were 18 aquatic incidents reported, and 12 of these were either unrelated or unlikely to be related to malathion use (Table I-2). All reported aquatic incidents involved effects to fish.

In three incidents (Site IDs 1403310602, 1403403601, and 510032502), the presence of other stressors (e.g., low oxygen levels, application of another chemical) made it impossible to attribute the mortalities solely to malathion. Mullet and perch mortalities were also reported in a pond (Site ID 3150110403) with a measured malathion concentration of 4.2 µg/L. However, the findings of this report were inconclusive due to the late reporting of the incident. Only one incident at site 302091501 in Arkansas was likely related to malathion exposure. The affected

pond was located 50 feet from the treated cotton field and 22 to 29 µg/L malathion was measured in the pond four days after application. Based on the size of the pond and distance from the cotton field, malathion concentrations immediately after application were estimated to be 38 to 68 µg/L (Table J-2). Based on reported LC50 data for sensitive fish species, the USDA determined that malathion could have been a factor in the observed bream mortalities (USDA, 2015).

Summary

Overall, the EIIS and BWEP data suggest that incidents resulting from the legal, registered uses of malathion are infrequent, particularly given the widespread use of malathion over the 37-year reporting period. The majority of the incidents resulted from misuse of malathion or had insufficient information provided to determine whether malathion was the cause of the observed effects. Very few incidents have occurred since 2000. The lack of recent incidents suggests that the current malathion labels are protective of aquatic biota.

Most of the malathion incidents reported since 2000 were related to applications made under the BWEP. As a result, the BWEP adopted a number of exposure mitigation measures and these are now part of the standard operating procedures used in the BWEP (USDA, 2012a,b). In addition, as of 2013, the boll weevil has been eradicated from all cotton-producing states except for Texas' Lower Rio Grande Valley area (USDA, 2013). As such, USDA Animal and Plant Health Inspection Services (APHIS) projects that during the post eradication phase, the program will apply malathion for boll weevil control only where outbreaks occur (USDA, 2009b).

Furthermore, Cheminova has improved its manufacturing process for malathion to reduce impurities(Hillwalker and Reiss, 2014 [MRID 49316501]), application rates have been adjusted and spray drift and runoff reduction measures have been added to labels (EPA, 2009). These factors will continue to reduce the likelihood of incidents occurring.

Table J-1 Ecological Incident Information System (EIIS) summary for malathion in aquatic environments (Accessed May 7, 2015; EPA, 2015).

Incident #	*Date*	*County, State*	*Certainty Code*	*Legality Code*	*End-use Product*	*Application Method*	*Taxon Affected*	*Magnitude*	*Exposure Route*
I018937-001	--	Sublette, WY	2	MA	--	Spray	Rainbow trout (*Oncorhynchus mykiss*), Whitefish (*Coregonus sp.*)	300	Flowing water
I005754-017	--	Riverside, CA	1	MA	NR	Spill	Unknown fish	13,000	Runoff
I000636-002	05/05/1970	Lincoln, MO	2	MI	--	NR	Unknown fish	Thousands	Spill
B0000-300-86	04/14/1973	Horry, SC	2	UN	--	NR	Unknown fish	300	Ingestion
B0000-225	05/17/1973	Wake, NC	4	MA	--	Spill	Unknown fish	1,000 or 10,000	Spill
B0000-218-05	08/02/1975	Sutter, CA	3	MA	--	Spray	Crappie (*Centrarchidae*), Shad (*Clupeidae*)	10,000	Drift
B0000-502-22	08/25/1976	Queen Annes, MD	3	UN	NR	Spray	Menhaden (*Brevoortia sp.*)	Thousands	Drift
B0000-502-04	08/12/1977	Charleston, SC	4	RU	--	Spray	Pompano (*Trachinotus sp.*)	200	Drift
B0000-300-27	08/28/1978	Beaufort, SC	2	UN	--	NR	Unknown fish	Unknown	--
B0000-502-05	04/14/1979	Horry, SC	3	UN	NR	NR	Bream (*Notemigonus crysoleucas*)	100	Runoff
							Bass (*Micropterus spp.*)	100	Runoff
							Crappie (*Centrarchidae*)	100	Runoff
B0000-502-25	07/31/1979	Howard, MD	4	UN	NR	NR	American eel (*Anguilla rostrata*), Crayfish (*Decapoda*), Golden shiner (*Notemigonus crysoleucas*), Green sunfish (*Lepomis cyanellus*), Largemouth bass (*Micropterus salmoides*), Minnow (*Cyprinidae*), Pumpkinseed (*Lepomis gibbosus*), Redfin pickerel (*Esox americanus*), Warmouth (*Lepomis gulosus*)	206	Drift

Table J-1 Ecological Incident Information System (EIIS) summary for malathion in aquatic environments (Accessed May 7, 2015; EPA, 2015).

Incident #	*Date*	*County, State*	*Certainty Code*	*Legality Code*	*End-use Product*	*Application Method*	*Taxon Affected*	*Magnitude*	*Exposure Route*
B0000-502-26	05/12/1980	Prince Georges, MD	3	RU	NR	NR	Bluegill (*Lepomis macrochirus*)	35	Runoff
							Carp (*Cyprinus carpio*)	100	Runoff
							Golden shiner (*Notemigonus crysoleucas*)	200	Runoff
							Goldfish (*Caassius auatus*)	15	Runoff
B0000-502-08	05/26/1981	Beaufort, SC	3	UN	NR	NR	Bream (*Notemigonus crysoleucas*)	11	NR
B0000-300-30	06/25/1981	Beaufort, SC	2	UN	--	NR	Blue crab (*Callinectes sapidus*)	500	Ingestion
							Eel (*Angulliformes*)	500	Ingestion
							Shad (*Clupeidae*)	500	Ingestion
B0000-300-33	09/22/1982	Beaufort, SC	3	UN	--	NR	Drum (*Aplodinotus grunniens*), Mullet (*Mugilidae*), Spot, Trout (*Salmonidae*)	Unknown	Ingestion
B0000-502-13	08/11/1984	Beaufort, SC	2	UN	NR	Spray	Bream (*Notemigonus crysoleucas*)	100	NR
							Croaker (*Seiaenidae sp.*)	100	NR
							Spot tail bass	100	NR
B0000-502-14	09/15/1985	Beaufort, SC	2	UN	NR	NR	Unknown fish	1000	NR
I000804-025	07/06/1987	Minnehaha, SD	3	UN	EC	Spray	Walleye (*Sander vitreus*)	Thousands	Drift
							Yellow pech (*Perca flavescens*)	Thousands	Drift
B0000-500-32	09/05/1988	GA	3	UN	--	NR	American alligator (*Alligator mississipiensis*)	1	Runoff
							Unknown fish	Unknown	Runoff
B0000-500-16	07/23/1989	Brooks, GA	2	RU	--	Spray	Bream (*Notemigonus crysoleucas*)	Many	Drift
B0000-500-14	10/06/1989	Brooks, GA	3	RU	F	Spray	Unknown fish	Unknown	NR
B0000-500-29	08/30/1990	Brooks, GA	3	UN	--	Spray	NR	Unknown	Drift
I002059-001	11/04/1994	Cherokee, AL	4	RU	ULV	NR	--	30	--
I002059-002	11/04/1994	Cherokee, AL	3	RU	ULV	NR	Largemouth bass (*Micropterus salmoides*)	Some out of 30 dead	Runoff
B0000-600-01	08/08/1998	Haywood, TN	2	RU	NR	Spray	Bream (*Notemigonus crysoleucas*)	Hundreds	Drift
							Sunfish (*Centrarchidae*)	Hundreds	Drift
B0000-503-52	08/11/1998	Holmes, MS	2	RU	NR	Spray	Catfish (*Ictaluridae*)	15	Drift

Table J-1 Ecological Incident Information System (EIIS) summary for malathion in aquatic environments (Accessed May 7, 2015; EPA, 2015).

Incident #	*Date*	*County, State*	*Certainty Code*	*Legality Code*	*End-use Product*	*Application Method*	*Taxon Affected*	*Magnitude*	*Exposure Route*
B0000-600-03	08/13/1998	Fayette, TN	1	RU	NR	Spray	Bream (*Notemigonus crysoleucas*), Bass (*Micropterus spp.),* Crappie (*Centrarchidae*)	Unknown	Drift
B0000-600-04	08/31/1998	Haywood, TN	2	RU	NR	Spray	Catfish (*Ictaluridae*)	16	Drift
I009790-001	09/24/1999	Richmond, NY	4	UN	NR	NR	Bluegill (*Lepomis macrochirus*)	14	Drift
							Unknown fish	1500	Treated directly
I014123-006	05/03/2003	Craven, NC	2	MA	--	Spill	Bowfin (*Amia calva*), Carp (*Cyprinus carpio*), Catfish (*Ictaluridae*), Crappie (*Centrarchidae*), Largemouth bass (*Micropterus salmoides*), Sunfish (*Centrarchidae*), Turtle (*Testudines*), Unknown snake	Unknown	Treated directly
							Unknown fish	Approx. 2000	Treated directly
I021178-001	07/26/2007	ON	2	MA	--	Spill	Unknown fish	5000	Runoff

--: Data not provided.
NR: Not reported.
Certainty Code: 0 = Unrelated, 1 = Unlikely, 2 = Possible, 3 = Probable, 4 = Highly Probable
Legality Code: RU = Registered Use, M = Misuse, MA = Misuse (Accidental), MI = Misuse (Intentional), UN = Unknown.
End-use Product: EC = emulsifiable concentrate; ULV = Ultra low volume

Table J-2 Boll Weevil Eradication Program (BWEP) summary for malathion in aquatic environments (Accessed October 6, 2015; USDA, 2015).

Site ID	*Date*	*State*	*Certainty*	*Taxon/ Species Affected*	*Magnitude*	*Exposure Route*	*Response*	*Measured malathion concentrations*			*Predicted initial malathion concentration in pond (ppb)*
								Fish (ppm)	*Pond (ppb)*	*Vegetation (ppm)*	
1403310602	07/06/2004	TX	Possible	Bass	1	Drift	Mortality	NR	0.51	NR	68
			Unrelated	Catfish	1	Drift	Mortality	NR	0.51	NR	68
1405090303	07/07/2004	TX	Unrelated	Catfish, perch, mullet, and redfish	NR	Drift	Mortality	NR	0.12-0.4	NR	NR
224142102	07/19/2004	AR	Unrelated	Carp, perch	NR	Drift	Mortality	NR	<0.12-0.4	<0.024-0.08	0.9
511051602	07/28/2004	AR	Unrelated	Catfish	20	Drift	Mortality	0.13	14	NR	NR
341820202	08/26/2004	TX	Unrelated	Koi	17	Drift	Mortality	NR	1.3	NR	1.1-2.3
502030501	08/30/2004	AR	Unrelated	Catfish	2 to 3	Drift	Mortality	NR	2.5[a]	1	NR
224231701	09/28/2004	AR	Unrelated	Perch and largemouth bass	Thousands	NA	Mortality	<0.024-0.08	<0.14	NR	NR
3150110403	09/29/2004	TX	Possible	Mullet and perch	NR	Drift	Mortality	NR	4.2	NR	NR
1406120701 1406120702 1406120705 1406120706	10/20/2004	TX	Unlikely	Perch and largemouth bass	NR	Drift	Mortality	NR	1.8	0.36	NR
329040302	06/03/2005	TX	Unrelated	Catfish	37	Drift	Mortality	NR	0.58	NR	NR
1404051503	08/30/2005	TX	Unlikely	Fish	NR	Drift	Mortality	NR	2	11	NR
1406092301	09/03/2005	TX	Unlikely	Fish	NR	Drift	Mortality	NR[b]	NR[c]	<0.024	NR
302091501	09/26/2005	AR	Probable	Bream	35-45	Drift	Mortality	NR	22-29	NR	38-68
			Probable	Crappie	1	Drift	Mortality	NR	22-29	NR	38-68
			Probable	Bass	1	Drift	Mortality	NR	22-29	NR	38-68
2315-4279	09/30/2005	MS	Possible	Bass and bream	100	Drift	Mortality	0.11-0.41	2.5	NR	19-25
1404041402	05/06/2006	TX	Unlikely	Goldfish	16	Drift	Mortality	NR[d]	0.12-0.40	NR	0.4-0.8
1403403601	09/10/2007	TX	Possible[e]	Mainly bass species	6 to 7	Drift	Mortality	NR	1.8	NR	0.1-8.3

Table J-2 Boll Weevil Eradication Program (BWEP) summary for malathion in aquatic environments (Accessed October 6, 2015; USDA, 2015).

Site ID	*Date*	*State*	*Certainty*	*Taxon/ Species Affected*	*Magnitude*	*Exposure Route*	*Response*	*Measured malathion concentrations*			*Predicted initial malathion concentration in pond (ppb)*
								Fish (ppm)	*Pond (ppb)*	*Vegetation (ppm)*	
510032502	09/17/2007	AR	Possible	Fish	Hundreds	Drift	Mortality	NR	7.1	NR	23-38
332021501	09/22/2008	TX	Unrelated	Catfish	NR	Drift	Mortality	NR	10	NR	NR

NR: Not reported

[a] Malathion concentration in the water sample could not be determined due to problems with the analytical equipment. Concentration at time of sampling was estimated based on residues observed on vegetation.

[b] Fish samples were not collected due to their advanced state of decay.

[c] Water samples were not collected since water had been added to the pond since the incident was observed, raising the water level by two feet.

[d] Fish sample was too small to be analyzed.

[e] Defoliant was applied prior to observed incident and could have contributed to fish mortality. However, the chemical, application rate and dates applied are unknown.

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