Water Quality Criteria Report for Permethrin

Phase III: Application of the pesticide water quality criteria methodology

Prepared for the Central Valley Regional Water Quality Control Board

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List of acronyms and abbreviations

ACR	Acute-to-Chronic Ratio
APHA	American Public Health Association
ASTM	American Society for Testing and Materials
BAF	Bioaccumulation Factor
BCF	Bioconcentration Factor
BMF	Biomagnification Factor
CA	Concentration Addition
CAS	Chemical Abstract Service
CDFG	California Department of Fish and Game
CDPR	California Department of Pesticide Regulation
CDWR	California Department of Water Resources
CSIRO	Commonwealth Scientific and Industrial Research Organization, Australia
CVRWQCB	Central Valley Regional Water Quality Control Board
DOC	Dissolved Organic Carbon
DOM	Dissolved Organic Matter
EC_x	Concentration that affects x% of exposed organisms
FDA	Food and Drug Administration
FT	Flow-through test
GMAV	Genus Mean Acute Value
IA	Independent Action
IC_x	Inhibition concentration; concentration causing *x*% inhibition
ICE	Interspecies Correlation Estimation
IUPAC	International Union of Pure and Applied Chemistry
K	Interaction Coefficient
K_H	Henry's law constant
K_{ow}	Octanol-Water partition coefficient
K_p or K_d	Solid-Water partition coefficient
LC_x	Concentration lethal to *x*% of exposed organisms
LD_x	Dose lethal to *x*% of exposed organisms
LL	Less relevant, Less reliable study
LOEC	Lowest-Observed Effect Concentration
LOEL	Lowest-Observed Effect Level
LR	Less relevant, Reliable study
MATC	Maximum Acceptable Toxicant Concentration
N	Not relevant or Not reliable study
n/a	Not applicable
NOAEL	No-Observed Adverse Effect Level
NOEC	No-Observed Effect Concentration
NR	Not reported
OC	Organic Carbon
OECD	Organization for Economic Co-operation and Development
PBO	Piperonyl butoxide
QSAR	Quantitative Structure Activity Relationship
pK_a	Acid dissociation constant

RL	Relevant, Less reliable study
RR	Relevant and Reliable study
S	Static test
SMAV	Species Mean Acute Value
SMCV	Species Mean Chronic Value
SPME	Solid-phase Microextraction
SR	Static renewal test
SSD	Species Sensitivity Distribution
TES	Threatened and Endangered Species
TIE	Toxicity Identification Evaluation
US	United States
USEPA	United States Environmental Protection Agency

1. Introduction

A new methodology for deriving freshwater water quality criteria for the protection of aquatic life was developed by the University of California, Davis (TenBrook *et al.* 2009a). The need for a new methodology was identified by the California Central Valley Regional Water Quality Control Board (CVRWQCB 2006) and findings from a review of existing methodologies (TenBrook & Tjeerdema 2006, TenBrook *et al.* 2009b). This new methodology is currently being used to derive aquatic life criteria for several pesticides of particular concern in the Sacramento River and San Joaquin River watersheds. The methodology report (TenBrook *et al.* 2009a) contains an introduction (Chapter 1); the rationale of the selection of specific methods (Chapter 2); detailed procedures for criteria derivation (Chapter 3); and a chlorpyrifos criteria report (Chapter 4). This criteria report for permethrin describes, section by section, the procedures used to derive criteria according to the UC-Davis methodology. Also included are references to specific sections of the methodology procedures detailed in Chapter 3 of the report so that the reader can refer to the report for further details (TenBrook *et al.* 2009a).

2. Basic information

Chemical: Permethrin (Fig. 1)

CAS: (3-phenoxyphenyl)methyl 3-(2,2-dichloroethenyl)-2,2-dimethylcyclopropanecarboxylate

IUPAC: 3-phenoxybenzyl (RS)-cis-trans-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropanecarboxylate

Chemical Formula: $C_{21}H_{20}Cl_2O_3$

CAS Number: 52645-53-1

CA DPR Chem Code: 2008

USEPA PC Code: 109701 (formerly 598600)

Trade names: Ambush, Dragnet, Ectiban, Exmin, FMC 33297, FMC 41665, ICI-PP 557, Kafil, Kestrel, NRDC-143, NIA 33297, Niagara 33297, Outflank, Outflank-stockade, Perthrine, Picket, Punce, Pramex, S 3151, SBP-1513, Talcord, WL 43479 (Mackay *et al.* 2006).

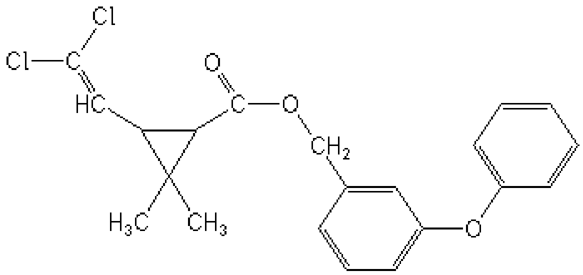

Figure 1. Structure of permethrin (http://www.alanwood.net/pesticides/permethrin.html).

3. Physical-chemical data

Molecular Weight
391.288 Mackay *et al.* 2006

Density
1.19-1.27 g/mL Mackay *et al.* 2006

Water Solubility
0.0055 mg/L at 20°C (mean, n=12) Laskowski 2002
0.006 mg/L at 20°C (pH 7) Tomlin 2003
Geomean: 0.0057 mg/L

Melting Point
Liquid at room temperature
34-39°C Worthing & Hance 1991
34-35°C Tomlin 2003
Geomean of extremes: 36.4°C

Vapor Pressure
4.5E-05 Pa (Mackay *et al.* 2006, Hartley & Kidd 1987)
1.3E-06 Pa (20°C, Mackay *et al.* 2006, Worthing & Hance 1991)
1.7E-06 Pa (20-25°C, Mackay *et al.* 2006, Wauchope *et al.* 1992, Hornsby *et al.* 1996)
1.48E-08 mm Hg (1.97E-06 Pa; 25°C, Laskowski 2002)
Geomean: 3.74E-06 Pa

Organic Carbon Sorption Partition Coefficients (K_{oc})
63,100 Meylan *et al.* 1992
277,000 soil adsorption (mean of 16 experiments) Laskowski 2002
GeoMean of K_{oc} values: 132,207

Henry's constant (K_H)
1.4 x 10^{-6} atm m^3 mol^{-1} at 20°C Laskowski 2002
1.1 x 10^{-6} atm m^3 mol^{-1} Mackay *et al.* 2006
Geomean: 1.2 x 10^{-6} atm m^3 mol^{-1}

Log K_{ow}

6.1 at 20°C — Laskowski 2002, Mackay *et al.* 2006, Tomlin 2003

6.5 — recommended by Sangster 2010

Geomean: 6.3

Environmental Fate

Table 1. Bioconcentration factors (BCF) for permethrin; FT: flow-through, S: static.

Species	BCF (L/kg)	Exposure	Reference
Anabaena (cyanobacteria)	57-813	S, 5 d	Kumar *et al.* 1988
Aulosira fertilissima (cyanobacteria)	46-2373	S, 5 d	Kumar *et al.* 1988
Chironomus dilutus	87.2	S, 96 h, 23°C	Harwood *et al.* 2009
Chironomus tentans	8-166	S, 24 h, water-sediment system	Muir *et al.* 1985
Crassostrea virginica	1900	FT	Schimmel *et al.* 1983
Cyprinodon variegatus	290-620	FT, 28 d	Hansen *et al.* 1983
Helisoma trivolvis (snail)	800	FT, 30 d	Spehar *et al.* 1983
Hydrophilus spp. (water scavenger beetle)	4.10 L/g	S, 6 h	Tang & Siegfried 1996
Hydropsyche & *Chematapshyche* spp. (caddisfly)	30.4 L/g	S, 6 h	Tang & Siegfried 1996
Ishnura & *Enallagma* spp. (damselfly)	6.87 L/g	S, 6 h	Tang & Siegfried 1996
Lepomis macrochirus	558	FT, 28 d	Burgess 1989
Lepomis macrochirus	681	FT, 28 d	Tullman 1989
Lumbriculus variegatus	1466	SR, 14 d	You *et al.* 2009
Oncorhynchus mykiss	328-631	FT, 4 d	Muir *et al.* 1994
Pimephales promelas	2800	FT, 30 d	Spehar *et al.* 1983
Salmo salar	14-73 L/g	S, 96 h	McLeese *et al.* 1980
Salmo salar	55	S, 96 h	Zitko *et al.* 1977

Simulium vittatum (black fly)	17.9 L/g	S, 6 h	Tang & Siegfried 1996
Stenacron spp. (mayfly)	23.6 L/g	S, 6 h	Tang & Siegfried 1996
Tetrahymena pyriformis (protozoa)	70-1110	2-12 h	Bhatnagar *et al.* 1988

Table 2. Permethrin hydrolysis, photolysis, and biodegradation.

	Half- life (d)	**Water**	**Temp (°C)**	**pH**	**Reference**
Hydrolysis	Stable	Sterile, buffered	25	5	Laskowski 2002
	Stable	Sterile, buffered	25	7	Laskowski 2002
	242	Sterile, buffered	25	9	Laskowski 2002
Aqueous Photolysis	110	NR	25	5	Amos & Donelan 1987, Laskowski 2002
Soil Biodegradation (aerobic)	39.5	3 soil types (n=8)	16-25	n/a	Laskowski 2002

4. Human and wildlife dietary values

There are no FDA action levels for permethrin (USFDA 2000). There are no food tolerances for human consumption of fish, but there are food tolerances for other meat products; tolerances of 0.05 mg/kg for the meat of poultry and hogs are the lowest recommended tolerances in the permethrin reregistration eligibility decision (USEPA 2006a).

Wildlife dietary NOECs for animals with significant food sources in water

A dietary NOEC of 125 mg/kg feed for 23-week old mallard ducks was determined over a 20 week period for the endpoints of hens with regressing ovary, food consumption, and number of eggs laid (Beavers *et al.* 1992). The LOEC was determined to be 500 mg/kg in this study.

5. Ecotoxicity data

Approximately 155 original studies on the effects of permethrin on aquatic life were identified and reviewed. In the review process, many parameters were rated for documentation and acceptability for each study, including, but not limited to: organism source and care, control description and response, chemical purity, concentrations tested, water quality conditions, and statistical methods (see Tables 3.6, 3.7, 3.8 in TenBrook *et al.* 2009a). Single-species effects studies that were rated relevant (R) or less relevant (L) according to the method (Table 3.6) were summarized in data summary sheets. Information in these summaries was used to evaluate each study for reliability using the rating systems described in the methodology (Tables 3.7 and 3.8, section 3-2.2, TenBrook *et al.* 2009a), to give a reliability rating of reliable (R), less reliable (L), or not reliable (N). Copies of completed summaries for all studies are included in Appendix B of this report. Permethrin studies deemed irrelevant from an initial screening were not summarized (*e.g.*, studies involving rodents or *in vitro* exposures). All data rated as acceptable (RR) or supplemental (RL, LR, LL) for criteria derivation are summarized in Tables 3 – 9, found at the end of this report. Acceptable studies rated as RR are used for numeric criteria derivation, while supplemental studies rated as RL, LR or LL are used for evaluation of the criteria to check that they are protective of particularly sensitive species and threatened and endangered species. These considerations are reviewed in sections 12 and 14 of this report, respectively. Studies that were rated not relevant (N) or not reliable (RN or LN) were not used for criteria derivation.

Using the data evaluation criteria (section 3-2.2, TenBrook *et al.* 2009a), 14 acute toxicity studies, yielding 66 toxicity values, were judged reliable and relevant (RR; Tables 3 and 4). Three chronic toxicity studies, yielding five toxicity values, were judged reliable and relevant (RR; Tables 6 and 7). Thirty four acute and three chronic studies were rated RL, LL, or LR and were used as supplemental information for evaluation of the derived criteria in section 12 (Tables 5 and 9, respectively).

Twelve mesocosm, microcosm and ecosystem (field and laboratory) studies were identified and reviewed using Table 3.9 (TenBrook *et al.* 2009a). Six of these studies were rated reliable (R) or less reliable (L) and were used as supporting data in section 13 to evaluate the derived criteria to ensure that they are protective of ecosystems (Table 10). Nine studies of permethrin effects on wildlife were identified and reviewed using Table 3.10 (TenBrook *et al.* 2009a) for consideration of bioaccumulation in section 15.

6. Data reduction

Multiple toxicity values for permethrin for the same species were reduced to one species mean acute toxicity value (SMAV) or one species mean chronic value (SMCV) according to procedures described in the methodology (section 3-2.4, TenBrook *et al.* 2009a). Acceptable acute and chronic data that were reduced, and the reasons for their exclusion, are shown in Tables 4 and 7, respectively. Reasons for reduction of data included: flow-through tests are preferred over static tests, more sensitive endpoints were available, a test at standard (vs. non-standard) conditions was available, and more appropriate or more sensitive test durations were available for the same test. The final acute and chronic data sets are shown in Tables 3 and 6, respectively. The final acute data set contains 19 SMAVs, and the final chronic data set contains three SMCVs.

7. Acute criterion calculation

At least five acceptable acute toxicity values were available and fulfilled the five taxa requirements of the species sensitivity distribution (SSD) procedure (section 3-3.1, TenBrook *et al.* 2009a). The five taxa requirements are a warm water fish, a fish from the family Salmonidae, a planktonic crustacean, a benthic crustacean, and an insect. Acute values were plotted in a histogram (Figure 2); the data could potentially be bimodal, as the invertebrates and fish are split, with the invertebrates encompassing the lower 7 SMAVs (with one duplicate value), and fish encompassing the upper 12 SMAVs.

The Burr Type III SSD procedure (section 3-3.2.1, TenBrook *et al.* 2009a) was used for the acute criterion calculation because more than eight acceptable acute toxicity values were available in the permethrin data set (Table 3). The Burr Type III SSD procedure was used to derive the median 5th percentile value and the median 1st percentile value. The software could not provide lower 95% confidence limits for the 1st or 5th percentiles. The median 5th percentile value is recommended for use in criteria derivation by the methodology because it is the most robust of the distributional estimates (section 3-3.2, TenBrook *et al.* 2009a).

Burr III distribution
Fit parameters: b=7.80465; c=6.599725; k=0.07608 (likelihood=35.742158)

5th percentile, 50% confidence limit: 0.020008 μg/L
1st percentile, 50% confidence limit: 0.000811 μg/L

Recommended acute value = 0.020008 μg/L (median 5th percentile value)

Acute criterion = acute value ÷ 2
= 0.020008 μg/L ÷ 2
= 0.010004 μg/L

Acute criterion = 0.01 μg/L
= 10 ng/L

The fit of the Burr III distribution from the BurrliOZ software (CSIRO 2001) is shown in Figure 3. This distribution provided a satisfactory fit (see Appendix A) according to the fit test described in section 3-3.2.4 of TenBrook *et al.* (2009a). No significant lack of fit was found (χ^2_{2n} = 0.3604) using a fit test based on cross validation and Fisher's combined test (section 3-3.2.4, TenBrook *et al.* 2009a), indicating that the data set is valid for criteria derivation. The final criterion is reported with one significant digit because there is variability in the first digit of the 5th percentile values generated in the fit test (see Appendix A), as described in section 3-3.2.6 (TenBrook *et al.* 2009a).

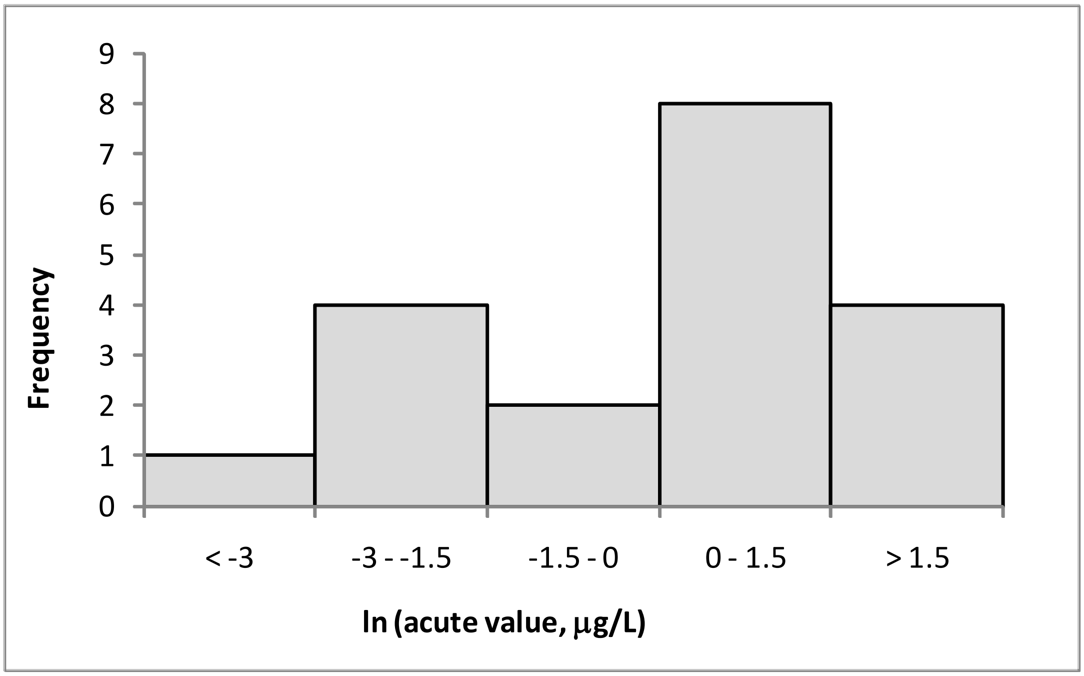

Figure 2. Histogram of the natural log of the permethrin species mean acute values.

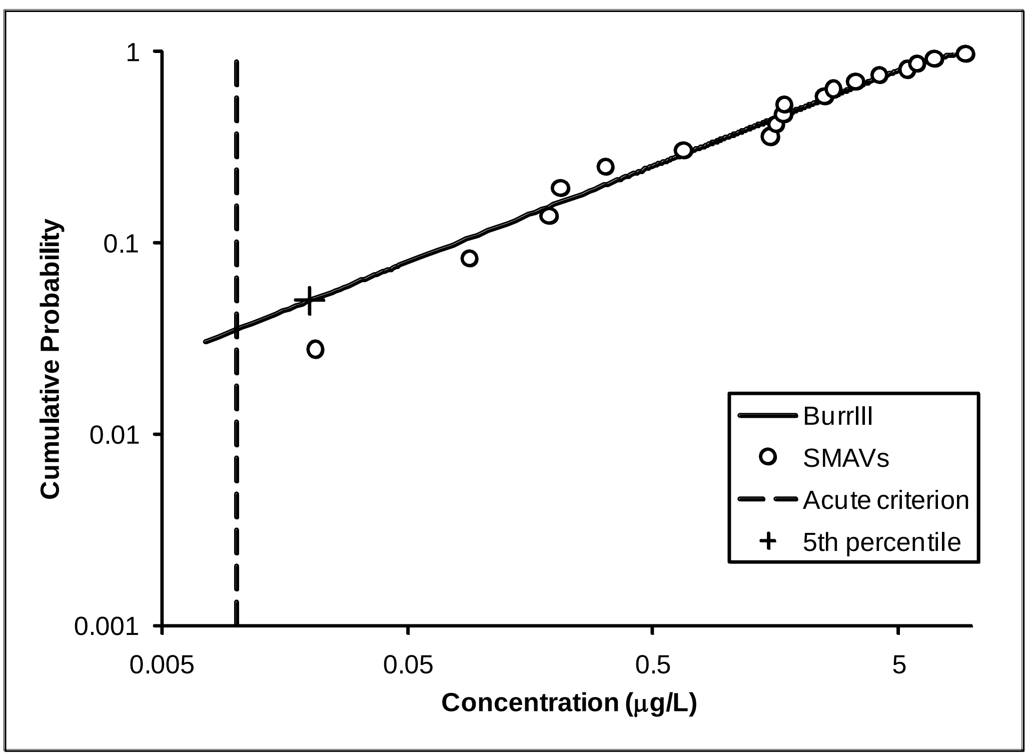

Figure 3. The fit of the Burr Type III distribution plotted with the acute toxicity values.

8. Chronic criterion calculation

Chronic toxicity values from fewer than five different families were available, thus the acute-to-chronic ratio (ACR) method was used to calculate the chronic criterion (section 3-4.2, TenBrook *et al.* 2009a). Two SMCVs are in the acceptable (rated RR) data set (Table 6), satisfying two of the five taxa requirements (section 3-3.1, TenBrook *et al.* 2009a): warm water fish (*Pimephales promelas)* and planktonic crustacean (*Daphnia magna)*.

There were no appropriate acute data to pair with any of the chronic freshwater data. One saltwater chronic toxicity value could be paired with an appropriate corresponding acute toxicity value to calculate an ACR for *Americamysis bahia*, satisfying one of the three family requirements: an invertebrate (section 3-4.2.1, TenBrook *et al.* 2009a). The species mean ACR (SMACR) for the measured data was calculated by dividing the acute LC_{50} by the chronic MATC. Data for two additional acutely sensitive species are required to derive an ACR based on measured data, but none were available, thus default ACRs were used for the second and third ACRs, as described in section 3-4.2.2 (TenBrook *et al.* 2009a). The default ACR of 12.4 is equal to the 80th percentile of the multispecies ACRs available in eight pesticide criteria reports (section 2-3.2.5.3, TenBrook *et al.* 2009a). This is the same procedure used by the USEPA to derive a default ACR in the Water Quality Guidance for the Great Lakes System (Host *et al.* 1995, USEPA 2003).

The final multi-species ACR of 8.96592 was obtained by calculating the geometric mean of the SMACR for *Americamysis bahia* and the two default ACRs (section 3-4.2.2, TenBrook *et al.* 2009a). The individual species and final multi-species ACRs generated are shown in Table 8.

The chronic criterion was calculated using the acute median 5th percentile and the final multi-species ACR as follows:

Chronic criterion = acute median 5th percentile ÷ ACR
= 0.020008 μg/L ÷ 8.96592
= 0.0022316 μg/L

Chronic criterion = 0.002 μg/L
= 2 ng/L

The chronic criterion is rounded to one significant figure because it is calculated with the acute value, so the same rounding used for the acute criterion was also used for the chronic criterion.

9. Bioavailability

Although permethrin and other pyrethroids are not very soluble in water, aquatic organisms are very sensitive to pyrethroids and toxicity does occur. Pyrethroids have been identified as a cause of toxicity in surface waters in the California Central Valley (Phillips *et al.* 2007, Weston *et al.* 2009, Weston and Lydy 2010). This toxicity is believed to occur primarily from the fraction of the pyrethroid that is dissolved in the water, not from the fraction that is associated with the particulate phase.

Several studies suggest that the binding of permethrin and other pyrethroids to suspended solids, dissolved organic matter (DOM), or sediment will make the bound fraction unavailable and thus nontoxic to aquatic organisms. Yang *et al.* (2006a, b) found uptake of permethrin by *Daphnia magna* and toxicity to *Ceriodaphnia dubia* decreased with increasing DOM concentration, and that the organism uptake was closely mimicked by a solid-phase microextraction (SPME) method using polydimethylsiloxane fibers. Regression analysis suggested that the portion of the pesticide sorbed to DOM was unavailable to organisms in the 24-96 hr study periods. Another study demonstrated that particulates and dissolved organic carbon (DOC) decreased the uptake and bioconcentration of permethrin in rainbow trout (Muir *et al.* 1994).

DeLorenzo *et al.* (2006) tested the toxicity of permethrin to grass shrimp larvae (*Palaemonetes pugio*) with and without sediment and the 24-h LC_{50} with sediment (0.22 μg/L) was a factor of 2.2 higher than when sediment was not present (0.10 μg/L). Hunter *et al.* (2008) found that the sediment organic carbon (OC)-normalized concentration of permethrin was highly correlated with the uptake of permethrin by *Chironomus dilutus* (formerly *C. tentans*), demonstrating a correlation between bioavailability of permethrin and sorption to OC. Uptake of permethrin by *C. dilutus* was also measured by Muir *et al.* (1985) in aquatic exposures with either sand, silt or clay and they found that uptake was most highly correlated to the dissolved concentration of permethrin in porewater, compared to concentrations in the sediment or whole water. They reported that sorption to sediments, suspended solids, and DOC, and hydrolysis all reduced bioavailability of pyrethroids. There are many studies on pyrethroids, not necessarily including permethrin, that also demonstrate decreased toxicity of pyrethroids in the presence of sediment, DOC, and other natural sorbents (Day 1991, Smith & Lizotte 2007, Xu *et al.* 2007). These studies indicate that the freely dissolved concentration will be the most accurate predictor of toxicity and that bound permethrin was unavailable to the organisms that were studied.

It can also be noted that bound pyrethroids can continue to desorb into the water column for long periods of time because pyrethroids have long equilibration times (~30 d, Bondarenko *et al.* 2006) and environmental systems are not likely at true equilibrium. The fraction of chemical that is potentially available to an organism is known as the bioaccessible fraction, and it has been linked to biological effects (Semple *et al.* 2004, You *et al.* 2011). Benthic organisms, such as *Hyalella azteca*, may be at greater risk because of their exposure to porewater and close proximity to sediments where dissolved concentrations may persist.

Additionally, the role of dietary exposure on bioavailability of pyrethroids has not been considered. Organisms living in contaminated waters are also ingesting food with sorbed hydrophobic compounds that can be desorbed by digestive juices (Mayer *et al.* 2001). The effects of dietary exposure may also be species-specific, depending on typical food sources; some species may have greater interaction with particles, increasing their exposure. Palmquist *et al.* (2008) examined the effects due to dietary exposure of the pyrethroid esfenvalerate on three aquatic insects with different feeding functions: a grazing scraper (*Cinygmula reticulata* McDunnough), an omnivore filter feeder (*Brachycentrus americanus* Banks), and a predator (*Hesperoperla pacifica* Banks). The researchers observed adverse effects in *C. reticulata* and *B. americanus* after feeding on esfenvalerate-laced food sources and that none of the three insects avoided the contaminated food. The effects included reduced growth and egg production of *C. reticulata* and abandonment and mortality in *B. americanus*. Stratton and Corke (1981) tested toxicity of permethrin to *Daphnia magna* with and without feeding of algae, and found that mortality at 24 h was significantly increased when daphnids were fed, although mortality at 48 h was not affected. The authors propose that permethrin may have been ingested by the daphnids if it was sorbed on the algal cells, and caused increased toxicity, although the same effect was not seen when bacteria were provided as a food source. These limited studies indicate that ingestion may be an important exposure route, but it is not currently possible to incorporate this exposure route into criteria compliance assessment.

Section 3-5.1 of the methodology (TenBrook *et al.* 2009a) suggests that if studies indicate that fewer than three phases of the pesticide (sorbed to solids, sorbed to dissolved solids, or freely dissolved in the water) are bioavailable, then compliance may be based on the concentration in the bioavailable phase(s). The studies above suggest that the freely dissolved fraction of permethrin is the primary bioavailable phase, and that this concentration is the best indicator of toxicity, thus, it is recommended that the freely dissolved fraction of permethrin be directly measured or calculated based on site-specific information for compliance assessment. If environemental managers choose to measure whole water concentrations for criteria compliance assessment, the bioavailable fraction will likely be overestimated.

The most direct way to determine compliance would be to measure the permethrin concentration in the dissolved phase to determine the total bioavailable concentration. Solid-phase microextraction only measures the freely dissolved concentration and has shown to be the best predictor of pyrethroid toxicity in several studies (Bondarenko *et al.* 2007, Bondarenko & Gan 2009, Hunter *et al.* 2008, Xu *et al.* 2007, Yang *et al.* 2006a, 2006b, 2007). Bondarenko & Gan (2009) report method detection limits of 2.0 ng/L for cis-permethrin and 3.0 for trans-permethrin, which are below the acute criterion and nearly identical to the chronic criterion, although method detection limits vary between laboratories. Li *et al.* (2009) report a method detection limit of 1.2 ng/L for permethrin using SPME, which is slightly below the chronic criterion. Filtration of particles is another option. Glass fiber filters with a nominal pore size of 0.7 μm or 0.45 μm are often used to remove the suspended sediments or both suspended sediments and dissolved organic matter, but the filters can interfere with the detection of hydrophobic contaminants. Gomez-Gutierrez *et al.* (2007) found that adsorption to filters was positively correlated with the log K_{ow} and solubility values of the compounds, and that on average 58% of a 50 ng/L solution of permethrin was lost on the filter. This loss may be critical for determining compliance at environmental concentrations.

Alternately, the following equation can be used to translate total permethrin concentrations measured in whole water to the associated dissolved permethrin concentrations:

$$C_{dissolved} = \frac{C_{total}}{1 + ((K_{OC} \cdot [SS]) / foc) + (K_{DOC} \cdot [DOC])} \qquad (1)$$

where: $C_{dissolved}$ = concentration of chemical in dissolved phase (μg/L);
C_{total} = total concentration of chemical in water (μg/L);
K_{OC} = organic carbon-water partition coefficient (L/kg);
[*SS*] = concentration of suspended solids in water (kg/L);
f_{oc} = fraction of organic carbon in suspended sediment in water;
[*DOC*] = concentration of dissolved organic carbon in water (kg/L);
K_{DOC} = organic carbon-water partition coefficient (L/kg) for DOC.

To determine compliance by this calculation, site-specific data are necessary, including: K_{OC}, K_{DOC}, the concentration of suspended solids, the concentration of DOC, and the fraction of organic carbon in the suspended solids. If all of these site-specific data, including the partition coefficients, are not available, then this equation should not be used for compliance determination. Site-specific data are required because the sorption of permethrin to suspended solids and dissolved organic matter depends on the physical and chemical properties of the suspended solids, and partition coefficients can vary by orders of magnitude. Such physical-chemical properties can vary both spatially and temporally, further complicating measurement of these properties and subsequent assessment of bioavailability using site-specific partition coefficients.

The freely dissolved permethrin concentration is recommended for determination of criteria compliance because the literature suggests that the freely dissolved concentrations are the most accurate predictor of toxicity. Environmental managers may choose an appropriate method for determination of the concentration of freely dissolved permethrin, or they may also choose to base compliance on whole water concentrations.

10. Mixtures

Permethrin often occurs in the environment with other pyrethroid pesticides (Trimble *et al.* 2009, Werner & Moran 2008), and the presence of chemicals in surface waters is ubiquitous. All pyrethroids have the same toxicological mode of action, and several studies have demonstrated that the toxicity of pyrethroid mixtures is additive and is well-predicted by the concentration addition model (Barata *et al.* 2006, Brander *et al.* 2009, Trimble *et al.* 2009). Definitions of additivity, synergism, antagonism, and non-additivity are available in the literature (Lydy and Austin 2004) and more detailed descriptions of mixture models can be found in the methodology (section 3-5.2, TenBrook *et al.* 2009a).

Brander *et al.* (2009) tested mixture toxicity of cyfluthrin and permethrin, and found that the combined toxicity was nearly additive. Although the binary mixture demonstrated slight antagonism, additivity was demonstrated when piperonyl butoxide (PBO) was added. Brander *et al.* (2009) offered several explanations for the observed antagonism between the two pyrethroids. Permethrin is a type I pyrethroid, and cyfluthrin is a type II pyrethroid, and type II pyrethroids might be able to outcompete type I pyrethroids for binding sites, which is known as competitive agonism; or binding sites may be saturated, so that complete additivity is not observed. They also note that cyfluthrin is metabolized more slowly than permethrin, so cyfluthrin can bind longer, and permethrin may be degraded when binding sites open. PBO may remove this effect because the rate of metabolism of both pyrethroids is reduced in the presence of PBO.

To examine if pyrethroid mixture toxicity is additive with a more comprehensive study design, Trimble *et al.* (2009) performed sediment toxicity tests with *Hyalella azteca* in three binary combinations: type I-type I (permethrin-bifenthrin), type II-type II (cypermethrin-λ-cyhalothrin), and type I-type II (bifenthrin-cypermethrin). The toxicity of these combinations were predicted with the concentration addition model, with model deviations within a factor of two, indicating that in general, pyrethroid mixture toxicity is additive.

Piperonyl butoxide (PBO) is commonly added to pyrethroid insecticide treatments because it is known to increase the toxic effects of pyrethroids (Weston *et al.* 2006). Many studies have demonstrated that the addition of PBO at a concentration that would be nonlethal on its own, increases the toxicity of permethrin for fish, insects, crustaceans and mollusks, with interaction coefficients ranging from 1.54-60, as summarized below. Brander *et al.* (2009) observed *Hyalella azteca* LC_{50}s decreased by a factor of 3.5 when a nonlethal concentration of PBO was mixed with permethrin. Paul and Simonin (2006) reported that toxicity to crayfish increased by a factor of 2.1 when testing a formulation that contained 31.28% permethrin and 66% PBO compared to a product that was 92% permethrin (0% PBO) based on the 96-h LC_{50}. Paul *et al.* (2005) reported a significant difference between technical permethrin vs. PBO-synergized permethrin in toxicity to brook trout from 24-96 h and an interaction coefficient (K) of 2.9. The addition of a nonlethal concentration of PBO reduced the LC_{50} of permethrin to snails with a K of 60 at 96 h (Singh & Agarwal 1986).

Permethrin toxicity with and without PBO was tested with mosquitoes by Hardstone *et al.* (2007, 2008) with a permethrin-susceptible strain, resulting in an K of 1.54. Kasai *et al.* (1998) also did experiments with *Culex quinquefasciatus* mosquitoes and demonstrated that a nonlethal concentration of 0.5 mg/L PBO decreased the LC_{50} of permethrin from 4 ug/L to 0.44 ug/L in a permethrin-susceptible strain. Xu *et al.* (2005) tested permethrin toxicity to *C. quinquefasciatus* with and without PBO and reported a K of 4.5 for a permethrin-susceptible strain. Paul *et al.* (2006) tested *Aedes aegypti* mosquitoes and reported a K for permethrin and PBO of 11. While many studies report interaction coefficients for synergism of PBO, none of them reported Ks for multiple PBO concentrations, so a relationship between PBO concentration and K cannot be determined for any given species. Consequently, it is not possible to quantify this non-additive toxicity and there is no accurate way to account for this interaction in compliance determination.

Corbel *et al.* (2003) tested the toxicity of permethrin in combination with propoxur, a carbamate, with mosquito larvae and found that equitoxic mixtures of the two chemicals demonstrated synergism, which the authors propose is due to the complementary modes of action acting on different parts of the nervous system. Zhang *et al.* (2010) tested mixtures of permethrin with the organophosphates dichlorvos or phoxim with zebrafish and reported that the toxicity of binary combinations was additive.

No studies on aquatic organisms were found in the literature that could provide a quantitative means to consider mixtures of permethrin with other classes of pesticides. Although there are examples of non-additive toxicity for permethrin and other chemicals, a multispecies interaction coefficient is not available for any chemical with permethrin, and therefore the concentrations of non-additive chemicals cannot be used for criteria compliance (section 3-5.2.2, TenBrook *et al.* 2009a).

11. Temperature, pH, other water quality effects

Temperature, pH, and other water quality effects on the toxicity of permethrin were examined to determine if any effects are described well enough in the literature to incorporate into criteria compliance (section 3-5.3, TenBrook *et al.* 2009a). Temperature has been found to be inversely proportional to the aquatic toxicity and bioavailability of pyrethroids (Miller & Salgado 1985, Werner & Moran 2008). In fact, the increase of toxicity of pyrethroids with decreasing temperature has been used to implicate pyrethroids as the source of toxicity in environmental samples (Phillips *et al.* 2004, Weston *et al.* 2009). The inverse relationship between temperature and pyrethroid toxicity is likely due to the increased sensitivity of an organism's sodium channels at low temperatures (Narahashi *et al.* 1998).

Harwood *et al.* (2009) tested permethrin toxicity to *Chironomus dilutus* in an aqueous exposure at 13˚C and 23˚C, and reported a 3.2-fold decrease of the 96-h LC_{50} at the lower temperature. The toxicities of six aqueous pyrethroids (cypermethrin, permethrin, fenvalerate, *d*-phenothrin, flucythrinate, and bioallethrin) were 1.33- to 3.63-fold greater at 20˚C compared to 30 ˚C for mosquito larvae (Cutkomp and Subramanyam 1986). Kumaraguru and Beamish (1981) reported that for small trout, toxicity of permethrin increased by a factor of 10 with a decrease in temperature from 20˚C to 5˚C, but showed little change from 10˚C to 5˚C. The enhanced toxic effects of pyrethroids at lower temperatures may not be as accurately represented by the results of typical laboratory toxicity tests, which tend to be run at warmer temperatures, 20-23 ˚C (USEPA 1996a, USEPA 1996b, USEPA 2000), than those of the habitats of coldwater fishes, about 15˚C or lower (Sullivan *et al.* 2000).

The toxicity of sediments contaminated with pyrethroids (including permethrin) was more than twice as toxic when tested at 18 ˚C compared to 23 ˚C (Weston *et al.* 2008). Weston *et al.* (2008) used a toxicity identification evaluation (TIE) procedure to determine the effect of temperature reduction (18 vs. 23 ˚C) on toxicity of a particular environmental sediment sample to *Hyalella azteca*. These results are not directly applicable for use in water quality criteria compliance because they were sediment exposures, and used environmental samples, instead of an exposure to a pure compound.

Unfortunately, there are limited data demonstrating increased toxicity at lower temperatures using aquatic exposures with relevant species, making it unfeasible to quantify the relationship between the toxicity of permethrin and temperature for water quality criteria at this time (section 3-5.3, TenBrook *et al.* 2009a). Several studies that examined the effects of DOC and suspended solids on permethrin toxicity are discussed in the bioavailability section 9. No other studies on permethrin were identified that examined the effects of pH or other water quality parameters on toxicity, thus, there is no way to incorporate any of these parameters into criteria compliance.

12. Sensitive species

The derived criteria are compared to toxicity values for the most sensitive species in both the acceptable (RR) and supplemental (RL, LR, LL) data sets to ensure that these species will be adequately protected (section 3-6.1, TenBrook *et al.* 2009a). The derived acute criterion (10 ng/L) is below all of the acute values in the available data sets. The lowest acute value in the data sets rated RR, RL, LR, or LL (Tables 3 - 5) is 21.1 ng/L for the amphipod *Hyalella azteca* (Anderson *et al.* 2006). The derived chronic criterion (2 ng/L) is below all of the chronic values in the available data sets. The lowest chronic value in the data sets rated RR, RL, LR, or LL (Tables 6-9) is a MATC of 16 ng/L for *Americamysis bahia* (Thompson *et al.* 1989). Based on the current data sets, the derived criteria appear to be protective of the most sensitive species.

13. Ecosystem and other studies

The derived criteria are compared to acceptable laboratory, field, or semi-field multispecies studies (rated R or L) to determine if the criteria will be protective of ecosystems (section 3-6.2, TenBrook *et al.* 2009a). Twelve studies describing effects of permethrin on mesocosm, microcosm and model ecosystems were identified and rated for reliability according to the methodology (Table 3.9, TenBrook *et al.* 2009a). Six of the studies were rated as less reliable (L; Conrad *et al.* 1999, Coulon 1982, Lutnicka *et al.* 1999, Poirier & Surgeoner 1988, Werner & Hilgert 1992, Yasuno *et al.* 1988) and are used as supporting data. All of the studies are listed in Table 10 with their ratings. Six studies rated as not reliable (N) and are not discussed in this report (Feng *et al.* 2009, Helson *et al.* 1986, 1993, Jensen *et al.* 1999, Milam *et al.* 2000, Mulla *et al.* 1978). None of the studies report a community NOEC to which the calculated chronic criterion may be compared. All of the reported test concentrations were significantly higher than the chronic criterion of 0.002 μg/L, with concentrations ranging from 0.02-100 μg/L, and all studies were conducted with formulations of permethrin. All of these studies reported adverse effects on aquatic organisms, but since the tested concentrations were much higher than the criterion, these data do not provide clear guidance as to whether the derived criterion is under- or overprotective.

Two studies reported increased invertebrate drifting after exposure to permethrin. Werner & Hilgert (1992) reported residues of 0.02-0.14 μg/L permethrin had drifted into an Alaskan stream after spruce trees were sprayed, and drifting of aquatic invertebrates (Chironomidae, ephemeropteran and, trichopteran larvae) significantly increased after the treatment, but trout fry, periphyton, and benthic invertebrates were not affected. Poirier & Surgeoner (1988) exposed various aquatic invertebrates to flowing stream water in constructed troughs with 1-h application of a permethrin formulation (Ambush® EC) at 7-10 concentrations. LC_{50}s were reported for six invertebrates ranging from 2.0-7.1 μg/L, although invertebrate drift occurred at all concentrations greater that 0.5 μg/L permethrin. Lutnicka *et al.* (1999) also set up model riverine systems containing sediment and moderately contaminated river water and stocked them with lab cultures of water-thyme (*Elodea*), snails and carp (*Cyprinus carpio*). Permethrin was added at two concentrations (4 and 20 μg/L) and snails and water-thyme were both adversely affected at both concentrations.

Pond exposures also demonstrated adverse effects on various aquatic invertebrates, while fish were unaffected. Yasuno *et al.* (1988) tested permethrin in enclosures set in a pond and studied the effects on the naturally occurring species of the pond, including phytoplankton and various types of zooplankton. Daphnids and their main predator, *Chaoborus*, where both seriously affected by permethrin, and both populations disappeared and did not seem to recover after two treatments of permethrin spaced 18 d apart at a nominal treatment level of 1.5 μg/L. Coulon (1982) tested the Ambush® formulation and reported no mortality of catfish reared in ponds at any of the exposures (0.53-11.09 μg/L measured at 24 h), but aquatic insects were temporarily eliminated. The insects reinhabited the ponds 10-d post-application. Conrad *et al.* (1999) dosed small artificial ponds with permethrin (nominal aqueous concentrations of 1, 10, 50, and 100 μg/L with the formulation Picket®) and conducted bioassays with chironomids and also observed aquatic invertebrate abundances. The field exposure data were compared to laboratory sediment toxicity tests with *Chironomus riparius*. The chironomid response in the ponds of reduced larval density and adult emergence was not predicted by bulk sediment chemistry, sediment toxicity tests or laboratory bioassay results – all three measurements underestimated the acute effects. Toxicity to *C. riparius* in the field was best predicted by acute water-only toxicity test data, indicating that the primary exposure route is via the water column. This study supports the use of the freely dissolved fraction for water quality criteria compliance and affirms the relevance of water quality criteria for highly sorptive pesticides like pyrethroids.

14. Threatened and endangered species

The derived criteria are compared to measured toxicity values for threatened and endangered species (TES), as well as to predicted toxicity values for TES, to ensure that they will be protective of these species (section 3-6.3, TenBrook *et al.* 2009a). Current lists of state and federally listed threatened and endangered plant and animal species in California were obtained from the California Department of Fish and Game (CDFG) website (http://www.dfg.ca.gov/biogeodata/cnddb/pdfs/TEAnimals.pdf; CDFG 2008).

Three California listed animal species are represented in the data set. Five Evolutionarily Significant Units of *Oncorhynchus mykiss* are listed as federally threatened or endangered throughout California. The acute data set includes a SMAV for *O. mykiss* of 7.0 μg/L. Lahontan cutthroat trout (*Oncorhynchus clarki henshawi*) is represented in the RR data set with a with an LC_{50} of 1.58 (1.1-2.2) μg/L, and the razorback sucker is also in the acute RR data set with an LC_{50} of 5.95 (4.6-7.7) μg/L. All three of these values in the data set were included in the acute criterion calculation and are well above the recommended acute criterion. The acute data set also contains SMAVs for five additional species that are federally listed (http://ecos.fws.gov/tess_public/pub/listedAnimals.jsp), but not specifically for California, including: *Etheostoma fonticola, Erimonax monachus, Notropis mekistocholas, Oncorhynchus apache,* and *Salmo salar*.

Some of the listed species are represented in the acute toxicity data set by members of the same family or genus. *Oncorhynchus mykiss* can serve as a surrogate in estimates for other species in the same family using the USEPA interspecies correlation estimation website (Web-ICE v. 2.0; Raimondo *et al.* 2007). Table 11 summarizes the results of the ICE analyses. The estimated acute toxicity values in Table 11 range from 3.48 μg/L for Greenback cutthroat trout to 11.88 μg/L for Chinook salmon.

No single-species plant studies were found in the literature for use in criteria derivation, so no estimation could be made for plants on the state or federal endangered, threatened or rare species lists. There are also no aquatic plants listed as state or federal endangered, threatened or rare species so they are not considered in this section. Based on the available data and estimated values for animals, there is no evidence that the calculated acute and chronic criteria will be underprotective of threatened and endangered species.

15. Bioaccumulation

Bioaccumulation was assessed to ensure that the derived criteria will not lead to unacceptable levels of permethrin in food items (section 3-7.1, TenBrook *et al.* 2009a). Permethrin has a log K_{ow} of 6.3 and a molecular weight of 391.3 (section 3), which indicates it has bioaccumulative potential (section 3-7.1, TenBrook *et al.* 2009a). No biomagnification factor (BMF) values were found in the literature for permethrin, but bioconcentration of permethrin has been measured in several studies (Table 1).

To check that these criteria are protective of terrestrial wildlife that may consume aquatic organisms, a bioaccumulation factor (BAF) was used to estimate the water concentration that would roughly equate to a reported toxicity value for consumption of fish by terrestrial wildlife. These calculations are further explained in section 3-7.1 of the methodology (TenBrook *et al.* 2009a). The BAF of a given chemical is the product of the bioconcentration factor (BCF) and a BMF, such that BAF=BCF*BMF. For a conservative estimate, the highest fish BCF of 2800 L/kg for *Pimephales promelas* (Table 1) and a default BMF of 10, chosen based on the log K_{ow} of permethrin (Table 3.15, TenBrook *et al.* 2009a), were used to calculate a BAF. A chronic dietary NOEC for an oral predator is preferred for this calculation because it is the most realistic value for extrapolation to bioaccumulation in the environment (section 3-7.1, TenBrook *et al.* 2009a), so the dietary NOEC for mallard duck of 125 mg/kg (Beavers *et al.* 1992) was used.

$$NOEC_{water} = \frac{NOEC_{oral\_predator}}{BCF_{food\_item} * BMF_{food\_item}}$$

Mallard: $$NOEC_{water} = \frac{125 \, mg/kg}{2800 \, L/kg * 10} = 0.00446 \, mg/L = 4.46 \, \mu g/L$$

In this example, the chronic criterion is 2230-fold below the estimated $NOEC_{water}$ for mallard, and is not likely to cause adverse effects to terrestrial wildlife. Bioaccumulation of permethrin is not likely because the $NOEC_{water}$ is approaching the aqueous solubility of permethrin (5.7 ug/L, see section 2) and there would likely be acute toxicity to aquatic organisms at this concentration.

16. Harmonization with air or sediment criteria

This section addresses how the maximum allowable concentration of permethrin might impact life in other environmental compartments through partitioning (section 3-7.2, TenBrook *et al.* 2009a). However, there are no federal or state sediment or air quality standards for permethrin (CARB 2005, CDWR 1995, USEPA 2006b, USEPA 2006c) to enable this kind of extrapolation. For biota, the limited data on bioconcentration or biomagnification of permethrin were addressed in the bioaccumulation section (section 15).

17. Assumptions, limitations and uncertainties

The assumptions, limitations and uncertainties involved in criteria derivation should be available to inform environmental managers of the accuracy and confidence in the derived criteria (section 3-8.0, TenBrook *et al.* 2009a). Chapter 2 of the methodology discusses these points for each section as different procedures were chosen, such as the list of assumptions associated with using a SSD (section 2-3.1.5.1), and there is a review of the assumptions in section 2-7.0 (TenBrook *et al.* 2009a). This section summarizes any data limitations that affected the procedure used to determine the final permethrin criteria.

There were enough highly rated acute permethrin data to use a SSD to calculate the acute criterion, but one limitation in the data set is that not all of the data are from flow-through tests that use measured concentrations to calculate the toxicity values. Flow-through tests and measurement of concentrations are particularly important in tests with pyrethroid pesticides because they are highly sorptive. Only two of the acute RR data are from flow-through tests, and only two data used measured concentrations, but the lowest value in the data set (*Hyalella azteca* SMAV=21.1 ng/L) is from a static test calculated with nominal concentrations, and could be overestimated.

For permethrin, the major limitation was in the chronic toxicity data set. Three of five taxa requirements were not met (the salmonid, benthic crustacean and insect), which precluded the use of a SSD; therefore, an ACR was used to derive the chronic criterion. There were no paired freshwater data available to calculate a multi-species ACR, so one data pair for a saltwater species was used with default ACRs for the other two ACR requirements (as specified in section 3-4.2.2, TenBrook *et al.* 2009a). Particularly of concern for the chronic toxicity data set was the lack of data on *Hyalella azteca* or another benthic organism, which was the most sensitive species in the acute toxicity data set. Uncertainty cannot be quantified for the chronic criterion because it was derived using an ACR, not an SSD.

Another concern that could not be accounted for quantitatively in criteria compliance is the increase in toxicity from lower temperatures. Most of the toxicity data were from tests performed at standard temperature, usually around 20 ˚C. Tests for seven of the 19 species in the acute data set used lower temperatures (*Erimonax monachus, Notropis mekistocholas, Oncorhynchus apache, O. clarki henshawi, O. mykiss, Orconectes immunis,* and *Salmo salar*). However, many streams in the California Central Valley often have lower water temperatures. If colder water bodies are impacted by concentrations of permethrin, it may be appropriate to apply an additional safety factor to the permethrin criteria for those areas, to ensure adequate protection. A rough factor of two could be estimated from a study by Weston *et al.* (2008), however, a study relating temperature to aqueous toxicity of permethrin in multiple species, including *Hyalella azteca*, would be ideal to derive such an adjustment factor. We do not recommend an additional safety factor to account for temperature effects at this time, but environmental managers may want to consider this application if the criteria do not appear to be protective of organisms in a colder water body. If aquatic exposure data for multiple species demonstrating temperature effects become available in the future, a regression equation describing the effect should be incorporated into criteria compliance.

Although greater than additive effects have been observed for mixtures of pyrethroids and PBO, there are insufficient data to account for this interaction for compliance determination. This is a significant limitation because formulations that contain both pyrethroids and PBO are now available on the market. When additional highly rated data are available, the criteria should be recalculated to incorporate new research.

18. Comparison to national standard methods

This section is provided as a comparison between the UC-Davis methodology for criteria calculation (TenBrook *et al.* 2009a) and the current USEPA (1985) national standard. The following example permethrin criteria were generated using the USEPA 1985 methodology with the data set generated in this permethrin criteria report.

The USEPA acute methods have three additional taxa requirement beyond the five required by the UC-Davis methodology (section 3-3.1, TenBrook *et al.* 2009a). They are:

1. A third family in the phylum Chordata (e.g., fish, amphibian);
2. A family in a phylum other than Arthropoda or Chordata (e.g., Rotifera, Annelida, Mollusca);
3. A family in any order of insect or any phylum not already represented.

Two out of the three of these additional requirements are met as follows:

1. The other fish/amphibian requirement is met with data from zebra danio or any of six other fish species available.
2. This requirement is not met because all data are from organisms in the phylum Arthropoda or Chordata.
3. This requirement is met because *Procloeon sp.* is an insect in a different family than *Chironomus dilutus*.

Strictly speaking, the USEPA methodology cannot be used to calculate an acute criterion for permethrin. However, since the California Department of Fish and Game have used data sets that met only seven of eight requirements in the USEPA methodology, this will be done here.

Using the log-triangular calculation (following the USEPA 1985 guidelines) and the permethrin data set from Table 3, but calculating 16 genus mean values instead of 19 species mean values, the following criterion was calculated (Note: USEPA methodology uses *genus* mean acute values, while *species* mean acute values are used in this methodology and are reported in Table 3. There are several species from the same genus in Table 3, so the final data sets are not the same in the two schemes.):

Example Final Acute Value (5^{th} percentile) = 0.020502 μg/L

Example Acute Criterion = final acute value ÷ 2
= 0.020502 μg/L ÷ 2
= 0.010251 μg/L
= 10 ng/L

According to the USEPA (1985) methodology, the criterion is rounded to two significant digits. This value is identical to the acute criterion calculated by the UC-Davis methodology.

For the chronic criterion, the permethrin data set only has data from two species, which are not enough for use in a SSD by either method. The USEPA 1985 methodology contains a similar ACR procedure as in the UC-Davis methodology, to be used when three acceptable ACRs are available. There was only one ACR available, therefore a chronic criterion cannot be calculated for permethrin using the EPA method.

19. Final criteria statement

The final criteria statement is:

Aquatic life in the Sacramento River and San Joaquin River basins should not be affected unacceptably if the four-day average concentration of permethrin does not exceed 0.002 μg/L (2 ng/L) more than once every three years on the average and if the one-hour average concentration does not exceed 0.01 μg/L (10 ng/L) more than once every three years on the average. Mixtures of permethrin and other pyrethroids should be considered in an additive manner (see Mixtures section).

While the aim of this criteria report was to derive criteria protective of aquatic life in the Sacramento and San Joaquin Rivers, these criteria would be appropriate for any freshwater ecosystem in North America, unless species more sensitive than are represented by the species examined in the development of these criteria are likely to occur in those ecosystems.

The final acute criterion was derived using the Burr Type III SSD procedure (section 7) and the acute data used in criteria calculation are shown in Table 3. The chronic criterion was derived by use of an ACR calculated from a combination of measured data and default ACRs (section 8); chronic data rated RR are shown in Table 6, and the ACRs are shown in Table 8. It is recommended that the freely dissolved permethrin concentration is measured for criteria compliance because this appears to be the best predictor of the bioavailable fraction (section 9).

Several other jurisdictions have established water quality criteria for permethrin. The Netherlands' freshwater criterion is 0.3 ng/L (Crommentuijn *et al.* 1997), the freshwater environmental quality standard in the United Kingdom is 10 ng/L (Zabel *et al.* 1988), Quebec has an interim acute criterion of 44 ng/L and an interim chronic criterion of 13 ng/L (Guay *et al.* 2000), and Canada has an interim water quality guideline of 4 ng/L (CCME 2006). The acute and chronic criteria derived using the UC-Davis methodology are within the range of criteria reported by other jurisdictions, and are not far above or below these other criteria that have been derived. The example acute criterion calculated by the USEPA 1985 method is identical to the criterion derived using this new methodology. The derived criteria appear to be protective considering bioaccumulation, ecosystem level toxicity and threatened and endangered species as discussed above in the report, but the criteria calculations should be updated whenever new data are available.

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Data Tables

Table 3. Final acute toxicity data set for permethrin. All studies were rated RR. S: static; SR: static renewal; FT: flow-through.

Species	Common Identifier	Family	Test type	Meas / Nom	Chemical grade	Duration	Temp (°C)	Endpoint	Age/ size	LC/EC$_{50}$ (µg/L) (95% CI)	Reference
Ceriodaphnia dubia	Daphnid	Daphniidae	S	Nom	99.0%	48 hr	25	Mortality	< 24 hr	0.250 (± 119)	Wheelock *et al.* 2004
Ceriodaphnia dubia	Daphnid	Daphniidae	S	Nom	99.3%	96 hr	21	Mortality	< 24 hr	0.652 (0.484-0.856)	Yang *et al.* 2007
Ceriodaphnia dubia	Daphnid	Daphniidae	S	Nom	99.3%	96 hr	21	Mortality	< 24 hr	0.788 (0.545-1.040)	Yang *et al.* 2007
Ceriodaphnia dubia	Daphnid	Daphniidae	S	Nom	99.3%	96 hr	21	Mortality	< 24 hr	0.622 (0.427-0.824)	Yang *et al.* 2007
Ceriodaphnia dubia	Daphnid	Daphniidae	S	Nom	99.3%	96 hr	21	Mortality	< 24 hr	0.772 (0.574-1.013)	Yang *et al.* 2007
Ceriodaphnia dubia	Daphnid	Daphniidae	S	Nom	99.3%	96 hr	21	Mortality	< 24 hr	0.745 (0.568-0.957)	Yang *et al.* 2007
Ceriodaphnia dubia	Daphnid	Daphniidae	S	Nom	99.3%	96 hr	21	Mortality	< 24 hr	0.858 (0.591-1.138)	Yang *et al.* 2007
Ceriodaphnia dubia	Daphnid	Daphniidae	S	Nom	99.3%	96 hr	21	Mortality	< 24 hr	0.571 (0.427-0.740)	Yang *et al.* 2007
Ceriodaphnia dubia	Daphnid	Daphniidae	S	Nom	99.3%	96 hr	21	Mortality	< 24 hr	0.580 (0.407-0.718)	Yang *et al.* 2007
Ceriodaphnia dubia	Daphnid	Daphniidae	S	Nom	99.3%	96 hr	21	Mortality	< 24 hr	0.609 (0.486-0.747)	Yang *et al.* 2007
Ceriodaphnia dubia	Daphnid	Daphniidae	S	Nom	99.3%	96 hr	21	Mortality	< 24 hr	0.570 (0.459-0.689)	Yang *et al.* 2007
Ceriodaphnia dubia	Daphnid	Daphniidae	S	Nom	99.3%	96 hr	21	Mortality	< 24 hr	0.827 (0.669-1.012)	Yang *et al.* 2007
Ceriodaphnia dubia	Daphnid	Daphniidae	S	Nom	99.3%	96 hr	21	Mortality	< 24 hr	0.585 (0.677-0.793)	Yang *et al.* 2007
Ceriodaphnia dubia	Daphnid	Daphniidae	S	Nom	99.3%	96 hr	21	Mortality	< 24 hr	0.849 (0.655-1.085)	Yang *et al.* 2007
Ceriodaphnia dubia	Daphnid	Daphniidae	S	Nom	99.3%	96 hr	21	Mortality	< 24 hr	0.889 (0.666-1.120)	Yang *et al.* 2007
Ceriodaphnia dubia	Daphnid	Daphniidae	S	Nom	99.3%	96 hr	21	Mortality	< 24 hr	0.865 (0.672-1.098)	Yang *et al.* 2007

Table 3. Final acute toxicity data set for permethrin. All studies were rated RR. S: static; SR: static renewal; FT: flow-through.

Species	Common Identifier	Family	Test type	Meas / Nom	Chemical grade	Duration	Temp (°C)	Endpoint	Age/ size	LC/EC_{50} (µg/L) (95% CI)	Reference
Ceriodaphnia dubia	GEOMEAN							Mortality		**0.664**	
Chironomus dilutus	Midge	Chironomidae	S	Meas	>96%	96 hr	23	Mortality	4th instar larvae	**0.189 (0.131-0.295)**	Harwood *et al.* 2009
Danio rerio	Zebra fish	Cyprinidae	SR	Nom	90.0%	96 hr	23	Mortality	3.0 cm, 0.3 g	**2.5 (1.7-3.2)**	Zhang *et al.* 2010
Daphnia magna	Daphnid	Daphniidae	S	Nom	Technical	48 hr	22	Immobility	< 24 hr	**0.32 (0.24-0.44)**	LeBlanc 1976
Erimonax monachus	Spotfin chub	Cyprinidae	S	Nom	95.2%	96 hr	17	Mortality	NR	**1.7**	Dwyer *et al.* 2005
Etheostoma fonticola	Fountain darter	Percidae	S	Nom	95.2%	96 hr	22	Mortality	62 mg, 20.2 mm	**3.34 (2.75-4.16)**	Dwyer *et al.* 1999, 2005
Etheostoma lepidum	Greenthroat darter	Percidae	S	Nom	95.2%	96 hr	22	Mortality	NR	**2.71 (2.36-3.13)**	Dwyer *et al.* 1999, 2005
Hyalella azteca	Amphipod	Hyalellidae	S	Nom	100.0%	96 hr	23	Mortality	3rd instar	**0.0211**	Anderson *et al.* 2006
Ictalurus punctatus	Catfish	Ictaluridae	S	Nom	92.4%	96 hr	21	Mortality	1.2 g, 35 mm	**5.4 (3.9-7.4)**	Buccafusco 1976a
Notropis mekistocholas	Cape Fear shiner	Cyprinidae	S	Nom	95.2%	96 hr	17	Mortality	NR	**4.16**	Dwyer *et al.* 2005
Oncorhynchus apache	Apache trout	Salmonidae	S	Nom	95.2%	96 hr	12	Mortality	0.615 g	**1.71 (1.3-2.2)**	Dwyer *et al.* 1995, 2005, Sappington et al. 2001
Oncorhynchus clarki henshawi	Lahontan cutthroat trout	Salmonidae	S	Nom	95.2%	96 hr	12	Mortality	0.46 g	**1.58 (1.1-2.2)**	Dwyer *et al.* 1995, 2005, Sappington et al. 2001

Table 3. Final acute toxicity data set for permethrin. All studies were rated RR. S: static; SR: static renewal; FT: flow-through.

Species	Common Identifier	Family	Test type	Meas / Nom	Chemical grade	Duration	Temp (°C)	Endpoint	Age/ size	LC/EC_{50} (µg/L) (95% CI)	Reference
Oncorhynchus mykiss	Rainbow trout	Salmonidae	FT	Meas	91.9%	96 hr	15.6	Mortality	Juvenile	**7.0 (7.0-7.0)**	Holcombe *et al.* 1982
Orconectes immunis	Crayfish	Astacidae	S	Nom	92.0%	96 hr	16.5	Mortality	Juvenile 2 g	**0.21 (0.17-0.25)**	Paul & Simonin 2006
Pimephales promelas	Fathead minnow	Cyprinidae	S	Nom	95.2%	96 hr	22	Mortality	0.41 g	**9.38 (6.7-16)**	Dwyer *et al.* 1995, 2005, Sappington et al. 2001
Procambarus blandingi	Crayfish	Cambaridae	FT	Nom	89.1%	96 hr	22	Mortality	24 g, 48 mm	**0.21 (0.13-0.33)**	Buccafusco 1977
Procloeon sp.	Mayfly	Baetidae	S	Nom	100.0%	48 hr	23	Mortality	0.5-1 cm	**0.0896**	Anderson *et al.* 2006
Salmo salar	Atlantic Salmon	Salmonidae	S	Nom	92.4%	96 hr	12	Mortality	1 g, 35 mm	**1.5 (1.1-2.0)**	Buccafusco 1976b
Xyrauchen texanus	Razorback sucker	Catostornidae	S	Nom	95.2%	96 hr	22	Mortality	0.32 g	**5.95 (4.6-7.7)**	Dwyer *et al.* 1995, 2005, Sappington et a. 2001

Table 4. Reduced acute data rated RR with given reason for exclusion. S: static; SR: static renewal; FT: flow-through.

Species	Common Identifier	Test type	Meas / Nom	Chemical grade	Duration	Temp (°C)	Endpoint	Age/size	LC/EC$_{50}$ (μg/L) (95% CI)	Reference	Reason
Chironomus dilutus	Midge	S	Meas	>96%	96 hr	13	Mortality	4th instar larvae	0.0585 (0.0426-0.0808)	Harwood *et al.* 2009	C
Chironomus dilutus	Midge	S	Nom	100.0%	96 hr	23	Mortality	3rd instar	10.450	Anderson *et al.* 2006	D
Danio rerio	Zebra fish	SR	Nom	90.0%	24 hr	23	Mortality	3.0 cm, 0.3 g	5.2 (4.1-6.6)	Zhang *et al.* 2010	A
Danio rerio	Zebra fish	SR	Nom	90.0%	48 hr	23	Mortality	3.0 cm, 0.3 g	3.0 (1.9-3.8)	Zhang *et al.* 2010	A
Danio rerio	Zebra fish	SR	Nom	90.0%	72 hr	23	Mortality	3.0 cm, 0.3 g	2.6 (1.8-3.3)	Zhang *et al.* 2010	A
Daphnia magna	Daphnid	S	Nom	NR	24 hr	22	Immobility	< 24 hr	0.93 (0.44-2.0)	LeBlanc 1976	A
Etheostoma fonticola	Fountain darter	S	Nom	95.2%	12 hr	22	Mortality	62 mg, 20.2 mm	5.60 (4.76-6.67)	Dwyer *et al.* 1999	A
Etheostoma fonticola	Fountain darter	S	Nom	95.2%	24 hr	22	Mortality	62 mg, 20.2 mm	4.26 (3.58-5.19)	Dwyer *et al.* 1999	A
Etheostoma fonticola	Fountain darter	S	Nom	95.2%	48 hr	22	Mortality	62 mg, 20.2 mm	3.34 (2.75-4.16)	Dwyer *et al.* 1999	A
Etheostoma fonticola	Fountain darter	S	Nom	95.2%	72 hr	22	Mortality	62 mg, 20.2 mm	3.34 (2.75-4.16)	Dwyer *et al.* 1999	A
Etheostoma lepidum	Greenthroat darter	S	Nom	95.2%	6 hr	22	Mortality	133 mg, 22.6 mm	4.31 (3.71-5.04)	Dwyer *et al.* 2005	A
Etheostoma lepidum	Greenthroat darter	S	Nom	95.2%	12 hr	22	Mortality	133 mg, 22.6 mm	3.10 (2.20-3.60)	Dwyer *et al.* 2005	A
Etheostoma lepidum	Greenthroat darter	S	Nom	95.2%	24 hr	22	Mortality	133 mg, 22.6 mm	2.71 (2.36-3.13)	Dwyer *et al.* 2005	A
Etheostoma lepidum	Greenthroat darter	S	Nom	95.2%	48 hr	22	Mortality	133 mg, 22.6 mm	2.71 (2.36-3.13)	Dwyer *et al.* 2005	A

Table 4. Reduced acute data rated RR with given reason for exclusion. S: static; SR: static renewal; FT: flow-through.

Species	Common Identifier	Test type	Meas / Nom	Chemical grade	Duration	Temp (°C)	Endpoint	Age/size	LC/EC_{50} (μg/L) (95% CI)	Reference	Reason
Etheostoma lepidum	Greenthroat darter	S	Nom	95.2%	72 hr	22	Mortality	133 mg, 22.6 mm	2.71 (2.36-3.13)	Dwyer *et al.* 2005	A
Ictalurus punctatus	Catfish	S	Nom	92.4%	24 hr	21	Mortality	1.2 g, 35 mm	6.0 (4.9-7.5)	Buccafusco 1976a	A
Ictalurus punctatus	Catfish	S	Nom	92.4%	48 hr	21	Mortality	1.2 g, 35 mm	5.4 (3.9-7.4)	Buccafusco 1976a	A
Oncorhynchus apache	Apache trout	S	Nom	95.2%	12 hr	12	Mortality	0.615 g	3.88 (3.7-4.1)	Dwyer *et al.* 1995, Sappington *et al.* 2001	A
Oncorhynchus apache	Apache trout	S	Nom	95.2%	24 hr	12	Mortality	0.615 g	2.27 (2.0-2.7)	Dwyer *et al.* 1995, Sappington *et al.* 2001	A
Oncorhynchus clarki henshawi	Lahontan cutthroat trout	S	Nom	95.2%	12 hr	12	Mortality	0.46 g	3.3 (2.4-4.7)	Dwyer *et al.* 1995, 2005, Sappington *et al.* 2001	A
Oncorhynchus clarki henshawi	Lahontan cutthroat trout	S	Nom	95.2%	24 hr	12	Mortality	0.46 g	1.9 (1.4-2.6)	Dwyer *et al.* 1995, 2005, Sappington *et al.* 2001	A
Oncorhynchus mykiss	Rainbow trout	S	Nom	95.2%	12 hr	12	Mortality	0.71 g	5.75 (3.4-8.3)	Dwyer *et al.* 1995, Sappington *et al.* 2001	A, B
Oncorhynchus mykiss	Rainbow trout	S	Nom	95.2%	24 hr	12	Mortality	0.71 g	3.78 (3.4-8.3)	Dwyer *et al.* 1995, Sappington *et al.* 2001	A, B

Table 4. Reduced acute data rated RR with given reason for exclusion. S: static; SR: static renewal; FT: flow-through.

Species	Common Identifier	Test type	Meas / Nom	Chemical grade	Duration	Temp (°C)	Endpoint	Age/size	LC/EC_{50} (µg/L) (95% CI)	Reference	Reason
Oncorhynchus mykiss	Rainbow trout	S	Nom	95.2%	96 hr	12	Mortality	0.71 g	3.31 (1.7-4.8)	Dwyer *et al.* 1995, 2005, Sappington et a. 2001	B
Orconectes immunis	Crayfish	S	Nom	92.0%	24 hr	16.5	Mortality	Juveniles, 2 g	0.53 (0.43-0.67)	Paul & Simonin 2006	A
Orconectes immunis	Crayfish	S	Nom	92.0%	48 hr	16.5	Mortality	Juveniles, 2 g	0.31 (0.26-0.36)	Paul & Simonin 2006	A
Pimephales promelas	Fathead minnow	S	Nom	95.2	24 hr	22	Mortality	0.41 g	9.73 (9.2-11)	Dwyer *et al.* 1995, Sappington et a. 2001	A
Procambarus blandingi	Crayfish	FT	Nom	89.1%	24 hr	22	Mortality	24 g, 48 mm	0.66 (0.16-2.6)	Buccafusco 1977	A
Procambarus blandingi	Crayfish	FT	Nom	89.1%	312 hr	22	Mortality	24 g, 48 mm	0.12 (0.071-0.20)	Buccafusco 1977	A
Salmo salar	Atlantic Salmon	S	Nom	92.4%	24 hr	12	Mortality	1 g, 35 mm	2.2 (1.7-2.8)	Buccafusco 1976b	A
Salmo salar	Atlantic Salmon	S	Nom	92.4%	48 hr	12	Mortality	1 g, 35 mm	1.8 (1.4-2.4)	Buccafusco 1976b	A
Xyrauchen texanus	Razorback sucker	S	Nom	95.2%	24 hr	22	Mortality	0.32 g	8.9	Dwyer *et al.* 1995, Sappington *et al.* 2001	A

Reduction Reasons

A. Not the most sensitive or appropriate duration
B. FT test preferred over S
C. Not standard conditions
D. Meas preferred over Nom

Table 5. Supplemental acute data rated RL, LR, LL with rating and reason for exclusion given below. S: static; SR: static renewal; FT: flow-through. NR: not reported.

Species	Common Identifier	Test type	Meas / Nom	Chemical grade	Duration	Temp (°C)	Endpoint	Age/size	LC/EC_{50} (µg/L) (95% CI)	Reference	Rating/ Reason
Acipensar brevirostrum	shortnose sturgeon	S	Nom	95.2%	48 hr	17	Mortality	0.74 g wet wt	>1.2	Dwyer *et al.* 2000	LL/8,6
Acipensar oxyrhynchus	atlantic sturgeon	S	Nom	95.2%	48 hr	17	Mortality	1.11 g wet wt	>1.2	Dwyer *et al.* 2000	LL/8,6
Aedes aegypti	mosquito	S	Nom	100.0%	24 hr	20	Mortality	3rd instar	0.27 (0.22-0.31)	Cutkomp & Subramanyam 1986	RL/1,6
Aedes aegypti	mosquito	S	Nom	100.0%	24 hr	30	Mortality	3rd instar	0.98 (0.90-1.06)	Cutkomp & Subramanyam 1986	RL/1,6
Aedes aegypti	mosquito	S	Nom	technical	24 hr	27	Mortality	late 3rd -early 4th instar	2.8 (2.7-3.0)	Canyon & Hii 1999	RL/6
Aedes aegypti	mosquito	S	Nom	technical	24 hr	27	Mortality	late 3rd -early 4th instar	2.5 (2.4-2.6)	Canyon & Hii 1999	RL/6
Aedes aegypti	mosquito	S	Nom	90.8%	2 x 1 hr pulses	25	Mortality	3rd instar	2.03 (Std error 0.06)	Parsons & Surgeoner 1991b	RL/1,6
Aedes aegypti	mosquito	S	Nom	90.8%	2 hr	25	Mortality	3rd instar	2.32 (Std error 0.46)	Parsons & Surgeoner 1991b	RL/1,6
Aedes aegypti	mosquito	S	Nom	90.8%	1 hr	25	Mortality	3rd instar	4.67 (Std error 0.59)	Parsons & Surgeoner 1991a	RL/1,6
Aedes aegypti	mosquito	S	Nom	90.8%	4 hr	25	Mortality	3rd instar	1.15 (Std error 0.13)	Parsons & Surgeoner 1991a	RL/1,6
Aedes aegypti	mosquito	S	Nom	90.8%	24 hr	25	Mortality	3rd instar	0.45 (Std error 0.08)	Parsons & Surgeoner 1991a	RL/1,6

Table 5. Supplemental acute data rated RL, LR, LL with rating and reason for exclusion given below. S: static; SR: static renewal; FT: flow-through. NR: not reported.

Species	Common Identifier	Test type	Meas / Nom	Chemical grade	Duration	Temp (°C)	Endpoint	Age/size	LC/EC_{50} (µg/L) (95% CI)	Reference	Rating/ Reason
Aedes aegypti	mosquito	S	Nom	90.8%	24 hr	25	Immobility	3rd instar	0.85	Parsons & Surgeoner 1991a	RL/1,6
Aedes atropalpus	mosquito	S	Nom	95.7%	24 hr	20	Mortality	late 3rd instar	6.168 (5.688-6.671)	Cilek *et al.* 1995	RL/1,6
Aedes hendersoni	mosquito	S	Nom	95.7%	24 hr	20	Mortality	late 3rd instar	3.507 (3.166-3.870)	Cilek *et al.* 1995	RL/1,6
Aedes triseriatus	mosquito	S	Nom	95.7%	24 hr	20	Mortality	late 3rd instar	8.39 (8.11-8.70)	Cilek *et al.* 1995	RL/1,6
Aedes triseriatus	mosquito	S	Nom	95.7%	24 hr	20	Mortality	late 3rd instar	7.68 (7.40-7.98)	Cilek *et al.* 1995	RL/1,6
Aedes triseriatus	mosquito	S	Nom	95.7%	24 hr	20	Mortality	late 3rd instar	7.38 (6.80-8.15)	Cilek *et al.* 1995	RL/1,6
Aedes triseriatus	mosquito	S	Nom	95.7%	24 hr	20	Mortality	late 3rd instar	6.39 (5.61-6.93)	Cilek *et al.* 1995	RL/1,6
Aedes triseriatus	mosquito	S	Nom	95.7%	24 hr	20	Mortality	late 3rd instar	6.23 (5.64-6.79)	Cilek *et al.* 1995	RL/1,6
Aedes triseriatus	mosquito	S	Nom	95.7%	24 hr	20	Mortality	late 3rd instar	4.46 (4.18-4.72)	Cilek *et al.* 1995	RL/1,6
Alonella sp.		S	Nom	42.0%	48 hr	21	Mortality	NR	4.0 (3.8-4.9)	Naqvi & Hawkins 1989	LL/1, 7
Alosa apidissima	American shad	S	Nom	95.2%	48 hr	22	Mortality	0.006 g dry wt	2.08 (1.78-2.37)	Dwyer *et al.* 2000	LL/4,6
Americamysis bahia	mysid shrimp	FT	Meas	90.8%	48 hr	25	Mortality	3-5 d	0.14 (0.12-0.19)	Thompson 1986	LR/2
Americamysis bahia	mysid shrimp	FT	Meas	90.8%	72 hr	25	Mortality	3-5 d	0.11 (0.090-0.14)	Thompson 1986	LR/2

Table 5. Supplemental acute data rated RL, LR, LL with rating and reason for exclusion given below. S: static; SR: static renewal; FT: flow-through. NR: not reported.

Species	Common Identifier	Test type	Meas / Nom	Chemical grade	Duration	Temp (°C)	Endpoint	Age/size	LC/EC_{50} (µg/L) (95% CI)	Reference	Rating/ Reason
Americamysis bahia	mysid shrimp	FT	Meas	90.8%	96 hr	25	Mortality	3-5 d	0.075 (0.059-0.096)	Thompson 1986	LR/2
Americamysis bahia	mysid shrimp	FT	Nom	10.0%	24 hr	25	Mortality	<24 hr	0.82 (0.69-1.0)	Kent *et al.* 1992	LR/2,7
Americamysis bahia	mysid shrimp	FT	Nom	10.0%	48 hr	25	Mortality	<24 hr	0.59 (0.50-0.71)	Kent *et al.* 1992	LR/2,7
Americamysis bahia	mysid shrimp	FT	Nom	10.0%	72 hr	25	Mortality	<24 hr	0.49 (0.40-0.61)	Kent *et al.* 1992	LR/2,7
Americamysis bahia	mysid shrimp	FT	Nom	10.0%	96 hr	25	Mortality	<24 hr	0.47 (0.39-0.59)	Kent *et al.* 1992	LR/2,7
Americamysis bahia	mysid shrimp	FT	Nom	92.0%	96 hr	26	Mortality	<24 hr	0.02 (0.017-0.024)	Schimmel *et al.* 1983	LL/2,6
Americamysis bahia	mysid shrimp	S	Nom	Technical	96 hr	25	Mortality	<24 hr	0.095 (0.077-0.12)	Cripe 1994	LR/2
Bufo boreas	toad	S	Nom	95.2%	96 hr	22	Mortality	12 mg, 9.6 mm	>10	Dwyer *et al.* 1999	LL/8,6
Bufo boreas boreas	boreal toad	S	Nom	95.2%	96 hr	22	Mortality	NR	>10	Dwyer *et al.* 2005	LL/8,6
Ceriodaphnia dubia	Daphnid	S	Nom	99.3%	96 hr	21	Mortality	<24 hr	0.52 (0.38-0.65)	Yang *et al.* 2006a	RL/4,6
Ceriodaphnia dubia	Daphnid	S	Nom	99.3%	96 hr	21	Mortality	<24 hr	0.57 (0.42-0.69)	Yang *et al.* 2006a	RL/4,6
Ceriodaphnia dubia	Daphnid	S	Nom	99.3%	96 hr	21	Mortality	<24 hr	0.54 (0.43-0.66)	Yang *et al.* 2006a	RL/4,6
Ceriodaphnia dubia	Daphnid	S	Nom	99.3%	96 hr	21	Mortality	<24 hr	0.74 (0.57-0.95)	Yang *et al.* 2006a	RL/4,6
Ceriodaphnia	Daphnid	S	Nom	99.3%	96 hr	21	Mortality	<24 hr	0.48	Yang *et al.*	RL/4,6

Table 5. Supplemental acute data rated RL, LR, LL with rating and reason for exclusion given below. S: static; SR: static renewal; FT: flow-through. NR: not reported.

Species	Common Identifier	Test type	Meas / Nom	Chemical grade	Duration	Temp (°C)	Endpoint	Age/size	LC/EC_{50} (µg/L) (95% CI)	Reference	Rating/ Reason
dubia									(0.39-0.58)	2006a	
Ceriodaphnia dubia	Daphnid	S	Nom	99.3%	96 hr	21	Mortality	<24 hr	0.52 (0.39-0.63)	Yang *et al.* 2006a	RL/4,6
Ceriodaphnia dubia	Daphnid	S	Nom	99.3%	96 hr	21	Mortality	<24 hr	0.49 (0.388-0.60)	Yang *et al.* 2006a	RL/4,6
Ceriodaphnia dubia	Daphnid	S	Nom	99.3%	96 hr	21	Mortality	<24 hr	0.59 (0.42-0.74)	Yang *et al.* 2006a	RL/4,6
Ceriodaphnia dubia	Daphnid	S	Nom	99.3%	96 hr	21	Mortality	<24 hr	0.56 (0.41-0.68)	Yang *et al.* 2006a	RL/4,6
Ceriodaphnia dubia	Daphnid	S	Nom	99.3%	96 hr	21	Mortality	<24 hr	0.51 (0.38-0.62)	Yang *et al.* 2006a	RL/4,6
Ceriodaphnia dubia	Daphnid	S	Nom	99.3%	96 hr	21	Mortality	<24 hr	0.59 (0.48-0.72)	Yang *et al.* 2006a	RL/4,6
Ceriodaphnia dubia	Daphnid	S	Nom	99.3%	96 hr	21	Mortality	<24 hr	0.66 (0.49-0.81)	Yang *et al.* 2006a	RL/4,6
Culex pipiens pallens	mosquito	S	Nom	92.0%	24 hr	26	Mortality	late 3rd-early 4th instar	3.85 (3.47-4.27)	Song *et al.* 2007	RL/1,6
Culex pipiens pallens	mosquito	S	Nom	92.0%	24 hr	26	Mortality	late 3rd-early 4th instar	9.904 (5.341-18.37)	Song *et al.* 2007	RL/1,6
Culex pipiens pallens	mosquito	S	Nom	91.2%	24 hr	26	Mortality	early 4th instar	7.7 (7.3-8.2)	Kasai *et al.* 2007	LL/1,5, 6
Culex quinquefasciatus	mosquito	S	Nom	94.4%	24 hr	27	Mortality	late 3rd & 5th instar	1.2	Corbel *et al.* 2003	RL/1,6
Cypria sp.	ostracod	S	Nom	42.0%	48 hr	21	Mortality	NR	5.0 (4.8-6.4)	Naqvi & Hawkins 1989	LL/1,7, 6
Cyprinodon variegatus	sheepshead minnow	FT	Meas	93.0%	96 hr	30	Mortality	NR	7.8 (6.2-10)	Schimmel *et al.* 1983	LL/2,6

Table 5. Supplemental acute data rated RL, LR, LL with rating and reason for exclusion given below. S: static; SR: static renewal; FT: flow-through. NR: not reported.

Species	Common Identifier	Test type	Meas / Nom	Chemical grade	Duration	Temp (°C)	Endpoint	Age/size	LC/EC$_{50}$ (μg/L) (95% CI)	Reference	Rating/ Reason
Daphnia magna	Daphnid	S	Nom	NR	48 hr	17	Immobility	< 20 hr	7.2 (5.8-8.9)	Aquatic Environmental Sciences 1976	LL/7,6
Daphnia magna	Daphnid	S	Nom	98.7%	24 hr	18	Immobility	1st instar	2.06 (1.65-2.58)	Doma & Evered 1977	RL/6
Daphnia magna	Daphnid	S	Nom	98.7%	48 hr	18	Immobility	1st instar	0.6 (0.53-0.67)	Doma & Evered 1977	RL/6
Daphnia magna conditioned ephippia	Daphnid	S	Nom	25.0%	48 hr	20	Survival, 7 d post-exposure	2 mon old resting egg	0.034	Doma & Evered 1977	LL/4,6, 7
Daphnia magna unconditioned ephippia	Daphnid	S	Nom	25.0%	48 hr	20	Survival, 7 d post-exposure	2 mon old resting egg	0.108 (0.035-0.339)	Doma & Evered 1977	LL/4,6, 7
Daphnia magna	Daphnid	S	Nom	25.0%	24 hr	18	Immobility	1st instar	1.82 (1.54-2.15)	Doma & Evered 1977	LL/6,7
Daphnia magna	Daphnid	S	Nom	25.0%	48 hr	18	Immobility	1st instar	0.76 (0.66-0.88)	Doma & Evered 1977	LL/6,7
Daphnia magna	Daphnid	S	Nom	95.7%	24 hr	21	Immobility	<12 hr	0.258 (0.014-0.476)	Bentley 1975	RL/6
Daphnia magna	Daphnid	S	Nom	95.7%	48 hr	21	Immobility	<12 hr	0.075 (0.054-0.103)	Bentley 1975	RL/6
Daphnia magna	Daphnid	S	Nom	95.7%	96 hr	21	Immobility	<12 hr	0.039 (0.025-0.062)	Bentley 1975	RL/6
Daphnia magna	Daphnid	S	Meas	26.2%	48 hr	20	Immobility	<24 hr	3.2 (2.6-4.0)	Kent *et al.* 1995b	RL/7

Table 5. Supplemental acute data rated RL, LR, LL with rating and reason for exclusion given below. S: static; SR: static renewal; FT: flow-through. NR: not reported.

Species	Common Identifier	Test type	Meas / Nom	Chemical grade	Duration	Temp (°C)	Endpoint	Age/size	LC/EC$_{50}$ (µg/L) (95% CI)	Reference	Rating/ Reason
Daphnia magna	Daphnid	S	Meas	98.0%	48 hr	20	Mortality	4-5 d old 4th instar	5.36 (2.5-10.6)	McWilliam & Baird 2002	LL/1,5, 6
Daphnia magna	Daphnid	S	Meas	98.0%	48 hr	20	Mortality	4-5 d old 4th instar	0.54 (0.03-19.3)	McWilliam & Baird 2002	LL/1,5, 6
Daphnia magna	Daphnid	S	Nom	NR	24 hr	18	Immobility	<24 hr	1.93 (1.76-2.12)	Hamer 1990	LL/7,6
Daphnia magna	Daphnid	S	Nom	NR	48 hr	18	Immobility	<24 hr	1.31 (1.17-1.48)	Hamer 1990	LL/7,6
Eucyclops sp.	copepod	S	Nom	42.0%	48 hr	21	Mortality	NR	5.0 (4.3-5.5)	Naqvi & Hawkins 1989	LL/1,7, 6
Gambusia affinis	Mosquito fish	FT	Meas	93.0%	96 hr	19.1	Mortality	0.13 g	8.02 (6.09-10.6)	Thurston *et al.* 1985	LL/1,5, 6
Gambusia affinis	Mosquito fish	FT	Meas	93.0%	96 hr	17.9	Mortality	0.12 g	4.6 (3.45-6.19)	Thurston *et al.* 1985	LL/1,5, 6
Gambusia affinis	Mosquito fish	S	Nom	47.0%	96 hr	20	Mortality	2.76 cm, 0.289 g	12.0 (10.52-13.34)	Naqvi & Hawkins 1989	LL/1,7, 6
Gammarus pulex	amphipod	SR	Meas	99.0%	96 hr	15	Mortality	>5 mm	0.44	McLoughlin *et al.* 2000	LR/1,4
Gammarus pulex	amphipod	SR	Meas	99.0%	120 hr	15	Mortality	>5 mm	0.26	McLoughlin *et al.* 2000	LR/1,4
Gammarus pulex	amphipod	SR	Meas	99.0%	144 hr	15	Mortality	>5 mm	0.17	McLoughlin *et al.* 2000	LR/1,4
Gila elegans	Bonytail chub	S	Nom	95.2%	96 hr	22	Mortality	0.41 g	>25	Dwyer *et al.* 1995, Sappington *et al.* 2001	LL/8,6
Hyalella azteca	amphipod	S	Nom	99.0%	48 hr	25	Mortality	<24 hr	0.0658 (0.0605-	Wheelock *et al.* 2005	RL/5,6

Table 5. Supplemental acute data rated RL, LR, LL with rating and reason for exclusion given below. S: static; SR: static renewal; FT: flow-through. NR: not reported.

Species	Common Identifier	Test type	Meas / Nom	Chemical grade	Duration	Temp (°C)	Endpoint	Age/size	LC/EC$_{50}$ (μg/L) (95% CI)	Reference	Rating/ Reason
									.00782)		
Hyalella azteca	amphipod	S	Nom	99.0%	48 hr	25	Mortality	<24 hr	0.0742 (0.0554-0.1057)	Wheelock *et al.* 2005	RL/5,6
Hyalella azteca	amphipod	S	Nom	99.0%	48 hr	25	Mortality	<24 hr	0.0781 (0.0584-0.1070)	Wheelock *et al.* 2005	RL/5,6
Hyalella azteca	amphipod	S	Nom	99.0%	48 hr	25	Mortality	<24 hr	0.0893 (0.0575-0.1464)	Wheelock *et al.* 2005	RL/5,6
Hyalella azteca	amphipod	S	Nom	99.0%	48 hr	25	Mortality	<24 hr	0.1402 (0.1064-0.1679)	Wheelock *et al.* 2005	RL/5,6
Ictalurus punctatus	channel catfish	FT	Meas	93.0%	96 hr	19.1	Mortality	2.81 g	3.44 (3.04-3.90)	Thurston *et al.* 1985	LL/1,5, 6
Ictalurus punctatus	channel catfish	FT	Meas	93.0%	96 hr	17.8	Mortality	2.94 g	2.06 (1.16-3.65)	Thurston *et al.* 1985	LL/1,5, 6
Lepomis macrochirus	bluegill	FT	Meas	93.0%	96 hr	18.5	Mortality	0.34 g	5.81 (4.67-7.22)	Thurston *et al.* 1985	LL/1,5, 6
Lepomis macrochirus	bluegill	FT	Meas	93.0%	96 hr	18	Mortality	0.58 g	4.56 (3.46-6.01)	Thurston *et al.* 1985	LL/1,5, 6
Lepomis macrochirus	Bluegill	S	Nom	NR	24 hr	22	Mortality	0.29 g, 30 mm	5.64 (4.52-7.03)	Aquatic Environmental Sciences 1976	LL/7,6
Lepomis macrochirus	Bluegill	S	Nom	NR	48 hr	22	Mortality	0.29 g, 30 mm	3.36 (2.78-4.05)	Aquatic Environmental Sciences 1976	LL/7,6
Lepomis macrochirus	Bluegill	S	Nom	NR	96 hr	22	Mortality	0.29 g, 30 mm	2.52 (1.88-3.66)	Aquatic Environmental	LL/7,6

Table 5. Supplemental acute data rated RL, LR, LL with rating and reason for exclusion given below. S: static; SR: static renewal; FT: flow-through. NR: not reported.

Species	Common Identifier	Test type	Meas / Nom	Chemical grade	Duration	Temp (°C)	Endpoint	Age/size	LC/EC$_{50}$ (μg/L) (95% CI)	Reference	Rating/ Reason
										Sciences 1976	
Lepomis macrochirus	Bluegill	S	Nom	Technical	24 hr	20	Mortality	1.0 g, 37 mm	9.6 (8.1-11.3)	Bentley 1974	RL/1,6
Lepomis macrochirus	Bluegill	S	Nom	Technical	48 hr	20	Mortality	1.0 g, 37 mm	6.4 (5.4-7.6)	Bentley 1974	RL/1,6
Lepomis macrochirus	Bluegill	S	Nom	Technical	96 hr	20	Mortality	1.0 g, 37 mm	6.1 (5.1-7.3)	Bentley 1974	RL/1,6
Menidia beryllina	Inland silverside	FT	Meas	94.6%	72 hr	22	Mortality	juvenile, 0.035 g, 15 mm	8.3 (6.9-10.6)	Ward & Rabe 1989	LR/2
Menidia beryllina	Inland silverside	FT	Meas	94.6%	96 hr	22	Mortality	juvenile, 0.035 g, 15 mm	6.2 (5.2-7.5)	Ward & Rabe 1989	LR/2
Menidia menidia	Atlantic silverside	FT	Meas	93.0%	96 hr	25.5	Mortality	NR	2.2 (1.2-6.4)	Schimmel *et al.* 1983	LL/2,6
Mugil cephalus	mullet	FT	Meas	93.0%	96 hr	24.5	Mortality	NR	5.5 (4.1-7.4)	Schimmel *et al.* 1983	LL/2,6
Oncorhynchus clarki stomias	Greenback cutthroat trout	S	Nom	95.2%	96 hr	12	Mortality	0.31 g	>1.0	Dwyer *et al.* 1995, 2005, Sappington *et al.* 2001	LR/LL/ 8,6
Oncorhynchus mykiss	Rainbow trout	S	Nom	95.2%	12 hr	12	Mortality	0.71 g	5.8 (3.4-8.3)	Sappington *et al.* 2001	RL/6
Oncorhynchus mykiss	Rainbow trout	S	Nom	95.2%	24 hr	12	Mortality	0.71 g	3.8 (3.4-8.3)	Sappington *et al.* 2001	RL/6
Oncorhynchus mykiss	Rainbow trout	S	Nom	95.2%	96 hr	12	Mortality	0.71 g	3.3 (1.7-4.8)	Sappington *et al.* 2001	RL/6

Table 5. Supplemental acute data rated RL, LR, LL with rating and reason for exclusion given below. S: static; SR: static renewal; FT: flow-through. NR: not reported.

Species	Common Identifier	Test type	Meas / Nom	Chemical grade	Duration	Temp (°C)	Endpoint	Age/size	LC/EC_{50} (μg/L) (95% CI)	Reference	Rating/ Reason
Oncorhynchus mykiss	Rainbow trout	S	Nom	Technical	96 hr	10	Mortality	1.0 g, 50 mm	9.8 (7.7-12.6)	Bentley 1974	RL/1,6
Oncorhynchus mykiss	Rainbow trout	FT	Meas	93.0%	96 hr	9.5	Mortality	2.65 g	5.47 (4.22-7.10)	Thurston *et al.* 1985	LL/1,5, 6
Oryzias latipes	medaka	SR	Meas	88.0%	48 hr	25	Mortality	juvenile, 30 d, 12 mm	11 (10-12)	Rice *et al.* 1997	LR/3
Penaeus aztecus	brown shrimp	S	Nom	89.1%	48 hr	20	Mortality	15-25 mm	0.38 (0.26-0.57)	Heitmuller 1977	LL/2,6
Penaeus aztecus	brown shrimp	S	Nom	89.1%	96 hr	20	Mortality	15-25 mm	0.34 (0.23-0.51)	Heitmuller 1977	LL/2,6
Penaeus duorarum	pink shrimp	S	Nom	95.7%	96 hr	19	Mortality	25-40 mm	0.354 (0.287-0.440)	Heitmuller 1975	LL/2,6
Penaeus duorarum	pink shrimp	FT	Meas	93.0%	96 hr	24.9	Mortality	NR	0.22 (0.06-0.79)	Schimmel *et al.* 1983	LL/2,6
Penaeus duorarum	pink shrimp	S	Nom	Technical	96 hr	25	Mortality	3-5 d old postlarvae	0.17 (0.15-0.19)	Cripe 1994	LR/2
Pimephales promelas	fathead minnow	FT	Meas	93.0%	96 hr	17.7	Mortality	0.42 g	6.40 (4.19-9.77)	Thurston *et al.* 1985	LL/1,5, 6
Poeciliopsis occidentalis occidentalis	Gila topminnow	S	Nom	95.2%	96 hr	22	Mortality	219 mg, 27.2 mm	>10	Dwyer *et al.* 1999, 2005	LL/8,6
Procambarus clarki	Crayfish	S	Nom	25.6%	96 hr	21.8	Mortality	8-12 mm, 0.017 g	0.438 (0.382-0.507)	Jarboe & Romaire 1991	LR/7,4
Procambarus clarki	Crayfish	S	Nom	25.6%	96 hr	21.2	Mortality	25-35 mm, 0.64 g	0.854 (0.725-1.030)	Jarboe & Romaire 1991	LR/7,4

Table 5. Supplemental acute data rated RL, LR, LL with rating and reason for exclusion given below. S: static; SR: static renewal; FT: flow-through. NR: not reported.

Species	Common Identifier	Test type	Meas / Nom	Chemical grade	Duration	Temp (°C)	Endpoint	Age/size	LC/EC_{50} (µg/L) (95% CI)	Reference	Rating/ Reason
Procambarus clarki	Crayfish	S	Nom	25.6%	96 hr	22.7	Mortality	45-55 mm, 2.45 g	1.298 (1.163-1.469)	Jarboe & Romaire 1991	LR/7,4
Procambarus clarki	Crayfish	S	Nom	25.6%	96 hr	23.1	Mortality	65-75 mm, 8.98 g	0.813 (0.515-0.938)	Jarboe & Romaire 1991	LR/7,4
Salvelinus fontinalis	trout	S	Nom	>92%	24 hr	9.5	Mortality	35-42 d, 42 mm, 1 g	4.80 (4.16-5.54)	Paul *et al.* 2005	LR/1,4
Salvelinus fontinalis	trout	S	Nom	>92%	48 hr	9.5	Mortality	35-42 d, 42 mm, 1 g	3.03 (2.86-3.22)	Paul *et al.* 2005	LR/1,4
Salvelinus fontinalis	trout	S	Nom	>92%	72 hr	9.5	Mortality	35-42 d, 42 mm, 1 g	2.91 (2.73-3.11)	Paul *et al.* 2005	LR/1,4
Salvelinus fontinalis	trout	S	Nom	>92%	96 hr	9.5	Mortality	35-42 d, 42 mm, 1 g	2.86 (2.69-3.05)	Paul *et al.* 2005	LR/1,4
Scaphirhynchus playtrynchus	Shovelnose sturgeon	S	Nom	95.2%	12 hr	22	Mortality	719 mg, 60.1 mm	10	Dwyer *et al.* 1999	RL/6
Uca pugilator	fiddler crab	S	Nom	95.7%	96 hr	19	Mortality	15-20 mm carapace width	2.39 (1.82-3.25)	Heitmuller 1975	LL/2,6
Uca pugilator	fiddler crab	S	Nom	89.1%	24 hr	20	Mortality	10-15 mm carpace width	5.3 (2.0-13)	Heitmuller 1977	LL/2,6
Uca pugilator	fiddler crab	S	Nom	89.1%	48 hr	20	Mortality	10-15 mm carpace width	2.8 (1.9-4.4)	Heitmuller 1977	LL/2,6
Uca pugilator	fiddler crab	S	Nom	89.1%	96 hr	20	Mortality	10-15 mm carpace width	2.2 (1.4-3.5)	Heitmuller 1977	LL/2,6

Exclusion Reasons

1. Not a standard method
2. Saltwater
3. Family not found in N. America

Table 5. Supplemental acute data rated RL, LR, LL with rating and reason for exclusion given below. S: static; SR: static renewal; FT: flow-through. NR: not reported.

Species	Common Identifier	Test type	Meas / Nom	Chemical grade	Duration	Temp (°C)	Endpoint	Age/size	LC/EC_{50} (µg/L) (95% CI)	Reference	Rating/ Reason

4. Unacceptable control response or NR
5. Control not described
6. Low reliability score
7. Low chemical purity or purity NR
8. No toxicity value calculable

95% CI: 95% confidance interval

Table 6. Final chronic toxicity data set for permethrin. All studies were rated RR. S: static; SR: static renewal; FT: flow-through. NR: not reported.

Species	Common identifier	Test type	Meas/ Nom	Chemical grade	Duration	Temp (°C)	Endpoint	Age/size	NOEC (µg/L)	LOEC (µg/L)	MATC (µg/L)	Reference
Brachycentrus americanus	Caddisfly	FT	Meas	Technical	21 d	15	Mortality	larvae			LC_{50}: 0.17 (0.09-0.34)	Anderson 1982
Daphnia magna	Daphnid	FT	Meas	98.6%	21 d	20	Reproduction	< 24 hr	0.03900	0.08400	0.05700	Kent *et al.* 1995a
Daphnia magna	Daphnid	FT	Meas	98.6%	21 d	20	Length	< 24 hr	0.03900	0.08400	0.05700	Kent *et al.* 1995a
Daphnia magna	Geomean										**0.05700**	
Pimephales promelas	Fathead minnow	FT	Meas	92.0%	32 d	25	Mortality	4-5 d old larvae	0.66	1.4	**0.96**	Spehar *et al.* 1983

Table 7. Acceptable reduced chronic data rated RR with reason for exclusion given below. S: static; SR: static renewal; FT: flow-through. NR: not reported

Species	Test type	Meas /Nom	Chemical grade	Duration	Temp (°C)	Endpoint	Age/size	NOEC (μg/L)	LOEC (μg/L)	MATC (μg/L)	Reference	Reason
Daphnia magna	S	Meas	98.0%	48 h	20	feeding rate during exposure	4-5 d old 4th instar			EC_{50}: 1.09 (0.1-1.2)	McWilliam & Baird 2002	A
Daphnia magna	S	Meas	98.0%	48 h	20	feeding rate during exposure	4-5 d old 4th instar	0.48	0.85	0.64	McWilliam & Baird 2002	A

Reasons for Exclusion

A. Less sensitive endpoint

Table 8. Acute-to-Chronic Ratios used for derivation of the permethrin chronic criterion.

Species	Common identifier	Test type	Meas/ Nom	Chemical grade	MATC	LC_{50}	SMACR (LC_{50}/MATC)	Chronic Reference	Acute Reference
Americamysis bahia	Mysid shrimp	FT	Meas	90-95%	0.016	0.075	4.6875	Thompson *et al.* 1989	Thompson 1986
Default							12.4[a]		
Default							12.4[a]		
Multi-species ACR = geomean (individual ACRs**)**							**8.96592**		

[a]The derivation and source data of the default ACR value of 12.4 are described in detail in section 2-3.2.5.3 of the UCD methodology (TenBrook *et al.* 2009).

Table 9. Supplemental chronic toxicity data from studies rated RL, LR, or LL. S: static; SR: static renewal; FT: flow-through. NR: not reported, NC: not calculable.

Species	Test type	Meas/ Nom	Chemical grade	Duration	Temp (°C)	Endpoint	Age/size	NOEC (µg/L)	LOEC (µg/L)	MATC (µg/L) (95% CI)	Reference	Rating/ Reason
Americamysis bahia	FT	Meas	95.0%	30 d	25	Mortality	<24 h	0.011	0.024	0.016	Thompson *et al.* 1989	LR/2
Cyprinodon variegatus	FT	Meas	93.0%	28 d	30	Embryo/fry survival	1.5-24 h old embryos	10 (std dev 2.6)	>2x solubility	>2x solubility	Hansen *et al.* 1983	LR/1,2
Salvelinus fontinalis	S	Nom	92.0%	6 h exposure, swim 10 min max.	9.5	Time to swimming exhaustion against a current	28-34 d post feeding, 37 mm, 1 g	1.6	3.2	2.3	Paul *et al.* 2005	LR/1,3
Salvelinus fontinalis	S	Nom	92.0%	24 h	9.5	Intoxication	35-42 d post feeding, 42 mm, 1 g	-	-	EC50: 3.01 (2.81-3.22)	Paul *et al.* 2005	LR/1,3
Salvelinus fontinalis	S	Nom	92.0%	48 h	9.5	Intoxication	35-42 d post feeding, 42 mm, 1 g	-	-	EC50: 2.44 (2.24-2.65)	Paul *et al.* 2005	LR/1,3
Salvelinus fontinalis	S	Nom	92.0%	72 h	9.5	Intoxication	35-42 d post feeding, 42 mm, 1 g	-	-	EC50: 2.44 (2.24-2.65)	Paul *et al.* 2005	LR/1,3
Salvelinus fontinalis	S	Nom	92.0%	96 h	9.5	Intoxication	35-42 d post feeding, 42 mm, 1 g	-	-	EC50: 2.86 (2.69-3.05)	Paul *et al.* 2005	LR/1,3

Exclusion Reasons

1. Not a standard method
2. Saltwater
3. Endpoint not linked to growth, reproduction or survival (Ch. 3, Section 3-2.1.3)

Table 10. Acceptable multispecies field, semi-field, laboratory, microcosm, mesocosm studies; R= reliable; L= less reliable; N= not reliable.

Reference	Habitat	Rating
Conrad *et al.* 1999	artificial pond	L
Coulon 1982	outdoor earthen ponds	L
Feng *et al.* 2009	Submerged in Tongan Bay, China	N
Helson *et al.* 1986	Outdoor artificial pools	N
Helson *et al.* 1993	Outdoor artificial pools	N
Jensen *et al.* 1999	Outdoor wetlands	N
Lutnicka *et al.* 1999	Indoor model river systems	L
Milam *et al.* 2000	Microcosms exposed in field	N
Mulla *et al.* 1978	Outdoor ponds and fields	N
Poirier & Surgeoner 1988	Model river systems	L
Werner & Hilgert 1992	Enclosures placed in natural stream	L
Yasuno *et al.* 1988	Enclosures placed in pond	L

Table 11. Threatened, Endangered, or Rare Species Predicted values by ICE.

Surrogate		Predicted	
Species	**LC_{50} (µg/L)**	**Species**	**LC_{50} (µg/L)**
Rainbow trout (*Oncorhynchus mykiss)*	7.0	Chinook salmon *(O. tshawytscha)*	11.88
		Coho salmon (*O. kisutch)*	8.41
		Paiute cutthroat trout (*O. clarki seleniris)*	8.93
		Greenback cutthroat trout (*O. c. stomias*)	8.93
		Gila trout (*O. gilae*)	3.48
		Chum salmon (*O. keta*)	9.4
		Sockeye salmon (*O. nerka*)	9.4

Table 12. Terrestrial wildlife studies of mallard ducks - permethrin; R= reliable; L= less reliable, N= not reliable.

Reference	Exposure	Toxicity value	Rating
Beavers *et al.* 1992	chronic reproduction - dietary	NOEC 125 mg/kg, LOEC 500 mg/kg	R
Fink 1975a	8-d dietary	LC_{50} > 10000 mg/kg	L
Fink 1975b	acute oral	LD_{50} > 4640 mg/kg	L
Hakin *et al.* 1991a	subacute dietary	LC_{50} > 500 mg/kg	L
Hakin *et al.* 1991b	acute oral	LD_{50} > 2000 mg/kg	L
Ross *et al.* 1976a	subacute	LC_{50} > 23000 mg/kg	L
Ross *et al.* 1976b	acute oral	no mortality	L
Fink 1976	chronic reproduction - dietary	not calculable	L
Ross *et al.* 1977	acute oral	LD_{50} > 10327 mg/kg	L

Appendix A

Fit test calculations

	Omit one										
SMAVs	1	2	3	4	5	6	7	8	9	10	11
0.0211		0.0211	0.0211	0.0211	0.0211	0.0211	0.0211	0.0211	0.0211	0.0211	0.0211
0.0896	0.0896		0.0896	0.0896	0.0896	0.0896	0.0896	0.0896	0.0896	0.0896	0.0896
0.189	0.189	0.189		0.189	0.189	0.189	0.189	0.189	0.189	0.189	0.189
0.21	0.21	0.21	0.21		0.21	0.21	0.21	0.21	0.21	0.21	0.21
0.21	0.21	0.21	0.21	0.21		0.21	0.21	0.21	0.21	0.21	0.21
0.32	0.32	0.32	0.32	0.32	0.32		0.32	0.32	0.32	0.32	0.32
0.664	0.664	0.664	0.664	0.664	0.664	0.664		0.664	0.664	0.664	0.664
1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5		1.5	1.5	1.5
1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58		1.58	1.58
1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7		1.7
1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	
2.500	2.500	2.500	2.500	2.500	2.500	2.500	2.500	2.500	2.500	2.500	2.500
2.71	2.71	2.71	2.71	2.71	2.71	2.71	2.71	2.71	2.71	2.71	2.71
3.34	3.34	3.34	3.34	3.34	3.34	3.34	3.34	3.34	3.34	3.34	3.34
4.16	4.16	4.16	4.16	4.16	4.16	4.16	4.16	4.16	4.16	4.16	4.16
5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4
5.95	5.95	5.95	5.95	5.95	5.95	5.95	5.95	5.95	5.95	5.95	5.95
7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
9.38	9.38	9.38	9.38	9.38	9.38	9.38	9.38	9.38	9.38	9.38	9.38

Omit one calculation continued from previous page

12	13	14	15	16	17	18	19
0.0211	0.0211	0.0211	0.0211	0.0211	0.0211	0.0211	0.0211
0.0896	0.0896	0.0896	0.0896	0.0896	0.0896	0.0896	0.0896
0.189	0.189	0.189	0.189	0.189	0.189	0.189	0.189
0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32
0.664	0.664	0.664	0.664	0.664	0.664	0.664	0.664
1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58
1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71
	2.500	2.500	2.500	2.500	2.500	2.500	2.500
2.71		2.71	2.71	2.71	2.71	2.71	2.71
3.34	3.34		3.34	3.34	3.34	3.34	3.34
4.16	4.16	4.16		4.16	4.16	4.16	4.16
5.4	5.4	5.4	5.4		5.4	5.4	5.4
5.95	5.95	5.95	5.95	5.95		5.95	5.95
7.00	7.00	7.00	7.00	7.00	7.00		7.00
9.38	9.38	9.38	9.38	9.38	9.38	9.38	

Omitted point, xi:	**0.0211**	**0.0896**	**0.189**	**0.21**	**0.21**	**0.32**	**0.664**	**1.5**	**1.58**	**1.7**
median 5th percentile	0.042364	0.030695	0.02624	0.025673	0.025673	0.02354	0.020289	0.017215	0.017036	0.016787
percentile	96.67	91.07	85.9	85.1	85.1	81.41	72.73	56.28	55.12	53.44
F-i(xi)	0.9667	0.9107	0.859	0.851	0.851	0.8141	0.7273	0.5628	0.5512	0.5344
1-F(xi)	0.0333	0.0893	0.141	0.149	0.149	0.1859	0.2727	0.4372	0.4488	0.4656
Min of F-i(xi) or 1-F(xi)	0.0333	0.0893	0.141	0.149	0.149	0.1859	0.2727	0.4372	0.4488	0.4656
p_i =2(min)	0.0666	0.1786	0.282	0.298	0.298	0.3718	0.5454	0.8744	0.8976	0.9312

Omitted point, xi:	**1.71**	**2.500**	**2.71**	**3.34**	**4.16**	**5.4**	**5.95**	**7.00**	**9.38**
median 5th percentile	0.016768	0.015543	0.015299	0.01471	0.014296	0.022546	0.023711	0.02404	0.018265
percentile	53.31	43.67	41.41	35.19	27.87	13.01	9.9	5.73	0.001
F-i(xi)	0.5331	0.4367	0.4141	0.3519	0.2787	0.1301	0.099	0.0573	0.00001
1-F(xi)	0.4669	0.5633	0.5859	0.6481	0.7213	0.8699	0.901	0.9427	0.99999
Min of F-i(xi) or 1-F(xi)	0.4669	0.4367	0.4141	0.3519	0.2787	0.1301	0.099	0.0573	0.00001
p_i =2(min)	0.9338	0.8734	0.8282	0.7038	0.5574	0.2602	0.198	0.1146	0.00002

p_i	$\ln(p_i)$	-2*Sum of ln (pi)	X^2_{2n}
0.0666	-2.7091	54.6159	0.039466244856
0.1786	-1.7226		
0.2820	-1.2658		
0.2980	-1.2107		
0.2980	-1.2107		
0.3718	-0.9894		
0.5454	-0.6062		
0.8744	-0.1342		
0.8976	-0.1080		
0.9312	-0.0713		
0.9338	-0.0685		
0.8734	-0.1354		
0.8282	-0.1885		
0.7038	-0.3513		
0.5574	-0.5845		
0.2602	-1.3463		
0.198	-1.6195		
0.1146	-2.1663		
0.00002	-10.8198		

0.039 < 0.05 so the distribution does not fit the permethrin acute data set

if $X^2 < 0.05$ significant lack of fit

if $X^2 > 0.05$ fit (no significant lack of fit)