CCME

Canadian Council of Ministers of the Environment
Le Conseil canadien des ministres de l'environnement

Scientific Criteria Document for the Development of the Canadian Water Quality Guidelines for ENDOSULFAN

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SCIENTIFIC CRITERIA DOCUMENT - CANADIAN WATER QUALITY GUIDELINES FOR ENDOSULFAN

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LIST OF ACRONYMS

a.i.	Active ingredient
CAS	Chemical Abstract Service
CCME	Canadian Council of the Ministers of the Environment
CL	Chemiluminescence
CWQG	Canadian Water Quality Guideline
DAD	Diode array detector
DT_{50}	Rate of degradation, half-life in soil
DWEL	Drinking water equivalent level
ELISA	Enzyme-linked immunosorbent assay
FI/CL	Flow-injection chemiluminescence
GLC	Gas-Liquid chromatography
HPLC	High performance liquid chromatography
IUPAC	International Union of Pure and Applied Chemistry
LC_{50}	Median lethal concentration
LOEC	Lowest observable effects concentration
MAC	Maximum acceptable concentration
MATC	Maximum acceptable toxicant concentration
MME	Micelle-mediated extraction
MPC	Maximum permissible concentration
MS	Mass Spectrometry
NOEC	No observable effects concentration
PMRA	Pest Management Regulatory Agency
PWQO	Provincial Water Quality Objective
RSD	Relative standard deviation
SDS	Sodium dodecylsulfate
TLC	Thin-layer chromatography
TLm	Median tolerance limit
US EPA	United States Environmental Protection Agency
UV	Ultraviolet
WHO	World Health Organization

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EXECUTIVE SUMMARY

This report describes the development of Canadian Water Quality Guidelines (CWQG) for the protection of freshwater and marine aquatic life for the pesticide active ingredient endosulfan. While information regarding formulations is investigated, guideline values are derived using toxicity data concerning the technical active endosulfan (> 90% active ingredient). Endosulfan (CAS Registry Number 115-29-7) is a broad spectrum organochlorine insecticide which exerts its effects through blockage of GABA-(gamma amino butyric acid) gated chlorine channels. The primary registrant of endosulfan is Bayer and Makteshim. It is registered to control a number of insect pests over a wide range of greenhouse crops such as cucumber, tomato, lettuce, and pepper as well as terrestrial food crops such as apple, pear, apricot, cherry, plum, peach, grapes, bean, broccoli, brussel sprots, cabbage, lettuce, tomato, celery, corn, potato, strawberry, and cauliflower.

Endosulfan has a molecular mass of 406.95 g/mol. It is a hydrophobic, nonpolar molecule. Endosulfan has a low water solubility, with the α and β-isomers having a reported solubility in water of 0.32 and 0.33 mg/L. It has an octanol/water partition coefficient (log K_{ow} 3.55), which indicates a potential for bioaccumulation in biota. Endosulfan is a non-ionic compound and thus will not dissociate at environmentally relevant pH (approximately pH 5.0 to pH 9.0). Endosulfan residues depurate rapidly in aquatic invertebrates and fish with a reported depuration half-life of 2.9 and 5.1 days for the α and β-isomers and 5.9 days for the endosulfan sulphate transformation product in zebra fish. The vapour pressure of 0.83 mPa at 20°C for technical endosulfan indicates that it has an intermediate to high volatility under field conditions. The calculated Henry's law constants of 4.54×10^{-5} atm•m^3/mole and 4.39×10^{-5} atm•m^3/mol and the calculated 1/H values of 540 and 560, respectively, for the α and β-isomers indicate that both endosulfan isomers have the potential to volatilize from water or moist soil surfaces

The short-term and long-term freshwater Canadian Water Quality Guidelines and the marine short-term and long-term Canadian Water Quality Guideline for endosulfan for the protection of aquatic life were developed based on the CCME protocol (CCME 2007). The short and long-term freshwater, as well as marine short-term CWQG was developed using the statistical or Type A approach, as there was sufficient data to meet the requirements. The data requirements were not satisfied to derive a long-term marine CWQG using the SSD approach or using the lowest endpoint approach (B1) according to the CCME protocol (CCME 2007). Therefore, following the tiered approach, the lowest endpoint approach (Type B2) guideline method was used to develop a long-term marine CWQG. The short-term, long-term freshwater and short-term, long-term marine guideline values are summarized in the table below.

Guideline	Value (µg a.i./L)
Short-term Freshwater	0.06
Long-term Freshwater	0.003
Short-term Marine	0.09
Long-term Marine	0.002

RÉSUMÉ

Le présent rapport décrit le processus d’élaboration des Recommandations canadiennes pour la qualité des eaux (RCQE) en vue de la protection de la vie aquatique dulcicole et marine relatives à l’endosulfan, matière active utilisée comme pesticide. Bien que des études soient menées au sujet des préparations, on se sert des données sur la toxicité de la matière active de qualité technique endosulfan (> 90 % de matière active) pour établir les valeurs des recommandations. L’endosulfan (numéro de registre CAS 115-29-7) est un insecticide organochloré à large spectre qui agit en bloquant les canaux chlorure à récepteurs GABA (acide gamma-aminobutyrique). Le principal titulaire de l’homologation de l’endosulfan est Bayer et Makhteshim. L’endosulfan est homologué contre plusieurs insectes ravageurs dans diverses cultures en serre (concombres, tomates, laitue et poivrons) ainsi que dans les cultures terrestres destinées à l’alimentation humaine (pommes, poires, abricots, cerises, prunes, pêches, raisins, haricots, brocoli, choux de Bruxelles, choux, laitue, tomates, céleri, maïs, pommes de terre, fraises et chou-fleur).

La masse moléculaire de l’endosulfan est de 406,95 g/mol. Il s’agit d’une molécule hydrophobe et non polaire qui est peu soluble dans l’eau, les isomères α et β présentant une solubilité dans l’eau respective de 0,32 et de 0,33 mg/L. Le coefficient de partage octanol-eau ($\log K_{oe}$) de 3,55 indique un potentiel de bioaccumulation dans le biote. L’endosulfan est un composé non ionique et ne se dissocie donc pas aux valeurs de pH observées dans l’environnement (environ 5,0 à 9,0). Les résidus d’endosulfan sont éliminés rapidement par dépuration chez les invertébrés aquatiques et les poissons. Les demi-vies de dépuration sont respectivement de 2,9 et de 5,1 jours pour les isomères α et β et de 5,9 jours pour le produit de transformation sulfate d’endosulfan chez le poisson-zèbre. La valeur de la pression de vapeur (0,83 mPa à 20 °C) de l’endosulfan de qualité technique indique qu’il a une volatilité intermédiaire à élevée dans des conditions naturelles. Les constantes calculées de la loi de Henry de $4{,}54 \times 10^{-5}$ atm•mol^{-1} et de $4{,}39 \times 10^{-5}$ atm•mol^{-1} ainsi que les valeurs calculées 1/H de 540 pour l’isomère α et de 560 pour l’isomère β indiquent que les deux isomères d’endosulfan peuvent se volatiliser à partir de la surface de l’eau ou du sol humide.

Les RCQE relatives à l’endosulfan concernant l’exposition de courte et de longue durée en eaux douces et marines en vue de la protection de la vie aquatique ont été élaborées d’après le protocole du CCME (CCME, 2007). La RCQE concernant l’exposition de courte et de longue durée en eaux douces ainsi que celle de courte durée en eaux marines ont été élaborées à l’aide de la méthode statistique de type A, car on disposait de suffisamment de données pour satisfaire aux exigences du protocole. D’après le protocole du CCME (CCME, 2007), les données n’étaient toutefois pas suffisantes pour établir des recommandations concernant l’exposition de longue durée en eaux marines au moyen de la méthode de la distribution de la sensibilité des espèces (DSE) ou encore de la méthode du paramètre ayant la valeur la plus faible (type B1). Par conséquent, selon la démarche à plusieurs volets, on a utilisé la méthode du paramètre d’effet ayant la valeur la plus faible (type B2) pour élaborer la RCQE pour une exposition à long terme en milieu marin. Les RCQE pour les expositions de courte et de longue durée en eaux douces de même que pour l’exposition de longue durée en eaux marines sont résumées dans le tableau ci-dessous.

Recommandation	**Valeur (µg m.a./L)**
Exposition de courte durée – eaux douces	0,06
Exposition de longue durée – eaux douces	0,003
Exposition de courte durée – eaux marines	0,09
Exposition de longue durée – eaux marines	0,002

1.0 INTRODUCTION

The Canadian Water Quality Guidelines (CWQG) for the Protection of Aquatic Life are developed through compilation and interpretation of aquatic toxicity data, thereby providing an important tool in the evaluation of ambient water quality. Endosulfan concentrations monitored in the environment can be compared to the guideline value to help predict whether sensitive species will be impacted in the ecosystem. Exceedance of the guideline values does not denote definite negative impacts to the environment, but rather that further investigation is necessary, for example site-specific analysis of water chemistry parameters and sensitive species residing in the ecosystem.

The Water Quality Task Group of the Canadian Council of the Ministers of the Environment (CCME) is charged with overseeing the development of Canadian Water Quality Guidelines for the Protection of Aquatic Life. In 2007, the guideline derivation protocol was revised. The goals of the revised protocol include: (i) accounting for the unique properties of contaminants which influence their toxicity; and (ii) incorporating the species sensitivity distribution (SSD) method, which uses acceptable data as outlined in the protocol (provided these data pass quality control criteria) in a more flexible approach.

The structure of the criteria document for endosulfan has been built to accommodate the changes in the protocol for guideline derivation. All of the customary components of scientific criteria documents have been included (physical and chemical properties, production and uses, environmental fate and behaviour, environmental concentrations, toxicity data). In addition, new cornerstones of the protocol, such as bioaccumulation/bioconcentration, and toxicity modifying factors have been given attention.

2.0 PHYSICAL AND CHEMICAL PROPERTIES

2.1 Identity:

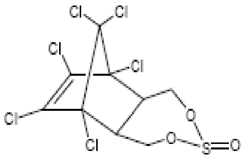
Endosulfan, a cyclodiene, was introduced as a broad spectrum organochlorine insecticide in 1956 (Maier-Bode 1968) and is still in current use in Canada and many other countries. Table 2.1 lists the physical-chemical properties of endosulfan.

Pure grade endosulfan is a colourless crystalline solid whereas the technical grade product consists of crystalline flakes with a cream to brown colour and a faint odour of sulfur dioxide. Technical grade endosulfan (CAS Registry Number 115-29-7) is a mixture of the two biologically active isomers (α and β) in an approximate 2:1 to 7:3 ratio, in addition to impurities and degradation products. In accordance with specifications of the Food and Agricultural Organization of the United Nations (FAO Specification 89/TC/S) (FAO Specifications for Plant Protection Products-Endosulfan 1989, AGP; CP/228.), technical endosulfan must contain at least 94% endosulfan with the content of the α isomer in the range of 64-67% and the β-isomer of 29-32%. The α isomer is asymmetric and exists as two twist chair forms while the β form is symmetric. The β-isomer is easily converted to α-endosulfan, but the α isomer is not easily converted to the β-isomer. Several transformation products of endosulfan have been identified in the environment with endosulfan sulphate being the predominant one (Tomlin 2000).

Endosulfan has a molecular mass of 406.95 g/mol (Mackay et al. 1997). It is a hydrophobic, nonpolar molecule. Endosulfan has a low water solubility, with the α and β-isomers having a reported solubility in water of 0.32 and 0.33 mg/L, respectively, at 20°C (Tomlin 2000). The melting point for technical endosulfan has been reported as 70 -100°C (Mackay et al.1997).

The vapour pressure of 0.83 mPa at 20°C for technical endosulfan indicates that it has an intermediate to high volatility under field conditions (Tomlin 2000). The calculated Henry's law constants of 4.54×10^{-5} atm•m^3/mole and 4.39×10^{-5} atm•m^3/mol and the calculated 1/H values of 540 and 560, respectively, for the α and β-isomers indicate that both endosulfan isomers have the potential to volatilize from water or moist soil surfaces (Mackay et al. 1997). Endosulfan has a log K_{ow} value of 3.55 (Mackay et al. 1997), which indicates a potential for bioaccumulation in biota. Endosulfan is a non-ionic compound and thus will not dissociate at environmentally relevant pH (approximately pH 5.0 to pH 9.0).

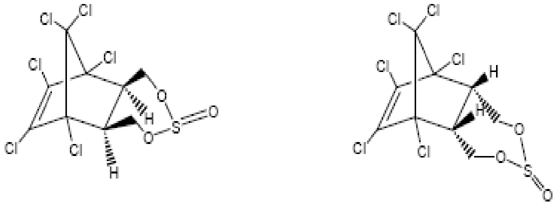
Additional properties of endosulfan are detailed in Table 2.1.



endosulfan

(115-29-7)

(stereochemistry unspecified)

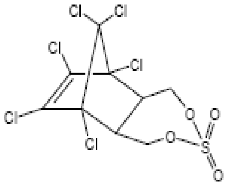


alpha-endosulfan

(959-98-8)

beta-endosulfan

(33213-65-9)



endosulfan sulfate

(1031-07-8)

Figure 2.1 Structure Diagram of Endosulfan and its isomers (CAS Numbers in brackets).

Table 2.1 Physical-Chemical Properties of Endosulfan

Physical-Chemical Property	Endosulfan	Reference(s)
Appearance	Technical: cream to brown, mostly beige	Tomlin 2000
Common Name	Endosulfan	Mackay et al. 1997
Trade Name	Thiodan®, Thionex, Endosan, Farmoz, Nufarm	Mackay et al. 1997
Class	organochlorine	
Chemical Name	CAS: 6,7,8,9,10,10-hexachloro-1, 5,5a,6,9,9a-hexahydro-6,9-methano-2,4,3-benzodioxathiepine-3-oxide IUPAC: (1,4,5,6,7,7-hexachloro-8,9, 10-trinorborn-5-en-2,3-ylenebismethylene) sulfite	Tomlin 2000
Chemical Formula	$C_9H_6Cl_6O_3S$	Mackay et al. 1997
CAS Registry Number	115-29-7	Mackay et al. 1997
Molecular Weight	406.95 g/mol	Mackay et al. 1997
Water Solubility	α endosulfan 0.32, β endosulfan 0.33 (both in mg/l, 22 °C)	Tomlin 2000
Melting Point	Technical: 70-100 °C	Mackay et al. 1997
Vapour Pressure	0.83 mPa (20 °C) for a 2:1 mixture of α and β endosulfan	Tomlin 2000
Partition Coefficient (log K_{ow})	3.55	Mackay et al. 1997
Soil Adsorption Coefficient (log K_{oc})	4.09 for soil, 20-25 °C.	Mackay et al. 1997
Henry's Law Constant	1.09 Pa.m^3/mol	Mackay et al. 1997
Stability	Stable at ambient temperatures. Stable to sunlight. Slowly hydrolysed in aqueous acids and alkalis, with the formation of the diol and sulfur dioxide.	Australian National Registration Review of Endosulfan 1998. Tomlin 2000

2.2 Analytical methods

One common determination of endosulfan involves the extraction from water using methylene chloride followed by gas chromatography combined with electron capture detection. In determining the residue levels, the sum of the α and β-isomers of endosulfan plus the endosulfan sulphate metabolite are to be considered. Detection limits are 0.015 µg a.i./L for α-endosulfan and, 0.024 µg a.i./L for β-endosulfan and 0.015 µg a.i./L for endosulfan sulfate (ATSDR 2000).

Lee et al. (1995) developed two enzyme immunoassays for the detection of endosulfan residues in water and soil. These optimized assays have detection limits of about 0.2 µg a.i./L endosulfan and detect in the range of 0.2-10 µg a.i./L. These immunoassays detect endosulfan sulphate with a sensitivity similar to that for endosulfan but are four to ten times less sensitive to endosulfan diol, and therefore the assays can potentially determine toxic compounds of endosulfan from the total endosulfan residues present in the environment.

You et al. (2004) utilized a gas chromatography method and an electron capture detector for the determination of endosulfan as well as other organochlorine pesticides in sediment. Four control sediments from different sources were spiked with a pesticide mixture and analysed for method validation. The method detection limits ranged from 0.22 to 0.85 μg a.i./kg dry sediment. Recoveries for the spiked samples (concentrations 1 to 400 μg a.i./kg dry sediment) were 71.9% to 129.8% with relative standard deviations (RSDs)< 11%. Taking the matrix effect into account, 1 μg a.i./kg was chosen for the threshold of detection, but 0.5 μg a.i./kg of spiked control sediment still provided good recoveries and RSDs.

Within a historical context, methods for the clean-up and determination of endosulfan have been summarized by Maier-Bode (1968), the National Research Council of Canada (1975), and Goebel et al., (1982), but the sensitivities and recoveries for the various methods are not always given. One useful method at that time involved a combination of gas chromatography with electron capture detection (GC-EC). The sensitivity of assays in water ranged from 0.01 – 2.0 g a.i./L with recoveries generally greater than 90% (Wegman and Greve 1978; 1980; Frank et al. 1979).

In soil and sediment, assays were not as sensitive, ranging from 0.001 to 0.1 mg a.i./kg with recoveries between 80 - 110%, but usually less than 90% (Miles and Harris 1973; Frank et al. 1976; Carey et al. 1979). Biological samples such as animal and plant tissues and milk, normally require more extensive clean-up procedures such as column methods. Sensitivities from 0.2 to 10 μg a.i./kg were usual with most recoveries greater than 90% (Cheng and Braun 1977; Chopra and Mahfouz 1977; Frank et al. 1979; Zanini et al. 1980). Clean-up methods employing high-pressure liquid chromatography (HPLC) have been used and these methods reduce the time involved in the preparation of such samples (Demeter and Heyndrickx 1979). Detection limits for the α and β- isomers of endosulfan usually differ, the α-isomer being easiest to detect (Goebel et al. 1982). At low concentrations, the identification of endosulfan residues can be hampered by a variety of other pesticides or plant components. Endosulfan residues in environmental samples can only be considered valid if α and β-isomers together with endosulfan sulphate are found simultaneously. Validation can be achieved by methods summarized by Goebel et al. (1982).

2.3 PRODUCTION AND USES

Endosulfan has been in commercial use since 1956 (Maier-Bode 1968). It is produced by a Diels-Alder addition of hexachloro-cyclo-pentadiene and cis-butene-1,4-diol in xylene. The adduct is then hydrolysed to form the cis-diol or di-alcohol. The reaction of this cis-diol with thionyl chloride forms the final product (German Federal Environment Agency 2007).

Worldwide production of endosulfan was estimated at 10,000 metric tonnes in 1984 (WHO Endosulfan 1984). Current global production is likely to be higher as its use remains widespread (German Federal Environment Agency, 2004). Endosulfan is available as an emulsifiable concentrate (EC), water dispersible powder (WP), dispersion, dust or granules (IPCS 1988). Endosulfan is typically applied to crops using air-blast or ground boom sprayers, thus allowing for chance of drift and longer-range atmospheric transport (WHO 1984).

In Canada technical endosulfan is manufactured by Bayer and Makhteshim. It is registered in Canada to control a number of insect pests over a wide range of greenhouse food crops such as cucumber, tomato, lettuce and pepper as well as terrestrial food crops such as apple, pear, apricot, cherry, plum, peach, grapes, bean, broccoli, brussels sprouts, cabbage, lettuce, tomato, celery, corn, potato, strawberry and cauliflower.

Brimble et al. (2005) state that 22,025.96 kg of endosulfan were sold in Canada. On an annual basis, the data were primarily taken from one of the years 2001 to 2003 for each of the provinces and territories and then summed across all of the provinces and territories using the data from the most recent year of data collection. The most frequent data year was 2003.

As of 2007, endosulfan was banned in the European Union, the Philippines, Cambodia, and several other countries. It is still used extensively in many countries including the US and India. In July, the European Commission proposed to add endosulfan to the list of chemicals banned under the Stockholm Convention on Persistent Organic Pollutants. If approved, all use and manufacture of endosulfan would be banned globally. Canada also announced that endosulfan is under consideration for phase-out.

3.0 SOURCES TO THE ENVIRONMENT

In Canada, endosulfan is used in agricultural and residential applications. It is produced in wettable powder and emulsifiable concentrate form that can be applied by dipping in a solution, high-pressure hand wand equipment or air blast equipment. All wettable powder formulations are to be packaged in water soluble bags. Direct application to soil, vegetation, trees and animals can result in exposure to non-target organisms.

In a set of interim mitigation measures taken in 2004 by PMRA to reduce possible contamination of aquatic environments, it is required that a ten metre vegetative buffer strip be maintained between all areas treated with endosulfan and sensitive freshwater habitats such as lakes, rivers, sloughs, ponds, coulees, prairie potholes, creeks, marshes, streams, reservoirs and wetlands, and estuarine/marine habitats. They also require a thirty metre buffer zone between the point of direct application and the closest downwind edge of sensitive freshwater habitats such as lakes, rivers, sloughs, ponds, coulees, prairie potholes, creeks, marshes, streams, reservoirs and wetlands, and estuarine/marine habitats. The application of endosulfan along with the possibility of accidental spillage, spray drift, leaching and runoff from terrestrial applications has the potential to expose aquatic biota to residues (PMRA 2004).

4.0 ENVIRONMENTAL FATE AND BEHAVIOUR

4.1 Transformation Products

In the environment, endosulfan can be transformed to a number of chemical products with endosulfan sulfate (CAS Number 1031-07-8) being the predominant product. Other products that have been identified are endosulfan diol, endosulfan hydroxycarboxylic acid and endosulfan lactone (German Federal Environment Agency 2004). The routes of degradation of endosulfan in soil and water are shown in Figure 4.1.

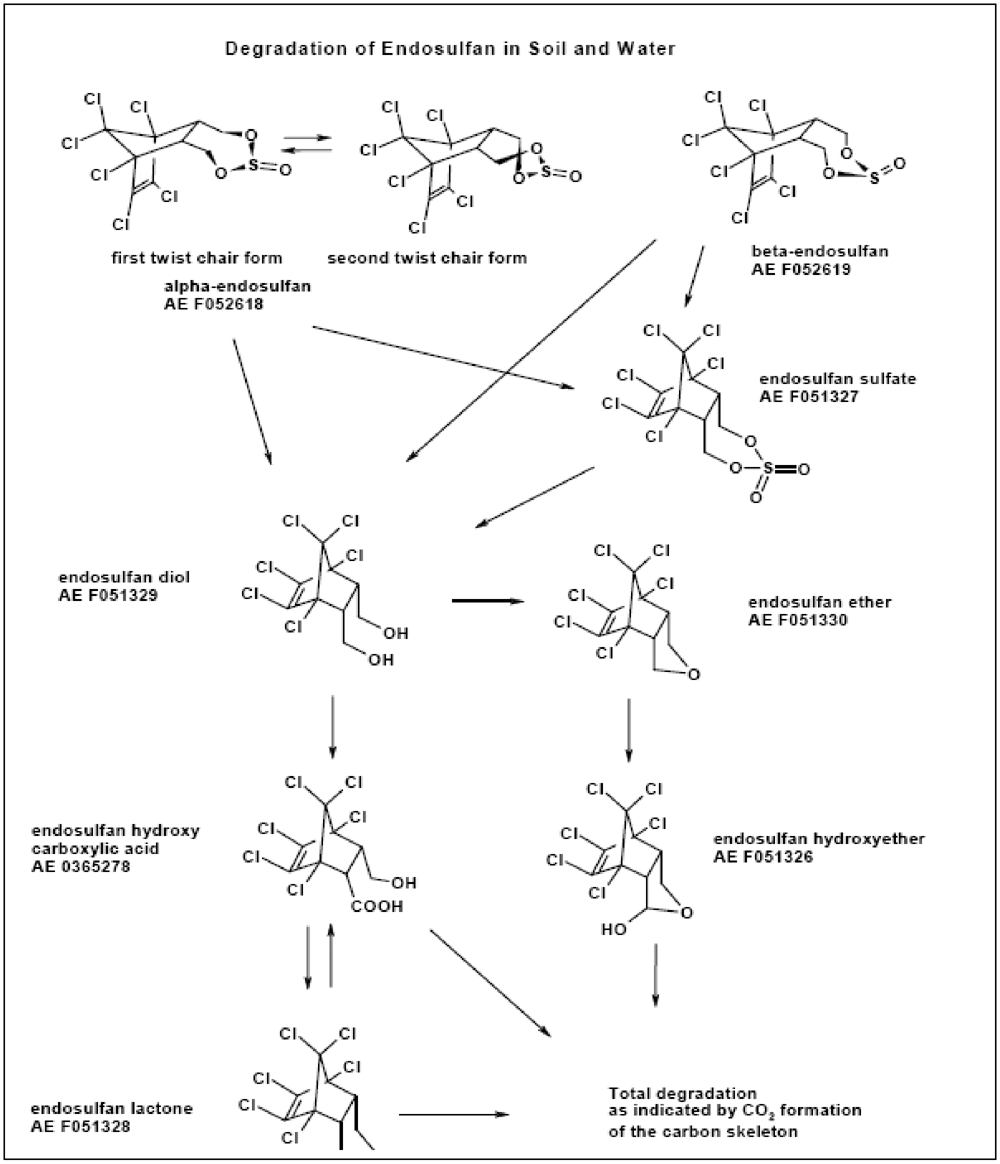


Figure 4.1. Routes of degradation of endosulfan in soil and water (German Federal Environment Agency 2007).

4.2 Fate in Water and Sediment

Endosulfan α and β-isomers have a reported solubility in water of 0.32 and 0.33 mg/L respectively at 22°C which classify them as being sparingly soluble. The major transformation product endosulfan sulfate has a reported solubility in water of 0.5 mg/L at 22°C which would also classify it as being sparingly soluble. The calculated Henry's law constants of 4.54×10^{-5} atm•m^3/mol and 4.39×10^{-5} atm•m^3/mol, respectively and the corresponding calculated 1/H values of 540 and 560 for the α and β-isomers indicate that both endosulfan isomers have the potential to volatilize from water or moist soil surfaces.

Hydrolysis of endosulfan α and β-isomers is pH dependent, with both isomers being very stable at pH's below 5, relatively stable at pH 5, and rapidly transformed at pH 9. The major transformation product was endosulfan-diol. Phototransformation is not expected to be an important route of transformation in the aquatic environment (German Federal Environment Agency 2007).

In sediments, α and β-endosulfan degrades primarily via microbial biotransformation to endosulfan sulphate (the major metabolite); other minor products include the diol, ether, a-hydroxy ether, and lactone forms. Alpha endosulfan disappears quickly in the environment, within 60 days in soil and within 7 days in river water (Eichelberger and Lichtenberg 1971; Steward and Cairns1974); β-endosulfan and endosulfan sulphate may not disappear for over two years (National Research Council of Canada1975). During the winter, degradation is effectively halted, and it may also be considerably slowed under conditions of low pH (below pH 7) or dissolved oxygen, or in highly organic soils or sediments (National Research Council of Canada1975). For example, Greve (1971) found that, under anaerobic conditions and neutral pH, the half-life of endosulfan in water was five weeks rather than one week; under anaerobic, acidic (pH 5.5) conditions, the half-life was extended to five months. This suggests that the environments most likely to act as sinks for endosulfan are marshy wetland adjacent to sprayed croplands, or muck crop areas. Stagnant water in such wetlands are subject to eutrophication, resulting in highly anaerobic sediments and seasonal lows in dissolved oxygen concentrations. Where peaty bottoms exist (an infrequent phenomenon given the predominance of limestone deposits in soils), there will be additional acidity (Harris et al. 2000a).

4.3 Fate in Soil

Numerous data are available from soil degradation studies carried out in various soils and under various climatic conditions. Aerobic and anaerobic biotransformation are routes of transformation of endosulfan in soil. Alpha endosulfan is slightly to moderately persistent and β-endosulfan is moderately persistent to persistent in soils according to the classification of Goring et al. (1975) under aerobic conditions. The major transformation product in all cases was endosulfan sulfate, which appears to be persistent. Alpha endosulfan and β-endosulfan are moderately persistent to persistent in soils according to the classification of Goring *et al.* (1975) under anaerobic conditions. Endosulfan sulfate is persistent in soils under anaerobic conditions (PMRA 2006).

Both endosulfan isomers are strongly adsorbed to soil as indicated by Koc values around 10,000 (Mackay et al.1997). Endosulfan sulfate is adsorbed to a similar extent as the parent compound, while affinity to organic surfaces is less pronounced for the endosulfan-diol, reported at Koc values around 1,000. Photolytic degradation of endosulfan on soil surfaces is of no relevance. Half-lives have been reported to be greater than 200 days under simulated (Gildemeister and Jordan 1983) and natural sunlight conditions (Ruzo et al. 1988).

Endosulfan, however, is mobile in the environment due to its volatility. Significant amounts volatilize from soil and leaf surfaces, particularly soon after application. The α-isomer is more volatile than the β-isomer, which in turn is more volatile than the sulfate transformation product. Endosulfan has been detected in air, water, biota and snow samples in remote areas such as the arctic which has resulted from long range atmospheric transport. The α-isomer dissipated fairly rapidly (50% loss in 40-60 days), but the β-isomer was more persistent (50% loss in 800 days) in a bare sandy loam soil in a field dissipation study conducted in Canada. The α-isomer is considered moderately persistent and the β-isomer persistent under these conditions according to the classification of Goring et al. (1975). Endosulfan sulfate was the major transformation product, which persisted throughout the study.

4.4 Bioconcentration and bioaccumulation

Bioconcentration data for endosulfan is available for several species of freshwater fish and invertebrates (Table 4.1). Estimates of a bioconcentration factors vary by almost four orders of magnitude ranging from 1.97 to 11583, likely due to the lipid content and the metabolic ability of the organisms tested. The endosulfan sulfate metabolite is generally included in the calculation of the bioconcentration factor, since it is just as toxic as the parent compound. Data for the white sucker exposed to endosulfan showed only a moderately low BCF ranging between 65 in muscle to 550 in liver (gill, kidney, gut and skin accumulation was also measured). Although endosulfan sulfate is typically the only metabolite included in bioconcentration calculations, investigators have detected many other metabolites; some have suggested that the sulfate is just an intermediate metabolic form in vertebrates (Schoettger 1970) and endosulfan ether is the main product of detoxification (Rao et al. 1981). Rao et al. (1981) reported finding ether, alcohol, a-hydroxy ether and lactone forms of endosulfan as well as two unidentified metabolites in tissues of the fish *Macrognathus aculeatum*.

Endosulfan residues depurate rapidly in aquatic invertebrates and fish. Toledo and Jonsson (1992) reported depuration half-lives of 2.9 and 5.1 days for the α and β-isomers and 5.9 days for the endosulfan sulphate transformation product in zebra fish (*Brachydanio rerio*). Ernst (1977) reported a depuration half-life of 34 hours for the α-isomer in marine mussels (*Mytilus edulis*).

Table 4.1. Bioconcentration factors for the endosulfan α and β-isomers and the major transformation product endosulfan sulfate in invertebrate and fish species.

Species	Endosulfan α-isomer	Endosulfan β-isomer	Endosulfan α and β sulfate	Reference
Louisiana crayfish (*Procambarus clarkii*)	-	1.97	-	Naqvi and Newton 1990
Mussel (*Mytilus edulis*)	-	-	600	Roberts 1975
Scallop (*Chlamys opercularis*)	-	-	26	Ernst 1977
Zebra fish (*Brachydanio rerio*)	2006	1398	2650	Toledo and Jonsson 1992
Yellow tetra (*Hyphessobrycon bifasciatus*)	10994	9908	11583	Jonsson and Toledo 1993
Mosquitofish (*Gambusia affinis*)	71.5	15.5	86.5	Novak and Ahmad 1989
White sucker (*Catostomus commersoni*)	-	-	65-550	Schoettger 1970
Goldldfish (*Carassius auratus*)	-	-	350	Oeser et al.1971

5.0 CONCENTRATIONS IN CANADIAN WATERS

Environment Canada initiated the first nation-wide water surveillance project in 2003 as part of the Pesticide Science Fund. The program provides monitoring data for in-use pesticides in aquatic ecosystems and source waters covering the five regions of Canada, namely the Pacific Yukon Region, the Prairie and Northern Region, the Ontario Region, the Quebec region and the Atlantic Region.

Endosulfan and its isomers were detected in sediment and water across Canada at low levels. Sediment concentrations of β-endosulfan ranged from <2.9 ng/g to 64.5 ng/g in Ontario. Alpha endosulfan was detected in Ontario at limits of detection (LODs) in water between 12 and 20 μg/L and β-endosulfan was detected at LODs between 10 and 60 μg/L. In British Columbia, maximum concentrations reported in water were 0.021 μg/L for α endosulfan, 0.0415 μg/L for β-endosulfan and 0.312 μg/L for endosulfan sulfate. In the United States, surface water samples generally contain less than 1 μg/L of endosulfan (WHO 2003).

Ontario

Surface water concentrations detected in Ontario over the past 2 decades ranged from <10 μg/L to 540 μg/L (Harris et al. 2000a). Samples collected from the open waters of Lake Erie in 1993 showed less than 0.001 μg/L endosulfan (Struger, Environment Canada, pers. comm.; cited in Harris et al. 2000a).

However, water monitoring for endosulfan is sporadic and limited in Ontario. One study of residues in sediment and green frog fat bodies collected from ponds in apple orchards suggests that environmental exposure to endosulfan is more widespread than estimated by random surface water collections (Harris et al. 1998). Sediment concentrations of β-endosulfan ranged from <2.9 ng/g to 64.5 ng/g (n=8 samples), while frog fat body concentrations of endosulfan sulfate ranged from 0.7 mg/g to 10.0 mg/g (n=6 samples). Sediment and frogs were collected from Ontario apple orchard ponds in the spring and fall, thus endosulfan was persisting over a year in some environments. Tree swallow eggs collected from the same orchards contained very little endosulfan (maximum residue of 0.057 mg/g wet weight), suggesting there was limited food chain transfer of contamination to a terrestrial insectivore (Bishop et al. 1998). The isomers α and β-endosulfan (as well as methoxychlor) were detected in precipitation at several locations along the northern edges of Lakes Ontario, Erie and Superior (Johnson et al. 1988; Chan et al. 1994) during comprehensive scans for persistent chlorinated contaminants. This suggests that some atmospheric transport of endosulfan occurs within and perhaps into Ontario.

The Canada Centre for Inland Water in Burlington Ontario sampled one site in the St. Lawrence River at Wolfe Island and two sites in the Niagara River (Fort Erie and at Niagara on the Lake). Sampling at these three sites were conducted from 1990 and 2001 (Struger unpublished data 2004b). Samples were collected throughout the year with one to three samples collected per month. This data represents alpha and beta-endosulfan present in the dissolved phase. Alpha endosulfan was detected at limits of detection (LODs) between 0.000012 and 0.00002 μg/L and beta endosulfan was detected at LODs between 0.00001 and 0.00006 μg/L. Some endosulfan detections were identified as trace (i.e., detections quantified below the LOD).

Struger et al. (2002) produced an interim report which presents concentrations of 159 pesticides (herbicides, insecticides and fungicides) and some of their metabolites measured in the Don and Humber River Watersheds. Nutrients such as phosphorus, nitrate and ammonia were also measured. Samples were collected on a total of 136 occasions (62 wet and 74 dry events) from the years 1998 to 2000. Sampling occurred from April to December in the year 1998, from March to November in the year 1999 and from August to November in the year 2000. The method detection limit (MDL) was 0.1µg/L. No detections of endosulfan were reported.

As part of the Ontario Region's Pesticide Science Fund monitoring program, 31 (2003) sample extracts from two Niagara Peninsula streams (Vineland Creek and 20 Mile Creek) were analyzed for endosulfan sulphate and alpha-endoslufan. Endosulfan sulphate was detected in 26/31 samples which were collected from May thru November. The highest concentration was 0.068 µg/L and the detection limit was 0.0004 µg/L. Alpha-endosulfan was detected in 13/31 samples with a maximum of 0.0043 µg/L and a detection limit of 0.0004 µg/L (PMRA 2006).

British Columbia

Fluegel et. al. (2004) conducted a study as part of the Georgia Basin Ecosystem Initiative implemented from 1998 to 2003. The purpose of this study was to assess the effects of non-point source pollution on the water quality and biological health of small streams in urban and agricultural areas of the Lower Fraser Valley B.C. Two creeks were chosen (Elk Creek, located in Chilliwack, B.C., which is primarily affected by agricultural activities and Yorkson Creek, located in Langley, B.C., which is mainly affected by urban activities). In Elk creek a reference site, a mid-agricultural site and a down stream site were sampled during the years 1999 to 2001. For Yorkson Creek, a reference and a downstream site were chosen and samples during 2000 to 2001. A total of 4 samples were collected for Elk Creek with detections being reported for one or more of the endosulfan isomers and endosulfan sulphate. Maximum concentrations reported were 0.52 µg/L for α-endosulfan, 0.752 µg/L for β-endosulfan and 2.0 µg/L for endosulfan sulfate. For Yorkson Creek, a total of three samples were collected with detections being reported for one or more of the endosulfan isomers and endosulfan sulphate. Maximum concentrations reported were 0.021 µg/L for α-endosulfan, 0.0415 µg/L for β-endosulfan and 0.312 µg/L for endosulfan sulfate. Detections of all three compounds were reported in the reference samples for both Elk and Yorkson Creeks. The detection limits ranged from 0.00011 to 0.099 µg/L.

Hii et. al. (2004) authored an unpublished report prepared by Environment Canada and investigated the impact of agriculture use of chemicals on a number of aquifers in the Lower Fraser Valley area of British Columbia. Various parameters were analyzed, including the presence of endosulfan. Sixteen impacted sites were analyzed along with four reference sites. One sample was taken from each site except one for which replicates were taken for quality control purposes. Water was collected from household taps and from piezometers via dedicated pumps. Endosulfan was analyzed for by GC-ECD. Endosulfan was found only in the impacted site samples and not in the reference site samples. Beta endosulfan was the most commonly detected (6 out of 16 samples) at a detection frequency of 38%. Alpha-endosulfan was detected in four sites (25%) and endosulfan sulfate was detected in three sites (19%). The limits of detection for α-endosulphan, β-endosulfan and endosulfan sulfate were, respectively, 0.000015-0.000045, 0.000015-0.000025 and 0.00001-0.00003 µg/L and the median calculated values were, respectively, 0.003, 0.00014 and 0.00026 µg/L. The data provided in this report indicate that endosulfan used in agriculture is impacting groundwater resources in British Columbia.

Environment Canada (Tuominen 2004) sampling data was conducted as part of the Pesticides Science Fund Project. The samples were collected throughout British Columbia to identify and quantify concentrations of in-use pesticide residues from agricultural and urban sources of surface water and groundwater in areas of high pesticide use. The data were summarized in groups according to the source of the water sampled (i.e., agricultural, urban, combined or groundwater). Within these groups individual water sources were sampled once. Some of the results were reported as being below the LOQ. The median calculated values for α-endosulphan, β-endosulfan and endosulfan sulfate were, respectively, 0.00001, 0.000006, 0.000008 µg/L and the limits of detection were not listed. This data indicted that endosulfan is detected in both surface and groundwater in British Columbia at low levels (< 0.005 µg/L).

Alberta

Water monitoring data were developed by Janet McLean of Alberta Environment (McLean 2002). Information on where the samples were collected was provided. The samples were collected over the years 1995 - 2001 and are considered preliminary. The values will be finalized by Alberta Environment and reported in a publication providing an overview on pesticides residues present in surface water and treated drinking water. Endosulfan was not detected in any of the treated water or surface water samples analyzed. The limits of detection or minimum detected for α endosulphan were 0.005 µg/L. Provincial and federal water monitoring data was also conducted in the early to mid 1990's. Endosulfan was not detected in any of the samples anlayzed. For the data provided by Alberta Environment, it was not clear if the samples were taken from endosulfan use areas or during times when endosulfan could potentially be present in water resources.

Quebec

During the summers of 1989 to 1991, water sampling was conducted in the tributaries of the St. Lawrence River (Yamaska, Nicolet, Richelieu, L'Assomption, Saint-François and de la Tortue Rivers) (Rondeau 1996). Samples were collected monthly during the summer of 1989 to 1991 and there was an attempt to coordinate the sampling with precipitation events. Beta-endosulfan was detected in one of six samples collected at a concentration of 0.0004 µg/L. The detection limit was 0.0004 µg/L.

Giroux (1995) studied a total of 72 private wells (130 samples) located in proximity to potato fields in the province of Quebec and were sampled for pesticides and nitrates from 1991 to 1993. Endosulfan was not detected in any samples analyzed. The detection limit was 0.009 µg/L. Most of the wells were sampled only once or twice (in the summer period and in the fall). Most wells are shallow, less than 10 metres. They would generally be located less than 50 metres away from potato fields. Giroux (1995) stated that it could not be concluded that groundwater will not be impacted since the location of the sampling related to the application field and the timing of the sampling in relation to the application of endosulfan are not known.

5.1 Guidelines from other jurisdictions

Table 5.1 sets out the endosulfan water quality criteria and guidelines for the protection of reshwater aquatic life. For endosulfan, the lowest water guideline was 0.003 µg a.i./L for the Ontario provincial water quality objective (OME 1994). The highest water guideline for endosulfan was 0.056 µg a.i./L for a continuous criterion set by Virginia (COV 1997). This same level of 0.056 µg a.i./L was also set by Washington (Washington State 1997), Oregon (ODEQ 1996) and Delaware (DDNREC 1993).

Table 5.1. Water Quality Criteria and Guidelines for the protection of freshwater aquatic life.

Chemical	**Water Category F=fresh M=marine E=estuarine**	**Guideline (µg a.i./L)**	**Application (C=criterion) (G=guideline) (S=standard)**	**Jurisdiction**	**Reference**
Endosulfan	F	0.003	Provincial Water Quality Objective	Ontario	OME 1994
	F	0.009	S. Chronic; Aquaculture	New York State	NYSDEC 1994
	F/E	0.01	S. Upper value	District of Columbia	US EPA 1988
	F/M	0.01	G.	Australia	ANZECC 1992
	F	0.02	G.	Canada	CCME 1991
	F	0.02	G.	Nova Scotia	NSDOE 1998
	F	0.02	C. Chronic	Quebec	MDEQ 1996
	F	0.056	S. Chronic C.	Virginia	COV 1997
	F	0.056	C. Chronic; Maximum 24 hr average	Washington	Washington State 1997
	F	0.056	C. Chronic	Oregon	ODEQ 1996
	F	0.056	C. Chronic	Delaware	DDNREC 1993
	F	0.11	C. Acute	Quebec	MDEQ 1996
	F	0.22	S. Acute C.	Virginia	COV 1997
	F	0.22	C. Acute	Oregon	ODEQ 1996
	F	0.22	C. Acute	Delaware	DDNREC 1993
	F	0.22	C. Acute; Maximum; Instantaneous	Washington	Washington State 1997
	F	0.22	S. Acute	New York State	NYSDEC 1998
Endosulfan (α)	F	0.056	Regulation. Chronic C.	New Hampshire	NHDES 1996
	F	0.056	C. Continuous	California	U.S. EPA 1997
	F	0.056	C. Chronic	Rhode Island	RIDEM 1997
	F	0.056	C. Continuous	United States	US EPA 1998
	F	0.22	Regulation: Acute C.	New Hampshire	NHDES 1996
	F	0.22	C. Acute	Rhode Island	RIDEM 1997
	F	0.22	C. Maximum	California	U.S. EPA 1997
	F	0.22	C. Maximum	United States	US EPA 1998
Endosulfan (α) Endosulfan sulphate (dissolved)	F	0.013	Ecotoxicological value	Netherlands	Stortelder et al. 1989
Endosulfan (α) Endosulfan sulphate (total)	F	0.014	Ecotoxicological value	Netherlands	Stortelder *et al.* 1989
Endosulfan (β)	F	0.056	C. Continuous	U.S.A.	U.S. EPA 1998
	F	0.056	C. Continuous	California	U.S. EPA 1997

F	0.056	C. Chronic	Rhode Island	RIDEM 1997
F	0.056	Regulation: Chronic C.	New Hampshire	NHDES 1996
F	0.22	Regulation: Acute C.	New Hampshire	NHDES 1996
F	0.22	C. Maximum	U.S.A.	U.S. EPA 1998
F	0.22	C. Acute	Rhode Island	RIDEM 1997

6.0 ENVIRONMENTAL TOXICITY

6.1 Mode of Action

Endosulfan acts as a toxic chemical to a wide variety of insects and mites on contact through the blockage of GABA-(gamma amino butyric acid) gated chlorine channels. GABA is an inhibitory neurotransmitter in the central nervous system that operates through membrane hyperpolarization as mediated by increased chloride flux into nerve cells. By impairing the inhibitory actions of this complex, and, thus, chloride influx into the nerve, hyper excitation results which, when prolonged, may lead to respiratory failure. External symptoms include depressed activity a few hours after exposure followed by hyper excitability, tremors and convulsions (Coats 1990). Convulsions can lead to death by interfering with pulmonary gas exchange and by generating severe metabolic acidosis (Coats 1990). Stimulation of the central nervous system, leading to convulsions, is the major characteristic of endosulfan toxicity (Ecobichon 1991).

An alternate hypothesis of cyclodiene toxicity is based on the observation that α endosulfan inhibits Ca$^+$Mg$^-$ATPase and Ca-ATPase (Coats 1990; Srikanth et al. 1989). This effect may be specific to the stereochemistry of the isomer, since the β endosulfan did not elicit the same response in rat brain during *in vitro* studies (Srikanth et al. 1989). An energetic mode of action is further supported by the observation that endosulfan impairs respiration in rat liver mitochondria, *in vitro* (Dubey et al. 1984) and in rainbow trout and catfish liver mitochondria, *in vitro* (Mishra and Shukla. 1994) and *in vivo* (Mishra and Shukla 1994; Arnold et al.1996).

Exposure to endosulfan has resulted in both reproductive and developmental effects in nontarget animals. Endosulfan exposure resulted in impaired development in amphibians, reduced cortisol secretion in fish, impaired development of the genital tract in birds and reduced hormone levels and sperm production and produced testicular atrophy in mammals. Further, endosulfan has been shown to bind to the human estrogen receptor and exhibit significant estrogenic activity. Whether the toxicity endpoints are a result of endocrine disruption is not known. However, it is clear that organisms treated with endosulfan did exhibit some toxic effects that have historically been associated with endocrine disrupting chemicals, *e.g.*, developmental and reproductive effects (U.S. EPA 2002).

Solvents and/or emulsifiers used with endosulfan in formulated products may influence its absorption into the system through all routes. Technical endosulfan is slowly and incompletely absorbed into the body whereas absorption is more rapid in the presence of alcohols, oils, and emulsifiers (Gupta and Gupta 1979).

6.2 Freshwater Aquatic Toxicity

Short-term and long-term toxicity data that were available for fish, invertebrates, algae and macrophytes are summarized in appendix A. Studies were evaluated for their suitability in guideline development and have been classified as primary, secondary, or unacceptable. Studies described below are those that were deemed as primary or secondary. Studies may be deemed unacceptable for several reasons, the most common of which was the use of a formulant for the toxicity test in which the active ingredient was not present at a sufficiently enough high percentage (< 90% a.i.). Units for concentrations below are expressed in terms of the concentration of active ingredient, or “a.i.”, and ranges given in brackets are the 95% confidence intervals.

6.3 Toxicity to Fish

An extensive number of studies on short-term toxicity of fish have been conducted by industry and non-industrial research institutes. The tests include static, semi-static and flowthrough systems as well as a range of different test species. The most sensitive fish LC_{50} were a 0.10 µg a.i./L for the common carp (*Cyprinus carpio*) (Sunderam *et al.* 1992) and 0.20 µg a.i./L for the bony bream (*Nematolosa erebi*) (Sunderam et al. 1992). The snake-head catfish (*Channa punctata*) was the most tolerant fish species to endosulfan (96-h LC_{50} of 5780 µg a.i./L, Khillare and Wagh 1987).

For long-term toxicity to fish, no observed effect concentrations (NOECs) were reported in the range of 0.05 to0.4 µg a.i./L. A NOEC of 0.05 µg a.i./L was reported from a 21-day juvenile growth-test.for rainbow trout (*Oncorhynchus mykiss*)(Knacker et al. 1991). A full life cycle exposure test (260 days) to fathead minnow (*Pimephales promelas*) (PMRA Monograph 2004) estimated a NOEC of 0.056 µg a.i./L. Several physiological, behavioural and morphological effects of endosulfan have been reported in literature at concentrations ranging from 0.5 to 5 µg a.i./L (Joshi et al. 1980; Gill et al. 1991)

6.3.1 *Toxicity to Invertebrates*

Aquatic invertebrates appear to be acutely susceptible to endosulfan concentrations in the order of 100 µg a.i./L, although considerable variation is evident, spanning several orders of magnitude. The lowest LC_{50} reported for a single species was the mayfly nymph (*Atalophlebia australis*) reported at 0.60 µg a.i./L (Leonard et al. 1999). The highest LC_{50} (15,000 µg a.i./L) reported was for the dragonfly nymph (*Pantala flavescens*) (Yadwad et al. 1990).

The lowest acceptable long-term endpoints (6-day MATC) reported were for the pink hydra (*Hydra vulgaris*) and green hydra (*Hydra viridissim*), reported at 0.06 and 0.07 µg a.i./L respectively (Polino and Holdway 1999). The highest long-term endpoint (1,000 µg a.i./L for a 10-d EC_{50} changes in reproduction study) reported was for the rotifer (*Brachionus calyciflorus*) (Fernandez-Casalderrey et al. 1991).

6.3.2 *Toxicity to Algae and Plants*

Much less data are available on algae and plants in comparison to invertebrates and fishes. Green algae appear to be fairly tolerant to endosulfan. A 72-hour and 96-hour growth test for *Scenedesmus subspicatus* and *Pseudokirchneriella subcapitatum* resulted in EC_{50}s of 560 and 427.8 µg a.i./L respectively (PMRA Monograph 2004; DeLorenzo et al. 2002).

6.3.3 *Toxicity to Amphibians*

No acceptable toxicity studies on amphibians were found. However studies using formulated products indicate that amphibians may be sensitive to endsulfan (Gopal et al. 1981; Berrill et al. 1998; Harris et al. 2000b; Park et al. 2001). Because a formulated product was used, it is not possible to determine how much of the observed effects were due directly to endosulfan, as opposed to other chemicals present in the formulation. The toxicity of the formulation to amphibians appears to fall in a similar range as the toxicity of endosulfan to some of the more sensitive invertebrates and fish.

6.3.4 *Field Studies*

Leonard et al. (2000) examined the effect of total endosulfan concentrations (α and β isomers and endosulfan sulfate) due to runoff from applications on cotton (2 to 3 applications at 720 g a.i./ha) on population densities of six dominant macroinvertebrate taxa (mayfly nymphs *Jappa kutera, Atalophlebia sp., Tasmanocoenis sp., Baetis* sp. and the caddisfly larvae *Cheumatopsyche* sp. and *Ecnomus* sp.) in the Namoi River (New South Wales, Australia). During the 1995/96 and 1997/98 cotton-growing seasons in the Namoi River, the population densities of these species were statistically significantly lower at downstream sites exposed to high concentrations of endosulfan compared with upstream reference sites. For the 1995/96 period, raw data on total endosulfan indicated water concentrations of 13 to 911 µg/L and for the 1997/98 season, water concentrations of 0 to 635 µg/L were observed. The authors attributed these effects to endosulfan desorbing from soil during rainfall events and entering the Namoi River in runoff.

Hose *et al.* (2002) exposed macroinvertebrate communities in artificial streams to a range of endosulfan concentrations for a 12-h period and then monitored for 96 hours. The endosulfan was prebound to fine river sediment and applied to the streams as a contaminated sediment slurry. The structure of benthic communities was not changed, however significant changes ($p<0.05$) in the abundance of several macroinvertebrate taxa in drift were detected in streams receiving the highest 6.14 µg a.i./L dose. The authors concluded that increased drift may have implications for re-colonization processes in lowland rivers, and therefore pulses of contaminated sediment are likely to result in significant effects on macroinvertebrate populations and communities.

Further field studies by Hose and Wilson (2005) assessed the acute toxicity of *Paratya australiensis* and *Jappa kutera* to endosulfan exposure of short durations to simulate storm runoff and overspray events. Impacts on field populations of *Paratya australiensis* were concluded as due to the acute toxicity of daily endosulfan concentrations and impacts from a daily exposure would be exacerbated by peak concentrations during storm events. For *Jappa kutera,* daily concentrations are not acutely toxic, but threats to populations exist from storm events and low-level chronic exposures. The greatest concentrations of endosulfan in rivers are likely to result from aerial overspray or storm runoff from adjacent farms, which create acute exposure scenarios. The average daily concentrations of endosulfan recorded at impacted sites over the pesticide spray season ranged from 0.005 to 0.40 µg/L, with the highest concentrations occurring in December (0.11-0.40 µg/L) and presumably causing the greatest impact. At the reference sites the overall range of endosulfan was 0.01 to 0.09 µg/L.

Hose et al. (2003) examined the toxicity of macroinvertebrate assemblages to endosulfan using 12 and 48-hour exposures. No-observed-effect concentrations (NOEC) for endosulfan on macroinvertebrate assemblages were 8.69 and 1.00 µg a.i./L for the 12- and 48-hour exposure studies, respectively. By establishing a causal link between endosulfan exposure to macroinvertebrate assemblages, this study adds further weight to the hypothesis that endosulfan is a major contributor to changes observed in rivers of the cotton-growing region of Australia during the pesticide spray season.

6.3.5 *Marine Toxicity*

Short-term and long-term toxicity data that were available for fish and invertebrates are summarized in appendix B. Studies were evaluated for their suitability in guideline development and have been classified as primary, secondary, or unacceptable. Studies described below are those that were deemed as primary or secondary. Studies may be deemed unacceptable for several reasons, the most common of which was the use of a formulant for the toxicity test in which the active ingredient was not present at a sufficiently enough high percentage (< 90% a.i.). Units for concentrations below are expressed in terms of the concentration of active ingredient, or "a.i.", and ranges given in brackets are the 95% confidence intervals.

6.3.6 *Toxicity to Fish*

Short-term toxicity estimates for marine/estuarine fish ranged from 0.1 µg a.i./L to 0.38 µg a.i./L. Striped bass (*Morone saxatilis*) were the most sensitive (LC_{50} = 0.1 µg a.i./L) species tested.

At the time of this review, the only long-term toxicity endpoints for estuarine/marine fish consisted of 28-d lowest observed effect concentrations (LOECs) for growth (0.6 µg a.i. /L) and survival (1.3 µg a.i./L) for the sheepshed minnow, *Cyprinodon variegatus*.

6.3.7 *Toxicity to Invertebrates*

Considerable variability was observed in toxicity estimates for estuarine/marine invertebrates exposed to technical grade endosulfan; each of the EC_{50} estimates of oysters differed by at least an order of magnitude. Estimated EC_{50} values ranged from 0.45 µg a.i./L to 460 µg a.i./L and represented a difference of three orders of magnitude. Key et al. (2003) investigated the toxicity of endosulfan to selected life stages of the grass shrimp *Palaemonetes pugio* and found, over 96-hour exposures to endosulfan, that the adult grass shrimp (LC_{50} of 1.01 µg a.i /L) were more sensitive than the larvae (LC_{50} of 2.56 µg a.i. /L. Embryonic grass shrimp exposed to endosulfan resulted in a LC_{50} of 117.0 µg a.i./L but with a large 95% confidence limit (0.73 to18,810 µg a.i./L). Low embryo toxicity could be partially explained by the presence of an embryonic coat which protects the embryo from potentially harmful conditions of the ambient water.

Long-term toxicity studies available for marine organisms consisted of a 28-d LC_{50} for the polychaete worm, *Nereis arenaceodentata*, which ranged between 80 to 145 µg a.i./L (Bishop et al.1983) and a 28-d NOEC for the mysid shrimp, *Mysidopsis bahia*, of 0.33 µg a.i./L (US EPA 1980).

6.3.8 *Toxicity-Modifying Factors*

Although water quality parameters such as water temperature, pH, and organism metabolic rate have been identified as possible endosulfan toxicity modifying factors, there is currently not enough data to present conclusive evidence and are not considered as factors in the development of the WQG.

Solvents and/or emulsifiers used with endosulfan in formulated products may influence its absorption into the system through all routes. Technical endosulfan is slowly and incompletely absorbed into the body whereas absorption is more rapid in the presence of alcohols, oils, and emulsifiers (Gupta and Gupta 1979).

6.3.9 *Toxicity of Transformation Products*

Metabolism of endosulfan occurs rapidly and it is oxidized to endosulfan sulfate which shows a similar acute toxicity as the parent compound. Short-term LC_{50}s of endosulfan sulphate to the golden ide (*Leuciscus idus melanotus*), goldfish (*Carassius auratus*), and guppy (*Poecilia reticulate*) ranged from 10 µg a.i./L to 100 µg a.i./L (Knauff and Schulze 1973). Short-term LC_{50}s for the turbifid worm (*Tubifex tubifex*) ranged between 10 and 1000 µg a.i./L. Sub-lethal endpoints (i.e., photosynthesis, biomass) for green algae (*Chlorella* vulgaris) ranged from 0.5 to 10 µg a.i./L. Endosulfan-diol (another metabolic breakdown product was found to be less toxic than endosulfan to fish by a factor of three orders of magnitude. No information was available for other species.

7.0 GUIDELINE DERIVATION

A CWQG for Endosulfan addresses its use in Canada and potential impacts to freshwater and marine aquatic systems. A CWQG provides guidance to risk assessors and risk managers in Canada on the level of endosulfan in an aquatic system, below which protection of the most sensitive species and lifestage indefinitely is expected to be maintained.

There are currently three options for developing a CWQG (CCME, 2007). These consist of:

1. Statistical Approach (Type A or SSD approach);
2. Lowest Endpoint Approach using only primary data (Type B1);
3. Lowest Endpoint Approach using primary and/or secondary data (Type B2)

The minimum data requirements for each of the three methods are presented in Table 7.1 and 7.2 (freshwater) and Table 7.3 and 7.4 (marine). A SSD is a statistical distribution that represents the variation in toxicological sensitivity among a given set of species to a contaminant. The species sensitivity distribution, often expressed as a cumulative distribution function (CDF), is composed of effect concentrations obtained during toxicity testing (e.g., LC_{50}, EC_{50}, LOEL, or NOEL) on the horizontal axis and cumulative probability on the vertical axis (Posthuma et al. 2002). The number of data points used to construct the curve depends on the number of species tested for the endpoint of interest. Emphasis is placed on organism-level effects (e.g., survival, growth, reproduction) that can be more confidently used to predict ecologically significant consequences at the population level (Forbes and Calow 1999; Meador 2000; Suter II et al. 2005). With the SSD method, the concentration of a substance in water that will be protective of at least 95% of aquatic biota is estimated. For the purposes of a Canadian Water Quality Guideline we develop a short-term SSD based on acceptable short-term LC_{50} data and a long-term SSD based preferentially on long-term no-effect data.

If insufficient data are available for deriving a CWQG using the statistical approach, the CWQG will be developed using the next tier method, the lowest endpoint approach. Depending on the quantity and quality of data a Type B1 or Type B2 approach is used. The Type B1 approach uses acceptable primary toxicity data only to derive the guideline, while the Type B2 approach can use acceptable primary and/or secondary data. In every case, a CWQG must be developed using the most advanced method that the data allow.

The following sections describe the derivation of CWQGs for the protection of freshwater and marine life in surface water for the insecticide endosulfan. The derived CWQGs are national in scope and do not take into account watershed-specific conditions.

Table 7.1 Minimum Data Set Requirements for the Generation of short-term freshwater CWQG.

Group	**Guideline**		
	Type A	**Type B1**	**Type B2**
Fish	Three species, including at least one salmonid and one non-salmonid.		Two species, including at least one salmonid and one non-salmonid.
Aquatic Invertebrates	Three aquatic or semi-aquatic invertebrates, at least one of which must be a planktonic crustacean. For semi-aquatic invertebrates, the life stages tested must be aquatic. It is desirable, but not necessary, that one of the aquatic invertebrate species be either a mayfly, caddisfly, or stonefly.		Two aquatic or semi-aquatic invertebrates, at least one of which must be a planktonic crustacean. For semi-aquatic invertebrates, the life stages tested must be aquatic. It is desirable, but not necessary, that one of the aquatic invertebrate species be either a mayfly, caddisfly, or stonefly.
Plants	Toxicity data for aquatic plants or algae are highly desirable, but not necessary. However, if a toxicity study indicates that a plant or algal species is among the most sensitive species in the data set, then this substance is considered to be phyto-toxic and two studies on nontarget freshwater plant or algal species are required.		
Amphibians	Toxicity data for amphibians are highly desirable, but not necessary. Data must represent fully aquatic stages.		
Preferred Endpoints	Acceptable LC_{50} or equivalent (e.g., EC_{50} for immobility in small invertebrates).		
Data Quality Requirement	Primary and secondary LC_{50} (or equivalents) data are acceptable to meet the minimum data set requirement. Both primary and secondary data will be plotted. A chosen model should sufficiently and adequately describe data and pass the appropriate goodness-of-fit test.	The minimum data requirement must be met with primary LC_{50} (or equivalents) data. The value used to set the guideline must be primary.	The minimum data requirement must be met with primary LC_{50} (or equivalents) data. Secondary data are acceptable. The value used to set the guideline may be secondary.

Table 7.2 Minimum Data Set Requirements for the Generation of long-term freshwater CWQG.

<table>
<tr><th rowspan="2">Group</th><th colspan="3">Guideline</th></tr>
<tr><th>Type A</th><th>Type B1</th><th>Type B2</th></tr>
<tr><td>Fish</td><td colspan="2">Three species, including at least one salmonid and one non-salmonid.</td><td>Two species, including at least one salmonid and one non-salmonid.</td></tr>
<tr><td>Aquatic Invertebrates</td><td colspan="2">Three aquatic or semi-aquatic invertebrates, at least one of which must be a planktonic crustacean. For semi-aquatic invertebrates, the life stages tested must be aquatic.
It is desirable, but not necessary, that one of the aquatic invertebrate species be either a mayfly, caddisfly, or stonefly.</td><td>Two aquatic or semi-aquatic invertebrates, at least one of which must be a planktonic crustacean. For semi-aquatic invertebrates, the life stages tested must be aquatic.
It is desirable, but not necessary, that one of the aquatic invertebrate species be either a mayfly, caddisfly, or stonefly.</td></tr>
<tr><td>Aquatic Plants</td><td colspan="2">At least one study on a freshwater vascular plant or freshwater algal species.
If a toxicity study indicates that a plant or algal species is among the most sensitive species in the data set, then this substance is considered to be phyto-toxic and three studies on nontarget freshwater plant or algal species are required.</td><td>Toxicity data for plants are highly desirable, but not necessary.
If a toxicity study indicates that a plant or algal species is among the most sensitive species in the data set, then this substance is considered to be phyto-toxic and two studies on nontarget freshwater plant or algal species are required.</td></tr>
<tr><td>Amphibians</td><td colspan="2">Toxicity data for amphibians are highly desirable, but not necessary. Data must represent fully aquatic stages.</td><td>Toxicity data for amphibians are highly desirable, but not necessary. Data must represent fully aquatic stages.</td></tr>
<tr><td>Preferred Endpoints</td><td>The acceptable endpoints representing the no-effects threshold and EC_{10}/IC_{10} for a species are plotted. The other, less preferred, endpoints may be added sequentially to the data set to fulfill the minimum data requirement condition and improve the result of the modelling for the guideline derivation if the more preferred endpoint for a given species is not available.
The preference ranking is done in the following order: Most appropriate EC_x/IC_x representing a no-effects threshold > EC_{10}/IC_{10} > MATC > NOEC > EC_{11-25}/IC_{11-25} > LOEC > EC_{26-49}/IC_{26-49} > nonlethal EC_{50}/IC_{50}.
Multiple comparable records for the same endpoint are to be combined by the geometric mean of these records to represent the averaged species effects endpoint.</td><td colspan="2">The most preferred acceptable endpoint representing a low-effects threshold for a species is used as the critical study; the next less preferred endpoint will be used sequentially only if the more preferred endpoint for a given species is not available.
The preference ranking is done in the following order: Most appropriate EC_x/IC_x representing a low-effects threshold > EC_{15-25}/IC_{15-25} > LOEC > MATC > EC_{26-49}/IC_{26-49} > nonlethal EC_{50}/IC_{50} > LC_{50}.</td></tr>
<tr><td>Data Quality Requirement</td><td>Primary and secondary no-effects and low-effects level data are acceptable to meet the minimum data set requirement. Both primary and secondary data will be plotted.
A chosen model should sufficiently and adequately describe data and pass the appropriate goodness-of-fit test.</td><td>The minimum data requirement must be met with primary data. The value used to set the guideline must be primary.
Only low-effect data can be used to fulfill the minimum data requirement.</td><td>Secondary data are acceptable. The value used to set the guideline may be secondary.
Only low-effect data can be used to fulfill the minimum data requirement.</td></tr>
</table>

Table 7.3 Minimum Data Set Requirements for the Generation of short-term marine CWQG.

Group	Guideline		
	Type A	**Type B1**	**Type B2**
Fish	At least three studies on three or more marine fish species, at least one of which is a temperate species.		At least two studies on two or more marine fish species, at least one of which is a temperate species.
Aquatic Invertebrates	At least two studies on two or more marine species from different classes, at least one of which is a temperate species.		At least two studies on two or more marine species.
Plants	At least **one** study on a temperate marine vascular plant or marine algal species. If a toxicity study indicates that a plant or algal species is among the most sensitive species in the data set, then this substance is considered to be phyto-toxic and two studies on nontarget marine plant or algal species are required.		Toxicity data for marine plants are highly desirable, but not necessary. If a toxicity study indicates that a plant or algal species is among the most sensitive species in the data set, then this substance is considered to be phyto-toxic and two studies on nontarget marine plant or algal species are required.
Preferred Endpoints	Acceptable LC_{50} or equivalent (e.g., EC_{50} for immobility in small invertebrates).		
Data Quality Requirement	Primary and secondary LC_{50} (or equivalents) data are acceptable to meet the minimum data set requirement. Both primary and secondary data will be plotted. A chosen model should sufficiently and adequately describe data and pass the appropriate goodness-of-fit test.	The minimum data requirement must be met with primary LC_{50} (or equivalents) data. The value used to set the guideline must be primary.	The minimum data requirement must be met with primary LC_{50} (or equivalents) data. Secondary data are acceptable. The value used to set the guideline may be secondary.

Table 7.4 Minimum Data Set Requirements for the Generation of long-term marine CWQG.

Group	**Guideline**		
	Type A	**Type B1**	**Type B2**
Fish	At least three studies on three or more marine fish species, at least one of which is a temperate species.		At least two studies on two or more marine fish species, at least one of which is a temperate species.
Aquatic Invertebrates	At least **two** studies on **two** or more marine species from different classes, at least **one** of which is a temperate species.		At least **two** studies on **two** or more marine species.
Plants	At least one study on a temperate marine vascular plant or marine algal species. If a toxicity study indicates that a plant or algal species is among the most sensitive species in the data set, then this substance is considered to be phyto-toxic and three studies on nontarget marine plant or algal species are required.	At least one study on a temperate marine vascular plant or marine algal species. If a toxicity study indicates that a plant or algal species is among the most sensitive species in the data set, then this substance is considered to be phyto-toxic and two studies on nontarget marine plant or algal species are required.	If a toxicity study indicates that a plant or algal species is among the most sensitive species in the data set, then this substance is considered to be phyto-toxic and two studies on nontarget marine plant or algal species are required.
Preferred Endpoints	The acceptable endpoints representing the no-effects threshold and EC_{10}/IC_{10} for a species are plotted. The other, less preferred, endpoints may be added sequentially to the data set to fulfill the minimum data requirement condition and improve the result of the modelling for the guideline derivation if the more preferred endpoint for a given species is not available. The preference ranking is done in the following order: Most appropriate EC_x/IC_x representing a no-effects threshold > EC_{10}/IC_{10} > MATC > NOEC > EC_{11-25}/IC_{11-25} > LOEC > EC_{26-49}/IC_{26-49} > nonlethal EC_{50}/IC_{50}. Multiple comparable records for the same endpoint are to be combined by the geometric mean of these records to represent the averaged species effects endpoint.	The most preferred acceptable endpoint representing a low-effects threshold for a species is used as the critical study; the next less preferred endpoint will be used sequentially only if the more preferred endpoint for a given species is not available. The preference ranking is done in the following order: Most appropriate EC_x/IC_x representing a low-effects threshold > EC_{15-25}/IC_{15-25} > LOEC > MATC EC_{26-49}/IC_{26-49} > nonlethal EC_{50}/IC_{50} > LC_{50}.	
Data Quality Requirement	Primary and secondary no-effects and low-effects level data are acceptable to meet the minimum data set requirement. Both primary and secondary data will be plotted. A chosen model should sufficiently and adequately describe data and pass the appropriate goodness-of-fit test.	The minimum data requirement must be met with primary data. The value used to set the guideline must be primary. Only low-effect data can be used to fulfill the minimum data requirement.	Secondary data are acceptable. The value used to set the guideline may be secondary. Only low-effect data can be used to fulfill the minimum data requirement.

7.1 Protection of Freshwater Aquatic Life

The complete set of toxicity data considered for use in CWQG derivation (including data classified as primary, secondary, and unacceptable) is presented in Appendix A.

A CWQG provides guidance separately for both short and long-term exposure. The short-term guidance offered by the CWQG is not intended to protect all species indefinitely, but rather is to protect most species against lethality during severe, but transient events. Examples include inappropriate application or disposal of the pesticide in question. This may include application under worst case conditions and/or through improper use of label instructions (e.g. heavy precipitation/wind events), and spill events. The long-term exposure value of the CWQG is intended to protect against negative effects to all species and life stages during indefinite exposure. Aquatic life may be chronically exposed to a pesticide as a result of persistence in the environment, including gradual release from soils/sediments and gradual entry through groundwater/runoff, multiple applications within the same localized region, and long range transport events.

7.1.1 *Short-term freshwater CWQG*

To be considered for inclusion in CWQG development, the aquatic toxicity studies must meet minimum data quality requirements as specified in the water quality protocol (CCME, 2007). Both primary and secondary data as described in the protocol (CCME, 2007) were considered acceptable for deriving the short-term freshwater SSD for endosulfan. Data may have been unacceptable due to several reasons. The most common reason why data may have been classified as unacceptable is due to the use of formulations where the active ingredient used in present as a small percentage of the pesticide (< 90% a.i.).

Several of the studies reported in Appendix A are for the same species, effect, endpoint or life stage, though the values of the LC_{50}s are different. This variation may be the result of differences in experimental conditions, species strain, and/or bioassay protocol. Multiple bioassay results for the same species should not be used in an SSD regression analysis. This is particularly important when there is a large amount of data available for very few test species. For the derivation of a SSD for endosulfan, intra-species variability was accounted for by taking the geometric mean of the studies considered to represent the most sensitive lifestage and endpoint, when experiment duration was the same. Table 7.5 presents the final dataset that was used to generate the fitted SSD for short-term freshwater exposure to endosulfan.

Values used in the final SSD dataset (Table 7.5) range from a 96h-LC_{50} of 0.10 µg a.i./L for the fish *Cyprinus carpio* (common carp), to a 24h-LC_{50} of 150 000 µg a.i./L for the invertebrate *Pantala flavescens* (dragonfly) (Sunderam et al. 1992; Yadwad et al. 1990). Geometric mean values were calculated for species where more than one EC/LC_{50} value was available for each for inclusion in the SSD. Effect concentrations reported for the remaining species were taken from single studies.

The short-term SSD was fitted using LC_{50} data and the final short-term guideline for endosulfan was the 5th percentile of the short-term SSD. Each species for which appropriate short-term toxicity data was available was ranked according to sensitivity, and its centralized position on the

SSD was determined using the following standard equation (Aldenberg et al., 2002; Newman et al., 2002):

$$\frac{i - 0.5}{N}$$

where

i = the species rank based on ascending EC_{50}s and LC_{50}s
N = the total number of species included in the SSD derivation

These positional rankings, along with their corresponding EC_{50} and LC_{50}s were used to derive the SSD. Several cumulative distribution functions (CDFs) (normal, logistic, Gompertz, Weibull, Fisher-Tippett and Burr Type III) were fit to the data (both in arithmetic space and log space) using regression methods. Model fit was assessed using statistical and graphical techniques. The best model was selected based on consideration of goodness-of-fit and model feasibility. Model assumptions were verified graphically and with statistical tests.

Table 7.5 Final Aquatic Toxicity Data Selected for Short-term SSD Development

Study No.	Organism	Life Stage	Endpoint	Effect Concentration (µg a.i./L)	References
1	*Cyprinus carpio* (common carp)	50 mm	96-h LC_{50}	0.10	Sunderam et al. 1992
2	*Nematolosa erebi* (bony bream)	50 mm	96-h LC_{50}	0.20	Sunderam et al. 1992
3	*Morone saxatilis* (striped bass)	6 d posthatch larva	96-h LC_{50}	0.22	Mayers and Barron 1991
4	*Macquaria ambigua* (golden perch)	40 mm	96-h LC_{50}	0.39*	
5	*Atalophlebia australis* (mayfly nymph)	4.2-4.6 mm	72-h LC_{50}	0.60	Leonard et al. 1999
6	*Oncorhynchus mykiss* (rainbow trout)	NR	96-h LC_{50}	0.73*	
7	*Cheumatopsyche sp.* (trichopteran)	5.7-6.3 mm	48-h LC_{50}	0.4	Leonard et al. 1999
8	*Lepomis macrochirus* (bluegill sunfish)	NR	96-h LC_{50}	1.20	Mayer and Ellersieck 1986
9	*Pimephales promelas* (fathead minnow)	0.1-0.5 g	96-h LC_{50}	1.30*	
10	*Jappa kutera* (mayfly nymph)	3 - 6 mm	96-h LC_{50}	1.47*	
11	*Ictalurus punctatus* (channel catfish)	1.7 g	96-h LC_{50}	1.50	Mayer and Ellersieck 1986
12	*Rana tigrina* (tiger frog, indian bullfrog)	tadpole	96-h LC_{50}	1.80	Gopal et al. 1981
13	*Gambusia affinis* (mosquitofish)	40 mm	96-h LC_{50}	2.30	Sunderam *et al.* 1992
14	*Pteronarcys californica* (stonefly)	2nd year	96-h LC_{50}	2.30	Sanders and Cope 1968
15	*Bidyanus bidyanus* (silver perch)	50 mm	96-h LC_{50}	2.35*	
16	*Melanotaenia duboulayi* (eastern rainbow fish)	40 mm	96-h LC_{50}	3.11*	

Table 7.5 Final Aquatic Toxicity Data Selected for Short-term SSD Development

Study No.	Organism	Life Stage	Endpoint	Effect Concentration (µg a.i./L)	References
17	*Gammarus fasciatus* (scud)	mature	96-h LC_{50}	5.80	Mayer and Ellersieck 1986
18	*Gammarus lacustris* (scud amphipod)	mature	96-h LC_{50}	6.00	Mayer and Ellersieck 1986
19	*Hyalella azteca* (scud)	2-9 d old	96-h LC_{50}	10.76*	
20	*Anguilla anguilla* (common eel)	20-30 g	96-h LC_{50}	33.66*	
21	*Moinodaphnia macleayi* (water flea)	neonates < 24-h	48-h LC_{50}	215	Sunderam *et al.* 1994
22	*Daphnia magna* (water flea)	< 24-h	48-h LC_{50}	366.33*	
23	*Daphnia carinata* (water flea)	neonates	48-h LC_{50}	478	Barry *et al.* 1995
24	*Ceriodaphnia dubia* (water flea)	neonates < 24-h	48-h LC_{50}	491	
25	*Procambarus clarkii* (red swamp crayfish)	adult	96-h LC_{50}	560*	
26	*Hydra viridissima* (green hydra)	NR	96-h LC_{50}	670	Polino and Holdway 1999
27	*Hydra vulgaris* (pink hydra)	NR	96-h LC_{50}	810	Polino and Holdway 1999
28	*Brachionus calyciflorus* (rotifer)	cysts	24-h LC_{50}	5150	
29	*Channa punctata* (snake-head catfish)	adult 59.8 g	96-h LC_{50}	5780	Khillare and Wagh 1987
30	*Oziotelphusa senex senex* (crab)	male 10 g	96-h LC_{50}	5834.15*	
31	*Brachionus plicatilis* (rotifer)	cysts	24-h LC_{50}	6432.13*	
32	*Pantala flavescens* (dragonfly)	NR	24-h LC_{50}	15000	Yadwad *et al.* 1990

***value shown is the geometric mean of comparable values, individual values and references can be seen in table 7.6**

Table 7.6 Studies Used To Derive Geometric Means for Short-term freshwater SSD

Organism	Endpoint	Effect Concentration (µg a.i./L)	Geometric Mean (µg a.i./L)	Reference
Macquaria ambigua	96-h LC_{50}	0.5 0.3	0.39	Sunderam *et al.* 1992
Oncorhynchus mykiss	96-h LC_{50}	0.69	0.73	Lemke 1981
		0.17		Lemke 1981
		0.3		Lemke 1981
		0.26		Lemke 1981
		0.32		Lemke 1981
		0.26		Lemke 1981
		0.75		Lemke 1981
		0.29		Lemke 1981
		0.27		Lemke 1981
		0.41		Lemke 1981

		0.42	Lemke 1981
		0.24	Lemke 1981
		1.21	Lemke 1981
		0.49	Lemke 1981
		1.34	Lemke 1981
		1.3	Lemke 1981
		1.69	Lemke 1981
		0.69	Lemke 1981
		0.89	Lemke 1981
		0.8	Lemke 1981
		2.43	Lemke 1981
		0.63	Lemke 1981
		1.63	Lemke 1981
		0.79	Lemke 1981
		2.9	Mayer and Ellersieck 1986
		1.7	Mayer and Ellersieck 1986
		1.4	Mayer and Ellersieck 1986
		1.1	Mayer and Ellersieck 1986
		0.37	PMRA Monograph 2004
		1.6	Sunderam et al. 1992
		0.7	Sunderam et al. 1992
		1.7	Nebeker et al. 1983
		1.6	Nebeker et al. 1983
		0.3	Nebeker et al. 1983
		0.4	Nebeker et al. 1983
		0.5	Wan et al. 2005
		3.3	Wan et al. 2005
		0.7	Wan et al. 2005
		1.4	Wan et al. 2005
Pimephales promelas	96-h LC_{50}	1.2	Lemke 1981
		0.29	Lemke 1981
		0.76	Lemke 1981
		0.81	Lemke 1981
		1.67	Lemke 1981
		0.75	Lemke 1981
		1.91	Lemke 1981
		0.45	Lemke 1981
		0.73	Lemke 1981
		0.8	Lemke 1981
		1.57	Lemke 1981
		1	Lemke 1981
		2.1	Lemke 1981
		2.1	Lemke 1981
		1.7	Lemke 1981
		1.9	Lemke 1981
		1.35	Lemke 1981
		3.2	Lemke 1981
		3.45	Lemke 1981
		3.2	Lemke 1981
		1.48	Lemke 1981
		0.97	Lemke 1981
		1.2	Lemke 1981
		2.5	Lemke 1981
		1.5	Mayer and Ellersieck 1986
		1.3	Lemke 1981
		0.8	Nebeker et al. 1983
		.3	Nebeker et al. 1983

		1.7		Nebeker et al. 1983
		1		Nebeker et al. 1983
Bidyanus bidyanus	96-h LC_{50}	2.3	2.35	Sunderam et al. 1992
		2.4		Sunderam et al. 1992
Melanotaenia duboulayi	96-h LC_{50}	5	3.11	Sunderam et al. 1992
		2.5		Sunderam et al. 1992
		2.4		Sunderam et al. 1992
Hyalella azteca	96-h LC_{50}	2.7	10.76	Wan et al. 2005
		153		Wan et al. 2005
		5.7		Wan et al. 2005
		5.7		Wan et al. 2005
Anguilla anguilla	96-h LC_{50}	38	33.66	Ferrando and Andreu
		41		Ferrando and Andreu
		20		Ferrando and Andreu
		39		Ferrando and Andreu
		46		Ferrando and Andreu
		26		Ferrando and Andreu
Daphnia magna	48-h LC_{50}	218	366.33	Lemke 1981
		250		Lemke 1981
		740		Lemke 1981
		266		Lemke 1981
		342		Lemke 1981
		372		Lemke 1981
		282		Lemke 1981
		630		Lemke 1981
		378		Lemke 1981
		158		Lemke 1981
		271		Lemke 1981
		328		Lemke 1981
		166		Macek et al. 1976
		166		PMRA Monograph 2004
		343		Nebeker et al. 1983
		271		Nebeker et al. 1983
		1180		Wan et al. 2005
		1520		Wan et al. 2005
		840		Wan et al. 2005
		2120		Wan et al. 2005
Procambarus clarkii	96-h LC_{50}	280	560	Naqvi and Newton 1990
		560		Naqvi and Newton 1990
		1120		Naqvi and Newton 1990
Oziotelphusa senex senex	96-h LC_{50}	4400	5834.15	Radhakrishnaiah and Renukadevi 1990
		6900		Radhakrishnaiah and Renukadevi 1990
		5300		Radhakrishnaiah and Renukadevi 1990
		7200		Radhakrishnaiah and Renukadevi 1990
Brachionus plicatilis	24-h LC_{50}	7200	6432.13	Serrano et al. 1992
		5600		Serrano et al. 1992
		6600		Serrano et al. 1992

The log Fisher-Tippett model provided the best fit of the twelve models tested (Anderson-Darling Statistic (A^2) = 0.910). The equation of the fitted Fisher-Tippett model is of the form:

$$f(x) = e^{-e^{\frac{(L-x)}{s}}}$$

where x is the concentration metameter, and the functional response, $f(x)$, is the proportion of taxa affected. The parameters, L and s, are the location and scale parameters of the model. The Gumbel distribution occurs when L is set to 0, and s is set to 1. The scale parameter in the Fisher-Tippett model must always be positive. For the fitted model $L = 3.4913$ and $s = 1.5665$.

The fitted SSD derived using the log Fisher-Tippett model and LC_{50} data for freshwater organisms is presented in Figure 7.1.

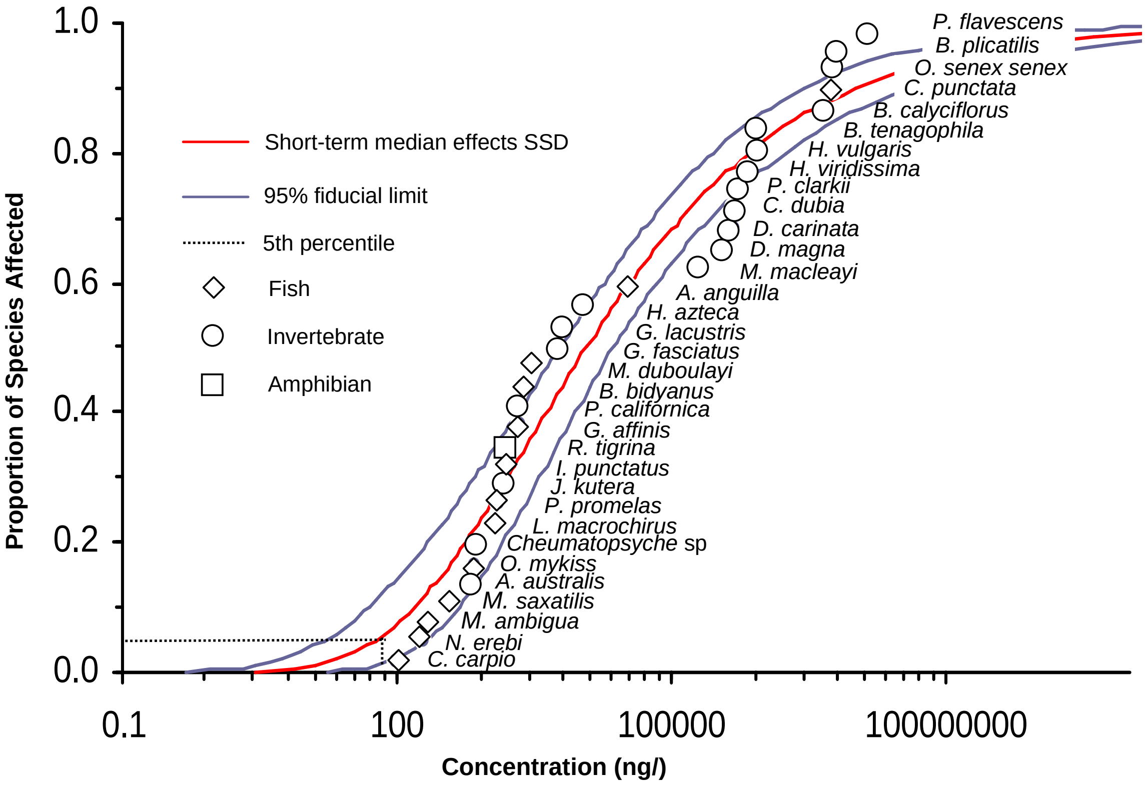


Figure 7.1 Short-term SSD representing the toxicity of endosulfan in freshwater consisting of acceptable short-term LC_{50}s of aquatic species versus proportion of species affected.

The short-term SSD for freshwater aquatic organisms is presented in Figure 7.1. Summary statistics for the shoter-term SSD are presented in Table 7.7. The 5th percentile on the short-term SSD is 0.06 µg a.i./L. The lower fiducial limit (5%) on the 5th percentile is 0.02 µg a.i./L, and the upper fiducial limit (95%) on the 5th percentile is 0.2 µg a.i./L. The final short-term guideline value for endosulfan is the 5th percentile on the SSD.

Table 7.7 Short-term freshwater SSD for endosulfan resulting from generic SSD method

Short-term guideline Metric	**Concentration**
SSD 5th percentile	0.06 µg a.i./L
SSD 5th percentile, 90% LFL (5%)	0.02 µg a.i./L
SSD 5th percentile, 90% UFL (95%)	0.2 µg a.i./L

Therefore, the short-term exposure benchmark concentration indicating the potential for severe effects (e.g. lethality or immobilization) to sensitive freshwater/marine life during transient events is 0.06 µg a.i./L.

7.1.2 *Long-term freshwater CWQG*

There were sufficient data to derive a long-term guideline using a generic SSD. Several of the studies reported in Appendix A are for the same species, effect, endpoint or life stage, though the values are different. This variation may be the result of differences in experimental conditions, species strain, and/or bioassay protocol. Multiple bioassay results for the same species should not be used in an SSD regression analysis. This is particularly important when there is a large amount of data available for very few test species. There are numerous methods that can be applied to account for multiple results for a single species (Duboudin et al. 2004). The final dataset was obtained from studies and endpoints deemed as acceptable (either of primary or secondary ranking) and from the endpoint deemed most acceptable for each species. For the long-term SSD, EC_{10}s are most preferred. Otherwise, the endpoint selection is, in order of preference: MATC, NOEC, EC_{11-25}, LOEC, and EC_{26-50}.

Values used in the final SSD dataset (Table 7.8) range from a 21-d NOEC for growth of 0.05 µg a.i./L for the fish *Oncorhynchus mykiss* (rainbow trout), to a 10-d EC_{50} for changes in reproduction of 1000 µg a.i./L for the rotifer *Brachionus calyciflorus* (Knacker et al. 1991; Fernandez-Casalderrey et al. 1991). Geometric mean values were calculated for species where more than one value for the most preferred endpoint was available for each for inclusion in the SSD. Effect concentrations reported for the remaining species were taken from single studies.

Table 7.8 Final Freshwater Toxicity Data Selected for long-term SSD Development.

Study No.	Organism	Life Stage	Endpoint	Effect Concentration (µg a.i./L)	Reference
1	*Oncorhynchus mykiss* (rainbow trout)	early life stage	21-d NOEC (growth)	0.05	Knacker et al. 1991
2	*Hydra vulgaris* (pink hydra)	NR	6-d MATC	0.06	Polino and Holdway 1999
3	*Hydra viridissima* (green hydra)	NR	6-d MATC	0.07	Polino and Holdway 1999
4	*Channa punctata* (snake-head catfish)	36 g	120-d changes in ovarian steroidogenesis	0.24	Inbaraj and Haider 1988
5	*Pimephales promelas* (fathead minnow)	early life stage	~ 1 year MATC (reduced survival and mean total length)	0.28	PMRA Monograph 2004
6	*Daphnia magna* (water flea)	< 24 h	21-d MATC reproduction	14.1	Fernandez-Casalderry et al. 1991
7	*Ceriodaphnia dubia* (water flea)	neonates < 24-h	14-d MATC	14.1	Sunderam et al. 1994
8	*Moinodaphnia macleayi* (water flea)	neonates < 24-h	14-d MATC	28.30	Sunderam et al. 1994
9	*Daphnia cephalata* (water flea)	neonates	14-d MATC (brood size)	113.14	Barry et al. 1995
10	*Pseudokirchneriella subcapitatum* (green algae)	NR	96-h EC_{50} growth rate	427.80	DeLorenzo et al. 2002
11	*Scenedesmus subspicatus* (green algae)	NR	72-h EC_{50}	560	PMRA Monograph 2004
12	*Brachionus calyciflorus* (rotifer)	neonates	10-d EC_{50} changes in reproduction	1,000	Fernandez-Casalderry et al. 1991

The long-term SSD was fitted using acceptable data (MATCs, NOECs, IC_{50}s, etc.) and the final guideline value for endosulfan was the 5th percentile of the SSD. Each species for which appropriate long-term toxicity data was available was ranked according to sensitivity, and its centralized position on the SSD was determined using the following standard equation (Aldenberg et al., 2002; Newman et al., 2002):

$$\frac{i - 0.5}{N}$$

where

i = the species rank based on ascending EC50s and LC50s
N = the total number of species included in the SSD derivation

These positional rankings, along with their corresponding long-term toxicity studies were used to derive the SSD. Several cumulative distribution functions (CDFs) (normal, logistic, Gompertz, Weibull, Fisher-Tippett and Burr Type III) were fit to the data (both in arithmetic space and log space) using regression methods. Model fit was assessed using statistical and graphical techniques. The best model was selected based on consideration of goodness-of-fit and model feasibility. Model assumptions were verified graphically and with statistical tests.

The log normal model provided the best fit of the twelve models tested (Anderson-Darling Statistic (A^2) = 0.464). The equation of the fitted normal model is of the form:

$$f(x) = \frac{1}{2}\left(1 + erf\left(\frac{x-\mu}{\sigma\sqrt{2}}\right)\right)$$

where x is the concentration metameter. In SSD Master, and in SSD fitting in general, the metameter is either the arithmetic concentration or, more commonly, the logarithmic transformation of concentration. The functional response, $f(x)$, is the proportion of taxa (most commonly, species) affected at the given concentration. The location and scale parameters, μ and σ, are the mean and standard deviation of the theoretical population, respectively, and *erf* is the error function (a.k.a. the Gauss error function). For the fitted model $u = 3.8089$ and $\sigma = 2.0219$.

The fitted SSD derived using the log-normal model and long-term no and low-effect data for freshwater organisms is presented in Figure 7.2.

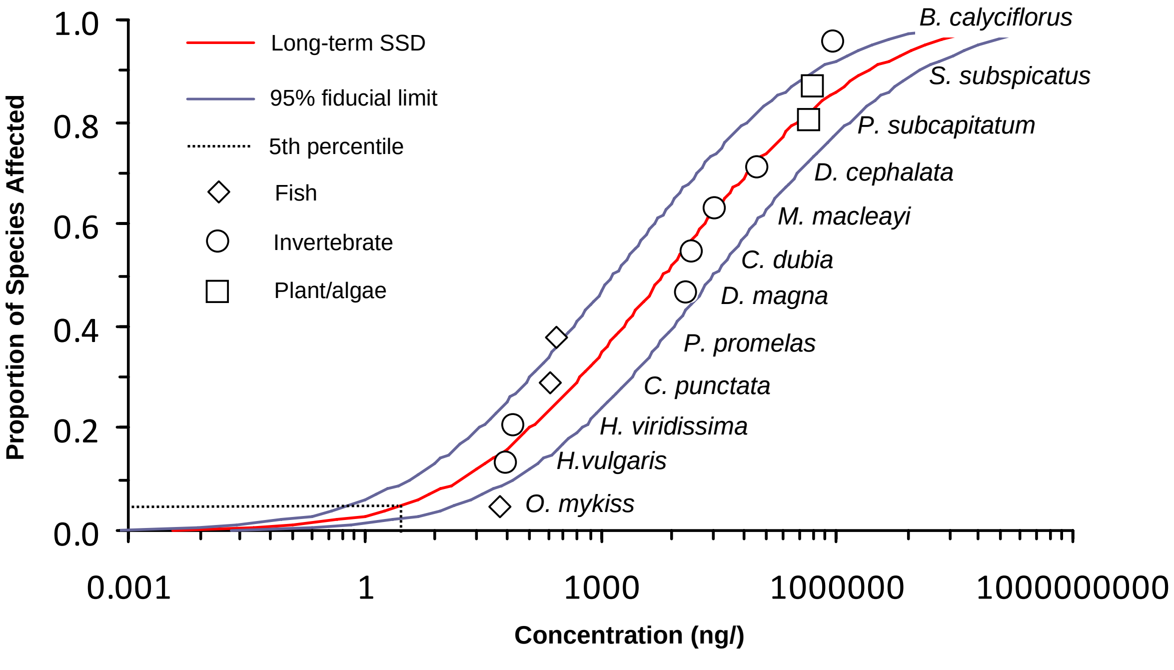


Figure 7.2 Long-term SSD representing the toxicity of endosulfan in freshwater consisting of acceptable long-term endpoints of aquatic species versus proportion of species affected.

The long-term SSD for freshwater aquatic organisms is presented in Figure 7.2. Summary statistics for the long-term SSD are presented in Table 7.9. The 5th percentile on the long-term

SSD is 0.0030 μg a.i./L. The lower fiducial limit (5%) on the 5th percentile is 0.0007 μg a.i./L, and the upper fiducial limit (95%) on the 5th percentile is 0.0144 μg a.i./L. The final long-term guideline value for endosulfan is the 5th percentile on the SSD.

Table 7.9 Long-term freshwater SSD for Endosulfan Resulting from generic SSD method

Acute guideline Metric	Concentration
SSD 5th percentile	0.003 μg a.i/L
SSD 5th percentile, 90% LFL (5%)	0.0007 μg a.i./L
SSD 5th percentile, 90% UFL (95%)	0.01 μg a.i./L

Therefore, the CWQG for long-term exposure benchmark concentration to freshwater/marin life is 0.003 μg a.i./L.

7.2 Protection of Marine Life

Aquatic toxicity studies meeting the requirements of primary or secondary classification based on the CCME (2007) protocol are presented in Appendix B. These studies represent data available for CWQG derivation. The complete set of toxicity data considered for use in CWQG derivation (including data classified as unacceptable) is presented in Appendix B.

7.2.1 *Short-term marine CWQG*

There were sufficient data to derive a short-term guideline using a generic SSD. Several of the studies reported in Appendix B are for the same species, effect, endpoint or life stage, though the values of the LC_{50}s are different. This variation may be the result of differences in experimental conditions, species strain, and/or bioassay protocol. Multiple bioassay results for the same species should not be used in an SSD regression analysis. This is particularly important when there is a large amount of data available for very few test species. For the derivation of a SSD for endosulfan, intra-species variability was accounted for by taking the geometric mean of the studies considered to represent the most sensitive lifestage and endpoint, when experiment duration was the same. Table 7.10 presents the final dataset that was used to generate the fitted SSD for short-term marine water exposure to endosulfan.

Values used in the final SSD dataset (Table 7.10) range from a 48h-LC_{50} of 0.04 μg a.i./L for the invertebrate *Penaeus duorarum* (pink shrimp) to a 96h-LC_{50} of 197 μg a.i./L for the invertebrate *Nereis arenaceodentata* (polychaete worm). Geometric mean values were calculated for species where more than one EC/LC_{50} value was available for each for inclusion in the SSD. Effect concentrations reported for the remaining species were taken from single studies.

The short-term SSD was fitted using LC_{50} data and the final short-term guideline for endosulfan was the 5th percentile of the short-term SSD. Each species for which appropriate short-term toxicity data was available was ranked according to sensitivity, and its centralized position on the SSD was determined using the following standard equation (Aldenberg et al., 2002; Newman et al., 2002):

$$\frac{i - 0.5}{N}$$

where

i = the species rank based on ascending EC_{50}s and LC_{50}s
N = the total number of species included in the SSD derivation

These positional rankings, along with their corresponding EC_{50} and LC_{50}s were used to derive the SSD. Several cumulative distribution functions (CDFs) (normal, logistic, Gompertz, Weibull, Fisher-Tippett and Burr Type III) were fit to the data (both in arithmetic space and log space) using regression methods. Model fit was assessed using statistical and graphical techniques. The best model was selected based on consideration of goodness-of-fit and model feasibility. Model assumptions were verified graphically and with statistical tests.

Table 7.10 Final Marine Toxicity Data Selected for Short-term SSD Development

Study No.	Organism	Life Stage	Endpoint	Effect Concentration (µg a.i./L)	Reference
1	*Penaeus duorarum* (pink shrimp)	NR	48-h LC_{50}	0.04	Schimmel 1977
2	*Morone saxatilis* (striped bass)	NR	48-h LC_{50}	0.1	Schimmel 1977
3	*Acartia tonsa* (copepod)	NR	48-h LC_{50}	0.144*	
4	*Leiostomus xanthurus* (spot)	NR	48-h LC_{50}	0.232*	
5	*Lagodon rhomboides* (pinfish)	NR	48-h LC_{50}	0.3	Schimmel 1977
6	*Mugil cephlus* (striped mullet)	NR	48-h LC_{50}	0.38	Schimmel 1977
7	*Crassostrea viginica* (eastern oyster)	NR	96-h LC_{50}	0.45	Butler 1964
8	*Mugil curema* (white mullet)	NR	48-h LC_{50}	0.6	Schimmel 1977
9	*Mysidopsis bahia* (mysid shrimp)	NR	48-h LC_{50}	0.692*	
10	*Atherinops affinis* (topsmelt)	28-d age group	96-h LC_{50}	1.3	Hemmer et al 1992
11	*Cyprinodon variegatus* (sheepshead minnow)	NR	48-h LC_{50}	1.302*	
12	*Palaemon puglo* (grass shrimp)	NR	48-h LC_{50}	1.31	Schimmel 1977
13	*Menidia beryllina* (inland silverside)	28-d age group	96-h LC_{50}	1.5	Hemmer et al 1992
14	*Gammarus palustris* (gammarid amphipod)	> 3 mm and < 4mm	48-h LC_{50}	3.59*	
15	*Farfantepenaeus aztecus* (brown shrimp)	NR	48-h LC_{50}	35	Portman and Wilson 1971
16	*Nereis arenaceodentata* (polychaete worm)	young adult, 1.5- to 2 cm	96-h LC_{50}	730	U.S. EPA 1980

***value shown is the geometric mean of comparable values, individual values and references can be seen in table 7.11**

Table 7.11 Studies Used To Derive Geometric Means for Short-term marine SSD

Organism	Endpoint	Effect Concentration (µg a.i./L)	Geometric Mean (µg a.i./L)	Reference
Acartia tonsa	48-h LC_{50}	0.12	0.144	Schimel 1980
		0.05		Schimel 1980
		0.28		Schimel 1980
		0.37		Schimel 1980
		0.45		Schimel 1980
		0.032		Schimel 1980
Leiostomus xanthurus	48-h LC_{50}	0.6	0.232	Butler 1964
		0.09		Schimel 1977
Gammarus palustris	48-h LC_{50}	5.63	3.59	Leight and Dolah 1999
		2.29		Leight and Dolah 1999
Mysidopsis bahia	48-h LC_{50}	0.46	0.692	Schimel 1980
		0.24		Schimel 1980
		1.47		Schimel 1980
		1.12		Schimel 1980
		0.73		Schimel 1980
		0.38		Schimel 1980
		0.94		Schimel 1980
		1.16		Schimel 1980
		1.29		Schimel 1980
		0.75		Schimel 1980
Cyprinodon variegatus	48-h LC_{50}	2.7	1.302	Schimel 1980
		1.4		Schimel 1980
		1.2		Schimel 1980
		2.87		Schimel 1980
		3.45		Schimel 1980
		2.21		Schimel 1980
		1.10		Schimel 1980
		0.34		Schimel 1980
		0.60		Schimel 1980
		0.88		Schimel 1980
		1.15		Schimel 1980
		0.83		Schimel 1980

The log Fisher-Tippett model provided the best fit of the twelve models tested (Anderson-Darling Statistic (A^2) = 0.374). The equation of the fitted Fisher-Tippett model is of the form:

$$f(x) = e^{-e^{\frac{(L-x)}{s}}}$$

where x is the concentration metameter, and the functional response, $f(x)$, is the proportion of taxa affected. The parameters, L and s, are the location and scale parameters of the model. The Gumbel distribution occurs when L is set to 0, and s is set to 1. The scale parameter in the Fisher-Tippett model must always be positive. For the fitted model $L = 2.585$ and $s = 0.584$.

The fitted SSD derived using the log Fisher-Tippett model and LC_{50} data for marine organisms is presented in Figure 7.3.

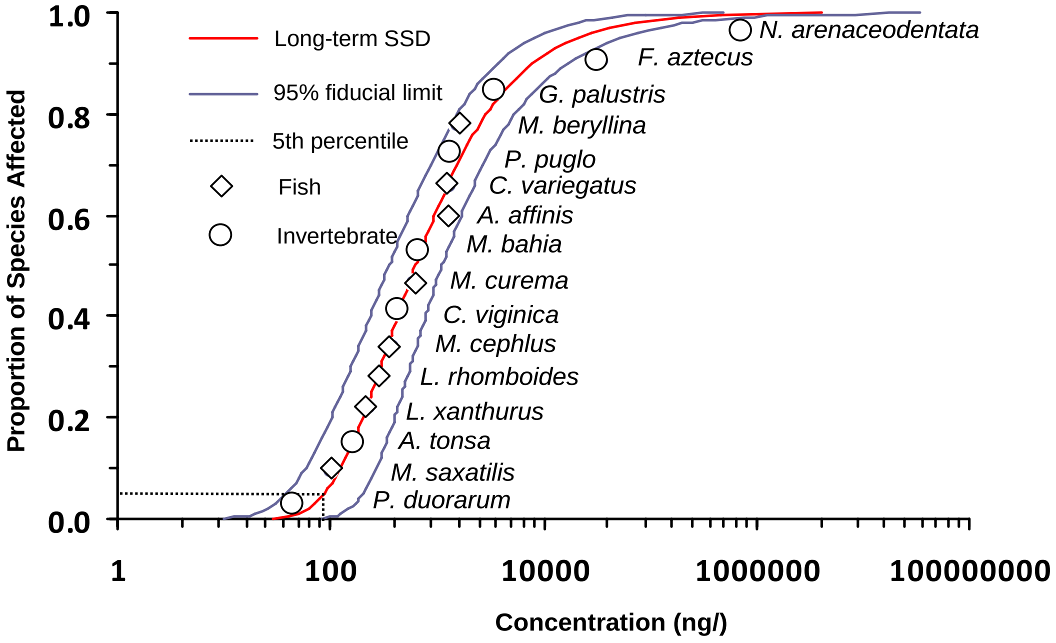


Figure 7.3 Short-term marine SSD representing the toxicity of endosulfan for marine organisms consisting of acceptable short-term LC_{50}s of aquatic species versus proportion of species affected.

The short-term SSD for marine aquatic organisms is presented in Figure 7.3. Summary statistics for the shoter-term SSD are presented in Table 7.12. The 5th percentile on the short-term SSD is 0.089 µg a.i./L. The lower fiducial limit (5%) on the 5th percentile is 0.039 µg a.i./L, and the upper fiducial limit (95%) on the 5th percentile is 0.204 µg a.i./L. The final short-term guideline value for endosulfan is the 5th percentile on the SSD.

Table 7.12 Short-term marine SSD for endosulfan resulting from generic SSD method

Short-term guideline Metric	Concentration
SSD 5th percentile	0.09 µg a.i./L
SSD 5th percentile, 90% LFL (5%)	0.04 µg a.i./L
SSD 5th percentile, 90% UFL (95%)	0.2 µg a.i./L

Therefore, the short-term marine CWQG value in surface water is 0.09 µg a.i./L.

Long-term marine CWQG

The acceptable long-term studies identified for marine species consisted of only the mysid shrimp (*Mysidopsis bahia*), the polychaete worm (*Nereis arenaceodentata*), and the sheepshead minnow (*Cyprinodon variegates*). Based on minimum data requirements (CCME 2007), there were insufficient data available to derive a long-term marine guideline using the statistical approach (Type A) and the lowest endpoint approach (Type B1). Therefore, following the tiered approach, the lowest endpoint approach (Type B2) guideline method was used to develop the long-term marine CWQG.

Using the Type B2 guideline method to derive the long-term CWQG, the critical endpoint was identified as a 48-h LC_{50} of 0.032 µg a.i./L for the copepod *Acartia tonsa* (Schimel 1980). A safety factor of 20 was applied to the lowest data to derive the long-term Type B2 guideline for endosulfan.

Therefore, in accordance with the CCME protocol (CCME 2007), the CWQG is based on a Type B2 approach, and is calculated as follows:
$CWQG= LC_{50} / 20$
$= 0.032 /20$
$=0.0016$ µg a.i./L

Therefore, the CWQG long-term exposure benchmark concentration for the the protection of marine life is 0.0016 µg a.i./L.

7.3 Data Gaps and Research Recommendations

There is a large body of available data concerning the short-term toxicity of technical endosulfan to freshwater fish and invertebrate species. Relatively speaking there is a paucity of long-term toxicology data. In the event that additional long-term freshwater toxicity test become available or are commissioned, it would be preferable that new long-term data generated would be available as EC_{10}s for incorporation in the long-term SSD. Marine data for all species, including aquatic plants, algae, fish and invertebrates are limited, especially concerning studies of long-term duration. Additional studies would be useful in order to derive a long-term guideline value using the SSD for the marine environment. It would be preferable that new long-term data generated would be available as EC_{10}s for incorporation in the long-term SSD.

7.4 Implementation and other considerations

The above guideline was developed using only toxicity data derived using the active ingredient. Formulated products which include endosulfan may be more or less toxic than the active ingredient. In regions of concern, additional sampling may be considered for fomulants to ensure aquatic life is not being impacted by other substances.

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APPENDIX A

TOXICITY VALUES FOR FRESHWATER AQUATIC SPECIES EXPOSED TO ENDOSULFAN

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Plants/Algae												
Anabaena doliolum	blue-green algae	pop	10-d LC50	2,150	NR	agar	27 ± 2	NR	NR	NR	Mohapatra and Mohanty 1992	U
Chlorella vulgaris	green algae	pop	10-d LC50	41,500	NR	agar	27 ± 2	NR	NR	NR	Mohapatra and Mohanty 1992	U
Scenedesmus subspicatus	green algae	NR	72-h LC50	560	100	NR	NR	NR	NR	NR	PMRA Monograph 2004	1
Anabaena sp.	blue-green algae	NR	4-d Nitrogen fixation	10,000	technical	S	28	NR	NR	NR	Tandon *et al.* 1988	U
Anabaena sp.	blue-green algae	NR	2-d Nitrogen fixation	20,000	NR	S	28	NR	NR	NR	Tandon *et al.* 1988	U
Aulosira fertilissima	blue-green algae	NR	3-d Nitrogen fixation	1,000	NR	S	28	NR	NR	NR	Tandon *et al.* 1988	U
Algae, algal mat		phytoplankton	4-h photosynthesis	1000	NR	S	NR	NR	NR	NR	Butler 1963	U
Anabaena sp.	blue-green algae	exponential growth phase	1.5-h photosynthesis	10,000	technical	S	28	NR	NR	NR	Tandon *et al.* 1988	U
Anabaena sp.	blue-green algae	exponential growth phase	1.5-h photosynthesis	20,000	technical	S	28	NR	NR	NR	Tandon *et al.* 1988	U
Aulosira fertilissima	blue-green algae	exponential growth phase	1.5-h photosynthesis	1,000	technical	S	28	NR	NR	NR	Tandon *et al.* 1988	U
Anabaena sp.	blue-green algae	NR	5-d population changes	1,000	technical	S	28	NR	NR	NR	Tandon *et al.* 1988	U
Aulosira fertilissima	blue-green algae	NR	10-d population changes	1,000	technical	S	28	NR	NR	NR	Tandon *et al.* 1988	U
Pseudokirchneriella subcapitatum	green algae	NR	96-h EC50 growth rate	428	technical	S	25	NR	NR	NR	DeLorenzo *et al.* 2002	2
Invertebrates												
Alonella sp.		NR	48-h LC50	0.2	formulation	S	20-22	6.6-7.5	26-28	8.0-8.5	Naqvi and Hawkins 1989	U
Aplexa hypnorum	snail	NR	96-h LC50	> 1,890	formulation	R, N	24.5	NR	48.8	7.1-7.2	Holcombe *et al.* 1983	U

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Atalophlebia australis	mayfly nymph	4.2-4.6 mm	24-h EC50 (mobility)	0.6	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al*. 1999	1
Atalophlebia australis	mayfly nymph	6.8-7.2 mm	24-h EC50 (mobility)	0.5	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al*. 1999	1
Atalophlebia australis	mayfly nymph	4.2-4.6 mm	24-h LC50	0.6	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al*. 1999	1
Atalophlebia australis	mayfly nymph	6.8-7.2 mm	24-h LC50	1	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al*. 1999	1
Atalophlebia australis	mayfly nymph	4.2-4.6 mm	24-h LOEC (mobility)	1	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al*. 1999	1
Atalophlebia australis	mayfly nymph	6.8-7.2 mm	24-h LOEC (mobility)	1	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al*. 1999	1
Atalophlebia australis	mayfly nymph	4.2-4.6 mm	24-h NOEC (mobility)	0.3	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al*. 1999	1
Atalophlebia australis	mayfly nymph	6.8-7.2 mm	24-h NOEC (mobility)	0.3	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al*. 1999	1
Atalophlebia australis	mayfly nymph	4.2-4.6 mm	48-h EC50 (mobility)	0.6	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al*. 1999	1
Atalophlebia australis	mayfly nymph	6.8-7.2 mm	48-h EC50 (mobility)	0.6	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al*. 1999	1
Atalophlebia australis	mayfly nymph	4.2-4.6 mm	48-h LC50	0.6	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al*. 1999	1
Atalophlebia australis	mayfly nymph	6.8-7.2 mm	48-h LC50	0.7	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al*. 1999	1
Atalophlebia australis	mayfly nymph	4.2-4.6 mm	48-h LOEC (mobility)	1	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al*. 1999	1
Atalophlebia australis	mayfly nymph	6.8-7.2 mm	48-h LOEC (mobility)	1	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al*. 1999	1
Atalophlebia australis	mayfly nymph	4.2-4.6 mm	48-h NOEC (mobility)	0.3	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al*. 1999	1
Atalophlebia australis	mayfly nymph	6.8-7.2 mm	48-h NOEC (mobility)	0.3	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al*. 1999	1

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Atalophlebia australis	mayfly nymph	4.2-4.6 mm	72-h EC50 (mobility)	0.6	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al*. 1999	1
Atalophlebia australis	mayfly nymph	4.2-4.6 mm	72-h LC50	0.6	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al*. 1999	1
Atalophlebia australis	mayfly nymph	4.2-4.6 mm	72-h LOEC (mobility)	1	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al*. 1999	1
Atalophlebia australis	mayfly nymph	4.2-4.6 mm	72-h NOEC (mobility)	0.3	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al*. 1999	1
Atalophlebia spp.	mayfly	NR	48-h LC50	12.3	technical	NR	NR	NR	NR	NR	PMRA Monograph 2004	1
Barytelphusa guerini	red swamp crab	male 24 g	NR-h	6,000	35	S	27	7.8-8.0	112	7.2-7.4	Reddy *et al*. 1995	U
Barytelphusa guerini	red swamp crab	male adult	NR-h	6,000	35	S	27	7.8-8.0	112	7.2-7.4	Reddy *et al.* 1991	U
Barytelphusa guerini	red swamp crab	male adult	NR-h	6,000	35	S	27	7.8-8.0	112	7.2-7.4	Reddy *et al.* 1991	U
Bellamya dissmillis	freshwater snail	1.6-2.3 cm sheel height	NR-h biochemical processes in skin	43.5-64.7	35	S	NR	NR	NR	NR	Padmaja Rambabu and Balaparameswara Rao 1994	U
Bellamya dissmillis	freshwater snail	adult	96-h histological changes	1,800	35	S	NR	NR	NR	NR	Padmaja Rambabu and Balaparameswara Rao 1996	U
Bellamya dissmillis	freshwater snail	adult	96-h LC50	1,800	35	S	NR	NR	NR	NR	Padmaja Rambabu and Balaparameswara Rao 1996	U
Biomphalaria tenagophila	snail	embryo	24-h LC50	15,520	98.7	S, N	25 ± 0	NR	40-48	7.1 ± 0.1	Oliveira-Filho *et al.* 2005	2
Biomphalaria tenagophila	snail	hatched	24-h LC50	480	102.7	S, N	29 ± 0	NR	40-52	7.1 ± 0.5	Oliveira-Filho *et al.* 2005	U
Biomphalaria tenagophila	snail	adult	24-h LC50	8,800	106.7	S, N	33 ± 0	NR	40-56	7.1 ± 0.9	Oliveira-Filho *et al.* 2005	U
Biomphalaria tenagophila	snail	embryo	48-h LC50	9,580	99.7	S, N	26 ± 0	NR	40-49	7.1 ± 0.2	Oliveira-Filho *et al.* 2005	2
Biomphalaria tenagophila	snail	hatched	48-h LC50	340	103.7	S, N	30 ± 0	NR	40-53	7.1 ± 0.6	Oliveira-Filho *et al.* 2005	U
Biomphalaria tenagophila	snail	adult	48-h LC50	1,770	107.7	S, N	34 ± 0	NR	40-57	7.1 ± 0.10	Oliveira-Filho *et al.* 2005	U

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Biomphalaria tenagophila	snail	embryo	72-h LC50	7,710	100.7	S, N	27 ± 0	NR	40-50	7.1 ± 0.3	Oliveira-Filho *et al.* 2005	U
Biomphalaria tenagophila	snail	hatched	72-h LC50	200	104.7	S, N	31 ± 0	NR	40-54	7.1 ± 0.7	Oliveira-Filho *et al.* 2005	U
Biomphalaria tenagophila	snail	adult	72-h LC50	1,410	108.7	S, N	35 ± 0	NR	40-58	7.1 ± 0.11	Oliveira-Filho *et al.* 2005	U
Biomphalaria tenagophila	snail	embryo	96-h LC50	5,810	101.7	S, N	28 ± 0	NR	40-51	7.1 ± 0.4	Oliveira-Filho *et al.* 2005	U
Biomphalaria tenagophila	snail	hatched	96-h LC50	120	105.7	S, N	32 ± 0	NR	40-55	7.1 ± 0.8	Oliveira-Filho *et al.* 2005	U
Biomphalaria tenagophila	snail	adult	96-h LC50	890	109.7	S, N	36 ± 0	NR	40-59	7.1 ± 0.12	Oliveira-Filho *et al.* 2005	U
Brachionus calyciflorus	rotifer	cysts	24-h LC50	5,150	NR	S, N	25	NR	80-100	7.4-7.8	Fernandez-Casalderrey *et al.* 1991	U
Brachionus calyciflorus	rotifer	cysts	24-h LC50	5,150	96	S, N	25	NR	80-100	7.4-7.8	Fernandez-Casalderrey *et al.* 1992	2
Brachionus calyciflorus	rotifer	cysts	24-h LC50	5,150	NR	NE	25	NR	80-100	7.4-7.8	Ferrando *et al.* 1992	U
Brachionus calyciflorus	rotifer	neonates	5-h EC50 filtration rate/feeding behaviour	2,960	NR	NE	25	NR	NR	NR	Fernandez-Casalderrey *et al.* 1992	2
Brachionus calyciflorus	rotifer	neonates	10-d EC50 changes in reproduction	1,000	technical	SR	25	NR	80-100	7.4-7.8	Fernandez-Casalderrey *et al.* 1991	2
Brachionus plicatilis	rotifer	cysts	24-h LC50	7,200	96	S, N	25	NR	80-100	7.4-7.8	Serrano *et al.* 1992	2
Brachionus plicatilis	rotifer	cysts	24-h LC50	5,600	96	S, N	25	NR	80-100	7.4-7.8	Serrano *et al.* 1992	2
Brachionus plicatilis	rotifer	cysts	24-h LC50	6,600	96	S, N	25	NR	80-100	7.4-7.8	Serrano *et al.* 1992	2
Ceriodaphnia dubia	water flea	neonates	LC50	53.3	96	S, N	24.5 ± 1.6	7.6 ± 0.5	NR	8.0 ± 0.1	Woods *et al.* 2002	U
Ceriodaphnia dubia	water flea	neonates < 24-h	24-h EC50 immobility	890	96	S, N	20-22	NR	NR	NR	Sunderam *et al.* 1994	2

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Ceriodaphnia dubia	water flea	neonates < 24-h	48-h EC50 immobility	491	96	S, N	20-22	NR	NR	NR	Sunderam *et al.* 1994	2
Ceriodaphnia dubia	water flea	neonates < 24-h	14-d LC50	66.2	96	S, N	20-22	NR	NR	NR	Sunderam *et al.* 1994	2
Ceriodaphnia dubia	water flea	neonates < 24-h	14-d EC50 reproduction	26.4	96	S, N	20-22	NR	NR	NR	Sunderam *et al.* 1994	2
Ceriodaphnia dubia	water flea	neonates < 24-h	14-d LOEC	20	96	S, N	20-22	NR	NR	NR	Sunderam *et al.* 1994	2
Ceriodaphnia dubia	water flea	neonates < 24-h	14-d NOEC	10	96	S, N	20-22	NR	NR	NR	Sunderam *et al.* 1994	2
Ceriodaphnia dubia	water flea	neonates < 24-h	14-d MATC	14.1	96	S, N	20-22	NR	NR	NR	Sunderam *et al.* 1994	2
Cheumatopsyche sp.	trichopteran	5.7-6.3 mm	24-h EC50 (mobility)	0.5	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Cheumatopsyche sp.	trichopteran	5.7-6.3 mm	24-h LC50	0.8	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Cheumatopsyche sp.	trichopteran	5.7-6.3 mm	24-h LOEC (mobility)	0.6	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Cheumatopsyche sp.	trichopteran	9.8-10.3 mm	24-h LOEC (mobility)	1.2	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Cheumatopsyche sp.	trichopteran	5.7-6.3 mm	24-h NOEC (mobility)	0.3	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Cheumatopsyche sp.	trichopteran	9.8-10.3 mm	24-h NOEC (mobility)	0.6	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Cheumatopsyche sp.	trichopteran	5.7-6.3 mm	48-h EC50 (mobility)	0.4	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Cheumatopsyche sp.	trichopteran	9.8-10.3 mm	48-h EC50 (mobility)	1	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Cheumatopsyche sp.	trichopteran	5.7-6.3 mm	48-h LC50	0.4	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Cheumatopsyche sp.	trichopteran	9.8-10.3 mm	48-h LC50	1.8	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Cheumatopsyche sp.	trichopteran	5.7-6.3 mm	48-h LOEC (mobility)	0.3	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Cheumatopsyche sp.	trichopteran	9.8-10.3 mm	48-h LOEC (mobility)	1.2	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Cheumatopsyche sp.	trichopteran	5.7-6.3 mm	48-h NOEC (mobility)	0.2	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Cheumatopsyche sp.	trichopteran	9.8-10.3 mm	48-h NOEC (mobility)	0.6	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Chitonomiidae spp.	bloodworms	NR	24-h LC50	> 607	formulation	Field	19.5-22	6.0-9.1	NR	7.5-9.0	Ernst *et al.* 1991	U
Chitonomiidae spp.	bloodworms	NR	24-h LC50	> 670	formulation	Field	18.0-20.5	7.6-10.0	NR	7.7-8.0	Ernst *et al.* 1991	U
Daphnia carinata	water flea	NR	24-h LC50 (reported as TLm)	500	technical	S, N	29-31	NR	NR	7.8-8.2	Santharam *et al.* 1976	U
Daphnia carinata	water flea	neonates	48-h LC50	478	technical	R, M	19-21	80-100% saturation	NR	6.8-7.0	Barry *et al.* 1995	2
Daphnia carinata	water flea	NR	48-h LC50 (reported as TLm)	180	technical	S, N	29-31	NR	NR	7.8-8.2	Santharam *et al.* 1976	U
Daphnia carinata	water flea	3-4 d	39-d population changes/reproduction	2.35	NR	FT	19-21	NR	NR	6.8-7.0	Barry 1996	U
Daphnia cephalata	water flea	neonates	14-d LOEC (brood size)	160	technical	R, N	21 ± 1	NR	NR	7.5	Barry *et al.* 1995	2
Daphnia cephalata	water flea	neonates	14-d LOEC (height)	80	technical	R, N	21 ± 1	NR	NR	7.5	Barry *et al.* 1995	2
Daphnia cephalata	water flea	neonates	14-d LOEC (length)	160	Technical	R, N	21 ± 1	NR	NR	7.5	Barry *et al.* 1995	2
Daphnia cephalata	water flea	neonates	14-d NOEC (brood size)	80	Technical	R, N	21 ± 1	NR	NR	7.5	Barry *et al.* 1995	2
Daphnia cephalata	water flea	neonates	14-d NOEC (height)	40	Technical	R, N	21 ± 1	NR	NR	7.5	Barry *et al.* 1995	2
Daphnia cephalata	water flea	neonates	14-d NOEC (length)	80	Technical	R, N	21 ± 1	NR	NR	7.5	Barry *et al.* 1995	2

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Daphnia magna	water flea	5-6 d	24-h LC50	> 607	Formulation	Field	19.5-22	7.8-8.4	NR	8.0-8.1	Ernst *et al.* 1991	U
Daphnia magna	water flea	5-6 d	24-h LC50	> 670	Formulation	Field	17.5-20.5	8.9-9.6	NR	7.8-8.1	Ernst *et al.* 1991	U
Daphnia magna	water flea	NR	120-h LC50 (reported as TLm)	47.5	Formulation	S, N	10	NR	45	NR	Schoettger 1970	U
Daphnia magna	water flea	NR	120-h LC50 (reported as TLm)	53.5	Formulation	S, N	19	NR	45	NR	Schoettger 1970	U
Daphnia magna	water flea	NR	21-d LOEC	7	100	NR	NR	NR	NR	NR	PMRA Monograph 2004	1
Daphnia magna	water flea	6 - 24 hrs	24-h LC50	620	NR	NE	25	NR	80-100	7.4-7.8	Ferrando *et al.* 1992	U
Daphnia magna	water flea	NR	24-h LC50 (reported as TLm)	178	Formulation	S, N	10	NR	45	NR	Schoettger 1970	U
Daphnia magna	water flea	NR	24-h LC50 (reported as TLm)	68	Formulation	S, N	19	NR	45	NR	Schoettger 1970	U
Daphnia magna	water flea	neonates	48-h LC50	218	Technical	S, N	NR	NR	48	7.74	Lemke 1981	2
Daphnia magna	water flea	neonates	48-h LC50	250	Technical	S, N	NR	9.3	255	7.8	Lemke 1981	2
Daphnia magna	water flea	neonates	48-h LC50	740	Technical	S, N	NR	NR	54	6.8-7.1	Lemke 1981	2
Daphnia magna	water flea	neonates	48-h LC50	266	Technical	S, N	NR	8.7	46.1	7.6	Lemke 1981	2
Daphnia magna	water flea	neonates	48-h LC50	342	Technical	S, N	NR	NR	NR	NR	Lemke 1981	2
Daphnia magna	water flea	neonates	48-h LC50	372	Technical	S, N	NR	NR	75	6.7-8.8	Lemke 1981	2
Daphnia magna	water flea	neonates	48-h LC50	282	Technical	S, N	NR	NR	48	7.74	Lemke 1981	2
Daphnia magna	water flea	neonates	48-h LC50	630	Technical	S, N	NR	9.3	255	7.8	Lemke 1981	2

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Daphnia magna	water flea	neonates	48-h LC50	378	Technical	S, N	NR	NR	54	6.8-7.1	Lemke 1981	2
Daphnia magna	water flea	neonates	48-h LC50	158	Technical	S, N	NR	8.7	46.1	7.6	Lemke 1981	2
Daphnia magna	water flea	neonates	48-h LC50	271	Technical	S, N	NR	NR	NR	NR	Lemke 1981	2
Daphnia magna	water flea	neonates	48-h LC50	328	Technical	S, N	NR	NR	75	6.7-8.8	Lemke 1981	2
Daphnia magna	water flea	< 24 h	48-h LC50	166	99	S, M	20 ± 1	7.0 ± 0.6	35 ± 3.1	6.8-7.1	Macek *et al.* 1976	1
Daphnia magna	water flea	NR	48-h LC50	166	100	NR	NR	NR	NR	NR	PMRA Monograph 2004	1
Daphnia magna	water flea	< 24 hrs	48-h LC50	343	technical	S, M	20	NR	35	NR	Nebeker *et al.* 1983	1
Daphnia magna	water flea	< 24 hrs	48-h LC50	271	technical	S, M	20	NR	3	NR	Nebeker *et al.* 1983	1
Daphnia magna	water flea	neonates	48-h LC50	1180	99.5	S, N	20 ± 2	NR	NR	NR	Wan *et al.* 2005	2
Daphnia magna	water flea	neonates	48-h LC50	1520	99.3	S, N	20 ± 2	NR	NR	NR	Wan *et al.* 2005	2
Daphnia magna	water flea	neonates	48-h LC50	840	99	S, N	20 ± 2	NR	NR	NR	Wan *et al.* 2005	2
Daphnia magna	water flea	neonates	48-h LC50	2120	98	S, N	20 ± 2	NR	NR	NR	Wan *et al.* 2005	2
Daphnia magna	water flea	NR	48-h LC50 (reported as TLm)	132	formulation	S, N	10	NR	45	NR	Schoettger 1970	U
Daphnia magna	water flea	NR	48-h LC50 (reported as TLm)	62	formulation	S, N	19	NR	45	NR	Schoettger 1970	U
Daphnia magna	water flea	NR	72-h LC50 (reported as TLm)	87.5	formulation	S, N	10	NR	45	NR	Schoettger 1970	U
Daphnia magna	water flea	NR	72-h LC50 (reported as TLm)	60.5	formulation	S, N	19	NR	45	NR	Schoettger 1970	U
Daphnia magna	water flea	NR	96-h LC50 (reported as TLm)	52.9	formulation	S, N	10	NR	45	NR	Schoettger 1970	U

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Daphnia magna	water flea	NR	96-h LC50 (reported as TLm)	56	formulation	S, N	19	NR	45	NR	Schoettger 1970	U
Daphnia magna	water flea	< 24 h	5-h EC50 filtration rate	440	technical	S	21-23	NR	NR	NR	Fernandez-Casalderrey *et al.* 1994	2
Daphnia magna	water flea	< 24 h	40-d reproductive differentiation	no difference at 150	technical	SR	19-21	NR	NR	7.0-7.2	Zou and Fingerman 1997	2
Daphnia magna	water flea	< 24 h	40-d moultin delay	significant difference at 50	technical	SR	19-21	NR	NR	7.0-7.2	Zou and Fingerman 1997	2
Daphnia magna	water flea	< 24 h	21-d MATC reproduction	14.1	technical	SR	19-21	NR	NR	7.0-7.2	Fernandez-Casalderrey *et al.* 1993	2
Daphnia magna	water flea	6-24 h	48-h LC50	220	formulation	S	19-21	NR	NR	NR	Ferrando et al. 1992	U
Daphnia magna	water flea	< 24-h	5-h LC50	620	formulation	S	19-21	NR	NR	NR	Fernandez-Casalderrey *et al.* 1994	U
Daphnia magna	water flea	< 24-h	5-h EC50 for filtration	165.57	technical	S	25	NR	160-180	7.8-8.0	DeLorenzo *et al*. 2002	2
Daphnia magna	water flea	< 24-h	5-h EC50 for ingestion	166.44	technical	S	25	NR	160-180	7.8-8.0	DeLorenzo *et al*. 2002	2
Daphnia magna	water flea	< 24-h	24-h EC50 immobility	366.33	technical	S	25	NR	160-180	7.8-8.0	DeLorenzo *et al*. 2002	2
Diaptomus sp.	calanoid copepod	NR	48-h LC50	0.6	formulation	S	20-22	NR	NR	NR	Naqvi and Hawkins 1989	U
Eucyclops sp.	calanoid copepod	NR	48-h LC50	0.1	formulation	S	20-22	NR	NR	NR	Naqvi and Hawkins 1989	U
Gammarus fasciatus	scud	mature	24-h LC50	9.2	96	S, N	21	NR	44	7.1	Mayer and Ellersieck 1986	2
Gammarus fasciatus	scud	mature	96-h LC50	5.8	96	S, N	21	NR	44	7.1	Mayer and Ellersieck 1986	2
Gammarus lacustris	scud amphipod	mature	24-h LC50	10	96	S, N	21	NR	44	7.1	Mayer and Ellersieck 1986	2
Gammarus lacustris	scud amphipod	NR	48-h LC50	5.8	technical	NR	NR	NR	NR	NR	PMRA Monograph 2004	1
Gammarus lacustris	scud amphipod	mature	96-h LC50	6	96	S, N	21	NR	44	7.1	Mayer and Ellersieck 1986	2
Hydra viridissima	green hydra	NR	96-h LC50	670	technical	SR	24	8.0-9.0	NR	7	Polino and Holdway 1999	1
Hydra vulgaris	pink hydra	NR	96-h LC50	810	technical	SR	24	8.0-9.0	NR	7	Polino and Holdway 1999	1

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Hydra viridissima	green hydra	NR	1-h NOEC tentacle clubbing	0.03	technical	S	24	8.0-9.0	NR	7	Polino and Holdway 1999	1
Hydra viridissima	green hydra	NR	2-h NOEC tentacle clubbing	0.03	technical	S	24	8.0-9.0	NR	7	Polino and Holdway 1999	1
Hydra vulgaris	pink hydra	NR	1-h LOEC tentacle clubbing	0.06	technical	S	24	8.0-9.0	NR	7	Polino and Holdway 1999	1
Hydra vulgaris	pink hydra	NR	2-h LOEC tentacle clubbing	0.06	technical	S	24	8.0-9.0	NR	7	Polino and Holdway 1999	1
Hydra viridissima	green hydra	NR	6-d NOEC	0.06	technical	SR	24	8.0-9.0	NR	7	Polino and Holdway 1999	1
Hydra viridissima	green hydra	NR	6-d LOEC	0.08	technical	SR	24	8.0-9.0	NR	7	Polino and Holdway 1999	1
Hydra vulgaris	pink hydra	NR	6-d NOEC	0.04	technical	SR	24	8.0-9.0	NR	7	Polino and Holdway 1999	1
Hydra vulgaris	pink hydra	NR	6-d LOEC	0.08	technical	SR	24	8.0-9.0	NR	7	Polino and Holdway 1999	1
Hydra viridissima	green hydra	NR	1-h EC50 tentacle clubbing	920	technical	S	24	8.0-9.0	NR	7	Polino and Holdway 1999	1
Hydra viridissima	green hydra	NR	2-h EC50 tentacle clubbing	600	technical	S	24	8.0-9.0	NR	7	Polino and Holdway 1999	1
Hydra vulgaris	pink hydra	NR	1-h EC50 tentacle clubbing	4890	technical	S	24	8.0-9.0	NR	7	Polino and Holdway 1999	1
Hydra vulgaris	pink hydra	NR	2-h EC50 tentacle clubbing	680	technical	S	24	8.0-9.0	NR	7	Polino and Holdway 1999	1
Hyalella azteca	scud	2-9 d old	96-h LC50	2.7	99.5	S, N	23 ± 1	NR	NR	NR	Wan *et al.* 2005	2
Hyalella azteca	scud	2-9 d old	96-h LC50	153	99.3	S, N	23 ± 1	NR	NR	NR	Wan *et al.* 2005	2
Hyalella azteca	scud	2-9 d old	96-h LC50	5.7	99	S, N	23 ± 1	NR	NR	NR	Wan *et al.* 2005	2
Hyalella azteca	scud	2-9 d old	96-h LC50	5.7	98	S, N	23 ± 1	NR	NR	NR	Wan *et al.* 2005	2

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Ischura sp.	damsefly naiads	0,25-0,50 in	120-h LC50 (reported as TLm)	62	Formulation	S, N	8	NR	45	NR	Schoettger 1970	U
Ischura sp.	damsefly naiads	0,25-0,50 in	120-h LC50 (reported as TLm)	75	Formulation	S, N	19	NR	45	NR	Schoettger 1970	U
Ischura sp.	damsefly naiads	0,25-0,50 in	24-h LC50 (reported as TLm)	235	Formulation	S, N	8	NR	45	NR	Schoettger 1970	U
Ischura sp.	damsefly naiads	0,25-0,50 in	24-h LC50 (reported as TLm)	275	Formulation	S, N	19	NR	45	NR	Schoettger 1970	U
Ischura sp.	damsefly naiads	0,25-0,50 in	48-h LC50 (reported as TLm)	120	Formulation	S, N	8	NR	45	NR	Schoettger 1970	U
Ischura sp.	damsefly naiads	0,25-0,50 in	48-h LC50 (reported as TLm)	175	Formulation	S, N	19	NR	45	NR	Schoettger 1970	U
Ischura sp.	damsefly naiads	0,25-0,50 in	72-h LC50 (reported as TLm)	84.5	Formulation	S, N	8	NR	45	NR	Schoettger 1970	U
Ischura sp.	damsefly naiads	0,25-0,50 in	72-h LC50 (reported as TLm)	150	Formulation	S, N	19	NR	45	NR	Schoettger 1970	U
Ischura sp.	damsefly naiads	0,25-0,50 in	96-h LC50 (reported as TLm)	71.8	Formulation	S, N	8	NR	45	NR	Schoettger 1970	U
Ischura sp.	damsefly naiads	0,25-0,50 in	96-h LC50 (reported as TLm)	107	Formulation	S, N	19	NR	45	NR	Schoettger 1970	U
Jappa kutera	mayfly nymph	< 10 mm	12-h mesocosm LC1	0.05	NR (96 previous)	S, M	20-26.4	30-118%	NR	8.0-9.7	Hose and Wilson 2005	U
Jappa kutera	mayfly nymph	< 10 mm	12-h mesocosm LC50	0.5	NR (96 previous)	S, M	20-26.4	30-118%	NR	8.0-9.7	Hose and Wilson 2005	U
Jappa kutera	mayfly nymph	5.1-5.8 mm	24-h EC50 (mobility)	1	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Jappa kutera	mayfly nymph	5.7-6.0 mm	24-h EC50 (mobility)	1.2	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Jappa kutera	mayfly nymph	5.1-5.8 mm	24-h LC50	2	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Jappa kutera	mayfly nymph	5.7-6.0 mm	24-h LC50	3.6	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Jappa kutera	mayfly nymph	3 - 6 mm	24-h LC50	3.6	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 2001	1
Jappa kutera	mayfly nymph	3 - 6 mm	24-h LOEC	0.9	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 2001	1
Jappa kutera	mayfly nymph	5.1-5.8 mm	24-h LOEC (mobility)	1.2	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Jappa kutera	mayfly nymph	5.7-6.0 mm	24-h LOEC (mobility)	0.3	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Jappa kutera	mayfly nymph	3 - 6 mm	24-h NOEC	0.3	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 2001	1
Jappa kutera	mayfly nymph	5.1-5.8 mm	24-h NOEC (mobility)	0.6	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Jappa kutera	mayfly nymph	9.0-10.4 mm	24-h NOEC (mobility)	2.4	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Jappa kutera	mayfly nymph	5.7-6.0 mm	24-h NOEC (mobility)	0.1	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Jappa kutera	mayfly nymph	NR	36-h LOEC	> 6,14	96	F, M	25.4-26.9	80.5-85.6%	NR	7.6-7.8	Hose *et al.* 2002	2
Jappa kutera	mayfly nymph	NR	36-h NOEC	1.07	96	F, M	25.4-26.9	80.5-85.6%	NR	7.6-7.8	Hose *et al.* 2002	2
Jappa kutera	mayfly nymph	5.1-5.8 mm	48-h EC50 (mobility)	1.1	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Jappa kutera	mayfly nymph	5.7-6.0 mm	48-h EC50 (mobility)	1.1	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Jappa kutera	mayfly nymph	5.1-5.8 mm	48-h LC50	1.3	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Jappa kutera	mayfly nymph	5.7-6.0 mm	48-h LC50	2	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Jappa kutera	mayfly nymph	5.1-5.8 mm	48-h LOEC (mobility)	1.2	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Jappa kutera	mayfly nymph	5.7-6.0 mm	48-h LOEC (mobility)	1	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Jappa kutera	mayfly nymph	< 10 mm	48-h mesocosm LC1	6.68	NR (96 previous)	R, M	20-26.4	30-118%	NR	8.0-9.7	Hose and Wilson 2005	U
Jappa kutera	mayfly nymph	< 10 mm	48-h mesocosm LC50	3.1	NR (96 previous)	R, M	20-26.4	30-118%	NR	8.0-9.7	Hose and Wilson 2005	U
Jappa kutera	mayfly nymph	5.1-5.8 mm	48-h NOEC (mobility)	0.6	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Jappa kutera	mayfly nymph	9.0-10.4 mm	48-h NOEC (mobility)	2.4	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Jappa kutera	mayfly nymph	5.7-6.0 mm	48-h NOEC (mobility)	0.3	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Jappa kutera	mayfly nymph	5.1-5.8 mm	72-h EC50 (mobility)	1.1	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Jappa kutera	mayfly nymph	5.7-6.0 mm	72-h EC50 (mobility)	1	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Jappa kutera	mayfly nymph	5.1-5.8 mm	72-h LC50	1	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Jappa kutera	mayfly nymph	5.7-6.0 mm	72-h LC50	1.9	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Jappa kutera	mayfly nymph	5.1-5.8 mm	72-h LOEC (mobility)	1.2	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Jappa kutera	mayfly nymph	5.7-6.0 mm	72-h LOEC (mobility)	1	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Jappa kutera	mayfly nymph	5.1-5.8 mm	72-h NOEC (mobility)	0.6	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Jappa kutera	mayfly nymph	5.7-6.0 mm	72-h NOEC (mobility)	0.3	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Jappa kutera	mayfly nymph	5.7-6.0 mm	96-h EC50 (mobility)	0.8	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Jappa kutera	mayfly nymph	5.7-6.0 mm	96-h LC50	1.2	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Jappa kutera	mayfly nymph	3 - 6 mm	96-h LC50	1.8	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 2001	1

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Jappa kutera	mayfly nymph	3 - 6 mm	96-h LOEC	0.3	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 2001	1
Jappa kutera	mayfly nymph	5.7-6.0 mm	96-h LOEC (mobility)	1	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Jappa kutera	mayfly nymph	3 - 6 mm	96-h NOEC	< 0.3	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 2001	1
Jappa kutera	mayfly nymph	5.7-6.0 mm	96-h NOEC (mobility)	0.3	96	S, M	26 ± 1	NR	NR	NR	Leonard *et al.* 1999	1
Lamellidens corrianus	bivalve	70-75 mm shell length	96-h LC50	17	35	S	28-31	NR	NR	8.4-8.8	Mane and Muley 1984	U
Lamellidens corrianus	bivalve	70-75 mm shell length	96-h LC50	40	35	S	25-27	NR	NR	2.6-8.0	Mane and Muley 1984	U
Lamellidens corrianus	bivalve	70-75 mm shell length	96-h LC50	44	35	S	19-24	NR	NR	7.2-7.6	Mane and Muley 1984	U
Lamellidens marginalis	mussel	65-70 mm shell length	96-h LC50	6	35	S	28-31	NR	NR	8.4-8.8	Mane and Muley 1984	U
Lamellidens marginalis	mussel	65-70 mm shell length	96-h LC50	36	35	S	25-27	NR	NR	2.6-8.0	Mane and Muley 1984	U
Lamellidens marginalis	mussel	65-70 mm shell length	96-h LC50	40	35	S	19-24	NR	NR	7.2-7.6	Mane and Muley 1984	U
Limnephilus spp.	caddisfly	larvae	24-h EC50 (case emergence)	72	Formulation	Field	19.5-22	0.9-9.0	NR	7.2-9.0	Ernst *et al.* 1991	U
Limnephilus spp.	caddisfly	larvae	24-h EC50 (case emergence)	174	Formulation	Field	17.5-18	6.4-9.8	NR	7.4-8.2	Ernst *et al.* 1991	U
Limnephilus spp.	caddisfly	larvae	24-h EC50 (case emergence)	< 99	Formulation	Field	18.0-19.5	8.2-10.5	NR	7.6-8.6	Ernst *et al.* 1991	U
Macrobrachium lamarrei	prawn	NR	24-h LOEC blood glucose	1.1	NR	S	NR	NR	NR	NR	Omkar and Shukla 1984	U
Macrobrachium lamarrei	prawn	NR	24-h LOEC hepatic glycogen	2.2	NR	S	NR	NR	NR	NR	Omkar and Shukla 1984	U
Macrobrachium lamarrei	prawn	NR	48-h LOEC hepatic glycogen	1.1	NR	S	NR	NR	NR	NR	Omkar and Shukla 1984	U

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Macrobrachium malcolsonii	prawn	NR	21-d change in gill cells	0.01	35	F,S	NR	NR	120	8.3	Saravana Bhavan and Geraldine 2000	U
Macrobrachium rosenbergii	prawn	NR	24-h LC50	1.64	formulation	S, N	26.9 ± 0.3	7.1 ± 0.1	44.8 ± 1.5	7.5 ± 0.1	Lombardi *et al.* 2001	U
Macrobrachium rosenbergii	prawn	NR	24-h LC50	2.08	formulation	F, N	27.6 ± 0.8	7.4 ± 0.2	46.8 ± 0.8	7.4 ± 0.2	Lombardi *et al.* 2001	U
Macrobrachium rosenbergii	prawn	NR	48-h LC50	0.99	formulation	S, N	26.9 ± 0.3	7.1 ± 0.1	44.8 ± 1.5	7.5 ± 0.1	Lombardi *et al.* 2001	U
Macrobrachium rosenbergii	prawn	NR	48-h LC50	0.57	formulation	F, N	27.6 ± 0.8	7.4 ± 0.2	46.8 ± 0.8	7.4 ± 0.2	Lombardi *et al.* 2001	U
Macrobrachium rosenbergii	prawn	NR	72-h LC50	0.96	formulation	S, N	26.9 ± 0.3	7.1 ± 0.1	44.8 ± 1.5	7.5 ± 0.1	Lombardi *et al.* 2001	U
Macrobrachium rosenbergii	prawn	NR	72-h LC50	0.31	formulation	F, N	27.6 ± 0.8	7.4 ± 0.2	46.8 ± 0.8	7.4 ± 0.2	Lombardi *et al.* 2001	U
Macrobrachium rosenbergii	prawn	NR	96-h LC50	0.93	formulation	S, N	26.9 ± 0.3	7.1 ± 0.1	44.8 ± 1.5	7.5 ± 0.1	Lombardi *et al.* 2001	U
Macrobrachium rosenbergii	prawn	NR	96-h LC50	0.2	formulation	F, N	27.6 ± 0.8	7.4 ± 0.2	46.8 ± 0.8	7.4 ± 0.2	Lombardi *et al.* 2001	U
Melanopsis dufouri	snail	1.4-1.8 mm shell length	96-h LC50	42,760	formulation	S	NR	NR	NR	NR	Almar *et al.* 1988	U
Melanopsis dufouri	snail	1.4-1.8 mm shell length	96-h LC50	39,770	formulation	S	NR	NR	NR	NR	Almar *et al.* 1988	U
Melanopsis dufouri	snail	1.4-1.8 mm shell length	96-h LC50	37,330	formulation	S	NR	NR	NR	NR	Almar *et al.* 1988	U
Micronecta sp.		NR	36-h NOEC	6.14	96	F, M	25.4-26.9	80.5-85.6%	NR	7.6-7.8	Hose *et al.* 2002	2
Moinodaphnia macleayi	water flea	neonates < 24-h	24-h EC50 immobility	515	96	S, N	20-22	NR	NR	NR	Sunderam *et al.* 1994	2
Moinodaphnia macleayi	water flea	neonates < 24-h	48-h EC50 immobility	215	96	S, N	20-22	NR	NR	NR	Sunderam *et al.* 1994	2
Moinodaphnia macleayi	water flea	neonates < 24-h	14-d LC50	112.5	96	S, N	20-22	NR	NR	NR	Sunderam *et al.* 1994	2

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Moinodaphnia macleayi	water flea	neonates < 24-h	14-d EC50 reproduction	28.8	96	S, N	20-22	NR	NR	NR	Sunderam *et al.* 1994	2
Moinodaphnia macleayi	water flea	neonates < 24-h	14-d LOEC	40	96	S, N	20-22	NR	NR	NR	Sunderam *et al.* 1994	2
Moinodaphnia macleayi	water flea	neonates < 24-h	14-d NOEC	20	96	S, N	20-22	NR	NR	NR	Sunderam *et al.* 1994	2
Moinodaphnia macleayi	water flea	neonates < 24-h	14-d MATC	28.3	96	S, N	20-22	NR	NR	NR	Sunderam *et al.* 1994	2
Notonectidae		NR	36-h LOEC	> 6,14	96	F, M	25.4-26.9	80.5-85.6%	NR	7.6-7.8	Hose *et al.* 2002	2
Notonectidae		NR	36-h NOEC	1.07	96	F, M	25.4-26.9	80.5-85.6%	NR	7.6-7.8	Hose *et al.* 2002	2
Oziotelphusa senex senex	crab	28 g	96-h variation in hemolymph	3,800	technical	S	NR	NR	NR	NR	Vijayakumari *et al* 1987	2
Oziotelphusa senex senex	crab	male 10 g	24-h LC50	7,300	technical	S	NR	NR	NR	NR	Radhakrishnaiah and Renukadevi 1990	2
Oziotelphusa senex senex	crab	male 10 g	48-h LC50	6,200	technical	S	NR	NR	NR	NR	Radhakrishnaiah and Renukadevi 1990	2
Oziotelphusa senex senex	crab	male 10 g	72-h LC50	5,800	technical	S	NR	NR	NR	NR	Radhakrishnaiah and Renukadevi 1990	2
Oziotelphusa senex senex	crab	male 10 g	96-h LC50	4,400	technical	S	NR	NR	NR	NR	Radhakrishnaiah and Renukadevi 1990	2
Oziotelphusa senex senex	crab	male 10 g	24-h LC50	10,100	technical	S	NR	NR	NR	NR	Radhakrishnaiah and Renukadevi 1990	2
Oziotelphusa senex senex	crab	male 10 g	48-h LC50	9,200	technical	S	NR	NR	NR	NR	Radhakrishnaiah and Renukadevi 1990	2
Oziotelphusa senex senex	crab	male 10 g	72-h LC50	8,000	technical	S	NR	NR	NR	NR	Radhakrishnaiah and Renukadevi 1990	2
Oziotelphusa senex senex	crab	male 10 g	96-h LC50	6,900	technical	S	NR	NR	NR	NR	Radhakrishnaiah and Renukadevi 1990	2
Oziotelphusa senex senex	crab	male 10 g	24-h LC50	9,800	technical	S	NR	NR	NR	NR	Radhakrishnaiah and Renukadevi 1990	2

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Oziotelphusa senex senex	crab	male 10 g	48-h LC50	8,400	technical	S	NR	NR	NR	NR	Radhakrishnaiah and Renukadevi 1990	2
Oziotelphusa senex senex	crab	male 10 g	72-h LC50	6,300	technical	S	NR	NR	NR	NR	Radhakrishnaiah and Renukadevi 1990	2
Oziotelphusa senex senex	crab	male 10 g	96-h LC50	5,300	technical	S	NR	NR	NR	NR	Radhakrishnaiah and Renukadevi 1990	2
Oziotelphusa senex senex	crab	male 10 g	24-h LC50	11,300	technical	S	NR	NR	NR	NR	Radhakrishnaiah and Renukadevi 1990	2
Oziotelphusa senex senex	crab	male 10 g	48-h LC50	9,400	technical	S	NR	NR	NR	NR	Radhakrishnaiah and Renukadevi 1990	2
Oziotelphusa senex senex	crab	male 10 g	72-h LC50	8,400	technical	S	NR	NR	NR	NR	Radhakrishnaiah and Renukadevi 1990	2
Oziotelphusa senex senex	crab	male 10 g	96-h LC50	7,200	technical	S	NR	NR	NR	NR	Radhakrishnaiah and Renukadevi 1990	2
Oziotelphusa senex senex	crab	intermolt stage 4	96-h physiological effect	6,200	formulation	S	NR	NR	NR	NR	Rajeswari *et al.* 1988	2
Oziotelphusa senex senex	crab	intermolt stage 4	NR-d physiological effect	6,200	formulation	S	NR	NR	NR	NR	Rafi *et al.* 1991	2
Pantala flavescens	dragonfly	NR	24-h LC50	15,000	technical	S	NR	NR	NR	NR	Yadwad *et al.* 1990	2
Pantala flavescens	dragonfly	NR	24-h ATP activity	2,000	technical	S	NR	NR	NR	NR	Yadwad *et al.* 1990	2
Paratya australiensis	decapod crustacean	1.5-2.0 cm	12-h mesocosm LC1	0.31	NR (96 previous)	S, M	25.4-26.9	81-86%	NR	7.6-7.8	Hose and Wilson 1996	U
Paratya australiensis	decapod crustacean	1.5-2.0 cm	12-h mesocosm LC1	0.18	NR (96 previous)	S, M	25.3-26.7	72-84%	NR	7.4-7.9	Hose and Wilson 1996	U
Paratya australiensis	decapod crustacean	1.5-2.0 cm	12-h mesocosm LC50	6.35	NR (96 previous)	S, M	25.4-26.9	81-86%	NR	7.6-7.8	Hose and Wilson 1996	U
Paratya australiensis	decapod crustacean	1.5-2.0 cm	12-h mesocosm LC50	3.01	NR (96 previous)	S, M	25.3-26.7	72-84%	NR	7.4-7.9	Hose and Wilson 1996	U
Paratya australiensis	decapod crustacean	1.5-2.0 cm	48-h lab LC50	11.1	NR (96 previous)	R, M	NR	NR	NR	NR	Hose and Wilson 1996	U

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Paratya australiensis	decapod crustacean	1.5-2.0 cm	48-h mesocosm LC1	0.03	NR (96 previous)	R, M	25.4-26.9	81-86%	NR	7.6-7.8	Hose and Wilson 1996	U
Paratya australiensis	decapod crustacean	1.5-2.0 cm	48-h mesocosm LC1	0.06	NR (96 previous)	R, M	25.3-26.7	72-84%	NR	7.4-7.9	Hose and Wilson 1996	U
Paratya australiensis	decapod crustacean	1.5-2.0 cm	48-h mesocosm LC50	0.96	NR (96 previous)	R, M	25.4-26.9	81-86%	NR	7.6-7.8	Hose and Wilson 1996	U
Paratya australiensis	decapod crustacean	1.5-2.0 cm	48-h mesocosm LC50	0.51	NR (96 previous)	R, M	25.3-26.7	72-84%	NR	7.4-7.9	Hose and Wilson 1996	U
Paratelphusa jacquemontii	crab	intermolt	24-h LC50	0.48	formulation	S	NR	NR	NR	NR	Patil *et al.* 1991	U
Paratelphusa jacquemontii	crab	intermolt	48-h LC50	0.32	formulation	S	NR	NR	NR	NR	Patil *et al.* 1991	U
Paratelphusa jacquemontii	crab	intermolt	72-h LC50	0.22	formulation	S	NR	NR	NR	NR	Patil *et al.* 1991	U
Paratelphusa jacquemontii	crab	intermolt	96-h LC50	0.16	formulation	S	NR	NR	NR	NR	Patil *et al.* 1991	U
Pila virens	freshwater snail	40 mm shell tickness	NR-h changes in enzyme activity	200-600	35	S	NR	NR	NR	NR	Reju *et al.* 1993	U
Pisidium spp.	bivalves	NR	24-h LC50	> 607	formulation	Field	19.5-22	6.0-9.1	NR	7.55-9.0	Ernst *et al.* 1991	U
Pisidium spp.	bivalves	NR	24-h LC50	> 670	formulation	Field	10.0-20.5	7.6-10.0	NR	7.7-8.0	Ernst *et al.* 1991	U
Procambarus clarkii	red swamp crayfish	juvenille	96-h LC50	24	formulation	S	NR	NR	NR	NR	Naqvi *et al.* 1987	U
Procambarus clarkii	red swamp crayfish	adult	96-h LC50	423	formulation	S	NR	NR	NR	NR	Naqvi *et al.* 1987	U
Procambarus clarkii	red swamp crayfish	adult	96-h LC50	280	technical	S	NR	NR	NR	NR	Naqvi and Newton 1990	2
Procambarus clarkii	red swamp crayfish	adult	96-h LC50	560	technical	S	NR	NR	NR	NR	Naqvi and Newton 1990	2
Procambarus clarkii	red swamp crayfish	adult	96-h LC50	1,120	technical	S	NR	NR	NR	NR	Naqvi and Newton 1990	2

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Procambarus clarkii	red swamp crayfish	adult	20-weeks, reproductive effects	600	formulation	S	NR	NR	NR	NR	Naqvi and Newton 1990	U
Pteronarcys californica	stonefly	2nd year	24-h LC50	24	96	S, N	15	NR	44	7.1	Mayer and Ellersieck, 1986	2
Pteronarcys californica	stonefly	2nd year	96-h LC50	2.3	96	S, N	15	NR	44	7.1	Mayer and Ellersieck, 1986	2
Pteronarcys californica	stonefly	NR	96-h LC50	2.3	Technical	NR	NR	NR	NR	NR	PMRA Monograph 2004	1
Pteronarcys californica	stonefly	2nd year	24-h LC50	24	96	S, N	15	NR	44	7.1	Sanders and Cope 1968	2
Pteronarcys californica	stonefly	2nd year	48-h LC50	5.6	96	S, N	15	NR	44	7.1	Sanders and Cope 1968	2
Pteronarcys californica	stonefly	2nd year	96-h LC50	2.3	96	S, N	15	NR	44	7.1	Sanders and Cope 1968	2
Sigara alternata	water boatmen	NR	24-h LC50	13	Formulation	Field	19.5-22	9.2-7.4	NR	8.2-9.0	Ernst *et al.* 1991	U
Sigara alternata	water boatmen	NR	24-h LC50	75	Formulation	Field	18.0-20.5	7.6-10.0	NR	7.9-8.0	Ernst *et al.* 1991	U
Sigara alternata	water boatmen	NR	24-h LC50	269	Formulation	Field	18.0-19.5	9.8-10.4	NR	8.0-8.6	Ernst *et al.* 1991	U
Spicodiaptomus chilospinus	calanoid copepod	adult	24-h LC50	50	Formulation	S	20-22	NR	NR	NR	Kader *et al.* 1976	U
Spicodiaptomus chilospinus	calanoid copepod	adult	24-h LC50	40	Formulation	S	20-22	NR	NR	NR	Kader *et al.* 1976	U
Tanypodinae		NR	36-h LOEC	> 6,14	96	F, M	25.4-26.9	80.5-85.6%	NR	7.6-7.8	Hose *et al*. 2002	2
Tanypodinae		NR	36-h NOEC	1.07	96	F, M	25.4-26.9	80.5-85.6%	NR	7.6-7.8	Hose *et al*. 2002	2
Tasmanocoenis sp.		NR	36-h NOEC	6.14	96	F, M	25.4-26.9	80.5-85.6%	NR	7.6-7.8	Hose *et al*. 2002	2
Triplectides sp.		NR	36-h LOEC	> 6,14	96	F, M	25.4-26.9	80.5-85.6%	NR	7.6-7.8	Hose *et al*. 2002	2

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Triplectides sp.		NR	36-h NOEC	1.07	96	F, M	25.4-26.9	80.5-85.6%	NR	7.6-7.8	Hose *et al*. 2002	2
Fish												
Anabas testudineus	climbing perch	adult	21-d changes to internal tissues	6	technical	S	25-29	8.0-9.0	134	7.5-8	Rao and Murty 1980	U
Anabas testudineus	climbing perch	8 g	24-h LC50	3	formulation	S	25-29	NR	NR	NR	Rao and Murty 1980	U
Anabas testudineus	climbing perch	8 g	48-h LC50	2.4	formulation	S	25-29	NR	NR	NR	Rao and Murty 1980	U
Anabas testudineus	climbing perch	8 g	72-h LC50	1.5	formulation	S	25-29	NR	NR	NR	Rao and Murty 1980	U
Anabas testudineus	climbing perch	8 g	96-h LC50	1.2	formulation	S	25-29	NR	NR	NR	Rao and Murty 1980	U
Anguilla anguilla	common eel	20-30 g	96-h LC50	38	technical	S	22	NR	NR	NR	Ferrando and Andreu-Moliner 1989	2
Anguilla anguilla	common eel	20-30 g	96-h LC50	41	technical	S	22	NR	NR	NR	Ferrando and Andreu-Moliner 1989	2
Anguilla anguilla	common eel	20-30 g	96-h LC50	20	technical	S	22	NR	NR	NR	Ferrando and Andreu-Moliner 1989	2
Anguilla anguilla	common eel	20-30 g	96-h LC50	39	technical	S	22	NR	NR	NR	Ferrando and Andreu-Moliner 1989	2
Anguilla anguilla	common eel	20-30 g	96-h LC50	46	technical	S	22	NR	NR	NR	Ferrando and Andreu-Moliner 1989	2
Anguilla anguilla	common eel	20-30 g	96-h LC50	26	technical	S	22	NR	NR	NR	Ferrando and Andreu-Moliner 1989	2
Anguilla anguilla	common eel	20-30 g	24-h LC50	40	formulation	S	22	NR	NR	NR	Ferrando *et al.* 1987	U
Anguilla anguilla	common eel	20-30 g	48-h LC50	39	formulation	S	22	NR	NR	NR	Ferrando *et al.* 1987	U
Anguilla anguilla	common eel	20-30 g	72-h LC50	38	formulation	S	22	NR	NR	NR	Ferrando *et al.* 1987	U

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Anguilla anguilla	common eel	20-30 g	96-h LC50	38	formulation	S	22	NR	NR	NR	Ferrando *et al.* 1987	U
Anguilla anguilla	common eel	20-30 g	24-h LC50	42	formulation	S	22	NR	NR	NR	Ferrando *et al.* 1987	U
Anguilla anguilla	common eel	20-30 g	48-h LC50	42	formulation	S	22	NR	NR	NR	Ferrando *et al.* 1987	U
Anguilla anguilla	common eel	20-30 g	72-h LC50	42	formulation	S	22	NR	NR	NR	Ferrando *et al.* 1987	U
Anguilla anguilla	common eel	20-30 g	96-h LC50	42	formulation	S	22	NR	NR	NR	Ferrando *et al.* 1987	U
Anguilla anguilla	common eel	20-30 g	24-h LC50	23	formulation	S	22	NR	NR	NR	Ferrando *et al.* 1987	U
Anguilla anguilla	common eel	20-30 g	48-h LC50	22	formulation	S	22	NR	NR	NR	Ferrando *et al.* 1987	U
Anguilla anguilla	common eel	20-30 g	72-h LC50	20	formulation	S	22	NR	NR	NR	Ferrando *et al.* 1987	U
Anguilla anguilla	common eel	20-30 g	96-h LC50	20	formulation	S	22	NR	NR	NR	Ferrando *et al.* 1987	U
Barbus conchonius	rosy barb	adult 4.5 g	48-h LC50	21.4	formulation	S	26-28	NR	NR	NR	Gill *et al.* 1991	U
Barbus javanicus	barb	adult 4.5 g	24-h LC50	10.4	formulation	S	22-25	NR	NR	NR	Paul and Raut 1987	U
Barbus javanicus	barb	adult 4.5 g	48-h LC50	10.3	formulation	S	22-25	NR	NR	NR	Paul and Raut 1987	U
Barbus javanicus	barb	adult 4.5 g	72-h LC50	8.82	formulation	S	22-25	NR	NR	NR	Paul and Raut 1987	U
Barbus javanicus	barb	adult 4.5 g	96-h LC50	8.69	formulation	S	22-25	NR	NR	NR	Paul and Raut 1987	U
Barbus javanicus	barb	fingerling 1.4-2.1 g	24-h LC50	8.72	formulation	S	22-25	NR	NR	NR	Paul and Raut 1987	U
Barbus javanicus	barb	fingerling 1.4-2.1 g	48-h LC50	8.69	formulation	S	22-25	NR	NR	NR	Paul and Raut 1987	U

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Barbus javanicus	barb	fingerling 1.4-2.1 g	72-h LC50	8.33	formulation	S	22-25	NR	NR	NR	Paul and Raut 1987	U
Barbus javanicus	barb	fingerling 1.4-2.1 g	96-h LC50	8.34	formulation	S	22-25	NR	NR	NR	Paul and Raut 1987	U
Barbus javanicus	barb	fingerling 1.4-2.1 g	24-h LC50	7.36	formulation	S	22-25	NR	NR	NR	Paul and Raut 1987	U
Barbus javanicus	barb	fingerling 1.4-2.1 g	48-h LC50	7.11	formulation	S	22-25	NR	NR	NR	Paul and Raut 1987	U
Barbus javanicus	barb	fingerling 1.4-2.1 g	72-h LC50	6.42	formulation	S	22-25	NR	NR	NR	Paul and Raut 1987	U
Barbus javanicus	barb	fingerling 1.4-2.1 g	96-h LC50	6.31	formulation	S	22-25	NR	NR	NR	Paul and Raut 1987	U
Barbus sophore	two spot barb	2.54-7.62 cm	23-h LC50	2.3	formulation	SR	24-28	NR	NR	NR	Arora *et al.* 1971	U
Barbus sophore	two spot barb	2.54-7.62 cm	48-h LC50	1.4	formulation	SR	24-28	NR	NR	NR	Arora *et al.* 1971	U
Barbus sophore	two spot barb	2.54-7.62 cm	96-h LC50	1.2	formulation	SR	24-28	NR	NR	NR	Arora *et al.* 1971	U
Barbus sophore	two spot barb	NR	96-h LC50	0.19	formulation	S	23-27	NR	NR	NR	Khillare and Wagh 1987	U
Bidyanus bidyanus	silver perch	50 mm	96-h LC50	2.3	96	R, M	25	NR	45	7.5	Sunderam *et al.* 1992	2
Bidyanus bidyanus	silver perch	50 mm	96-h LC50	2.4	96	R, M	26	NR	100	8	Sunderam *et al.* 1992	2
Catastomus commersoni	western white sucker	0.9-2.5 g	120-h LC50 (reported as TLm)	2.5	formulation	S, N	10	NR	45	NR	Schoettger 1970	U
Catastomus commersoni	western white sucker	0.9-2.5 g	120-h LC50 (reported as TLm)	2.8	formulation	S, N	19	NR	45	NR	Schoettger 1970	U
Catastomus commersoni	western white sucker	0.9-2.5 g	24-h LC50 (reported as TLm)	8.1	formulation	S, N	10	NR	45	NR	Schoettger 1970	U
Catastomus commersoni	western white sucker	0.9-2.5 g	24-h LC50 (reported as TLm)	6.6	formulation	S, N	19	NR	45	NR	Schoettger 1970	U

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Catastomus commersoni	western white sucker	0.9-2.5 g	48-h LC50 (reported as TLm)	6.4	formulation	S, N	10	NR	45	NR	Schoettger 1970	U
Catastomus commersoni	western white sucker	0.9-2.5 g	48-h LC50 (reported as TLm)	4.3	formulation	S, N	19	NR	45	NR	Schoettger 1970	U
Catastomus commersoni	western white sucker	0.9-2.5 g	72-h LC50 (reported as TLm)	4.9	formulation	S, N	10	NR	45	NR	Schoettger 1970	U
Catastomus commersoni	western white sucker	0.9-2.5 g	72-h LC50 (reported as TLm)	3.1	formulation	S, N	19	NR	45	NR	Schoettger 1970	U
Catastomus commersoni	western white sucker	0.9-2.5 g	96-h LC50 (reported as TLm)	3.5	formulation	S, N	10	NR	45	NR	Schoettger 1970	U
Catastomus commersoni	western white sucker	0.9-2.5 g	96-h LC50 (reported as TLm)	3	formulation	S, N	19	NR	45	NR	Schoettger 1970	U
Catla catla	catla	fingerling 2.3-2.7 g	24-h LC50	4.89	formulation	S	25-30	NR	NR	NR	Paul and Raut 1987	U
Catla catla	catla	fingerling 2.3-2.7 g	48-h LC50	4.81	formulation	S	25-30	NR	NR	NR	Paul and Raut 1987	U
Catla catla	catla	fingerling 2.3-2.7 g	72-h LC50	3.34	formulation	S	25-30	NR	NR	NR	Paul and Raut 1987	U
Catla catla	catla	fingerling 2.3-2.7 g	96-h LC50	3.2	formulation	S	25-30	NR	NR	NR	Paul and Raut 1987	U
Catla catla	catla	fingerling 2.3-2.7 g	24-h LC50	3.25	formulation	S	25-30	NR	NR	NR	Paul and Raut 1987	U
Catla catla	catla	fingerling 2.3-2.7 g	48-h LC50	3.1	formulation	S	25-30	NR	NR	NR	Paul and Raut 1987	U
Catla catla	catla	fingerling 2.3-2.7 g	72-h LC50	2.79	formulation	S	25-30	NR	NR	NR	Paul and Raut 1987	U
Catla catla	catla	fingerling 2.3-2.7 g	96-h LC50	2.8	formulation	S	25-30	NR	NR	NR	Paul and Raut 1987	U
Catla catla	catla	fingerling 2.3-2.7 g	24-h LC50	1.92	formulation	S	25-30	NR	NR	NR	Paul and Raut 1987	U
Catla catla	catla	fingerling 2.3-2.7 g	48-h LC50	1.67	formulation	S	25-30	NR	NR	NR	Paul and Raut 1987	U

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Catla catla	catla	fingerling 2.3-2.7 g	72-h LC50	1.02	formulation	S	25-30	NR	NR	NR	Paul and Raut 1987	U
Catla catla	catla	fingerling 2.3-2.7 g	96-h LC50	0.89	formulation	S	25-30	NR	NR	NR	Paul and Raut 1987	U
Catla catla	catla	juvenile, 300 mg	96-LC50	0.36	isomer A	NR	26-30	NR	155	6.8-7	Rao 1989	U
Catla catla	catla	juvenile, 300 mg	96-LC50	1.05	formulation	NR	26-30	NR	155	6.8-7	Rao 1989	U
Catla catla	catla	juvenile, 300 mg	96-LC50	1.84	technical	NR	26-30	NR	155	6.8-7	Rao 1989	U
Catla catla	catla	juvenile, 300 mg	96-LC50	7.67	isomer B	NR	26-30	NR	155	6.8-7	Rao 1989	U
Catla catla	catla	10 g	48-LC50	371	formulation	NR	24-28	NR	NR	NR	Bashamohideen *et al.* 1989	U
Catla catla	catla	10 g	48-LC50	346	formulation	NR	24-28	NR	NR	NR	Bashamohideen *et al.* 1989	U
Catla catla	catla	10 g	48-LC50	424	formulation	NR	24-28	NR	NR	NR	Bashamohideen *et al.* 1989	U
Channa orientalis	smooth-breasted snakefish	NR	96-h LC50	1.67	formulation	SR	18-22	NR	NR	NR	Khillare and Wagh 1987	U
Channa punctata	snake-head catfish	adult	5-d histological changes	2.2	formulation	SR	20-24	NR	NR	NR	Johal and Dua 1994	U
Channa punctata	snake-head catfish	mature	10-d enzyme level changes	1491 significantly different than control	formulation	SR	18-22	NR	NR	NR	Dalela *et al.* 1978	U
Channa punctata	snake-head catfish	80-95 g	60-d enzyme level changes	1.74significantly different than control	formulation	SR	18-22	NR	NR	NR	Dalela *et al.* 1978	U
Channa punctata	snake-head catfish	36 g	120-d changes in brain acetylcholinesterase	0.24 no different than controls	technical	SR	19	NR	NR	NR	Inbaraj and Haider 1988	U
Channa punctata	snake-head catfish	36 g	120-d changes in ovarian steroidogenesis	0.24 significant from control	technical	SR	19	NR	NR	NR	Inbaraj and Haider 1988	2

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Channa punctata	snake-head catfish	6-9 cm	6-h LC50	4.8	formulation	FT	19	NR	NR	NR	Gopal *et al.* 1981	U
Channa punctata	snake-head catfish	6-9 cm	6-h LC50	2.5	formulation	FT	19	NR	NR	NR	Gopal *et al.* 1981	U
Channa punctata	snake-head catfish	6-9 cm	6-h LC50	16	formulation	FT	19	NR	NR	NR	Gopal *et al.* 1981	U
Channa punctata	snake-head catfish	adult 59.8 g	24-h LC50	11,260	technical	SR	20-23	NR	NR	6.8-7.0	Khillare and Wagh 1987	2
Channa punctata	snake-head catfish	adult 59.8 g	48-h LC50	9,680	technical	SR	20-23	NR	NR	6.8-7.0	Khillare and Wagh 1987	2
Channa punctata	snake-head catfish	adult 59.8 g	72-h LC50	7,560	technical	SR	20-23	NR	NR	6.8-7.0	Khillare and Wagh 1987	2
Channa punctata	snake-head catfish	adult 59.8 g	96-h LC50	5,780	technical	SR	20-23	NR	NR	6.8-7.0	Khillare and Wagh 1987	2
Channa punctata	snake-head catfish	adult 59.8 g	24-h LC50	7,440	formulation	SR	20-23	NR	NR	6.8-7.0	Khillare and Wagh 1987	U
Channa punctata	snake-head catfish	adult 59.8 g	48-h LC50	5,830	formulation	SR	20-23	NR	NR	6.8-7.0	Khillare and Wagh 1987	U
Channa punctata	snake-head catfish	adult 59.8 g	72-h LC50	4,390	formulation	SR	20-23	NR	NR	6.8-7.0	Khillare and Wagh 1987	U
Channa punctata	snake-head catfish	adult 59.8 g	96-h LC50	3,070	formulation	SR	20-23	NR	NR	6.8-7.0	Khillare and Wagh 1987	U
Channa punctata	snake-head catfish	NR	96-h LC50	2.08	formulation	S	20-23	NR	NR	6.8-7.0	Khillare and Wagh 1987	U
Clarias batrachus	walking catfish	NR	96-h LC50	2.78	formulation	S	18-22	6.0-8.0	120-140	6.5-7.0	Khillare and Wagh 1987	U
Clarias batrachus	walking catfish	juvenille	24-h LC50	22.50	formulation	S	20	NR	80-100	6.5-7.0	Gopal *et al.* 1981	U
Clarias batrachus	walking catfish	juvenille	48-h LC50	17.50	formulation	S	20	NR	80-100	6.5-7.0	Gopal *et al.* 1981	U
Clarias batrachus	walking catfish	juvenille	96-h LC50	14.00	formulation	S	20	NR	80-100	6.5-7.0	Gopal *et al.* 1981	U

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Clarias batrachus	walking catfish	25-30 g	24-h LC50	8.70	formulation	S	18-20	NR	70-95	6.5-7.0	Bhatnagar *et al.* 1988	U
Clarias batrachus	walking catfish	25-30 g	48-h LC50	6.90	formulation	S	18-20	NR	70-95	6.5-7.0	Bhatnagar *et al.* 1988	U
Clarias batrachus	walking catfish	25-30 g	72-h LC50	5.40	formulation	S	18-20	NR	70-95	6.5-7.0	Bhatnagar *et al.* 1988	U
Clarias batrachus	walking catfish	25-30 g	96-h LC50	3.80	formulation	S	18-20	NR	70-95	6.5-7.0	Bhatnagar *et al.* 1988	U
Ctenopharyngodon idella	grass carp	fingerling, 2.7-3.1 g	24-h LC50	5.74	formulation	S	19-24	NR	NR	6.8-7.2	Paul and Raut 1987	U
Ctenopharyngodon idella	grass carp	fingerling, 2.7-3.1 g	48-h LC50	5.70	formulation	S	19-24	NR	NR	6.8-7.2	Paul and Raut 1987	U
Ctenopharyngodon idella	grass carp	fingerling, 2.7-3.1 g	72-h LC50	4.20	formulation	S	19-24	NR	NR	6.8-7.2	Paul and Raut 1987	U
Ctenopharyngodon idella	grass carp	fingerling, 2.7-3.1 g	96-h LC50	4.08	formulation	S	19-24	NR	NR	6.8-7.2	Paul and Raut 1987	U
Ctenopharyngodon idella	grass carp	fingerling, 2.7-3.1 g	24-h LC50	4.12	formulation	S	19-24	NR	NR	6.8-7.2	Paul and Raut 1987	U
Ctenopharyngodon idella	grass carp	fingerling, 2.7-3.1 g	48-h LC50	4.10	formulation	S	19-24	NR	NR	6.8-7.2	Paul and Raut 1987	U
Ctenopharyngodon idella	grass carp	fingerling, 2.7-3.1 g	72-h LC50	3.70	formulation	S	19-24	NR	NR	6.8-7.2	Paul and Raut 1987	U
Ctenopharyngodon idella	grass carp	fingerling, 2.7-3.1 g	96-h LC50	3.71	formulation	S	19-24	NR	NR	6.8-7.2	Paul and Raut 1987	U
Ctenopharyngodon idella	grass carp	fingerling, 2.7-3.1 g	24-h LC50	2.80	formulation	S	19-24	NR	NR	6.8-7.2	Paul and Raut 1987	U
Ctenopharyngodon idella	grass carp	fingerling, 2.7-3.1 g	48-h LC50	2.52	formulation	S	19-24	NR	NR	6.8-7.2	Paul and Raut 1987	U
Ctenopharyngodon idella	grass carp	fingerling, 2.7-3.1 g	72-h LC50	1.87	formulation	S	19-24	NR	NR	6.8-7.2	Paul and Raut 1987	U
Ctenopharyngodon idella	grass carp	fingerling, 2.7-3.1 g	96-h LC50	1.71	formulation	S	19-24	NR	NR	6.8-7.2	Paul and Raut 1987	U

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Cymatogaster aggregata	shiner perch	adult	96-h LC50	1.10	technical	FT	18-22	NR	150	6.7-6.9	Dinnel *et al.* 1989	
Cyprinus carpio	common carp	NR	7-d LC0	0.5	formulation	S, N	20-25	7.3	NR	7	Basak and Konar 1977	U
Cyprinus carpio	common carp	NR	7-d LC100	2.5	formulation	S, N	20-25	7.3	NR	7	Basak and Konar 1977	U
Cyprinus carpio	common carp	NR	7-d LC5	0.33	formulation	S, N	20-25	7.3	NR	7	Basak and Konar 1977	U
Cyprinus carpio	common carp	NR	7-d LC50	0.92	formulation	S, N	20-25	7.3	NR	7	Basak and Konar 1977	U
Cyprinus carpio	common carp	NR	7-d LC95	2.5	formulation	S, N	20-25	7.3	NR	7	Basak and Konar 1977	U
Cyprinus carpio	common carp	NR	96-h LC50	0.1	100	NR	NR	NR	NR	NR	PMRA Monograph 2004	1
Cyprinus carpio	common carp	50 mm	96-h LC50	0.1	96	SR	25	NR	100	8	Sunderam *et al*. 1992	2
Cyprinus carpio	common carp	eyed egg	24-h LC50	2,500	technical	S	24	NR	80	7.5	Hashimoto *et al.* 1982	2
Cyprinus carpio	common carp	sac fry	24-h LC50	560	technical	S	24	NR	80	7.5	Hashimoto *et al.* 1982	2
Cyprinus carpio	common carp	floating fry	24-h LC50	410	technical	S	24	NR	80	7.5	Hashimoto *et al.* 1982	2
Cyprinus carpio	common carp	0.007-0.02 g	24-h LC50	11	technical	S	24	NR	80	7.5	Hashimoto *et al.* 1982	2
Cyprinus carpio	common carp	17-19 d	24-h LC50	2	technical	S	24	NR	80	7.5	Hashimoto *et al.* 1982	2
Cyprinus carpio	common carp	0.19-0.28 g	24-h LC50	2	technical	S	24	NR	80	7.5	Hashimoto *et al.* 1982	2
Cyprinus carpio	common carp	0.62-1.37 g	24-h LC50	2	technical	S	24	NR	80	7.5	Hashimoto *et al.* 1982	2
Cyprinus carpio	common carp	1.46-3.6 g	24-h LC50	5	technical	S	24	NR	80	7.5	Hashimoto *et al.* 1982	2

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Danio rerio	zebrafish	embryo	24-h changes in distribution of primordial germ cells	40.7	technical	S	28	NR	NR	NR	Willey and Krone 2001	2
Fundulus heteroclitus	mummichog	adult	96-h LC50	1.15	formulation	SR	18-22	NR	NR	NR	Dinnel *et al.* 1989	U
Gambusia affinis	mosquitofish	40 mm	96-h LC50	2.3	96	S, N	25	NR	45	7.5	Sunderam *et al.* 1992	2
Gambusia affinis	mosquitofish	females 0.68-0.81 g	96-h LC50	3.2	formulation	S	26-30	NR	NR	NR	Joshi and Rege 1980	U
Gambusia affinis	mosquitofish	females 0.68-0.81 g	72-h LC50	3.8	formulation	S	26-30	NR	NR	NR	Joshi and Rege 1980	U
Gambusia affinis	mosquitofish	females 0.68-0.81 g	24-h LC50	6	formulation	S	26-30	NR	NR	NR	Joshi and Rege 1980	U
Gambusia affinis	mosquitofish	females 0.68-0.81 g	48-h LC50	4.8	formulation	S	26-30	NR	NR	NR	Joshi and Rege 1980	U
Gambusia affinis	mosquitofish	females 0.68-0.81 g	24-h LC50	12	formulation	S	26-30	NR	NR	NR	Joshi and Rege 1980	U
Gambusia affinis	mosquitofish	females 0.68-0.81 g	48-h LC50	9.4	formulation	S	26-30	NR	NR	NR	Joshi and Rege 1980	U
Gambusia affinis	mosquitofish	females 0.68-0.81 g	72-h LC50	7	formulation	S	26-30	NR	NR	NR	Joshi and Rege 1980	U
Gambusia affinis	mosquitofish	females 0.68-0.81 g	96-h LC50	8	formulation	S	26-30	NR	NR	NR	Joshi and Rege 1980	U
Gambusia affinis	mosquitofish	females 0.68-0.81 g	96-h LC50	1.3	formulation	S	26-30	NR	NR	NR	Joshi and Rege 1980	U
Gasterosteus aculeatus	threespine stickleback	NR	24-h LC50	< 11	formulation	Field	19.5-22	0.9-9.0	NR	7.2-9.0	Ernst *et al.* 1991	U
Gasterosteus aculeatus	threespine stickleback	NR	24-h LC50	< 3	formulation	Field	17.5-18	7.2-9.8	NR	7.5-8.2	Ernst *et al.* 1991	U
Gasterosteus aculeatus	threespine stickleback	NR	24-h LC50	< 4	formulation	Field	18.0-19.5	5.1-10.5	NR	8.1-8.6	Ernst *et al.* 1991	U
Heteropneustes fossilis	Asian stinging catfish	NR	7-d LC0	1	formulation	S, N	20-25	7.3	NR	7	Basak and Konar 1977	U

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Heteropneustes fossilis	Asian stinging catfish	NR	7-d LC100	2.5	formulation	S, N	20-25	7.3	NR	7	Basak and Konar 1977	U
Heteropneustes fossilis	Asian stinging catfish	NR	7-d LC5	1.1	formulation	S, N	20-25	7.3	NR	7	Basak and Konar 1977	U
Heteropneustes fossilis	Asian stinging catfish	NR	7-d LC50	1.57	formulation	S, N	20-25	7.3	NR	7	Basak and Konar 1977	U
Heteropneustes fossilis	Asian stinging catfish	NR	7-d LC95	2	formulation	S, N	20-25	7.3	NR	7	Basak and Konar 1977	U
Hypophthalmichthys molitrix	silver carp	fingerling 1.15-2.5 g	24-h LC50	4.3	formulation	S	20	NR	80-120	7-7.5	Paul and Raut 1987	U
Hypophthalmichthys molitrix	silver carp	fingerling 1.15-2.5 g	48-h LC50	4.08	formulation	S	20	NR	80-120	7-7.5	Paul and Raut 1987	U
Hypophthalmichthys molitrix	silver carp	fingerling 1.15-2.5 g	72-h LC50	2.6	formulation	S	20	NR	80-120	7-7.5	Paul and Raut 1987	U
Hypophthalmichthys molitrix	silver carp	fingerling 1.15-2.5 g	96-h LC50	2.43	formulation	S	20	NR	80-120	7-7.5	Paul and Raut 1987	U
Hypophthalmichthys molitrix	silver carp	fingerling 1.15-2.5 g	24-h LC50	2.67	formulation	S	20	NR	80-120	7-7.5	Paul and Raut 1987	U
Hypophthalmichthys molitrix	silver carp	fingerling 1.15-2.5 g	48-h LC50	2.61	formulation	S	20	NR	80-120	7-7.5	Paul and Raut 1987	U
Hypophthalmichthys molitrix	silver carp	fingerling 1.15-2.5 g	72-h LC50	2.24	formulation	S	20	NR	80-120	7-7.5	Paul and Raut 1987	U
Hypophthalmichthys molitrix	silver carp	fingerling 1.15-2.5 g	96-h LC50	2.27	formulation	S	20	NR	80-120	7-7.5	Paul and Raut 1987	U
Hypophthalmichthys molitrix	silver carp	fingerling 1.15-2.5 g	24-h LC50	1.33	formulation	S	20	NR	80-120	7-7.5	Paul and Raut 1987	U
Hypophthalmichthys molitrix	silver carp	fingerling 1.15-2.5 g	48-h LC50	1.08	formulation	S	20	NR	80-120	7-7.5	Paul and Raut 1987	U
Hypophthalmichthys molitrix	silver carp	fingerling 1.15-2.5 g	72-h LC50	0.38	formulation	S	20	NR	80-120	7-7.5	Paul and Raut 1987	U
Hypophthalmichthys molitrix	silver carp	fingerling 1.15-2.5 g	96-h LC50	0.26	formulation	S	20	NR	80-120	7-7.5	Paul and Raut 1987	U

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Ictalurus punctatus	channel catfish	1.7 g	24-h LC50	1.8	96	S, N	18	NR	44	7.1	Mayer and Ellersieck 1986	2
Ictalurus punctatus	channel catfish	1.7 g	96-h LC50	1.5	96	S, N	18	NR	44	7.1	Mayer and Ellersieck 1986	2
Lepomis macrochirus	bluegill sunfish	1.0 g	24-h LC50	3.3	96	S, N	18	NR	44	7.1	Mayer and Ellersieck 1986	2
Lepomis macrochirus	bluegill sunfish	1.0 g	96-h LC50	1.2	96	S, N	18	NR	44	7.1	Mayer and Ellersieck 1986	2
Lepomis macrochirus	bluegill sunfish	NR	96-h LC50	1.2	technical	NR	NR	NR	NR	NR	PMRA Monograph 2004	1
Macquaria ambigua	golden perch	40 mm	96-h LC50	0.5	96	R, M	25	NR	45	7.5	Sunderam *et al*. 1992	2
Macquaria ambigua	golden perch	40 mm	96-h LC50	0.3	96	R, M	26	NR	100	8	Sunderam *et al*. 1992	2
Melanotaenia duboulayi	eastern rainbow fish	40 mm	96-h LC50	5	96	S, M	25	NR	45	7.5	Sunderam *et al*. 1992	2
Melanotaenia duboulayi	eastern rainbow fish	40 mm	96-h LC50	2.5	96	R, M	25	NR	45	7.5	Sunderam *et al*. 1992	2
Melanotaenia duboulayi	eastern rainbow fish	40 mm	96-h LC50	2.4	96	R, M	26	NR	100	8	Sunderam *et al*. 1992	2
Menidia beryllina	island silverside	larva 26.6 mg	96-h LC50	1.5	formulation	S	24-26	NR	60-85	6.5-7	Hemmer *et al.* 1992	U
Morone saxatilis	striped bass	6 d posthatch larva	96-h LC50	0.22	technical	FT	15-20	6.0-8.0	NR	6.8-7.2	Mayers and Barron 1991	2
Morone saxatilis	striped bass	13 d posthatch larva	96-h LC50	0.35	technical	FT	15-20	6.0-8.0	NR	6.8-7.2	Mayers and Barron 1991	2
Morone saxatilis	striped bass	45 d posthatch larva	96-h LC50	0.23	technical	FT	15-20	6.0-8.0	NR	6.8-7.2	Mayers and Barron 1991	2
Morone saxatilis	striped bass	39 d posthatch larva	96-h LC50	0.33	technical	FT	15-20	6.0-8.0	NR	6.8-7.2	Mayers and Barron 1991	2
Morone saxatilis	striped bass	13 d posthatch larva	96-h LC50	0.29	technical	FT	15-20	6.0-8.0	NR	6.8-7.2	Mayers and Barron 1991	2
Morone saxatilis	striped bass	13 d posthatch larva	96-h LC50	0.23	technical	FT	15-20	6.0-8.0	NR	6.8-7.2	Mayers and Barron 1991	2
Morone saxatilis	striped bass	45 d posthatch larva	96-h LC50	0.43	technical	FT	15-20	6.0-8.0	NR	6.8-7.2	Mayers and Barron 1991	2

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Mystus vittatus	striped catfish	4 g	96-h LC50	1.9	formulation	FT	19-23	6.0-9.0	80	6.8-7.4	Rao and Murty 1982	U
Mystus vittatus	striped catfish	6.0-10 g	24-h LC50	0.32	formulation	S	24-28	NR	NR	NR	Reddy and Gomathy 1977	U
Mystus vittatus	striped catfish	6.0-10 g	48-h LC50	0.26	formulation	S	24-28	NR	NR	NR	Reddy and Gomathy 1977	U
Mystus vittatus	striped catfish	6.0-10 g	96-h LC50	0.24	formulation	S	24-28	NR	NR	NR	Reddy and Gomathy 1977	U
Mystus vittatus	striped catfish	6.0-10 g	96-h LC50	2.2	formulation	FT	24-28	NR	NR	NR	Reddy and Gomathy 1977	U
Nematolosa erebi	bony bream	50 mm	96-h LC50	0.2	96	R, M	26	NR	100	8	Sunderam et al. 1992	2
Oncorhynchus mykiss	rainbow trout	1.0-1.8 g	120-h LC50 (reported as TLm)	0.7	Formulation	S, N	1.5	NR	45	NR	Schoettger 1970	U
Oncorhynchus mykiss	rainbow trout	1.0-1.8 g	120-h LC50 (reported as TLm)	0.3	Formulation	S, N	10	NR	45	NR	Schoettger 1970	U
Oncorhynchus mykiss	rainbow trout	1.3 g	24-h LC50	13	96	S, N	2	NR	44	7.1	Mayer and Ellersieck 1986	2
Oncorhynchus mykiss	rainbow trout	1.3 g	24-h LC50	6.2	96	S, N	7	NR	44	7.1	Mayer and Ellersieck 1986	2
Oncorhynchus mykiss	rainbow trout	1.3 g	24-h LC50	4.3	96	S, N	13	NR	44	7.1	Mayer and Ellersieck 1986	2
Oncorhynchus mykiss	rainbow trout	1.3 g	24-h LC50	2.3	96	S, N	18	NR	44	7.1	Mayer and Ellersieck 1986	2
Oncorhynchus mykiss	rainbow trout	0.3-1.5 g	24-h LC50	0.9	99.5	S, N	15 ± 1	NR	NR	NR	Wan *et al.* 2005	2
Oncorhynchus mykiss	rainbow trout	0.3-1.5 g	24-h LC50	6.9	99.3	S, N	15 ± 1	NR	NR	NR	Wan *et al.* 2005	2
Oncorhynchus mykiss	rainbow trout	0.3-1.5 g	24-h LC50	1.5	99	S, N	15 ± 1	NR	NR	NR	Wan *et al.* 2005	2
Oncorhynchus mykiss	rainbow trout	0.3-1.5 g	24-h LC50	2.5	98	S, N	15 ± 1	NR	NR	NR	Wan *et al.* 2005	2

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Oncorhynchus mykiss	rainbow trout	1.0-1.8 g	24-h LC50 (reported as TLm)	5.9	Formulation	S, N	1.5	NR	45	NR	Schoettger 1970	U
Oncorhynchus mykiss	rainbow trout	1.0-1.8 g	24-h LC50 (reported as TLm)	2.1	Formulation	S, N	10	NR	45	NR	Schoettger 1970	U
Oncorhynchus mykiss	rainbow trout	0.3-1.5 g	48-h LC50	0.6	99.5	S, N	15 ± 1	NR	NR	NR	Wan *et al.* 2005	2
Oncorhynchus mykiss	rainbow trout	0.3-1.5 g	48-h LC50	4.9	99.3	S, N	15 ± 1	NR	NR	NR	Wan *et al.* 2005	2
Oncorhynchus mykiss	rainbow trout	0.3-1.5 g	48-h LC50	1	99	S, N	15 ± 1	NR	NR	NR	Wan *et al.* 2005	2
Oncorhynchus mykiss	rainbow trout	0.3-1.5 g	48-h LC50	1.5	98	S, N	15 ± 1	NR	NR	NR	Wan *et al.* 2005	2
Oncorhynchus mykiss	rainbow trout	1.0-1.8 g	48-h LC50 (reported as TLm)	2.1	Formulation	S, N	1.5	NR	45	NR	Schoettger 1970	U
Oncorhynchus mykiss	rainbow trout	1.0-1.8 g	48-h LC50 (reported as TLm)	1.1	Formulation	S, N	10	NR	45	NR	Schoettger 1970	U
Oncorhynchus mykiss	rainbow trout	0.3-1.5 g	72-h LC50	0.6	99.5	S, N	15 ± 1	NR	NR	NR	Wan *et al.* 2005	2
Oncorhynchus mykiss	rainbow trout	0.3-1.5 g	72-h LC50	3.7	99.3	S, N	15 ± 1	NR	NR	NR	Wan *et al.* 2005	2
Oncorhynchus mykiss	rainbow trout	0.3-1.5 g	72-h LC50	0.8	99	S, N	15 ± 1	NR	NR	NR	Wan *et al.* 2005	2
Oncorhynchus mykiss	rainbow trout	0.3-1.5 g	72-h LC50	1.5	98	S, N	15 ± 1	NR	NR	NR	Wan *et al.* 2005	2
Oncorhynchus mykiss	rainbow trout	1.0-1.8 g	72-h LC50 (reported as TLm)	1.4	Formulation	S, N	1.5	NR	45	NR	Schoettger 1970	U
Oncorhynchus mykiss	rainbow trout	1.0-1.8 g	72-h LC50 (reported as TLm)	0.4	Formulation	S, N	10	NR	45	NR	Schoettger 1970	U
Oncorhynchus mykiss	rainbow trout	3-10 g	96-h LC50	0.69	Technical	F, M	NR	NR	48	7.74	Lemke 1981	2
Oncorhynchus mykiss	rainbow trout	NR	96-h LC50	0.17	Technical	F, M	NR	9.3	255	7.8	Lemke 1981	2

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Oncorhynchus mykiss	rainbow trout	1-3 g	96-h LC50	0.3	Technical	F, M	NR	NR	54	6.8-7.1	Lemke 1981	2
Oncorhynchus mykiss	rainbow trout	1.0-1.5 g	96-h LC50	0.26	Technical	F, M	NR	8.7	46.1	7.6	Lemke 1981	2
Oncorhynchus mykiss	rainbow trout	1-3 g	96-h LC50	0.32	Technical	F, M	NR	NR	NR	NR	Lemke 1981	2
Oncorhynchus mykiss	rainbow trout	0.25-1.0 g	96-h LC50	0.26	Technical	F, M	NR	NR	75	6.8-7.1	Lemke 1981	2
Oncorhynchus mykiss	rainbow trout	3-10 g	96-h LC50	0.75	Technical	F, M	NR	NR	48	7.74	Lemke 1981	2
Oncorhynchus mykiss	rainbow trout	NR	96-h LC50	0.29	Technical	F, M	NR	9.3	255	7.8	Lemke 1981	2
Oncorhynchus mykiss	rainbow trout	1-3 g	96-h LC50	0.27	Technical	F, M	NR	NR	54	6.8-7.1	Lemke 1981	2
Oncorhynchus mykiss	rainbow trout	1.0-1.5 g	96-h LC50	0.41	Technical	F, M	NR	8.7	46.1	7.6	Lemke 1981	2
Oncorhynchus mykiss	rainbow trout	1-3 g	96-h LC50	0.42	Technical	F, M	NR	NR	NR	NR	Lemke 1981	2
Oncorhynchus mykiss	rainbow trout	0.25-1.0 g	96-h LC50	0.24	Technical	F, M	NR	NR	75	6.7-8.8	Lemke 1981	2
Oncorhynchus mykiss	rainbow trout	1-3 g	96-h LC50	1.21	Technical	S, N	NR	NR	48	7.74	Lemke 1981	2
Oncorhynchus mykiss	rainbow trout	NR	96-h LC50	0.49	Technical	S, M	NR	9.3	255	7.8	Lemke 1981	2
Oncorhynchus mykiss	rainbow trout	1-3 g	96-h LC50	1.34	Technical	S, M	NR	NR	54	6.8-7.1	Lemke 1981	2
Oncorhynchus mykiss	rainbow trout	2.5-3.5 g	96-h LC50	1.3	Technical	S, M	NR	8.7	46.1	7.6	Lemke 1981	2
Oncorhynchus mykiss	rainbow trout	0.3-6.5 g	96-h LC50	1.69	Technical	S, M	NR	NR	NR	NR	Lemke 1981	2
Oncorhynchus mykiss	rainbow trout	0.25-1.0 g	96-h LC50	0.69	Technical	S, M	NR	NR	75	6.7-8.8	Lemke 1981	2

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Oncorhynchus mykiss	rainbow trout	1-3 g	96-h LC50	0.89	Technical	S, M	NR	NR	48	7.74	Lemke 1981	2
Oncorhynchus mykiss	rainbow trout	NR	96-h LC50	0.8	Technical	S, M	NR	9.3	255	7.8	Lemke 1981	2
Oncorhynchus mykiss	rainbow trout	1-3 g	96-h LC50	2.43	Technical	S, M	NR	NR	54	6.8-7.1	Lemke 1981	2
Oncorhynchus mykiss	rainbow trout	2.5-3.5 g	96-h LC50	0.63	Technical	S, M	NR	8.7	46.1	7.6	Lemke 1981	2
Oncorhynchus mykiss	rainbow trout	0.3-6.5 g	96-h LC50	1.63	Technical	S, M	NR	NR	NR	NR	Lemke 1981	2
Oncorhynchus mykiss	rainbow trout	0.25-1.0 g	96-h LC50	0.79	Technical	S, M	NR	NR	75	6.7-8.8	Lemke 1981	2
Oncorhynchus mykiss	rainbow trout	1.3 g	96-h LC50	2.9	96	S, N	2	NR	44	7.1	Mayer and Ellersieck 1986	2
Oncorhynchus mykiss	rainbow trout	1.3 g	96-h LC50	1.7	96	S, N	7	NR	44	7.1	Mayer and Ellersieck 1986	2
Oncorhynchus mykiss	rainbow trout	1.3 g	96-h LC50	1.4	96	S, N	13	NR	44	7.1	Mayer and Ellersieck 1986	2
Oncorhynchus mykiss	rainbow trout	1.3 g	96-h LC50	1.1	96	S, N	18	NR	44	7.1	Mayer and Ellersieck 1986	2
Oncorhynchus mykiss	rainbow trout	NR	96-h LC50	0.37	100	NR	NR	NR	NR	NR	PMRA Monograph 2004	1
Oncorhynchus mykiss	rainbow trout	55 mm	96-h LC50	1.6	96	S, M	4	NR	45	7.5	Sunderam *et al.* 1992	2
Oncorhynchus mykiss	rainbow trout	55 mm	96-h LC50	0.7	96	S, M	12	NR	45	7.5	Sunderam *et al.* 1992	2
Oncorhynchus mykiss	rainbow trout	1.3 g	96-h LC50	1.7	Technical	S, M	12	NR	34	NR	Nebeker *et al.* 1983	1
Oncorhynchus mykiss	rainbow trout	1.3 g	96-h LC50	1.6	Technical	S, M	12	NR	30	NR	Nebeker *et al.* 1983	1
Oncorhynchus mykiss	rainbow trout	0.6 g	96-h LC50	0.3	Technical	F, M	12	NR	27	NR	Nebeker *et al.* 1983	1

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Oncorhynchus mykiss	rainbow trout	0.8 g	96-h LC50	0.4	Technical	F, M	13	NR	40	NR	Nebeker *et al.* 1983	1
Oncorhynchus mykiss	rainbow trout	0.3-1.5 g	96-h LC50	0.5	99.5	S, N	15 ± 1	NR	NR	NR	Wan *et al*. 2005	2
Oncorhynchus mykiss	rainbow trout	0.3-1.5 g	96-h LC50	3.3	99.3	S, N	15 ± 1	NR	NR	NR	Wan *et al*. 2005	2
Oncorhynchus mykiss	rainbow trout	0.3-1.5 g	96-h LC50	0.7	99	S, N	15 ± 1	NR	NR	NR	Wan *et al*. 2005	2
Oncorhynchus mykiss	rainbow trout	0.3-1.5 g	96-h LC50	1.4	98	S, N	15 ± 1	NR	NR	NR	Wan *et al*. 2005	2
Oncorhynchus mykiss	rainbow trout	1.0-1.8 g	96-h LC50 (reported as TLm)	0.8	Formulation	S, N	1.5	NR	45	NR	Schoettger 1970	U
Oncorhynchus mykiss	rainbow trout	1.0-1.8 g	96-h LC50 (reported as TLm)	0.3	Formulation	S, N	10	NR	45	NR	Schoettger 1970	U
Oncorhynchus mykiss	rainbow trout	0.6-1.5g	24-h LC50 (reported as TL50)	13	Formulation	S, N	1.6	NR	NR	NR	Macek *et al.* 1969	U
Oncorhynchus mykiss	rainbow trout	0.6-1.5g	24-h LC50 (reported as TL50)	6.1	Formulation	S, N	7.2	NR	NR	NR	Macek *et al.* 1969	U
Oncorhynchus mykiss	rainbow trout	0.6-1.5g	24-h LC50 (reported as TL50)	3.2	Formulation	S, N	12.7	NR	NR	NR	Macek *et al.* 1969	U
Oncorhynchus mykiss	rainbow trout	0.6-1.5g	96-h LC50 (reported as TL50)	13	Formulation	S, N	1.6	NR	NR	NR	Macek *et al.* 1969	U
Oncorhynchus mykiss	rainbow trout	0.6-1.5g	96-h LC50 (reported as TL50)	6.1	Formulation	S, N	7.2	NR	NR	NR	Macek *et al.* 1969	U
Oncorhynchus mykiss	rainbow trout	0.6-1.5g	96-h LC50 (reported as TL50)	3.2	Formulation	S, N	12.7	NR	NR	NR	Macek *et al.* 1969	U
Oncorhynchus mykiss	rainbow trout	NR	21-d NOEC growth	0.05	Technical	NR	NR	NR	NR	NR	Knacker *et al.* 1991	1
Oryzias latipes	medaka, high-eyes	juvenille, 21-32-d	24-h startle response and escape from predation	0.5	Technical	S	28	NR	NR	NR	Carlson *et al.* 1998	U
Pimephales promelas	fathead minnow	0,7g	24-h LC50	2.4	96	S, N	18	NR	44	7.1	Mayer and Ellersieck 1986	2

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Pimephales promelas	fathead minnow	53-d old	6-d LC50	0.86	99	F, M	NR	7,8 ± 1,0	35 ± 3,4	6,6-7,2	Macek *et al*. 1976	1
Pimephales promelas	fathead minnow	53-d old	6-d LC50	0.83	NR	F	25 ± 1	NR	NR	NR	U.S. Department of Commerce, PB-262-912	U
Pimephales promelas	fathead minnow	0,5-1,5 g	96-h LC50	1.2	Technical	F, M	NR	NR	48	7.74	Lemke 1981	2
Pimephales promelas	fathead minnow	NR	96-h LC50	0.29	Technical	F, M	NR	9.3	255	7.8	Lemke 1981	2
Pimephales promelas	fathead minnow	0,5-0,7 g	96-h LC50	0.76	Technical	F, M	NR	NR	54	6,8-7,1	Lemke 1981	2
Pimephales promelas	fathead minnow	0,05-0,2 g	96-h LC50	0.81	Technical	F, M	NR	8.7	46.1	7.6	Lemke 1981	2
Pimephales promelas	fathead minnow	0,5-0,9 g	96-h LC50	1.67	Technical	F, M	NR	NR	NR	NR	Lemke 1981	2
Pimephales promelas	fathead minnow	0,5-1 g	96-h LC50	0.75	Technical	F, M	NR	NR	75	6,7-8,8	Lemke 1981	2
Pimephales promelas	fathead minnow	0,5-1,5 g	96-h LC50	1.91	Technical	F, M	NR	NR	48	7.74	Lemke 1981	2
Pimephales promelas	fathead minnow	NR	96-h LC50	0.45	Technical	F, M	NR	9.3	255	7.8	Lemke 1981	2
Pimephales promelas	fathead minnow	0,5-0,7 g	96-h LC50	0.73	Technical	F, M	NR	NR	54	6,8-7,1	Lemke 1981	2
Pimephales promelas	fathead minnow	0,05-0,2 g	96-h LC50	0.8	Technical	F, M	NR	8.7	46.1	7.6	Lemke 1981	2
Pimephales promelas	fathead minnow	0,5-0,9 g	96-h LC50	1.57	Technical	F, M	NR	NR	NR	NR	Lemke 1981	2
Pimephales promelas	fathead minnow	0,5-1 g	96-h LC50	1	Technical	F, M	NR	NR	75	6,7-8,8	Lemke 1981	2
Pimephales promelas	fathead minnow	0.5-0.7 g	96-h LC50	2.1	Technical	S, M	NR	NR	48	7.74	Lemke 1981	2
Pimephales promelas	fathead minnow	NR	96-h LC50	2.1	Technical	S, M	NR	9.3	255	7.8	Lemke 1981	2

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Pimephales promelas	fathead minnow	0.5-0.7 g	96-h LC50	1.7	Technical	S, M	NR	NR	54	6,8-7,1	Lemke 1981	2
Pimephales promelas	fathead minnow	0.2-0.5 g	96-h LC50	1.9	Technical	S, M	NR	8.7	46.1	7.6	Lemke 1981	2
Pimephales promelas	fathead minnow	0.5-0.9 g	96-h LC50	1.35	Technical	S, M	NR	NR	NR	NR	Lemke 1981	2
Pimephales promelas	fathead minnow	0.5-1 g	96-h LC50	3.2	Technical	S, M	NR	NR	75	6,7-8,8	Lemke 1981	2
Pimephales promelas	fathead minnow	0.5-0.7 g	96-h LC50	3.45	Technical	S, M	NR	NR	48	7.74	Lemke 1981	2
Pimephales promelas	fathead minnow	NR	96-h LC50	3.2	Technical	S, M	NR	9.3	255	7.8	Lemke 1981	2
Pimephales promelas	fathead minnow	0.5-0.7 g	96-h LC50	1.48	Technical	S, M	NR	NR	54	6,8-7,1	Lemke 1981	2
Pimephales promelas	fathead minnow	0.2-0.5 g	96-h LC50	0.97	Technical	S, M	NR	8.7	46.1	7.6	Lemke 1981	2
Pimephales promelas	fathead minnow	0.5-0.9 g	96-h LC50	1.2	Technical	S, M	NR	NR	NR	NR	Lemke 1981	2
Pimephales promelas	fathead minnow	0.5-1 g	96-h LC50	2.5	Technical	S, M	NR	NR	75	6,7-8,8	Lemke 1981	2
Pimephales promelas	fathead minnow	0,7g	96-h LC50	1.5	96	S, N	18	NR	44	7.1	Mayer and Ellersieck 1986	2
Pimephales promelas	fathead minnow	0.1 g	96-h LC50	1.3	technical	S, M	20	NR	41	NR	Nebeker *et al.* 1983	1
Pimephales promelas	fathead minnow	0.1 g	96-h LC50	0.8	technical	S, M	20	NR	41	NR	Nebeker *et al.* 1983	1
Pimephales promelas	fathead minnow	0.1 g	96-h LC50	1.3	technical	S, M	20	NR	36	NR	Nebeker *et al.* 1983	1
Pimephales promelas	fathead minnow	0.2 g	96-h LC50	1.7	technical	F, M	21	NR	33	NR	Nebeker *et al.* 1983	1
Pimephales promelas	fathead minnow	0.1 g	96-h LC50	1	technical	F, M	22	NR	39	NR	Nebeker *et al.* 1983	1

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Pimephales promelas	fathead minnow	NR	life-cycle LOEC (reduced survival and mean total length)	0.4	technical	NR	NR	NR	NR	NR	PMRA Monograph 2004	1
Pimephales promelas	fathead minnow	NR	life-cycle NOEC (reduced survival and mean total length)	0.2	technical	NR	NR	NR	NR	NR	PMRA Monograph 2004	1
Tandanus tandanus	catfish	adult	24-h cell changes	100	formulation	S	18-20	NR	NR	NR	Nowak 1996	U
Tilapia mossambic	tilapia	NR	7-d LC0	0.64	formulation	S, N	20-25	7.3	NR	7	Basak and Konar 1977	U
Tilapia mossambic	tilapia	NR	7-d LC100	3.2	formulation	S, N	20-25	7.3	NR	7	Basak and Konar 1977	U
Tilapia mossambic	tilapia	NR	7-d LC5	0.44	formulation	S, N	20-25	7.3	NR	7	Basak and Konar 1977	U
Tilapia mossambic	tilapia	NR	7-d LC50	1.4	formulation	S, N	20-25	7.3	NR	7	Basak and Konar 1977	U
Tilapia mossambic	tilapia	NR	7-d LC95	4.6	formulation	S, N	20-25	7.3	NR	7	Basak and Konar 1977	U
Amphibians												
Bufo americanus	american toad	tadpole, newly hatched (<1 cm)	96-h avoidance	43	formulation	S	15	NR	NR	7.8	Berrill *et al.* 1998	U
Bufo americanus	american toad	tadpole (2 weeks)	96-h avoidance	41	formulation	S	15	NR	NR	7.8	Berrill *et al.* 1998	U
Bufo americanus	american toad	NR	96-h abnormal development	0.47	formulation	SR	20	NR	NR	NR	Harris *et al.* 2000b	U
Bufo americanus	american toad	NR	abnormal development	47	formulation	SR	20	NR	NR	NR	Harris *et al.* 2000b	U
Bufo americanus	american toad	NR	abnormal development	4.7	formulation	SR	20	NR	NR	NR	Harris *et al.* 2000b	U
Bufo americanus	american toad	NR	48 h abnormal development	47	formulation	SR	20	NR	NR	NR	Harris *et al.* 2000b	U

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Bufo americanus	american toad	tadpole, prematamorph	96-h abnormal development	307	formulation	S	15	NR	NR	7.8	Berrill *et al.* 1998	U
Bufo americanus	american toad	NR	Development (metamorphosis)	0.47	formulation	S	20	NR	NR	NR	Harris *et al.* 2000b	U
Bufo americanus	american toad	NR	48-h development (metamorphosis)	47	formulation	S	20	NR	NR	NR	Harris *et al.* 2000b	U
Bufo americanus	american toad	tadpole (2 weeks)	96-h feeding behavior	41	formulation	S	15	NR	NR	7.8	Berrill *et al.* 1998	U
Bufo americanus	american toad	newly hatched	96-h mortality	43	formulation	S	20	NR	NR	NR	Berrill *et al.* 1998	U
Bufo americanus	american toad	tadpole (2 weeks)	96-h mortality	41	formulation	S	20	NR	NR	7.8	Berrill *et al.* 1998	U
Bufo americanus	american toad	NR	96-h mortality	NR	formulation	S	20	NR	NR	NR	Harris *et al.* 2000b	U
Bufo americanus	american toad	NR	mortality	NR	formulation	S	20	NR	NR	NR	Harris *et al.* 2000b	U
Bufo americanus	american toad	NR	48-h mortality	47	formulation	S	20	NR	NR	NR	Harris *et al.* 2000b	U
Notophthalmus viridescens	salamander	female	96-h activity no difference from control	5	technical	NR	NR	NR	NR	NR	Park *et al*. 2001	U
Notophthalmus viridescens	salamander	female	96-h surfacing no difference from control	5	technical	NR	NR	NR	NR	NR	Park *et al*. 2001	U
Notophthalmus viridescens	salamander	female	4-d feeding behavior no difference from control	5	technical	NR	NR	NR	NR	NR	Park *et al*. 2001	U
Notophthalmus viridescens	salamander	female	4-d hormone (17-beta-estradiol)	5	formulation	S	NR	NR	NR	NR	Park *et al*. 2001	U
Notophthalmus viridescens	salamander	female	4-d morphology (area)	5	technical	S	NR	NR	NR	NR	Park *et al*. 2001	U
Notophthalmus viridescens	salamander	female	4-d morphology (area)	10	technical	S	NR	NR	NR	NR	Park *et al*. 2001	U

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Notophthalmus viridescens	salamander	female	96-h reproductive behaviour changes no difference from controls	5	technical	NR	NR	NR	NR	NR	Park *et al*. 2001	U
Notophthalmus viridescens	salamander	female	96-h reproductive success - LOEC	5	technical	NR	NR	NR	NR	NR	Park *et al*. 2001	U
Rana clamitans	green frog	tadpole, newly hatched (<1 cm)	96-h avoidance	48	formulation	S	20	NR	NR	7.8	Berrill *et al.* 1998	U
Rana clamitans	green frog	tadpole (2 weeks)	96-h avoidance	53	formulation	S	20	NR	NR	7.8	Berrill *et al.* 1998	U
Rana clamitans	green frog	stage 8 embryo to stage 25 tadpoles	16-d EC50 defomation	2430	formulation	S	19	NR	NR	NR	Harris *et al.* 1998	U
Rana clamitans	green frog	tadpole, newly hatched (<1 cm)	96-h feeding behavior	48	formulation	S	20	NR	NR	7.8	Berrill *et al.* 1998	U
Rana clamitans	green frog	tadpole (2 weeks)	96-h feeding behavior	53	formulation	S	20	NR	NR	7.8	Berrill *et al.* 1998	U
Rana clamitans	green frog	tadpole, newly hatched (<1 cm)	96-h growth	132	formulation	S	20	NR	NR	7.8	Berrill *et al.* 1998	U
Rana clamitans	green frog	tadpole (2 weeks)	96-h growth	130	formulation	S	20	NR	NR	7.8	Berrill *et al.* 1998	U
Rana clamitans	green frog	stage 8 embryo to stage 25 tadpoles	13-d growth	0.47	formulation	SR	15	NR	NR	NR	Harris *et al.* 1998	U
Rana clamitans	green frog	stage 8 embryo to stage 25 tadpoles	16-d growth	0.47	formulation	SR	15	NR	NR	NR	Harris *et al.* 1998	U
Rana clamitans	green frog	stage 8 embryo to stage 25 tadpoles	13-D hatch mortality	0.47	formulation	S	19	NR	NR	NR	Harris *et al.* 1998	U
Rana clamitans	green frog	stage 8 embryo to stage 25 tadpoles	16-D hatch mortality	0.47	formulation	S	19	NR	NR	NR	Harris *et al.* 1998	U
Rana clamitans	green frog	stage 8 embryo to stage 25 tadpoles	96-h LC50	11,750	formulation	SR	15	NR	NR	NR	Harris *et al.* 1998	U

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Rana clamitans	green frog	stage 8 embryo to stage 25 tadpoles	13-dLC50	15	formulation	SR	15	NR	NR	NR	Harris *et al.* 1998	U
Rana clamitans	green frog	stage 8 embryo to stage 25 tadpoles	96-h LC50	4,700	formulation	SR	15	NR	NR	NR	Harris *et al.* 1998	U
Rana clamitans	green frog	stage 8 embryo to stage 25 tadpoles	16-d LC50	15	formulation	SR	15	NR	NR	NR	Harris *et al.* 1998	U
Rana clamitans	green frog	tadpole newly hatched < 1.0 cm	96-h mortality	48	formulation	S	20	NR	NR	7.8	Berrill *et al.* 1998	U
Rana clamitans	green frog	tadpole (2 weeks)	96-h mortality	53	formulation	S	20	NR	NR	7.8	Berrill *et al.* 1998	U
Rana pipiens	leopard frog	NR	96-h abnormal development	0.47	formulation	SR	20	NR	NR	NR	Harris *et al.* 2000b	U
Rana pipiens	leopard frog	NR	48-h abnormal development	4,700	formulation	SR	20	NR	NR	NR	Harris *et al.* 2000b	U
Rana pipiens	leopard frog	NR	abnormal development	0.47	formulation	SR	20	NR	NR	NR	Harris *et al.* 2000b	U
Rana pipiens	leopard frog	NR	48-h development (metamorphosis)	4,700	formulation	S	20	NR	NR	NR	Harris *et al.* 2000b	U
Rana pipiens	leopard frog	NR	48-h development (metamorphosis)	0.47	formulation	S	20	NR	NR	NR	Harris *et al.* 2000b	U
Rana pipiens	leopard frog	NR	biomass (stage 46)	0.47	formulation	S	20	NR	NR	NR	Harris *et al.* 2000b	U
Rana pipiens	leopard frog	NR	48-h biomass	4,700	formulation	S	20	NR	NR	NR	Harris *et al.* 2000b	U
Rana pipiens	leopard frog	NR	growth (stage 46)	0.47	formulation	S	20	NR	NR	NR	Harris *et al.* 2000b	2
Rana pipiens	leopard frog	NR	48-h growth	4,700	formulation	S	20	NR	NR	NR	Harris *et al.* 2000b	2
Rana pipiens	leopard frog	NR	48-h morphlology, imposex	4,700	formulation	S	20	NR	NR	NR	Harris *et al.* 2000b	2

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Rana pipiens	leopard frog	NR	46-h morphlology, imposex	0.47	formulation	S	20	NR	NR	NR	Harris *et al.* 2000b	U
Rana pipiens	leopard frog	NR	48-h mortality	4,700	formulation	S	20	NR	NR	NR	Harris *et al.* 2000b	U
Rana pipiens	leopard frog	NR	96-h mortality	0.47	formulation	S	20	NR	NR	NR	Harris *et al.* 2000b	U
Rana pipiens	leopard frog	NR	mortality	0.47	formulation	S	20	NR	NR	NR	Harris *et al.* 2000b	U
Rana pipiens	leopard frog	NR	48-h population (sex ratio)	4,700	formulation	S	20	NR	NR	NR	Harris *et al.* 2000b	U
Rana sylvatica	wood frog	tadpole, newly hatched (<1 cm)	96-h avoidance	32	formulation	S	15	NR	NR	7.8	Berrill *et al.* 1998	U
Rana sylvatica	wood frog	embryo, stage 10	96-h avoidance	50	formulation	S	15	NR	NR	7.8	Berrill *et al.* 1998	U
Rana sylvatica	wood frog	tadpole (2 weeks)	96-h avoidance	68	formulation	S	15	NR	NR	7.8	Berrill *et al.* 1998	U
Rana sylvatica	wood frog	tadpole (2 weeks)	96-h feeding behavior	68	formulation	S	15	NR	NR	7.8	Berrill *et al.* 1998	U
Rana sylvatica	wood frog	embryos, stage 10	96-h growth	50	formulation	S	15	NR	NR	7.8	Berrill *et al.* 1998	U
Rana sylvatica	wood frog	tadpole (2 weeks)	96-h growth	68	formulation	S	15	NR	NR	NR	Berrill *et al.* 1998	U
Rana sylvatica	wood frog	tadpole newly hatched < 1.0 cm	96-h mortality	32	formulation	S	15	NR	NR	7.8	Berrill *et al.* 1998	U
Rana sylvatica	wood frog	tadpole (2 weeks)	96-h mortality	68	formulation	S	15	NR	NR	7.8	Berrill *et al.* 1998	U
Rana tigrina	tiger frog, indian bullfrog	tadpole	24-h LC50	2.1	technical	S	18-22	NR	118-122	6.9-7.2	Gopal *et al.* 1981	U
Rana tigrina	tiger frog, indian bullfrog	tadpole	48-h LC50	2	technical	S	18-22	NR	118-122	6.9-7.2	Gopal *et al.* 1981	U
Rana tigrina	tiger frog, indian bullfrog	tadpole	96-h LC50	1.8	technical	S	18-22	NR	118-122	6.9-7.2	Gopal *et al.* 1981	2

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank

Notes:

F - Flowthrough; S - Static; R - Renewal; M - Measured; N - Nominal.

1 - Primary; 2 - Secondary; U - Unacceptable.

MAD = Minimal Active Dose

NR = Not reported.

ELS = Early life stage.

APPENDIX B

TOXICITY VALUES FOR MARINE AQUATIC SPECIES EXPOSED TO ENDOSULFAN

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Invertebrates												
Acartia tonsa	copepod	NR	48-h LC50	0.12	technical	S	NR	NR	NR	NR	Schimel, 1980	2
Acartia tonsa	copepod	NR	48-h LC50	0.05	technical	S	NR	NR	NR	NR	Schimel, 1980	2
Acartia tonsa	copepod	NR	48-h LC50	0.28	technical	S	NR	NR	NR	NR	Schimel, 1980	2
Acartia tonsa	copepod	NR	48-h LC50	0.37	technical	S	NR	NR	NR	NR	Schimel, 1980	2
Acartia tonsa	copepod	NR	48-h LC50	0.45	technical	S	NR	NR	NR	NR	Schimel, 1980	2
Acartia tonsa	copepod	NR	48-h LC50	0.032	technical	S	NR	NR	NR	NR	Schimel, 1980	2
Callinectes sapidus	blue crab	NR	48-h LC50	35	technical	S	NR	NR	NR	NR	Butler, 1963	U
Crassostrea virginica	eastern oyster	NR	96-h LC50	0.45	technical	NR	NR	NR	NR	NR	PMRA Monograph 2004	1
Crassostrea viginica	eastern oyster	NR	48-h LC50	65	technical	FT	28	NR	NR	NR	Butler, 1963	U
Crassostrea viginica	eastern oyster	NR	48-h LC50	380	technical	FT	10	NR	NR	NR	Butler, 1964	2
Farfantepenaeus aztecus	brown shrimp	NR	48-h LC50	35	technical	S	NR	NR	NR	NR	Butler, 1963	U
Farfantepenaeus aztecus	brown shrimp	NR	48-h LC50	35	technical	S	NR	NR	NR	NR	Portman and Wilson, 1971	2
Gammarus palustris	gammarid amphipod	> 3 mm and < 14mm	48-h LC50	5.63	technical	S	20	NR	NR	NR	Leight and Dolah, 1999	1
Gammarus palustris	gammarid amphipod	> 3 mm and < 14mm	72-h LC50	1.53	technical	S	20	NR	NR	NR	Leight and Dolah, 1999	1
Gammarus palustris	gammarid amphipod	> 3 mm and < 14mm	96-h LC50	0.43	technical	S	20	NR	NR	NR	Leight and Dolah, 1999	1
Gammarus palustris	gammarid amphipod	> 3 mm and < 14mm	48-h LC50	2.29	technical	SR	20	NR	NR	NR	Leight and Dolah, 1999	1

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Gammarus palustris	gammarid amphipod	> 3 mm and < 14mm	72-h LC50	0.99	technical	SR	20	NR	NR	NR	Leight and Dolah, 1999	1
Gammarus palustris	gammarid amphipod	> 3 mm and < 14mm	96-h LC50	0.54	technical	SR	20	NR	NR	NR	Leight and Dolah, 1999	1
Gammarus palustris	gammarid amphipod	> 3 mm and < 14mm	48-h LC15	0.58	technical	S	20	NR	NR	NR	Leight and Dolah, 1999	1
Gammarus palustris	gammarid amphipod	> 3 mm and < 14mm	72-h LC15	0.17	technical	S	20	NR	NR	NR	Leight and Dolah, 1999	1
Gammarus palustris	gammarid amphipod	> 3 mm and < 14mm	96-h LC15	0.10	technical	S	20	NR	NR	NR	Leight and Dolah, 1999	1
Gammarus palustris	gammarid amphipod	> 3 mm and < 14mm	48-h LC15	0.33	technical	SR	20	NR	NR	NR	Leight and Dolah, 1999	1
Gammarus palustris	gammarid amphipod	> 3 mm and < 14mm	72-h LC15	0.14	technical	SR	20	NR	NR	NR	Leight and Dolah, 1999	1
Gammarus palustris	gammarid amphipod	> 3 mm and < 14mm	96-h LC15	0.09	technical	SR	20	NR	NR	NR	Leight and Dolah, 1999	1
Mysidopsis bahia	mysid shrimp	NR	48-h LC50	0.46	technical	S	NR	NR	NR	NR	Schimel, 1980	2
Mysidopsis bahia	mysid shrimp	NR	48-h LC50	0.24	technical	S	NR	NR	NR	NR	Schimel, 1980	2
Mysidopsis bahia	mysid shrimp	NR	48-h LC50	1.47	technical	S	NR	NR	NR	NR	Schimel, 1980	2
Mysidopsis bahia	mysid shrimp	NR	48-h LC50	1.12	technical	S	NR	NR	NR	NR	Schimel, 1980	2
Mysidopsis bahia	mysid shrimp	NR	48-h LC50	0.73	technical	S	NR	NR	NR	NR	Schimel, 1980	2
Mysidopsis bahia	mysid shrimp	NR	48-h LC50	0.38	technical	FT	NR	NR	NR	NR	Schimel, 1980	1
Mysidopsis bahia	mysid shrimp	NR	48-h LC50	0.94	technical	FT	NR	NR	NR	NR	Schimel, 1980	1
Mysidopsis bahia	mysid shrimp	NR	48-h LC50	1.16	technical	FT	NR	NR	NR	NR	Schimel, 1980	1

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Mysidopsis bahia	mysid shrimp	NR	48-h LC50	1.29	technical	FT	NR	NR	NR	NR	Schimel, 1980	1
Mysidopsis bahia	mysid shrimp	NR	48-h LC50	0.75	technical	FT	NR	NR	NR	NR	Schimel, 1980	1
Mysidopsis bahia	mysid shrimp	NR	28-d NOEC	0.33	technical	FT	NR	NR	NR	NR	US EPA, 1980	1
Nereis arenaceodentata	polychaete worm	NR	48-h LC50	730	technical	S	NR	NR	NR	NR	U.S. EPA, 1980	U
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	96-h EC50 behaviour	195	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	96-h EC50 behaviour	169	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	96-h EC50 behaviour	150	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	96-h EC50 behaviour	186	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	96-h EC50 behaviour	114	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	96-h EC50 behaviour	169	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	96-h EC50 behaviour	128	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	96-h EC50 behaviour	158	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	96-h EC50 behaviour	114	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	96-h EC50 behaviour	145	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	96-h EC50 behaviour	77	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	96-h EC50 behaviour	116	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	96-h EC50 behaviour	89	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	96-h EC50 behaviour	92	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	28-d LC50	114	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	28-d LC50	145	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	28-d LC50	80	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	28-d LC50	116	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	28-d LC50	89	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	28-d LC50	95	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	96-h LC50	220	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	96-h LC50	190	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	96-h LC50	161	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	96-h LC50	222	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	10-d LC50	114	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	10-d LC50	169	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	10-d LC50	132	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	10-d LC50	158	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	28-d LC50	114	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	28-d LC50	145	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	28-d LC50	80	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	28-d LC50	116	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	28-d LC50	89	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis arenaceodentata	polychaete worm	young adult, 1.5-2 cm	28-d LC50	95	technical	FT	NR	NR	NR	NR	Bishop *et al.*1983	2
Nereis virens	polychaete worm	young adult, 1.5-2 cm	28-d LC50	95	technical	FT	NR	NR	NR	NR	McLeese *et al.* 1982	2
Palaemon macrodactylus	korean or oriental shrimp	NR	96-h LC50	17.1	formulation	S	NR	NR	NR	NR	Schoettger, R.A. 1970	U
Palaemon macrodactylus	korean or oriental shrimp	NR	96-h LC50	3.4	formulation	FT	NR	NR	NR	NR	Schoettger, R.A. 1970	U
Palaemon puglo	grass shrimp	NR	48-h LC50	1.31	technical	FT	NR	NR	NR	NR	Schimmel, 1977	2
Penaeus duorarum	pink shrimp	NR	48-h LC50	0.04	technical	FT	NR	NR	NR	NR	Schimmel, 1977	2
Uca pugilator	fiddler crab	<0.1 g	48-h LC50	789.5	formulation	S	NR	NR	NR	NR	Office of Pesticide Programs 2000	U
Fish												
Atherinops affinis	topsmelt	28-d age group	96-h LC50	1.3	analytical	S	20	45-99%	NR	7.1-8.2	Hemmer et al., 1992	1
Cyprinodon variegatus	sheepshead minnow	NR	48-h LC50	2.7	technical	S	NR	NR	NR	NR	Schimmel, 1980	2
Cyprinodon variegatus	sheepshead minnow	NR	48-h LC50	1.4	technical	S	NR	NR	NR	NR	Schimmel, 1980	2

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Cyprinodon variegatus	sheepshead minnow	NR	48-h LC50	1.2	technical	S	NR	NR	NR	NR	Schimmel, 1980	2
Cyprinodon variegatus	sheepshead minnow	NR	48-h LC50	2.87	technical	S	NR	NR	NR	NR	Schimmel, 1980	2
Cyprinodon variegatus	sheepshead minnow	NR	48-h LC50	3.45	technical	S	NR	NR	NR	NR	Schimmel, 1980	2
Cyprinodon variegatus	sheepshead minnow	NR	48-h LC50	2.81	technical	S	NR	NR	NR	NR	Schimmel, 1980	2
Cyprinodon variegatus	sheepshead minnow	NR	48-h LC50	1.10	technical	FT	NR	NR	NR	NR	Schimmel, 1980	1
Cyprinodon variegatus	sheepshead minnow	NR	48-h LC50	0.34	technical	FT	NR	NR	NR	NR	Schimmel, 1980	1
Cyprinodon variegatus	sheepshead minnow	NR	48-h LC50	0.60	technical	FT	NR	NR	NR	NR	Schimmel, 1980	1
Cyprinodon variegatus	sheepshead minnow	NR	48-h LC50	0.88	technical	FT	NR	NR	NR	NR	Schimmel, 1980	1
Cyprinodon variegatus	sheepshead minnow	NR	48-h LC50	1.15	technical	FT	NR	NR	NR	NR	Schimmel, 1980	1
Cyprinodon variegatus	sheepshead minnow	NR	48-h LC50	0.83	technical	FT	NR	NR	NR	NR	Schimmel, 1980	1
Cyprinodon variegatus	sheepshead minnow	ELS	28-d NOEC	0.27	technical	FT	NR	NR	NR	NR	US EPA, 1980	1
Cyprinodon variegatus	sheepshead minnow	ELS	28-d LOEC growth	0.6	technical	FT	NR	NR	NR	NR	US EPA, 1980	1
Cyprinodon variegatus	sheepshead minnow	ELS	28-d LOEC survival	1.3	technical	FT	NR	NR	NR	NR	US EPA, 1980	1
Lagodon rhomboides	pinfish	NR	48-h LC50	0.3	technical	FT	NR	NR	NR	NR	Schimmel, 1977	1
Leiostomus xanthurus	spot	NR	48-h LC50	0.6	technical	S	NR	NR	NR	NR	Butler, 1964	2
Leiostomus xanthurus	spot	NR	48-h LC50	0.09	technical	FT	NR	NR	NR	NR	Schimmel, 1977	1

Organism	Common name	Life Stage	Endpoint	Effect Conc. (ug a.i./L)	% a.i.	Test Type	Temp (oC)	DO (mg/L)	Hardness (mg/L)	pH	Reference	Rank
Menidia beryllina	inland silverside	28-d age group	96-h LC50	1.5	analytical	S	20	45-99%	NR	7.1-8.2	Hemmer et al., 1992	1
Morone saxatilis	striped bass	NR	48-h LC50	0.10	technical	FT	NR	NR	NR	NR	Schimmel, 1977	1
Mugil cephlus	striped mullet	NR	48-h LC50	0.38	technical	FT	NR	NR	NR	NR	Schimmel, 1977	1
Mugil curema	white mullet	NR	48-h LC50	0.6	technical	S	NR	NR	NR	NR	Butler, 1963	2

Notes:
F - Flowthrough; S - Static; R - Renewal; M - Measured; N - Nominal.
1 - Primary; 2 - Secondary; U - Unacceptable.

MAD = Minimal Active Dose

NR = Not reported.

ELS = Early life stage.