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 CARBARYL

PN 1436

ISBN 978-1-896997-88-9 PDF

NOTE TO READERS

The Canadian Council of Ministers of the Environment (CCME) is the major intergovernmental forum in Canada for discussion and joint action on environmental issues of national, international and global concern. The 14 member governments work as partners in developing nationally consistent environmental standards, practices and legislation.

This document provides the background information and rationale for the development of the Canadian Water Quality Guidelines for carbaryl. They were developed by the National Guidelines and Standards Office of Environment Canada. For additional technical information regarding these guidelines, please contact:

National Guidelines and Standards Office
Environment Canada
Fontaine
200 Sacre-Cœur Blvd.
Gatineau, QC K1A 0H3
K1A 0H3
Phone: 819-953-1550
Email: ceqg-rcqe@ec.gc.ca
Website: http://www.ec.gc.ca/ceqg-rcqe

This scientific supporting document is available in English only. Ce document scientifique du soutien n'est disponible qu'en anglais avec un résumé en français.

Reference listing:

CCME. 2009. Canadian Water Quality Guidelines : Carbaryl. Scientific Criteria Document. Canadian Council of Ministers of the Environment, Winnipeg.

PN 1436

ISBN 978-1-896997-88-9

SCIENTIFIC CRITERIA DOCUMENT - CANADIAN WATER QUALITY GUIDELINES FOR CARBARYL

Table of Contents

List of Figures

List of Tables

List of Appendices

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

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 carbaryl. While information regarding formulations is investigated, guideline values are derived using toxicity data concerning the technical active carbaryl. Carbaryl (CAS Registry Number 63-25-2) is a carbamate insecticide which exerts its effects through cholinesterase inhibition. The primary registrant of carbaryl is Bayer CropScience, which sells formulations containing carbaryl under the trade name Sevin®. The pesticide is applied to a variety of crops including vegetables, fruit and tobacco as well as to lawns and ornamentals. Carbaryl is an insecticide which controls a variety of pests including ants, beetles, hoppers, worms and catepillars to name a few. In addition, it has application of controlling fleas and ticks on domestic animals.

Carbaryl is rapidly metabolized and degraded. On account of its low octanol/water partition coefficient (log K_{ow} 1.59-2.3), it is not likely to pose a bioaccumulation risk in alkaline water; however, the risk increases in conditions below neutrality as carbaryl is considered stable in acidic water (half-life at pH 5 is 1500 days) (Howard 1991). The hydrolysis half-life ranges from several minutes to several weeks at pH values of 7 and higher. Carbaryl is not expected to persist in the environment with a DT_{50} of <30 days (Oddy 2002). Although potentially mobile (average K_{oc} for adsorption and desorption are 211 and 624, respectively) (Skinner 1994), it is unlikely to be found in groundwater because of its rapid degradation.

The short-term and long-term freshwater Canadian Water Quality Guidelines and the marine short-term and long-term Canadian Water Quality Guideline for carbaryl for the protection of aquatic life were developed based on the CCME protocol (CCME 2007). The short-term freshwater 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 freshwater CWQG or a short-term and 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 freshwater CWQG and short-term and long-term marine CWQG. The short-term freshwater, long-term freshwater and short-term and long-term marine guideline values are summarized in the table below.

Guideline	Value (µg a.i./L)
Short-term Freshwater	3.3
Long-term Freshwater	0.20
Short-term Marine	0.57
Long-term Marine	0.29

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 au carbaryl, 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 pour établir les valeurs des recommandations. Le carbaryl (numéro de registre du CAS 63-25-2) est un insecticide du groupe des carbamates dont les effets toxiques inhibent la cholinestérase. Le principal titulaire d'homologation du carbaryl est Bayer CropScience, qui met sur le marché des préparations contenant du carbaryl sous le nom commercial Sevin®. Cet insecticide est appliqué sur diverses cultures, notamment sur les légumes, les fruits et le tabac, ainsi que sur les pelouses et les plantes ornementales. Le carbaryl élimine une grande variété de ravageurs, par exemple les fourmis, les coléoptères, les sauterelles, les vers et les chenilles. Il permet également d'éliminer les puces et les tiques chez les animaux domestiques.

Le carbaryl se métabolise et se dégrade rapidement. En raison de son faible coefficient de partage octanol/eau (log K_{oe} de 1,59 à 2,3), il est peu susceptible de se bioaccumuler dans des eaux alcalines. Toutefois, les risques de bioaccumulation augmentent dans des eaux en deçà du pH neutre, car le carbaryl est considéré stable en eaux acides (demi-vie de 1 500 jours à pH 5) (Howard, 1991). À pH égal ou supérieur à 7, la demi-vie d'hydrolyse du carbaryl va de plusieurs minutes à plusieurs semaines. Le carbaryl ne devrait pas être persistant dans l'environnement, car son TD_{50} est de moins de 30 jours (Oddy, 2002). Même s'il est potentiellement mobile (K_{co} moyens pour l'adsorption et la désorption respectivement de 211 et 624) (Skinner, 1994), le carbaryl est peu susceptible de se trouver dans des eaux souterraines, en raison de sa dégradation rapide.

Les RCQE relatives au carbaryl concernant l'exposition de courte et de longue durée dans les 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 durée en eaux douces a été élaborée 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 pas suffisantes pour établir des recommandations concernant l'exposition de longue durée en eaux douces et l'exposition de courte et 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, en suivant la méthode par étapes, la méthode du paramètre dont la valeur est la plus faible (type B2) a été utilisée pour établir une RCQE pour l'exposition de longue durée en eaux douces ainsi que des RCQE pour l'exposition de courte et de longue durée en eaux marines. Les RCQE pour les expositions de courte et de longue durée en eaux douces et marines sont résumées dans le tableau ci-dessous.

Recommandation	**Valeur (µg m.a./L)**
Exposition de courte durée – eaux douces	3,3
Exposition de longue durée – eaux douces	0,20
Exposition de courte durée – eaux marines	0,57
Exposition de longue durée – eaux marines	0,29

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. Carbaryl concentrations monitored in the environment can be compared to the guideline value to help predict whether there is a possibility that harm will occur to 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 all available toxicity data (provided these data pass quality control criteria) in a more flexible approach. In 1997, Canadian Water Quality Guidelines were derived for carbaryl using the previous protocol (CCME 1991) and were 0.20 and 0.32 µg/L for freshwater and marine aquatic life, respectively. These values have now been updated for the technical active carbaryl using the new protocol and are derived separately based on media (freshwater and marine) and duration (long-term and short-term).

The structure of the criteria document for carbaryl 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

Carbaryl belongs to the N-methyl carbamate class of pesticides which all share the toxic mode of action of cholinesterase inhibition. The molecular formula of carbaryl (CAS registry number 63-25-2) is $C_{12}H_{11}NO_2$ with a molecular mass of 201 g/mol. The CAS and IUPAC chemical names are 1-naphthalenyl methylcarbamate and 1-naphthyl methylcarbamate, respectively (IPCS 1993).

The chemical structure can be seen from Figure 2.1, while physical properties are listed in Table 2.1.

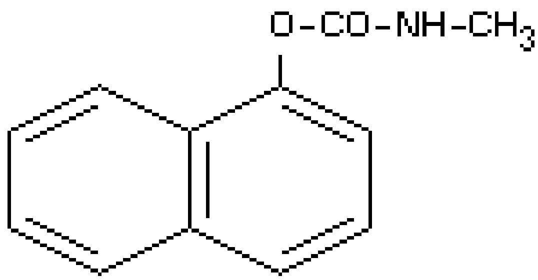

Figure 2.1. Chemical structure of carbaryl.

Table 2.1 Physical/ Chemical Properties of Carbaryl.

Property	**Value**	**Reference**
Melting point (°C)	142	IPCS, 1993
Boiling point (°C)	Decomposing	IPCS, 1993
Solubility in water (at 30°C)	40 mg/litre	IPCS, 1993
Specific density (at 20°C)	1.23 g/cm^3	IPCS, 1993
Vapour pressure (mmHg at 24-25°C)	1.17 x 10^{-6} – 3.2 x 10^{-7}	IPCS, 1993
Flash point (°C)	193	IPCS, 1993
Octanol/water partition coefficient (log K_{ow})	1.59-2.3	IPCS, 1993
Henry's Law Constant	5.3 x 10^{-6}	IPCS, 1994

Carbaryl is a white, odourless and crystalline solid. It is non-corrosive and has low volatility; however, volatility may increase 4-fold when relative humidity increases from 8 to 80%. The Henry's Law Constant (dimensionless air-water partitioning constant) is 5.3 x 10^{-6} (IPCS 1994) and with a vapour pressure of 1.17 x 10^{-6} to 3.2 x 10^{-7} mmHg (IPCS 1993) carbaryl is not likely to volatize into air. It is stable to light and to heat below 70°C and is easily hydrolysed by alkaline materials (IPCS 1993). Carbaryl is a strong oxidizer (IPCS 1994).

Carbaryl is lipophilic. It is sparingly soluble in water but soluble in ethanol, petroleum ether, diethyl ether, chloroform, and dimethyl sulfoxide. It is moderately soluble in petroleum oils, dimethyl formamide, acetone, isophorone and cyclohexanone. At 20°C, the solubility in the organic solvents methanol and ethylacetate have been found to be 76.0 g/L and 77.4g/L, respectively (Mühlberger 2002). The solubility of carbaryl in water is affected by pH; carbaryl has a mean solubility of 9.4 at pH 4, while at pH 9 the solubility is 7.2 mg/L.

2.2 Analytical methods

The majority of analytical methods used to quantify carbaryl and its metabolites are based on separation by chromatographic techniques including gas-liquid chromatography (GLC), thin-layer chromatography (TLC) and high pressure liquid chromatography (HPLC) using detectors such as ultraviolet (UV), mass spectrometry (MS) and diode array detector (DAD) (Zhu et al. 2008). The detection limits of the aforementioned techniques can be below one nanogram per litre and recovery is generally greater than 80% (IPCS (International Programme on Chemical Safety) 1994).

While the above mentioned techniques are both accurate and selective, they require expensive instrumentation, consumption of organic reagents and have exhaustive preparation and clean-up procedures (Tanimoto de Albuquerque and Ferreira 2007). Therefore, advances have been made to minimize the cost and maximize the efficiency of carbaryl detection methods.

A relatively new detection technique, chemiluminescence (CL), is used in combination with HPLC because it has a wide working range and enhanced sensitivity and selectivity (Perez-Ruiz et al. 2007). This automated solid-phase extraction-HPLC method detects traces of N-methylcarbamate pesticides, such as carbaryl, in aqueous solutions and in fruit. CL is based on the post-column conversion of the N-methylcarbamate pesticides into methylamine by UV irradiation and has detection limits in the range of 3.9 - 36.7 ng/L for aqueous solutions (Perez-Ruiz et al. 2007). Tsogas et al. (2006) presented a novel flow injection-chemiluminescence (FI/CL) method of carbaryl determination in environmental samples. The method is based on the CL-emission made by the oxidation of the carbaryl with potassium permangante in sulfuric acid medium. The limit of detection was 14.8 µg/L and the method had high reproducibility (relative standard deviation (RSD) of 2.29%) (Tsogas et al. 2006). Interference from organic and inorganic species likely to co-exist in the samples was investigated and slight interference was reported. A benefit of this method in addition to its sensitivity, rapidity and high reproducibility is its capability to be fully automated (Tsogas et al. 2006).

Immunoassay techniques, which are used in conjunction with gas or liquid chromatography, offer low detection limits and minimal sample preparation (Wang et al. 2005). Wang et al (2005), describe how specifically the enzyme-linked immunosorbent assay (ELISA), previously a laboratory assay for carbaryl detection in water and soil, can be redeveloped for suitable field use. A membrane-based competitive enzyme immunoassay was developed in flow-through and dipstick format to rapidly and qualitatively detect carbaryl. Anti-carbaryl antibody was used to coat a nylon membrane and a carbaryl-horseradish peroxidise conjugate was used as the labelled antigen in the competitive assay (Wang et al. 2005). The results are interpreted visually and are convenient qualitative tools for field screening of environmental samples. Both the flow-through and dipstick test formats had detection limits of 10 µg/L and had assay times of 5 and 15 minutes respectively (Wang et al. 2005).

In general, immunosensing detection systems, such as the ELISA format, use labels to identify the immunological reaction and require multiple steps for washing and incubation. Mauriz et al. (2006) report an immunoassay method which overcomes these requirements by implementing a sensor system which quickly and directly responds to the presence of analytes in the water sample. Mauriz et al. (2006) developed an optical sensor for the determination of carbaryl in water samples based on surface plasmon resonance (SPR). The system detects biomolecular recognitions, as an increase in refractive index, that occur at the surface of the sensor (Mauriz et al. 2006). The gold-coated sensor surface was covered with an alkanethiol self-assembled monolayer to allow the sensor surface to be reused. The lowest detection limit was of 1.38 µg/L and the assay could be completed in 10 minutes (Mauriz et al. 2006).

In the past decade, biosensing methods of pesticide determination have been developed and incorporate enzyme- and affinity-based sensors. The enzymatic determination method is most often based on inhibition (Suwansa-ard et al. 2005). Suwanasa-ard et al. (2005) developed flow-injection biosensor systems using semi disposable enzyme reactor to detect carbaryl in water samples. Through covalent binding, acetylcholine was immobilized on silica gel. Electrodes measuring pH and conductivity detected ionic changes in the sample that occurred due to the hydrolysis of acetylcholine (Suwansa-ard et al. 2005). Because carbaryl inhibits acetylcholinesterase, the decrease in the enzyme activity can be used to determine the pesticide. The carbaryl detection limit of the potentiometric (pH electrode which detects increase in hydrogen ions) and conductimetric (detects increase in conductivity due to increased ions) systems was 30 µg/L (Suwansa-ard et al. 2005).

Traditional extraction methods from water generally include liquid-liquid extraction, solid-phase extraction and Soxhlet extraction (Jia et al. 2007). These methods, however, can be time- and sample-consuming, waste organic solvent and require extensive clean-up procedures. Jia et al. (2007) presented a micelle-mediated extraction (MME) to overcome the above mentioned limitations. Anionic surfactant MME with sodium dodecylsulfate (SDS) as an extraction agent was used as a preconcentration step prior to the method of fluorescence spectrophotometry without further clean-up (Jia et al. 2007). Carbaryl and 1-Naphthol were used as test compounds. Detection limits were approximately 1 µg/L, recoveries obtained from environmental water samples varied from 90.7 to 98.6% and RSD were of less than 6% (Jia et al. 2007).

3.0 PRODUCTION AND USES

Carbaryl was first introduced in 1956 and was the first carbamate insecticide to be marketed successfully for agricultural and household uses. The current registrant of technical grade carbaryl is Bayer CropScience Inc. and the insecticide is registered in countries worldwide including Canada, the United States, Madagascar, South Africa, Tanzania, Australia, India, New Zealand, Phillipines, Hungary, Portugal, and the United Kingdom. Other registrants incorporating carbaryl into formulation pesticides include Sure Gro IP Inc., Interprovincial Cooperative Limited, Biedermann Packaging Inc., Wellmark International, Ontario Limited D.B.A. Manchester Products, King Home and Garden Inc., Nu Gro PR Inc., Vétoquinol N.-A. Inc., Sergeant’s Pet Care Products, Inc., Rolf C. Hagen Inc., Peacock Industries, Scotts Canada Ltd. and Dominion Veterinary Laboratories Limited (PMRA (Pest Management Regulatory Agency) 2007). As seen in Figure 3.1, carbaryl can be synthesized from 1-naphthol and methyl isocyanate in a direct reaction, or by the reaction of naphthyl chloroformate (formed from the reaction of 1-naphthol and carbonylchloride) with methylamine (International Labour Office 1983).

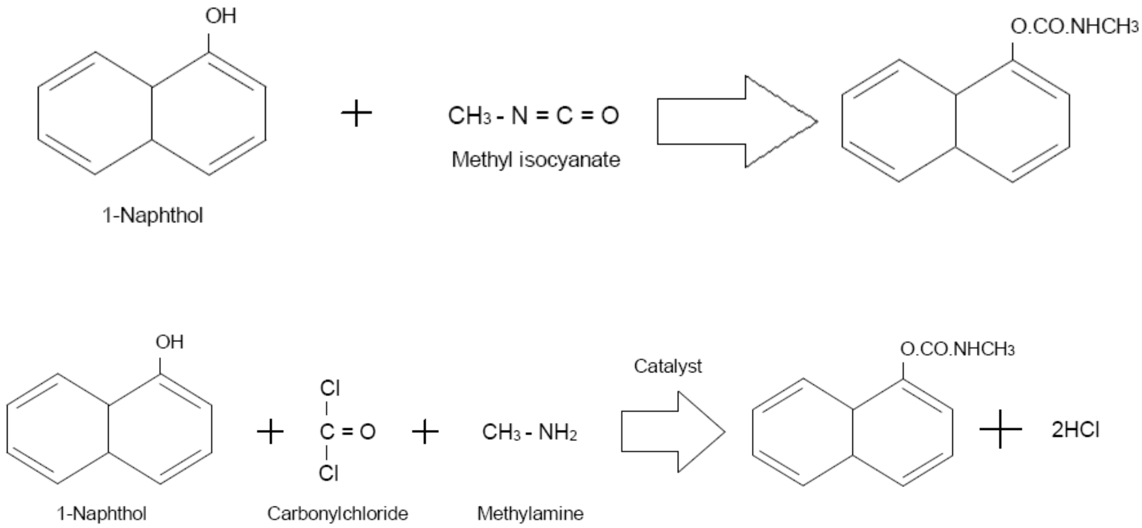

Figure 3.1 Synthesis Reactions for the Production of Carbaryl (Orica Limited 1999).

In Canada, carbaryl is registered for and available in multiple end-use formulations including dusts, bait dusts, granules, soluble concentrates, wettable powders and ready-to-use spray formulations (PMRA 2007). It is a broad-spectrum insecticide used for the control of pests on agricultural crops as well as being used residentially on lawns and gardens and for control of fleas and lice on pets (CCOHS 2008). It controls more than 100 species of insects on crops including fruit, nuts, ornamentals and shade trees as well as on poultry and livestock (EXTOXNET 1993). The PMRA registers carbaryl for the application methods of dusting and air and ground spraying. Specific application rates of carbaryl depend on the application target and the formulation. For example, the formulation Sevin SL, containing 43% technical carbaryl, has application rates for vegetable crops ranging from 1.25 to 6.4 L of Sevin SL per hectare and for tobacco ranging from 2 to 5.25 L Sevin SL per hectare. The application rates for this formula to tree fruit crops typically range from 2000-3000 litres per hectare for dilute sprays and from 300-1000 and 100-200 litres per hectare for concentrate and aerial sprays respectively (PMRA 2007). The formulation Chipco Sevin RP2, containing 22.5% technical carbaryl, has typical spray volumes of 8 to 16 litres per 100 m^2 (0.01 hectares) for vegetables crops and 11-34 litres per 100 m^2 for small fruit crops (PMRA 2007). In Canada, Bayer CropScience, has proposed several risk mitigation measures for this active ingredient (PMRA 2003), details on the implementation of these measures are under discussion and will be communicated in the near future.

Data regarding pesticide utilization in Canada, including sales and use, was compiled by Environment Canada as a commitment to the Environment Canada Pesticide Program Coordinating Committee. Canada does not have a national system which collects and reports pesticide sales and use data, however many provinces and territories do collect this information. The data is collected in numerous ways depending on the province or territory, for example some report pesticide use while others report pesticide sales. Not all provinces collect this data and hence there is a data gap regarding pesticide utilization in Canada. The available information regarding pesticide sales and use reported by Environment Canada can be seen in Table 3.1 (Brimble et al. 2005).

Table 3.1 Carbaryl Sales and Use Data in Canada

Province	**Year**	**Quantity of carbaryl used/sold (kg of active ingredient)**
Manitoba	2003	49 295.51
Nova Scotia	2003	5773.16
Newfoundland and Labrador	2003	941.64
British Columbia	2003	12 363
Ontario	2003	4851
New Brunswick	2003	1906.56
Alberta	1998	3142.85

4.0 SOURCES TO THE ENVIRONMENT

Carbaryl is applied in agriculture, forestry and residential uses. Its direct application to soil and vegetation can result in exposure of carbaryl to non-target species. In Canada, carbaryl is not registered for direct application to the water. Carbaryl can enter the aquatic environment through spray drift and run-off from agricultural application. Accidental spills, dumping of tank residues or washing of application equipment can cause elevated but transient levels of carbaryl in the environment.

5.0 ENVIRONMENTAL FATE AND BEHAVIOUR

5.1 Fate in Water and Sediment

The hydrolysis half-life of carbaryl in water ranges from several minutes to several weeks and is dependent on temperature, pH and the initial concentrations (IPCS 1994). In sterilized water and under dark conditions, the half-life of carbaryl at pH 7 is between 10 and 16 days. At pH 8 the half-life decreases to 1.3-1.9 days, and at pH levels above 8 the half-life of carbaryl is in the range of several hours (IPCS 1994). In acidic water, hydrolysis is not significant. At a pH value of 6 the half-life of carbaryl is 406 days at 25°C. At a pH value of 5 and a temperature of 27°C the half-life of carbaryl is 1500 days and the pesticide is considered stable (Howard 1991) A photolysis study in water held at pH 5 found the half-life of carbaryl to be 21 days (Libelo and Chiri 2002). The main products of hydrolysis for carbaryl in water are 1-naphthol and carbon dioxide. In surface water, carbaryl can be broken down by bacteria (EXTOXNET 1993).

The adsorption isotherm of carbaryl in aqueous suspended sediment was determined using the Freundlich equation: $x/m = KC^{l/n}$, where x/m is the amount of carbaryl adsorbed per gram of sediment, C is the equilibrium solution concentration and K and l/n are constants (Sharom et al. 1980). The K value (pmol/g), which denotes the extent of adsorption, was found to be 8, while the l/n value, which denotes the degree of non-linearity between adsorption and solution concentration, was found to be 0.96 (Sharom et al. 1980).

5.2 Fate in Soil

Using the batch equilibrium method, the soil adsorption and desorption of 14-C labelled carbaryl was investigated. The average K_{OC} value for adsorption for silty clay loam, sandy loam, sediment and silt loam was 211, while the average K_{OC} value was 624 for desorption. Using K_{OC} values to predict leaching potential, carbaryl is anticipated to have medium mobility in silty clay loam, sandy loam, sediment and silt loam. In sand soils of low organic matter, the mobility is predicted to be high as desorption K values were positively correlated with the percent organic matter of the soil tested (Skinner 1994). Adsorption of carbaryl on soils with a high percent of organic matter occurs more readily compared to adsorption on sandy soils (IPCS 1994).

Under laboratory conditions, the degradation half-life (DT_{50}) for carbaryl at 20 +/- 2°C in 75% of the soils tested was found to be less than 31 days. In one soil with very low pH and a high content of organic matter the DT_{50} was 99 days. With a decrease in temperature to 10°C, the rate of degradation was found to be 2.7 times slower. From these results it is predicted that carbaryl is unlikely to persist in the environment (Oddy 2002).

Environmental factors influence the rate of degradation of carbaryl in soil, for example soil type, soil aeration and soil temperature. A laboratory study found that at room temperature (23 to 25°C) and aerobic conditions, light textured soil had a half-life of 11 days compared to 21-27 days for a heavy textured soil. Lowering the temperature to 15°C caused a 2-fold increase in the half life of carbaryl (Khasawinah 1978).

Carbaryl is degraded relatively quickly by microbial processes under aerobic conditions, but is degraded more slowly under anaerobic conditions (Libelo and Chiri 2002). In aerobic sandy loam soil under dark conditions and at a temperature of 25°C, the half-life of carbaryl was found to be 4 days. The major degradation product was 1-Naphthol, which further degraded beyond detection limits within 14 days (Libelo and Chiri 2002). In an anaerobic soil study the half-life of carbaryl was found to be 72.2 days. Soil micro-organisms which are capable of degrading carbaryl include *Pseudomonas* sp., *Rhodoccus* sp., *Bacillus* sp., *Arthrobacter* sp. and *Achromobacter* sp. (Libelo and Chiri 2002).

5.3 Fate in Vegetation

A study exposed the roots of rice seedlings to carbaryl and investigated the uptake and distribution of the pesticide. Carbaryl was found to be rapidly absorbed by the roots and was transported upwards to the stems and leaves. After terminating exposure, carbaryl loss occurred mainly through root exudation (22%) and less through volatization from the leaves (4.2%) (IPCS 1994). Another study examined the release of carbaryl and 1-naphthol labelled with ^{14}C from soil-bound residues when barley was grown. The ^{14}C residues could be detected in the roots and shoots of the barley in the experiment involving carbaryl, whereas in the experiments involving 1-naphthol, ^{14}C residues were only detected in the roots of barley (IPCS 1994). The rate at which carbaryl decomposes in vegetation is dependent upon climatic conditions. Factors contributing to a rapid rate of decomposition include high temperatures and large amounts of ultraviolet radiation (IPCS 1994).

5.4 Bioconcentration and Bioaccumulation

Carbaryl is not likely to bioaccumulate significantly in aquatic organisms. Bioconcentration factors have been found to be between 14 and 75 for freshwater species of fish (IPCS 1994). Because carbaryl is rapidly metabolized and degraded, and because of the low octanol/water partition coefficient, it is not likely to pose a bioaccumulation risk in alkaline water, however the risk increases under conditions below neutrality (EXTOXNET 1993). An aerial application of carbaryl in the form of Sevin-2-oil was studied to assess the persistence of carbaryl in the tissue of brook trout (*Salvelinus fontinalis*) and slimy sculpin (*Cottus cognatus*). One day following the application, fish tissue residues were 40-50 µg/L and 30 µg/L for brook trout and slimy sculpin respectively. After 3 days, no carbaryl was detected, illustrating the rapid ability of fish to metabolize and eliminate carbaryl residues (Sundaram and Szeto 1987).

6.0 CONCENTRATIONS IN CANADIAN WATERS

Recent data concerning the concentrations of carbaryl detected in Canadian waters was limited. The presence and level of priority pesticides in select aquatic ecosystems in Canada was monitored in a project by Environment Canada Pesticides Science Fund. Carbaryl was monitored in the Atlantic region and the region of Quebec during the surveillance which took place between 2003 and 2005. In an other monitoring programs conducted by the Quebec Governement between 2005 and 2007, four rivers were sampled in watersheds with intensive corn and soybean cultivation. Carbaryl was detected in 3 % to 14% of the samples, the maximum concentration detected was 1.7 ug/L. Surveillance monitoring did not detect any level of carbaryl in surface waters of New Brunswick (at 4 sites), Prince Edward Island (at 6 sites) and Nova Scotia (at 4 sites). No detectable levels of the insecticide were found in surface waters of the Quebec region over the course of the study; detection limits were 0.01 to 0.03 µg/L (Cantox Environmental 2006). Between 1998 and 2006 the Quebec government carried out monitoring of pesticide concentrations along the St. Lawrence River including the tributaries L'Assomption, Bayonne, Maskinongé and du Loup. In 2006, carbaryl was detected at a frequency of 3% in the tributary Bayonne and at a frequency of 4% in the tributary Maskinongé. The concentration of carbaryl detected at Maskinongé in July 2006 was 0.07 µg/L with a method detection limit of 0.07 µg/L (Giroux 2007).

7.0 GUIDELINES FROM OTHER JURISDICTIONS

The Canadian Water Quality Guideline for the Protection of Aquatic Life, derived in 1997 is 0.20 µg/L for freshwater life and 0.32 µg/L for marine life (Canadian Council of the Ministers of the Environment 1999). The Ontario Ministry of the Environment, which develops guidelines for water management policies, has adopted the freshwater value as the Provincial Water Quality Objective (PWQO). PWQOs are numerical and narrative ambient surface water quality criteria which can be applied to all waters in the province unless otherwise specified. The PWQOs represent a desirable level of water quality which protect all forms of aquatic life and all aspects of the life cycle over an indefinite exposure to the water (Ministry of the Environment 2005). The method of derivation is based on lowest effect concentration with an application of a safety factor.

The province of British Columbia has also adopted the CWQGs developed by the CCME as Working Guidelines for the water column. The provincial water quality guidelines for British Columbia are environmental benchmarks which denote safe levels of substances for various uses of water including drinking, recreation, and agriculture and for aquatic life. The Working Guidelines are guidelines obtained from other sources, for example the CCME, and provide benchmarks for substances not yet assessed and formally endorsed by the B.C. Ministry of the Environment (Nagpal et al. 2006). The province of Quebec also cites the CCME CWQG values for the protection of aquatic life to chronic effects of carbaryl in its Surface Water Quality Criteria (Développement durable 2002).

The Netherlands publishes Environmental Quality Standards including standards for surface water which take into account scientific risk limits. For carbaryl, these standards include a target value, which is a non-statutory standard indicating negligible environmental effects, and a maximum permissible concentration (MPC), which is based on ecological risk assessment and specifies the concentration of a substance at which no harmful effects are expected to the ecosystem or to humans. The target value and MPC for carbaryl are 0.002 µg/L and 0.23 µg/L, respectively (The Ministry of Housing 1999). The Netherlands additionally has function-oriented quality standards in which a surface water quality standard for the production of drinking water is cited. This value for carbaryl is 0.1 µg/L.

The Guideline for Canadian Drinking Water Quality for carbaryl is a maximum acceptable concentration (MAC) of 90 µg/L (Health Canada 1991). The United States Environmental Protection Agency (US EPA) does not have a drinking water standard developed for carbaryl but does have health advisory information in the form of a Drinking Water Equivalent Level (DWEL). This denotes a concentration protective of adverse health effects (excluding cancer effects) from a lifetime exposure where all exposure of a contaminant is assumed to be from drinking water. The DWEL for carbaryl is 400 µg/L (US EPA 2006).

The Australian and New Zealand Environment and Conservation Council develop Water Quality Guidelines for fresh and marine waters through the National Water Quality Management Strategy. Although no value for the protection of aquatic life is reported for carbaryl, they do have a Water Quality Guideline for Recreational Purposes for carbaryl, a maximum concentration of 60 µg/L. This guideline value is intended to protect water for recreational activities including swimming and boating. The guideline value determines the suitability of water for recreational purposes and preserves the aesthetic appeal of the water body (ANZECC 2000). The Australian drinking water guidelines are divided into two categories including guideline values and health values. The guideline value is intended to be used by regulatory authorities for surveillance and enforcement and thereby provides a mechanism to measure whether or not the approved label directions are being complied with. Exceedance of the guideline value indicates the drinking water is contaminated, but does not necessarily signify hazard to human health. The health value is intended to be used by health authorities to manage health risks related to inadvertent pesticide exposure, and is calculated using a range of safety factors. The guideline and health values are 5 and 30 µg/L, respectively (Australian Government 2004).

The various guideline values listed above have been summarized in Table 7.1 below.

Table 7.1 Water Quality Guideline Values for Carbaryl from Other Jurisdictions

Jurisdiction	**Guideline**	**Value (µg/L)**
Ontario	PWQO (freshwater), protection of aquatic life	0.20
British Columbia	Working Guideline (freshwater), protection of aquatic life	0.20
British Columbia	Working Guideline (marine), protection of aquatic life	0.32
Québec	Critères de qualité de l'eau de surface- Protection de la vie aquatique (effet chronique)	0.20
Québec	Critères de qualité de l'eau de surface- Protection de la vie aquatique (effet chronique, eaux salées)	0.32
Netherlands	Target value, protection of aquatic life	0.002
Netherlands	MPC, protection of aquatic life	0.23
Netherlands	Drinking water	0.1
Health Canada	Drinking water MAC	90
United States EPA	Drinking Water Equivalent Level	400
Australia and New Zealand	Recreation purposes	60
Australia and New Zealand	Drinking water guideline	5
Australia and New Zealand	Drinking water health value	30

8.0 ENVIRONMENTAL TOXICITY

In the following sections, all concentrations of carbaryl expressed in µg/L refer to µg of active ingredient (a.i.) per litre.

8.1 Mode of action

Carbaryl is a member of the N-methyl carbamate family which affect the nervous system through cholinesterase inhibition (IPCS 1993). Degradation of the neurotransmitter acetylcholine is inhibited causing it to build up and overstimulate the central nervous system. An antidote of carbaryl toxicity is atropine sulphate, which reverses the overstimulation of the cholinergic nervous system. Barahona and Sánchez-Fortún (1999) investigated the prevention of carbaryl-induced lethality in the brine shrimp (*Artemia salina*) by pre-treatment with atropine. With increasing concentrations of atropine pre-treatment, carbaryl-induced mortality was increasingly inhibited until a maximum protection level of 100% was obtained with 150081.12, 66841.68 and 38215.1 µg/L atropine for brine shrimp aged 24-, 48- and 72-h respectively (carbaryl concentrations were 50% lethal concentration for each age group, being 27567.14, 5915.87 and 350.12 µg a.i./L respectively) (Barahona and Sánchez-Fortún 1999).

The effects on pests are exerted after carbaryl is ingested into the stomach or absorbed through direct contact. Hydrolysis and ring hydroxylation are the principal metabolic pathways. The resulting products of hydrolysis include 1-naphthol, carbon dioxide and methylamine while the products of hydroxylation include 4-hydroxycarbaryl, 5-hydroxycarbaryl, *N*-hydroxymethylcarbaryl, 5-6-dihydro-5-6-dihydroxycarbaryl and 1,4-napthalendiol. The major degradation product of carbaryl is 1-napthol (IPCS 1993).

8.2 Aquatic toxicity

8.2.1 Toxicity to Freshwater Life

8.2.1.1. Short-term toxicity to freshwater fish

The most sensitive endpoint in the overall dataset for a freshwater fish was a 48-h LC_{50} of 15.83 µg/L for the spotted snakehead (*Channa punctatus*) (Bhattacharya, 1993). There was a range of values for the 96-h LC_{50} endpoint for rainbow trout across a number of studies, spanning from 860 µg/L to 5400 µg/L. The least sensitive fish species to technical carbaryl in the data set was the fathead minnow (*Pimephales promelas*) with a 24-h TLm of >32000 µg/L (Henderson et al. 1960).

The toxic effects of short-term carbaryl exposure to a variety of physiological processes in fish have been investigated in numerous laboratory studies. Basha et al. (1984) found changes in the rate of oxygen consumption in the fish *Tilapia mossambica* exposed to carbaryl at a concentration one third that of the LC_{50} (5495µg/L) for 48 hours. The rate of oxygen consumption initially increased in the first 24 hours, and then decreased afterwards accompanied by significantly decreased levels of the respiratory enzymes succinate dehydrogenase and malate dehydrogenase in brain and liver tissues (Basha et al. 1984). Another study regarding respiratory-cardiovascular effects of carbaryl on rainbow trout (*Salmo gairdneri*) found similar results (McKim et al. 1987). Following an acute carbaryl exposure (24- to 48-h) at highly toxic concentrations (24- to 48-h LC_{95}), oxygen utilization and heart rate of the fish decreased. Ventilation volume increased to compensate for the decreased oxygen utilization however it was insufficient to increase oxygen consumption (McKim et al. 1987). In the catfish, *Clarias batrachus,* exposure to sublethal concentrations of carbaryl (1000, 2000 and 4000 µg/L) for durations of 96 hours and 15 days caused lactic acid to accumulate in different fish tissues including the liver, heart, muscle, gills, kidney and spleen (Sharma 1995). Carbaryl exposure at all concentrations also caused an increased level of lactic acid in the blood and caused an inhibitory effect on the enzyme lactic dehydrogenase (Sharma, 1995). Carlson et al. (1998) found 24- and 48-h exposure of juvenile medaka (*Oryzias latipes*) to sublethal carbaryl concentrations impaired signal transmission between Mauthner cells (involved in escape response) and motoneurons and caused neuromuscular effects including muscular weakness, tremors, convulsions and involuntary muscle spasms. Additionally, medaka appeared to be more vulnerable to predation following carbaryl exposure, possibly explained by neurological injury (Carlson et al. 1998).

Other neurotoxic, behavioural and physiological impairments caused by carbaryl exposure in laboratory experiments include decreased swimming speed in larval rainbow trout (*Oncorhynchus mykiss*) exposed to 188, 375 and 750 µg/L (Beauvais et al. 2001), altered levels of detoxifying enzymes in the liver and kidney of juvenile rainbow trout (*Oncorhynchus mykiss*) exposed to 1000 and 3000 µg/L (Ferrari et al. 2007a) and altered levels of the biogenic amines norepinephrine, dopamine and serotonin in the brain of the catfish (*Clarias batrachus*) at 2000 and 6000 µg/L (Sharma et al. 1993). Solomon and Weis (1979) found an ED_{50} (effective dose) of 2500 µg/L caused abnormal development of the circulatory system in medaka eggs (*Oryzias latipes*), including defects in heart morphology, pericardial edema, irregular heart beat and blood clots (Solomon and Weis 1979).

8.2.1.2. Short-term toxicity to freshwater invertebrates

Among the most sensitive endpoints for invertebrate species in the dataset for short-term freshwater exposure was the stonefly (*Chloroperla grammatica*) which had a 96-h NOEC for mortality of 3.4 µg/L for the larval stage (Schafers 2002a). The lowest LC_{50} for an invertebrate species was 4.075 µg/L for an adult cladoceran (*Bosmina fatalis*) for an exposure duration of 24-h (Sakamoto et al. 2005). The most tolerant species were the paramecium (*Paramecium aurelia*) with a 24-h LC_{50} of 46000 µg/L (Edmiston et al. 1984) followed by the pondmussel (*Ligumia subrostrata*) with a 24-h LC_{50} of 43100 µg/L for the glochidia life stage and the paper pondshell mussel (*Utterbackia imbecellus*) with a 24-h LC_{50} of 40200µg/L for the glochidia life stage (Milam et al. 2005).

The damselfly (*Xanthocnemis zealandica*) was exposed to carbaryl (80% active ingredient) for a duration of 48 hours at various stages in the life cycle including the 2^{nd}, 6^{th}, 8^{th}, 10^{th}, 12^{th} and 13^{th} instars. The most sensitive life stage was the 2^{nd} instar with a 48-h LC_{50} of 156.6 µg/L. The most tolerant was the 10^{th} instar with a 48-h LC_{50} of 770 µg/L, followed very closely by the 13^{th} instar with a 48-h LC_{50} of 760 µg/L (Hardersen and Wratten 2000). There was an overall pattern that earlier life stages were more sensitive.

8.2.1.3. Short-term toxicity to freshwater amphibians

The most sensitive amphibian species to the short-term toxicity of carbaryl was the African clawed frog (*Xenopus laevis*) at the embryo life stage with a 24-h EC_{50} for development of 110 µg/L (Elliott-Feeley and Armstrong 1982). The green frog (*Rana clamitans*) was the most tolerant species with short-term LC_{50}'s for tadpoles ranging from 11320 to 26010 µg/L.

Bridges (1997) reported the effects of sublethal concentrations of carbaryl (3500, 5000 and 7200 µg/L) on the swimming activity of tadpoles of the plains leopard frog (*Rana blairi*) for periods of exposure up to 96-hours. Tadpole activity decreased by approximately 90% at the concentration of 3500 µg/L and ceased completely at the concentration of 7200 µg/L (Bridges 1997).

8.2.1.4. Short-term toxicity to freshwater plants

Only one study was available regarding the short-term toxicity of carbaryl to freshwater plants. Water lettuce (*Pistia stratiotes*) and water spinach (*Ipomoea aquatica*) were assessed for changes in chlorophyll content following a 96-h exposure of carbaryl with an unreported percent purity. The EC50 values for each species were 785 000 and 996 000 µg/L for the water lettuce and water spinach, respectively (Boonyawanich et al. 2001).

8.2.1.5. Long-term toxicity to freshwater fish

The most sensitive endpoint for a long-term study was a 9-month LC_{20} of 32.46 µg/L for fathead minnow larva (*Pimephales promelas*) (Carlson 1971). 7-d toxicity of carbaryl to the fathead minnow ranged from 200 µg/L for a LOEC for growth to 4000 µg/L for a NOEC for survival (Pickering et al. 1996).

Sastry et al. (1988) exposed the spotted snakehead (*Channa punctatus)* to carbaryl at 10500 µg/L for 96 hours and at 1050 µg/L for 120 days. During both exposures fish were hyperglycaemic, hyperlactemic and had depleted glycogen levels in the liver and muscles. Other haematological and enzymatic effects included altered levels of lactic acid and altered activity levels of hexokinase, lactate dehydrogenase, pyruvate dehydrogenase and succinate dehydrogenase in various tissues (Sastry et al. 1988). The catfish *Clarias Batrachus* was exposed to sublethal concentrations of carbaryl (1000, 2000 and 4000 µg/L) for 96 hours and for 15 days. Total protein and glucose levels in the blood decreased while inorganic phosphates, cholesterol and lactic acid increased (Sharma 1999). Additional observations of pesticide toxicity included changes in body colour, opercular movement, and swimming behaviour (Sharma 1999).

8.2.1.6. Long-term toxicity to freshwater invertebrates

Many invertebrate species were highly sensitive to the toxicity of carbaryl during long-term exposure. The zooplankton *Daphnia ambigua* had an EC_{50} for survival of 2 µg/L for an exposure period spanning the 1^{st} to the 6^{th} instar stage (Hanazato 1991a). Adult waterfleas (*Daphnia magna*) had a 21-d MATC for survival and reproduction of >3.3 µg/L (Springborn Bionomics 1985a), and the zooplankton (*Daphnia galeata*) had a 7-d IC_{70} of 5 µg/L for abundance (Havens 1995). The midge (*Chironomus riparius*) was a relatively more tolerant species with a 28-d NOEC of 147.25 µg/L and a 28-d LOEC of 318.31 µg/L for larval development (Ebeling and Radix 2002).

Oris et al. (1991) compared the sensitivity of 4-d versus 7-d toxicity of 12 toxicants, including carbaryl, to the water flea (*Ceriodaphnia dubia*). Concerning carbaryl, there was no significant difference in sensitivity between the two methods of toxicity testing as analyzed with four statistical measures including Wilcoxon, Kruskal-Wallis, regression analysis and by examining the 4-d NOEC versus the 7-d LOEC (Oris et al. 1991). These results suggest that concerning *Ceriodaphnia dubia* survival and reproduction tests, a 4-d test could be used as a replacement to the traditional 7-d to conserve time, effort and costs (Oris et al. 1991).

Kaushik and Kumar (1998) studied the intestinal pathology of a freshwater crab (*Paratelphusa masoniana*) exposed to 252 µg/L of carbaryl for a period of 30 days. The insecticide induced persistent hyperplasia and proliferation of the mucosal epithelium causing folds to develop in the lumen of the gut (Kaushik and Kumar 1998).

8.2.1.7. Long-term toxicity to freshwater amphibians

The most sensitive amphibian species in a long-term toxicity test was the gray tree frog (*Hyla versicolor*) which had a 10-d EC_{60} for survival of 50 µg/L for tadpoles (Relyea and Mills 2001).

Rohr et al. (2003) examined the effects of carbaryl exposure (0.5, 5 and 50 µg/L) to the salamander (*Ambystoma barbouri*) for a study period of 37 days. At all three concentrations of carbaryl, no significant changes occurred to the hatching success or embryo rate of survival of the salamanders. The tanks containing carbaryl treatments did however contain significantly more larvae with limb deformities compared to control tanks (Rohr et al. 2003).

8.2.1.8. Long-term toxicity to freshwater aquatic plants

Carbaryl is not considered a phytotoxic substance when used as directed. The most sensitive endpoint for a freshwater plant was a 5-d EC_{10} of 140 µg/L for blue-green alga (*Anabaena flos-aquae*) (Lintott 1992b) while the least sensitive endpoint was an IC_{48} of 5000 µg/L for green algae (*Scenedesmus bijugatus*) (Megharaj et al. 1989).

8.2.2 Toxicity to Marine Life

8.2.2.1. Short-term toxicity to marine fish

Three euryhaline species of fish were examined for sensitivity to carbaryl toxicity in static acute tests conducted at a salinity of 2‰. The 96-h LC_{50} values for the sheepshead minnow (*Cyprindodon variegatus*) and the Leon Springs pupfish (*Cyprindodon bovinus*) were very similar at 4400 µg/L and 4500 µg/L, respectively (Sappington et al. 2001). The 96-h LC_{50} for the desert pupfish (*Cyprindodon macularius*) was 7200 µg/L, almost two-fold that of the other two species. Other studies assessing the toxicity of carbaryl to the sheepshead minnow found a 72-h LC_{50} value of 2700 µg/L at a salinity of 32‰ (Springborn Bionomics 1985b) and a 96-h LC_{50} of 2600 µg/L for juveniles at a salinity of 20‰ (Lintott 1992c).

The most sensitive fish tested in acute saltwater conditions was the striped bass (*Morone saxatilus*) with a 96-h LC50 of 2300 µg/L (Palawski et al. 1985), while the least sensitive was the mosquitofish (*Gambusia affinis*) with a 96-h TL_m of 31800 µg/L (Chaiyarach et al. 1975).

8.2.2.2. Short-term toxicity to marine invertebrates

Three acute studies regarding the toxicity of carbaryl to the mysid shrimp (*Mysidopsis bahia*) were available. In the first, the 96-h LC_{50} value was 6.7 µg/L conducted at a salinity of 20‰ and with test organisms between 1 and 5 days old (Springborn Bionomics 1985c). In the second study, also conducted at a salinity of 20‰, the 96-h LC_{50} value was 5.7 µg/L for test organisms less than 24-hours old (Lintott 1992a). A 24-h LC_{50} of >7.7 µg/L was calculated for the mysid in a flow-through study (Nimmo et al. 1981). The brine shrimp (*Artemia salina*) was assessed for sensitivity to carbaryl at three age classes during acute 24-h toxicity tests. The LC_{50} values for 24-, 48- and 72-hour old shrimp were 27 567.27 µg/L, 5915.90 µg/L and 350.1 µg/L, respectively (Barahona and Sánchez-Fortún 1999). For this marine species, the sensitivity to the insecticide carbaryl increased with increased development.

Among marine invertebrates, the most sensitive species was the protozoan *Euplotes sp.* with a 24-h LC_{50} of 1 µg/L (Weber et al. 1982) followed by the mysid shrimp. The species demonstrating the least sensitivity was the macrid clam (*Rangea cuneata*) with a 96-h TL_m of 125000 µg/L (Chaiyarach et al. 1975).

Reddy and Rao (1991) investigated the effects of carbaryl to the nitrogen metabolism of the prawn (*Penaeus indicus*) in 96-h static bioassays. A concentration of 7 µg/L carbaryl induced increased levels of ammonia and shifted nitrogen metabolism to the production of urea and glutamine. Glutamate oxidation to ammonia was inhibited as a response to the elevated level of ammonia, and the increased levels of alanine and aspartate aminotransferases were indicative of the onset of gluconeogenesis (Reddy and Rao 1991).

8.2.2.3. Long-term toxicity to marine aquatic plants

A 6-day old culture of the saltwater diatom *Skeletonema costatum* was exposed to carbaryl for a period of 5 days and growth inhibition was observed. The EC_{10}, EC_{50} and EC_{90} values were calculated to be 180, 350 and 680 µg/L, respectively (Lintott 1992d).

8.3 Toxicity modifying factors

8.3.1 pH

Current available data regarding the effect of pH on the toxicity of carbaryl are both limited and inconsistent. Woodward and Mauck (1980) found changes in pH values caused differential toxicity modification depending on the species of invertebrate tested. A decrease in pH from 8.5 to 6.5 increased the toxicity of carbaryl to stoneflies (*Pteronarcella badia*) by a factor of 2.6. Conversely, amphipods (*Gammarus pseudolimnaeus*) were twice as sensitive to carbaryl at a pH of 7.5 and 8.5 compared to a pH of 6.5 (Woodward and Mauck 1980).
A separate study regarding the midge (*Chironomus riparius*) found the toxicity of carbaryl to be greater at pH 4 (24-h LC_{50} of 106 µg/L) compared to that at pH 6 (24-h LC50 of 133 µg/L) (Fisher and Lohner 1986).

Other data concerning yellow perch (*Perca flavescens*) and cutthroat trout (*Salmo clarki*) suggests carbamate toxicity increases with increasing pH, which was attributed to the formation of toxic hydrolysis products under alkaline conditions (Mayer and Ellersieck 1986). Consistent with these findings, the toxicity of carbaryl to bluegills (*Lepomis macrochirus*) increased three-fold with an increase in pH from 6.5 to 8.5 according to a separate study (Sanders et al. 1983).

<u>Decision</u>: There are insufficient data regarding the effects of pH on the toxicity of carbaryl to reliably identify patterns of toxicity modifying effects or to normalize toxicity data.

8.3.2 Hardness

Hard water consists of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions which enter the water from calcium carbonate ($CaCO_3$) (or calcium sulphate ($CaSO_4$)) and dolomite $CaMg(CO_3)_2$, respectively. Hardness is an important toxicity modifying factor concerning ionic and inorganic substances, however generally has minimal effect on the toxicity of organic chemicals. Current available data regarding the effect of hardness on the toxicity of carbaryl are very limited, and any changes in toxicity seen could possibly be attributed to differences in pH (Mayer and Ellersieck 1986). For fathead minnows (*Pimephales promelas*), an acute toxicity test found lower TL_m values in hard water (pH 8.2, alkalinity 360 ppm, hardness 400 ppm) compared to soft water (pH 7.4, alkalinity 18 ppm, hardness 20 ppm). The hard water TL_m values at 24, 48 and 96-h were 12 000, 7100 and 7000 µg/L respectively, while those for soft water were >32 000, 20 000 and 13 000 µg/L demonstrating a higher toxicity in hard water (Henderson et al. 1960).

Decision: There are insufficient data regarding the effects of hardness on the toxicity of carbaryl to reliably identify patterns of toxicity modifying effects or to normalize toxicity data.

8.3.3 Temperature

Toxicity and temperature are positively correlated for most chemicals. Temperature may modify toxicity through changes in solubility and kinetics or through changes to the metabolic rate of the organism being tested. Current available data regarding the effect of temperature on the toxicity of carbaryl are limited. Isolating for temperature, Sanders et al. (1983) found no change in carbaryl toxicity to rainbow trout (*Oncorhynchus mykiss*) between 7, 12 and 22 °C, however toxicity to bluegills (*Lepomis macrochirus*) at 12°C was approximately half that at 22°C (Sanders et al. 1983). Tadpoles of the green frog (*Rana clamitans*) demonstrated decreased survival with increased temperatures during exposure to carbaryl. After 24-h, survival at 27°C was significantly lower compared to survival at 17 and 22°C (Boone and Bridges 1999). The same pattern was seen in molluscs (*Melanopsis dufouri*) exposed to carbaryl at 15, 22 and 29°C, where mortality increased with increasing temperature (Almar et al. 1988). The increased susceptibility of the organisms to pesticides could be attributed to higher enzymatic activity at higher temperatures and/or to an increased rate of general metabolism (Almar et al. 1988). Additionally, differences in toxicity associated with temperature can be attributed to differences in respiration rate, chemical absorption, and excretion and detoxification of chemicals (Mayer and Ellersieck 1986).

Decision: There are insufficient data regarding the effects of temperature on the toxicity of carbaryl to reliably normalize toxicity data.

8.3.4 UV Radiation

Zaga et al. (1998) examined the photoenhanced toxicity of carbaryl to the African clawed frog (*Xenopus laevis*) and the gray tree frog (*Hyla versicolor*). Static tests were conducted with carbaryl concentrations ranging from 240 µg/L to 30000 µg/L and in combination with ultraviolet radiation. In the absence of UV radiation, *Xenopus laevis* embryos demonstrated 30% mortality by day 4 of exposure at a carbaryl concentration of 15000 µg/L. In contrast, when exposed to low UV-B (4 $\mu W/cm^2$) radiation at carbaryl concentrations of up to 15000 µg/L the mortality observed was between 80 and 100% by the second day of exposure. Embryos of *Hyla versicolor* demonstrated similar results. When exposed to 15000 µg/L carbaryl under low UV-B radiation mortality was 93.3% by day 2 of exposure, while for the same exposure duration no significant mortality resulted from exposure to either low UV-B or carbaryl alone (Zaga et al. 1998). Additionally, the study examined the photoactivation of carbaryl. An irradiated carbaryl treatment of 7500 µg/L induced 100% mortality in embryos of *Xenopus laevis* after 24 hours, compared to a nonirradiated carbaryl treatment at the same concentration which did not induce any mortality over the 4-day duration of the experiment (Zaga et al. 1998). The results suggest carbaryl is photoactivated by UV-B, and the photochemical transformation is most likely the cause of the synergistic effects seen on mortality.

8.4 Toxic interactions with other substances

Biotic factors may also play a role in modifying the toxicity of a substance in an aquatic system. In a laboratory experiment, Relyea and Mills (2001) found chemical cues emitted by a caged predator, a salamander (*Ambystoma maculatum)*, caused a 2-4 fold increase in carbaryl toxicity to the larval gray tree frog (*Hyla versicolor*). At low concentrations of carbaryl (3-4% of 4-d LC_{50}) mortality increased from 10-60% to 60-98% if predatory cues were present. Another laboratory experiment by Relyea (2003) looked at effect of predatory cues on various species of amphibian and found synergistic interactions between carbaryl and predatory cues in several species. The chemical cues emitted by a caged predator, a red-spotted newt (*Notophthalmus viridescens*) caused increased mortality in wood frogs (*Rana sylvatica*) both at low concentrations of carbaryl (30-1600 µg/L) and in the absence of carbaryl. In green frogs (*Rana clamitans*) a concentration of 1.6 mg/L of carbaryl caused mortality in 10% of the sample, but caused 80% mortality in the presence of predator cues, an 8-fold increase in lethality. In bullfrogs (*Rana catesbeiana*), the presence of predatory cues increased the lethality of carbaryl 46-fold. The mechanism of the synergy is unknown, but could be attributed to the combined physiological stress of the predators and the inhibition of cholinesterase caused by the insecticide. Alternatively, it could be caused by changes in abiotic variables, for example oxygen or ammonium concentration, brought about through the introduction of the predator. These abiotic variables were investigated in the study and did not appear to drive the synergistic interaction between the predatory cues and carbaryl (Relyea, 2003).

Under environmental conditions in the field, the effect of predatory cues on the toxicity of carbaryl may not be the same as was established in controlled laboratory studies. A mesocosm study by Relyea (2001) found no effect of predatory stress on the toxicity of carbaryl to bullfrogs (*Rana catesbeiana*) or to green frogs (*Rana clamitans*), contrary to previous laboratory findings. Discrepancies in these results compared to previous laboratory studies could be attributed to several factors, including the single-pulse protocol of a mesocosm study versus static-renewal laboratory experiments, the exposure of test water to sunlight in mesocosm studies which causes more rapid break-down of carbaryl, or the community of organisms contained in mesocosm studies which may cause a variety of effects not present in laboratory experiments concerning only a single species.

8.5 Toxicity of Transformation Products

The major degradation product of carbaryl is 1-naphthol, which, for some aquatic species, has been found to be more toxic than carbaryl itself. In a continuous flow-through study with the carp *Cirrhinus mrigala*, the LC_{50} of technical grade carbaryl was 2500 µg/L, compared to1460 µg/L for 1-naphthol (Rao et al. 1984). A marine study by Stewart et al. (1967) assessed the toxicity of Sevin (80% active ingredient) compared to 1-naphthol to the development of various marine species in a 24-hour acute test. Sevin was found to be 30 to 300 times more toxic to crustacean species including mud shrimp (*Upogebia pugettensis*), ghost shrimp (*Callianassa californisnsis*), shore crab (*Hemigrapsus oregonensis*) and dungeness crab (*Cancer magister*), whereas 1-naphthol was found to be more toxic to molluscs including bay mussel (*Mytilus edulis*), pacific oyster (*Crassostrea gigas*) and cockle clam (*Clinocardium nuttallii*) and fish including shiner perch (*Cymatogaster aggregata*), English sole (*Parophrys vetulus*) and threespine stickleback (*Gasterosteus aculeatus*) (Stewart et al. 1967). A flow-through study by Tilak et al. (1980) compared the toxicity of technical grade carbaryl to reagent grade 1-naphthol concerning the freshwater fish Indian major carp, *Labeo rohita.* The 96-h LC_{50} for the small sized fish was 4600 µg/L for carbaryl and 2600 µg/L for 1-naphthol. For the larger sized fish, the LC_{50} values were 7750 µg/L for carbaryl compared to 3130 µg/L for 1-naphthol, demonstrating the metabolite is more toxic than the parent compound for this aquatic species (Tilak et al. 1980). Goldfish (*Carassius auratus*) and killifish (*Fundulus heteroclitus*) are another two species where research has found the toxicity of carbaryl is less than that of the degradation product. A study by Shea and Berry analyzed the toxicity of technical grade carbaryl compared to technical grade 1-naphthol in parallel experiments with goldfish and killifish. In both species, 1-naphthol was found to be more toxic and also induced neurological trauma not seen in the study organisms exposed to carbaryl. Some examples include tremors, increased opercular beats and erratic swimming behaviour (Shea and Berry 1983).

8.6 Toxicity of Formulations versus Technical Active

The toxicities of technical and commercial formulations of carbaryl to the freshwater catfish (*Clarias batrachus*) were compared in 24, 48, 72 and 96-h static exposures. The $LC(I)_{50}$ values (initial concentration of toxicant lethal to 50% of the population) for the commercial formulation were 162 600, 134 080, 123 360, and 107 660 µg/L for 24, 48, 72 and 96-h exposure durations respectively (Tripathi and Shukla 1988). The $LC(I)_{50}$ values for technical carbaryl were 61 140, 53 650, 48 580 and 46 850 µg/L for the same exposure durations. These results indicate that technical carbaryl is 2.5 times more toxic to this fish species than the commercial formulation, and suggests that technical carbaryl rather than the additional formulants is the active principle in the acute toxicity (Tripathi and Shukla 1988). Woodward and Mauck (1980) found similar results when comparing the toxicities of technical carbaryl (99% active ingredient) and commercial formulations (49% active ingredient) to the cutthroat trout (*Salmo clarki*). The 96-h LC_{50} of the technical carbaryl was 3950 µg/L while that for the field formulation of carbaryl was 6700 µg/L (Woodward and Mauck 1980).

9.0 GUIDELINE DERIVATION

A CWQG for carbaryl 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 carbaryl in an aquatic system, below which the structure and function of an aquatic community 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 9.1 (freshwater) and Table 9.2 (marine). For a more comprehensive list of the data requirements refer to the CCME protocol (CCME, 2007). 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 our purposes 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 carbaryl. The derived CWQGs are national in scope and do not take into account watershed-specific conditions.

Table 9.1 Minimum Data Set Requirements for the Generation of freshwater CWQG

Derivation Method	Minimum Toxicity Dataset
Generic SSD	Toxicity tests required for the generation of an SSD, broken out as follows: Fish: 3 tests on 3 different species including 1 salmonid, 1 non-salmonid. Invertebrates: 3 tests on 3 different species including 1 planktonic crustacean, 2 others. 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. Plant/Algae: For short-term guidance: none (for non-phytotoxic substances), 2 (for phytotoxic substances). For long-term guidance: At least one study on a freshwater vascular plant or freshwater algal species (for non-phytotoxic substances), 3 studies (for phytotoxic substances) Toxicity data for amphibians are highly desirable, but not necessary. Data must represent fully aquatic stages. Acceptable endpoints for acute guidance: LC/EC_{50} (severe effects) Acceptable endpoints for chronic guidance: 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}. Note: Primary or secondary data are acceptable.

Table 9.1 Minimum Data Set Requirements for the Generation of freshwater CWQG

Derivation Method	Minimum Toxicity Dataset
Type B1 Guideline	Toxicity tests required for the generation of a Type B1 guideline, broken out as follows: Fish: 3 tests on 3 different species including 1 salmonid, 1 non-salmonid. Invertebrates: 3 tests on 3 different species including 1 planktonic crustacean, 2 others. 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. Plant/Algae: For short-term guidance: none (for non-phytotoxic substances), 2 (for phytotoxic substances). For long-term guidance: At least one study on a freshwater vascular plant or freshwater algal species (for non-phytotoxic substances), 3 studies (for phytotoxic substances) Toxicity data for amphibians are highly desirable, but not necessary. Data must represent fully aquatic stages. Acceptable endpoints for acute guidance: LC/EC_{50} (severe effects) Acceptable endpoints for chronic guidance: Most appropriate ECx/ICx 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}. Note: only primary data are acceptable. Only short-term studies for acute guidance, and long-term for chronic.
Type B2 Guideline	Toxicity tests required for the generation of a Type B1 guideline, broken out as follows: Fish: 2 short-term and/or long-term studies on two or more fish species, including 1 salmonid, 1 non-salmonid. Invertebrates: 2 short-term and/or long-term studies on 2 or more invertebrate species from different classes, including 1 planktonic sp. Plants: For acute guidance: none (for non-phytotoxic substances), 2 (for phytotoxic substances) For chronic guidance: none (for non-phytotoxic substances), 2 (for phytotoxic substances) Acceptable endpoints for acute guidance: LC/EC_{50} (severe effects) Acceptable endpoints for chronic guidance: Most appropriate ECx/ICx 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}. Note: primary and/or secondary data are acceptable. Only short-term studies for short-term guidance, and short or long-term for long-term guidance.

Table 9.2 Minimum Data Set Requirements for the Generation of marine CWQG

Derivation Method	Minimum Toxicity Dataset
Generic SSD	Toxicity tests required for the generation of an SSD, broken out as follows: Fish: 3 tests on 3 different species including at least one temperate species. Invertebrates: At least 2 studies on two or more marine species from different classes, including at least one temperate species. Plant/Algae: At least one study on a temperate marine vascular plant for non-phytotoxic substances. For phytotoxic substances, three studies on nontarget marine plant or algal species are required for long-term guidance. For short-term guidance, two studies on nontarget marine plant or algal species are required for phytotoxic substances. Acceptable endpoints for acute guidance: LC/EC_{50} (severe effects) Acceptable endpoints for chronic guidance: 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}. Note: Primary or secondary data are acceptable.
Type B1 Guideline	Toxicity tests required for the generation of a Type B1 guideline, broken out as follows: Fish: 3 tests on 3 different species including at least one temperate species. Invertebrates: At least 2 studies on two or more marine species from different classes, including at least one temperate species. Plant/Algae: At least one study on a temperate marine vascular plant for non-phytotoxic substances. For phytotoxic substances, three studies on nontarget marine plant or algal species are required for long-term guidance. For short-term guidance, two studies on nontarget marine plant or algal species are required for phytotoxic substances. Acceptable endpoints for acute guidance: LC/EC_{50} (severe effects) Acceptable endpoints for chronic guidance: Most appropriate ECx/ICx 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}. Note: only primary data are acceptable. Only short-term studies for acute guidance, and long-term for chronic.
Type B2 Guideline	Toxicity tests required for the generation of a Type B1 guideline, broken out as follows: Fish: At least two studies on two or more marine fish species, including at least one temperate species. Invertebrates: 2 short-term and/or long-term studies on 2 or more invertebrate species. Plants: For acute guidance: none (for non-phytotoxic substances), 2 (for phytotoxic substances) For chronic guidance: none (for non-phytotoxic substances), 2 (for phytotoxic substances) Acceptable endpoints for acute guidance: LC/EC_{50} (severe effects) Acceptable endpoints for chronic guidance: Most appropriate ECx/ICx 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}. Note: primary and/or secondary data are acceptable. Only short-term studies for short-term guidance, and short or long-term for long-term guidance.

9.1 Protection of Freshwater Aquatic 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 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 components of aquatic ecosystem function 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.

9.1.1 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 carbaryl. Industry aquatic toxicity data retrieved through the Bayer CropScience internal database was considered acceptable for guideline derivation and was incorporated, when applicable, into the dataset used to derive the guideline values. 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.

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 carbaryl, 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 9.2 presents the final dataset that was used to generate the fitted SSD for short-term freshwater exposure to carbaryl.

Table 9.3 Final Aquatic Toxicity Data Selected For Generic SSD Development

Study No.	Organism	Latin Name	Endpoint	Effect Concentration (µg a.i./L)	Reference
1	Cladoceran	*Bosmina fatalis*	24-h LC_{50}	4.075	(Sakamoto et al. 2005)
2	Stonefly	*Chloroperla grammatica*	96-h LC_{50}	5.8	(Schafers 2002a)
3	Cladoceran	*Bosmina longirostris*	24-h LC_{50}	8.597	(Sakamoto et al. 2005)
4	Water flea	*Daphnia similis*	48-h EC_{50} (immobility)	8.8	(Bortoleto 1992)
5	Water flea	*Ceriodaphnia dubia*	48-h LC_{50}	11.6	(Oris et al. 1991)
6	Cladoceran	*Chydorus sphaericus*	48-h EC_{50} (immobility)	12.4	(Schafers 2002d)
7	Water flea	*Daphnia magna*	48-h EC_{50} (immobility)	16	(Ebeling and Nguyen 2002)
8	Prawn	*Macrobrachium lamarrei*	96-h LC_{50}	19	(Omkar and Shukla 1985)
9	Scud	*Gammarus fossarum*	96-h LC_{50}	31	(Schafers 2002g)
10	Black fly	*Simulium vittatum*	48-h EC_{50} (immobility)	32.43*	(Overmyer et al. 2003)
11	Mayfly	*Ephemera danica*	96-h LC_{50}	153	(Schafers 2002e)
12	Mysid shrimp	*Mysis relicta*	96-h LC_{50}	230	(Landrum and Dupuis 1990)
13	Amphipod	*Pontoporeia hoyi*	96-h LC_{50}	250	(Landrum and Dupuis 1990)
14	Mosquito	*Aedes aegypti*	24-h LC_{50}	510	(Parsons and Surgeoner 1991b)
15	Atlantic sturgeon	*Acipenser oxyrhynchus*	48-h LC_{50}	1280	(Dwyer et al. 2000)
16	Apache trout	*Oncorhynchus gilae apache*	96-h LC_{50}	1540	(Dwyer et al. 1995)
17	Greenback cutthroat trout	*Oncorhynchus clarki stomias*	96-h LC_{50}	1550	(Dwyer et al. 1995)
18	Rainbow trout	*Oncorhynchus mykiss*	96-h LC_{50}	1880	(Dwyer et al. 1995)
19	Colorado squawfish	*Ptychocheilus lucius*	96-h LC_{50}	2005.42*	(Beyers et al. 1994;Dwyer et al. 1995)
20	Fountain darter	*Etheostoma fonticola*	96-h LC_{50}	2020	(Dwyer et al. 2005b)
21	Greenthroat darter	*Etheostoma lepidum*	96-h LC_{50}	2140	(Dwyer et al. 2005b)
22	Lahontan cutthroat trout	*Oncorhynchus clarki henshawi*	96-h LC_{50}	2250	(Dwyer et al. 1995)
23	Toad	*Bufo arenarum*	96-h LC_{50}	2464	(Ferrari et al. 2004a)
24	Guppy	*Poecilia reticulata*	96-h LC_{50}	2515.26	(Gallo et al. 1995)
25	Bonytail	*Gila elegans*	96-h LC_{50}	2655.15*	(Beyers et al. 1994;Dwyer et al. 1995)
26	Gila topminnow	*Poeciliopsis occidentalis occidentalis*	96-h LC_{50}	3000	(Dwyer et al. 2005b)
27	Spotfin chub	*Hybopsis monacha*	96-h LC_{50}	3410	(Dwyer et al. 2005b)
28	Shortnose sturgeon	*Acipenser brevirostrum*	48-h LC_{50}	4230	(Dwyer et al. 2000)
29	Razorback sucker	*Xyrauchen texanus*	96-h LC_{50}	4350	(Dwyer et al. 1995)
30	Cape Fear shiner	*Notropis mekistocholas*	96-h LC_{50}	4510	(Dwyer et al. 2005b)
31	Fathead minnow	*Pimephales promelas*	96-h LC_{50}	5210	(Dwyer et al. 1995)
32	Dwarf gouramy	*Colisa fasciatus*	96-h LC_{50}	8000	(Singh et al. 2004)
33	Southern leopard frog	*Rana sphenocephala*	96-h LC_{50}	8400	(Bridges et al. 2002)

Table 9.3 Final Aquatic Toxicity Data Selected For Generic SSD Development

Study No.	Organism	Latin Name	Endpoint	Effect Concentration (µg a.i./L)	Reference
34	Fragile papershell mussel	*Leptodea fragilis*	24-h LC_{50}	9100	(Milam et al. 2005)
35	Zebrafish	*Brachydanio rerio*	96-h LC_{50}	9256.17	(Gallo et al. 1995)
36	Goldfish	*Carassius auratus*	96-h LC_{50}	13900	(Ferrari et al. 2004b)
37	Snail	*Pomacea patula*	96-h LC_{50}	14600	(Mora et al. 2000)
38	Green frog	*Rana clamitans*	96-h LC_{50}	16295.63*	(Boone and Bridges 1999)
39	Washboard mussel	*Megalonaias nervosa*	24-h LC_{50}	27400	(Milam et al. 2005)
40	Fatmucket mussel	*Lampsilis siliquoidea*	24-h LC_{50}	31100	(Milam et al. 2005)
41	Plain pocketbook mussel	*Lampsilis cardium*	24-h LC_{50}	33900	(Milam et al. 2005)
42	Paper pondshell mussel	*Utterbackia imbecellis*	24-h LC_{50}	40200	(Milam et al. 2005)
43	Pondmussel	*Ligumia subrostrata*	24-h LC_{50}	43100	(Milam et al. 2005)

***value shown is the geometric mean of comparable values**

The values reported in Table 9.2 range from a 24h-LC_{50} of 4.075 µg/L for the cladoceran, *Bosmina fatalis,* to a 24-h LC_{50} of 43100 µg/L for the pondmussel, *Ligumia subrostrata*(Milam et al. 2005;Sakamoto et al. 2005). Geometric mean values were calculated for *Simulium vittatum, Ptychocheilus lucius, Gila elegans* and *Rana clamitans* (Table 9.3). Effect concentrations reported for the remaining species were taken from single studies.

Table 9.4 Studies Used To Derive Geometric Means

Organism	Endpoint	Effect Concentration (µg/L)	Geometric Mean (µg a.i./L)	Reference
Simulium vittatum (Black fly)	48-h LC_{50}	23.72 44.34	32.43	(Overmyer et al. 2003)
Ptychocheilus lucius (Colorado squawfish	96-h LC_{50}	1310 3070	2005.42	(Beyers et al. 1994;Dwyer et al. 1995)
Gila elegans (Bonytail)	96-h LC_{50}	2020 3490	2655.15	(Beyers et al. 1994;Dwyer et al. 1995)
Rana clamitans (Green frog)	96-h LC_{50}	11320 17360 22020	16295.63	(Boone and Bridges 1999)

Short-term freshwater toxicity data were lacking for algae and aquatic plant species. Despite the absence of acceptable data for these species, there are still sufficient data available for the derivation of a CWQG using the generic SSD approach (Table 9.1). This method estimates the concentration of carbaryl in water that will be protective of at least 95% of aquatic biota. Short-term freshwater toxicity data for aquatic plant and algae species with carbaryl are very limited, possibly on account of the fact it is an insecticide that is designed to be applied to terrestrial plants without adversely affecting them. Long-term toxicity studies with algae and aquatic plants have shown a generally high tolerance of these species to carbaryl. The diatom *Navicula pelliculosa,* the blue-green algae *Anabaena flos-aquae,* and the green algae *Pseudokirchneriella subcapitata* had 5-d EC_{10} values for growth inhibition of 290, 140, and 560 µg/L, respectively

(Lintott 1992e) (Lintott 1992b) (Lintott 1992f). The primary mode of action of carbaryl toxicity is through inhibition of acetylcholinesterase, causing the build-up of acetylcholine and over-stimulation of the central nervous system. This exposure pathway is absent in plant and algal species, and may explain the increased tolerance of these species to the insecticide. On account of the relatively high tolerance of algae and plant species to carbaryl, determining the level of protection to more sensitive invertebrate and vertebrate species should provide an adequate level of protection for primary producers.

The short-term SSD is preferentially derived from LC/EC_{50} data for short-term, severe effects. The final CWQG value for carbaryl was the 5th percentile of the short-term SSD.

Each species for which appropriate short-term toxicity data were available was ranked according to sensitivity, and its centralized position on the SSD was determined using the following standard equation for Hazen plotting positions (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.

According to the CCME Protocol for the Derivation of Water Quality Guidelines for the Protection of Aquatic Life (CCME 2007), datasets displaying bimodal or multimodal distributions may have separate SSD curves plotted and the most sensitive taxonomic level may be used to derive the guideline. Concerning carbaryl, SSDs were plotted for all taxa together (in a lumped distribution) as well as for arthropods separately (in a split distribution). Plotting separate SSDs for major taxa, specifically arthropods, is appropriate for carbaryl given its targeted mode of action towards insect species, and hence their increased sensitivity to carbaryl exposure. The increased sensitivity of arthropods is apparent from the bimodal distribution that results when all aquatic species are plotted together (Figure 9.1). Plotting arthropods separately (Figure 9.2) allows for an increased goodness-of-fit at the lower tail of the model.

Concerning the lumped distribution, the Gompertz model provided the best fit of the twelve models tested (Anderson-Darling Statistic (A^2) = 0.843). The equation of the fitted Gompertz is of the form

$$f(x) = 1 - e^{-e^{\frac{(x-\mu)}{s}}}$$

Where x is the concentration metameter, and the functional response, *f(x)*, is the proportion of taxa affected. The parameters, *μ* and *s*, are the location and scale parameters of the model. The scale parameter in the Gompertz model must always be positive. For the fitted model μ = 3.6350 and *s*= 0.96701.

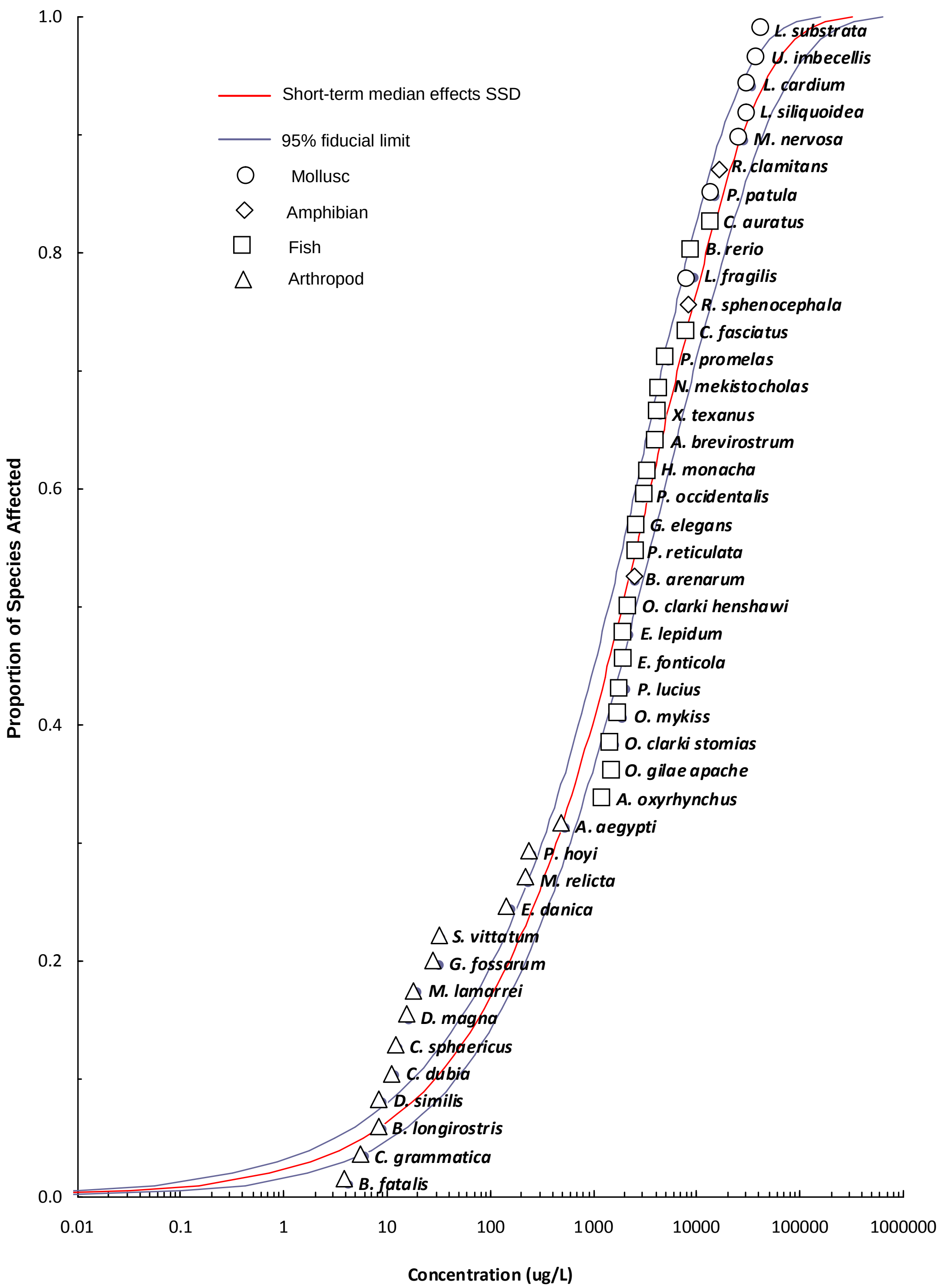

Figure 9.1 Short-term SSD representing the toxicity of carbaryl in freshwater consisting of acceptable short-term LC_{50}s of aquatic species versus proportion of species affected.

From Figure 9.1 there can be seen some discontinuity of the data and an apparent bimodal distribution. This can be explained by the targeted mode of action of carbaryl to insect species, and hence the increased sensitivity of arthropods.

Concerning the split distribution, in which the most sensitive taxa, arthropods, are plotted, the Fisher-Tippett model provided the best fit of the 12 models tested (Anderson-Darling Statistic (A^2) = 0.350). The equation of the fitted Fisher-Tippett 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*= 1.1179and *S*= 0.545123. The dataset for the fitted short-term SSD for arthropod species can be found in Table 9.4 and the fitted SSD to this dataset can be seen in Figure 9.2.

Table 9.5 Arthropod Aquatic Toxicity Data for SSD Development for Carbaryl

Study No.	Organism	Latin Name	Endpoint	Effect Concentration (µg a.i./L)	Reference
1	Cladoceran	*Bosmina fatalis*	24-h LC_{50}	4.075	(Sakamoto et al. 2005)
2	Stonefly	*Chloroperla grammatica*	96-h LC_{50}	5.8	(Schafers 2002a)
3	Cladoceran	*Bosmina longirostris*	24-h LC_{50}	8.597	(Sakamoto et al. 2005)
4	Water flea	*Daphnia similis*	48-h EC_{50} (immobility)	8.8	(Bortoleto 1992)
5	Water flea	*Ceriodaphnia dubia*	48-h LC_{50}	11.6	(Oris et al. 1991)
6	Cladoceran	*Chydorus sphaericus*	48-h EC_{50} (immobility)	12.4	(Schafers 2002d)
7	Water flea	*Daphnia magna*	48-h EC_{50} (immobility)	16	(Ebeling and Nguyen 2002)
8	Prawn	*Macrobrachium lamarrei*	96-h LC_{50}	19	(Omkar and Shukla 1985)
9	Scud	*Gammarus fossarum*	96-h LC_{50}	31	(Schafers 2002g)
10	Black fly	*Simulium vittatum*	48-h EC_{50} (immobility)	32.43*	(Overmyer et al. 2003)
11	Mayfly	*Ephemera danica*	96-h LC_{50}	153	(Schafers 2002e)
12	Mysid shrimp	*Mysis relicta*	96-h LC_{50}	230	(Landrum and Dupuis 1990)
13	Amphipod	*Pontoporeia hoyi*	96-h LC_{50}	250	(Landrum and Dupuis 1990)
14	Mosquito	*Aedes aegypti*	24-h LC_{50}	510	(Parsons and Surgeoner 1991b)

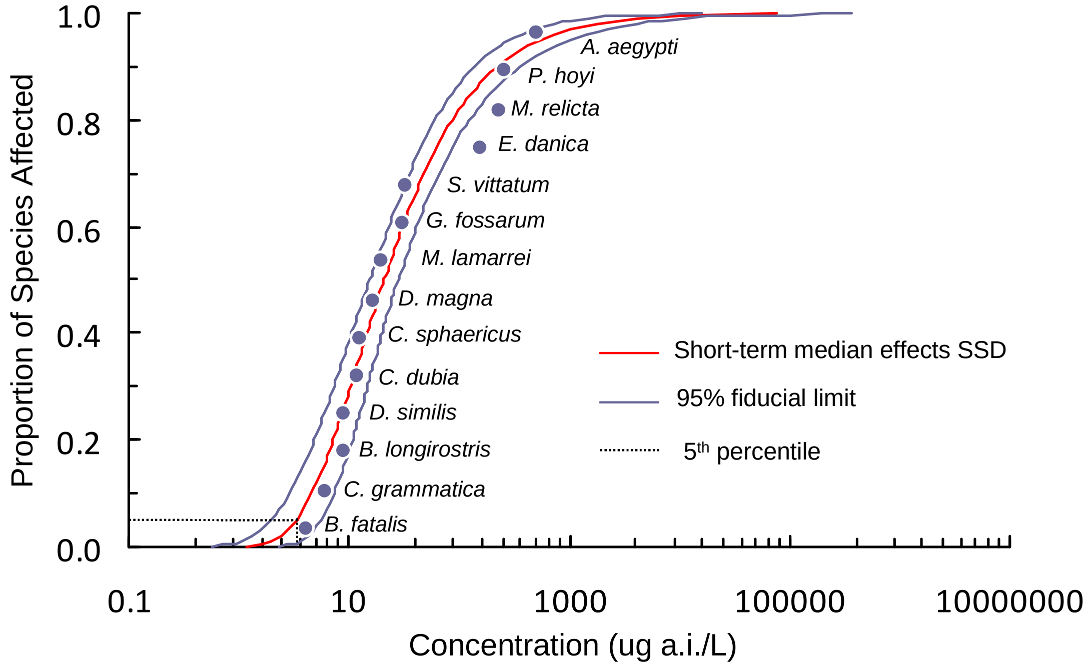

Figure 9.2. Short-term SSD representing the toxicity of carbaryl in freshwater consisting of acceptable short-term LC_{50}s of arthropod species versus proportion of species affected.

The lower A^2 value of the split distribution (0.350) compared to the lumped distribution (0.843), indicates splitting the data by taxa provides a better goodness-of-fit. Therefore, given that there were sufficient data to separate out the most sensitive group of taxa and tenerate an SSD with an improved fit, it was decided that the short-term guidelines should be based on the split distribution. The 5th percentile on the short-term SSD for the split distribution is 3.31. The lower fiducial limit (5%) on the 5th percentile is 1.98 µg/L and the upper fiducial limit (95%) on the 5th percentile is 5.53 µg/L.

Table 9.6 Short-term CWQG for Carbaryl Resulting from the SSD Method

CWQG Metric	Concentration
SSD 5th percentile	3.31 µg a.i./L
SSD 5th percentile, 90% LFL (5%)	1.98 µg a.i./L
SSD 5th percentile, 90% UFL (95%)	5.53 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 3.3 µg a.i.•L^{-1}, for carbaryl

9.1.2 Long-term freshwater CWQG

Despite the relatively low persistence of carbaryl under the majority of environmental conditions, aquatic organisms may experience long-term exposure to the insecticide if they inhabit water receiving frequent applications of a pesticide or if pesticide input occurs simultaneously from multiple sources.

The acceptable long-term studies identified in this review consisted of three invertebrate species, four fish species, and three algal species. Other data points 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. Based on the minimum data requirements, there were insufficient data to derive a long-term SSD for carbaryl according to CCME (2007) protocol, as there was no long-term study regarding a salmonid fish species. There were also insufficient data to derive a long-term guideline using 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 freshwater CWQG.

Using the Type B2 guideline method to derive the long-term CWQG, the critical (lowest acceptable) endpoint was identified as a 24h-LC_{50} of 4.075 µg a.i.•L^{-1}, for the cladoceran *Bosmina fatalis* (Sakamoto et al. 2005). A safety factor of 20 was applied to the lowest data to derive the Type B2 guideline for carbaryl. The safety factor accounts for differences in sensitivity to carbaryl due to differences in species, exposure conditions, and test endpoints, as well as scarcity of toxicological data, cumulative exposures and policy requirements, for example extrapolating a low-effect threshold to derive a protective environmental benchmark (CCME 2007).

Therefore, in accordance with the CCME protocol (CCME 2007), the CWQG is based on a Type B2 approach, and is calculated as follows:

CWQG = LOEC / 10
= 4.075/20
= 0.20 µg a.i./L

Therefore, the long-term exposure CWQG for the protection of freshwater life is 0.20 µg a.i.•L^{-1}, for carbaryl.

9.2 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 A.

9.2.1 Short-term marine CWQG

The acceptable short-term studies identified in this review consisted of four invertebrate species and three fish species. Based on the minimum data requirements; there were insufficient data to derive a short-term SSD for carbaryl according to the CCME (2007) protocol, as there was no study regarding a temperate marine fish species. There were also insufficient data to derive a short-term guideline using the lowest endpoint approach (Type B1). Therefore, following the tiered approach, the lowest endpoint approach (Type B2) guideline method was used to develop the short-term marine CWQG.

Using the Type B2 guideline method to derive the short-term CWQG, the critical endpoint was identified as a 96-h LC_{50} of 5.7 µg/L for the mysid *Mysidopsis bahia* (24-h old) (Lintott 1992a). A safety factor of 10 was applied to the critical endpoint to derive a Type B2 guideline.

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} / 10
= 5.7 /10
=0.57 µg a.i./L

Therefore, the short-term exposure benchmark concentration indicating the potential for severe effects (e.g. lethality or immobilization) to sensitive marine life during transient events is 0.57 µg a.i./L, for carbaryl.

9.2.2 Long-term marine CWQG

The acceptable long-term studies identified for marine species consisted of only the diatom *Skeletonema costatum*. 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 96-h LC_{50} of 5.7 µg a.i.•L^{-1} for the mysid *Mysidopsis bahia* (24-h old) (Lintott 1992a). A safety factor of 20 was applied to the lowest data to derive the long-term Type B2 guideline for carbaryl.

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
= 5.7 /20
=0.29 µg a.i./L

Therefore, the long-term exposure CWQG for the protection of marine life in surface waters is 0.29 µg a.i./L, for carbaryl.

9.3 Data Gaps and Research Recommendations

There is a large body of available data concerning the short-term toxicity of technical carbaryl to freshwater fish and invertebrate species. Concerning long-term freshwater studies, there was a data gap of one salmonid study which prevented use of the SSD guideline derivation method, and hence the lowest endpoint approach (Type B2) was implemented. In the event that a long-term freshwater toxicity test with a salmonid becomes available or is commissioned, it is recommended that the guideline value be updated using the SSD approach, as all other data requirements had been satisfied. In addition, 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 for the marine environment.

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APPENDIX A

TOXICITY VALUES FOR FRESHWATER AQUATIC SPECIES EXPOSED TO CARBARYL

Table A1 Toxicity Values for Freshwater Long-term Aquatic Species Exposed to Carbaryl

Latin name	Common name	Life stage	Duration	Endpoint	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp. (°C)	Hard-ness mg/L	Reference
Algae														
Anabaena fertilissima	Cyanobact-eria	NR	15 d	EC50	7400	Growth	50	S	U	7.8		26 +/- 1		(Das and Adhikary 1996)
Anabaena flos-aquae	Blue-green alga	6 d	5 d	EC10	140	Growth	99.7	S	1	7.1-7.3		23.5-24.1		(Lintott 1992b)
Anabaena flos-aquae	Blue-green alga	6 d	5 d	EC50	380	Growth	99.7	S	1	7.1-7.3		23.5-24.1		(Lintott 1992b)
Anabaena flos-aquae	Blue-green alga	6 d	5 d	EC90	1100	Growth	99.7	S	1	7.1-7.3		23.5-24.1		(Lintott 1992b)
Anabaena variabilis	Cyanobact-eria	NR	15 d	EC50	5100	Growth	50	S	U	7.8		26 +/- 1		(Das and Adhikary 1996)
Calothrix parietina	Cyanobact-eria	NR	15 d	EC50	28100	Growth	50	S	U	7.8		26 +/- 1		(Das and Adhikary 1996)
Calothrix sp.	Cyanobact-eria	NR	15 d	EC50	50900	Growth	50	S	U	7.8		26 +/- 1		(Das and Adhikary 1996)
Chlorella pyrenoidosa	Green algae	NR	96 h	EC50	4184.5	Abundance	92	S	U			24		(Ma et al. 2006)
Chlorella pyrenoidosa	Green algae	NR	96 h	NOEC	200	Abundance	92	S	U			24		(Ma et al. 2006)
Chlorella pyrenoidosa	Green algae	NR	96 h	LOEC	500	Abundance	92	S	U			24		(Ma et al. 2006)
Chlorella vulgaris	Green algae	NR	96 h	EC50	3561.5	Abundance	92	S	U			24		(Ma et al. 2006)
Chlorella vulgaris	Green algae	NR	96 h	NOEC	200	Abundance	92	S	U			24		(Ma et al. 2006)
Chlorella vulgaris	Green algae	NR	96 h	LOEC	500	Abundance	92	S	U			24		(Ma et al. 2006)
Eubosmina coregoni	Zooplankt-on	NR	4 d	IC40	10	Abundance		NR	U	8-9				(Havens 1995)
Eubosmina coregoni	Zooplankt-on	NR	4 d	IC50	20	Biomass reduction		NR	U	8.7	8	21		(Havens 1994)
Navicula pelliculosa	Diatom	5 d	5 d	EC10	290	Growth	99.7	S	1	7.3-8.4		24.1-24.5		(Lintott 1992e)

Latin name	Common name	Life stage	Duration	Endpoint	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp. (°C)	Hard-ness mg/L	Reference
Navicula pelliculosa	Diatom	5 d	5 d	EC50	610	Growth	99.7	S	1	7.3-8.4		24.1-24.5		(Lintott 1992e)
Navicula pelliculosa	Diatom	5 d	5 d	EC90	1300	Growth	99.7	S	1	7.3-8.4		24.1-24.5		(Lintott 1992e)
Nostoc linckia	Cyanobact-eria	NR	15 d	EC50	15400	Growth	50	S	U	7.8		26 +/-1		(Das and Adhikary 1996)
Nostoc muscorum	Cyanobact-eria	NR	15 d	EC50	22500	Growth	50	S	U	7.8		26 +/-1		(Das and Adhikary 1996)
Nostoc sphaericum	Cyanobact-eria	NR	15 d	EC50	9000	Growth	50	S	U	7.8		26 +/-1		(Das and Adhikary 1996)
Pseudokirchner iella subcapitata	Green algae	NR	96 h	EC50	1370	Growth	99.1	S	2	6.6-9.2	6.9-9.1	24-25.7	0.20 mmol /L	(Ebeling and Gosch 2002)
Raphidocelis subcapitata	Green algae	NR	6 d	LOEC	5030.5	Growth	NR	S	U			24		(Bierkens et al. 1998)
Scenedesmus bijugatus	Green algae	NR	6 d	IC48	5000	Growth	99.9	NR	U					(Megharaj et al. 1989)
Scenedesmus obliquus	Green algae	NR	96 h	EC50	2797	Abundance	92	S	U			24		(Ma et al. 2006)
Scenedesmus obliquus	Green algae	NR	96 h	NOEC	200	Abundance	92	S	U			24		(Ma et al. 2006)
Scenedesmus obliquus	Green algae	NR	96 h	LOEC	500	Abundance	92	S	U			24		(Ma et al. 2006)
Scenedesmus quadricauda	Green algae	NR	96 h	EC50	6101.4	Abundance	92	S	U			24		(Ma et al. 2006)
Scenedesmus quadricauda	Green algae	NR	96 h	NOEC	500	Abundance	92	S	U			24		(Ma et al. 2006)
Scenedesmus quadricauda	Green algae	NR	96 h	LOEC	1000	Abundance	92	S	U			24		(Ma et al. 2006)
Scytonema multiramosum	Cyanobact-eria	NR	15 d	EC50	18300	Growth	50	S	U	7.8		26 +/-1		(Das and Adhikary 1996)
Scytonema sp.	Cyanobact-eria	NR	15 d	EC50	22700	Growth	50	S	U	7.8		26 +/-1		(Das and Adhikary 1996)
Selenastrum capricornumtu m	Green algae	NR	4 d	EC20	1040	Growth		S	U	8.2		24 +/-1	171	(Versteeg 1990)

Latin name	Common name	Life stage	Duration	Endpoint	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp. (°C)	Hard-ness mg/L	Reference
Selenastrum capricornumtum	Green algae	NR	96 h	EC(I)50	3384	Growth	99	S	U	7.0		24 +/- 2		(Vargas and Bonetti 1992)
Selenastrum capricornumtum	Green algae	7 d	5 d	EC10	560	Reduced population	99.7	S	2	7.4-7.6		24 +/- 2		(Lintott 1992f)
Selenastrum capricornumtum	Green algae	7 d	5 d	EC50	1200	Reduced population	99.7	S	2	7.4-7.6		24 +/- 2		(Lintott 1992f)
Selenastrum capricornumtum	Green algae	7 d	5 d	EC90	2400	Reduced population	99.7	S	2	7.4-7.6		24 +/- 2		(Lintott 1992f)
Selenastrum capricornumtum	Green algae	NR	96 h	EC50	3067.3	Abundance	92	S	U			24		(Ma et al. 2006)
Selenastrum capricornumtum	Green algae	NR	96 h	NOEC	200	Abundance	92	S	U			24		(Ma et al. 2006)
Selenastrum capricornumtum	Green algae	NR	96 h	LOEC	500	Abundance	92	S	U			24		(Ma et al. 2006)
Westiellopsis sp.	Cyanobact-eria	NR	15 d	EC50	9600	Growth	50	S	U	7.8		26 +/- 1		(Das and Adhikary 1996)
Amphibians														
Bufo americanus	American toad	Tadpol-e	16 d	LC50	3400	Mortality		R	U	7.8-8.0		18.2-20.0		(Relyea 2003)
Hyla versicolor	Gray tree frog	Tadpol-e	10 d	EC60	50	Survival	99.8	R	U					(Relyea and Mills 2001)
Hyla versicolor	Gray tree frog	Tadpol-e	16 d	LC50	2500	Mortality		R	U	7.8-8.0		18.2-20.0		(Relyea 2003)
Rana catesbeiana	Bullfrog	Tadpol-e	16 d	LC50	2300	Mortality		R	U	7.8-8.0		18.2-20.0		(Relyea 2003)
Rana clamitans	Green frog	Tadpol-e	16 d	LC50	2600	Mortality		R	U	7.8-8.0		18.2-20.0		(Relyea 2003)
Rana pipiens	Leopard frog	Tadpol-e	16 d	LC50	2200	Mortality		R	U	7.8-8.0		18.2-20.0		(Relyea 2003)

Latin name	Common name	Life stage	Duration	Endpoint	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp. (°C)	Hard-ness mg/L	Reference
Rana sylvatica	Woodfrog	Tadpol-e	16 d	LC50	1200	Mortality		R	U	7.8-8.0		18.2-20.0		(Relyea 2003)
Fish														
Cyprinus carpio	Common carp	Larva	60 d	MATC	50-80	Growth and survival		R	U	7.2	6.9-7.4	20-23.2	60-88	(Verma et al. 1981)
Gila elegans	Bonytail	Larva	32 d	NOEC	650	Growth	99	R	2	7.9-8.2	6.1-7.0	21.2-22.7	344-378	(Beyers et al. 1994)
Gila elegans	Bonytail	Larva	32 d	NOEC	650	Survival	99	R	2	7.9-8.2	6.1-7.0	21.2-22.7	344-378	(Beyers et al. 1994)
Gila elegans	Bonytail	Larva	32 d	LOEC	1240	Growth	99	R	2	7.9-8.2	6.1-7.0	21.2-22.7	344-378	(Beyers et al. 1994)
Gila elegans	Bonytail	Larva	32 d	LOEC	1240	Survival	99	R	2	7.9-8.2	6.1-7.0	21.2-22.7	344-378	(Beyers et al. 1994)
Gila elegans	Bony tail Chub	2 d	7 d	IC25	250	Survival	99.7	R	2	7.8-8.0		22	160-180	(Dwyer et al. 2005a)
Gila elegans	Bony tail Chub	2 d	7 d	IC25	250	Survival	99.7	R	2	8.0-8.6		22	160-180	(Dwyer et al. 2005a)
Pimephales promelas	Fathead minnow	Larva	9 months	LC20	32.465	Mortality	80	FT	U	7.1-7.6	7.1-8.0	18-29	44.9-45.2	(Carlson 1971)
Pimephales promelas	Fathead minnow	24h	7 d	MATC	569	Growth	99	FT	2				4-49	(Norberg-King 1989)
Pimephales promelas	Fathead minnow	24h	7 d	MATC	976	Growth and survival	99	FT	2				4-49	(Norberg-King 1989)
Pimephales promelas	Fathead minnow	24h	7 d	NOEC	400	Growth	99	FT	2				4-49	(Norberg-King 1989)
Pimephales promelas	Fathead minnow	24h	7 d	NOEC	680	Growth and survival	99	FT	2				4-49	(Norberg-King 1989)
Pimephales promelas	Fathead minnow	24h	7 d	LOEC	810	Growth	99	FT	2				4-49	(Norberg-King 1989)
Pimephales promelas	Fathead minnow	24h	7 d	LOEC	1400	Growth and survival	99	FT	2				4-49	(Norberg-King 1989)
Pimephales promelas	Fathead minnow	24h	7 d	MATC	576	Growth	99	R	2				4-49	(Norberg-King 1989)
Pimephales promelas	Fathead minnow	24h	7 d	MATC	1018	Survival	99	R	2				4-49	(Norberg-King 1989)

Latin name	Common name	Life stage	Duration	Endpoint	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp. (°C)	Hard-ness mg/L	Reference
Pimephales promelas	Fathead minnow	24h	7 d	NOEC	390	Growth	99	R	2				4-49	(Norberg-King 1989)
Pimephales promelas	Fathead minnow	24h	7 d	NOEC	740	Survival	99	R	2				4-49	(Norberg-King 1989)
Pimephales promelas	Fathead minnow	24h	7 d	LOEC	1600	Growth	99	R	2				4-49	(Norberg-King 1989)
Pimephales promelas	Fathead minnow	24h	7 d	LOEC	1400	Survival	99	R	2				4-49	(Norberg-King 1989)
Pimephales promelas	Fathead minnow	24h	7 d	IC25	420	Survival	99.7	R	2	8.0-8.6		22	160-180	(Dwyer et al. 2005a)
Pimephales promelas	Fathead minnow	7 d	7 d	NOEC	4000	Survival	99.8	FT	2	7.24-8.4	6.0 (4.4-7.2)	25 +/- 1	86-94	(Pickering et al. 1996)
Pimephales promelas	Fathead minnow	7 d	7 d	NOEC	1000	Growth	99.8	FT	2	7.24-8.4	6.0 (4.4-7.2)	25 +/- 1	86-94	(Pickering et al. 1996)
Pimephales promelas	Fathead minnow	7 d	7 d	NOEC	500	Growth	99.8	FT	2	7.24-8.4	6.0 (4.4-7.2)	25 +/- 1	86-94	(Pickering et al. 1996)
Pimephales promelas	Fathead minnow	7 d	7 d	LOEC	1000	Growth	99.8	FT	2	7.24-8.4	6.0 (4.4-7.2)	25 +/- 1	86-94	(Pickering et al. 1996)
Pimephales promelas	Fathead minnow	7 d	7 d	LOEC	2000	Growth	99.8	FT	2	7.24-8.4	6.0 (4.4-7.2)	25 +/- 1	86-94	(Pickering et al. 1996)
Pimephales promelas	Fathead minnow	1 d	7 d	NOEC	1000	Survival	99.8	FT	2	7.24-8.4	6.0 (4.4-7.2)	25 +/- 1	86-94	(Pickering et al. 1996)
Pimephales promelas	Fathead minnow	1 d	7 d	NOEC	500	Growth	99.8	FT	2	7.24-8.4	6.0 (4.4-7.2)	25 +/- 1	86-94	(Pickering et al. 1996)
Pimephales promelas	Fathead minnow	1 d	7 d	NOEC	500	Growth	99.8	FT	2	7.24-8.4	6.0 (4.4-7.2)	25 +/- 1	86-94	(Pickering et al. 1996)
Pimephales promelas	Fathead minnow	1 d	7 d	NOEC	500	Survival	99.8	FT	2	7.24-8.4	6.0 (4.4-7.2)	25 +/- 1	86-94	(Pickering et al. 1996)

Latin name	Common name	Life stage	Duration	Endpoint	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp. (°C)	Hard-ness mg/L	Reference
Pimephales promelas	Fathead minnow	1 d	7 d	LOEC	1000	Growth	99.8	FT	2	7.24-8.4	6.0 (4.4-7.2)	25 +/- 1	86-94	(Pickering et al. 1996)
Pimephales promelas	Fathead minnow	1 d	7 d	LOEC	1000	Survival	99.8	FT	2	7.24-8.4	6.0 (4.4-7.2)	25 +/- 1	86-94	(Pickering et al. 1996)
Pimephales promelas	Fathead minnow	1 d	7 d	LOEC	2000	Survival	99.8	FT	2	7.24-8.4	6.0 (4.4-7.2)	25 +/- 1	86-94	(Pickering et al. 1996)
Pimephales promelas	Fathead minnow	4 d	7 d	NOEC	< 250	Growth	99.8	FT	U	7.24-8.4	6.0 (4.4-7.2)	25 +/- 1	86-94	(Pickering et al. 1996)
Pimephales promelas	Fathead minnow	4 d	7 d	NOEC	1000	Growth	99.8	FT	2	7.24-8.4	6.0 (4.4-7.2)	25 +/- 1	86-94	(Pickering et al. 1996)
Pimephales promelas	Fathead minnow	4 d	7 d	NOEC	2000	Survival	99.8	FT	2	7.24-8.4	6.0 (4.4-7.2)	25 +/- 1	86-94	(Pickering et al. 1996)
Pimephales promelas	Fathead minnow	4 d	7 d	LOEC	200	Growth	99.8	FT	2	7.24-8.4	6.0 (4.4-7.2)	25 +/- 1	86-94	(Pickering et al. 1996)
Pimephales promelas	Fathead minnow	4 d	7 d	LOEC	2000	Growth	99.8	FT	2	7.24-8.4	6.0 (4.4-7.2)	25 +/- 1	86-94	(Pickering et al. 1996)
Pimephales promelas	Fathead minnow	4 d	7 d	LOEC	4000	Survival	99.8	FT	2	7.24-8.4	6.0 (4.4-7.2)	25 +/- 1	86-94	(Pickering et al. 1996)
Ptychocheilus lucius	Colorado Squawfish	Larva	32 d	NOEC	445	Growth	99	R	2	7.9-8.2	6.1-7.0	21.2-22.7	344-378	(Beyers et al. 1994)
Ptychocheilus lucius	Colorado Squawfish	Larva	32 d	NOEC	445	Survival	99	R	2	7.9-8.2	6.1-7.0	21.2-22.7	344-378	(Beyers et al. 1994)
Ptychocheilus lucius	Colorado Squawfish	Larva	32 d	LOEC	866	Growth	99	R	2	7.9-8.2	6.1-7.0	21.2-22.7	344-378	(Beyers et al. 1994)
Ptychocheilus lucius	Colorado Squawfish	Larva	32 d	LOEC	866	Survival	99	R	2	7.9-8.2	6.1-7.0	21.2-22.7	344-378	(Beyers et al. 1994)

Latin name	Common name	Life stage	Duration	Endpoint	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp. (°C)	Hard-ness mg/L	Reference
Ptychocheilus lucius	Colorado pikeminno-w	6 d	7 d	IC25	1330	Survival	99.7	R	2	7.8-8.0		22	160-180	(Dwyer et al. 2005a)
Ptychocheilus lucius	Colorado pikeminno-w	6 d	7 d	IC25	1330	Survival	99.7	R	2	8.0-8.6		22	160-180	(Dwyer et al. 2005a)
Xyrauchen texanus	Razorback Sucker	7 d	7 d	IC25	2060	Survival	99.7	R	2	7.8-8.0		22	160-180	(Dwyer et al. 2005a)
Xyrauchen texanus	Razorback Sucker	7 d	7 d	IC25	2060	Survival	99.7	R	2	8.0-8.6		22	160-180	(Dwyer et al. 2005a)
Invertebrates														
Bosmina longirostris	Zooplankt-on	NR	4 d	IC50	7	Biomass reduction		NR	U	8.7	8	21		(Havens 1994)
Calanoid copepodids	Zooplankt-on	NR	4 d	IC50	200	Biomass reduction		NR	U	8.7	8	21		(Havens 1994)
Calanoid nauplii	Zooplankt-on	NR	4 d	IC50	100	Biomass reduction		NR	U	8.7	8	21		(Havens 1994)
Ceriodaphnia dubia	Water flea	Neona-te	7 d	MATC	10.6	Reproduction	99	R	1	8.18+/-0.04		25	57.07 +/- 4.14	(Oris et al. 1991)
Ceriodaphnia dubia	Water flea	Neona-te	7 d	MATC	7.2	Reproduction	99	R	1	8.18+/-0.04		25	57.07 +/- 4.14	(Oris et al. 1991)
Ceriodaphnia dubia	Water flea	Neona-te	7 d	IC50	10.6	Reproduction	99	R	1	8.18+/-0.04		25	57.07 +/- 4.14	(Oris et al. 1991)
Ceriodaphnia dubia	Water flea	Neona-te	7 d	IC50	8.6	Reproduction	99	R	1	8.18+/-0.04		25	57.07 +/- 4.14	(Oris et al. 1991)
Ceriodaphnia dubia	Water flea	Neona-te	4 d	MATC	10.6	Reproduction	99	R	1	8.18+/-0.04		25	57.07 +/- 4.14	(Oris et al. 1991)
Ceriodaphnia dubia	Water flea	Neona-te	4 d	IC50	8.3	Reproduction	99	R	1	8.18+/-0.04		25	57.07 +/- 4.14	(Oris et al. 1991)

Latin name	Common name	Life stage	Duration	Endpoint	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp. (°C)	Hard-ness mg/L	Reference
Ceriodaphnia dubia	Water flea	Neona-te	4 d	IC50	9.7	Reproduction	99	R	1	8.18+/-0.04		25	57.07 +/-4.14	(Oris et al. 1991)
Ceriodaphnia dubia	Water flea	24 h	NR	IC25	< 330	Survival	99.7	R	U	7.8-8.0		22	160-180	(Dwyer et al. 2005a)
Ceriodaphnia dubia	Water flea	24 h	NR	IC25	< 330	Survival and reproduction	99.7	R	U	8.0-8.6		22	160-180	(Dwyer et al. 2005a)
Chironomus riparius	Midge	Larva	28 d	NOEC	147.25	Emergence and development	99.1	S	2	7.2-8.1	6.1-8.9	19.4-19.9	3.45 mmol /L	(Ebeling and Radix 2002)
Chironomus riparius	Midge	Larva	28 d	LOEC	318.31	Emergence and development	99.1	S	2	7.2-8.1	6.1-8.9	19.4-19.9	3.45 mmol /L	(Ebeling and Radix 2002)
Chydorus sphaericus	Zooplankt-on	NR	4 d	IC50	20	Biomass reduction		NR	U	8.7	8	21		(Havens 1994)
cyclopoid copepodids	Zooplankt-on	NR	4 d	IC50	200	Biomass reduction		NR	U	8.7	8	21		(Havens 1994)
Cyclopoid nauplii	Zooplankt-on	NR	4 d	IC50	200	Biomass reduction		NR	U	8.7	8	21		(Havens 1994)
Daphnia ambigua	Zooplankt-on	1st instar	1st 6 instars	EC50	2	Survival	99	R	U			23 +/-0.5		(Hanazato 1991a)
Daphnia galeata	Zooplankt-on	NR	4 d	IC70	5	Abundance		NR	U	8-9				(Havens 1995)
Daphnia galeata	Zooplankt-on	NR	4 d	IC50	5	Biomass reduction		NR	U	8.7	8	21		(Havens 1994)
Daphnia magna	Water flea	4-24h	21 d	EC10	6.4	Reproduction	99.8	R	1	7.8	7.7	20.0-20.3	0.7-1.0m mol/L	(Schafers 2006)
Daphnia magna	Water flea	4-24h	21 d	EC10	6.5	Survival	99.8	R	1	7.8	7.7	20.0-20.3	0.7-1.0m mol/L	(Schafers 2006)
Daphnia magna	Water flea	4-24h	21 d	NOEC	5.9	Survival and reproduction	99.8	R	1	7.8	7.7	20.0-20.3	0.7-1.0m mol/L	(Schafers 2006)

Latin name	Common name	Life stage	Duration	Endpoint	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp. (°C)	Hard-ness mg/L	Reference
Daphnia magna	Water flea	4-24h	21 d	LOEC	6.6	Survival and reproduction	99.8	R	1	7.8	7.7	20.0-20.3	0.7-1.0m mol/L	(Schafers 2006)
Daphnia magna	Water flea	Adult	21 d	MATC	>3.3	Survival and reproduction	99	FT	1	7.9-8.3	8.1-8.4	20 +/- 1	160-180	(Springborn Bionomics 1985a)
Wyeomyia smithii	Mosquito	2nd Instar	7 d	NR	1000	Development	93-100	NR	U			27		(Strickman 1985)
Wyeomyia smithii	Mosquito	2nd Instar	7 d	NR	1000	Survival	93-100	NR	U			27		(Strickman 1985)

Table 2. Toxicity Values for Freshwater Short-term Aquatic Species Exposed to Carbaryl

Latin Name	Common Name	Life Stage	Duration	End-point	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp (°C)	Hard-ness	Reference
Amphibians														
Bufo arenarum	Toad	Larva	96 h	LC50	2464	Mortality	99	S	2	7.4-7.6	8	16 +/- 1		(Ferrari et al. 2004a)
Bufo arenarum	Toad	Larva	96 h	IC50	7580	ChE inhibition	99	S	2*	7.4-7.6	8	16 +/- 1		(Ferrari et al. 2004a)
Hyla versicolor	Gray tree frog	Tadpole	96 h	LC50	2470	Mortality	99.7	S	U					(Zaga et al. 1998)
Rana clamitans	Green frog	Tadpole	24 h	LC50	17570	Mortality	99.7	S	2	7.8		27	286	(Boone and Bridges 1999)
Rana clamitans	Green frog	Tadpole	24 h	LC50	22550	Mortality	99.7	S	2	7.8		22	286	(Boone and Bridges 1999)
Rana clamitans	Green frog	Tadpole	48 h	LC50	16170	Mortality	99.7	S	2	7.8		27	286	(Boone and Bridges 1999)
Rana clamitans	Green frog	Tadpole	48 h	LC50	21760	Mortality	99.7	S	2	7.8		22	286	(Boone and Bridges 1999)
Rana clamitans	Green frog	Tadpole	72 h	LC50	14880	Mortality	99.7	S	2	7.8		27	286	(Boone and Bridges 1999)
Rana clamitans	Green frog	Tadpole	72 h	LC50	20020	Mortality	99.7	S	2	7.8		22	286	(Boone and Bridges 1999)
Rana clamitans	Green frog	Tadpole	96 h	LC50	11320	Mortality	99.7	S	2	7.8		27	286	(Boone and Bridges 1999)
Rana clamitans	Green frog	Tadpole	96 h	LC50	17360	Mortality	99.7	S	2	7.8		22	286	(Boone and Bridges 1999)
Rana clamitans	Green frog	Tadpole	24 h	LC50	<30000	Mortality	99.7	S	U	7.8		17	286	(Boone and Bridges 1999)
Rana clamitans	Green frog	Tadpole	48 h	LC50	26010	Mortality	99.7	S	2	7.8		17	286	(Boone and Bridges 1999)
Rana clamitans	Green frog	Tadpole	72 h	LC50	24800	Mortality	99.7	S	2	7.8		17	286	(Boone and Bridges 1999)
Rana clamitans	Green frog	Tadpole	96 h	LC50	22020	Mortality	99.7	S	2	7.8		17	286	(Boone and Bridges 1999)
Rana sphenocephala	Southern Leopard Frog	Tadpole	96 h	LC50	8400	Mortality	99.7	S	2	8.32	7.3 - 8.5	22	171	(Bridges et al. 2002)
Rana tigrina	Bullfrog	Tadpole	96 h	LC50	6200	Mortality	50	S	U					(Marian et al. 1983)

Latin Name	Common Name	Life Stage	Duration	End-point	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp (°C)	Hard-ness	Reference
Xenopus laevis	African clawed frog	Embryo	96 h	LC50	15250	Mortality	99.7	S	U					(Zaga et al. 1998)
Xenopus laevis	African clawed frog	Tadpole	96 h	LC50	1730	Mortality	99.7	S	U					(Zaga et al. 1998)
Xenopus laevis	African clawed frog	Embryo	24 h	EC50	110	Development	NR	NR	U					(Elliott-Feeley and Armstrong 1982)
Xenopus laevis	African clawed frog	Embryo	24 h	LC50	4700	Mortality	NR	NR	U					(Elliott-Feeley and Armstrong 1982)
Fish														
Acipenser brevirostrum	Shortnose sturgeon	0.74 g	48 h	LC50	4230	Mortality	99.7	S	2	8.4 (7.8-8.6)	8.7 (5.2-9.1)	17	160-180	(Dwyer et al. 2000)
Acipenser oxyrhynchus	Atlantic sturgeon	1.11 g	48 h	LC50	1280	Mortality	99.7	S	2	8.4 (7.8-8.6)	8.7 (4.8-9.4)	17	160-180	(Dwyer et al. 2000)
Alosa sapidissima	American Shad	0.006 g	48 h	LC50	< 80	Mortality	99.7	S	U	8.6 (8.1-8.8)	8.5 (8.0-9.2)	22	160-180	(Dwyer et al. 2000)
Aplocheilus lineatus	Striped panchax	NR	48 h	LC50	3747	Mortality	50	S	U					(Jacob et al. 1982)
Brachydanio rerio	Zebrafish	NR	96 h	LC50	9256.17	Mortality	99	R	2					(Gallo et al. 1995)
Carassius auratus	Goldfish	Juvenile	96 h	LC50	13900	Mortality	99	S	2	7.4-7.6	8 +/-1	20 +/- 1		(Ferrari et al. 2004b)
Carassius auratus	Goldfish	Juvenile	96 h	IC50	2620	Brain ChE inhibition	99	S	2*	7.4-7.6	8 +/-1	20 +/- 1		(Ferrari et al. 2004b)
Carassius auratus	Goldfish	Juvenile	96 h	LC90	18000	Mortality	99	S	2	7.4-7.6	8 +/-1	20 +/- 1		(Ferrari et al. 2004b)

Latin Name	Common Name	Life Stage	Duration	End-point	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp (°C)	Hard-ness	Reference
Carassius auratus	Goldfish	Juvenile	96 h	LC10	10600	Mortality	99	S	2	7.4-7.6	8 +/- 1	20 +/- 1		(Ferrari et al. 2004b)
Carassius auratus	Goldfish	Juvenile	96 h	NOEC	9000	Mortality	99	S	2	7.4-7.6	8 +/- 1	20 +/- 1		(Ferrari et al. 2004b)
Carassius auratus	Goldfish	NR	96 h	LC50	16700	Mortality	NR	FT	U	7.1-7.8	7.5 +/- 1.6	17.3 +/- 0.6	40.7-46.6	(Phipps and Holcombe 1985)
Carassius auratus	Goldfish	NR	96 h	TL50	13200	Mortality	99	S	U	7.1		18		(Macek and McAllister 1970)
Catla catla	Major carp	Larva	96 h	TL50	1420	Mortality		S	U	6.8-7.6	4.5 - 6.2	24.3-28.4	38-47	(Bansal et al. 1980)
Catla catla	Catla	NR	96 h	LC50	6400	Mortality	NR	FT	U	8.4	8-10	28 +/- 2	152	(Tilak et al. 1981)
Channa punctata	Murrel	Adult	2 d	NR	1658	Reduced glutathione		R	U	7.6-7.8		28-30		(Ghosh et al. 1993)
Channa punctata	Spotted snakehead	NR	48 h	LC50	15.83	NR	50	NR	U					(Bhattacharya 1993)
Channa punctata	Spotted snakehead	NR	96 h	LC50	15000	Mortality	NR	S	U			26 +/- 2		(Thakur and Sahai 1994)
Channa punctata	Spotted snakehead	NR	96 h	TLm	14000	Mortality	NR	S	U			27 +/- 1		(Mishra et al. 1991)
Channa punctatus	Murrel	NR	NR	LC50	NR	NR		NR	U					(Sambasiva Rao and Ramana Rao 1989)
Channa punctatus	Green snakehead	NR	24 h	LC50	2120	Immobility	50	NR	U					(Singh et al. 1984)
Channa punctatus	Green snakehead	NR	48 h	LC50	2053	Immobility	50	NR	U					(Singh et al. 1984)
Channa punctatus	Green snakehead	NR	72 h	LC50	2002	Immobility	50	NR	U					(Singh et al. 1984)
Channa punctatus	Green snakehead	NR	96 h	LC50	1950	Immobility	50	NR	U					(Singh et al. 1984)
Channa striatus	Snakehead	NR	96 h	LC50	17500	Mortality	NR	S	U			26 +/- 2		(Thakur and Sahai 1994)

Latin Name	Common Name	Life Stage	Duration	End-point	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp (°C)	Hard-ness	Reference
Chironomus riparius	Midge	4th instar	24 h	LC50	106	Immobility	99.7	S	U	4		20		(Fisher and Lohner 1986)
Chironomus riparius	Midge	4th instar	24 h	LC50	127	Immobility	99.7	S	U	8		20		(Fisher and Lohner 1986)
Chironomus riparius	Midge	4th instar	24 h	LC50	133	Immobility	99.7	S	U	6		20		(Fisher and Lohner 1986)
Cirrhina mrigala	Indian major carp	Fingerlin-g	96 h	LD50	9250	Mortality	50	NR	U			19-21		(Kaur and Toor 1995)
Cirrhina mrigala	Major carp	Larva	96 h	TL50	1370	Mortality		S	U	6.8-7.6	4.5 - 6.2	24.3-28.4	38-47	(Bansal et al. 1980)
Cirrhinus mrigala	Indian major carp	NR	72 h	LC50	2500	Mortality	Tech.	FT	U	8.4	7-8	28 +/- 2	123	(Rao et al. 1984)
Clarias batrachus	Catfish	NR	24 h	LC(I) 50	6114	Mortality		R	U	7.5		27		(Tripathi and Shukla 1988)
Clarias batrachus	Catfish	NR	48 h	LC(I) 50	5365	Mortality		R	U	7.5		27		(Tripathi and Shukla 1988)
Clarias batrachus	Catfish	NR	72 h	LC(I) 50	4858	Mortality		R	U	7.5		27		(Tripathi and Shukla 1988)
Clarias batrachus	Catfish	NR	96 h	LC(I) 50	4685	Mortality		R	U	7.5		27		(Tripathi and Shukla 1988)
Clarias batrachus	Catfish	NR	96 h	LC50	46000	NR		NR	U					(Jyothi and Narayan 1999)
Clarias batrachus	Catfish	NR	95 h	TLm	Non-toxic	Mortality	100	S	U	7.4-8.4	4.6 - 7.2	25-35	68-88	(Jyotsana et al. 1981)
Colisa fasciatus	Dwarf gouramy	Adult	24 h	LC50	9040	Mortality	99	R	2	7.3 +/- 0.2	7.2 +/- 0.3	23 +/- 0.7		(Singh et al. 2004)
Colisa fasciatus	Dwarf gouramy	Adult	24 h	LC90	1097	Mortality	99	R	2	7.3 +/- 0.2	7.2 +/- 0.3	23 +/- 0.7		(Singh et al. 2004)
Colisa fasciatus	Dwarf gouramy	Adult	24 h	LC10	7450	Mortality	99	R	2	7.3 +/- 0.2	7.2 +/- 0.3	23 +/- 0.7		(Singh et al. 2004)

Latin Name	Common Name	Life Stage	Duration	End-point	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp (°C)	Hard-ness	Reference
Colisa fasciatus	Dwarf gouramy	Adult	48 h	LC50	8590	Mortality	99	R	2	7.3 +/- 0.2	7.2 +/- 0.3	23 +/- 0.7		(Singh et al. 2004)
Colisa fasciatus	Dwarf gouramy	Adult	48 h	LC90	9970	Mortality	99	R	2	7.3 +/- 0.2	7.2 +/- 0.3	23 +/- 0.7		(Singh et al. 2004)
Colisa fasciatus	Dwarf gouramy	Adult	48 h	LC10	7390	Mortality	99	R	2	7.3 +/- 0.2	7.2 +/- 0.3	23 +/- 0.7		(Singh et al. 2004)
Colisa fasciatus	Dwarf gouramy	Adult	72 h	LC50	8300	Mortality	99	R	2	7.3 +/- 0.2	7.2 +/- 0.3	23 +/- 0.7		(Singh et al. 2004)
Colisa fasciatus	Dwarf gouramy	Adult	72 h	LC90	9470	Mortality	99	R	2	7.3 +/- 0.2	7.2 +/- 0.3	23 +/- 0.7		(Singh et al. 2004)
Colisa fasciatus	Dwarf gouramy	Adult	72 h	LC10	7290	Mortality	99	R	2	7.3 +/- 0.2	7.2 +/- 0.3	23 +/- 0.7		(Singh et al. 2004)
Colisa fasciatus	Dwarf gouramy	Adult	96 h	LC50	8000	Mortality	99	R	2	7.3 +/- 0.2	7.2 +/- 0.3	23 +/- 0.7		(Singh et al. 2004)
Colisa fasciatus	Dwarf gouramy	Adult	96 h	LC90	8830	Mortality	99	R	2	7.3 +/- 0.2	7.2 +/- 0.3	23 +/- 0.7		(Singh et al. 2004)
Colisa fasciatus	Dwarf gouramy	Adult	96 h	LC10	7250	Mortality	99	R	2	7.3 +/- 0.2	7.2 +/- 0.3	23 +/- 0.7		(Singh et al. 2004)
Cyprinus carpio	Common carp	Fry	NR	LC50	10360	NR	NR	NR	U			26 +/- 1		(Kaur and Toor 1977)
Cyprinus carpio	Common carp	Egg	NR	LC50	1400	NR	NR	NR	U			26 +/- 1		(Kaur and Toor 1977)
Cyprinus carpio	Common carp	Fry	96 h	LC50	4220	Mortality	97.6	S	U	7.1	6	18		(Lakota et al. 1981)
Cyprinus carpio	Common carp	Egg	96 h	LC50	1190	Mortality		S	U	7.5	5.5	24	272	(Kaur and Dhawan 1993)
Cyprinus carpio	Common carp	Larva	96 h	LC50	2860	Mortality		S	U	7.5	5.5	24	272	(Kaur and Dhawan 1993)

Latin Name	Common Name	Life Stage	Duration	End-point	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp (°C)	Hard-ness	Reference
Cyprinus carpio	Common carp	Fry	96 h	LC50	3300	Mortality		S	U	7.5	5.5	24	272	(Kaur and Dhawan 1993)
Cyprinus carpio	Major carp	Larva	96 h	TL50	2000	Mortality		S	U	6.8-7.6	4.5 - 6.2	24.3-28.4	38-47	(Bansal et al. 1980)
Cyprinus carpio	Common carp	NR	96 h	TL50	5280	Mortality	99	S	U	7.1		18		(Macek and McAllister 1970)
Cyprinus carpio	Common carp	Fry	96 h	LC50	7850	Mortality	85	S	U	7.3	5.6	27.9		(De Mel and Pathiratne 2005)
Danio rerio	Zebrafish	4 h post fertilizati-on	24 h	EC50	7520	Development	99.9	S	U					(Lin et al. 2007)
Danio rerio	Zebrafish	4 h post fertilizati-on	24 h	LC50	44660	Mortality	99.9	S	U					(Lin et al. 2007)
Etheostoma fonticola	Fountain darter	NR	96 h	LC50	2020	Immobility	99.7	S	2	>8.0		22	160-180	(Dwyer et al. 2005b)
Etheostoma lepidum	Greenthro-at Darter	NR	96 h	LC50	2140	Immobility	99.7	S	2	>8.0		22	160-180	(Dwyer et al. 2005b)
Gambusia affinis	Mosquitofi-sh	Adult	96 h	LC50	204000	Mortality	5	S	U	7.8	6.5 -7	20	12	(Naqvi and Hawkins 1988)
Gambusia affinis	Mosquitofi-sh	Adult	96 h	LC5	103000	Mortality	5	S	U	7.8	6.5 -7	20	12	(Naqvi and Hawkins 1988)
Gambusia affinis	Mosquitofi-sh	Adult	96 h	LC99	536000	Mortality	5	S	U	7.8	6.5 -7	20	12	(Naqvi and Hawkins 1988)
Garra gotyla gotyla	Sucker head	NR	96 h	LC50	7500	Mortality	NR	S	U			26 +/- 2		(Thakur and Sahai 1994)
Gila elegans	Bonytail	Larva	4 d	LC50	2020	Mortality	99	R	2	8.5-8.6	7.1 - 7.2	22-22.8	212-216	(Beyers et al. 1994)
Gila elegans	Bony tail Chub	0.29-0.52 g	24 h	LC50	6130	Mortality	99.7	S	2	8.35 +/- 0.29		22	173 +/- 9	(Dwyer et al. 1995)
Gila elegans	Bony tail Chub	0.29-0.52 g	96 h	LC50	3490	Mortality	99.7	S	2	8.35 +/- 0.29		22	173 +/- 9	(Dwyer et al. 1995)

Latin Name	Common Name	Life Stage	Duration	End-point	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp (°C)	Hard-ness	Reference
Gila elegans	Bony tail Chub	0.29-0.52 g	12 h	LC50	7930	Mortality	99.7	S	2	8.35 +/- 0.29		22	173 +/- 9	(Dwyer et al. 1995)
Heteropneustes fossilis	Indian catfish	NR	96 h	LC50	19990	Mortality	50	S	U					(James and Sampath 1994)
Heteropneustes fossilis	Asian stinging catfish	NR	24 h	LC50	2295	Immobility	50	NR	U					(Singh et al. 1984)
Heteropneustes fossilis	Asian stinging catfish	NR	48 h	LC50	2230	Immobility	50	NR	U					(Singh et al. 1984)
Heteropneustes fossilis	Asian stinging catfish	NR	72 h	LC50	2145	Immobility	50	NR	U					(Singh et al. 1984)
Heteropneustes fossilis	Asian stinging catfish	NR	96 h	LC50	2010	Immobility	50	NR	U					(Singh et al. 1984)
Hybopsis monacha	Spotfin Chub	Fry	96 h	LC50	3410	Immobility	99.7	S	2	>8.0		17	160-180	(Dwyer et al. 2005b)
Ictalurus melas	Black bullhead	NR	96 h	TL50	20000	Mortality	99	S	U	7.1		18		(Macek and McAllister 1970)
Ictalurus punctatus	Channel catfish	NR	96 h	LC50	15800	Mortality	99.5	S	U	7.4		22	40	(Sanders et al. 1983)
Ictalurus punctatus	Channel catfish	NR	96 h	LC50	12400	Mortality	NR	FT	U	7.1-7.8	7.5 +/- 1.6	17.3 +/- 0.6	40.7-46.6	(Phipps and Holcombe 1985)
Ictalurus punctatus	Catfish	NR	96 h	TL50	15800	Mortality	99	S	U	7.1		18		(Macek and McAllister 1970)
Labeo rohita	Major carp	Larva	96 h	TL50	1870	Mortality		S	U	6.8-7.6	4.5 - 6.2	24.3-28.4	38-47	(Bansal et al. 1980)
Labeo rohita	Indian major carp	NR	96 h	LC50	4600	Mortality	NR	FT	U		7-7.8	28 +/- 2		(Tilak et al. 1980)
Labeo rohita	Indian major carp	NR	72 h	LC50	7750	Mortality	NR	FT	U		7-7.8	28 +/- 2		(Tilak et al. 1980)
Lebistes reticulatus	Guppy	Juvenile	36 h	LC50	3840	Mortality	97.6	S	U	7.1		20 +/- 0.2		(Lakota et al. 1981)

Latin Name	Common Name	Life Stage	Duration	End-point	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp (°C)	Hard-ness	Reference
Lebistes reticulatus	Guppies	Adult	96 h	LC50	4600	Mortality	NR	S	U	7.2-7.6		28-32		(Manna and Ghosh 1987)
Lebistes reticulatus	Guppies	NR	96 h	LC50	9740	Mortality	97	S	U			20		(Lejczak 1977)
Lepomis macrochirus	Bluegill	NR	96 h	LC50	7000	Mortality	99.5	S	U	7.4		22	40	(Sanders et al. 1983)
Lepomis macrochirus	Bluegill	NR	96 h	LC50	6970	Mortality	NR	FT	U	7.1-7.8	7.5 +/- 1.6	17.3 +/- 0.6	40.7-46.6	(Phipps and Holcombe 1985)
Lepomis macrochirus	Bluegill	NR	24 h	TLm	11000	Mortality	95	S	U	7.4	8.0	25	20	(Henderson et al. 1960)
Lepomis macrochirus	Bluegill	NR	24 h	TLm	12000	Mortality	95	S	U	8.2	8.0	25	400	(Henderson et al. 1960)
Lepomis macrochirus	Bluegill	NR	48 h	TLm	11000	Mortality	95	S	U	7.4	8.0	25	20	(Henderson et al. 1960)
Lepomis macrochirus	Bluegill	NR	48 h	TLm	7100	Mortality	95	S	U	8.2	8.0	25	400	(Henderson et al. 1960)
Lepomis macrochirus	Bluegill	NR	96 h	TLm	5600	Mortality	95	S	U	7.4	8.0	25	20	(Henderson et al. 1960)
Lepomis macrochirus	Bluegill	NR	96 h	TLm	7000	Mortality	95	S	U	8.2	8.0	25	400	(Henderson et al. 1960)
Lepomis macrochirus	Bluegill	NR	96 h	TL50	6760	Mortality	99	S	U	7.1		18		(Macek and McAllister 1970)
Lepomis macrochirus	Bluegill sunfish	13 months	96 h	LC50	> 7900	Mortality	99.1	FT	U	7.6-8.0	5.3 - 8.2	21.5-22.4	1.22-1.23 mmol / L	(Sowig and Gosch 2002)
Lepomis macrochirus	Bluegill sunfish	13 months	96 h	NOEC	4200	Activity and behaviour	99.1	FT	2	7.6-8.0	5.3 - 8.2	21.5-22.4	1.22-1.23 mmol / L	(Sowig and Gosch 2002)
Lepomis microlophus	Redear sunfish	NR	96 h	TL50	11200	Mortality	99	S	U	7.1		18		(Macek and McAllister 1970)

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Leptodora kindtii	Cladoceran	Large juvenile to middle-sized adult	24 h	LC50	3.477	Mortality	99	S	U			20 +/-1		(Sakamoto et al. 2005)
Micropterus slamoides	Largemou-th bass	NR	96 h	TL50	6400	Mortality	99	S	U	7.1		18		(Macek and McAllister 1970)
Morone saxatilis	Striped bass	35- 80 days	96 h	LC50	760	Mortality	NR	S	U	8.1		20 +/- 2	40	(Palawski et al. 1985)
Mystus cavasius	Gangetic mystus	NR	96 h	LC50	4600	Mortality	NR	FT	U	8.4	8-10	28 +/- 2	152	(Tilak et al. 1981)
Mystus vittatus	Catfish	Juvenile	72 h	LC50	17500	Mortality	50	S	U					(Arunachalam et al. 1980)
Mystus vittatus	Striped catfish	NR	96 h	LC50	2400	Mortality	NR	FT	U	8.4	8-10	28 +/- 2	152	(Tilak et al. 1981)
Notropis mekistocholas	Cape Fear Shiner	Fry	96 h	LC50	4510	Immobility	99.7	S	2	>8.0		17	160-180	(Dwyer et al. 2005b)
Oncorhynchus clarki henshawi	Lahontan cutthroat trout	0.34-0.57 g	24 h	LC50	3600	Mortality	99.7	S	2	8.24 +/- 0.29		12	169 +/- 10	(Dwyer et al. 1995)
Oncorhynchus clarki henshawi	Lahontan cutthroat trout	0.34-0.57 g	96 h	LC50	2250	Mortality	99.7	S	2	8.24 +/- 0.29		12	169 +/- 10	(Dwyer et al. 1995)
Oncorhynchus clarki henshawi	Lahontan cutthroat trout	0.34-0.57 g	12 h	LC50	4380	Mortality	99.7	S	2	8.24 +/- 0.29		12	169 +/- 10	(Dwyer et al. 1995)
Oncorhynchus clarki stomias	Greenback Cutthroat trout	0.31 g	24 h	LC50	3590	Mortality	99.7	S	2	8.24 +/- 0.29		12	169 +/- 10	(Dwyer et al. 1995)
Oncorhynchus clarki stomias	Greenback Cutthroat trout	0.31 g	96 h	LC50	1550	Mortality	99.7	S	2	8.24 +/- 0.29		12	169 +/- 10	(Dwyer et al. 1995)
Oncorhynchus clarki stomias	Greenback Cutthroat trout	0.31 g	12 h	LC50	8500	Mortality	99.7	S	2	8.24 +/- 0.29		12	169 +/- 10	(Dwyer et al. 1995)

Latin Name	Common Name	Life Stage	Duration	End-point	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp (°C)	Hard-ness	Reference
Oncorhynchus gilae apache	Apache trout	0.38-0.85 g	24 h	LC50	2500	Mortality	99.7	S	2	8.24 +/- 0.29		12	169+/- 10	(Dwyer et al. 1995)
Oncorhynchus gilae apache	Apache trout	0.38-0.85 g	96 h	LC50	1540	Mortality	99.7	S	2	8.24 +/- 0.29		12	169+/- 10	(Dwyer et al. 1995)
Oncorhynchus gilae apache	Apache trout	0.38-0.85 g	12 h	LC50	3290	Mortality	99.7	S	2	8.24 +/- 0.29		12	169+/- 10	(Dwyer et al. 1995)
Oncorhynchus kisutch	Coho salmon	NR	96 h	TL50	1300	Mortality	98	S	U	7.2-7.6	5.9 - 6.0	13.6-14.6	318-348	(Post and Schroeder 1971)
Oncorhynchus kisutch	Coho salmon	Juvenile	96 h	TL50	997	Mortality	95	S	U	6.8-7.4		20 +/- 0.5		(Katz 1961)
Oncorhynchus kisutch	Coho salmon	NR	96 h	TL50	764	Mortality	99	S	U	7.1		13		(Macek and McAllister 1970)
Oncorhynchus mykiss	Rainbow trout	Juvenile	96 h	LC50	4330	Mortality	99	R	U					(Douglas et al. 1986)
Oncorhynchus mykiss	Rainbow trout	Juvenile	96 h	LC50	5400	Mortality	99	R	U					(Douglas et al. 1986)
Oncorhynchus mykiss	Rainbow trout	Larva	96 h	LC50	5400	Mortality	99	S	U	7.4-7.6	8	16 +/- 1		(Ferrari et al. 2004a)
Oncorhynchus mykiss	Rainbow trout	Larva	96 h	IC50	19	ChE inhibition	99	S	U	7.4-7.6	8	16 +/- 1		(Ferrari et al. 2004a)
Oncorhynchus mykiss	Rainbow trout	Juvenile	96 h	EC50	270	Brain ChE inhibition	99	S	2*	7.4-7.6	8 +/- 1	16 +/- 1		(Ferrari et al. 2007b)
Oncorhynchus mykiss	Rainbow trout	Juvenile	96 h	EC50	19.24	Muscular ChE inhibition	99	S	2*	7.4-7.6	8 +/- 1	16 +/- 1		(Ferrari et al. 2007b)
Oncorhynchus mykiss	Rainbow trout	0.5- 1.0 g	96 h	LC50	1950	Mortality	99.5	S	U	7.8		16	272	(Little et al. 1990)
Oncorhynchus mykiss	Rainbow trout	0.27-1.25 g	24 h	LC50	4040	Mortality	99.7	S	2	8.24 +/- 0.29		12	169+/- 10	(Dwyer et al. 1995)

Latin Name	Common Name	Life Stage	Duration	End-point	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp (°C)	Hard-ness	Reference
Oncorhynchus mykiss	Rainbow trout	0.27-1.25 g	96 h	LC50	1880	Mortality	99.7	S	2	8.24 +/- 0.29		12	169+/- 10	(Dwyer et al. 1995)
Oncorhynchus mykiss	Rainbow trout	0.27-1.25 g	12 h	LC50	6760	Mortality	99.7	S	2	8.24 +/- 0.29		12	169+/- 10	(Dwyer et al. 1995)
Oncorhynchus mykiss	Rainbow trout	NR	24 h	LC50	1410	Mortality	Tech.	S	U			13		(Zinkl et al. 1987)
Oncorhynchus mykiss	Rainbow trout	Juvenile	96 h	LC50	522	Mortality	85	S	U	7.4 +/- 0.21	9.4 +/- 0.3	15.3 +/- 0.9	99 +/- 5	(Boran et al. 2007)
Perca flavescens	Perch	NR	96 h	TL50	745	Mortality	99	S	U	7.1		18		(Macek and McAllister 1970)
Pimephales promelas	Fathead minnow	NR	96 h	LC50	14600	Mortality	99.5	S	U	7.4		22	40	(Sanders et al. 1983)
Pimephales promelas	Fathead minnow	0.32-0.56 g	24 h	LC50	8250	Mortality	99.7	S	2	8.35 +/- 0.29		22	173 +/- 9	(Dwyer et al. 1995)
Pimephales promelas	Fathead minnow	0.32-0.56 g	96 h	LC50	5210	Mortality	99.7	S	2	8.35 +/- 0.29		22	173 +/- 9	(Dwyer et al. 1995)
Pimephales promelas	Fathead minnow	0.32-0.56 g	12 h	LC50	12000	Mortality	99.7	S	2	8.35 +/- 0.29		22	173 +/- 9	(Dwyer et al. 1995)
Pimephales promelas	Fathead minnow	NR	96 h	LC50	5010	Mortality	NR	FT	U	7.1-7.8	7.5 +/- 1.6	17.3 +/- 0.6	40.7-46.6	(Phipps and Holcombe 1985)
Pimephales promelas	Fathead minnow	NR	24 h	TLm	>32000	Mortality	95	S	U	7.4	8.0	25	20	(Henderson et al. 1960)
Pimephales promelas	Fathead minnow	NR	48 h	TLm	20000	Mortality	95	S	U	7.4	8.0	25	20	(Henderson et al. 1960)
Pimephales promelas	Fathead minnow	NR	96 h	TLm	13000	Mortality	95	S	U	7.4	8.0	25	20	(Henderson et al. 1960)
Pimephales promelas	Fathead minnow	NR	96 h	TL50	14600	Mortality	99	S	U	7.1		18		(Macek and McAllister 1970)
Poecilia reticulata	Guppy	NR	96 h	LC50	2515.26	Mortality	99	R	2					(Gallo et al. 1995)

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Poecilia reticulata	Guppy	Juvenile	96 h	LC50	1383	Mortality	85	S	U	7.35 +/- 0.11	8.58 +/- 0.2	21 +/- 0.5	95 +/- 1	(Boran et al. 2007)
Poeciliopsis occidentalis occidentalis	Gila topminnow	NR	96 h	LC50	>3000	Immobility	99.7	S	2	>8.0		22	160-180	(Dwyer et al. 2005b)
Ptychocheilus lucius	Colorado Squawfish	Larva	4 d	LC50	1310	Mortality	99	R	2	8.5-8.6	7.1 - 7.2	22-22.8	212-216	(Beyers et al. 1994)
Ptychocheilus lucius	Colorado Squawfish	8.0g, 74mm	24 h	NOEC	29.3	AChE inhibition	99	S	2*	7.9-8.0	8.0 - 8.2	21.2-22.0	361-379	(Beyers and Sikoski 1994)
Ptychocheilus lucius	Colorado Squawfish	8.0g, 74mm	24 h	LOEC	49.1	AChE inhibition	99	S	2*	7.9-8.0	8.0 - 8.2	21.2-22.0	361-379	(Beyers and Sikoski 1994)
Ptychocheilus lucius	Colorado Squawfish	0.32-0.34g	24 h	LC50	6310	Mortality	99.7	S	2	8.35 +/- 0.29		22	173 +/- 9	(Dwyer et al. 1995)
Ptychocheilus lucius	Colorado Squawfish	0.32-0.34g	96 h	LC50	3070	Mortality	99.7	S	2	8.35 +/- 0.29		22	173 +/- 9	(Dwyer et al. 1995)
Ptychocheilus lucius	Colorado Squawfish	0.32-0.34g	12 h	LC50	>10000	Mortality	99.7	S	2	8.35 +/- 0.29		22	173 +/- 9	(Dwyer et al. 1995)
Saccobranchus fossilis	Asian stinging catfish	NR	96 h	LC50	19580	Immobility	50	S	U	7.2 +/- 0.2	4.84	18.2 +/- 2		(Verma et al. 1982)
Salmo clarki	Cutthroat trout	NR	96 h	TL50	1500	Mortality	98	S	U	7.2-7.6	5.9 - 6.0	13.6-14.6	318-348	(Post and Schroeder 1971)
Salmo clarki	Cutthroat trout	NR	96 h	LC50	3950	Mortality	99	S	U	7.5		12	0.04	(Woodward and Mauck 1980)
Salmo clarki	Cutthroat trout	NR	96 h	LC50	5000	Mortality	99	S	U	6.5		12	0.04	(Woodward and Mauck 1980)
Salmo clarki	Cutthroat trout	NR	96 h	LC50	3950	Mortality	99	S	U	7.8		12	0.32	(Woodward and Mauck 1980)

Latin Name	Common Name	Life Stage	Duration	End-point	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp (°C)	Hard-ness	Reference
Salmo clarki	Cutthroat trout	NR	96 h	LC50	6000	Mortality	99	S	U	7.5		7	0.04	(Woodward and Mauck 1980)
Salmo clarki	Cutthroat trout	NR	96 h	LC50	970	Mortality	99	S	U	8.5		12	0.04	(Woodward and Mauck 1980)
Salmo gairdneri	Rainbow trout	NR	96 h	TL50	1470	Mortality	98	S	U	7.2-7.6	5.9 - 6.0	13.6-14.6	318-348	(Post and Schroeder 1971)
Salmo gairdneri	Rainbow trout	NR	96 h	LC50	2200	Mortality	99.5	S	U	7.4		17	40	(Sanders et al. 1983)
Salmo gairdneri	Rainbow trout	Juvenile	96 h	TL50	1350	Mortality	95	S	U	6.8-7.4		20 +/- 0.5		(Katz 1961)
Salmo gairdneri	Rainbow trout	NR	96 h	LC50	860	Mortality	NR	FT	U	7.1-7.8	7.5 +/- 1.6	17.3 +/- 0.6	40.7-46.6	(Phipps and Holcombe 1985)
Salmo gairdneri	Rainbow trout	NR	96 h	TL50	4340	Mortality	99	S	U	7.1		13		(Macek and McAllister 1970)
Salmo trutta	Brown trout	Fry	96 h	LC50	700	Mortality	97.6	S	U	7.1	6	16		(Lakota et al. 1981)
Salmo trutta	Brown trout	NR	96 h	TL50	1950	Mortality	99	S	U	7.1		13		(Macek and McAllister 1970)
Salvelinus fontinalis	Brook Trout	NR	96 h	TL50	1070	Mortality	98	S	U	7.2-7.6	5.9 - 6.0	13.6-14.6	318-348	(Post and Schroeder 1971)
Tilapia mossambica	Tilapia	NR	48 h	LC50	5495	Mortality	NR	S	U	7.0 +/- 0.2		26-28	140 +/-20	(Basha et al. 1983)
Tilapia sp.	Tilapia	NR	96 h	LC50	10000	Mortality	85	S	U	7.3-8.4		27-31	10-16 ppm	(Liong et al. 1988)
Xyrauchen texanus	Razorback Sucker	0.31-0.032 g	24 h	LC50	6670	Mortality	99.7	S	2	8.35 +/- 0.29		22	173 +/- 9	(Dwyer et al. 1995)
Xyrauchen texanus	Razorback Sucker	0.31-0.032 g	96 h	LC50	4350	Mortality	99.7	S	2	8.35 +/- 0.29		22	173 +/- 9	(Dwyer et al. 1995)
Xyrauchen texanus	Razorback Sucker	0.31-0.032 g	12 h	LC50	8880	Mortality	99.7	S	2	8.35 +/- 0.29		22	173 +/- 9	(Dwyer et al. 1995)

Latin Name	Common Name	Life Stage	Duration	End-point	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp (°C)	Hard-ness	Reference
Invertebrates														
Aedes aegypti	Yellow fever mosquito	Larva	36 h	LC50	336	Mortality	97.6	S	U	7.1		20 +/- 0.2		(Lakota et al. 1981)
Aedes aegypti	Mosquito	3rd instar	24 h	LC50	510	Immobility	99.5	S	2	7.8 - 8.0		25		(Parsons and Surgeoner 1991b)
Aedes aegypti	Mosquito	3rd instar	1 h	LC50	7800	Immobility	99.5	S	2	7.8 - 8.0		25		(Parsons and Surgeoner 1991b)
Aedes aegypti	Mosquito	3rd instar	4 h	LC50	1410	Immobility	99.5	S	2	7.8 - 8.0		25		(Parsons and Surgeoner 1991b)
Aedes aegypti	Mosquito	3rd instar	2 h	LC50	3040	Immobility	99.5	S	U	7.8- 8.0		25		(Parsons and Surgeoner 1991a)
Aedes aegypti	Mosquito	3rd instar	2 h	LC50	3470	Immobility	99.5	S	2	7.8- 8.0		25		(Parsons and Surgeoner 1991a)
Aedes aegypti	Mosquito	3rd instar	4 h	LC50	1400	Immobility	99.5	S	2	7.8- 8.0		25		(Parsons and Surgeoner 1991a)
Aedes aegypti	Mosquito	3rd instar	4 h	LC50	1700	Immobility	99.5	S	U	7.8- 8.0		25		(Parsons and Surgeoner 1991a)
Aedes aegypti	Mosquito	4th instar	24 h	LC50	167	Immobility		S	U					(Shamaan et al. 1993)
Aedes aegypti	Mosquito	4th instar	24 h	LC50	380	Immobility		S	U					(Shamaan et al. 1993)
Aedes aegypti	Mosquito	4th instar	24 h	LC95	2170	Immobility		S	U					(Shamaan et al. 1993)
Aedes aegypti	Mosquito	4th instar	24 h	LC95	2280	Immobility		S	U					(Shamaan et al. 1993)
Ameletus sp.	Mayfly	NR	96 h	LC50	20.4	Immobility	43	S	U	7.0 - 7.5		10	30 - 40	(Peterson et al. 2001a)
Ameletus sp.	Mayfly	NR	96 h	LC1	7.5	Immobility	43	S	U	7.0 - 7.5		10	30 - 40	(Peterson et al. 2001a)
Aplexa hypnorum	Snail	Adult	96 h	LC50	> 27	Mortality	NR	FT	U	7.1- 7.8	7.5 +/- 1.6	17.3 +/- 0.6	40.7- 46.6	(Phipps and Holcombe 1985)
Bosmina fatalis	Cladoceran	Adult	24 h	LC50	4.075	Mortality	99	S	2			20 +/- 1		(Sakamoto et al. 2005)
Bosmina longirostris	Cladoceran	Adult	24 h	LC50	8.597	Mortality	99	S	2			20 +/- 1		(Sakamoto et al. 2005)
Brachycentrus americanus	Caddisfly	NR	96 h	LC50	41.2	Immobility	43	S	U	7.0 - 7.5		10	30 - 40	(Peterson et al. 2001a)
Brachycentrus americanus	Caddisfly	NR	96 h	LC1	28.8	Immobility	43	S	U	7.0 - 7.5		10	30 - 40	(Peterson et al. 2001a)

Latin Name	Common Name	Life Stage	Duration	End-point	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp (°C)	Hard-ness	Reference
Brachythemis contaminata	Dragonfly	Nymph	48 h	LC50	106.5	Mortality	10	S	U	6.8-7.2		24+/- 3		(Shukla and Mishra 1980)
Calineuria californica	Stonefly	NR	96 h	LC50	17.3	Immobility	43	S	U	7.0 - 7.5		10	30 - 40	(Peterson et al. 2001a)
Calineuria californica	Stonefly	NR	96 h	LC1	9	Immobility	43	S	U	7.0 - 7.5		10	30 - 40	(Peterson et al. 2001a)
Calineuria californica	Stonefly	Nymph	1 h	LC12.5	173	Mortality	43	S	U	7.37-7.87		10	30-40	(Peterson et al. 2001b)
Calineuria californica	Stonefly	Nymph	15 min	LC30	17.3	Mortality	43	S	U	7.37-7.87		10	30-40	(Peterson et al. 2001b)
Calineuria californica	Stonefly	Nymph	30 min	LC14.3	173	Mortality	43	S	U	7.37-7.87		10	30-40	(Peterson et al. 2001b)
Ceriodaphnia dubia	Water flea	Neonate	48 h	LC50	11.6	Immobility	99	S	1	8.18 +/- 0.04		25	57.07 +/- 4.14	(Oris et al. 1991)
Ceriodaphnia dubia	Water flea	NR	24 h	LC50	100	Immobility	NR	S	2[1]	8.2-8.3	7.6 - 8.1	22 +/- 0.5	162-178	(Milam et al. 2005)
Ceriodaphnia dubia	Water flea	NR	24 h	NOEC	50	Immobility	NR	S	2[1]	8.2-8.3	7.6 - 8.1	22 +/- 0.5	162-178	(Milam et al. 2005)
Chironomus plumosus	Midge	Larva	48 h	EC50	10	Immobility	99.5	S	U	7.4		17	40	(Sanders et al. 1983)
Chironomus riparius	Midge	4th instar	24 h	EC50	96	Behavioral	99	S	2	8		10		(Lohner and Fisher 1990)
Chironomus riparius	Midge	4th instar	24 h	EC50	107	Behavioral	99	S	2	8		30		(Lohner and Fisher 1990)
Chironomus riparius	Midge	4th instar	24 h	EC50	110	Behavioral	99	S	2	4		20		(Lohner and Fisher 1990)
Chironomus riparius	Midge	4th instar	24 h	EC50	110	Behavioral	99	S	2	6		20		(Lohner and Fisher 1990)
Chironomus riparius	Midge	4th instar	24 h	EC50	128	Behavioral	99	S	2	8		20		(Lohner and Fisher 1990)
Chironomus riparius	Midge	4th instar	24 h	EC50	133	Behavioral	99	S	2	6		10		(Lohner and Fisher 1990)
Chironomus riparius	Midge	4th instar	24 h	EC50	133	Behavioral	99	S	2	4		10		(Lohner and Fisher 1990)

Latin Name	Common Name	Life Stage	Duration	End-point	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp (°C)	Hard-ness	Reference
Chironomus riparius	Midge	4th instar	24 h	EC50	61	Behavioral	99	S	2	4		30		(Lohner and Fisher 1990)
Chironomus riparius	Midge	4th instar	24 h	EC50	71	Behavioral	99	S	2	6		30		(Lohner and Fisher 1990)
Chloroperla grammatica	Stonefly	Larva	96 h	LC50	5.8	Mortality	99.1	S	2	8.1-9.1	8.5 - 11.7	10.3-10.4	0.7m mol/L	(Schafers 2002a)
Chloroperla grammatica	Stonefly	Larva	96 h	LC10	4.2	Mortality	99.1	S	2	8.1-9.1	8.5 - 11.7	10.3-10.4	0.7m mol/L	(Schafers 2002a)
Chloroperla grammatica	Stonefly	Larva	96 h	NOEC	3.4	Mortality	99.1	S	2	8.1-9.1	8.5 - 11.7	10.3-10.4	0.7m mol/L	(Schafers 2002a)
Chloroperla grammatica	Stonefly	Larva	96 h	LOEC	5.1	Mortality	99.1	S	2	8.1-9.1	8.5 - 11.7	10.3-10.4	0.7m mol/L	(Schafers 2002a)
Chloroperla grammatica	Stonefly	Larva	1 h	EC50	29	Immobility	99.1	S	2	8.3-8.6	8.6 - 10.8	10.2-10.4		(Schafers 2002c)
Chloroperla grammatica	Stonefly	Larva	1 h	NOEC	100	Mortality	99.1	S	2	8.3-8.6	8.6 - 10.8	10.2-10.4		(Schafers 2002c)
Chydorus sphaericus	Cladoceran	Adult	48 h	EC50	12.4	Immobility	99.1	S	2	8.2-8.6	6.6 - 8.0	19.9-20.2	1.8 mmol /L	(Schafers 2002d)
Cinygma sp.	Mayfly	NR	96 h	LC50	11.1	Immobility	43	S	U	7.0 - 7.5		10	30 - 40	(Peterson et al. 2001a)
Cinygma sp.	Mayfly	NR	96 h	LC1	3	Immobility	43	S	U	7.0 - 7.5		10	30 - 40	(Peterson et al. 2001a)
Cinygma sp.	Mayfly	Nymph	1 h	LC10	102	Mortality	43	S	U	7.37-7.87		10	30-40	(Peterson et al. 2001b)

Latin Name	Common Name	Life Stage	Duration	End-point	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp (°C)	Hard-ness	Reference
Cinygma sp.	Mayfly	Nymph	15 min	LC33.3	408	Mortality	43	S	U	7.37-7.87		10	30-40	(Peterson et al. 2001b)
Cinygma sp.	Mayfly	Nymph	30 min	LC10	10.2	Mortality	43	S	U	7.37-7.87		10	30-40	(Peterson et al. 2001b)
Colpidium campylum	Protozoan	NR	43 h	TL50	740	Survival		NR	U			20		(Dive et al. 1980)
Corbicula striatella	Bivalve	NR	96 h	LC50	5100	Mortality	NR	NR	U	7.2 +/- 0.5	4.5 +/- 1	27 +/- 2		(Jadhav et al. 1996)
Daphnia ambigua	Water flea	Embryo	NR	EC100	5	Helmet formation	99	R	U			23		(Hanazato 1991b)
Daphnia magna	Water flea	NR	96 h	LC50	3280	Mortality	97	S	U			20		(Lejczak 1977)
Daphnia magna	Water flea	5 d	48 h	LC50	7.2	Mortality	97.6	S	U	7.1		20 +/- 0.2		(Lakota et al. 1981)
Daphnia magna	Water flea	Neonate	48 h	EC50	19	Immobility	99.1	S	2	7.3-7.6	5.0 - 7.6	19.7-20.1	2.5 mmom/L	(Ebeling 2002)
Daphnia magna	Water flea	1st instar	48 h	EC50	5.6	Immobility	99.5	S	U	7.4		17	40	(Sanders et al. 1983)
Daphnia magna	Water flea	NR	24 h	LC50	1900	Immobility	NR	S	2[1]	8.2-8.3	7.6 - 8.1	22 +/- 0.5	162-178	(Milam et al. 2005)
Daphnia magna	Water flea	NR	24 h	NOEC	2150	Immobility	NR	S	U	8.2-8.3	7.6 - 8.1	22 +/- 0.5	162-178	(Milam et al. 2005)
Daphnia magna	Water flea	NR	48 h	EC50	16	Immobility	99.1	S	2	7.8	8.9 - 9.1	19.2-20.0	1.66 mmol/L	(Ebeling and Nguyen 2002)
Daphnia obtusa	Water flea	< 24hrs	24 h	EC50	15	Immobility	99.6	S	U	7.8 +/- 0.2			250	(Rossini and Ronco 1996)
Daphnia obtusa	Water flea	< 24hrs	48 h	EC50	11.5	Immobility	99.6	S	U	7.8 +/- 0.2			250	(Rossini and Ronco 1996)

Latin Name	Common Name	Life Stage	Duration	End-point	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp (°C)	Hard-ness	Reference
Daphnia similis	Water flea	Adult	48 h	EC(I) 50	8.8	Immobility	99	S	2	7.4-7.5	7.7 - 8.0	20	43	(Bortoleto 1992)
Echinogammarus tibaldii	Amphipod	Adult	96 h	LC50	6.5	Immobility	99	S	U	7.9 +/- 0.5		8 +/- 0.5	240	(Pantani et al. 1997)
Ephemera danica	Mayfly	Larva	96 h	LC50	153	Mortality	99.1	S	2	8.1-8.7	8.3 - 9.3	15.0-15.4	1.8 mmol /L	(Schafers 2002e)
Gammarus fossarum	Scud	Young	96 h	LC50	31	Mortality	99.1	S	1	7.3-8.7	8.1 - 9.7	15.0-15.2	1.2 mmol /L	(Schafers 2002g)
Gammarus fossarum	Scud	Young	96 h	LC50	31	Mortality	99.1	S	1	7.3-8.7	8.1 - 9.7	15.0-15.2	1.2 mmol /L	(Schafers 2002g)
Gammarus italicus	Scud	Adult	96 h	LC50	28	Immobility	99	S	U	7.9 +/- 0.5		8 +/- 0.5	240	(Pantani et al. 1997)
Gammarus pseudolimnaeus	Amphipod	NR	96 h	LC50	13	Mortality	99	S	U	6.5		12	0.04	(Woodward and Mauck 1980)
Gammarus pseudolimnaeus	Amphipod	Adult	96 h	LC50	16	Mortality	99.5	S	U	7.4		17	40	(Sanders et al. 1983)
Lampsilis cardium	Plain pocketbook mussel	Glochidia	24 h	LC50	33900	Immobility	NR	S	2[1]	8.2-8.3	7.6 - 8.1	22 +/- 0.5	162-178	(Milam et al. 2005)
Lampsilis cardium	Plain pocketbook mussel	Glochidia	24 h	NOEC	9300	Immobility	NR	S	2[1]	8.2-8.3	7.6 - 8.1	22 +/- 0.5	162-178	(Milam et al. 2005)
Lampsilis siliquoidea	Fatmucket mussel	Glochidia	24 h	LC50	31100	Immobility	NR	S	2[1]	8.2-8.3	7.6 - 8.1	22 +/- 0.5	162-178	(Milam et al. 2005)
Lampsilis siliquoidea	Fatmucket mussel	Glochidia	24 h	NOEC	<16700	Immobility	NR	S	U	8.2-8.3	7.6 - 8.1	22 +/- 0.5	162-178	(Milam et al. 2005)
Lepidostoma unicolor	Caddisfly	NR	96 h	LC50	29	Immobility	43	S	U	7.0 - 7.5		10	30 - 40	(Peterson et al. 2001a)

Latin Name	Common Name	Life Stage	Duration	End-point	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp (°C)	Hard-ness	Reference
Lepidostoma unicolor	Caddisfly	NR	96 h	LC1	9.5	Immobility	43	S	U	7.0 - 7.5		10	30 - 40	(Peterson et al. 2001a)
Leptodea fragilis	Fragile papershell mussel	Glochidia	24 h	LC50	9100	Immobility	NR	S	2[1]	8.2-8.3	7.6 - 8.1	22 +/- 0.5	162-178	(Milam et al. 2005)
Leptodea fragilis	Fragile papershell mussel	Glochidia	24 h	NOEC	3500	Immobility	NR	S	2[1]	8.2-8.3	7.6 - 8.1	22 +/- 0.5	162-178	(Milam et al. 2005)
Ligumia subrostrata	Pondmuss-el	Glochidia	24 h	LC50	43100	Immobility	NR	S	2[1]	8.2-8.3	7.6 - 8.1	22 +/- 0.5	162-178	(Milam et al. 2005)
Ligumia subrostrata	Pondmuss-el	Glochidia	24 h	NOEC	5180	Immobility	NR	S	2[1]	8.2-8.3	7.6 - 8.1	22 +/- 0.5	162-178	(Milam et al. 2005)
Macrobrachium dayanum	Prawn	NR	96 h	LC50	35.2	Mortality		S	U	7.6 +/- 0.2	7.8 +/- 0.3	26 +/- 1.5	112.32 +/- 1.64	(Omkar and Mutri 1985)
Macrobrachium lamarrei	Prawn	NR	96 h	LC50	32.6	Mortality	50	S	U	7.5 +/- 0.2	8.2 +/- 0.25	25 +/- 1	110.35 +/- 2.5	(Shukla and Omkar 1984)
Macrobrachium lamarrei	Prawn	NR	24 h	LC50	33	Immobility	99.9	R	2	7.5 +/- 0.2	7.6 +/- 0.3	26 +/- 2	113.5 +/- 1.5	(Omkar and Shukla 1985)
Macrobrachium lamarrei	Prawn	NR	48 h	LC50	27	Immobility	99.9	R	2	7.5 +/- 0.2	7.6 +/- 0.3	26 +/- 2	113.5 +/- 1.5	(Omkar and Shukla 1985)
Macrobrachium lamarrei	Prawn	NR	72 h	LC50	24	Immobility	99.9	R	2	7.5 +/- 0.2	7.6 +/- 0.3	26 +/- 2	113.5 +/- 1.5	(Omkar and Shukla 1985)
Macrobrachium lamarrei	Prawn	NR	96 h	LC50	19	Immobility	99.9	R	2	7.5 +/- 0.2	7.6 +/- 0.3	26 +/- 2	113.5 +/- 1.5	(Omkar and Shukla 1985)
Megalonaias nervosa	Washboard mussel	Glochidia	24 h	LC50	27400	Immobility	NR	S	2[1]	8.2-8.3	7.6 - 8.1	22 +/- 0.5	162-178	(Milam et al. 2005)

Latin Name	Common Name	Life Stage	Duration	End-point	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp (°C)	Hard-ness	Reference
Megalonaias nervosa	Washboard mussel	Glochidia	24 h	NOEC	< 6000	Immobility	NR	S	U	8.2-8.3	7.6 - 8.1	22 +/- 0.5	162-178	(Milam et al. 2005)
Melanopsis dufouri	Mollusc	NR	96 h	LC50	10100	Immobility	NR	S	U	7.9 +/- 0.2		29	250 ppm	(Almar et al. 1988)
Melanopsis dufouri	Mollusc	NR	96 h	LC50	12800	Immobility	NR	S	U	7.9 +/- 02		22	250 ppm	(Almar et al. 1988)
Melanopsis dufouri	Mollusc	NR	96 h	LC50	14870	Immobility	NR	S	U	7.9 +/- 0.2		15	250 ppm	(Almar et al. 1988)
Moina micrura	Cladoceran	Pre-adult instar	24 h	LC50	119.6	Mortality	97	S	U					(Krishnan and Chockalingam 1989)
Moina micrura	Cladoceran	Pre-adult instar	6 h	LC50	159.8	Mortality	97	S	U					(Krishnan and Chockalingam 1989)
Moina micrura	Cladoceran	Pre-adult instar	12 h	LC50	141.9	Mortality	97	S	U					(Krishnan and Chockalingam 1989)
Moina micrura	Cladoceran	Pre-adult instar	4 h	LC50	246.3	Mortality	97	S	U					(Krishnan and Chockalingam 1989)
Moina micrura	Cladoceran	Pre-adult instar	3 h	LC50	311.3	Mortality	97	S	U					(Krishnan and Chockalingam 1989)
Mysis relicta	Mysid shrimp	NR	48 h	LC50	550	Immobility	98	R	1	8.0		4	139.9 +/- 1.6	(Landrum and Dupuis 1990)
Mysis relicta	Mysid shrimp	NR	72 h	LC50	400	Immobility	98	R	1	8.0		4	139.9 +/- 1.6	(Landrum and Dupuis 1990)
Mysis relicta	Mysid shrimp	NR	96 h	LC50	230	Immobility	98	R	1	8.0		4	139.9 +/- 1.6	(Landrum and Dupuis 1990)
Orconectes immunis	Crayfish	NR	96 h	LC50	2870	Mortality	NR	FT	U	7.1-7.8	7.5 +/- 1.6	17.3 +/- 0.6	40.7-46.6	(Phipps and Holocombe 1985)
Paramecium aurelia	Parameci-um	7 d	24 h	LC50	46000	Mortality	97.5	S	U					(Edmiston et al. 1984)

Latin Name	Common Name	Life Stage	Duration	End-point	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp (°C)	Hard-ness	Reference
Paramecium bursaria	Parameci-um	7 d	24 h	LC50	31000	Mortality	97.5	S	U					(Edmiston et al. 1984)
Paramecium caudatum	Protozoan	NR	24 h	LC50	7900	Mortality	97	S	U			20		(Lejczak 1977)
Paramecium caudatum	Parameci-um	7 d	24 h	LC50	10000	Mortality	97.5	S	U					(Edmiston et al. 1984)
Paramecium multimicronucleatum	Parameci-um	7 d	24 h	LC50	24000	Mortality	97.5	S	U					(Edmiston et al. 1984)
Paramecium multimicronucleatum	Protozoan	12 d	24 h	LC50	28000	Immobility	97.5	S	U					(Edmiston et al. 1985)
Paratelphusa masoniana	Crab	NR	96 h	LC50	1006.6	Mortality	50	S	U	7.5-8.0	7.8 - 8.9 ppm	17-20	390-410 ppm	(Kaushik and Kumar 1993)
Paratya compressa improvisa	Shrimp	2 weeks	48 h	LC50		Mortality	99	NR	U					(Hatakeyama and Sugaya 1989)
Parreysia cylindrica	Bivalve	NR	96 h	LC50	11655.74	Mortality	50	S	U	7.06 +/- 0.1699		27.75 +/- 1.2731		(Waykar and Lomte 2001)
Planorbarius corneus	Snail	Juvenile	96 h	LC50	> 3110	Mortality	99.1	S	U	7.7-8.4	3.8 - 7.1	20.0-21.0	1.5 mmol /L	(Schafers 2002f)
Pomacea patula	Snail	NR	96 h	LC50	14600	Immobility	99	R	2	6.5			48	(Mora et al. 2000)
Pontoporeia hoyi	Amphipod	NR	24 h	LC50	460	Immobility	98	R	1	8.0		4	139.9 +/- 1.6	(Landrum and Dupuis 1990)
Pontoporeia hoyi	Amphipod	NR	48 h	LC50	370	Immobility	98	R	1	8.0		4	139.9 +/- 1.6	(Landrum and Dupuis 1990)
Pontoporeia hoyi	Amphipod	NR	72 h	LC50	290	Immobility	98	R	1	8.0		4	139.9 +/- 1.6	(Landrum and Dupuis 1990)

Latin Name	Common Name	Life Stage	Duration	End-point	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp (°C)	Hard-ness	Reference
Pontoporeia hoyi	Amphipod	NR	96 h	LC50	250	Immobility	98	R	1	8.0		4	139.9 +/- 1.6	(Landrum and Dupuis 1990)
Procambarus clarkii	Crayfish	Adult	96 h	LC20	800	Mortality	80	S	U	7.8		19 +/- 0.5	250	(Andreu-Moliner et al. 1986)
Pseudechinus magellanicus	Sea urchin	Pluteus	96 h	EC50	92.5	Development	99	S	U			13		(Hernandez et al. 1990)
Psychoglypha sp.	Caddisfly	Early instar	96 h	LC50	30.3	Immobility	43	S	U	7.0 - 7.5		10	30 - 40	(Peterson et al. 2001a)
Psychoglypha sp.	Caddisfly	Early instar	96 h	LC1	14.8	Immobility	43	S	U	7.0 - 7.5		10	30 - 40	(Peterson et al. 2001a)
Psychoglypha sp.	Caddisfly	Late instar	96 h	LC50	61	Immobility	43	S	U	7.0 - 7.5		10	30 - 40	(Peterson et al. 2001a)
Psychoglypha sp.	Caddisfly	Late instar	96 h	LC1	33.8	Immobility	43	S	U	7.0 - 7.5		10	30 - 40	(Peterson et al. 2001a)
Pteronarcella badia	Stonefly	NR	96 h	LC50	11	Mortality	99	S	U	6.5		12	0.04	(Woodward and Mauck 1980)
Pteronarcella badia	Amphipod	NR	96 h	LC50	7	Mortality	99	S	U	7.5		12	0.04	(Woodward and Mauck 1980)
Pteronarcella badia	Amphipod	NR	96 h	LC50	7.2	Mortality	99	S	U	8.5		12	0.04	(Woodward and Mauck 1980)
Pteronarcella badia	Stonefly	NR	96 h	LC50	13	Mortality	99	S	U	7.5		12	0.04	(Woodward and Mauck 1980)
Pteronarcella badia	Stonefly	NR	96 h	LC50	29	Mortality	99	S	U	8.5		12	0.04	(Woodward and Mauck 1980)
Ranatra elongata	Water scorpion	NR	96 h	LC50	624	Mortality	50	S	U	7.4 +/- 0.2	7.2 +/- 0.3	25 +/- 1	110.35 +/- 1.2	(Shukla et al. 1982)
Simulium vittatum	Black Fly	Larva	48 h	LC50	23.72	Immobility	98	S	1	7.94-8.01	8.90-8.94	20.30-21.0	90	(Overmyer et al. 2003)
Simulium vittatum	Black Fly	Larva	48 h	LC50	44.34	Immobility	98	S	2	7.94-8.01	8.90-8.94	20.30-21.0	90	(Overmyer et al. 2003)

Latin Name	Common Name	Life Stage	Duration	End-point	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp (°C)	Hard-ness	Reference
Sphaerium corneum	Clam	Adult	96 h	NOEC	3650	Mortality	99.1	S	U	8.1-8.6	4.9 - 9.2	15.4-15.5	1.7 mmol /L	(Schafers 2002b)
Utterbackia imbecellis	Paper pondshell mussel	Glochidia	24 h	LC50	40200	Immobility	NR	S	2[1]	8.2-8.3	7.6 - 8.1	22 +/- 0.5	162-178	(Milam et al. 2005)
Utterbackia imbecellis	Paper pondshell mussel	Glochidia	24 h	NOEC	3600	Immobility	NR	S	2[1]	8.2-8.3	7.6 - 8.1	22 +/- 0.5	162-178	(Milam et al. 2005)
Utterbackia imbecellis	Freshwater Mussel	Glochidia	24 h	LC50	7900	Mortality	23.5	S	U	8.33		25	85	(Conners and Black 2004)
Xanthocnemis zealandica	Damselfly	Adult	NR	EC100	100	Emergence	80	R	U	2.9				(Hardersen and Frampton 1999)
Xanthocnemis zealandica	Damselfly	2nd instar	48 h	LC50	156.6	Immobility	80	S	U					(Hardersen and Wratten 2000)
Xanthocnemis zealandica	Damselfly	6th instar	48 h	LC50	381.8	Immobility	80	S	U					(Hardersen and Wratten 2000)
Xanthocnemis zealandica	Damselfly	8th instar	48 h	LC50	437.7	Immobility	80	S	U					(Hardersen and Wratten 2000)
Xanthocnemis zealandica	Damselfly	10th instar	48 h	LC50	770	Immobility	80	S	U					(Hardersen and Wratten 2000)
Xanthocnemis zealandica	Damselfly	12th instar	48 h	LC50	600	Immobility	80	S	U					(Hardersen and Wratten 2000)
Xanthocnemis zealandica	Damselfly	13th instar	48 h	LC50	760	Immobility	80	S	U					(Hardersen and Wratten 2000)
Plants														
Ipomoea aquatica	Water spinach	NR	96 h	EC50	996000	Chlorophyll content	NR	NR	U	4.0		25 +/- 2	113	(Boonyawanich et al. 2001)
Pistia stratiotes	Water lettuce	NR	96 h	EC50	785000	Chlorophyll content	NR	NR	U	4.0		25 +/- 2	113	(Boonyawanich et al. 2001)

Table A3 Toxicity Values for Marine Long-term Aquatic Species Exposed to Carbaryl

Latin Name	Common Name	Life Stage	Duration	Endpoint	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp (°C)	Salinity (‰)	Reference
Algae														

Latin Name	Common Name	Life Stage	Duration	Endpoint	Conc µg/L	Effect	% a.i.	Test Type	Rank	pH	DO	Temp (°C)	Salinity (‰)	Reference
Amphiprora	Diatom	NR	48 h	IC60	500	Growth	NR	NR	U			23-32	27	(Maly and Ruber 1983)
Amphora coffeaformis v. borealis	Diatom	NR	48 h	IC99	1000	Growth	NR	NR	U			23-32	27	(Maly and Ruber 1983)
Chlorococcum sp.	Green algae	NR	48 h	IC40	2000	Growth	NR	NR	U			23-32	27	(Maly and Ruber 1983)
Gonyaulax sp.	Dinoflagellate	NR	48 h	IC41	10000	Germination success	NR	NR	U			23-32	27	(Maly and Ruber 1983)
Nitzschia closterium	Diatom	NR	48 h	IC10	1000	Growth	NR	NR	U			23-32	27	(Maly and Ruber 1983)
Skeletonema costatum	Diatom	6 d	5 d	EC10	180	Growth inhibition	99.7	S	1	8 +/- 1		20 +/- 2	20	(Lintott 1992d)
Skeletonema costatum	Diatom	6 d	5 d	EC50	350	Growth inhibition	99.7	S	1	8 +/- 1		20 +/- 2	20	(Lintott 1992d)
Skeletonema costatum	Diatom	6 d	5 d	EC90	680	Growth inhibition	99.7	S	1	8 +/- 1		20 +/- 2	20	(Lintott 1992d)

Table A4 Toxicity Values for Marine Short-term Aquatic Species Exposed to Carbaryl

Latin Name	Common Name	Life Stage	Duration	Endpoint	Conc. (µg/L)	Effect	% a.i.	Test Type	Rank	pH	DO	Temp (°C)	Salinity (‰)	Reference
Fish														
Cymatogaster aggregata	Shiner perch	Juvenile	24 h	EC50	3900	Immobility	80	S	U	7.9-8.1		20 +/- 2	25	(Stewart et al. 1967)

Latin Name	Common Name	Life Stage	Duration	Endpoint	Conc. (µg/L)	Effect	% a.i.	Test Type	Rank	pH	DO	Temp (°C)	Salinity (‰)	Reference
Cyprinodon bovinus	Leon Springs pupfish	0.42 g	24 h	LC50	> 8000	Immobility	99.7	S	2			20 +/- 1	2	(Sappington et al. 2001)
Cyprinodon bovinus	Leon Springs pupfish	0.42 g	96 h	LC50	4500	Immobility	99.7	S	2			20 +/- 1	2	(Sappington et al. 2001)
Cyprinodon macularius	Desert pupfish	Adult	24 h	LC50	> 8000	Immobility	99.7	S	2			20 +/- 1	2	(Sappington et al. 2001)
Cyprinodon macularius	Desert pupfish	Adult	96 h	LC50	7200	Immobility	99.7	S	2			20 +/- 1	2	(Sappington et al. 2001)
Cyprinodon variegatus	Sheepshead minnow	0.24 g	24 h	LC50	> 4800	Immobility	99.7	S	2			20 +/- 1	2	(Sappington et al. 2001)
Cyprinodon variegatus	Sheepshead minnow	0.24 g	96 h	LC50	4400	Immobility	99.7	S	2			20 +/- 1	2	(Sappington et al. 2001)
Cyprinodon variegatus	Sheepshead minnow	NR	72 h	LC50	2700	Mortality	99	S	2	7.6 -7.9		22	31-34	(Springborn Bionomics 1985b)
Cyprinodon variegatus	Sheepshead minnow	Juvenile	96 h	LC50	2600	Mortality	99.7	FT	U	8.3-8.4	5.8-8.4	24.1-25.6	20 +/- 1	(Lintott 1992c)
Cyprinus carpio	Common carp	NR	96 h	LC50	29000	Mortality	100	R	U	7.0-7.3		19.6-22.6		(Dorgerloh 2004)
Cyprinus carpio	Common carp	NR	96 h	NOEC	1650	Mortality	100	R	U	7.0-7.3		19.6-22.6		(Dorgerloh 2004)
Gambusia affinis	Mosquitofish	NR	96 h	TLm	31800	Mortality	80	S	U				5	(Chaiyarach et al. 1975)
Gasterosteus aculeatus	Threespine stickleback	Adult	96 h	TL50	3990	Mortality	95	S	U	6.8-7.4		20 +/- 0.5	5	(Katz 1961)
Gasterosteus aculeatus	Threespine stickleback	Juvenile	24 h	EC50	6700	Immobility	80	S	U	7.9-8.1		20 +/- 2	25	(Stewart et al. 1967)
Morone saxatilis	Striped bass	35- 80 d	96 h	LC50	2300	Mortality	NR	S	U	7.9		20 +/- 2		(Palawski et al. 1985)
Parophrys vetulus	English sole	Juvenile	24 h	EC50	4100	Immobility	80	S	U	7.9-8.1		20 +/- 2	25	(Stewart et al. 1967)

Latin Name	Common Name	Life Stage	Duration	Endpoint	Conc. (µg/L)	Effect	% a.i.	Test Type	Rank	pH	DO	Temp (°C)	Salinity (‰)	Reference
Therapon jarbua	Tigerfish	6-9 months	96 h	LC50	2200	Mortality		S	U	7.9	4.8	29 +/- 1	19.21	(Lingaraja and Venugopalan 1978)
Invertebrates														
Arenicola marina	Lugworm	NR	48 h	LC50	7200	Mortality	99	R	U	8.05		15		(Conti 1987)
Artemia salina	Brine shrimp	24h	24 h	LC50	27567.27	Immobility	97	S	2	8.6		25	35	(Barahona and Sánchez-Fortún 1999)
Artemia salina	Brine shrimp	48h	24 h	LC50	5915.9	Immobility	97	S	2	8.6		25	35	(Barahona and Sánchez-Fortún 1999)
Artemia salina	Brine shrimp	72h	24 h	LC50	350.1	Immobility	97	S	2	8.6		25	35	(Barahona and Sánchez-Fortún 1999)
Callianassa californisnis	Ghost shrimp	Larva	48 h	EC50	30	Immobility	80	S	U	7.9-8.1		20 +/- 2	25	(Stewart et al. 1967)
Cancer magister	Dungerness crab	Juvenile	24 h	EC50	600	Immobility	80	S	U	7.9-8.1		20 +/- 2	25	(Stewart et al. 1967)
Clinocardium nuttallii	Cockle clam	Adult	24 h	EC50	7300	Immobility	80	S	U	7.9-8.1		20 +/- 2	25	(Stewart et al. 1967)
Crassostrea gigas	Pacific oyster	Larva	48 h	EC50	2200	Immobility	80	S	U	7.9-8.1		20 +/- 2	25	(Stewart et al. 1967)
Crassostrea virginica	Oyster	Embryo	48 h	EC50	2700	Development	99	S	2	7.8		20	30	(Springborn Bionomics 1985d)
Euplotes sp.	Protozoan	NR	24 h	LC50	1	NR	NR	NR	U					(Weber et al. 1982)
Hemigrapsus oregonensis	Shore crab	Adult	24 h	EC50	270	Immobility	80	S	U	7.9-8.1		20 +/- 2	25	(Stewart et al. 1967)
Litopenaeus stylirostris	Shrimp	Larva	48 h	LC50	29.8	Mortality	NR	S	U	8.4-8.7		22-24	33-35	(Galindo Reyes et al. 2002)

Latin Name	Common Name	Life Stage	Duration	Endpoint	Conc. (µg/L)	Effect	% a.i.	Test Type	Rank	pH	DO	Temp (°C)	Salinity (‰)	Reference
Metapenaeus monoceros	Prawn	NR	96 h	LC50	24.87	Mortality	99	S	U	7.1 +/- 0.2		23 +/- 2	15 +/- 1	(Reddy et al. 1990)
Metapenaeus monoceros	Prawn	2.5 g	96 h	LC50	249	Mortality	99	S	U	7.1 +/- 0.2		23 +/- 2	15 +/- 1	(Reddy and Rao 1992)
Metapenaeus monoceros	Prawn	NR	96 h	LC50	24.87	Mortality	99	S	U	7.1 +/- 0.2		23 +/- 2	15 +/- 1	(Jayaprada and Rao 1991)
Mysidopsis bahia	Mysid	Juvenile	96 h	LC50	> 7.7	Mortality	NR	FT	U					(Nimmo et al. 1981)
Mysidopsis bahia	Mysid	1- 5 d	24 h	LC50	12	Mortality	99	S	2	7.7-7.9	6.2-7.2	21-23	20	(Springborn Bionomics 1985c)
Mysidopsis bahia	Mysid	24h	96 h	LC50	5.7	Mortality	99.7	FT	1	8.2-8.5	3.9-5.2	21.5-23.1	20+/-1	(Lintott 1992a)
Mytilus edulis	Marine mussel	NR	NR	EC50	6821.39	Feeding rate	98	NR	U			15	33-35	(Donkin et al. 1997)
Mytilus edulis	Bay mussel	Larva	48 h	EC50	2300	Immobility	80	S	U	7.9-8.1		20 +/- 2	25	(Stewart et al. 1967)
Mytilus edulis	Mussel	Adult	96 h	TL50	22700	Immobility	99.7	S	2	7.95	7.2	19.5	25.4	(Liu and Lee 1975)
Palaemonetes kadiakensis	Grass shrimp	NR	96 h	TLm	120	Mortality	80	S	U				5	(Chaiyarach et al. 1975)
Penaeus indicus	Prawn	NR	96 h	LC50	21	Mortality	99	S	U	7.1 +/- 0.2		23 +/- 2	15 +/- 1	(Reddy and Rao 1991)
Procambarus simulans	Crayfish	NR	96 h	TLm	2430	Mortality	80	S	U				5	(Chaiyarach et al. 1975)
Pseudechinus magellanicus	Sea urchin	Blastula	12 h	EC50	6.3	Development	99	S	U			13		(Hernandez et al. 1990)
Pseudechinus magellanicus	Sea urchin	Gastrula	36 h	EC50	10.7	Development	99	S	U			13		(Hernandez et al. 1990)
Pseudechinus magellanicus	Sea urchin	Prism	48 h	EC50	157.4	Development	99	S	U			13		(Hernandez et al. 1990)
Rangia cuneata	Mactrid clam	NR	96 h	TLm	125000	Mortality	80	S	U				5	(Chaiyarach et al. 1975)

Latin Name	Common Name	Life Stage	Duration	Endpoint	Conc. (µg/L)	Effect	% a.i.	Test Type	Rank	pH	DO	Temp (°C)	Salinity (‰)	Reference
Scylla serrata	Crab	Juvenile	96 h	LC50	466.27	Mortality	Technical	S	U	7.2-7.5	4.3 +/- 0.16 ml/L	28 +/- 1.0	30 +/- 1.5	(Rao and Kannupandi 1990)
Scylla serrata	Crab	Juvenile	120 h	LC50	401.62	Mortality	Technical	S	U	7.2-7.5	4.3 +/- 0.16 ml/L	28 +/- 1.0	30 +/- 1.5	(Rao and Kannupandi 1990)
Uca minax	Fiddler crab	Zoeae	25 h	LC50	100	Mortality	27	S	U				5	(Capaldo 1987)
Upogebia pugettensis	Mud shrimp	Larva	48 h	EC50	90	Immobility	80	S	U	7.9-8.1		20 +/- 2	25	(Stewart et al. 1967)

NOTES:
NR= Not Reported
Test Type: S= Static, FT= Flow-through, R= Renewal
Ranking: 1= Primary, 2= Secondary, U= Unacceptable, * Acceptable ranking however endpoint not severe and therefore not included in SSD dataset.

[1]These endpoints were ranked as secondary despite the lack of reported percent purity for carbaryl. The decision was made using best scientific judgement and was based on other reported variables and cited references in the published study.

APPENDIX B

SUMMARY OF PRIMARY AND SECONDARY AQUATIC TOXICITY DATA FOR CARBARYL

Table B-1 Summary of primary and secondary freshwater ecotoxicity data for carbaryl

Latin Name	Common Name	Duration	Endpoint	Effect	Conc. µg/L	Reference	Rank
Acipenser brevirostrum	Shortnose sturgeon	48 h	LC50	Mortality	4230	(Dwyer et al. 2000)	2
Acipenser oxyrhynchus	Atlantic sturgeon	48 h	LC50	Mortality	1280	(Dwyer et al. 2000)	2
Aedes aegypti	Mosquito	1 h	LC50	Immobility	7800	(Parsons and Surgeoner 1991b)	2
Aedes aegypti	Mosquito	2 h	LC50	Immobility	3470	(Parsons and Surgeoner 1991a)	2
Aedes aegypti	Mosquito	24 h	LC50	Immobility	510	(Parsons and Surgeoner 1991b)	2
Aedes aegypti	Mosquito	4 h	LC50	Immobility	1410	(Parsons and Surgeoner 1991b)	2
Aedes aegypti	Mosquito	4 h	LC50	Immobility	1400	(Parsons and Surgeoner 1991a)	2
Anabaena flos-aquae	Blue-green alga	5 d	EC10	Growth	140	(Lintott 1992b)	1
Anabaena flos-aquae	Blue-green alga	5 d	EC50	Growth	380	(Lintott 1992b)	1
Anabaena flos-aquae	Blue-green alga	5 d	EC90	Growth	1100	(Lintott 1992b)	1
Bosmina fatalis	Cladocerans	24 h	LC50	Mortality	4.075	(Sakamoto et al. 2005)	2
Bosmina longirostris	Cladocerans	24 h	LC50	Mortality	8.597	(Sakamoto et al. 2005)	2
Brachydanio rerio	Zebrafish	96 h	LC50	Mortality	9256.17	(Gallo et al. 1995)	2
Bufo arenarum	Toad	96 h	LC50	Mortality	2464	(Ferrari et al. 2004a)	2
Bufo arenarum	Toad	96 h	IC50	ChE inhibition	7580	(Ferrari et al. 2004a)	2*
Carassius auratus	Goldfish	96 h	IC50	Brain ChE inhibition	2620	(Ferrari et al. 2004b)	2*
Carassius auratus	Goldfish	96 h	LC10	Mortality	10600	(Ferrari et al. 2004b)	2
Carassius auratus	Goldfish	96 h	LC50	Mortality	13900	(Ferrari et al. 2004b)	2
Carassius auratus	Goldfish	96 h	LC90	Mortality	18000	(Ferrari et al. 2004b)	2
Carassius auratus	Goldfish	96 h	NOEC	Mortality	9000	(Ferrari et al. 2004b)	2
Ceriodaphnia dubia	Water flea	7 d	IC50	Reproduction	10.6	(Oris et al. 1991)	1
Ceriodaphnia dubia	Water flea	7 d	IC50	Reproduction	8.6	(Oris et al. 1991)	1
Ceriodaphnia dubia	Water flea	4 d	IC50	Reproduction	8.3	(Oris et al. 1991)	1
Ceriodaphnia dubia	Water flea	4 d	IC50	Reproduction	9.7	(Oris et al. 1991)	1
Ceriodaphnia dubia	Water flea	7 d	MATC	Reproduction	10.6	(Oris et al. 1991)	1
Ceriodaphnia dubia	Water flea	7 d	MATC	Reproduction	7.2	(Oris et al. 1991)	1
Ceriodaphnia dubia	Water flea	4 d	MATC	Reproduction	10.6	(Oris et al. 1991)	1
Ceriodaphnia dubia	Water flea	48 h	LC50	Immobility	11.6	(Oris et al. 1991)	1
Ceriodaphnia dubia	Water flea	24 h	LC50	Immobility	100	(Milam et al. 2005)	2

Ceriodaphnia dubia	Water flea	24 h	NOEC	Immobility	50	(Milam et al. 2005)	2
Chironomus riparius	Midge	28 d	LOEC	Emergence and development	318.31	(Ebeling and Radix 2002)	2
Chironomus riparius	Midge	28 d	NOEC	Emergence and development	147.25	(Ebeling and Radix 2002)	2
Chironomus riparius	Midge	24 h	EC50	Behavioral	96	(Lohner and Fisher 1990)	2
Chironomus riparius	Midge	24 h	EC50	Behavioral	107	(Lohner and Fisher 1990)	2
Chironomus riparius	Midge	24 h	EC50	Behavioral	110	(Lohner and Fisher 1990)	2
Chironomus riparius	Midge	24 h	EC50	Behavioral	110	(Lohner and Fisher 1990)	2
Chironomus riparius	Midge	24 h	EC50	Behavioral	128	(Lohner and Fisher 1990)	2
Chironomus riparius	Midge	24 h	EC50	Behavioral	133	(Lohner and Fisher 1990)	2
Chironomus riparius	Midge	24 h	EC50	Behavioral	61	(Lohner and Fisher 1990)	2
Chironomus riparius	Midge	24 h	EC50	Behavioral	71	(Lohner and Fisher 1990)	2
Chloroperla grammatica	Stonefly	1 h	EC50	Immobility	29	(Schafers 2002c)	2
Chloroperla grammatica	Stonefly	1 h	NOEC	Mortality	100	(Schafers 2002c)	2
Chloroperla grammatica	Stonefly	96 h	LC10	Mortality	4.2	(Schafers 2002a)	2
Chloroperla grammatica	Stonefly	96 h	LC50	Mortality	5.8	(Schafers 2002a)	2
Chloroperla grammatica	Stonefly	96 h	LOEC	Mortality	5.1	(Schafers 2002a)	2
Chloroperla grammatica	Stonefly	96 h	NOEC	Mortality	3.4	(Schafers 2002a)	2
Chydorus sphaericus	Cladocerans	48 h	EC50	Immobility	12.4	(Schafers 2002d)	2
Colisa fasciatus	Dwarf gouramy	24 h	LC10	Mortality	7450	(Singh et al. 2004)	2
Colisa fasciatus	Dwarf gouramy	24 h	LC50	Mortality	9040	(Singh et al. 2004)	2
Colisa fasciatus	Dwarf gouramy	24 h	LC90	Mortality	1097	(Singh et al. 2004)	2
Colisa fasciatus	Dwarf gouramy	48 h	LC10	Mortality	7390	(Singh et al. 2004)	2
Colisa fasciatus	Dwarf gouramy	48 h	LC50	Mortality	8590	(Singh et al. 2004)	2
Colisa fasciatus	Dwarf gouramy	48 h	LC90	Mortality	9970	(Singh et al. 2004)	2
Colisa fasciatus	Dwarf gouramy	72 h	LC10	Mortality	7290	(Singh et al. 2004)	2
Colisa fasciatus	Dwarf gouramy	72 h	LC50	Mortality	8300	(Singh et al. 2004)	2
Colisa fasciatus	Dwarf gouramy	72 h	LC90	Mortality	9470	(Singh et al. 2004)	2
Colisa fasciatus	Dwarf gouramy	96 h	LC10	Mortality	7250	(Singh et al. 2004)	2
Colisa fasciatus	Dwarf gouramy	96 h	LC50	Mortality	8000	(Singh et al. 2004)	2
Colisa fasciatus	Dwarf gouramy	96 h	LC90	Mortality	8830	(Singh et al. 2004)	2
Daphnia magna	Water flea	21 d	EC10	Reproduction	6.4	(Schafers 2006)	1
Daphnia magna	Water flea	21 d	EC10	Survival	6.5	(Schafers 2006)	1

Daphnia magna	Water flea	21 d	LOEC	Survival and reproduction	6.6	(Schafers 2006)	1
Daphnia magna	Water flea	21 d	MATC	Survival and reproduction	>3.3	(Springborn Bionomics 1985a)	1
Daphnia magna	Water flea	21 d	NOEC	Survival and reproduction	5.9	(Schafers 2006)	1
Daphnia magna	Water flea	24 h	LC50	Immobility	1900	(Milam et al. 2005)	2
Daphnia magna	Water flea	48 h	EC50	Immobility	19	(Ebeling 2002)	2
Daphnia magna	Water flea	48 h	EC50	Immobility	16	(Ebeling and Nguyen 2002)	2
Daphnia similis	Water flea	48 h	EC(I)50	Immobility	8.8	(Bortoleto 1992)	2
Ephemera danica	Mayfly	96 h	LC50	Mortality	153	(Schafers 2002e)	2
Etheostoma fonticola	Fountain darter	96 h	LC50	Mortality	2020	(Dwyer et al. 2005b)	2
Etheostoma lepidum	Greenthroat Darter	96 h	LC50	Mortality	2140	(Dwyer et al. 2005b)	2
Gammarus fossarum	Scud	96 h	LC50	Mortality	31	(Schafers 2002g)	1
Gammarus fossarum	Scud	96 h	LC50	Mortality	31	(Schafers 2002g)	1
Gila elegans	Bonytail	32 d	NOEC	Growth	650	(Beyers et al. 1994)	2
Gila elegans	Bonytail	32 d	LOEC	Growth	1240	(Beyers et al. 1994)	2
Gila elegans	Bonytail	32 d	NOEC	Survival	650	(Beyers et al. 1994)	2
Gila elegans	Bonytail	32 d	LOEC	Survival	1240	(Beyers et al. 1994)	2
Gila elegans	Bony tail Chub	7 d	IC25	Survival	250	(Dwyer et al. 2005a)	2
Gila elegans	Bony tail Chub	7 d	IC25	Survival	250	(Dwyer et al. 2005a)	2
Gila elegans	Bony tail Chub	12 h	LC50	Mortality	7930	(Dwyer et al. 1995)	2
Gila elegans	Bony tail Chub	24 h	LC50	Mortality	6130	(Dwyer et al. 1995)	2
Gila elegans	Bonytail	96 h	LC50	Mortality	2020	(Beyers et al. 1994)	2
Gila elegans	Bony tail Chub	96 h	LC50	Mortality	3490	(Dwyer et al. 1995)	2
Hybopsis monacha	Spotfin Chub	96 h	LC50	Mortality	3410	(Dwyer et al. 2005b)	2
Lampsilis cardium	Plain pocketbook mussel	24 h	LC50	Immobility	33900	(Milam et al. 2005)	2
Lampsilis cardium	Plain pocketbook mussel	24 h	NOEC	Immobility	9300	(Milam et al. 2005)	2
Lampsilis siliquoidea	Fatmucket mussel	24 h	LC50	Immobility	31100	(Milam et al. 2005)	2
Lepomis macrochirus	Bluegill sunfish	96 h	NOEC	Behaviour	4200	(Sowig and Gosch 2002)	2
Leptodea fragilis	Fragile papershell mussel	24 h	LC50	Immobility	9100	(Milam et al. 2005)	2
Leptodea fragilis	Fragile papershell mussel	24 h	NOEC	Immobility	3500	(Milam et al. 2005)	2

Ligumia subrostrata	Pondmussel	24 h	LC50	Immobility	43100	(Milam et al. 2005)	2
Ligumia subrostrata	Pondmussel	24 h	NOEC	Immobility	5180	(Milam et al. 2005)	2
Macrobrachium lamarrei	Prawn	24 h	LC50	Immobility	33	(Omkar and Shukla 1985)	2
Macrobrachium lamarrei	Prawn	48 h	LC50	Immobility	27	(Omkar and Shukla 1985)	2
Macrobrachium lamarrei	Prawn	72 h	LC50	Immobility	24	(Omkar and Shukla 1985)	2
Macrobrachium lamarrei	Prawn	96 h	LC50	Immobility	19	(Omkar and Shukla 1985)	2
Megalonaias nervosa	Washboard mussel	24 h	LC50	Immobility	27400	(Milam et al. 2005)	2
Mysis relicta	Mysid shrimp	48 h	LC50	Immobility	550	(Landrum and Dupuis 1990)	1
Mysis relicta	Mysid shrimp	72 h	LC50	Immobility	400	(Landrum and Dupuis 1990)	1
Mysis relicta	Mysid shrimp	96 h	LC50	Immobility	230	(Landrum and Dupuis 1990)	1
Navicula pelliculosa	Diatom	5 d	EC10	Growth	290	(Lintott 1992e)	1
Navicula pelliculosa	Diatom	5 d	EC50	Growth	610	(Lintott 1992e)	1
Navicula pelliculosa	Diatom	5 d	EC90	Growth	1300	(Lintott 1992e)	1
Notropis mekistocholas	Cape Fear Shiner	96 h	LC50	Immobility	4510	(Dwyer et al. 2005b)	2
Oncorhynchus clarki henshawi	Lahontan cutthroat trout	12 h	LC50	Mortality	4380	(Dwyer et al. 1995)	2
Oncorhynchus clarki henshawi	Lahontan cutthroat trout	24 h	LC50	Mortality	3600	(Dwyer et al. 1995)	2
Oncorhynchus clarki henshawi	Lahontan cutthroat trout	96 h	LC50	Mortality	2250	(Dwyer et al. 1995)	2
Oncorhynchus clarki stomias	Greenback cutthroat trout	12 h	LC50	Mortality	8500	(Dwyer et al. 1995)	2
Oncorhynchus clarki stomias	Greenback cutthroat trout	24 h	LC50	Mortality	3590	(Dwyer et al. 1995)	2
Oncorhynchus clarki stomias	Greenback cutthroat trout	96 h	LC50	Mortality	1550	(Dwyer et al. 1995)	2
Oncorhynchus gilae apache	Apache trout	12 h	LC50	Mortality	3290	(Dwyer et al. 1995)	2
Oncorhynchus gilae apache	Apache trout	24 h	LC50	Mortality	2500	(Dwyer et al. 1995)	2
Oncorhynchus gilae apache	Apache trout	96 h	LC50	Mortality	1540	(Dwyer et al. 1995)	2
Oncorhynchus mykiss	Rainbow trout	12 h	LC50	Mortality	6760	(Dwyer et al. 1995)	2
Oncorhynchus mykiss	Rainbow trout	24 h	LC50	Mortality	4040	(Dwyer et al. 1995)	2
Oncorhynchus mykiss	Rainbow trout	96 h	EC50	Brain ChE inhibition	270	(Ferrari et al. 2007b)	2*
Oncorhynchus mykiss	Rainbow trout	96 h	EC50	Muscular ChE inhibition	19.24	(Ferrari et al. 2007b)	2*
Oncorhynchus mykiss	Rainbow trout	96 h	LC50	Mortality	1880	(Dwyer et al. 1995)	2

Pimephales promelas	Fathead minnow	7 d	LOEC	Growth	1000	(Pickering et al. 1996)	2
Pimephales promelas	Fathead minnow	7 d	NOEC	Growth	500	(Pickering et al. 1996)	2
Pimephales promelas	Fathead minnow	7 d	NOEC	Growth	500	(Pickering et al. 1996)	2
Pimephales promelas	Fathead minnow	7 d	LOEC	Growth	810	(Norberg-King 1989)	2
Pimephales promelas	Fathead minnow	7 d	LOEC	Growth	1600	(Norberg-King 1989)	2
Pimephales promelas	Fathead minnow	7 d	MATC	Growth	569	(Norberg-King 1989)	2
Pimephales promelas	Fathead minnow	7 d	MATC	Growth	576	(Norberg-King 1989)	2
Pimephales promelas	Fathead minnow	7 d	NOEC	Growth	400	(Norberg-King 1989)	2
Pimephales promelas	Fathead minnow	7 d	NOEC	Growth	390	(Norberg-King 1989)	2
Pimephales promelas	Fathead minnow	7 d	LOEC	Growth	200	(Pickering et al. 1996)	2
Pimephales promelas	Fathead minnow	7 d	LOEC	Growth	2000	(Pickering et al. 1996)	2
Pimephales promelas	Fathead minnow	7 d	NOEC	Growth	1000	(Pickering et al. 1996)	2
Pimephales promelas	Fathead minnow	7 d	LOEC	Growth	1000	(Pickering et al. 1996)	2
Pimephales promelas	Fathead minnow	7 d	LOEC	Growth	2000	(Pickering et al. 1996)	2
Pimephales promelas	Fathead minnow	7 d	NOEC	Growth	1000	(Pickering et al. 1996)	2
Pimephales promelas	Fathead minnow	7 d	NOEC	Growth	500	(Pickering et al. 1996)	2
Pimephales promelas	Fathead minnow	7 d	LOEC	Growth and survival	1400	(Norberg-King 1989)	2
Pimephales promelas	Fathead minnow	7 d	MATC	Growth and survival	976	(Norberg-King 1989)	2
Pimephales promelas	Fathead minnow	7 d	NOEC	Growth and survival	680	(Norberg-King 1989)	2
Pimephales promelas	Fathead minnow	7 d	LOEC	Survival	1000	(Pickering et al. 1996)	2
Pimephales promelas	Fathead minnow	7 d	LOEC	Survival	2000	(Pickering et al. 1996)	2
Pimephales promelas	Fathead minnow	7 d	NOEC	Survival	1000	(Pickering et al. 1996)	2
Pimephales promelas	Fathead minnow	7 d	NOEC	Survival	500	(Pickering et al. 1996)	2
Pimephales promelas	Fathead minnow	7 d	IC25	Survival	420	(Dwyer et al. 2005a)	2
Pimephales promelas	Fathead minnow	7 d	IC25	Survival	420	(Dwyer et al. 2005a)	2
Pimephales promelas	Fathead minnow	7 d	LOEC	Survival	1400	(Norberg-King 1989)	2
Pimephales promelas	Fathead minnow	7 d	MATC	Survival	1018	(Norberg-King 1989)	2
Pimephales promelas	Fathead minnow	7 d	NOEC	Survival	740	(Norberg-King 1989)	2
Pimephales promelas	Fathead minnow	7 d	LOEC	Survival	4000	(Pickering et al. 1996)	2
Pimephales promelas	Fathead minnow	7 d	NOEC	Survival	2000	(Pickering et al. 1996)	2
Pimephales promelas	Fathead minnow	7 d	NOEC	Survival	4000	(Pickering et al. 1996)	2

Pimephales promelas	Fathead minnow	12 h	LC50	Mortality	12000	(Dwyer et al. 1995)	2
Pimephales promelas	Fathead minnow	24 h	LC50	Mortality	8250	(Dwyer et al. 1995)	2
Pimephales promelas	Fathead minnow	96 h	LC50	Mortality	5210	(Dwyer et al. 1995)	2
Poecilia reticulata	Guppy	96 h	LC50	Mortality	2515.26	(Gallo et al. 1995)	2
Poeciliopsis occidentalis occidentalis	Gila topminnow	96 h	LC50	Immobility	> 3000	(Dwyer et al. 2005b)	2
Pomacea patula	Snail	96 h	LC50	Immobility	14600	(Mora et al. 2000)	2
Pontoporeia hoyi	Amphipod	24 h	LC50	Immobility	460	(Landrum and Dupuis 1990)	1
Pontoporeia hoyi	Amphipod	48 h	LC50	Immobility	370	(Landrum and Dupuis 1990)	1
Pontoporeia hoyi	Amphipod	72 h	LC50	Immobility	290	(Landrum and Dupuis 1990)	1
Pontoporeia hoyi	Amphipod	96 h	LC50	Immobility	250	(Landrum and Dupuis 1990)	1
Pseudokirchneriella subcapitata	Green algae	96 h	EC50	Growth	1370	(Ebeling and Gosch 2002)	2
Pseudokirchneriella subcapitata (formerly Selenastrum capricornumtum)	Green algae	5 d	EC10	Reduced population	560	(Lintott 1992f)	2
Pseudokirchneriella subcapitata (formerly Selenastrum capricornumtum)	Green algae	5 d	EC50	Reduced population	1200	(Lintott 1992f)	2
Pseudokirchneriella subcapitata (formerly Selenastrum capricornumtum)	Green algae	5 d	EC90	Reduced population	2400	(Lintott 1992f)	2
Ptychocheilus lucius	Colorado Squawfish	32 d	NOEC	Growth	445	(Beyers et al. 1994)	2
Ptychocheilus lucius	Colorado Squawfish	32 d	LOEC	Growth	866	(Beyers et al. 1994)	2
Ptychocheilus lucius	Colorado Squawfish	32 d	NOEC	Survival	445	(Beyers et al. 1994)	2
Ptychocheilus lucius	Colorado Squawfish	32 d	LOEC	Survival	866	(Beyers et al. 1994)	2
Ptychocheilus lucius	Colorado pikeminnow	7 d	IC25	Survival	1330	(Dwyer et al. 2005a)	2
Ptychocheilus lucius	Colorado pikeminnow	7 d	IC25	Survival	1330	(Dwyer et al. 2005a)	2
Ptychocheilus lucius	Colorado Squawfish	12 h	LC50	Mortality	> 10000	(Dwyer et al. 1995)	2
Ptychocheilus lucius	Colorado Squawfish	24 h	LC50	Mortality	6310	(Dwyer et al. 1995)	2
Ptychocheilus lucius	Colorado Squawfish	24 h	LOEC	AchE inhibition	49.1	(Beyers and Sikoski 1994)	2*
Ptychocheilus lucius	Colorado Squawfish	24 h	NOEC	AchE inhibition	29.3	(Beyers and Sikoski 1994)	2*
Ptychocheilus lucius	Colorado Squawfish	4 d	LC50	Mortality	1310	(Beyers et al. 1994)	2
Ptychocheilus lucius	Colorado Squawfish	96 h	LC50	Mortality	3070	(Dwyer et al. 1995)	2

Rana clamitans	Green frog	24 h	LC50	Mortality	17570	(Boone and Bridges 1999)	2
Rana clamitans	Green frog	24 h	LC50	Mortality	22550	(Boone and Bridges 1999)	2
Rana clamitans	Green frog	48 h	LC50	Mortality	16170	(Boone and Bridges 1999)	2
Rana clamitans	Green frog	48 h	LC50	Mortality	21760	(Boone and Bridges 1999)	2
Rana clamitans	Green frog	72 h	LC50	Mortality	14880	(Boone and Bridges 1999)	2
Rana clamitans	Green frog	72 h	LC50	Mortality	20020	(Boone and Bridges 1999)	2
Rana clamitans	Green frog	96 h	LC50	Mortality	11320	(Boone and Bridges 1999)	2
Rana clamitans	Green frog	96 h	LC50	Mortality	17360	(Boone and Bridges 1999)	2
Rana clamitans	Green frog	48 h	LC50	Mortality	26010	(Boone and Bridges 1999)	2
Rana clamitans	Green frog	72 h	LC50	Mortality	24800	(Boone and Bridges 1999)	2
Rana clamitans	Green frog	96 h	LC50	Mortality	22020	(Boone and Bridges 1999)	2
Rana sphenocephala	Southern Leopard Frog	96 h	LC50	Mortality	8400	(Bridges et al. 2002)	2
Simulium vittatum	Black Fly	48 h	LC50	Immobility	23.72	(Overmyer et al. 2003)	1
Simulium vittatum	Black Fly	48 h	LC50	Immobility	44.34	(Overmyer et al. 2003)	2
Utterbackia imbecellis	Paper pondshell mussel	24 h	LC50	Immobility	40200	(Milam et al. 2005)	2
Utterbackia imbecellis	Paper pondshell mussel	24 h	NOEC	Immobility	3600	(Milam et al. 2005)	2
Xyrauchen texanus	Razorback Sucker	7 d	IC25	Survival	2060	(Dwyer et al. 2005a)	2
Xyrauchen texanus	Razorback Sucker	7 d	IC25	Survival	2060	(Dwyer et al. 2005a)	2
Xyrauchen texanus	Razorback Sucker	12 h	LC50	Mortality	8880	(Dwyer et al. 1995)	2
Xyrauchen texanus	Razorback Sucker	24 h	LC50	Mortality	6670	(Dwyer et al. 1995)	2
Xyrauchen texanus	Razorback Sucker	96 h	LC50	Mortality	4350	(Dwyer et al. 1995)	2

Notes:
Rank: *Endpoint acceptable but not severe and therefore not included in the SSD dataset.

Table B-2 Summary of primary and secondary marine ecotoxicity data for carbaryl

Latin Name	Common Name	Duration	Endpoint	Effect	Conc. µg/L	Reference	Rank
Artemia salina	Brine shrimp	24 h	LC50	Immobility	27567.27	(Barahona and Sánchez-Fortún 1999)	2
Artemia salina	Brine shrimp	24 h	LC50	Immobility	5915.90	(Barahona and Sánchez-Fortún 1999)	2
Artemia salina	Brine shrimp	24 h	LC50	Immobility	350.1	(Barahona and Sánchez-Fortún 1999)	2
Crassostrea virginica	Oyster	48 h	EC50	Development	2700	(Springborn Bionomics 1985d)	2
Cyprinodon bovinus	Leon Springs pupfish	24 h	LC50	Immobility	> 8000	(Sappington et al. 2001)	2
Cyprinodon bovinus	Leon Springs pupfish	96 h	LC50	Immobility	4500	(Sappington et al. 2001)	2
Cyprinodon macularius	Desert pupfish	24 h	LC50	Immobility	> 8000	(Sappington et al. 2001)	2
Cyprinodon macularius	Desert pupfish	96 h	LC50	Immobility	7200	(Sappington et al. 2001)	2
Cyprinodon variegatus	Sheepshead minnow	24 h	LC50	Immobility	>4800	(Sappington et al. 2001)	2
Cyprinodon variegatus	Sheepshead minnow	96 h	LC50	Immobility	4400	(Sappington et al. 2001)	2
Cyprinodon variegatus	Sheepshead minnow	72 h	LC50	Mortality	2700	(Springborn Bionomics 1985b)	2
Mysidopsis bahia	Mysid	96 h	LC50	Mortality	5.7	(Lintott 1992a)	1
Mysidopsis bahia	Mysid	24 h	LC50	Mortality	12	(Springborn Bionomics 1985c)	2
Mytilus edulis	Mussel	96 h	TL50	Immobility	22700	(Liu and Lee 1975)	2
Skeletonema costatum	Diatom	5 d	EC10	Growth	180	(Lintott 1992d)	1
Skeletonema costatum	Diatom	5 d	EC50	Growth	350	(Lintott 1992d)	1
Skeletonema costatum	Diatom	5 d	EC90	Growth	680	(Lintott 1992d)	1