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

Scientific Criteria Document for the Development of the Canadian Water Quality Guidelines for the Protection of Aquatic Life

CADMIUM

PN 1515
ISBN 978-1-77202-000-7 PDF

NOTE TO READERS

The Canadian Council of Ministers of the Environment (CCME) is the primary minister-led intergovernmental forum for collective action on environmental issues of national and international concern.

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

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Reference listing:

CCME. 2014. Canadian Water Quality Guidelines: Cadmium. Scientific Criteria Document. Canadian Council of Ministers of the Environment, Winnipeg.

PN 1515
ISBN 978-1-77202-000-7 PDF

ACKNOWLEDGEMENTS

This document was prepared under the direction of the National Guidelines and Standards Office (NGSO) of Environment Canada. NGSO thanks Ariane Bouffard, Tamzin El-Fityani and Jocelyn Leney for their major scientific contribution to this work. Supporting contributors Susan Roe, Uwe Schneider and Sushil Dixit are also gratefully acknowledged. Ashley Schormans and Kyla Vanderzwet provided much appreciated statistical, technical and editorial support. NGSO thanks Patti Orr of Minnow Environmental Inc. for her administrative and scientific support.

NGSO extends its appreciation to members of the Canadian Council of Ministers of the Environment (CCME) Water Quality Task Group (WQTG). NGSO would also like to thank public and peer reviewers for their comments.

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LIST OF ABBREVIATIONS

ANCOVA	Analysis of Covariance
BAF	Bioaccumulation Factor
BCF	Bioconcentration Factor
CASN	Chemical Abstracts Service Number
CCME	Canadian Council of Ministers of the Environment
Cd	Cadmium
CWQG	Canadian Water Quality Guideline
DL	Detection Limit
DOM	Dissolved Organic Matter
dw	Dry Weight
EC_X	Effective Concentration. The concentration which causes the specified percentage of the population (represented in the X) of the experimental biota to show an observed effect. The effect may be immobilization, changes in reproductive potential, growth, or some other ecologically relevant endpoint
FIAM	Free Ion Activity Model
h	Hour(s). *e.g.* 96 h is 96 hours.
IC_X	Inhibitory Concentration. The concentration of inhibitor which causes the specified percentage (X) of inhibition in the target (*e.g.* molecule, enzyme, cell, microorganism etc.)
K_d	Partition or distribution co-efficient
LC_X	Lethal Concentration. The concentration which is lethal to the specified (X) percentage of the experimental biota
LA_{50}	Median lethal Accumulation
LOEC	Lowest-Observed-Effect Concentration
MATC	Maximum Acceptable Toxicant Concentration; calculated as the geometric mean of the LOEC and the NOEC
MDEC	Minimum Detectable Effect Concentration. The concentration at which the response becomes significantly ($p \leq 0.05$) lower than the control.
MPC	Maximum permissible concentration
NGSO	National Guidelines and Standards Office
NOEC	No-Observed-Effect Concentration
NOM	Natural Organic Matter
NTA	Nitrilotriacetate
ON	Ontario
PBT	Persistence (P), bioaccumulation (B), toxicity (T); these criteria are commonly used in hazard identification
pH	The negative log of the concentration of the hydrogen cation, $-\log[H^+]$
PNEC	Predicted No Effect Concentration
ppb	Parts Per Billion

ppm	Parts Per Million
PSL	Priority Substances List
SOD	Superoxide dismutase
SSD	Species Sensitivity Distribution
US EPA	United States Environmental Protection Agency
WHAM	Windermere Humic Aqueous Model; a program used to calculate metal speciation in water
ww	Wet Weight

EXECUTIVE SUMMARY

Cadmium occurs naturally in the environment. It is a transition metal of Subgroup IIB in the Periodic Table, with an atomic mass of 112.4 $g \cdot mol^{-1}$. The Chemical Abstracts Service (CAS) number for cadmium is 7440-43-9. It is typically found in rocks as a minor constituent in mineral sulphides, particularly zinc sulphides such as sphalerite and wurtzite (Nriagu, 1980). Common compounds of cadmium include cadmium chloride ($CdCl_2$), cadmium nitrate ($Cd(NO_3)_2$), and cadmium sulphate ($CdSO_4$). The two oxidation states of cadmium are metallic (Cd^0) and divalent (Cd^{2+}). The metallic state is rare and the divalent state predominates in most natural deposits (NRCC, 1979). While metallic cadmium is insoluble in water, several of its salts (such as $CdCl_2$ and $CdSO_4$) are freely soluble (Merck, 1989).

Modern methods used to measure cadmium concentrations in environmental samples involve spectrophotometry of various types, including flame atomic absorption, graphite furnace absorption, direct current plasma emission, inductively coupled plasma emission, and inductively-coupled plasma-mass spectrometry. Reported detection limits vary between methods and sample preparation, but can range from about 0.001 to 2 $\mu g \cdot L^{-1}$ for total cadmium (Hall, 1992). Cadmium may exist as a variety of different chemical species in natural waters. Such chemical speciation is significant in relation to its geochemical and biochemical processes in the environment.

Cadmium is mainly recovered as a by-product from the smelting of zinc and other metal ores, and from precipitates obtained during the purification of zinc sulphate (Brown, 1977). Hence, the production of cadmium in Canada is determined largely by the level of zinc production (Nriagu, 1980). Canadian zinc ores contain from 0.001% to 0.067% recoverable cadmium by weight (Brown, 1977). The major industrial uses of cadmium include: nickel-cadmium batteries, pigments, coatings, stabilizers in plastics and synthetic products, and alloys (NRCan, 2005).

As a naturally occurring element, the presence of cadmium in water does not necessarily indicate pollution. As a result of geochemical processes, some areas naturally contain elevated concentrations of cadmium in underlying rock. However, the spatial and temporal variability in natural background concentrations of cadmium in water bodies is determined not only by the mineral composition of the surrounding environment, but also depends on abiotic processes such as weathering, climate, soil type, pH, dilution (*e.g.*, due to rainfall, snowmelt, other seasonal variations), and redox potential (NRCan, 2004).

The environmental fate and behaviour of cadmium is dependent on abiotic conditions, such as hardness, alkalinity, pH, and dissolved organic matter. These abiotic factors influence the toxicity and mobility of cadmium by altering the speciation, or physical-chemical forms, of cadmium in aquatic systems. Although the speciation of cadmium in water is quite complex, the conditions which favour the formation of the free ion Cd^{2+} include low pH and low concentrations of organic matter (Guéguen *et al.*, 2003). For cadmium in particular, the majority of evidence suggests that the free ion Cd^{2+} is the most toxic form.

Cadmium is a relatively rare element that is considered a non-essential metal in aquatic organisms except for a marine diatom (*Thalassiosira weissflogii*) for which it is a minor nutrient at low concentrations (Lane and Morel, 2000; Lee *et al*., 1995; Price and Morel, 1990). Cadmium is toxic to aquatic life at concentrations that are only slightly higher (US EPA, 2001). Cadmium, certainly at least in short-term exposures, exerts its toxic effects in aquatic organisms by blocking the uptake of calcium from water and resulting in calcium deficiency, also known as hypocalcaemia (Hollis *et al.*, 2000a).

Water hardness (*i.e.,* the concentration of calcium [Ca^{2+}] and magnesium [Mg^{2+}] in water) strongly influences the toxicity of cadmium to aquatic organisms. Higher water hardness reduces the toxicity of cadmium to aquatic organisms. Other toxicity modifying factors for cadmium include alkalinity, pH and dissolved organic matter. Alkalinity generally covaries with hardness, and hardness has been shown to be a better predictor of aquatic toxicity than alkalinity (US EPA, 2001). In general, uptake of cadmium by aquatic plants and fish tends to be greatest at neutral pH values (near 7), while at higher and lower pH values, uptake of cadmium is reduced (Playle *et al.*, 1993a; Rai *et al*., 1990; Vigneault and Campbell, 2005; Wang *et al.*, 1998). For fish cadmium toxicity is greatest at neutral pH values, and fish are protected from the toxic effects of cadmium at lower (Cusimano *et al.*, 1986; Hansen *et al*., 2002b) and higher pH values. However in aquatic plants, the effect of pH on cadmium toxicity is not as clear; in some cases, toxicity is greatest at near-neutral pH values (Skowroñski *et al.,* 1991), whereas in other cases, toxic effects were observed to a lesser degree at near-neutral pH values than at either low or high pH (Rai *et al.*, 1990; Uysal and Taner, 2007). The uptake and toxicity of cadmium by aquatic organisms can also be affected by the amount of dissolved organic matter in the water. Although it is recognized that some types of dissolved organic material (DOM) can influence the toxicity of cadmium to aquatic organisms, the exact nature of these relationships can vary widely depending on the specific properties of the organic matter. As a result, there is currently insufficient information to develop empirical relationships between cadmium toxicity and DOM in water. Hardness was the only toxicity modifying factor for which the guideline was modified. However, because this factor had by far the greatest effect on cadmium toxicity (up to a 10-fold effect compared to <2-3-fold for pH and DOM) the hardness adjustment will take into account the majority of toxicity influence observed at a specific site.

In order for cadmium toxicity values from different studies to be compared, they must be converted to a common hardness value, normally 50 $mg \cdot L^{-1}$ ($CaCO_3$ equivalents). Empirical relationships have been derived (for both short-term and long-term studies) to convert toxicity data to a standardized hardness. Accordingly, Canadian Water Quality Guidelines for cadmium are presented as equations with water hardness rather than single values, allowing the user to derive a cadmium guideline based on the water hardness of the site under consideration.

The cadmium freshwater short-term benchmark concentration and long-term Canadian water quality guideline (CWQG) for cadmium for the protection of aquatic life were developed based on the CCME protocol (CCME, 2007) using the statistical or Type A approach. Because the freshwater guideline values depend on water hardness, examples are provided below of what the guideline value would be at sites with various hardness levels (see Table 11.2 for a more detailed distribution of hardness values). These guidelines apply to the total concentration of cadmium in unfiltered water. Marine CWQGs for cadmium were not assessed as part of the present update.

Canadian Water Quality Guidelines (CWQG) for the Protection of Aquatic Life for Cadmium

	Short-Term Exposure ($\mu g \cdot L^{-1}$)	Long-Term Exposure ($\mu g \cdot L^{-1}$)
Freshwater hardness equation	Benchmark = $10^{\{1.016(\log[\text{hardness}]) - 1.71\}}$ (Where hardness is in $mg \cdot L^{-1}$ as $CaCO_3$)	CWQG = $10^{\{0.83(\log[\text{hardness}]) - 2.46\}}$ (Where hardness is in $mg \cdot L^{-1}$ as $CaCO_3$)
Marine	NRG	0.12*

Note: Hardness equations must be used in order to obtain a site-specific guideline based on the hardness of the water body of interest (see table below for examples of guideline values at various levels of water hardness.). The short-term hardness relationship covers a range from 5.3 to 360 mg $CaCO_3 \cdot L^{-1}$ and applies only within that range. The long-term hardness relationship covers a range from 17 to 280 mg $CaCO_3 \cdot L^{-1}$and applies only within that range. Additionally, there may be some site specific instances in which the water quality guideline may not be adequately protective in accounting for toxicity from cadmium accumulation in tissue and in sediment, as these variables can be specific to the organisms and chemical conditions of the site. For further guidance on sediment toxicity, refer to the Cadmium Sediment Quality Guideline for the Protection of Aquatic Life (CCME, 1999).
NRG = no recommended guideline
*This value was not assessed as part of the present update; value is from the 1996 CWQG (CCME, 1996).

Canadian Water Quality Guidelines for the Protection of Aquatic Life in Fresh Water at Various Levels of Water Hardness

Water Hardness (mg/L as $CaCO_3$)	Short-Term Exposure ($\mu g\ Cd \cdot L^{-1}$)	Long-Term Exposure ($\mu g\ Cd \cdot L^{-1}$)
Lower limit*	0.11	0.04
Soft (60)	1.2	0.10
Medium (120)	2.5	0.18
Hard (180)	3.8	0.26
Upper limit**	7.7	0.37

Note: Guideline values obtained using the freshwater hardness equations for soft, medium and hard water as defined in CCREM (1987). Where site-specific hardness is known, the equation should be used to calculate a guideline value for that particular hardness. Lower and upper limits for hardness reflect the minimum and maximum hardness values, respectively, that were used in the derivation of hardness slopes, beyond which values should not be extrapolated.
*A lower limit of 0.11 $\mu g \cdot L^{-1}$ is the short-term benchmark value that applies to all waters of hardness below 5.3 mg $CaCO_3 \cdot L^{-1}$. A lower limit of 0.04 $\mu g \cdot L^{-1}$ is the long-term guideline value that applies to all waters of hardness below 17 mg $CaCO_3 \cdot L^{-1}$.
**An upper limit of 7.7 $\mu g \cdot L^{-1}$ is the short-term benchmark value that applies to all waters of hardness above 360 mg $CaCO_3 \cdot L^{-1}$. An upper limit of 0.37 $\mu g \cdot L^{-1}$ is the long-term guideline that applies to all waters of hardness above 280 mg $CaCO_3 \cdot L^{-1}$.

RÉSUMÉ

On trouve le cadmium à l'état naturel dans l'environnement. C'est un métal de transition du sous-groupe IIB du tableau périodique; sa masse atomique est de 112,4 $g \cdot mol^{-1}$. Le numéro CAS (Chemical Abstracts Service) du cadmium est 7440-43-9. On le trouve généralement dans des roches sous la forme de constituant mineur dans des sulfures minéraux, particulièrement les sulfures de zinc, comme la sphalérite et la wurtzite (Nriagu, 1980). Les composés courants de cadmium comprennent le chlorure de cadmium ($CdCl_2$), le nitrate de cadmium ($Cd(NO_3)_2$) et le sulfate de cadmium ($CdSO_4$). Les deux états d'oxydation du cadmium sont l'état métallique (Cd^0) et l'état divalent (Cd^{2+}). L'état métallique est rare et l'état divalent est celui qui prédomine dans la plupart des dépôts naturels (NRCC, 1979). Le cadmium métallique est insoluble dans l'eau, mais plusieurs de ses sels (comme $CdCl_2$ et $CdSO_4$) sont librement solubles (Merck, 1989).

Les méthodes modernes utilisées pour mesurer les teneurs en cadmium des échantillons prélevés dans l'environnement utilisent diverses formes de spectrophotométrie : absorption atomique de flamme, absorption dans un four à tubes de graphite, émission de plasma à courant continu, émission de plasma à couplage inductif, ou encore la spectrométrie de masse à plasma inductif. Les limites de détection déclarées varient selon les méthodes et la préparation des échantillons, la plage allant de 0,001 à 2 $\mu g \cdot L^{-1}$ pour le cadmium total (Hall, 1992). Le cadmium peut se trouver sous diverses espèces chimiques différentes dans les eaux naturelles. Sa spéciation chimique est importante en ce qui concerne les processus géochimiques et biochimiques auxquels il participe dans l'environnement.

Le cadmium est surtout récupéré comme sous-produit de la fusion du zinc et d'autres minerais métalliques, et de précipités obtenus durant la purification du sulfate de zinc (Brown, 1977). Par conséquent, au Canada la production de cadmium est surtout déterminée par le niveau de production du zinc (Nriagu, 1980). Les minerais de zinc canadiens contiennent entre 0,001 et 0,067 % de cadmium récupérable en poids (Brown, 1977). L'industrie utilise le cadmium principalement dans les batteries nickel-cadmium, les pigments, les revêtements, les stabilisants incorporés au plastique et aux produits synthétiques, et les alliages (CNRC, 2005).

Le cadmium étant un élément naturel, sa présence dans l'eau n'est pas nécessairement un signe de pollution. Par suite de processus géochimiques, certaines zones contiennent naturellement de fortes concentrations de cadmium dans la roche sous-jacente. Cependant, les variabilités spatiale et temporelle des concentrations naturelles de cadmium dans les masses d'eau sont déterminées non seulement par la composition minérale du milieu environnant, mais également par des processus abiotiques comme l'altération météorologique, le climat, le type de sol, le pH, la dilution (par exemple causée par les chutes de pluie, la fonte des neiges et d'autres variations saisonnières) et le potentiel d'oxydoréduction (CNRC, 2004).

Le devenir et le comportement du cadmium dans l'environnement dépendent de conditions abiotiques, comme la dureté, l'alcalinité, le pH et les matières organiques dissoutes. Ces facteurs abiotiques influent sur la toxicité et la mobilité du cadmium en modifiant sa spéciation ou ses formes physico-chimiques dans les systèmes aquatiques. La spéciation du cadmium dans l'eau

est assez complexe, mais les conditions qui favorisent la formation de l'ion libre Cd^{2+} sont, entre autres, un faible pH et de faibles concentrations de matières organiques (Guéguen *et al.*, 2003). Pour le cadmium en particulier, la plus grande partie des renseignements recueillis porte à croire que l'ion libre Cd^{2+} en est la forme la plus toxique.

Le cadmium est un élément relativement rare considéré comme métal non essentiel dans les organismes aquatiques, sauf en ce qui concerne une diatomée marine (*Thalassiosira weissflogii*) pour laquelle, à faible concentration, il constitue un nutriment mineur (Lane et Morel, 2000; Lee *et al.*, 1995; Price et Morel, 1990). Le cadmium est toxique pour la vie aquatique à des concentrations seulement un peu plus élevées (US EPA, 2001). Il produit ses effets toxiques dans les organismes aquatiques en bloquant l'absorption du calcium de l'eau, ce qui produit une carence en calcium appelée hypocalcémie (Hollis *et al.*, 2000a).

La dureté de l'eau (c'est-à-dire la concentration de [Ca^{2+}] et de magnésium [Mg^{2+}] dans l'eau) a un effet important sur la toxicité du cadmium pour les organismes aquatiques. Celle-ci diminue quand la dureté de l'eau augmente. L'alcalinité, le pH et les matières organiques dissoutes sont autant d'autres facteurs de modification de la toxicité. En général, l'alcalinité augmente avec la dureté et on a constaté que celle-ci est un meilleur prédicteur de la toxicité aquatique que l'alcalinité (US EPA, 2001). En général, l'absorption du cadmium par les plantes aquatiques et les poissons est maximale à un pH neutre (voisin de 7), et elle est moindre à un pH plus élevé ou plus faible (Playle *et al.*, 1993a; Rai *et al.*, 1990; Vigneault et Campbell, 2005; Wang *et al.*, 1998). En ce qui concerne les poissons, la toxicité du cadmium est maximale à un pH neutre et les poissons sont protégés contre les effets toxiques du cadmium à des pH plus faibles (Cusimano *et al.*, 1986; Hansen *et al.*, 2002b) et plus élevés. L'effet du pH sur la toxicité du cadmium n'est pas aussi net dans les plantes aquatiques; dans certains cas, la toxicité est maximale à des pH à peu près neutres (Skowroñski *et al.*, 1991), mais on a également observé, à des pH à peu près neutres, des effets toxiques moins prononcés qu'à des pH plus faibles ou plus élevés (Rai *et al.*, 1990; Uysal et Taner, 2007). La quantité de cadmium absorbée par les organismes aquatiques et la toxicité du cadmium peuvent également dépendre de la quantité de matières organiques dissoutes (DOM) dans l'eau. On sait que certains types de DOM peuvent avoir un effet sur la toxicité du cadmium pour les organismes aquatiques, la nature exacte de cette relation peut varier considérablement selon les propriétés particulières de la matière organique. En conséquence, on ne dispose pas à l'heure actuelle d'informations suffisantes pour établir une relation empirique entre la toxicité du cadmium et la quantité de DOM dans l'eau. La dureté était le seul facteur de modification de la toxicité pour lequel la recommandation a été modifiée. Cependant, étant donné que ce facteur était de loin celui qui avait le plus grand effet sur la toxicité du cadmium (par un facteur 10 comparativement à un facteur inférieur à 2 ou 3 pour le pH et les DOM), l'ajustement concernant la dureté tiendra compte de l'effet prépondérant sur la toxicité observé à un site donné.

Pour comparer les toxicités du cadmium déterminées dans des études différentes, il faut les convertir à une dureté commune, normalement 50 $mg \cdot L^{-1}$ (équivalent $CaCO_3$). On a établi des relations empiriques (pour des études sur les expositions de courte et de longue durées) afin de convertir les données de toxicité à une dureté normalisée. C'est pourquoi les Recommandations pour la qualité des eaux au Canada (RQEC) sont présentées sous la forme d'équations comportant la dureté de l'eau plutôt que sous la forme de valeurs particulières, ce qui permet à l'utilisateur d'obtenir une recommandation concernant le cadmium fondée sur la dureté de l'eau au site examiné.

La concentration limite et la recommandation canadiennes pour la qualité des eaux (RCQE) visant de cadmium en vue de la protection de la vie aquatique relativement à des expositions de courte et de longue durées ont été élaborées à l'aide du protocole du CCME (CCME, 2007) par la méthode statistique ou méthode de type A. Étant donné que les recommandations concernant l'eau douce dépendent de la dureté de l'eau, on donne ci-dessous des exemples de valeurs recommandées selon le degré de dureté (voir le tableau 11,2 pour une répartition plus fine des valeurs de dureté). Les RCQE relatives aux milieux marins pour le cadmium n'ont pas été évaluées dans la présente mise à jour.

Les RQEC ci-dessous visent à protéger indéfiniment les espèces aquatiques les plus sensibles à tous les stades de leur vie. Ces recommandations s'appliquent à la concentration totale de cadmium dans l'eau non filtrée.

Recommandations pour la qualité des eaux au Canada (RQEC) en vue de la protection de la vie aquatique contre le cadmium

	Recommandation concernant l'exposition de courte durée ($\mu g \cdot L^{-1}$)	**Recommandation concernant l'exposition de longue durée ($\mu g \cdot L^{-1}$)**
Équation déterminant la dureté de l'eau douce	Concentration limite = $10^{\{1,016(\log [\text{dureté}]) - 1,71\}}$ (où la dureté en mg $CaCO_3 \cdot L^{-1}$)	RQEC = $10^{\{0,83(\log [\text{dureté}]) - 2,46\}}$ (où la dureté en mg $CaCO_3 \cdot L^{-1}$)
Milieu marin	AR	0,12*

Remarque : L'équation déterminant la dureté doit être utilisée pour obtenir à chaque site une recommandation basée sur la dureté du plan d'eau examiné (voir le tableau ci-dessous pour des exemples de recommandations à divers degrés de dureté de l'eau). L'équation déterminant la dureté à court terme a été obtenue à partir de données de dureté dans la plage 5,3-360 mg $CaCO_3 \cdot L^{-1}$ et ne peut donc être utilisée que dans cette plage. L'équation déterminant la dureté à long terme a été obtenue à partir de données de dureté dans la plage 17-280 mg $CaCO_3 \cdot L^{-1}$ et ne peut donc être utilisée que dans cette plage. En outre, pour certains sites, la recommandation pour la qualité de l'eau pourrait être inadéquate comme protection à l'égard de la toxicité résultant de l'accumulation du cadmium dans les tissus et les sédiments étant donné que ces variables peuvent varier selon les organismes et les conditions chimiques du site. Pour de plus amples renseignements sur la toxicité des sédiments, voir les Recommandations canadiennes pour la qualité des sédiments : protection de la vie aquatique – Cadmium (CCME, 1999).
AR = aucune recommandation
*Cette valeur n'a pas été évaluée dans la présente mise à jour; elle provient des RQEC de 1996 (CCME, 1996).

Recommandations pour la qualité des eaux au Canada pour la protection de la vie aquatique dans l'eau douce à divers degrés de dureté de l'eau

Dureté de l'eau (mg $CaCO_3$/L)	Recommandation pour l'exposition de courte durée (µg $Cd \cdot L^{-1}$)	Recommandation pour l'exposition de longue durée (µg $Cd \cdot L^{-1}$)
Limite inférieure*	0,11	0,04
Faible (60)	1,2	0,10
Moyenne (120)	2,5	0,18
Élevée (180)	3,8	0,26
Limite supérieure**	7,7	0,37

Remarque : Recommandations obtenues au moyen des équations déterminant la dureté de l'eau douce pour les duretés faible, moyenne et élevée définies par le CCMRE (1987). Quand la dureté à un site est connue, il faut utiliser l'équation pour calculer une valeur recommandée pour cette dureté particulière. Les limites supérieures et inferieures de la dureté indiquent respectivement les valeures minimales et maximales qui ont été utilisées dans la dérivation des pentes de la dureté et au delà desquelles, l'extrapolation ne doit pas être faite.

* La limite inférieure de 0,11 µg$\cdot L^{-1}$ est la valeur recommandée à court terme qui s'applique à toutes les eaux de dureté inférieure à 5.3 mg $CaCO_3 \cdot L^{-1}$. La limite inférieure de 0,04 µg$\cdot L^{-1}$ est la valeur recommandée à long terme qui s'applique à toutes les eaux de dureté inférieure à 17 mg $CaCO_3 \cdot L^{-1}$.

**La limite supérieure de 7,7 µg$\cdot L^{-1}$ est la valeur recommandée à court terme qui s'applique à toutes les eaux de dureté supérieure à 360 mg $CaCO_3 \cdot L^{-1}$. La limite supérieure de 0,37 µg$\cdot L^{-1}$ est la valeur recommandée à long terme qui s'applique à toutes les eaux de dureté supérieure à 280 mg $CaCO_3 \cdot L^{-1}$.

1.0 INTRODUCTION

Cadmium is a by-product of zinc mining and refining (NRCan, 2005) because cadmium co-occurs in areas where zinc is mined. In 2003, Canada was the world's fourth largest producer of cadmium (NRCan, 2005). Mining and refining activities can redistribute cadmium, and may cause concentrations in ambient water to exceed background concentrations, which in turn could lead to adverse environmental effects.

Canadian Water Quality Guidelines (CWQGs) fulfill the role of compiling and interpreting the aquatic toxicity data, providing an important tool in the evaluation of ambient water quality. By comparing environmental concentrations with cadmium toxicity data and the guideline value, it is possible to determine the level of cadmium present that is likely to cause impact 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. Recently, the protocol used to develop these guidelines was revised (CCME, 2007). 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.

The structure of the supporting document for cadmium has been designed 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 bioavailability and toxicity modifying factors have been given special attention.

2.0 PHYSICAL AND CHEMICAL PROPERTIES

2.1 Identity

Cadmium occurs naturally in the environment. It is a transition metal of Subgroup IIB in the Periodic Table, with a molecular mass of 112.40 $g \cdot mol^{-1}$. The Chemical Abstracts Service (CAS) number for cadmium is 7440-43-9. It is typically found in rock as a minor constituent in mineral sulphides, particularly zinc sulphides such as sphalerite and wurtzite (Nriagu, 1980).

The two oxidation states of cadmium are metallic (Cd^0) and divalent (Cd^{2+}). The metallic state is rare, and thus, the divalent state predominates in most natural deposits (NRCC, 1979). While metallic cadmium is insoluble in water, several of its salts are freely soluble (Merck, 1989).

The compounds of cadmium which are most commonly used in toxicity tests include:

- cadmium chloride ($CdCl_2$) (CAS # 10108-64-2)

- cadmium nitrate ($Cd(NO_3)_2$) (CAS # 10325-94-7)
- cadmium sulphate ($CdSO_4$) (CAS # 10124-36-4)

Other cadmium compounds include:

- cadmium oxide (CdO) (CAS # 1306-19-0)
- cadmium sulphide (CdS) (CAS # 1306-23-6)
- cadmium acetate ($C4H_6CdO_4$) (CAS # 543-90-8)
- cadmium hydroxide ($Cd(OH)_2$)
- cadmium sulphite ($CdSO_3$)

Cadmium has a vapour pressure of approximately zero, but the value increases to 0.76 and 7.6 mmHg at extremely high temperatures of 382 and 473°C, respectively (Chemical Evaluation Search and Retrieval System (CESARS), 1999). The vapour can be quickly oxidized in air to produce cadmium oxide. In the presence of reactive gases or vapour, for example carbon dioxide, water vapour, sulphur dioxide, sulphur trioxide, or hydrogen chloride, the vapour reacts to form cadmium carbonate, hydroxide, sulphite, sulphate, or chloride respectively (WHO, 1992a). The physical and chemical properties of cadmium and its salts are provided in Table 1.1.

Table 2.1 Physical and chemical properties of cadmium and its salts

	Chemical Formula	**Relative atomic or molecular mass**	**Relative density**	**Water Solubility[b] ($mg \cdot L^{-1}$)**	**Melting Point (ºC)**	**Boiling Point (ºC)**	**Reference**
Cadmium	Cd	112.41	8.642	Insoluble	320.9	765	(World Health Organization (WHO) 1992b)
Cadmium acetate	$C_4H_6CdO_4$	230.50	2.341	Very soluble	256	decomposes	(World Health Organization (WHO) 1992b)
Cadmium carbonate	$CdCO_3$			Insoluble			(Weast 2008)
Cadmium chloride[a]	$CdCl_2$	183.32	4.047	1 400 000 $mg \cdot L^{-1}$ (at 20ºC)	568	960	(Weast 2008;World Health Organization (WHO) 1992b)
Cadmium hydroxide	$Cd(OH)_2$	146.41	4.79	2.6 $mg \cdot L^{-1}$ (at 26°C)	300 (decompo ses)	N/A	(World Health Organization (WHO) 1992b)
Cadmium nitrate[a]	$Cd(NO_3)_2$			1 090 000 $mg \cdot L^{-1}$ (at 0ºC)			(Weast 2008)
Cadmium oxide	CdO	128.40	6.95	Insoluble	<1426	900-1000 (decomposes)	(World Health Organization (WHO) 1992b)

	Chemical Formula	Relative atomic or molecular mass	Relative density	Water Solubility[b] (mg·L^{-1})	Melting Point (ºC)	Boiling Point (ºC)	Reference
Cadmium Sulphate[a]	$CdSO_4$	208.46	4.691	755 000 mg·L^{-1} (at 0ºC)	1000	N/A	(Weast 2008;World Health Organization (WHO) 1992b)
Cadmium sulphide	CdS	144.46	4.82	1.3 mg·L^{-1} (at 18ºC)	1750	N/A	(Weast 2008;World Health Organization (WHO) 1992b)
Cadmium sulphite	$CdSO_3$	192.46		Slightly soluble	decomposes	N/A	(World Health Organization (WHO) 1992b)

[a] Commonly used in toxicity tests
[b]Where insoluble, slightly soluble, and very soluble are defined as <1g·L^{-1}, 1-10g·L^{-1}, and >1000g·L^{-1}, respectively (IPCS, 2005).

Cadmium may exist as a variety of different chemical species in natural waters. Such chemical speciation is significant in relation to its geochemical and biochemical processes in the environment. In the dissolved phase, cadmium may be present as hydrated ions, chloride salts, complexed with inorganic ligands, or chelated to form complexes with organic ligands. Sediment, suspended solids, and colloidal particles may contain a variety of components that can complex with cadmium and influence its fate in aquatic systems. These components include mixed hydroxides, oxides, silicates, sulphides, or other compounds. Further adsorption and ion exchange can occur with clay, silica, or organic matter (Raspor, 1980). Association and dissociation of cadmium with these various ligands are primarily dependent on environmental conditions (especially pH, redox potential, hardness, and the relative abundance of each ligand) and the medium (sediments, water, and biota) under consideration (Lum, 1987).

2.2 Detection methods for environmental samples

Some of the methods used to measure cadmium concentrations in environmental samples (including air, water, and soil) are shown in Table 1.2. Common sample preparations include concentration, solvent extraction, acid digestion and filtration.

Table .2.2 Methods for measuring concentrations of cadmium in environmental samples

Detection Method	Acronym	Single-Element or Multi-Element	Sensitivity (Detection Limit)*
Flame atomic absorption	FAA	Single	Moderate (~1 $\mu g \cdot L^{-1}$)
Graphite furnace absorption	GFAA	Single	Excellent (~0.001 $\mu g \cdot L^{-1}$)
Direct current plasma emission	DCP	Multi	Moderate (not reported)
Inductively coupled plasma emission	ICP	Multi	Moderate (~2 $\mu g \cdot L^{-1}$)
Inductively-coupled plasma-mass spectrometry	ICP-MS	Multi	Excellent (~0.2 $\mu g \cdot L^{-1}$)

(Modified from (Beaty and Kerber, 2002)
* Detection limits from (Hall, 1992)

Speciation of metals, including cadmium, in water is often related to the observed toxicity. However, most detection methods measure the total amount of cadmium in a sample, and provide little or no information on its speciation in water. Speciation of cadmium can be predicted using geochemical models, for example the Windermere Humic Aqueous Model (WHAM) (Tipping, 1994; Vigneault and Campbell, 2005). However, in most environmental monitoring and toxicity studies, cadmium concentrations are reported as total or dissolved cadmium, where "dissolved" is defined operationally as that which passes through a 0.45 µm filter.

3.0 PRODUCTION AND USES

3.1 Mining and Refining in Canada

Knowledge of the location of cadmium deposits (where background levels of cadmium would be naturally high) as well as anthropogenic sources of cadmium into the environment are important in guideline derivation. This information supports the determination of natural and acceptable levels of cadmium, especially in cadmium-rich areas.

Of the approximately 77 active metal mines in Canada, only one is listed as a producer of cadmium in 2007. It is the Kidd Creek Mine (operated by Xstrata Copper Canada) which sends ores to Kidd Metallurgical Site, located in Timmins, Ontario (NRCan, 2007). Other mines operated previously in British Columbia, Manitoba, New Brunswick, Northwest Territories, Ontario and Québec. Cadmium production (all forms) remained relatively constant through the late 1980s and 1990s but has been decreasing since 1999 (Table 2.1). Preliminary estimates for 2005 (Table 2.2) indicate that production (all forms) is only 30-50% that seen in the mid-1990s. With only one active mine since 2007, production is likely to decrease further.

Cadmium contamination can occur in areas where other metals, for example zinc, are mined, even if cadmium is not the primary metal being produced. Zinc is mined on Vancouver Island, British Columbia; around Flin Flon and Snow Lake, Manitoba; near Timmins, Ontario; near Rouyn-Noranda, Québec; and near Bathurst, New Brunswick (NRCan, 2006). There are primary production facilities for zinc in Trail, British Columbia; Flin Flon, Manitoba; and Timmins, Ontario, and there is a zinc refinery in Valleyfield, Québec (NRCan, 2006).

Table 3.1 Cadmium production in Canada, 1988-2004

Year	Production (kg) All Forms[a]	Production (kg) Refined[b]
1988	1 663 978	1 693 708
1989	1 710 527	1 619 798
1990	1 333 664	1 470 229
1991	1 549 087	1 829 059
1992	1 393 099	1 962 813
1993	1 161 173	1 888 255
1994	1 499 996	2 173 018
1995	1 686 439	2 349 256
1996	1 540 072	2 432 681
1997	1 272 172	2 260 172
1998	1 179 427	2 090 052
1999	1 114 921	1 910 527
2000	934 084	1 940 917
2001	978 564	1 492 683
2002	898 895	1 706 223
2003	715 791	1 759 263
2004	739 633	1 880 147

(Reference NRCan, 2005)

[a] Production includes recoverable content of cadmium in the zinc-lead concentrates produced from domestic mines.

[b] Refined metal produced from domestic and imported ores and recycled materials.

Table 3.1 Cadmium production in several Canadian provinces, 2003-2005.

Province	2003	2004	2005 [a]
Production (All forms[b])	**(kg)**	**(kg)**	**(kg)**
New Brunswick	134 339	101 464	233 478
Québec	324 919	401 769	149 569
Ontario	256 533	236 400	205 000
Total	715 791	739 633	588 047
Refined[c]	1 759 263	1 880 147	1 703 070

(Reference NRCan, 2005)

[a] Preliminary values

[b] Production included recoverable content of cadmium in the zinc-lead concentrates shipped.

[c] Refined metal produced from domestic and foreign ores and recycled materials

3.2 Cadmium Products and End Uses

In 2004, the five major industrial uses of cadmium worldwide were as follows:

- nickel-cadmium batteries (79%)
- pigments (11%)
- coatings (7%)
- stabilizers in plastics and synthetic products (2%)
- alloys (<1%) (NRCan, 2005).

A small amount of cadmium use (<0.5% in the United States) is in thin film photovoltaic cells which use the photoelectric properties of CdS or CdTe to capture solar energy (Hawkins *et al.*, 2006). Nickel–cadmium batteries are not manufactured in Canada (Environment Canada, 1994). Cadmium is mainly recovered as a by-product from the smelting of zinc and other metal ores, and from precipitates obtained during the purification of zinc sulphate (Brown, 1977). Hence, the production of cadmium in Canada is determined largely by the level of zinc production (Nriagu, 1980). Canadian zinc ores contain from 0.001% to 0.067% recoverable cadmium by weight (Brown, 1977). In 1994, Canada was the world's fourth-largest producer of cadmium (NRCan, 2005). Canada produced about 1880 tonnes of refined cadmium in 2004 and about 1703 tonnes in 2005 (NRCan, 2005). About 90% of Canadian production is exported, mostly to the United States and Japan (NRCan, 2005). In 2004, 210 tonnes of cadmium were used in Canada (NRCan, 2005).

4.0 SOURCES AND PATHWAYS INTO THE ENVIRONMENT

Global anthropogenic releases of cadmium into freshwater aquatic environments are estimated at 2100 to 17 000 tonnes per year, approximately 40% of which can be attributed to effluents from smelting and refining industries, and to atmospheric fallout (Nriagu and Pacyna, 1988). In the marine environment, 2600 tonnes per year enter the world's oceans through atmospheric deposition, while 1500–2000 tonnes per year enter via river runoff (Yeats and Bewers, 1987). The sources of cadmium to sediments are generally the same as those for water, as most cadmium entering water eventually becomes associated with bottom sediments (Kersten and Förstner, 1987; Lum, 1987).

The most recent available data indicate that at least 159 tonnes of cadmium are released annually to the Canadian environment as a result of domestic anthropogenic activities (*e.g.* smelting and refining of metals, iron and steel production, fuel combustion, transportation, and solid waste disposal) (Environment Canada, 1994). Of this total, base metal smelting and refining operations contribute 82% (130 tonnes) of total environmental releases (Environment Canada, 1994). In addition, an unknown amount of cadmium has been applied as a fungicide for turf grass production and as a pesticide for worms in horses and pigs. In the past, pesticides containing cadmium as the active ingredient were marketed in Canada, but registration was discontinued by 1990. The estimates of usage of these products were not available (Agriculture Canada, 1992).

4.1 Natural Sources

Cadmium can occur naturally in the environment. As a result of geochemical processes, some areas naturally contain elevated concentrations of cadmium in underlying rock. However, the spatial and temporal variability in natural background concentrations of cadmium in water bodies is determined not only by the mineral composition of the surrounding environment, but also depends on abiotic processes such as weathering, climate, soil type, pH, dilution (*e.g.*, due to rainfall, snowmelt, other seasonal variations), and redox potential (NRCan, 2004).

Anthropogenic activities, such as mining and related industries, can release cadmium deposits within the earth to surface environments, resulting in concentrations of cadmium that exceed natural background concentrations. In these cases, statistical methodologies and comparisons with non-impacted environments may be used to differentiate anthropogenic contributions of cadmium from natural background.

4.2 Concentrations in surface freshwater in Canada

The natural background concentration of naturally occurring substances is a very site-specific matter. Naturally elevated levels of such a substance, if toxic, or low levels, if essential, may lead to specific, locally-adapted ecological communities, which may respond differently to anthropogenic releases of this substance when compared to non-adapted communities. This aspect cannot be incorporated into a nationally applicable guideline value. Therefore, in some situations, such as when the recommended national guideline value falls below (or outside) the natural background concentration, it may be necessary or advantageous to derive a site-specific guideline (or objective). It should also be noted that natural background levels may vary seasonally, allowing for more than one value, or a range of values, for the concentration of cadmium in water at any given site.

The following section includes natural background levels of cadmium and concentrations at impacted sites in Canadian surface waters. There are limited data and further study is therefore recommended. All study sites identified as impacted sites in the data source will be reported as such in the following text. There were insufficient data to make reliable inferences as to how cadmium concentrations vary geographically, as the amount of data available for each province or region was inconsistent.

The Environmental Water Quality Database reported cadmium levels of <0.1 $\mu g \cdot L^{-1}$-1.3 $\mu g \cdot L^{-1}$ (mean= 0.1 $\mu g \cdot L^{-1}$) in the Yukon and <0.1-15.4 $\mu g \cdot L^{-1}$ (mean=0. 4 $\mu g \cdot L^{-1}$) in the Northwest Territories. The Dezadeash River in the Yukon is not impacted by anthropogenic activity and has a natural background concentration estimate of 0.071 $\mu g\ Cd \cdot L^{-1}$using the 95th percentile as an approximation of the upper limit of the normal range (Tri-Star Environmental Consulting, 2006).

Data from the Environmental Water Quality Database indicate that freshwater cadmium concentrations in British Columbia ranged from <0.1-8.6 $\mu g \cdot L^{-1}$, with a mean of 0.2 $\mu g \cdot L^{-1}$ (ENVIRODAT, 1992). Beaver River and Kicking Horse River, two mountain watersheds in British Columbia which represent non-impacted areas, had natural background cadmium estimates of 0.98 and 0.035 µg $Cd{\cdot}L^{-1}$ using the 95th percentile as an approximation of the upper limit of the normal range. The regional background concentration was estimated as 0.034 µg $Cd{\cdot}L^{-1}$ (Tri-Star Environmental Consulting, 2006). Cahill Creek, British Columbia, a site with data available prior to being potentially impacted from mine development in the mid 1980's, had estimated natural background levels of cadmium of 10 $µg{\cdot}L^{-1}$, also estimated using the 95th percentile (Tri-Star Environmental Consulting, 2006).

Regarding the prairie provinces, surface waters had cadmium concentrations ranging from <0.1-112 $µg{\cdot}L^{-1}$ (an extreme value) (mean=0.3 $µg{\cdot}L^{-1}$) in Alberta, from <0.1- 0.4 $µg{\cdot}L^{-1}$ (mean = 0.2 $µg{\cdot}L^{-1}$) in Saskatchewan, and from <0.1- 2.2 $µg{\cdot}L^{-1}$ (mean = 0.2 $µg{\cdot}L^{-1}$) in Manitoba (ENVIRODAT, 1992). More specifically, in Lake Winnipeg, Manitoba, 90 sites were sampled during the June-August 2001 season with surface water samples taken from the littoral zone. Mean cadmium concentrations were 2.6 $µg{\cdot}L^{-1}$, with a minimum of <0.1 $µg{\cdot}L^{-1}$and a maximum of 7.0 $µg{\cdot}L^{-1}$ (Pip, 2006). Recent monitoring data (from 2000 to 2007) for various rivers, lakes and creeks in Manitoba can be found in Appendix B. For rivers, the highest maximum cadmium concentration was reported in the Red River, at 7.2 $µg{\cdot}L^{-1}$, however the median concentration for this site was 0.07 µg $Cd{\cdot}L^{-1}$ (Armstrong and Manitoba Water Stewardship, 2008). The majority of rivers had maximum cadmium levels below or near the detection limits (0.2 $µg{\cdot}L^{-1}$ prior to March 2001, 0.04 $µg{\cdot}L^{-1}$ after March 2001). Relatively higher cadmium concentrations were observed in Manitoba lakes compared to rivers, with Wood Lake, Lake Winnipeg, Camp Lake and Big Island Lake having the highest maximum concentrations at 29.2, 3.2, 1.3 and 1.3 $µg{\cdot}L^{-1}$, respectively (Armstrong and Manitoba Water Stewardship, 2008). Twenty of the 35 lakes sampled for cadmium in surface waters had maximum concentrations below the detection limits. The highest cadmium concentrations in Manitoba creeks were observed in Big Island Lake and Shannon Creek, with maximum values of 1.4 and 1.9 $µg{\cdot}L^{-1}$, respectively (Armstrong and Manitoba Water Stewardship, 2008). Lake Wabamun, the most heavily used lake in Alberta, is subject to both anthropogenic and agricultural impact and had cadmium concentrations ranging between 0.02 and 0.04 $µg{\cdot}L^{-1}$ monitored between 1996 and 2000 (Alberta Environment, 2003b). Higher cadmium concentrations were seen at another impacted site in Alberta, Lesser Slave River, which supports fisheries and recreation and receives treated municipal and pulp mill effluent. General ranges were from below detection limits to 0.656 $µg{\cdot}L^{-1}$ however one sample from effluents of Slave Lake Pulp mill had cadmium concentrations reaching 15.8 $µg{\cdot}L^{-1}$ (Alberta Environment, 2000). At Ells River, Alberta, sampled between 1972 and 1996 at a variety of locations, the majority of cadmium concentrations were below detection limits (<1.0 $µg{\cdot}L^{-1}$), while in 2000 and 2001 cadmium concentrations were 0.055 and 0.09 $µg{\cdot}L^{-1}$, respectively (Alberta Environment, 2001). Five lakes were sampled from the Key Lake uranium mine area in north-central Saskatchewan, approximately 600 km north of Saskatoon. Water samples had total and dissolved cadmium concentration ranges of 0.01-1.96 $µg{\cdot}L^{-1}$ and 0.01-1.90 $µg{\cdot}L^{-1}$, respectively (Pyle *et al.*, 2001).

Dissolved and particulate concentrations of cadmium in surface waters from Ontario have ranged from <0.001-4.78 $µg{\cdot}L^{-1}$ (Allan and Ball, 1990; Campbell and Evans, 1991; Couture *et al.*, 2008; Hinch and Stephenson, 1987; Lum, 1987; Stephenson and Mackie, 1988b). Yan *et al.* (1990) reported cadmium concentrations from 33 nonacidified lakes from south central Ontario to range from 0.002-0.122 $µg{\cdot}L^{-1}$. Campbell and Evans sampled 21 small lakes in south central Ontario and cadmium concentrations ranged from 0.02-0.14 $µg{\cdot}L^{-1}$ (see Appendix B) (Campbell and Evans, 1991). Lum *et al.* (1991) reported mean dissolved concentrations ranging from 0.007-

0.018 $\mu g \cdot L^{-1}$ for various locations along the St. Lawrence River sampled in 1987. In Ontario, cadmium concentrations in the upper St.Lawrence River and in the North Shore tributaries of the Ottawa River were found to be 0.07 and 0.09 $nmol \cdot L^{-1}$, respectively, as measured using inductively coupled plasma-mass spectrometry (Rondeau *et al.*, 2005). Studies examining cadmium in the water of several lakes in the Sudbury region found concentrations ranging from 0.02-0.52 $\mu g \cdot L^{-1}$ (Couture *et al.*, 2008; Gauthier *et al.*, 2006; Niyogi *et al.*, 2004).

Sampling of the water in the St. Lawrence River in Québec took place between July 2000 and July 2001 at the Lévis municipal water filtration plant located at the mouth of the river. The composition of the water entering this plant is typical of St. Lawrence River water with respect to trace metals. Additionally, measurements were taken from the Montréal wastewater treatment plant for comparison. The concentrations of dissolved cadmium at the St. Lawrence River mouth and the Montréal Effluent were 0.0226 (±0.0245) $\mu g \cdot L^{-1}$ and 0.24 (± 0.321) $\mu g \cdot L^{-1}$ respectively (Gobeil *et al.*, 2005). Quémerais and Lum (1997) sampled cadmium concentrations at various sites in the St. Lawrence River watershed between March to November 1991 and April to June 1992. Dissolved cadmium concentrations at Les Grèves, the entrance of Lake Saint Pierre, ranged between 0.009 and 0.012 $\mu g \cdot L^{-1}$. Dissolved cadmium concentrations at Port St. François, the outlet of Lake Saint Pierre, were reported to be 0.011 $\mu g \cdot L^{-1}$. More recently, cadmium concentrations measured in the water of several lakes in the Rouyn-Noranda area, northwestern Québec, ranged from 0.01-0.62 $\mu g \cdot L^{-1}$ (Couture *et al.*, 2008). In 2009, dissolved cadmium concentrations were sampled in 15 sites from Montréal to Île d'Orléans and have ranged from 0.004-0.015 $\mu g \cdot L^{-1}$ (S. Hébert, MDDEP pers. comm.). Median concentrations were all between 0.007 and 0.009 $\mu g \cdot L^{-1}$ (S. Hébert, MDDEP pers. com.). The south shore tributaries of Lake Saint Pierre including the Richelieu, Yamaska, Saint Francis and Nicolet Rivers were also sampled and dissolved cadmium concentrations were reported to be 0.01 $\mu g \cdot L^{-1}$ (Quémerais and Lum, 1997). In 2009 and 2010, median concentrations for those tributaries were 0.003, 0.012, 0.010 and 0.008 $\mu g \cdot L^{-1}$ and concentrations ranged from <0.003-0.018 $\mu g \cdot L^{-1}$ (S. Hébert, MDDEP pers. comm.). Median concentrations of dissolved cadmium in the north shore tributaries, including L'Assomption, St. Maurice, Batiscan and Jacques-Cartier Rivers were 0.006, 0.006, 0.013 and 0.010 $\mu g \cdot L^{-1}$, respectively and concentrations ranged from <0.003-0.017 $\mu g \cdot L^{-1}$ (S. Hébert, MDDEP pers. com.).

Surface water monitoring data from the Great Lakes reported cadmium concentrations for Lake Huron sampled between 2003 and 2006 to range from below detection limits (<0.001 $\mu g \cdot L^{-1}$) to 0.015 $\mu g \cdot L^{-1}$ with a median of 0.008 $\mu g \cdot L^{-1}$. Concentrations specifically for Georgian Bay in Lake Huron were between 0.002 and 0.008 $\mu g \cdot L^{-1}$ with a median 0.0035 $\mu g \cdot L^{-1}$ (Lochner and Water Quality Monitoring and Surveillance, 2008). Lake Erie cadmium concentrations ranged from below detection limits (<0.001 $\mu g \cdot L^{-1}$)-0.098 $\mu g \cdot L^{-1}$ with a median of 0.015 $\mu g \cdot L^{-1}$ sampled between 2004 and 2006. Lake Ontario, sampled between 2003 and 2006, had minimum cadmium concentrations below detection limits (<0.001 $\mu g \cdot L^{-1}$) and maximum concentrations of 0.028 $\mu g\ Cd \cdot L^{-1}$ with a median value of 0.016 $\mu g \cdot L^{-1}$ (Lochner and Water Quality Monitoring and Surveillance, 2008). Cadmium concentrations ranged from below detection limits (<0.001 $\mu g \cdot L^{-1}$)-0.015 $\mu g \cdot L^{-1}$ for Lake Superior between 2003 and 2005, with a median value of 0.01 $\mu g \cdot L^{-1}$ (Lochner and Water Quality Monitoring and Surveillance, 2008).

For the Niagara region, water samples from Fort Erie on the Niagara River had predicted annual mean cadmium concentration ranging between 0.0184 and 0.025 $\mu g \cdot L^{-1}$ between 2001 and 2005.

At Niagara-on-the-Lake predicted annual mean cadmium concentrations between 2001 and 2005 ranged from 0.0188 and 0.0346 $\mu g \cdot L^{-1}$ (Hill, 2008).

Cadmium concentrations in surface water samples from various lakes and ponds in Nova Scotia can be found in Appendix B. From 42 sample sites, the median cadmium concentration was <0.6 $\mu g \cdot L^{-1}$, with a range of <0.6-2.9 $\mu g \cdot L^{-1}$ (Nova Scotia Environment, 2008). Eighty-six percent of data was sampled in 1984, while the remainder was sampled in 2004 and 2005. Natural background concentrations for various stream surface waters in Nova Scotia have been reported as a median of 0.05 $\mu g \cdot L^{-1}$, with minimum and maximum concentrations of 0.05 and 0.59 $\mu g \cdot L^{-1}$, respectively (Reimann and De Caritat, 1998).

4.3 Concentrations in biota

Outridge and Noller (1991) examined the levels of cadmium in tissues of several Canadian freshwater vascular plants, including water arum (*Calla pallustris*), bur reed (*Sparganium sp*.), cattail (*Typha vulgaris*), milfoil (*Myriophyllum exalbescens*), water lily (*Nuphar variegatum*), and pickerelweed (*Pontederia cordata*) and cadmium concentrations in the tissues ranged from <0.1-31 $mg \cdot kg^{-1}$ dw.

In the freshwater mussel (*Pyganodon grandis,* formerly *Anodonta grandis)* sampled in Lake Winnipeg in 1986, cadmium concentrations ranged from <1.0-10 $mg \cdot kg^{-1}$ (Pip 1990). This same species sampled in 11 lakes of the Royne-Noranda mining area had whole organism soft tissue concentrations ranging from 15.7-129.3 $mg \cdot kg^{-1}$ dw, and gill tissue concentrations ranging from 29.2-269.7 $mg \cdot kg^{-1}$ dw (Couillard *et al.*, 1993). Freshwater mussels (*Elliptio complanata*) sampled from 21 small lakes in south central Ontario had cadmium concentrations ranging from 0.6-6.9 $mg \cdot kg^{-1}$ (see Appendix B) (Campbell and Evans, 1991). The zebra mussel, *Dreissena polymorpha,* sampled along the upper St.Lawrence River in Ontario, had reported tissue cadmium concentrations of approximately 2.5-12 $mg \cdot kg^{-1}$, estimated from graphical interpolation (Johns, 2001). Blaise *et al*. (2002) studied cadmium concentrations in the soft-shell clam, *Mya arenaria,* in Québec in the Saguenay Fjord and from adjacent sites in the St.Lawrence River. Cadmium concentrations in the soft tissue of the clam ranged from 0.04-0.12 $mg \cdot kg^{-1}$ (Blaise *et al.*, 2002).

Zooplankton from 33 nonacidified lakes from south central Ontario had cadmium concentrations ranging from 0.16-29.8 $mg \cdot kg^{-1}$ dw (Yan *et al.*, 1990). *Hyallela azteca* sampled in 69 lakes in central Ontario had cadmium concentrations ranging from 0.13-565.6 $mg \cdot kg^{-1}$ g dw (Stephenson and Mackie, 1988a). Several studies from Ontario reported crayfish body concentrations of cadmium ranging from 2.9-12.8 $mg \cdot kg^{-1}$ in whole body tissues and from 5-205 $mg \cdot kg^{-1}$ in gill tissues (Alikhan *et al.*, 1990; Bagatto and Alikhan, 1987; Bendell-Young and Harvey, 1991; Keenan and Alikhan, 1991). The American lobster, *Homarus americanus,* sampled from the Inner Bay of Fundy in Atlantic Canada, had mean cadmium concentrations in the digestive glands ranging from 11.6-22.9 $mg \cdot kg^{-1}$ (Chou *et al.*, 2000). Amphipods (*Hyalella azteca*) sampled from 69 lakes in central Ontario had tissue cadmium levels ranging from 0.13-56.6 $mg \cdot kg^{-1}$, with a mean of 8.2 $mg \cdot kg^{-1}$ (Stephenson and Mackie, 1988b). Mayflies (*Hexagenia sp.*) from Lake Joannes in Québec sampled in 1987 had a mean concentration of cadmium of 18 mg·kg^{-1} (Hare *et al.*, 1989). Chironomids sampled in Lakes Saint Francois, Saint-Louis, and Saint-Pierre and in the Montréal Harbour had cadmium concentrations of 0.06-0.11, 0.04-0.61, 0.07-0.96 mg·kg^{-1} dw, respectively. Oligochetes sampled at these same locations had concentrations of 0.02-1.09, 0.5, NR, and 0.18 mg·kg^{-1} dw, respectively (Desrosiers, 2008). Benthic invertebrates from a metal-contaminated lake (Hannah Lake, Sudbury, Ontario), including damselfly larvae, adult notonectids, adult dragonflies and dragonfly nymphs, had cadmium concentrations of 0.92 mg·kg^{-1} with detection limits of 0.1. Benthic invertebrates from an uncontaminated lake (James Lake, North Bay, Ontario), including damselfly larvae, dragonfly nymph, snails, caddisfly larvae, dytiscid beetles and dytiscid larvae, had cadmium concentrations of 0.29 mg·kg^{-1} (Klinck *et al.*, 2007).

Rainbow trout (*Onchorhynchus mykiss*) sampled from lakes in British Columbia were found to have cadmium concentrations in the liver ranging from 1.17-19.4 mg·kg^{-1} ww (Deniseger *et al.*, 1990; Roch *et al.*, 1982). Sampling conducted in British Columbia lakes from 1966 to 1986 found mean cadmium concentrations in liver tissue of the cutthroat trout (*Oncorhynchus clarki*) and Dolly Varden char (*Salvelinus malma*) to range from 1.01–6.5 mg·kg^{-1} ww and 1.04–6.3 mg·kg^{-1} ww, respectively (Deniseger *et al.*, 1990). Northern pike (*Esox lucius*) and white sucker (*Catastomus commerson*) fish from Saskatchewan lakes were found to have liver and muscle cadmium concentrations ranging from <0.01-0.67 mg·kg^{-1} ww (Harrison and Klaverkamp, 1990). The same fish species sampled in Manitoba lakes had liver and muscle tissue cadmium concentrations of <0.01-1.03 mg·kg^{-1} ww (Harrison and Klaverkamp, 1990). In Tadenac Lake, Ontario, dorsal muscle cadmium concentrations of the bluntnose minnow (*Pimephales notatus*) ranged from 0.16–0.29 mg·kg^{-1} ww (Wren *et al.*, 1983). Yellow perch (*Perca flavescens*) sampled from a metal-contaminated lake (Hannah Lake, Sudbury, Ontario) had a mean liver cadmium concentration of 5.36 mg·kg^{-1} ww, compared to those sampled from an uncontaminated lake (James Lake, North Bay, Ontario) which had a mean liver cadmium concentration of 0.24 mg·kg^{-1} ww (Klinck *et al.*, 2007). Other research on yellow perch from lakes in the Sudbury area determined total liver cadmium concentrations to be 0.78-1.34 µg·g^{-1} dw in fish from reference lakes, and 1.19-22.37 µg·g^{-1} dw in fish from near- and far-field lakes (Pyle *et al.*, 2005). The same study found total cadmium concentrations in the intestine of yellow perch to be 0.15-0.56 µg·g^{-1} dw in fish from reference lakes, and 0.28-1.34 µg·g^{-1} dw in fish from near- and far-field lakes (Pyle *et al.*, 2005). A regional study examining lakes in the Sudbury and Rouyn-Noranda areas of Ontario and Québec, respectively, measured cadmium concentrations in kidney and liver tissues of yellow perch. In the Sudbury lakes (Crowley, Geneva, James and Whitson), kidney and liver cadmium concentrations ranged from below detection to 116.9 µg·g^{-1} dw, and from below detection to 75.5 µg·g^{-1} dw, respectively (Couture *et al*., 2008; source data provided by authors). In the Rouyn-Noranda lakes (Bousquet, Dufault, Ollier, Opasatica and Osisko), kidney and liver cadmium concentrations ranged from below detection to 178 µg·g^{-1} dw, and from below detection to 77.1 µg·g^{-1} dw, respectively (Couture *et al*., 2008; source data provided by authors).

In lakes of New Brunswick and Nova Scotia brook trout (*Salvelinus fontinalis*) had whole body concentrations of cadmium between 41 and 514 mg·kg^{-1} ww and from 132 to 660 mg·kg^{-1} ww, respectively. Yellow perch (*Perca flavescens*) sampled in New Brunswick and Nova Scotia had reported body cadmium concentrations from 84-235 mg·kg^{-1} ww and from 183-228 mg·kg^{-1} ww, respectively. Similarly, white sucker (*Catastomus commersoni*) in New Brunswick and Nova Scotia had concentrations from 84-235 mg·kg^{-1} ww and from 72-264 mg·kg^{-1} ww, respectively

(Peterson *et al.,* 1989). Fish sampled in 2007 from the power station at Grand Lake, New Brunswick had cadmium concentration ranges of 0.01-0.022 $\mu g \cdot g^{-1}$, 0.004-0.011 $\mu g \cdot g^{-1}$ and 0.009-0.032 $mg \cdot kg^{-1}$ for chain pickerel, longnose sucker and white perch, respectively (Lalonde and Aquatic Ecosystem Protection Research Division, 2008). Brook trout, mummichog, silverside, stickleback and white perch sampled from the power station at East River, Nova Scotia in 2007 had cadmium concentrations of 0.005, 0.005, 0.005-0.01, 0.01-0.03and 0.005 $mg \cdot kg^{-1}$, respectively (Lalonde and Aquatic Ecosystem Protection Research Division, 2008).

4.4 Concentrations in sediment

There was a large data gap for natural background concentrations of cadmium in sediment for Canadian environments. Additionally, many sites for which monitoring data were available were not identified by the data source as to the degree of anthropogenic impact. All sites classified as impacted will be reported as such in the current section.

In New Brunswick, sediment samples taken at the power station on Grand Lake in 2007 had cadmium concentrations ranging from 0.3-1.2 $mg \cdot kg^{-1}$, with a median of 0.6 $mg \cdot kg^{-1}$(Lalonde and Aquatic Ecosystem Protection Research Division 2008). In Nova Scotia, sediment sampled at the power station on East River and on Porter's Lake in 2007 had cadmium concentration ranges of 0.5-2.1 $mg \cdot kg^{-1}$ and 0.9-2.0 $mg \cdot kg^{-1}$, respectively (Lalonde and Aquatic Ecosystem Protection Research Division, 2008).

Concerning regions of Québec and Ontario, sediments from 21 small lakes in south central Ontario had cadmium concentrations ranging from 0.05-0.38 $mg \cdot kg^{-1}$ (see Appendix B) (Campbell and Evans, 1991). Natural background levels of cadmium in sediments of the fluvial section and fluvial estuary of the St. Lawrence River were determined by taking core samples and adopting the 90th percentile of metal concentration data as the natural level. In pre-industrial sediment cores (representing concentrations before 1920) and in post-glacial cores (representing samples deposited 8000 years ago) cadmium concentrations were both 0.20 $mg \cdot kg^{-1}$. Ambient levels were monitored in the surficial sediment of the fluvial section of the river between 1999 and 2003 and correspond to the 75th percentile (thereby excluding samples from zones potentially affected by local contamination). Cadmium concentration in the surficial sediment of Lake Saint-Francois, Lake Saint-Louis and Lake Saint-Pierre were 0.80, 1.0 and 0.40 $mg \cdot kg^{-1}$, respectively (Environment Canada and Ministère du Développement durable, de l'Environnement et des Parcs du Québec, 2007). Five lakes sampled each in Sudbury, Ontario and Rouyn-Noranda, Québec were examined for cadmium concentrations in the top 5 cm of sediment. Cadmium concentrations in contaminated lakes ranged from 26.85-96.42 $mg \cdot kg^{-1}$ in Rouyn-Noranda and from 2.67-3.83 $mg \cdot kg^{-1}$ in Sudbury. Concentrations in intermediate and reference lakes ranged from 0.18-1.62 $mg \cdot kg^{-1}$ in Rouyn-Noranda and from 1.60-2.34 $mg \cdot kg^{-1}$ in Sudbury (Couture et al. 2008). Other research conducted in 12 lakes of the Sudbury region found consistent results, with total cadmium concentrations in sediment ranging from 0.7-2.4 $mg \cdot kg^{-1}$ dw in reference lakes, and from 1.5-4.6 $mg \cdot kg^{-1}$ dw in near- and far-field lakes (Pyle *et al.*, 2005).

Concerning the prairie provinces, maximum cadmium concentrations in the sediment of Manitoba lakes (Appendix B) sampled between 2000 and 2007 ranged from 0.5 $mg \cdot kg^{-1}$ for

Betula and Caddy Lake, respectively, to 16.3 and 22.5 mg·kg^{-1} for Big Island and Schist Lake, respectively (Armstrong and Manitoba Water Stewardship, 2008). In the Red River, Manitoba, cadmium concentrations in sediment ranged from 0.4-0.5 mg·kg^{-1} (Armstrong and Manitoba Water Stewardship, 2008). The North Saskatchewan River had total and extractable cadmium concentrations ranges in sediment of 0.14-0.306 mg·kg^{-1} and 0.127 -0.304 mg·kg^{-1}, respectively, while one of its tributaries, Battle River, had total and extractable sediment concentrations of 0.04-0.44 mg·kg^{-1} and 0.0385-0.439 mg·kg^{-1}, respectively (Raven and Alberta Environment, 2008). Bow River in Alberta, a tributary of the South Saskatchewan River, had total and extractable cadmium ranges of 0.22- 0.363 mg·kg^{-1} and 0.203- 0.349 mg·kg^{-1}, respectively, while the South Saskatchewan River had total and extractable cadmium ranges of 0.217-0.323 mg·kg^{-1} and 0.216-0.312 mg·kg^{-1}, respectively. In a similar concentration range, Red Deer River, Alberta, had total and extractable cadmium concentration ranges of 0.198-0.407 mg·kg^{-1} and 0.179-0.357 mg·kg^{-1}, respectively and Oldman River, Alberta, had total and extractable cadmium concentration ranges of 0.221-0.257 mg·kg^{-1} and 0.207-0.248 mg·kg^{-1}, respectively (Raven and Alberta Environment 2008). Milk River, Alberta had total and extractable cadmium concentration in sediment samples of 0.133 and 0.134 mg·kg^{-1}, respectively (Raven and Alberta Environment, 2008). Cadmium concentrations in lake sediments of Wabamun Lake (heavily impacted by anthropogenic activity) ranged from <0.3-0.75 mg·kg^{-1}, while concentrations in sediments of various other Alberta lakes (including Amisk, Bonnie, Isle, Lac Ste Anne, Pigeon, Sylvan, Wizard and Gull) were between 0.1 and 0.5 mg·kg^{-1} (Alberta Environment, 2003a).

5.0 ENVIRONMENTAL FATE AND BEHAVIOUR

The environmental fate and behaviour of cadmium is dependent on abiotic conditions, such as pH, hardness, alkalinity and natural organic matter (NOM). These factors influence the toxicity and mobility of cadmium by altering the speciation, or physio chemical forms, of cadmium in aquatic systems. First, factors such as pH, oxidation/reduction potential (redox), and the type and abundance of organic ligands, hydroxides, and cations present can influence the speciation of cadmium (Raspor, 1980). However, those factors only become important in water at pH higher than 9. At lower pH values (pH<9), the divalent cadmium ion (Cd^{2+}) predominates (Callahan *et al.*, 1979); at pH values greater than 9, hydroxide and carbonate complexes are present to a greater degree. Because cadmium has a high affinity for negatively charged particle surfaces such as hydroxides, carbonates, and organic matter, sorption and complexation processes could affect cadmium fate in waters containing high concentrations of organic and inorganic ligands (Callahan *et al.*, 1979). Consequently, cadmium can be removed rapidly from solution and accumulate in bottom sediments in both marine and freshwater systems (Kersten and Förstner, 1987). However, changes in environmental conditions, such as reduced pH, changes in redox status (*e.g.*, due to spring and fall turnover), and biological and chemical oxidation of organic matter, have the potential to remobilize and transport cadmium to other compartments of the ecosystem

Although most of the total cadmium entering the ocean from continental runoff is retained in estuaries, 85% or more of the dissolved cadmium may enter the marine pelagic environment (Bewers *et al.* 1987). Dissolved cadmium predominates in coastal waters where it may constitute 60% or more of total cadmium (Lum 1987), however, a large proportion of the total cadmium entering the ocean is deposited in deep-water ocean sediments (Bewers *et al.* 1987). There is a consistent pattern of recycling of cadmium in oceans, with residence times in the Pacific Ocean mixed layer of less than one year (Bewers *et al.* 1987). Much of the total cadmium in seawater bound to, or incorporated in, organic matter is constantly removed from surface waters through biogenesis and sinking (Bewers *et al.* 1987). As a result, surface waters (<500 m) are depleted of cadmium. Upon decomposition at depth, or through oxidation in sediments, cadmium associated with organic matter may be released to overlying waters and recirculated to the euphotic zone via upwelling (Bewers *et al.* 1987).

5.1 Sorption of Cadmium

Sorption of cadmium is an important consideration for environmental fate and movement. How quickly and easily cadmium species adsorb to other compounds, and what compounds those are, can affect the bioavailability of cadmium in aquatic systems. Leaching of cadmium through soil profiles can cause cadmium to accumulate in the root zone and poses the potential of contamination of surface and ground water (Kookana and Naidu,, 1998).

Speciation of metals in soil solution is dependent upon adsorption to the surfaces of soil components and precipitation as separate phases. Cadmium forms surface complexes in soil on layer silicates, iron oxide minerals, manganese oxide minerals and organic matter through ion exchange. An experiment by Choi (2006) assessed the adsorption of cadmium on both reference smectite and Vertisol fractions and found the process was influenced by mineralogy, organic matter, and the content of iron and manganese oxides. The adsorption of cadmium decreased with decreasing content of organic matter, iron oxide and manganese oxide. Cadmium adsorption was also influenced by pH. Increasing pH resulted in increased cadmium adsorption which is caused by the changes in the net proton charge on soil particles (Choi, 2006).

Kookana and Naidu (1998) measured adsorption and transport of cadmium in soil in the presence of calcium and sodium salts of varying ionic strengths using the techniques of batch and miscible displacement. Soils with lower clay content were found to have an adsorption coefficient (K) four fold greater than that of a tested clay-rich soil, which could be attributed to a large surface negative charge density of the soil with low clay content (Kookana and Naidu, 1998). The study also found that at low ionic strength, small increases in the background concentration of calcium can significantly increase the mobility of cadmium (Kookana and Naidu, 1998).

Yuan *et al*. (2007) studied the desorption behaviour of cadmium in soil enhanced with organic acid. The desorption of cadmium increased with an increase in ionic strength and decreased with an increase in pH. The organic acids citric acid and tartaric acid negligibly affected the desorption of cadmium while EDTA enhanced desorption and oxalic acid enhanced desorption between the pH range of 6.4 to 10.7 (Yuan *et al.*, 2007).

A field study by Lawrence *et al*. (1996) added cadmium to an experimental lake containing 500 to 900 µmol DOC$\cdot L^{-1}$to assess various results including the fate of cadmium. Spiked cadmium left the water column quickly by sedimentation. Added cadmium disappeared from the water column at a rate of 1-5% per day, which was comparable to what has been measured for other metals in the same region. They observed that one year after the addition had stopped, less than

1% of the cadmium added to the lake was remaining in the water column. The majority of the added cadmium was contained in the lake sediments.

Nowierski *et al.* (2005) showed that pH and calcium concentration affected cadmium partitioning between sediment and the water column. Cadmium concentrations in the water overlying the sediments were generally higher in water with low pH and calcium concentration in both, *in situ* measurement and in laboratory experiments.

There is significant current research directed at the utility of sorbents in removing cadmium from wastewater as alternatives to traditional methods of precipitation, ion exchange and adsorption. Biomaterials tested for application as low-cost sorbents include plant stems, stalks, leaves, peels and fruit shells (Benaissa, 2006). Benaissa (2006) tested several biomaterials for adsorption of cadmium from aqueous solutions and found broad bean peel, peas peel, fig leaves and medlar leaves to have maximum sorption capacities of 147.71, 118.91, 103.09 and 98.14 $mg \cdot g^{-1}$ respectively. Hydroxyapatite was studied as a cadmium removal agent from aqueous solutions both when cadmium was applied as a single metal and when applied in combination with lead, zinc and copper. Hydroxyapatite immoblized cadmium from both treatment solutions with sorption rates in the single metal treatment ranging from 0.058 to 1.681 $mmol \cdot g^{-1}$ and sorption rates for the multi-metal solution reduced by 63-83% on account of the competitive sorption among the other heavy metals (Corami *et al.*, 2008).

5.2 Uptake in Vegetation

The most important soil factors influencing the accumulation of cadmium in plants are soil pH and soil concentration of cadmium. Although cadmium is distributed between a number of soil fractions, only cadmium in soil solutions is directly available for uptake by plants (WHO, 1992b). Uptake of cadmium by plants decreases with an increase in soil pH, and increases with an increase in soil cadmium content (WHO, 1992b).

Cation exchange capacity, the amount of manganese and iron hydrous oxides, the amount of organic matter and the amount of calcium carbonate are other factors influencing cadmium distribution between soil and soil solution (WHO 1992b). An increase in these factors causes a reduced amount of cadmium in the soil solution, and hence the amount of cadmium available to plants is decreased (WHO, 1992b).

6.0 BIOCONCENTRATION AND BIOACCUMULATION

While bioconcentration and bioaccumulation are not considered in the derivation of a Canadian Water Quality Guideline, a discussion on this topic is included here for three reasons: (i) to highlight the active debate among experts on the use of bioaccumulation as an index of metal hazard in general; (ii) to briefly compile information on tissue concentrations of cadmium reported in the literature; and (iii) to evaluate the cadmium water quality guideline in relation to bioconcentration/bioaccumulation.

6.1 Bioaccumulation and bioconcentration of cadmium in aquatic biota

The most common terms regarding bioaccumulation are the BAF (bioaccumulation factor) and BCF (bioconcentration factor), which are ratios of the internal concentration of a contaminant within an organism to the contaminant concentration in the surrounding water. BAFs include contaminant intake from both food and ambient water, and therefore are generally applicable to field measurements. In contrast, BCFs only include uptake from ambient water, and are therefore usually derived from laboratory data[1]. With regards to organic lipophilic contaminants, as well as some metals such as mercury, bioaccumulation and bioconcentration could indicate the risk of biomagnification and trophic transfer of the contaminant up the food chain (Government of Canada and Environment Canada, 1995). Biomagnification is the process wherein the concentration of a contaminant in organism tissues increases with increasing trophic level (Nfon *et al*., 2009).

Data regarding bioaccumulation of cadmium in aquatic biota is variable. While tissue concentrations generally increase with increasing water-borne concentrations of cadmium, the bioconcentration factor (BCF) does not remain constant over a wide range of exposure conditions. BCFs have been found to decrease at elevated exposure levels in phytoplankton, zooplankton, aquatic insects, mollusks, and fish (Benoit *et al*., 1976; Cain *et al*., 1980; Frazier, 1979; Giesy *et al*., 1980; Marshall, 1978; Spehar *et al*., 1978). This suggests that saturation of the cadmium-binding capacity of the tissues may occur at high concentrations (Frazier, 1979), potentially leading to altered rate constants.

Taylor (1983) reviewed the literature regarding whole body bioconcentration laboratory studies and reported BCFs ranging from 1 to 10 000 for freshwater algae, crustacea, and vertebrates. Cain *et al.* (1980) studied the uptake of cadmium by the freshwater phytoplankton *Scenedesmus obliquus* and reported BCFs ranging from 329 to 4940 after a 25-day exposure to cadmium levels ranging from 10 to 2000 $\mu g \cdot L^{-1}$. Other studies have reported BCFs in phytoplankton to range from 1200 to 23 000 (Conway and Williams, 1979; Ferard *et al*.,. 1983; Ray, 1984). Freshwater zooplankton *Daphnia galeata mendotae* and *Moina macrocopa* were observed to have BCFs from 6463 to 17 600 and from 8124 to 13 902, respectively (Hatakeyama and Yasuno, 1982; Marshall, 1978).

A study of odonate larvae (*Pachydiplax longipennis* and *Erythemis simplicicollis*) that were exposed up to 2.232 mM (250 mg $Cd \cdot L^{-1}$) for 7 days showed that *P. longipennis* were tolerant of high concentrations of cadmium. No appreciable mortality was observed in either species at concentrations below 0.893 mM (100 mg $Cd \cdot L^{-1}$) but *P. longipennis* were able to tolerate up to 2.232 mM (250 mg $Cd \cdot L^{-1}$) (Tollett *et al*., 2009). It is postulated that in this study the high body concentrations are due to cadmium not being bioavailable but instead adhered onto or sequestered into the exoskeleton based on the observation of the lack of toxicity at high exposure concentrations (Tollett *et al*., 2009).

[1] Although in theory, BCFs and BAFs differ in the denominator used in the ratio, in practice, both can be calculated using the concentration of contaminant in water as the denominator (Environment Canada 1999). For the purposes of this brief section, they will be treated as measures of the same phenomenon, and will not be differentiated.

Freshwater molluscs have been used extensively as biomonitors and a large body of data exists regarding their bioaccumulation potentials. BCFs in these organisms have been reported in the range of 140 to 19 500 on a whole body basis (McCracken, 1987; McLeese and Ray, 1984; Zaroogian and Cheer, 1976). In the American oyster (*Crassostrea virginica*) BCFs have been reported from 475 to 1900 in soft tissues, from 159 to 2800 in the mantle, from 1544 to 3267 in gill tissues, from 1304 to 3222 in hepatopancreas tissues, and from 307 to 560 in adductor muscle tissues (Frazier, 1979; Hung, 1982). Spehar *et al.* (1978) reported whole body BCFs in the snail (*Physa integra*) ranging from 5400 to 10 000 following a 28-d exposure to cadmium.

Crustaceans and insects bioaccumulate cadmium to similar levels. Whole body BCFs in the stonefly (*Pteronarcys dorsata*) and caddisfly (*Hydropsyche betteni*) ranged from 639 to 30 000 (Spehar *et al*., 1978). Giesy *et al.* (1981) reported BCFs ranging from 820 to 17 600 in mayflies (Ephemeroptera), dragonflies (Odonata), beetles (Coleoptera), and midges (Chironomidae and Ceratopogonidae) after exposure duration of 1 year in microcosm studies. BCFs in crayfish (*Cambarus latimanus* and *Procambarus acutus*) were approximately 3000 on a whole body basis (Thorpe *et al*., 1979), 100 to 1400 in muscle tissues, and 18 000 to 40 000 in gill tissues (Dickson *et al*., 1982).

A study of freshwater perch (*Perca fluviatilis*) exposed to 22 $\mu g \cdot L^{-1}$ of cadmium for 39 days showed BCFs of 409, 227 and 164, for the kidney, liver, and gill tissues respectively. Various other tissues of the perch had BCFs ranging from 5 to 50 (Edgren and Notter, 1980). Brook trout (*Salvelinus fontinalis*) exposed to cadmium for a duration of 84 days was found to have whole body BCF's ranging from 371 to 756 (Benoit *et al*., 1976). Sullivan *et al.* (1978) found a BCF of 152 for fathead minnows (*Pimephales promelas*) following an exposure duration of 63 days.

Harrison and Klaverkamp (1989) examined bioaccumulation in rainbow trout (*Oncorhynchus mykiss*) and the lake whitefish (*Coregonus clupeaformis*). The fish were exposed to cadmium in commercial trout food or in water using a flow-through system. Following treatment duration of 72 days, both species accumulated significantly more cadmium from food compared to water. The water-exposed rainbow trout and whitefish accumulated 0.15% and 0.11%, respectively, of the cadmium passed over their gills. The food-exposed rainbow trout and whitefish accumulated 1.03% and 1.01%, respectively, of the cadmium to which they were exposed (Harrison and Klaverkamp, 1989).

The evidence as to whether or not cadmium biomagnifies in aquatic foodwebs is not conclusive, but several studies show biomagnification is not significant. Hart (1977) and Parker *et al.* (1982) found that uptake of cadmium by zooplankton through contaminated algae was negligible. Ferard *et al.* (1983) reported minimal transfer of cadmium from contaminated zooplankton to fish (*Leucaspius delineatus*). Additionally, accumulation in the fish was found to be independent of zooplankton cadmium concentrations and remained two orders of magnitude lower than that of the zooplankton at the highest concentration tested (Ferard *et al*., 1983). Similarly, Hatakeyama and Yasuno (1982) found that guppies accumulated <3% of the total cadmium in their tissues from zooplankton and most cadmium was obtained directly from water. The crayfish (*Procambarus acutus*) accumulated cadmium to similar levels when exposed to cadmium in either food or water independently, but when exposed to cadmium in both water and food simultaneously accumulation of cadmium was not significantly different than when exposed to the water phase alone (Giesy *et al*., 1977). The majority of the data concerning piscivorous fish indicate that no biomagnification occurs at this trophic level (Williams and Giesy, 1978).

One study, performed by Croteau *et al.* (2005), correlated nitrogen isotope ratios (indicative of trophic position) and cadmium concentrations in organisms. The results showed an increase in cadmium concentration with increasing trophic level. However, this trend only existed in epiphyte-based food chains, and only within the divisions of either macrophyte-dwelling invertebrates, or fishes. Among all data, there was no relationship demonstrated between trophic position and cadmium concentration. Hendrickx *et al.* (2003) also found that cadmium biomagnified through the food chain (this time in terrestrial organisms) by feeding contaminated fruit flies to wolf spiders.

7.0 EXPOSURE AND ROUTE OF UPTAKE

7.1 Mode of action

Cadmium is a non-essential metal in aquatic organisms except for a marine diatom (*Thalassiosira weissflogii*) for which it is a minor nutrient at low concentrations (Lane and Morel, 2000; Lee *et al*., 1995; Price and Morel, 1990). Cadmium, certainly at least in short-term exposures, exerts its toxic effects in aquatic organisms by blocking the uptake of calcium from water. Calcium (Ca^{2+}) is an essential element which is taken up by organisms from water via specialized calcium channels. However, when cadmium (Cd^{2+}) is present in water, this metal competes with calcium for binding sites, inhibiting calcium uptake and resulting in hypocalcaemia (Roch and Maly, 1979).

7.2 Cadmium speciation and the Biotic Ligand Model (BLM)

In most well oxygenated fresh waters with low organic carbon content, free divalent cadmium (Cd^{2+}) will be the predominant form (US EPA 2001). The Free Ion Activity Model (FIAM) predicts that toxicity caused by metals typically results from interaction of the “free” metal with organisms (Paquin *et al*., 2002). Complexed forms of metals are not expected to contribute substantially to toxicity because, when considering aqueous exposure, only free metals are available for binding and uptake at biological membranes (although sediment and food are also potential sources of contamination, as outlined in section 6.3 below). Extensive efforts have been undertaken to produce and validate models to predict acute toxicity of metals based on various input variables that can affect bioavailability and toxicity, including Dissolved Organic Matter (DOM, often reported as Dissolved Organic Carbon (DOC)). These models are generically referred to as Biotic Ligand Models (Paquin *et al.*, 2002). Biotic Ligand Models (BLM) are used to predict the effects of complexing ligands and competing cations on accumulation of toxic metals by organisms. Accumulation of metals is then used to predict toxic effects on the organisms.

A central premise of the BLM is that water chemistry of the system is at equilibrium, and therefore thermodynamic and conditional binding constants can be used to calculate the metal concentrations in the system, including metal bound to the biotic ligand (Paquin *et al.*, 2002). There are three components to the conceptual model including i) the chemistry of the solution in bulk water, allowing estimation of the free metal ion of interest, ii) binding of the toxic metal to the biotic ligand, and iii) the relationship between the binding of the toxic metal to the biotic ligand and the toxic response (Paquin *et al.*, 2002). The free metal ion is the primary toxic metal species, however the BLM also incorporates toxicity caused by other species. Additionally, the BLM incorporates competition of the toxic free metal with other cations, for example Ca^{2+}, Na^+ and H^+, together with complexation by abiotic ligands, for example dissolved organic matter (Niyogi and Wood, 2004; Paquin *et al.*, 2002).

There is currently no published cadmium BLM for fish, although a cadmium BLM was developed for *Daphnia pulex* (Clifford and McGeer, 2010). Unpublished acute versions of cadmium BLM for rainbow trout (*Oncorhynchus mykiss*), fathead minnow (*Pimephales promelas*) and cladoceran (*Daphnia magna*) are available on the Hydroqual website (http://www.hydroqual.com/blm), which adopts some affinity constants (log K_{CdBL} and log K_{HBL}) from Playle *et al*. (Playle *et al*., 1993a; Playle *et al*., 1993b) and uses others (log K_{CaBl}, log K_{NaBL}, and log K_{MgBL}) from unknown references (Niyogi *et al*,. 2008). Recent work by Niyogi *et al*. has developed a preliminary version of an acute cadmium BLM in rainbow trout (*Oncorhynchus mykiss*) through determining short-term cadmium gill binding characteristics, the effects of Ca^{2+}, Mg^{2+}, Na^+, pH, alkalinity and DOC on short-term cadmium accumulation at the gill, and the effect of the aforementioned water quality parameters of the acute toxicity of cadmium (Niyogi *et al.*, 2008). Only calcium and DOC caused a significant reduction in both cadmium gill accumulation and cadmium toxicity. Affinity constants were determined for cadmium to the biotic ligand (log K_{CdBL}= 8.0), cadmium to DOC (log K_{CdDOC} = 7.3) and calcium to the biotic ligand (log K_{CaBL} = 3.9). The total number of binding sites on the gill (B_{max}) was 0.6 $nmol \cdot g^{-1}$ wwt and the accumulation of cadmium on the gill associated with 50% mortality (LA_{50}) was 0.2 $nmol \cdot g^{-1}$ wwt (Niyogi *et al.*, 2008). The affinity constants for cationic interactions with DOC (DOC-Ca^{2+} and DOC-H^+) were adopted from Playle *et al.* (1993a) and Van Ginneken *et al.* (2001), respectively. These values were incorporated in the BLM and used to predict the 96-h toxicity of cadmium to rainbow trout. The model predicted values for control, calcium and DOC treatments within the 95% confidence intervals of experimental values (Niyogi *et al*., 2008). Two limitations of this preliminary BLM are not accounting for high pH or alkalinity. Future research is required to focus on these factors as well as further validation of the model.

One study, performed by Davies *et al*. (1993), noted that over a 100-day exposure period of rainbow trout to cadmium, water hardness only moderately affected toxicity. At nominal hardness concentrations of 50, 200, and 400 $mg \cdot L^{-1}$, chronic values (defined as the geometric mean of no-effect/effect concentrations) were 1.47, 3.58, and 3.64 $\mu g \cdot L^{-1}$, respectively. For all tests, hardness was adjusted using $MgSO_4$. Unlike many other toxicity studies, water alkalinity did not change with hardness; alkalinity values were consistently low, at nominal concentrations of 30 $mg \cdot L^{-1}$. The authors suggest that, while many studies have shown that hardness impacts cadmium toxicity, the water alkalinity must also be considered. At the same time, the authors concede that the relative strengths of the antagonistic effects of calcium and magnesium ions on cadmium toxicity must to be tested to support their conclusions. At any rate, a BLM that also accounts for water alkalinity would be advantageous for predicting cadmium toxicity.

7.3 Exposure and route of uptake

Most cadmium toxicity tests attempt to isolate water as the main route of exposure; however, in long-term studies, animals must be fed, hence some of the toxicity results which are interpreted as water-only exposures could be confounded with cadmium-contaminated food supplies. Long-term tests often manage food based on approximate consumption from previous feeding, and excess food is removed. Cadmium is expected to partition into sediment, and accordingly, in the environment sediment ingestion may be a route of exposure. Sediment ingestion is likely an issue with benthic deposit feeders. It is difficult to partition out sediment versus pore water exposure for those benthic organisms that are not deposit feeders.

For *Ceriodaphnia dubia*, both aqueous and dietary exposures to cadmium cause adverse affects to survival, reproduction and feeding rate (Sofyan *et al*., 2007a). In this filter-feeding species, cadmium has been shown to accumulate from water and diet independently and cause additive effects. Uptake and body burdens from water were higher than those from diet, but were highest in combined exposure (Sofyan *et al.*, 2007b). Consistent with these results Barata *et al.* (2002) exposed *Daphnia magna* to water (10 µg $Cd \cdot L^{-1}$), food (1 L algae pre-loaded with Cd at 10 µg $Cd \cdot L^{-1}$), and water + food treatments and found cadmium uptake from water and food was additive in effect. However, although *D. magna* accumulated twice as much cadmium from aqueous exposure compared to dietary, more cadmium was retained from the diet. Additionally, uptake and toxic responses were found to be inversely related in this species. Tolerant strains of *D. magna* accumulated greater amounts of cadmium, which, according to the study authors, could suggest a mechanism other than decreased uptake may govern cadmium toxicity for this species (Barata *et al.*, 2002). For the isopod *Asellus aquaticus* water is the primary route of exposure, accounting for 50-98% of body burdens in long-term exposure (van Hattum *et al.* 1998).

In a predatory species, *Sialis velata*, different results were found whereby cadmium uptake from prey was more important than from aqueous exposure. Similarly, in the chironomid prey species, *Cryptochironomus* sp., the majority of cadmium was taken up from the diet compared to the water column (Roy and Hare, 1999). Consistent with these findings, *Chaoborus punctipennis* larvae in field studies took up more cadmium from its prey than from the water column (Munger *et al.*, 1999). Other species for which cadmium uptake through dietary exposure has been shown to be more important than through aqueous exposure include the freshwater amphipod *Hyalella azteca* (Stephenson and Tuner, 1993), mites (*Limnesia maculata*) and caddisfly larvae (*Mystacides* sp.) (Timmermans *et al.*, 1992) and the deposit feeding polychete *Capitella* sp. (Selck *et al.*, 1998).

The primary route of exposure and uptake of cadmium varies between different organisms and is an important consideration in risk assessment. Hence, the presence of sediment and food in experimental systems was taken into consideration during the evaluation of toxicity studies for inclusion in guideline derivation. Water quality guideline derivation should focus primarily on studies in which exposure was principally via water (CCME, 2007).

8.0 TOXICITY OF CADMIUM TO AQUATIC LIFE

Cadmium is added to water in experimental exposures in a variety of forms, most commonly cadmium chloride ($CdCl_2$), cadmium nitrate ($Cd(NO_3)_2$), or cadmium sulphate ($Cd(SO_4)$). The main toxic form of Cd is the free Cd^{2+} ion; however other forms of cadmium, for example those bound to various ligands, may also cause adverse effects. As with all metals, the cadmium speciation at the given conditions (*e.g.*, hardness, pH, temperature, etc.) is more indicative of toxicity than the nominal concentration and the original cadmium salt used (Paquin *et al*., 2002). However, because the actual concentrations of Cd^{2+} (and other toxic Cd species) are difficult to measure, Cd concentrations in toxicity studies are often reported as total dissolved cadmium, rather than any particular form.

Toxic responses to cadmium for aquatic organisms are reported as effects on mortality (*e.g.*, LC_{50}), reproduction, growth, and weight, or as a lack of response, such as reduced valve movement in bivalves and reduced swimming activity in fish.

8.1 Toxicity modifying factors

Water chemistry survey data has an important role in the application of the CWQG since toxicity of many metals is modified by water hardness, alkalinity, pH and dissolved organic matter. Because these water variables are important in the application of CWQG, development of the guidelines should also be sensitive to and aware of common water chemistry conditions. Four main water chemistry parameters (hardness, alkalinity, pH and dissolved organic matter (DOM)) are known to affect the toxicity of cadmium. Temperature, a physical property, is also briefly discussed.

The *Protocol for the Derivation of Canadian Water Quality Guidelines* does not specify data requirements for quantifying the influence of toxicity modifying factors (CCME, 2007). For the purposes of this CWQG, all relevant literature was examined for general trends in the effect of a given TMF over a range of species. Hardness was the only TMF for which we observed consistent trends for several species representing different taxonomic groups.

8.1.1 Hardness

Hardness is defined as the sum of polyvalent cations, principally calcium (Ca^{2+}) and magnesium (Mg^{2+}) cations in solution. Hardness can be expressed as either calcium hardness or magnesium hardness, or, most commonly, total hardness (calcium plus magnesium hardness) and is usually expressed as $CaCO_3$ equivalents. Hardness can be calculated from reported Ca^{2+} and Mg^{2+} concentrations using the following equation: Total hardness ($mg \cdot L^{-1}$ $CaCO_3$) = 2.5 [Ca^{2+}] + 4.12 [Mg^{2+}], where concentrations of calcium and magnesium are reported in $mg \cdot L^{-1}$.

Water hardness strongly influences the toxicity of cadmium to aquatic organisms. Higher water hardness generally reduces the toxicity of cadmium to aquatic organisms. Since cadmium toxicity in aquatic organisms is caused by calcium deficiency, higher water hardness (particularly calcium hardness) reduces cadmium toxicity because the calcium ions compete more successfully with cadmium for uptake sites (Niyogi and Wood, 2004). Carroll *et al.* (1979) found that calcium, but not magnesium, sodium, sulphate, or carbonate, reduced the acute toxicity of cadmium. Many studies are available investigating the effect of hardness on the toxicity of cadmium to aquatic species. Data from some of these studies have been summarized in Table 8.1.

Table 8.1 Effects of hardness on Cadmium toxicity, accumulation, elimination and binding for various aquatic species

Species	**Effect on: (uptake rate, toxicity etc.)**	**Effect seen at higher hardness**	**Magnitude of effect compared to controls**	**Concentration of $CaCO_3$ equiv. causing effect ($mg \cdot L^{-1}$)**	**Reference**
Hyalella azteca (0 to 1 week old)	Toxicity (according to the saturation model)	Increase	1.6 fold	Not reported	(Borgmann *et al.*, 1991; Borgmann *et al.*, 2004a)
Daphnia magna (cladoceran) (< 24h old)	Toxicity	Decrease	~5 to ~40 fold (from graphical interpolation)	8.3, 16.6, 41.5 compared to 124.5 or 207.5	(Penttinen *et al.*, 1998)
Oncorhynchus mykiss (juvenile)	Toxicity	Decrease	10 fold	20 compared to 140	(Hollis *et al.*, 2000a)
Oncorhynchus mykiss (juvenile)	Toxicity	Decrease	2 fold higher LC_{50} in hard water than soft water	Soft: 70 Hard: 280	(Pascoe *et al.*, 1986)
Oncorhynchus mykiss (juvenile)	Toxicity	Decrease	78% mortality at background Ca, 39% at low Ca, 7% at medium Ca, and 10% at high Ca	Background:27.0 Low: 50.2 Medium: 60.3 High: 122	(Hollis *et al.*, 2000b)
Oncorhynchus mykiss (fry)	Toxicity	Decrease	3.9 fold from low to medium hardness, 10.3 fold from medium to high hardness	Low: 20 Medium: 80 High: 320	(Calamari *et al.*, 1980)
Salvelinus confluentus (juvenile)	Toxicity	Decrease	6.3 fold from low to high hardness	Low: 30 High: 90	(Hansen *et al.*, 2002a)
Oncorhynchus mykiss (juvenile)	Toxicity	Decrease	3.9 fold from low to high hardness	Low: 30 High: 90	(Hansen *et al.*, 2002a)
Danio rerio (zebrafish) (embryos -->larvae)	Toxicity (humic acid absent)	Decrease	97% survival at high Ca vs. 0% at low Ca	**(see Table 8.2)**	(Meinelt *et al*,. 2001)
Danio rerio (zebrafish) (embryos -->larvae)	Toxicity (humic acid present)	Decrease	63% survival at high Ca vs. 0% at low Ca	**(see Table 8.2)**	(Meinelt *et al*,. 2001)

Species	Effect on: (uptake rate, toxicity etc.)	Effect seen at <u>higher</u> hardness	Magnitude of effect compared to controls	Concentration of $CaCO_3$ equiv. causing effect ($mg \cdot L^{-1}$)	Reference
Platyhypnidium riparioides (aquatic moss)	Accumulation rate	Decrease	Ranged from 1.3 to 1.5 fold	11.7 <u>compared to</u> 92. 3	(Gagnon *et al.*, 1998)
Fontinalis dalecarlica (aquatic moss)	Accumulation rate	Decrease	Ranged from 1.4 to 2.1 fold	11.7 <u>compared to</u> 92.3	(Gagnon *et al.*, 1998)
Hyalella azteca (0 to 1 week old)	Maximum Cd accumulation	Decrease	7 fold	Not reported	(Borgmann *et al.*, 1991; Borgmann *et al.*, 2004a)
Oncorhynchus mykiss (juvenile)	Whole-body Cd accumulation	No change	-	Soft: 70 Hard: 280	(Pascoe *et al.*, 1986)
Oncorhynchus mykiss (juvenile)	Gill Cd accumulation	Decrease	1.75 fold less accumulation in high Ca vs. background Ca	Background:27.0 Low: 50.2 Medium: 60.3 High: 122	(Hollis *et al.*, 2000b)
Pimephales promelas (fathead minnow)	Gill Cd accumulation	Decrease	3.7 fold for medium hardness, 2.8 fold for high hardness	Soft: 9.5 Med: 106 Hard: 200 (at pH 6.3)	(Playle *et al.*, 1993b)
Oncorhynchus mykiss (juvenile)	Affinity of gills for Cd	Decrease	1.1 fold lower affinity in high Ca vs. background Ca	Background:27.0 Low: 50.2 Medium: 60.3 High: 122	(Hollis *et al.*, 2000b)
Oncorhynchus mykiss (juvenile)	Number of Cd binding sites on gills	Decrease	2 fold fewer binding sites in high Ca vs. background Ca	Background:27.0 Low: 50.2 Medium: 60.3 High: 122	(Hollis *et al.*, 2000b)
Lymnaea stagnalis (freshwater snail)	Cd-tissue binding affinity	Decrease	1.2 fold	0 <u>compared to</u> 160-180	(Croteau and Luoma, 2007)
Lymnaea stagnalis (freshwater snail)	Uptake rate	Decrease	2.5 fold	0 <u>compared to</u> 160-180	(Croteau and Luoma, 2007)
Fontinalis dalecarlica (aquatic moss)	Elimination rate	No change	-	11.7 <u>compared to</u> 92.3	(Gagnon *et al.*, 1998)
Platyhypnidium riparioides (aquatic moss)	Elimination rate	No change	-	11.7 <u>compared to</u> 92.3	(Gagnon *et al.*, 1998)
Oncorhynchus mykiss (juvenile)	Acclimation	Increase	(*i.e.* no acclimation at low hardness)	20 <u>compared to</u> 140	(Hollis *et al.*, 2000a); (Hollis *et al.*, 1999)
N/A	Binding of Cd to DOM	Decrease	10 fold	8.3, 16.6, 41.5 <u>compared to</u> 124.5 or 207.5	(Penttinen *et al.*, 1998)

Acute cadmium toxicity to the cladoceran *Daphnia magna* is reduced at high hardness (Penttinen *et al.*, 1998). Cadmium did not bind to dissolved organic matter as readily in high hardness conditions compared to low hardness conditions (Penttinen *et al.*, 1998). Slower cadmium accumulation was observed in two species of aquatic moss (*Fontinalis dalecarlica* and *Platyhypnidium riparioides*) at higher hardness, however no change was observed in the elimination rate for either moss species (Gagnon *et al.*, 1998). Slower cadmium uptake and lower cadmium-tissue binding affinity was seen in the freshwater snail with increasing hardness (Croteau and Luoma, 2007). With an increase in water hardness *Hyallela azteca* demonstrated a decrease in maximum cadmium accumulation (Borgmann *et al.*, 1991). In rainbow trout (*Oncorhynchus mykiss*), both acute and chronic toxicity of cadmium is reduced with increasing hardness, and additionally a reduction was seen in gill cadmium accumulation, affinity of gills for cadmium and number of gill cadmium binding sites (Hollis *et al.*, 2000a; Hollis *et al*., 2000b). Pascoe *et al*., (1986) found changing the conditions from harder water (280 $mg{\cdot}L^{-1}$ $CaCO_3$) to softer water (70 $mg{\cdot}L^{-1}$ $CaCO_3$) did not alter the whole-body cadmium accumulation of rainbow trout after 29 days of exposure. In fathead minnows (*Pimephales promelas)* no difference was observed in gill accumulation at a hardness of 35 and 95 µM of calcium, however there was a large reduction in gill accumulation at hardness values of 1055 and 2000 µM calcium (Playle *et al.*, 1993b).

<u>Interactions between DOM and hardness</u>

Some studies have reported greater toxicity of cadmium in the presence of DOM while others have reported lower toxicity. Studies which found an increase in toxicity in the presence of DOM must ensure the toxicity modifying effect can be attributed solely to DOM and not in part to other parameters that are altered with the addition of DOM (for example if DOM binds to hardness or salinity cations this mechanism may cause an increase in toxicity, alternatively when metals complex with humic substances protons are liberated causing a decrease in pH) (Guéguen *et al*., 2003; Penttinen *et al*., 1998). In the study by Penttinen *et al*., (1998), DOM demonstrated less protection against cadmium toxicity to the cladoceran (*Daphnia magna*) when water hardness was higher, which can be explained by calcium competing with cadmium for binding sites on DOM and a resulting lower amount of cadmium binding to DOM. Additionally, calcium ions (Ca^{2+}) can interfere with the uptake of cadmium (Cd^{2+}) by competing for transport through cell membranes or by reducing membrane permeability (Penttinen *et al.* 1998). At high hardness, no difference was observed in toxicity between humic waters and reference waters, indicating DOM only exerts its protective effects at low hardness (Penttinen *et al.*, 1998). Meinelt *et al*. (2001) found in hard water zebrafish did not experience additional protection due to the presence of humic acids, however in soft water, humic acid protected fish from Cd toxicity as seen by the lower mortality rate.

Table 8.2 Percent survival of zebrafish (*Dania rerio*) after 100-h exposure to cadmium under various calcium and humic substance (HS) conditions ((Meinelt *et al.*, 2001)

Cd conc ($mg{\cdot}L^{-1}$)	High Ca (200 $mg{\cdot}L^{-1}$ $CaCO_3$ equivalent) No HS	High Ca (200 $mg{\cdot}L^{-1}$ $CaCO_3$ equivalent) With HS (5 $mg{\cdot}L^{-1}$ C)	Low Ca (20 $mg{\cdot}L^{-1}$ $CaCO_3$ equivalent) No HS	Low Ca (20 $mg{\cdot}L^{-1}$ $CaCO_3$ equivalent) With HS (5 $mg{\cdot}L^{-1}$ C)
control	100	96	90	96
1.8	100	95	75	98
2.8	97	90	65	90
4.2	97	90	25	85
6.2	95	92	5	38
9.3	97	63	0	0

In high calcium conditions, fish were protected from cadmium toxicity regardless of the content of humic acid (Table 8.2). This was not true, however, at the highest concentration of cadmium (9.3 $mg \cdot L^{-1}$) where cadmium toxicity caused increased mortality in the presence of humic acid compared to its absence. The opposite trend was seen in low calcium conditions, where fish mortality was reduced in the presence of humic acid compared to conditions without humic acid. The best protection from cadmium toxicity was seen in the High Ca No HS group, followed by the High Ca with HS group, then the Low Ca with HS group. The percent survival was lowest in the Low Ca no HS group (Meinelt *et al.*, 2001).

Adjustments made to toxicity data on the basis of water hardness:

Of water quality parameters that could potentially influence the Cd uptake (hardness, pH, alkalinity, and dissolved organic matter (DOM)), hardness is the major factor influencing Cd toxicity (Calamari *et al*., 1980; Clifford and McGeer, 2010; Hansen *et al*., 2002a; Hollis *et al*., 1997; Hollis *et al*., 2000a; Hollis *et al*., 2000b; Mebane, 2006; Niyogi *et al*., 2008; Penttinen *et al*., 1998).

The relationship between water hardness and cadmium toxicity is well established. To compare toxicity data from various studies they may be converted to a common hardness value, normally 50 $mg \cdot L^{-1}$ ($CaCO_3$ equivalents). Empirical relationships have been derived (for both short-term and long-term studies) to convert these data to a standardized hardness, and these relationships were then used in deriving this CWQG for cadmium.

Cadmium water quality guideline values vary on a site-specific basis depending on the hardness of the water body. Therefore, cadmium guidelines are presented as equations rather than single values, allowing the user to derive a cadmium guideline which is based on the water hardness of the site under consideration.

Briefly, previous investigations have found that log-log relationships can be used to characterise hardness-toxicity relationships (Stephan *et al*., 1985 and Meyer, 1999 in Mebane, 2006). The standard methods used here to establish such relationships are described by Stephan *et al*. (1985). Toxicity values for different species were plotted at variable water hardness values; an analysis of covariance was performed to produce a pooled slope, giving an all-species estimate of the relationship between hardness and toxicity. Australia and New Zealand are other jurisdictions that have previously set guideline equations by performing ln-ln toxicity-hardness regressions to obtain pooled slopes (Zajdlik *et al*., 2009). The CWQG was derived based on the methods established by Stephan *et al.* (1985) by investigating the log-log relationships and deriving a pooled slope based on an analysis of covariance.

Short-term hardness adjustment equation:

The NGSO quantified the relationship between water hardness and acute cadmium toxicity. This relationship was established by selecting those freshwater aquatic species for which acute toxicity data were available over a wide range of hardness. In order for a species to be included, definitive acute values had to be available over a range of hardness such that the highest hardness was at least three times the lowest, and such that the highest was at least 100 $mg \cdot L^{-1}$ higher than the lowest (US EPA, 2001). Thirteen species met these criteria: *Tubifex tubifex* (tubificid worms), *Ceriodaphnia reticulata*, *Daphnia magna* and *Daphnia pulex* (cladocerans), *Hyalella azteca* (amphipod), *Oncorhynchus tshawytscha* (chinook salmon), *Oncorhynchus mykiss* (rainbow trout), *Carassius auratus* (goldfish), *Pimephales promelas* (fathead minnow), *Danio rerio* (zebrafish), *Morone saxatilis* (striped bass), *Lepomis cyanellus* (green sunfish), and *Salmo trutta* (brown trout). The selected data were plotted into a regression of logarithmic (log) of toxicant concentration as the dependent variable against the log of hardness as the independent variable (Figure 8.1). A slope of the hardness-toxicity relationship was calculated for each of these fish and invertebrate species. The slopes ranged between 0.293 and 1.729 (Table 8.3). The regressions were able to explain a large portion of the variability because the coefficients of determination (R^2) varied from 0.504 to 0.993. An F-test showed that the slopes for the thirteen species were not significantly different from each other ($p = 0.286$). An analysis of covariance was performed to calculate the pooled slope for hardness using the logarithm of acute values as the dependant variable, species as the treatment or grouping variable, and the logarithm of hardness as the covariate or independent variable. The pooled slope is thus equivalent to a regression slope from a pooled data set, where every variable is adjusted relative to its mean (US EPA, 2001). The pooled slope was 1.016 with an R^2 value of 0.966, and this slope was found to be significantly different from zero ($p<0.05$) (Table 8.3).

This slope value (1.016) relating short-term toxicity with hardness was used to normalize all of the short-term toxicity values used in the species sensitivity distribution (SSD) to a hardness of 50 mg/L using the following equation:

$$EC_{x\ (\text{at 50 mg}\cdot\text{L}^{-1}\ \text{hardness})} = 10^{\{([\log(50) - \log(\text{original hardness})] \cdot 1.016) + \log(\text{original ECx})\}}$$

where EC_x is the short-term toxicity value in μg/L and hardness is measured as $CaCO_3$ equivalents in $mg\cdot L^{-1}$.

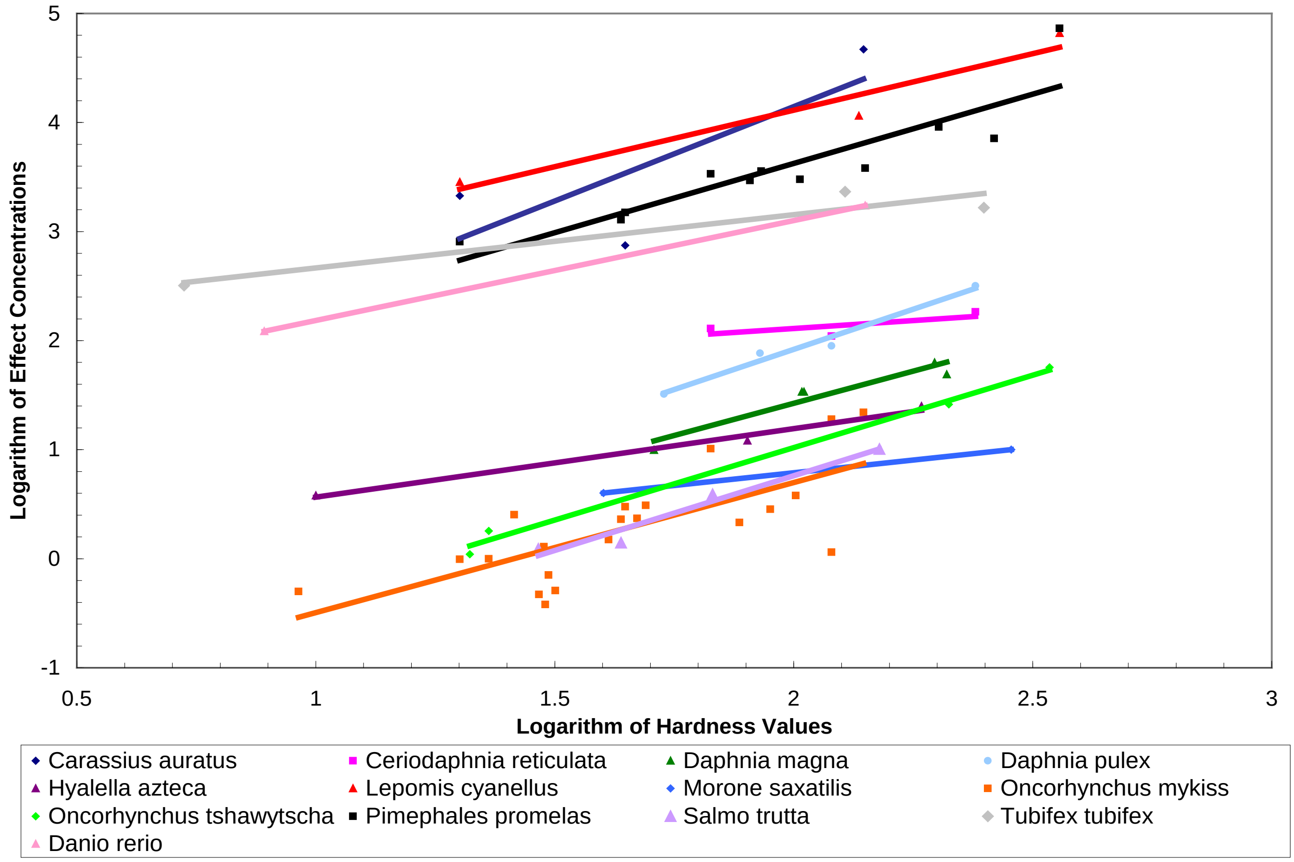

Figure 8.0.1 Hardness-toxicity relationships for short-term data.

Table 8.3 Short-term hardness-toxicity individual regression slope for each species and the overall pooled regression slope. n represents the number of observations used in the regression, R^2 is the coefficient of determination of the regression. A summary table describing studies used here is included in Appendix A (iii).

Species	n	Slope	R^2	Degrees of Freedom
Carassius auratus	3	1.729	0.619	1
Ceriodaphnia reticulata	3	0.293	0.504	1
Daphnia magna (data only from Chapman et al. (1980))	5	1.179[a]	0.909	3
Daphnia magna (all data)[c]	15	0.469	0.133	13
Daphnia pulex	4	1.473[a]	0.975	2
Hyalella azteca (data only from first experiment of Jackson et al. (2000))	3	0.629	0.988	1
Hyalella azteca (all data)[c]	9	0.460	0.122	7
Lepomis cyanellus	3	1.037	0.938	1
Morone saxatilis	2	0.467	-	0
Oncorhynchus mykiss (all data)	21	1.197[a]	0.53	19
Oncorhynchus tshawytscha	4	1.329[a]	0.993	2
Pimephales promelas (adults only)	11	1.27[a]	0.814	9
Pimephales promelas (all data)[c]	17	0.586	0.04	15
Salmo trutta	4	1.37[a]	0.96	2
Tubifex tubifex	3	0.418	0.9	1
Danio rerio	2	0.917	-	0
Pooled slope for all species, with data for *D. magna* from Chapman *et al.* (1980) only, data for *H. azteca* from first experiment of Jackson et al. (2000) only, adult data for *P. promelas* only and all *O. mykiss* data	68	1.016[a,b]	0.966	

[a] Slope is significantly different than 0 ($p<0.05$).
[b] Individual slopes not significantly different ($p = 0.286$).
[c] Relationship not plotted in Figure 8.1.
Note: The pooled slope obtained from the reduced data set (*D. magna* data from Chapman *et al*. (1980) only, only adult data for *P. promelas* and only data from the first experiment of Jackson *et al.* (2000) for *H. azteca*) was used in the hardness equation. This selectivity allowed for the reduction of variability caused by factors other than hardness.

Long-term hardness adjustment equation:

The NGSO has also created a regression equation which quantifies the relationship between water hardness and chronic cadmium toxicity. This relationship was established by selecting those freshwater, aquatic species for which chronic toxicity data were available over a wide range of hardness conditions. In order for a species to be included, definitive chronic values had to be available over a range of hardness such that the highest hardness was at least three times the lowest, and such that the highest was at least 100 mg·L^{-1} higher than the lowest (US E.P.A., 2001). A slope of the hardness-toxicity relationship could be calculated for 7 species of fish and invertebrates: *Daphnia pulex and Daphnia magna* (cladocerans), *Hyalella azteca (*amphipod), *Aeolosoma headleyi (*Oligochaete), *Salmo trutta* (brown trout) *Salvelinus fontinalis* (brook trout) and *Pimephales promelas* (fathead minnow). The selected data were plotted into a regression of logarithmic (log) of toxicant concentration as the dependent variable against the log of hardness as the independent variable (Figure 8.2). The species slopes ranged between 0.504 and 1.234 (Table 8.4). An F-test showed that the slopes for the three species were not significantly different from each other ($p = 0.397$). The pooled slope was 0.83 with an R^2 value of 0.985, and this slope was found to be significantly different from zero ($p<0.05$) (Table 8.4; US E.P.A., 2001).

This slope value (0.83) relating long-term toxicity with hardness was used to normalize all of the long-term toxicity values used in the species sensitivity distribution (SSD) to a hardness of 50 mg·L^{-1} using the following equation:

$$EC_{x\ (\text{at } 50\ \text{mg}\cdot\text{L}^{-1}\ \text{hardness})} = 10^{\{([\log(50) - \log(\text{original hardness})] \cdot 0.83) + \log(\text{original ECx})\}}$$

where EC_x is the long-term toxicity value in µg/L and hardness is measured as $CaCO_3$ equivalents in mg·L^{-1}.

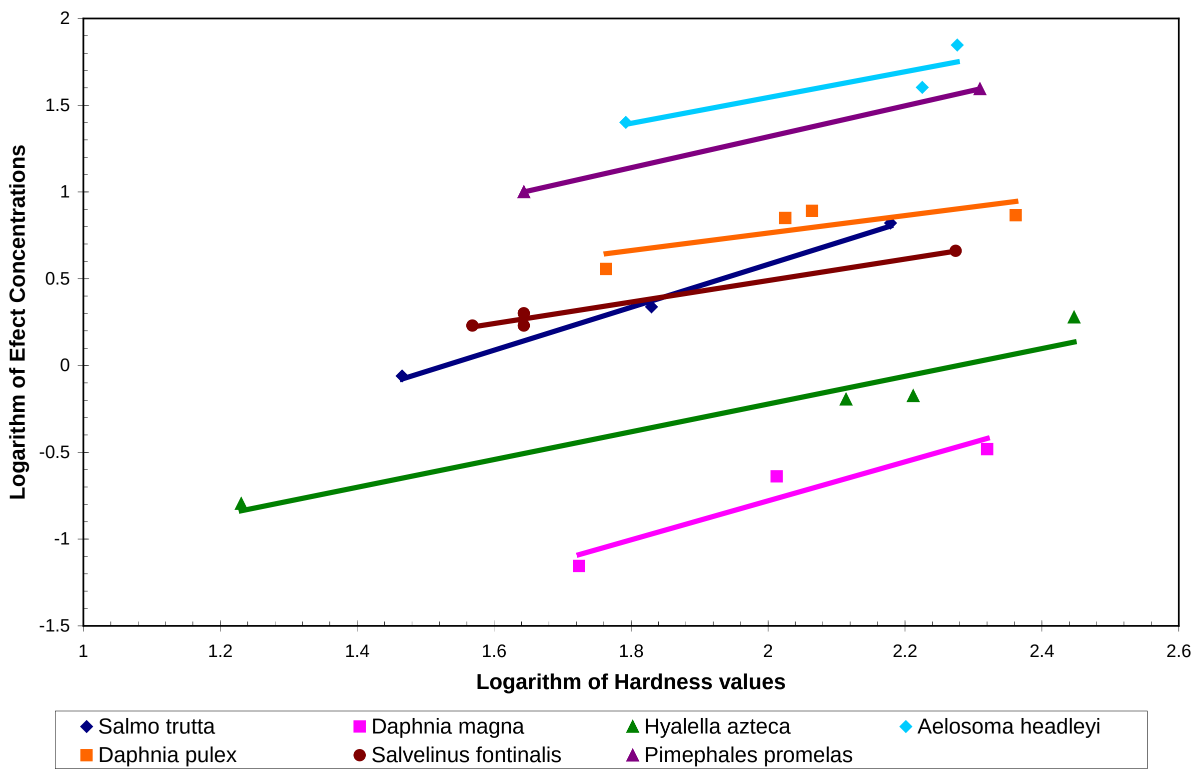

Figure 8.2 Hardness-toxicity relationships for long-term data.

Table 8.4 Long-term hardness-toxicity individual regression slope for each species and the overall pooled regression slope. n represents the number of observations used in the regression, R^2 is the coefficient of determination of the regression and p is the probability that the regression slope is not significantly different from zero. A summary table describing the studies used here is provided in Appendix A (iv).

Species	n	Slope	R^2	Degrees of Freedom
Salmo trutta (Data from biomass (preferred) endpoint)	3	1.234[a]	0.995	1
Salmo trutta (Data from lethal endpoint)[c]	5	0.699[a]	0.926	3
Daphnia magna (only Chapman *et al*. (1980) data)	3	1.123	0.903	1
Daphnia magna (all data)[c]	7	1.466	0.403	
Hyalella azteca	4	0.799[a]	0.93	2
Aeolosoma headleyi	3	0.749	0.786	1
Daphnia pulex	4	0.504	0.617	2
Salvelinus fontinalis	4	0.619[a]	0.98	2
Pimephales promelas	2	0.891	-	0
Pooled slope for all species, with data for *D. magna* from Chapman *et al.* (1980) only and preferred biomass endpoint for Salmo trutta	23	0.83[a,b]	0.985	

[a] Slope is significantly different than 0 ($p<0.05$).
[b] Individual slopes not significantly different ($p = 0.397$).
[c] Relationship not plotted in Figure 8.2.

8.1.2 Alkalinity

Alkalinity and hardness are somewhat similar and are often confused, thus it is important to distinguish between these two parameters. In contrast to hardness, alkalinity is defined as the capacity of water to neutralize acid, and in many surface waters, it is primarily due to carbonate concentrations (Environment Canada, 2003). In the environment, one main source of both hardness and alkalinity is dissolved limestone ($CaCO_3$), which creates conditions in which hardness and alkalinity can co-vary. However, conceptually, hardness and alkalinity alter toxicity through different mechanisms. While both hardness and alkalinity reduce the concentration of the toxic metal at the biological receptor, Ca^{2+} generally reduces toxicity through competition at the biological receptor, whereas CO_3^{2-} and HCO_3^- form complexes with the toxic metal that generally do not elicit a toxic response (Jackson *et al.*, 2000). If hardness is experimentally increased by adding calcium in the form of $CaCO_3$, this will result not only in higher hardness, but higher alkalinity as well. In these cases, it is not possible to determine whether changes in cadmium toxicity are due to the higher hardness or to the higher alkalinity.

Benaduce *et al*. (2008) evaluated the toxicity of cadmium at two alkalinity levels (63 and 92 $mg{\cdot}L^{-1}$ $CaCO_3$) to embryos and larvae of the silver catfish (*Rhamdia quelen*). At higher cadmium concentrations and lower alkalinity there was an increased number of eggs with irregular surfaces, an increased rate of post-hatch mortality and a higher incident of barbel and spinal column deformities compared to the controls (Benaduce *et al.*, 2008). The results suggest that higher alkalinity reduces the toxicity of cadmium to this species of fish. The mean water hardness, which showed no significant difference among treatments, was 22.9 ± 1.3 $mg{\cdot}L^{-1}$ $CaCO_3$ (Benaduce *et al.*, 2008). Kock *et al*. (1995) found a negative relationship between bioconcentration factors and alkalinity for cadmium in the arctic char (*Salvelinus alipinus*) sampled from oligotrophic alpine lakes.

Adjustments made to toxicity data on the basis of alkalinity:
Although alkalinity can influence cadmium toxicity; alkalinity generally covaries with hardness, and hardness has been shown to be a better predictor of aquatic toxicity than alkalinity (US EPA, 2001). Therefore, no adjustments to the data were made on the basis of alkalinity.

8.1.3 pH

The effect of pH on cadmium uptake and toxicity to aquatic organisms is complex and is not clearly understood (Table 8.5). In general, cadmium uptake appears to be greatest at neutral pH (near 7), and reduced at both higher and lower pH (Playle *et al*., 1993b; Rai *et al*., 1990; Vigneault and Campbell, 2005;Wang *et al*., 1998). This effect may be explained as follows: at low pH values, the H^+ concentration is greater, therefore the H^+ ions compete with cadmium for binding sites, which reduces the uptake of cadmium. At high pH , cadmium is less likely to be found in the form of free Cd^{2+} ions in solution (Guéguen *et al.*, 2003), therefore the metal is less readily taken up by aquatic organisms.

In terms of cadmium toxicity, it would be expected that greater toxic effects would be observed at near-neutral pH values (*i.e.*, the pH values at which cadmium uptake is generally highest). Indeed, some studies on fish found cadmium toxicity to be higher at neutral pH values than lower pH values; however, high pH values were not tested (Cusimano *et al*., 1986; Hansen *et al*., 2002a). Cadmium toxicity to bull trout and rainbow trout was up to 3 times lower at pH 6.5 than 7.5, suggesting that H^+ ions may also compete with Cd for binding sites on fish gills (Hansen *et al.*, 2002a). A reduction in cadmium toxicity with decreasing pH was also demonstrated in rainbow trout by Cusimano *et al*. (1986) but the trend was not statistically significant. Dave (1985) demonstrated that LC_{50} values in zebrafish decreased significantly with increasing pH; however, for long-term exposure, embryo-larval survival was not correlated to pH. Mayflies *Baetis rhodani* and *Leptophlebi amarginata* seem to exhibit a positive relationship with pH but with only two data points, the significance could not be tested (Gerhardt, 1992). Effects of pH >8 on cadmium toxicity are still poorly characterized (Niyogi and Wood, 2004).

In aquatic plants the effect of pH on cadmium toxicity is not as clear: in some cases, toxicity is greatest at near-neutral pH values, as expected (Skowroñski *et al.*, 1991), whereas in other cases, toxic effects were observed to a lesser degree at near-neutral pH values than at either low or high pH (Uysal and Taner, 2007). While the uptake of cadmium by cyanobacteria was highest at the intermediate pH tested, the lysis of cyanobacterial cell walls was lowest at the intermediate pH (Rai *et al.*, 1990). Cadmium toxicity to a variety of plants in very hard water was lower or remained the same when tested at progressively lower water pH from 8-8.5 to 7-7.5 or 6-6.5 (Schubauerbergian *et al.*, 1993).

pH appears to affect the number and/or characteristics of metal binding sites of algae, whereas the binding characteristics for higher organisms is believed to be independent of the test medium characteristics) (François *et al.*, 2007). .

Table 8.5 Effects of pH on cadmium toxicity/accumulation in various aquatic species

Species	**Effect on: uptake rate, toxicity etc.**	**Adverse Response**	**Magnitude of effect observed at each pH**	**Reference**
Filamentous algae *Phormidium sp.*	Maximum specific adsorption of Cd	Greater at intermediate pH	Adsorption: 3100 mg·kg^{-1} at pH 3 9600 mg·kg^{-1} at pH 5 8800 mg·kg^{-1} at pH 7	(Wang *et al.*, 1998)
Green algae *Pseudokirchne-rella supcapitata*	Cd uptake	Lower at lower pH	Cd uptake was 23 times lower at pH 5 compared to pH 7	(Vigneault and Campbell, 2005)
Green algae *Chlamydomonas reinhardtii*	Maximum Cd transport flux	Lower at lower pH	Cd flux was: 34.9 µmol/m^2/min at pH 5.0 57.2 µmol/m^2/min at pH 6.5	(François *et al.*, 2007)
Green algae *Stichococcus bacillaris*	Dry weight	Greater at intermediate pH	Dry wt was greatest to least at pH values of: 3, 9, 5, 8, 6, 7	(Skowroñski *et al.*, 1991)
Duckweed *Lemna minor*	Growth rate	Lower at lower pH	Growth rate was: 0.02 d^{-1} at pH 4.5 0.09 d^{-1} at pH 8 (when Cd conc. was 10 mg·L^{-1})	(Uysal and Taner, 2007)
Cyanobacterium *Anabaena flosaquae*	Uptake of Cd	Greater at intermediate pH	Uptake of Cd/cell 1.75 x 10^{-10} µM at pH 4.0 4.64 x 10^{-10} µM at pH 5.5 8.89 x 10^{-10} µM at pH 7.2 5.95 x 10^{-10} µM at pH 10.0 (at a Cd conc. of 1.18 µM)	(Rai *et al.*, 1990)
Cyanobacterium *Anabaena flosaquae*	Lysis of cell wall	Greater at lower pH	Lysis was greatest to least at pH values of: 4.0, 5.5, 10.0, 9.0, 7.2 (at a Cd conc. of 1.18 µM)	(Rai *et al.*, 1990)
Mayfly *Leptophlebia marginata*	Mortality (5d LC_{50})	Greater at low pH	Average LC_{50} value was: 3600 µg·L^{-1} at pH 5 4400 µg·L^{-1} at pH 7	(Gerhardt, 1992)
Mayfly *Baetis rhodani*	Mortality 5d LC_{50}	Greater at low pH	Average LC_{50} value was: 1000 µg·L^{-1} at pH 5 2500 µg·L^{-1} at pH 7	(Gerhardt, 1992)
Bull trout *Salvelinus confluentus*	Mortality (5d LC_{50})	Lower at low pH	Average LC_{50} was: 2.4 µg·L^{-1} at pH 6.5 0.85 µg·L^{-1} at pH 7.5	(Hansen *et al.*, 2002a)
Fathead minnow *Pimephales promelas*	Cd accumulation on gills	Lower at low pH	Gill Cd accumulation was: ~0.26 µg·g^{-1} at pH 4.8 ~0.48 µg·g^{-1} at pH 6.3	(Playle *et al.*,1993b)

Species	Effect on: uptake rate, toxicity etc.	Adverse Response	Magnitude of effect observed at each pH	Reference
Rainbow trout *Onchorynchus mykiss*	Mortality (5d LC_{50})	Lower at low pH	Average LC_{50} was: 0.84 $\mu g \cdot L^{-1}$ at pH 6.5 0.41 $\mu g \cdot L^{-1}$ at pH 7.5	(Hansen *et al.*, 2002a)
Rainbow trout *Oncorhynchus mykiss*	Mortality (96h LC_{50})	Lower at low pH	Average LC_{50} value was: 28.0 $\mu g \cdot L^{-1}$ at pH 4.7 0.7 $\mu g \cdot L^{-1}$ at pH 5.7 <0.5 at pH 7.0	(Cusimano *et al.*,1986)
Rainbow trout *Oncorhynchus mykiss*	Mortality (7d LC_{50})	Lower at low pH	Average LC_{50} value was: 6.3 $\mu g \cdot L^{-1}$ at pH 4.7 0.7 $\mu g \cdot L^{-1}$ at pH 5.7 <0.5 at pH 7.0	(Cusimano *et al*,1986)
Zebrafish, *Brachidanio rerio*	Mortality (24h LC_{50})	Lower at low pH	Tested pH 4.9 to 9.0 24h LC_{50} values negatively related to pH with the equation: log LC_{50} ($\mu g \cdot L^{-1}$)=4.77-0.263(pH) (r=0.9906)	(Dave, 1985)
Zebrafish, *Brachidanio rerio*	Mortality (48h LC_{50})	Lower at low pH	48h LC_{50} values followed a line with equation[2]: LC_{50} ($\mu g \cdot L^{-1}$)= 2261-230.5(pH) (r=0.9999)	(Dave, 1985)
Zebrafish, *Brachidanio rerio*	Mortality Embryo-larval	No trend demonstrated	Median survival times were dose dependent, with similar ranges at all pH values tested	(Dave, 1985)

In general, adsorption and uptake of cadmium appears to be greatest at intermediate pH values, as was seen when more than two pH values were tested. Because many studies only test cadmium toxicity at two pH values, it is difficult to state trends that are meaningful over a wide range of pH. Additional studies testing greater ranges of pH would be useful in understanding the influence of pH on cadmium toxicity.

Adjustments made to toxicity data on the basis of pH:
Although it is recognized that pH can affect cadmium toxicity, there is currently not sufficient, consistent information available to reliably adjust or normalize toxicity data for this variable.

8.1.4 Dissolved Organic Matter (DOM)

The toxicity, bioavailability, and uptake of cadmium by aquatic organisms can also be affected by the amount of dissolved organic matter in the water. Dissolved organic matter (DOM) is a general term which refers to many different forms and size fractions of organic material in water. Similar to the ameliorating effects of alkalinity, DOM has the potential to bind the toxic (free ion) forms of a metal and hence reduce toxicity. However, unlike alkalinity, DOM refers to an extraordinarily heterogeneous class of organic molecules with differing physical-chemical

[2] The 48-h equation could not be recalculated (*i.e.*, confirmed) with the data provided by Dave (1985).

properties, including binding affinity for metals. DOM can also be referred to as natural organic matter, or, more specifically, dissolved organic carbon, humic acid, or fulvic acid. Because DOM can vary widely in terms of composition, molecular size, and chemical properties, it is difficult to classify and quantify. Current data on the effect of DOM on cadmium toxicity from several studies are presented below.

<u>Effect of DOM on the Toxicity of cadmium</u>

Several studies have been conducted evaluating the effect of DOM on toxicity of cadmium to the algae *Pseudokirchneriella subcapitata.* The toxicity of cadmium was reduced at low concentrations (1 and 5 mg·L^{-1}) of soil humic acid and peat humic acids, but not Suwannee River fulvic acid (Koukal *et al.*, 2003). In samples from a dystrophic bog with high humic influence (18 – 25 mg·L^{-1} DOC), *P. subcapitata* was found to have a much lower sensitivity to cadmium than in tests with water of less humic influence (6 – 8 mg·L^{-1}) (Laegreid *et al.*, 1983). Errecalde and Campbell (2000) found the toxicity of free cadmium to *P. subcapitata* increased in the presence of 5 and 100 µM citrate, which appeared the result of uptake of cadmium-citrate complexes by the cells.

Several studies were available concerning the influence of DOM on the toxicity of cadmium to invertebrates. Studies with the cladoceran *Daphnia magna* have reported some conflicting results regarding the effectiveness of DOM in the reduction of toxicity of cadmium. Penttinen *et al.*, (1998) reported a significant reduction in the toxicity of cadmium with the addition of small amounts of DOM (2 mg·L^{-1} DOC). The effect of hardness was also examined in this study, and the results demonstrated that the combination of elevated hardness with 19.6 mg·L^{-1} DOC caused a significant decrease in the toxicity of cadmium when compared to hardness alone (Penttinen *et al.*, 1998). Conversely, a different study found lake water with DOC measuring 20 mg·L^{-1} was eight times more toxic to *D. magna* than laboratory (Oikari *et al.*, 1992). In acute exposures of cadmium to *Daphnia pulex*, addition of 50 mg·L^{-1} humic acid reduced the toxicity of cadmium by a factor of 3.5, corresponding to an 82% decrease in the available free ion concentration. No significant change in toxicity was observed when tested with 0.5 and 5 mg·L^{-1} humic acid (Stackhouse and Benson, 1988). In a chronic exposure of *Daphnia pulex*, small amounts of humic acid (0.75 mg·L^{-1}) did not reduce cadmium toxicity but rather resulted in more rapid mortality compared to exposures without humic acid (Winner and Gauss, 1986). Clifford and McGeer (2010) found that organic matter from natural water sources (DOC from 9 to 16 mg·L^{-1}) resulted in decreased toxicity to *Daphnia pulex* when expressed on a total cadmium basis. The addition of 11.2 mg·L^{-1} fulvic acid did not alter cadmium toxicity to the freshwater bivalve, *Hyridella depressa* (Markich *et al.*, 2003).

Rainbow trout (*Oncorhynchus mykiss*) exposed to cadmium and copper at 0.03 µM and 0.2 µM, respectively in soft water for 15 days in the presence of natural DOM (containing a mixture of fulvic and humic acids) resulted in 0% mortality following the addition of 10 and 20 mg·L^{-1} DOM. The addition of 5 mg·L^{-1}DOM partially protected (13% mortality) rainbow trout from the toxic effects of the metal mixture (Hollis *et al.*, 1996). Niyogi *et al.* (2008) found Cd accumulation on the gills of *O. mykiss* was not significantly different from controls in the presence of up to 10 mg·L^{-1} DOC, and at 19 and 38 mg·L^{-1} DOC a significant decrease in Cd accumulation on the gills was seen. Further, an increase in DOC from 0-20 mg·L^{-1}resulted in a decrease of acute toxicity by 2.5 fold (Niyogi *et al.*, 2008). Five mg·L^{-1} DOM increased the survival of larval zebrafish (*Danio rerio*) when exposed to cadmium at concentrations up to 6.2 $mg \cdot L^{-1}$ (Meinelt *et al.,* 2001). Natural DOM isolated from surface waters in Ontario lakes reduced the toxicity of a metal mixture (0.1 µM cadmium, 1.3 µM copper, 0.2 µM lead, 0.1 µM mercury, 0.05 µM silver and 3.5 µM cobalt) to rainbow trout, however the effectiveness depended on the source of DOM (Richards *et al.,* 2001).

<u>Effect of DOM on the Bioavailability and Uptake of Cadmium</u>

How DOM affects bioavailability and uptake of cadmium by unicellular algae have generally focused on one of three mechanisms: decreased free ion concentration as a result of complexation of DOM with cadmium; increased uptake as a result of passive diffusion of non-charged Cd-DOM complexes across the cell membrane; and formation of ternary complexes between cadmium, DOM and the cell membrane. In general, it appears that DOM primarily influences bioavailability and uptake of cadmium by changing the amount of free cadmium ion available to the algae.

A study by Vigneault and Campbell (2005) found cadmium uptake by *P. subcapitata* and *Chlamydomoas reinhardtii* could be effectively predicted by the concentration of free cadmium ion when assessed in the presence of nitrilotriacetate (NTA) and Suwannee River Standard fulvic and humic acids at pH values of 5 and 7. Significantly less cadmium uptake by *P. subcapitata* occurred at pH 5 compared to pH 7, apparently attributed to hydrogen ion competition for cadmium binding and uptake sites. The authors concluded that DOM mediates cadmium uptake by algal cells through alteration of free ion concentration and not through interactions of DOM with the cell membrane and cadmium (Vigneault and Campbell, 2005).

Regarding the algae *Chlorella kesslerii,* formation of a ternary complex between the algal cell membrane, DOM and cadmium was shown not to substantially influence the bioavailability of cadmium (Lamelas and Slaveykova, 2007). Citric acid (5×10^{-3} M) and Suwannee River humic acid (10 $mg \cdot L^{-1}$) each decreased cadmium uptake by reducing free cadmium ions through the binding of cadmium to citric and humic acids.

The diffusive uptake of metal complexes by *P. subcapitata* exposed to cadmium and diethyldithiocarbamate (DDC) increased significantly compared to uptake of cadmium alone; DDC is a strong metal chelator and forms lipophilic non-charged compounds with divalent metals (for example cadmium), which enter cells through passive diffusion. Uptake of $Cd(DDC)_2$ was slightly increased in the presence of Suwannee River humic acid (SRHA) at 6.5 mg $C \cdot L^{-1}$ at pH 5.5. At pH of 7, however, the uptake was markedly decreased, apparently as a result of formation of $Cd(DDC)_2$-SRHA complexes (Boullemant *et al.,* 2004). Enhanced cadmium uptake has also been found in the presence of the organic compound citrate, and appears to be the result of active uptake of a charged Cd-citrate complex, not a result of passive diffusion (Errécalde and Campbell, 2000).

Studies evaluating the effect of DOM on uptake of cadmium by invertebrates have had inconsistent results; some report increased uptake or accumulation of cadmium in the presence of DOM while others report decreased or unaltered uptake. Humic acid decreased cadmium uptake by 40 to 50% by the freshwater zebra mussel, *Dreissena polymorpha* exposed to cadmium concentrations of 0.72 and 0.218 µM. However, accumulation of cadmium by *D. polymorpha* exceeded that predicted by the FIAM which suggests uptake of some humic acid-bound cadmium occurred (Voets *et al.,* 2004). *Daphnia magna* exposed to various chelating agents, including humic acid, exhibited decreased cadmium uptake, with the exception of DDC which resulted in increased cadmium uptake (Poldoski, 1979). Another study with *Daphnia magna* found 50 $mg{\cdot}L^{-1}$ humic acid over a 96-h exposure decreased cadmium accumulation two-fold, whereas no changes were observed with 0.5 and 5 $mg{\cdot}L^{-1}$ humic acid (Stackhouse and Benson, 1989). Penttinen *et al*. (1995) found *Daphnia magna* exposed to natural DOM at 14.2 $mg{\cdot}L^{-1}$ over a 28-day period had increased cadmium accumulation (by 40-64%), and a faster rate of accumulation compared to organisms in water containing no natural humic substances. The authors also examined the effects of hardness on cadmium accumulation in the presence and absence of humic acid and concluded that hardness was a more important factor in the reduction of cadmium accumulation (Penttinen *et al.,* 1995).

Fathead minnows exposed to cadmium with 5 $mg{\cdot}L^{-1}$ DOM did not exhibit reduced accumulation of cadmium at the gill, which suggests gill binding affinity was stronger than for the different sources of DOM (Playle *et al.,* 1993b). The common carp, *Cyprinus carpio,* however, was reported to have reduced cadmium uptake in the presence of 6.5 $mg{\cdot}L^{-1}$ humic acid, explained by free ion activity being reduced through the binding of cadmium with humic acids (Van Ginneken *et al.,* 2001). Cadmium accumulation on the gill surface of rainbow trout in a combined exposure to six metals was not reduced in the presence of DOM from three lakes in Ontario, unlike for mercury, lead, and copper (Richards *et al.,* 2001). Chinook salmon eggs exposed to cadmium and 10 $mg{\cdot}L^{-1}$ humic acid for 30 minutes showed a 20% reduction in uptake of cadmium compared to controls (Hammock *et al.,* 2003).

Adjustments made to toxicity data on the basis of DOM:
Although it is recognized that some types of DOM can influence the toxicity of cadmium to aquatic organisms, the exact nature of these relationships can vary widely depending on the specific properties of the organic matter. As a result, there is currently insufficient information to develop empirical relationships between cadmium toxicity and DOM in water.

8.1.5 Temperature

Cadmium toxicity may also depend on water temperature, via changes in solubility, speciation or kinetics, or in the metabolic rate of the organism and hence uptake of toxics.

Hallare *et al*. (2005) assessed the interaction between cadmium and temperature on zebrafish (*Dania rerio*) development by exposing fertilized eggs to three temperature levels (21, 26 and 33°C) and six cadmium concentrations ranging from 0 to 10.0 $mg{\cdot}L^{-1}$. Development was accelerated by increasing temperature irrespective of cadmium concentration. Simultaneous exposure to both cadmium and cold stress (21°C) in embryos caused pronounced mortality and reduced heart rate and hatchability (Hallare *et al.,* 2005). These effects were not observed at control (26°C) and high (33°C) temperatures, which can be explained by the higher expression of heat shock protein 70 at these temperatures. Upon hatching, however, larvae showed an increased sensitivity to temperature, which the severity of malformations in the order: hot cadmium stress> cold cadmium stress> cadmium stress alone> no stress (Hallare *et al.,* 2005).

In the cladoceran *Daphnia magna*, increasing temperature lowered the internal threshold concentration, increased the rate of mortality, and increased the rate of cadmium uptake (Heugens *et al.*, 2003). The primary factor for the temperature-dependent toxicity was found to be enhanced sensitivity of *D. magna* (Heugens *et al.*, 2003). Other studies with invertebrates have shown similar results. Lewis and Horning (1991) found a four-fold increase in sensitivity of *Daphnia magna* to cadmium at 26°C compared to 20°C (mean LC_{50}= 0.038 $mg{\cdot}L^{-1}$ at 20°C, mean LC_{50}=0.009 $mg{\cdot}L^{-1}$ at 26°C) and a seven-fold increase in sensitivity of *Daphnia pulex* (mean LC_{50}= 0.042 $mg{\cdot}L^{-1}$ at 20°C, mean LC_{50}= 0.006 $mg{\cdot}L^{-1}$ at 26°C). A rise in temperature (from 20 to 25°C) in combination with sublethal levels of cadmium induced decreased swimming behaviour in *Daphnia magna* (Wolf *et al.*, 1998).

Several studies found a positive relationship between accumulation of cadmium and temperature, in that uptake rates and amount of cadmium accumulated increased at higher temperatures. In the Japanese eel (*Anguilla japonica*), an increase in temperature resulted in increased cadmium accumulation in kidney, liver and gill tissues but not in the intestines (Yang and Chen, 1996). In fingerlings of perch (*Perca fluviatilis*) an increase in temperature (from 5 to 15°C) resulted in an increase in cadmium uptake, with a Q10 for metal uptake of 2.2 (Edgren and Notter 1980). An increase in temperature from 9 to 21°C resulted in a two-fold increase in cadmium accumulation in the Asiatic clam (*Corbicula flumineau*) in cadmium exposures of 0.05 $mg{\cdot}L^{-1}$ (Graney *et al.*, 1984).

Adjustments made to toxicity data on the basis of temperature:
There is currently not enough information on the effects of temperature on cadmium toxicity to reliably adjust or normalize toxicity data for this variable.

8.1.6 Acclimation

Unlike for some metals, pre-exposure to sublethal cadmium concentrations followed by subsequent exposure to lethal cadmium concentrations had not always resulted in the increased tolerance (higher LC_{50}s) indicative of an acclimation response. Szebedinszky *et al.* (2001) reported that dietary, but not aqueous pre-exposure to low cadmium concentrations significantly reduced acute cadmium toxicity to rainbow trout. Cadmium tolerance increased by 15- to 20-fold among adult rainbow trout pre-exposed to sublethal cadmium concentrations (Stubblefield *et al.*, 1999). Juvenile trout tested in the same study were more tolerant of cadmium than adults, and pre-exposure increased juvenile tolerance by a much smaller amount (≤2 times) (Stubblefield *et al.*, 1999). Acclimation resulted in changes in cadmium tolerance of <5 times for trout and other species tested in other studies (Stubblefield *et al.*, 1999). Variable results in acclimation tests may pertain to differences in fish size (and associated metabolic differences) and/or pre-exposure cadmium concentration relative to the toxic level for each species (Stubblefield *et al.*, 1999). The data from several studies regarding the toxicity modifying effects of cadmium acclimation are summarized in Table 8.6

Table 8.6 Effects of acclimation on cadmium toxicity to various aquatic species

Species	Effect on: (uptake rate, toxicity etc.)	Effects seen after chronic exposure	Magnitude of effect (vs. controls)	Water pre-exposure concentration and exposure time	Reference
Onchorynchus mykiss (juvenile)	Incipient lethal level (breakpoint in LC_{50} vs time graph)	Increase	1.4-2.0 fold	For pre-exposure concentrations, see note below; duration = 21 days	(Stubblefield *et al.*, 1999)
Notes: Nominal pre-exposure concentrations were 0, 1.2, 2.4, 4.9, and 9.7 $\mu g \cdot L^{-1}$ High mortality (24.5%) during pre-exposure period at 9.7 $\mu g \cdot L^{-1}$ Pre-exposure to 1.2 $\mu g \cdot L^{-1}$ was not sufficient to produce tolerance Pre-exposure to 2.4 $\mu g \cdot L^{-1}$ was sufficient to produce tolerance No significant difference between the amount of tolerance gained by pre-exposure to 4.9, and 9.7 $\mu g \cdot L^{-1}$ Cd (*i.e.* maximum inducible tolerance had developed using 4.9 $\mu g \cdot L^{-1}$)					
Onchorynchus mykiss (adult)	Incipient lethal level (breakpoint in LC_{50} vs time graph)	Increase	15-20 fold	For pre-exposure concentrations, see note below; duration = 21 d	(Stubblefield *et al.*, 1999)
Notes: Nominal pre-exposure concentrations were 0, 1.2, 2.4, 4.9, and 9.7 $\mu g \cdot L^{-1}$ High mortality (15%) during pre-exposure period at 9.7 $\mu g \cdot L^{-1}$ Also, no significant difference between the amount of tolerance gained by pre-exposure to 1.2, 5.6, and 10.2 $\mu g \cdot L^{-1}$ Cd (*i.e.* maximum inducible tolerance had developed using 1.2 $\mu g \cdot L^{-1}$)					
Pimephales promelas (adult)	LC_{50}	Increase	1.7 fold	10 $\mu g \cdot L^{-1}$ for 35 days	(Benson and Birge, 1985)
Catostomus commersoni (adult)	LC_{50}	Increase	2.5 fold	410 or 730 $\mu g \cdot L^{-1}$ for 7 days	(Duncan and Klaverkamp, 1983)
Onchorynchus mykiss (alevin)	48h LC_{50}	Increase	>1.1 fold (for 1 $\mu g \cdot L^{-1}$) or >15 fold (for 10 $\mu g \cdot L^{-1}$)	1 or 10 $\mu g \cdot L^{-1}$ for 7 days	(Pascoe and Beattie, 1979)
Onchorynchus mykiss (juvenile)	96 h LC_{50}	Increase	11-13 fold	3 or 10 $\mu g \cdot L^{-1}$ for 30 days	(Hollis *et al.*, 1999)
Notes: Fish chronically exposed to 10 $\mu g \cdot L^{-1}$ Cd for 30 days showed 30% mortality in the first 3 days due to acute toxicity However there was no acute toxicity in the chronically exposed 3 $\mu g \cdot L^{-1}$ group There was no significant difference in the acclimation ability gained by the fish chronically exposed to 10 $\mu g \cdot L^{-1}$ vs those exposed to 3 $\mu g \cdot L^{-1}$, therefore the benefits of long-term acclimation can still be gained without acute toxicity occurring					

Species	Effect on: (uptake rate, toxicity etc.)	Effects seen after chronic exposure	Magnitude of effect (vs. controls)	Water pre-exposure concentration and exposure time	Reference
Onchorynchus mykiss (juvenile)	96h LC_{50}	No change	-	0.07 or 0.11 $\mu g \cdot L^{-1}$ for 30 days	(Hollis *et al.*, 2000a)
Note: Experiment was carried out in soft water LC_{50} for control was 2.07 $\mu g \cdot L^{-1}$ whereas for 0.07 it was 0.77 and for 0.11 it was 0.61, therefore LC_{50} values were lower for acclimated fish					
Onchorynchus mykiss (juvenile)	Uptake of new Cd in 3 h gill binding experiments	Increase	~2.5 fold	3 or 75 $\mu g \cdot L^{-1}$ for 30 days	(McGeer *et al.*, 2007)
Onchorynchus mykiss (life stage not reported)	Survival for 2 months in 54 $\mu g \cdot L^{-1}$	Increase	70% died in controls, increased survival in 2 week- or 3 month-old fish and complete protection in 6-10 month-old fish	9 $\mu g \cdot L^{-1}$ for either 2 weeks, 3 months, 6 months or 10 months	(Kay *et al.*, 1986)

From Table 8.6 it can be seen that pre-exposure of *Onchorynchus mykiss* to cadmium in water at 1.2 $\mu g \cdot L^{-1}$ was not sufficient to produce tolerance, however 2.4 $\mu g \cdot L^{-1}$ was sufficient. There was no additional tolerance gained by pre-exposure to 4.9 or 9.7 $\mu g \cdot L^{-1}$ (Stubblefield *et al.*, 1999). In the fish *Pimephales promelas*, *Catostomus commersoni* and *Onchorynchus mykiss*, water pre-exposure to cadmium increased the subsequent LC_{50} or LT_{50} values (Benson and Birge 1985;Duncan and Klaverkamp 1983;Hollis *et al.*, 1999;Kay *et al.*, 1986;Pascoe and Beattie 1979). However, in a similar experiment carried out with *Onchorynchus mykiss* in soft water the LC_{50} value did not change, and pre-exposed fish demonstrated increased sensitivity to cadmium compared to controls (Hollis *et al.*, 2000a). A separate study regarding *Onchorynchus mykiss* pre-exposed to cadmium in water resulted in an increased uptake of new Cd in gill binding experiments (McGeer *et al.*, 2007).

The costs of acclimation in *juvenile* rainbow trout have been observed to be subtle, as no significant effects of chronic water-borne Cd exposure were seen in growth rate, swimming performance, routine oxygen consumption or whole body ion levels. Depressed levels of whole-body calcium were noted, but in an irregular pattern (Hollis *et al.*, 1999). A significant dose-dependent decrease in foraging rate was observed in adult lake trout (*Salvelinus namaycush*) exposed chronically to water-borne cadmium at 0.5 and 5 $\mu g \cdot L^{-1}$ (Scherer *et al.*, 1997). Effects of sublethal concentrations of cadmium on the swimming activities of the bluegill (*Lepomis macrochirus*) included locomotor activities of fish in 0.1 and 0.25 $mg \cdot L^{-1}$ cadmium which were respectively 1.5 and 7.8 times the activities of control fish. Fish in the 0.5 $mg \cdot L^{-1}$ cadmium conditions were less active compared to the controls (0.6 times), indicating metals can affect hyperactive locomotor responses of the bluegill in a concentration-dependent relationship (Ellgaard *et al.,* 1978). In an experiment by Brown *et al*. (1994) adult rainbow trout (*Onchorynchus mykiss*) were exposed to cadmium concentrations near water quality standard levels for periods of up to 90 weeks. Survival and growth was assessed and sperm and eggs were stripped from test fish to conduct early-life-stage tests. Continuous exposure of adult rainbow trout to cadmium concentrations of up to 5.5 $\mu g \cdot L^{-1}$ did not affect survival or growth, however eggs obtained from rainbow trout exposed to 1.8 and 3.4 $\mu g \cdot L^{-1}$ cadmium failed to develop to the fry stage (Brown *et al.*, 1994).

<u>Adjustments made to toxicity data on the basis of acclimation:</u>
There is currently not enough information on the effects of acclimation on cadmium toxicity to reliably adjust or normalize toxicity data for this variable.

8.2 Toxic interactions with other substances and metals

Cadmium toxicity may be modified through interaction with other chemicals and metals. Cadmium exposure can cause disturbance in zinc uptake, while the intake of zinc through the diet affects cadmium adsorption, accumulation and toxicity (Brzóska and Moniuszko-Jakoniuk, 2001). Increasing the supply of zinc can reduce the adsorption and accumulation of cadmium and prevent or decrease the adverse actions of cadmium, while a deficiency in zinc can intensify the accumulation and toxicity of cadmium (Brzóska and Moniuszko-Jakoniuk, 2001). Some examples of toxic effects of cadmium which were prevented or reduced in laboratory animals through pre-treatment or co-administration of zinc include testicular and bone damage, nephrotoxicity, hepatotoxicity, mortality, carcinogenesis, cytotoxiciy, teratogenesis and foetal toxicity (Brzóska and Moniuszko-Jakoniuk, 2001).

A mixture of cadmium, zinc and mercury appeared to have a synergistic effect on the Nile tilapia, *Oreochromis niloticus*, (Lourdes and Cuvin-Aralar, 1994). Mixtures of copper and cadmium and of zinc and cadmium demonstrated additive toxicity in experiments with chinook salmon (*Oncorhynchus tshawytscha*) (Finlayson and Verrue, 1982). In other experiments with zinc and cadmium mixtures, rainbow trout showed essentially equivalent toxicity to that of cadmium alone, while bull trout were more sensitive to the mixture than to Cd-only exposure (Hansen *et al.*, 2002a). In the fathead minnow, *Pimephales promelas,* the toxicity of a tri-metal mixture (copper, cadmium and zinc) did not have strictly additive effects; the toxic effects attributable to copper demonstrated an increase whereas the toxic effects attributable to cadmium demonstrated a decrease (Eaton, 1973).

Interaction of cadmium and other metals in invertebrates have been studied. A study assessing bioconcentration of metals singly and in mixtures in the amphipod *Hyalella azteca* found the K_1 value (rate constant for uptake) for cadmium decreased in binary (Cd-Cu, Cd-Zn) and tertiary (Cd-Zn-Cu) metal mixtures compared to single metal exposures, suggesting some inhibition in uptake by the other metals (Shuhaimi-Othman and Pascoe, 2007). Similar results were found by Norwood *et al.* (2007)since they observed a significant reduction up to 75% in Cd accumulation in *Hyallela azteca* in a mixture of up to 10 metals compared to cadmium alone exposure. Barata *et al*. (2006) assessed the toxicity of cadmium-copper binary metal mixture to the cladoceran *Daphnia magna* and found antagonistic effects of the two metals. This is consistent with previously reported evidence that zinc, copper and cadmium are metallothionein inducers in aquatic invertebrates and therefore their combined toxicity is expected to be antagonistic (Barata *et al.*, 2006).

Several species of algae (*Scenedesmus subspicatus, Scenedesmus obliquus and Scenedesmus microspina*) were studied to assess the interactive effects between cadmium, anthracene and chloridazone on growth and activity of superoxide dismutase (SOD) izoformes in 12-, 24- and 48-h exposures. The combination of anthracene and cadmium resulted in additive effects for all algal species (Zbigniew and Wojciech, 2006). The combination of cadmium and chloridazone produced both antagonistic and additive effects to algal growth inhibition. The combination of all three substances produced only antagonistic effects in *S. subspicatus* and *S. obliquus*, whereas additive effects dominated for the treatment to *S. microspina* (Zbigniew and Wojciech, 2006).

8.3 Toxicity of Cadmium to Aquatic Life

Toxicity of cadmium to aquatic life is affected by ambient water quality. As previously discussed, the data to be included in developing the water quality guideline were normalized to 50 mg·L^{-1} total hardness (as $CaCO_3$) (see section 8.1.1). However, the toxicity data were not adjusted to account for any other water quality parameters. Differences between studies of similar design and execution may be due to water chemistry parameters other than hardness (*e.g.*, pH, DOM, alkalinity, temperature, etc.). The information from Section 7.3 is expanded upon in Appendix A, and includes some of the water quality parameters for each study, as originally reported. Note that all of the toxicity values reported below have been adjusted to 50 mg·L^{-1} hardness (as $CaCO_3$ equivalents) where possible to ensure comparisons.

8.3.1 Short-term toxicity

The following section summarizes the most sensitive and least sensitive species in each taxonomic group (*e.g.*, fish, invertebrates, amphibians, plants/algae). Note that this section relates only to those data selected for inclusion in the short-term species sensitivity distribution (SSD). See the section 'Guideline Derivation' for a full description of the data selection criteria. A list of the 62 short-term toxicity data points that were used in the SSD is presented in Table 8.7. Toxicity values described in the text of this section that have been adjusted to 50 mg·L^{-1} hardness (as $CaCO_3$ equivalents) have been identified as so using the term "hardness-adjusted".

Table 8.7 Toxicity data points used in the species sensitivity distribution (SSD) to determine the short-term benchmark concentration for cadmium.

Species	SSD Rank Order	Endpoint	Life Stage	Ranking	Effect concentration ($\mu g \cdot L^{-1}$ cadmium) (Variation)	Hardness ($mg \cdot L^{-1}$)	Effect concentration ($\mu g \cdot L^{-1}$ cadmium) (Adjusted to 50 $mg \cdot L^{-1}$ hardness as $CaCO_3$) (Variation)[a]	Reference
Fish								
Rainbow trout *(Oncorhynchus mykiss*)	1	96 h LC_{50}	Juvenile	1	1.15 (±0.53)	120	0.47 (±0.22)	(Hollis et al., 2000b)
Brown trout (*Salmo trutta*)	4	96 h LC_{50}	Juvenile	2	1.4 (95% CI 1.1-1.8)	43.5	1.61 (95% CI 1.27-2.07)	(Spehar and Carlson, 1984)
Striped bass (*Morone saxatilis*)	5	96 h LC_{50}	35-80 days old	2	10 (6-16)	285	1.71 (1.02-2.73)	(Palawski et al., 1985)
Mottled sculpin (*Cottus bairdi*)	6	96 h LC_{50}	Swim-up fry	1	3.6 (95% CI 3.4-3.8)	102	1.74 (95% CI 1.65-1.84)	(Besser et al., 2007)
Bull trout (*Salvenlinus confluentus*)	7	96 h LC_{50}	Fry	-	-	-	1.97[b]	(Stratus Consulting Inc., 1999)
Chinook Salmon (*Oncorhynchus tshawytscha*)	8	96 h LC_{50}	Swim-up fry	2	1.8 (1.7-2.0)	23	3.96 (3.74-4.4)	(Chapman, 1978)
Coho salmon (*Oncorhynchus kisutch*)	9	96 h LC_{50}	Juvenile	2	3.4 (2.2-5.1)	41	4.16 (2.69-6.24)	(Buhl and Hamilton, 1991)
Arctic grayling (*Thymallus arcticus*)	10	96 h LC_{50}	Juvenile	2	4 (1.5-9.7)	41	4.89 (1.84-11.9)	(Buhl and Hamilton, 1991)
Mountain whitefish (*Prosopium williamsoni*)	11	96 h LC_{50}	Embryo	1	4.7	47.8	4.92	(Brinkman and Vieira, 2008)
Fathead minnow (*Pimephales promelas)*	13	96 h LC_{50}	< 24 h	2	60 (53-68)	290	10.1 (8.88-11.4)	(Schubauerbergian et al., 1993)
Zebrafish (*Danio rerio*)	33	96 h LC_{50}	Larva	2	1730 (1107-2363)	141	603 (386-824)	(Alsop and Wood, 2011)
Goldfish (*Carassius auratus*)	36	96 h LC_{50}	Adult	2	748 (408-1307)	44.4	844 (460-1475)	(Phipps and Holcombe, 1985)
White sucker (*Catostomus commersoni*)	44	96 h LC_{50}	Juvenile	2	1110	18	3130	(Duncan and Klaverkamp, 1983)
Guppy (*Lebistes reticulatus*)	45	96 h LC_{50}	1-2 g	2	1270	20	3220	(Pickering and Henderson, 1966)
Yellow perch (*Perca flavescens*)	46	96 h LC_{50}	Juvenile	2	8140 (6230-11290)	120	3350 (2560-4640)	(Niyogi et al., 2004)

Species	SSD Rank Order	Endpoint	Life Stage	Ranking	Effect concentration ($\mu g \cdot L^{-1}$ cadmium) (Variation)	Hardness ($mg \cdot L^{-1}$)	Effect concentration ($\mu g \cdot L^{-1}$ cadmium) (Adjusted to 50 $mg \cdot L^{-1}$ hardness as $CaCO_3$) (Variation)[a]	Reference
Bluegill (*Lepomis macrochirus*)	52	96 h LC_{50}	1-2 g	2	1940 (1330-2350)	20	4920 (3370-5960)	(Pickering and Henderso,n 1966)
Channel catfish (*Ictalurus punctatus*)	53	96 h LC_{50}	Juvenile	2	4480 (3230-6210)	44.4	5050 (3640-7010)	(Phipps and Holcomb,e 1985)
Green sunfish (*Lepomis cyanellus*)	57	96 h LC_{50}	1-2 g	2	2840 (2100-84400)	20	7210 (5330-214000)	(Pickering and Henderson, 1966)
Grass carp (*Ctenopharyngodon idellus*)	58	96 h LC_{50}	Adult	2	9420	-	9420	(Yorulmazlar and Gül, 2003)
Invertebrates								
Amphipod (*Hyalella azteca*)	2	96 h LC_{50}	4-14 d	2	5	290	0.84	(Schubauer-Berigan et al., 1993)
Cladoceran (*Daphnia magna*)	3	72 h LC_{50}	Adult	2	3.34 (1.81-6.22)	179	0.91 (0.495-1.70)	(Barata and Baird, 2000)
Green hydra (*Hydra viridissima*)	12	96 h LC_{50}	Not reported	2	3 (0.0 SE)	19.5	7.81	(Holdway *et al.*, 2001)
Cladoceran (*Daphnia ambigua*)	14	48 h LC_{50}	< 24 h	2	10.1 (95% CI 5.62-12.36)	-	10.1 (95% CI 5.62-12.36)	(Shaw *et al.*, 2006)
Neosho mucket (*Lampsilis rafinesqueana*)	15	96 h EC_{50}	Juvenile	1	20 (19-22)	44	22.8 (21.6-25.1)	(Wang et al., 2010)
Cladoceran (*Simocephalus serrulatus*)	16	48 h LC_{50}	Neonate	2	24.5 (95% CI 18.6-32.1)	43.5	28.2 (95% CI 21.4-37.0)	(Spehar and Carlson, 1984)
Cladoceran (*Daphnia pulex*)	17	96 h LC_{50}	< 24 h	2	32.4 (29.6-35.7)	53.5	30.3 (27.6-33.3)	(Stackhouse and Benson, 1988)
Cladoceran (*Ceriodaphnia dubia*)	18	48 h LC_{50}	< 24 h	2	31.5 (95% CI 21.4-38.2)	-	31.5 (95% CI 21.4-38.2)	(Shaw et al., 2006)
Cladoceran (*Ceriodaphnia reticulata*)	19	48 h LC_{50}	< 24 h	2	184 (159-208)	240	37.4 (32.3-42.6)	(Elnabarawy et al., 1986)
Amphipod (*Gammarus pseudolimnaeus*)	20	96 h LC_{50}	< 24 h	2	54.4 (95% CI 35.7-82.9)	67	40.4 (95% CI 26.5-61.6)	(Spehar and Carlson, 1984)
Fatmucket (*Lampsilis siliquoidea*)	21	48 h EC_{50}	Glochidia	-	-	-	44.6[b]	(Wang et al., 2010)

Species	SSD Rank Order	Endpoint	Life Stage	Ranking	Effect concentration ($\mu g \cdot L^{-1}$ cadmium) (Variation)	Hardness ($mg \cdot L^{-1}$)	Effect concentration ($\mu g \cdot L^{-1}$ cadmium) (Adjusted to 50 $mg \cdot L^{-1}$ hardness as $CaCO_3$) (Variation)[a]	Reference
Pink hydra (*Hydra vulgaris*)	22	96 h LC_{50}	Juvenile	2	120 (95% CI 110-130)	108	54.9 (95% CI 50.3-59.4)	(Beach and Pascoe, 1998)
Cladoceran (*Simocephalus vetulus*)	23	48 h LC_{50}	< 24 h	2	89.3 (95% CI 73.6-108)	67	66.3 (95% CI 54.7-80.2)	(Spehar and Carlson, 1984)
Moss bladder snail (*Aplexa hypnorum*)	24	96 h LC_{50}	Adult	2	93 (54-160)	44.4	104.9 (60.9-180.5)	(Phipps and Holcombe, 1985)
Oligochaete (*Lumbriculus variegatus*)	25	96 h LC_{50}	Adult	2	780	290	131	(Schubauer-Berigan et al., 1993)
Sludge worm (*Tubifex tubifex*)	26	96 h LC_{50}	Immature	2	250 (210-290)	-	250 (210-290)	(Maestre et al., 2009)
Midge (*Chironomus plumosus*)	27	96 h LC_{50}	Larva	2	300 (100-400)	-	300 (100-400)	(Vedamanikam and Shazili, 2009)
Mayfly (*Paraleptophlebia praepedita*)	28	96 h LC_{50}	Juvenile	2	449 (95% CI 166-1217)	67	334 (95% CI 123-904)	(Spehar and Carlson, 1984)
White River crayfish (*Procambarus acutus*)	29	96 h LC_{50}	Adult	2	368 (95% CI 196-646)	44.5	414 (95% CI 221-727)	(Wigginton and Birge, 2007)
Placid crayfish (*Orconectes placidus*)	31	96 h LC_{50}	Adult	2	487 (95% CI 295-785)	44.1	553 (95% CI 335-892)	(Wigginton and Birge, 2007)
Red swamp crayfish (*Procambarus clarkii*)	32	96 h LC_{50}	Juvenile	2	624 (95% CI 399-894)	52.9	589 (95% CI 377-844)	(Wigginton and Birge, 2007)
Midge (*Chironomus tentans*)	34	96 h LC_{50}	Second instar	1	1680 (95% CI 800-3400)	114	727 (95% CI 346-1472)	(Watts and Pascoe, 2000)
Midge (*Chironomus riparius*)	35	96 h LC_{50}	Second instar	1	1760 (95% CI 1000-3100)	114	762 (95% CI 433-1342)	(Watts and Pascoe, 2000)
Oligochaete (*Limnodrilus hoffmeisteri*)	38	96 h LC_{50}	Adult	2	170	5.3	1660	(Chapman *et al.*, 1982)
Oligochaete (*Brachiura sowerbyi*)	39	96 h LC_{50}	Adult	2	240	5.3	2350	(Chapman *et al.*, 1982)
Bivalve (*Pisidium casertanum*)	40	96 h LC_{50}	Not reported	-	-	-	2570[b]	(Mackie, 1989)
Bivalve (*Pisidium compressum*)	41	96 h LC_{50}	Not reported	-	-	-	2690[b]	(Mackie, 1989)

Species	SSD Rank Order	Endpoint	Life Stage	Ranking	Effect concentration (μg·L^{-1} cadmium) (Variation)	Hardness (mg·L^{-1})	Effect concentration (μg·L^{-1} cadmium) (Adjusted to 50 mg·L^{-1} hardness as $CaCO_3$) (Variation)[a]	Reference
Kentucky River crayfish *(Orconectes juvenilis)*	42	96 h LC_{50}	Adult	2	2440 (95% CI 1840-3490)	44.1	2770 (95% CI 2090-3965)	(Wigginton and Birge, 2007)
Oligochaete (*Quistadrilus multisetosus*)	43	96 h LC_{50}	Adult	2	320	5.3	3130	(Chapman *et al.*, 1982)
Electric blue dragon crayfish *(Procambarus alleni*)	47	96 h LC_{50}	Adult	2	3070 (95% CI 1740-5450)	45.8	3360 (95% CI 1902-5958)	(Wigginton and Birge, 2007)
Oligochaete (*Spirosperma ferox*)	48	96 h LC_{50}	Adult	2	350	5.3	3420	(Chapman *et al.*, 1982)
Oligochaete (*Varichaeta pacifica*)	49	96 h LC_{50}	Adult	2	380	5.3	3720	(Chapman *et al.*, 1982)
Northern crayfish *(Orconectes virilis*)	50	96 h LC_{50}	Adult	2	3300 (95% CI 2100-5200)	42.5	3890 (95% CI 2477-6134)	(Wigginton and Birge, 2007)
Oligochaete (*Spirosperma nikolskyi*)	51	96 h LC_{50}	Adult	2	450	5.3	4400	(Chapman *et al.*, 1982)
Oligochaete (*Stylodrilus heringianus*)	54	96 h LC_{50}	Adult	2	550	5.3	5380	(Chapman *et al.*, 1982)
Oligochaete (*Rhyacodrilus montana*)	55	96 h LC_{50}	Adult	2	630	5.3	6160	(Chapman *et al.*, 1982)
Mud snail (*Potamopyrgus antipodarum*)	56	48 h LC_{50}	Adult	2	7200 (95% CI 5700-9070)	-	7200 (95% CI 5700-9070)	(Moller *et al.*, 1996)
Mayfly (*Rhithrogena hageni*)	59	96 h LC_{50}	Nymph	1	10500	48	10900	(Brinkman and Johnston, 2008)
Nail polish crayfish *(Orconectes immunis*)	60	96 h LC_{50}	Adult	2	>10200	44.1	11 500	(Phipps and Holcombe, 1985)
Gastropod (*Amnicola limosa*)	61	96 h LC_{50}	Not reported	-	-	-	13 400[b]	(Mackie, 1989)
Damselfly (*Enallagma sp.*)	62	96 h LC_{50}	Not reported	-	-	-	28 900[b]	(Mackie, 1989)
Amphibians								
Northwestern salamander *(Ambystoma gracile*)	30	96 h LC_{50}	Larva	1	468.4	45	521	(Nebeker *et al.*, 1995)

Species	SSD Rank Order	Endpoint	Life Stage	Ranking	Effect concentration (µg·L^{-1} cadmium) (Variation)	Hardness (mg·L^{-1})	Effect concentration (µg·L^{-1} cadmium) (Adjusted to 50 mg·L^{-1} hardness as $CaCO_3$) (Variation)[a]	Reference
Argentine toad *(Bufo arenarum*)	37	96 h LC_{50}	Stage 26	2	2190 (95% CI 1990-2410)	80	1360 (95% CI 1234-1495)	(Ferrari *et al.*, 1993)

[a] The same short-term hardness correction equation

$$EC_{x\ (\text{at } 50\ mg \cdot L^{-1}\ \text{hardness})} = 10^{\{([\log(50) - \log(\text{original hardness})] \cdot 1.016) + \log(\text{original ECx})\}}$$

used to standardize the effect concentrations to 50 mg·L^{-1} hardness was applied to the endpoint variation (C. Schwarz, pers.comm.).

[b]Value shown is the geometric mean of comparable values: see Table 8.8 for data used to calculate geometric means. Geometric mean values are calculated whenever there are multiple endpoints for the same species with the same life stage, duration, effect and relevant ambient water quality parameters. The most sensitive geometric mean or single value (values without comparable data with which to include in a geometric mean) is selected for plotting in the SSD.

Table 8.8 Calculation of geometric means for short-term aquatic toxicity data considered for guideline derivation. (Concentrations standardised to a hardness of 50 mg·L^{-1} $CaCO_3$)

Organism	Endpoint	Effect Concentration (µg·L^{-1} cadmium) (Variation)	Effect Concentration ((µg·L^{-1} cadmium) (Corrected to 50 mg·L^{-1} hardness as $CaCO_3$) (Variation)[a]	Geometric Mean (µg·L^{-1})	Inclusion in SSD[b]	Reference
Amnicola limosa (Gastropod)	96 h LC_{50}	2710 (770)	9025.60 (2565)	13418	Yes	Mackie, 1989
		3800 (880)	12655.83 (2931)			
		6350 (1120)	21148.56 (3730)			
Cottus bairdi (Mottled sculpin)	96 h LC_{50}	17 (95% CI 15-18)	8.32 (95% CI 7.34-8.81)	9.68	No	Besser *et al.*, 2007
		23 (95% CI 19-28)	11.26 (95% CI 9.3-13.7)			
Onchorhynchus mykiss (Rainbow trout, fry)	96 h LC_{50}	0.38 (0.35-0.41)	0.63 (0.58-0.68)	1.01	No	Stratus Consulting Ltd., 1999
		0.47 (0.41-0.53)	0.809 (0.71-0.91)			
		0.51 (0.44-0.58)	0.810 (0.699-0.922)			
		0.71 (0.63-0.79)	1.165 (1.03-1.30)			
		1.29 (1.00-1.58)	2.167 (1.68-2.66)			
Onchorhynchus mykiss (Rainbow trout, juvenile)[c]	96 h LC_{50}	0.61 (± 0.34)	1.55 (± 0.863)	2.74	No	Spehar and Carlson, 1984; Phipps and Holcombe, 1985; Buhl and Hamilton, 1991; Hollis *et al.*, 2000
		1.5 (1.2-1.8)	1.84 (1.47-2.2)			
		0.77 (± 0.49)	1.95 (± 1.24)			
		2.35 (± 0.16)	2.50 (± 0.17)			
		2.3 (95% CI 1.6-3.3)	2.65 (95% CI 1.84-3.8)			
		3 (2-4)	3.38 (2.26-4.51)			
		2.53 (± 1.91)	4.91 (± 3.71)			
		2.07 (± 1.73)	5.25 (± 4.39)			
Salvelinus confluentus (Bull trout)	96 h LC_{50}	0.91 (0.81-1.01)	1.49 (1.33-1.66)	1.97	Yes	Stratus Consulting Ltd., 1999
		0.9 (0.81-0.99)	1.50 (1.35-1.65)			
		1 (0.82-1.18)	1.59 (1.3-1.88)			
		0.99 (0.87-1.11)	1.70 (1.50-1.91)			
		2.89 (2.21-3.57)	4.86 (3.71-6.00)			
Ceriodaphnia dubia (Cladoceran, <24-h)	48 h LC_{50}	49.8	33.44	115.00	No	Diamond *et al.*, 1997
		107.4	78.58			
		160.2	88.17			
		189.7	123.97			
		213.3	139.39			
		315.7	173.75			
		252	184.38			
		355.3	238.57			
Enallagma sp. (Damselfly)	96 h LC_{50}	10660 (2750)	35502.93 (9159)	28862.13	Yes	Mackie, 1989
		7050 (3450)	23479.89 (11490)			
		8660 (3120)	28841.97 (10391)			

Lampsilis siliquoidea (Fatmucket, Glochidia)	24 h EC_{50}	8	9.11	44.56	No	Wang et al., 2010
		33	37.58			
		227	258.48			
Lampsilis siliquoidea (Fatmucket, Glochidia)	48 h EC_{50}	8	9.11	44.56	Yes	Wang et al., 2010
		33	37.58			
		227	258.48			
Lampsilis siliquoidea (Fatmucket, Juvenile)	48 h EC_{50}	34	38.71	76.49	No	Wang et al., 2010
		42 (39-45)	47.82 (44.4-51.2)			
		62	70.59			
		230	261.89			
Lampsilis siliquoidea (Fatmucket, Juvenile)	96 h EC_{50}	16 (13-20)	18.22 (14.8-22.8)	57.96	No	Wang et al., 2010
		34	38.72			
		62	70.59			
		199 (118-337)	226.59 (134.4-383.7)			
Pisidium casertanum (Bivalve)	96 h LC_{50}	1370 (320)	4562.76 (1066)	2571.54	Yes	Mackie, 1989
		480 (180)	1598.63 (599.5)			
		700 (260)	2331.34 (865.9)			
Pisidium compressum (Bivalve)	96 h LC_{50}	2080 (510)	6927.40 (1699)	2685.31	Yes	Mackie, 1989
		360 (130)	1198.97 (433)			
		700 (320)	2331.34 (1066)			
Simocephalus serrulatus (Cladoceran, <24-h)	48 h LC_{50}	35	179.56	76.16	No	Giesy *et al.*, 1977
		7 (5.4-9.1)	32.30 (24.9-42.0)			

[a] The same short-term hardness correction equation

$$EC_{x\ (\text{at } 50\ mg\cdot L^{-1}\ \text{hardness})} = 10^{\{([\log(50) - \log(\text{original hardness})] \cdot 1.016) + \log(\text{original ECx})\}}$$

used to standardize the effect concentrations to 50 mg·L^{-1} hardness was applied to the endpoint variation (C. Schwarz, pers.comm.).

[b]Geometric mean values are calculated whenever studies report the same endpoint type for the same species, life stage, duration, effect and relevant ambient water quality parameters. Geometric means were included in the SSD if they represented the lowest LC_{50}/EC_{50} for the species.

[c]As a point of clarification, the data from Hansen *et al.* (2002 a) were not included in these geometric mean calculations. This paper produced 120-h LC_{50} values, as opposed to the 96-h LC_{50} values determined by other experiments. For bull trout, it was also a different life stage that was tested by Hansen *et al.* (2002 a).

<u>Short-term toxicity to freshwater fish</u>

Short-term (96-h or less) LC_{50} values for cadmium were available for 19 freshwater fish species. In general, salmonids (*e.g.*, trout, salmon, graylings) were more sensitive than other types of fish, although there were exceptions. The most sensitive fish species was the rainbow trout (*Oncorhynchus mykiss*) (formerly *Salmo gairdneri*) with a hardness-adjusted 96-hour LC_{50} value of 0.47 µg·L^{-1} (Hollis et al., 2000b). The second most sensitive fish species was the brown trout (*Salmo trutta*), with a hardness-adjusted 96-h LC_{50} value of 1.61 µg·L^{-1} (Spehar and Carlson

1984). Among the seven salmonid species, the lowest hardness-adjusted 96-h LC_{50} values (*i.e.*, the values used in the SSD (or geometric means, where applicable)) ranged from 0.47 $\mu g \cdot L^{-1}$ for *O. mykiss* to 4.92 $\mu g \cdot L^{-1}$ for the mountain whitefish (*Prosopium williamsoni*) (Brinkman and Vieira, 2008). In the twelve non-salmonid species, the lowest hardness-adjusted 96-h LC_{50} values used in the SSD (or geometric means, where applicable) ranged from 1.71 $\mu g \cdot L^{-1}$ for *M. saxatilis* (Palawski et al., 1985) to 9420 $\mu g \cdot L^{-1}$ for the grass carp (*Ctenopharyngodon idellus*) (Yorulmazlar and Gül, 2003). Further details can be found in Appendix A

<u>Short-term toxicity to freshwater invertebrates</u>

Short-term LC_{50} values were obtained for 41 freshwater invertebrates for fully aquatic life stages. The most sensitive were the cladocerans (water fleas, daphnids), amphipods (*e.g. Hyalella sp.*), and hydras. The least sensitive were gastropods and damselfly. The most sensitive invertebrate species was *Hyalella azteca*, with a hardness-adjusted 96-h LC_{50} of 0.84 $\mu g \cdot L^{-1}$ (Schubauer-Berigan *et al.*, 1993). The least sensitive species was the damselfly (*Enallagma sp.*), with a hardness-adjusted 96-h LC_{50} value of 28900 $\mu g \cdot L^{-1}$ (Mackie, 1989).

<u>Short-term toxicity to freshwater amphibians</u>

Short-term LC_{50} values were obtained for fully aquatic stages of 2 amphibian species. The most sensitive amphibian species was the northwestern salamander (*Ambystoma gracile*) with a hardness-adjusted 96-h LC_{50} value of 521 $\mu g \cdot L^{-1}$ (Nebeker *et al.,* 1995). The least sensitive species was the Argentine toad (*Bufo arenarum*) with a hardness-adjusted 96-h LC_{50} value of 1360 $\mu g \cdot L^{-1}$ (Ferrari *et al.,* 1993).

<u>Short-term toxicity to freshwater plants/algae</u>

Due to the rapid growth and turnover of algal/aquatic plant species, it is difficult to obtain short-term data. Most toxicity studies are carried out over a period of 1-4 days, which would be classified as long-term relative to the lifespan of many algae/plants. Thus, no suitable short-term toxicity data were obtained for algae/plants.

8.3.2 Long-term toxicity

The following section summarizes the most sensitive and least sensitive species in each taxonomic group, including fish, invertebrates, amphibians and plants/algae. Note that this section relates only to the 36 data points that were selected for use in the long-term species sensitivity distribution (SSD) to derive the long-term water quality guideline. A full description of how these data points were selected can be found in the section ‘Guideline Derivation’. See Table 8.9 for a list of the 36 long-term toxicity data points used in the SSD. Toxicity values described in the text of this section that have been adjusted to 50 $mg \cdot L^{-1}$ hardness (as $CaCO_3$ equivalents) have been identified as so using the term “hardness-adjusted”.

Table 8.9 Toxicity data points used in the species sensitivity distribution (SSD) to determine the long-term Canadian Water Quality Guideline (CWQG) for cadmium.

Species	SSD Rank Order	Endpoint	Observed Effect	Life Stage	Ranking	Effect concentration ($\mu g \cdot L^{-1}$ cadmium) (Variation)	Hardness ($mg \cdot L^{-1}$)	Effect concentration ($\mu g \cdot L^{-1}$ cadmium) (Corrected to 50 $mg \cdot L^{-1}$ hardness as $CaCO_3$) (Variation)[a]	Reference
Fish									
Rainbow trout (*Oncorhynchus mykiss*)	4	62 d EC_{10}	Weight	Early life stage	1	0.15 (0.12-1.6)	29.4	0.233 (0.187-2.49)	(Mebane *et al.*, 2008)
Bull trout (*Salvelinus confluentus*)	5	55 d MATC	Growth	Juvenile	1	0.549	30.6	0.825	(Hansen *et al.*, 2002b)
Mottled sculpin (*Cottus bairdi*)	8	21 d EC_{50}	Biomass, decrease	Fry	1	1.77 (95% CI 1.7-1.9)	104	0.964 (95% CI 0.926-1.03)	(Besser *et al.*, 2007)
Atlantic salmon (*Salmo salar*)	9	496 d MATC	Biomass, decrease	Egg	2	0.61	28	0.987	(Rombough and Garside, 1982)
Sturgeon (*Acipenser transmontanus*)	10	58 d LC_{20}	Mortality	Fry	2	1.5 (1.2-1.8)	70	1.14 (0.908-1.36)	(Vardy et al., 2011)
Mountain Whitefish (*Prosopium williamsoni*)	11	90 d IC_{10}	Weight, biomass	Embryo and fry	1	1.2	47.8	1.25	(Brinkman and Vieira, 2008)
Brown trout (*Salmo trutta*)	14	30 d IC_{20}	Biomass, decrease	Fry	1	0.87 (95% CI 0.82-0.93)	29.2	1.36 (95% CI 1.28-1.45)	(Brinkman and Hansen, 2007)
Brook trout (*Salvelinus fontinalis*)	17	126 d MATC	Biomass, decrease	Larva	2	2	45	2.23	(Eaton *et al.*, 1978)
Chinook salmon (*Oncorhynchus tshawytscha*)	18	8 d LC_{10}	Mortality	Fry	2	1.2 (0.9-1.4)	23	2.29 (1.72-2.67)	(Chapman, 1978)
Fathead minnow (*Pimephales promelas*)	19	7 d MATC	Mortality	Larva	1	9.8	278	2.36	(Castillo and Longley, 2001)
White sucker (*Catostomus commersoni*)	23	40 d MATC	Biomass, decrease	Embryo	1	7.1	45	7.75	(Eaton *et al.*, 1978)
Coho salmon (*Oncorhynchus kisutch*)	24	62 d MATC	Biomass, decrease	Larva	1	7.2	45	7.81	(Eaton *et al.*, 1978)

Species	SSD Rank Order	Endpoint	Observed Effect	Life Stage	Ranking	Effect concentration (μg·L^{-1} cadmium) (Variation)	Hardness (mg·L^{-1})	Effect concentration (μg·L^{-1} cadmium) (Corrected to 50 mg·L^{-1} hardness as $CaCO_3$) (Variation)[a]	Reference
Lake trout (*Salvelinus namaycush*)	25	64 d MATC	Biomass, decrease	Larva	1	7.4	45	8.03	(Eaton *et al.*, 1978)
Northern pike (*Esox lucius*)	26	35 d MATC	Biomass, decrease	Embryo	1	7.4	45	8.03	(Eaton *et al.*, 1978)
Invertebrates									
Cladoceran (*Daphnia magna*)	1	7 d EC_{10}	Feeding inhibition	Adult	2	0.13 (0.04-0.21)	179	0.045 (0.014-0.073)	(Barata and Baird, 2000)
Cladoceran (*Ceriodaphnia reticulata*)	2	7 d MATC	Reproduction - Number of young per adult	Adult	2	0.43	240	0.117	(Elnabarawy *et al.*, 1986)
Amphipod (*Hyalella azteca*)	3	28 d IC_{25}	Biomass, decrease	7-8 days	2	0.51	280	0.122	(Ingersoll and Kemble 2001)
Green hydra (*Hydra viridissima*)	6	7 d NOEC ·L^{-1}	Population growth inhibition	Not reported	2	0.4	19.5	0.874	(Holdway *et al.*, 2001)
Midge (*Chironomus tentans*)	7	60 d IC_{25}	Hatching success	< 24 h	2	4	280	0.957	(Ingersoll and Kemble, 2001)
Amphipod (*Echinogammarus meridionalis*)	12	6 d MATC	Feeding inhibition	Adult	1	5.16	263	1.30	(Pestana *et al.*, 2007)
European shrimp (*Atyaephyra desmarestii*)	13	6 d MATC	Feeding inhibition	Adult	1	5.24	263	1.32	(Pestana *et al.*, 2007)
Amphipod (*Gammarus pulex*)	15	7 d NOEC ·L^{-1}	Feeding inhibition	Adult	2	7.5	269	1.86	(Felten *et al.*, 2007)
Cladoceran (*Daphnia pulex*)	16	42 d MATC	Reproduction – Brood size	<24 h	2	7.35	230	2.07	(Winner, 1986)
Cladoceran (*Ceriodaphnia dubia*)	20	14 d MATC	Reproduction	Not reported	1	2	17	4.90	(Suedel *et al.*, 1997)
Fatmucket (*Lampsilis siliquoidea*)	22	28 d IC_{10}	Length	Juvenile	2	4.6 (3.8-4.8)	44	5.12 (4.23-5.34)	(Wang *et al.*, 2010)
Olgiochaete (*Aeolosoma headleyi*)	27	14 d MATC	Population growth	Young worms	2	40.1	168	14.7	(Niederlehner *et al.*, 1984)

Species	SSD Rank Order	Endpoint	Observed Effect	Life Stage	Ranking	Effect concentration ($\mu g \cdot L^{-1}$ cadmium) (Variation)	Hardness ($mg \cdot L^{-1}$)	Effect concentration ($\mu g \cdot L^{-1}$ cadmium) (Corrected to 50 $mg \cdot L^{-1}$ hardness as $CaCO_3$) (Variation)[a]	Reference
Great marsh snail *(Lymnaea stagnalis)*	28	4 wk NOEC $\cdot L^{-1}$	Growth	Adult	2	80	284	18.9	(Coeurdassier *et al.*, 2003)
Midge *(Chironomus riparius)*	30	17 d MATC	Mortality	First instar	2	47.4	98	27.1	(Pascoe *et al.*, 1989)
Marsh snail *(Lymnaea palustris)*	31	4 wk EC_{50}	Growth	Adult	2	58.2	58.2	58.2	(Coeurdassier *et al.*, 2003)
Mayfly (*Rhithrogena hageni*)	34	10 d EC_{10}	Mortality	Nymph	1	2571 (1650-4000)	48	2659 (1707-4138)	(Brinkman and Johnston, 2008)
Dragonfly (*Erythemis simplicicollis)*	35	7 d NOEC $\cdot L^{-1}$	Survival	Larva	2	100000	120	48 400	(Tollett *et al.*, 2009)
Dragonfly (*Pachydiplax longipennis*)	36	7 d MATC	Survival	Larva	2	160000	120	76 500	(Tollett *et al.*, 2009)
Amphibians									
Northwestern salamander *(Ambystoma gracile*)	33	24 d MATC	Weight	Larva	1	97.2	45	106	(Nebeker et al., 1995)
Algae/Plants									
Alga *(Ankistrodesmus falcatus*)	21	96 h NOEC $\cdot L^{-1}$	Growth	Population	2	10	118	4.9	(Baer *et al.*, 1999)
Alga *(Pseudokirchneriella subcapitata*)	29	72 h EC_{10}	Growth rate	Population	-	-	-	19.8[b]	(Källqvist, 2007)
Duckweed *(Lemna minor*)	32	7 d EC_{50}	Growth rate	Not reported	2	214 (95% CI 192-239)	166	79.0 (95% CI 70.9-88.3)	(Drost *et al.*, 2007)

[a] The same long-term hardness correction equation

$$EC_{x\ (\text{at 50 mg}\cdot L^{-1}\ \text{hardness})} = 10^{\{([\log(50) - \log(\text{original hardness})] \cdot 0.83) + \log(\text{original ECx})\}}$$

used to standardize the effect concentrations to 50 $mg \cdot L^{-1}$ hardness was applied to the endpoint variation (C. Schwarz, pers.comm.).

[b]Value shown is the geometric mean of comparable values: see Table 8.10 for data used to calculate geometric means. Geometric mean values are calculated whenever there are multiple endpoints for the same species with the same life stage, duration, effect and relevant ambient water quality parameters. The most sensitive geometric mean or single value (values without comparable data with which to include in a geometric mean) is selected for plotting in the SSD.

Note: MATC values calculated as the geometric mean of the reported NOEC/L and LOEC/L.

Table 8.10 Calculation of geometric means for long-term aquatic toxicity data considered for guideline derivation. (Concentrations standardised to a hardness of 50 mg·L^{-1} $CaCO_3$.)

Organism	Endpoint	Effect Concentration (µg·L^{-1} cadmium) (Variation)	Effect Concentration ((µg·L^{-1} cadmium) (Corrected to 50 mg·L^{-1} hardness as $CaCO_3$) (Variation)[a]	Geometric Mean (µg·L^{-1})	Inclusion in SSD[b]	Reference
Pseudokirchneriella subcapitata (Green algae, population)	72-h EC_{10} (growth)	2.8 (95% CI 2.2-3.5)	25.95 (95% CI 20.39-32.43)	19.76	Yes	Källqvist, 2007
		6 (95% CI 3.5-11.6)	6.41 (95% CI 3.74-12.38)			
		7.5 (95% CI 5.5-10.2)	42.36 (95% CI 31.06-57.6)			
		8.5 (95% CI 7.1-10.2)	21.65 (95% CI 18.08-25.98)			

[a] The same long-term hardness correction equation

$$EC_{x\ (\text{at } 50\ mg \cdot L^{-1}\ \text{hardness})} = 10^{\{(\ [\ \log(50) - \log(\text{original hardness})] \cdot 0.83) + \log(\text{original ECx})\}}$$

used to standardize the effect concentrations to 50 mg·L^{-1} hardness was applied to the endpoint variation (C. Schwarz, pers.comm.).

[b] Geometric mean values are calculated whenever studies report the same endpoint type for the same species, life stage, duration, effect and relevant ambient water quality parameters. Geometric means were included in the SSD if they represented the lowest no-effect endpoint for the species.

Long-term toxicity to freshwater fish

Acceptable long-term cadmium toxicity values for fish include:

1) endpoints obtained in tests with durations of 21 days or longer for adult fish
2) endpoints 7 days or longer for eggs/larvae.

In terms of the data points selected for the SSD, toxicity values (or geometric means) for cadmium were selected for 14 freshwater fish species. No clear trends were observed in terms of sensitivity of fish types (*i.e.*, salmonids vs. non-salmonids). This is likely due to the fact that many different effects were included in the long-term SSD, and not all effects were recorded for all fish species, therefore, there was variability in terms of effect concentrations. For long-term toxicity, the most sensitive endpoint for fish was obtained for the rainbow trout (*Oncorhynchus mykiss*) (formerly known as *Salmo gairdneri*). The hardness-adjusted 62-day EC_{10} for weight in the early life stage of *O. mykiss* was 0.23 $\mu g \cdot L^{-1}$ (Mebane *et al.*, 2008). The least sensitive long-term endpoint for fish was a hardness-adjusted 35-day MATC of 8.03 $\mu g \cdot L^{-1}$ for decrease in biomass for embryos of the Northern pike (*Esox lucius*) (Eaton *et al.*, 1978).

<u>Long-term toxicity to freshwater invertebrates</u>

Acceptable long-term cadmium toxicity endpoints for invertebrates include:

1) non-lethal endpoints obtained in tests with durations of at least 96 h for shorter-lived invertebrates (*e.g.*, *Ceriodaphnia dubia*)
2) non-lethal endpoints obtained in tests with durations of at least 7 days for longer-lived invertebrates (*e.g.*, crayfish)
3) lethal endpoints obtained in tests with durations of at least 21 days for long-lived invertebrates (*e.g.*, crayfish) (CCME 2007)

In terms of the data points selected for the SSD, toxicity values for cadmium were selected for 18 freshwater invertebrate species. Toxicity endpoints for invertebrates were only collected for fully aquatic life stages. Similar to the short-term results, in general, the lowest effect concentrations were obtained for the following: cladocerans (water fleas, daphnids), amphipods (*e.g.*, *Hyalella* sp.), and hydras. The least sensitive were mayflies, and dragonflies (*Erythemis simplicicollis* and *Pachydiplax longipennis*).

Overall, the most sensitive invertebrate species was the cladoceran, *Daphnia magna*, with hardness-adjusted 7-day EC_{10} values (for both reproduction and feeding inhibition) of 0.045 $\mu g \cdot L^{-1}$ (Barata and Baird, 2000). The least sensitive invertebrate endpoint was a hardness-adjusted 7-day MATC for the survival of a dragonfly, *Pachydiplax longipennis*, with a value of 76500 $\mu g \cdot L^{-1}$ (Tollett *et al*., 2009).

<u>Long-term toxicity to freshwater amphibians</u>

Acceptable long-term cadmium toxicity values for amphibians include endpoints obtained in tests with durations of 21 days or longer for adults, and 7 days or longer for eggs/larvae. Only one long-term toxicity value was obtained for an amphibian species. Toxicity endpoints for amphibians were only collected for fully aquatic life stages. The amphibian species was the northwestern salamander (*Ambystoma gracile*) with a hardness-adjusted 24-day MATC of 106 $\mu g \cdot L^{-1}$ (Nebeker *et al.*, 1995). See Table 8.9 for more details.

<u>Long-term toxicity to freshwater plants/algae</u>

Due to the rapid growth and turnover of algal/aquatic plant standard test species, most toxicity tests are considered "long-term" relative to the lifespan of the alga/plant. All toxicity tests for *Lemna* sp. following standard test protocols are generally considered long-term exposures. All algal toxicity tests with durations longer than 24 hours are considered long-term exposures (CCME, 2007).

The most sensitive species was the green alga *Ankistrodesmus falcatus*, with a hardness-adjusted 96 h NOEC for growth of 4.9 $\mu g \cdot L^{-1}$ (Baer *et al.*, 1999). The least sensitive species was duckweed, *Lemna minor*, with a hardness-adjusted 7day EC_{50} for growth of 79.04 $\mu g \cdot L^{-1}$ (Drost *et al.*, 2007). See Table 8.9 for more details.

8.4 Toxicity to marine life

Marine guidelines for cadmium were not part of the present update due to limited resources. In the present approved cadmium CWQG, the long-term value for the protection of marine life was 0.12 $\mu g \cdot L^{-1}$ (CCME, 1996). No short-term value for marine life has been established.

9.0 EXISTING CADMIUM WATER QUALITY CRITERIA FOR OTHER JURISDICTIONS AND PREVIOUS CANADIAN CRITERIA

9.1 Existing Cadmium Water Quality Criteria for the Protection of Aquatic Life in other jurisdictions

The toxicity of cadmium in fresh water is affected fundamentally by water hardness. As hardness increases, organisms become less susceptible to the effects of cadmium. Rather than establishing a single numerical value, many jurisdictions use hardness relationships to determine site-specific water quality criteria for cadmium.

The US EPA (2001) uses the following equation to determine the concentration of total cadmium ($\mu g \cdot L^{-1}$) that will protect aquatic life in fresh water for short-term exposure:

Criterion maximum concentration (*i.e.*, acute criterion) = $e^{(1.017[\ln(\text{hardness})]-3.924)}$

(where hardness is measured in $mg \cdot L^{-1}$ $CaCO_3$ equivalents)

At a hardness of 50 $mg \cdot L^{-1}$ as $CaCO_3$, the US EPA acute (*i.e.*, short-term) criterion value would therefore be 1.0 $\mu g \cdot L^{-1}$.

The US EPA (2001) uses the following equation to determine the concentration of total cadmium ($\mu g \cdot L^{-1}$) that will protect aquatic life in fresh water for long-term exposure:

Criterion continuous concentration (*i.e.* chronic criterion) = $e^{(0.7409[\ln(\text{hardness})]-4.719)}$

(where hardness is measured in $mg \cdot L^{-1}$ $CaCO_3$ equivalents)

At a hardness of 50 $mg \cdot L^{-1}$ as $CaCO_3$, the US EPA chronic (*i.e.*, long-term) guideline value would therefore be 0.16 $\mu g \cdot L^{-1}$.

Québec has adopted the US EPA cadmium criterion (MDDEPQ, 2007).

Ontario uses two hardness ranges to determine its interim long-term water quality objectives, as shown below:

For hardness 0-100 mg·L^{-1}, the objective for cadmium is 0.1 µg·L^{-1}
For hardness >100 mg·L^{-1}, the objective for cadmium is 0.5 µg·L^{-1}
(OMOEE, 1994).

The Netherlands has designated a single numerical value for water quality criteria. The Netherlands publishes Environmental Quality Standards including standards for surface water which take into account scientific risk limits. These standards include target values for total and dissolved cadmium, which are non-statutory standards indicating negligible environmental effects, and maximum permissible concentrations (MPC) for total and dissolved cadmium, which are based on ecological risk assessment and specify the concentration of a substance at which no harmful effects are expected to the ecosystem or to humans. The target values for total and dissolved cadmium are 0.4 and 0.08 µg·L^{-1} respectively (Ministry of Housing, Spatial Planning and the Environment, 2001). The MPC's for total and dissolved cadmium are 2 and 0.4 µg·L^{-1}, respectively ((Ministry of Housing, Spatial Planning and the Environment,, 2001).

Water quality criteria for Australia and New Zealand, termed Trigger Values, are derived using a statistical distribution method. The Trigger Values for cadmium for protection levels of 99, 95, 90 and 80% of species are 0.06, 0.2, 0.4 and 0.8 µg·L^{-1}, respectively (Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, 2007).

9.2 Previous Canadian Water Quality Guidelines for the Protection of Aquatic Life for cadmium

In 1979, the long-term Canadian Water Quality Guideline for the protection of freshwater aquatic life for cadmium was set at 0.2 µg·L^{-1} for waters of hardness lower than 60 mg·L^{-1} (as $CaCO_3$). No hardness equation was provided; however different guideline values were recommended for various hardness ranges. In 1996, the CWQG for cadmium was updated, and the long-term guideline value was set at 0.017 µg·L^{-1} (at a hardness of 48.5 mg·L^{-1} as $CaCO_3$). In this case, the guideline included a hardness equation that could be used to derive different CWQGs for waters of different hardness. The 1996 hardness equation was as follows:

$$\text{CWQG} = 10^{\{0.86(\log[\text{hardness}]) - 3.2\}}$$

Using the above hardness equation, the 1996 long-term CWQG would be 0.018 µg·L^{-1} at the standard hardness of 50 mg·L^{-1}. No short-term guideline was recommended. The 1996 long-term value was obtained by taking the lowest scientifically acceptable cadmium toxicity endpoint for an aquatic species and applying a safety factor of 10. This pivotal endpoint was a 21-day EC_{16} for reproduction in the cladoceran (*Daphnia magna*) with a value of 0.17 µg·L^{-1} at a hardness of 45 mg·L^{-1} as $CaCO_3$. This guideline value has been criticized because (i) the guideline value has been viewed as being unreasonably low: far lower than background cadmium concentrations in some areas of Canada, and below the detection limits of most analytical instruments; (ii) the application of the safety factor of 10 has been considered arbitrary, and perhaps excessive; and (iii) the guideline derivation method has high dependence on a single study.

The revised Protocol (CCME, 2007) uses a statistical approach to derive guideline values using analysis of species sensitivity distributions, or SSDs. This approach takes into account the sensitivity of numerous species to the substance of interest, and produces a guideline value that will protect 95% of species.

10.0 DERIVATION OF CANADIAN WATER QUALITY GUIDELINES (CWQGS)

10.1 Evaluation of cadmium toxicological data

Cadmium toxicity data were screened for use in the derivation of the CWQG. Data were ranked as primary, secondary, or unacceptable using ranking criteria of CCME (2007); outlined briefly here.

In order for a toxicity data point to be considered primary, the concentration of the toxicant must be measured at the beginning and end of the exposure period and the measurement of water quality parameters (hardness, pH, temperature, etc.) must be reported. Adequate replication must be performed, suitable statistical procedures should be used, and control mortality should be low (typically less than 10%).

Secondary data are those where primary data criteria are lacking, but are still of acceptable quality. For example, a study may use calculated rather than measured substance concentrations. Appropriate replication is still necessary, but pseudo-replication may be acceptable for secondary studies (*e.g.*, all test organisms in only one aquarium per concentration). Unacceptable data are those that do not meet the criteria of primary or secondary data.

10.2 Adjusting toxicity data points for water chemistry conditions

All cadmium toxicity data were adjusted to a hardness of 50 $mg \cdot L^{-1}$ as $CaCO_3$ using the short-term and long-term hardness correction equations derived by the NGSO (see the section 8.1.1). If hardness was not reported in the original study and could not be determined by calculation or through author communication, the toxicity data were unadjusted. Only six of the 62 data points used in the short-term SSD could not be adjusted for hardness, and all points used in the long-term SSD were hardness-corrected. Cadmium toxicity data were not adjusted for any other factors, *e.g.*, pH, alkalinity, DOM, or temperature due to a lack of clear empirical relationships between toxicity and these parameters.

10.3 Derivation of Canadian Water Quality Guidelines (CWQGs)

A CWQG for cadmium is required to address its use in Canada and potential impacts to aquatic systems. A CWQG provides guidance to risk assessors and risk managers in Canada on the level of cadmium in an aquatic system below which the structure and function of an aquatic community is expected to be maintained. The *Protocol for the derivation of Canadian Water Quality Guidelines* (CCME, 2007) includes guideline values for both long- and short-term exposure. The long-term exposure guideline is derived such that it is consistent with the guiding principle of the CWQG, namely to protect all species and all life stages over an indefinite exposure to the substance in water. Aquatic life may experience long-term exposure to a substance as a result of continuous release from point or non-point sources, gradual release from soils/sediments and gradual entry through groundwater/runoff, and long range transport. The short-term exposure value is derived for use as an additional management tool. It is intended to protect most species against lethality during severe, but transient events such as spills or inappropriate use/disposal of the substance in question.

While separate data sets are used to calculate short-term and long-term guidelines, both are derived using one of three approaches. The three approaches are detailed in CCME (2007) and only briefly outlined here. In order of preference, the approaches are:

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)

A CWQG derived using the statistical approach is called a Type A guideline. A SSD captures the variation in toxicological sensitivity among a set of species to a contaminant. A SSD is a cumulative distribution function (CDF), with effect concentrations plotted on the x-axis and cumulative probability, expressed as a percentage, plotted on the y-axis (Posthuma *et al.*, 2002). Short-term, lethal endpoints (*e.g.,* 24-h LC_{50}) comprise the data set for short-term guidelines, while long-term exposure, no- or low-effect endpoints (*e.g.*, 21-d EC_{10} for growth) comprises the data set for long-term guidelines. From each data set, the guideline value is equal to the concentration on the x-axis that corresponds to 5% cumulative probability on the y-axis. In contrast, the lowest end-point approach (Types B1 and B2) uses, as the name implies, the lowest acceptable endpoint with a safety factor to estimate the guideline.

The minimum data requirements for application of each of the three methods are presented in Table 9.1 (for short-term guideline values) and table 9.2 (for long-term guideline values). If available data are insufficient for deriving a CWQG using the statistical approach, the CWQG be developed using 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 only acceptable primary toxicity data 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 highest ranked method that the data allow.

The following sections describe the derivation of the short-term benchmark concentration and long-term CWQG for the protection of freshwater life in surface water for cadmium. Note that the SSD-derived values only apply to waters of 50 $mg{\cdot}L^{-1}$ hardness as $CaCO_3$ since all toxicity data were adjusted to this hardness before being entered into the SSD. Short-term and long-term hardness equations were also developed so that the derived benchmark concentration and CWQG value can be adjusted for waters of any hardness.

Data *considered* in the derivation of the cadmium short-term benchmark concentration and long-term CWQGs are presented in Appendix A. These should not be considered an exhaustive list of all cadmium studies available in the literature, but instead ensure that a broad selection of species and endpoints were represented.

Table 10.1 Minimum data set requirements for the derivation of a short-term exposure guideline for freshwater environments.

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

Table 10.2 Minimum data set requirements for the derivation of a long-term exposure guideline for freshwater environments.

Group	Guideline		
	Type A	**Type B1**	**Type B2**
Fish	Three species, including at least one salmonid and one non-salmonid.		Two species, including at least one salmonid and one non-salmonid.
Aquatic Invertebrates	Three aquatic or semi-aquatic invertebrates, at least one of which must be a planktonic crustacean. For semi-aquatic invertebrates, the life stages tested must be aquatic. It is desirable, but not necessary, that one of the aquatic invertebrate species be either a mayfly, caddisfly, or stonefly.		Two aquatic or semi-aquatic invertebrates, at least one of which must be a planktonic crustacean. For semi-aquatic invertebrates, the life stages tested must be aquatic. It is desirable, but not necessary, that one of the aquatic invertebrate species be either a mayfly, caddisfly, or stonefly.
Aquatic Plants	At least one study on a freshwater vascular plant or freshwater algal species. If a toxicity study indicates that a plant or algal species is among the most sensitive species in the data set, then this substance is considered to be phyto-toxic and three studies on nontarget freshwater plant or algal species are required.		Toxicity data for plants are highly desirable, but not necessary. If a toxicity study indicates that a plant or algal species is among the most sensitive species in the data set, then this substance is considered to be phyto-toxic and two studies on nontarget freshwater plant or algal species are required.
Amphibians	Toxicity data for amphibians are highly desirable, but not necessary. Data must represent fully aquatic stages.		Toxicity data for amphibians are highly desirable, but not necessary. Data must represent fully aquatic stages.
Preferred Endpoints	The acceptable endpoints representing the no-effects threshold and EC_{10}/IC_{10} for a species are plotted. The other, less preferred, endpoints may be added sequentially to the data set to fulfill the minimum data requirement condition and improve the result of the modelling for the guideline derivation if the more preferred endpoint for a given species is not available. The preference ranking is done in the following order: Most appropriate EC_x/IC_x representing a no-effects threshold > EC_{10}/IC_{10} > $EC_{11\text{-}25}/IC_{11\text{-}25}$ > MATC > NOEC > LOEC > $EC_{26\text{-}49}/IC_{26\text{-}49}$ > nonlethal EC_{50}/IC_{50}.	The most preferred acceptable endpoint representing a low-effects threshold for a species is used as the critical study; the next less preferred endpoint will be used sequentially only if the more preferred endpoint for a given species is not available. The preference ranking is done in the following order: Most appropriate EC_x/IC_x representing a low-effects threshold > $EC_{15\text{-}25}/IC_{15\text{-}25}$ > LOEC > MATC > $EC_{26\text{-}49}/IC_{26\text{-}49}$ > nonlethal EC_{50}/IC_{50} > LC_{50}.	

	Multiple comparable records for the same endpoint are to be combined by the geometric mean of these records to represent the averaged species effects endpoint.		
Data Quality Requirement	Primary and secondary no-effects and low-effects level data are acceptable to meet the minimum data set requirement. Both primary and secondary data will be plotted. A chosen model should sufficiently and adequately describe data and pass the appropriate goodness-of-fit test.	The minimum data requirement must be met with primary data. The value used to set the guideline must be primary. Only low-effect data can be used to fulfill the minimum data requirement.	Secondary data are acceptable. The value used to set the guideline may be secondary. Only low-effect data can be used to fulfill the minimum data requirement.

10.4 Derivation of Short-term Benchmark Concentration

In total, 550 short-term freshwater toxicity data points were obtained for cadmium. Of these, 96 were deemed unacceptable for guideline derivation for various reasons. Of the remaining 454 data points, 89 were excluded from use in a short-term species sensitivity distribution (SSD). Short-term data points were considered inappropriate if they were low- or no-effects endpoints, for example any endpoints other than LC_{50} values (such as EC_{10} values) (see *A Protocol for the Derivation of Water Quality Guidelines for the Protection of Aquatic Life* (CCME 2007) for a full description of types of endpoints considered suitable for inclusion in a short-term SSD). Of the remaining 365 toxicity data points considered for inclusion in the short-term SSD, 62 were included in the SSD (Table 8.7). The other 302 data points were omitted in order to avoid including multiple data points for a single species in the SSD. The Protocol (CCME 2007) requires that only one short-term endpoint (*i.e.*, LC_{50} value) can be included in the short-term SSD for each species. In some cases, there were several data points for a given species and life stage with the same duration (for example several 96 h LC_{50} values for juveniles of a species). The values of these data points, however, were not identical; this variation may be the result of differences in experimental conditions, species strain, and/or bioassay protocol.

There are numerous methods that can be applied to account for multiple similar data points for a single species (Duboudin *et al.*, 2004). For the derivation of the short-term SSD for cadmium, the geometric mean of the toxicity values was taken when multiple data points were obtained for the same species, life stage, endpoint, duration, effect and experimental conditions. The short-term SSD for cadmium included 6 (of 62) data points which were geometric mean values (see Table 8.7 for the final data set that was used to generate the short-term SSD for cadmium).

In some cases, there was more than one toxicity value available for a given species, but the duration, effect, experimental conditions and/or life stages differed, meaning that the geometric mean of the values could not be taken. In these cases, the most sensitive data point (or geometric mean value) was selected for inclusion in the short-term SSD. Full details regarding short-term data point selection are in CCME (2007).

The values reported in Table 8.7 for the short-term SSD range from a 96 h LC_{50} of 0.47 µg·L^{-1} for rainbow trout; *Oncorhynchus mykiss* to a 96 h LC_{50} of 28900 µg/L for damselfly; *Enallagma sp*. The short-term SSD is preferentially derived from LC/EC_{50} data for short-term effects. The final short-term benchmark concentration for cadmium was the 5th percentile of the short-term SSD.

Each species for which appropriate short-term toxicity data was available was ranked according to effect concentration, and its position on the SSD (Hazen plotting position) was determined using the following standard equation (Aldenberg et al., 2002; Newman et al., 2002):

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

where

i = the species rank based on ascending EC_{50}s and LC_{50}s

N = the total number of species included in the SSD derivation

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

The log-normal model provided the best fit of the models tested (Anderson-Darling statistic (A^2) = 1.5; mean square error (MSE) = 0.003). The equation of the model is:

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

Where, for the fitted model: x = log (concentration), µ = 2.52 and σ = 1.52. The functional response, *f(x)*, is the proportion of taxa affected at the given concentration. The location and scale parameters, μ and σ, are the mean and standard deviation of the theoretical population, respectively, and *erf* is the error function.

The short-term SSD is shown in Figure 9.1. The benchmark concentration resulting from the short-term SSD is presented in Table 9.3. The 5th percentile on the short-term SSD is 1.04 µg·L^{-1} cadmium. The lower fiducial limit (5%) on the 5th percentile is 0.86 µg·L^{-1}, and the upper fiducial limit (95%) on the 5th percentile is 1.25 µg·L^{-1}.

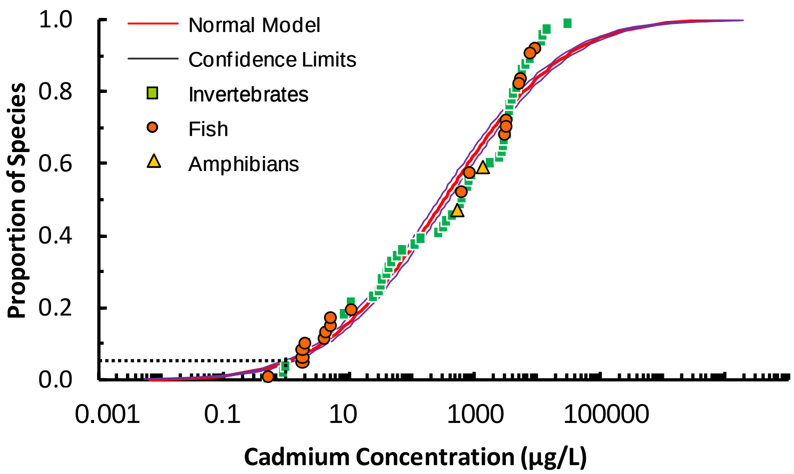

Figure 10.1 Short-term species sensitivity distribution (SSD) for cadmium in freshwater derived by fitting the log-normal model to the short-term LC_{50}s of 62 aquatic species. The intercept of the 5th percentile of the fitted curve (benchmark concentration) was determined to be 1.04 µg·L^{-1} cadmium, with 95% confidence intervals of 0.86 and 1.25 µg·L^{-1}. Curve statistics: Anderson-Darling statistic (A^2) = 1.5; mean square error (MSE) = 0.003.

Table 10.3 Short-term benchmark concentration for cadmium derived using the SSD method (LFL = lower fiducial limit; UFL = upper fiducial limit).

	Cadmium concentration (µg·L^{-1})
SSD 5th percentile	1.0
SSD 5th percentile, 90% LFL (5%)	0.86
SSD 5th percentile, 90% UFL (95%)	1.3

10.5 Derivation of Long-term CWQG

In total, 422 long-term freshwater toxicity data points were obtained for cadmium. Of these, 46 were deemed unacceptable for guideline derivation. Of the remaining 376 toxicity data points, 49 were considered inappropriate for use in a long-term SSD (*e.g.*, long-term endpoints for severe effects (*e.g.*, LC_{50} values). In brief, only low- or no-effect endpoints may be included in a long-term SSD, (*i.e.*, no LC_{50} values are included, since these are considered severe-effects endpoints).

Of the remaining 308 data points for inclusion in a long-term SSD, 36 were selected (Table 8.9). The other data points were omitted in order to avoid including multiple data points for the same species. There are numerous methods that can be applied to account for multiple similar endpoints for a single species (Duboudin *et al.*, 2004). For the derivation of the long-term SSD for cadmium, the geometric mean of the toxicity values was taken when multiple data points were obtained for the same species, life stage, endpoint, duration, effect, and experimental conditions. The long-term SSD for cadmium included 1 data point which was a geometric mean value (see Table 8.9 for the final data set that was used to generate the long-term SSD for cadmium).

In some cases, there was more than one toxicity value available for a given species, but the life stage, duration, effect, experimental conditions, and/or endpoint type differed, meaning that the geometric mean of the values could not be taken. According to the Protocol (CCME, 2007) if there is more than one long-term endpoint type (*e.g.*, an EC_{10} and a NOEC) for a given species and effect, the most preferred endpoint will be selected for inclusion in the SSD.

The preferred rank order of endpoints for a long-term SSD is as follows (CCME, 2007):

1) most appropriate EC_x/IC_x representing a no-effects threshold
2) EC_{10}/IC_{10}
3) EC_{11-25}/IC_{11-25}
4) MATC
5) NOEC
6) LOEC
7) EC_{26-49}/IC_{26-49}
8) Non-lethal EC_{50}/IC_{50}

If more than one toxicity value (or geometric mean) is available for a given species, effect, and endpoint, but the duration and/or life stage differs (*e.g.*, a 48 h EC_{10} and a 96 h EC_{10} value for adults, or a 48 h EC_{10} for juveniles and a 48 h EC_{10} for adults), the most sensitive data point (or geometric mean value) (*i.e.*, the lowest endpoint value) will be selected for inclusion in the long-term SSD. Full details of long-term endpoint selection are given in CCME (2007).

The values reported in Table 8.9 for the long-term SSD range from a 7-day EC_{10} (for both reproduction and feeding inhibition) of 0.045 $\mu g \cdot L^{-1}$ for the cladoceran *Daphnia magna* to a 7-day MATC for survival of 76500 $\mu g \cdot L^{-1}$ for dragonfly, *Pachydiplax longipennis.* The long-term SSD is preferentially derived from no-effects data for long-term effects. The final CWQG value for cadmium was the 5th percentile of the long-term SSD.

Each species for which appropriate long-term toxicity data was available was ranked according to effect concentration and its position on the SSD (Hazen plotting position) was determined using the following standard equation (Aldenberg *et al.*, 2002; Newman *et al.*, 2002):

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

where

i = the species rank based on ascending toxicity values (*e.g.* EC_x values)
N = the total number of species included in the SSD derivation

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

The log-logistic model provided the best fit of the models tested (Anderson-Darling statistic (A^2) = 1.07; mean square error (MSE) = 0.002). The equation of the logistic model is:

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

Where, in the case of the fitted model, x = log (concentration), μ = 0.55, and *s* = 0.54. The functional response, *f(x)*, is the proportion of taxa affected at the given concentration. The parameters μ and *s* are the location and scale parameters of the model, respectively.

The long-term SSD is shown in Figure 9.2. Guideline values resulting from the long-term SSD are presented in Table 9.4. The 5th percentile on the long-term SSD is 0.09 μg·L^{-1}. The lower fiducial limit (5%) on the 5th percentile is 0.04 μg·L^{-1}, and the upper fiducial limit (95%) on the 5th percentile is 0.24 μg·L^{-1}.

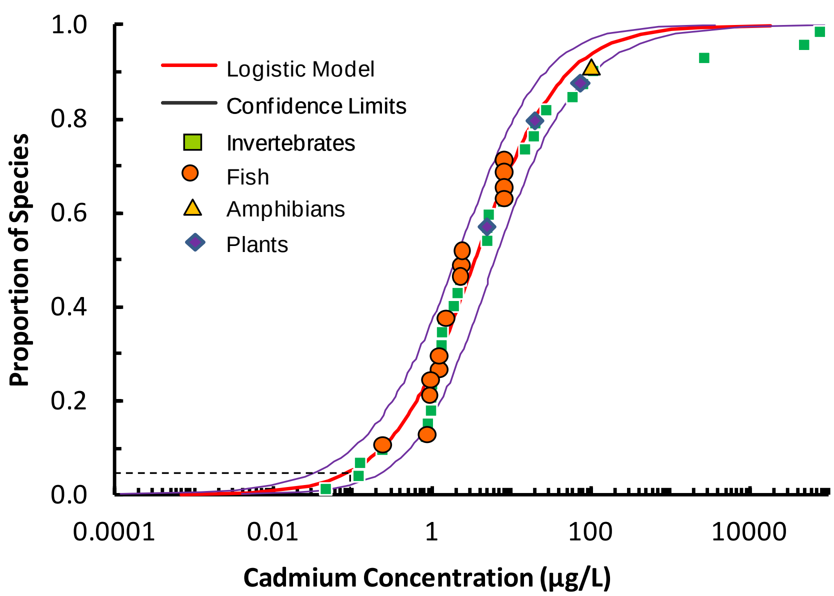

Figure 10.2 Long-term species sensitivity distribution (SSD) for cadmium in freshwater derived by fitting the log-logistic model to the long-term endpoints of 36 aquatic species. The intercept of the 5th percentile of the fitted curve (guideline value) was determined to be 0.09 µg·L^{-1} cadmium, with 95% confidence intervals of 0.04 and 0.24 µg·L^{-1}. Curve statistics: Anderson-Darling statistic (A^2) = 1.07; mean square error (MSE) = 0.002.

Table 10.4 Long-term CWQG for cadmium derived using the SSD method
(LFL = lower fiducial limit; UFL = upper fiducial limit).

	Cadmium concentration ($\mu g \cdot L^{-1}$)
SSD 5th percentile	0.09
SSD 5th percentile, 90% LFL (5%)	0.04
SSD 5th percentile, 90% UFL (95%)	0.24

10.6 Derivation of hardness equations for freshwater short-term benchmark concentration and long-term Canadian Water Quality Guideline

Water hardness affects cadmium toxicity, so it is necessary that freshwater guideline values be adjusted on a site-specific basis. Cadmium guideline values from short- and long-term SSDs apply only to waters of a 50 $mg \cdot L^{-1}$ as $CaCO_3$ (standard hardness value). Below is an explanation of the derivation of both the short-term and long-term equations that are used to adjust the guideline values for site-waters of different hardness.

10.6.1 Short-term benchmark hardness-dependent equation

The short-term benchmark equation is based on the US EPA toxicity-hardness procedure outlined in Stephan *et al.* (1985).The data that was included in the derivation of the benchmark was combined from the US EPA and the United States Geological Survey (USGS) and NGSO which resulted in a value of 1.016. This slope represents the relationship between the logarithm of cadmium concentration (y-axis) and the logarithm of water hardness (x-axis). It is known that the short-term cadmium 5^{th} percentile value at 50 $mg \cdot L^{-1}$ hardness is 1.04 $\mu g \cdot L^{-1}$ (because all of the toxicity values used in the SSD were converted to 50 $mg \cdot L^{-1}$ hardness). Since the slope of this line is known (1.016), as well as the x,y co-ordinates of one point on this line (50, 1.04), one can determine the general equation describing this line by solving for the y-intercept. If the equation $\log(y) = m \cdot \log(x) + b$ is rearranged to solve for b (*i.e.*, the y-intercept), the following result is obtained:

$$\begin{aligned} \text{y-intercept (b)} &= \log(5^{th}\text{ percentile}) - [\text{slope} \cdot \log(\text{hardness})] \\ &= \log(1.04) - [1.016 \cdot \log(50)] \\ &= -1.71 \end{aligned}$$

Therefore, the resulting equation to derive the short-term benchmark concentration to protect freshwater life is:

$$\text{Benchmark} = 10^{\{1.016(\log[\text{hardness}]) - 1.71\}}$$

where the benchmark concentration is in $\mu g \cdot L^{-1}$ and hardness is measured as $CaCO_3$ equivalents in $mg \cdot L^{-1}$.

10.6.2 Long-term CWQG hardness-dependent equation

The long-term CWQG equation is based on the US EPA toxicity-hardness procedure outlined in Stephan et al. (1985).The data that was included in the derivation of CWQG was combined from the US EPA and the USGS and NGSO which resulted in a value of 0.83. This slope represents the relationship between the natural logarithm of cadmium concentration (y-axis) and the natural logarithm of water hardness (x-axis). It is known that the long-term cadmium 5^{th} percentile value at 50 $mg\cdot L^{-1}$ hardness is 0.09 $\mu g\cdot L^{-1}$ (because all of the toxicity values used in the SSD were converted to 50 $mg\cdot L^{-1}$ hardness). Since the slope of this line is known (0.83), as well as the x,y co-ordinates of one point on this line (50, 0.09), one can determine the general equation describing this line by solving for the y-intercept. If the equation log(y) = m·log(x) + b is rearranged to solve for b (*i.e.*, the y-intercept), the following result is obtained:

$$\begin{aligned}\text{y-intercept (b)} &= \log(5^{th}\ \text{percentile}) - [\text{slope} \cdot \log(\text{hardness})] \\ &= \log(0.09) - [0.83 \cdot \log(50)] \\ &= -2.46\end{aligned}$$

Therefore, the resulting equation to derive the long-term Canadian Water Quality Guideline (CWQG) to protect freshwater life is:

$$\text{CWQG} = 10^{\{0.83(\log[\text{hardness}]) - 2.46\}}$$

where the CWQG is in $\mu g\cdot L^{-1}$ and hardness is measured as $CaCO_3$ equivalents in $mg\cdot L^{-1}$.

10.6.3 Back Transformation Bias of Hardness Relationships

In the context of incorporating toxicity modifying factors, such as hardness, transformation of an arithmetic data set to logarithms results in biased estimates when predicted values from a least squares regression are back-transformed to arithmetic units (Newman, 1991). Back-transformed predictions will underestimate the value in question, that is, the guideline value at a given hardness will be conservative. CCME (2007) recommends that this issue be examined on a case-by-case basis. Using methods of Newman (1991, 1993) and Rothery 1988, we examined the potential for back-transformation bias for the short- and long-term hardness relationships. We found the short-term hardness relationship low-biased by 1% to 40% with the exception of goldfish that had a bias of 480% and the long-term relationship low-biased by <7%. For comparison, we also calculated the bias of the US EPA (2001) short- and long-term relationships. The US EPA (2001) short-term relationship was low-biased <1% to 30% except for goldfish which low-biased 177%. The US EPA (2001) long-term relationship was low-biased 1%. USGS (Mebane, 2006) analysed the potential for back-transformation bias and found the short-term low-biased by 17% and the long-term low-biased by <2%. The USGS (Mebane, 2006) concluded that the benefit of improving model precision was off-set by a more complex equation. Moreover, we found removing goldfish from the short-term data set would have a negligible effect on the pooled slope (from 1.061 to 0.99). Therefore, no correction for back-transformation bias was made herein for the hardness equations.

11.0 Additional cadmium toxicity data: Assessing the protection of the guideline equations

11.1 Examination of the protectiveness of the hardness adjusted short-term benchmark

As explained earlier (section 8.1.1), the hardness adjustment of the short-term benchmark was based on the slope of the hardness-toxicity relationship developed from 14 species. In order to ensure that the hardness corrected benchmark is adequately protective of all organisms, all acceptable toxicity values uncorrected for hardness were plotted against hardness (Figure 10.1). Those values were compared to the benchmark, which is represented by a straight line on the graph. All values that fell under the benchmark regression were examined.

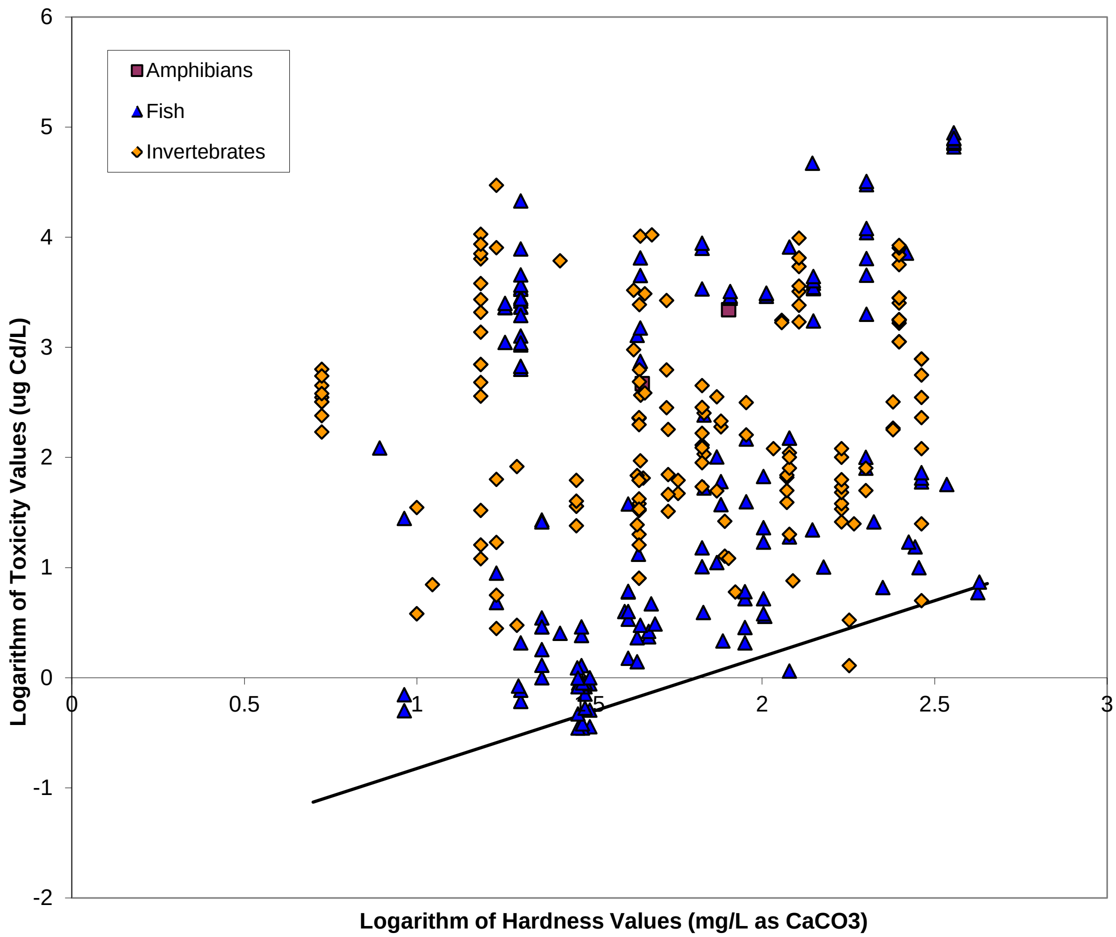

Figure 11.1 Comparison of acceptable toxicity values plotted against hardness to the short-term benchmark. The short-term benchmark is shown by the straight line.

Out of a total of 454 toxicity values, 13 endpoints fell under the short-term benchmark for cadmium: 1 point for *H. azteca* (96h LC_{50}); 2 points for *D. magna* (72h LC_{10} & LC_{50}); and, 10 points for *O. mykiss* (4: 5d LC_{50}s and 6: 96h LC_{50}s). For each of these species, there numerous other data points that are above the benchmark, specifically 14, 26 and 32 data point for *H. azteca*, *D. magna*, and *O. mykiss*, respectively. As short-term benchmarks are intended to protect most species against lethality during intermittent and transient events, the protection clause does not apply (CCME, 2007). This verification of the protectiveness of the hardness adjusted long-term guideline demonstrated the long-term CWQG for cadmium should adequately protect all species present in an ecosystem.

11.2 Examination of the protectiveness of the hardness adjusted long-term guideline

The hardness adjustment of the long-term guideline was based on the slope of the hardness-toxicity relationship developed from only 7 species. The effectiveness of this guideline could thus be questionable for other species that may respond differently to hardness. In order to ensure that the hardness corrected guideline protect adequately all organisms, all acceptable toxicity values uncorrected for hardness were plotted against hardness (Figure 10.2). Those values were compared to the guideline, which is represented by a straight line on the graph. All values that fell under the guideline regression were examined.

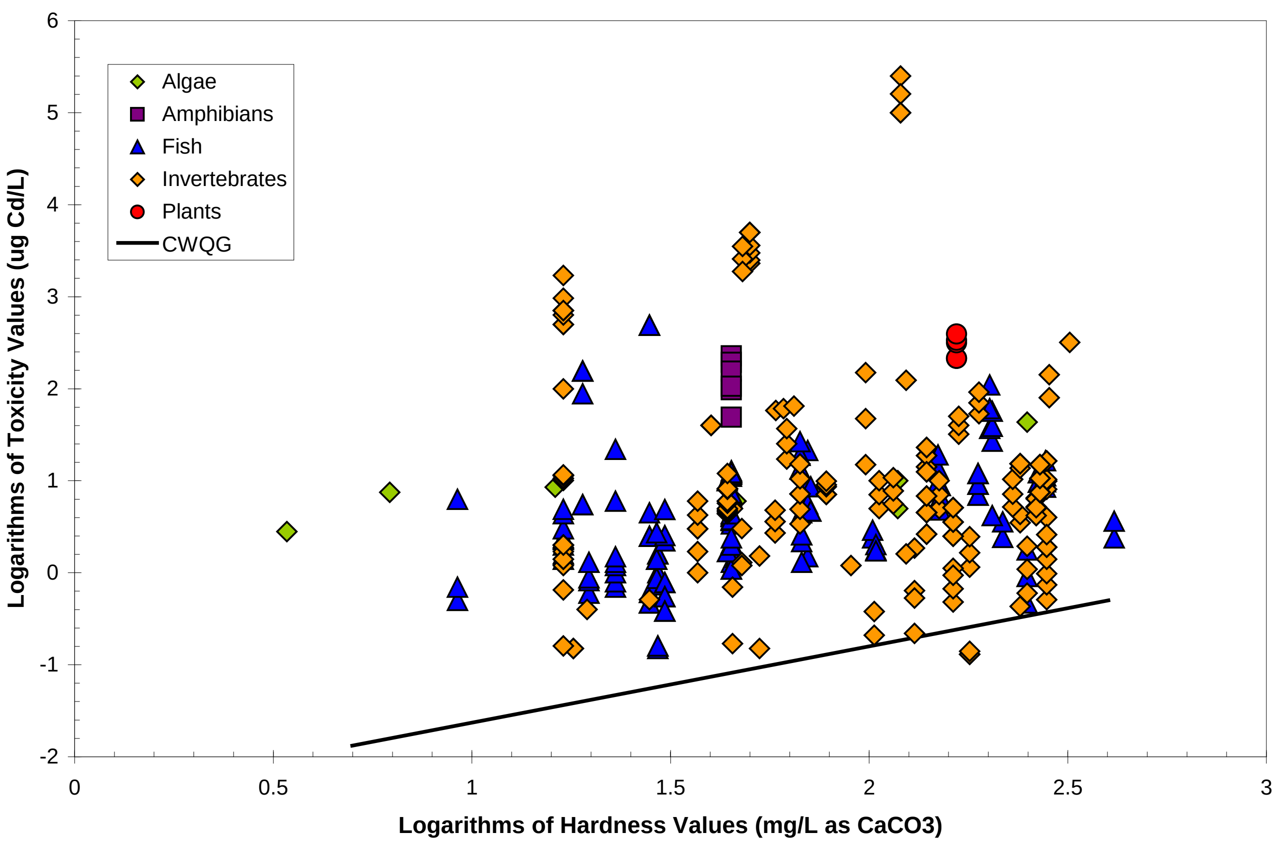

Figure 11.2 Comparison of acceptable toxicity values plotted against hardness to the long-term guideline.

Four points on a total of 376 toxicity values fell under the long-term CWQG for cadmium.

No toxicity values reported from a study on fish, amphibian, algae or plant were under the regression line. All four values under the CWQG at a specific hardness were reported for *Daphnia magna*. Three of those points were 7-d EC_{10} on reproduction and feeding (Barata and Baird, 2000). Chapman *et al.* (1980) also reported a low 21-d MATC on reproduction for *Daphnia magna*. Finally, Borgmann *et al.* (1989) reported a 7-d NOEC of 0.22 $\mu g \cdot L^{-1}$ that fell under the CWQG. However, the equivalent MATC was 0.64 $\mu g \cdot L^{-1}$, which was above the guideline of 0.26 $\mu g \cdot L^{-1}$ at hardness of 130 $mg \cdot L^{-1}$ as $CaCO_3$. Moreover, if the geometric mean of all acceptable data on *D. magna* was plot on Figure 10.2 the co-ordinates of this point would be above the CWQG line. No short-term data points fall below the long-term guideline.

This verification of the protectiveness of the hardness adjusted long-term guideline demonstrated that even though the hardness corrected equation was developed from only 7 species hardness-toxicity relationship, the long-term CWQG for cadmium should adequately protect all species present in an ecosystem.

11.3 Examination of toxic effects near or below the long-term cadmium guideline

To determine whether the long-term cadmium guideline value is sufficiently protective, results of acceptable aquatic toxicity studies in which toxic effects were observed at concentrations near or below the long-term cadmium guideline value were examined. The Protocol (CCME, 2007) includes a section called the Protection Clause, which applies only to the long-term guideline:

> “If an acceptable single (or geometric mean) lethal-effects endpoint (*i.e.* LCx, where x is greater than or equal to 15%) for any species is lower than the proposed guideline (*i.e.*, is below the 5th percentile intercept to the fitted long-term SSD curve), then that endpoint becomes the recommended guideline value.
>
> Furthermore, special consideration will be required if multiple endpoints for a single taxon (*e.g.*, fish, invertebrates, or plants/algae) and/or an elevated number of secondary studies are clustered around the 5th percentile. Best scientific judgment should be used in deciding whether this situation is present (*e.g.* due consideration should be given to the percentage of data points in question to the whole data set) and in determining the best path forward to address this situation.”

Some of the studies that will be discussed in this section have already been included in the SSD, but in other cases, the data could not be included in the SSD for various reasons.

Table 11.1 summarizes effect concentrations near or below the long-term freshwater cadmium guideline (of 0.09 $\mu g \cdot L^{-1}$ at a hardness of 50 $mg \cdot L^{-1}$ as CaCO3).

There were four cases in which the cadmium effect concentration (at 50 mg·L^{-1} hardness) was below the guideline value (*i.e.*, below 0.09 µg·L^{-1} at 50 mg·L^{-1} hardness). These included three 7-day EC_{10} values (feeding inhibition and reproduction) for *Daphnia magna* of 0.045 µg·L^{-1} (Barata and Baird, 2000), a 21-d NOEC (reproduction) for *Daphnia magna* of 0.10 µg·L^{-1} (Borgmann, 1989), and a 21-d MATC (reproduction) for *Daphnia magna* of 0.12 µg·L^{-1} (Chapman *et al.,* 1980). However, the Protection Clause would not be invoked because none represent severe, lethal endpoints (*e.g.*, LC_{15} – LC_{100} values).

There were some effect concentrations (corrected to 50 mg·L^{-1} hardness) which were not below the long-term guideline value, but were relatively close to it. Of these studies, some may raise concern because they represent severe-effects endpoints (*i.e.*, LC_{50} values) and their values are approximately twice the value of the long-term guideline, *i.e.*, 0.09 µg·L^{-1} (at 50 mg·L^{-1} hardness). These included:

- a 7-day LC_{50} for *Hyalella azteca* of 0.35 µg·L^{-1} (Borgmann *et al.*, 2005)
- a 42-day LC_{50} for *Hyalella azteca* of 0.24 µg·L^{-1} (Borgmann *et al.*, 2005)

Table 51.1 Studies reporting effect concentrations near or below the long-term freshwater cadmium guideline value (0.09 µg·L^{-1} at hardness of 50 mg·L^{-1} as CaCO3).

Species	Duration	Endpoint	Effect	Life stage	Ranking	Effect concentration (µg·L^{-1}) (Variation)	Hardness (mg·L^{-1})	Effect conc. (µg·L^{-1}) (Corrected to 50 mg·L^{-1} hardness)* (Variation)	References
Daphnia magna (Cladoceran)	7 d	EC10	Reproduction (Brood mass)	Adult	2	0.13 (0.02-0.23)	179	0.045 (0.007-0.0798)	Barata and Baird, 2000
Daphnia magna (Cladoceran)	7 d	EC10	Feeding inhibition	Adult	2	0.13 (0.04-0.21)	179	0.045 (0.0139-0.0729)	Barata and Baird, 2000
Daphnia magna (Cladoceran)	7 d	EC10	Reproduction (Brood size)	Adult	2	0.14 (0.04-0.24)	179	0.049 (0.0139-0.0833)	Barata and Baird, 2000
Daphnia magna (Cladoceran)	21 d	NOEC	Reproduction (Number of young per adult)	Not Reported	2	0.22	130	0.100	Borgmann *et al.*, 1989
Daphnia magna (Cladoceran)	21 d	MATC	Reproduction (Number of young/ survivor)	Less than 24 h	1	0.21	103	0.115	Chapman *et al.*, 1980
Ceriodaphnia reticulata (Cladoceran)	7 d	MATC	Reproduction (Number of young per adult)	Less than 24 h	2	0.43	240	0.117	Elnabarawy *et al.*, 1986
Hyalella azteca (amphipod)	28 d	IC25	Biomass	7-8 d	2	0.51	280	0.122	Ingersoll and Kemble 2001
Oncorhynchus mykiss (Rainbow trout)	65 w	NOEC	Reproduction (Delay in oogenesis)	Adult	2	0.47	250	0.124	Brown *et al.*, 1994
Daphnia magna (Cladoceran)	21 d	MATC	Reproduction (Number of	Less than 24 h	1	0.15	53	0.143	Chapman *et al.*, 1980

Species	Duration	Endpoint	Effect	Life stage	Ranking	Effect concentration ($\mu g \cdot L^{-1}$) (Variation)	Hardness ($mg \cdot L^{-1}$)	Effect conc. ($\mu g \cdot L^{-1}$) (Corrected to 50 $mg \cdot L^{-1}$ hardness)* (Variation)	References
			young per adult)						
Daphnia magna (Cladoceran)	21 d	NOEC	Reproduction	24 h	2	0.6	250	0.158	Kuhn *et al.*, 1989
Hyalella azteca (amphipod)	42 d	NOEC	Mortality	Unknown	1	0.48	163	0.180	Stanley *et al.*, 2005
Daphnia magna (Cladoceran)	21 d	EC16	Reproduction	Less than 24 h	2	0.17	45	0.185	Biesinger and Christensen 1972
Daphnia magna (Cladoceran)	21 d	MATC	Reproduction (Number of young per adult)	Less than 24 h	1	0.38	103	0.209	Chapman *et al.*, 1980
Oncorhynchus mykiss (Rainbow trout)	62 d	EC10	Weight	Early life stage	1	0.15 (0.12-1.6)	29	0.236 (0.189-2.52)	Mebane *et al.*, 2008
Hyalella azteca (Amphipod)	42 d	LC50	Mortality	0-7 d old	2	0.53 (0.33-0.84)	130	0.240 (0.149-0.38)	(Borgmann *et al.*, 1991)
Oncorhynchus mykiss (Rainbow trout)	62 d	LOEC	Length	Early life stage	1	0.16	29	0.249	Mebane *et al.*, 2008
Oncorhynchus mykiss (Rainbow trout)	62 d	LOEC	Weight	Early life stage	1	0.16	29	0.249	Mebane *et al.*, 2008
Hyalella azteca (Amphipod)	7 d	LC50	Mortality	Juvenile	2	0.15 (95% CI 0.12-0.19)	18	0.35 (95% CI 0.28-0.44)	(Borgmann *et al.*, 2005)

* The same hardness correction equation used to standardize the effect concentrations to 50 $mg \cdot L^{-1}$ hardness was applied to the endpoint variation (C. Schwarz, pers.comm.).

In addition to the toxicity study results listed in Table 10.1, some field/mesocosm data will be discussed below to further examine the protectiveness of the cadmium Water Quality Guideline.

11.3.1 Field Studies

The results of several related field studies may cause concern about whether the long-term guideline value of 0.09 $\mu g \cdot L^{-1}$ (at 50 $mg \cdot L^{-1}$ hardness) is sufficiently protective. These studies include the following: (Couillard *et al.*, 1993; Couillard *et al.*, 1995a; Couillard *et al.*, 1995b; Perceval *et al.*, 2002; Perceval *et al.*, 2004). Due to the large volume of information presented in these studies, only selected results are described here.

One study involved transplanting freshwater mussels (*Pyganodon grandis* or *Anodonta grandis*) from a reference lake to cadmium-contaminated lakes in northern Québec (Perceval *et al.*, 2006). Mussel mortality was greater than 55% in the two most contaminated lakes. In Lake Dasserat, with a measured dissolved Cd concentration of 0.116 $\mu g \cdot L^{-1}$, 56% mussel mortality was observed. In Lake Dufault, with a measured dissolved Cd concentration of 0.38 $\mu g \cdot L^{-1}$ Cd, 63% mortality occurred. However, several factors should be noted i) lakes were contaminated with several other metals such as zinc and copper, ii) mussels were placed directly onto the sediments, thus some observed toxicity may be attributed to contamination via sediments in addition to aquatic toxicity and iii) results were obtained in the field, and many uncontrolled abiotic and biotic factors could be contributing to toxicity. As a result of these three considerations it is not possible to conclude that the dissolved cadmium concentrations cited above were fully responsible for the percentages of mussel mortality that was observed.

Borgmann *et al.* (2004b) reported an absence of benthic organisms in the same cadmium-contaminated Québec lakes used in the mussel studies above, where the sediments contained elevated levels of cadmium, copper, lead, and zinc. In order to determine the causes of the toxicity, sediments were tested for toxicity in the lab using *Hyalella azteca*. Toxic effects in these amphipods were observed. Metal concentrations in the (originally clean) overlying water were measured after contaminated sediments were added. It was found that the cadmium concentrations in the overlying water were 98% of the LC_{25} value for *H. azteca* (Borgmann *et al.*, 2004b). However, copper concentrations in the overlying water were 60% of the LC_{25} value for *H. azteca*. Thus, although it is clear that cadmium levels pose a greater threat than copper levels, the authors noted that some degree of toxicity due to copper (or due to metal interactions) could not be ruled out. In any case, this study dealt with sediment toxicity, thus these data do not apply directly to the goal of developing a *water* quality guideline value. For further information regarding the cadmium toxicity from sediment and recommended levels, refer to the Sediment Quality Guideline for Protection of Aquatic Life (CCME, 1999).

Malley (1996) reported data from a field experiment which suggest that the guideline value of 0.09 $\mu g \cdot L^{-1}$ (at 50 $mg \cdot L^{-1}$ hardness) would be protective of aquatic organisms (at least over a span of several years). This study involved the experimental addition of cadmium to a pristine lake in northwestern Ontario (Lake 382, in the Experimental Lakes Area) over a period of 6 years (1987-1992) (Malley, 1996). The total concentrations of cadmium in the water each year are shown in Table 10.2.

Table 61.2 Loadings of cadmium to Lake 382, mass of Cadmium in the entire lake volume calculated from aqueous levels, and cadmium concentrations in the epilimnion and surface sediments from 1987 to 1994 (from (Lawrence *et al.,* 1996;Malley 1996;Stephenson *et al.,* 1996).

Year	Total experimental loading of Cd $g \cdot year^{-1}$	Mass of Cd in water column as % of cumulative Cd added (Autumn)	Addition period[a] average total [Cd] in water $\mu g \cdot L^{-1}$	Surface sediment [Cd] ($\mu g \cdot g^{-1}$ dry wt)
1987	978	15.9	0.075	-
1988	641	10.2	0.06	1.58
1989	780	12.6	0.1	<3
1990	1442	6.3	0.126	-
1991	1546	7.9	0.178	2 - 4
1992	1289	5.5	0.185	-
1993	0	0.8	<0.015[b]	4 - 5
1994	0	0.8	<0.015	-

[a] This period covers the end of May to October; epilimnetic Cd concentrations are reported
[b] 0.015 $\mu g \cdot L^{-1}$ is the limit of detection.

It should be noted that Lake 382 has an extremely low level of hardness: calcium concentrations were between 1.87 and 2.84 $mg \cdot L^{-1}$ in 1986-88 (Lawrence and Holoka 1991), meaning that the total hardness in Lake 382 would likely be approximately 5-15 $mg \cdot L^{-1}$ (as $CaCO_3$) . Thus it would be expected that a cadmium concentration of 0.178 $\mu g \cdot L^{-1}$ (observed in 1991) or 0.185 $\mu g \cdot L^{-1}$ (observed in 1992) would pose a much greater threat to aquatic organisms than a cadmium concentration of 0.09 $\mu g \cdot L^{-1}$ (the long-term cadmium guideline value) in a water body with a hardness of 50 $mg \cdot L^{-1}$. Therefore, if the long-term cadmium guideline value is not sufficiently protective, we would expect to see evidence of toxicity in Lake 382. Prior to and through the period of experimental addition of cadmium, the aquatic community was assessed. After 6 years of increasing cadmium concentrations (up to 0.185 $\mu g \cdot L^{-1}$ at a hardness of about 5-15 $mg \cdot L^{-1}$ as $CaCO_3$), no population losses or shifts were observed in the lake (Malley 1996). *Pyganodon grandis*, the same mussel species that suffered high rates of mortality in the metal-contaminated lakes in northern Québec (as described above, Perceval *et al.*, 2006) had no population losses in Lake 382, even with cadmium concentrations upwards of 0.185 $\mu g \cdot L^{-1}$. This discrepancy could not be explained by lower water hardness in the Québec lakes than in the Lake 382 because hardness values were actually higher in the Québec lakes (a minimum of 48 and 23 $mg \cdot L^{-1}$ in Lake Dufault and Lake Dasserat, respectively) (Perceval *et al.*, 2006). Therefore, it is clear there must be other factors in addition to cadmium contributing to the high mortality of the mussels in the Québec lakes.

Over the 6-year duration of cadmium addition to Experimental Lake 382 (1987-1992), the concentration of cadmium in the sediments increased. In 1993, after cadmium addition had ceased and dissolved cadmium concentrations in the water were below detection limits (0.015 $\mu g \cdot L^{-1}$), concentrations of cadmium in the sediments were at their highest level (4-5 $\mu g \cdot g^{-1}$ dry weight). Malley (1996) stated that waterborne cadmium was leaving the water column relatively quickly (*i.e.*, at a rate of approximately 1-5% per day) and accumulating in the sediments. This result suggests that if cadmium were continuously entering a water body, concentrations in water could remain relatively constant, while the cadmium concentrations in sediments could increase over time. Thus, concerning environmental monitoring, it is recommended that samples from both sediment and water be compared to the respective Environmental Quality Guidelines in order to provide the most accurate assessment of environmental quality at that particular site.

Other mesocosm or artificial stream studies, unrelated to the Experimental Lakes studies above, have demonstrated some behavioural or ecological effects at concentrations near the guideline value. Riddell *et al.* (2005a) examined the effects of cadmium on prey choice, capture efficiency, reaction distance, and condition factor of brook trout (*Salvelinus fontinalis*). Fish exposed to cadmium in artificial stream channels for 30 days demonstrated significant effects on prey type attack ratios and on condition factor in cadmium exposed trout at 0.5 and 5 $\mu g \cdot L^{-1}$. Riddell *et al.* (2005b) found significant effects to behaviour of *Baetis tricaudatus* (drift and grazing rate) and *Kogotus nonus* (activity) nymphs at exposure of 5.0 $\mu g\ Cd \cdot L^{-1}$. *Salvelinus fontinalis* demonstrated significant reduction in capture efficiency at 0.5 $\mu g\ Cd \cdot L^{-1}$ and significant increase in activity at 5.0 $\mu g\ Cd \cdot L^{-1}$ (Riddell *et al.* 2005b). The effects observed in the Riddell studies (2005a;b) were above the long-term guideline value of 0.09 $\mu g\ Cd \cdot L^{-1}$ and were not for lethal effects.

12.0 GUIDELINE SUMMARY

The short-term data met the toxicological and statistical requirements for the Type A guideline derivation method and the log-normal model provided the best fit for the data in the SSD. As seen in Table 8.7, the data requirements for the SSD were surpassed, and a total of 62 data points (LC_{50} values) from 62 species were used in the derivation of the guideline.

The long-term data met the toxicological and statistical requirements for the Type A guideline derivation method and the log-logistic model provided the best fit for the data in the SSD. As seen in Table 8.9, the data requirements for the SSD were surpassed, and a total of 36 data points from 36 species were used in the derivation of the guideline.

The marine guideline values were not assessed as part of the present update due to limited resources. However, in 1996, the long-term CWQG for cadmium in marine and estuarine waters was 0.12 $\mu g \cdot L^{-1}$ (CCME, 1999). No short-term marine CWQG value was recommended.

The following Canadian water quality guidelines (CWQGs) are recommended to protect the most sensitive aquatic species at all life stages, indefinitely. (Table 11.1). Table 11.2 provides examples of short-term benchmark concentrations and long-term CWQG values in freshwaters of various hardness. These guidelines apply to the total concentration of cadmium in unfiltered water.

Canadian Water Quality Guideline Summary Tables: Cadmium

Table 12.1 Canadian Water Quality Guidelines (CWQG) for the protection of aquatic life for cadmium

	Short-Term Exposure ($\mu g \cdot L^{-1}$)	Long-Term Exposure ($\mu g \cdot L^{-1}$)
Freshwater hardness equation	Benchmark = $10^{\{1.016(\log[\text{hardness}]) - 1.71\}}$ (Where hardness is in $mg \cdot L^{-1}$ as $CaCO_3$)	CWQG = $10^{\{0.83(\log[\text{hardness}]) - 2.46\}}$ (Where hardness is in $mg \cdot L^{-1}$ as $CaCO_3$)
Marine	NRG	0.12*

Note: Hardness equations must be used in order to obtain a site-specific guideline based on the hardness of the water body of interest (see table below for examples of guideline values at various levels of water hardness.). The short-term hardness relationship covers a range from 5.3 to 360 mg $CaCO_3 \cdot L^{-1}$ and applies only within that range. The long-term hardness relationship covers a range from 17 to 280 mg $CaCO_3 \cdot L^{-1}$ and applies only within that range. Additionally, there may be some site specific instances in which the water quality guideline may not be adequately protective in accounting for toxicity from cadmium accumulation in tissue and in sediment, as these variables can be specific to the organisms and chemical conditions of the site. For further guidance on sediment toxicity, refer to the Cadmium Sediment Quality Guideline for the Protection of Aquatic Life (CCME 1999).
NRG = no recommended guideline
*This value was not assessed as part of the present update; value is from the 1996 CWQG (CCME 1996).

Table 12.2 Canadian Water Quality Guidelines for the protection of aquatic life in freshwater at various levels of water hardness

Water Hardness ($mg\cdot L^{-1}$ as $CaCO_3$)	Short-Term Exposure ($\mu g\ Cd\cdot L^{-1}$)	Long-Term Exposure ($\mu g\ Cd\cdot L^{-1}$)
Lower limit*	0.11	0.04
20	0.41	0.04
30	0.62	0.06
40	0.83	0.07
50	1.0	0.09
Soft (60)	1.2	0.10
70	1.5	0.12
80	1.7	0.13
90	1.9	0.15
100	2.1	0.16
110	2.3	0.17
Medium (120)	2.5	0.18
130	2.7	0.20
140	3.0	0.21
150	3.2	0.22
160	3.4	0.23
170	3.6	0.25
Hard (180)	3.8	0.26
190	4.0	0.27
200	4.2	0.28
210	4.5	0.29
220	4.7	0.30
230	4.9	0.32
240	5.1	0.33
250	5.3	0.34
260	5.5	0.35
270	5.8	0.36
Upper limit**	7.7	0.37

Note: Guideline values obtained using the freshwater hardness equations (Table 11.1) for soft, medium and hard water as defined in CCREM (1987). Where site-specific hardness is known, the equation should be used to calculate a guideline value for that particular hardness. Lower and upper limits for hardness reflect the minimum and maximum hardness values, respectively, that were used in the derivation of hardness slopes, beyond which values should not be extrapolated.

*A lower limit of 0.11 $\mu g\cdot L^{-1}$ is the short-term benchmark value that applies to all waters of hardness below 5.3 mg $CaCO_3.L^{-1}$. A lower limit of 0.04 $\mu g\cdot L^{-1}$ is the long-term guideline value that applies to all waters of hardness below 17 mg $CaCO_3\cdot L^{-1}$.

** An upper limit of 7.7 $\mu g\cdot L^{-1}$ is the short-term benchmark value that applies to all waters of hardness above 360 mg $CaCO_3\cdot L^{-1}$. An upper limit of 0.37 $\mu g\cdot L^{-1}$ is the long-term guideline value that applies to all waters of hardness above 280 mg $CaCO_3\cdot L^{-1}$.

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APPENDICES

Appendix 1: Summary of toxicity data considered for guideline derivation and toxicity-hardness slope

(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium
(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium
(iii): List of studies used to evaluate the effect of hardness on short-term toxicity (from US EPA 2001). Values in bold selected to calculate short-term toxicity-hardness slope. See US EPA (2001) for details.
(iv): List of studies used to estimate long-term toxicity-hardness slope, from US EPA 2001.

Appendix 2: Environmental Concentrations, Raw Data

(i): Cadmium concentrations in sediment, water and mussel samples from 21 lakes in south central Ontario (Campbell and Evans 1991).
(ii): Minimum, maximum and median cadmium concentrations from water sampled between 2000 and 2007 from rivers in Manitoba (Armstrong and Manitoba Water Stewardship 2008).
(iii): Minimum, maximum and median cadmium concentrations from water sampled between 2000 and 2007 from lakes in Manitoba (Armstrong and Manitoba Water Stewardship 2008).
(iv): Minimum, maximum and median cadmium concentrations from water sampled between 2000 and 2007 from creeks in Manitoba (Armstrong and Manitoba Water Stewardship 2008).
(v): Minimum, maximum and median cadmium concentrations from sediment sampled between 2000 and 2007 from sites in Manitoba (Armstrong and Manitoba Water Stewardship 2008).
(vi): Cadmium concentrations in surface waters of Nova Scotia (Nova Scotia Environment 2008)

Appendix 1: Summary of Toxicity Data Considered for Guideline Derivation and Toxicity-Hardness Slope

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Amphibians															
Ambystoma gracile (Northwestern salamander)	96 h LC50	Mortality	CdCl2	Larva	468.4	521.3	X	45	6.8		1	no O2, would have been better to have more replicates, no variation reported	FT	(Nebeker et al. 1995)	
Bufo arenarum (Argentine toad)	96 h LC50	Mortality	CdCl2	Stage 26	2190	1358.5	X	80			2	no pH, O2, alk, conductivity, and I had to calculated hardness myself, concs nominal only, 95% CI methods a bit sketchy, feeding not reported	R	(Ferrari et al. 1993)	
Fish															
Carassius auratus (Goldfish)	96 h LC50	Mortality	CdCl2	Adult	748	843.9	X	44.4 (40.7-46.6)	7.1-7.8	7.5 (4.7-10.0)	2	no conductivity, control mortality not reported (but see Notes section), number of concs tested was confusing but seems that range was ok	FT	(Phipps and Holcombe 1985)	H
Carassius auratus (Goldfish)	96 h LC50	Mortality	cadmium chloride (CdCl2 2.5H2O)	1-2 g and 1.5-2.5 inches long	2340	5936.4		20	7.5	7.8	2	Nominal concentrations	S	(Pickering and Henderson 1966)	H
Carassius auratus (Goldfish)	48 h LC50	Mortality	cadmium chloride (CdCl2 2.5H2O)	1-2 g and 1.5-2.5 inches long	2620	6646.7		20	7.5	7.8	2	Nominal concentrations	S		
Carassius auratus (Goldfish)	24 h LC50	Mortality	cadmium chloride (CdCl2 2.5H2O)	1-2 g and 1.5-2.5 inches long	3460	8777.8		20	7.5	7.8	2	Nominal concentrations	S		
Carassius auratus (Goldfish)	96 h LC50	Mortality	CdCl2	1.93 ± 0.73 g	46800	16441.2		140	NR	>4	2	Nominal concentrations	S	(MacKay et al. 2001)	H
Carassius auratus	96 h	Mortality	CdCl2	1.93 ± 0.73 g	21300	54036.4		20	NR	>4	2	Nominal concentrations	S		H

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
(Goldfish)	LC50														
Catostomus commersoni (White Sucker)	96 h LC50	Mortality	CdCl2	Juvenile	1110	3134.2	X	18.0 (SD = 0.77)	6.37 (SD=0.13)	7.90 (SD=1.64)	2	no conductivity, control mortality not specified, variation not reported	FT	(Duncan and Klaverkamp 1983)	
Cottus bairdi (Mottled sculpin)	96 h LC50	Mortality	cadmium chloride	Juvenile	17	8.32		101	8.3	9.3	1	no problems	FT	(Besser et al. 2007)	
Cottus bairdi (Mottled sculpin)	96 h LC50	Mortality	cadmium chloride	Juvenile	23	11.3		101	8.3	9.3	1	no problems	FT		
Cottus bairdi (Mottled sculpin)	96 h LC50	Mortality	cadmium chloride	Swim-up fry	3.6	1.74	X	102	8.21	8.8	1	no problems	FT		
Cottus bairdi (Mottled sculpin)	96 h LC50	Mortality	cadmium chloride	Yearling	>67	32.8		101	8.22	9.3	2		FT		
Ctenopharyngodon idellus (Grass carp)	96 h LC50	Mortality	CdSO4.H2O	Adult	9420	9420.00	X		8.73-8.78	>4	2	no alk, hardness, nominal only, pseudoreplication (all 10 fish in same tank), confidence intervals not reported	S	(Yorulmazlar and Gül 2003)	
Danio rerio (Zebrafish)	96 h LC50	Mortality	Cadmium nitrate Cd(NO3)2 4H20	larvae	1730	603.8	X	141	7.8	NR	2	Control mortality not reported	R	(Alsop and Wood 2011)	H
Danio rerio (Zebrafish)	96 h LC50	Mortality	Cadmium nitrate Cd(NO3)2 4H20	Adult	3822	1333		141	7.8	NR	2	Control mortality not reported	R		
Danio rerio (Zebrafish)	96 h LC50	Mortality	Cadmium nitrate Cd(NO3)2 4H20	larvae	121.8	804.3		7.8	7.34	NR	2	Control mortality not reported	R		H
Ictalurus punctatus (Channel catfish)	96 h LC50	Mortality	cadmium chloride	Juvenile	7940	5897.7		55.0-79.0	7.2-7.8		2	no units given for any WQ parameters (but can assume units), no DO value given, they don't specifically mention how many organisms were used per replicate, but they followed ASTM procedures so presumably it was enough, no control mortality reported, feed	S	(Spehar and Carlson 1984)	

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Ictalurus punctatus (Channel catfish)	96 h LC50	Mortality	CdCl2	Juvenile	4480	5054.6	X	44.4 (40.7-46.6)	7.1-7.8	7.5 (4.7-10.0)	2	no conductivity, control mortality not reported (but see Notes section), number of concs tested was confusing but seems that range was ok	FT	(Phipps and Holcombe 1985)	
Lebistes reticulatus (Guppy)	24 h LC50	Mortality	cadmium chloride (CdCl2 2.5H2O)	1-2 g and 1.5-2.5 inches long	3370	8549.4		20	7.5	7.8	2	Nominal concentrations	S	(Pickering and Henderson 1966)	
Lebistes reticulatus (Guppy)	48 h LC50	Mortality	cadmium chloride (CdCl2 2.5H2O)	1-2 g and 1.5-2.5 inches long	2310	5860.3		20	7.5	7.8	2	Nominal concentrations	S		
Lebistes reticulatus (Guppy)	96 h LC50	Mortality	cadmium chloride (CdCl2 2.5H2O)	1-2 g and 1.5-2.5 inches long	1270	3221.9	X	20	7.5	7.8	2	Nominal concentrations	S		
Lepomis cyanellus (Green sunfish)	96 h LC50	Mortality	cadmium chloride (CdCl2 2.5H2O)	1-2 g and 1.5-2.5 inches long	2840	7204.9	X	20	7.5	7.8	2	Nominal concentrations	S		H
Lepomis cyanellus (Green sunfish)	48 h LC50	Mortality	cadmium chloride (CdCl2 2.5H2O)	1-2 g and 1.5-2.5 inches long	3680	9335.9		20	7.5	7.8	2	Nominal concentrations	S		
Lepomis cyanellus (Green sunfish)	96 h LC50	Mortality	cadmium chloride (CdCL2 2.5H2O)	1-2 g and 1.5-2.5 inches long	66000	8881.7		360	8.2	7.8	2	Nominal concentrations	S		H
Lepomis cyanellus (Green sunfish)	48 h LC50	Mortality	cadmium chloride (CdCL2 2.5H2O)	1-2 g and 1.5-2.5 inches long	71300	9594.9		360	8.2	7.8	2	Nominal concentrations	S		
Lepomis cyanellus (Green	24 h	Mortality	cadmium	1-2 g and 1.5-	88600	11923		360	8.2	7.8	2	Nominal concentrations	S		

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
sunfish)	LC50		chloride (CdCL2 2.5H2O)	2.5 inches long											
Lepomis cyanellus (Green sunfish)	24 h LC50	Mortality	cadmium chloride (CdCl2 2.5H2O)	1-2 g and 1.5-2.5 inches long	7840	19889.5		20	7.5	7.8	2	Nominal concentrations	S		
Lepomis cyanellus (Green sunfish)	96 h LC50	Mortality	CdSO4	Juvenile	4231.76 9134	1522		136.8	8.0		U	-not appropriate range, LC50 value was not within the range of tested concs, no WQ data reported for 96h study, only for a similar 10-d study, D.O measured but not reported (for either study), conductivity not measured, not sure whether LC50 was based on	S	(Carrier and Bettinger 1988)	H
Lepomis macrochirus (Bluegill sunfish)	96 h LC50	Mortality	cadmium chloride	Juvenile	8810	6543.9		55.0-79.0	7.2-7.8		2	no units given for any WQ parameters (but can assume units), no DO value given, they don't specifically mention how many organisms were used per replicate, but they followed ASTM procedures so presumably it was enough, no control mortality reported, feed	S	(Spehar and Carlson 1984)	
Lepomis macrochirus (Bluegill sunfish)	96 h LC50	Mortality	CdCl2	Juvenile	6470	7299.9		44.4 (40.7-46.6)	7.1-7.8	7.5 (4.7-10.0)	2	no conductivity, control mortality not reported (but see Notes section), number of concs tested was confusing but seems that range was ok	FT	(Phipps and Holcombe 1985)	
Lepomis macrochirus (Bluegill)	96 h LC50	Mortality	cadmium chloride (CdCl2 2.5H2O)	1-2 g and 1.5-2.5 inches long	1940	4921.6	X	20	7.5	7.8	2	Nominal concentrations	S	(Pickering and Henderson 1966)	
Lepomis macrochirus (Bluegill)	48 h LC50	Mortality	cadmium chloride (CdCl2 2.5H2O)	1-2 g and 1.5-2.5 inches long	2760	7001.9		20	7.5	7.8	2	Nominal concentrations	S		
Lepomis macrochirus (Bluegill)	24 h LC50	Mortality	cadmium chloride (CdCl2 2.5H2O)	1-2 g and 1.5-2.5 inches long	4560	11568.4		20	7.5	7.8	2	Nominal concentrations	S		

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Lepomis macrochirus (Bluegill)	96 h LC50	Mortality	CdCl2.H2O	Adult	2300	6494.2		18 (14-20)	7.4-7.7	8.5 (7.7-8.9)	2	Population 2, replicate 2, control mortality not specified (but assume ok since EPA methods used), concs not specified so can't tell if range is appropriate	S	(Bishop and McIntosh 1981)	
Lepomis macrochirus (Bluegill)	96 h LC50	Mortality	CdCl2.H2O	Adult	2300	6494.2		18 (14-20)	7.4-7.7	8.5 (7.7-8.9)	2	Population 1 replicate 2, control mortality not specified (but assume ok since EPA methods used), concs not specified so can't tell if range is appropriate	S		
Lepomis macrochirus (Bluegill)	96 h LC50	Mortality	CdCl2.H2O	Adult	2300	6494.2		18 (14-20)	7.4-7.7	8.5 (7.7-8.9)	2	Population 2 replicate 1, control mortality not specified (but assume ok since EPA methods used), concs not specified so can't tell if range is appropriate	S		
Lepomis macrochirus (Bluegill)	96 h LC50	Mortality	CdCl2.H2O	Adult	2500	7058.9		18 (14-20)	7.4-7.7	8.5 (7.7-8.9)	2	Population 1 replicate 1, control mortality not specified (but assume ok since EPA methods used), concs not specified so can't tell if range is appropriate	S		
Morone saxatilis (Striped bass)	96 h LC50	Mortality		35 to 80 day old fish used	4	5.02		40	8.1		2	Nominal concentrations, analytical methods not specified	S	(Palawski et al. 1985)	H
Morone saxatilis (Striped bass)	96 h LC50	Mortality	NR	35 to 80 day old fish used	10	1.71	X	285	7.9		2	Nominal concentrations and analytical methods not specified	S		H
Morone saxatilis (Striped bass)	96 h LC50	Mortality	cadmium chloride	Larva	1.44658 8988	2.1		34.5		<5	U	Analytical methods not specified, control mortality not reported, most experimental design information and abiotic factors are located in another paper	S	(Hughes 1973)	H
Morone saxatilis (Striped bass)	96 h LC50	Mortality	cadmium chloride	Fingerling	2.89317 7976	4.21		34.5		<5	U	Analytical methods not specified, control mortality not reported, most experimental design information and abiotic factors are located in another paper	S		H
Oncorhynchus kisutch (Coho salmon)	96 h LC50	Mortality	CdCl2	Alevin	6	7.34		41 (40-43)	6.1-7.9	>40% saturation	2	nominal only, pseudoreplication, concs tested not reported, so can't tell if range was appropriate	S	(Buhl and Hamilton 1991)	
Oncorhynchus kisutch (Coho salmon)	96 h LC50	Mortality	CdCl2	Juvenile	3.4	4.16	X	41 (40-43)	6.1-7.9	>40% saturation	2	nominal only, pseudoreplication, concs tested not reported, so can't tell if range was appropriate	S		
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	cadmium nitrate	Juvenile	1.15	0.47	X	120	7.2	NR	1		FT	(Hollis et al. 2000b)	H
Oncorhynchus mykiss	96 h	Mortality	cadmium	Juvenile	2.15	1.39		77	7.2	NR	1		FT		H

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
(Rainbow trout)	LC50		nitrate												
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	cadmium nitrate	Juvenile	0.61	1.55		20	7.2	NR	1	Acclimated at a Cd concentration of 0.11 ug Cd/L	FT		H
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	cadmium nitrate	Juvenile	0.77	1.95		20	7.2	NR	1	Acclimated at a Cd concentration of 0.07 ug Cd/L	FT	(Hollis et al. 2000a)	H
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	cadmium nitrate	Juvenile	2.35	2.5		47	7.2	NR	1		FT		H
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	cadmium nitrate	Juvenile	2.53	4.92		26	7.2	NR	1		FT		H
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	cadmium nitrate	Juvenile	2.07	5.25		20	7.2	NR	1	Acclimated at a Cd concentration of 0.02 ug Cd/L (control)	FT		H
Oncorhynchus mykiss (Rainbow trout)	5 d LC50	Mortality	CdCl2	Juvenile	0.36	0.57		SEE RATIONALE SECTION	SEE RATIONALE SECTION	92-100% sat	1	pH = 7.53, hardness = 31.7, temp = 8.1, alk = 33.0	FT	(Hansen et al. 2002a)	H
Oncorhynchus mykiss (Rainbow trout)	5 d LC50	Mortality	CdCl2	Juvenile	0.35	0.58		SEE RATIONALE SECTION	SEE RATIONALE SECTION	92-100% sat	1	pH = 7.56, hardness = 30.2, temp = 12.1, alk = 31.9	FT		H
Oncorhynchus mykiss (Rainbow trout)	5 d LC50	Mortality	CdCl2	Juvenile	0.35	0.60		SEE RATIONALE SECTION	SEE RATIONALE SECTION	92-100% sat	1	pH = 7.50, hardness = 29.3, temp = 8.0, alk = 37.3	FT		H
Oncorhynchus mykiss (Rainbow trout)	5 d LC50	Mortality	CdCl2	Juvenile	0.53	0.87		SEE RATIONALE SECTION	SEE RATIONALE SECTION	92-100% sat	1	pH = 7.43, hardness = 30.7, temp = 7.6, alk = 30.1	FT		H
Oncorhynchus mykiss	5 d	Mortality	CdCl2	Juvenile	2.07	1.15		SEE	SEE	92-	1	pH = 7.49, hardness = 89.3, temp = 7.9, alk = 76.0	FT		H

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
(Rainbow trout)	LC50							RATIONALE SECTION	RATIONALE SECTION	100% sat					
Oncorhynchus mykiss (Rainbow trout)	5 d LC50	Mortality	CdCl2	Juvenile	0.84	1.41		SEE RATIONALE SECTION	SEE RATIONALE SECTION	92-100% sat	1	pH = 6.52, hardness = 30.0, temp = 7.8, alk = 12.8	FT		H
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	CdCl2	Fry	0.38	0.634		30.2	7.56	7.84	1	no problems	FT	(Stratus Consulting Inc. 1999)	H
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	CdCl2	Fry	0.47	0.809		29.3	7.50	8.82	1	no problems	FT		H
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	CdCl2	Fry	0.51	0.810		31.7	7.53	8.39	1	no problems	FT		H
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	CdCl2	Fry	0.71	1.17		30.7	7.43	8.64	1	no problems	FT		H
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	CdCl2	Fry	2.85	1.58		89.3	7.49	8.44	1	no problems	FT		H
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	CdCl2	Fry	1.29	2.17		30	6.52	8.66	1	no problems	FT		H
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	Cd	~ 36 g	5.92	0.678		422	6.96	8.1	2	Thoroughly reported study with standard methods, the hardness solution is made up from MgSO4 creating an unnatural ratio of Mg:Ca that would not occur in the environment, not valuable to use in the derivation of a guideline	FT	(Davies et al. 1993)	
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	Cd	~ 36 g	7.4	0.837		427	6.78	8.7	2	Thoroughly reported study with standard methods, the hardness solution is made up from MgSO4 creating an unnatural ratio of Mg:Ca that would not occur in the environment, not valuable to use in the derivation of a guideline	FT		
Oncorhynchus mykiss	96 h	Mortality	Cd	~ 36 g	6.57	1.43		224	7.03	8.3	2	Thoroughly reported study with standard methods, the	FT		

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
(Rainbow trout)	LC50											hardness solution is made up from MgSO4 creating an unnatural ratio of Mg:Ca that would not occur in the environment, not valuable to use in the derivation of a guideline			
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	Cd	~ 36 g	2.64	2.81		47	6.87	8.4	1	Thoroughly reported study with standard methods.	FT		
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	Cd	~ 36 g	3.08	3.14		49	6.98	8.2	1	Thoroughly reported study with standard methods.	FT		H
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality		Swim-up fry	0.89	1.53		29.4 (SD = 3.6)	7.19 (SD = 0.30)	9.2 (SD = 0.9)	2		R	(Mebane et al. 2008)	H
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality		Swim-up fry	0.84	2.16		19.7 (17-21)	6.75 (5.0-7.7)	10.2 (8.3-11.9)`	2		R	(Mebane et al. 2008)	H
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	CdCl2	Juvenile	1.5	1.84		41 (40-43)	6.1-7.9	>40% saturation	2	nominal only, pseudoreplication, concs tested not reported, so can't tell if range was appropriate	S	(Buhl and Hamilton 1991)	H
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	CdCl2	Alevin	37.9	46.4		41 (40-43)	6.1-7.9	>40% saturation	2	nominal only, pseudoreplication, concs tested not reported, so can't tell if range was appropriate	S		H
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	cadmium chloride	Swim-up fry	3.8	1.86		101	8.22	9.3	1	no problems	FT	(Besser et al. 2007)	H
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	cadmium chloride	Juvenile	5.2	2.55		101	8.22	9.3	1	no problems	FT		H
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	cadmium chloride	Swim-up fry	2.605677972	1.24		104	8.23	9.5	U	Based on chronic toxicity values, an estimated value	FT		
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	CdCl2	parr	1	2.2		23 +- 1 (SD)	7.1-7.5	10.2 +- 0.2 (SD)	2	no conductivity, stats not very well explained, 5 metal concs used, but didn't say what they were so can't tell if range was appropriate	FT	(Chapman 1978)	H
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	CdCl2	Swim-up fry	1.3	2.86		23 +- 1 (SD)	7.1-7.5	10.2 +- 0.2	2	no conductivity, stats not very well explained, 5 metal concs used, but didn't say what they were so can't tell if range was	FT		H

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
										(SD)		appropriate			
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	CdCl2	smolt	> 2.9	6.38		23 +- 1 (SD)	7.1-7.5	10.2 +- 0.2 (SD)	2	no conductivity, stats not very well explained, 5 metal concs used, but didn't say what they were so can't tell if range was appropriate	FT		
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	CdCl2	Alevin	> 27	59.4		23 +- 1 (SD)	7.1-7.5	10.2 +- 0.2 (SD)	2	no conductivity, stats not very well explained, 5 metal concs used, but didn't say what they were so can't tell if range was appropriate	FT	(Chapman 1978)	H
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	cadmium chloride	Juvenile	2.3	2.65		39.0-48.0	7.0-7.9		2	no units given for any WQ parameters (but can assume units), no DO value given, they don't specifically mention how many organisms were used per replicate, but they followed ASTM procedures so presumably it was enough, no control mortality reported, feed	S	(Spehar and Carlson 1984)	H
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	cadmium chloride	Juvenile	10.2	7.58		55.0-79.0	7.2-7.8		2	no units given for any WQ parameters (but can assume units), no DO value given, they don't specifically mention how many organisms were used per replicate, but they followed ASTM procedures so presumably it was enough, no control mortality reported, feed	S		H
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	CdCl2	Juvenile	3	3.38		44.4 (40.7-46.6)	7.1-7.8	7.5 (4.7-10.0)	2	no conductivity, control mortality not reported (but see Notes section), number of concs tested was confusing but seems that range was ok	FT	(Phipps and Holcombe 1985)	H
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	Cd(NO3)2 - 4H2O	Juvenile	22	7.73		140	8.0	NR	1		FT	(Hollis et al. 1999)	H
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	Cd(NO3)2 . 4H2O	Juvenile	19	7.81		120	8.0		2	no O2 or cond, control mort not reported, feeding not specified	FT	(Niyogi et al. 2004)	H
Oncorhynchus mykiss (Rainbow trout)	NR EC50	Not reported		Unknown				7.5-32			U	Hardness: 21, this is for an RBT-Sandpoint	R	(Windward Environmental 2002)	
Oncorhynchus mykiss (Rainbow trout)	NR EC50	Not reported		Unknown	1.20199945	8.24		7.5-32			U	Hardness: 7.5	R		
Oncorhynchus mykiss (Rainbow trout)	NR EC50	Not reported		Unknown	2.094049356	3.7		7.5-32			U	Hardness: 28.5	R		
Oncorhynchus mykiss	NR	Not		Unknown	2.11672	5.12		7.5-32			U	Hardness: 21	R		

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
(Rainbow trout)	EC50	reported			8591										
Oncorhynchus mykiss (Rainbow trout)	NR EC50	Not reported		Unknown	2.24272434	3.52		7.5-32			U	Hardness: 32	R		
Oncorhynchus mykiss (Rainbow trout)	NR EC50	Not reported		Unknown	2.436757795	9.22		7.5-32			U	Hardness: 13.5	R		
Oncorhynchus mykiss (Rainbow trout)	NR EC50	Not reported		Unknown	2.489676009	4.18		7.5-32			U	Hardness: 30	R		
Oncorhynchus mykiss (Rainbow trout)	NR EC50	Not reported		Unknown	3.268329741	6.89		7.5-32			U	Hardness: 24	R		
Oncorhynchus mykiss	96 h LC50	Mortality	CdCl2* 2.5H2O	Mean weight of control fish was 3.36g; treatment group mean was 2.88g	28	156.4		9.2	4.67		1	Standard methods used and thoroughly reported	FT	(Cusimano et al. 1986)	
Oncorhynchus mykiss	96 h LC50	Mortality	CdCl2*2.5 H2O	Mean weight of control fish was 3.36g; treatment group mean was 2.65g.	<0.5	2.79		9.2	6.96		1	Standard methods used and thoroughly reported	FT		
Oncorhynchus mykiss	96 h LC50	Mortality	CdCl2*2.5 H2O	Mean weight of control fish was 3.36g; treatment group mean was 2.70g.	0.7	3.9		9.2	5.68		1	Standard methods used and thoroughly reported	FT		
Oncorhynchus tshawytscha (Chinook salmon)	96 h LC50	Mortality	CdCl2	Alevin	> 26	57.2		23 +- 1 (SD)	7.1-7.5	10.2 +- 0.2 (SD)	2	no conductivity, stats not very well explained, 5 metal concs used, but didn't say what they were so can't tell if range was appropriate	FT	(Chapman 1978)	
Oncorhynchus tshawytscha (Chinook	96 h LC50	Mortality	CdCl2	Swim-up fry	1.8	3.96	X	23 +- 1 (SD)	7.1-7.5	10.2 +- 0.2	2	no conductivity, stats not very well explained, 5 metal concs used, but didn't say what they were so can't tell if range was	FT		H

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
salmon)										(SD)		appropriate			
Oncorhynchus tshawytscha (Chinook salmon)	96 h LC50	Mortality	CdCl2	parr	3.5	7.70		23 +- 1 (SD)	7.1-7.5	10.2 +- 0.2 (SD)	2	no conductivity, stats not very well explained, 5 metal concs used, but didn't say what they were so can't tell if range was appropriate	FT		H
Oncorhynchus tshawytscha (Chinook salmon)	96 h LC50	Mortality	CdCl2	smolt	> 2.9	6.38		23 +- 1 (SD)	7.1-7.5	10.2 +- 0.2 (SD)	2	no conductivity, stats not very well explained, 5 metal concs used, but didn't say what they were so can't tell if range was appropriate	FT		H
Oncorhynchus tshawytscha (Chinook salmon)	96 h LC50	Mortality	cadmium chloride	Fry	26	6.02		211 ± 1	7.4-8.3	NR	2	Nominal concentrations and pseudoreplication	S	(Hamilton and Buhl 1990)	H
Oncorhynchus tshawytscha (Chinook salmon)	96 h LC50	Mortality	cadmium chloride	Fry	57	8.06		343 ± 14	7.6-8.1	NR	2	Nominal concentrations and pseudoreplication	S		H
Oncorhynchus tshawytscha (Chinook salmon)	96 h LC50	Mortality	3CdSO4.8 H2O	Juvenile	2.60771 2094	6.27		20-22	7.0-7.3	avg 90% sat	U	control mortality not reported, didn't specify what concs were tested, so can't tell if range was appropriate, no conductivity, stats a bit sketchy	FT	(Finlayson and Verrue 1982)	H
Oreochromis niloticus (Tilapia)	96 h LC50	Mortality	cadmium chloride	Adult					6.5-7.5	6.8	U	tilapia is not native to North America and lives in warm water (no Canadian surrogates), not sure if many of the parameters were measured in the test tanks or not, control mortality not specified	S	(Garcia-Santos et al. 2006)	
Perca flavescens (Yellow perch)	96 h LC50	Mortality	Cd(NO3)2 . 4H2O	Juvenile	8140	3344.5	X	120	8.0		2	no O2 or cond, control mort not reported, feeding not specified	FT	(Niyogi et al. 2004)	
Pimephales promelas (Fathead minnow)	7 d LC50	Mortality	CdCl2	4 to 6 days old	15.43	2.7		270-286	8.37-8.56	7.7-8.6	1	reported at the front of the document	R	(Castillo, III and Longley 2001)	
Pimephales promelas (Fathead minnow)	7 d LC50	Mortality	CdCl2	4 to 6 days old	16.99	3.1		234-299	8.37-8.50	7.3-8.6	1	reported at the front of the document	R		
Pimephales promelas (Fathead minnow)	48 h LC50	Mortality	CdCl2	Larva	11.1	7.45		74			2	FOR JULY TEST, hardness = 74; ph, conductivity and O2 measured but not reported, control mort not specified, at least 6 concs tested, but actual concs not reported, so can't tell if range was appropriate	R	(Diamond et al. 1997)	
Pimephales promelas	48 h	Mortality	CdCl2	Larva	39.5	21.7		90			2	FOR AUGUST TEST, hardness = 90; ph, conductivity and	R		

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
(Fathead minnow)	LC50											O2 measured but not reported, control mort not specified, at least 6 concs tested, but actual concs not reported, so can't tell if range was appropriate			
Pimephales promelas (Fathead minnow)	48 h LC50	Mortality	CdCl2	Larva	37.4	24.4		76			2	FOR OCTOBER TEST, hardness = 76; ph, conductivity and O2 measured but not reported, control mort not specified, at least 6 concs tested, but actual concs not reported, so can't tell if range was appropriate	R		
Pimephales promelas (Fathead minnow)	48 h LC50	Mortality	CdCl2	Larva	52.8	38.63		68			2	FOR NOVEMBER TEST, hardness = 68; ph, conductivity and O2 measured but not reported, control mort not specified, at least 6 concs tested, but actual concs not reported, so can't tell if range was appropriate	R		
Pimephales promelas (Fathead minnow)	48 h LC50	Mortality	CdCl2	Larva	60.4	39.47		76	7.5		2	O2 measured but not reported, control mort not specified, at least 6 concs tested, but actual concs not reported, so can't tell if range was appropriate	R		
Pimephales promelas (Fathead minnow)	48 h LC50	Mortality	CdCl2	Larva	100.7	67.6		74	6.8		2	O2 measured but not reported, control mort not specified, at least 6 concs tested, but actual concs not reported, so can't tell if range was appropriate	R		
Pimephales promelas (Fathead minnow)	48 h LC50	Mortality	CdCl2	Larva	146.6	80.7		90	6.9-7.5		2	O2 measured but not reported, control mort not specified, at least 6 concs tested, but actual concs not reported, so can't tell if range was appropriate	R		
Pimephales promelas (Fathead minnow)	48 h LC50	Mortality	CdCl2	Larva	242.9	177.7		68	6.6-7.4		2	O2 measured but not reported, control mort not specified, at least 6 concs tested, but actual concs not reported, so can't tell if range was appropriate	R		
Pimephales promelas (Fathead minnow)	96 h LC50	Mortality	Cd(NO3)2 - 4H2O	Less than 24hrs	60	10.06	X	280-300	6.0-8.5	>5	2	pH 7-7.5, control mortality high	S	(Schubauerbergian et al. 1993)	H
Pimephales promelas (Fathead minnow)	96 h LC50	Mortality	Cd(NO3)2 - 4H2O	Less than 24hrs	65	10.9		280-300	6.0-8.5	>5	2	pH 8-8.5, control mortality high	S		H
Pimephales promelas (Fathead minnow)	96 h LC50	Mortality	Cd(NO3)2 - 4H2O	Less than 24hrs	73	12.2		280-300	6.0-8.5	>5	2	pH 6-6.5, control mortality high	S		H
Pimephales promelas (Fathead minnow)	96 h LC50	Mortality	CdCl2	Larva	4.8	14.36		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs	S	(Suedel et al. 1997)	H

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
												didn't decline over time, temps were in the high range			
Pimephales promelas (Fathead minnow)	48 h LC50	Mortality	CdCl2	Larva	8.9	26.6		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S	(Suedel et al. 1997)	H
Pimephales promelas (Fathead minnow)	96 h LC50	Mortality	cadmium nitrate	~ 30 days old	13.2	15.1		43.9 ± 1.0	6.0-8.1		1		FT	(Spehar and Fiandt 1986)	
Pimephales promelas (Fathead minnow)	96 h LC50	Mortality	CdCl2	14 to 30 days old	80	19.6		200 ± 10	7.7 ± 0.4		U	Nominal concentrations, dilution water used is unacceptable (contained metals)	S	(Hall et al. 1986)	
Pimephales promelas (Fathead minnow)	48 h LC50	Mortality	CdCl2	14 to 30 days old	100	24.45		200 ± 10	7.7 ± 0.4		U	Nominal concentrations, dilution water used is unacceptable (contained metals)	S		
Pimephales promelas (Fathead minnow)	48 h LC50	Mortality	CdCl2	14 to 30 days old	>150	61.63		120 ± 10	7.8 ± 0.3		2	Nominal concentrations	S		H
Pimephales promelas (Fathead minnow)	96 h LC50	Mortality	CdCl2	14 to 30 days old	>150	61.63		120 ± 10	7.8 ± 0.3		2	Nominal concentrations	S		H
Pimephales promelas (Fathead minnow)	96 h TL50	Mortality	cadmium sulfate	Immature	2000	486.6		201 ± 6.1	7.7 ± 0.20	6.5 ± 1.5	2	completed on the same organisms following the chronic toxicity test	FT	(Pickering and Gast 1972)	H
Pimephales promelas (Fathead minnow)	96 h TL50	Mortality	cadmium sulfate	Immature	4500	1094.8		201 ± 6.1	7.7 ± 0.20	6.5 ± 1.5	2	completed on the same organisms following the chronic toxicity test	FT		H
Pimephales promelas (Fathead minnow)	96 h TL50	Mortality	cadmium sulfate	Immature	6400	1557		201 ± 6.1	7.7 ± 0.20	6.5 ± 1.5	2	completed on the same organisms following the chronic toxicity test	FT		H
Pimephales promelas (Fathead minnow)	96 h TL50	Mortality	cadmium sulfate	Immature	11000	2676.1		201 ± 6.1	7.7 ± 0.20	6.5 ± 1.5	2	completed on the same organisms following the chronic toxicity test	FT		H
Pimephales promelas (Fathead minnow)	96 h TL50	Mortality	cadmium sulfate	Immature	12000	2919.4		201 ± 6.1	7.7 ± 0.20	6.5 ± 1.5	2	completed on the same organisms following the chronic toxicity test	FT		H
Pimephales promelas (Fathead minnow)	96 h TL50	Mortality	cadmium sulfate	Immature	30000	7298.4		201 ± 6.1	7.7 ± 0.20	6.5 ± 1.5	2	completed on the same organisms following the chronic toxicity test	S		H
Pimephales promelas (Fathead minnow)	96 h TL50	Mortality	cadmium sulfate	Immature	32000	7785		201 ± 6.1	7.7 ± 0.20	6.5 ± 1.5	2	completed on the same organisms following the chronic toxicity test	S		H
Pimephales promelas (Fathead minnow)	96 h LC50	Mortality	CdCl2 2 1/2H2O	Juvenile	3420	1192.8		141	8.2 ± 0.4	7.8 ± 0.2	1		S	(Sherman et al. 1987)	H

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Pimephales promelas (Fathead minnow)	96 h LC50	Mortality	CdCl2 2 1/2H2O	Juvenile	3510	1224.2		141	8.2 ± 0.4	7.8 ± 0.2	1		S		H
Pimephales promelas (Fathead minnow)	96 h LC50	Mortality	CdCl2 2 1/2H2O	Juvenile	4020	1402.1		141	8.2 ± 0.4	7.8 ± 0.2	2	Nominal concentrations	S		H
Pimephales promelas (Fathead minnow)	96 h LC50	Mortality	CdCl2 2 1/2H2O	Juvenile	4390	1531.1		141	8.2 ± 0.4	7.8 ± 0.2	2	Nominal concentrations	S		H
Pimephales promelas (Fathead minnow)	96 h LC50	Mortality	CdCl2 - 2 1/2H2O	Juvenile	2780	1702.9		81	7.5 ± 0.7	7.6 ± 0.2	1		S		H
Pimephales promelas (Fathead minnow)	96 h LC50	Mortality	CdCl2 - 2 1/2H2O	Juvenile	2900	1776.4		81	7.5 ± 0.7	7.6 ± 0.2	2	Nominal concentrations	S		H
Pimephales promelas (Fathead minnow)	96 h LC50	Mortality	CdCl2 - 2 1/2H2O	Juvenile	2910	1782.5		81	7.5 ± 0.7	7.6 ± 0.2	2	Nominal concentrations	S		H
Pimephales promelas (Fathead minnow)	96 h LC50	Mortality	CdCl2 - 2 1/2H2O	Juvenile	3200	1960.1		81	7.5 ± 0.7	7.6 ± 0.2	1		S		H
Pimephales promelas (Fathead minnow)	96 h LC50	Mortality	cadmium chloride (CDCl2 - 2.5H2O)	Adult	7160	1328.1		254-271	7.4	7.0	2	Control mortality not reported	S	(Birge et al. 1983)	H
Pimephales promelas (Fathead minnow)	96 h LC50	Mortality	cadmium chloride (Cdcl2- 2.5H2O)	Adult	2900	1391.5		103	7.4	7.0	2	After 7 days in reconstituted water before testing	S		H
Pimephales promelas (Fathead minnow)	96 h LC50	Mortality	cadmium chloride (Cdcl2- 2.5H2O)	Adult	3060	1468.4		103	7.4	7.0	2	Control mortality not reported	S		H
Pimephales promelas (Fathead minnow)	96 h LC50	Mortality	cadmium chloride (Cdcl2- 2.5H2O)	Adult	3100	1487.6		103	7.4	7.0	2	After 14 days in reconstituted water before testing	S		H
Pimephales promelas	96 h	Mortality	cadmium	Juvenile	1280	1474.5		39.0-48.0	7.0-7.9		2	no units given for any WQ parameters (but can assume	S	(Spehar and	H

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Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
(Fathead minnow)	LC50		chloride									units), no DO value given, they don't specifically mention how many organisms were used per replicate, but they followed ASTM procedures so presumably it was enough, no control mortality reported, feed		Carlson 1984)	
Pimephales promelas (Fathead minnow)	96 h LC50	Mortality	cadmium chloride	Juvenile	3390	2518		55.0-79.0	7.2-7.8		2	no units given for any WQ parameters (but can assume units), no DO value given, they don't specifically mention how many organisms were used per replicate, but they followed ASTM procedures so presumably it was enough, no control mortality reported, feed	S		H
Pimephales promelas (Fathead minnow)	96 h LC50	Mortality	CdCl2	Juvenile	1500	1692.4		44.4 (40.7-46.6)	7.1-7.8	7.5 (4.7-10.0)	2	no conductivity, control mortality not reported (but see Notes section), number of concs tested was confusing but seems that range was ok	FT	(Phipps and Holcombe 1985)	H
Pimephales promelas (Fathead minnow)	96 h LC50	Mortality	cadmium chloride (CdCl2 2.5H2O)	1-2 g and 1.5-2.5 inches long	630	1598.3		20	7.5	7.8	2	Nominal concentrations	S	(Pickering and Henderson 1966)	H
Pimephales promelas (Fathead minnow)	24 h LC50	Mortality	cadmium chloride (CdCl2 2.5H2O)	1-2 g and 1.5-2.5 inches long	670	1699.7		20	7.5	7.8	2	Nominal concentrations	S		H
Pimephales promelas (Fathead minnow)	48 h LC50	Mortality	cadmium chloride (CdCl2 2.5H2O)	1-2 g and 1.5-2.5 inches long	670	1699.7		20	7.5	7.8	2	Nominal concentrations	S		H
Pimephales promelas (Fathead minnow)	96 h LC50	Mortality	cadmium chloride (CdCl2 2.5H2O)	1-2 g and 1.5-2.5 inches long	1050	2663.8		20	7.5	7.8	2	Nominal concentrations	S		H
Pimephales promelas (Fathead minnow)	24 h LC50	Mortality	cadmium chloride (CdCl2 2.5H2O)	1-2 g and 1.5-2.5 inches long	1090	2765.2		20	7.5	7.8	2	Nominal concentrations	S		H

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Pimephales promelas (Fathead minnow)	48 h LC50	Mortality	cadmium chloride (CdCl2 2.5H2O)	1-2 g and 1.5-2.5 inches long	1090	2765.2		20	7.5	7.8	2	Nominal concentrations	S		H
Pimephales promelas (Fathead minnow)	48 h LC50	Mortality	cadmium chloride (CdCL2 2.5H2O)	1-2 g and 1.5-2.5 inches long	72600	9769.8		360	8.2	7.8	2	Nominal concentrations	S		H
Pimephales promelas (Fathead minnow)	96 h LC50	Mortality	cadmium chloride (CdCL2 2.5H2O)	1-2 g and 1.5-2.5 inches long	72600	9769.8		360	8.2	7.8	2	Nominal concentrations	S		H
Pimephales promelas (Fathead minnow)	96 h LC50	Mortality	cadmium chloride (CdCL2 2.5H2O)	1-2 g and 1.5-2.5 inches long	73500	9890.9		360	8.2	7.8	2	Nominal concentrations	S		H
Pimephales promelas (Fathead minnow)	24 h LC50	Mortality	cadmium chloride (CdCL2 2.5H2O)	1-2 g and 1.5-2.5 inches long	78100	10510		360	8.2	7.8	2	Nominal concentrations	S		H
Pimephales promelas (Fathead minnow)	24 h LC50	Mortality	cadmium chloride (CdCL2 2.5H2O)	1-2 g and 1.5-2.5 inches long	79300	10671.4		360	8.2	7.8	2	Nominal concentrations	S		H
Pimephales promelas (Fathead minnow)	48 h LC50	Mortality	cadmium chloride (CdCL2 2.5H2O)	1-2 g and 1.5-2.5 inches long	79300	10671.4		360	8.2	7.8	2	Nominal concentrations	S		H
Pimephales promelas (Fathead minnow)	96 h LC50	Mortality		Adult	2099.190715	1217.1		85.5			U	Missing abiotic factors, no control mortality reported, no replications	S	(Carrier and Bettinger 1988)	H
Poecilia reticulata (Guppy)	24 h LC50	Mortality	cadmium chloride	3 to 4 weeks	8674.253308	2028.2		209			U	Control mortality not reported, only temperature and hardness provided and not toxicity methods mentioned.	R	(Canton and Slooff 1982)	

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Poecilia reticulata (Guppy)	48 h LC50	Mortality	cadmium chloride	3 to 4 weeks	5300.932577	1239.5		209			U	Control mortality not reported, only temperature and hardness provided and not toxicity methods mentioned.	R		
Poecilia reticulata (Guppy)	72 h LC50	Mortality	cadmium chloride	3 to 4 weeks	3855.223693	901.4		209			U	Control mortality not reported, only temperature and hardness provided and not toxicity methods mentioned.	R		
Poecilia reticulata (Guppy)	96 h LC50	Mortality	cadmium chloride	3 to 4 weeks	2891.417769	676.1		209			U	Control mortality not reported, only temperature and hardness provided and not toxicity methods mentioned.	R		
Poecilia reticulata (Guppy)	24 h LC50	Mortality	cadmium chloride	3 to 4 weeks	5066.378908	2384.1		105			U	Control mortality not reported, only temperature and hardness provided and not toxicity methods mentioned.	R		
Poecilia reticulata (Guppy)	48 h LC50	Mortality	cadmium chloride	3 to 4 weeks	2772.169591	1304.5		105			U	Control mortality not reported, only temperature and hardness provided and not toxicity methods mentioned.	R		
Poecilia reticulata (Guppy)	72 h LC50	Mortality	cadmium chloride	3 to 4 weeks	2103.025207	989.6		105			U	Control mortality not reported, only temperature and hardness provided and not toxicity methods mentioned.	R		
Poecilia reticulata (Guppy)	96 h LC50	Mortality	cadmium chloride	3 to 4 weeks	1864.04507	877.2		105			U	Control mortality not reported, only temperature and hardness provided and not toxicity methods mentioned.	R		
Prosopium williamsoni (Mountain Whitefish)	96 h LC50	Weight	cadmium sulphate	Embryo	4.7	4.92	X	47.8 ± 6.2	6.81 ± 0.18	9.2 ± 0.6	1	Fry tests, controls reported, good concentrations and clear dose response relationship	FT	(Brinkman and Vieira 2008)	
Rutilus frisii Kutum (White fish)	96 h LC50	Mortality	cadmium chloride	Fingerling				NR	NR	NR	U	No abiotic factors reported and this is not a resident species of Canada	S	(Gholami et al. 2010)	
Rutilus frisii Kutum (White fish)	96 h LC90	Mortality	cadmium chloride	Fingerling				NR	NR	NR	U	No abiotic factors reported and this is not a resident species of Canada	S		
Rutilus frisii Kutum (White fish)	96 h LC10	Mortality	cadmium chloride	Fingerling				NR	NR	NR	U	No abiotic factors reported and this is not a resident species of Canada	S		
Salmo trutta (Brown trout)	96 h LC50	Mortality	$CdSO_4$	Swim-up fry	10.1	3.29		151 (2)	7.51 (0.12)	8.58 (0.14)	1	no problems	FT	(Brinkman and Hansen 2007)	H
Salmo trutta (Brown trout)	96 h LC50	Mortality	$CdSO_4$	Swim-up fry	1.23	2.12		29.2 (0.9)	7.54 (0.13)	8.61 (0.22)	1	no problems	FT		H
Salmo trutta (Brown trout)	96 h LC50	Mortality	$CdSO_4$	Swim-up fry	3.9	2.87		67.6 (1.5)	7.60 (0.10)	8.88 (0.17)	1	no problems	FT		H
Salmo trutta (Brown trout)	96 h LC50	Mortality	cadmium chloride	Juvenile	1.4	1.61	X	39.0-48.0	7.0-7.9		2	no units given for any WQ parameters (but can assume units), no DO value given, they don't specifically mention how many organisms were used per replicate, but they	S	(Spehar and Carlson 1984)	H

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
												followed ASTM procedures so presumably it was enough, no control mortality reported, feedi			
Salmo trutta (Brown trout)	96 h LC50	Mortality	cadmium chloride	Juvenile	15.1	11.2		55.0-79.0	7.2-7.8		2	no units given for any WQ parameters (but can assume units), no DO value given, they don't specifically mention how many organisms were used per replicate, but they followed ASTM procedures so presumably it was enough, no control mortality reported, feedi	S		
Salvelinus confluentus (Bull trout)	5 d LC50	Mortality	CdCl2	Juvenile	0.83	1.36		SEE RATIONALE SECTION	SEE RATIONALE SECTION	92-100% sat	1	pH = 7.43, hardness = 30.7, temp = 7.6, alk = 30.1	FT	(Hansen et al. 2002a)	H
Salvelinus confluentus (Bull trout)	5 d LC50	Mortality	CdCl2	Juvenile	0.83	1.39		SEE RATIONALE SECTION	SEE RATIONALE SECTION	92-100% sat	1	pH = 7.56, hardness = 30.2, temp = 12.1, alk = 31.9	FT		H
Salvelinus confluentus (Bull trout)	5 d LC50	Mortality	CdCl2	Juvenile	0.88	1.4		SEE RATIONALE SECTION	SEE RATIONALE SECTION	92-100% sat	1	pH = 7.53, hardness = 31.7, temp = 8.1, alk = 33.0	FT		H
Salvelinus confluentus (Bull trout)	5 d LC50	Mortality	CdCl2	Juvenile	0.83	1.43		SEE RATIONALE SECTION	SEE RATIONALE SECTION	92-100% sat	1	pH = 7.50, hardness = 29.3, temp = 8.0, alk = 37.3	FT		H
Salvelinus confluentus (Bull trout)	5 d LC50	Mortality	CdCl2	Juvenile	5.23	2.90		SEE RATIONALE SECTION	SEE RATIONALE SECTION	92-100% sat	1	pH = 7.49, hardness = 89.3, temp = 7.9, alk = 76.0	FT		H

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Salvelinus confluentus (Bull trout)	5 d LC50	Mortality	CdCl2	Juvenile	2.41	4.05		SEE RATIONALE SECTION	SEE RATIONALE SECTION	92-100% sat	1	pH = 6.52, hardness = 30.0, temp = 7.8, alk = 12.8	FT		H
Salvelinus confluentus (Bull trout)	96 h LC50	Mortality	CdCl2	Fry	0.91	1.49	x	30.7	7.43	8.64	1	no problems	FT	(Stratus Consulting Inc. 1999)	H
Salvelinus confluentus (Bull trout)	96 h LC50	Mortality	CdCl2	Fry	0.9	1.50	x	30.2	7.56	7.84	1	no problems	FT		H
Salvelinus confluentus (Bull trout)	96 h LC50	Mortality	CdCl2	Fry	1	1.59	x	31.7	7.53	8.39	1	no problems	FT		H
Salvelinus confluentus (Bull trout)	96 h LC50	Mortality	CdCl2	Fry	0.99	1.70	x	29.3	7.5	8.82	1	no problems	FT		H
Salvelinus confluentus (Bull trout)	96 h LC50	Mortality	CdCl2	Fry	6.06	3.36		89.3	7.49	8.44	1	no problems	FT		H
Salvelinus confluentus (Bull trout)	96 h LC50	Mortality	CdCl2	Fry	2.89	4.86	x	30	6.52	8.66	1	no problems	FT		H
Thymallus arcticus (Arctic grayling)	96 h LC50	Mortality	CdCl2	Alevin	6.1	7.47		41 (40-43)	6.1-7.9	>40% saturation	2	nominal only, pseudoreplication, concs tested not reported, so can't tell if range was appropriate, there was 0% mortality at 1 conc and 100% at the next	S	(Buhl and Hamilton 1991)	
Thymallus arcticus (Arctic grayling)	96 h LC50	Mortality	CdCl2	Juvenile	4	4.89	X	41 (40-43)	6.1-7.9	>40% saturation	2	nominal only, pseudoreplication, concs tested not reported, so can't tell if range was appropriate	S		
Tinca tinca (trench fish)			Cadmium chloride								U	Does not report and lethal concentration values, only reported percentage of food accumulation in larval gut region	NR	(Sikorska and Wolnicki 2010)	
Invertebrates															
Aeolosoma headleyi (Oligochaete)	48 h LC50	Mortality	cadmium chloride	Other	502.1934691	206.3		60-180	NR	NR	U	hardness: 62, only duplications completed, few abiotic factors completed and static conditions	S	(Niederlehner et al. 1984)	
Aeolosoma headleyi (Oligochaete)	48 h LC50	Mortality	cadmium chloride	Other	2084.102897	856.25		60-180	NR	NR	U	hardness: 168, only duplications completed, few abiotic factors completed and static conditions	S		

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Amnicola limosa (Gastropod)	96 h LC50	Mortality	cadmium chloride	Not reported	2710	9025.6	x	15.3 ± 3.4	NR	NR	2	pH: 4.5, nominal concentrations and control mortality not reported	S	(Mackie 1989)	
Amnicola limosa (Gastropod)	96 h LC50	Mortality	cadmium chloride	Not reported	3800	12655.8	x	15.3 ± 3.4	NR	NR	2	pH: 4.0, nominal concentrations and control mortality not reported	S		
Amnicola limosa (Gastropod)	96 h LC50	Mortality	cadmium chloride	Not reported	6350	21148.6	x	15.3 ± 3.4	NR	NR	2	pH: 3.5, nominal concentrations and control mortality not reported	S		
Anodonta imbecilis (Freshwater mussel)	48 h LC50	Mortality	CdCl2	Juvenile							U	control mortality not reported, no WQ parameters reported except temp, which was very high (23 degrees), not sure if concs measured at end, not sure if values based on nominal or measured, concs used not reported so can't tell if range was appropriate	S	(Keller and Zam 1991)	
Anodonta imbecilis (Freshwater mussel)	96 h LC50	Mortality	CdCl2	Juvenile							U	control mortality not reported, no WQ parameters reported except temp, which was very high (23 degrees), not sure if concs measured at end, not sure if values based on nominal or measured, concs used not reported so can't tell if range was appropriate	S		
Anodonta imbecilis (Freshwater mussel)	48 h LC50	Mortality	CdCl2	Juvenile	57	57		50?			U	control mortality not reported, no WQ parameters reported except temp, which was very high (23 degrees), and hardness (indirectly, i.e. assumed based on Table 8, not sure if concs measured at end, not sure if values based on nominal or measured, concs use	S		
Anodonta imbecilis (Freshwater mussel)	96 h LC50	Mortality	CdCl2	Juvenile	9	9		50?			U	control mortality not reported, no WQ parameters reported except temp, which was very high (23 degrees), and hardness (indirectly, i.e. assumed based on Table 8, not sure if concs measured at end, not sure if values based on nominal or measured, concs use	S		
Aplexa hypnorum (Moss bladder snail)	96 h LC50	Mortality	CdCl2	Adult	93	104.9	X	44.4 (40.7-46.6)	7.1-7.8	7.5 (4.7-10.0)	2	no conductivity, control mortality not reported (but see Notes section), number of concs tested was confusing but seems that range was ok	FT	(Phipps and Holcombe 1985)	
Aspidisca cicada (Ciliate)	24 h LC50	Mortality	hydrated cadmium chloride	Adult					7.3 (range: 7.0-7.8)		U	all variables missing except pH, nominal concs only, control mortality not reported, can't tell if range was appropriate	S	(Madoni et al. 1992)	

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Atyaephyra desmarestii (European shrimp)	96 h LC50	Mortality	cadmium chloride	Adult							U	no chemical or physical properties given, nominal concs only, not many replicates, control mortality not reported, number of concs tested and range not known	S	(Pestana et al. 2007)	
Baetis tricaudatus (Blue-winged olive (mayfly))	96 h LC50	Mortality	cadmium chloride	nymph					7.8 +- 0.4	>90% saturation	U	metal concs were measured at 0, 48, and 96 h but concs declined dramatically in the higher tests, but they appeared to use nominal values anyway. They eliminated the 5000 ug/L test, which was good, but they left in the 2600 ug/L test, which had declined	S	(Irving et al. 2003)	
Blepharisma americanum (Ciliate)	24 h LC50	Mortality	hydrated cadmium chloride	Adult					7.3 (range: 7.0-7.8)		U	all variables missing except pH, nominal concs only, control mortality not reported, can't tell if range was appropriate	S	(Madoni et al. 1992)	
Brachionus havanaensis (Rotifer)	24 h LC50	Mortality									U	they used this species because they wanted something representative of tropical waters (25 degrees) in Mexico, so it would not be appropriate for Canadian purposes		(Juarez-Franco et al. 2007)	
Brachiura sowerbyi (Oligochaete)	96 h LC50	Mortality	3CdSO4 (8H2O)	Adult	240	2346.9	X	5.30 ± 0.64	7.0 ± 0.2		2	Control mortality not reported	R	(Chapman et al. 1982)	
Ceriodaphnia dubia (Cladocerans)	48 h LC50	Mortality	Cd(NO3)2 - 4H2O	Less than 48h old	120	20.1		280-300	6.0-8.5	>5	2	pH 8-8.5, control mortality high	S	(Schubauerbergian et al. 1993)	
Ceriodaphnia dubia (Cladocerans)	48 h LC50	Mortality	Cd(NO3)2 - 4H2O	Less than 48h old	350	58.7		280-300	6.0-8.5	>5	2	pH 7-7.5, control mortality high	S		
Ceriodaphnia dubia (Cladocerans)	48 h LC50	Mortality	Cd(NO3)2 - 4H2O	Less than 48h old	560	93.9		280-300	6.0-8.5	>5	2	pH 6-6.5, control mortality high	S		
Ceriodaphnia dubia (Water flea)	48 h LC15	Mortality	cadmium chloride	Less than 24hrs	16.86				7.4 +- 0.07	91.4% +- 2.4% saturation	2	used nominal concs only (even though test solutions measured at beginning), missing temp, alkalinity, hardness	S	(Shaw et al. 2006)	
Ceriodaphnia dubia (Water flea)	48 h LC50	Mortality	cadmium chloride	Less than 24hrs	31.472		X		7.4 +- 0.07	91.4% +- 2.4% saturation	2	used nominal concs only (even though test solutions measured at beginning), missing temp, alkalinity, hardness	S		

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Ceriodaphnia dubia (Water flea)	48 h LC85	Mortality	cadmium chloride	Less than 24hrs	55.076				7.4 +- 0.07	91.4% +- 2.4% saturation	2	used nominal concs only (even though test solutions measured at beginning), missing temp, alkalinity, hardness	S		
Ceriodaphnia dubia (Water flea)	96 h LC50	Mortality	CdCl2	Less than 24hrs	16.9	50.57		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S	(Suedel et al. 1997)	
Ceriodaphnia dubia (Water flea)	48 h LC50	Mortality	CdCl2	Less than 24hrs	63.1	188.8		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S		
Ceriodaphnia dubia (Water flea)	48 h LC50	Mortality	CdCl2	Less than 24hrs	49.8	33.4		74			2	FOR JULY TEST, hardness = 74; ph, conductivity and O2 measured but not reported, control mort not specified, at least 6 concs tested, but actual concs not reported, so can't tell if range was appropriate	R	(Diamond et al. 1997)	
Ceriodaphnia dubia (Water flea)	48 h LC50	Mortality	CdCl2	Less than 24hrs	107.4	78.6		68			2	FOR NOVEMBER TEST, hardness = 68; ph, conductivity and O2 measured but not reported, control mort not specified, at least 6 concs tested, but actual concs not reported, so can't tell if range was appropriate	R		
Ceriodaphnia dubia (Water flea)	48 h LC50	Mortality	CdCl2	Less than 24hrs	160.2	88.2		90			2	FOR AUGUST TEST, hardness = 90; ph, conductivity and O2 measured but not reported, control mort not specified, at least 6 concs tested, but actual concs not reported, so can't tell if range was appropriate	R		
Ceriodaphnia dubia (Water flea)	48 h LC50	Mortality	CdCl2	Less than 24hrs	189.7	124		76	7.5		2	O2 measured but not reported, control mort not specified, at least 6 concs tested, but actual concs not reported, so can't tell if range was appropriate	R		
Ceriodaphnia dubia (Water flea)	48 h LC50	Mortality	CdCl2	Less than 24hrs	213.3	139.4		76			2	FOR OCTOBER TEST, hardness = 76; ph, conductivity and O2 measured but not reported, control mort not specified, at least 6 concs tested, but actual concs not reported, so can't tell if range was appropriate	R		

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Ceriodaphnia dubia (Water flea)	48 h LC50	Mortality	CdCl2	Less than 24hrs	315.7	173.7		90	6.9-7.5		2	O2 measured but not reported, control mort not specified, at least 6 concs tested, but actual concs not reported, so can't tell if range was appropriate	R		
Ceriodaphnia dubia (Water flea)	48 h LC50	Mortality	CdCl2	Less than 24hrs	252	184.4		68	6.6-7.4		2	O2 measured but not reported, control mort not specified, at least 6 concs tested, but actual concs not reported, so can't tell if range was appropriate	R		
Ceriodaphnia dubia (Water flea)	48 h LC50	Mortality	CdCl2	Less than 24hrs	355.3	238.6		74	6.8		2	O2 measured but not reported, control mort not specified, at least 6 concs tested, but actual concs not reported, so can't tell if range was appropriate	R		
Ceriodaphnia reticulata (Cladocerans)	48 h LC50	Mortality	cadmium chloride	Less than 24hrs	129	95.8		55.0-79.0	7.2-7.8		2	no units given for any WQ parameters (but can assume units) , they don't specifically mention how many organisms were used per replicate, but they followed ASTM procedures, no control mortality reported	S	(Spehar and Carlson 1984)	H
Ceriodaphnia reticulata (Water flea)	48 h LC50	Mortality	CdCl2	Less than 6 hrs	70	17.1		200 ± 10	7.7 ± 0.4		U	Nominal concentrations	S	(Hall et al. 1986)	
Ceriodaphnia reticulata (Water flea)	48 h LC50	Mortality	CdCl2	Less than 6 hrs	90	22		200 ± 10	7.7 ± 0.4		U	Nominal concentrations	S		
Ceriodaphnia reticulata (Water flea)	48 h LC50	Mortality	CdCl2	Less than 6 hrs	110	45.2		120 ± 10	7.8 ± 0.3		2	Nominal concentrations	S		H
Ceriodaphnia reticulata (Water flea)	48 h LC50	Mortality	CdCl2	Less than 24hrs	184	37.38	X	240 +- 10	8.0 +- 0.3	>5	2	nominal only, temp 23 degrees - warm	S	(Elnabarawy et al. 1986)	H
Chironomus plumosus (Midge)	96 h LC50	Mortality	cadmium chloride	Larva	NR						2	Temperature: 40, control mortality not reported	S	(Vedamanikam and Shazili 2009)	
Chironomus plumosus (Midge)	96 h LC50	Mortality	cadmium chloride	Larva	NR						2	Temperature: 40, silica gel substrate, control mortality not reported	S		
Chironomus plumosus (Midge)	96 h LC50	Mortality	cadmium chloride	Larva	1060	1060.00					2	Temperature: 25, silica gel substrate, control mortality not reported	S		
Chironomus plumosus (Midge)	96 h LC50	Mortality	cadmium chloride	Larva	1060	1060.00					2	Temperature: 28, silica gel substrate, control mortality not reported	S		
Chironomus plumosus (Midge)	96 h LC50	Mortality	cadmium chloride	Larva	1690	1690.00					2	Temperature: 23, silica gel substrate, control mortality not reported	S		

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Chironomus plumosus (Midge)	96 h LC50	Mortality	cadmium chloride	Larva	1690	1690.00					2	Temperature: 30, silica gel substrate, control mortality not reported	S		
Chironomus plumosus (Midge)	96 h LC50	Mortality	cadmium chloride	Larva	1690	1690.00					2	Temperature: 35, silica gel substrate, control mortality not reported	S		
Chironomus plumosus (Midge)	96 h LC50	Mortality	cadmium chloride	Larva	300	300.00	X				2	Temperature: 10, control mortality not reported	S		
Chironomus plumosus (Midge)	96 h LC50	Mortality	cadmium chloride	Larva	300	300.00					2	Temperature: 15, control mortality not reported	S		
Chironomus plumosus (Midge)	96 h LC50	Mortality	cadmium chloride	Larva	300	300.00					2	Temperature: 20, control mortality not reported	S		
Chironomus plumosus (Midge)	96 h LC50	Mortality	cadmium chloride	Larva	400	400.00					2	Temperature: 25, control mortality not reported	S		
Chironomus plumosus (Midge)	96 h LC50	Mortality	cadmium chloride	Larva	400	400.00					2	Temperature: 28, control mortality not reported	S		
Chironomus plumosus (Midge)	96 h LC50	Mortality	cadmium chloride	Larva	600	600.00					2	Temperature: 23, control mortality not reported	S		
Chironomus plumosus (Midge)	96 h LC50	Mortality	cadmium chloride	Larva	600	600.00					2	Temperature: 30, control mortality not reported	S		
Chironomus plumosus (Midge)	96 h LC50	Mortality	cadmium chloride	Larva	600	600.00					2	Temperature: 35, control mortality not reported	S		
Chironomus plumosus (Midge)	96 h LC50	Mortality	cadmium chloride	Larva	670	670.00					2	Temperature: 10, silica gel substrate, control mortality not reported	S		
Chironomus plumosus (Midge)	96 h LC50	Mortality	cadmium chloride	Larva	890	890.00					2	Temperature: 15, silica gel substrate, control mortality not reported	S		
Chironomus plumosus (Midge)	96 h LC50	Mortality	cadmium chloride	Larva	890	890.00					2	Temperature: 20, silica gel substrate, control mortality not reported	S		
Chironomus plumosus (Midge)	96 h LC50	Mortality		Larva				NR	NR	NR	U	Generation 5, test organisms reared in contaminated environment	S	(Vedamanikam and Shazilli 2008b)	
Chironomus plumosus (Midge)	96 h LC50	Mortality		Larva				NR	NR	NR	U	Generation 6, test organisms reared in contaminated environment	S		
Chironomus plumosus	96 h	Mortality		Larva				NR	NR	NR	U	Generation 1, test organisms reared in contaminated	S		

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Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
(Midge)	LC50											environment			
Chironomus plumosus (Midge)	96 h LC50	Mortality		Larva				NR	NR	NR	U	Generation 2, test organisms reared in contaminated environment	S		
Chironomus plumosus (Midge)	96 h LC50	Mortality		Larva				NR	NR	NR	U	Generation 9, test organisms reared in contaminated environment	S		
Chironomus plumosus (Midge)	96 h LC50	Mortality		Larva				NR	NR	NR	U	Generation 3, test organisms reared in contaminated environment	S		
Chironomus plumosus (Midge)	96 h LC50	Mortality		Larva				NR	NR	NR	U	Generation 4, test organisms reared in contaminated environment	S		
Chironomus plumosus (Midge)	96 h LC50	Mortality	cadmium chloride	Larva				NR	NR	NR	U	Temperature: 20-26, no abiotic factors listed, control mortality not reported, adequate statistics not completed	S	(Vedamanikam and Shazilli 2008a)	
Chironomus plumosus (Midge)	96 h LC50	Mortality	cadmium chloride	Larva				NR	NR	NR	U	Temperature: 25, no abiotic factors listed, control mortality not reported, adequate statistics not completed	S		
Chironomus plumosus (Midge)	96 h LC50	Mortality	cadmium chloride	Larva				NR	NR	NR	U	Temperature: 25-28, no abiotic factors listed, control mortality not reported, adequate statistics not completed	S		
Chironomus riparius (Midge)	96 h LC50	Mortality	not specified	2nd instar	1760	761.8	X	114	7.2	>=80 % of air saturation	1	no alkalinity reported, form of Cd not specified	R	(Watts and Pascoe 2000)	
Chironomus riparius (Midge)	24 h LC50	Mortality	cadmium nitrate	First-instar larvae	58090.2781	373865.6		8	6.52	NR	U	CIs could not be calculated due to hetergeneity of the data	S	(Béchard et al. 2008)	
Chironomus tentans (Midge)	96 h LC50	Mortality	CdCl2	2nd instar	8000	23939.1		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S	(Suedel et al. 1997)	
Chironomus tentans (Midge)	48 h LC50	Mortality	CdCl2	2nd instar	29560	88454.9		6-28	5.5-7.7	4.2-9.3	2	conc range tested was too low: 50% mortality was never actually reached using the concs tested - extrapolation was used, nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nomin	S		

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Chironomus tentans (Midge)	96 h LC50	Mortality	not specified	2nd instar	1680	727.2	X	114	7.2	>=80 % of air saturation	1	no alkalinity reported, form of Cd not specified	R	(Watts and Pascoe 2000)	
Chironomus tentans (Midge)	24 h LC50	Mortality	cadmium chloride	4th instar				NR	NR	NR	U	Nominal concentrations, control mortality not reported and no abiotic factors listed	S	(Ha and Choi 2008)	
Chironomus tentans (Midge)	24 h LC90	Mortality	cadmium chloride	4th instar				NR	NR	NR	U	Nominal concentrations, control mortality not reported and no abiotic factors listed	S		
Chironomus tentans (Midge)	24 h LC10	Mortality	cadmium chloride	4th instar				NR	NR	NR	U	Nominal concentrations, control mortality not reported and no abiotic factors listed	S		
Colpidium campylum (Ciliate)	24 h LC50	Mortality	hydrated cadmium chloride	Adult					7.3 (range: 7.0-7.8)		U	all variables missing except pH, nominal concs only, control mortality not reported, can't tell if range was appropriate	S	(Madoni et al. 1992)	
Culicoides furens (Midge)	96 h LC50	Mortality		Larva				NR	NR	NR	U	Generation 5, test organisms reared in contaminated environment	S	(Vedamanikam and Shazilli 2008b)	
Culicoides furens (Midge)	96 h LC50	Mortality		Larva				NR	NR	NR	U	Generation 6, test organisms reared in contaminated environment	S		
Culicoides furens (Midge)	96 h LC50	Mortality		Larva				NR	NR	NR	U	Generation 1, test organisms reared in contaminated environment	S		
Culicoides furens (Midge)	96 h LC50	Mortality		Larva				NR	NR	NR	U	Generation 2, test organisms reared in contaminated environment	S		
Culicoides furens (Midge)	96 h LC50	Mortality		Larva				NR	NR	NR	U	Generation 9, test organisms reared in contaminated environment	S		
Culicoides furens (Midge)	96 h LC50	Mortality		Larva				NR	NR	NR	U	Generation 3, test organisms reared in contaminated environment	S		
Culicoides furens (Midge)	96 h LC50	Mortality		Larva				NR	NR	NR	U	Generation 4, test organisms reared in contaminated environment	S		
Culicoides furens (Midge)	96 h LC50	Mortality	cadmium chloride	Larva				NR	NR	NR	U	Temperature: 20-26, no abiotic factors listed, control mortality not reported, adequate statistics not completed	S	(Vedamanikam and Shazilli 2008a)	
Culicoides furens (Midge)	96 h	Mortality	cadmium	Larva				NR	NR	NR	U	Temperature: 25-28, no abiotic factors listed, control	S		

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
	LC50		chloride									mortality not reported, adequate statistics not completed			
Culicoides furens (Midge)	96 h LC50	Mortality	cadmium chloride	Larva				NR	NR	NR	U	Temperature: 25, no abiotic factors listed, control mortality not reported, adequate statistics not completed	S		
Daphnia ambigua (Water flea)	48 h LC50	Mortality	cadmium chloride	Less than 24hrs	10.116	10.12	X		7.4 +- 0.07	91.4% +- 2.4% saturation	2	used nominal concs only (even though test solutions measured at beginning), missing temp, alkalinity, hardness	S	(Shaw et al. 2006)	
Daphnia ambigua (Water flea)	48 h LC15	Mortality	cadmium chloride	Less than 24hrs	5.62	5.62			7.4 +- 0.07	91.4% +- 2.4% saturation	2	used nominal concs only (even though test solutions measured at beginning), missing temp, alkalinity, hardness	S		
Daphnia ambigua (Water flea)	48 h LC85	Mortality	cadmium chloride	Less than 24hrs	16.86	16.86			7.4 +- 0.07	91.4% +- 2.4% saturation	2	used nominal concs only (even though test solutions measured at beginning), missing temp, alkalinity, hardness	S		
Daphnia magna (Water flea)	24 h EC10	Feeding inhibition	3CdSO4.8 H2O	4th instar	0.05	0.05			8.2 +- 0.2	90% sat.	2	0.05 was the lowest concentration tested, only missing hardness, alk, and conductivity	R	(Barata et al. 2000)	
Daphnia magna (Water flea)	24 h EC10	Feeding inhibition	3CdSO4.8 H2O	4th instar	0.08	0.08			8.2 +- 0.2	90% sat.	1	only missing hardness, alk, and conductivity	R		
Daphnia magna (Water flea)	24 h EC20	Feeding inhibition	3CdSO4.8 H2O	4th instar	0.2	0.20			8.2 +- 0.2	90% sat.	1	only missing hardness, alk, and conductivity	R		
Daphnia magna (Water flea)	24 h EC10	Feeding inhibition	3CdSO4.8 H2O	4th instar	0.24	0.24			8.2 +- 0.2	90% sat.	1	only missing hardness, alk, and conductivity	R		
Daphnia magna (Water flea)	24 h EC10	Feeding inhibition	3CdSO4.8 H2O	4th instar	0.3	0.30			8.2 +- 0.2	90% sat.	1	only missing hardness, alk, and conductivity	R		
Daphnia magna (Water flea)	24 h EC20	Feeding inhibition	3CdSO4.8 H2O	4th instar	0.6	0.60			8.2 +- 0.2	90% sat.	1	only missing hardness, alk, and conductivity	R		
Daphnia magna (Water	24 h	Feeding	3CdSO4.8	4th instar	0.61	0.61			8.2 +-	90%	1	only missing hardness, alk, and conductivity	R		

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
flea)	EC20	inhibition	H2O						0.2	sat.					
Daphnia magna (Water flea)	24 h EC20	Feeding inhibition	3CdSO4.8 H2O	4th instar	0.65	0.65			8.2 +- 0.2	90% sat.	1	only missing hardness, alk, and conductivity	R		
Daphnia magna (Water flea)	24 h EC50	Feeding inhibition	3CdSO4.8 H2O	4th instar	1.87	1.87			8.2 +- 0.2	90% sat.	1	only missing hardness, alk, and conductivity	R		
Daphnia magna (Water flea)	24 h EC50	Feeding inhibition	CdSO4.8H 20	4th instar	2.4	2.40			8.3	91% saturation	2	acetone used in all treatments, responses based on nominal (though actual concs were measured), don't know pH range, just the mean, no temp, alk, hardness or conductivity	S		
Daphnia magna (Water flea)	24 h EC50	Feeding inhibition	3CdSO4.8 H2O	4th instar	2.73	2.73			8.2 +- 0.2	90% sat.	1	only missing hardness, alk, and conductivity	R		
Daphnia magna (Water flea)	24 h EC50	Feeding inhibition	3CdSO4.8 H2O	4th instar	2.78	2.78			8.2 +- 0.2	90% sat.	1	only missing hardness, alk, and conductivity	R		
Daphnia magna (Water flea)	24 h EC50	Feeding inhibition	3CdSO4.8 H2O	4th instar	5.29	5.29			8.2 +- 0.2	90% sat.	1	only missing hardness, alk, and conductivity	R		
Daphnia magna (Water flea)	48 h LC50	Mortality	CdSO4.8H 20	4th instar	5.44	5.44			8.3	91% saturation	2	acetone used in all treatments, responses based on nominal (though actual concs were measured), don't know pH range, just the mean, no temp, alk, hardness or conductivity	S		
Daphnia magna (Water flea)	24 h EC80	Feeding inhibition	3CdSO4.8 H2O	4th instar	8.66				8.2 +- 0.2	90% sat.	1	only missing hardness, alk, and conductivity	R		
Daphnia magna (Water flea)	24 h EC80	Feeding inhibition	3CdSO4.8 H2O	4th instar	10.6				8.2 +- 0.2	90% sat.	1	only missing hardness, alk, and conductivity	R		
Daphnia magna (Water flea)	24 h EC80	Feeding inhibition	3CdSO4.8 H2O	4th instar	11.48				8.2 +- 0.2	90% sat.	1	only missing hardness, alk, and conductivity	R		
Daphnia magna (Water flea)	48 h LC50	Mortality	3CdSO4.8 H2O	4th instar	29.9				8.2 +- 0.2	90% sat.	1	only missing hardness, alk, and conductivity	R		
Daphnia magna (Water flea)	24 h EC80	Feeding inhibition	3CdSO4.8 H2O	4th instar	40.8				8.2 +- 0.2	90% sat.	2	outside range of concs tested (highest conc was 40), only missing hardness, alk, and conductivity	R		
Daphnia magna (Water flea)	48 h LC50	Mortality	3CdSO4.8 H2O	4th instar	54.5				8.2 +- 0.2	90% sat.	1	only missing hardness, alk, and conductivity	R		
Daphnia magna (Water flea)	48 h LC50	Mortality	3CdSO4.8 H2O	4th instar	62.1				8.2 +- 0.2	90% sat.	1	only missing hardness, alk, and conductivity	R		

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Daphnia magna (Water flea)	48 h LC50	Mortality	3CdSO4.8 H2O	4th instar	210.9				8.2 +- 0.2	90% sat.	1	only missing hardness, alk, and conductivity	R		
Daphnia magna (Water flea)	72 h LC10	Mortality	3CdSO4.8 H2O	Adult	1.29	0.353		179 +- 3.72	8.07 +- 0.07		2	nominal concs used (although concs were measured at start and end and were not found to differ by more than 10% from nominal), also no O2	R	(Barata and Baird 2000)	
Daphnia magna (Water flea)	72 h LC50	Mortality	3CdSO4.8 H2O	Adult	3.34	0.914	X	179 +- 3.72	8.07 +- 0.07		2	nominal concs used (although concs were measured at start and end and were not found to differ by more than 10% from nominal), also no O2	R		
Daphnia magna (Water flea)	48 h LC50	Mortality	cadmium chloride	Neonate	26 (approx)	7.50		160-180	<8		2	CULTURE 1: need better values for parameters, was it static or renewal?, were concs measured at start and end, were they fed, what concs were tested, what were the actual values for the LC50s and 95% CIs?	NR	(Ward and Robinson 2005)	H
Daphnia magna (Water flea)	48 h LC50	Mortality	cadmium chloride	Neonate	34 (approx)	9.81		160-180	<8		2	CULTURE 2: need better values for parameters, was it static or renewal?, were concs measured at start and end, were they fed, what concs were tested, what were the actual values for the LC50s and 95% CIs?	NR		H
Daphnia magna (Water flea)	48 h LC50	Mortality	cadmium chloride	Neonate	38 (approx)	11.0		160-180	<8		2	CULTURE 3: need better values for parameters, was it static or renewal?, were concs measured at start and end, were they fed, what concs were tested, what were the actual values for the LC50s and 95% CIs?	NR		H
Daphnia magna (Water flea)	48 h LC50	Mortality	cadmium chloride	Neonate	48 (approx)	13.8		160-180	<8		2	CULTURE 4: need better values for parameters, was it static or renewal?, were concs measured at start and end, were they fed, what concs were tested, what were the actual values for the LC50s and 95% CIs?	NR		H
Daphnia magna (Water flea)	48 h LC50	Mortality	cadmium chloride	Neonate	54 (approx)	15.6		160-180	<8		2	CULTURE 5: need better values for parameters, was it static or renewal?, were concs measured at start and end, were they fed, what concs were tested, what were the actual values for the LC50s and 95% CIs?	NR		H
Daphnia magna (Water flea)	48 h LC50	Mortality	cadmium chloride	Neonate	63 (approx)	18.2		160-180	<8		2	CULTURE 6: need better values for parameters, was it static or renewal?, were concs measured at start and end, were they fed, what concs were tested, what were the actual values for the LC50s and 95% CIs?	NR		H

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Daphnia magna (Water flea)	48 h LC50	Mortality	cadmium chloride	Neonate	100 (approx)	28.8		160-180	<8		2	CULTURE 7: need better values for parameters, was it static or renewal?, were concs measured at start and end, were they fed, what concs were tested, what were the actual values for the LC50s and 95% CIs?	NR		H
Daphnia magna (Water flea)	48 h LC50	Mortality	cadmium chloride	Neonate	>120 (approx)	34.6		160-180	<8		2	CULTURE 8: "greater than" value, need better values for parameters, was it static or renewal?, were concs measured at start and end, were they fed, what concs were tested, what were the actual values for the LC50s and 95% CIs?	NR		H
Daphnia magna (Water flea)	96 h LC50	Mortality	CdCl2	Less than 24hrs	12.7	8.08		69-87	6.9-8.3	7.7-9.0	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S	(Suedel et al. 1997)	H
Daphnia magna (Water flea)	48 h LC50	Mortality	CdCl2	Less than 24hrs	26.4	16.8		69-87	6.9-8.3	7.7-9.0	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S		H
Daphnia magna (Water flea)	48 h LC50	Mortality	CdCl2	Less than 24hrs	20	8.22		120 ± 10	7.8 ± 0.3		2	Nominal concentrations	S	(Hall et al. 1986)	H
Daphnia magna (Water flea)	48 h LC50	Mortality	CdCl2	Less than 24hrs	20	8.22		120 ± 10	7.8 ± 0.3		2	Nominal concentrations	S		H
Daphnia magna (Water flea)	48 h LC50	Mortality	CdCl2	Less than 24hrs	50	12.2		200 ± 10	7.7 ± 0.4		2	Nominal concentrations	S		
Daphnia magna (Water flea)	48 h LC50	Mortality	CdCl2	Less than 24hrs	80	19.6		200 ± 10	7.7 ± 0.4		2	Nominal concentrations	S		
Daphnia magna (Water flea)	48 h NOEC/L	Mortality	CdCl2	Less than 24hrs	39	16.3		118 (94-123)	7.7 (7.2-8.2)	8.5 (7.4-9.3)	2	concs tested not reported, so can't tell if range of concs was appropriate, control mortality not reported (but assume within appropriate range because EPA protocols were followed)	S	(Baer et al. 1999)	
Daphnia magna (Water flea)	48 h NOEC/L	Mortality	CdCl2	Less than 24hrs	50	20.9		118 (94-123)	7.7 (7.2-8.2)	8.5 (7.4-9.3)	2	concs tested not reported, so can't tell if range of concs was appropriate, control mortality not reported (but assume within appropriate range because EPA protocols were followed)	S		

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Daphnia magna (Water flea)	48 h LC50	Mortality	CdCl2	Less than 24hrs	66	27.6		118 (94-123)	7.7 (7.2-8.2)	8.5 (7.4-9.3)	2	concs tested not reported, so can't tell if range of concs was appropriate, control mortality not reported (but assume within appropriate range because EPA protocols were followed)	S		
Daphnia magna (Water flea)	48 h LC50	Mortality	CdCl2	Less than 24hrs	69	28.8		118 (94-123)	7.7 (7.2-8.2)	8.5 (7.4-9.3)	2	concs tested not reported, so can't tell if range of concs was appropriate, control mortality not reported (but assume within appropriate range b/c EPA protocols were followed)	S		
Daphnia magna (Water flea)	48 h LC15	Mortality	cadmium chloride	Less than 24hrs	30.348				7.4 +- 0.07	91.4% +- 2.4% saturation	2	used nominal concs only (even though test solutions measured at beginning), missing temp, alkalinity, hardness	S	(Shaw et al. 2006)	
Daphnia magna (Water flea)	48 h LC50	Mortality	cadmium chloride	Less than 24hrs	101.16				7.4 +- 0.07	91.4% +- 2.4% saturation	2	used nominal concs only (even though test solutions measured at beginning), missing temp, alkalinity, hardness	S		
Daphnia magna (Water flea)	48 h LC85	Mortality	cadmium chloride	Less than 24hrs	336.076				7.4 +- 0.07	91.4% +- 2.4% saturation	2	used nominal concs only (even though test solutions measured at beginning), missing temp, alkalinity, hardness	S		
Daphnia magna (Water flea)	48 h LC50	Mortality	CdCl2	Less than 24hrs	178	36.2		240 +- 10	8.0 +- 0.3	>5	2	nominal only, temp 23 degrees - warm	S	(Elnabarawy et al. 1986)	H
Daphnia magna (Water flea)	48 h LC50	Mortality	commercial reference standard	Less than 24hrs	24	41.7		26-32	6.6-6.7	7.5-9	1	no problems except it's from 1984	S	(Schuytema et al. 1984)	H
Daphnia magna (Water flea)	48 h LC50	Mortality	commercial reference standard	Less than 24hrs	36	62.6		26-32	7.5-7.8	7.5-9	1	no problems except it's from 1984	S		H

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Daphnia magna (Water flea)	48 h LC50	Mortality	commercial reference standard	Less than 24hrs	>36	62.6		26-32	7.8	7.5-9	2	"greater than" value, and it's from 1984	S		H
Daphnia magna (Water flea)	48 h LC50	Mortality	commercial reference standard	Less than 24hrs	40	69.6		26-32	6.6-6.7	7.5-9	1	no problems except it's from 1984	S		H
Daphnia magna (Water flea)	48 h LC50	Mortality	commercial reference standard	Less than 24hrs	62	107.8		26-32	7.5-7.8	7.5-9	1	no problems except it's from 1984	S		H
Daphnia magna (Water flea)	48 h LC50	Mortality	commercial reference standard	Less than 24hrs	56.74179708	98.6		26-32	7.8	7.5-9	U	control mortality was 20%	S		
Daphnia magna (Water flea)	48 h LC50	Mortality	CdCl2.1/2 H2O	Less than 24hrs	65	71.9		45.3 (44-53)	7.74 (7.4-8.2)	9	2	control mortality not specified, no confidence intervals, didn't specify whether measured concs were for beginning or end of week (i.e. can't be sure metal concs were constant throughout the week), Cd concs used not reported (but presumably ok since they	R	(Biesinger and Christensen 1972)	H
Daphnia magna (Water flea)	48 h LC50	Mortality	cadmium chloride	Less than 24hrs	166	123.3		55.0-79.0	7.2-7.8		2	no units given for any WQ parameters (but can assume units), they don't specifically mention how many organisms were used per replicate, but they followed ASTM procedures so presumably it was enough, no control mortality reported	S	(Spehar and Carlson 1984)	H
Daphnia magna (Water flea)	24 h LC50	Mortality	cadmium chloride	Less than 24hrs	225 (approx)						2	all LC5o values given are approximate because they were read from the graphs, numbers and variations were not stated anywhere in the paper, missing pH, hardness, conductivity, can't tell if appropriate Cd range was used, concs not stated	NR	(Heugens et al. 2003)	
Daphnia magna (Water	24 h	Mortality	cadmium	Less than	250						2	See comments above	NR		

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
flea)	LC50		chloride	24hrs	(approx)										
Daphnia magna (Water flea)	48 h LC50	Mortality	cadmium chloride	Less than 24hrs	250 (approx)						2	See comments above	NR		
Daphnia magna (Water flea)	48 h LC50	Mortality	cadmium chloride	Less than 24hrs	50 (approx)						2	all LC5o values given are approximate because they were read from the graphs, numbers and variations were not stated anywhere in the paper, missing pH, hardness, conductivity, can't tell if appropriate Cd range was used, concs not stated	NR		
Daphnia magna (Water flea)	48 h LC50	Mortality	cadmium chloride	Less than 24hrs	50 (approx)						2	See comments above	NR		
Daphnia magna (Water flea)	48 h LC50	Mortality	cadmium chloride	Less than 24hrs	75 (approx)						2	all LC5o values given are approximate because they were read from the graphs, numbers and variations were not stated anywhere in the paper, missing pH, hardness, conductivity, can't tell if appropriate Cd range was used, concs not stated	NR		
Daphnia magna (Water flea)	24 h LC50	Mortality	cadmium chloride	Less than 24hrs	350 (approx)						2	all LC5o values given are approximate because they were read from the graphs, numbers and variations were not stated anywhere in the paper, missing pH, hardness, conductivity, can't tell if appropriate Cd range was used, concs not stated	NR		
Daphnia magna (Water flea)	48 h LC50	Mortality	cadmium chloride	Less than 24hrs	800 (approx)						2	See comments above	NR		
Daphnia magna (Water flea)	24 h LC50	Mortality	cadmium chloride	Less than 24hrs	900 (approx)						2	See comments above	NR		
Daphnia magna (Water flea)	48 h LC50	Mortality	cadmium chloride	Less than 24hrs	900 (approx)						2	See comments above	NR		
Daphnia magna (Water flea)	48 h LC50	Mortality	cadmium chloride	Less than 24hrs	1200 (approx)						2	See comments above	NR		
Daphnia magna (Water flea)	24 h LC50	Mortality	cadmium chloride	Less than 24hrs	1300 (approx)						2	See comments above	NR		
Daphnia magna (Water	24 h	Mortality	cadmium	Less than	1575						2	See comments above	NR		

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
flea)	LC50		chloride	24hrs	(approx)										
Daphnia magna (Water flea)	24 h LC50	Mortality	cadmium chloride	Less than 24hrs	2200 (approx)						2	See comments above	NR		
Daphnia magna (Water flea)	24 h LC50	Mortality	cadmium chloride	Less than 24hrs							U	temp was too high to be appropriate for Canadian guideline derivation, all LC5o values given are approximate b/c they were read from the graphs, numbers and variations were not stated anywhere in the paper, missing pH, hardness, conductivity	NR		
Daphnia magna (Water flea)	48 h LC50	Mortality	cadmium chloride	Less than 24hrs							U	temp was too high to be appropriate for Canadian guideline derivation, all LC5o values given are approximate b/c they were read from the graphs, numbers and variations were not stated anywhere in the paper, missing pH, hardness, cond	NR		
Daphnia magna (Water flea)	48 h LC50	Mortality	cadmium chloride	Neonate	104.9			NR	NR	0.1-1.9	2	Dissolved Oxygen: 9.0, multiple abiotic factors are incomplete	R	(Ferreira et al. 2008)	
Daphnia magna (Water flea)	48 h LC50	Mortality	cadmium chloride	Neonate	66.8			NR	NR	0.1-1.9	2	Dissolved Oxygen: 1.0	R		
Daphnia magna (Water flea)	48 h LC50	Mortality	cadmium chloride	Neonate	8.2			NR	NR	0.1-1.9	2	Dissolved Oxygen: 0.5	R		
Daphnia magna (Water flea)	48 h LC50	Mortality	cadmium chloride	Neonate	90.1			NR	NR	0.1-1.9	2	Dissolved Oxygen: 1.5	R		
Daphnia magna (Water flea)	48 h LC50	Mortality	cadmium chloride	Neonate	97.8			NR	NR	0.1-1.9	2	Dissolved Oxygen: 2.5	R		
Daphnia magna (Water flea)	48 h LC50	Mortality	cadmium chloride	Neonate	98			NR	NR	0.1-1.9	2	Dissolved Oxygen: 2.0	R		
Daphnia magna (Water flea) #	48 h LC50	Mortality	CdCl2 . 1/2 H2O	Less than 24hrs	16.40612056	7.79		104	8.2		U	Control mortality not reported	S	(Chapman et al. 1980)	H
Daphnia magna (Water flea)	48 h LC50	Mortality	CdCl2 . 1/2 H2O	Less than 24hrs	16.25064933	7.65		105	8.0		U	Control mortality not reported	S		H
Daphnia magna (Water flea)	48 h LC50	Mortality	CdCl2 . 1/2 H2O	Less than 24hrs	11.80662256	2.76		209	8.5		U	Control mortality not reported	S		H
Daphnia magna (Water	48 h	Mortality	CdCl2 .	Less than	16.0998	4.00		197	7.9		U	Control mortality not reported	S		H

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
flea)	LC50		1/2 H2O	24hrs	4922										
Daphnia magna (Water flea)	48 h LC50	Mortality	CdCl2 . 1/2 H2O	Less than 24hrs	9.70684 341	9.5		51	7.5		U	Control mortality not reported	S		H
Daphnia magna (Water flea)	24 h LC50	Mortality	CdCl2	24h	383.375 4364	74.8		249.8	8.0 +- 0.2	69-100% sat	U	nominal only, concs NOT measured for acute, temp very high (25 degrees), no cond, alk, and hardness had to be calculated from Ca and Mg, no stats reported i.e. how LC50 was calculated, concs not reported for acute, can't tell what upper range was so can't	S	(Kühn et al. 1989)	H
Daphnia pulex (Water flea)	48 h LC50	Mortality	CdCl2	Less than 24hrs	70	17.1		200 ± 10	7.7 ± 0.4		U	Nominal concentrations	S	(Hall et al. 1986)	
Daphnia pulex (Water flea)	48 h LC50	Mortality	CdCl2	Less than 24hrs	110	26.9		200 ± 10	7.7 ± 0.4		U	Nominal concentrations	S		
Daphnia pulex (Water flea)	48 h LC50	Mortality	CdCl2	Less than 24hrs	80	32.9		120 ± 10	7.8 ± 0.3		2	Nominal concentrations	S		H
Daphnia pulex (Water flea)	48 h LC50	Mortality	CdCl2	Less than 24hrs	100	41.1		120 ± 10	7.8 ± 0.3		2	Nominal concentrations	S		H
Daphnia pulex (Water flea)	96 h LC50	Mortality	CdCl2 x 2 1/2H20	Less than 24hrs	32.4	30.24	X	53.5 ± 3.8	7.65 ± 0.12	NR	2	Control mortality not reported but results are compared statistically and abiotic factors are not complete	S	(Stackhouse and Benson 1988)	H
Daphnia pulex (Water flea)	72 h LC50	Mortality	CdCl2 x 2 1/2H20	Less than 24hrs	46.3	43.2		53.5 ± 3.8	7.65 ± 0.12	NR	2	Control mortality not reported but results are compared statistically and abiotic factors are not complete	S		
Daphnia pulex (Water flea)	48 h LC50	Mortality	CdCl2 x 2 1/2H20	Less than 24hrs	70.1	65.44		53.5 ± 3.8	7.65 ± 0.12	NR	2	Control mortality not reported but results are compared statistically and abiotic factors are not complete	S		H
Daphnia pulex (Water flea)	24 h LC50	Mortality	CdCl2 x 2 1/2H20	Less than 24hrs	179.9	167.9		53.5 ± 3.8	7.65 ± 0.12	NR	2	Control mortality not reported but results are compared statistically and abiotic factors are not complete	S		
Daphnia pulex (Water flea)	48 h LC15	Mortality	cadmium chloride	Less than 24hrs	37.092				7.4 +- 0.07	91.4% +- 2.4% saturation	2	used nominal concs only (even though test solutions measured at beginning), missing temp, alkalinity, hardness	S	(Shaw et al. 2006)	
Daphnia pulex (Water flea)	48 h LC50	Mortality	cadmium chloride	Less than 24hrs	44.96				7.4 +- 0.07	91.4% +-	2	used nominal concs only (even though test solutions measured at beginning), missing temp, alkalinity, hardness	S		

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
										2.4% saturation					
Daphnia pulex (Water flea)	48 h LC85	Mortality	cadmium chloride	Less than 24hrs	53.952				7.4 +- 0.07	91.4% +- 2.4% saturation	2	used nominal concs only (even though test solutions measured at beginning), missing temp, alkalinity, hardness	S		
Daphnia pulex (Water flea)	72 h LC50	Mortality	CdCl2	Less than 24hrs	62	54.18		57.1	7.7		2	No control mortality reported and toxicant concentrations are calculated	S	(Bertram and Hart 1979)	
Daphnia pulex (Water flea)	96 h LC50	Mortality	CdCl2	Less than 24hrs	47	41.1		57.1	7.7		2	No control mortality reported and toxicant concentrations are calculated	S		
Daphnia pulex (Water flea)	48 h LC50	Mortality	CdCl2	Less than 24hrs	319	64.81		240 +- 10	8.0 +- 0.3	>5	2	nominal only, temp 23 degrees - warm	S	(Elnabarawy et al. 1986)	H
Daphnia pulex (Water flea)	48 h LC50	Mortality	CdCl2	Less than 24hrs	66	38.5		80-90			U	many WQ parameters missing, e.g. pH, O2, cond, alk, also not sure whether concs were measured or not (don't think so, and they weren't reported), concs not reported (for acute)	S	(Roux et al. 1993)	H
Daphnia pulex (Water flea)	48 h LC50	Mortality	CdCl2	Less than 24hrs	70	40.82		80-90			U	many WQ parameters missing, e.g. pH, O2, cond, alk, also not sure whether concs were measured or not (don't think so, and they weren't reported), concs not reported (for acute)	S		H
Daphnia pulex (Water flea)	48 h LC50	Mortality	CdCl2	Less than 24hrs	78	45.49		80-90			U	Average of the three replicates, many WQ parameters missing, e.g. pH, O2, cond, alk, also not sure whether concs were measured or not (don't think so, and they weren't reported), concs not reported	S		
Daphnia pulex (Water flea)	48 h LC50	Mortality	CdCl2	Less than 24hrs	99	57.74		80-90			U	many WQ parameters missing, e.g. pH, O2, cond, alk, also not sure whether concs were measured or not (don't think so, and they weren't reported), concs not reported (for acute)	S		H
Echinogammarus meridionalis (Gammarid	96 h LC50	Mortality	cadmium chloride	Adult							U	no chemical or physical properties given, nominal concs only, not many replicates, control mortality not reported,	S	(Pestana et al. 2007)	

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
amphipod)												number of concs tested and range not known			
Enallagma sp. (Damselfly)	96 h LC50	Mortality	cadmium chloride	Not reported	10660	35502.9	x	15.3 ± 3.4	NR	NR	2	pH: 4.5, nominal concentrations and control mortality not reported	S	(Mackie 1989)	
Enallagma sp. (Damselfly)	96 h LC50	Mortality	cadmium chloride	Not reported	7050	23479.9	x	15.3 ± 3.4	NR	NR	2	pH: 3.5, nominal concentrations and control mortality not reported	S		
Enallagma sp. (Damselfly)	96 h LC50	Mortality	cadmium chloride	Not reported	8660	28842	x	15.3 ± 3.4	NR	NR	2	pH: 4.0, nominal concentrations and control mortality not reported	S		
Euplotes affinis (Ciliate)	24 h LC50	Mortality	hydrated cadmium chloride	Adult					7.3 (range: 7.0-7.8)		U	all variables missing except pH, nominal concs only, control mortality not reported, can't tell if range was appropriate	S	(Madoni et al. 1992)	
Euplotes patella (Ciliate)	24 h LC50	Mortality	hydrated cadmium chloride	Adult					7.3 (range: 7.0-7.8)		U	all variables missing except pH, nominal concs only, control mortality not reported, can't tell if range was appropriate	S		
Gammarus fossarum (Amphipod)	96 h LC50	Mortality	Cadmium chloride	Adults	0.19	0.19		NR	8.0 ± 0.18	7.8 ± 0.85	2	Not a resident of Canada. Nominal concentrations, concentrations determined from a graph	R	(Alonso et al. 2010)	
Gammarus fossarum (Amphipod)	48 h LC50	Mortality	Cadmium chloride	Adults	0.7	0.70		NR	8.0 ± 0.18	7.8 ± 0.85	2	Not a resident of Canada. Nominal concentrations, concentrations determined from a graph	R		
Gammarus fossarum (Amphipod)	96 h EC50	Mortality	Cadmium chloride	Adults	0.2	0.20		NR	8.0 ± 0.18	7.8 ± 0.85	2	Not a resident of Canada. Nominal concentrations, concentrations determined from a graph	R		
Gammarus fossarum (Amphipod)	48 h EC50	Mortality	Cadmium chloride	Adults	0.48	0.48		NR	8.0 ± 0.18	7.8 ± 0.85	2	Not a resident of Canada. Nominal concentrations, concentrations determined from a graph	R		
Gammarus fossarum (Amphipod)	96 h LC50	Mortality	Cadmium chloride	Juvenile	0.043	0.04		NR	8.0 ± 0.19	7.7 ± 0.61	2	Not a resident of Canada. Nominal concentrations, concentrations determined from a graph	R		
Gammarus fossarum (Amphipod)	48 h LC50	Mortality	Cadmium chloride	Juvenile	0.14	0.14		NR	8.0 ± 0.19	7.7 ± 0.61	2	Not a resident of Canada. Nominal concentrations, concentrations determined from a graph	R		
Gammarus fossarum (Amphipod)	96 h EC50	Mortality and Inactivity	Cadmium chloride	Juvenile	0.033	0.03		NR	8.0 ± 0.19	7.7 ± 0.61	2	Not a resident of Canada. Nominal concentrations, concentrations determined from a graph	R		
Gammarus fossarum (Amphipod)	48 h EC50	Mortality and Inactivity	Cadmium chloride	Juvenile	0.043	0.04		NR	8.0 ± 0.19	7.7 ± 0.61	2	Not a resident of Canada. Nominal concentrations, concentrations determined from a graph	R		

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Gammarus pseudolimnaeus (Amphipod)	96 h LC50	Mortality	cadmium chloride	Less than 24hrs	54.4	40.41	X	55.0-79.0	7.2-7.8		2	no units given for any WQ parameters (but can assume units), no DO value given, they don't specifically mention how many organisms were used per replicate, but they followed ASTM procedures so presumably it was enough, no control mortality reported, feedi	S	(Spehar and Carlson 1984)	
Gammarus pseudolimnaeus (Amphipod)	96 h LC50	Mortality	cadmium chloride	Less than 24hrs	68.3	78.68		39.0-48.0	7.0-7.9		2	no units given for any WQ parameters (but can assume units), no DO value given, they don't specifically mention how many organisms were used per replicate, but they followed ASTM procedures so presumably it was enough, no control mortality reported, feedi	S		
Gammarus pulex (Amphipod)	96 h EC50	Mortality and Inactivity	Cadmium chloride	Juvenile	0.41	0.41		NR	8.1 ± 0.17	8.5 ± 0.43	2	Not a resident of Canada. Nominal concentrations, concentrations determined from a graph	R	(Alonso et al. 2010)	
Gammarus pulex (Amphipod)	96 h LC50	Mortality	Cadmium chloride	Juvenile	0.58	0.58		NR	8.1 ± 0.17	8.5 ± 0.43	2	Not a resident of Canada. Nominal concentrations, concentrations determined from a graph	R		
Gammarus pulex (Amphipod)	48 h EC50	Mortality and Inactivity	Cadmium chloride	Juvenile	0.86	0.86		NR	8.1 ± 0.17	8.5 ± 0.43	2	Not a resident of Canada. Nominal concentrations, concentrations determined from a graph	R		
Gammarus pulex (Amphipod)	96 h EC50	Mortality	Cadmium chloride	Adult	1.17	1.17		NR	8.2 ± 0.10	8.8 ± 0.45	2	Not a resident of Canada. Nominal concentrations, concentrations determined from a graph	R		
Gammarus pulex (Amphipod)	48 h LC50	Mortality	Cadmium chloride	Juvenile	1.19	1.19		NR	8.1 ± 0.17	8.5 ± 0.43	2	Not a resident of Canada. Nominal concentrations, concentrations determined from a graph	R		
Gammarus pulex (Amphipod)	96 h LC50	Mortality	Cadmium chloride	Adult	1.71	1.71		NR	8.2 ± 0.10	8.8 ± 0.45	2	Not a resident of Canada. Nominal concentrations, concentrations determined from a graph	R		
Gammarus pulex (Amphipod)	48 h EC50	Mortality	Cadmium chloride	Adult	3.52	3.52		NR	8.2 ± 0.10	8.8 ± 0.45	2	Not a resident of Canada. Nominal concentrations, concentrations determined from a graph	R		
Gammarus pulex (Amphipod)	48 h LC50	Mortality	Cadmium chloride	Adult	8.37	8.37		NR	8.2 ± 0.10	8.8 ± 0.45	2	Not a resident of Canada. Nominal concentrations, concentrations determined from a graph	R		
Gammarus pulex (Amphipod)	48 h LC50	Mortality	CdCl2.2.5 H2O	Adult	21	10.99		94.6 +-7.2	7.7 +- 0.8	9.81 +- 0.8	2	replication not clear at all: how many test containers? How many beakers? How many organisms per beaker of each type? Was there pseudoreplication since all beakers within a test container were exposed to the same water? Also,	R	(McCahon and Pascoe 1988)	

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
												although concs were measu			
Gammarus pulex (Amphipod)	96 h LC50	Mortality	CdCl2.2.5 H2O	Adult	30	15.70		94.6 +-7.2	7.7 +- 0.8	9.81 +- 0.8	2	replication not clear at all: how many test containers? How many beakers? How many organisms per beaker of each type? Was there pseudoreplication since all beakers within a test container were exposed to the same water? Also, although concs were measu	R		
Gammarus pulex (Amphipod)	24 h LC50	Mortality	CdCl2.2.5 H2O	Adult	100	52.32		94.6 +-7.2	7.7 +- 0.8	9.81 +- 0.8	2	replication not clear at all: how many test containers? How many beakers? How many organisms per beaker of each type? Was there pseudoreplication since all beakers within a test container were exposed to the same water? Also, although concs were measu	R		
Gammarus pulex (Amphipod)	48 h LC50	Mortality	CdCl2.2.5 H2O	Adult	140	73.24		94.6 +-7.2	7.7 +- 0.8	9.81 +- 0.8	2	replication not clear at all: how many test containers? How many beakers? How many organisms per beaker of each type? Was there pseudoreplication since all beakers within a test container were exposed to the same water? Also, although concs were measu	R		
Gammarus pulex (Amphipod)	48 h LC50	Mortality	CdCl2.2.5 H2O	Adult	210	109.87		94.6 +-7.2	7.7 +- 0.8	9.81 +- 0.8	2	replication not clear at all: how many test containers? How many beakers? How many organisms per beaker of each type? Was there pseudoreplication since all beakers within a test container were exposed to the same water? Also, although concs were measu	R		
Gammarus pulex (Amphipod)	24 h LC50	Mortality	CdCl2.2.5 H2O	Adult	954.412 1924	499.3		94.6 +-7.2	7.7 +- 0.8	9.81 +- 0.8	U	Conc was outside of the range tested, replication not clear at all: how many test containers? How many beakers? How many organisms per beaker of each type? Was there pseudoreplication since all beakers within a test container were exposed to the same w	R		
Gammarus pulex (Amphipod)	24 h LC50	Mortality	CdCl2	Adult	211.673 9182	38.27		269.2	7.19 +- 0.02		U	value was outside the range of concs tested, no O2 or alk, hardness had to be calculated, concs were measured but didn't say how or when, no variation reported	FT	(Felten et al. 2007)	
Gammarus pulex (Amphipod)	96 h LC50	Mortality	CdCl2	Adult	82.1	14.84		269.2	7.19 +- 0.02		2	no O2 or alk, hardness had to be calculated, concs were measured but didn't say how or when, no variation reported	FT		
Gammarus pulex	48 h	Mortality	CdCl2	Adult	494	89.31		269.2	7.19 +-		2	no O2 or alk, hardness had to be calculated, concs were	FT		

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
(Amphipod)	LC50								0.02			measured but didn't say how or when, no variation reported			
Hyalella azteca (Amphipod)	96 h LC50	Mortality	Cd(NO3)2 - 4H2O	7- to 14-d old	5	0.838	X	280-300	6.0-8.5	>5	2	pH 8-8.5, control mortality high	S	(Schubauerbergian et al. 1993)	
Hyalella azteca (Amphipod)	96 h LC50	Mortality	Cd(NO3)2 - 4H2O	7- to 14-d old	<25	4.19		280-300	6.0-8.5	>5	2	pH 7-7.5, control mortality high	S		
Hyalella azteca (Amphipod)	96 h LC50	Mortality	Cd(NO3)2 - 4H2O	7- to 14-d old	230	38.56		280-300	6.0-8.5	>5	2	pH 6-6.5, control mortality high	S		
Hyalella azteca (Amphipod)	96 h LC50	Mortality	NR	7 to 10 d	7.6	3.05		10-380	7.0 ± 0.2	NR	2	Hardness: 123, magnesium concentration varied, control mortality not reported	S	(Jackson et al. 2000)	H
Hyalella azteca (Amphipod)	96 h LC50	Mortality	NR	7 to 10 d	6	3.56		10-380	7.0 ± 0.2	NR	2	Hardness: 83.7, magnesium concentration varied, control mortality not reported	S		H
Hyalella azteca (Amphipod)	96 h LC50	Mortality	NR	7 to 10 d	25	6.62		10-380	7.0 ± 0.2	NR	2	Hardness: 185, calcium concentration varied, control mortality not reported	S		H
Hyalella azteca (Amphipod)	96 h LC50	Mortality	NR	7 to 10 d	12.1	7.51		10-380	7.0 ± 0.2	NR	2	Hardness: 80, calcium concentration varied, control mortality not reported	S		H
Hyalella azteca (Amphipod)	96 h LC50	Mortality	NR	7 to 10 d	3.8	19.5		10-380	7.0 ± 0.2	NR	2	Hardness: 10, calcium concentration varied, control mortality not reported	S		H
Hyalella azteca (Amphipod)	96 h LC50	Mortality	NR	7 to 10 d	3.8	19.5		10-380	7.0 ± 0.2	NR	2	Hardness: 10, magnesium concentration varied, control mortality not reported	S		H
Hyalella azteca (Amphipod)	96 h LC50	Mortality	NR	7 to 10 d	3.12374 8685	0.437		10-380	7.0 ± 0.2	NR	U	Hardness: 346, hardness too high not likely to occur in the environment, magnesium concentration varied, control mortality not reported	S		H
Hyalella azteca (Amphipod)	96 h LC50	Mortality	NR	7 to 10 d	14.2504 8987	1.82		10-380	7.0 ± 0.2	NR	U	Hardness: 380, hardness too high not likely to occur in the environment, calcium concentration varied, control mortality not reported	S		H
Hyalella azteca (Amphipod)	96 h LC50	Mortality	cadmium chloride	Less than 24hrs	285	211.7		55.0-79.0	7.2-7.8		2	no units given for any WQ parameters (but can assume units, they don't specifically mention how many organisms were used per replicate, but they followed ASTM procedures, no control mortality reported	S	(Spehar and Carlson 1984)	
Hyalella azteca (Scud)	96 h LC50	Mortality	CdCl2	Juvenile	2.8	8.38		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day	S	(Suedel et al. 1997)	

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
												14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range			
Hyalella azteca (Scud)	48 h LC50	Mortality	CdCl2	Juvenile	5.6	16.76		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S		
Hyalella azteca (Scud)	96 h LC50	Mortality	cadmium chloride	Not reported	12	39.97		15.3 ± 3.4	NR	NR	2	pH: 5.0, nominal concentrations and control mortality not reported	S	(Mackie 1989)	H
Hyalella azteca (Scud)	96 h LC50	Mortality	cadmium chloride	Not reported	16	53.29		15.3 ± 3.4	NR	NR	2	pH: 5.5, nominal concentrations and control mortality not reported	S		H
Hyalella azteca (Scud)	96 h LC50	Mortality	cadmium chloride	Not reported	33	109.9		15.3 ± 3.4	NR	NR	2	pH: 6.0, nominal concentrations and control mortality not reported	S		H
Hydra viridissima (Green hydra)	96 h LC50	Mortality	cadmium chloride	Nonbudding	3	7.81	X	19-20	7.25-7.53	7.73-9.44	2	Nominal concentrations only - not measured, control survival not reported for acute tests	S	(Holdway et al. 2001)	
Hydra vulgaris (Pink hydra)	96 h LC50	Mortality	cadmium chloride	Nonbudding	82.5	214.75		19-20	7.25-7.53	7.73-9.44	2	Nominal concentrations only - not measured, control survival not reported for acute tests	S		H
Hydra vulgaris (Pink hydra)	96 h LC50	Mortality	CdCl2 . 2.5 H20	Juvenile	120	54.88	X	108 (SE = 3.6)	7.2-7.8		2	no O2, alk, cond, concs measured at beginning but not sure if measured at end, control mortality and feeding not reported	S	(Beach and Pascoe 1998)	H
Lampsilis rafinesqueana (Neosho mucket)	48 h EC50	Mortality	cadmium nitrate	Juvenile	38	43.27		40-48	7.2-7.6	> 7.0	1	No problems	R	(Wang et al. 2010)	
Lampsilis rafinesqueana (Neosho mucket)	96 h EC50	Mortality	cadmium nitrate	Juvenile	20	22.77	X	40-48	7.2-7.6	> 7.0	1	No problems	R		
Lampsilis siliquoidea (fatmucket)	24 h EC50	Mortality	cadmium nitrate	glochidia	>8.0	9.11		40-48	7.2-7.6	> 7.0	2	Nominal concentrations used, Not in the range of concentrations tested	S		
Lampsilis siliquoidea (fatmucket)	24 h EC50	Mortality	cadmium nitrate	glochidia	>33	37.58		40-48	7.2-7.6	> 7.0	2	Not in the range of concentrations tested	S		
Lampsilis siliquoidea (fatmucket)	24 h EC50	Mortality	cadmium nitrate	glochidia	>227	258.5		40-48	7.2-7.6	> 7.0	2	Not in the range of concentrations tested	S		
Lampsilis siliquoidea (fatmucket)	48 h EC50	Mortality	cadmium nitrate	glochidia	>8.0	9.11	x	40-48	7.2-7.6	> 7.0	2	Nominal concentrations used, Not in the range of concentrations tested	S		

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Lampsilis siliquoidea (fatmucket)	48 h EC50	Mortality	cadmium nitrate	glochidia	>33	37.58	x	40-48	7.2-7.6	> 7.0	2	Not in the range of concentrations tested	S		
Lampsilis siliquoidea (fatmucket)	48 h EC50	Mortality	cadmium nitrate	glochidia	>227	258.8	x	40-48	7.2-7.6	> 7.0	2	Not in the range of concentrations tested	S		
Lampsilis siliquoidea (fatmucket)	48 h EC50	Mortality	cadmium nitrate	Juvenile	<34	38.72		40-48	7.2-7.6	> 7.0	2	Not in the range of concentrations tested	R		
Lampsilis siliquoidea (fatmucket)	48 h EC50	Mortality	cadmium nitrate	Juvenile	42	47.8		40-48	7.2-7.6	> 7.0	1	No problems	R		
Lampsilis siliquoidea (fatmucket)	48 h EC50	Mortality	cadmium nitrate	Juvenile	>62	70.60		40-48	7.2-7.6	> 7.0	2	Not in the range of concentrations tested	R		
Lampsilis siliquoidea (fatmucket)	48 h EC50	Mortality	cadmium nitrate	Juvenile	>230	2461.9		40-48	7.2-7.6	> 7.0	2	Not in the range of concentrations tested	R		
Lampsilis siliquoidea (fatmucket)	96 h EC50	Mortality	cadmium nitrate	Juvenile	16	18.22		40-48	7.2-7.6	> 7.0	1	No problems	R		
Lampsilis siliquoidea (fatmucket)	96 h EC50	Mortality	cadmium nitrate	Juvenile	<34	38.72		40-48	7.2-7.6	> 7.0	2	Not in the range of concentrations tested	R		
Lampsilis siliquoidea (fatmucket)	96 h EC50	Mortality	cadmium nitrate	Juvenile	>62	70.61		40-48	7.2-7.6	> 7.0	2	Not in the range of concentrations tested	R		
Lampsilis siliquoidea (fatmucket)	96 h EC50	Mortality	cadmium nitrate	Juvenile	199	226.6		40-48	7.2-7.6	> 7.0	1	No problems	R		
Limnodrilus hoffmeisteri (Oligochaete)	96 h LC50	Mortality	3CdSO4 (8H2O)	Adult	170	1662.4	X	5.30 ± 0.64	7.0 ± 0.2		2	Control mortality not reported	R	(Chapman et al. 1982)	
Lumbriculus variegatus (Oligochaete)	96 h LC50	Mortality	Cd(NO3)2 - 4H2O	Adult	780	130.75	X	280-300	6.0-8.5	>5	2	pH 6-6.5, control mortality high	S	(Schubauerbergian et al. 1993)	
Lumbriculus variegatus (Oligochaete)	96 h LC50	Mortality	Cd(NO3)2 - 4H2O	Adult	780	130.75		280-300	6.0-8.5	>5	2	pH 7-7.5, control mortality high	S		
Lumbriculus variegatus (Oligochaete)	96 h LC50	Mortality	Cd(NO3)2 - 4H2O	Adult	780	130.75		280-300	6.0-8.5	>5	2	pH 8-8.5, control mortality high	S		
Neomysis integer (Mysid)	96 h LC50	Mortality	Cd2+	Population							U	no O2 or pH measured, nominal Cd concs, only 3 Cd concs tested, which was an insufficient range for the salinity of 20), high control mortality (may not have been fed for 9	NR	(Wildgust and Jones 1998)	

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
												days!), BIGGEST PROBLEM: LC50 values don't make sense based on their raw data			
Neomysis integer (Mysid)	96 h LC50	Mortality	Cd2+	Not reported							U	no O2 or pH measured, nominal Cd concs, only 3 Cd concs tested, which was an insufficient range for the salinity of 20), high control mortality (may not have been fed for 9 days!), BIGGEST PROBLEM: LC50 values don't make sense based on their raw data	NR		
Neomysis integer (Mysid)	96 h LC50	Mortality	Cd2+	Not reported							U	no O2 or pH measured, nominal Cd concs only, only 3 Cd concs tested, which was an insufficient range for the salinity of 20), high control mortality (may not have been fed for 9 days!), BIGGEST PROBLEM: LC50 values don't make sense based on their raw data	NR		
Notropis lutrensis (Red shiner)	96 h LC50	Mortality		Adult	3881.74 3725	2250.6		85.5			U	Missing abiotic factors, no control mortality reported, no replications	S	(Carrier and Bettinger 1988)	
Orconectes immunis (Nail polish crayfish)	96 h LC50	Mortality	CdCl2	Adult	> 10200	11508.3	X	44.4 (40.7-46.6)	7.1-7.8	7.5 (4.7-10.0)	2	greater than value, no conductivity, control mortality not reported (but see Notes section), number of concs tested was confusing but seems that range was ok	FT	(Phipps and Holcombe 1985)	
Orconectes juvenilis (Kentucky River crayfish)	96 h LC50	Mortality	cadmium chloride	Adult	2440	2772.0	X	44.1		>4.0	2	Control mortality not reported, just for the ones that were molting, what was the pH (and cond and alk), source of water, were they fed, are these values for the free Cd ion or total Cd?	R	(Wigginton and Birge 2007)	
Orconectes juvenilis (Kentucky River crayfish)	96 h LC10	Mortality	cadmium chloride	Adult	623	707.77		44.1		>4.0	2	Control mortality not reported, just for the ones that were molting, what was the pH (and cond and alk), source of water, were they fed, are these values for the free Cd ion or total Cd?	R		
Orconectes placidus (Placid crayfish)	96 h LC50	Mortality	cadmium chloride	Adult	487	553.3	X	44.1		>4.0	2	Control mortality not reported, just for the ones that were molting, what was the pH (and cond and alk), source of water, were they fed, are these values for the free Cd ion or total Cd?	R		
Orconectes virilis (Northern crayfish)	96 h LC50	Mortality	CdCl2.2.5 H2O	Adult	6100	11854.2		26 (24-28	6.9 (6.7-7.0)	8.4 (8.1-8.6)	1	no conductivity	FT	(Mirenda 1986)	

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Orconectes virilis (Northern crayfish)	96 h LC50	Mortality	cadmium chloride	Adult	3300	3892.5	X	42.5		>4.0	2	Control mortality not reported, just for the ones that were molting, what was the pH (and cond and alk), source of water, were they fed, are these values for the free Cd ion or total Cd?	R	(Wigginton and Birge 2007)	
Orconectes virilis (Northern crayfish)	96 h LC10	Mortality	cadmium chloride	Adult	947	1117.0		42.5		>4.0	2	Control mortality not reported, just for the ones that were molting, what was the pH (and cond and alk), source of water, were they fed, are these values for the free Cd ion or total Cd?	R		
Paraleptophlebia praepedita (Mayfly)	96 h LC50	Mortality	cadmium chloride	Juvenile	449	333.5	X	55.0-79.0	7.2-7.8		2	no units given for any WQ parameters (but can assume units), they don't specifically mention how many organisms were used per replicate, but they followed ASTM, no control mortality reported,	S	(Spehar and Carlson 1984)	
Paramecium caudatum (Ciliate)	24 h LC50	Mortality	hydrated cadmium chloride	Adult					7.3 (range: 7.0-7.8)		U	all variables missing except pH, nominal concs only, control mortality not reported, can't tell if range was appropriate	S	(Madoni et al. 1992)	
Pisidium casertanum (Bivalve)	96 h LC50	Mortality	cadmium chloride	Not reported	1370	4562.8	x	15.3 ± 3.4	NR	NR	2	pH: 3.5, nominal concentrations and control mortality not reported	S	(Mackie 1989)	
Pisidium casertanum (Bivalve)	96 h LC50	Mortality	cadmium chloride	Not reported	480	1598.6	x	15.3 ± 3.4	NR	NR	2	pH: 4.0, nominal concentrations and control mortality not reported	S		
Pisidium casertanum (Bivalve)	96 h LC50	Mortality	cadmium chloride	Not reported	700	2331.3	x	15.3 ± 3.4	NR	NR	2	pH: 4.5, nominal concentrations and control mortality not reported	S		
Pisidium compressum (Bivalve)	96 h LC50	Mortality	cadmium chloride	Not reported	2080	6927.4	x	15.3 ± 3.4	NR	NR	2	pH: 3.5, nominal concentrations and control mortality not reported	S		
Pisidium compressum (Bivalve)	96 h LC50	Mortality	cadmium chloride	Not reported	360	1199.0	x	15.3 ± 3.4	NR	NR	2	pH: 4.5, nominal concentrations and control mortality not reported	S		
Pisidium compressum (Bivalve)	96 h LC50	Mortality	cadmium chloride	Not reported	700	2331.3	x	15.3 ± 3.4	NR	NR	2	pH: 4.0, nominal concentrations and control mortality not reported	S		
Potamopyrgus antipodarum (Mud snail)	48 h LC50	Mortality	CdCl2.H20	Adult	7200		X				2	nominal only, weird study design: they put the orgs into the Cd concs for 48 hrs, then took them out and put them in clean water for 24 hrs to assess mortality! Also no pH, O2, alk, hardness, conduct	S	(Moller et al. 1996)	

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Procambarus acutus (White River crayfish)	96 h LC50	Mortality	cadmium chloride	Adult	368	414.3	X	44.5		>4.0	2	Control mortality not reported, just for the ones that were molting, what was the pH (and cond and alk), source of water, were they fed, are these values for the free Cd ion or total Cd?	R	(Wigginton and Birge 2007)	
Procambarus alleni (Electric blue dragon crayfish)	96 h LC50	Mortality	cadmium chloride	Adult	3070	3356.2	X	45.8		>4.0	2	Control mortality not reported, just for the ones that were molting, what was the pH (and cond and alk), source of water, were they fed, are these values for the free Cd ion or total Cd?	R		
Procambarus alleni (Electric blue dragon crayfish)	96 h LC10	Mortality	cadmium chloride	Adult	386	421.99		45.8		>4.0	2	Control mortality not reported, just for the ones that were molting, what was the pH (and cond and alk), source of water, were they fed, are these values for the free Cd ion or total Cd?	R		
Procambarus clarkii (Red swamp crawfish)	96 h LC50	Mortality	cadmium chloride	Juvenile	624	589.3	X	52.9		>4.0	2	Control mortality not reported, just for the ones that were molting, what was the pH (and cond and alk), source of water, were they fed, are these values for the free Cd ion or total Cd?	R		
Procambarus clarkii (Red swamp crawfish)	96 h LC10	Mortality	cadmium chloride	Juvenile	283	267.2		52.9		>4.0	2	Control mortality not reported, just for the ones that were molting, what was the pH (and cond and alk), source of water, were they fed, are these values for the free Cd ion or total Cd?	R		
Procambarus clarkii (Red swamp crawfish)	96 h LC50	Mortality	cadmium chloride	Adult	2660	2511.9		52.9		>4.0	2	Control mortality not reported, just for the ones that were molting, what was the pH (and cond and alk), source of water, were they fed, are these values for the free Cd ion or total Cd?	R		
Quistadrilus multisetosus (Oligochaete)	96 h LC50	Mortality	3CdSO4 (8H2O)	Adult	320	3129.2	X	5.30 ± 0.64	7.0 ± 0.2		2	Control mortality not reported	R	(Chapman et al. 1982)	
Rhithrogena hageni (Mayfly)	96 h LC50	Mortality	cadmium sulfate	nymph	10500	10944.7	X	48.0 ± 2.0	7.66 ± 0.1	9.07 ± 0.15	1	No problems	FT	(Brinkman and Johnston 2008)	
Rhyacodrilus montana (Oligochaete)	96 h LC50	Mortality	3CdSO4 (8H2O)	Adult	630	6160.7	X	5.30 ± 0.64	7.0 ± 0.2		2	Control mortality not reported	R	(Chapman et al. 1982)	
Simocephalus serrulatus (Cladocerans)	48 h LC50	Mortality	cadmium chloride	Less than 24hrs	123	91.36		55.0-79.0	7.2-7.8		2	no units given for WQ parameters (but can assume units), they don't specifically mention how many organisms were	S	(Spehar and Carlson 1984)	

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
												used per replicate, but they followed ASTM procedures, no control mortality reported			
Simocephalus serrulatus (Cladocerans)	48 h LC50	Mortality	cadmium chloride	Less than 24hrs	24.5	28.22	X	39.0-48.0	7.0-7.9		2	no units given for WQ parameters (but can assume units), they don't specifically mention how many organisms were used per replicate, but they followed ASTM procedures, no control mortality reported	S		
Simocephalus serrulatus (Water flea)	48 h LC50	Mortality	not reported	Neonate	35	179.6		10	5.6	>80% sat	2	other metals present, not sure if concs were measured at end (or at all?), control mort not specified, variation not reported	S	(Giesy et al. 1977)	
Simocephalus serrulatus (Water flea)	48 h LC50	Mortality	not reported	Neonate	7	32.30		11.1	6.5	>80% sat	2	other metals present, not sure if concs were measured at end (or at all?), control mort not specified	S		
Simocephalus vetulus (Cladocerans)	48 h LC50	Mortality	cadmium chloride	Less than 24hrs	89.3	66.33	X	55.0-79.0	7.2-7.8		2	no units given for WQ parameters (but can assume units), they don't specifically mention how many organisms were used per replicate, but they followed ASTM procedures, no control mortality reported	S	(Spehar and Carlson 1984)	
Spirosperma ferox (Oligochaete)	96 h LC50	Mortality	3CdSO4 (8H2O)	Adult	350	3422.6	X	5.30 ± 0.64	7.0 ± 0.2		2	Control mortality not reported	R	(Chapman et al. 1982)	
Spirosperma nikolskyi (Oligochaete)	96 h LC50	Mortality	3CdSO4 (8H2O)	Adult	450	4400.5	X	5.30 ± 0.64	7.0 ± 0.2		2	Control mortality not reported	R		
Stylodrilus heringianus (Oligochaete)	96 h LC50	Mortality	3CdSO4 (8H2O)	Adult	550	5378.4	X	5.30 ± 0.64	7.0 ± 0.2		2	Control mortality not reported	R		
Tubifex tubifex (Oligochaete)	96 h LC10	Mortality	CdCl2 - 2.5H2O	Immature	160	160.00			7.03	> 6.5	2	nominal concentrations	S	(Maestre et al. 2009)	
Tubifex tubifex (Oligochaete)	96 h NOEC/L	Mortality	CdCl2 - 2.5H2O	Immature	170	170.00			7.03	> 6.5	1		S		
Tubifex tubifex (Oligochaete)	96 h LC5	Mortality	CdCl2 - 2.5H2O	Immature	170	170.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex (Oligochaete)	96 h LC15	Mortality	CdCl2 - 2.5H2O	Immature	170	170.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex (Oligochaete)	96 h LC10	Mortality	CdCl2 - 2.5H2O	Immature	200	200.00			7.03	> 6.5	2	nominal concentrations	S		

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Tubifex tubifex (Oligochaete)	96 h LC15	Mortality	CdCl2 - 2.5H2O	Immature	210	210.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex (Oligochaete)	96 h LC5	Mortality	CdCl2 - 2.5H2O	Immature	220	220.00			7.03	> 6.5	1		S		
Tubifex tubifex (Oligochaete)	72 h LC5	Mortality	CdCl2 - 2.5H2O	Immature	220	220.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex (Oligochaete)	72 h LC10	Mortality	CdCl2 - 2.5H2O	Immature	230	230.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex (Oligochaete)	96 h LC5	Mortality	CdCl2 - 2.5H2O	Immature	240	240.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex (Oligochaete)	72 h LC10	Mortality	CdCl2 - 2.5H2O	Immature	250	250.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex (Oligochaete)	72 h LC15	Mortality	CdCl2 - 2.5H2O	Immature	250	250.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex (Oligochaete)	96 h LC50	Mortality	CdCl2 - 2.5H2O	Immature	250	250.00	X		7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex (Oligochaete)	96 h LC10	Mortality	CdCl2 - 2.5H2O	Immature	260	260.00			7.03	> 6.5	1		S		
Tubifex tubifex (Oligochaete)	96 h LC10	Mortality	CdCl2 - 2.5H2O	Immature	270	270.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex (Oligochaete)	72 h LC5	Mortality	CdCl2 - 2.5H2O	Immature	280	280.00			7.03	> 6.5	1		S		
Tubifex tubifex (Oligochaete)	96 h LC15	Mortality	CdCl2 - 2.5H2O	Immature	280	280.00			7.03	> 6.5	1		S		
Tubifex tubifex (Oligochaete)	72 h LC15	Mortality	CdCl2 - 2.5H2O	Immature	280	280.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex (Oligochaete)	96 h LC15	Mortality	CdCl2 - 2.5H2O	Immature	290	290.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex (Oligochaete)	96 h LC50	Mortality	CdCl2 - 2.5H2O	Immature	300	300.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex	72 h	Mortality	CdCl2 -	Immature	320	320.00			7.03	> 6.5	1		S		

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Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
(Oligochaete)	NOEC/L		2.5H2O												
Tubifex tubifex (Oligochaete)	96 h LOEC/L	Mortality	CdCl2 - 2.5H2O	Immature	320	320.00			7.03	> 6.5	1		S		
Tubifex tubifex (Oligochaete)	96 h LC50	Mortality	CdCl2 - 2.5H2O	Immature	320	320.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex (Oligochaete)	72 h LC10	Mortality	CdCl2 - 2.5H2O	Immature	330	330.00			7.03	> 6.5	1		S		
Tubifex tubifex (Oligochaete)	72 h LC15	Mortality	CdCl2 - 2.5H2O	Immature	340	340.00			7.03	> 6.5	1		S		
Tubifex tubifex (Oligochaete)	72 h LC50	Mortality	CdCl2 - 2.5H2O	Immature	340	340.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex (Oligochaete)	72 h LC50	Mortality	CdCl2 - 2.5H2O	Immature	380	380.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex (Oligochaete)	96 h LC50	Mortality	CdCl2 - 2.5H2O	Immature	390	390.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex (Oligochaete)	96 h LC50	Mortality	CdCl2 - 2.5H2O	Immature	400	400.00			7.03	> 6.5	1		S		
Tubifex tubifex (Oligochaete)	48 h LC5	Mortality	CdCl2 - 2.5H2O	Immature	420	420.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex (Oligochaete)	72 h LC50	Mortality	CdCl2 - 2.5H2O	Immature	420	420.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex (Oligochaete)	48 h LC10	Mortality	CdCl2 - 2.5H2O	Immature	470	470.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex (Oligochaete)	48 h LC5	Mortality	CdCl2 - 2.5H2O	Immature	480	480.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex (Oligochaete)	24 h LC10	Mortality	CdCl2 - 2.5H2O	Immature	500	500.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex (Oligochaete)	48 h LC15	Mortality	CdCl2 - 2.5H2O	Immature	500	500.00			7.03	> 6.5	2	nominal concentrations	S		

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Tubifex tubifex (Oligochaete)	48 h LC50	Mortality	CdCl2 - 2.5H2O	Immature	510	510.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex (Oligochaete)	48 h LC10	Mortality	CdCl2 - 2.5H2O	Immature	530	530.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex (Oligochaete)	72 h LC50	Mortality	CdCl2 - 2.5H2O	Immature	560	560.00			7.03	> 6.5	1		S		
Tubifex tubifex (Oligochaete)	48 h LC15	Mortality	CdCl2 - 2.5H2O	Immature	560	560.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex (Oligochaete)	72 h LC50	Mortality	CdCl2 - 2.5H2O	Immature	580	580.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex (Oligochaete)	48 h LC5	Mortality	CdCl2 - 2.5H2O	Immature	590	590.00			7.03	> 6.5	1		S		
Tubifex tubifex (Oligochaete)	48 h LC10	Mortality	CdCl2 - 2.5H2O	Immature	650	650.00			7.03	> 6.5	1		S		
Tubifex tubifex (Oligochaete)	96 h LC50	Mortality	CdCl2	Not reported	1700	654.15		119-137	7.8-8.3	NR	2	Nominal conc, control mortality not reported, Compared with other lit. values and the results were fairly similar	S		H
Tubifex tubifex (Oligochaete)	48 h NOEC/L	Mortality	CdCl2 - 2.5H2O	Immature	670	670.00			7.03	> 6.5	1		S		
Tubifex tubifex (Oligochaete)	72 h LOEC/L	Mortality	CdCl2 - 2.5H2O	Immature	670	670.00			7.03	> 6.5	1		S		
Tubifex tubifex (Oligochaete)	48 h LC50	Mortality	CdCl2 - 2.5H2O	Immature	670	670.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex (Oligochaete)	48 h LC15	Mortality	CdCl2 - 2.5H2O	Immature	690	690.00			7.03	> 6.5	1		S		
Tubifex tubifex (Oligochaete)	24 h LC50	Mortality	CdCl2 - 2.5H2O	Immature	710	710.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex (Oligochaete)	48 h LC50	Mortality	CdCl2 - 2.5H2O	Immature	750	750.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex	48 h	Mortality	CdCl2 -	Immature	770	770.00			7.03	> 6.5	2	nominal concentrations	S		

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
(Oligochaete)	LC50		2.5H2O												
Tubifex tubifex (Oligochaete)	48 h LC50	Mortality	CdCl2 - 2.5H2O	Immature	920	920.00			7.03	> 6.5	1		S		
Tubifex tubifex (Oligochaete)	24 h LC50	Mortality	CdCl2 - 2.5H2O	Immature	1240	1240.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex (Oligochaete)	24 h LC50	Mortality	CdCl2 - 2.5H2O	Immature	1350	1350.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex (Oligochaete)	24 h NOEC/L	Mortality	CdCl2 - 2.5H2O	Immature	1360	1360.00			7.03	> 6.5	1		S		
Tubifex tubifex (Oligochaete)	48 h LOEC/L	Mortality	CdCl2 - 2.5H2O	Immature	1360	1360.00			7.03	> 6.5	1		S		
Tubifex tubifex (Oligochaete)	24 h LC50	Mortality	CdCl2 - 2.5H2O	Immature	1390	1390.00			7.03	> 6.5	2	nominal concentrations	S		
Tubifex tubifex (Oligochaete)	24 h LC50	Mortality	CdCl2 - 2.5H2O	Immature	1620	1620.00			7.03	> 6.5	1		S		
Tubifex tubifex (Oligochaete)	24 h LOEC/L	Mortality	CdCl2 - 2.5H2O	Immature	2350	2350.00			7.03	> 6.5	1		S		
Tubifex tubifex (Oligochaete)	72 h LC50	Mortality	CdCl2	Not reported	2400	923.5		119-137	7.8-8.3	NR	2	Nominal concentrations, control mortality not reported, They did compare with other literature values and the results were fairly similar	S	(Reynoldson et al. 1996)	
Tubifex tubifex (Oligochaete)	96 h LC50	Mortality	CdCl2	Not reported	3200	1231.3		119-137	7.8-8.3	NR	2	Nominal concentrations, control mortality not reported, They did compare with other literature values and the results were fairly similar	S		H
Tubifex tubifex (Oligochaete)	48 h LC50	Mortality	CdCl2	Not reported	3600	1385.3		119-137	7.8-8.3	NR	2	Nominal conc, control mortality not reported, Compared with other literature values and the results were fairly similar	S		
Tubifex tubifex (Oligochaete)	72 h LC50	Mortality	CdCl2	Not reported	5400	2077.9		119-137	7.8-8.3	NR	2	Nominal conc, control mortality not reported, Compared with other literature values and the results were similar	S		

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Tubifex tubifex (Oligochaete)	24 h LC50	Mortality	CdCl2	Not reported	9800	3771.0		119-137	7.8-8.3	NR	2	Nominal concentrations, control mortality not reported, They did compare with other literature values and the results were fairly similar	S		
Tubifex tubifex (Oligochaete)	24 h LC50	Mortality	CdCl2	Not reported	6500	2501.2		119-137	7.8-8.3	NR	2	Nominal conc, control mortality not reported. Compared with other literature values and the results were fairly similar	S		
Tubifex tubifex (Oligochaete)	48 h LC50	Mortality	CdCl2	Not reported	6500	2501.2		119-137	7.8-8.3	NR	2	Nominal conc, control mortality not reported, Compared with other literature values and the results were fairly similar	S		
Tubifex tubifex (Oligochaete)	96 h LC50	Mortality	3CdSO4 (8H2O)	Adult	320	3129.2		5.30 ± 0.64	7.0 ± 0.2		2	Control mortality not recorded	R	(Chapman et al. 1982)	H
Tubifex tubifex (Sludge worm)	48 h NOEC/L	Mortality	cadmium chloride monohydrate	Mixed	1124	219.1		250	7.7 +- 0.2	9.64 +- 0.35	2	Control mortality not reported (but there was a graph so you can get a rough idea), nominal only	NR	(Redeker and Blust 2004)	
Tubifex tubifex (Sludge worm)	72 h NOEC/L	Mortality	cadmium chloride monohydrate	Mixed	1124	219.1		250	7.7 +- 0.2	9.64 +- 0.35	2	Control mortality not reported (but there was a graph so you can get a rough idea), nominal only	NR		
Tubifex tubifex (Sludge worm)	96 h NOEC/L	Mortality	cadmium chloride monohydrate	Mixed	1124	219.1		250	7.7 +- 0.2	9.64 +- 0.35	2	Control mortality not reported (but there was a graph so you can get a rough idea), nominal only	NR		
Tubifex tubifex (Sludge worm)	96 h LC50	Mortality	cadmium chloride monohydrate	Mixed	1657.9	323.2		250	7.7 +- 0.2	9.64 +- 0.35	2	Control mortality not reported (but there was a graph so you can get a rough idea), nominal only	NR		H
Tubifex tubifex (Sludge worm)	72 h LC50	Mortality	cadmium chloride monohydrate	Mixed	1751.19	341.3		250	7.7 +- 0.2	9.64 +- 0.35	2	Control mortality not reported (but there was a graph so you can get a rough idea), nominal only	NR		
Tubifex tubifex (Sludge	48 h	Mortality	cadmium	Mixed	1777	346.4		250	7.7 +-	9.64	2	Control mortality not reported (but there was a graph so you	NR		

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
worm)	MATC		chloride monohydrate						0.2	+- 0.35		can get a rough idea), nominal only			
Tubifex tubifex (Sludge worm)	72 h MATC	Mortality	cadmium chloride monohydrate	Mixed	1777	346.4		250	7.7 +- 0.2	9.64 +- 0.35	2	Control mortality not reported (but there was a graph so you can get a rough idea), nominal only	NR		
Tubifex tubifex (Sludge worm)	96 h MATC	Mortality	cadmium chloride monohydrate	Mixed	1777	346.4		250	7.7 +- 0.2	9.64 +- 0.35	2	Control mortality not reported (but there was a graph so you can get a rough idea), nominal only	NR		
Tubifex tubifex (Sludge worm)	48 h LC50	Mortality	cadmium chloride monohydrate	Mixed	2525.63	492.3		250	7.7 +- 0.2	9.64 +- 0.35	2	Control mortality not reported (but there was a graph so you can get a rough idea), nominal only	NR		
Tubifex tubifex (Sludge worm)	48 h LOEC/L	Mortality	cadmium chloride monohydrate	Mixed	2810	547.7		250	7.7 +- 0.2	9.64 +- 0.35	2	Control mortality not reported (but there was a graph so you can get a rough idea), nominal only	NR		
Tubifex tubifex (Sludge worm)	72 h LOEC/L	Mortality	cadmium chloride monohydrate	Mixed	2810	547.7		250	7.7 +- 0.2	9.64 +- 0.35	2	Control mortality not reported (but there was a graph so you can get a rough idea), nominal only	NR		
Tubifex tubifex (Sludge worm)	96 h LOEC/L	Mortality	cadmium chloride monohydrate	Mixed	2810	547.7		250	7.7 +- 0.2	9.64 +- 0.35	2	Control mortality not reported (but there was a graph so you can get a rough idea), nominal only	NR		
Tubifex tubifex (Sludge worm)	24 h NOEC/L	Mortality	cadmium chloride monohydrate	Mixed	5620	1095.4		250	7.7 +- 0.2	9.64 +- 0.35	2	Control mortality not reported (but there was a graph so you can get a rough idea), nominal only	NR		
Tubifex tubifex (Sludge	24 h	Mortality	cadmium	Mixed	6883	1341.6		250	7.7 +-	9.64	2	Control mortality not reported (but there was a graph so you	NR		

Appendix 1(i): Short-Term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolved Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
worm)	MATC		chloride monohydrate						0.2	+- 0.35		can get a rough idea), nominal only			
Tubifex tubifex (Sludge worm)	24 h LC50	Mortality	cadmium chloride monohydrate	Mixed	7957.92	1551.1		250	7.7 +- 0.2	9.64 +- 0.35	2	Control mortality not reported (but there was a graph so you can get a rough idea), nominal only	NR		
Tubifex tubifex (Sludge worm)	24 h LOEC/L	Mortality	cadmium chloride monohydrate	Mixed	8430	1643.1		250	7.7 +- 0.2	9.64 +- 0.35	2	Control mortality not reported (but there was a graph so you can get a rough idea), nominal only	NR		
Tubifex tubifex (Sludge worm)	17 d LC50	Mortality	cadmium chloride monohydrate	Mixed	38.07113626	7.42		250	7.7 +- 0.2	9.64 +- 0.35	U	Static test (presumably) for 17 d, and concs nominal only, also orgs not fed for 17 days? control mortality not reported (but there was a graph so you can get a rough idea)	NR		
Uronema nigricans (Ciliate)	24 h LC50	Mortality	hydrated cadmium chloride	Adult					7.3 (range: 7.0-7.8)		U	all variables missing except pH, nominal concs only, control mortality not reported, can't tell if range was appropriate	S	(Madoni et al. 1992)	
Varichaeta pacifica (Oligochaete)	96 h LC50	Mortality	3CdSO4 (8H2O)	Adult	380	3716.0	X	5.30 ± 0.64	7.0 ± 0.2		2	Control mortality not reported	R	(Chapman et al. 1982)	

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Algae															
Ankistrodesmus falcatus (Green algae)	96 h NOEC/L	Growth	CdCl2	Population	10	4.90	X	118 (94-123)	7.7 (7.2-8.2)	8.5 (7.4-9.3)	2	water quality parameters not reported for algal, doesn't specify how many replicate beakers they used for algae (followed EPA protocols), concs tested not reported	S	(Baer et al. 1999)	
Pseudokirchneriella subcapitata (Green algae)	96 h NOEC/L	Growth	CdCl2	Population	5	2.45		118 (94-123)	7.7 (7.2-8.2)	8.5 (7.4-9.3)	2	water quality parameters not reported for algal, doesn't specify how many replicate beakers they used for algae (followed EPA protocols), concs tested not reported	S		
Pseudokirchneriella subcapitata (Green algae)	72 h EC50	Growth	CdCl2	Population	43.5	11.44		250	8.1	N/A	2	temp in high range, no alkalinity or conductivity, nominal only, concs not reported so can't tell if appropriate range used, EC50s determined by eye	R	(Benhra et al. 1997)	
Pseudokirchneriella subcapitata (Green algae)	72 h EC10	Growth rate	CdCl2	Population	2.8	25.95	x	3.42	6.71	N/A	2	nominal was used even though concs at start were tested and measured (at start) was found to be 83-87% of nominal, alkalinity was measured but not reported	S	(Källqvist 2007)	
Pseudokirchneriella subcapitata (Green algae)	72 h EC10	Growth rate	CdCl2	Population	6	6.41	x	46.21	6.65	N/A	2	nominal was used even though concs at start were tested and measured (at start) was found to be 83-87% of nominal, alkalinity was measured but not reported	S		
Pseudokirchneriella subcapitata (Green algae)	72 h EC10	Growth rate	CdCl2	Population	7.5	42.36	x	6.21	6.85	N/A	2	nominal was used even though concs at start were tested and measured (at start) was found to be 83-87% of nominal, alkalinity was measured but not reported	S		
Pseudokirchneriella subcapitata (Green algae)	72 h EC10	Growth rate	CdCl2	Population	8.5	21.65	x	16.21	6.74	N/A	2	nominal was used even though concs at start were tested and measured (at start) was found to be 83-87% of nominal, alkalinity was measured but not reported	S		
Amphibians															
Ambystoma gracile (Northwestern salamander)	10 d LOEC/L	Weight	CdCl2	Larva	227.3	248.07		45	6.8		1	no O2, would have been better to have more replicates	FT	(Nebeker et al. 1995)	
Ambystoma gracile (Northwestern salamander)	24 d LOEC/L	Weight	CdCl2	Larva	193.1	210.75		45	6.8		1	no O2, would have been better to have more replicates	FT		
Ambystoma gracile (Northwestern salamander)	10 d MATC	Weight	CdCl2	Larva	155.4	169.60		45	6.8		1	no O2, would have been better to have more replicates	FT		
Ambystoma gracile (Northwestern salamander)	24 d MATC	Weight	CdCl2	Larva	97.2	106.05	X	45	6.8		1	no O2, would have been better to have more replicates	FT		
Ambystoma gracile (Northwestern salamander)	10 d NOEC/L	Weight	CdCl2	Larva	106.3	116.01		45	6.8		1	no O2, would have been better to have more replicates	FT		

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Ambystoma gracile (Northwestern salamander)	24 d NOEC/L	Weight	CdCl2	Larva	48.9	53.37		45	6.8		1	no O2, would have been better to have more replicates	FT		
Fish															
Acipenser transmontanus (sturgeon)	58 d LC20	Mortality	cadmium chloride hemi-pentahydrate	Fry	1.5	1.13	X	70 ± 9.8	7.9 ± 0.2	8.9 ± 0.9	2	Duration was reported as days post hatch (dph), control was very high but it was expected and explained in the discussion of the paper and therefore ok	FT	(Vardy et al. 2011)	
Acipenser transmontanus (sturgeon)	19 d LC20	Mortality	cadmium chloride hemi-pentahydrate	Fry	8.7	6.58		70 ± 9.8	7.9 ± 0.2	8.9 ± 0.9	2	Duration was reported as days post hatch (dph), control was very high but it was expected and explained in the discussion of the paper and therefore appropriate for use.	FT		
Acipenser transmontanus (sturgeon)	58 d LC50	Mortality	cadmium chloride hemi-pentahydrate	Fry	5.6	4.24		70 ± 9.8	7.9 ± 0.2	8.9 ± 0.9	2	Duration was reported as days post hatch (dph), control was very high but it was expected and explained in the discussion of the paper and therefore appropriate for use.	FT		
Acipenser transmontanus (sturgeon)	19 d LC50	Mortality	cadmium chloride hemi-pentahydrate	Fry	21.4	16.19		70 ± 9.8	7.9 ± 0.2	8.9 ± 0.9	2	Duration was reported as days post hatch (dph), control was very high but it was expected and explained in the discussion of the paper and therefore appropriate for use.	FT		
Catostomus commersoni (White Sucker)	40 d LOEC/L	Biomass, decrease in	CdCl2	Embryo	12	13.10		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 18.1 C , no conductivity	FT	(Eaton et al. 1978)	
Catostomus commersoni (White Sucker)	40 d MATC	Biomass, decrease in	CdCl2	Embryo	7.1	7.75	X	45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 18.1 C , no conductivity	FT		
Catostomus commersoni (White Sucker)	40 d NOEC/L	Biomass, decrease in	CdCl2	Embryo	4.2	4.58		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 18.1 C , no conductivity	FT		
Cottus bairdi (Mottled	28 d	Biomass,	cadmium	Swim-up	2.4	1.33		102	8.21	8.8	1	no problems	FT	(Besser et al. 2007)	

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
sculpin)	EC50	decrease in	chloride	fry											
Cottus bairdi (Mottled sculpin)	21 d EC50	Biomass, decrease in	cadmium chloride	Swim-up fry	1.77	0.96	X	104	8.23	9.5	1	no problems	FT		
Cottus bairdi (Mottled sculpin)	28 d LC50	Mortality	cadmium chloride	Swim-up fry	2.9	1.60		102	8.21	8.8	1	no problems	FT		
Cottus bairdi (Mottled sculpin)	14 d LC50	Mortality	cadmium chloride	Swim-up fry	2.02	1.10		104	8.23	9.5	1	no problems	FT		
Cottus bairdi (Mottled sculpin)	21 d LC50	Mortality	cadmium chloride	Swim-up fry	1.73	0.94		104	8.23	9.5	1	no problems	FT		
Esox lucius (Northern pike)	35 d LOEC/L	Biomass, decrease in	CdCl2	Embryo	12.9	14.08		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 15.9 C, no conductivity	FT	(Eaton et al. 1978)	
Esox lucius (Northern pike)	35 d MATC	Biomass, decrease in	CdCl2	Embryo	7.4	8.03	X	45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 15.9 C, no conductivity	FT		
Esox lucius (Northern pike)	35 d NOEC/L	Biomass, decrease in	CdCl2	Embryo	4.2	4.58		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 15.9 C, no conductivity	FT		
Micropterus dolomieui (Smallmouth bass)	33 d NOEC/L	Biomass, decrease in	CdCl2	Embryo	4.3			45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	U	temp 20.2 C, no cond, control mortality 30-50% due to fungus	FT		
Micropterus dolomieui (Smallmouth bass)	33 d LOEC/L	Biomass, decrease in	CdCl2	Embryo	12.7			45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	U	temp 20.2 C, no cond, control mortality 30-50% due to fungus	FT		
Micropterus dolomieui (Smallmouth bass)	33 d MATC	Biomass, decrease in	CdCl2	Embryo	7.4			45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	U	temp 20.2 C, no cond, control mortality 30-50% due to fungus	FT		
Oncorhynchus kisutch (Coho salmon)	27 d LOEC/L	Biomass, decrease in	CdCl2	Embryo	3.4	3.71		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 10.1 C, no conductivity	FT		
Oncorhynchus kisutch (Coho salmon)	47 d LOEC/L	Biomass, decrease in	CdCl2	Embryo	12.5	13.64		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 9.7 C, no conductivity	FT		

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Oncorhynchus kisutch (Coho salmon)	62 d LOEC/L	Biomass, decrease in	CdCl2	Larva	12.5	13.64		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 9.7 C, no conductivity	FT		
Oncorhynchus kisutch (Coho salmon)	27 d MATC	Biomass, decrease in	CdCl2	Embryo	2.1	2.29		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 10.1 C, no conductivity	FT		
Oncorhynchus kisutch (Coho salmon)	47 d MATC	Biomass, decrease in	CdCl2	Embryo	7.2	7.86		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 9.7 C, no conductivity	FT		
Oncorhynchus kisutch (Coho salmon)	62 d MATC	Biomass, decrease in	CdCl2	Larva	7.2	7.81	X	45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 9.7 C, no conductivity	FT		
Oncorhynchus kisutch (Coho salmon)	27 d NOEC/L	Biomass, decrease in	CdCl2	Embryo	1.3	1.42		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 10.1 C, no conductivity	FT		
Oncorhynchus kisutch (Coho salmon)	47 d NOEC/L	Biomass, decrease in	CdCl2	Embryo	4.1	4.47		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 9.7 C, no conductivity	FT		
Oncorhynchus kisutch (Coho salmon)	62 d NOEC/L	Biomass, decrease in	CdCl2	Larva	4.1	4.47		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 9.7 C, no conductivity	FT		
Oncorhynchus mykiss (Rainbow trout)	65 wks NOEC/L	Reproduction - delay in oogenesis	3CdSO4 . 8H2O	Adult	0.47	0.12		250	7.4-8.0	>85% air sat	2	no alk or cond, Cd concs were measured, but methods not specified, stats not reported, pseudoreplication (all fish in one tank), range of concs tested not ideal	FT	(Brown et al. 1994)	H
Oncorhynchus mykiss (Rainbow trout)	65 wks MATC	Reproduction - delay in oogenesis	3CdSO4 . 8H2O	Adult	0.91	0.24		250	7.4-8.0	>85% air sat	2	no alk or cond, Cd concs were measured, but methods not specified, stats not reported, pseudoreplication (all fish in one tank), range of concs tested not ideal	FT		H
Oncorhynchus mykiss (Rainbow trout)	65 wks LOEC/L	Reproduction - delay in oogenesis	3CdSO4 . 8H2O	Adult	1.77	0.47		250	7.4-8.0	>85% air sat	2	no alk or cond, Cd concs were measured, but methods not specified, stats not reported, pseudoreplication (all fish in one tank), range of concs tested not ideal	FT		H
Oncorhynchus mykiss (Rainbow trout)	62 d EC10	Weight	CdCl2	Early life stage	0.15	0.23	X	29.4 (SD = 3.6)	7.19 (SD = 0.30)	9.2 (SD = 0.9)	1		FT	(Mebane et al. 2008)	H

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Oncorhynchus mykiss (Rainbow trout)	62 d LOEC/L	Length	CdCl2	Early life stage	0.16	0.25		29.4 (SD = 3.6)	7.19 (SD = 0.30)	9.2 (SD = 0.9)	1		FT		H
Oncorhynchus mykiss (Rainbow trout)	62 d LOEC/L	Weight	CdCl2	Early life stage	0.16	0.25		29.4 (SD = 3.6)	7.19 (SD = 0.30)	9.2 (SD = 0.9)	1		FT		H
Oncorhynchus mykiss (Rainbow trout)	53 d NOEC/L	Mortality	CdCl2	Early life stage	0.6	1.30		19.7 (17-21)	6.75 (5.0-7.7)	10.2 (8.3-11.9)`	1		FT		H
Oncorhynchus mykiss (Rainbow trout)	62 d NOEC/L	Mortality	CdCl2	Early life stage	1	1.55		29.4 (SD = 3.6)	7.19 (SD = 0.30)	9.2 (SD = 0.9)	1		FT		H
Oncorhynchus mykiss (Rainbow trout)	53 d EC10	Mortality	CdCl2	Early life stage	0.82	1.78		19.7 (17-21)	6.75 (5.0-7.7)	10.2 (8.3-11.9)`	1		FT		H
Oncorhynchus mykiss (Rainbow trout)	53 d MATC	Mortality	CdCl2	Early life stage	0.88	1.91		19.7 (17-21)	6.75 (5.0-7.7)	10.2 (8.3-11.9)`	1		FT		H
Oncorhynchus mykiss (Rainbow trout)	62 d EC10	Mortality	CdCl2	Early life stage	1.6	2.49		29.4 (SD = 3.6)	7.19 (SD = 0.30)	9.2 (SD = 0.9)	1		FT		H
Oncorhynchus mykiss (Rainbow trout)	62 d MATC	Mortality	CdCl2	Early life stage	1.6	2.49		29.4 (SD = 3.6)	7.19 (SD = 0.30)	9.2 (SD = 0.9)	1		FT		H
Oncorhynchus mykiss (Rainbow trout)	53 d LOEC/L	Mortality	CdCl2	Early life stage	1.3	2.82		19.7 (17-21)	6.75 (5.0-7.7)	10.2 (8.3-11.9)`	1		FT		H
Oncorhynchus mykiss (Rainbow trout)	62 d EC10	Length	CdCl2	Early life stage	>2.5	3.88		29.4 (SD = 3.6)	7.19 (SD = 0.30)	9.2 (SD = 0.9)	2	greater than value	FT		H
Oncorhynchus mykiss (Rainbow trout)	62 d LOEC/L	Mortality	CdCl2	Early life stage	2.5	3.88		29.4 (SD = 3.6)	7.19 (SD = 0.30)	9.2 (SD = 0.9)	1		FT		H

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Oncorhynchus mykiss (Rainbow trout)	62 d NOEC/L	Length	CdCl2	Early life stage	<0.16			29.4 (SD = 3.6)	7.19 (SD = 0.30)	9.2 (SD = 0.9)	U	less than value	FT		H
Oncorhynchus mykiss (Rainbow trout)	62 d NOEC/L	Weight	CdCl2	Early life stage	< 0.16			29.4 (SD = 3.6)	7.19 (SD = 0.30)	9.2 (SD = 0.9)	U	less than value	FT		H
Oncorhynchus mykiss (Rainbow trout)	62 d MATC	Length	CdCl2	Early life stage	< 0.16			29.4 (SD = 3.6)	7.19 (SD = 0.30)	9.2 (SD = 0.9)	U	less than value	FT		H
Oncorhynchus mykiss (Rainbow trout)	62 d MATC	Weight	CdCl2	Early life stage	< 0.16			29.4 (SD = 3.6)	7.19 (SD = 0.30)	9.2 (SD = 0.9)	U	less than value	FT		H
Oncorhynchus mykiss (Rainbow trout)	100 d LC1	Mortality	Cd	Unknown	2.39	0.41		414	6.90	7.6	1	Thoroughly reported study with standard methods	FT	(Davies et al. 1993)	
Oncorhynchus mykiss (Rainbow trout)	100 d NOEC/L	Mortality	Cd	Unknown	3.64	0.63		414	6.90	7.6	1	Thoroughly reported study with standard methods	FT		
Oncorhynchus mykiss (Rainbow trout)	100 d LC1	Mortality	Cd	Unknown	2.43	0.72		217	6.93	7.4	1	Thoroughly reported study with standard methods.	FT		
Oncorhynchus mykiss (Rainbow trout)	100 d NOEC/L	Mortality	Cd	Unknown	3,58	1.06		217	6.93	7.4	1	Thoroughly reported study with standard methods.	FT		
Oncorhynchus mykiss (Rainbow trout)	96 h LC50	Mortality	Cd	Unknown	4.2	1.31		204	6.88	8.6	2	Thoroughly reported study with standard methods, the hardness solution is made up from MgSO4 creating an unnatural ratio of Mg:Ca that would not occur in the environment, not valuable to use in the derivation of a guideline	FT		
Oncorhynchus mykiss (Rainbow trout)	100 d ChV	Mortality	Cd	Unknown	1.47	1.57		46.2	6.89	7.4	1	Thoroughly reported study with standard methods.	FT		
Oncorhynchus mykiss (Rainbow trout)	100 d LC1	Mortality	Cd	Unknown	1.58	1.69		46.2	6.89	7.4	1	Thoroughly reported study with standard methods.	FT		
Oncorhynchus mykiss (Rainbow trout)	8 d LC10	Mortality	CdCl2	parr	0.7	1.33		23 +- 1 (SD)	7.1-7.5	10.2 +- 0.2 (SD)	2	no conductivity, stats not very well explained, 5 metal concs used, but didn't say what they were so can't tell if range was appropriate	FT	(Chapman 1978)	
Oncorhynchus mykiss	8 d	Mortality	CdCl2	smolt	0.8	1.52		23 +- 1	7.1-7.5	10.2 +-	2	no conductivity, stats not very well explained, 5 metal concs	FT		

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
(Rainbow trout)	LC10							(SD)		0.2 (SD)		used, but didn't say what they were so can't tell if range was appropriate			
Oncorhynchus mykiss (Rainbow trout)	8 d LC10	Mortality	CdCl2	Swim-up fry	1	1.91		23 +- 1 (SD)	7.1-7.5	10.2 +- 0.2 (SD)	2	no conductivity, stats not very well explained, 5 metal concs used, but didn't say what they were so can't tell if range was appropriate	FT		
Oncorhynchus mykiss (Rainbow trout)	8 d LC10	Mortality	CdCl2	Alevin	> 6	11.43		23 +- 1 (SD)	7.1-7.5	10.2 +- 0.2 (SD)	2	no conductivity, stats not very well explained, 5 metal concs used, but didn't say what they were so can't tell if range was appropriate	FT		
Oncorhynchus mykiss	7 d LC50	Mortality	CdCl2* 2.5H2O	Unknown	6.3	25.68		9.2	4.67		1	Standard methods used and thoroughly reported	FT	(Cusimano et al. 1986)	
Oncorhynchus mykiss	7 d LC50	Mortality	CdCl2*2.5 H2O	Unknown	<0.5	2.04		9.2	6.96		1	Standard methods used and thoroughly reported	FT		
Oncorhynchus mykiss	7 d LC50	Mortality	CdCl2*2.5 H2O	Unknown	0.7	2.85		9.2	5.68		1	Standard methods used and thoroughly reported	FT		
Oncorhynchus tshawytscha (Chinook salmon)	8 d LC10	Mortality	CdCl2	Alevin	18-26	41.91		23 +- 1 (SD)	7.1-7.5	10.2 +- 0.2	2	no cond, stats not well explained, 5 metal concs used, but didn't say what they were so can't tell if range was appropriate	FT	(Chapman 1978)	
Oncorhynchus tshawytscha (Chinook salmon)	8 d LC10	Mortality	CdCl2	Swim-up fry	1.2	2.29	X	23 +- 1 (SD)	7.1-7.5	10.2 +- 0.2	2	no cond, stats not very well explained, 5 metal concs used, but didn't say what they were so can't tell if range was appropriate	FT		
Oncorhynchus tshawytscha (Chinook salmon)	8 d LC10	Mortality	CdCl2	parr	1.3	2.48		23 +- 1 (SD)	7.1-7.5	10.2 +- 0.2	2	no cond, stats not very well explained, 5 metal concs used, but didn't say what they were so can't tell if range was appropriate	FT		
Oncorhynchus tshawytscha (Chinook salmon)	8 d LC10	Mortality	CdCl2	smolt	1.5	2.86		23 +- 1 (SD)	7.1-7.5	10.2 +- 0.2	2	no cond, stats not very well explained, 5 metal concs used, but didn't say what they were so can't tell if range was appropriate	FT		
Pimephales promelas (Fathead minnow)	7 d NOEC/L	Mortality	CdCl2	4 to 6 days old	8.5	2.05		270-286	8.37-8.56	7.7-8.6	1	reported at the front of the document	R	(Castillo, III and Longley 2001)	
Pimephales promelas (Fathead minnow)	7 d NOEC/L	Mortality	CdCl2	4 to 6 days old	9.6	2.39		234-299	8.37-8.50	7.3-8.6	1	reported at the front of the document	R		
Pimephales promelas (Fathead minnow)	7 d LOEC/L	Mortality	CdCl2	4 to 6 days old	11.3	2.72		270-286	8.37-8.56	7.7-8.6	1	reported at the front of the document	R		
Pimephales promelas	7 d	Growth	CdCl2	4 to 6 days	11.3	2.72		270-286	8.37-	7.7-8.6	1	reported at the front of the document	R		

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
(Fathead minnow)	NOEC/L			old					8.56						
Pimephales promelas (Fathead minnow)	7 d LOEC/L	Mortality	CdCl2	4 to 6 days old	12.2	3.04		234-299	8.37-8.50	7.3-8.6	1	reported at the front of the document	R		
Pimephales promelas (Fathead minnow)	7 d MATC	Mortality	CdCl2	4 to 6 days old	9.8	2.36	X	270-286	8.37-8.56	7.3-8.6	1		R		
Pimephales promelas (Fathead minnow)	7 d LOEC/L	Growth	CdCl2	Other	16.5	3.97		270-286	8.37-8.56	7.7-8.6	1	reported at the front of the document	R		
Pimephales promelas (Fathead minnow)	10 d MATC	Mortality	CdCl2	Larva	1.4	3.43		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time	S	(Suedel et al. 1997)	
Pimephales promelas (Fathead minnow)	10 d LC50	Mortality	CdCl2	Larva	1.6	3.92		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time	S		
Pimephales promelas (Fathead minnow)	10 d NOEC/L	Growth	CdCl2	Larva	2	4.90		6-28	5.5-7.7	4.2-9.3	2	the corresponding LOEC was a greater than value, so this weakens the NOEC, nominal concs used, concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal,	S		
Pimephales promelas (Fathead minnow)	14 d LC50	Mortality	CdCl2	Larva	2.3	5.63		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal	S		
Pimephales promelas (Fathead minnow)	14 d MATC	Mortality	CdCl2	Larva	2.4	5.88		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal	S		
Pimephales promelas (Fathead minnow)	14 d NOEC/L	Growth	CdCl2	Larva	3	7.35		6-28	5.5-7.7	4.2-9.3	2	the corresponding LOEC was a greater than value, so this weakens the NOEC, nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal	S		
Pimephales promelas (Fathead minnow)	7 d LC50	Mortality	CdCl2	Larva	4.4	10.77		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S		

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Pimephales promelas (Fathead minnow)	7 d MATC	Mortality	CdCl2	Larva	4.9	12.00		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal	S		
Pimephales promelas (Fathead minnow)	250 d NOEC/L	Mortality	cadmium sulfate	Fry	27	8.40		204 ± 8.4	7.6 ± 0.14	6.6 ± 1.2	2	Pseudoreplication	FT	(Pickering and Gast 1972)	H
Pimephales promelas (Fathead minnow)	300 d NOEC/L	Mortality	cadmium sulfate	Adult	37	11.66		201 ± 6.1	7.7 ± 0.2	6.5 ± 1.5	2	pseudoreplication	FT		
Pimephales promelas (Fathead minnow)	250 d MATC	Mortality	cadmium sulfate	Fry	39.2	12.20		204 ± 8.4	7.6 ± 0.14	6.6 ± 1.2	2	Pseudoreplication	FT		
Pimephales promelas (Fathead minnow)	250 d LOEC/L	Mortality	cadmium sulfate	Fry	57	17.74		204 ± 8.4	7.6 ± 0.14	6.6 ± 1.2	2	Pseudoreplication	FT		
Pimephales promelas (Fathead minnow)	300 d MATC	Mortality	cadmium sulfate	Adult	60.83	19.17		201 ± 6.1	7.7 ± 0.2	6.5 ± 1.5	2	pseudoreplication	FT		
Pimephales promelas (Fathead minnow)	300 d LOEC/L	Mortality	cadmium sulfate	Adult	110	34.66		201 ± 6.1	7.7 ± 0.2	6.5 ± 1.5	2	pseudoreplication	FT	(Pickering and Gast 1972)	
Pimephales promelas (Fathead minnow)	32 d NOEC/L	Mortality	cadmium chloride	Juvenile	13.4	10.51		55.0-79.0	7.2-7.8		2	no units given for WQ parameters (units assumed) , they don't specifically mention how many organisms were used per replicate, but they followed ASTM procedures so presumably it was enough, no control mortality reported	S	(Spehar and Carlson 1984)	
Pimephales promelas (Fathead minnow)	32 d MATC	Mortality	cadmium chloride	Juvenile	18.9	14.82		55.0-79.0	7.2-7.8		2	no units given for any WQ parameters (but can assume units), they don't specifically mention how many organisms were used per replicate, but they followed ASTM procedures so presumably it was enough, no control mortality reported	S		
Pimephales promelas (Fathead minnow)	32 d LOEC/L	Mortality	cadmium chloride	Juvenile	26.7	20.94		55.0-79.0	7.2-7.8		2	no units given for any WQ parameters (but can assume units), they don't specifically mention how many organisms were used per replicate, but they followed ASTM procedures so presumably it was enough, no control mortality reported	S		
Pimephales promelas (Fathead minnow)	32 d MATC	Mortality	cadmium nitrate	NR	10	11.14		43.9 ± 1.0	6.0-8.1		1		R	(Spehar and Fiandt 1986)	H
Prosopium williamsoni (Mountain Whitefish)	30 d IC20	Biomass and Weight	cadmium sulphate	Embryo	3.02	3.13		47.8 ± 6.2	6.81 ± 0.18	9.2 ± 0.6	1	Fry tests, controls reported, good concentrations and clear dose response relationship	FT	(Brinkman and Vieira 2008)	

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Prosopium williamsoni (Mountain Whitefish)	90 d IC20	Biomass and Weight	cadmium sulphate	Embryo	1.29	1.34		47.8 ± 6.2	6.81 ± 0.18	9.2 ± 0.6	1	ELS test, (preferred endpoint) controls reported, good concentrations and clear dose response relationship	FT		
Prosopium williamsoni (Mountain Whitefish)	90 d IC10	Biomass, decrease in	cadmium sulphate	Embryo	1.2	1.25	X				1	Calculated by the NGSO based on data from Table 5	FT		
Salmo salar (Atlantic salmon)	496 d LOEC/L	Length	CdCl2	Egg	0.47	0.76		28	7.3 (6.8-7.5)	11.1	2	pseudoreplication - all eggs presumed to be in a single chamber for each conc. (doesn't specify otherwise), feeding not reported	R	(Rombough and Garside 1982)	
Salmo salar (Atlantic salmon)	496 d LOEC/L	Weight	CdCl2	Egg	0.47	0.76		28	7.3 (6.8-7.5)	11.1	2	pseudoreplication - all eggs presumed to be in a single chamber for each conc. (doesn't specify otherwise), feeding not reported	R		
Salmo salar (Atlantic salmon)	496 d MATC	Biomass, decrease in	CdCl2	Egg	0.61	0.99	X	28	7.3 (6.8-7.5)	11.1	2	pseudoreplication - all eggs presumed to be in a single chamber for each conc. (doesn't specify otherwise), feeding not reported	R		
Salmo salar (Atlantic salmon)	470 d LOEC/L	Weight	CdCl2	Egg	2.5	4.05		28	7.3 (6.8-7.5)	11.1	2	pseudoreplication - all eggs presumed to be in a single chamber for each conc. (doesn't specify otherwise), feeding not reported	R		
Salmo salar (Atlantic salmon)	470 d LOEC/L	Biomass, decrease in	CdCl2	Egg	2.5	4.05		28	7.3 (6.8-7.5)	11.1	2	pseudoreplication - all eggs presumed to be in a single chamber for each conc. (doesn't specify otherwise), feeding not reported	R		
Salmo salar (Atlantic salmon)	92 d MATC	Mortality	CdCl2	Egg	4.5	7.28		28	7.3 (6.8-7.5)	11.1	2	pseudoreplication - all eggs presumed to be in a single chamber for each conc. (doesn't specify otherwise), feeding not reported	R		
Salmo salar (Atlantic salmon)	402 d MATC	Weight	CdCl2	Egg	5.5	12.28		19	6.5 (6.3-6.8)	12.5	2	pseudoreplication - all eggs presumed to be in a single chamber for each conc. (doesn't specify otherwise), feeding not reported	R		
Salmo salar (Atlantic salmon)	402 d MATC	Biomass, decrease in	CdCl2	Egg	5.5	12.28		19	6.5 (6.3-6.8)	12.5	2	pseudoreplication - all eggs presumed to be in a single chamber for each conc. (doesn't specify otherwise), feeding not reported	R		
Salmo salar (Atlantic salmon)	78 d MATC	Hatching success	CdCl2	Early gastrulation	88	196.45		19	6.5 (6.3-6.8)	12.5	2	pseudoreplication - all eggs presumed to be in a single chamber for each conc. (doesn't specify otherwise)	R		
Salmo salar (Atlantic salmon)	96 d MATC	Hatching success	CdCl2	Egg	156	348.26		19	6.5 (6.3-	12.5	2	pseudoreplication - all eggs presumed to be in a single chamber for each conc. (doesn't specify otherwise)	R		

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
									6.8)						
Salmo salar (Atlantic salmon)	158 d MATC	Mortality	CdCl2	Egg	156	348.26		19	6.5 (6.3-6.8)	12.5	2	pseudoreplication - all eggs presumed to be in a single chamber for each conc. (doesn't specify otherwise), feeding not reported	R		
Salmo salar (Atlantic salmon)	45 d MATC	Hatching success	CdCl2	Eyed egg stage	156	348.26		19	6.5 (6.3-6.8)	12.5	2	pseudoreplication - all eggs presumed to be in a single chamber for each conc. (doesn't specify otherwise)	R		
Salmo salar (Atlantic salmon)	45 d MATC	Hatching success	CdCl2	Egg	490	792.87		28	7.3 (6.8-7.5)	11.1	2	pseudoreplication - all eggs presumed to be in a single chamber for each conc. (doesn't specify otherwise)	R		
Salmo salar (Atlantic salmon)	48 d MATC	Hatching success	CdCl2	Egg	490	792.87		28	7.3 (6.8-7.5)	11.1	2	pseudoreplication - all eggs presumed to be in a single chamber for each conc. (doesn't specify otherwise)	R		
Salmo salar (Atlantic salmon)	92 d MATC	Mortality	CdCl2	Egg	490	792.87		28	7.3 (6.8-7.5)	11.1	2	pseudoreplication - all eggs presumed to be in a single chamber for each conc. (doesn't specify otherwise), feeding not reported	R		
Salmo trutta (Brown trout)	30 d NOEC/L	Mortality	CdSO4	Swim-up fry	1.3	1.01		67.6 (1.5)	7.60 (0.10)	8.88 (0.17)	1	no problems	FT	(Brinkman and Hansen 2007)	
Salmo trutta (Brown trout)	30 d NOEC/L	Mortality	CdSO4	Swim-up fry	0.74	1.16		29.2 (0.9)	7.54 (0.13)	8.61 (0.22)	1	no problems	FT		
Salmo trutta (Brown trout)	30 d IC20	Biomass, decrease in	CdSO4	Swim-up fry	0.87	1.36	X	29.2 (0.9)	7.54 (0.13)	8.61 (0.22)	1	no problems	FT		H
Salmo trutta (Brown trout)	30 d IC20	Biomass, decrease in	CdSO4	Swim-up fry	2.18	1.70		67.6 (1.5)	7.60 (0.10)	8.88 (0.17)	1	no problems	FT		H
Salmo trutta (Brown trout)	30 d NOEC/L	Mortality	CdSO4	Swim-up fry	4.81	1.92		151 (2)	7.51 (0.12)	8.58 (0.14)	1	no problems	FT		H
Salmo trutta (Brown trout)	30 d LOEC/L	Mortality	CdSO4	Swim-up fry	2.58	2.01		67.6 (1.5)	7.60 (0.10)	8.88 (0.17)	1	no problems	FT		H
Salmo trutta (Brown trout)	30 d NOEC/L	Weight	CdSO4	Swim-up fry	2.58	2.01		67.6 (1.5)	7.60 (0.10)	8.88 (0.17)	1	no problems	FT		H
Salmo trutta (Brown trout)	30 d LOEC/L	Mortality	CdSO4	Swim-up fry	1.4	2.19		29.2 (0.9)	7.54 (0.13)	8.61 (0.22)	1	no problems	FT		H
Salmo trutta (Brown trout)	30 d	Weight	CdSO4	Swim-up	1.4	2.19		29.2 (0.9)	7.54	8.61	2	based on only 1 surviving fish at highest conc.	FT		H

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
	NOEC/L			fry					(0.13)	(0.22)					
Salmo trutta (Brown trout)	30 d IC20	Biomass, decrease in	CdSO4	Swim-up fry	6.62	2.65		151 (2)	7.51 (0.12)	8.58 (0.14)	1	no problems	FT		H
Salmo trutta (Brown trout)	55 d IC20	Biomass, decrease in	CdSO4	Egg	2.22	3.34		30.6 (2.1)	7.72 (0.12)	8.49 (0.58)	1	no problems	FT		H
Salmo trutta (Brown trout)	55 d NOEC/L	Mortality	CdSO4	Egg	4.68	3.49		71.3 (2.7)	7.75 (0.14)	8.61 (0.67)	1	no problems	FT		H
Salmo trutta (Brown trout)	30 d LOEC/L	Weight	CdSO4	Swim-up fry	4.49	3.50		67.6 (1.5)	7.60 (0.10)	8.88 (0.17)	1	no problems	FT		H
Salmo trutta (Brown trout)	55 d IC20	Biomass, decrease in	CdSO4	Egg	4.71	3.51		71.3 (2.7)	7.75 (0.14)	8.61 (0.67)	1	no problems	FT		H
Salmo trutta (Brown trout)	30 d LOEC/L	Mortality	CdSO4	Swim-up fry	8.88	3.55		151 (2)	7.51 (0.12)	8.58 (0.14)	1	no problems	FT		H
Salmo trutta (Brown trout)	55 d NOEC/L	Mortality	CdSO4	Egg	2.54	3.82		30.6 (2.1)	7.72 (0.12)	8.49 (0.58)	1	no problems	FT		H
Salmo trutta (Brown trout)	55 d NOEC/L	Mortality	CdSO4	Egg	9.62	3.89		149 (7)	7.83 (0.14)	8.32 (0.64)	1	no problems	FT		H
Salmo trutta (Brown trout)	30 d LOEC/L	Weight	CdSO4	Swim-up fry	2.72	4.25		29.2 (0.9)	7.54 (0.13)	8.61 (0.22)	2	based on only 1 surviving fish at highest conc.	FT		H
Salmo trutta (Brown trout)	55 d IC20	Mortality	CdSO4	Egg	13.6	5.49		149 (7)	7.83 (0.14)	8.32 (0.64)	1	no problems	FT		H
Salmo trutta (Brown trout)	55 d LOEC/L	Mortality	CdSO4	Egg	8.64	6.44		71.3 (2.7)	7.75 (0.14)	8.61 (0.67)	1	no problems	FT		H
Salmo trutta (Brown trout)	55 d LOEC/L	Mortality	CdSO4	Egg	4.87	7.32		30.6 (2.1)	7.72 (0.12)	8.49 (0.58)	1	no problems	FT		H
Salmo trutta (Brown trout)	55 d LOEC/L	Mortality	CdSO4	Egg	19.1	7.72		149 (7)	7.83 (0.14)	8.32 (0.64)	1	no problems	FT		H
Salmo trutta (Brown trout)	61 d NOEC/L	Biomass, decrease in	CdCl2	Larva	1.1	1.20		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 10.0 C, no conductivity	FT	(Eaton et al. 1978)	
Salmo trutta (Brown trout)	61 d MATC	Biomass, decrease in	CdCl2	Larva	2	2.18		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 10.0 C, no conductivity	FT		

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Salmo trutta (Brown trout)	61 d LOEC/L	Biomass, decrease in	CdCl2	Larva	3.7	4.04		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 10.0 C, no conductivity	FT		H
Salmo trutta (Brown trout)	31 d NOEC/L	Biomass, decrease in	CdCl2	Embryo	3.7	4.04		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 10.0 C, no conductivity	FT		H
Salmo trutta (Brown trout)	83 d NOEC/L	Biomass, decrease in	CdCl2	Embryo	3.8	4.15		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 9.7 C, control mort may be a bit high but probably ok, no conductivity	FT		H
Salmo trutta (Brown trout)	60 d NOEC/L	Biomass, decrease in	CdCl2	Larva	3.8	4.15		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 9.7 C, no conductivity	FT		H
Salmo trutta (Brown trout)	31 d MATC	Biomass, decrease in	CdCl2	Embryo	6.4	6.98		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 10.0 C, no conductivity	FT		H
Salmo trutta (Brown trout)	83 d MATC	Biomass, decrease in	CdCl2	Embryo	6.7	7.31		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 9.7 C, control mort may be a bit high but probably ok, no conductivity	FT		H
Salmo trutta (Brown trout)	60 d MATC	Biomass, decrease in	CdCl2	Larva	6.7	7.31		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 9.7 C, no conductivity	FT		H
Salmo trutta (Brown trout)	31 d LOEC/L	Biomass, decrease in	CdCl2	Embryo	11.2	12.22		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 10.0 C, no conductivity	FT		H
Salmo trutta (Brown trout)	83 d LOEC/L	Biomass, decrease in	CdCl2	Embryo	11.7	12.77		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 9.7 C, control mort may be a bit high but probably ok, no conductivity	FT		H
Salmo trutta (Brown trout)	60 d LOEC/L	Biomass, decrease in	CdCl2	Larva	11.7	12.77		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 9.7 C, no conductivity	FT		H
Salvelinus confluentus (Bull trout)	55 d LOEC/L	Growth	CdCl2	Juvenile	0.786	1.18		30.6 (SD = 1.90)	7.55 (SD = 0.12)	8.69 (SD = 0.26)	1	no conductivity	FT	(Hansen et al. 2002b)	

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (μg/L)	Hardness Corrected Effect (μg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Salvelinus confluentus (Bull trout)	55 d LOEC/L	Mortality	CdCl2	Juvenile	0.786	1.18		30.6 (SD = 1.90)	7.55 (SD = 0.12)	8.69 (SD = 0.26)	1	no conductivity	FT		
Salvelinus confluentus (Bull trout)	55 d MATC	Growth	CdCl2	Juvenile	0.549	0.82	X	30.6 (SD = 1.90)	7.55 (SD = 0.12)	8.69 (SD = 0.26)	1	no conductivity	FT		
Salvelinus confluentus (Bull trout)	55 d MATC	Mortality	CdCl2	Juvenile	0.549	0.83		30.6 (SD = 1.90)	7.55 (SD = 0.12)	8.69 (SD = 0.26)	1	no conductivity	FT		
Salvelinus confluentus (Bull trout)	55 d NOEC/L	Growth	CdCl2	Juvenile	0.383	0.58		30.6 (SD = 1.90)	7.55 (SD = 0.12)	8.69 (SD = 0.26)	1	no conductivity	FT		
Salvelinus confluentus (Bull trout)	55 d NOEC/L	Mortality	CdCl2	Juvenile	0.383	0.58		30.6 (SD = 1.90)	7.55 (SD = 0.12)	8.69 (SD = 0.26)	1	no conductivity	FT		
Salvelinus fontinalis (Brook Trout)	126 d NOEC/L	Biomass, decrease in	CdCl2	Larva	1.1	1.20		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	2	temp 9.7 C, unexplained effects at 30 and 60 days, therefore these results may not be 100% reliable, no conductivity	FT	(Eaton et al. 1978)	
Salvelinus fontinalis (Brook Trout)	126 d MATC	Biomass, decrease in	CdCl2	Larva	2	2.23	X	45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	2	temp 9.7 C, unexplained effects at 30 and 60 days, therefore these results may not be 100% reliable, no conductivity	FT		H
Salvelinus fontinalis (Brook Trout)	126 d LOEC/L	Biomass, decrease in	CdCl2	Larva	3.8	4.15		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	2	temp 9.7 C, unexplained effects at 30 and 60 days, therefore these results may not be 100% reliable, no conductivity	FT		
Salvelinus fontinalis (Brook Trout)	55 d NOEC/L	Biomass, decrease in	CdCl2	Embryo	3.8	8.06		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	U	temp 9.7 C, unexplained effect at low AND higher Cd concs, intermediate not affected, no conductivity	FT		
Salvelinus fontinalis (Brook Trout)	55 d LOEC/L	Biomass, decrease in	CdCl2	Embryo	0.48 AND 11.7			45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	U	temp 9.7 C, unexplained effect at low AND higher Cd concs, intermediate not affected, no conductivity	FT		
Salvelinus fontinalis (Brook Trout)	65 d NOEC/L	Biomass, decrease in	CdCl2	Larva	1.1	2.33		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	U	temp 9.7 C, unexplained effect at low AND higher Cd concs, intermediate not affected, no conductivity	FT		

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Salvelinus fontinalis (Brook Trout)	65 d LOEC/L	Biomass, decrease in	CdCl2	Larva	0.48 AND 3.8			45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	U	temp 9.7 C, unexplained effect at low AND higher Cd concs, intermediate not affected, no conductivity	FT		
Salvelinus fontinalis (Brook Trout)	1100 d NOEC/L	Mortality	cadmium chloride	Mixed	1.7	1.89		44 (42-47)	7-8	7 (4-12)	1		FT	(Benoit et al. 1976)	H
Salvelinus fontinalis (Brook Trout)	1100 d MATC	Mortality	cadmium chloride	Mixed	2.4	2.62		44 (42-47)	7-8	7 (4-12)	2	The LOEC was deemed unacceptable and therefore an appropriate MATC cannot be calculated	FT		
Salvelinus fontinalis (Brook Trout)	1100 d LOEC/L	Mortality	cadmium chloride	Mixed	3.4	7.35		44 (42-47)	7-8	7 (4-12)	U	Resulted in the complete mortality of spawning males	FT		
Salvelinus fontinalis (Brook Trout)	60 d LOEC/L	Mortality	cadmium chloride	Fry	7	2.33		188 ± 27	6.7-7.1	10.6 ± 1.5	2	Only duplicates were used in the experiment	R	(Sauter et al. 1976)	
Salvelinus fontinalis (Brook Trout)	60 d NOEC/L	Weight	cadmium chloride	Fry	7	2.33		188 ± 27	6.7-7.1	10.6 ± 1.5	2	Only duplicates were used in the experiment	R		
Salvelinus fontinalis (Brook Trout)	60 d MATC	Mortality	cadmium chloride	Fry	9.17	3.05		188 ± 27	6.7-7.1	10.6 ± 1.5	2	Only duplicates were used in the experiment	R		H
Salvelinus fontinalis (Brook Trout)	60 d MATC	Weight	cadmium chloride	Fry	9.17	3.05		188 ± 27	6.7-7.1	10.6 ± 1.5	2	Only duplicates were used in the experiment	R		
Salvelinus fontinalis (Brook Trout)	60 d LOEC/L	Weight	cadmium chloride	Fry	12	4.00		188 ± 27	6.7-7.1	10.6 ± 1.5	2	Only duplicates were used in the experiment	R		
Salvelinus fontinalis (Brook Trout)	60 d NOEC/L	Mortality	cadmium chloride	Fry	12	4.00		188 ± 27	6.7-7.1	10.6 ± 1.5	2	Only duplicates were used in the experiment	R		
Salvelinus fontinalis (Brook Trout)	60 d NOEC/L	Weight	cadmium chloride	Fry	1	1.28		37 ± 7.2	6.5-7.2	10 ± 0.8	2	Only duplicates were used in the experiment	R		
Salvelinus fontinalis (Brook Trout)	60 d MATC	Weight	cadmium chloride	Fry	1.7	2.22		37 ± 7.2	6.5-7.2	10 ± 0.8	2	Only duplicates were used in the experiment	R		H
Salvelinus fontinalis (Brook Trout)	60 d LOEC/L	Weight	cadmium chloride	Fry	3	3.85		37 ± 7.2	6.5-7.2	10 ± 0.8	2	Only duplicates were used in the experiment	R		
Salvelinus fontinalis (Brook Trout)	60 d NOEC/L	Mortality	cadmium chloride	Fry	3	3.85		37 ± 7.2	6.5-7.2	10 ± 0.8	2	Only duplicates were used in the experiment	R		
Salvelinus fontinalis (Brook Trout)	60 d MATC	Mortality	cadmium chloride	Fry	4.24	5.44		37 ± 7.2	6.5-7.2	10 ± 0.8	2	Only duplicates were used in the experiment	R		
Salvelinus fontinalis (Brook Trout)	60 d LOEC/L	Mortality	cadmium chloride	Fry	6	7.70		37 ± 7.2	6.5-7.2	10 ± 0.8	2	Only duplicates were used in the experiment	R		

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Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Salvelinus namaycush (Lake Trout)	41 d LOEC/L	Biomass, decrease in	CdCl2	Embryo	12.3	13.42		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 9.6 C, no conductivity	FT	(Eaton et al. 1978)	
Salvelinus namaycush (Lake Trout)	64 d LOEC/L	Biomass, decrease in	CdCl2	Larva	12.3	13.42		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 9.6 C, no conductivity	FT		
Salvelinus namaycush (Lake Trout)	41 d MATC	Biomass, decrease in	CdCl2	Embryo	7.4	8.08		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 9.6 C, no conductivity	FT		
Salvelinus namaycush (Lake Trout)	64 d MATC	Biomass, decrease in	CdCl2	Larva	7.4	8.03	X	45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 9.6 C, no conductivity	FT		
Salvelinus namaycush (Lake Trout)	41 d NOEC/L	Biomass, decrease in	CdCl2	Embryo	4.4	4.80		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 9.6 C, no conductivity	FT		
Salvelinus namaycush (Lake Trout)	64 d NOEC/L	Biomass, decrease in	CdCl2	Larva	4.4	4.80		45 (44-46)	7.6 (7.2-7.8)	10.3 (8.0-12.2)	1	temp 9.6 C, no conductivity	FT		
Invertebrates															
Aeolosoma headleyi (Oligochaete)	14 d NOEC/L	Population growth		Young worms	32	11.70		60-180	NR	NR	2	hardness: 168, concentrations only measured at the beginning and few abiotic factors reported	R	(Niederlehner et al. 1984)	
Aeolosoma headleyi (Oligochaete)	10 d NOEC/L	Population growth		Young worms	17.2	14.39		60-180	NR	NR	2	hardness: 62, concentrations only measured at the beginning and few abiotic factors reported	R		
Aeolosoma headleyi (Oligochaete)	14 d MATC	Population growth		Young worms	40.1	14.66	X	60-180	NR	NR	2	Hardness: 168, calculated from the geometric mean of the NOEC and the LOEC	R		H
Aeolosoma headleyi (Oligochaete)	12 d NOEC/L	Population growth		Young worms	53.6	17.78		60-180	NR	NR	2	hardness: 189, concentrations only measured at the beginning and few abiotic factors reported	R		
Aeolosoma headleyi (Oligochaete)	14 d LOEC/L	Population growth		Young worms	50.2	18.36		60-180	NR	NR	2	hardness: 168, concentrations only measured at the beginning and few abiotic factors reported	R		
Aeolosoma headleyi (Oligochaete)	10 d MATC	Population growth		Young worms	25.2	21.08		60-180	NR	NR	2	Hardness: 62, calculated from the geometric mean of the NOEC and the LOEC	R		H
Aeolosoma headleyi (Oligochaete)	12 d MATC	Population growth		Young worms	70.2	23.28		60-180	NR	NR	2	Hardness: 189, calculated from the geometric mean of the NOEC and the LOEC	R		H

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Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Aeolosoma headleyi (Oligochaete)	12 d LOEC/L	Population growth		Young worms	92	30.51		60-180	NR	NR	2	hardness: 189, concentrations only measured at the beginning and few abiotic factors reported	R		
Aeolosoma headleyi (Oligochaete)	10 d LOEC/L	Population growth		Young worms	36.9	30.87		60-180	NR	NR	2	hardness: 62, concentrations only measured at the beginning and few abiotic factors reported	R		
Atyaephyra desmarestii (European shrimp)	6 d LOEC/L	Feeding inhibition	cadmium chloride	Adult	6.53	1.64		263.43 (+- 12.15)	7.92 (+- 0.02)	>90% sat	1	low power and only 3 concs tested but conc. range was good so overall ok	S	(Pestana et al. 2007)	
Atyaephyra desmarestii (European shrimp)	6 d NOEC/L	Feeding inhibition	cadmium chloride	Adult	4.2	1.06		263.43 (+- 12.15)	7.92 (+- 0.02)	>90% sat	1	low power and only 3 concs tested but conc. range was good so overall ok	S		
Atyaephyra desmarestii (European shrimp)	6 d MATC	Feeding inhibition	cadmium chloride	Adult	5.24	1.32	X	263.43 (+- 12.15)	7.92 (+- 0.02)	>90% sat	1	low power and only 3 concs tested but conc. range was good so overall ok	S		
Baetis rhodani (Mayfly)	5 d LC50	Mortality	not specified	Unknown	2300	2298.28		0.5 mmol/L	7		2	Not all test parameters reported	S	(Gerhardt 1992)	
Baetis rhodani (Mayfly)	5 d LC50	Mortality	not specified	Unknown	2500	2498.13		0.5 mmol/L	7		2	Not all test parameters reported	FT		
Baetis rhodani (Mayfly)	5 d LC50	Mortality	not specified	Unknown	3000	2997.76		0.5 mmol/L	5		2	Not all test parameters reported	FT		
Capitella capitata sp. Y (Gallery worm)	10 d LC50	Mortality	not reported	Larva	35						U	all controls had died by day 34, and 40% of controls had died by day 10 (duration of LC50), organisms were not fed during expt, sediments were included in containers (could confound results), solutions were renewed only every 7 days, and concs remaining i	R	(Mendez and Green-Ruiz 2006)	
Ceriodaphnia dubia (Water flea)	7 d MATC	Reproductio n	CdCl2	Not reported	2	4.90		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S	(Suedel et al. 1997)	
Ceriodaphnia dubia (Water flea)	10 d MATC	Reproductio n	CdCl2	Not reported	2	4.90		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S		
Ceriodaphnia dubia (Water	14 d	Reproductio	CdCl2	Not	2	4.90	X	6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a	S		

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Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
flea)	MATC	n		reported								preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range			
Ceriodaphnia dubia (Water flea)	14 d LC50	Mortality	CdCl2	Not reported	10.1	24.73		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S		
Ceriodaphnia dubia (Water flea)	10 d LC50	Mortality	CdCl2	Not reported	10.6	25.95		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S		
Ceriodaphnia dubia (Water flea)	7 d MATC	Mortality	CdCl2	Not reported	11.4	27.91		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S		
Ceriodaphnia dubia (Water flea)	10 d MATC	Mortality	CdCl2	Not reported	11.4	27.91		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S		
Ceriodaphnia dubia (Water flea)	14 d MATC	Mortality	CdCl2	Not reported	11.4	27.91		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S		
Ceriodaphnia dubia (Water flea)	7 d LC50	Mortality	CdCl2	Not reported	11.6	28.40		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S		
Ceriodaphnia reticulata (Water flea)	7 d MATC	Reproduction - Number of young per adult	CdCl2	Less than 24hrs	0.43	0.12	X	240 +- 10	8.0 +- 0.3	>5	2	nominal only, temp 23 degrees - warm, reported toxicant concs sometimes don't match up with values given in results table e.g. Table 6 says ">15.3" but the highest value tested was 25?, their LOEC and MATC values don't make sense based on the data but it'	R	(Elnabarawy et al. 1986)	
Ceriodaphnia reticulata	7 d	Reproductio	CdCl2	Less than	>15.3	4.16		240 +- 10	8.0 +-	>5	2	nominal only, temp 23 degrees - warm, reported toxicant	R		

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
(Water flea)	EC50	n - Number of young per adult		24hrs					0.3			concs sometimes don't match up with values given in results table e.g. Table 6 says ">15.3" but the highest value tested was 25?, their LOEC and MATC values don't make sense based on the data but it'			
Ceriodaphnia reticulata (Water flea)	7 d LC50	Mortality	CdCl2	Less than 24hrs	>15.3	4.16		240 +- 10	8.0 +- 0.3	>5	2	nominal only, temp 23 degrees - warm, reported toxicant concs sometimes don't match up with values given in results table e.g. Table 6 says ">15.3" but the highest value tested was 25?, their LOEC and MATC values don't make sense based on the data but it'	R		
Ceriodaphnia reticulata (Cladocerans)	9 d NOEC/L	Reproduction	cadmium chloride	Less than 24hrs	3.4	2.67		55.0-79.0	7.2-7.8		2	no units given for any WQ parameters (but can assume units), no DO value given, they don't specifically mention how many organisms were used per replicate, but they followed ASTM procedures so presumably it was enough, no control mortality reported, feed	S	(Spehar and Carlson 1984)	
Ceriodaphnia reticulata (Cladocerans)	9 d MATC	Reproduction	cadmium chloride	Less than 24hrs	4.9	3.84		55.0-79.0	7.2-7.8		2	no units given for any WQ parameters (but can assume units), no DO value given, they don't specifically mention how many organisms were used per replicate, but they followed ASTM procedures so presumably it was enough, no control mortality reported, feed	S		
Ceriodaphnia reticulata (Cladocerans)	9 d LOEC/L	Reproduction	cadmium chloride	Less than 24hrs	7.2	5.65		55.0-79.0	7.2-7.8		2	no units given for any WQ parameters (but can assume units), no DO value given, they don't specifically mention how many organisms were used per replicate, but they followed ASTM procedures so presumably it was enough, no control mortality reported, feed	S		
Ceriodaphnia reticulata (Cladocerans)	9 d NOEC/L	Mortality	cadmium chloride	Less than 24hrs	7.2	5.65		55.0-79.0	7.2-7.8		2	no units given for any WQ parameters (but can assume units), no DO value given, they don't specifically mention how many organisms were used per replicate, but they followed ASTM procedures so presumably it was enough, no control mortality reported, feed	S		
Ceriodaphnia reticulata (Cladocerans)	9 d MATC	Mortality	cadmium chloride	Less than 24hrs	10.5	8.24		55.0-79.0	7.2-7.8		2	no units given for any WQ parameters (but can assume units), no DO value given, they don't specifically mention how many organisms were used per replicate, but they followed ASTM procedures so presumably it was enough,	S		

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
												no control mortality reported, feed			
Ceriodaphnia reticulata (Cladocerans)	9 d LOEC/L	Mortality	cadmium chloride	Less than 24hrs	15.2	11.92		55.0-79.0	7.2-7.8		2	no units given for any WQ parameters (but can assume units), no DO value given, they don't specifically mention how many organisms were used per replicate, but they followed ASTM procedures so presumably it was enough, no control mortality reported, feed	S		
Chironomus riparius (Midge)	17 d NOEC/L	Mortality	not reported	1st instar	15	8.58		98 +- 26	7.6	>90% air sat	2	no alkalinity, concs measured but not significantly different from nominal, so nominal was used, filter paper was used as a substrate, food was added, control mortality was greater than 10%	R	(Pascoe et al. 1989)	
Chironomus riparius (Midge)	17 d MATC	Mortality	not reported	1st instar	47.4	27.13	X	98 +- 26	7.6	>90% air sat	2	no alkalinity, concs measured but not significantly different from nominal, so nominal was used, filter paper was used as a substrate, food was added, control mortality was greater than 10%	R		
Chironomus riparius (Midge)	17 d LOEC/L	Mortality	not reported	1st instar	150	85.81		98 +- 26	7.6	>90% air sat	2	no alkalinity, concs measured but not significantly different from nominal, so nominal was used, filter paper was used as a substrate, food was added, control mortality was greater than 10%	R		
Chironomus tentans (Midge)	60 d IC25	Hatching success	CdCl2	Less than 24hrs	4	0.96	X	280	7.80	>2.5	2	analytical techniques not reported (but likely ok), stats not reported (but likely ok), not sure when concs were measured (but likely every 2 weeks), no variation reported, temp 23 degrees - warm, chironomids had sand substrate (uncontaminated)	FT	(Ingersoll and Kemble 2001)	
Chironomus tentans (Midge)	60 d IC25	Percent emergence	CdCl2	Less than 24hrs	8.1	1.94		280	7.80	>2.5	2	analytical techniques not reported (but likely ok), stats not reported (but likely ok), not sure when concs were measured (but likely every 2 weeks), no variation reported, temp 23 degrees - warm, chironomids had sand substrate (uncontaminated)	FT		
Chironomus tentans (Midge)	20 d IC25	Weight	CdCl2	Less than 24hrs	9.9	2.37		280	7.80	>2.5	2	analytical techniques not reported (but likely ok), stats not reported (but likely ok), not sure when concs were measured (but likely every 2 weeks), no variation reported, temp 23 degrees - warm, chironomids had sand substrate (uncontaminated)	FT		

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Chironomus tentans (Midge)	20 d IC25	Biomass, decrease in	CdCl2	Less than 24hrs	10.3	2.47		280	7.80	>2.5	2	analytical techniques not reported (but likely ok), stats not reported (but likely ok), not sure when concs were measured (but likely every 2 weeks), no variation reported, temp 23 degrees - warm, chironomids had sand substrate (uncontaminated)	FT		
Chironomus tentans (Midge)	20 d IC25	Mortality	CdCl2	Less than 24hrs	>16.4	3.93		280	7.80	>2.5	2	analytical techniques not reported (but likely ok), stats not reported (but likely ok), not sure when concs were measured (but likely every 2 weeks), no variation reported, temp 23 degrees - warm, chironomids had sand substrate (uncontaminated)	FT		
Chironomus tentans (Midge)	60 d IC25	Repro - No. eggs per individual	CdCl2	Less than 24hrs	>16.4	3.93		280	7.80	>2.5	2	analytical techniques not reported (but likely ok), stats not reported (but likely ok), not sure when concs were measured (but likely every 2 weeks), no variation reported, temp 23 degrees - warm, chironomids had sand substrate (uncontaminated)	FT		
Chironomus tentans (Midge)	14 d LOEC/L	Growth	CdCl2	2nd instar	100	244.83		6-28	5.5-7.7	4.2-9.3	2	the corresponding NOEC was a less than value, so this weakens the LOEC, nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline of	S	(Suedel et al. 1997)	
Chironomus tentans (Midge)	7 d LOEC/L	Growth	CdCl2	2nd instar	500	1224.17		6-28	5.5-7.7	4.2-9.3	2	the corresponding NOEC was a less than value, so this weakens the LOEC, nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline of	S		
Chironomus tentans (Midge)	10 d LOEC/L	Growth	CdCl2	2nd instar	500	1224.17		6-28	5.5-7.7	4.2-9.3	2	the corresponding NOEC was a less than value, so this weakens the LOEC, nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline of	S		
Chironomus tentans (Midge)	14 d LC50	Mortality	CdCl2	2nd instar	635	1554.70		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs	S		

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
												didn't decline over time, temps were in the high range			
Chironomus tentans (Midge)	7 d MATC	Mortality	CdCl2	2nd instar	707	1730.98		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S		
Chironomus tentans (Midge)	10 d MATC	Mortality	CdCl2	2nd instar	707	1730.98		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S		
Chironomus tentans (Midge)	10 d LC50	Mortality	CdCl2	2nd instar	963	2357.76		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S		
Chironomus tentans (Midge)	7 d LC50	Mortality	CdCl2	2nd instar	1700	4162.19		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S		
Chironomus tentans (Midge)	14 d MATC	Mortality	CdCl2	2nd instar	707	1730.98		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S		
Daphnia magna (Water flea)	7 d EC10	Feeding inhibition	3CdSO4.8 H2O	Adult	0.13	0.05	X	179 +- 3.72	8.07 +- 0.07		2	nominal concs used (although concs were measured at start and end and were not found to differ by more than 10% from nominal), also no O2	R	(Barata and Baird 2000)	
Daphnia magna (Water flea)	7 d EC10	Repro - brood mass	3CdSO4.8 H2O	Adult	0.13	0.05		179 +- 3.72	8.07 +- 0.07		2	nominal concs used (although concs were measured at start and end and were not found to differ by more than 10% from nominal), also no O2	R		
Daphnia magna (Water flea)	7 d EC10	Reproduction - Brood size	3CdSO4.8 H2O	Adult	0.14	0.05		179 +- 3.72	8.07 +- 0.07		2	nominal concs used (although concs were measured at start and end and were not found to differ by more than 10% from nominal), also no O2	R		
Daphnia magna (Water flea)	7 d LC10	Mortality	3CdSO4.8 H2O	Adult	1.15	0.40		179 +- 3.72	8.07 +- 0.07		2	nominal concs used (although concs were measured at start and end and were not found to differ by more than 10% from nominal), also no O2	R		

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Daphnia magna (Water flea)	7 d EC10	Weight	3CdSO4.8 H2O	Adult	1.65	0.57		179 +- 3.72	8.07 +- 0.07		2	nominal concs used (although concs were measured at start and end and were not found to differ by more than 10% from nominal), also no O2	R		
Daphnia magna (Water flea)	7 d LC50	Mortality	3CdSO4.8 H2O	Adult	2.47	0.86		179 +- 3.72	8.07 +- 0.07		2	nominal concs used (although concs were measured at start and end and were not found to differ by more than 10% from nominal), also no O2	R		
Daphnia magna (Water flea)	21 d NOEC/L	Reproduction - Number of young per adult	Cd standard	Not reported	0.22	0.10		130			2	no pH, O2 (no mention of aeration), no conductivity, number of replicates not reported, life stage not reported	R	(Borgmann et al. 1989)	H
Daphnia magna (Water flea)	21 d MATC	Reproduction - Number of young per adult	Cd standard	Not reported	0.64	0.29		130			2	no pH, O2 (no mention of aeration), no conductivity, number of replicates not reported, life stage not reported	R		H
Daphnia magna (Water flea)	21 d LOEC/L	Reproduction - Number of young per adult	Cd standard	Not reported	1.86	0.84		130			2	no pH, O2 (no mention of aeration), no conductivity, number of replicates not reported, life stage not reported	R		H
Daphnia magna (Water flea)	21 d MATC	Repro - Number of young per survivor	CdCl2 . 1/2 H2O	Less than 24hrs	0.21	0.12		103 +- 19	7.9 +- 0.3	6.4 +- 0.8	1	no problems	R	(Chapman et al. 1980)	H
Daphnia magna (Water flea)	21 d MATC	Reproduction - Number of young per adult	CdCl2 . 1/2 H2O	Less than 24hrs	0.15	0.14		53 +- 3	7.5 +- 0.2	6.2 +- 1.0	1	no problems	R		H
Daphnia magna (Water flea)	21 d MATC	Reproduction - Number of young per adult	CdCl2 . 1/2 H2O	Less than 24hrs	0.38	0.21		103 +- 19	7.9 +- 0.3	6.4 +- 0.8	1	no problems	R		H
Daphnia magna (Water flea)	21 d MATC	Repro - Number of young per	CdCl2 . 1/2 H2O	Less than 24hrs	1.52	1.45		53 +- 3	7.5 +- 0.2	6.2 +- 1.0	1	no problems	R		

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
		survivor													
Daphnia magna (Water flea)	21 d MATC	Reproduction - Number of young per adult	CdCl2 . 1/2 H2O	Less than 24hrs	0.43			209 +- 4	8.2 +- 0.1	6.8 +- 0.7	U	Control mortality was too high - 20%	R		
Daphnia magna (Water flea)	21 d MATC	Repro - Number of young per survivor	CdCl2 . 1/2 H2O	Less than 24hrs	0.67			209 +- 4	8.2 +- 0.1	6.8 +- 0.7	U	Control mortality was too high - 20%	R		
Daphnia magna (Water flea)	21 d NOEC/L	Reproduction	CdCl2	24h	0.6	0.16		249.8	8.0 +- 0.2	69-100% sat	2	nominal concs used, but concs were measured and were apparently no more than 20% lower than nominal, but analytical techniques not specified, temp very high (25 degrees), no cond, alk, also O2 was low in old water (69% sat) but fully sat. at start of test	R	(Kühn et al. 1989)	H
Daphnia magna (Water flea)	21 d MATC	Reproduction	CdCl2	24h	1.09	0.29		249.8	8.0 +- 0.2	69-100% sat	2	nominal concs used, but concs were measured and were apparently no more than 20% lower than nominal, but analytical techniques not specified, temp very high (25 degrees), no cond, alk, also O2 was low in old water (69% sat) but fully sat. at start of test	R		H
Daphnia magna (Water flea)	21 d LOEC/L	Reproduction	CdCl2	24h	1.94	0.51		249.8	8.0 +- 0.2	69-100% sat	2	nominal concs used, but concs were measured and were apparently no more than 20% lower than nominal, but analytical techniques not specified, temp very high (25 degrees), no cond, alk, also O2 was low in old water (69% sat) but fully sat. at start of test	R		H
Daphnia magna (Water flea)	7 d MATC	Growth	CdSO4	Neonate	1.2	0.74		90			2	nominal only, no measurements made at all, no pH, O2 or conductivity (but 100% of controls survived so assume O2 was fine), temp was in high range	R	(Winner 1988)	
Daphnia magna (Water flea)	21 d EC50	Reproduction	CdCl2.1/2 H2O	Less than 24hrs	0.7	0.76		45.3 (44-53)	7.74 (7.4-8.2)	9	2	control mortality not specified, no confidence intervals, didn't specify whether measured concs were for beginning or end of week (i.e. can't be sure metal concs were constant throughout the week), Cd concs used not reported (but presumably ok since they	R	(Biesinger and Christensen 1972)	H
Daphnia magna (Water	21 d	Reproductio	CdCl2.1/2	Less than	0.17	0.18		45.3 (44-	7.74	9	2	control mortality not specified, no confidence intervals,	R		H

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
flea)	EC16	n	H2O	24hrs				53)	(7.4-8.2)			didn't specify whether measured concs were for beginning or end of week (i.e. can't be sure metal concs were constant throughout the week), Cd concs used not reported (but presumably ok since they			
Daphnia magna (Water flea)	21 d LC50	Mortality	CdCl2.1/2 H2O	Less than 24hrs	5	5.43		45.3 (44-53)	7.74 (7.4-8.2)	9	2	control mortality not specified, didn't specify whether measured concs were for beginning or end of week (i.e. can't be sure metal concs were constant throughout the week), Cd concs used not reported (but presumably ok since they did range-finding tests),	R		H
Daphnia magna (Water flea)	14 d EC50	Reproduction - Number of young per adult	CdCl2	Less than 24hrs	3.5	0.95		240 +- 10	8.0 +- 0.3	>5	2	nominal only, temp 23 degrees - warm, reported toxicant concs sometimes don't match up with values given in results table e.g. Table 6 says ">15.3" but the highest value tested was 25?, their LOEC and MATC values don't make sense based on the data but it'	R	(Elnabarawy et al. 1986)	
Daphnia magna (Water flea)	14 d MATC	Reproduction - Number of young per adult	CdCl2	Less than 24hrs	4.3	1.17		240 +- 10	8.0 +- 0.3	>5	2	nominal only, temp 23 degrees - warm, reported toxicant concs sometimes don't match up with values given in results table e.g. Table 6 says ">15.3" but the highest value tested was 25?, their LOEC and MATC values don't make sense based on the data but it'	R		
Daphnia magna (Water flea)	14 d LC50	Mortality	CdCl2	Less than 24hrs	>15.3	4.16		240 +- 10	8.0 +- 0.3	>5	2	nominal only, temp 23 degrees - warm, reported toxicant concs sometimes don't match up with values given in results table e.g. Table 6 says ">15.3" but the highest value tested was 25?, their LOEC and MATC values don't make sense based on the data but it'	R		
Daphnia magna (Water flea)	21 d NOEC/L	Reproduction	CdCl2 - H2O	Less than 24hrs	5	2.01		150	8.4 ± 0.2	NR	2	Missing abiotic factors and toxicity methods not clearly defined, but otherwise it was an ok study	R	(Bodar et al. 1988)	
Daphnia magna (Water flea)	21 d MATC	Reproduction	CdCl2 - H2O	Less than 24hrs	7.07	2.84		150	8.4 ± 0.2	NR	2	Missing abiotic factors and toxicity methods not clearly defined, but otherwise it was an ok study	R		H
Daphnia magna (Water flea)	21 d LOEC/L	Reproduction	CdCl2 - H2O	Less than 24hrs	10	4.02		150	8.4 ± 0.2	NR	2	Missing abiotic factors and toxicity methods not clearly defined, but otherwise it was an ok study	R		
Daphnia magna (Water flea)	7 d MATC	Mortality	CdCl2	Not reported	7.1	4.91		69-87	6.9-8.3	7.7-9.0	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs	S	(Suedel et al. 1997)	

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
												didn't decline over time, temps were in the high range			
Daphnia magna (Water flea)	10 d MATC	Mortality	CdCl2	Not reported	7.1	4.91		69-87	6.9-8.3	7.7-9.0	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S		
Daphnia magna (Water flea)	14 d MATC	Mortality	CdCl2	Not reported	7.1	4.91		69-87	6.9-8.3	7.7-9.0	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S		
Daphnia magna (Water flea)	14 d LC50	Mortality	CdCl2	Not reported	8.6	5.95		69-87	6.9-8.3	7.7-9.0	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S		
Daphnia magna (Water flea)	10 d LC50	Mortality	CdCl2	Not reported	9	6.22		69-87	6.9-8.3	7.7-9.0	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S		
Daphnia magna (Water flea)	7 d LC50	Mortality	CdCl2	Not reported	9.9	6.84		69-87	6.9-8.3	7.7-9.0	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S		
Daphnia pulex (Water flea)	42 d NOEC/L	Reproduction - Brood size	3CdSO4 8H2O	Less than 24hrs	5.2	1.47		50-200	8.3-9.0	NR	2	Hardness: 230, pseudoreplication and test conditions not reported	NR	(Winner 1986)	
Daphnia pulex (Water flea)	42 d MATC	Reprod - Brood size	3CdSO4 8H2O	Less than 24hrs	7.35	2.07	X	50-200	8.3-9.0	NR	2	Hardness: 230, pseudoreplication and test conditions not reported	NR		H
Daphnia pulex (Water flea)	42 d NOEC/L	Reproduction - Brood size	3CdSO4 8H2O	Less than 24hrs	2.7	2.39		50-200	8.3-9.0	NR	2	Hardness: 58, pseudoreplication and test conditions not reported	NR		
Daphnia pulex (Water flea)	42 d NOEC/L	Reproduction - Brood size	3CdSO4 8H2O	Less than 24hrs	5.6	2.81		50-200	8.3-9.0	NR	2	Hardness: 115, pseudoreplication and test conditions not reported	NR		
Daphnia pulex (Water flea)	42 d	Reproductio	3CdSO4	Less than	10.4	2.93		50-200	8.3-9.0	NR	2	Hardness: 230, pseudoreplication and test conditions not	NR		

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
	LOEC/L	n - Brood size	8H2O	24hrs								reported			
Daphnia pulex (Water flea)	42 d MATC	Reproduction - Brood size	3CdSO4 8H2O	Less than 24hrs	3.6	3.18		50-200	8.3-9.0	NR	2	Hardness: 58, pseudoreplication and test conditions not reported	NR		H
Daphnia pulex (Water flea)	42 d MATC	Reproduction - Brood size	3CdSO4 8H2O	Less than 24hrs	7.78	3.90		50-200	8.3-9.0	NR	2	Hardness: 115, pseudoreplication and test conditions not reported	NR		H
Daphnia pulex (Water flea)	42 d LOEC/L	Reproduction - Brood size	3CdSO4 8H2O	Less than 24hrs	4.8	4.24		50-200	8.3-9.0	NR	2	Hardness: 58, pseudoreplication and test conditions not reported	NR		
Daphnia pulex (Water flea)	42 d LOEC/L	Reproduction - Brood size	3CdSO4 8H2O	Less than 24hrs	10.8	5.41		50-200	8.3-9.0	NR	2	Hardness: 115, pseudoreplication and test conditions not reported	NR		
Daphnia pulex (Water flea)	58 d NOEC/L	Reproduction	3CdSO4-8H2O	Less than 24hrs	5	2.68		106	8.49	NR	2	These are the results for the third chronic test completed, the other tests had higher concentrations but showed no effects on reproduction, pseudoreplication was also used for this experiment	R	(Ingersoll and Winner 1982)	
Daphnia pulex (Water flea)	58 d MATC	Reproduction	3CdSO4-8H2O	Less than 24hrs	7.07	3.79		106	8.49	NR	2	These are the results for the third chronic test completed, the other tests had higher concentrations but showed no effects on reproduction, pseudoreplication was also used for this experiment	R		H
Daphnia pulex (Water flea)	58 d LOEC/L	Reproduction	3CdSO4-8H2O	Less than 24hrs	10	5.36		106	8.49	NR	2	These are the results for the third chronic test completed, the other tests had higher concentrations but showed no effects on reproduction, pseudoreplication was also used for this experiment	R		
Daphnia pulex (Water flea)	58 d NOEC/L	Reproduction - Brood size	3CdSO4-8H2O	Less than 24hrs	10			106	8.49	NR	U	Chronic test 2, confliction between the three tests completed (they all provide different results for the NOEC and the LOEC)	R		
Daphnia pulex (Water flea)	58 d NOEC/L	Reproduction - Brood size	3CdSO4-8H2O	Less than 24hrs	15			106	8.49	NR	U	Chronic test 1, confliction between the three tests completed (they all provide different results for the NOEC and the LOEC)	R		
Daphnia pulex (Water flea)	58 d	Reproductio	3CdSO4-	Less than	5			106	8.49	NR	U	Chronic test 3, confliction between the three tests completed	R		

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
	NOEC/L	n - Brood size	8H2O	24hrs								(they all provide different results for the NOEC and the LOEC)			
Daphnia pulex (Water flea)	58 d LOEC/L	Reproduction - Brood size	3CdSO4-8H2O	Less than 24hrs	10			106	8.49	NR	U	Chronic test 3, confliction between the three tests completed (they all provide different results for the NOEC and the LOEC)	R		
Daphnia pulex (Water flea)	58 d LOEC/L	Reproduction - Brood size	3CdSO4-8H2O	Less than 24hrs	15			106	8.49	NR	U	Chronic test 2, confliction between the three tests completed (they all provide different results for the NOEC and the LOEC)	R		
Daphnia pulex (Water flea)	58 d LOEC/L	Reproduction - Brood size	3CdSO4-8H2O	Less than 24hrs	20			106	8.49	NR	U	Chronic test 1, confliction between the three tests completed (they all provide different results for the NOEC and the LOEC)	R		
Daphnia pulex (Water flea)	14 d MATC	Reproduction - Number of young per adult	CdCl2	Less than 24hrs	13.7	3.73		240 +- 10	8.0 +- 0.3	>5	2	nominal only, temp 23 degrees - warm, reported toxicant concs sometimes don't match up with values given in results table e.g. Table 6 says ">15.3" but the highest value tested was 25?, their LOEC and MATC values don't make sense based on the data but it'	R	(Elnabarawy et al. 1986)	
Daphnia pulex (Water flea)	14 d EC50	Reproduction - Number of young per adult	CdCl2	Less than 24hrs	>15.3	4.16		240 +- 10	8.0 +- 0.3	>5	2	nominal only, temp 23 degrees - warm, reported toxicant concs sometimes don't match up with values given in results table e.g. Table 6 says ">15.3" but the highest value tested was 25?, their LOEC and MATC values don't make sense based on the data but it'	R		
Daphnia pulex (Water flea)	14 d LC50	Mortality	CdCl2	Less than 24hrs	>15.3	4.16		240 +- 10	8.0 +- 0.3	>5	2	nominal only, temp 23 degrees - warm, reported toxicant concs sometimes don't match up with values given in results table e.g. Table 6 says ">15.3" but the highest value tested was 25?, their LOEC and MATC values don't make sense based on the data but it'	R		
Daphnia pulex (Water flea)	21 d LOEC/L	Repro - Number of young per survivor	CdCl2	Less than 24hrs	0.003			80-90			U	many WQ parameters missing, e.g. pH, O2, cond, alk, also not sure whether concs were measured or not (don't think so, and they weren't reported), NO STATS used for chronic, doesn't really look like the values were sig. diff from controls, also results don	R	(Roux et al. 1993)	
Echinogammarus meridionalis (Gammarid	6 d LOEC/L	Feeding inhibition	cadmium chloride	Adult	6.35	1.60		263.43 (+- 12.15)	7.92 (+-	>90% sat	1	ow power and only 3 concs tested but conc. range was good so overall ok	S	(Pestana et al. 2007)	

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
amphipod)									0.02)						
Echinogammarus meridionalis (Gammarid amphipod)	6 d NOEC/L	Feeding inhibition	cadmium chloride	Adult	4.2	1.06		263.43 (+- 12.15)	7.92 (+- 0.02)	>90% sat	1	low power and only 3 concs tested but conc. range was good so overall ok	S		
Echinogammarus meridionalis (Gammarid amphipod)	6 d MATC	Feeding inhibition	cadmium chloride	Adult	5.16	1.3	X	263.43 (+- 12.15)	7.92 (+- 0.02)	>90% sat	1	low power and only 3 concs tested but conc. range was good so overall ok	S		
Erythemis simplicicollis (Dragonfly)	7 d NOEC/L	Mortality	cadmium chloride hemipentah ydrate	Larva	100000	48353.14	X	120	6.24	NR	2	Nominal concentrations used during the experiment, but otherwise a good study	R	(Tollett et al. 2009)	
Gammarus fasciatus (Amphipod)	42 d NOEC/L	Mortality	Cd metal standard	0 - 7 d old	1.49			130	8.2-8.8		U	control mortality was too high (55%, but probably shouldn't have been more than 20%), temp too high (25 degrees), no O2 reported, no aeration reported, water only renewed every 7 days	R	(Borgmann et al. 1989)	
Gammarus fasciatus (Amphipod)	42 d LOEC/L	Mortality	Cd metal standard	0 - 7 d old	2.23			130	8.2-8.8		U	control mortality was too high (55%, but probably shouldn't have been more than 20%), temp too high (25 degrees), no O2 reported, no aeration reported, water only renewed every 7 days	R		
Gammarus fasciatus (Amphipod)	42 d MATC	Mortality	Cd metal standard	0 - 7 d old	1.82			130	8.2-8.8		U	control mortality was too high (55%, but probably shouldn't have been more than 20%), temp too high (25 degrees), no O2 reported, no aeration reported, water only renewed every 7 days	R		
Gammarus pulex (Amphipod)	5 d LOEC/L	Behaviour - Inhibition of swimming ability	CdCl2	Adult	7.5	1.85		269.2	7.19 +- 0.02		2	no O2 or alk, hardness had to be calculated, concs were measured but didn't say how or when, no variation reported	FT	(Felten et al. 2007)	
Gammarus pulex (Amphipod)	7 d LOEC/L	Behaviour - Inhibition of swimming ability	CdCl2	Adult	7.5	1.85		269.2	7.19 +- 0.02		2	no O2 or alk, hardness had to be calculated, concs were measured but didn't say how or when, no variation reported	FT		
Gammarus pulex (Amphipod)	7 d NOEC/L	Feeding inhibition	CdCl2	Adult	7.5	1.85	X	269.2	7.19 +- 0.02		2	no O2 or alk, hardness had to be calculated, concs were measured but didn't say how or when, no variation reported	FT		

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Gammarus pulex (Amphipod)	5 d LOEC/L	Mortality	CdCl2	Adult	7.5	1.85		269.2	7.19 +- 0.02		2	no O2 or alk, hardness had to be calculated, concs were measured but didn't say how or when, no variation reported	FT		
Gammarus pulex (Amphipod)	7 d NOEC/L	Mortality	CdCl2	Adult	7.5	1.85		269.2	7.19 +- 0.02		2	no O2 or alk, hardness had to be calculated, concs were measured but didn't say how or when, no variation reported	FT		
Gammarus pulex (Amphipod)	7 d LOEC/L	Respiration	CdCl2	Adult	7.5	1.85		269.2	7.19 +- 0.02		2	no O2 or alk, hardness had to be calculated, concs were measured but didn't say how or when, no variation reported	FT		
Gammarus pulex (Amphipod)	5 d NOEC/L	Respiration	CdCl2	Adult	7.5	1.85		269.2	7.19 +- 0.02		2	no O2 or alk, hardness had to be calculated, concs were measured but didn't say how or when, no variation reported	FT		
Gammarus pulex (Amphipod)	7 d MATC	Feeding inhibition	CdCl2	Adult	10.6	2.62		269.2	7.19 +- 0.02		2	no O2 or alk, hardness had to be calculated, concs were measured but didn't say how or when, no variation reported	FT		
Gammarus pulex (Amphipod)	7 d MATC	Mortality	CdCl2	Adult	10.6	2.62		269.2	7.19 +- 0.02		2	no O2 or alk, hardness had to be calculated, concs were measured but didn't say how or when, no variation reported	FT		
Gammarus pulex (Amphipod)	5 d MATC	Respiration	CdCl2	Adult	10.6	2.62		269.2	7.19 +- 0.02		2	no O2 or alk, hardness had to be calculated, concs were measured but didn't say how or when, no variation reported	FT		
Gammarus pulex (Amphipod)	7 d LOEC/L	Feeding inhibition	CdCl2	Adult	15	3.71		269.2	7.19 +- 0.02		2	no O2 or alk, hardness had to be calculated, concs were measured but didn't say how or when, no variation reported	FT		
Gammarus pulex (Amphipod)	7 d LOEC/L	Mortality	CdCl2	Adult	15	3.71		269.2	7.19 +- 0.02		2	no O2 or alk, hardness had to be calculated, concs were measured but didn't say how or when, no variation reported	FT		
Gammarus pulex (Amphipod)	5 d LOEC/L	Respiration	CdCl2	Adult	15	3.71		269.2	7.19 +- 0.02		2	no O2 or alk, hardness had to be calculated, concs were measured but didn't say how or when, no variation reported	FT		
Gammarus pulex (Amphipod)	5 d NOEC/L	Mortality	CdCl2	Adult	< 7.5			269.2	7.19 +- 0.02		U	less than value, no O2 or alk, hardness had to be calculated, concs were measured but didn't say how or when, no variation reported	FT		
Gammarus pulex (Amphipod)	5 d NOEC/L	Behaviour - Inhibition of swimming ability	CdCl2	Adult	< 7.5			269.2	7.19 +- 0.02		U	less than value, no O2 or alk, hardness had to be calculated, concs were measured but didn't say how or when, no variation reported	FT		
Gammarus pulex (Amphipod)	5 d MATC	Mortality	CdCl2	Adult	< 7.5			269.2	7.19 +- 0.02		U	less than value, no O2 or alk, hardness had to be calculated, concs were measured but didn't say how or when, no variation reported	FT		
Gammarus pulex (Amphipod)	5 d MATC	Behaviour - Inhibition of swimming	CdCl2	Adult	< 7.5			269.2	7.19 +- 0.02		U	less than value, no O2 or alk, hardness had to be calculated, concs were measured but didn't say how or when, no variation reported	FT		

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
		ability													
Gammarus pulex (Amphipod)	7 d NOEC/L	Behaviour - Inhibition of swimming ability	CdCl2	Adult	< 7.5			269.2	7.19 +- 0.02		U	less than value, no O2 or alk, hardness had to be calculated, concs were measured but didn't say how or when, no variation reported	FT		
Gammarus pulex (Amphipod)	7 d NOEC/L	Respiration	CdCl2	Adult	< 7.5			269.2	7.19 +- 0.02		U	less than value, no O2 or alk, hardness had to be calculated, concs were measured but didn't say how or when, no variation reported	FT		
Gammarus pulex (Amphipod)	7 d MATC	Behaviour - Inhibition of swimming ability	CdCl2	Adult	< 7.5			269.2	7.19 +- 0.02		U	less than value, no O2 or alk, hardness had to be calculated, concs were measured but didn't say how or when, no variation reported	FT		
Gammarus pulex (Amphipod)	7 d MATC	Respiration	CdCl2	Adult	< 7.5			269.2	7.19 +- 0.02		U	less than value, no O2 or alk, hardness had to be calculated, concs were measured but didn't say how or when, no variation reported	FT		
Hyalella azteca (Amphipod)	7 d LC50	Mortality	AA Standard	Juvenile	0.15	0.35		18	7.39 (6.44-8.52)	NR	2	Stats	S	(Borgmann et al. 2005)	
Hyalella azteca (Scud)	7 d LC50	Mortality	Cd atomic absorption standard	Juvenile	0.15	0.35		18 mg/L (is this CaCO3 hardness?)	6.44-8.52 * (measured at end)	7-10 (END) - not aerated during test	2	Initially confusing because methods say that metal concs weren't measured in the hard water test solutions at the end of the 7 days but then they give values for "measured" as well as "nominal" LC50s for hard water. but I emailed the author and he gave	S		
Hyalella azteca (Scud)	7 d LC50	Mortality	Cd atomic absorption standard	Juvenile	1.6	0.75		124 mg/L (is this CaCO3 hardness?)	7.23-8.83 * (measured at end)	7-10 (END) - not aerated during test	2	Initially confusing because methods say that metal concs weren't measured in the hard water test solutions at the end of the 7 days but then they give values for "measured" as well as "nominal" LC50s for hard water. but I emailed the author and he gave	S		
Hyalella azteca (Amphipod)	42 d LC50	Mortality	Cd metal standard	0 - 7 d old	0.53	0.24		130	7.9-9		2	pH sometimes reached 9 by end of week - too high? , temp was 25 degrees - too warm? , no O2 reported, solutions only changed weekly!, Cd concs measured only at end of each	R	(Borgmann et al. 1991)	

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
												week, not at start (right after being changed)			
Hyalella azteca (Scud)	14 d LC50	Mortality	CdCl2	Juvenile	0.65	1.59		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S	(Suedel et al. 1997)	
Hyalella azteca (Scud)	10 d LC50	Mortality	CdCl2	Juvenile	1.2	2.94		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S		
Hyalella azteca (Scud)	7 d LC50	Mortality	CdCl2	Juvenile	1.7	4.16		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S		
Hyalella azteca (Scud)	14 d MATC	Mortality	CdCl2	Juvenile	0.16	0.39		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S		H
Hyalella azteca (Scud)	7 d MATC	Mortality	CdCl2	Juvenile	1.4	3.43		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S		
Hyalella azteca (Scud)	10 d MATC	Mortality	CdCl2	Juvenile	1.4	3.43		6-28	5.5-7.7	4.2-9.3	1	nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline over time, temps were in the high range	S		
Hyalella azteca (Scud)	14 d NOEC/L	Growth	CdCl2	Juvenile	2	4.90		6-28	5.5-7.7	4.2-9.3	2	the corresponding LOEC was a greater than value, so this weakens the NOEC, nominal concs used, but concs were measured at start, and a preliminary experiment showed that Cd measured on Day 14 was 102% of nominal, so we can assume that concs didn't decline	S		
Hyalella azteca (Amphipod)	28 d IC25	Biomass, decrease in	CdCl2	7-8 d old	0.51	0.12	X	280	7.80	>2.5	2	analytical techniques not reported (but likely ok), stats not reported (but likely ok), not sure when concs were measured (but likely every 2 weeks), no variation reported,	FT	(Ingersoll and Kemble 2001)	H

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
												temp 23 degrees - warm			
Hyalella azteca (Amphipod)	28 d IC25	Weight	CdCl2	7-8 d old	0.74	0.18		280	7.80	>2.5	2	analytical techniques not reported (but likely ok), stats not reported (but likely ok), not sure when concs were measured (but likely every 2 weeks), no variation reported, temp 23 degrees - warm	FT		H
Hyalella azteca (Amphipod)	28 d MATC	Mortality	CdCl2	7-8 d old	0.98	0.23		280	7.80	>2.5	2		FT		H
Hyalella azteca (Amphipod)	42 d IC25	Reproduction	CdCl2	7-8 d old	1.4	0.34		280	7.80	>2.5	2	analytical techniques not reported (but likely ok), stats not reported (but likely ok), not sure when concs were measured (but likely every 2 weeks), no variation reported, temp 23 degrees - warm	FT		H
Hyalella azteca (Amphipod)	42 d IC25	Mortality	CdCl2	7-8 d old	1.9	0.45		280	7.80	>2.5	2	analytical techniques not reported (but likely ok), stats not reported (but likely ok), not sure when concs were measured (but likely every 2 weeks), no variation reported, temp 23 degrees - warm	FT		H
Hyalella azteca (Amphipod)	28 d LOEC/L	Mortality	CdCl2	7-8 d old	1.9	0.45		280	7.80	>2.5	2		FT		
Hyalella azteca (Amphipod)	28 d IC25	Length	CdCl2	7-8 d old	2.6	0.62		280	7.80	>2.5	2	analytical techniques not reported (but likely ok), stats not reported (but likely ok), not sure when concs were measured (but likely every 2 weeks), no variation reported, temp 23 degrees - warm	FT		
Hyalella azteca (Amphipod)	28 d NOEC/L	Mortality	CdCl2	7-8 d old	0.51	0.12		280	7.80	>2.5	2		FT		
Hyalella azteca (Scud)	28 d NOEC/L	Mortality	3CdSO4.8 H2O	7-8 d old	2.49	0.94		162.7 (6.1)	7.9 (0.1)	6.1 (1.8)	1	no problems	R	(Stanley et al. 2005)	
Hyalella azteca (Amphipod)	28 d NOEC/L	Mortality	Cadmium sulfate (3CdSO4-8H20)	Unknown	2.49	0.94		162.7 ± 6.1	7.9 ± 0.1	6.1 ± 1.8	2	Control mortality was 55%, but the rest of the conditions were perfect	R		
Hyalella azteca (Amphipod)	28 d MATC	Mortality	Cadmium sulfate (3CdSO4-8H20)	Unknown	2.63	1.12		139.6 ± 9.0	7.1 ± 0.2	5.9 ± 1.1	2	Nominal concentrations used.	R		

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Hyalella azteca (Amphipod)	42 d MATC	Mortality	Cadmium sulfate (3CdSO4-8H20)	Unknown	2.63	1.12		139.6 ± 9.0	7.1 ± 0.2	5.9 ± 1.1	2	Nominal concentrations used.	R		
Hyalella azteca (Scud)	28 d MATC	Mortality	3CdSO4.8 H2O	7-8 d old	3.56	1.34		162.7 (6.1)	7.9 (0.1)	6.1 (1.8)	1	no problems	R		
Hyalella azteca (Amphipod)	28 d MATC	Mortality	Cadmium sulfate (3CdSO4-8H20)	Unknown	3.56	1.34		162.7 ± 6.1	7.9 ± 0.1	6.1 ± 1.8	2	Control mortality was 55%, but the rest of the conditions were perfect	R		
Hyalella azteca (Scud)	28 d LOEC/L	Mortality	3CdSO4.8 H2O	7-8 d old	5.09	1.91		162.7 (6.1)	7.9 (0.1)	6.1 (1.8)	1	no problems	R		
Hyalella azteca (Amphipod)	28 d LOEC/L	Mortality	Cadmium sulfate (3CdSO4-8H20)	Unknown	5.09	1.91		162.7 ± 6.1	7.9 ± 0.1	6.1 ± 1.8	2	Control mortality was 55%, but the rest of the conditions were perfect	R		
Hyalella azteca (Amphipod)	28 d LOEC/L	Mortality	Cadmium sulfate (3CdSO4-8H20)	Unknown	4.53	1.93		139.6 ± 9.0	7.1 ± 0.2	5.9 ± 1.1	2	Nominal concentrations used.	R		
Hyalella azteca (Amphipod)	42 d LOEC/L	Mortality	Cadmium sulfate (3CdSO4-8H20)	Unknown	4.53	1.93		139.6 ± 9.0	7.1 ± 0.2	5.9 ± 1.1	2	Nominal concentrations used.	R		
Hyalella azteca (Amphipod)	28 d NOEC/L	Mortality	Cadmium sulfate (3CdSO4-8H20)	Unknown	<4.53	1.93		139.6 ± 9.0	7.1 ± 0.2	5.9 ± 1.1	2	Nominal concentrations used.	R		
Hyalella azteca (Amphipod)	42 d NOEC/L	Mortality	Cadmium sulfate (3CdSO4-8H20)	Unknown	<4.53	1.93		139.6 ± 9.0	7.1 ± 0.2	5.9 ± 1.1	2	Nominal concentrations used.	R		
Hyalella azteca (Scud)	28 d	Mortality	3CdSO4.8	7-8 d old	6.82	2.91		139.6 (9.0)	7.0	6.7	2	this NOEC value is the lowest conc. tested in the series so it	FT		

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
	NOEC/L		H2O						(0.3)	(1.1)		is likely that the NOEC is actually lower than this			
Hyalella azteca (Scud)	42 d NOEC/L	Mortality	3CdSO4.8 H2O	7-8 d old	6.82	2.91		139.6 (9.0)	7.0 (0.3)	6.7 (1.1)	2	this NOEC value is the lowest conc. tested in the series so it is likely that the NOEC is actually lower than this	FT		
Hyalella azteca (Scud)	28 d MATC	Mortality	3CdSO4.8 H2O	7-8 d old	12.52	5.34		139.6 (9.0)	7.0 (0.3)	6.7 (1.1)	2	big gap between NOEC and LOEC, so this value may not be as accurate as it could be	FT		
Hyalella azteca (Scud)	42 d MATC	Mortality	3CdSO4.8 H2O	7-8 d old	12.52	5.34		139.6 (9.0)	7.0 (0.3)	6.7 (1.1)	2	big gap between NOEC and LOEC, so this value may not be as accurate as it could be	FT		
Hyalella azteca (Scud)	28 d LOEC/L	Mortality	3CdSO4.8 H2O	7-8 d old	22.97	9.80		139.6 (9.0)	7.0 (0.3)	6.7 (1.1)	2	this LOEC value is the next highest conc. tested after the NOEC (which is 6.82). Because there's such a big gap between the two concs tested in this case (i.e. only 3 concs were tested), there's a good chance that the LOEC would actually be quite a bit lo	FT		
Hyalella azteca (Scud)	42 d LOEC/L	Mortality	3CdSO4.8 H2O	7-8 d old	22.97	9.80		139.6 (9.0)	7.0 (0.3)	6.7 (1.1)	2	this LOEC value is the next highest conc. tested after the NOEC (which is 6.82). Because there's such a big gap between the two concs tested in this case (i.e. only 3 concs were tested), there's a good chance that the LOEC would actually be quite a bit lo	FT		
Hyalella azteca (Amphipod)	28 d LC50	Mortality	Cadmium sulfate (3CdSO4-8H20)	Unknown	14.22			139.6 ± 9.0	7.0 ± 0.3	6.7 ± 1.1	U	This test only had one replicate	NA		
Hyalella azteca (Amphipod)	28 d NOEC/L	Mortality	Cadmium sulfate (3CdSO4-8H20)	Unknown	6.82			139.6 ± 9.0	7.0 ± 0.3	6.7 ± 1.1	U	This test only had one replicate	NA		
Hyalella azteca (Amphipod)	28 d LOEC/L	Mortality	Cadmium sulfate (3CdSO4-8H20)	Unknown	22.97			139.6 ± 9.0	7.0 ± 0.3	6.7 ± 1.1	U	This test only had one replicate	NA		
Hyalella azteca (Amphipod)	28 d MATC	Mortality	Cadmium sulfate (3CdSO4-8H20)	Unknown	12.52			139.6 ± 9.0	7.0 ± 0.3	6.7 ± 1.1	U	This test only had one replicate	NA		

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Hyalella azteca (Amphipod)	42 d LC50	Mortality	Cadmium sulfate (3CdSO4-8H20)	Unknown	14.10			139.6 ± 9.0	7.0 ± 0.3	6.7 ± 1.1	U	This test only had one replicate	NA		
Hyalella azteca (Amphipod)	42 d NOEC/L	Mortality	Cadmium sulfate (3CdSO4-8H20)	Unknown	6.82			139.6 ± 9.0	7.0 ± 0.3	6.7 ± 1.1	U	This test only had one replicate	NA		
Hyalella azteca (Amphipod)	42 d LOEC/L	Mortality	Cadmium sulfate (3CdSO4-8H20)	Unknown	22.97			139.6 ± 9.0	7.0 ± 0.3	6.7 ± 1.1	U	This test only had one replicate	NA		
Hyalella azteca (Amphipod)	42 d MATC	Mortality	Cadmium sulfate (3CdSO4-8H20)	Unknown	12.52			139.6 ± 9.0	7.0 ± 0.3	6.7 ± 1.1	U	This test only had one replicate	NA		
Hyalella azteca (Scud)	28 d LC50	Mortality	3CdSO4.8 H2O	7-8 d old	> 5.09 (5.66 is the estimated value using TSK meth	1.91		162.7 (6.1)	7.9 (0.1)	6.1 (1.8)	2	"greater than" values are not ideal, they also give an actual number but it's estimated by the Trimmed Spearman-Karber method. also note that LC50s were adjusted for control mortality	R		
Hyalella azteca (Amphipod)	28 d LC50	Mortality	Cadmium sulfate (3CdSO4-8H20)	Unknown	> 5.09	1.91		162.7 ± 6.1	7.9 ± 0.1	6.1 ± 1.8	2	Control mortality was 55%, but the rest of the conditions were perfect	R		
Hyalella azteca (Scud)	42 d LC50	Mortality	3CdSO4.8 H2O	7-8 d old	14.1	6.01		139.6 (9.0)	7.0 (0.3)	6.7 (1.1)	1	fine but note that LC50s were adjusted for control mortality	FT		
Hyalella azteca (Scud)	28 d LC50	Mortality	3CdSO4.8 H2O	7-8 d old	14.22	6.06		139.6 (9.0)	7.0 (0.3)	6.7 (1.1)	1	fine but note that LC50s were adjusted for control mortality	FT		
Hyalella azteca (Scud)	28 d	Mortality	3CdSO4.8	7-8 d old	18.77	8.00		139.6 (9.0)	7.1	5.9	1	fine but note that LC50s were adjusted for control mortality	R		

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
	LC50		H2O						(0.2)	(1.1)					
Hyalella azteca (Amphipod)	28 d LC50	Mortality	Cadmium sulfate (3CdSO4-8H20)	Unknown	18.77	8.00		139.6 ± 9.0	7.1 ± 0.2	5.9 ± 1.1	2	Nominal concentrations used.	R		
Hyalella azteca (Amphipod)	42 d LC50	Mortality	Cadmium sulfate (3CdSO4-8H20)	Unknown	<4.53	1.93		139.6 ± 9.0	7.1 ± 0.2	5.9 ± 1.1	2	Nominal concentrations used.	R		
Hyalella azteca (Amphipod)	42 d NOEC/L	Mortality	Cadmium sulfate (3CdSO4-8H20)	Unknown	0.48	0.18		162.7 ± 6.1	7.9 ± 0.1	6.1 ± 1.8	2	Control mortality was 55%, but the rest of the conditions were perfect	R		
Hyalella azteca (Amphipod)	42 d MATC	Mortality	Cadmium sulfate (3CdSO4-8H20)	Unknown	0.67	0.25		162.7 ± 6.1	7.9 ± 0.1	6.1 ± 1.8	2	Control mortality was 55%, but the rest of the conditions were perfect	R		H
Hyalella azteca (Amphipod)	42 d LOEC/L	Mortality	Cadmium sulfate (3CdSO4-8H20)	Unknown	0.94	0.35		162.7 ± 6.1	7.9 ± 0.1	6.1 ± 1.8	2	Control mortality was 55%, but the rest of the conditions were perfect	R		
Hyalella azteca (Amphipod)	42 d LC50	Mortality	Cadmium sulfate (3CdSO4-8H20)	Unknown	1.12	0.42		162.7 ± 6.1	7.9 ± 0.1	6.1 ± 1.8	2	Control mortality was 55%, but the rest of the conditions were perfect	R		
Hyalella azteca (Amphipod)	42 d NOEC/L	Mortality	Cd metal standard	0 - 7 d old	0.57			130	8.2-8.8		U	control mortality was too high (36%, but shouldn't have been more than 20%), temp too high (25 degrees), no O2 reported, no aeration reported, water only renewed every 7 days	R	(Borgmann et al. 1989)	
Hyalella azteca (Amphipod)	42 d LOEC/L	Mortality	Cd metal standard	0 - 7 d old	0.92			130	8.2-8.8		U	control mortality was too high (36%, but shouldn't have been more than 20%), temp too high (25 degrees), no O2 reported, no aeration reported, water only renewed every 7 days	R		

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Hyalella azteca (Amphipod)	42 d MATC	Mortality	Cd metal standard	0 - 7 d old	0.72			130	8.2-8.8		U	control mortality was too high (36%, but shouldn't have been more than 20%), temp too high (25 degrees), no O2 reported, no aeration reported, water only renewed every 7 days	R		H
Hydra viridissima (Green hydra)	7 d NOEC/L	Population growth inhibition	cadmium chloride		0.4	0.87	X	19-20	7.25-7.53	7.73-9.44	2	Nominal concentrations only - not measured	R	(Holdway et al. 2001)	
Hydra vulgaris (Pink hydra)	7 d NOEC/L	Population growth inhibition	cadmium chloride		<12.5			19-20	7.25-7.53	7.73-9.44	U	No concentrations used that were lower than 12.5 ug/L so this is a meaningless value for the NOEC. Also, nominal concentrations only - not measured	R		
Lampsilis siliquoidea (fatmucket)	28 d NOEC/L	Mortality	cadmium nitrate (Cd(NO3)2)	Juvenile	4.4	4.89		40-48	7.2-7.6	>7.0	2	Control mortality a little high but it meets the requirements based on the criteria set by the ASTM	FT	(Wang et al. 2010)	
Lampsilis siliquoidea (fatmucket)	28 d NOEC/L	Length	cadmium nitrate (Cd(NO3)2)	Juvenile	4.4	4.89		40-48	7.2-7.6	>7.0	2	Control mortality a little high but it meets the requirements based on the criteria set by the ASTM	FT		
Lampsilis siliquoidea (fatmucket)	28 d IC10	Length	cadmium nitrate (Cd(NO3)2)	Juvenile	4.6	5.11	X	40-48	7.2-7.6	>7.0	2	Control mortality a little high but it meets the requirements based on the criteria set by the ASTM	FT		
Lampsilis siliquoidea (fatmucket)	28 d IC10	Mortality	cadmium nitrate (Cd(NO3)2)	Juvenile	4.8	5.34		40-48	7.2-7.6	>7.0	2	Control mortality a little high but it meets the requirements based on the criteria set by the ASTM	FT		
Lampsilis siliquoidea (fatmucket)	28 d IC20	Length	cadmium nitrate (Cd(NO3)2)	Juvenile	5	5.56		40-48	7.2-7.6	>7.0	2	Control mortality a little high but it meets the requirements based on the criteria set by the ASTM	FT		
Lampsilis siliquoidea (fatmucket)	28 d IC20	Mortality	cadmium nitrate (Cd(NO3)2	Juvenile	5.7	6.34		40-48	7.2-7.6	>7.0	2	Control mortality a little high but it meets the requirements based on the criteria set by the ASTM	FT		

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
			)												
Lampsilis siliquoidea (fatmucket)	28 d ChV	Mortality	cadmium nitrate (Cd(NO3)2)	Juvenile	6	6.67		40-48	7.2-7.6	>7.0	2	Control mortality a little high but it meets the requirements based on the criteria set by the ASTM	FT		
Lampsilis siliquoidea (fatmucket)	28 d ChV	Length	cadmium nitrate (Cd(NO3)2)	Juvenile	6	6.67		40-48	7.2-7.6	>7.0	2	Control mortality a little high but it meets the requirements based on the criteria set by the ASTM	FT		
Lampsilis siliquoidea (fatmucket)	28 d EC50	Mortality	cadmium nitrate (Cd(NO3)2)	Juvenile	8.1	9.01		40-48	7.2-7.6	>7.0	2	Control mortality a little high but it meets the requirements based on the criteria set by the ASTM	FT		
Lampsilis siliquoidea (fatmucket)	28 d LOEC/L	Mortality	cadmium nitrate (Cd(NO3)2)	Juvenile	8.2	9.12		40-48	7.2-7.6	>7.0	2	Control mortality a little high but it meets the requirements based on the criteria set by the ASTM	FT		
Lampsilis siliquoidea (fatmucket)	28 d LOEC/L	Length	cadmium nitrate (Cd(NO3)2)	Juvenile	8.2	9.12		40-48	7.2-7.6	>7.0	2	Control mortality a little high but it meets the requirements based on the criteria set by the ASTM	FT		
Lampsilis siliquoidea (fatmucket)	21 d EC50	Mortality	cadmium nitrate (Cd(NO3)2)	Juvenile	12	13.34		40-48	7.2-7.6	>7.0	2	Control mortality a little high but it meets the requirements based on the criteria set by the ASTM	FT		
Leptophlebia marginata (Mayfly)	5 d LC50	Mortality	Not specified	Unknown	>5000	4996.27		0.5 mmol/L	5		2	Not all test parameters reported	S	(Gerhardt 1992)	
Leptophlebia marginata (Mayfly)	5 d LC50	Mortality	not specified	Unknown	>5000	4996.27		0.5 mmol/L	7		2	some test parameters NR	S		
Leptophlebia marginata (Mayfly)	5 d LC50	Mortality	not specified	Unknown	3600	3597.31		0.5 mmol/L	5		2	Not all test parameters reported	FT		
Leptophlebia marginata (Mayfly)	5 d LC50	Mortality	not specified	Unknown	>5000	4996.27		0.5 mmol/L	7		2	Not all test parameters reported	FT		

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Lymnaea palustris (Marsh snail)	4 weeks EC50	Growth	cadmium chloride	Adult	58.2	58.20	X		6.65-8.14		2	many variables lacking: O2, alk, hardness, conduct, also pH varied during a given expt (as much as a 1.5 unit decrease) because water was only changed once per week, also no variation reported, concs were nominal only	R	(Coeurdassier et al. 2003)	
Lymnaea palustris (Marsh snail)	4 weeks EC50	Repro - No. egg masses per individual	cadmium chloride	Adult	60.9	60.90			6.65-8.14		2	many variables lacking: O2, alk, hardness, conduct, also pH varied during a given expt (as much as a 1.5 unit decrease) because water was only changed once per week, also no variation reported, concs were nominal only	R		
Lymnaea palustris (Marsh snail)	4 weeks EC50	Repro - No. eggs per individual	cadmium chloride	Adult	64.7	64.70			6.65-8.14		2	many variables lacking: O2, alk, hardness, conduct, also pH varied during a given expt (as much as a 1.5 unit decrease) because water was only changed once per week, also no variation reported, concs were nominal only	R		
Lymnaea palustris (Marsh snail)	4 weeks EC50	Repro - No. eggs per egg mass	cadmium chloride	Adult	124	124.00			6.65-8.14		2	many variables lacking: O2, alk, hardness, conduct, also pH varied during a given expt (as much as a 1.5 unit decrease) because water was only changed once per week, also no variation reported, concs were nominal only	R		
Lymnaea palustris (Marsh snail)	4 weeks LC50	Mortality	cadmium chloride	Adult	>320	320.00			6.65-8.14		2	values shouldn't be greater than, many variables lacking: O2, alk, hardness, conduct, also pH varied during a given expt (as much as a 1.5 unit decrease) because water was only changed once per week, also no variation reported, concs were nominal only	R		
Lymnaea palustris (Marsh snail)	4 weeks NOEC/L	Growth	cadmium chloride	Adult	40	40.00			6.65-8.14		2	many variables lacking: O2, alk, hardness, conduct, also pH varied during a given expt (as much as a 1.5 unit decrease) because water was only changed once per week, concs were nominal only	R		
Lymnaea palustris (Marsh snail)	4 weeks NOEC/L	Repro - No. egg masses per individual	cadmium chloride	Adult	40	40.00			6.65-8.14		2	many variables lacking: O2, alk, hardness, conduct, also pH varied during a given expt (as much as a 1.5 unit decrease) because water was only changed once per week, concs were nominal only	R		
Lymnaea palustris (Marsh snail)	4 weeks NOEC/L	Repro - No. eggs per individual	cadmium chloride	Adult	40	40.00			6.65-8.14		2	many variables lacking: O2, alk, hardness, conduct, also pH varied during a given expt (as much as a 1.5 unit decrease) because water was only changed once per week, concs were nominal only	R		

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
Lymnaea palustris (Marsh snail)	4 weeks NOEC/L	Mortality	cadmium chloride	Adult	320				6.65-8.14		U	this value isn't meaningful for a NOEC since this was the highest conc. tested! many variables lacking: O2, alk, hardness, conduct, also pH varied during a given expt (as much as a 1.5 unit decrease) because water was only changed once per week, concs were	R		
Lymnaea stagnalis (Great pond snail)	4 weeks EC50	Growth	cadmium chloride	Adult	142.2	33.63		284	6.65-8.14		2	many variables lacking: O2, alk, hardness, conduct, also pH varied during a given expt (as much as a 1.5 unit decrease) because water was only changed once per week, also no variation reported, concs were nominal only	R		
Lymnaea stagnalis (Great pond snail)	4 weeks NOEC/L	Growth	cadmium chloride	Adult	80	18.92	X	284	6.65-8.14		2	many variables lacking: O2, alk, hardness, conduct, also pH varied during a given expt (as much as a 1.5 unit decrease) because water was only changed once per week, concs were nominal only	R		
Pachydiplax longipennis (Dragonfly)	7 d LOEC/L	Mortality	cadmium chloride hemipentahydrate	Larva	250000	120882.85		120	6.24	NR	2	Nominal concentrations used during the experiment, but otherwise a good study	R	(Tollett et al. 2009)	
Pachydiplax longipennis (Dragonfly)	7 d MATC	Mortality	cadmium chloride hemipentahydrate	Larva	160000	76453.02	X	120	6.24	NR	2	Nominal concentrations used during the experiment, but otherwise a good study, MATC was calculated from the geometric mean of the NOEC and the LOEC	R		
Pachydiplax longipennis (Dragonfly)	7 d NOEC/L	Mortality	cadmium chloride hemipentahydrate	Larva	100000	48353.14		120	6.24	NR	2	Nominal concentrations used during the experiment, but otherwise a good study	R		
Rhithrogena hageni (Mayfly)	10 d EC10	Mortality	cadmium sulfate	nymph	2571	2659.60	X	48.0 ± 2.0	7.66 ± 0.1	9.07 ± 0.15	1	Calculated using the Australian Calculator	FT	(Brinkman and Johnston 2008)	
Rhithrogena hageni (Mayfly)	10 d LOEC/L	Mortality	cadmium sulfate	nymph	3520	3641.31		48.0 ± 2.0	7.66 ± 0.1	9.07 ± 0.15	1	No problems	FT		
Rhithrogena hageni (Mayfly)	10 d NOEC/L	Mortality	cadmium sulfate	nymph	1880	1944.79		48.0 ± 2.0	7.66 ± 0.1	9.07 ± 0.15	1	No problems	FT		
Aquatic Plants															
Lemna minor (Duckweed)	7 d	Growth rate	cadmium	Not	214	79.04	X	166	5.5 +-		2	some variables lacking: O2 (but ok for plants), alkalinity,	NR	(Drost et al. 2007)	

Appendix 1(ii): Long-term Toxicity Data for Aquatic Species Exposed to Cadmium

Species Latin name (Common Name)	Endpoint	Observed effect	Formulation	Life stage	Effect concentration (µg/L)	Hardness Corrected Effect (µg/L)	Inclusion in SSD	Hardness (as $CaCO_3$)	pH	Dissolve Oxygen (mg/L)	Rank	Rationale and details for ranking	Test Type	Reference	Notes
	EC50		sulphate	reported					0.2			hardness, conductivity; nominal concs only, temp a bit high			
Lemna minor (Duckweed)	6 d EC50	Growth rate	cadmium sulphate	Not reported	214	79.04		166	5.5 +- 0.2		2	See comment above	NR		
Lemna minor (Duckweed)	5 d EC50	Growth rate	cadmium sulphate	Not reported	315	116.35		166	5.5 +- 0.2		2	See comment above	NR		
Lemna minor (Duckweed)	4 d EC50	Growth rate	cadmium sulphate	NR	337	124.48		166	5.5 +- 0.2		2	See comment above	NR		
Lemna minor (Duckweed)	3 d EC50	Growth rate	cadmium sulphate	NR	393	145.16		166	5.5 +- 0.2		2	See comment above	NR		

Notes:

H, data was used in the evaluation of cadmium toxicity-water hardness relationship.

Endpoint Abbreviations: EC= Effect Concentration, LC= Lethal Concentration, IC= Inhibitory Concentration, NOEC= No Observed Effect Concentration, LOEC= Lowest Observed Effect Concentration, MATC= Maximum Acceptable Toxicant Concentration
(calculate as the geometric mean of the reported NOEC and LOEC)

Effect Concentration: ** = concentration approximated from graphical interpolation, *** = estimated using TSK method

Effect Concentration adjusted to 50mg/L hardness:

Adjustment equation for short-term:

$$EC_x\ (_{\text{at 50 mg·L}^{-1}\text{ hardness}}) = 10^{\{(\ [\ \log(50) - \log(\text{original hardness})]\ \cdot\ 1.016) + \log(\text{original ECx})\}}$$

Adjustment equation for long-term:

$$EC_x(_{\text{at 50 mg·L}^{-1}\text{ hardness}}) = 10^{\{(\ [\ \ln(50) - \log(\text{original hardness})]\ \cdot\ 0.83) + \log(\text{original ECx})\}}$$

Control Mortality: A= appropriate, N/A= not needed/applicable, Not A= not appropriate

Test Type: S= Static, FT= Flow=through, R= Renewal

pH/conductivity/DO: value[1]= value measured at end of experiment

DO
(Dissolved Oxygen): % sat. = percentage saturation, ave.= average dissolved oxygen

Comments: temp.= temperature, conc.= concentration, NR= not reported

Rank: *= study ranked as primary or secondary; however, endpoint not acceptable for guideline derivation
(e.g., long-term LC50s are not acceptable according to the data hierarchy)

Inclusion in SSD: 'X' denotes the single value endpoint was included in the Species Sensitivity Distribution; 'x' denotes the value was a component of the calculated geometric mean that was included in the Species Sensitivity Distribution.

Appendix 1(iii): List of studies selected to calculate short-term toxicity-hardness slope

For the studies used to evaluate the short-term toxicity-hardness relationship see Appendix (i), endpoints that were used in the evaluation are bolded. All of the data that was used in the calculation of the short-term toxicity-hardness slope measured mortality as the endpoint.

Species	Life Stage	Duration	Hardness (mg/L as $CaCO_3$)	LC50 or TL50 (µg/L)[a]	Reference
Carassius auratus	1.93 g	96 h	20	2130	McCarty et al 1978
	Adult	96 h	44.4	748	Phipps and Holcombe 1985
	1.93 g	96 h	140	46800	McCarty et al 1978
Ceriodaphnia reticulata	Less than 24hrs	48 h	67	129	Spehar and Carlson 1984
	Less than 6 hrs	48 h	120	110	Hall et al. 1986
	Less than 24hrs	48 h	240	184	Elnabarawy et al 1986
Daphnia magna	Less than 24hrs	48 h	51	9.9	Chapman et al 1980
	Less than 24hrs	48 h	104	34	Chapman et al 1980
	Less than 24hrs	48 h	105	34	Chapman et al 1980
	Less than 24hrs	48 h	197	63	Chapman et al 1980
	Less than 24hrs	48 h	209	49	Chapman et al 1980
Daphnia pulex	Less than 24hrs	48 h	53.5	70.1	Stackhouse and Benson 1988
	Less than 24hrs	48 h	85	77.05*	Roux et al. 1993
	Less than 24hrs	48 h	120	89.44*	Hall et al. 1986
	Less than 24hrs	48 h	240	319	Elnabarawy et al 1986
Hyalella azteca	7 to 10 d	96 h	10	3.8	Jackson et al 2000
	7 to 10 d	96 h	80	12.1	Jackson et al 2000
	7 to 10 d	96 h	185	25	Jackson et al 2000
Lepomis cyanellus	Other	96 h	20	2840	Pickering and Henderson 1966
	Juvenile	96 h	136.8	11520	Carrier and Beitinger 1988
	Other	96 h	360	66000	Pickering and Henderson 1966
Morone saxatilis	Other	96 h	40	4	Palawski et al 1985
	Other	96 h	285	10	Palawski et al 1985
Oncorhynchus mykiss	Unknown	96 h	9.2	0.50	Cusimano et al 1986
	Juvenile	96 h	20	0.99067294	Hollis et al 2000
	parr	96 h	23	1	Chapman 1978
	Juvenile	96 h	26	2.53	Hollis et al 2000
	Fry	96 h	29.3	0.47	Stratus Consulting Ltd. 1999
	Fry	96 h	30	1.29	Stratus Consulting Ltd. 1999

Species	Life Stage	Duration	Hardness (mg/L as $CaCO_3$)	LC50 or TL50 (µg/L)[a]	Reference
	Fry	96 h	30.2	0.38	Stratus Consulting Ltd. 1999
	Fry	96 h	30.7	0.71	Stratus Consulting Ltd. 1999
	Fry	96 h	31.7	0.51	Stratus Consulting Ltd. 1999
	Juvenile	96 h	41	1.5	Buhl and Hamilton 1991
	Juvenile	96 h	43.5	2.3	Spehar and Carlson 1984
	Juvenile	96 h	44.4	3	Phipps and Holcombe 1985
	Juvenile	96 h	47	2.35	Hollis et al 2000
	Unknown	96 h	49	3.08	Davies et al 1993
	Juvenile	96 h	67	10.2	Spehar and Carlson 1984
	Juvenile	96 h	77	2.15	Hollis et al 2000
	Fry	96 h	89.3	2.85	Stratus Consulting Ltd. 1999
	Swim-up fry	96 h	101	3.8	Besser et al. 2007
	Juvenile	96 h	120	1.15	Hollis et al 2000
	Juvenile	96 h	120	19	Niyogi et al. 2004
	Juvenile	96 h	140	22	Hollis et al 1999
Oncorhynchus tshawytscha	Swim-up fry	96 h	23	1.8	Chapman 1978
	Juvenile	96 h	21	1.1	Finlayson and Verrue 1982
	Fry	96 h	211	26	Hamilton and Buhl 1990
	Fry	96 h	343	57	Hamilton and Buhl 1990
Pimephales promelas	1-2 g and 1.5-2.5 inches long	96 h	20	813*	Pickering and Henderson 1966
	Juvenile	96 h	43.5	1280	Spehar and Carlson 1984
	Juvenile	96 h	44.4	1500	Phipps and Holcombe 1985
	Juvenile	96 h	67	3390	Spehar and Carlson 1984
	Juvenile	96 h	81	2944*	Sherman et al 1987
	Adult	96 h	85.5	3580	Carrier and Beitinger 1988
	Adult	96 h	103	3019*	Birge et al 1983
	Juvenile	96 h	141	3815*	Sherman et al 1987
	Immature	96 h	201	9560*	Pickering and Gast 1972
	Adult	96 h	262.5	7160	Birge et al 1983
	1-2 g and 1.5-2.5 inches long	96 h	360	73049*	Pickering and Henderson 1966
Salmo trutta	Swim-up fry	96 h	29.2	1.23	Brinkman and Hansen 2007
	Juvenile	96 h	43.5	1.4	Spehar and Carlson 1984
	Swim-up fry	96 h	67.6	3.9	Brinkman and Hansen 2007
	Swim-up fry	96 h	151	10.1	Brinkman and Hansen 2007

Species	Life Stage	Duration	Hardness (mg/L as $CaCO_3$)	LC50 or TL50 (µg/L)[a]	Reference
Tubifex tubifex	Adult	96 h	5.3	320	Chapman et al 1982
	Not reported	96 h	128	2332*	Reynoldson et al. 1996
	Mixed	96 h	250	1657.9	Redeker and Blust 2004
Danio rerio	larvae	96 h	141	1730	Alsop and Wood 2011
	larvae	96 h	7.8	121.8	Alsop and Wood 2011

Geometric means were taken of endpoints with the same hardness, see Appendix A(i) for a list of values used.

Appendix 1(iv): List of studies used to estimate long-term toxicity hardness slope

Species	Endpoint	Effect	Hardness (mg/L)	Effect Concentration (µg Cd/L)	Reference
Salmo trutta	30 day, IC20	Biomass, decrease in	151	6.62	Brinkman and Hansen 2007
	30 day, IC20	Biomass, decrease in	29.2	0.87	Brinkman and Hansen 2007
	30 day, IC20	Biomass, decrease in	67.6	2.18	Brinkman and Hansen 2007
Daphnia magna	21 day, EC20	Reproduction (Number of young per survivor)	103	0.23[a,b]	Chapman et al 1980
	21 day, EC20	Reproduction (Number of young per adult)	53	0.07[a,b]	Chapman et al 1980
	21 day, EC20	Reproduction	209	0.33[a,b]	Chapman et al. 1980
Hyalella azteca	14 day, MATC	Mortality	17	0.16	Suedel et al 1997
	42 day, IC25	Mortality	280	1.9	Ingersoll and Kemble 2001
	42 day, MATC	Mortality	130	0.64[a,b]	Borgmann et al. 1989
	42 day, MATC	Mortality	163	0.67	Stanley et al. 2005
Aelosoma headleyi	10 day, MATC	Population	62	25.2	Niederlehner et al. 1984
	14 day, MATC	Population	168	40.1	Niederlehner et al. 1984
	12 day, MATC	Population	189	70.2	Niederlehner et al. 1984
Daphnia pulex	58 day, MATC	Reproduction	106	7.07	Ingersoll and Winner 1982
	42 day, MATC	Reproduction	58	3.6	Winner 1986
	42 day, MATC	Reproduction	116	7.78	Winner 1986
	42 day, MATC	Reproduction	230	7.35	Winner 1986
Salvelinus fontinalis	1096d (3 years), NOEC	Mortality	44	1.7	Benoit et al 1976
	60 day, MATC	Mortality	37	1.7	Sauter et al. 1976
	60 day, MATC	Mortality	188	4.58	Sauter et al. 1976
	126 day, MATC	Mortality	44	2	Eaton 1978
Pimephales promelas	32 day, MATC	Mortality	44	10	Spehar and Fiandt 1986
	250 day, MATC	Mortality	204	39.23	Pickering and Gast 1972

[a] Calculated by the NGSO based on data provided in the paper
[b] Published in USGS (2010)

Appendix 2: Environmental Concentrations, Raw Data

Appendix 2 (i) Cadmium concentrations in sediment, water and mussel samples from 21 lakes in south central Ontario (Campbell and Evans 1991). Minimum detection limits were not reported, though concentrations were reported to be "substantially above the detection limit" (Campbell and Evans 1991).

Lake	Cd in sediment (µg/g)	Cd in water (µg/L)	Cd in mussels (µg/g DW)
Gullfeather	0.378	0.14	5.9
Wolfe	NR	NR	3.2
Brady	0.25	0.13	1.5
Bigwind	0.361	0.13	6.9
Ansthruther	NR	NR	3.1
Drag	NR	NR	1.5
Beech	NR	NR	4.9
Looncall	NR	NR	4.1
Kashagawigamog	NR	NR	5
Saskatchewan	NR	NR	4.8
12 Mile	0.197	0.08	2.2
Mountain	0.107	0.04	1.6
Dalhousie	0.191	0.07	1.4
Round	0.072	0.05	0.9
Fourmile	0.197	0.08	2.1
Clear	0.051	0.03	0.8
Young	0.202	0.1	0.6
Deer Bay	0.079	0.05	1
Head	0.093	0.02	0.6
Patterson	0.321	0.11	0.6
Silver	0.205	0.12	1.2

Appendix 2 (ii) Minimum, maximum and median cadmium concentrations from water sampled between 2000 and 2007 from rivers in Manitoba (Armstrong and Manitoba Water Stewardship 2008). Where sample concentrations were below the minimum limit of detection, values are reported as <MDL. In these cases, the median total Cd was calculated as ½ of the MDL.

River	Min. Total Cd (µg/L)	Max. Total Cd (µg/L)	Median Total Cd (µg/L)
Assiniboine	<0.04	1.9	0.05
Assiniboine River Watershed	<0.04	<0.04	0.02
Birdtail	<0.04	<0.04	0.02
Black	<0.04	<0.04	0.02
Boyne	<0.04	0.41	0.065
Brokenhead	<0.04	<0.2	0.02
Burntwood	<0.04	<0.2	0.02
Churchill	<0.04	<0.2	0.02
Cypress	<0.04	0.86	0.09
Dauphin	<0.04	<0.04	0.02
Fairford	<0.04	<0.04	0.02
Falcon	<0.04	<0.2	0.06
Fisher	<0.04	<0.04	0.02
Grass	<0.04	<0.04	0.02
Icelandic	<0.04	<0.04	0.02
La Salle	<0.04	0.1	0.02
Laurie	<0.2	<0.2	0.1
Little Morris	0.22	0.22	0.22
Little Saskatchewan	<0.04	<0.2	0.02
Morris	<0.04	<0.04	0.02
Mossy	<0.04	<0.2	0.02
Nelson	<0.04	<0.2	0.02
North Duck	<0.04	0.21	0.02
Ochre	<0.04	0.4	0.02
Poplar	<0.04	<0.04	0.02
Qu'Appelle	<0.04	0.32	0.02
Rat	<0.04	<0.2	0.02
Red	<0.04	7.3	0.07
Roseau	<0.04	<0.2	0.02
Seine	<0.04	<0.2	0.02
Shell	<0.04	<0.04	0.02
Souris	<0.04	1	0.02
Swan	<0.04	0.45	0.05
Turtle	<0.04	0.23	0.02
Valley	<0.04	0.31	0.02
Vermilion	<0.04	0.68	0.09
Winipigow	<0.04	<0.04	0.02
Waterhen	<0.04	<0.2	0.02
White Mud	<0.04	<0.2	0.02
Winnipeg	<0.04	<0.04	0.02
Woody	<0.04	0.44	0.02

***Not every site was sampled each year.**

Appendix 2 (iii) Minimum, maximum and median cadmium concentrations from water sampled between 2000 and 2007 from lakes in Manitoba (Armstrong and Manitoba Water Stewardship 2008). Where sample concentrations were below the minimum limit of detection, values are reported as <MDL.

Lake	Min. Total Cd (µg/L)	Max. Total Cd (µg/L)	Median Total Cd (µg/L)
Athapapuskow	0.07	0.16	0.135
Bazinet	0.05	0.05	0.05
Betula	<0.04	<0.04	0.02
Big Island	0.8	1.3	1
Brereton	<0.04	<0.04	0.02
Camp	<0.04	1.3	0.87
Childs	<0.04	<0.04	0.02
Cold	<0.04	0.6	0.28
Cross	<0.04	<0.2	0.02
East Blue	<0.04	<0.04	0.02
Embury	0.55	0.57	0.55
Falcon	<0.04	<0.04	0.02
Footprint	<0.04	<0.2	0.02
Glad	<0.04	<0.04	0.02
Jessica	<0.04	<0.04	0.02
Kississing	0.04	0.5	0.1
Manitoba Narrows	<0.04	<0.04	0.02
Winnipeg	<0.04	3.2	0.02
Little Spruce	0.65	0.65	0.65
Pelican	<0.04	<0.04	0.02
Red Rock	<0.04	<0.04	0.02
Salt	<0.04	0.33	0.26
Schist	<0.04	0.27	0.1
Setting	<0.2	<0.2	0.1
Singuish	<0.04	<0.04	0.02
Sipiwesk	<0.04	<0.2	0.02
Snow	<0.2	<0.2	0.1
Southern Indian	<0.04	0.4	0.02
Split	<0.04	0.7	0.02
Winipigow	<0.04	<0.04	0.02
Wekusko	<0.04	<0.04	0.02
Wellman	<0.04	<0.04	0.02
White	<0.04	<0.04	0.02
White Lake North	<0.04	0.14	0.02
Wood	29.2	29.2	29.2

***Not every site was sampled each year.**

Appendix 2 (iv) Minimum, maximum and median cadmium concentrations from water sampled between 2000 and 2007 from creeks in Manitoba (Armstrong and Manitoba Water Stewardship 2008). Where sample concentrations were below the minimum limit of detection, values are reported as <MDL.

Creek	Min. Total Cd (µg/L)	Max. Total Cd (µg/L)	Median Total Cd (µg/L)
Bazinet	0.09	<0.2	0.095
Beaver Creek Tile Drain East Drainage	<0.04	0.49	0.02
Beaver Creek Tile Drain South Drainage	<0.04	0.05	0.02
Beaver Creek Watershed	<0.04	<0.04	0.02
Big Island	0.7	1.4	1
Boggy	<0.04	<0.2	0.02
Cooks	<0.04	<0.2	0.02
Edwards	<0.04	0.87	0.02
Graham	<0.04	<0.04	0.02
Joubert	<0.2	<0.2	0.1
North Tobacco	0.11	0.11	0.11
Oak Island	<0.2	<0.2	0.1
Omands	<0.04	<0.2	0.1
Pipestone	<0.04	<0.2	0.02
Shannon	1.9	1.9	1.9
Sherlett	0.14	<0.2	0.12
South Tobacco	0.12	0.15	0.135
Sturgeon	<0.2	<0.2	0.1
Sturgeon Creek Watershed	<0.04	<0.04	0.02
Tobacco	0.13	0.27	0.2
Tobacco Creek Watershed	0.1	0.1	0.1
Wavey	<0.04	<0.04	0.02

***Not every site was sampled each year. Data provided by Manitoba Water Stewardship.**

Appendix 2 (v) Minimum, maximum and median cadmium concentrations from sediment sampled between 2000 and 2007 from sites in Manitoba (Armstrong and Manitoba Water Stewardship 2008). Where sample concentrations were below the minimum limit of detection, values are reported as <MDL.

Site	Min. Cd Conc. (µg/g)	Max. Cd Conc. (µg/g)	Median
Barren Lake	0.3	0.6	0.4
Betula Lake	<0.2	0.5	0.45
Big Island Lake	1.2	16.3	4.25
Brereton Lake	0.6	0.8	0.7
Caddy Lake	0.4	0.5	0.5
Camp Lake	<1.0	<1.0	0.5
Cold Lake	4.8	11.5	9.05
Falcon Lake	0.5	2.5	0.8
Florence Lake	0.2	0.9	0.7
Hunt Lake	0.3	1	0.4
Jessica Lake	<0.2	0.5	0.1
Kississing Lake	1.9	7	5
Lake Winnipeg	0.2	3	0.3
Madge Lake	0.2	0.8	0.4
Marion Lake	0.2	0.9	0.35
Red River	0.4	0.5	0.5
Red Rock Lake	<0.2	0.8	0.65
Schist Lake	1.8	22.5	8.3
Shirley Lake	0.4	0.9	0.65
Star Lake	0.3	0.8	0.4
White Lake	<0.2	0.6	0.55

***Not every site was sampled each year.**

Appendix 2 (vi) Cadmium concentrations in surface waters of Nova Scotia (Nova Scotia Environment 2008)**.** Where sample concentrations were below the minimum limit of detection, values are reported as <MDL.

Site Name	Sampling Date	Cadmium Conc. (µg/L)
Anderson Lake	13-Dec-84	1.2
Bayers Lake	07-Dec-84	<0.6
Bell Lake	10-Dec-84	<0.6
Big Bridge, Bog Pond	17-Dec-84	<0.6
Cochran Lake	13-Dec-84	<0.6
Cooper Lake	14-Dec-84	<0.6
Cox's Lake	17-Dec-84	<0.6
Duncan's Pond	18-Dec-84	<0.6
Eagle Lake	12-Dec-84	2.9
First Pond	18-Dec-84	0.7
Grand Lake	12-Dec-84	<0.6
Herb Mill Pond	21-Jul-04	<2.0
Horseshoe Lake	13-Dec-84	0.7
Howe Lake	12-Dec-84	1.1
Hubley Big Lake	14-Dec-84	<0.6
Jack Lake	07-Dec-84	<0.6
Kearney Lake	07-Dec-84	<0.6
Kidston Lake	14-Dec-84	0.9
Land of Laziness Lake	17-Dec-84	<0.6
Lansdowne Lake	29-Aug-05	<2.0
Lewis Lake	13-Dec-84	<0.6
Little Lake	02-Aug-05	<2.0
Long Canal Lake	18-Dec-84	<0.6
Long Lake	12-Dec-84	<0.6
Long Lake	18-Dec-84	<0.6
McCabe Lake	29-Aug-05	<2.0
McQuade lake	13-Dec-84	<0.6
Milipsigate Lake	21-Jul-04	<2.0
O'Brien Lake	12-Dec-84	<0.6
Otter Lake	14-Dec-84	1.2
Paces Lake	07-Dec-84	<0.6
Peters Lake	14-Dec-84	<0.6
Purcells Pond	18-Dec-84	<0.6
Ragged Lake	14-Dec-84	0.8
Shortts Lake	30-Aug-05	<2.0
Silver Lake	18-Dec-84	<0.6
Spectacle Lake	07-Dec-84	<0.6
Spruce Hill	14-Dec-84	1.8
Susies Lake	07-Dec-84	<0.6
Uniacke Lake	13-Dec-84	1.8