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2001 UPDATE OF AMBIENT WATER QUALITY CRITERIA FOR CADMIUM

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U.S. Environmental Protection Agency
Office of Water
Office of Science and Technology
Washington, D.C.

NOTICES

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John G. Eaton
(freshwater author)
Environmental Research Laboratory
Duluth, Minnesota

Charles E. Stephan
(document coordinator)
Environmental Research Laboratory
Duluth, Minnesota

John H. Gentile
(saltwater author)
Environmental Research Laboratory
Narragansett, Rhode Island

David J. Hansen
(saltwater coordinator)
Environmental Research Laboratory
Narragansett, Rhode Island

Statistical Support: John W. Rogers
Clerical Support: Terry L. Highland

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Gregory J. Smith
(freshwater contributor)
Great Lakes Environmental Center
Columbus, Ohio

Cindy Roberts
(document coordinator)
U.S. EPA
Health and Ecological Effects Criteria Division
Washington, D.C.

Statistical Support: Dan Tholen, Great Lakes Environmental Center, Traverse City, Michigan

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INTRODUCTION[1]

This update document provides guidance to States and Tribes authorized to establish water quality standards under the Clean Water Act (CWA) to protect aquatic life from acute and chronic effects of cadmium. Under the CWA, States and Tribes are to establish water quality criteria to protect designated uses. While this document constitutes U.S. EPA's scientific recommendations regarding ambient concentrations of cadmium, this document does not substitute for the CWA or U.S. EPA's regulations; nor is it a regulation itself. Thus, it cannot impose legally binding requirements on U.S. EPA, States, Tribes, or the regulated community, and might not apply to a particular situation based upon the circumstances. State and Tribal decision-makers retain the discretion to adopt approaches on a case-by-case basis that differ from this guidance when appropriate. U.S. EPA may change this guidance in the future.

Cadmium is a relatively rare element that is a minor nutrient for plants at low concentrations (Lane and Morel 2000; Lee et al. 1995; Price and Morel 1990), but is toxic to aquatic life at concentrations only slightly higher. It occurs mainly as a component of minerals in the earth's crust at an average concentration of 0.18 ppm (Babich and Stotzky 1978). Cadmium levels in soils usually range from approximately 0.01 to 1.8 ppm (Lagerwerff and Specht 1970). In natural freshwaters, cadmium sometimes occurs at concentrations of less than 0.1 μg/L, but in environments impacted by man, concentrations can be several micrograms per liter or greater (Abbasi and Soni 1986; Allen 1994; Annune et al. 1994; Flick et al. 1971; Friberg et al. 1971; Henriksen and Wright 1978; Nilsson 1970; Spry and Wiener 1991). Cadmium can enter the environment from various anthropogenic sources, such as by-products from zinc refining, coal combustion, mine wastes, electroplating processes, iron and steel production, pigments, fertilizers and pesticides (Hutton 1983; Pickering and Gast 1972).

The impact of cadmium on aquatic organisms depends on a variety of possible chemical forms of cadmium (Callahan et al. 1979), which can have different toxicities and bioconcentration factors. In most well oxygenated freshwaters that are low in total organic carbon, free divalent cadmium will be the predominant form. Precipitation by carbonate or hydroxide and formation of soluble complexes by chloride, sulfate, carbonate, and hydroxide should usually be of little importance. In saltwaters with

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[1] An understanding of the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" (Stephan et al. 1985), hereafter referred to as the Guidelines, is necessary in order to understand the following text, tables, and calculations.

salinities from about 10 to 35 g/kg, cadmium chloride complexes predominate. In both fresh and saltwaters, particulate matter and dissolved organic material may bind a substantial portion of the cadmium, and under these conditions cadmium may not be bioavailable due to this binding (Callahan et al. 1979; Kramer et al. 1997).

Because of the variety of forms of cadmium (Callahan et al. 1979) and lack of definitive information about their relative toxicities, no available analytical measurement is known to be ideal for expressing aquatic life criteria for cadmium. Previous aquatic life criteria for cadmium (U.S. EPA 1980) were expressed in terms of total recoverable cadmium (U.S. EPA 1983a), but this measurement is probably too rigorous in some situations. U.S. EPA (1985) has also expressed cadmium criteria as acid-soluble cadmium in the past, but now recommends use of dissolved metal concentrations (operationally defined as the metal in solution that passes through a 0.45 μm membrane filter) to set and measure compliance with water quality standards (Prothro 1993; U.S. EPA 1993, 1994a).

The criteria presented herein supersede previous aquatic life water quality criteria for cadmium (U.S. EPA 1999a) because these new criteria were derived based on the most recent science. Whenever appropriate, a national criterion may be replaced by a site-specific criterion (U.S. EPA 1994a), which may include not only site-specific criterion concentrations (U.S. EPA 1994b), but also site-specific durations of averaging periods and site-specific frequencies of allowed exceedences (U.S. EPA 1991). All concentrations are expressed as cadmium, not as the chemical tested. The latest literature search for information for this document was conducted in June 1999; some newer information was also used.

Because the revisions being considered build from principles set forth in the 1985 Guidelines (Stephen et al. 1985), it is useful to have some understanding of how those Guidelines are ordinarily applied: (1) Acute toxicity test data must be available for species from a minimum of eight diverse taxonomic groups. The diversity of tested species is intended to assure protection of various components of an aquatic ecosystem. (2) The Final Acute Value (FAV) is derived by extrapolation or interpolation to a hypothetical genus more sensitive than 95 percent of all tested genera. The FAV, which represents an LC50 or EC50, is divided by two in order to obtain an acute criterion protective of nearly all individuals in such a genus. (3) Chronic toxicity test data (longer-term survival, growth, or reproduction) must be available for at least three taxa. Most often the chronic criterion is set by determining an appropriate acute-chronic ratio (the ratio of acutely toxic concentrations to the chronically toxic concentrations) and applying that ratio to the acute value of the hypothetical genus more sensitive than 95 percent of all tested genera. If sufficient data are available to meet the eight diverse taxonomic group minimum, then the chronic value is derived using the same procedure as used for the FAV derivation. (4) When necessary, the acute and/or chronic criterion may be lowered to protect recreationally or commercially important species. (5) When evaluating time-variable ambient concentrations generally, 1-hour average concentration are considered to be appropriate for comparison with the acute criterion, and 4-day averages with the chronic criterion. (6) The allowable frequency for exceeding a criterion is set at once every three years, on the average.

ACUTE TOXICITY TO FRESHWATER ANIMALS

Acceptable data on the acute effects of cadmium in freshwater are available for 39 species of invertebrates, 24 species of fish, one salamander species, and one frog species (Table 1a). These 65 species satisfy the eight different family requirements specified in the Guidelines. A tendency for increased tolerance to toxicity with increasing size or age has been reported (Table 1a) in the snail, *Physa gyrina* (Wier and Walter 1976), the coho salmon (Chapman 1975), and the common carp (Suresh et al. 1993a). No such effect was observed with increasing age (Table 1a) in the cladoceran, *Daphnia magna* (Stuhlbacher et al. 1993), the rainbow trout (Chapman 1975, 1978), or in the striped bass (Hughes 1973; Palawski et al. 1985). Data are unavailable for a sufficient number of species and life stages to allow general adjustment of test results or criteria on the basis of size or life stage. Where relationships were apparent between life-stage and sensitivity, only values for the most sensitive life-stage were considered.

Water Quality Parameters Affecting Toxicity

Although many factors might affect the results of tests of the toxicity of cadmium to aquatic organisms (Sprague 1985), water quality criteria can quantitatively take into account only factors for which enough data are available to show that the factor similarly affects the results of tests with a variety of species. Hardness is often thought of as having a major effect on the toxicity of cadmium, although the observed effect may be due to one or more of a number of usually interrelated ions, such as hydroxide, carbonate, calcium, and magnesium. Acute tests were conducted at three different levels of water hardness with *Daphnia magna* (Chapman et al. Manuscript), demonstrating that daphnids were at least five times more sensitive to cadmium in soft water than in hard water (Table 1a). Data in Table

1a also indicate that cadmium was more toxic to the tubificid worms *Limnodrilus hoffmeisteri* and *Tubifex tubifex*, the mussel *Vilosa vibex*, *Daphnia pulex*, chinook salmon, goldfish, fathead minnow, guppy, striped bass, green sunfish and bluegill in soft than in hard water. Carroll et al. (1979) found that calcium, but not magnesium, reduced the acute toxicity of cadmium.

Other water quality characteristics could potentially influence the toxicity of cadmium to aquatic species. Giesy et al. (1977) found that dissolved organics substantially reduced the toxicity of cadmium to daphnids, but had little effect on its toxicity to fish. No consistent relationship between toxicity and organic particle size was observed. Development of the "biotic ligand model" (BLM - formerly the "gill model") in recent years has attempted to better account for the bioavailability of metals to aquatic life. The BLM, which quantifies the capacity of metals to bind to the gills of aquatic organisms, has been proposed as a reliable method for estimating the bioavailable portion of dissolved metals in the water column based on site-specific water quality parameters such as alkalinity, pH and dissolved organic carbon (McGeer et al. 2000; Meyer et al. 1999; Pagenkopf 1983; Paquin et al. 1999; U.S. EPA 1999b, 2000). Future development of the BLM for cadmium may help better quantify the bioavailable fraction of cadmium. Nonetheless, the model is in the preliminary development phase for cadmium and it will likely not be available for a number of years still.

Hardness Correction

Currently, the primary quantitative correlation used to modify metal toxicity estimates is water hardness (viz. the U.S. EPA 1995 water quality criteria for cadmium). Hardness (as calcium or magnesium ions) almost certainly has some direct effect on cadmium toxicity (e.g., by influencing membrane integrity). Calcium and magnesium ions compete with the metal for binding sites on the gill (Carroll et al. 1979; Evans 1987; Morel and Hering 1993; Pagenkopf 1983). Hardness also serves as a general surrogate for pH, alkalinity, and ionic strength, because waters of higher hardness usually have higher pH, alkalinity, and ionic strength. Other parameters such as pH, alkalinity, dissolved organic carbon, humic matter, ionic strength (anions and cations) and dissolved inorganic carbon also affect metal speciation and bioavailability, and thus metal toxicity. The pH is also important in determining the metal complexation capacity of dissolved organic matter.

Hardness is used here as a surrogate for the ions which affect the results of toxicity tests on cadmium. However, it should be emphasized that the hardness adjustment is not a precise measure, but an estimation. The variability associated with different life stages, clones and test conditions of the studies used to determine the hardness slope all contribute to the uncertainty of the hardness correction. In selected cases, only one life stage was used in the analysis (e.g., only adult fathead minnow data). Thus, in spite of all its limitations, hardness is currently the best surrogate available for metal toxicity adjustment.

To account for the apparent relationship of cadmium acute toxicity to hardness, an analysis of covariance (Dixon and Brown 1979; Neter and Wasserman 1974) as noted in the guidelines (Stephan et al. 1985) was performed using the Statistical Analysis System (SAS Inc., Cary, NC) software program to calculate the pooled slope for hardness using the natural logarithm of the acute value as the dependent variable, species as the treatment or grouping variable, and the natural logarithm of hardness as the covariate or independent variable. The pooled slope is a regression slope from a pooled data set, where every variable is adjusted relative to its mean. The species are adjusted separately, then pooled for a single conventional least squares regression analysis. The slope of the regression line is the best estimate of the all-species relationship between toxicity and hardness. With analysis of covariance, different species will be weighted relative to the number of data points they have. In this case, the *D. magna* and the fathead minnow each have 28 data points out of the total of 97, and the next most frequent species has just eight data points.

This analysis of covariance model was fit to the data in Table 1a for the 12 species for which definitive acute values (less than or greater than values were not used) are available over a range of hardness such that the highest hardness is at least three times the lowest, and the highest is also at least 100 mg/L higher than the lowest (other species in Table 1a either did not meet these criteria or did not show any hardness-toxicity trend due to differences in exposure methods, species age, etc.). For *D. magna*, only acute toxicity tests that were initiated with less than 24-hr old neonates were used to estimate the hardness slope. For the fathead minnow, only tests conducted with adults were used (not those conducted with the more sensitive fry life stage). A list of the species and acute toxicity-hardness values used to estimate the acute hardness slope is provided in Table 1d. The slopes for all 12 species ranged from 0.1086 to 2.031, and the pooled slope for these 12 species was 1.174 (see Table 1c). An F-test was used to test whether a model with separate species slopes for each species gives significantly better fit to the data than the model with parallel slopes. This test showed that the separate slopes model is not significantly better, and therefore the slopes are not significantly different than the overall pooled slope (P=0.27). The slopes and confidence intervals associated with the 12 species indicated that *D. magna* (all available data) had a very flat slope and a large confidence interval (and large standard error). If only the *D. magna* data from Chapman et al. (Manuscript) were used, the resultant *D. magna* slope was 1.182, with smaller confidence intervals than for the all *D. magna* slope. Likewise, when only the adult fathead minnow data were used (not the fry data), the resultant fathead minnow slope was 1.221 and smaller confidence intervals were present. If this reduced data set is used (all species but using only data from Chapman et al. (Manuscript) for *D. magna* and only adult fathead minnow data), the pooled slope for these species was 1.0166 (see Table 1c). The test for equality of the 12 slopes using the reduced data set (all species but only Chapman *D. magna* and adult fathead minnow data) produced P=0.69. Under analysis of covariance, it therefore is reasonable to assume that the slopes for these 12 species are the same, and that the overall slope is a reasonable estimate of the average relationship between hardness and toxicity. Either P value indicated that it was reasonable to assume that the slopes were the same, however, the second model was considered the better model and was therefore selected. The pooled slope of 1.0166 is close to the slope of 1.0 that is expected on the basis that cadmium, calcium, magnesium, and carbonate all have a charge of two (Meyer 1999). A plot of the acute effect level (EC50 or LC50) versus total hardness is provided in Figure 1.

The possible relationship of cadmium acute toxicity to water quality parameters other than hardness were also considered. Both hardness and/or alkalinity were investigated by subjecting any acute toxicity data in Table 1a having both hardness and alkalinity values available to a multiple stepwise regression analysis using the SAS (Cary, NC) software program. The analysis was run using the natural logarithm of the acute value as the dependent variable, species as the treatment or grouping variable, and the natural logarithm of hardness and alkalinity as the covariates or independent variables. As with the analysis of covariance evaluation discussed above, the only data used in Table 1a (seven species) were those for which definitive acute values are available over a range of both hardness and alkalinity such that the highest hardness (and alkalinity) is at least three times the lowest, and the highest is also at least 100 mg/L higher than the lowest. The results obtained indicate that either variable works well alone in the regression model (R^2 value for each was 0.688), but the other variable cannot increase the strength of the model once the first variable is included (when both were used the R^2 value only increased to 0.689). This lack of model improvement is due to the very strong correlation between hardness and alkalinity (effect of colinearity), thus these two independent variables should not be used together in the same regression model. Based on these results and the availability of data for water quality parameters other than hardness, the best approach at this time is to use only hardness (analysis of covariance discussed above) as a surrogate for the ions which affect the results of toxicity tests on cadmium.

Conversion Factors

Although past water quality criteria for cadmium (and other metals) have been established upon the loosely defined term of "acid soluble metals," U.S. EPA made the decision to allow the expression of metal criteria on the basis of dissolved metal (U.S. EPA 1994a), operationally defined as that metal that passes through a 0.45 micron filter. Because most of the data in existing databases are from tests that were either nominal concentrations, or provided only total cadmium measurements, some procedure was required to estimate their dissolved equivalents. The approach taken by U.S. EPA involves the use of conversion factors (CF), that when applied to the total metal concentration, gives a dissolved metal concentration. Thus, the CF corresponds to the percent of the total recoverable metal that is dissolved. These CFs were determined by conducting a number of "simulation tests" using solutions simulating those used in the toxicity tests that were most important in the derivation of aquatic life criteria for each metal (static, flow-through, fed, and unfed conditions that typified standard acute and chronic toxicity tests from which criteria are derived). The intent was to mimic the way criteria would have been derived if dissolved metal had been measured in each of the toxicity tests (Lussier et al. 1995; Stephan 1995; Univ. of Wisconsin-Superior 1995). For certain metals like cadmium, these CFs are hardness dependent.

The appropriate CFs were used only when determining the final cadmium criteria values, and are hardness dependent in freshwater. Acute freshwater total cadmium concentrations were converted to dissolved concentrations using the factor of 0.973 at a total hardness level of 50 mg/L as $CaCO_3$, 0.944 at a total hardness level of 100 mg/L as $CaCO_3$, and 0.915 at a total hardness level of 200 mg/L as $CaCO_3$. The equation for the acute freshwater conversion factor is CF = 1.136672 - [(ln hardness) (0.041838)] where the (ln hardness) is the natural logarithm of the hardness (Stephen 1995). Acute saltwater total cadmium values were converted to dissolved using the factor of 0.994.

Criteria Development

The pooled slope of 1.0166 was used to adjust the freshwater acute values in Table 1a to hardness = 50 mg/L, except where it was not possible because no hardness was reported. Species Mean Acute Values (SMAV) were calculated as geometric means of the adjusted acute values (only the underlined EC50/LC50 species values were used to calculate the respective SMAV). As stated in the

Guidelines (Stephen et al. 1985), flow-through measured study data are normally given preference over non-flow-through data for a particular species. In certain cases flow-through measured results were available, yet preference was given to the sensitive life stage for certain species in calculating SMAVs. In addition, all underlined Table 1a data for *D. magna* and fathead minnow fry were used to calculate the respective SMAVs (*D. magna* tests initiated with >24-hr old neonates were not used to calculate the SMAV). Only data from Chapman (1975) were used for coho salmon to avoid using test results from studies in which the life stage tested is known to be less sensitive, or in which the life stage tested is unreported and the higher LC50s may be due primarily to the use of less sensitive life stages. The data for Palawski et al. (1985) were used for striped bass because they were considered better data than those given in U.S. EPA (1985), although the data from Hughes (1973) support the newer data. Only brook trout data reported by Carroll et al. (1979), and not by Holcombe et al. (1983) were used in the calculation of the brook trout Final Acute Value because the reported bull trout data (Stratus Consulting 1999) in the same genus support the Carroll et al. (1979) results. Drummond and Benoit (Manuscript) reported that stress greatly affected the sensitivity of brook trout to cadmium.

The SMAV for freshwater invertebrates ranged from 13.41 μg/L total cadmium for the cladoceran, *D. magna* to 96,880 μg/L total cadmium for the midge, *Chironomus riparius*. Of the fish species tested, the brown trout, *Salmo trutta*, had the lowest SMAV of 1.613 μg/L total cadmium, and the tilapia, *Oreochromis mossambica*, recorded the highest fish SMAV of 10,663 μg/L total cadmium. As indicated by the data, both invertebrate and fish species display a wide range of sensitivities to cadmium.

Fish species represent eight of the nine most sensitive species to cadmium (Table 3a). Salmonids (*Salmo trutta*, *Salvelinus confluentus, Salvelinus fontinalis, Oncorhynchus kisutch, Oncorhynchus mykiss* and *Oncorhynchus tshawytscha*) are six of the seven most sensitive species listed in Table 1a, and thus are more acutely sensitive to cadmium than any other freshwater animal species thus far tested (Carroll et al. 1979; Chapman 1975, 1978, 1982; Cusimano et al. 1986; Davies et al. 1993; Finlayson and Verrue 1982; Phipps and Holcombe 1985; Spehar and Carlson 1984a,b; Stratus Consulting 1999). The cladoceran, *D. magna*, is the eighth most sensitive species to cadmium, and thus the most acutely sensitive invertebrate species tested thus far.

Genus Mean Acute Values (GMAV) at a hardness of 50 mg/L were then calculated (Table 3a) as geometric means of the available freshwater Species Mean Acute Values and ranked. Of the 55 genera for which acute values are available, the most sensitive genus, *Salmo*, is over 60,062 times more sensitive than the most resistant, *Chironomus*. The first through fourth most sensitive genera (a total n of 55) were used in the computation of the final acute value. The sensitivity of these four most sensitive genera are within a factor of 2.4, and all are fish. Of the ten most sensitive genera, six are fish, two are mussels, and two are cladocerans (Figure 2; Table 3a). Hardness-adjusted acute values are available for more than one species in nine genera, and the range of SMAVs within each genus is less than a factor of 4.0 for eight of the nine genera. The ninth genus, *Ptychocheilus*, has two SMAVs that differ by a factor of 98.5, possibly due to differences in the test conditions between species.

The freshwater Final Acute Value (FAV) for total cadmium at a hardness of 50 mg/L was calculated to be 2.763 μg/L total cadmium (Table 3d) from the Genus Mean Acute Values in Table 3a using the procedure described in the Guidelines. The Species Mean Acute Values for the rainbow trout, brook trout, bull trout and brown trout are lower than the FAV of 2.763 μg/L total cadmium, but the acute value for the brook trout and brown trout are from static tests, whereas flow-through measured tests have been conducted with the remaining two salmonid species. The freshwater Final Acute Value for total cadmium at a hardness of 50 mg/L was lowered to 2.108 μg/L to protect the commercially important rainbow trout (Table 3d). This value is above the SMAV of 1.613 μg/L for the brown trout and <1.791 μg/L for brook trout, but below all other SMAVs listed in Table 3a (Figure 2). The resultant freshwater Criterion Maximum Concentration (CMC) at a hardness of 50 mg/L for total cadmium (in μg/L) = $e^{(1.0166[\ln(\text{hardness})]-3.924)}$. If the CMC based on total cadmium values is converted to dissolved cadmium using the 0.973 factor at a hardness of 50 mg/L determined by U.S. EPA (Stephan 1995; Univ. of Wisconsin-Superior 1995), the freshwater CMC for dissolved cadmium (in μg/L) = 0.973 $[e^{(1.0166[\ln(\text{hardness})]-3.924)}]$. Thus, the 1.0 μg/L CMC for dissolved cadmium at a hardness of 50 mg/L is below all of the SMAVs presented in Table 3a (Figure 2). Conversion from total to dissolved was used because hardness relationships were established based upon total cadmium concentrations as this minimized the number of conversions required. In a few cases where only dissolved cadmium was reported in freshwater (Table 1a), conversion to total used the same appropriate factor.

ACUTE TOXICITY TO SALTWATER ANIMALS

Tests of the acute toxicity of cadmium to saltwater organisms have been conducted with 50 species of invertebrates and 11 species of fish (Table 1b), representing the required eight different taxonomic families. A pattern of increased tolerance to toxicity with increasing size or age has been reported (Table 1b) in the polychaete worm *Capitella capitata* (Reish and LeMay 1991; Reish et al. 1976), the blue mussel (Ahsanullah 1976; Martin et al. 1981; Nelson et al. 1988), the copepod *Eurytemora affinis* (Gentile 1982; Sullivan et al. 1983), the amphipods *Marinogammarus obtusatus* (Wright and Frain 1981) and *Leptocheirus plumulosus* (McGee et al. 1998), the pink shrimp *Penaeus duorarum* (Nimmo et al. 1977b; Cripe 1994), the rivulus (Park et al. 1994; Lin and Dunson 1993), the Atlantic silverside (Cardin 1982) and the striped mullet (Hilmy et al. 1985). No such effect was observed with increasing age (Table 1b) in the polychaete worm *Neanthes arenaceodentata* (Reish and LeMay 1991; Reish et al. 1976), the mysid *Americamysis bahia*, formerly *Mysidopsis bahia* (De Lisle and Roberts 1988), the grass shrimp *Palaemonetes pugio* (Khan et al. 1988; Burton and Fisher 1990), and the mummichog *Fundulus heteroclitus* (Voyer 1975). Data are unavailable for a sufficient number of species and life stages to allow general adjustment of test results or criteria on the basis of size or life stage. Where relationships were apparent between life-stage and sensitivity, only values for the most sensitive life-stage were considered.

Water Quality Parameters Affecting Toxicity

Frank and Robertson (1979) reported that the acute toxicity to juvenile blue crabs was related to salinity. The 96-hr LC50s were 320, 4,700, and 11,600 μg/L at salinities of 1, 15, and 35 g/kg, respectively (Table 1b). Studies with *A. bahia* by Gentile et al. (1982) and Nimmo et al. (1977a) also support a relationship between salinity and the acute toxicity of cadmium. O'Hara (1973a) investigated the effect of temperature and salinity on the toxicity of cadmium to the fiddler crab. The LC50s at 20°C were 32,300, 46,600, and 37,000 μg/L at salinities of 10, 20, and 30 g/kg, respectively. Increasing the temperature from 20 to 30°C lowered the LC50 at all salinities tested. Toudal and Riisgard (1987) reported that increasing the temperature from 13 to 21 °C at a salinity of 20 g/kg also lowered the LC50 value of cadmium to the copepod, *Acartia tonsa*.

Saltwater fish species were generally more resistant to cadmium than freshwater fish species with SMAVs ranging from 75.0 μg/L for the striped bass (at a salinity of 1 g/kg) to 50,000 μg/L for the sheepshead minnow (Table 3b). In a study of the interaction of dissolved oxygen and salinity on the acute toxicity of cadmium to the mummichog, Voyer (1975) found that 96-hr LC50s at a salinity of 32 g/kg were about one-half what they were at 10 and 20 g/kg. Sensitivity of the mummichog to acute cadmium poisoning was not influenced by reduction in dissolved oxygen concentration to 4 mg/L. This increase in toxicity with increasing salinity conflicts with other data reported in Tables 1b and 6b. Since there was no consistent salinity-toxicity trend observed for the data, a salinity correction factor was not attempted.

Criteria Development

Of the 54 saltwater genera for which acute values are available, the most sensitive, *Americamysis*, is 3,270 times more sensitive than the most resistant, *Monopylephorus* (Table 3b). The SMAVs for saltwater invertebrate species range from 41.29 µg/L for a mysid to 135,000 µg/L for an oligochaete worm (Tables 1b and 3b). The acute values for saltwater polychaetes range from 200 µg/L for *C. capitata* to 14,100 µg/L for *N. arenaceodentata* (Reish and LeMay 1991). Saltwater molluscs have Species Mean Acute Values from 227.9 µg/L for the Pacific oyster to 19,170 µg/L for the mud snail. Acute values are available for more than one species in each of seven genera, and the range of Species Mean Acute Values within each genus is no more than a factor of 3.6 for six of the seven genera. The seventh genus, *Crassostrea*, has two SMAVs that differ by a factor of 16.7, possibly due to different exposure conditions between species. Only the data from Reish et al. (1976) were used for *C. capitat*a, only data from Martin et al. (1981) and Nelson et al. (1988) were used for *M. edulis*, only data from Sullivan et al. (1983) were used for *E. affinis,* only data from Cripe (1994) were used for *P. duorarum*, and only data from Park et al. (1994) were used for *Rivulus marmoratus* to avoid using test results from studies in which the life stage tested is known to be less sensitive or in which the life stage tested is unreported and the higher LC50s may be due primarily to the use of less sensitive life stages. The sensitivities of the four most sensitive genera differed by a factor of 2.7, which includes two mysids, the striped bass and the American lobster (Table 3b).

The saltwater Final Acute Value for total cadmium calculated from the Genus Mean Acute Values in Table 3b is 80.55 µg/L. This Final Acute Value is below the SMAV for the mysid, *Mysidopsis bigelowi* (110 µg/L), but is aproximately three percent above the American lobster (78 µg/L), approximately seven percent higher than the striped bass (75.0 µg/L), and approximately 95 percent above the SMAV for the mysid, *A. bahia* (41.29 µg/L, geometric mean of two flow-through measured tests). The resultant saltwater Criterion Maximum Concentration (CMC) for total cadmium is 40 µg/L (FAV/2 or 80.55 µg/L/2). If the total cadmium CMC is converted to dissolved cadmium using the 0.994 factor determined experimentally by U.S. EPA, the saltwater CMC for dissolved cadmium is 40 µg/L (Table 3d). The resultant 40 µg/L CMC for dissolved cadmium is below all of the saltwater SMAVs presented in Table 3a (Figure 3).

CHRONIC TOXICITY TO FRESHWATER ANIMALS

Acceptable chronic toxicity tests have been conducted on cadmium in freshwater with 21 species, including seven invertebrates and 14 fishes in 16 genera (Table 2a). Several related values are in Table 6a. Among the unused values in Table 6a, a 21-day *Daphnia magna* test in which the test concentrations were not measured, Biesinger and Christensen (1972) found a 16 percent reduction in reproduction at 0.17 μg/L. Bertram and Hart (1979) and Ingersoll and Winner (1982) found chronic toxicity to *Daphnia pulex* at less than 1 and 10 μg/L, respectively. A 32-day flow-through measured juvenile bluegill study conducted by Cope et al. (1994) determined a growth NOEC value of >32.3 μg/L (Table 6a), which supports the 49.8 μg/L chronic value (Table 2a) reported by Eaton (1974). The 200-hr LC10 of 0.7 μg/L obtained with rainbow trout (Table 6a) by Chapman (1978) probably would be close to the result of an early life-stage test because of the extent to which various life stages were investigated. Effects on other salmonids and many invertebrates have been observed at 5 μg/L (adjusted for hardness when available) or less (Table 6a). These invertebrate species include protozoans (Fernandez-Leborans and Noville-Villajos 1993; Niederlehner et al. 1985), *C. dubia* (Winner 1988; Zuiderveen and Birge 1997), *D. magna* (Enserink et al. 1993; Winner and Whitford 1987), zooplankton (Lawrence and Holoka 1987), amphipods (Borgmann et al. 1991; Phipps et al. 1995), midges (Anderson et al. 1980), and mayflies (Spehar et al. 1978).

An acceptable *C. dubia* seven-day static-renewal toxicity test was conducted by Jop et al. (1995) using reconstituted soft laboratory water. The <24-hr old neonates were exposed to 1, 5, 10, 19 and 41 μg/L measured cadmium concentrations in addition to a laboratory water control at 25°C. The NOEC and LOEC were 10 and 19 μg/L cadmium, respectively, with a resultant chronic value of 13.78 μg/L cadmium (Table 2a).

The effects of water hardness on the toxicity of cadmium to *D. magna* was evaluated by Chapman et al. (Manuscript) under static-renewal conditions at a temperature of 20 $\pm$ 2°C. As part of the experimental design, the total hardness level was adjusted to either 53, 103 or 209 mg/L (as $CaCO_3$) in three distinct tests. Daphnids were individually exposed to six measured cadmium concentrations (exposures ranged from 0.15 to 22.1 μg/L cadmium among the three tests) and a control (0.08 μg/L cadmium) for 21 days. Based on an analysis of variance hypothesis testing procedure, they reported reproductive (mean number of young per adult) chronic values of 0.1523, 0.2117 and 0.4371 μg/L cadmium at hardness levels of 53, 103 and 209 mg/L, respectively (Table 2a). These same data were also subjected to a regression analysis procedure, whereby the 20 percent reproductive (mean number of young per adult) inhibition concentration (IC20) was estimated for each hardness level. The resultant IC20 values were 0.07, 0.23 and 0.33 μg/L cadmium for the 53, 103 and 209 mg/L hardness levels, respectively. Overall, the results obtained by the two different procedures are similar.

The effect of cadmium on the reproduction strategy of *D. magna* was investigated by Bodar et al. (1988b). After a 25-day exposure of the 12 $\pm$ 12-hr old neonates to 0 (control), 0.5, 1.0, 5.0, 10.0, 20.0 and 50 μg/L cadmium at 20 $\pm$ 1°C, the authors compared the survival, number of neonates per female, first day of reproduction and neonate size of the cadmium exposures to the controls. The 25-day reproductive NOEC was 5.0 μg/L cadmium, and the reproductive LOEC was 10.0 μg/L cadmium. The resultant chronic value was 7.07 μg/L cadmium (Table 2a).

Borgman et al. (1989) also investigated the effect of cadmium on *D. magna* reproduction. The 21-day static-renewal test was conducted at 20°C using measured exposure concentrations of 0.22 (control), 1.86, 4.10, 7.78 and 22.9 μg/L cadmium. Reproduction was significantly reduced at the lowest measured exposure concentration of 1.86 μg/L cadmium. Thus, the reproductive NOEC and LOEC were <1.86 and 1.86 μg/L cadmium, respectively, with a chronic value of <1.86 μg/L cadmium (Table 2a).

Brown et al. (1994) exposed 270-day old rainbow trout to cadmium under flow-through conditions for 65 weeks using borehole water with a total hardness of 250 mg/L (as $CaCO_3$). Mean cadmium concentrations during the exposure of adult fish were 0.47 (control), 1.77, 3.39 and 5.48 μg/L. After 65 weeks of exposure, the three most mature males and females were selected from each treatment, anesthetized and striped of their gametes when possible, with the milt and ova combined in a bucket. The fertilized eggs from each treatment group were then divided into four approximately equal-sized subsamples and exposed for seven weeks in 30-liter aquaria under flow-through conditions to nominal concentrations of 0 (control), 2.0, 5.0 and 8.0 μg/L cadmium. Second generation fry development was significantly affected when the parents were exposed to 1.77 μg/L cadmium, but not when exposed to 0.47 μg/L cadmium (control). However, second generation embryo survival for all groups was less than 60 percent, which may have influenced the fry development effect levels. A more representative endpoint was the ability of the first generation adults to reach sexual maturity, with NOEC and LOEC values of 3.39 and 5.48 μg/L cadmium, respectively. The resultant chronic value was 4.310 μg/L cadmium (Table 2a).

Brown et al. (1994) also exposed two-year old brown trout to cadmium under flow-through conditions for 95 weeks using the same borehole water. Mean cadmium concentrations during the exposure of adult fish were 0.27 (control), 5.13, 9.34 and 29.1 μg/L. After 60 weeks of exposure, the three most mature males and females were selected from each treatment, anesthetized and striped of their gametes, with the milt and ova combined in a bucket. The fertilized eggs from each treatment group were then divided into four approximately equal-sized subsamples and exposed for 50 days in 30-liter aquaria under flow-through conditions to cadmium concentrations similar to those in which the parents were exposed. After the 90 week exposure, the survival NOEC and LOEC were 9.34 and 29.1 μg/L cadmium, respectively, with a resultant chronic value of 16.49 μg/L cadmium (Table 2a).

A 32-day fathead minnow early life stage toxicity test was conducted by Spehar and Fiandt (1986) under flow-through conditions using sand filtered Lake Superior dilution water (Table 2a). They reported a chronic value of 10.0 μg/L cadmium, which when coupled with their 96-hour LC50 of 13.2 μg/L cadmium, gives an acute-chronic ratio of 1.320.

Ingersoll and Kemble (unpublished) investigated the chronic toxicity of cadmium to the amphipod *Hyalella azteca*. The organisms were exposed under flow-through measured conditions (control, low, middle and high exposures) at a mean temperature of 23°C and a total hardness of 280 mg/L (as $CaCO_3$). A 3-m nylon mesh substrate was provided during the test. The seven- to eight-day old amphipods were exposed to water only mean total cadmium concentrations of 0.10 (control), 0.12, 0.32, 0.51, 1.9 and 3.2 μg/L for 42 days. The most sensitive endpoint was survival, with an NOEC and LOEC of 0.51 and 1.9 μg/L cadmium, respectively, after both 28 and 42 days of exposure. The resultant chronic value was 0.9844 μg/L total cadmium (Table 2a), which was similar to the estimated 42-day survival IC25 value of 1.9 μg/L.

Ingersoll and Kemble (unpublished) also exposed the midge *Chironomus tentans* to cadmium under the same conditions listed above for the amphipod, except that a thin 5 mm layer of sand was provided as a substrate. The <24-hr old larvae were exposed to water only mean measured total cadmium concentrations of 0.15 (control), 0.50, 1.5, 3.1, 5.8 and 17.4 μg/L for 20 days. The mean weight, biomass, percent emergence and percent hatch endpoints all had 20-day NOEC and LOEC values of 5.8 and 17.4 μg/L cadmium, respectively (Table 2a). The resultant chronic value was 10.05 μg/L total cadmium. The data were also subjected to regression analysis with resultant IC25 values of 10.3, 10.7, 8.3 and 4.0 μg/L for weight, biomass, percent emergence and percent hatch, respectively.

All four IC25 values were similar to the 10.05 μg/L chronic value determined for each endpoint.

Hardness Correction

Chronic values are available over a wide range of hardness for three species (Tables 2a and 2d). To account for the apparent relationship of cadmium chronic toxicity to hardness, an analysis of covariance (same as the analysis performed on the acute data) was performed to calculate the pooled slope for hardness using the natural logarithm of the chronic value as the dependent variable, species as the treatment or grouping variable, and the natural logarithm of hardness as the covariate or independent variable. This analysis of covariance model was fit to the data in Table 2a for the three species for which definitive chronic values are available over a range of hardness such that the highest hardness is at least three times the lowest, and the highest is also at least 100 mg/L higher than the lowest (other species in Table 2a did not meet these criteria). The slopes for the three species ranged from 0.5212 to 1.579, and the pooled slope for these three species was 0.9685 with P=0.90 (Table 2c). As with the acute slope determination, the all *D. magna* data set was too divergent, and only the Chapman et al. (Manuscript) *D. magna* data were used with the two other species (brown trout and fathead minnow) to estimate the overall slope. If this reduced data set is used (all species but using only data from Chapman et al. (Manuscript) for *D. magna*), the pooled slope for these species was 0.7409 with P=0.35 (see Table 2c). A plot of the chronic effect level versus total hardness is provided in Figure 4.

Criteria Development

The slope of 0.7409 was used to adjust each chronic value to a hardness of 50 mg/L. Generally, replicate adjusted chronic values for a species agreed well, as did values for species within a genus. The two values for Atlantic salmon are very different, but one agrees well with the value for the other tested species in the same genus. Twenty-one Species Mean Chronic Values (SMCV) were then calculated from the underlined values in Table 2a. When both early life stage (ELS) and life cycle (LC) data were available for a species, the SMCV was calculated using only the LC data per the Guideline recommendations. From these 21 SMCVs, sixteen Genus Mean Chronic Values were calculated and ranked (Table 3c).

A freshwater Final Chronic Value was calculated from the sixteen Genus Mean Chronic Values using the procedure used to calculate a Final Acute Value. This approach was appropriate since a number of chronic tests have been conducted with a large variety of species and these species met the eight different taxonomic family Guideline requirement. Thus, the freshwater Final Chronic Value for total cadmium at a hardness of 50 mg/L is (in μg/L) = $e^{(0.7409[\ln(\text{hardness})]-4.719)}$, or equal to 0.16 μg/L. For dissolved cadmium, the Final Chronic value at a hardness of 50 mg/L is (in μg/L) = 0.938 [$e^{(0.7409[\ln(\text{hardness})]-4.719)}$], or equal to 0.15 μg/L. The equation for the chronic freshwater conversion factor is CF = 1.101672 - [(ln hardness) (0.041838)] where the (ln hardness) is the natural logarithm of the hardness (Stephen 1995). At a hardness of 50 mg/L, all Genus Mean Chronic Values are above the dissolved Final Chronic Value (Figure 5).

Another option for calculating the Final Chronic Value is to use the Final Acute-Chronic Ratio in conjunction with the Final Acute Value. However, the acute-chronic ratios ranged from 0.9021 for the chinook salmon to 433.8 for the flagfish (greater than a factor of ten), with other values scattered throughout this range (Tables 2e and 3c). These ratios do not seem to follow any of the patterns (Table 3c) recommended in the Guidelines, and so it does not seem reasonable to use a freshwater Final Acute-Chronic Ratio to calculate a Final Chronic Value.

CHRONIC TOXICITY TO SALTWATER ANIMALS

Three chronic toxicity tests have been conducted with the saltwater invertebrate, *Americamysis bahia*, formerly classified as *Mysidopsis bahia* (Table 2b). Nimmo et al. (1977a) conducted a 23-day life-cycle test at 20 to 28°C and salinity of 15 to 23 g/kg. Survival was 10 percent at 10.6 μg/L, 84 percent at the next lower test concentration of 6.4 μg/L, and 95 percent in the controls. No unacceptable effects were observed at 6.4 μg/L or any lower concentration. The chronic toxicity limits, therefore, are 6.4 and 10.6 μg/L, with a chronic value of 8.237 μg/L. The 96-hr LC50 was 15.5 μg/L, resulting in an acute-chronic ratio of 1.882.

Another life-cycle test was conducted on cadmium with *A. bahia* under different environmental conditions, including a constant temperature of 21°C and salinity of 30 g/kg (Gentile et al. 1982; Lussier et al. 1985). All organisms died in 28 days at 23 μg/L. At 10 μg/L a series of morphological abberations occurred at the onset of sexual maturity. External genitalia in males were abberant, females failed to develop brood pouches, and both sexes developed a carapace malformation that prohibited molting after the release of the initial brood. Although initial reproduction at this concentration was successful, successive broods could not be born because molting resulted in death.

No malformations or effects on initial or successive reproductive processes were noted in the controls or at 5.1 μg/L. Thus, the chronic limits for this study are 5.1 and 10 μg/L for a chronic value of 7.141 μg/L (Table 2b). The LC50 at 21°C and salinity of 30 g/kg was 110 μg/L which results in an acute-chronic ratio of 15.40 from this study.

These two studies showed excellent agreement between the chronic values but considerable divergence between the acute values and acute-chronic ratios. Several studies have demonstrated an increase in acute toxicity of cadmium with decreasing salinity and increasing temperature (Table 6b). The observed differences in acute toxicity to the mysids might be explained on this basis. Nimmo et al. (1977a) conducted their acute test at 20 to 28°C and salinity of 15 to 23 g/kg, whereas the other test was performed at 21°C and salinity of 30 g/kg.

A third *A. bahia* chronic study was conducted by Carr et al. (1985) at a salinity of 30 g/kg, but the temperature varied from 14 to 26°C over the 33 day study (Table 2b). At test termination, >50 percent of the organisms had died in cadmium exposures ≥8 μg/L. After 18 days of exposure, growth in the 4 μg/L, the lowest concentration treatment group was significantly reduced when compared to the controls. The resultant chronic limits for this study are <4 and 4 μg/L cadmium. Acute data were not presented by the authors. The lower chronic value observed for this study as compared to the two studies described above may have been due to unexpected temperature fluctuations over the study period (due to mechanical problems).

Gentile et al. (1982) also conducted a life-cycle test with another mysid, *Mysidopsis bigelowi*, and the results were very similar to those for *A. bahia*. Thus, the chronic value was 7.141 μg/L and the acute-chronic ratio was 15.40.

Because they covered such a wide range, it would be inappropriate to use any of the available freshwater acute-chronic ratios in the calculation of the saltwater Final Chronic Value. The two saltwater species for which acute-chronic ratios are available (Table 3b) have Species Mean Acute Values in the same range as the saltwater Final Acute Value, and so it seems reasonable to use the geometric mean of these two ratios. When the saltwater Final Acute Value of 80.55 μg/L is divided by the mean acute-chronic ratio of 9.106, a saltwater Final Chronic Value of 8.9 μg/L is obtained. The dissolved cadmium FCV is computed using the CF (0.994 x 8.846 μg/L), and is equal to 8.8 μg/L.

TOXICITY TO AQUATIC PLANTS

Thirty-three acceptable tests are available with freshwater plant species exposed to cadmium which lasted from 4 to 28 days (Table 4a). Growth reduction was the major toxic effect observed with freshwater aquatic plants, and several values are in the range of concentrations causing chronic effects on animals. The influence that plant growth media might have had on the toxicity tests is unknown, but is probably minor at least in the case of Conway (1978) who used a medium patterned after natural Lake Michigan water. The freshwater plant and animal data presented in this document were compared and the lowest toxicity values for fish and invertebrate species are lower than the lowest values for plants. A plot of the freshwater plant values is provided in Figure 6a. Thus, water quality criteria which protect freshwater animals should also protect freshwater plants. A final plant value was not calculated.

Toxicity values are available for five species of saltwater diatoms and two species of macroalgae (Table 4b). Concentrations causing fifty percent reductions in the growth rates of diatoms range from 60 μg/L for *Ditylum brightwelli* to 22,390 μg/L for *Phaeodactylum tricornutum*, the most resistant to cadmium. The brown macroalga (kelp) exhibited mid-range sensitivity to cadmium, with an EC50 of 860 μg/L. The most sensitive saltwater plant tested was the red alga, *Champia parvula*, with significant reductions in the growth of both the tetrasporophyte plant and female plant occurring at 22.8 μg/L. The saltwater plant and animal data were also compared, and the most sensitive plant species (*C. parvula*) is more resistant than the chronically most sensitive animal species tested. A plot of the saltwater plant values is provided in Figure 7. Therefore, water quality criteria for cadmium that protect saltwater animals should also protect saltwater plants. A final plant value was not calculated.

BIOACCUMULATION

Bioconcentration factors (BCFs) for cadmium in freshwater (Table 5a) range from 3 for brook trout muscle (Benoit et al. 1976) to 6,910 for the soft tissue of the snail *Viviparus georgianus* (Tessier et al. 1994b). Usually, fish accumulate only small amounts of cadmium in muscle as compared to most other tissues and organs (Benoit et al. 1976; Jarvinen and Ankley 1999; Sangalang and Freeman 1979). However, specific studies summarized by Jarvinen and Ankley (1999) showed that the skin, spleen, gill, fin, otolith and bone also have low bioconcentration factors. Sangalang and Freeman (1979) found that cadmium residues in fish reach steady-state only after exposure periods greatly exceeding 28 days. *D. magna*, and presumably other invertebrates of about this size or smaller, often reach steady-state within a few days (Poldoski 1979). Cadmium accumulated by fish from water is eliminated slowly (Benoit et al. 1976: Kumada et al. 1980), but Kumada et al. (1980) found that cadmium accumulated from food is eliminated much more rapidly. If all variables, except temperature, were kept the same, Tessier et al. (1994a) found that increased exposure temperatures generally increased the soft tissue bioconcentration factor observed for the snail, *V. georgianus*, but not for the mussel, *Elliptio complanata*. Poldoski (1979) reported that humic acid decreased the uptake of cadmium by *D. magna*, but Winner (1984) did not find any effect. Ramamoorthy and Blumhagen (1984) reported that fulvic and humic acids increased uptake of cadmium by rainbow trout.

The only BCF reported for a saltwater fish is a value of 48 from a 21-day exposure of the mummichog (Table 6b). However, among ten species of invertebrates, the BCFs range from 22 to 3,160 for whole body and from 5 to 2,040 for muscle (Table 5b). The highest BCF was reported for the polychaete, *Ophryotrocha diadema* (Klockner 1979). Although a BCF of 3,160 was attained after sixty-four days exposure using the renewal technique, tissue residues had not reached steady-state.

BCFs for four species of saltwater bivalve molluscs range from 113 for the blue mussel (George and Coombs 1977) to 2,150 for the eastern oyster (Zaroogian and Cheer 1976). In addition, the range of reported BCFs is rather large for some individual species. BCFs for the oyster include 149 and 677 (Table 6b), as well as 1,220, 1,830 and 2,150 (Table 5b). Similarly, two studies with the bay scallop resulted in BCFs of 168 (Eisler et al. 1972) and 2,040 (Pesch and Stewart 1980) and three studies with the blue mussel reported BCFs of 113, 306, and 710 (Tables 5b and 6b). George and Coombs (1977) studied the importance of metal speciation on cadmium accumulation in the soft tissues of *Mytilus edulis*. Cadmium complexed as Cd-EDTA, Cd-alginate, Cd-humate, and Cd-pectate (Table 6b) was bioconcentrated at twice the rate of inorganic cadmium (Table 5b). Because bivalve molluscs usually do not reach steady-state, comparisons between species may be difficult and the length of exposure may be the major determinant in the size of the BCF.

BCFs for five species of saltwater crustaceans range from 22 to 307 for whole body and from 5 to 25 for muscle (Tables 5b and 6b). Nimmo et al. (1977b) reported whole-body BCFs of 203 and 307 for two species of grass shrimp, *Palaemonetes pugio* and *P. vulgaris*. Vernberg et al. (1977) reported a factor of 140 for *P. pugio* at 25°C (Table 6b), whereas Pesch and Stewart (1980) reported a BCF of 22 for the same species exposed at 10°C, indicating that temperature might be an important variable. The commercially important crustaceans, the pink shrimp and lobster, were not effective bioaccumulators of cadmium with factors of 57 for whole body and 25 for muscle, respectively (Tables 5b and 6b).

Mallard ducks are a native wildlife species whose chronic sensitivity to cadmium has been studied. These birds can be expected to ingest many of the freshwater and saltwater plants and animals listed in Tables 4a and 4b. White and Finley (1978a,b) and White et al. (1978) found significant damage at a cadmium concentration of 200 mg/kg in food for 90 days. Di Giulio and Scanlon (1984) found significant effects on energy metabolism at 450 mg/kg, but not at 150 mg/kg. These are concentrations which would cause damage to mallard ducks. More recent information may be available, but these data would not have been identified during the literature search conducted for this update.

The bioaccumulation data provided in this document is for information purposes only. Calculation of a Final Residue Value for cadmium will not be presented at this time.

OTHER DATA

Data presented in Table 6 are not acceptable for inclusion in Tables 1-5, but provide useful information on the effects of cadmium to aquatic organisms. Several studies were reported in Table 6 and not in Table 1 either because the organisms were fed during acute studies (Lewis and Horning 1991; Ingersoll and Winner 1982; Mount and Norberg 1984; Pascoe et al. 1986; Schubauer-Berigan et al. 1993; Williams and Dusenbery 1990; Wiliams et al. 1986; Winner 1984) or the tests used unusual or uncharacterized dilution water (Hall et al. 1986; Hickey and Vickers 1992; Khangarot and Ray 1989a).

Although a number of the values in Tables 6a and 6b have already been discussed, the following section presents information supporting data presented in Tables 1-5, plus other useful trends or relationships. The effects of prior cadmium exposure to the resistence of the marine copepod, *Acartia clausi*, was investigated by Moraitou-Apostolopoulou et al. (1979). They observed that an *A. clausi* population collected from a metal impacted area displayed a greater tolerance to lethal cadmium concentrations when compared to a population obtained from a non-polluted site. The pollution acclimated population also had greater longevity than the non-adapted population when exposed to sublethal levels of cadmium.

The cumulative mortality resulting from exposure to cadmium for more than 96 hours is clearly evident from the studies with phytoplankton (Fargasova 1993; Findlay et al. 1996), duckweed (Outridge

1992), protozoa (Niederlehner et al. 1985), zooplankton (Lawrence and Holoka (1987), snails (Spehar et al. 1978), zebra mussels (Kraak et al. 1992a,b), crayfish (Thorp et al. 1979), macroinvertebrates (Giesy et al. 1979), polychaetes (Reish et al. 1976), bivalve molluscs, crabs, and starfish (Eisler and Hennekey 1977), scallops, shrimp, and crabs (Pesch and Stewart 1980), and a mysid (Gentile et al. 1982; Nimmo et al. 1977a).

In unmeasured flow-through sockeye salmon cadmium exposures, Servizi and Martens (1978) reported 7-day LC50 values that ranged from 8 to 4,500 μg/L for fry and alevins, respectively. The range and life stage sensitivity pattern observed by the authors were similar to other salmonid studies reported in Table 1a.

Nimmo et al. (1977a) in studies with the mysid, *Americamysis bahia*, reported a 96-hr LC50 of 15.5 μg/L (Table 1) and a 17-day LC50 of 11 μg/L (Table 6) at 25 to 28°C and salinity of 10 to 17 g/kg in the 96-hr study and 15 to 23 g/kg in the 17-day study. In another series of studies with this mysid (Gentile et al. 1982), the 96-hr LC50 was 110 μg/L (Table 1) and the 16-day LC50 was 28 μg/L (Table 6b) at 20°C and salinity of 30 g/kg. These data suggest that short-term acute toxicity might be strongly influenced by environmental variables, whereas long-term effects, even mortality, are not.

Considerable information exists concerning the effect of salinity and temperature on the acute toxicity of cadmium. Unfortunately, the conditions and durations of exposure are so different that adjustment of acute toxicity data for salinity is not possible. Rosenberg and Costlow (1976) studied the synergistic effects of cadmium and salinity combined with constant and cycling temperatures on the larval development of two estuarine crab species. They reported reduction in survival and significant delay in development of the blue crab with decreasing salinity. Cadmium was three times as toxic at a salinity of 10 g/kg than at 30 g/kg. Studies with the mud crab resulted in a similar cadmium-salinity response. In addition, the authors report that cycling temperature may have a stimulating effect on survival of larvae compared to constant temperature.

Theede et al. (1979) investigated the effect of temperature and salinity on the acute toxicity of cadmium to the colonial hydroid, *Laomedea loveni*. At 17.5 °C cadmium concentrations inducing irreversible retraction of half of the polyps ranged from 12.4 μg/L at a salinity of 25 g/kg to 3.0 μg/L at 10 g/kg (Table 6). At a temperature of 17.5°C, the toxicity of cadmium increased as salinity decreased from 25 g/kg to 10 g/kg.

A similar acute toxicity-salinity relationship was observed by Hall et al. (1995) for the copepod, *Eurytemora affinis*, whereby the 96-hour toxicity increased four-fold (from 213 to 51.6 μg/L cadmium) when the salinity was decreased from 15 to 5 g/kg at a test temperature of 25°C. Hall et al. (1995) also observed an approximate three-fold toxicity increase to the sheepshead minnow when the salinity was lowered in similar fashion at the same temperature. Likewise, the 21-day toxicity of cadmium to the blue crab, *Callinectes sapidus*, increased over nine-fold when the salinity was lowered from 25 to 2.5 g/kg, and the temperature was held constant at 22-23°C (Guerin and Stickle 1995). In contrast, Snell and Personne (1989b) observed little difference in the 24-hour toxicity of cadmium to the rotifer, *Brachionus plicatilis*, exposed under 15 and 30 g/kg salinity regimes and a temperature of 25°C.

The effect of environmental factors on the acute toxicity of cadmium is also evident from tests with the early life stages of saltwater vertebrates. Alderdice et al. (1979a,b,c) reported that salinity influenced the effects of cadmium on the volume, capsule strength, and osmotic response of embryos of the Pacific herring. Studies with embryos of the winter flounder indicated a quadratic salinity-cadmium relationship (Voyer et al. 1977), whereas Voyer et al. (1979) reported a linear relationship between salinity and cadmium toxicity to Atlantic silverside embryos.

Several studies have reported chronic sublethal effects of cadmium on saltwater fishes (Table 6b). Significant reduction in gill tissue respiratory rate was reported for the cunner after a 30-day exposure to 50 μg/L (MacInnes et al. 1977). Dawson et al. (1977) also reported a significant decrease in gill-tissue respiration of striped bass at 0.5 μg/L above ambient levels after a 30-day, but not a 90-day, exposure. A similar study with the winter flounder (Calabrese et al. 1975) demonstrated a significant alteration in gill tissue respiration rate measured *in vitro* after a 60-day exposure to 5 μg/L.

UNUSED DATA

Based on the requirements set forth in the guidelines (Stephen et al. 1985), the following studies are not acceptable for the following reasons and are classified as unused data.

Studies Were Conducted with Species That Are Not Resident in North America

Abbasi and Soni (1986)
Abel and Papoutsoglou (1986)
Abel and Garner (1986)
Abel and Barlocher (1988)
Ahsanullah et al. (1981)
Ahsanullah and Williams (1991)
Amiard-Triquet et al. (1987)
Annune et al. (1994)
Arshaduddin et al. (1989)
Austen et al. (1997)
Avery et al. (1996)
Azeez and Banerjee (1987)
Baby and Menon (1987)
Bambang et al. (1994)
Bednarz and Warkowska-Dratnal (1983/1984)
Birmelin et al. (1995)
Bresler and Yanko (1995)
Brooks et al. (1996)
Brunetti et al. (1991)
Calevro et al. (1998)

Canli and Furness (1993, 1995)
Cassini et al. (1986)
Castille and Lawrence (1981)
Centeno et al. (1993)
Chan (1988)
Chandini (1988, 1988, 1989, 1991)
Chandra and Garg (1992)
Charpentier et al. (1987)
Chattopadhyay et al. (1995)
Cheung and Lam (1998)
Coppellotti (1994)
D'Agostino and Finney (1974)
Dallinger et al. (1989)
Darmono (1990)
Darmono et al. (1990)
Datta et al. (1987)
Demon et al. (1989)
Den Besten et al. (1989, 1991)
De Nicola Giudici and Guarino (1989)
De Nicola Giudici and Migliore (1988)
Denton and Burdon-Jones (1986 1986)
Devi (1987, 1996)
Devi and Rao (1989)
Devineau and Triquet (1985)
Dorgelo et al. (1995)
Douben (1989)
Drbal et al. (1985)
Duquesne and Coll (1995)
Evtushenko et al. (1986)
Evtushenko et al. (1990)
Ferrari et al. (1993)
Fisher et al. (1996)
Fisher et al. (1996)
Forget et al. (1998)
Francesconi (1989)
Francesconi et al. (1994)
Forbes (1991)
Gaur et al. (1994)
Gerhardt (1992, 1995)
Ghosh and Chakrabarti (1990)
Glynn (1996)
Glynn et al. (1992, 1994)
Gopal and Devi (1991)
Green et al. (1986)
Greenwood and Fielder (1983)
Gupta and Rajbanshi (1991)
Gupta et al. (1992)
Hader et al. (1997)
Hansten et al. (1996)
Heinis et al. (1990)
Herkovits and Coll (1993)
Hiraoka et al. (1985)
Hu et al. (1996)
Huebner and Pynnonen (1992)
Husaini et al. (1991)
Ikuta (1987)
Jenkins and Sanders (1985)
Karlsson-Norrgren and Runn (1985)
Kasuga (1980)
Keduo et al. (1987)
Khangarot and Ray. (1987)
Khristoforova et al. (1984)
Kobayashi (1971)
Krassoi and Julli (1994)
Krishnaja et al. (1987)
Kuhn and Pattard (1990)
Kuroshima (1987)
Kuroshima and Kimura (1990)
Kuroshima et al. (1993)
Lam (1996, 1996)
Lam et al. (1997)
Lee and Xu (1984)
Loumbourdis et al. (1999)
McCahon et al. (1988)
McCahon and Pascoe (1988, 1988, 1988)
McCahon et al. (1989)
McClurg (1984)
Ma et al. (1999)
Malea (1994)
Markich and Jeffree (1994, 1994)
Martinez et al. (1996)
Metayer et al. (1982)
Michibata et al. (1986)
Michibata et al. (1987)
Migliore and Giudici (1987)
Moller et al. (1994)
Mostafa and Khalil (1986)
Muino et al. (1990)
Musko et al. (1990)
Nakagawa and Ishio (1988, 1989)
Nassiri et al. (1997)
Negilski (1976)
Nir et al. (1990)
Noraho and Gaur (1995)
Notenboom et al. (1992)
Nott and Nicolaidou (1994)
Nugegoda and Rainbow (1995)
Ojaveer et al. (1980)
Pantani et al. (1997)
Papathanassiou (1995)
Pavicic et al. (1994)
Perez-Coll and Herkovits (1996)
Pynnonen (1995)
Rainbow and Kwan (1995)
Rainbow et al. (1980)
Rainbow and White (1989)
Ralph and Burchett (1998)
Ramachandran et al. (1997)
Rao and Madhyastha (1987)
Rebhun and Ben-Amotz (1984)
Reish et al. (1988)
Ringwood (1990, 1992)
Ritterhoff et al. (1996)
Romeo and Gnassia-Barelli (1995)
Safadi (1998)
Sastry and Shukla (1994)

Sastry and Sunita (1982)
Saxena et al. (1990, 1993)
Schafer et al. (1994)
Sehgal and Saxena (1987)
Shanmukhappa and Neelakantan (1990)
Shivaraj and Patil (1988)
Simoes Goncalves (1989)
Stuhlbacher and Maltby (1992)
Takamura et al. (1989)
Temara et al. (1996a,b)
Ten Hoopen et al. (1985)
Thaker and Haritos (1989)
Thebault et al. (1996)
Theede et al. (1979)
Tomasik et al. (1995)
Tyurin and Khristoforova (1993)
Udoidiong and Akpan (1991)
Valencia et al. (1998)
Van Gemert (1985)
Vashchenko and Zhadan (1993)
Verriopoulos and Moraitou-Apostolopoulou (1981, 1982)
Visviki and Rachlin (1991)
Vogiatzis and Loumbourdis (1998)
Vranken et al. (1985)
Vuori (1994)
Vymazal (1990, 1995)
Walsh et al. (1995)
Warnau et al. (1995a,b,c, 1996a,b, 1997)
Westernhagen and Dethlefsen (1975)
Westernhagen et al. (1975, 1978)
Wildgust and Jones (1998)
White and Rainbow (1986)
Wicklund and Runn (1988)
Wicklund et al. (1988)
Wu et al. (1997)
Wundram et al. (1996)
Zanders and Rojas (1992, 1996)
Zou and Bu (1994)

Brown and Ahsanullah (1971) conducted tests with a brine shrimp species, that are too atypical to be used in deriving national criteria.

Cadmium Was a Component of a Drilling Mud, Effluent, Mixture, Sediment or Sludge

Allen (1994, 1995)
Amiard-Triquet et al. (1988)
Andres et al. (1999)
Arnac and Lassus (1985)
Austen and McEvoy (1997)
Bartsch et al. (1999)
Beiras et al. (1998)
Bendell-Young (1994)
Bendell-Young et al. (1986)
Besser and Rabeni (1987)
Biesinger et al. (1986)
Bigelow and Lasenby (1991)
Bodar et al. (1990)
Buckley et al. (1985)
Burden and Bird (1994)
Busch et al. (1998)
Campbell and Evans (1991)
Camusso et al. (1995)
Carlisle and Clements (1999)
Casini and Depledge (1997)
Cuvin-Aralar (1994)
Cuvin-Aralar and Aralar (1993)
Dallinger et al. (1997)
de March (1988)
Elliott et al. (1986)
Farag et al. (1994, 1998)
Gully and Mason (1993)
Hall et al. (1984, 1987, 1988)
Hardy and Raber (1985)
Hare et al. 1991, (1994)
Haritonidis et al. (1994)
Hartwell (1997)
Haynes et al. (1989)
Hendriks (1995)
Hickey and Clements (1998)
Hickey and Martin (1995)
Hickey and Roper (1992)
Hogstrand et al. (1991)
Hollis et al. (1996)
Hooten and Carr (1998)
Hylland et al. (1996)
Inza et al. (1998)
Jak et al. (1996)
Janssens de Bisthoven et al. (1992)
Jop (1991)
Keenan and Alikhan (1991)
Kelly and Whitton (1989)
Kettle and deNoyelles (1986)
Khan and Weis (1993)
Khan et al. (1989)
Kiffney and Clements (1996)

Klerks and Bartholomew (1991)
Kock et al. (1995)
Koivisto et al. (1997)
Kolok et al. (1998)
Kraak et al. (1993, 1994)
Krantzberg (1989a,b)
Krantzberg and Stokes (1988, 1989)
Kumar (1991)
Lee and Luoma (1998)
Lithner et al. (1995)
Lucker et al. (1997)
Macdonald and Sprague (1988)
Maloney (1996)
Manz et al. (1994)
Marr et al. (1995a, b)
Mathew and Menon (1992)
Mersch et al. (1996)
Nalewajko (1995)
Nelson (1994)
Odin et al. (1996, 1997)
Palawski et al. (1985)
Pedersen and Petersen (1996)
Pellegrini et al. (1993)
Playle et al. (1993)
Polar and Kucukcezzar (1986)
Poulton et al. (1995)
Prevot and Soyer-Gobillard (1986)
Qichen et al. (1988)
Rachlin and Grosso (1993)
Reynoldson et al. (1996)
Richelle et al. (1995)
Roch and McCarter (1984)
Roesijadi and Fellingham (1987)
Sanchiz et al. (1999)
Schaeffer et al. (1991)
Smokorowski et al. (1997)
Stephenson and Macki (1989)
Stern and Stern (1980)
Talbot (1985, 1987)
Tessier et al. (1993)
Vuori (1993)
Vymazal (1984)
Wall et al. (1996)
Walsh and Hunter (1992)
Wang et al. (1996)
Warren et al. (1998)
Weimin et al. (1994)
Wong et al. (1982)
Woodling (1993)
Woodward et al. (1995)

These Reviews Only Contain Data That Have Been Published Elsewhere

Barnthouse et al. (1987)
Bay et al. (1993)
Cairns et al. (1985)
Chapman et al. (1968)
Dierickx and Bredael-Rozen (1996)
Dyer et al. (1997)
Eisler (1981)
Bisler et al. (1979)
Enserink et al. (1991)
Florence et al. (1992)
Guilhermino et al. (1997)
Hare (1992)
Hornstrom (1990)
Jonnalagadda and Rao (1993)
Khangarot and Ray (1987)
Kooijman and Bedaux (1996)
Kraak et al. (1994a,b)
LeBlanc (1984)
Mark and Solbe (1998)
Meyer (1999)
Nendza et al. (1997)
Oikari et al. (1992)
Papoutsoglou and Abel (1993)
Pesonen and Andersson (1997)
Phillips and Russo (1978)
Ramesha et al. (1996)
Rice (1984)
Skowronski et al. (1998)
Spry and Wiener (1991)
Thomann et al. (1997)
Thompson et al. (1972)
Toussaint et al. (1995)
Trevors et al. (1986)
Van Leeuwen et al. (1987)
Vymazal (1990)
Wright and Welbourn (1994)
Wong (1987)

Organisms Were Exposed to Cadmium in Food or by Injection or Gavage

Bodar et al. (1988)
Brouwer et al. (1992)
Chou et al. (1986)
Davies et al. (1997)
Decho and Luoma (1994)
Gottofrey and Tjalve (1991)
Handy (1993)
Kluttgen and Ratte (1994)
Kuroshima (1992)
Lasenby and Van Duyn (1992)
Lawrence and Holoka (1991)
Lomagin and Ul'yanova (1993)
Malley and Chang (1991)
Melgar et al. (1997)
Mount et al. (1994)
Munger and Hare (1997)
Postma et al. (1994)
Postma and Davids (1995)
Reinfelder and Fisher (1994, 1994)
Reddy et al. (1997)
Rhodes et al. (1985)
Van den Hurk et al. (1998)
Wallace and Lopez (1997)
Wang and Fisher (1996)
Wen-Xiong and Fisher (1996)
Wong (1989)

No Interpretable Concentration, Time, Response Data or Examined Only a Single Concentration

Berglind (1985)
Bitton et al. (1994)
Block and Part (1992)
Block et al. (1991)
Blondin et al. (1989)
Bowen and Engel (1996)
Bressan and Brunetti (1988)
Castano et al. (1996)
Christoffers and Ernst (1983)
Clausen et al. (1993)
Fargasova (1994)
Fernandez-Pinas et al. (1995)
George et al. (1983)
Iftode et al. (1985)
Ilangovan et al. (1998)
Issa et al. (1995)
Jana and Sahana (1988)
Kluytmans et al. (1988)
Kraak et al. (1993b)
Kosakowska et al. (1988)
Lussier et al. (1999)
Mateo et al. (1993)
Palackova et al. (1994)
Pereira et al. (1993)
Prasad et al. (1998)
Rachlin and Grosso (1991)
Reader et al. (1989)
Reddy and Fingerman (1994)
Reid and McDonald (1991)
Ribo (1997),
Rombough (1985)
Rosas and Ramirez (1993)
Sauvant et al. (1997)
Skowronski et al. (1991)
Sunila and Lindstrom (1985)
Trehan and Maneesha (1994)
Verbost et al. (1987)
Visviki and Rachlin (1994)
Wang et al. (1995)
Woodall et al. (1988)
Wundram et al. (1996)
Xue and Sigg (1998)

No Useable Data on Cadmium Toxicity or Bioconcentration

Battaglini et al. (1993)
Borchardt (1983)
Craig et al. (1998)
Gargiulo et al. (1996)
Gomot (1998)
Harvey and Luoma (1985)
Kraal et al. (1995)
Penttinen et al. (1995)
Rouleau et al. (1998)
Sobhan and Sternberg (1999)

Organisms Were Selected, Adapted or Acclimated for Increased Resistance to Cadmium

Anadu et al. (1989)
Bodar et al. (1990)
Currie et al. (1998)
Ramo et al. (1987)
Herkovits and Perez-Coll (1995)
Kaplan et al. (1995)
McNicol and Scherer (1993)
Madoni et al. (1994)
Nagel and Voigt (1995)
Thomas et al. (1985)
Van Steveninck et al. (1992)

Data were not used if the results were only presented graphically (Laegreild et al. 1983; Laube 1980; Remacle et al. 1982), if the organisms were not exposed to cadmium in water (Foster 1982; Hatakeyama and Yasuno 1981a; O'Neill 1981), or if there was no pertinent adverse effect (Carr and Neff 1982; DeFilippis et al. 1981; Dickson et al. 1982; Fisher and Fabris 1982; Fisher and Jones 1981; Tucker and Matte 1980; Watling 1981; Weis et al. 1981).

Either the Materials, Methods or Results Were Insufficiently Described

Abbasi and Soni (1989)
Ball (1967)
Belabed et al. (1994)
Bendell-Young (1999)
Bitton et al. (1995)
Bjerregaard and Depledge (1994)
Bolanos et al. (1992)
Burnison et al. (1975)
Calevro et al. (1998)
Canton and Slooff (1979)
Carpene and Boni (1992)
D'Aniello et al. (1990)
Davies et al. (1994)
Department of the Environment (1973)
Errecalde et al. (1998)
Fennikoh et al. (1978)
Fernandez-Leborans and Antonio-Garcia (1988)
Galic and Sipos (1987)
Glubokov (1990)
Gorman and Skogerboe (1987)
Guanzon et al. (1994)
Guerin et al. (1994)
Hofslagare et al. (1985)
Janssen and Persoone (1993)
Jaworska et al. (1997)
Kay et al. (1986)
Kessler (1985)
Khangarot et al. (1987)
Koyama et al. (1992)
Landner and Jernelov (1969)
Lee and Oshima (1998)
Liao and Hsieh (1990)
Maas (1978)
Mansour (1993)
Ministry of Technology (1967)
Moza et al. (1995)
Munger et al. (1999)
Naylor et al. (1992)
Nwadukwe and Erondu (1996)
Pascoe and Shazili (1986)
Pauli and Berger (1997)
Penttinen et al. (1998)
Peterson (1991)
Peterson et al. (1984)
Rayms-Keller et al. (1998)
Rombough (1985)
Sandau et al. (1996)
Sekkat et al. (1992)
Shcherban (1977)
Sheela et al. (1995)
Sovenyi and Szakolczai (1993)
Stom and Zubareva (1994)
Stubblefield et al. (1999)
Tarzwell and Henderson (1960)
Verma et al. (1980)
Vykusova and Svobodova (1987)
Wani (1986)
Witeska et al. (1995)
Yamamoto and Inque (1985)
Zhang et al. (1992)

High control mortalities occurred in testing reported by Asato and Reish (1988), Hong and Reish (1987), Sauter et al. (1976) and Wright (1988). The 96-hr values reported by Buikema et al. (1974a,b) were subject to error because of possible reproductive interactions (Buikema et al. 1977). Bringmann and Kuhn (1982) and Dave et al. (1981) cultured daphnids in one water and tested them in a different water. The acceptability of the dilution water or medium used in some studies (e.g., Brkovic-Popovic and Popovic 1977a,b; Cearley and Coleman 1973, 1974; Nasu et al. 1983) was open to question because of its origin or content.

Inappropriate Medium or Medium Contained Too Much of a Complexing Agent for Algal Studies

Baillieul and Blust (1999)
Brand et al. (1986)
Chen et al. (1997)
Couillard (1989)
Hockett and Mount (1996)
Huebert et al. (1993)
Huebert and Shay (1991, 1992, 1993)
Jenkins and Mason (1988)
Jenkins and Sanders (1986)
Jenner and Janssen-Mommen (1993)
Kessler (1986)
Lue-Kim et al. (1980)
Macfie et al. (1994)
Meteyer et al. (1988)
Muller and Payer (1979)
Nasu et al. (1988)
Rebhun and Ben-Amotz (1986, 1988)
Stary and Kratzer (1982)
Stary et al. (1983)
Sloof et al. (1995)
Sunda and Huntsman (1996)
Thongra-ar and Matsuda (1993)
Thorpe and Costlow (1989)
Tortell and Price (1996)
Vasseur and Pandard (1988)
Wright et al. (1985)

Questionable Treatment of Test Organisms or Inappropriate Test Conditions or Methodology

Babich and Stotsky (1982)
Brown et al. (1984)
Bryan (1971)
Chan et al. (1981)
Dorfman (1977)
Eisler and Gardner (1973)
Greig (1979)
Hung (1982)
Hutcheson (1975)
Moraitou-Apostolopoulou et al. (1979)
Parker (1984)
Pecon and Powell (1981)
Rehwoldt et al. (1972, 1973)
Ridlington et al. (1981)
Servizi and Martens (1978)
Sunda et al. (1978)
Wikfors and Ukeles (1982)

Bioconcentration Studies Conducted in Distilled Water, Not Conducted Long Enough, Not Flow-through or Water Concentrations Not Adequately Measured

Allen (1995)
Amiard et al. (1993)
Amiard-Triquet et al. (1986)
Balogh and Salanki (1984)
Baudrimont et al. (1997)
Beattie and Pascoe (1978)
Bentley (1991)
Berglind (1986)
Bernds (1998)
Bervoets et al. (1995, 1996)
Bjerregaard (1982, 1985, 1991)
Block and Glynn (1992)

Brown et al. (1986)
Burrell and Weihs (1983)
Carmichael and Fowler (1981)
Carr and Neff (1982)
Chan et al. (1992)
Chander et al. (1991)
Chawla et al. (1991)
Chitguppa et al. (1997)
Chou and Uthe (1991)
Collard and Matagne (1994)
Craig et al. (1999)
Davies et al. (1981)
De Conto Cinier et al. (1997)
De Conto Cinier et al. (1998)
De Nicola et al. (1993)
Denton and Burdon-Jones (1981)
Elliott et al. (1985)
Engel (1999)
Everaarts (1990)
Fair and Sick (1983)
Frazier and George (1983)
Freeman (1978, 1980)
Giles (1988)
Gottofrey et al. (1988)
Graney et al. (1984)
Gupta and Devi (1993)
Haines and Brumbaugh (1994)
Hansen et al. (1995)
Hardy and O'Keeffe (1985)
Hashim et al. (1997)
Hatakeyama (1987)
Herwig et al. (1989)
Hollis et al. (1997)
Irato and Piccinni (1996)
John et al. (1987)
Katti and Sathyanesan (1985)
Kerfoot and Jacobs (1976)
Khoshmanesh et al. (1996, 1997)
Klaverkamp and Duncan (1987)
Koelmans et al. (1996)
Kohler and Riisgard (1982)
Kwan and Smith (1991)
Langston and Zhou (1987)
Les and Walker (1984)
McLeese and Ray (1984)
Maeda et al. (1990)
Malley et al. (1989)
Maranhao et al. (1999)
Mersch et al. (1993)
Mizutani et al. (1991)
Muramoto (1980)
Mwangi and Alikhan (1993)
Nolan and Duke (1983)
Norey et al. (1990)
Oakley et al. (1983)
Olesen and Weeks (1994)
Papathanassiou (1986)
Pawlik and Skowronski (1994)
Pawlik et al. (1993)
Pelgrom et al. (1994)
Pelgrom et al. (1997)
Playle and Dixon (1993)
Presing et al. (1993)
Postma et al. (1996)
Poulsen et al. (1982)
Rai et al. 1995
Rainbow (1985)
Ramirez et al. (1989)
Ray et al. (1981)
Reichert et al. (1979)
Reinfelder et al. (1997)
Riisgard et al. (1987)
Ringwood (1989, 1992, 1993)
Roseman et al. (1994)
Rubinstein et al. (1983)
Santojanni et al. (1998)
Sedlacek et al. (1989)
Sidoumou et al. (1997)
Simoes Goncalves et al. (1988)
Sinha et al. (1994)
Skowronski and Przytocka-Jusiak (1986)
Srivastava and Appenroth (1995)
Stary et al. (1982)
Sunil et al. (1995)
Suzuki et al. (1987)
Swinehart (1990)
Taylor et al. (1988)
Tessier et al. (1996)
Thomas et al. (1983)
Van Leeuwen et al. (1985)
Van Ginneken et al. (1999)
Vymazal (1995)
Wang and Fisher (1998)
Watling (1983a)
White and Rainbow (1982)
Williams et al. (1998)
Windom et al. (1982)
Winner and Gauss (1986)
Winter (1996)
Woodworth and Pascoe (1983)
Xiaorong et al. (1997)
Yager and Harry (1964)
Zauke et al. (1995)
Zia and McDonald (1994)

The bioconcentration tests of Eisler (1974), Jennings and Rainbow (1979b), O'Hara (1973b), Phelps (1979), and Sick and Baptist (1979), which used radioactive isotopes of cadmium, were not used because of the possibility of isotope discrimination. Reports on the concentrations of cadmium in wild aquatic organisms, such as Anderson et al. (1978), Bouquegneau and Martoja (1982), Boyden (1977), Bryan et al. (1983), Frazier (1979), Gordon et al. (1980), Greig and Wenzloff (1978), Hazen and Kneip (1980), Kneip and Hazen (1979), McLeese et al. (1981), Noel-Lambot et al. (1980), Pennington et al. (1982), Ray et al. (1981), Smith et al. (1981), and Uthe et al. (1982) were not used for the calculation of bioaccumulation factors due to an insufficient number of measurements of the concentration of cadmium in the water.

SUMMARY

Freshwater Species Mean Acute Values (SMAV) for cadmium are available for species in 55 genera and hardness adjusted values range from 1.613 μg/L for brown trout to 96,880 μg/L for a midge. Freshwater invertebrate SMAVs range from 13.41 μg/L for *D. magna* to 96,880 μg/L for a midge and SMAVs for 24 fish species from 1.613 μg/L for the brown trout to 10,663 μg/L for the tilapia. The antagonistic effect of hardness on acute toxicity has been demonstrated with 12 species. Acceptable chronic tests have been conducted on cadmium with 14 freshwater fish species and seven invertebrate species with hardness adjusted Species Mean Chronic Values (SMCV) ranging from 0.2747 μg/L for *Hyalella azteca* to 27.17 μg/L for *Ceriodaphnia dubia*. Acute-chronic ratios are available for six species and range from 0.9021 for the chinook salmon to 433.8 for the flagfish.

Freshwater aquatic plants are affected by cadmium at concentrations ranging from 2 to 20,000 μg/L. These values are in the same range as the acute toxicity values for fish and invertebrate species, and are considerably above the chronic values. Bioconcentration factors (BCFs) for cadmium in freshwater range from 7 to 6,910 for invertebrates and from 3 to 2,213 for fishes.

Saltwater cadmium SMAVs are available for species in 54 genera and SMAVs for 50 species of invertebrates range from 41.29 μg/L for a mysid to 135,000 μg/L for an oligochaete worm. SMAVs for 11 fish species range from 75.0 μg/L for striped bass to 50,000 μg/L for sheepshead minnow. The acute toxicity of cadmium generally increases as salinity decreases. The effect of temperature seems to be species-specific. Chronic tests have been conducted with two mysid species, *Americamysis bahia* and *Mysidopsis bigelowi*, with SMCVs of 6.173 μg/L and 7.141 μg/L, respectively. Acute-chronic ratios are available for each species, 5.384 for *A. bahia* and 15.40 for *M. bigelowi*. The acute values appear to reflect effects of varying salinity and temperature levels, whereas the few available chronic values apparently do not.

Studies with macroalgae and microalgae revealed effects at 22.8 to 22,390 μg/L, respectively.

These values are in the same range as acute toxicity values for fish and invertebrate species, and are above the chronic values. BCFs determined with a variety of saltwater invertebrates range from 5 to 3,160. BCFs for bivalve molluscs were generally above 1,000 in long exposures, with no indication that steady-state had been reached.

A comparison of the criteria developed in this document with the previous National recommended water quality criteria (which is based on the 1995 update for freshwater and the 1984 update for saltwater) indicates that the updated 2001 freshwater CMC of 1.0 μg/L dissolved cadmium has remained approximately the same (the value was lowered each time to protect the commercially important rainbow trout), but the freshwater chronic CCC has been lowered to 0.15 μg/L dissolved cadmium in this document from 1.3 μg/L in the 1995 document. This 2001 update contains a database of 55 freshwater genera for acute toxicity (43 genera were in the 1995 update), and 15 genera for freshwater chronic toxicity (12 genera were provided in the 1995 document). As a result of the additional data, the acute and chronic hardness derived slopes are different in this update relative to previous versions. This update did not use an adjusted "n" value to calculate the Final Chronic Value (the 1995 update modified the total "n" for the chronic value to be the same as the acute "n" value). Included in this updated document are toxicity results for certain threatened and endangered species that were not available earlier. Saltwater cadmium criteria remained relatively the same between the 1999 National recommended water quality criteria and 2001 documents. The new saltwater CMC of 40 μg/L dissolved cadmium presented in this document is only slightly lower than the 42 μg/L cadmium found in the previous national recommended water quality criteria. The chronic CCC dropped slightly to 8.8 μg/L cadmium in this document from the 9.3 μg/L value previously recommended. There are 54 genera in the acute saltwater database of this document (the 1984 document had 33 genera), and the same two saltwater chronic genera are presented in both documents (a third *A. bahia* chronic value was added to this document).

NATIONAL CRITERIA

The available toxicity data, when evaluated using the procedures described in the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" indicate that, except possibly where a locally important species is unusually sensitive, freshwater aquatic life should be protected at a total hardness of 50 mg/L as $CaCO_3$ if the four-day average concentration (in μg/L) of dissolved cadmium does not exceed the numerical value given by

$0.938\ [e^{(0.7409[\ln(\text{hardness})]-4.719)}]$ more than once every three years on the average, and if the 24-hour average dissolved concentration (in μg/L) does not exceed the numerical value given by $0.973\ [e^{(1.0166[\ln(\text{hardness})]-3.924)}]$ more than once every three years on the average. For example, at hardnesses of 50, 100, and 200 mg/L as $CaCO_3$ the four-day average dissolved concentrations of cadmium are 0.15, 0.25 and 0.40 μg/L, respectively, and the 24-hour average dissolved concentrations are 1.0, 2.0, and 3.9 μg/L.

The procedures described in the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" indicate that, except possibly where a locally important species is unusually sensitive, saltwater aquatic life should be protected if the four-day average dissolved concentration of cadmium does not exceed 8.8 μg/L more than once every three years on the average and if the 24-hour average dissolved concentration does not exceed 40 μg/L more than once every three years on the average. However, the limited data suggest that the acute toxicity of cadmium is salinity-dependent; therefore the 24-hour average concentration might be underprotective at low salinities and overprotective at high salinities.

U.S. EPA believes that the use of dissolved cadmium will provide a more scientifically correct basis upon which to establish water-column criteria for metals. The criteria were developed on this basis. The use of dissolved criteria reduces the amount of conservatism that was present in earlier cadmium criteria. It is recognized that a considerable proportion of dissolved cadmium in organic-rich waters may be less toxic than freely dissolved cadmium. On the other hand, some particulate forms of cadmium might contribute to cadmium loading of organisms, possibly through ingestion.

A return interval of three years continues to be the Agency's general recommendation. The resilience of ecosystems and their ability to recover differ greatly, however, and site-specific criteria may be established if adequate justification is provided.

The use of criteria in designing waste treatment facilities requires the selection of an appropriate wasteload allocation model. Dynamic models are preferred for the application of these criteria. Limited data or other factors may make their use impractical, in which case one should rely on a steady-state model. The Agency recommends the interim use of 1Q5 or 1Q10 for Criterion Maximum Concentration (CMC) design flow and 7Q5 or 7Q10 for the Criterion Continuous Concentration (CCC) design flow in steady-state models for unstressed and stressed systems respectively. These matters are discussed in more detail in the Technical Support Document for Water Quality-Based Toxics Control (U.S. EPA 1991).

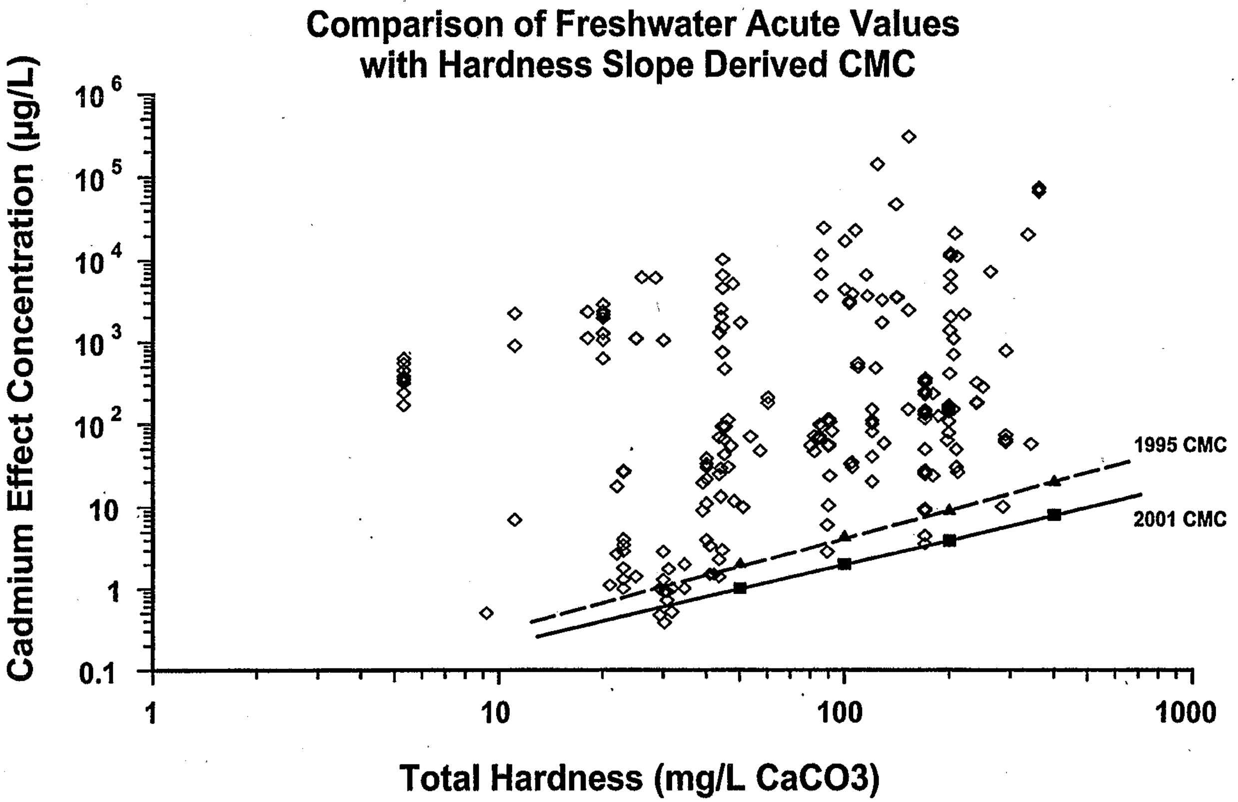

Figure 1. Comparison of All Table 1 Freshwater Acute Toxicity Test EC50s and LC50s with the Hardness Slope Derived CMC. (2001 CMC: solid line; 1995 CMC: dashed line)

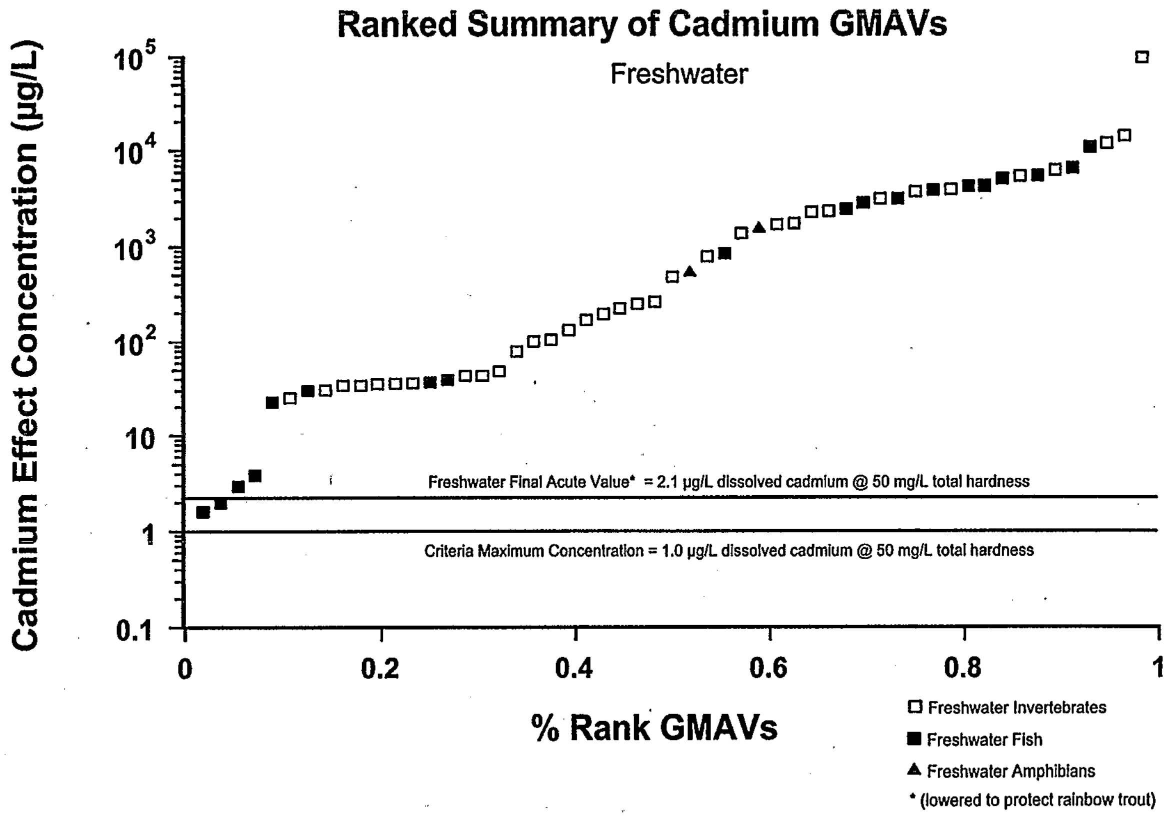

Figure 2. Ranked Summary of Cadmium GMAVs (Freshwater).

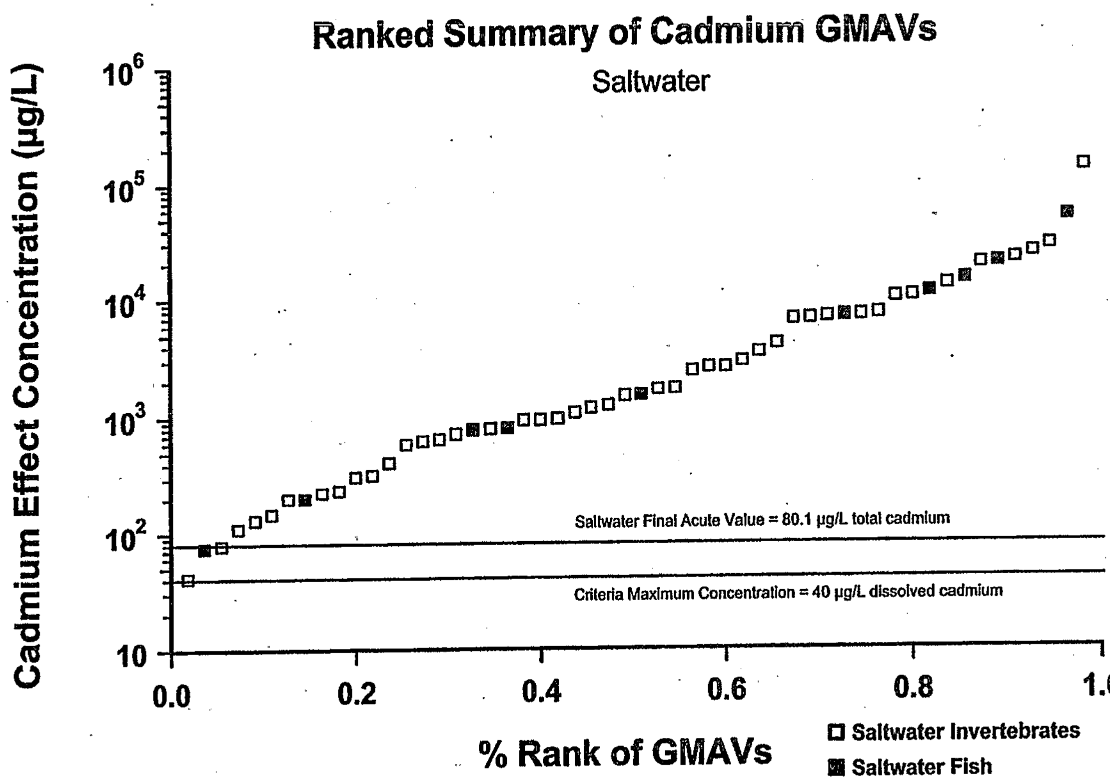

Figure 3. Ranked Summary of Cadmium GMAVs (Saltwater).

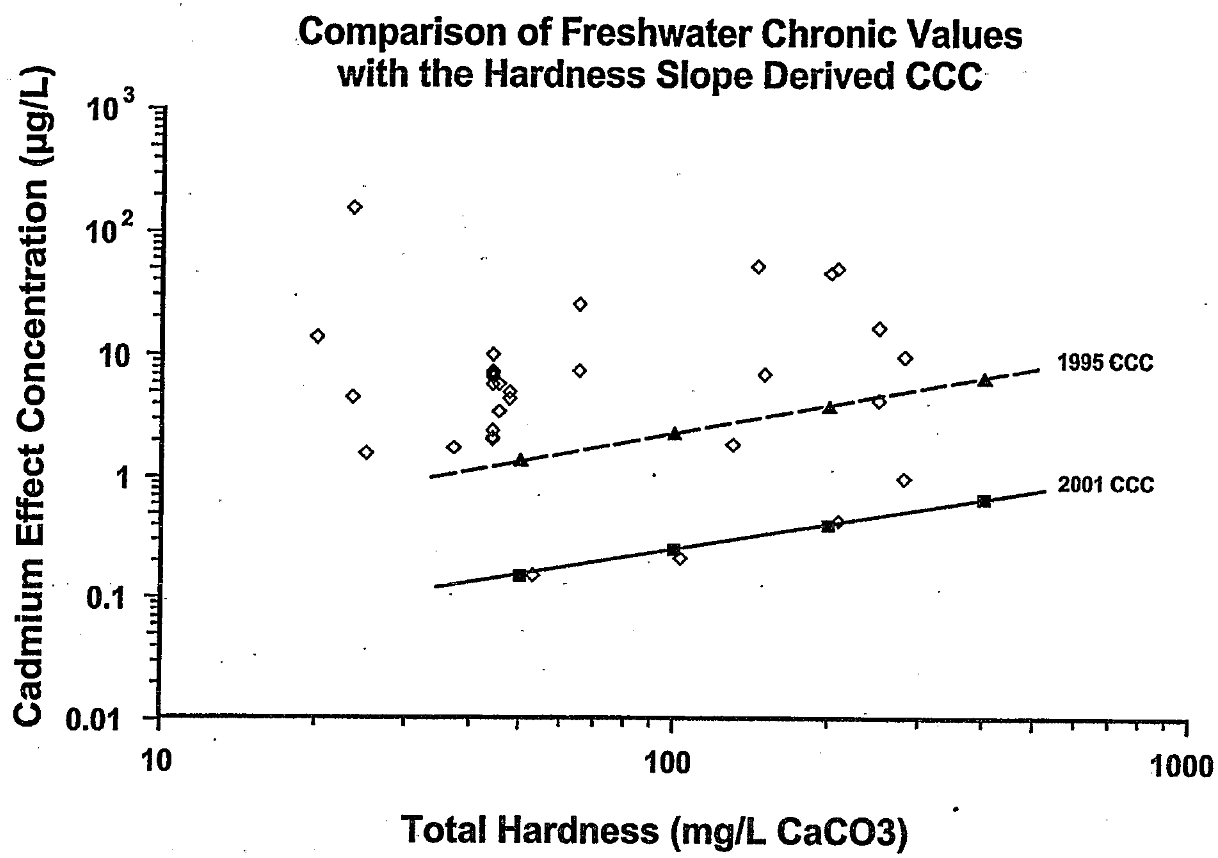

Figure 4. Comparison of All Table 2 Freshwater Chronic Values with the Hardness Slope Derived CCC. (2001 CCC: solid line; 1995 CCC: dashed line)

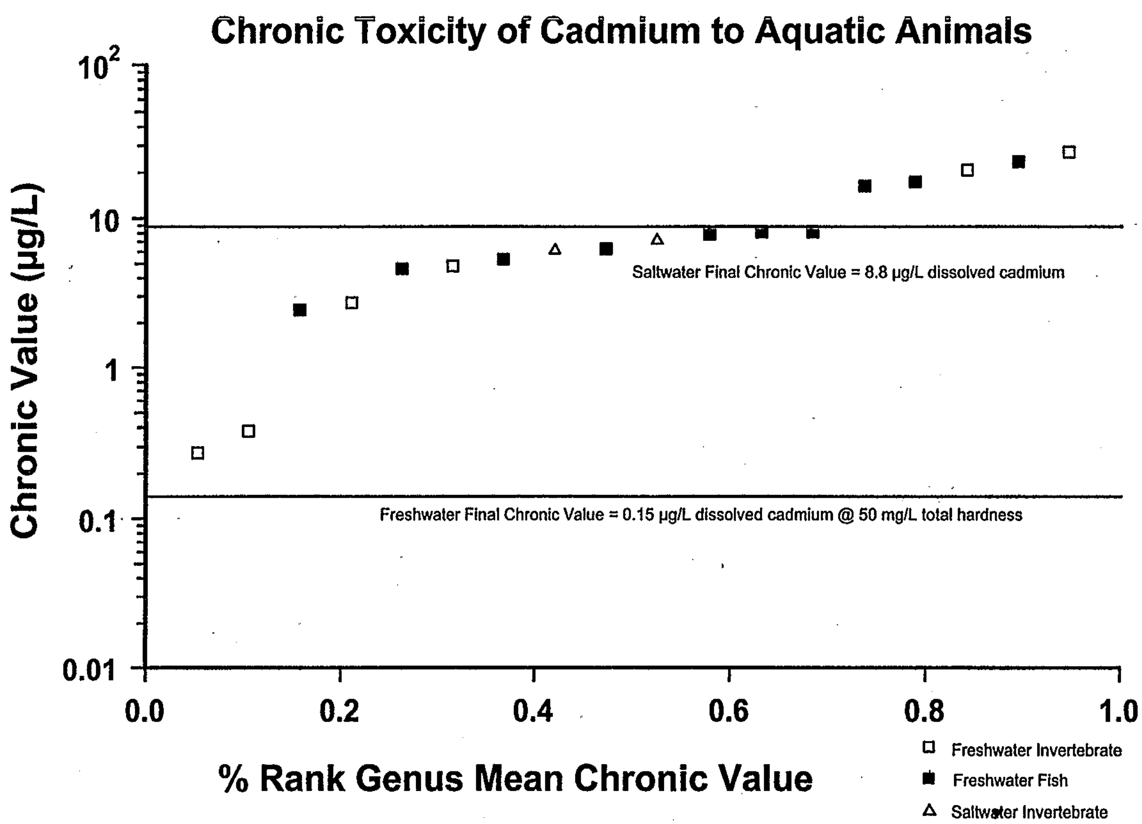

Figure 5. Chronic Toxicity of Cadmium to Aquatic Animals.

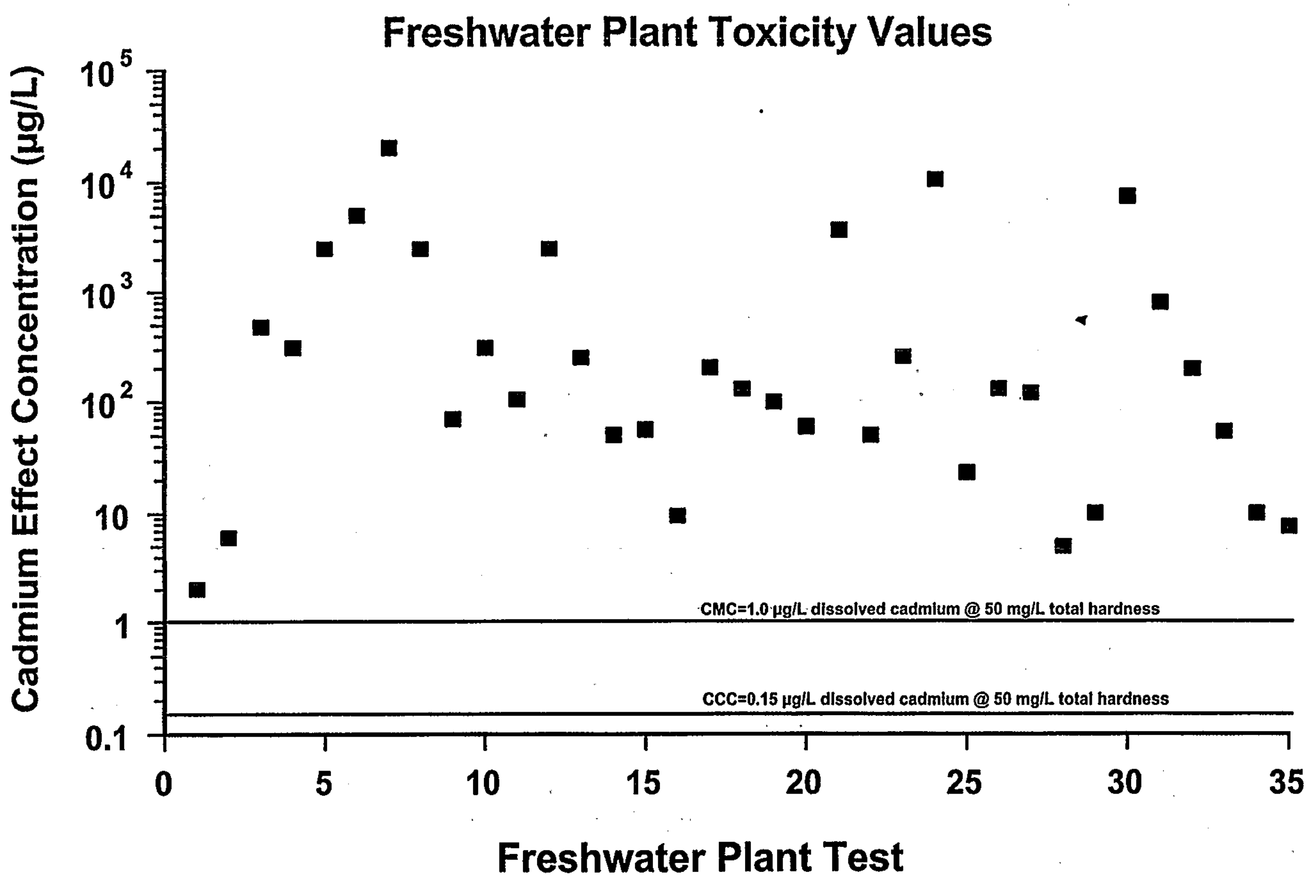

Figure 6. Comparison of Freshwater Plant Toxicity Values (Table 4) and Freshwater CMC and CCC Values.

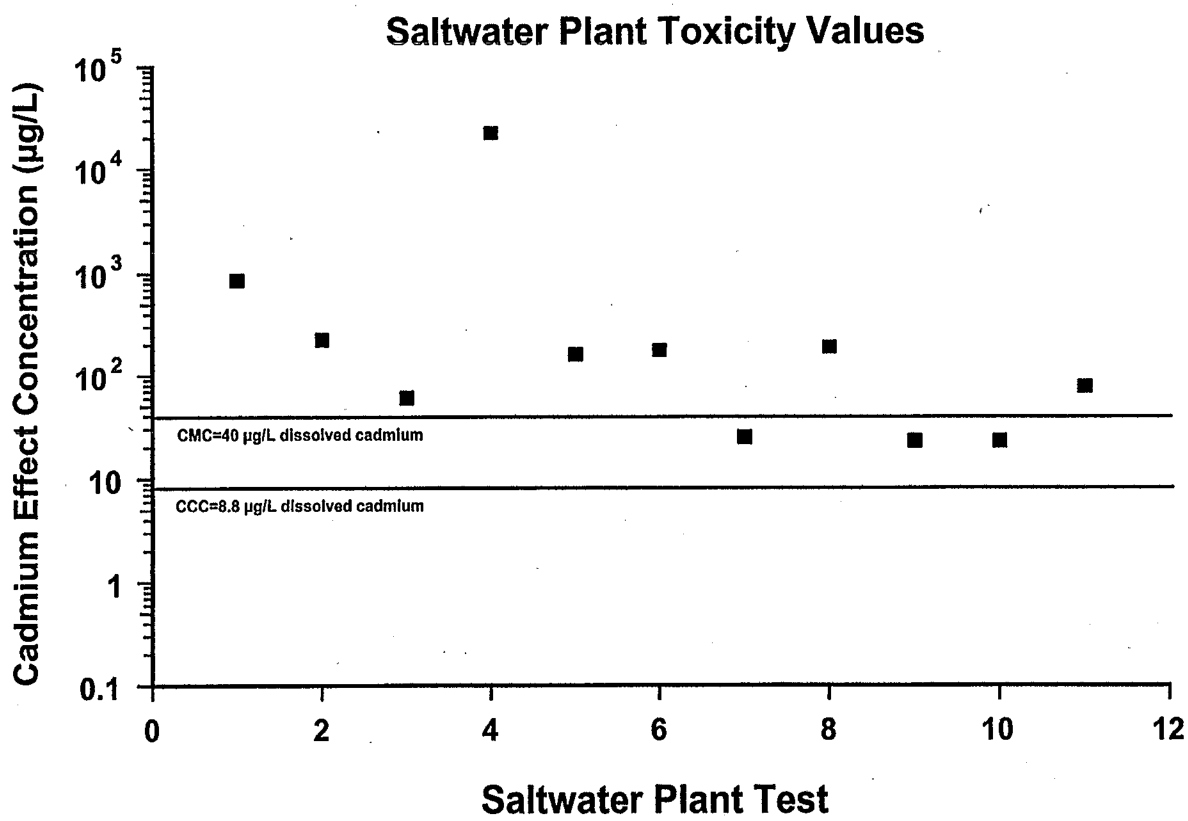

Figure 7. Comparison of Saltwater Plant Toxicity Values (Table 4) and Saltwater CMC and CCC Values.

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Planarian, *Dendrocoelum lacteum*	R, M, T	Cadmium chloride	87	24,702	23,220	14,067	14,067	Ham et al. 1995
Worm (adult), *Lumbriculus variegatus*	S, M, T	Cadmium nitrate	290 (280-300)	780	-	130.6	130.6	Schubauer-Berigan et al. 1993
Tubificid worm, *Branchiura sowerbyi*	S, M	Cadmium sulfate	5.3	240	-	2,350	2,350	Chapman et al. 1982
Tubificid worm, *Limnodrilus hoffmeisteri*	S, M	Cadmium sulfate	5.3	170	-	1,665	-	Chapman et al. 1982
Tubificid worm (30-40 mm) *Limnodrilus hoffmeisteri*	F, M, T	-	152	2,400	-	775.0	775.0	Williams et al. 1985
Tubificid worm, *Quistadrilus multisetosus*	S, M	Cadmium sulfate	5.3	320	-	3,133	3,133	Chapman et al. 1982
Tubificid worm, *Rhyacodrilus montana*	S, M	Cadmium sulfate	5.3	630	-	6,169	6,169	Chapman et al. 1982
Tubificid worm, *Spirosperma ferox*	S, M	Cadmium sulfate	5.3	350	-	3,427	3,427	Chapman et al. 1982
Tubificid worm, *Spirosperma nikolskyi*	S, M	Cadmium sulfate	5.3	450	-	4,406	4,406	Chapman et al. 1982
Tubificid worm, *Stylodrilus heringlianus*	S, M	Cadmium sulfate	5.3	550	-	5,386	5,386	Chapman et al. 1982
Tubificid worm, *Tubifex tubifex*	S, M, T	Cadmium chloride	128 (119-137)	3,200	-	1,231	-	Reynoldson et al. 1996
Tubificid worm, *Tubifex tubifex*	S, M, T	Cadmium chloride	128 (119-137)	1,700	-	653.8	-	Reynoldson et al. 1996
Tubificid worm, *Tubifex tubifex*	S, U	Cadmium chloride	-	1,032	-	-	-	Fargasova 1994a
Tubificid worm, *Tubifex tubifex*	S, M	Cadmium sulfate	5.3	320	-	3,133	1,361	Chapman et al. 1982

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Tubificid worm, *Varichaeta pacifica*	S, M	Cadmium sulfate	5.3	380	-	**3,721**	3,721	Chapman et al. 1982
Leech, *Glossiponia complanta*	R, M, T	Cadmium chloride	122.8	480	-	**192.5**	192.5	Brown and Pascoe 1988
Snail, *Aplexa hypnorum*	F, M	Cadmium chloride	45.3	93	-	**102.8**	-	Holcombe et al. 1984
Snail (adult), *Aplexa hypnorum*	F, M, T	Cadmium chloride	44.4	93	-	**104.9**	103.9	Phipps and Holcombe 1985
Snail (adult), *Physa gyrina*	S, M	-	200	1,370	-	334.7[d]	-	Wier and Walter 1976
Snail (immature), *Physa gyrina*	S, M	-	200	410	-	**100.2**	100.2	Wier and Walter 1976
Mussel (juvenil), *Actinonaia pectorosa*	S,M,T	-	82	46.4	-	**28.06**	-	Keller Unpublished
Mussel (juvenile), *Actinonaia pectorosa*	S,M,T	-	84	69	-	**40.72**	33.80	Keller Unpublished
Mussel (juvenile), *Lampsilis straminea claibornensis*	S,M,T	-	40	38	-	**47.68**	47.68	Keller Unpublished
Mussel, *Lampsilis teres*	S,M,T	-	40	11	-	**13.80**	-	Keller Unpublished
Mussel (juvenile), *Lampsilis teres*	S,M,T	-	40	33	-	**41.40**	23.90	Keller Unpublished
Mussel, *Utterbackia imbecilis*	S, M, T	Cadmium chloride	90	114.7	-	**63.10**	-	Keller Unpublished
Mussel, *Utterbackia imbecilis*	S, M, T	Cadmium chloride	90	111.8	-	**61.51**	-	Keller Unpublished
Mussel (juvenile), *Utterbackia imbecilis*	S,M,T	Cadmium chloride	92	81.9	-	**44.06**	-	Keller Unpublished
Mussel (juvenile), *Utterbackia imbecilis*	S,M,T	Cadmium chloride	86	93.0	-	**53.59**	-	Keller Unpublished
Mussel (juvenile), *Utterbackia imbecilis*	S, M, T	Cadmium chloride	39	9	-	**11.59**	-	Keller and Zam 1991

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Mussel (juvenile), *Utterbackia imbecilis*	S, M, T	Cadmium chloride	90	107	-	58.87	42.92	Keller and Zam 1991
Mussel, *Vilosa vibex*	S, M, T	-	40	30	-	37.64	-	Keller Unpublished
Mussel, *Vilosa vibex*	S, M, T	-	186	125	-	32.88	35.18	Keller Unpublished
Cladoceran, *Alona affinis*	S, U	Cadmium nitrate	109	546	-	247.2	247.2	Ghosh et al. 1990
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U	Cadmium chloride	90 (80-100)	54	-	29.71	-	Bitton et al. 1996
Cladoceran (<24 hr), *Ceriodaphnia dubia*	R, M, T	Cadmium chloride	80 (70-90)	54.5	-	33.80	-	Diamond et al. 1997
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U	Cadmium chloride	90 (80-100)	55.9	-	30.75	31.37	Lee et al. 1997
Cladoceran (<24 hr) *Ceriodaphnia reticulata*	S, U	Cadmium chloride	240	184	-	37.35	-	Elnabarawy et al. 1986
Cladoceran (<6 hr) *Ceriodaphnia reticulata*	S, U	Cadmium chloride	120	110	-	45.17	41.07	Hall et al. 1986
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	-	<1.6[h]	-	-	-	Anderson 1948
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	45	65	-	72.35	-	Biesinger and Christensen 1972
Cladoceran (<24 hr), *Daphnia magna*	S, U	Cadmium nitrate	-	27.07	-	-	-	Canton and Adema 1978
Cladoceran (<24 hr), *Daphnia magna*	S, U	Cadmium nitrate	-	28.36	-	-	-	Canton and Adema 1978
Cladoceran (<24 hr), *Daphnia magna*	S, U	Cadmium nitrate	-	35.45	-	-	-	Canton and Adema 1978
Cladoceran (<24 hr), *Daphnia magna*	R, M	Cadmium Chloride	105	30	-	14.11	-	Canton and Slooff 1982
Cladoceran (<24 hr), *Daphnia magna*	R, M	Cadmium Chloride	209.2	30	-	7.002	-	Canton and Slooff 1982

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	120	20	-	8.213	-	Hall et al. 1986
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	120	40	-	16.43	-	Hall et al. 1986
Cladoceran (<24 hr), *Daphnia magna*	S, U	Cadmium chloride	240	178	-	36.13	-	Elnabarawy et al. 1986
Cladoceran, *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	3.6 (genotype A)	-	1.038	-	Baird et al. 1991
Cladoceran, *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	9.0 (genotype A-1)	-	2.594	-	Baird et al. 1991
Cladoceran, *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	9.0 (genotype A-2)	-	2.594	-	Baird et al. 1991
Cladoceran, *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	4.5 (genotype B)	-	1.297	-	Baird et al. 1991
Cladoceran, *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	27.1 (genotype E)	-	7.810	-	Baird et al. 1991
Cladoceran, *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	115.9 (genotype S-1)	-	33.40	-	Baird et al. 1991
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	24.5 (Clone F)	-	7.061	-	Stuhlbacher et al. 1992
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	129.4 (Clone S-1)	-	37.29	-	Stuhlbacher et al. 1992
Cladoceran (3 d), *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	25.4 (Clone F)	-	7.320[f]	-	Stuhlbacher et al. 1993
Cladoceran (3 d), *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	228.8 (Clone S-1)	-	65.94[f]	-	Stuhlbacher et al. 1993
Cladoceran (6 d), *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	49.1 (Clone F)	-	14.15[f]	-	Stuhlbacher et al. 1993
Cladoceran (6 d), *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	250.1 (Clone S-1)	-	72.08[f]	-	Stuhlbacher et al. 1993
Cladoceran (10 d), *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	131.2 (Clone F)	-	37.81[f]	-	Stuhlbacher et al. 1993
Cladoceran (10 d), *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	319.3 (Clone S-1)	-	92.02[f]	-	Stuhlbacher et al. 1993

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Cladoceran (20 d), *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	139.9 (Clone F)	-	40.32[f]	-	Stuhlbacher et al. 1993
Cladoceran (20 d), *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	326.3 (Clone S-1)	-	94.04[f]	-	Stuhlbacher et al. 1993
Cladoceran (30 d), *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	146.7 (Clone F)	-	42.28[f]	-	Stuhlbacher et al. 1993
Cladoceran (30 d), *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	355.3 (Clone S-1)	-	102.4[f]	-	Stuhlbacher et al. 1993
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	-	360	-	-	-	Fargasova 1994a
Cladoceran, *Daphnia magna*	S, U	Cadmium sulfate	250	280	-	<u>54.52</u>	-	Crisinel et al. 1994
Cladoceran (<24 hr), *Daphnia magna*	S, U	Cadmium chloride	170 (160-180)	9.5	-	<u>2.738</u>	-	Guilhermino et al. 1996
Cladoceran, *Daphnia magna*	S, M, T	Cadmium sulfate	46.1	112 (clone S-1)	104	<u>121.6</u>	-	Barata et al. 1998
Cladoceran, *Daphnia magna*	S, M, T	Cadmium sulfate	90.7	106 (clone S-1)	91.4	<u>57.86</u>	-	Barata et al. 1998
Cladoceran, *Daphnia magna*	S, M, T	Cadmium sulfate	179	233 (clone S-1)	179	<u>63.72</u>	-	Barata et al. 1998
Cladoceran, *Daphnia magna*	S, M, T	Cadmium sulfate	46.1	30.1 (clone A)	27.8	<u>32.69</u>	-	Barata et al. 1998
Cladoceran, *Daphnia magna*	S, M, T	Cadmium sulfate	90.7	23.4 (clone A)	20.2	<u>12.77</u>	-	Barata et al. 1998
Cladoceran, *Daphnia magna*	S, M, T	Cadmium sulfate	179	23.6 (clone A)	18.1	<u>6.454</u>	-	Barata et al. 1998
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium Chloride	51	9.9	-	<u>9.703</u>	-	Chapman et al. Manuscript
Cladoceran (<24 hr) *Daphnia magna*	S, M, T	Cadmium Chloride	104	33	-	<u>15.67</u>	-	Chapman et al. Manuscript
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium Chloride	105	34	-	<u>15.99</u>	-	Chapman et al. Manuscript
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium Chloride	197	63	-	<u>15.63</u>	-	Chapman et al. Manuscript

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium Chloride	209	49	-	11.45	-	Chapman et al. Manuscript
Cladoceran (<24 hr), *Daphnia magna*	F, M, T	Cadmium Chloride	130	58	-	21.96	13.41	Attar and Maly 1982
Cladoceran (<24 hr), *Daphnia pulex*	S, U	Cadmium nitrate	-	90.23	-	-	-	Canton and Adema 1978
Cladoceran, *Daphnia pulex*	S, U	Cadmium chloride	57	47	-	41.14	-	Bertram and Hart 1979
Cladoceran (<24 hr), *Daphnia pulex*	S, U	Cadmium chloride	240	319	-	64.75	-	Elnabarawy et al. 1986
Cladoceran (<24 hr), *Daphnia pulex*	S, U	Cadmium chloride	120	80	-	32.85	-	Hall et al. 1986
Cladoceran (<24 hr), *Daphnia pulex*	S, U	Cadmium chloride	120	100	-	41.07	-	Hall et al. 1986
Cladoceran (<24 hr), *Daphnia pulex*	S, M, T	Cadmium chloride	53.5	70.1	-	65.44	-	Stackhouse and Benson 1988
Cladoceran, *Daphnia pulex*	S, U	Cadmium chloride	85 (80-90)	66	-	38.48	-	Roux et al. 1993
Cladoceran, *Daphnia pulex*	S, U	Cadmium chloride	85 (80-90)	99	-	57.72	-	Roux et al. 1993
Cladoceran, *Daphnia pulex*	S, U	Cadmium chloride	85 (80-90)	70	-	40.82	46.36	Roux et al. 1993
Cladoceran, *Moina macrocopa*	S, U	Cadmium chloride	82 (80-84)	71.25	-	43.09	43.09	Hatakeyama and Yasuno 1981b
Cladoceran, *Simocephalus serrulatus*	S, M	Cadmium chloride	11.1	7.0	-	32.33	-	Giesy et al. 1977
Cladoceran, *Simocephalus serrulatus*	S, M	Cadmium chloride	43.5 (39-48)	24.5	-	28.23	30.21	Spehar and Carlson 1984a,b
Copepod, *Cyclops varicans*	S, U	Cadmium nitrate	109	493	-	223.2	223.2	Ghosh et al. 1990
Isopod, *Asellus bicrenata*	F, M	Cadmium chloride	220	2,129[g]	-	472.1	472.1	Bosnak and Morgan 1981

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Isopod, *Lirceus alabamae*	F, M	Cadmium chloride	152	150[g]	-	48.44	48.44	Bosnak and Morgan 1981
Amphipod (4 mm), *Crangonyx pseudogracilis*	R, U	Cadmium chloride	50	1,700	-	1,700	1,700	Martin and Holdich 1986
Amphipod, *Gammarus pseudolimnaeus*	S, M	Cadmium chloride	43.5 (39-48)	68.3	-	78.69	78.69	Spehar and Carlson 1984a,b
Crayfish (1.8 g), *Orconectes immunis*	F, M, T	Cadmium chloride	44.4	>10,200	-	>11,509	>11,509	Phipps and Holcombe 1985
Crayfish, *Orconectes limosus*	S, M	Cadmium chloride	-	400	-	-	-	Boutet and Chaisemartin 1973
Crayfish, *Orconectes virilis*	F, M, T	Cadmium chloride	26	6,100	-	11,859	11,859	Mirenda 1986
Crayfish (juvenile), *Procambarus clarkii*	S, M	Cadmium chloride	30	1,040	-	1,748	1,748	Naqvi and Howell 1993
Mayfly, *Ephemerella grandis*	F, M	Cadmium chloride	-	28,000	-	-	-	Clubb et al. 1975
Mayfly, *Ephemerella grandis*	S, U	Cadmium sulfate	44	2,000	-	2,278	2,278	Warnick and Bell 1969
Stonefly, *Pteronarcella badia*	F, M	Cadmium chloride	-	18,000	-	-	-	Clubb et al. 1975
Midge (4th instar), *Chironomus riparius*	R, M, T	Cadmium chloride	124	140,000	-	55,607	-	Pascoe et al. 1990
Midge (10-12 mm), *Chironomus riparius*	F, M, T	-	152	300,000	-	96,880	96,880	Williams et al. 1985
Bryozoan, *Pectinatella magnifica*	S, U	-	205 (190-220)	700	-	166.8	166.8	Pardue and Wood 1980
Bryozoan, *Lophopodella carteri*	S, U	-	205 (190-220)	150	-	35.74	35.74	Pardue and Wood 1980
Bryozoan, *Plumatella emarginata*	S, U	-	205 (190-220)	1,090	-	259.7	259.7	Pardue and Wood 1980
Coho salmon (1 year), *Oncorhynchus kisutch*	S, U	Cadmium chloride	90	10.4	-	5.722	-	Lorz et al. 1978

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Coho salmon (juvenile), *Oncorhynchus kisutch*	S, U	Cadmium chloride	41	3.4	-	4.160	-	Buhl and Hamilton 1991
Coho salmon (adult), *Oncorhynchus kisutch*	F, M	Cadmium chloride	22	17.5[d]	-	40.32[d]	-	Chapman 1975
Coho salmon (parr), *Oncorhynchus kisutch*	F, M	Cadmium chloride	22	2.7	-	<u>6.221</u>	6.221	Chapman 1975
Chinook salmon (9-13 wk), *Oncorhynchus tshawytscha*	S, U	Cadmium chloride	211	26	-	6.016	-	Hamilton and Buhl 1990
Chinook salmon (18-21 wk), *Oncorhynchus tshawytscha*	S, U	Cadmium chloride	343	57	-	8.048	-	Hamilton and Buhl 1990
Chinook salmon (alevin), *Oncorhynchus tshawytscha*	F, M	Cadmium chloride	23	>26[d]	-	>57.26[d]	-	Chapman 1975, 1978
Chinook salmon (swim-up), *Oncorhynchus tshawytscha*	F, M	Cadmium chloride	23	1.8	-	<u>3.964</u>	-	Chapman 1975, 1978
Chinook salmon (parr), *Oncorhynchus tshawytscha*	F, M	Cadmium chloride	23	3.5	-	<u>7.707</u>	-	Chapman 1975, 1978
Chinook salmon (smolt), *Oncorhynchus tshawytscha*	F, M	Cadmium chloride	23	>2.9	-	<u>>6.386</u>	-	Chapman 1975, 1978
Chinook salmon (juvenile), *Oncorhynchus tshawytscha*	F, M	Cadmium chloride	25	1.41	-	<u>2.853</u>	-	Chapman 1982
Chinook salmon (juvenile), *Oncorhynchus tshawytscha*	F, M	Cadmium sulfate	21 (20-22)	1.1	-	<u>2.657</u>	4.305	Finlayson and Verrue 1982

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Rainbow trout, *Oncorhynchus mykiss*	S, U	-	-	6	-	-	-	Kumada et al. 1973
Rainbow trout, *Oncorhynchus mykiss*	S, U	-	-	7	-	-	-	Kumada et al. 1973
Rainbow trout, *Oncorhynchus mykiss*	S, U	Cadmium chloride	-	6.0	-	-	-	Kumada et al. 1980
Rainbow trout, *Oncorhynchus mykiss*	S, M	Cadmium chloride	43.5 (39-48)	2.3	-	2.650	-	Spehar and Carlson 1984a,b
Rainbow trout (juvenile), *Oncorhynchus mykiss*	S, U	Cadmium chloride	41	1.5	-	1.835	-	Buhl and Hamilton 1991
Rainbow trout (alevin), *Oncorhynchus mykiss*	F, M	Cadmium chloride	23	>27[d]	-	>59.46[d]	-	Chapman 1975, 1978
Rainbow trout (swim-up), *Oncorhynchus mykiss*	F, M	Cadmium chloride	23	1.3	-	<u>2.863</u>	-	Chapman 1975, 1978
Rainbow trout (parr), *Oncorhynchus mykiss*	F, M	Cadmium chloride	23	1.0	-	<u>2.202</u>	-	Chapman 1978
Rainbow trout (smolt), *Oncorhynchus mykiss*	F, M	Cadmium chloride	23	4.1 >2.9	-	<u>9.029</u> <u>>6.386</u>	- -	Chapman 1975
Rainbow trout (2 mo), *Oncorhynchus mykiss*	F, M	Cadmium nitrate	-	6.6	-	-	-	Hale 1977
Rainbow trout, *Oncorhynchus mykiss*	F, M	Cadmium sulfate	31	1.75	-	<u>2.845</u>	-	Davies 1976
Rainbow trout (8.8 g), *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	44.4	3	-	<u>3.385</u>	-	Phipps and Holcombe 1985
Rainbow trout (fry), *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	9.2	<0.5	-	<u><2.795</u>	-	Cusimano et al. 1986
Rainbow trout (263 mg), *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	30.7	0.71 (pH=7.5 @ 8°C)	-	<u>1.166</u>	-	Stratus Consulting 1999
Rainbow trout (659 mg), *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	29.3	0.47 (pH=7.5 @ 8°C)	-	<u>0.8092</u>	-	Stratus Consulting 1999

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Rainbow trout (1150 mg), *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	31.7	0.51 (pH=7.5 @ 8°C)	-	**0.8105**	-	Stratus Consulting 1999
Rainbow trout (1130 mg), *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	30.2	0.38 (pH=7.5 @ 12°C)	-	**0.6344**	-	Stratus Consulting 1999
Rainbow trout (299 mg), *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	30.0	1.29 (pH=6.5 @ 8°C)	-	**2.168**	-	Stratus Consulting 1999
Rainbow trout (289 mg), *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	89.3	2.85 (pH=7.5 @ 8°C)	-	**1.581**	2.108	Stratus Consulting 1999
Brown trout, *Salmo trutta*	S, M	Cadmium chloride	43.5 (39-48)	1.4	-	**1.613**	1.613	Spehar and Carlson 1984a,b
Brook trout, *Salvelinus fontinalis*	F, M	Cadmium chloride	47.4	5,080[e]	-	5,363[e]	-	Holcombe et al. 1983
Brook trout, *Salvelinus fontinalis*	S, M	Cadmium sulfate	42	<1.5	-	**<1.791**	<1.791	Carroll et al. 1979
Bull trout (76.1 mg), *Salvelinus confluentus*	F, M, T	Cadmium chloride	30.7	0.91 (pH=7.5 @ 8°C)	-	**1.494**	-	Stratus Consulting 1999
Bull trout (200 mg), *Salvelinus confluentus*	F, M, T	Cadmium chloride	29.3	0.99 (pH= 7.5 @ 8°C)	-	**1.705**	-	Stratus Consulting 1999
Bull trout (221 mg), *Salvelinus confluentus*	F, M, T	Cadmium chloride	31.7	1.00 (pH=7.5 @ 8°C)	-	**1.589**	-	Stratus Consulting 1999
Bull trout (218 mg), *Salvelinus confluentus*	F, M, T	Cadmium chloride	30.2	0.90 (pH=7.5 @ 12°C)	-	**1.503**	-	Stratus Consulting 1999
Bull trout (84.2 mg), *Salvelinus confluentus*	F, M, T	Cadmium chloride	30.0	2.89 (pH=6.5 @ 8°C)	-	**4.858**	-	Stratus Consulting 1999
Bull trout (72.7 mg), *Salvelinus confluentus*	F, M, T	Cadmium chloride	89.3	6.06 (pH=7.5 @ 8°C)	-	**3.361**	2.152	Stratus Consulting 1999
Goldfish, *Carassius auratus*	S, U	Cadmium chloride	20	2,340	-	5,940	-	Pickering and Henderson 1966
Goldfish, *Carassius auratus*	S, M	Cadmium chloride	20	2,130	-	5,407	-	McCarty et al. 1978

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Goldfish, *Carassius auratus*	S, M	Cadmium chloride	140	46,800	-	16,431	-	McCarty et al. 1978
Goldfish (8.8 g), *Carassius auratus*	F, M, T	Cadmium chloride	44.4	748	-	844.0	844.0	Phipps and Holcombe 1985
Common carp (yolk absorbed), *Cyprinus carpio*	R, U	Cadmium chloride	-	140	-	-	-	Ramesha et al. 1997
Common carp (fry), *Cyprinus carpio*	R, U	Cadmium chloride	-	2,840	-	-	-	Ramesha et al. 1997
Common carp (advanced fry), *Cyprinus carpio*	R, U	Cadmium chloride	-	2,910	-	-	-	Ramesha et al. 1997
Common carp (fingerling), *Cyprinus carpio*	R, U	Cadmium chloride	-	4,560	-	-	-	Ramesha et al. 1997
Common carp (fry), *Cyprinus carpio*	S, U	Cadmium nitrate	100	4,300	-	2,125	-	Suresh et al. 1993a
Common carp (fingerling), *Cyprinus carpio*	S, U	Cadmium nitrate	100	17,100	-	8,452	4,238	Suresh et al. 1993a
Red shiner (0.8 - 2.0g) *Notropis lutrensis*	S, M, T	Cadmium sulfate	85.5	6,620	-	3,837	3,837	Carrier and Beitinger 1988a
Fathead minnow, *Pimephales promelas*	S, U	Cadmium chloride	20	1,050[d]	-	2,665[d]	-	Pickering and Henderson 1966
Fathead minnow, *Pimephales promelas*	S, U	Cadmium chloride	20	630[d]	-	1,599[d]	-	Pickering and Henderson 1966
Fathead minnow, *Pimephales promelas*	S, U	Cadmium chloride	360	72,600[d]	-	9,758[d]	-	Pickering and Henderson 1966
Fathead minnow, *Pimephales promelas*	S, U	Cadmium chloride	360	73,500[d]	-	9,879[d]	-	Pickering and Henderson 1966
Fathead minnow, *Pimephales promelas*	F, M	Cadmium sulfate	201	11,200[d]	-	2,722[d]	-	Pickering and Gast 1972
Fathead minnow, *Pimephales promelas*	F, M	Cadmium sulfate	201	12,000[d]	-	2,917[d]	-	Pickering and Gast 1972

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Fathead minnow, *Pimephales promelas*	F, M	Cadmium sulfate	201	6,400[d]	4,600[d]	1,556[d]	-	Pickering and Gast 1972
Fathead minnow, *Pimephales promelas*	F, M	Cadmium sulfate	201	2,000[d]	1,400[d]	486.2[d]	-	Pickering and Gast 1972
Fathead minnow, *Pimephales promelas*	F, M	Cadmium sulfate	201	4,500[d]	2,800[d]	1,094[d]	-	Pickering and Gast 1972
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	40	21.5	-	<u>26.97</u>	-	Spehar 1982
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	48	11.7	-	<u>12.20</u>	-	Spehar 1982
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	39	19.3	-	<u>24.85</u>	-	Spehar 1982
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	45	42.4	-	<u>47.19</u>	-	Spehar 1982
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	47	54.2	-	<u>57.72</u>	-	Spehar 1982
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	44	29.0	-	<u>33.02</u>	-	Spehar 1982
Fathead minnow (adult), *Pimephales promelas*	S, M	Cadmium chloride	103	3,060[d]	-	1,468[d]	-	Birge et al. 1983
Fathead minnow (adult), *Pimephales promelas*	S, M	Cadmium chloride	103	2,900[d]	-	1,391[d]	-	Birge et al. 1983
Fathead minnow (adult), *Pimephales promelas*	S, M	Cadmium chloride	103	3,100[d]	-	1,487[d]	-	Birge et al. 1983
Fathead minnow (adult), *Pimephales promelas*	S, M	Cadmium chloride	262.5 (254-271)	7,160[d]	-	1,327[d]	-	Birge et al. 1983

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Fathead minnow, *Pimephales promelas*	S, M	Cadmium chloride	43.5 (39-48)	1,280[d]	-	1,475[d]	-	Spehar and Carlson 1984a,b
Fathead minnow (14-30 d), *Pimephales promelas*	S, U	Cadmium chloride	120	>150[h]	-	>61.60[h]	-	Hall et al. 1986
Fathead minnow (0.8 - 2.0 g) *Pimephales promelas*	S, M, T	Cadmium sulfate	85.5	3,580[d]	-	2,075[d]	-	Carrier and Beitinger 1988a
Fathead minnow (<24 hr), *Pimephales promelas*	S, U	Cadmium nitrate	60	210	-	<u>174.5</u>	-	Rifici et al. 1996
Fathead minnow (1-2 d), *Pimephales promelas*	S, U	Cadmium nitrate	60	180	-	<u>149.5</u>	-	Rifici et al. 1996
Fathead minnow (<24 hr), *Pimephales promelas*	S, M, T	Cadmium nitrate	290 (280-300)	73 (pH=6-6.5) 60 (pH=7-7.5) 65 (pH=8-8.8)	- - -	<u>12.22</u> <u>10.05</u> <u>10.88</u>	- - -	Schubauer-Berigan et al. 1993
Fathead minnow (juvenile), *Pimephales promelas*	S, M, T	Cadmium chloride	141	3,420[d]	2,590	1,192[d]	-	Sherman et al. 1987
Fathead minnow (juvenile), *Pimephales promelas*	S, M, T	Cadmium chloride	141	3,510[d]	2,430	1,223[d]	-	Sherman et al. 1987
Fathead minnow (0.6 g), *Pimephales promelas*	F, M, T	Cadmium chloride	44.4	1,500[d]	-	1,693[d]	-	Phipps and Holcombe 1985
Fathead minnow (30 d), *Pimephales promelas*	F, M, T	Cadmium nitrate	44	13.2	-	<u>15.03</u>	29.21	Spehar and Fiandt 1986
Colorado squawfish (larva), *Ptychocheilus lucius*	S, U	Cadmium chloride	199	78	-	<u>19.15</u>	-	Buhl 1997
Colorado squawfish (juvenile), *Ptychocheilus lucius*	S, U	Cadmium chloride	199	108	-	<u>26.52</u>	22.54	Buhl 1997

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Northern pike minnow (juvenile), *Ptychocheilus oregonensis*	F, M	Cadmium chloride	25 (20-30)	1,092	-	**2,209**	-	Andros and Garton 1980
Northern pike minnow (juvenile), *Ptychocheilus oregonensis*	F, M	Cadmium chloride	25 (20-30)	1,104	-	**2,234**	2,221	Andros and Garton 1980
Bonytail (larva), *Gila elegans*	S, U	Cadmium chloride	199	148	-	**36.34**	-	Buhl 1997
Bonytail (juvenile), *Gila elegans*	S, U	Cadmium chloride	199	168	-	**41.25**	38.72	Buhl 1997
White sucker, *Catostomus commersoni*	F, M	Cadmium chloride	18	1,110	-	**3,136**	3,136	Duncan and Klaverkamp 1983
Razorback sucker (larva), *Xyrauchen texanus*	S, U	Cadmium chloride	199	139	-	**34.13**	-	Buhl 1997
Razorback sucker (juvenile), *Xyrauchen texanus*	S, U	Cadmium chloride	199	160	-	**39.29**	36.62	Buhl 1997
Channel catfish (7.4 g), *Ictalurus punctatus*	F, M, T	Cadmium chloride	44.4	4,480	-	**5,055**	5,055	Phipps and Holcombe 1985
Flagfish, *Jordanella floridae*	F, M	Cadmium chloride	44	2,500	-	**2,847**	2,847	Spehar 1976a,b
Mosquitofish, *Gambusia affinis*	F, M	Cadmium chloride	11.1	900	-	**4,157**	-	Giesy et al. 1977
Mosquitofish, *Gambusia affinis*	F, M	Cadmium chloride	11.1	2,200	-	**10,161**	6,499	Giesy et al. 1977
Guppy, *Poecilia reticulata*	S, U	Cadmium chloride	20	1,270	-	**3,224**	-	Pickering and Henderson 1966
Guppy (3-4 wk), *Poecilia reticulata*	R, M, T	Cadmium chloride	105	3,800	-	**1,787**	-	Canton and Slooff 1982
Guppy (3-4 wk), *Poecilia reticulata*	R, M, T	Cadmium chloride	209.2	11,100	-	**2,591**	2,462	Canton and Slooff 1982

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Threespine stickleback, *Gasterosteus aculeatus*	S, U	Cadmium chloride	115	6,500	-	2,787	-	Pascoe and Cram 1977
Threespine stickleback, *Gasterosteus aculeatus*	R, M	Cadmium chloride	107 (103-111)	23,000	-	10,613	5,439	Pascoe and Mattey 1977
Striped bass (larva), *Morone saxatilis*	S, U	Cadmium chloride	34.5	1	-	1.458[e]	-	Hughes 1973
Striped bass (fingerling), *Morone saxatilis*	S, U	Cadmium chloride	34.5	2	-	2.917[e]	-	Hughes 1973
Striped bass (63 d), *Morone saxatilis*	S, U	Cadmium chloride	40	4	-	5.019	-	Palawski et al. 1985
Striped bass (63 d), *Morone saxatilis*	S, U	Cadmium chloride	285	10	-	1.704	2.925	Palawski et al. 1985
Green sunfish, *Lepomis cyanellus*	S, U	Cadmium chloride	20	2,840	-	7,208	-	Pickering and Henderson 1966
Green sunfish, *Lepomis cyanellus*	S, U	Cadmium chloride	360	66,000	-	8,871	-	Pickering and Henderson 1966
Green sunfish (juvenile), *Lepomis cyanellus*	S, M, T	Cadmium sulfate	85.5	11,520	-	6,677	-	Carrier and Beitinger 1988b
Green sunfish, *Lepomis cyanellus*	F, M	Cadmium chloride	335	20,500	-	2,965	2,965	Jude 1973
Bluegill, *Lepomis macrochirus*	S, U	Cadmium chloride	20	1,940	-	4,924	-	Pickering and Henderson 1966
Bluegill, *Lepomis macrochirus*	S, M, T	Cadmium chloride	18	2,300	-	6,498	-	Bishop and McIntosh 1981
Bluegill, *Lepomis macrochirus*	S, M, T	Cadmium chloride	18	2,300	-	6,498	-	Bishop and McIntosh 1981
Bluegill, *Lepomis macrochirus*	F, M	Cadmium chloride	207	21,100	-	4,978	-	Eaton 1980

Table 1a. Acute Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	LC50 or EC50 Adj. to TH=50 (Total µg/L)	Species Mean Acute Value at TH=50 (Total µg/L)[c]	Reference
				FRESHWATER SPECIES				
Bluegill (1.0 g), *Lepomis macrochirus*	F, M, T	Cadmium chloride	44.4	6,470	-	<u>7,300</u>	6,028	Phipps and Holcombe 1985
Tilapia *Oreochromis mossambica*	R, U	Cadmium chloride	28.4	6,000[d]	-	<u>10,663</u>	10,663	Gaikwad 1989
African clawed frog, *Xenopus laevis*	R, U	Cadmium chloride	116 (112-120)	3,597	-	<u>1,529</u>	1,529	Sunderman et al. 1991
Salamander (3 mo larva), *Ambystoma gracile*	F, M, T	Cadmium chloride	45	468.4	-	<u>521.4</u>	521.4	Nebeker et al. 1995

a S=static, R=renewal, F=flow-through, M=measured, U=unmeasured, T=total measured concentration, D=dissolved metal concentration measured.
b Results are expressed as cadmium, not as the chemical.
c Freshwater Species Mean Acute Values are calculated at a hardness of 50 mg/L using the pooled slope. SMAVs calculated using Lotus spreadsheet, values presented may be different than those calculated with a hand held calculator due to rounding.
<u>Note:</u> Each SMAV was calculated from the associated underlined number(s) in the preceding column.
d Not used in calculations because data are available for a more sensitive life stage.
e Not used in calculations (see text).
f Not used in calculations because data are available for a more sensitive test condition.
g Average of values calculated using log-probit and Spearman-Karber statistical methods.
h "Greater than" and "less than" values were not used in calculations.

Table 1b. Acute Toxicity of Cadmium to Saltwater Animals

Species	Method[a]	Chemical	Salinity (g/kg)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	Species Mean Acute Value (Total µg/L)	Reference
				SALTWATER SPECIES			
Polychaete worm (adult), *Neanthes arenaceodentata*	S, U	Cadmium chloride	-	12,000	-	-	Reish et al. 1976
Polychaete worm (juvenile), *Neanthes arenaceodentata*	S, U	Cadmium chloride	-	12,500	-	-	Reish et al. 1976
Polychaete worm, *Neanthes arenaceodentata*	S, U	Cadmium chloride	-	14,100	-	12,836	Reish and LeMay 1991
Polychaete worm, *Nereis grubei*	S, U	Cadmium chloride	-	4,700	-	4,700	Reish and LeMay 1991
Sand worm, *Nereis virens*	S, U	Cadmium chloride	-	11,000	-	-	Eisler 1971
Sand worm, *Nereis virens*	S, U	Cadmium chloride	-	9,300	-	10,114	Eisler and Hennekey 1977
Polychaete worm (adult), *Capitella capitata*	S, U	Cadmium chloride	-	7,500[c]	-	-	Reish et al. 1976
Polychaete worm, *Capitella capitata*	S, U	Cadmium chloride	-	2,800[c]	-	-	Reish and LeMay 1991
Polychaete worm (larva), *Capitella capitata*	S, U	Cadmium chloride	-	200	-	200	Reish et al. 1976
Polychaete worm, *Pectinaria californiensis*	S, U	Cadmium chloride	-	2,600	-	2,600	Reish and LeMay 1991
Oligochaete worm, *Limnodriloides verrucosus*	R, U	Cadmium sulfate	-	10,000	-	10,000	Chapman et al. 1982
Oligochaete worm, *Monopylephorus cuticulatus*	R, U	Cadmium sulfate	-	135,000	-	135,000	Chapman et al. 1982
Oligochaete worm, *Tubificoides gabriellae*	R, U	Cadmium sulfate	-	24,000	-	24,000	Chapman et al. 1982
Oyster drill, *Urosalpinx cinerea*	S, U	Cadmium chloride	-	6,600	-	6,600	Eisler 1971

Table 1b. Acute Toxicity of Cadmium to Saltwater Animals (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	Species Mean Acute Value (Total µg/L)[c]	Reference
				SALTWATER SPECIES			
Mud snail, *Nassarius obsoletus*	S, U	Cadmium chloride	-	10,500	-	-	Eisler 1971
Mud snail, *Nassarius obsoletus*	S, U	Cadmium chloride	-	35,000	-	19,170	Eisler and Hennekey 1977
Blue mussel, *Mytilus edulis*	S, U	Cadmium chloride	-	25,000[e]	-	-	Eisler 1971
Blue mussel, *Mytilus edulis*	S, M	Cadmium chloride	-	1,620[e]	-	-	Ahsanullah 1976
Blue mussel, *Mytilus edulis*	F, M	Cadmium chloride	-	3,600[e]	-	-	Ahsanullah 1976
Blue mussel, *Mytilus edulis*	F, M	Cadmium chloride	-	4,300[e]	-	-	Ahsanullah 1976
Blue mussel (embryo), *Mytilus edulis*	S, U	Cadmium chloride	-	1,200	-	-	Martin et al. 1981
Blue Mussel (juvenile), *Mytilus edulis*	R, U	Cadmium chloride	2.5	960	-	1,073	Nelson et al. 1988
Bay scallop (juvenile), *Argopecten irradians*	S, U	Cadmium chloride	-	1,480	-	1,480	Nelson et al. 1976
Pacific oyster (embryo), *Crassostrea gigas*	S, U	Cadmium chloride	-	611	-	-	Martin et al. 1981
Pacific oyster (larva), *Crassostrea gigas*	S, U	Cadmium chloride	-	85	-	227.9	Watling 1982
Eastern oyster (larva), *Crassostrea virginica*	S, U	Cadmium chloride	-	3,800	-	3,800	Calabrese et al. 1973
Soft-shell clam, *Mya arenaria*	S, U	Cadmium chloride	-	2,200	-	-	Eisler 1971
Soft-shell clam, *Mya arenaria*	S, U	Cadmium chloride	-	2,500	-	-	Eisler and Hennekey 1977
Soft-shell clam, *Mya arenaria*	S, U	Cadmium chloride	-	850	-	1,672	Eisler 1977
Squid (larva), *Loligo opalescens*	S, M, T	Cadmium chloride	30	>10,200	-	>10,200	Dinnel et al. 1989
Copepod, *Pseudodiaptomus coronatus*	S, U	Cadmium chloride	-	1,708	-	1,708	Gentile 1982

Table 1b. Acute Toxicity of Cadmium to Saltwater Animals (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	Species Mean Acute Value (Total µg/L)[c]	Reference
				SALTWATER SPECIES			
Copepod, *Eurytemora affinis*	S, U	Cadmium chloride	-	1,080[e]	-	-	Gentile 1982
Copepod (naupilus), *Eurytemora affinis*	S, U	Cadmium chloride	-	147.7	-	147.7	Sullivan et al. 1983
Copepod, *Acartia clausi*	S, U	Cadmium chloride	-	144	-	144	Gentile 1982
Copepod, *Acartia tonsa*	S, U	Cadmium chloride	-	90	-	-	Sosnowski and Gentile 1978
Copepod, *Acartia tonsa*	S, U	Cadmium chloride	-	122	-	-	Sosnowski and Gentile 1978
Copepod, *Acartia tonsa*	S, U	Cadmium chloride	-	220	-	-	Sosnowski and Gentile 1978
Copepod, *Acartia tonsa*	S, U	Cadmium chloride	-	337	-	-	Sosnowski and Gentile 1978
Copepod (adult), *Acartia tonsa*	S, U	Cadmium chloride	15	93 (18°C)	-	-	Toudal and Riisgard 1987
Copepod (adult), *Acartia tonsa*	S, U	Cadmium chloride	20	151 (13°C)	-	-	Toudal and Riisgard 1987
Copepod (adult), *Acartia tonsa*	S, U	Cadmium chloride	20	29 (21°C)	-	118.7	Toudal and Riisgard 1987
Copepod, *Amphiascus tenuiremis*	S, M, T	Cadmium nitrate	30.7	224	-	224	Green et al. 1993
Copepod, *Nitocra spinipes*	S, U	Cadmium chloride	-	1,800	-	-	Bengtsson 1978
Copepod, *Nitocra spinipes*	F, U	Cadmium chloride	3	430	-	-	Bengtsson and Bergstrom 1987
Copepod, *Nitocra spinipes*	F, U	Cadmium chloride	7	660	-	-	Bengtsson and Bergstrom 1987
Copepod, *Nitocra spinipes*	F, U	Cadmium chloride	15	780	-	794.5	Bengtsson and Bergstrom 1987

Table 1b. Acute Toxicity of Cadmium to Saltwater Animals (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	LC50 or EC50 (Total μg/L)[b]	LC50 or EC50 (Diss. μg/L)	Species Mean Acute Value (Total μg/L)[c]	Reference
				SALTWATER SPECIES			
Mysid (7 d), *Americamysis bahia*	S, M, T, D	Cadmium chloride	6	14.7	2.8	-	De Lisle and Roberts 1988
Mysid (7 d), *Americamysis bahia*	S, M, T, D	Cadmium chloride	14	38.0	3.6	-	De Lisle and Roberts 1988
Mysid (7 d), *Americamysis bahia*	S, M, T, D	Cadmium chloride	22	70.4	4.1	-	De Lisle and Roberts 1988
Mysid (7 d), *Americamysis bahia*	S, M, T, D	Cadmium chloride	30	77.3	2.9	-	De Lisle and Roberts 1988
Mysid (7 d), *Americamysis bahia*	S, M, T, D	Cadmium chloride	38	90.3	2.3	-	De Lisle and Roberts 1988
Mysid (<24 hr), *Americamysis bahia*	S, M, T	-	10	30.9 (20°C) <11.1 (30°C)	- -	- -	Voyer and Modica 1990
Mysid (<24 hr), *Americamysis bahia*	S, M, T	-	30	82.0 (20°C) 32.8 (25°C) <11.1 (30°C)	- - -	- - -	Voyer and Modica 1990
Mysid, *Americamysis bahia*	F, M	Cadmium chloride	10-17	<u>15.5</u>	-	-	Nimmo et al. 1977a
Mysid, *Americamysis bahia*	F, M	Cadmium chloride	30	<u>110</u>	-	41.29	Gentile et al. 1982; Lussier et al. 1985
Mysid, *Mysidopsis bigelowi*	F, M	Cadmium chloride	30	<u>110</u>	-	110	Gentile et al. 1982
Iosopd, *Jaeropsis* sp.	S, U	Cadmium chloride	35	<u>410.0</u>	-	410.0	Hong and Reish 1987
Isopod, *Limnoria tripunctata*	S, U	Cadmium chloride	35	<u>7,120</u>	-	7,120	Hong and Reish 1987
Amphipod (adult), *Ampelisca abdita*	F, M	Cadmium chloride	-	<u>2,900</u>	-	2,900	Scott et al. Manuscript
Amphipod (adult), *Marinogammarus obtusatus*	S, M	Cadmium chloride	-	13,000[c]	-	-	Wright and Frain 1981
Amphipod (young), *Marinogammarus obtusatus*	S, M	Cadmium chloride	-	<u>3,500</u>	-	3,500	Wright and Frain 1981

Table 1b. Acute Toxicity of Cadmium to Saltwater Animals (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	Species Mean Acute Value (Total µg/L)[c]	Reference
				SALTWATER SPECIES			
Amphipod, *Chelura terebrans*	S, U	Cadmium chloride	35	630	-	630	Hong and Reish 1987
Amphipod, *Corophium insidiosum*	S, U	Cadmium chloride	35	1,270	-	-	Hong and Reish 1987
Amphipod (8-12 mm), *Corophium insidiosum*	S, U	Cadmium chloride	-	680	-	929.3	Reish 1993
Amphipod (juvenile), *Diporeia* spp.	S, M, T	Cadmium chloride	20 (4°C)	49,400[d]	-	-	Gossiaux et al. 1992
			20 (10°C)	17,500[d]	-	-	
			20 (15°C)	6,700	-	6,700	
Amphipod, *Elasmopus bampo*	S, U	Cadmium chloride	35	570	-	-	Hong and Reish 1987
Amphipod (8-12 mm), *Elasmopus bampo*	S, U	Cadmium chloride	-	900	-	716.2	Reish 1993
Amphipod (3-5 mm), *Eohaustorius estuarius*	R, M, T	Cadmium chloride	30	41,900 (held 11 d before testing)	-	-	Meador 1993
				36,100 (held 17 d before testing)	-	-	
				14,500 (held 121 d before testing)	-	27,992	
Amphipod, *Grandidierella japonica*	S, U	Cadmium chloride	35	1,170	-	1,170	Hong and Reish 1987
Amphipod (500 µm), *Leptocheirus plumulosus*	S, U	Cadmium chloride	8	360	-	-	McGee et al. 1998
Amphipod (700 µm), *Leptocheirus plumulosus*	S, U	Cadmium chloride	8	650	-	-	McGee et al. 1998
Amphipod (1,000 µm), *Leptocheirus plumulosus*	S, U	Cadmium chloride	8	880	-	590.5	McGee et al. 1998
Pink shrimp (subadult), *Penaeus duorarum*	F, M	Cadmium chloride	-	3,500[e]	-	-	Nimmo et al. 1977b
Pink shrimp (2nd post larva), *Penaeus duorarum*	S, U	cadmium chloride	25	310.5	-	310.5	Cripe 1994

Table 1b. Acute Toxicity of Cadmium to Saltwater Animals (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	Species Mean Acute Value (Total µg/L)[c]	Reference
				SALTWATER SPECIES			
Grass shrimp (adult), *Palaemonetes pugio*	S, U	Cadmium chloride	20	1,830 (Big Sheepshead Creek)	-	-	Khan et al. 1988
Grass shrimp (adult), *Palaemonetes pugio*	S, U	Cadmium chloride	20	3,280 (Pine Creek)	-	-	Khan et al. 1988
Grass shrimp (juvenile). *Palaemonetes pugio*	S, M, T	Cadmium chloride	10	1,300	-	1,983	Burton and Fisher 1990
Grass shrimp, *Palaemonetes vulgaris*	S, U	Cadmium chloride	-	420	-	-	Eisler 1971
Grass shrimp, *Palaemonetes vulgaris*	F, M	Cadmium chloride	-	760	-	760	Nimmo et al. 1977b
Sand shrimp, *Crangon septemspinosa*	S, U	Cadmium chloride	-	320	-	320	Eisler 1971
American Lobster (larva), *Homarus americanus*	S, U	Cadmium chloride	-	78	-	78	Johnson and Gentile 1979
Hermit crab, *Pagurus longicarpus*	S, U	Cadmium chloride	-	320	-	-	Eisler 1971
Hermit crab, *Pagurus longicarpus*	S, U	Cadmium chloride	-	1,300	-	645.0	Eisler and Hennekey 1977
Rock crab (zoea), *Cancer irroratus*	F, M	Cadmium chloride	-	250	-	250	Johns and Miller 1982
Dungeness crab (zoea), *Cancer magister*	S, U	Cadmium chloride	-	247	-	-	Martin et al. 1981
Dungeness crab (zoea), *Cancer magister*	S, M, T	Cadmium chloride	30	200	-	222.3	Dinnel et al. 1989
Blue crab (juvenile), *Callinectes sapidus*	S, U	Cadmium chloride	35	11,600	-	-	Frank and Robertson 1979
Blue crab (juvenile), *Callinectes sapidus*	S, U	Cadmium chloride	15	4,700	-	-	Frank and Robertson 1979
Blue crab (juvenile), *Callinectes sapidus*	S, U	Cadmium chloride	1	320	-	2,594	Frank and Robertson 1979
Green crab, *Carcinus maenas*	S, U	Cadmium chloride	-	4,100	-	4,100	Eisler 1971
Fiddler crab, *Uca pugilator*	S, U	Cadmium chloride	20	46,600	-	-	O'Hara 1973a

Table 1b. Acute Toxicity of Cadmium to Saltwater Animals (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	Species Mean Acute Value (Total µg/L)[c]	Reference
				SALTWATER SPECIES			
Fiddler crab, *Uca pugilator*	S, U	Cadmium chloride	30	37,000	-	-	O'Hara 1973a
Fiddler crab, *Uca pugilator*	S, U	Cadmium chloride	10	32,300	-	-	O'Hara 1973a
Fiddler crab, *Uca pugilator*	S, U	Cadmium chloride	-	23,300	-	-	O'Hara 1973a
Fiddler crab, *Uca pugilator*	S, U	Cadmium chloride	-	10,400	-	-	O'Hara 1973a
Fiddler crab, *Uca pugilator*	S, U	Cadmium chloride	-	6,800	-	21,238	O'Hara 1973a
Starfish, *Asterias forbesi*	S, U	Cadmium chloride	-	820	-	-	Eisler 1971
Starfish, *Asterias forbesi*	S, U	Cadmium chloride	-	7,100	-	2,413	Eisler and Hennekey 1977
Green sea urchin (embryo), *Strongylocentrotus droebachiensis*	S, M, T	Cadmium chloride	30	1,800	-	1,800	Dinnel et al. 1989
Purple sea urchin (embryo), *Strongylocentrotus purpuratus*	S, M, T	Cadmium chloride	30	500	-	500	Dinnel et al. 1989
Sand dollar (embryo), *Dendraster excentricus*	S, M, T	Cadmium chloride	30	7,400	-	7,400	Dinnel et al. 1989
Coho salmon (smolt), *Oncorhynchus kisutch*	F, M, T	Cadmium chloride	28.3	1,500	-	1,500	Dinnel et al. 1989
Sheepshead minnow, *Cyprinodon variegatus*	S, U	Cadmium chloride	-	50,000	-	50,000	Eisler 1971
Mummichog (adult), *Fundulus heteroclitus*	S, U	Cadmium chloride	-	49,000	-	-	Eisler 1971
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	20	114,000	-	-	Voyer 1975
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	20	92,000	-	-	Voyer 1975
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	20	78,000	-	-	Voyer 1975
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	10	73,000	-	-	Voyer 1975

Table 1b. Acute Toxicity of Cadmium to Saltwater Animals (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	Species Mean Acute Value (Total µg/L)[c]	Reference
				SALTWATER SPECIES			
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	10	63,000	-	-	Voyer 1975
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	32	31,000	-	-	Voyer 1975
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	32	30,000	-	-	Voyer 1975
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	32	29,000	-	-	Voyer 1975
Mummichog (adult), *Fundulus heteroclitus*	S, U	Cadmium chloride	-	22,000	-	-	Eisler and Hennekey 1977
Mummichog (12-20 mm), *Fundulus heteroclitus*	F, M, T	Cadmium sulfate	14	**18,200**	-	18,200	Lin and Dunson 1993
Striped killifish (adult), *Fundulus majalis*	S, U	Cadmium chloride	-	**21,000**	-	21,000	Eisler 1971
Rivulus (30 d juvenile) *Rivulus marmoratus*	S, M, T	Cadmium chloride	10	18,800[e]	-	-	Park et al. 1994
Rivulus (120 d adult), *Rivulus marmoratus*	S, M, T	Cadmium chloride	10	32,200[e]	-	-	Park et al. 1994
Rivulus (11-18 mm), *Rivulus marmoratus*	F, M, T	Cadmium sulfate	14	23,700[e]	-	-	Lin and Dunson 1993
Rivulus (11-18 mm), *Rivulus marmoratus*	F, M, T	Cadmium sulfate	14	18,500[e]	-	-	Lin and Dunson 1993
Rivulus (7 d larva), *Rivulus marmoratus*	S, M, T	Cadmium chloride	10	**800**	-	800	Park et al. 1994
Atlantic silverside (adult), *Menidia menidia*	S, U	Cadmium chloride	-	2,032[e]	-	-	Cardin 1982
Atlantic silverside (juvenile), *Menidia menidia*	S, U	Cadmium chloride	-	28,532[e]	-	-	Cardin 1982
Atlantic silverside (juvenile), *Menidia menidia*	S, U	Cadmium chloride	-	13,652[e]	-	-	Cardin 1982
Atlantic silverside (larva), *Menidia menidia*	S, U	Cadmium chloride	-	**1,054**	-	-	Cardin 1982
Atlantic silverside (larva), *Menidia menidia*	S, U	Cadmium chloride	-	**577**	-	779.8	Cardin 1982

Table 1b. Acute Toxicity of Cadmium to Saltwater Animals (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	LC50 or EC50 (Total µg/L)[b]	LC50 or EC50 (Diss. µg/L)	Species Mean Acute Value (Total µg/L)[c]	Reference
				SALTWATER SPECIES			
Striped bass (63 d), *Morone saxatilis*	S, U	Cadmium chloride	1	75.0	-	75.0	Palawski et al. 1985
Cabezon (larva), *Scorpaenichthys marmoratus*	S, M, T	Cadmium chloride	27	>200	-	>200.0	Dinnel et al. 1989
Shiner perch (87 mm adult), *Cymatogaster aggregata*	F, M, T	Cadmium chloride	30.1	11,000	-	11,000	Dinnel et al. 1989
Striped mullet (50 mm juvenile), *Mugil cephalus*	S, U	Cadmium chloride	37.3	28,000[c]	-	-	Hilmy et al. 1985
Striped mullet (10 mm fry), *Mugil cephalus*	S, U	Cadmium chloride	37.3	7,079	-	7,079	Hilmy et al. 1985
Winter flounder (larva), *Pseudopleuronectes americanus*	S, U	Cadmium chloride	-	602[e]	-	-	Cardin 1982
Winter flounder (larva), *Pseudopleuronectes americanus*	S, U	Cadmium chloride	-	14,297	-	14,297	Cardin 1982

a S=static, R=renewal, F=flow-through, M=measured, U=unmeasured, T=total measured concentration, D=dissolved metal concentration measured.
b Results are expressed as cadmium, not as the chemical.
c Not used in calculations because data are available for a more sensitive life stage.
d Not used in calculations because data are available for a more sensitive test condition.
e Not used in calculations because this lower value was obtained in artificial sea water.

Table 1c. Results of Covariance Analysis of Freshwater Acute Toxicity Versus Hardness

Species	n	Slope	R^2 Value	95% Confidence Limits	Degrees of Freedom
Limnodrilus hoffmeisteri	2	0.7888	---	cannot calculate	0
Tubifex tubifex	3	0.6238	0.929	-1.5619, 2.8095	1
Vilosa vibex	2	0.9286	---	cannot calculate	0
Daphnia magna (all data)	28	0.1086	0.002	-0.7975, 1.0147	26
Daphnia magna (Chapman et al. Manuscript)	5	1.1824*	0.915	0.5195, 1.8454	3
Daphnia pulex	8	1.0633*	0.792	0.5191, 1.6074	6
Chinook salmon	6	1.2576*	0.947	0.8461, 1.6691	4
Goldfish	4	1.4608	0.570	-2.3973, 5.3190	2
Fathead minnow (all data)	28	2.0305*	0.450	1.1247, 2.9362	26
Fathead minnow (adults only)	18	1.2209*	0.699	0.7962, 1.6456	16
Guppy	3	0.8752	0.949	-1.6995, 3.4499	1
Striped bass	4	0.8089	0.722	-0.7182, 2.3359	2
Green sunfish	4	0.8986	0.880	-0.1127, 1.9098	2
Bluegill	5	0.9531*	0.974	0.6667, 1.2395	3
All of above using all data for *D. magna*	97	1.1741*@	0.778	0.8346, 1.5136	85
All of above except using only data from Chapman et al. (Manuscript) for *D. magna* and only adult fathead minnow data	64	1.0166*#	0.967	0.9745, 1.0588	52

* Slope is significantly different than 0 ($p<0.05$).
@ Individual slopes not significantly different ($p=0.27$).
\# Individual slopes not significantly different ($p=0.69$).

Table 1d. List of Studies Used to Estimate Acute Cadmium Hardness Slope

Species[a]	Method[b]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[c]	Reference
		FRESHWATER SPECIES			
Tubificid worm, *Limnodrilus hoffmeisteri*	S, M	Cadmium sulfate	5.3	170	Chapman et al. 1982a
Tubificid worm (30-40 mm), *Limnodrilus hoffmeisteri*	F, M, T	-	152	2,400	Williams et al. 1985
Tubificid worm, *Tubifex tubifex*	S, M, T	Cadmium chloride	128 (119-137)	3,200	Reynoldson et al. 1996
Tubificid worm, *Tubifex tubifex*	S, M, T	Cadmium chloride	128 (119-137)	1,700	Reynoldson et al. 1996
Tubificid worm, *Tubifex tubifex*	S, M	Cadmium sulfate	5.3	320	Chapman et al. 1982a
Mussel, *Vilosa vibex*	S, M, T	-	40	30	Keller Unpublished
Mussel, *Vilosa vibex*	S, M, T	-	186	125	Keller Unpublished
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	45	65	Biesinger and Christensen 1972
Cladoceran (<24 hr), *Daphnia magna*	R, M	Cadmium Chloride	105	30	Canton and Slooff 1982
Cladoceran (<24 hr), *Daphnia magna*	R, M	Cadmium Chloride	209.2	30	Canton and Slooff 1982
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	120	20	Hall et al. 1986
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	120	40	Hall et al. 1986

Table 1d. List of Studies Used to Estimate Acute Cadmium Hardness Slope (Continued)

Species[a]	Method[b]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[c]	Reference
		FRESHWATER SPECIES			
Cladoceran (<24 hr), *Daphnia magna*	S, U	Cadmium chloride	240	178	Elnabarawy et al. 1986
Cladoceran, *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	3.6 (genotype A)	Baird et al. 1991
Cladoceran, *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	9.0 (genotype A-1)	Baird et al. 1991
Cladoceran, *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	9.0 (genotype A-2)	Baird et al. 1991
Cladoceran, *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	4.5 (genotype B)	Baird et al. 1991
Cladoceran, *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	27.1 (genotype E)	Baird et al. 1991
Cladoceran, *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	115.9 (genotype S-1)	Baird et al. 1991
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	24.5 (Clone F)	Stuhlbacher et al. 1992
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium chloride	170 (160-180)	129.4 (Clone S-1)	Stuhlbacher et al. 1992
Cladoceran, *Daphnia magna*	S, U	Cadmium sulfate	250	280	Crisinel et al. 1994
Cladoceran (<24 hr), *Daphnia magna*	S, U	Cadmium chloride	170 (160-180)	9.5	Guilhermino et al. 1996
Cladoceran, *Daphnia magna*	S, M, T	Cadmium sulfate	46.1	112 (clone S-1)	Barata et al. 1998
Cladoceran, *Daphnia magna*	S, M, T	Cadmium sulfate	90.7	106 (clone S-1)	Barata et al. 1998

Table 1d. List of Studies Used to Estimate Acute Cadmium Hardness Slope (Continued)

Species[a]	Method[b]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[c]	Reference
		FRESHWATER SPECIES			
Cladoceran, *Daphnia magna*	S, M, T	Cadmium sulfate	179	233 (clone S-1)	Barata et al. 1998
Cladoceran, *Daphnia magna*	S, M, T	Cadmium sulfate	46.1	30.1 (clone A)	Barata et al. 1998
Cladoceran, *Daphnia magna*	S, M, T	Cadmium sulfate	90.7	23.4 (clone A)	Barata et al. 1998
Cladoceran, *Daphnia magna*	S, M, T	Cadmium sulfate	179	23.6 (clone A)	Barata et al. 1998
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium Chloride	51	9.9	Chapman et al. Manuscript
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium Chloride	104	33	Chapman et al. Manuscript
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium Chloride	105	34	Chapman et al. Manuscript
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium Chloride	197	63	Chapman et al. Manuscript
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium Chloride	209	49	Chapman et al. Manuscript
Cladoceran (<24 hr), *Daphnia magna*	F, M, T	Cadmium Chloride	130	58	Attar and Maly 1982
Cladoceran, *Daphnia pulex*	S, U	Cadmium chloride	57	47	Bertram and Hart 1979
Cladoceran (<24 hr), *Daphnia pulex*	S, U	Cadmium chloride	240	319	Elnabarawy et al. 1986
Cladoceran (<24 hr), *Daphnia pulex*	S, U	Cadmium chloride	120	80	Hall et al. 1986

Table 1d. List of Studies Used to Estimate Acute Cadmium Hardness Slope (Continued)

Species[a]	Method[b]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[c]	Reference
		FRESHWATER SPECIES			
Cladoceran (<24 hr), *Daphnia pulex*	S, U	Cadmium chloride	120	100	Hall et al. 1986
Cladoceran (<24 hr), *Daphnia pulex*	S, M, T	Cadmium chloride	53.5	70.1	Stackhouse and Benson 1988
Cladoceran, *Daphnia pulex*	S, U	Cadmium chloride	85 (80-90)	66	Roux et al. 1993
Cladoceran, *Daphnia pulex*	S, U	Cadmium chloride	(85) (80-90)	99	Roux et al. 1993
Cladoceran, *Daphnia pulex*	S, U	Cadmium chloride	85 (80-90)	70	Roux et al. 1993
Chinook salmon (9-13 wk), *Oncorhynchus tshawytscha*	S, U	Cadmium chloride	211	26	Hamilton and Buhl 1990
Chinook salmon (18-21 wk), *Oncorhynchus tshawytscha*	S, U	Cadmium chloride	343	57	Hamilton and Buhl 1990
Chinook salmon (swim-up), *Oncorhynchus tshawytscha*	F, M	Cadmium chloride	23	1.8	Chapman 1975, 1978
Chinook salmon (parr), *Oncorhynchus tshawytscha*	F, M	Cadmium chloride	23	3.5	Chapman 1975, 1978
Chinook salmon (juvenile), *Oncorhynchus tshawytscha*	F, M	Cadmium chloride	25	1.41	Chapman 1982
Chinook salmon (juvenile), *Oncorhynchus tshawytscha*	F, M	Cadmium sulfate	21 (20-22)	1.1	Finlayson and Verrue 1982
Goldfish, *Carassius auratus*	S, U	Cadmium chloride	20	2,340	Pickering and Henderson 1966
Goldfish, *Carassius auratus*	S, M	Cadmium	20	2,130	McCarty et al. 1978

Table 1d. List of Studies Used to Estimate Acute Cadmium Hardness Slope (Continued)

Species[a]	Method[b]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[c]	Reference
		FRESHWATER SPECIES			
Goldfish, *Carassius auratus*	S, M	Cadmium chloride	140	46,800	McCarty et al. 1978
Goldfish (8.8 g), *Carassius auratus*	F, M, T	Cadmium chloride	44.4	748	Phipps and Holcombe 1985
Fathead minnow, *Pimephales promelas*	S, U	Cadmium chloride	20	1,050[d]	Pickering and Henderson 1966
Fathead minnow, *Pimephales promelas*	S, U	Cadmium chloride	20	630[d]	Pickering and Henderson 1966
Fathead minnow, *Pimephales promelas*	S, U	Cadmium chloride	360	72,600[d]	Pickering and Henderson 1966
Fathead minnow, *Pimephales promelas*	S, U	Cadmium chloride	360	73,500[d]	Pickering and Henderson 1966
Fathead minnow, *Pimephales promelas*	F, M	Cadmium sulfate	201	11,200[d]	Pickering and Gast 1972
Fathead minnow, *Pimephales promelas*	F, M	Cadmium sulfate	201	12,000[d]	Pickering and Gast 1972
Fathead minnow, *Pimephales promelas*	F, M	Cadmium sulfate	201	6,400[d]	Pickering and Gast 1972
Fathead minnow, *Pimephales promelas*	F, M	Cadmium sulfate	201	2,000[d]	Pickering and Gast 1972
Fathead minnow, *Pimephales promelas*	F, M	Cadmium sulfate	201	4,500[d]	Pickering and Gast 1972
Fathead minnow (adult), *Pimephales promelas*	S, M	Cadmium chloride	103	3,060[d]	Birge et al. 1983
Fathead minnow (adult), *Pimephales promelas*	S, M	Cadmium chloride	103	2,900[d]	Birge et al. 1983

Table 1d. List of Studies Used to Estimate Acute Cadmium Hardness Slope (Continued)

Species[a]	Method[b]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[c]	Reference
			FRESHWATER SPECIES		
Fathead minnow (adult), *Pimephales promelas*	S, M	Cadmium chloride	103	3,100[d]	Birge et al. 1983
Fathead minnow (adult), *Pimephales promelas*	S, M	Cadmium chloride	262.5 254-271	7,160[d]	Birge et al. 1983
Fathead minnow, *Pimephales promelas*	S, M	Cadmium chloride	43.5 39-48	1,280[d]	Spehar and Carlson 1984a,b
Fathead minnow (0.8 - 2.0 g), *Pimephales promelas*	S, M, T	Cadmium sulfate	85.5	3,580[d]	Carrier and Beitinger 1988a
Fathead minnow (juvenile), *Pimephales promelas*	S, M, T	Cadmium chloride	141	3,420[d]	Sherman et al. 1987
Fathead minnow (juvenile), *Pimephales promelas*	S, M, T	Cadmium chloride	141	3,510[d]	Sherman et al. 1987
Fathead minnow (0.6 g), *Pimephales promelas*	F, M, T	Cadmium chloride	44.4	1,500[d]	Phipps and Holcombe 1985
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	40	21.5	Spehar 1982
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	48	11.7	Spehar 1982
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	39	19.3	Spehar 1982
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	45	42.4	Spehar 1982
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	47	54.2	Spehar 1982
Fathead minnow (fry), *Pimephales promelas*	S, M	Cadmium chloride	44	29.0	Spehar 1982

Table 1d. List of Studies Used to Estimate Acute Cadmium Hardness Slope (Continued)

Species[a]	Method[b]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[c]	Reference
			FRESHWATER SPECIES		
Fathead minnow (<24 hr), *Pimephales promelas*	S, U	Cadmium nitrate	60	210	Rifici et al. 1996
Fathead minnow (1-2 d), *Pimephales promelas*	S, U	Cadmium nitrate	60	180	Rifici et al. 1996
Fathead minnow (<24 hr), *Pimephales promelas*	S, M, T	Cadmium nitrate	290 280-300	60 (pH=7-7.5)	Schubauer-Berigan et al. 1993
Fathead minnow (30 d), *Pimephales promelas*	F, M, T	Cadmium nitrate	44	13.2	Spehar and Fiandt 1986
Guppy, *Poecilia reticulata*	S, U	Cadmium chloride	20	1,270	Pickering and Henderson 1966
Guppy (3-4 wk), *Poecilia reticulata*	R, M, T	Cadmium chloride	105	3,800	Canton and Slooff 1982
Guppy (3-4 wk), *Poecilia reticulata*	R, M, T	Cadmium chloride	209.2	11,100	Canton and Slooff 1982
Striped bass (larva), *Morone saxatilis*	S, U	Cadmium chloride	34.5	1	Hughes 1973
Striped bass (fingerling), *Morone saxatilis*	S, U	Cadmium chloride	34.5	2	Hughes 1973
Striped bass (63 d), *Morone saxatilis*	S, U	Cadmium chloride	40	4	Palawski et al. 1985
Striped bass (63 d), *Morone saxatilis*	S, U	Cadmium chloride	285	10	Palawski et al. 1985
Green sunfish, *Lepomis cyanellus*	S, U	Cadmium chloride	20	2,840	Pickering and Henderson 1966

Table 1d. List of Studies Used to Estimate Acute Cadmium Hardness Slope (Continued)

Species[a]	Method[b]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (Total µg/L)[c]	Reference
		FRESHWATER SPECIES			
Green sunfish, *Lepomis cyanellus*	S, U	Cadmium chloride	360	66,000	Pickering and Henderson 1966
Green sunfish (juvenile), *Lepomis cyanellus*	S, M, T	Cadmium sulfate	85.5	11,520	Carrier and Beitinger 1988b
Green sunfish, *Lepomis cyanellus*	F, M	Cadmium chloride	335	20,500	Jude 1973
Bluegill, *Lepomis macrochirus*	S, U	Cadmium chloride	20	1,940	Pickering and Henderson 1966
Bluegill, *Lepomis macrochirus*	S, M, T	Cadmium chloride	18	2,300	Bishop and McIntosh 1981
Bluegill, *Lepomis macrochirus*	S, M, T	Cadmium chloride	18	2,300	Bishop and McIntosh 1981
Bluegill, *Lepomis macrochirus*	F, M	Cadmium chloride	207	21,100	Eaton 1980
Bluegill (1.0 g), *Lepomis macrochirus*	F, M, T	Cadmium chloride	44.4	6,470	Phipps and Holcombe 1985

a Only those species listed in Table 1a that satisfied EPA Guideline requirements for inclusion were used to determine acute hardness slope. In addition, less than or greater than values were not used, nor were daphnid tests initiated with >24 hr old neonates.
b S=static, R=renewal, F=flow-through, M=measured, U=unmeasured, T=total measured concentration, D=dissolved metal concentration measured.
c Results are expressed as cadmium, not as the chemical.

Table 2a. Chronic Toxicity of Cadmium to Freshwater Animals

Species	Test[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Chronic Limits Total (µg/L)[b]	Chronic Limits Diss. (µg/L)[b]	Chronic Value Total (µg/L)[b]	Chronic Value Diss. (µg/L)[b]	Chronic Value Adj. to TH=50 (Total µg/L)	Species Mean Chronic Value at TH=50 (Total µg/L)[c]	Reference
FRESHWATER SPECIES										
Oligochaete, *Aeolosoma headleyi*	LC	-	65	-	-	25.19	-	20.74	20.74	Niederlehner 1984
Snail, *Aplexa hypnorum*	LC	Cadmium chloride	45.3	4.41-7.63	-	5.801	-	6.241	-	Holcombe et al. 1984
Snail, *Aplexa hypnorum*	LC	Cadmium chloride	45.3	2.50-4.79	-	3.460	-	3.723	4.820	Holcombe et al. 1984
Cladoceran, *Ceriodaphnia dubia*	LC	-	20	10-19	-	13.78	-	27.17	27.17	Jop et al. 1995
Cladoceran, *Daphnia magna*	LC	Cadmium chloride	53	0.08-0.29	-	0.1523	-	0.1459	-	Chapman et al. Manuscript
Cladoceran, *Daphnia magna*	LC	cadmium chloride	103	0.16-0.28	-	0.2117	-	0.1239	-	Chapman et al. Manuscript
Cladoceran, *Daphnia magna*	LC	Cadmium chloride	209	0.21-0.91	-	0.4371	-	0.1515	-	Chapman et al. Manuscript
Cladoceran, *Daphnia magna*	LC	Cadmium chloride	150	5.0-10.0	-	7.07	-	3.133	-	Bodar et al. 1988b
Cladoceran, *Daphnia magna*	LC	Cadmium chloride	130	<1.86-1.86	-	<1.86	-	<0.9163	<0.3794	Borgmann et al. 1989
Cladoceran, *Daphnia pulex*	LC	-	65	-	-	7.49	-	6.167	6.167	Niederlehner 1984
Amphipod, *Hyalella azteca*	LC	Cadmium chloride	280	0.51-1.9	-	0.9844	-	0.2747	0.2747	Ingersoll and Kemble Unpublished
Midge, *Chironomus tentans*	LC	Cadmium chloride	280	5.8-17.4	-	10.05	-	2.804	2.804	Ingersoll and Kemble Unpublished

Table 2a. Chronic Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Test[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Chronic Limits Total (µg/L)[b]	Chronic Limits Diss. (µg/L)[b]	Chronic Value Total (µg/L)[b]	Chronic Value Diss. (µg/L)[b]	Chronic Value Total at TH=50 (Total µg/L)	Species Mean Chronic Value at TH=50 (Total µg/L)[c]	Reference
					FRESHWATER SPECIES					
Coho salmon (Lake Supr.), *Oncorhynchus kisutch*	ELS	Cadmium chloride	44	1.3-3.4	-	2.102	-	**2.311**	-	Eaton et al. 1978
Coho salmon (West Coast), *Oncorhynchus kisutch*	ELS	Cadmium chloride	44	4.1-12.5	-	7.159	-	**7.870**	4.265	Eaton et al. 1978
Chinook salmon, *Oncorhynchus tshawytscha*	ELS	Cadmium chloride	25	1.3-1.88	-	1.563	-	**2.612**	2.612	Chapman 1975
Rainbow trout (270 d), *Oncorhynchus mykiss*	LC	Cadmium sulfate	250	3.39-5.48	-	4.310	-	**1.308**	1.308	Brown et al. 1994
Atlantic salmon, *Salmo salar*	ELS	Cadmium chloride	23.5 (19-28)	90-270 (5oC)	-	155.9[e]	-	272.8[d]	-	Rombough and Garside 1982
				2.5-8.2 (9.6oC)	-	4.528	-	**7.922**	7.922	
Brown trout, *Salmo trutta*	ELS	Cadmium chloride	44	3.8-11.7	-	6.668	-	7.330	-	Eaton et al. 1978
Brown trout, *Salmo trutta*	LC	Cadmium sulfate	250	9.34-29.1	-	16.49	-	**5.004**	5.004	Brown et al. 1994
Brook trout, *Salvelinus fontinalis*	ELS	Cadmium chloride	37	1-3	-	1.732	-	2.165	-	Sauter et al. 1976
Brook trout, *Salvelinus fontinalis*	ELS	Cadmium chloride	44	1.1-3.8	-	2.045	-	2.248	-	Eaton et al. 1978
Brook trout, *Salvelinus fontinalis*	LC	Cadmium chloride	44	1.7-3.4	-	2.404	-	**2.643**	2.643	Benoit et al. 1976
Lake trout, *Salvelinus namaycush*	ELS	Cadmium chloride	44	4.4-12.3	-	7.357	-	**8.088**	8.088	Eaton et al. 1978
Northern pike, *Esox lucius*	ELS	Cadmium chloride	44	4.2-12.9	-	7.361	-	**8.092**	8.092	Eaton et al. 1978

Table 2a. Chronic Toxicity of Cadmium to Freshwater Animals (Continued)

Species	Test[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Chronic Limits Total (μg/L)[b]	Chronic Limits Diss. (μg/L)[b]	Chronic Value Total (μg/L)[b]	Chronic Value Diss. (μg/L)[b]	Chronic Value Total at TH=50 (Total μg/L)	Species Mean Chronic Value at TH=50 (Total μg/L)[c]	Reference
					FRESHWATER SPECIES					
Fathead minnow, *Pimephales promelas*	ELS	Cadmium nitrate	44	-	-	10.0	-	10.99	-	Spehar and Fiandt 1986
Fathead minnow, *Pimephales promelas*	LC	Cadmium sulfate	201	37-57	-	45.92	-	16.38	16.38	Pickering and Gast 1972
White sucker, *Catostomus commersoni*	ELS	Cadmium chloride	44	4.2-12.0	-	7.099	-	7.804	7.804	Eaton et al. 1978
Flagfish, *Jordanella floridae*	LC	Cadmium chloride	44	4.1-8.1	-	5.763	-	6.336	-	Spehar 1976a
Flagfish, *Jordanella floridae*	LC	Cadmium chloride	47.5 (44-51)	3.0-6.5	-	4.416	-	4.587	-	Carlson et al. 1982
Flagfish, *Jordanella floridae*	LC	Cadmium chloride	47.5 (44-51)	3.4-7.3	-	4.982	-	5.175	5.318	Carlson et al. 1982
Bluegill, *Lepomis macrochirus*	LC	Cadmium sulfate	207	31-80	-	49.80	-	17.38	17.38	Eaton 1974
Smallmouth bass, *Micropterus dolomieui*	ELS	Cadmium chloride	44	4.3-12.7	-	7.390	-	8.124	8.124	Eaton et al. 1978
Blue tilapia, *Oreochromis aurea*	LC	Cadmium nitrate	145	>52	-	>52	-	>23.63	>23.63	Papoutsoglou and Abel 1988

a ELS = early life stage, LC = life cycle or partial life cycle.
b Results are expressed as cadmium, not as the chemical.
c Each SMCV was calculated from the associated underlined number(s) in the preceding column.
d Not used in calculations (see text).

Table 2b. Chronic Toxicity of Cadmium to Saltwater Animals

Species	Test[a]	Chemical	Salinity (g/kg)	Chronic Limits Total (μg/L)[b]	Chronic Limits Dissolved (μg/L)	Chronic Value Total (μg/L)	Chronic Value Dissolved (μg/L)	Species Mean Chronic Value (Total μg/L)[c]	Reference
SALTWATER SPECIES									
Mysid, *Americamysis bahia*	LC	Cadmium chloride	15-23	6.4-10.6	-	8.237	-	-	Nimmo et al. 1977a
Mysid, *Americamysis bahia*	LC	Cadmium chloride	30	5.1-10	-	7.141	-	-	Gentile et al. 1982; Lussier et al. 1985
Mysid, *Americamysis bahia*	LC	Cadmium chloride	30	<4-4	-	≤4	-	6.173	Carr et al. 1985
Mysid, *Mysidopsis bigelowi*	LC	Cadmium chloride	-	5.1-10	-	7.141	-	7.141	Gentile et al. 1982

a ELS = early life stage, LC = life cycle or partial life cycle.
b Results are expressed as cadmium, not as the chemical.
c Each SMCV was calculated from the associated underlined number(s) in the preceding column.

Table 2c. Results of Covariance Analysis of Freshwater Chronic Toxicity Versus Hardness

Species	n	Slope	R^2 Value	95% Confidence Limits	Degrees of Freedom
Daphnia magna - All	4	1.5792	0.284	-6.0524, 9.2108	2
Daphnia magna (only Chapman et al. Manuscript)	3	0.7712	0.962	-1.1663, 2.7087	1
Brown trout	2	0.5212	---	Cannot be calculated	0
Fathead minnow	2	1.0034	---	Cannot be calculated	0
All species	8	0.9685@	0.779	-0.9716, 2.9087	5
All species (Chapman only)	7	0.7409*#	0.994	0.3359, 1.1459	4

* Slope is significantly different from 0 ($p<0.05$).
@ Individual slopes not significant different ($p=0.90$).
# Individual slopes not significant different ($p=0.35$).

Table 2d. List of Studies Used to Estimate Chronic Cadmium Hardness Slope

Species[a]	Test[b]	Chemical	Hardness (mg/L as $CaCO_3$)	Chronic Limits Total (µg/L)[c]	Chronic Value Total (µg/L)[c]	Reference
Cladoceran, *Daphnia magna*	LC	Cadmium chloride	53	0.08-0.29	0.1523	Chapman et al. Manuscript
Cladoceran, *Daphnia magna*	LC	Cadmium chloride	103	0.16-0.28	0.2117	Chapman et al. Manuscript
Cladoceran, *Daphnia magna*	LC	Cadmium chloride	209	0.21-0.91	0.4371	Chapman et al. Manuscript
Cladoceran, *Daphnia magna*	LC	Cadmium chloride	150	5.0-10.0	7.07	Bodar et al. 1988b
Brown trout, *Salmo trutta*	ELS	Cadmium chloride	44	3.8-11.7	6.668	Eaton et al. 1978
Brown trout, *Salmo trutta*	LC	Cadmium sulfate	250	9.34-29.1	16.49	Brown et al. 1994
Fathead minnow, *Pimephales promelas*	LC	Cadmium sulfate	201	37-57	45.92	Pickering and Gast 1972
Fathead minnow, *Pimephales promelas*	ELS	Cadmium nitrate	44	-	10.0	Spehar and Fiandt 1986

a Only those species listed in Table 2a that satisfied EPA Guideline requirements for inclusion were used to determine chronic hardness slope. In addition, less than or greater than values were not used.
b ELS = early life stage, LC = life cycle or partial life cycle.
c Results are expressed as cadmium, not as the chemical.

Table 2e. Cadmium Acute-Chronic Ratios

Species	Reference	Hardness (mg/L as $CaCO_3$)	Acute Value (μg/L)	Chronic Value (μg/L)	Ratio	Species Mean Acute-Chronic Ratio
Freshwater Species						
Snail, *Aplexa hypnorum*	Holcombe et al. 1984	45.3	93	5.801	16.03	-
Snail, *Aplexa hypnorum*	Holcombe et al. 1984	45.3	93	3.460	26.88	20.76
Cladoceran, *Daphnia magna*	Chapman et al. Manuscript	51	9.9	0.1523	65.00	-
Cladoceran, *Daphnia magna*	Chapman et al. Manuscript	104	33	0.2117	155.9	-
Cladoceran, *Daphnia magna*	Chapman et al. Manuscript	209	49	0.4371	112.1	104.3
Chinook salmon, *Oncorhynchus tshawytscha*	Chapman 1975, 1982	25	1.41	1.563	0.9021	0.9021
Fathead minnow, *Pimephales promelas*	Pickering and Gast 1972	201	5,995[a]	45.92	130.6	-
Fathead minnow, *Pimephales promelas*	Spehar and Fiandt 1986	44	13.2	10.0	1.320	13.13
Flagfish, *Jordanella floridae*	Spehar 1976a	44	2,500	5.763	433.8	433.8
Bluegill, *Lepomis macrochirus*	Eaton 1974	207	21,100	49.80	423.7	423.7
Saltwater Species						
Mysid, *Americamysis bahia*	Nimmo et al. 1977a	-	15.5	8.237	1.882	-
Mysid, *Americamysis bahia*	Gentile et al. 1982	-	110	7.141	15.40	5.384
Mysid, *Mysidopsis bigelowi*	Gentile et al. 1982	-	110	7.141	15.40	15.40

[a] Geometric mean of five values in Table 1 from Pickering and Gast (1972).

Table 3a. Ranked Freshwater Genus Mean Acute Values with Species Mean Acute-Chronic Ratios

Rank[a]	Genus Mean Acute Value (Total µg/L)[b]	Species	Species Mean Acute Value (Total µg/L)[b]	Species Mean Acute-Chronic Ratio
		FRESHWATER SPECIES		
55	96,880	Midge, *Chironomus riparius*	96,880	-
54	14,067	Planarian, *Dendrocoelum lacteum*	14,067	-
53	>11,683	Crayfish, *Orconectes virilis*	11,859	-
		Crayfish, *Orconectes immunis*	>11,509	-
52	10,663	Tilapia, *Oreochromis mossambica*	10,663	-
51	6,499	Mosquitofish, *Gambusia affinis*	6,499	-
50	6,169	Tubificid worm, *Rhyacodrilus montana*	6,169	-
49	5,439	Threespine stickleback, *Gasterosteus aculeatus*	5,439	-
48	5,386	Tubificid worm, *Stylodrilus heringianus*	5,386	-
47	5,055	Channel catfish, *Ictalurus punctatus*	5,055	-
46	4,238	Common carp, *Cyprinus carpio*	4,238	-

Table 3a. Ranked Freshwater Genus Mean Acute Values with Species Mean Acute-Chronic Ratios (Continued)

Rank[a]	Genus Mean Acute Value (Total μg/L)[b]	Species	Species Mean Acute Value (Total μg/L)[b]	Species Mean Acute-Chronic Ratio
		FRESHWATER SPECIES		
45	4,228	Green sunfish, *Lepomis cyanellus*	2,965	-
		Bluegill, *Lepomis macrochirus*	6,028	423.7
44	3,886	Tubificid worm, *Spirosperma ferox*	3,427	-
		Tubificid worm, *Spirosperma nikolskyi*	4,406	-
43	3,837	Red shiner, *Notropis lutrenis*	3,837	-
42	3,721	Tubificid worm, *Varichaeta pacifica*	3,721	-
41	3,136	White sucker, *Catostomus commersoni*	3,136	-
40	3,133	Tubificid worm, *Quistradilus multisetosus*	3,133	-
39	2,847	Flagfish, *Jordanella floridae*	2,847	433.8
38	2,462	Guppy, *Poecilia reticulata*	2,462	-
37	2,350	Tubificid worm, *Branchiura sowerbyi*	2,350	-
36	2,278	Mayfly, *Ephemerella grandis*	2,278	-

Table 3a. Ranked Freshwater Genus Mean Acute Values with Species Mean Acute-Chronic Ratios (Continued)

Rank[a]	Genus Mean Acute Value (Total µg/L)[b]	Species	Species Mean Acute Value (Total µg/L)[b]	Species Mean Acute-Chronic Ratio
		FRESHWATER SPECIES		
35	1,748	Crayfish, *Procambarus clarkii*	1,748	-
34	1,700	Amphipod, *Crangonyx pseudogracilis*	1,700	-
33	1,529	African clawed frog, *Xenopus laevis*	1,529	-
32	1,361	Tubificid worm, *Tubifex tubifex*	1,361	-
31	844.0	Goldfish, *Carassius auratus*	844.0	-
30	775.0	Tubificid worm, *Limnodrilus hoffmeisteri*	775.0	-
29	521.4	Salamander, *Ambystoma gracile*	521.4	-
28	472.1	Isopod, *Asellus bicrenata*	472.1	-
27	259.7	Bryozoan, *Plumatella emarginata*	259.7	-
26	247.2	Cladoceran, *Alona affinis*	247.2	-
25	223.2	Copepod, *Cyclops varicans*	223.2	-
24	192.5	Leech, *Glossiponia complanta*	192.5	-

Table 3a. Ranked Freshwater Genus Mean Acute Values with Species Mean Acute-Chronic Ratios (Continued)

Rank[a]	Genus Mean Acute Value (Total μg/L)[b]	Species	Species Mean Acute Value (Total μg/L)[b]	Species Mean Acute-Chronic Ratio
		FRESHWATER SPECIES		
23	166.8	Bryozoan, *Pectinatella magnifica*	166.8	-
22	130.6	Worm, *Lumbriculus variegatus*	130.6	-
21	103.9	Snail, *Aplexa hypnorum*	103.9	20.76[c]
20	100.2	Snail, *Physa gyrina*	100.2	-
19	78.69	Amphipod, *Gammarus pseudolimnaeus*	78.69	-
18	48.44	Isopod, *Lirceus alabamae*	48.44	-
17	43.09	Cladoceran, *Moina macrocopa*	43.09	-
16	42.92	Mussel, *Utterbackia imbecilis*	42.92	-
15	38.72	Bonytail, *Gila elegans*	38.72	-
14	36.62	Razorback sucker, *Xyrauchen texanus*	36.62	-
13	35.90	Cladoceran, *Ceriodaphnia dubia*	31.37	-
		Cladoceran, *Ceriodaphnia reticulata*	41.07	-

Table 3a. Ranked Freshwater Genus Mean Acute Values with Species Mean Acute-Chronic Ratios (Continued)

Rank[a]	Genus Mean Acute Value (Total $\mu g/L$)[b]	Species	Species Mean Acute Value (Total $\mu g/L$)[b]	Species Mean Acute-Chronic Ratio
		FRESHWATER SPECIES		
12	35.74	Bryozoan, *Lophopodella carteri*	35.74	-
11	35.18	Mussel, *Vilosa vibex*	35.18	-
10	33.80	Mussel, *Actinonaia pectorosa*	33.80	-
9	33.76	Mussel, *Lampsilis straminea claibornensis*	47.68	-
		Mussel, *Lampsilis teres*	23.90	-
8	30.21	Cladoceran, *Simocephalus serrulatus*	30.21	-
7	29.21	Fathead minnow, *Pimephales promelas*	29.21	13.13[c]
6	24.93	Cladoceran, *Daphnia magna*	13.41	104.3[d]
		Cladoceran, *Daphnia pulex*	46.36	-
5	22.54	Colorado squawfish, *Ptychocheilus lucius*	22.54	-
		Northern pike minnow *Ptychocheilus oregonensis*	2,221[e]	-

Table 3a. Ranked Freshwater Genus Mean Acute Values with Species Mean Acute-Chronic Ratios (Continued)

Rank[a]	Genus Mean Acute Value (Total μg/L)[b]	Species	Species Mean Acute Value (Total μg/L)[b]	Species Mean Acute-Chronic Ratio
		FRESHWATER SPECIES		
4	3.836	Coho salmon, *Oncorhynchus kisutch*	6.221	-
		Chinook salmon, *Oncorhynchus tshawytscha*	4.305	0.9021
		Rainbow trout, *Oncorhynchus mykiss*	2.108	-
3	2.925	Striped bass, *Morone saxatilis*	2.925	-
2	<1.963	Brook trout, *Salvelinus fontinalis*	<1.791	-
		Bull trout, *Salvelinus confluentus*	2.152	-
1	1.613	Brown trout, *Salmo trutta*	1.613	-

a Ranked from most resistant to most sensitive based on Genus Mean Acute Value.
b Freshwater Genus Mean Acute Values and Freshwater Species Mean Acute Values are at a hardness of 50 mg/L.
c Geometric mean of two values in Table 2e.
d Geometric mean of three values in Table 2e.
e Species values are too divergent to use the geometric mean for the genus value, therefore, the most sensitive value used.

Table 3b. Ranked Saltwater Genus Mean Acute Values with Species Mean Acute-Chronic Ratios

Rank[a]	Genus Mean Acute Value (Total μg/L)[b]	Species	Species Mean Acute Value (Total μg/L)[b]	Species Mean Acute-Chronic Ratio
		SALTWATER SPECIES		
54	135,000	Oligochaete worm, *Monopylephorus cuticulatus*	135,000	-
53	50,000	Sheepshead minnow, *Cyprinodon variegatus*	50,000	-
52	27,992	Amphipod, *Eohaustoris estuarius*	27,992	-
51	24,000	Oligochaete worm, *Tubificoides gabriellae*	24,000	-
50	21,238	Fiddler crab, *Uca pugilator*	21,238	-
49	19,550	Mummichog, *Fundulus heteroclitus*	18,200	-
		Striped killifish, *Fundulus majalis*	21,000	-
48	19,170	Mud snail, *Nassarius obsoletus*	19,170	-
47	14,297	Winter flounder, *Pseudopleuronectes americanus*	14,297	-
46	12,836	Polychaete worm, *Neanthes arenaceodentata*	12,836	-
45	11,000	Shiner perch, *Cymatogaster aggregata*	11,000	-

Table 3b. Ranked Saltwater Genus Mean Acute Values with Species Mean Acute-Chronic Ratios (Continued)

Rank[a]	Genus Mean Acute Value (Total µg/L)[b]	Species	Species Mean Acute Value (Total µg/L)[b]	Species Mean Acute-Chronic Ratio
		SALTWATER SPECIES		
44	>10,200	Squid, *Loligo opalescens*	>10,200	-
43	10,000	Oligochaete worm, *Limnodriloides verrucosus*	10,000	-
42	7,400	Sand dollar, *Dendraster excentricus*	7,400	-
41	7,120	Isopod, *Limnoria tripunctata*	7,120	-
40	7,079	Striped mullet, *Mugil cephalus*	7,079	-
39	6,895	Polychaete worm, *Nereis grubei*	4,700	-
		Sand worm, *Nereis virens*	10,114	-
38	6,700	Amphipod, *Diporeia spp.*	6,700	-
37	6,600	Oyster drill, *Urosalpinx cinerea*	6,600	-
36	4,100	Green crab, *Carcinus maenas*	4,100	-
35	3,500	Amphipod, *Marinogammarus obtusatus*	3,500	-
34	2,900	Amphipod, *Ampelisca abdita*	2,900	-

Table 3b. Ranked Saltwater Genus Mean Acute Values with Species Mean Acute-Chronic Ratios (Continued)

Rank[a]	Genus Mean Acute Value (Total μg/L)[b]	Species	Species Mean Acute Value (Total μg/L)[b]	Species Mean Acute-Chronic Ratio
		SALTWATER SPECIES		
33	2,600	Polychaete worm, *Pectinaria californiensis*	2,600	-
32	2,594	Blue crab, *Callinectes sapidus*	2,594	-
31	2,413	Starfish, *Asterias forbesi*	2,413	-
30	1,708	Copepod, *Pseudodiaptomus coronatus*	1,708	-
29	1,672	Soft-shell clam, *Mya arenaria*	1,672	-
28	1,500	Coho salmon, *Oncorhynchus kisutch*	1,500	-
27	1,480	Bay scallop, *Argopecten irradians*	1,480	-
26	1,228	Grass shrimp, *Palaemonetes pugio*	1,983	-
		Grass shrimp, *Palaemonetes vulgaris*	760	-
25	1,170	Amphipod, *Grandidierella japonica*	1,170	-
24	1,073	Blue mussel, *Mytilus edulis*	1,073	-

Table 3b. Ranked Saltwater Genus Mean Acute Values with Species Mean Acute-Chronic Ratios (Continued)

Rank[a]	Genus Mean Acute Value (Total μg/L)[b]	Species	Species Mean Acute Value (Total μg/L)[b]	Species Mean Acute-Chronic Ratio
		SALTWATER SPECIES		
23	948.7	Green sea urchin, *Strongylocentrotus droebachiensis*	1,800	-
		Purple sea urchin, *Strongylocentrotus purpuratus*	500	-
22	930.6	Pacific oyster, *Crassostrea gigas*	227.9	-
		Eastern oyster, *Crassostrea virginica*	3,800	-
21	929.3	Amphipod, *Corophium insidiosum*	929.3	-
20	800	Rivulus, *Rivulus marmoratus*	800	-
19	794.5	Copepod, *Nitocra spinipes*	794.5	-
18	779.8	Atlantic silverside, *Menidia menidia*	779.8	-
17	716.2	Amphipod, *Elasmopus bampo*	716.2	-
16	645.0	Hermit crab, *Pagurus longicarpus*	645.0	-
15	630.0	Amphipod, *Chelura terebrans*	630.0	-
14	590.5	Amphipod, *Leptocheirus plumulosus*	590.5	-

Table 3b. Ranked Saltwater Genus Mean Acute Values with Species Mean Acute-Chronic Ratios (Continued)

Rank[a]	Genus Mean Acute Value (Total µg/L)[b]	Species	Species Mean Acute Value (Total µg/L)[b]	Species Mean Acute-Chronic Ratio
		SALTWATER SPECIES		
13	410.0	Isopod, *Jaeropsis sp.*	410.0	-
12	320.0	Sand shrimp, *Crangon septemspinosa*	320.0	-
11	310.5	Pink shrimp, *Penaeus duorarum*	310.5	-
10	235.7	Rock crab, *Cancer irroratus*	250.0	-
		Dungeness crab, *Cancer magister*	222.3	-
9	224	Copepod, *Amphiascus tenuiremis*	224	-
8	>200	Cabezon, *Scorpaenichthys marmoratus*	>200	-
7	200	Polychaete worm, *Capitella capitata*	200	-
6	147.7	Copepod, *Eurytemora affinis*	147.7	-
5	130.7	Copepod, *Acartia clausi*	144	-
		Copepod, *Acartia tonsa*	118.7	-
4	110	Mysid, *Mysidopsis bigelowi*	110	15.40

Table 3b. Ranked Saltwater Genus Mean Acute Values with Species Mean Acute-Chronic Ratios (Continued)

Rank[a]	Genus Mean Acute Value (Total µg/L)[b]	Species	Species Mean Acute Value (Total µg/L)[b]	Species Mean Acute-Chronic Ratio
		SALTWATER SPECIES		
3	78	American lobster, *Homarus americanus*	78	-
2	75.0	Striped bass, *Morone saxatilis*	75.0	-
1	41.29	Mysid, *Americamysis bahia*	41.29	5.384[c]

a Ranked from most resistant to most sensitive based on Genus Mean Acute Value.
b Freshwater Genus Mean Acute Values and Freshwater Species Mean Acute Values are at a hardness of 50 mg/L.
c Geometric mean of two values in Table 2e.
d Geometric mean of three values in Table 2e.
e Species values are too divergent to use the geometric mean for the genus value, therefore, the most sensitive value used.

Table 3c. Ranked Freshwater Genus Mean Chronic Values

Rank[a]	Genus Mean Chronic Value (μg/L)	Species	Species Mean Chronic Value (μg/L)[b]	Species Mean Acute-Chronic Ratio
16	27.17	Cladoceran, *Ceriodaphnia dubia*	27.17	-
15	>23.63	Blue Tilapia, *Oreochromis aurea*	>23.63	-
14	20.74	Oligochaete, *Aeolosoma headleyi*	20.74	-
13	17.38	Bluegill, *Lepomis macrochirus*	17.38[c]	423.7
12	16.38	Fathead minnow, *Pimephales promelas*	16.38[c]	13.13[c]
11	8.124	Smallmouth bass, *Micropterus dolomieui*	8.124	-
10	8.092	Northern pike, *Esox lucius*	8.092	-
9	7.804	White sucker, *Catostomus commersoni*	7.804	-
8	6.296	Atlantic salmon, *Salmo salar*	7.922	-
		Brown trout, *Salmo trutta*	5.004[c]	-
7	5.318	Flagfish, *Jordanella floridae*	5.318[d]	433.8
6	4.820	Snail, *Aplexa hypnorum*	4.820[c]	20.76[c]
5	4.624	Brook trout, *Salvelinus fontinalis*	2.643[d]	-
		Lake trout, *Salvelinus namaycush*	8.088	-
4	2.804	Midge, *Chironomus tentans*	2.804	-
3	2.443	Coho salmon, *Oncorhynchus kisutch*	4.265[c]	-
		Rainbow trout, *Oncorhynchus mykiss*	1.308	-
		Chinook salmon, *Oncorhynchus tshawytscha*	2.612	0.9021

Table 3c. Ranked Freshwater Genus Mean Chronic Values (Continued)

Rank[a]	Genus Mean Chronic Value (μg/L)	Species	Species Mean Chronic Value (μg/L)[b]	Species Mean Acute-Chronic Ratio
2	<0.3794[f]	Cladoceran, *Daphnia magna*	<0.3794[e]	104.3[d]
		Cladoceran, *Daphnia pulex*	6.167[f]	-
1	0.2747	Amphipod, *Hyalella azteca*	0.2747	-

a Ranked from most resistant to most sensitive based on Genus Mean Chronic Value.
b Genus Mean Chronic Values and Species Mean Chronic Values are at a hardness of 50 mg/L.
c Geometric mean of two values.
d Geometric mean of three values.
e Geometric mean of five values.
f Species values are too divergent to use the geometric mean for the genus value, therefore, the most sensitive value used.

Table 3d. Freshwater and Saltwater Cadmium Criteria Values

Fresh water

CMC:

Final Acute Value = 2.763 μg/L (calculated at a hardness of 50 mg/L from Genus Mean Acute Values)

Final Acute Value = 2.108 μg/L (lowered to protect rainbow trout at a hardness of 50 mg/L; see text)

Criterion Maximum Concentration = (2.108 μg/L) /2 = 1.054 μg/L Total Cadmium (at a hardness of 50 mg/L)

Pooled Slope = 1.0166 (see Table 1)

ln (Criterion Maximum Intercept) = ln(1.054) - [slope x ln(50)]

= 0.0526 - (1.0166 x 3.912) = -3.924

Criterion Maximum Concentration for Total Cadmium (at a hardness of 50 mg/L) = $e^{(1.0166[\ln(\text{hardness})]-3.924)}$

Criterion Maximum Concentration for Dissolved Cadmium (at 50 mg/L hardness) = 0.973 $[e^{(1.0166[\ln(\text{hardness})]-3.924)}]$

CCC:

Total Cadmium Freshwater Final Chronic Value = 0.1618 μg/L (see text)

Slope = 0.7409 (see text)

ln (Final Chronic intercept) = ln (0.1618) - [slope x ln(50)]

= -1.821 - (0.7409 x 3.912) = -4.719

Total Cadmium Freshwater Final Chronic Value (at a hardness of 50 mg/L) = $e^{(0.7409\,[\ln(\text{hardness})]-4.719)}$

Dissolved Cadmium Freshwater Final Chronic Value (at 50 mg/L hardness) = 0.938 $[e^{(0.7409\,[\ln(\text{hardness})]-4.719)}]$

Salt water

CMC:

Total Cadmium Final Acute Value = 80.55 μg/L

Total Cadmium Criterion Maximum Concentration = (80.55 μg/L)/2 = 40.28 μg/L

Dissolved Cadmium Criterion Maximum Concentration = 0.994 (40.28 μg/L) = 40 μg/L

Final Acute-Chronic Ratio = 9.106 (see text)

CCC:

Total Cadmium Final Chronic Value = (80.55 μg/L)/9.106 = 8.846 μg/L

Dissolved Cadmium Final Chronic Value = 0.994 (8.846 μg/L) = 8.8 μg/L

Table 3d. Freshwater and Saltwater Cadmium Criteria Values (Continued)

Calculated Freshwater FAV based on 4 lowest values: Total Number of GMAVs in Data Set = 55

Rank	GMAV	lnGMAV	$(lnGMAV)^2$	P=R/(n+1)	SQRT(P)
4	3.836	1.345	1.808	0.0714	0.2673
3	2.925	1.073	1.152	0.0536	0.2315
2	1.963	0.6745	0.4549	0.0357	0.1890
1	1.613	0.4781	0.2286	0.0179	0.1336
Sum:		**3.571**	**3.644**	**0.1786**	**0.8213**

S =	6.781
L =	-0.4997
A =	1.017
Calculated FAV =	**2.764**

Calculated Saltwater FAV based on 4 lowest values: Total Number of GMAVs in Data Set = 54

Rank	GMAV	lnGMAV	$(lnGMAV)^2$	P=R/(n+1)	SQRT(P)
4	110	4.700	22.095	0.0727	0.2697
3	78	4.357	18.981	0.0545	0.2335
2	75.0	4.317	18.641	0.0364	0.1907
1	41.29	3.721	13.843	0.0182	0.1348
Sum:		**17.095**	**73.559**	**0.1818**	**0.8288**

S =	7.012
L =	2.821
A =	4.389
Calculated FAV =	**80.55**

Table 3d. Freshwater and Saltwater Cadmium Criteria Values (Continued)

Calculated Freshwater FCV based on 4 lowest values: Total Number of GMAVs in Data Set = 16

Rank	GMAV	lnGMAV	$(\ln GMAV)^2$	P=R/(n+1)	SQRT(P)
4	2.804	1.031	1.063	0.2353	0.4851
3	2.443	0.8932	0.7979	0.1765	0.4201
2	0.3794	-0.9692	0.9393	0.1176	0.3430
1	0.2747	-1.292	1.669	0.0588	0.2425
Sum:		**-0.3370**	**4.470**	**0.5882**	**1.491**

S =	11.65
L =	-4.428
A =	-1.822
Calculated FCV =	**0.1618**

Table 4a. Toxicity of Cadmium to Freshwater Plants

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result[b] (Total $\mu g/L$)	Reference
				FRESHWATER SPECIES			
Diatom, *Asterionella formosa*	-	-	-	-	Factor of 10 growth rate decrease	2	Conway 1978
Diatom, *Scenedesmus quadracauda*	-	Cadmium chloride	-	-	Reduction in cell count	6.1	Klass et al. 1974
Diatom, *Nitzschia costerium*	-	Cadmium chloride	-	-	96-hr EC50	480	Rachlin et al. 1982
Diatom, *Navicula incerta*	-	Cadmium chloride	-	-	96-hr EC50	310	Rachlin et al. 1982
Green alga, *Scenedesmus obliquus*	-	Cadmium chloride	-	-	39% reduction in growth	2,500	Devi Prasad and Devi Prasad 1982
Alga, *Euglena gracilis*	-	Cadmium chloride	-	-	Morphological abnormalities	5,000	Nakano et al. 1980
Alga, *Euglena gracilis anabaena*	-	Cadmium nitrate	-	-	Cell division inhibition	20,000	Nakano et al. 1980
Green alga, *Ankistrodesmus falcatus*	-	Cadmium chloride	-	-	58% reduction in growth	2,500	Devi Prasad and Devi Prasad 1982
Blue alga, *Microcystis aeruginosa*	-	Cadmium nitrate	-	-	incipient inhibition	70	Bringmann 1975; Bringmann and Kuhn 1976, 1978a,b
Green alga. *Scenedesmus quadricauda*	-	Cadmium nitrate	-	-	incipient inhibition	310	Bringmann and Kuhn 1977a, 1978a,b, 1979, 1980b
Green alga, *Chlorella saccharophila*	-	Cadmium chloride	-	-	96-hr EC50	105	Rachlin et al. 1984
Alga, *Chlorococcum* sp.	-	Cadmium chloride	-	-	42% reduction in growth	2,500	Devi Prasad and Devi Prasad 1982

Table 4a. Toxicity of Cadmium to Freshwater Plants (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result[b] (Total µg/L)	Reference
				FRESHWATER SPECIES			
Green alga, *Chlorella pyrenoidosa*	-	-	-	-	Reduction in growth	250	Hart and Scaife 1977
Green alga, *Chlorella vulgaris*	-	-	-	-	Reduction in growth	50	Hutchinson and Stokes 1975
Alga, *Chara vulgaris*	S, M, T	Cadmium sulfate	-	7 days	Lethal dose	56.2	Heumann 1987
Alga, *Chara vulgaris*	S, M, T	Cadmium sulfate	-	14 days	EC50 growth	9.5	Heumann 1987
Green alga, *Chlamydomonas reinhardi*	F, M, T	Cadmium chloride	24	4 days 7 days 10 days	EC50 (cell density) EC50 (cell density) EC50 (cell density)	203 130 99	Schafer et al. 1993
Green alga, *Clorella vulgaris*	-	Cadmium chloride	-	-	50% reduction in growth	60	Rosko and Rachlin 1977
Green alga, *Clorella vulgaris*	-	Cadmium chloride	50	-	96-hr EC50 (growth inhibition)	3,700	Canton and Slooff 1982
Green alga, *Selenastrum capricornutum*	-	Cadmium chloride	-	-	Reduction in growth	50	Bartlett et al. 1974
Green alga, *Selenastrum capricornutum*	-	Cadmium nitrate	-	-	Reduction in growth	255	Slooff et al. 1983
Green alga, *Selenastrum capricornutum*	S, U	Cadmium chloride	-	4 days	IC 50 growth	10,500	Bozeman et al. 1989
Green alga, *Selenastrum capricornutum*	S, U	Cadmium chloride	-	4 days	EC50 growth	23.2	Thellen et al. 1989
Green alga, *Selenastrum capricornutum*	S, U	Cadmium chloride	171	4 days	EC50 growth	130	Versteeg 1990

Table 4a. Toxicity of Cadmium to Freshwater Plants (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result[b] (Total μg/L)	Reference
			FRESHWATER SPECIES				
Alga, *Anabaena flos-aquae*	-	Cadmium chloride	-	-	96-hr EC50	120	Rachlin et al. 1984
Algae (mixed spp.)	-	Cadmium chloride	11.1	-	Significant reduction in population	5	Giesy et al. 1979
Fern, *Salvina natans*	-	Cadmium nitrate	-	-	Reduction in number of fronds	10	Hutchinson and Czyrska 1972
Eurasian watermilfoil, *Myriophyllum spicatum*	-	-	-	-	32-day EC50 (root weight)	7,400	Stanley 1974
Duckweed, *Lemna gibba*	S, M, T	Cadmium nitrate	-	7 days	EC50 growth	800	Devi et al. 1996
Duckweed, *Lemna minor*	S, U	-	-	4 days	EC50 growth	200	Wang 1986
Duckweed, *Lemna minor*	R, M, T	Cadmium chloride	39	4 days	Reduced chlorophyll	54	Taraldsen and Norberg-King 1990
Duckweed, *Lemna valdiviana*	-	Cadmium nitrate	-	-	Reduction in number of fronds	10	Hutchinson and Czyrska 1972
Duckweed, *Spirodela polyrhiza*	R, U	Cadmium sulfate	-	28 days	LOEC growth	7.63	Sajwan and Ornes 1994

a S=static: R=renewal; F=flow through; U=unmeasured; M=measured; T=total metal conc. measured; D=dissolved metal conc. measured.
b Results are expressed as cadmium, not as the chemical.

Table 4b. Toxicity of Cadmium to Saltwater Plants

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Result[b] (Total µg/L)	Reference
			SALTWATER SPECIES				
Kelp, *Laminana saccharina*	-	Cadmium chloride	-	-	8-day EC50 (growth rate)	860	Markham et al. 1980
Diatom, *Asterionella japonica*	-	Cadmium chloride	-	-	72-hr EC50 (growth rate)	224.8	Fisher and Jones 1981
Diatom, *Ditylum brightwellii*	-	Cadmium chloride	-	-	5-day EC50 (growth)	60	Canterford and Canterford 1980
Diatom, *Phaeodactylum tricornutum*	S, U	Cadmium chloride	35	4 days	EC50 growth	22,390	Torres et al. 1998
Diatom, *Thalassiosira pseudonana*	-	Cadmium chloride	-	-	96-hr EC50 (growth rate)	160	Gentile and Johnson, 1982
Diatom, *Skeletonema costatum*	-	Cadmium chloride	-	-	96-hr EC50 (growth rate)	175	Gentile and Johnson 1982
Red alga, *Champia parvula*	-	Cadmium chloride	-	-	Reduced tetrasporophyte growth	24.9	Steele and Thursby 1983
Red alga, *Champia parvula*	-	Cadmium chloride	-	-	Reduced tetrasporangia production	>189	Steele and Thursby 1983
Red alga, *Champia parvula*	-	Cadmium chloride	-	-	Reduced female growth	22.8	Steele and Thursby 1983
Red alga, *Champia parvula*	-	Cadmium chloride	-	-	Stopped sexual reproduction	22.8	Steele and Thursby 1983
Red alga, *Champia parvula*	R, U	Cadmium chloride	28-30	14 days	NOEC sexual reproduction	77	Thursby and Steele 1986

a S=static: R=renewal; F=flow through; U=unmeasured; M=measured; T= total metal conc. measured; D=dissolved metal conc. measured.
b Results are expressed as cadmium, not as the chemical.

Table 5a. Bioaccumulation of Cadmium by Freshwater Organisms

Species	Tissue	Chemical	Hardness (mg/L as $CaCO_3$)	Concentration in Water (μg/L)[a]	Duration (days)	BCF or BAF	Reference
			FRESHWATER SPECIES				
Aufwuchs (attached microscopic plants and animals	-	Cadmium chloride	-	-	365	720	Giesy et al. 1979
Aufwuchs (attached microscopic plants and animals	-	Cadmium chloride	-	-	365	580	Giesy et al. 1979
Duckweed, *Lemna valdiviana*	Whole plant	Cadmium nitrate	-	-	21	603	Hutchinson and Czyrska 1972
Fern, *Salvinia natans*	Whole plant	Cadmium nitrate	-	-	21	960	Hutchinson and Czyrska 1972
Snail, *Physa integra*	Whole body	Cadmium chloride	-	-	28	1,750	Spehar et al. 1978
Snail, *Viviparus georgianus*	Soft tissue (1 yr old)	Cadmium chloride	-	100(10°C) 100(15°C) 100(25°C)	20 20 20	71[b] 74[b] 109[b]	Tessier et al. 1994a
	Soft tissue (2 yrs old)	Cadmium chloride	-	100(10°C) 100(15°C) 100(25°C)	20 20 20	28[b] 42[b] 60[b]	
	Soft tissue (3 yrs old)	Cadmium chloride	-	100(10°C) 100(15°C) 100(25°C)	20 20 20	27[b] 42[b] 26[b]	
Snail, *Viviparus georgianus*	Soft tissue (1 yr old)	Cadmium chloride	-	10 50	60 60	6,910[b] 2,238[b]	Tessier et al. 1994b
	Soft tissue (2 yrs old)	Cadmium chloride	-	10 50	60 60	1,758[b] 758[b]	
	Soft tissue (3 yrs old)	Cadmium chloride	-	10 50	60 60	1,258[b] 617[b]	

Table 5a. Bioaccumulation of Cadmium by Freshwater Organisms (Continued)

Species	Tissue	Chemical	Hardness (mg/L as $CaCO_3$)	Concentration in Water ($\mu g/L$)[a]	Duration (days)	BCF or BAF	Reference
			FRESHWATER SPECIES				
Mussel, *Elliptio complanata*	Soft tissue (0-74 mm length)	Cadmium chloride	-	100(10°C) 100(15°C) 100(25°C)	20 20 20	15[b] 16[b] 28[b]	Tessier et al. 1994a
	Soft tissue (74-86 mm length)	Cadmium chloride	-	100(10°C) 100(15°C) 100(25°C)	20 20 20	16[b] 16[b] 14[b]	
	Soft tissue (86-100 mm length)	Cadmium chloride	-	100(10°C) 100(15°C) 100(25°C)	20 20 20	8[b] 7[b] 8[b]	
Mussel, *Elliptio complanata*	Soft tissue (0-74 mm length)	Cadmium chloride	-	10 50	60 60	1,256[b] 918[b]	Tessier et al. 1994b
	Soft tissue (74-86 mm)	Cadmium chloride	-	10 50	60 60	945[b] 613[b]	
	Soft tissue (86-100 mm)	Cadmium chloride	-	10 50	60 60	574[b] 254[b]	
Asiatic clam, *Corbicula fluminea*	Whole body	Cadmium sulfate	-	-	28	3,770	Graney et al. 1983
Asiatic clam, *Corbicula fluminea*	Whole body	Cadmium sulfate	-	-	28	1,752	Graney et al. 1983
Cladoceran, *Daphnia magna*	Whole body	Cadmium sulfate	-	-	2-4	320	Poldoski 1979
Cladoceran, *Daphnia magna*	Whole body	Cadmium sulfate	-	-	7	484[b]	Winner 1984
Crayfish, *Orconectes propinquus*	Whole body	-	-	-	8	184	Gillespie et al. 1977

Table 5a. Bioaccumulation of Cadmium by Freshwater Organisms (Continued)

Species	Tissue	Chemical	Hardness (mg/L as $CaCO_3$)	Concentration in Water ($\mu g/L$)[a]	Duration (days)	BCF or BAF	Reference
			FRESHWATER SPECIES				
Mayfly, *Ephemeroptera* sp.	Whole body	Cadmium chloride	-	-	365	1,630	Giesy et al. 1979
Mayfly, *Ephemeroptera* sp.	Whole body	Cadmium chloride	-	-	365	3,520	Giesy et al. 1979
Dragonfly, *Pantala hymenea*	Whole body	Cadmium chloride	-	-	365	736	Giesy et al. 1979
Dragonfly, *Pantala hymenea*	Whole body	Cadmium chloride	-	-	365	680	Giesy et al. 1979
Damselfly, *Ischnura* sp.	Whole body	Cadmium chloride	-	-	365	1,300	Giesy et al. 1979
Damselfly, *Ischnura* sp.	Whole body	Cadmium chloride	-	-	365	928	Giesy et al. 1979
Stonefly, *Pteronarcys dorsata*	Whole body	Cadmium chloride	-	-	28	373	Spehar et al. 1978
Beetle, Dytiscidae	Whole body	Cadmium chloride	-	-	365	164	Giesy et al. 1979
Beetle, Dytiscidae	Whole body	Cadmium chloride	-	-	365	260	Giesy et al. 1979
Caddisfly, *Hydropsyche betteni*	Whole body	Cadmium chloride	-	-	28	4,190	Spehar et al. 1978
Caddisfly, *Hydropsyche* sp.	Whole body	Cadmium chloride	-	-	2-8	228.2[b]	Dressing et al. 1982
Biting midge, Ceratopogonidae	Whole body	Cadmium chloride	-	-	365	936	Giesy et al. 1979

Table 5a. Bioaccumulation of Cadmium by Freshwater Organisms (Continued)

Species	Tissue	Chemical	Hardness (mg/L as $CaCO_3$)	Concentration in Water (μg/L)[a]	Duration (days)	BCF or BAF	Reference
			FRESHWATER SPECIES				
Biting midge, Ceratopogonidae	Whole body	Cadmium chloride	-	-	365	662	Giesy et al. 1979
Midge, Chironomidae	Whole body	Cadmium chloride	-	-	365	2,200	Giesy et al. 1979
Midge, Chironomidae	Whole body	Cadmium chloride	-	-	365	1,830	Giesy et al. 1979
Midge, *Chironomus riparius*	Whole body	-	-	10,000	28	1,370[b]	Timmermans et al. 1992
Lake whitefish, *Coregonus clupeaformis*	Whole body	Cadmium chloride	82.5	2.07	72	42	Harrison and Klaverkamp 1989
Rainbow trout, *Oncorhynchus mykiss*	Whole body	-	-	-	140	540	Kumada et al. 1973
Rainbow trout, *Oncorhynchus mykiss*	Whole body	Cadmium chloride	-	-	70	33	Kumada et al. 1980
Rainbow trout, *Oncorhynchus mykiss*	Whole body	Cadmium chloride	82.5	3.39	72	55	Harrison and Klaverkamp 1989
Rainbow trout, *Oncorhynchus mykiss*	Muscle	Cadmium sulfate	250	1.8	231	333	Brown et al. 1994
				3.4	231	294	
				5.5	231	509	
				1.8	455	89	
				3.4	455	182	
				5.5	455	127	

Table 5a. **Bioaccumulation of Cadmium by Freshwater Organisms (Continued)**

Species	Tissue	Chemical	Hardness (mg/L as $CaCO_3$)	Concentration in Water (μg/L)[a]	Duration (days)	BCF or BAF	Reference
			FRESHWATER SPECIES				
Atlantic salmon, *Salmo salar*	Whole body (egg)	Cadmium chloride	-	0.87 (pH=6.8) 1.74 (pH=6.8) 1.01 (pH=4.5) 2.09 (pH=4.5)	91 91 91 91	229 176 4 7	Peterson et al. 1985
Brook trout, *Salvelinus fontinalis*	Muscle	Cadmium chloride	-	-	490	3	Benoit et al. 1976
Brook trout, *Salvelinus fontinalis*	Muscle	Cadmium chloride	-	-	84	151	Benoit et al. 1976
Brook trout, *Salvelinus fontinalis*	Muscle	Cadmium chloride	-	-	93	22	Sangalang and Freeman 1979
Mosquitofish, *Gambusia affinis*	Whole body (estimated steady state)	Cadmium chloride	-	-	180	2,213	Giesy et al. 1979
Mosquitofish, *Gambusia affinis*	Whole body (estimated steady state)	Cadmium chloride	-	-	180	1,891	Giesy et al. 1979
Guppy, *Poecilia reticulata*	Whole body	-	-	-	32	280	Canton and Slooff 1982

Table 5a. Bioaccumulation of Cadmium by Freshwater Organisms (Continued)

Species	Tissue	Chemical	Hardness (mg/L as $CaCO_3$)	Concentration in Water (μg/L)[a]	Duration (days)	BCF or BAF	Reference
FRESHWATER SPECIES							
Bluegill sunfish, *Lepomis macrochirus*	Whole body	Cadmium chloride	134	0.8	28	113	Cope et al. 1994
				1.8	28	78	
				2.2	28	86	
				2.8	28	68	
				3.6	28	67	
				4.4	28	66	
				5.2	28	69	
				6.2	28	50	
				7.7	28	48	
				8.4	28	62	
				13.2	28	55	
				16.1	28	37	
				19.7	28	34	
				32.3	28	41	
Blue tilapia, *Tilapia aurea*	Muscle	Cadmium nitrate	145	6.8	112	17.6	Papoutsoglou and Abel 1988
				14	112	16.4	
				28	112	25.7	
				52	112	17.7	
African clawed frog, *Xenopus laevis*	Whole body	-	-	-	100	130	Canton and Slooff 1982
Mallard duck, *Anas platyrhynchos*	Kidney tubule degeneration, Testis weight reduction, inhibited spermatozoa production	-	-	200 mg/kg[c] (in food)	90	-	White and Finley 1978a,b; White et al. 1978

a Results are based on cadmium, not the chemical.
b Bioconcentration factor was converted from dry weight to wet weight basis.
c More recent information may be available for this species.

Table 5b. Bioaccumulation of Cadmium by Saltwater Organisms

Species	Tissue	Chemical	Salinity (g/kg)	Concentration in Water (μg/L)[a]	Duration (days)	BCF or BAF	Reference
SALTWATER SPECIES							
Polychaete worm, *Ophryotrocha diadema*	Whole body	Cadmium chloride	-	-	64	3,160	Klockner 1979
Blue mussel, *Mytilus edulis*	Soft parts	Cadmium chloride	-	-	28	113	George and Coombs1977
Blue mussel, *Mytilus edulis*	Soft parts	Cadmium chloride	-	-	35	306	Phillips 1976
Bay scallop, *Argopecten irradians*	Muscle	Cadmium chloride	-	-	42	2,040	Pesch and Stewart 1980
Eastern oyster, *Crassostrea virginica*	Soft parts	Cadmium chloride	-	-	280	2,150	Zaroogian and Cheer 1976
Eastern oyster, *Crassostrea virginica*	Soft parts	Cadmium chloride	-	-	280	1,830	Zaroogian 1979
Eastern oyster, *Crassostrea virginica*	Soft parts	Cadmium nitrate	-	-	98	1,220	Schuster and Pringle 1969
Soft-shell clam, *Mya arenaria*	Soft parts	Cadmium nitrate	-	-	70	160	Pringle et al. 1968
Pink shrimp, *Penaeus duorarum*	Whole body	Cadmium chloride	-	-	30	57	Nimmo et al. 1977b
Grass shrimp, *Paleomonetes pugio*	Whole body	Cadmium chloride	-	-	42	22	Pesch and Stewart 1980
Grass shrimp, *Paleomonetes pugio*	Whole body	Cadmium chloride	-	-	28	203	Nimmo et al. 1977b
Grass shrimp, *Paleomonetes vulgaris*	Whole body	Cadmium chloride	-	-	28	307	Nimmo et al. 1977b

Table 5b. Bioaccumulation of Cadmium by Saltwater Organisms (Continued)

Species	Tissue	Chemical	Salinity (g/kg)	Concentration in Water (μg/L)[a]	Duration (days)	BCF or BAF	Reference
			SALTWATER SPECIES				
Green crab, *Carcinus maenas*	Muscle	Cadmium chloride	-	-	68	5	Wright 1977
Green crab, *Carcinus maenas*	Muscle	Cadmium chloride	-	-	40	7	Jennings and Rainbow 1979a

a Results are based on cadmium, not the chemical.
b Bioconcentration factor was converted from dry weight to wet weight basis.
c More recent information may be available for this species.

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Mixed natural fungi and bacterial colonies on leaf litter	-	Cadmium chloride	10.7	28 wk	Inhibition of leaf decomposition	5	15.67	-	Giesy 1978
Plankton	-	-	-	2 wk	Reduced crustacean, zooplankton, and rotifers	1-3	-	-	Marshall et al. 1981, 1983
Mixed algal species	S, U	Cadmium chloride	-	10 days	Growth inhibition	50	-	-	Lasheen et al. 1990
Phytoplankton community	S, M, T	Cadmium chloride	-	150 days	NOEC biomas and photosynthesis	0.185	-	-	Findlay et al. 1996
Duckweed, *Lemna minor*	R, U	-	-	10 days	EC50 (frond production)	191	-	-	Smith and Kwan 1989
Duckweed, *Spirodela punctata*	S, M, T	-	-	30 days	Reduced growth rate	25	-	-	Outridge 1992
Water fern, *Salvinia minima*	S, M, T	-	-	30 days	Reduced growth rate	10	-	-	Outridge 1992
Cyanophyceae, *Microcystis aeroginosa*	S, U	Cadmium chloride	-	24 hr	EC50 growth	0.56	-	-	Guanzon et al. 1994
Cyanobacterium, *Anacystis nidulans*	S, U	Cadmium chloride	-	14 days	No growth	50,000	-	-	Lee et al. 1992
Green alga, *Selenastrum capricornutum*	R, U	Cadmium chloride	24.2	72 hr	EC50 (cell counts)	20.6	43.08	-	Radetski et al. 1995

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Green alga, *Selenastrum capricornutum*	S, U	Cadmium chloride	24.2	72 hr	EC50 (cell counts)	42.7	89.29	-	Radetski et al. 1995
Green alga, *Chlamydomonas reinhardi*	S, U	Cadmium chloride	-	72 hr	EC50 (growth)	789	-	-	Schafer et al. 1994
Green alga, *Scenedesmus dimorphus*	S, U	Cadmium nitrate	11.3	48 hr	LC50 (density)	63	285.7	-	Ghosh et al. 1990
Green alga, *Scenedesmus quadricauda*	S, U	Cadmium chloride	-	20 days	LC50	9	-	-	Fargasova 1993
Green alga, *Selenastrum capricornutum*	S, M, T	Cadmium nitrate	-	120 hr	LOEC growth	30	-	-	Thompson and Couture 1991
Green alga, *Selenastrum capricornutum*	S, U	-	-	72 hr	EC50 (cell number)	164	-	-	Van der Heever and Grobbelaar 1996
		-	-		EC50 (chlorophyll)	97	-	-	
Green alga, *Scenedesmus quadricauda*	S, U	Cadmium chloride	-	24 hr	EC50 growth	1.9	-	-	Guanzon et al. 1994
Green alga, *Stichococcus bacillaris*	S, U	Cadmium chloride	-	96 hr	Reduced growth	5,000	-	-	Skowronski et al. 1985
Green alga, *Chlorella vulgaris*	S, U	Cadmium chloride	-	72 hr	Reduced progeny formation	100	-	-	Wilczok et al. 1994

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Green alga, *Chlorella vulgaris*	S, U	Cadmium nitrate	-	72 hr	EC50 growth	50,000	-	-	Wren and McCarroll 1990
Green alga, *Scenedesmus quadricauda*	-	Cadmium chloride	-	96 hr	Incipient inhibition (river water)	100	-	-	Bringmann and Kuhn 1959a,b
Bacteria, *Escherichia coli*	-	Cadmium chloride	-	-	Incipient inhibition	150	-	-	Bringmann and Kuhn 1959a
Bacteria, *Salmonella typhimurium*	-	Cadmium chloride	50	8 hr	EC50 (growth inhibition)	10,400	10,400	-	Canton and Slooff 1982
Bacteria, *Pseudomonas putida*	-	Cadmium chloride	-	16 hr	Incipient inhibition	80	-	-	Bringmann and Kuhn 1976, 1977a, 1979, 1980b
Bacteria, (6 species)	-	Cadmium chloride	-	18 hr	Reduced growth	5,000 100,000	-	-	Seyfreid and Horgan 1983
Protozoan community	S, M, T	Cadmium chloride	70	2 days	EC50 (number of species)	4,600	3,267	-	Niederlehner et al. 1985
				28 days	EC20 (colonization)	1	-	-	
Protozoan community	S, U	Cadmium chloride	-	240 hr	Reduced biomas	1	-	-	Fernandez-Leborans and Novillo-Villajos 1993

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Protozoan, *Entosiphon sulcatum*	-	Cadmium nitrate	-	72 hr	Incipient inhibition	11	-	-	Bringmann 1978; Bringmann and Kuhn 1979, 1980b, 1981
Protozoan, *Microregma heterostoma*	-	Cadmium chloride	-	28 hr	Incipient inhibition	100	-	-	Bringmann and Kuhn 1959b
Protozoan, *Chilomonas paramecium*	-	Cadmium nitrate	-	48 hr	Incipient inhibition	160	-	-	Bringmann et al. 1980
Protozoan, *Uronema parduezi*	-	Cadmium nitrate	-	20 hr	Incipient inhibition	26	-	-	Bringman and Kuhn 1980a, 1981
Protozoan, *Spirostomum ambiguum*	S, U	Cadmium chloride	28 250	24 hr 24 hr	LC50 LC50	78.1 5,270	140.8 1,026	- -	Nalecz-Jawecki et al. 1993
Protozoan, *Spirostomum ambiguum*	S, U	Cadmium nitrate	-	48 hr	LC50	168	-	-	Nalecz-Jawecki and Sawicki 1998
Ciliate, *Tetrahymena pyriformis*	S, U	Cadmium chloride	-	72 hr	Growth inhibition	3,372	-	-	Krawczynska et al. 1989
Ciliate, *Tetrahymena pyriformis*	S, U	Cadmium chloride	-	96 hr	EC50 growth	1,045	-	-	Schafer et al. 1994
Ciliate, *Tetrahymena pyriformis*	S, U	Cadmium acetate	-	30 min	Complete mortality	56,205	-	-	Larsen and Svensmark 1991
Ciliate, *Colpidium campylum*	S, U	Cadmium sulfate	-	24 hr	EC50 growth	75	-	-	Dive et al. 1989

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Ciliate, *Tetrahymena pyriformis*	S, U	Cadmium chloride	-	9 hr	IC50 growth	3,000	-	-	Sauvant et al. 1995
Ciliate, *Spirostomum teres*	S, U	Cadmium chloride	-	24 hr	LC50	1,950	-	-	Twagilimana et al. 1998
Hydra, *Hydra oligactis*	-	Cadmium nitrate	-	48 hr	LC50	583	-	-	Slooff 1983: Slooff et al. 1983
Hydra, *Hydra littoralis*	-	Cadmium chloride	70	12 days	Reduced growth	20	15.59	-	Santiago-Fandino 1983
Planarian, *Dendrocoelum lacteum*	R, M, T	Cadmium chloride	122.8	48 hr	LC50	46,000	18,452	-	Brown and Pascoe 1988
Planarian, *Dugesia lugubris*	-	Cadmium nitrate	-	48 hr	LC50	>20,000	-	-	Slooff 1983
Mixed macro invertebrates	-	Cadmium chloride	11.1	52 wk	Reduced taxa	5	15.25	-	Giesy et al. 1979
Rotifer, *Brachionus calyciflorus*	S, U	Cadmium nitrate	80-100	72 hr	Chronic value (asexual reproduction)	20	12.94	-	Snell and Carmona 1995
					Chronic Value (sexual reproduction)	20	12.94	-	
Rotifer, *Brachionus calyciflorus*	S, U	Cadmium nitrate	80-100	48 hr	EC50	70	38.51	-	Snell and Moffat 1992
					Chronic value	60	38.82	-	
Rotifer, *Brachionus calyciflorus*	S, U	Cadmium nitrate	80-100	24 hr	LC50	1,300	715.2	-	Snell et al. 1991a

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Rotifer, *Brachionus rubens*	S, U	Cadmium chloride	80-100	24 hr	LC50 NOEC (survival)	810 280	445.6 154.1	- -	Snell and Persoone 1989a
Rotifer, *Brachionus calyciflorus*	S, U	Cadmium chloride	170	35 min	NOEC (ingestion rate)	250	72.05	-	Juchelka and Snell 1994
Rotifer, *Brachionus calyciflorus*	S, U	Cadmium nitrate	80-100	48 hr	EC50	10	5.502	-	Radix et al. 1999
Mixed zooplankton community	F, M, T	-	-	14 days	60% reduced biomass	1	-	-	Lawrence and Holoka 1987
Tubificid worm, *Tubifex tubifex*	-	Cadmium chloride	224	48 hr	LC50	320,000	69,672	-	Qureshi et al. 1980
Tubificid worm, *Tubifex tubifex*	R, U	Cadmium chloride	245	96 hr	LC50	47,530	9,447	-	Khangarot 1991
Worm, *Lumbriculus variegatus*	F, M, T	Cadmium chloride	44-47	10 days	LC50	158	169.4	-	Phipps et al. 1995
Worm, *Pristina* sp.	-	Cadmium chloride	11.1	52 wk	Population reduction	5	15.25	-	Giesy et al. 1979
Worm, *Pristina leidyi*	S, M, T	Cadmium chloride	95	48 hr	LC50	215	112.0	-	Smith et al. 1991
Nematode, *Caenorhabditis elegans*	S, U	Cadmium chloride	-	96 hr	LC50 (fed)	61	-	-	Williams and Dusenbery 1990
Leech (cocoon), *Nephelopsis obscura*	S, M, T	Cadmium chloride	-	96 hr	LC50	832.6	-	-	Wicklum et al. 1997

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
				FRESHWATER SPECIES					
Snail, *Amnicola limosa*	S, M, T	Cadmium chloride	15.3	96 hr	LC50	6,350 (pH=3.5)	21,164	-	Mackie 1989
						3,800 (pH=4.0)	12,665	-	
						2,710 (pH=4.5)	9,032	-	
Snail, *Lymnaea stagnalis*	-	Cadmium chloride	-	48 hr	LC50	583	-	-	Slooff 1983; Slooff et al. 1983
Snail, *Physa integra*	-	Cadmium chloride	44-58	28 days	LC50	10.4	10.25	-	Spehar et al. 1978
Snail, *Vivpara bengalensis*	S, U	Cadmium chloride	140-190	96 hr	LC50	1,550	460.5	-	Gadkari and Marathe 1983
Mussel, *Utterbackia imbecilis*	S, M, T	Cadmium chloride	39	48 hr	LC50	57	73.38	-	Keller and Zam 1991
			80-100	48 hr	LC50	137	75.37	-	
Zebra mussel, *Dreissena polymorpha*	R, M, T	Cadmium chloride	150	48 hr	EC50	388	127.0	-	Kraak et al. 1994a
								-	
Zebra mussel, *Dreissena polymorpha*	R, M, T	Cadmium chloride	268	10 wk	LOEC filtration rate	9	2.594	-	Kraak et al. 1992b
				11 wk	EC50	130	37.47	-	
Bivalve, *Pisidium casertanum*	S, M, T	Cadmium chloride	15.3	96 hr	LC50	1,370 (pH=3.5)	4,566	-	Mackie 1989
						480 (pH=4.0)	1,600	-	
						700 (pH=4.5)	2,333	-	

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Bivalve, *Pisidium compressum*	S, M, T	Cadmium chloride	15.3	96 hr	LC50	2,080 (pH=3.5)	6,932	-	Mackie 1989
						700 (pH=4.0)	2,333	-	
						360 (pH=4.5)	1,200	-	
Cladoceran (<24 hr) *Ceriodaphnia dubia*	R,M,T	Cadmium nitrate	100	48 hr	LC50	27.3 (High TOC)	13.49	-	Spehar and Fiandt 1986
Cladoceran, *Ceriodaphnia*	R, U	Cadmium sulfate	169	7 days	Chronic value reproduction	<14	<5.679	-	Masters et al. 1991
Cladoceran, *Ceriodaphnia dubia*	S, U	Cadmium chloride	80-100	1 hr	EC50 feeding inhibition	54	29.71	-	Bitton et al. 1996
Cladoceran, *Ceriodaphnia dubia*	S, U	Cadmium chloride	80-100	1 hr	EC50 feeding inhibition	76.2	41.92	-	Lee et al. 1997
Cladoceran (<48 hr), *Ceriodaphnia dubia*	S, M, T	Cadmium nitrate	280-300	48 hr	LC50 (fed)	560	93.78	-	Schubauer-Berigan et al. 1993
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U	Cadmium chloride	80	48 hr	LC50	49.5	30.70	-	Hockett and Mount 1996
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U	Cadmium chloride	172	48 hr	LC50	221	62.94	-	Hockett and Mount 1996
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, M, D	Cadmium sulfate	160-180	120 min	Reduced mobility	2,500	720.5	-	Brent and Herricks 1998
Cladoceran, *Ceriodaphnia dubia*	R, U	Cadmium chloride	80-100	7 days	Chronic value	1.4	0.9057	-	Zuiderveen and Birge 1997

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Cladoceran (<24 hr), *Ceriodaphnia dubia*	S, U	Cadmium nitrate	80-100	48 hr	LC50	78.2 (fed)	43.02	-	Nelson and Roline 1998
Cladoceran, *Ceriodaphnia dubia*	R, U	Cadmium sulfate	90	10 days	NOEC reproduction	0.5	0.3235	-	Winner 1988
Cladoceran, *Ceriodaphnia reticulata*	S, U	-	45	48 hr	LC50	66 (fed bacterial suspension)	73.46	-	Mount and Norberg 1984
Cladoceran, *Ceriodaphnia reticulata*	S, M	Cadmium chloride	55-79	48 hr	LC50	129 (High TOC)	95.80	-	Spehar and Carlson 1984a,b
Cladoceran (<6 hr), *Ceriodaphnia reticulata*	S, U	Cadmium chloride	200 (well water)	48 hr	LC50	79.4	19.40	-	Hall et al. 1986
Cladoceran, *Ceriodaphnia reticulata*	S, M, T	Cadmium sulfate	37.6	48 hr	LC50	1,900	2,539	-	Sharma and Selvaraj 1994
Cladoceran, *Daphnia carinata*	S, M, T	Cadmium sulfate	37.6	48 hr	LC50	280	374.1	-	Sharma and Selvaraj 1994
Cladoceran, *Daphnia galeata mendotae*	-	Cadmium chloride	-	22 wk	Reduced biomass	4.0	-	-	Marshall 1978a
Cladoceran, *Daphnia galeata mendotae*	-	Cadmium chloride	-	15 days	Reduced rate of increase	5.0	-	-	Marshall 1978b

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Cladoceran, *Daphnia magna*	-	Cadmium chloride	-	48 hr	EC50 (river water)	100	-	-	Bringmann and Kuhn 1959a,b
Cladoceran, *Daphnia magna*	-	Cadmium chloride	45	21 days	Reproductive impairment	0.17	0.184	-	Biesinger and Christensen 1972
Cladoceran, *Daphnia magna*	-	Cadmium chloride	163	72 hr	LC50	15.4 (14-17)	4.632	-	Debelak 1975
Cladoceran, *Daphnia magna*	-	Cadmium nitrate	-	24 hr	LC50	600	-	-	Bringmann and Kuhn 1977b
Cladoceran (3-5 days), *Daphnia magna*	-	Cadmium sulfate	-	72 hr	LC50 (10°C)	224	-	-	Braginskly and Shcherban 1978
					(15°C)	224	-	-	
					(25°C)	12	-	-	
					(30°C)	0.1	-	-	
Cladoceran (adult), *Daphnia magna*	-	Cadmium sulfate	-	72 hr	LC50 (10°C)	479	-	-	Braginskly and Shcherban 1978
					(15°C)	187	-	-	
					(25°C)	10.2	-	-	
					(30°C)	2.4	-	-	
Cladoceran, *Daphnia magna*	-	Cadmium nitrate	200	24 hr	EC50	160	39.09	-	Bellavera and Gorbi 1981
Cladoceran, *Daphnia magna*	-	Cadmium chloride	130	96 hr	EC50	5	1.893	-	Attar and Maly 1982
Cladoceran, *Daphnia magna*	-	Cadmium chloride	200	20 days	LC50	670	239.9	-	Canton and Slooff 1982

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Cladoceran, *Daphnia magna*	S, U	-	45	48 hr	LC50	118 (fed bacterial suspension)	131.3	-	Mount and Norberg 1984
Cladoceran, *Daphnia magna*	S, M	Cadmium chloride	55-79	48 hr	LC50	166 (High TOC)	123.3	-	Spehar and Carlson 1984a,b
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium chloride	160-180	48 hr	LC50	140	40.35	-	Lewis and Weber 1985
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	200 (well water)	48 hr	LC50	49.0	11.97	-	Hall et al. 1986
Cladoceran (<4 hr), *Daphnia magna*	S, U	Cadmium chloride	38	48 hr	LC50	164	216.8	-	Nebeker et al. 1986a
			41			99	121.1	-	
			71			101	70.71	-	
			74			120	80.56	-	
			76			65	42.47	-	
Cladoceran (<4 hr), *Daphnia magna*	S, U	Cadmium chloride	38	48 hr	LC50	16	21.15	-	Nebeker et al. 1986a
			74			146	98.01	-	
Cladoceran (1 d), *Daphnia magna*	S, U	Cadmium chloride	38	48 hr	LC50	307	405.8	-	Nebeker et al. 1986a
			71			135	94.52	-	
			74			200	134.3	-	
			76			45	29.40	-	
Cladoceran (2 d), *Daphnia magna*	S, U	Cadmium chloride	38	48 hr	LC50	131	173.2	-	Nebeker et al. 1986a
			71			18	12.60	-	
			74			38	25.51	-	
			76			21	13.72	-	

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Cladoceran (5 d), *Daphnia magna*	S, M, T	Cadmium chloride	34	48 hr	LC50	24	35.52	-	Nebeker et al. 1986b
Cladoceran (5 d), *Daphnia magna*	R, M, T	Cadmium chloride	225	21 days	LOEC reproduction	2.3	0.755	-	Enserink et al. 1993
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	-	48 hr	LC50	48 (fed)	-	-	Domal-Kwiatkowska et al. 1994
Cladoceran (14 days), *Daphnia magna*	S, M, T	Cadmium chloride	160-180	48 hr	LC50	80	23.06	-	Allen et al. 1995
Cladoceran (egg), *Daphnia magna*	S, M, T	Cadmium chloride	150	46 hr	Profound effect on egg development	>1,000	>327.3	-	Bodar et al. 1989
Cladoceran, *Daphnia magna*	S, U	Cadmium sulfate	240	48 hr	LC50	1,880	381.6	-	Khangarot and Ray 1989a
Cladoceran, *Daphnia magna*	S, U	Cadmium chloride	250	48 hr (fed)	LC50 (small neonates)	98	19.08	-	Enserink et al. 1990
					LC50 (large neonates)	294	57.25	-	
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium chloride	160-180	48 hr	LC50 (20°C) (fed)	38	10.95	-	Lewis and Horning 1991
					LC50 (26°C) (fed)	9	2.594	-	
Cladoceran (<24 hr), *Daphnia magna*	S, M, T	Cadmium chloride	10	48 hr	LC50	37.9	194.6	-	Hickey and Vickers 1992

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
				FRESHWATER SPECIES					
Cladoceran, *Daphnia magna*	S, U	Cadmium acetate	-	24 hr	EC50	980	-	-	Sorvari and Sillanpaa 1996
Cladoceran (<24 hr), *Daphnia magna*	R, M, T	Cadmium chloride	-	24 hr	EC50	1,900	-	-	Kuhn et al. 1989
				24 days	NOEC reproduction	0.6	-	-	
Cladoceran, *Daphnia magna*	R, U	Cadmium sulfate	90	10 days	NOEC reproduction	2.5	1.617	-	Winner 1988
Cladoceran, *Daphnia magna*	R, U	Cadmium sulfate	100	25 days	NOEC (20°C) reproduction	2.25	1.346	-	Winner and Whitford 1987
					NOEC (25°C) reproduction	0.75	0.4488	-	
Cladoceran, *Daphnia pulex*	-	Cadmium chloride	57	140 days	Reduced reproduction	1	0.9075	-	Bertram and Hart 1979
Cladoceran, *Daphnia pulex*	-	Cadmium chloride	110	48 hr	LC50 (fed)	115 (104-127)	51.59	-	Ingersoll and Winner 1982
Cladoceran, *Daphnia pulex*	-	Cadmium chloride	106	58 days	MATC	7.1 (5-10)	4.069	-	Ingersoll and Winner 1982
Cladoceran, *Daphnia pulex*	S, U	-	45	48 hr	LC50	68 (fed bacterial suspension)	75.69	-	Mount and Norberg 1984
Cladoceran, *Daphnia pulex*	-	Cadmium sulfate	100	72 hr	LC50 (fed)	85.8 (80-92)	42.41	-	Winner 1984

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Cladoceran (<24 hr), *Daphnia pulex*	S, U	Cadmium chloride	200 (well water)	48 hr	LC50	100	24.43	-	Hall et al. 1986
Cladoceran (adult), *Daphnia pulex*	S, U	Cadmium chloride	124-130	48 hr	LC50	87.9	34.08	-	Jindal and Verma 1990
Cladoceran (<24 hr), *Daphnia pulex*	S, M, T	Cadmium chloride	80-90	48 hr	LC50	24	13.99	-	Lewis and Weber 1985
Cladoceran (<24 hr), *Daphnia pulex*	S, M, T	Cadmium chloride	80-90	48 hr	LC50 (20°C) (fed) LC50 (26°C) (fed)	42 6	24.49 3.498	- -	Lewis and Horning 1991
Cladoceran (<24 hr), *Daphnia pulex*	S, U	Cadmium chloride	80-90	21 days	NOEC reproduction	<0.003	<0.0020	-	Roux et al. 1993
Cladoceran (<24 hr), *Daphnia pulex*	R, M, T	Cadmium chloride	58 115 230	21 days 21 days 21 days	NOEC survival NOEC brood size NOEC brood size	3.8 7.5 7.5	3.404 4.046 2.421	- - -	Winner 1986
Cladoceran, *Moina macrocopa*	-	Cadmium chloride	80-84	20 days	Reduced survival	0.2	0.1386	-	Hatakeyama and Yasuno 1981b
Cladoceran, *Moina macrocopa*	R, M, T	Cadmium chloride	-	240 hr	Reduced survival	10	-	-	Wong and Wong 1990
Cladoceran, *Moina macrocopa*	S, M, T	Cadmium sulfate	37.6	48 hr	LC50	320	427.6	-	Sharma and Selvaraj 1994
Cladoceran, *Simocephalus serrulatus*	S, M	Cadmium chloride	55-79	48 hr	LC50	123 (high TOC)	91.35	-	Spehar and Carlson 1984a,b

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Cladoceran, *Simocephalus vetulus*	S, U	-	45	48 hr	LC50	24 (fed bacterial suspension)	26.71	-	Mount and Norberg 1984
Cladoceran, *Simocephalus vetulus*	S, M	Cadmium chloride	55-79	48 hr	LC50	89.3 (high TOC)	66.32	-	Spehar and Carlson 1984a,b
Copepod, *Acanthocyclops viridis*	-	Cadmium sulfate	-	72 hr	LC50	0.5	-	-	Braginskly and Shcherban 1978
Copepod, *Eucyclops agilis*	-	Cadmium chloride	11.1	52 wk	Population reduction	5	15.25	-	Giesy et al. 1979
Copepod, *Mesocyclops hyalinus*	S, M, T	Cadmium sulfate	37.6	48 hr	LC50	870	1,162	-	Sharma and Selvaraj 1994
Copepod, *Heliodinptomus vidus*	S, M, T	Cadmium sulfate	37.6	48 hr	LC50	150	200.4	-	Sharma and Selvaraj 1994
Copepod, *Tropocyclops prasinus mexicanus*	S, U	Cadmium chloride	10	48 hr	LC50	149	765.2	-	Lalande and Pinel-Alloul 1986
Copepod, *Stenocypris malcolmsoni*	S, M, T	Cadmium sulfate	37.6	48 hr	LC50	11,500	15,365	-	Sharma and Selvaraj 1994
Amphipod, *Diporeia* sp.	S, M, T	Cadmium chloride	-	96 hr	LC50 (4°C) LC50 (10°C) LC50 (15°C)	800 280 60	- - -	- - -	Gossiaux et al. 1992

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Amphipod, *Gammarus pseudolimnaeus*	S, M	Cadmium chloride	55-79	96 hr	LC50	54.4	40.40	-	Spehar and Carlson 1984a,b
Amphipod, *Hyalella azteca*	S, M	Cadmium chloride	217-301	24 hr	LC50	140	26.30	-	McNulty et al. 1999
Amphipod, *Hyalella azteca*	S, M	Cadmium chloride	55-79	96 hr	LC50	285 (high TOC)	211.7	-	Spehar and Carlson 1984a,b
Amphipod, *Hyalella azteca*	S, M, T	Cadmium chloride	15.3	96 hr	LC50	12 (pH-5.0) 16 (pH=5.5) 33 (pH=6.0)	40.00 53.33 110.0	- - -	Mackie 1989
Amphipod (0-2 d), *Hyalella azteca*	S, M, T	Cadmium chloride	90	96 hr	LC50	≈13	≈7.15	-	Collyard et al. 1994
Amphipod (2-4 d), *Hyalella azteca*	S, M, T	Cadmium chloride	90	96 hr	LC50	≈7.5	≈4.13	-	Collyard et al. 1994
Amphipod (4-6 d), *Hyalella azteca*	S, M, T	Cadmium chloride	90	96 hr	LC50	≈9.5	≈5.23	-	Collyard et al. 1994
Amphipod (10-12 d), *Hyalella azteca*	S, M, T	Cadmium chloride	90	96 hr	LC50	≈7	≈3.85	-	Collyard et al. 1994
Amphipod (16-18 d), *Hyalella azteca*	S, M, T	Cadmium chloride	90	96 hr	LC50	≈11.5	≈6.33	-	Collyard et al. 1994
Amphipod (24-26 d), *Hyalella azteca*	S, M, T	Cadmium chloride	90	96 hr	LC50	≈14	≈7.70	-	Collyard et al. 1994

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Amphipod, *Hyalella azteca*	R, M, T	Cadmium nitrate	130	6 wk	EC50	0.53	0.2006	-	Borgmann et al. 1991
Amphipod, *Hyalella azteca*	F, M, T	Cadmium chloride	44-47	10 days	LC50	2.8	3.003	-	Phipps et al. 1995
Amphipod, *Hyalella azteca*	S, M, T	Cadmium nitrate	280-300	96 hr	LC50 (fed)	230	38.52	-	Schubauer-Berigan et al. 1993
Crayfish, *Cambarus latimanus*	-	Cadmium chloride	11.1	5 mo	Significant mortality	5	15.25	-	Thorp et al. 1979
Crayfish, *Orconectes immunis*	S, M, T	Cadmium chloride	50.3	96 hr	LC50	>10,000	>9,939	-	Thorp and Gloss 1986
Anostracan crustacean, *Brachionus calyciflorus*	S, U	Cadmium sulfate	250	24 hr	EC50	120	23.37	-	Crisinel et al. 1994
Anostracan crustacean, *Streptocephalus rubricaudatus*	S, U	Cadmium sulfate	250	24 hr	EC50	250	48.68	-	Crisinel et al. 1994
Anostracan crustacean, *Thamnocephalus platyurus*	S, U	Cadmium chloride	80-100	24 hr	LC50	400	220.1	-	Centeno et al. 1995
Mayfly, *Cloeon dipterum*	-	Cadmium sulfate	-	72 hr	LC50 (10°C)	70,600	-	-	Braginskly and Shcherban 1978
					(15°C)	28,600	-	-	
					(25°C)	6,990	-	-	
					(30°C)	930	-	-	

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Mayfly, *Cloeon dipterum*	-	Cadmium nitrate	-	48 hr	LC50	56,000	-	-	Slooff et al. 1983
Damselfly, *Enallagma* sp.	S, M, T	Cadmium chloride	15.3	96 hr	LC50	7,050 (pH=3.5)	23,497	-	Mackie 1989
						8,660 (pH=4.0)	28,863	-	
						10,660 (pH=4.5)	35,528	-	
Mayfly, *Ephemerella* sp.	-	Cadmium chloride	44-48	28 days	LC50	<3.0	<3.191	-	Spehar et al. 1978
Mayfly, *Paraleptophlebia praepedita*	S, M	Cadmium chloride	55-77	96 hr	LC50	449	338.6	-	Spehar and Carlson 1984a,b
Mayfly, *Hexagenia rigida*	-	Cadmium nitrate	79.1	96 hr	LC50	≥1,000	≥627.3	-	Leonhard et al. 1980
Mosquito, *Aedes aegypti*	-	Cadmium nitrate	-	48 hr	LC50	4,000	-	-	Slooff et al. 1983
Mosquito, *Culex pipiens*	-	Cadmium nitrate	-	48 hr	LC50	765	-	-	Slooff et al. 1983
Midge, *Chironomus tentans*	S, U	Cadmium chloride	25	48 hr	LC50	8,050	16,286	-	Khangarot and Ray 1989b
Midge (1st instar), *Chironomus riparius*	S, M, T	-	100	1 hr	Reduced emergence	2,100	1,038	-	McCahon and Pascoe 1991
				10 hr	Reduced emergence	210	103.8	-	

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Midge (4th instar), *Chironomus riparius*	S, M, T	-	100	1 hr	Reduced emergence	2,000	988.6	-	McCahon and Pascoe 1991
				10 hr	Reduced emergence	200	98.86	-	
Midge (1st instar), *Chironomus riparius*	R, M, T	-	98	17 days	LOEC survival, development and growth	150	91.11	-	Pascoe et al. 1989
Midge (2nd instar), *Chironomus riparius*	R, M, T	Cadmium chloride	100-110	96 hr	LC50 (fed)	13,000	6,115	-	Williams et al. 1986
Midge (3rd instar), *Chironomus riparius*	R, M, T	Cadmium chloride	100-110	96 hr	LC50 (fed)	22,000	10,348	-	Williams et al. 1986
Midge (4th instar), *Chironomus riparius*	R, M, T	Cadmium chloride	100-110	96 hr	LC50 (fed)	54,000	25,400	-	Williams et al. 1986
Midge, *Chironomus riparius*	S, U	Cadmium chloride	98	120 hr	LOEC (egg viability)	30,000	18,222	-	Williams et al. 1987
				10 days	LOEC (number of eggs ovipositioned)	100,000	60,739	-	
Midge, *Tanytarsus dissimilis*	-	Cadmium chloride	47	10 days	LC50	3.8	3.978	-	Anderson et al. 1980
Pink salmon (newly hatched alevin), *Oncorhynchus gobuscha*	F, U	Cadmium chloride	83.1	168 hr	LC50	3,600	2,148	-	Servizi and Martens 1978
Pink salmon (alevin), *Oncorhynchus gobuscha*	F, U	Cadmium chloride	83.1	168 hr	LC50	3,160	1,885	-	Servizi and Martens 1978

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
				FRESHWATER SPECIES					
Pink salmon (fry), *Oncorhynchus gobuscha*	F, U	Cadmium chloride	83.1	168 hr	LC50	2,700	1,611	-	Servizi and Martens 1978
Coho salmon (juvenile), *Oncorhynchus kisutch*	-	Cadmium chloride	22	217 hr	LC50	2.0	4.608	-	Chapman and Stevens 1978
Coho salmon (adult), *Oncorhynchus kisutch*	-	Cadmium chloride	22	215 hr	LC50	3.7	8.524	-	Chapman and Stevens 1978
Coho salmon (alevin), *Oncorhynchus kisutch*	S, U	Cadmium chloride	41	96 hr	LC50	6.0	7.341	-	Buhl and Hamilton 1991
Sockeye salmon (newly hatched alevin), *Oncorhynchus nerka*	F, U	Cadmium chloride	83.1	168 hr	LC50	4,500	2,685	-	Servizi and Martens 1978
Sockeye salmon (alevin), *Oncorhynchus nerka*	F, U	Cadmium chloride	83.1	168 hr	LC50	1,000	596.6	-	Servizi and Martens 1978
Sockeye salmon (alevin), *Oncorhynchus nerka*	F, U	Cadmium chloride	83.1	168 hr	LC50	500	298.3	-	Servizi and Martens 1978
Sockeye salmon (fry), *Oncorhynchus nerka*	F, U	Cadmium chloride	83.1	168 hr	LC50	30	17.90	-	Servizi and Martens 1978
Sockeye salmon (fry), *Oncorhynchus nerka*	F, U	Cadmium chloride	83.1	168 hr	LC50	8	4.773	-	Servizi and Martens 1978
Sockeye salmon (smolt), *Oncorhynchus nerka*	F, U	Cadmium chloride	83.1	168 hr	LC50	360	214.8	-	Servizi and Martens 1978

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
				FRESHWATER SPECIES					
Chinook salmon (alevin), *Oncorhynchus tshawytscha*	-	Cadmium chloride	23	200 hr	LC10	21.6 (18-26)	47.57	-	Chapman 1978
Chinook salmon (swim-up), *Oncorhynchus tshawytscha*	-	Cadmium chloride	23	200 hr	LC10	1.2	2.643	-	Chapman 1978
Chinook salmon (parr), *Oncorhynchus tshawytscha*	-	Cadmium chloride	23	200 hr	LC10	1.3	2.863	-	Chapman 1978
Chinook salmon (smolt), *Oncorhynchus tshawytscha*	-	Cadmium chloride	23	200 hr	LC10	1.5	3.303	-	Chapman 1978
Rainbow trout, *Oncorhynchus mykiss*	-	Cadmium stearate	-	96 hr	LC50	6.0	-	-	Kumada et al. 1980
Rainbow trout, *Oncorhynchus mykiss*	-	Cadmium acetate	-	96 hr	LC50	6.2	-	-	Kumada et al. 1980
Rainbow trout, *Oncorhynchus mykiss*	-	Cadmium chloride	112	80 min	Significant avoidance	52	22.91	-	Black and Birge 1980
Rainbow trout, *Oncorhynchus mykiss*	-	-	112	18 mo	Reduced survival	0.2	0.1100	-	Birge et al. 1981
Rainbow trout, (embryo, larva) *Oncorhynchus mykiss*	-	Cadmium chloride	104	28 days	EC50 (death and deformity)	140	81.37	-	Birge 1978; Birge et al. 1980

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total μg/L)[b]	Result Adjusted to TH=50 (Total μg/L)	Result Adjusted to TH=50 (Dissolved μg/L)	Reference
					FRESHWATER SPECIES				
Rainbow trout, *Oncorhynchus mykiss*	-	-	-	240 hr	LC50	7 5	-	-	Kumada et al. 1973
Rainbow trout (adult), *Oncorhynchus mykiss*	-	Cadmium chloride	54	408 hr	LC50	5.2	4.912	-	Chapman and Stevens 1978
Rainbow trout (alevin), *Oncorhynchus mykiss*	-	Cadmium chloride	23	186 hr	LC10	>6	>13.21	-	Chapman 1978
Rainbow trout (swim-up), *Oncorhynchus mykiss*	-	Cadmium chloride	23	200 hr	LC10	1.0	2.202	-	Chapman 1978
Rainbow trout (parr), *Oncorhynchus mykiss*	-	Cadmium chloride	23	200 hr	LC10	0.7	1.541	-	Chapman 1978
Rainbow trout (smolt), *Oncorhynchus mykiss*	-	Cadmium chloride	23	200 hr	LC10	0.8	1.762	-	Chapman 1978
Rainbow trout, *Oncorhynchus mykiss*	-	Cadmium sulfate	326	96 hr	LC20	20	2.973	-	Davies 1976
Rainbow trout, *Oncorhynchus mykiss*	-	Cadmium stearate	-	10 wk	BCF = 27 BCF = 40	-	-	-	Kumada et al. 1980
Rainbow trout, *Oncorhynchus mykiss*	-	Cadmium acetate	-	10 wk	BCF = 63	-	-	-	Kumada et al. 1980
Rainbow trout, *Oncorhynchus mykiss*	-	Cadmium chloride	125	10 days	LC50 (18°C) (12°C) (6°C)	17.3 (10-30) 30 17.3 (10-30)	6.816 11.82 6.816	- - -	Roch and Maly 1979

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Rainbow trout, *Oncorhynchus mykiss*	-	Cadmium sulfate	240	234 days	Increased gill diffusion	2	0.6256	-	Hughes et al. 1979
Rainbow trout, *Oncorhynchus mykiss*	-	Cadmium chloride	320	4 mo	Physiological effects	10	2.528	-	Arillo et al. 1982, 1984
Rainbow trout, *Oncorhynchus mykiss*	-	Cadmium chloride	98.6	47 days	Reduced growth and survival	100	60.47	-	Woodworth and Pascoe 1982
Rainbow trout, (embryo, larva) *Oncorhynchus mykiss*	-	Cadmium sulfate	100	62 days	Reduced Survival	<5	<2.992	-	Dave et al. 1981
Rainbow trout (larva), *Oncorhynchus mykiss*	-	Cadmium chloride	89-107	7 days	LC50	700	353.2	-	Birge et al. 1983
Rainbow trout (larva), *Oncorhynchus mykiss*	-	Cadmium chloride	89-107	7 days	LC50 after 24 days acclimated to 5.9 µg/L	1,590	802.2	-	Birge et al. 1983
Rainbow trout, *Oncorhynchus mykiss*	-	Cadmium nitrate	-	48 hr	LC50	55	-	-	Slooff et al. 1983
Rainbow trout, *Oncorhynchus mykiss*	S, M	Cadmium chloride	55-79	96 hr	LC50	10.2 (high TOC)	7.575	-	Spehar and Carlson 1984a,b
Rainbow trout, *Oncorhynchus mykiss*	-	Cadmium chloride	82	11 days	LC50 (10°C)	16.0	9.676	-	Majewski and Giles 1984
Rainbow trout, *Oncorhynchus mykiss*	-	Cadmium chloride	82	8 days	LC50 (15°C)	16.6	10.04	-	Majewski and Giles 1984

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Rainbow trout, *Oncorhynchus mykiss*	-	Cadmium chloride	82	178 days	Physiological effects	4.8 (3.6-6.4)	3.327	-	Majewski and Giles 1984
Rainbow trout, (egg-0 hr) *Oncorhynchus mykiss*	R, U	Cadmium chloride	50	96 hr	LC50	13,000	13,000	-	Van Leeuwen et al. 1985a
Rainbow trout, (egg-24 hr) *Oncorhynchus mykiss*	R, U	Cadmium chloride	50	96 hr	LC50	13,000	13,000	-	Van Leeuwen et al. 1985a
Rainbow trout, (eyed egg-14 d) *Oncorhynchus mykiss*	R, U	Cadmium chloride	50	96 hr	LC50	7,500	7,500	-	Van Leeuwen et al. 1985a
Rainbow trout, (eyed egg-28 d) *Oncorhynchus mykiss*	R, U	Cadmium chloride	50	96 hr	LC50	9,200	9,200	-	Van Leeuwen et al. 1985a
Rainbow trout, (sac fry-42 d) *Oncorhynchus mykiss*	R, U	Cadmium chloride	50	96 hr	LC50	30	30.00	-	Van Leeuwen et al. 1985a
Rainbow trout, (early fry-77 d) *Oncorhynchus mykiss*	R, U	Cadmium chloride	50	96 hr	LC50	10	10.00	-	Van Leeuwen et al. 1985a
Rainbow trout, *Oncorhynchus mykiss*	R, M, D	Cadmium chloride	63 300	96 hr 96 hr	LC50 (fed) LC50 (fed)	1,300 2,600	1,028 420.6	- -	Pascoe et al. 1986
Rainbow trout, (5 d post fertilization) *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	87.7	48 hr	LC50	>100,000	>56,483	-	Shazili and Pascoe 1986

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
				FRESHWATER SPECIES					
Rainbow trout, (10 d post fertilization) *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	87.7	48 hr	LC50	3,300	1,864	-	Shazili and Pascoe 1986
Rainbow trout, (15 d post fertilization) *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	87.7	48 hr	LC50	7,200	4,067	-	Shazili and Pascoe 1986
Rainbow trout, (22 d post fertilization) *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	87.7	48 hr	LC50	8,000	4,519	-	Shazili and Pascoe 1986
Rainbow trout, (29 d post fertilization) *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	87.7	48 hr	LC50	12,500	7,060	-	Shazili and Pascoe 1986
Rainbow trout, (36 d post fertilization) *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	87.7	48 hr	LC50	16,500	9,320	-	Shazili and Pascoe 1986
Rainbow trout, (alevin, 2 d post hatch) *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	87.7	48 hr	LC50	5,800	3,276	-	Shazili and Pascoe 1986
Rainbow trout, (alevin, 7 d post hatch) *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	87.7	48 hr	LC50	8,300	4,688	-	Shazili and Pascoe 1986
Rainbow trout (alevin), *Oncorhynchus mykiss*	S, U	Cadmium chloride	41	96 hr	LC50	37.9	46.37	-	Buhl and Hamilton 1991

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Rainbow trout (fry), *Oncorhynchus mykiss*	F, M, T	Cadmium chloride	9.2	96 hr	LC50	28 (pH=4.7) 0.7 (pH=5.7)	156.5 3.913	- -	Cusimano et al. 1986
Rainbow trout (36 g), *Oncorhynchus mykiss*	F, M, T	-	50	96 hr	LC50	2.7	2.700	-	Davies et al. 1993
Rainbow trout (36 g), *Oncorhynchus mykiss*	F, M, T	-	200	96 hr	LC50	3.2	0.7818	-	Davies et al. 1993
Rainbow trout (36 g), *Oncorhynchus mykiss*	F, M, T	-	400	96 hr	LC50	7.6	0.9178	-	Davies et al. 1993
Brown trout, *Salmo trutta*	S, M	Cadmium chloride	55-79	96 hr	LC50	15.1	11.21	-	Spehar and Carlson 1984a,b
Atlantic salmon, *Salmo salar*	-	Cadmium chloride	13	70 days	Reduced growth	2	5.426	-	Peterson et al. 1983
Atlantic salmon (alevin), *Salmo salar*	R, M, T	Cadmium chloride	28	92 days	Net water uptake inhibited	0.78	1.199	-	Rombough and Garside 1984
Brook trout, *Salvelinus fontinalis*	-	Cadmium chloride	10	21 days	Testicular damage	10	32.95	-	Sangalang and O'Halloran 1972, 1973
Brook trout (8 months), *Salvelinus fontinalis*	R, M, T	-	20	10 days	NOEL survival	8	20.31	-	Jop et al. 1995
Lake trout, *Salvelinus namaycush*	F, M, T	Cadmium chloride	90	8-9 mo	Decreased thyroid follicle epithelial cell height	5	3.235	-	Scherer et al. 1997

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Arctic grayling (alevin), *Thymallus arcticus*	S, U	Cadmium chloride	41	96 hr	LC50	6.1 (1-d acclimation)	7.464	-	Buhl and Hamilton 1991
Arctic grayling (juvenile), *Thymallus arcticus*	S, U	Cadmium chloride	41	96 hr	LC50	4.0 (low D.O.)	4.894	-	Buhl and Hamilton 1991
Goldfish (embryo, larva), *Carassius auratus*	-	Cadmium chloride	195	7 days	EC50 (death and deformity)	170	43.62	-	Birge 1978
Goldfish, *Carassius auratus*	-	-	-	50 days	Reduced plasma sodium	44.5	-	-	McCarty and Houston 1976
Common carp (embryo), *Cyprinus carpio*	-	Cadmium sulfate	360	-	EC50 (hatch)	2,094	281.5	-	Kapur and Yadav 1982
Common carp (fry), *Cyprinus carpio*	S, U	-	100	96 hr	LC50	4,260	2,106	-	Suresh et al. 1993a
Common carp (fingerling), *Cyprinus carpio*	S, U,	-	100	96 hr	LC50	17,050	8,428	-	Suresh et al. 1993a
Common carp (embryo, larva), *Cyprinus carpio*	F, M, T	Cadmium chloride	101.6	8 days	LC50 (multiple-species test)	139	67.61	-	Birge et al. 1985
Common shiner (0.75-3.5 mg), *Notropis cornutus*	R, M, D	Cadmium chloride	48	7 days	67% reduced growth	200	208.5	-	Borgmann and Ralph 1986

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
				FRESHWATER SPECIES					
Fathead minnow, *Pimephales promelas*	-	Cadmium chloride	63	96 hr	LC50	80.8	63.88	-	Spehar 1982
Fathead minnow, *Pimephales promelas*	-	Cadmium chloride	55	96 hr	LC50	40.9	37.12	-	Spehar 1982
Fathead minnow, *Pimephales promelas*	-	Cadmium chloride	59	96 hr	LC50	64.8	54.77	-	Spehar 1982
Fathead minnow, *Pimephales promelas*	-	Cadmium chloride	66	96 hr	LC50	135	101.8	-	Spehar 1982
Fathead minnow, *Pimephales promelas*	-	Cadmium chloride	65	96 hr	LC50	120	91.91	-	Spehar 1982
Fathead minnow, *Pimephales promelas*	-	Cadmium chloride	74	96 hr	LC50	86.3	57.93	-	Spehar 1982
Fathead minnow, *Pimephales promelas*	-	Cadmium chloride	79	96 hr	LC50	86.6	54.40	-	Spehar 1982
Fathead minnow, *Pimephales promelas*	-	Cadmium chloride	62	96 hr	LC50	114	91.61	-	Spehar 1982
Fathead minnow, *Pimephales promelas*	-	Cadmium chloride	63	96 hr	LC50	80.8	63.88	-	Spehar 1982
Fathead minnow, *Pimephales promelas*	-	Cadmium nitrate	-	48 hr	LC50	2,200	-	-	Slooff et al. 1983
Fathead minnow, *Pimephales promelas*	-	Cadmium chloride	103	6.8 hr	LT50	6,000	2,878	-	Birge et al. 1983

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Fathead minnow, *Pimephales promelas*	-	Cadmium chloride	254-271	3.7 hr	LT50	16,000	2,965	-	Birge et al. 1983
Fathead minnow (larva), *Pimephales promelas*	-	Cadmium chloride	89-107	7 days	LC50	200	100.9	-	Birge et al. 1983
Fathead minnow (larva), *Pimephales promelas*	-	Cadmium chloride	89-107	7 days	LC50 after 4 days acclimated to 5.6 µg/L	540	272.5	-	Birge et al. 1983
Fathead minnow, *Pimephales promelas*	-	Cadmium chloride	-	4 days	Histological effects	12,000	-	-	Stromberg et al. 1983
Fathead minnow, *Pimephales promelas*	-	Cadmium nitrate	209	48 hr	LC50	802	187.4	-	Slooff et al. 1983
Fathead minnow, *Pimephales promelas*	S, M	Cadmium chloride	55-79	96 hr	LC50	3,390	2,518	-	Spehar and Carlson 1984a,b
Fathead minnow, *Pimephales promelas*	F, M	Cadmium chloride	55-79	96 hr	LC50	1,830	1,359	-	Spehar and Carlson 1984a,b
Fathead minnow (1-7 d), *Pimephales promelas*	R, M, T	Cadmium chloride	70-90	48 hr	LC50	35.4	21.95	-	Diamond et al. 1997
Fathead minnow (embryo, larva), *Pimephales promelas*	F, M, T	Cadmium chloride	101.6	8 days	LC50	125 (20.1°C) 84 (22.8°C) 76 (25.7°C) 87 (27.9°C)	60.80 40.86 36.96 42.31	- - - -	Birge et al. 1985

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Fathead minnow (embryo, larva), *Pimephales promelas*	R, M, T	Cadmium chloride	101.6	8 days	LC50 NOEC	41 12	19.94 5.836	- -	Birge et al. 1985
Fathead minnow (embryo, larva), *Pimephales promelas*	F, M, T	Cadmium chloride	101.6	8 days	LC50 (multiple-species test)	107	52.04	-	Birge et al. 1985
Fathead minnow (30 d), *Pimephales promelas*	F, M, T	Cadmium nitrate	44	96 hr	LC50	13.2	15.03	-	Spehar and Fiandt 1986
Fathead minnow (14-30 d), *Pimephales promelas*	S, U	Cadmium chloride	200	96 hr	LC50	90	21.99	-	Hall et al. 1986
White sucker (larva), *Catostomus commersoni*	R, M, D	Cadmium chloride	48	7 days	46% reduced growth	36	37.53	-	Borgmann and Ralph 1986
Brown bullhead, *Ictalurus nebulosus*	-	Cadmium chloride	-	2 hr	Affected gills and kidney	61,300	-	-	Blickens 1978; Garofano 1979
Channel catfish, *Ictalurus punctatus*	-	Cadmium chloride	-	-	Increased albinism	0.5	-	-	Westerman and Birge 1978
Channel catfish, *Ictalurus punctatus*	-	Cadmium chloride	-	-	BCF = 4.0-6.7	-	-	-	Birge et al. 1979
Channel catfish, *Ictalurus punctatus*	S, M	Cadmium chloride	55-79	96 hr	LC50	7,940	5,897	-	Spehar and Carlson 1984a,b
Walking catfish, *Clarias batrachus*	S, U	Cadmium chloride	-	14 days	60% mortality	8,993	-	-	Jana and Sahana 1989

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Mummichog, *Fundulus heteroclitus*	S, U	Cadmium chloride	5	96 hr	TL50	12.2	126.8	-	Gill and Epple 1992
Mosquitofish, *Gambusia affinis*	-	Cadmium chloride	-	8 wk	BCF = 6,100 at 0.02 µg/L & 1.13 ppm added to food	-	-	-	Williams and Giesy 1978
Mosquitofish, *Gambusia affinis*	-	Cadmium chloride	29	8 wk	BCF = 1,430 at 10 µg/L & 1.13 ppm added to food	-	-	-	Williams and Giesy 1978
Mosquitofish, *Gambusia affinis*	R, M, T	Cadmium sulfate	45	48 hr	LC50	7,260	8,081	-	Chagnon and Guttman 1989
Guppy, *Poecilla reticulata*	-	Cadmium nitrate	209	48 hr	LC50	41,900	9,789	-	Slooff et al. 1983
Guppy, *Lebistes reticulatus*	S, U	Cadmium chloride	140-190	96 hr	LC50 (fry) LC50 (male) LC50 (female)	2,500 12,750 16,000	742.7 3,788 4,753	- - -	Gadkari and Marathe 1983
Threespine stickleback, *Gasterosteus aculeatus*	F, M, T	Cadmium sulfate	299	18 days	Kidney cell tissue breakdown	6,000	1,595	-	Oronsaye 1989
Bluegill, *Lepomis macrochirus*	-	Cadmium chloride	112	80 min	Significant avoidance	>41.1	>18.10	-	Black and Birge 1980
Bluegill, *Lepomis macrochirus*	-	Cadmium chloride	340-360	3 days	Increased cough rate	50	6.916	-	Bishop and McIntosh 1981
Bluegill, *Lepomis macrochirus*	S, M	Cadmium chloride	55-79	96 hr	LC50	8,810	6,543	-	Spehar and Carlson 1984a,b

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Bluegill (juvenile), *Lepomis macrochirus*	F, M, T	Cadmium chloride	134	32 days	NOEC growth	>32.3	>15.56	-	Cope et al. 1994
Bluegill (31.1 ± 1.3 mm), *Lepomis macrochirus*	F, M, T	Cadmium chloride	174	22 days	LOEC prey attack rate	37.3	14.81	-	Bryan et al. 1995
Largemouth bass, *Micropterus salmoides*	-	Cadmium chloride	112	80 min	Significant avoidance	8.83	3.890	-	Black and Birge 1980
Largemouth bass, (embryo, larva) *Micropterus salmoides*	-	Cadmium chloride	99	8 days	EC50 (death and deformity)	1,640	818.9	-	Birge et al. 1978
Largemouth bass, *Micropterus salmoides*	-	-	-	24 hr	Affected opercular activity	150	-	-	Morgan 1979
Largemouth bass, (embryo, larva), *Micropterus salmoides*	F, M, T	Cadmium chloride	101.6	8 days	LC50 (multiple-species test)	244	118.7	-	Birge et al. 1985
Orangethroat darter (embryo), *Etheostoma spectabile*	R, M, T	Cadmium chloride	180	96 hr	LC50	>500	>136.0	-	Sharp and Kaszubski 1989
Tilapia (larva <1 d), *Oreochromis mossambica*	S, U	Cadmium chloride	-	96 hr	LC50	205	-	-	Hwang et al. 1995
Tilapia (larva, 1 d), *Oreochromis mossambica*	S, U	Cadmium chloride	-	96 hr	LC50	83	-	-	Hwang et al. 1995

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
Tilapia (larva, 2 d), *Oreochromis mossambica*	S, U	Cadmium chloride	-	96 hr	LC50	33	-	-	Hwang et al. 1995
Tilapia (larva, 3 d), *Oreochromis mossambica*	S, U	Cadmium chloride	-	96 hr	LC50	22	-	-	Hwang et al. 1995
Tilapia (larva, 7 d), *Oreochromis mossambica*	S, U	Cadmium chloride	-	96 hr	LC50	29	-	-	Hwang et al. 1995
Tilapia (72 hr), *Oreochromis mossambica*	S, U	Cadmium chloride	28	96 hr	LC50	21.4	38.58	-	Chang et al. 1998
Narrow-mouthed toad (embryo, larva), *Gastrophyryne carolinensis*	-	Cadmium chloride	195	7 days	EC50 (death and deformity)	40	10.03	-	Birge 1978
African clawed frog, *Xenopus laevis*	-	Cadmium nitrate	209	48 hr	LC50	11,700	2,733	-	Slooff and Baerselman 1980; Slooff et al. 1983
African clawed frog, *Xenopus laevis*	-	-	170	48 hr	LC50	3,200	922.3	-	Canton and Slooff 1982
African clawed frog, *Xenopus laevis*	-	-	170	100 days	Inhibited development	650	262.5	-	Canton and Slooff 1982
African clawed frog, *Xenopus laevis*	S, U	Cadmium chloride	-	24 hr	LC50 (stage 40)	1,000	-	-	Herkovits et al. 1997

Table 6a. Other Data on Effects of Cadmium on Freshwater Organisms (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH=50 (Total µg/L)	Result Adjusted to TH=50 (Dissolved µg/L)	Reference
					FRESHWATER SPECIES				
African clawed frog, *Xenopus laevis*	S, U	Cadmium chloride	-	72 hr	LC50 (stage 40) LC50 (stage 47)	0.2 1.6	- -	- -	Herkovits et al. 1998
Northwestern salamander (3 mo larva), *Ambystoma gracile*	F, M, T	Cadmium chloride	45	10 days	LOAEC (limb regeneration)	44.6	49.64	-	Nebeker et al. 1994
Northwestern salamander, *Ambystoma gracile*	F, M, T	Cadmium chloride	45	10 days	LOAEL growth	227	252.7	-	Nebeker et al. 1995
Marbled salamander (embryo, larva), *Ambystoma opacum*	-	Cadmium chloride	99	8 days	EC50 (death and deformity)	150	74.90	-	Birge et al. 1978
Lake study, Periphyton and amphipods	S, M, T	Cadmium chloride	-	120 days	BCF = 64,000 (periphyton) BCF = 24,000 (*Hyalella azteca*)	- -	- -	- -	Stephenson and Turner 1993
Stream microcosm	F, M, T	Cadmium nitrate	-	21 days	No effect on periphyton structure, but adverse effect on invertebrate grazers and collectors	22	-	-	Selby et al. 1985

[a] S= static, R= renewal, F= flow-through, M= measured, U= unmeasured, T= total measured concentration, D=dissolved metal concentration measured.
[b] Results are expressed as cadmium, not as the chemical.

Table 6b. Other Data on Effects of Cadmium on Saltwater Organisms

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH = 50 (Total µg/L)	Result (Dissolved µg/L)	Reference
					SALTWATER SPECIES				
Bacterium (Microtox®), *Vibrio fischeri*	S, U	Cadmium nitrate	35	22 hr	EC50	214	-	-	Radix et al. 1999
Natural phytoplankton population	-	Cadmium chloride	-	4 days	Reduced biomass	112	-	-	Hollibaugh et al. 1980
Green alga, *Acetabularia acetabulum*	S, U	Cadmium chloride	-	3 wk	Morphological deformities	100	-	-	Karez et al. 1989
					Decreased cell elongation	1	-	-	
Phytoflagellate, *Olisthodiscus luteus*	S, M, T	Cadmium chloride	-	192 hr	27% biovolume reduction	500	-	-	Fernandez-Leborans and Novillo 1996
Red alga, *Champia parvula*	R, U	Cadmium chloride	28-30	2 days	NOEC sexual reproduction	>100	-	-	Thursby and Steele 1986
Alga, *Tetraselmis gracilis*	S, U	-	-	96 hr	LC50	1,800	-	-	Okamoto et al. 1996
Diatom, *Minutocellus polymorphus*	S, U	Cadmium chloride	-	48 hr	EC50	66	-	-	Walsh et al. 1988
Diatom, *Skeletonema costatum*	S, U	-	-	10 days	EC50 growth	450	-	-	Govindarajan et al. 1993
Diatom, *Skeletonema costatum*	S, U	Cadmium chloride	-	72 hr	EC50	144	-	-	Walsh et al. 1988

Table 6b. Other Data on Effects of Cadmium on Saltwater Organisms (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH = 50 (Total µg/L)	Result (Dissolved µg/L)	Reference
					SALTWATER SPECIES				
Hydroid, *Campanularia flexuosa*	-	-	-	-	Enzyme inhibition	40-75	-	-	Moore and Stebbing 1976
Hydroid, *Campanularia flexuosa*	-	-	-	11 days	Growth rate	110-280	-	-	Stebbing 1976
Rotifer, *Brachionus plicatilis*	S, U	Cadmium chloride	15	24 hr	LC50	54,900	-	-	Snell and Personne 1989b
Rotifer, *Brachionus plicatilis*	S, U	Cadmium chloride	30	24 hr	LC50	56,800	-	-	Snell and Personne 1989b
Rotifer, *Brachionus plicatilis*	S, U	Cadmium nitrate	15	24 hr	LC50	>39,000	-	-	Snell et al. 1991b
Polychaete worm, *Neanthes arenaceodentata*	-	Cadmium chloride	-	28 days	LC50	3,000	-	-	Reish et al. 1976
Polychaete worm, *Capitella capitata*	-	Cadmium chloride	-	28 days	LC50	630	-	-	Reish et al. 1976
Polychaete worm, *Capitella capitata*	-	Cadmium chloride	-	28 days	LC50	700	-	-	Reish et al. 1976
Polychaete worm, *Nereis virens*	R, M	Cadmium chloride	-	144 hr	LC50	170	-	-	McLeese and Ray 1986
Clam, *Macoma balthica*	R, M	Cadmium chloride	-	144 hr	LC50	1,710	-	-	McLeese and Ray 1986
Blue mussel, *Mytilus edulis*	-	Cadmium EDTA	-	28 days	BCF = 252	-	-	-	George and Coombs 1977

Table 6b. Other Data on Effects of Cadmium on Saltwater Organisms (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH = 50 (Total µg/L)	Result (Dissolved µg/L)	Reference
					SALTWATER SPECIES				
Blue mussel, *Mytilus edulis*	-	Cadmium alginate	-	28 days	BCF = 252	-	-	-	George and Coombs 1977
Blue mussel, *Mytilus edulis*	-	Cadmium humate	-	28 days	BCF = 252	-	-	-	George and Coombs 1977
Blue mussel, *Mytilus edulis*	-	Cadmium pectate	-	28 days	BCF = 252	-	-	-	George and Coombs 1977
Blue mussel, *Mytilus edulis*	-	Cadmium chloride	-	21 days	BCF = 710	-	-	-	Janssen and Scholz 1979
Blue mussel, *Mytilus edulis*	F, M, T	Cadmium chloride	28	2 wk	LT50 = 9.5 days (anoxic conditions)	47	-	-	Veldhuizen-Tsoerkan et al. 1991
Bay scallop, *Argopecten irradians*	-	Cadmium chloride	-	42 days	EC50 (growth reduction)	78	-	-	Pesch and Stewart 1980
Bay scallop, *Argopecten irradians*	-	Cadmium chloride	-	21 days	BCF = 168	-	-	-	Eisler et al. 1972
Eastern oyster, *Crassostrea virginica*	-	Cadmium iodide	-	40 days	BCF = 677	-	-	-	Kerfoot and Jacobs 1976
Eastern oyster, *Crassostrea virginica*	-	Cadmium chloride	-	21 days	BCF = 149	-	-	-	Eisler et al. 1972
Eastern oyster, *Crassostrea virginica*	-	Cadmium chloride	-	2 days	Reduction in embryonic development	15	-	-	Zaroogian and Morrison 1981

Table 6b. Other Data on Effects of Cadmium on Saltwater Organisms (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH = 50 (Total µg/L)	Result (Dissolved µg/L)	Reference
				SALTWATER SPECIES					
Pacific oyster, *Crassostrea gigas*	-	Cadmium chloride	-	6 days	50% reduction in settlement	20-25	-	-	Watling 1983b
Pacific oyster, *Crassostrea gigas*	-	Cadmium chloride	-	14 days	Growth reduction	10	-	-	Watling 1983b
Pacific oyster, *Crassostrea gigas*	-	Cadmium chloride	-	23 days	LC50	50	-	-	Watling 1983b
Soft-shell clam, *Mya arenaria*	-	Cadmium chloride	-	7 days	LC50	150	-	-	Eisler 1977
Soft-shell clam, *Mya arenaria*	-	Cadmium chloride	-	7 days	LC50	700	-	-	Eisler and Hennekey 1977
Copepod (nauplius), *Eurytemora affinis*	-	Cadmium chloride	-	1 day	Reduction in swimming speed	130	-	-	Sullivan et al. 1983
Copepod (nauplius), *Eurytemora affinis*	-	Cadmium chloride	-	2 days	Reduction in development rate	116	-	-	Sullivan et al. 1983
Copepod, *Eurytemora affinis*	S, M, T	Cadmium chloride	5 15	96 hr 96 hr	LC50 (fed) LC50 (fed)	51.6 213	- -	- -	Hall et al. 1995
Copepod, *Tisbe holothurlae*	-	Cadmium chloride	-	48 hr	LC50	970	-	-	Moraitou-Apostolopoulou and Verriopoulos 1982
Mysid, *Americamysis bahia*	-	-	15-23	17 days	LC50	11	-	-	Nimmo et al. 1977a

Table 6b. Other Data on Effects of Cadmium on Saltwater Organisms (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH = 50 (Total µg/L)	Result (Dissolved µg/L)	Reference
					SALTWATER SPECIES				
Mysid, *Americamysis bahia*	-	Cadmium chloride	30	16 days	LC50	28	-	-	Gentile et al. 1982
Mysid, *Americamysis bahia*	-	Cadmium chloride	-	8 days	LC50	60	-	-	Gentile et al. 1982
Mysid, *Americamysis bahia*	F, M, T	-	13-29	28 days	NOEC survival, growth and reproduction	4-5	-	-	Voyer and McGovern 1991
Mysid, *Americamysis bahia*	S, M, T	-	12	24 hr	Reduced serum osmolality	3.62	-	-	De Lisle and Roberts 1994
Mysid (8 d), *Americamysis bahia*	R, U	Cadmium chloride	25	96 hr	NOEC survival and growth	5	-	-	Khan et al. 1992
				7 days	NOEC survival and growth	5	-	-	
Mysid (<72 hr), *Americamysis bahia*	F, M, T	-	10	96 hr	LC50	47.0 (20°C)	-	-	Voyer and Modica 1990
						15.5 (25°C)	-	-	
Mysid (<72 hr), *Americamysis bahia*	F, M, T	-	20	96 hr	LC50	73.0 (20°C)	-	-	Voyer and Modica 1990
						20.5 (25°C)	-	-	
Mysid (<72 hr), *Americamysis bahia*	F, M, T	-	30	96 hr	LC50	85.0 (20°C)	-	-	Voyer and Modica 1990
						28.0 (25°C)	-	-	

Table 6b. Other Data on Effects of Cadmium on Saltwater Organisms (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH = 50 (Total µg/L)	Result (Dissolved µg/L)	Reference
				SALTWATER SPECIES					
Mysid, *Mysidopsis bigelowi*	-	Cadmium chloride	-	8 days	LC50	70	-	-	Gentile et al. 1982
Mysid, *Mysidopsis bigelowi*	-	Cadmium chloride	-	28 days	LC50	18	-	-	Gentile et al. 1982
Isopod, *Idotea baltica*	-	Cadmium sulfate	3	5 days	LC50	10,000	-	-	Jones 1975
Isopod, *Idotea baltica*	-	Cadmium sulfate	21	3 days	LC50	10,000	-	-	Jones 1975
Isopod, *Idotea baltica*	-	Cadmium sulfate	14	1.5 days	LC50	10,000	-	-	Jones 1975
Sand shrimp, *Crangon septemspinosa*	R, M	Cadmium chloride	-	144 hr	LC50	1,160	-	-	McLeese and Ray 1986
Pink shrimp, *Pandalus montagui*	R, M	Cadmium chloride	-	144 hr	LC50	1,280	-	-	McLeese and Ray 1986
Pink shrimp, *Penaeus duorarum*	-	Cadmium chloride	-	30 days	LC50	720	-	-	Nimmo et al. 1977b
White shrimp, *Penaeus setiferus*	S, M, T	Cadmium chloride	11	96 hr	LC50	990	-	-	Vanegas et al. 1997
Grass shrimp, *Palaemonetes pugio*	-	Cadmium chloride	-	42 days	LC50	300	-	-	Pesch and Stewart 1980
Grass shrimp, *Palaemonetes pugio*	-	Cadmium chloride	5	21 days	LC25	50	-	-	Vernberg et al. 1977

Table 6b. Other Data on Effects of Cadmium on Saltwater Organisms (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH = 50 (Total µg/L)	Result (Dissolved µg/L)	Reference
				SALTWATER SPECIES					
Grass shrimp, *Palaemonetes pugio*	-	Cadmium chloride	10	21 days	LC10	50	-	-	Vernberg et al. 1977
Grass shrimp, *Palaemonetes pugio*	-	Cadmium chloride	20	21 days	LC5	50	-	-	Vernberg et al. 1977
Grass shrimp, *Palaemonetes pugio*	-	Cadmium chloride	10	6 days	LC75	300	-	-	Middaugh and Floyd 1978
Grass shrimp, *Palaemonetes pugio*	-	Cadmium chloride	15	6 days	LC50	300	-	-	Middaugh and Floyd 1978
Grass shrimp, *Palaemonetes pugio*	-	Cadmium chloride	30	6 days	LC25	300	-	-	Middaugh and Floyd 1978
Grass shrimp, *Palaemonetes pugio*	-	Cadmium chloride	-	21 days	BCF = 140	-	-	-	Vernberg et al. 1977
Grass shrimp, *Palaemonetes pugio*	-	Cadmium chloride	-	29 days	LC50	120	-	-	Nimmo et al. 1977b
American lobster, *Homarus americanus*	-	Cadmium chloride	-	21 days	BCF = 25	-	-	-	Eisler et al. 1972
American lobster, *Homarus americanus*	-	Cadmium chloride	-	30 days	Increase in ATPase activity	6	-	-	Tucker 1979
Hermit crab, *Pagurus longicarpus*	-	Cadmium chloride	-	7 days	25% mortality	270	-	-	Eisler and Hennekey 1977
Hermit crab, *Pagurus longicarpus*	-	Cadmium chloride	-	60 days	LC56	70	-	-	Pesch and Stewart 1980

Table 6b. Other Data on Effects of Cadmium on Saltwater Organisms (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH = 50 (Total µg/L)	Result (Dissolved µg/L)	Reference
					SALTWATER SPECIES				
Yellow crab, *Cancer anthonyi*	R, U	Cadmium chloride	34	7 days	28% mortality	1,000	-	-	Macdonald et al. 1988
Rock crab, *Cancer irroratus*	-	Cadmium chloride	-	96 hr	Enzyme activity	1,000	-	-	Gould et al. 1976
Rock crab (larva), *Cancer irroratus*	-	Cadmium chloride	-	28 days	Delayed development	50	-	-	Johns and Miller 1982
Blue crab, *Callinectes sapidus*	-	Cadmium nitrate	10	7 days	LC50	50	-	-	Rosenberg and Costlow 1976
Blue crab, *Callinectes sapidus*	-	Cadmium nitrate	30	7 days	LC50	150	-	-	Rosenberg and Costlow 1976
Blue crab (juvenile), *Callinectes sapidus*	-	Cadmium chloride	1	4 days	LC50	320	-	-	Frank and Robertson 1979
Blue crab, *Callinectes sapidus*	R, M, T	Cadmium chloride	2.5 25	21 days 21 days	LC50 LC50	19 186	- -	- -	Guerin and Stickle 1995
Blue crab, *Callinectes sapidus*	S, M, T	Cadmium chloride	28	6-8 days	EC50 hatching	0.25	-	-	Lee et al. 1996
Mud crab (larva), *Eurypanopeus depressus*	-	Cadmium chloride	-	8 days	LC50	10	-	-	Mirkes et al. 1978
Mud crab (larva), *Eurypanopeus depressus*	-	Cadmium chloride	-	44 days	Delay in metamorphysis	10	-	-	Mirkes et al. 1978
Mud crab, *Rhithropanopeus harasil*	-	Cadmium nitrate	10	11 days	LC80	50	-	-	Rosenberg and Costlow 1976

Table 6b. Other Data on Effects of Cadmium on Saltwater Organisms (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH = 50 (Total µg/L)	Result (Dissolved µg/L)	Reference
					SALTWATER SPECIES				
Mud crab, *Rhithropanopeus harasil*	-	Cadmium nitrate	20	11 days	LC75	50	-	-	Rosenberg and Costlow 1976
Mud crab, *Rhithropanopeus harasil*	-	Cadmium nitrate	30	11 days	LC40	50	-	-	Rosenberg and Costlow 1976
Fiddler crab, *Uca pugilator*	-	-	-	10 days	LC50	2,900	-	-	O'Hara 1973a
Fiddler crab, *Uca pugilator*	-	Cadmium chloride	-	-	Effect on respiration	1.0	-	-	Vernberg et al. 1974
Starfish, *Asterias forbesi*	-	Cadmium chloride	-	7 days	25% mortality	270	-	-	Eisler and Hennekey 1977
Sea urchin, *Arbacia punctulata*	S, U	Cadmium chloride	30	1 hr	EC50 (sperm cell)	38,000	-	-	Nacci et al. 1986
				4 hr	EC50 (embryo growth	13,900	-	-	
Green sea urchin, *Strongylocentrotus droebachiensis*	S, M, T	Cadmium chloride	30	80 min	EC50 (sperm- fert.)	26,000	-	-	Dinnel et al. 1989
Red sea urchin, *Strongylocentrotus franciscanus*	S, M, T	Cadmium chloride	30	80 min	EC50 (sperm- fert.)	12,000	-	-	Dinnel et al. 1989
Purple sea urchin, *Strongylocentrotus purpuratus*	S, M, T	Cadmium chloride	30	80 min	EC50 (sperm- fert.)	18,000	-	-	Dinnel et al. 1989

Table 6b. Other Data on Effects of Cadmium on Saltwater Organisms (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH = 50 (Total µg/L)	Result (Dissolved µg/L)	Reference
					SALTWATER SPECIES				
Purple sea urchin, *Strongylocentrotus purpuratus*	S, U	Cadmium chloride	30	40 min	NOEC sperm-fertilization	>67	-	-	Bailey et al. 1995
Sand dollar, *Dendraster excentricus*	S, M, T	Cadmium chloride	30	80 min	EC50 (sperm- fert.)	8,000	-	-	Dinnel et al. 1989
Sand dollar, *Dendraster excentricus*	S, U	Cadmium chloride	30	40 min	NOEC sperm-fertilization	>67	-	-	Bailey et al. 1995
Herring (larva), *Clupea harengus*	-	Cadmium chloride	-	-	100% embryonic survival	5,000	-	-	Westernhagen et al. 1979
Pacific herring (embryo), *Clupea harengus pallasi*	-	Cadmium chloride	-	<24 hr	17% reduction in volume	10,000	-	-	Alderdice et al. 1979a
Pacific herring (embryo), *Clupea harengus pallasi*	-	Cadmium chloride	-	96 hr	Decrease in capsule strength	1,000	-	-	Alderdice et al. 1979b
Pacific herring (embryo), *Clupea harengus pallasi*	-	Cadmium chloride	-	48 hr	Reduced osmolality of periviteline fluid	1,000	-	-	Alderdice et al. 1979c
Sheepshead minnow, *Cyprinodon variegatus*	R, M, T	Cadmium chloride	34-35	96 hr 7 days	LC50 (fed) NOEC survival and growth	1,230 560	- -	- -	Hutchinson et al. 1994
Sheepshead minnow, *Cyprinodon variegatus*	S, M, T, D	Cadmium chloride	5 15 25	96 hr 96 hr 96 hr	LC50 (fed) LC50 (fed) LC50 (fed)	180 312 496	- - -	- - -	Hall et al. 1995

Table 6b. Other Data on Effects of Cadmium on Saltwater Organisms (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH = 50 (Total µg/L)	Result (Dissolved µg/L)	Reference
				SALTWATER SPECIES					
Mummichog (adult), *Fundulus heteroclitus*	-	Cadmium chloride	20	48 hr	LC50	60,000	-	-	Middaugh and Dean 1977
Mummichog (adult), *Fundulus heteroclitus*	-	Cadmium chloride	30	48 hr	LC50	43,000	-	-	Middaugh and Dean 1977
Mummichog, *Fundulus heteroclitus*	-	Cadmium chloride	-	21 days	BCF = 48	-	-	-	Eisler et al. 1972
Mummichog (larva), *Fundulus heteroclitus*	-	Cadmium chloride	20	48 hr	LC50	32,000	-	-	Middaugh and Dean 1977
Mummichog (larva), *Fundulus heteroclitus*	-	Cadmium chloride	30	48 hr	LC50	7,800	-	-	Middaugh and Dean 1977
Mummichog (<23 d), *Fundulus heteroclitus*	S, M, T	Cadmium chloride	10	48 hr	LC50	44,400	-	-	Burton and Fisher 1990
Atlantic silverside (adult), *Menidia menidia*	-	Cadmium chloride	20	48 hr	LC50	13,000	-	-	Middaugh and Dean 1977
Atlantic silverside (adult), *Menidia menidia*	-	Cadmium chloride	30	48 hr	LC50	12,000	-	-	Middaugh and Dean 1977
Atlantic silverside, *Menidia menidia*	-	Cadmium chloride	12	19 days	LC50	<160	-	-	Voyer et al. 1979
Atlantic silverside, *Menidia menidia*	-	Cadmium chloride	20	19 days	LC50	540	-	-	Voyer et al. 1979

Table 6b. Other Data on Effects of Cadmium on Saltwater Organisms (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH = 50 (Total µg/L)	Result (Dissolved µg/L)	Reference
					SALTWATER SPECIES				
Atlantic silverside, *Menidia menidia*	-	Cadmium chloride	30	19 days	LC50	>970	-	-	Voyer et al. 1979
Atlantic silverside (larva), *Menidia menidia*	-	Cadmium chloride	20	48 hr	LC50	2,200	-	-	Middaugh and Dean 1977
Atlantic silverside (larva), *Menidia menidia*	-	Cadmium chloride	30	48 hr	LC50	1,600	-	-	Middaugh and Dean 1977
Striped bass (juvenile), *Morone saxatilis*	-	Cadmium chloride	-	90 days	Significant decrease in enzyme activity	5	-	-	Dawson et al. 1977
Striped bass (juvenile), *Morone saxatilis*	-	Cadmium chloride	-	30 days	Significant decrease in oxygen consumption	0.5-5.0	-	-	Dawson et al. 1977
Spot (larva), *Leiostomus xanthurus*	-	Cadmium chloride	-	9 days	Incipient LC50	200	-	-	Middaugh and Dean 1977
Cunner (adult), *Tautogolabrus adspersus*	-	Cadmium chloride	-	60 days	37.5% mortality	100	-	-	MacInnes et al. 1977
Cunner (adult), *Tautogolabrus adspersus*	-	Cadmium chloride	-	30 days	Depressed gill tissue oxygen consumption	50	-	-	MacInnes et al. 1977
Cunner (adult), *Tautogolabrus adspersus*	-	Cadmium chloride	-	96 hr	Decreased enzyme activity	3,000	-	-	Gould and Karolus 1974

Table 6b. Other Data on Effects of Cadmium on Saltwater Organisms (Continued)

Species	Method[a]	Chemical	Salinity (g/kg)	Duration	Effect	Result (Total µg/L)[b]	Result Adjusted to TH = 50 (Total µg/L)	Result (Dissolved µg/L)	Reference
					SALTWATER SPECIES				
Winter flounder, *Pseodopleuronectes americanus*	-	Cadmium chloride	-	8 days	50% viable hatch	300	-	-	Voyer et al. 1977
Winter flounder, *Pseodopleuronectes americanus*	-	Cadmium chloride	-	60 days	Increased gill tissue respiration	5	-	-	Calabrese et al. 1975
Winter flounder, *Pseodopleuronectes americanus*	-	Cadmium chloride	-	17 days	Reduction of viable hatch	586	-	-	Voyer et al. 1982

[a] S= static, R= renewal, F= flow-through, M= measured, U= unmeasured, T= total measured concentration, D=dissolved metal concentration measured.
[b] Results are expressed as cadmium, not as the chemical.

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