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Ambient Water Quality Criteria for

Cadmium - 1984

AMBIENT AQUATIC LIFE WATER QUALITY CRITERIA FOR

CADMIUM

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FOREWORD

Section 304(a)(1) of the Clean Water Act of 1977 (P.L. 95-217) requires the Administrator of the Environmental Protection Agency to publish criteria for water quality accurately reflecting the latest scientific knowledge on the kind and extent of all identifiable effects on health and welfare which may be expected from the presence of pollutants in any body of water, including ground water. This document is a revision of proposed criteria based upon a consideration of comments received from other Federal agencies, State agencies, special interest groups, and individual scientists. The criteria contained in this document replace any previously published EPA aquatic life criteria.

The term "water quality criteria" is used in two sections of the Clean Water Act, section 304(a)(1) and section 303(c)(2). The term has a different program impact in each section. In section 304, the term represents a non-regulatory, scientific assessment of ecological effects. The criteria presented in this publication are such scientific assessments. Such water quality criteria associated with specific stream uses when adopted as State water quality standards under section 303 become enforceable maximum acceptable levels of a pollutant in ambient waters. The water quality criteria adopted in the State water quality standards could have the same numerical limits as the criteria developed under section 304. However, in many situations States may want to adjust water quality criteria developed under section 304 to reflect local environmental conditions and human exposure patterns before incorporation into water quality standards. It is not until their adoption as part of the State water quality standards that the criteria become regulatory.

Guidelines to assist the States in the modification of criteria presented in this document, in the development of water quality standards, and in other water-related programs of this Agency, have been developed by EPA.

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Introduction*

In natural fresh waters cadmium sometimes occurs at concentrations of less than 0.01 µg/L, but in environments impacted by man, concentrations can be several micrograms per liter or greater. The impact of cadmium on aquatic organisms depends on a variety of possible chemical forms of cadmium (Callahan, et al. 1979), which might have different toxicities and bioconcentration factors. In most well oxygenated fresh waters 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 salt waters with salinities from about 10 to 35 g/kg, cadmium chloride complexes predominate. In both fresh and salt waters particulate matter and dissolved organic material may bind a substantial portion of the cadmium.

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. Acid-soluble cadmium (operationally defined as the cadmium that passes through a 0.45 µm membrane filter after the sample is acidified to pH = 1.5 to 2.0 with

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*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.

nitric acid) is probably the best measurement at the present for the following reasons:

1. This measurement is compatible with all available data concerning toxicity of cadmium to, and bioaccumulation of cadmium by, aquatic organisms. No test results were rejected just because it was likely that they would have been substantially different if they had been reported in terms of acid-soluble cadmium. For example, results reported in terms of dissolved cadmium would not have been used if the concentration of precipitated cadmium was substantial.
2. On samples of ambient water, measurement of acid-soluble cadmium should measure all forms of cadmium that are toxic to aquatic life or can be readily converted to toxic forms under natural conditions. In addition, this measurement should not measure several forms, such as cadmium that is occluded in minerals, clays, and sand or is strongly sorbed to particulate matter, that are not toxic and are not likely to become toxic under natural conditions. Although this measurement (and many others) will measure soluble, complexed forms of cadmium, such as the EDTA complex of cadmium, that probably have low toxicities to aquatic life, concentrations of these forms probably are negligible in most ambient water.
3. Although water quality criteria apply to ambient water, the measurement used to express criteria is likely to be used to measure cadmium in aqueous effluents. Measurement of acid-soluble cadmium should be applicable to effluents because it will measure precipitates, such as carbonate and hydroxide precipitates of cadmium, that might exist in an effluent and dissolve when effluent is diluted with receiving water. If desired, dilution of effluent with receiving water before measurement of

acid-soluble cadmium might be used to determine whether the receiving water can decrease the concentration of acid-soluble cadmium because of sorption.

4. The acid-soluble measurement should be useful for most metals, thus minimizing the number of samples and procedures that are necessary.
5. The acid-soluble measurement does not require filtration at the time of collection, as does the dissolved measurement.
6. The only treatment required at the time of collection is preservation by acidification to pH = 1.5 to 2.0, similar to that required for the total recoverable measurement.
7. Durations of 10 minutes to 24 hours between acidification and filtration probably will not affect the result substantially.
8. The carbonate system has a much higher buffer capacity from pH = 1.5 to 2.0 than it does from pH = 4 to 9 (Weber and Stumm, 1963).
9. Differences in pH within the range of 1.5 to 2.0 probably will not affect the result substantially.
10. The acid-soluble measurement does not require a digestion step, as does the total recoverable measurement.
11. After acidification and filtration of the sample to isolate the acid-soluble cadmium, the analysis can be performed using either atomic absorption spectroscopy or ICP-emission spectroscopy (U.S. EPA, 1983a), as with the total recoverable measurement.

Thus, expressing aquatic life criteria for cadmium in terms of the acid-soluble measurement has both toxicological and practical advantages. On the other hand, because no measurement is known to be ideal for expressing aquatic life criteria for cadmium or for measuring cadmium in ambient water or aqueous effluents, measurement of both acid-soluble cadmium and total recoverable cadmium in ambient water or effluent or both might be useful. For example, there might be cause for concern if total recoverable cadmium is much above an applicable limit, even though acid-soluble cadmium is below the limit.

Unless otherwise noted, all concentrations reported herein are expected to be essentially equivalent to acid-soluble cadmium concentrations. All concentrations are expressed as cadmium, not as the chemical tested. The criteria presented herein supersede previous aquatic life water quality criteria for cadmium (U.S. EPA, 1976, 1980) because these new criteria were derived using improved procedures and additional information. Whenever adequately justified, a national criterion may be replaced by a site-specific criterion (U.S. EPA, 1983b), which may include not only site-specific criterion concentrations (U.S. EPA, 1983c), but also site-specific durations of averaging periods and site-specific frequencies of allowed exceedences (U.S. EPA, 1985). The latest literature search for information for this document was conducted in May, 1984; some newer information was also used.

Acute Toxicity to Aquatic Animals

Carroll, et al. (1979) found that calcium, but not magnesium, reduced the acute toxicity of cadmium. 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.

The available acute values for both striped bass and brook trout covered such a wide range that data for these species were not used in the calculation of the Final Acute Value. Drummond and Benoit (Manuscript) reported that stress greatly affected the sensitivity of brook trout to cadmium.

Different species exhibit different sensitivities to cadmium, and many other factors might affect the results of tests of the toxicity of cadmium to aquatic organisms. Criteria can quantitatively take into account such a factor, however, only if 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. Hardness is used here as a surrogate for the ions which affect the results of toxicity tests on cadmium. An analysis of covariance (Dixon and Brown, 1979; Neter and Wasserman, 1974) was performed using the natural logarithm of the acute value as the dependent variable, species as the treatment or grouping variable, and natural logarithm of hardness as the covariate or independent variable. This analysis of covariance model was fit to the data in Table 1 for the five species for which acute 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 100 mg/L higher than the lowest. For the fathead minnow the data from Birge, et al. (1983), Pickering and Gast (1972), Pickering and Henderson (1966), and Spehar and Carlson (1984a,b) were used, but those from Spehar (1982) using a more sensitive life stage were not. The slopes for the four fishes ranged from 0.868 to 1.564 and the pooled slope for these four species was 1.125 (see end of Table 1). An F-test showed that, under the assumption of equality of slopes, the probability of obtaining four slopes as dissimilar as these is P=0.44. This was interpreted as indicating that it is reasonable to assume that the slopes for these four species are the same.

All of the data available for Daphnia magna gave a slope of -0.145, but the data from Chapman, et al. (Manuscript) gave a slope of 1.182. The pooled slope for the four fishes and all the data for D. magna was 0.975, whereas using only data from Chapman, et al. (Manuscript) the pooled slope was 1.128. The test for equality of the five slopes produced P=0.04 when all the data for D. magna were used, but P=0.54 when only the data from Chapman, et al. (Manuscript) were used. Both pooled slopes are close to the value of 1.0 that is expected on the basis that cadmium, calcium, magnesium, and carbonate all have a charge of two. However, because of the much higher value of P for equality of slopes, it seems reasonable to use only the data from Chapman, et al. (Manuscript) for D. magna and the pooled slope of 1.128.

The pooled slope of 1.128 was then used with the data in Table 1 to calculate Species Mean Acute Values at a hardness of 50 mg/L (Table 1). Only the data from Chapman, et al. (Manuscript) were used for Daphnia magna and only the data from Spehar (1982) were used for the fathead minnow, to protect this sensitive life stage. Genus Mean Acute Values were then calculated (Table 3) as geometric means of the available Species Mean Acute Values. Of the 44 genera for which values are available, the most sensitive genus, Salmo, is 3,400 times more sensitive than the most resistant, Carassius. Both the most sensitive and the most resistant genera are fishes. Acute values are available for more than one species in seven genera, and the range of Species Mean Acute Values within each genus is less than a factor of 5.2. The freshwater Final Acute Value was calculated to be 8.917 μg/L at a hardness of 50 mg/L from the Genus Mean Acute Values in Table 3 using the procedure described in the Guidelines. The Species Mean Acute Values for four salmonids are lower, but the acute value for brown trout is from a static test, whereas flow-through tests have been conducted with the other three species. The Final Acute Value at a hardness of 50 mg/L was lowered to 3.589 µg/L to protect the important rainbow trout (Table 3). Thus, the freshwater Criterion Maximum Concentration (in µg/L) = $e^{(1.128[\ln(\text{hardness})]-3.828)}$.

The acute values for saltwater invertebrate species range from 41.29 µg/L for a mysid to 135,000 µg/L for an oligochaete worm (Tables 1 and 3). The acute values for adult saltwater polychaetes range from 7,500 µg/L for Capitella capitata to 12,000 µg/L for Neanthes arenaceodentata (Reish et al., 1976), but the larvae of C. capitata are thirty-seven times more sensitive than the adults. 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.

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. The LC50 at the very low salinity is in Table 6 and was not used in deriving criteria. 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. Studies with Mysidopsis bahia by Gentile, et al. (1982) and Nimmo, et al. (1977a) also support a relationship between salinity and the acute toxicity of cadmium.

Saltwater fish species were generally more resistant to cadmium than freshwater fish species with acute values ranging from 779.8 µg/L for the Atlantic silverside to 50,570 µg/L for the mummichog. In a study of the interaction of dissolved oxygen and salinity on the acute toxicity of cadmium to the mummichog, Voyer (1975) found that the 96-hr LC50 at a salinity of 30 g/kg was about one-half what it was 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.

Of the 33 saltwater genera for which acute values are available, the most sensitive, Mysidopsis, is 2,000 times more sensitive than the most resistant, Monopylephorus (Table 3). Acute values are available for more than one species in each of four genera, and the range of Species Mean Acute Values within each genus is less than a factor of 3.3. The saltwater Final Acute Value calculated from the Genus Mean Acute Values in Table 3 is 85.09 µg/L. This Final Acute Value is slightly above the Species Mean Acute Value of 78 µg/L for the American lobster, which is from a static toxicity test in which the concentrations were measured.

Chronic Toxicity to Aquatic Animals

Chronic toxicity tests have been conducted on cadmium with sixteen species, including four invertebrates and twelve fishes, in thirteen genera. Several related values are in Table 6. In a 21-day test in which the test concentrations were not measured, Biesinger and Christensen (1972) found a 16% 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. The 200-hr LC10 of 0.7 µg/L obtained with rainbow trout (Table 6) 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 or less (Table 6). These species include decomposers (Giesy, 1978), crayfish (Thorp, et al. 1979), copepods and annelids (Giesy, et al. 1979), midges (Anderson, et al. 1980), and mayflies (Spehar, et al. 1978).

Chronic values are available over a wide range of hardness for two species (Table 2). Regression of the natural logarithm of the chronic value against the natural logarithm of hardness (similar to the regressions performed on the acute data) gave a slope of 0.77 for Daphnia magna and a slope of 0.81 for the fathead minnow. These two slopes are very similar, and the pooled slope for the two species is 0.7852, with 95% confidence limits of 0.4190 and 1.1514.

On the other hand, the acute-chronic ratios ranged from 0.9021 for the chinook salmon to 433.8 for the flagfish, with other values scattered throughout this range (Tables 2 and 3). These ratios do not seem to follow a pattern (Table 3), and so it does not seem reasonable to use a freshwater Final Acute-Chronic Ratio to calculate a Final Chronic Value.

Although a Final Chronic Value cannot be calculated using a Final Acute-Chronic Ratio, the close agreement between the two slopes and the large variety of species with which chronic tests have been conducted make possible the calculation of the Final Chronic Value in the same way the Final Acute Value was calculated. The slope of 0.7852 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. Sixteen Species Mean Chronic Values were then calculated, and from these, the thirteen Genus Mean Chronic Values were calculated and ranked (Table 2). A Final Chronic Value was calculated from the thirteen Genus Mean Acute Values using the procedure used to calculate a Final Acute Value. However, because the thirteen Genus Mean Chronic Values contain values for five of the six freshwater genera that are acutely most sensitive to cadmium, it seemed more appropriate to calculate the Final Chronic Value using N = 44, rather than N = 13 (Table 2). Thus, the freshwater Final Chronic Value for cadmium is 0.6582 µg/L at a hardness of 50 mg/L, and the Final Chronic Value (in µg/L) = $e^{(0.7852[\ln(\text{hardness})]-3.490)}$. At a hardness of 50 mg/L the Genus Mean Chronic Values for both Moina and Daphnia are below the Final Chronic Value.

Two chronic toxicity tests have been conducted with the saltwater invertebrate, Mysidopsis bahia (Table 2). 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% at 10.6 µg/L, 84% at the next lower test concentration of 6.4 µg/L, and 95% 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 Mysidopsis 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. Manuscript). All organisms died in 28 days at 23 ug/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 borne 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. 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 6). The observed differences in acute toxicity to the mysids might be explained on this basis. Nimmo, et al. (1977a) conducted their acute test at 25 to 28 C and salinity of 10 to 17 g/kg, whereas the other test was performed at 21 C and salinity of 30 g/kg.

Gentile, et al. (1982) also conducted a life-cycle test with another mysid, *Mysidopsis bigelowi*, and the results were identical to those for *M. 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 3) have Species Mean Acute Values very close to the saltwater Final Acute Value and so it seems reasonable to use the geometric mean of these two ratios. When the Final Acute Value of 85.09 µg/L is divided by the mean acute-chronic ratio of 9.105, a saltwater Final Chronic Value of 9.345 µg/L is obtained.

Toxicity to Aquatic Plants

Growth reduction was the major toxic effect observed with freshwater aquatic plants (Table 4), 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. Because the lowest toxicity values for fish and invertebrate species are lower than the lowest values for plants, water quality criteria which protect freshwater animals should also protect freshwater plants.

Toxicity values are available for three species of saltwater diatoms and two species of macroalgae (Table 4). Concentrations causing fifty percent reductions in the growth rates of diatoms range from 60 µg/L for Ditylum brightwelli to 175 µg/L for Skeletonema costatum. The brown macroalga (kelp) was the least sensitive to cadmium with an EC50 of 860 µg/L. The most sensitive 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. This plant is more resistant than the chronically most sensitive animal species tested. Therefore, water quality criteria for cadmium that protect saltwater animals should also protect saltwater plants.

Bioaccumulation

Bioconcentration factors (BCFs) for cadmium in fresh water (Table 5) range from 3 for brook trout muscle (Benoit, et al. 1976) to 12,400 for the whole body of mosquitofish (Giesy, et al. 1977). Usually, fish accumulate only small amounts of cadmium in muscle as compared to most other tissues and organs (Benoit, et al. 1976; Sangalang and Freeman, 1979). Also, cadmium residues in fish reach steady-state only after exposure periods greatly exceeding 28 days (Benoit, et al. 1976; Giesy, et al. 1977; Sangalang and Freeman, 1979). Daphnia 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. Poldoski (1979) reported that humic acid decreased the uptake of cadmium by Daphnia 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 6). 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 5). 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 five species of bivalve molluscs range from 113 for the blue mussel (George and Combs, 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 6) as well as 1,220 and 2,600 (Table 5). 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 5 and 6). 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 6) was bioconcentrated at twice the rate of inorganic cadmium (Table 5). Because bivalve molluscs usually do not reach steadystate, comparisons between species may be difficult and the length of exposure may be the major determinant in the size of the BCF.

BCFs for six species of crustaceans range from 22 to 307 for whole body and from 5 to 25 for muscle (Table 6). 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, whereas Pesch and Stewart (1980) reported a BCF of 42 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.

Mallard ducks are the only 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 Table 4. 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. Division of 200 mg/kg by the geometric mean BCF of 648.6 gives a freshwater Final Residue Value of 308.4 µg/L. Similarly, division of 200 mg/kg by the saltwater geometric mean BCF of 225.7 results in a saltwater Final Residue Value of 886.1 µg/L. These are concentrations which would cause damage to mallard ducks, but no additional data are available.

Although a high degree of variability exists between the BCFs reported for saltwater species, shellfish that are consumed by humans can accumulate high concentrations of cadmium. The emetic threshold of cadmium is 13 to 15 mg/kg of weight of human consumers (Anon., 1950). The highest reported BCF for the edible portion of a consumed species is 2,150. Even using this highest BCF, a person who weighed 70 kg would have to eat about 50 kg of oysters that had been exposed to the saltwater Final Chronic Value of 8.695 µg/L in order to reach the emetic threshold.

Other Data

Cadmium-binding proteins were isolated from Amoeba proteus (Al-atia, 1978, 1980) and rainbow trout (Roberts, et al. 1979). The cumulative mortality resulting from exposure to cadmium for more than 96 hours is clearly evident from the studies with 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). Nimmo et al. (1977a) in studies with the mysid, Mysidopsis 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 15 to 23 g/kg. In another series of studies with this mysid (Gentile, et al. 1982), the 96-hr LC50 was 105 µg/L (Table 1) and the 28-day LC50 was 16 µg/L (Table 6) 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. This pattern was also reflected in the similarity of reproductive effects on this species (Table 2) tested under dissimilar environmental conditions.

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 salinity of 25 g/kg the toxicity of cadmium decreased as temperature increased.

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 6). Significant reduction in gill tissue respiratory rate and alteration of liver enzyme activity 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 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

Some data on the effects of cadmium on aquatic organisms were not used because the studies were conducted with species that are not resident in North America, e.g., Ahsanullah, et al. (1981), Castille and Lawrence (1981), D'Agostino and Finney (1974), Greenwood and Fielder (1983), Kobayashi (1971), McClurg (1984), Metayer, et al. (1982), Negilski (1976), Ojaveer, et al. (1980), Rainbow, et al. (1980), Sastry and Sunita (1982), Theede, et al. (1979), Verriopoulos and Moraitou-Apostolopoulou (1981, 1982), Westernhagen and Dethlefsen (1975), and Westernhagen, et al. (1975, 1978). Brown and Ahsanullah (1971) conducted tests with a brine shrimp, which species is too atypical to be used in deriving national criteria.

Data were also not used if cadmium was a component of a mixture (Stern and Stern, 1980; Wong, et al. 1982). Reviews by Chapman, et al. (1968), Eisler (1981), Eisler, et al. (1979), Phillips and Russo (1978), and Thompson, et al. (1972) only contain data that have been published elsewhere.

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). Data in publications such as Ball (1967), Burnison, et al. (1975), Canton and Slooff (1979), Department of the Environment (1973), Fennikoh, et al. (1978), Landner and Jernelov (1969), Maas (1978), Ministry of Technology (1967), Shcherban (1977), Tarzwell and Henderson (1960), and Verma, et al. (1980) were not used because either the materials, methods, or results were insufficiently described. High control mortalities occurred in all except one test reported by Sauter, et al. (1976). 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. Algal studies were not used if they were not conducted in an appropriate medium (Stary and Kratzer, 1982; Stary, et al. 1983) or if the medium contained too much of a complexing agent such as EDTA (Lue-Kim, et al. 1980; Muller and Payer, 1979). Some papers were omitted because of questionable treatment of test organisms or inappropriate test conditions or methodology (e.g., 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; Peton and Powell, 1981; Ridlington, et al. 1981; Sunda, et al. 1978; Wikfors and Ukeles, 1982).

Data on bioconcentration by aquatic organisms were not used if the test was conducted in distilled water, was not long enough, was not flow-through, or if the concentrations in water were not adequately measured (e.g., Beattie and Pascoe, 1978; Bjerregaard, 1982; Burrell and Weihs, 1983; Carmichael and Fowler, 1981; Carr and Neff, 1982; Davies, et al. 1981; Denton and Burdon-Jones, 1981; Fair and Sick, 1983; Frazier and George, 1983; Freeman, 1978, 1980; Kerfoot and Jacobs, 1976; Kohler and Riisgard, 1982; McLeese and Ray, 1984; Muramoto, 1980; Nolan and Duke, 1983; Oakley, et al. 1983; Poulsen, et al. 1982; Ray, et al. 1981; Reichert, et al. 1979; Rubinstein, et al. 1983; Stary, et al. 1982; Watling, 1983a; White and Rainbow, 1982; Windom, et al. 1982; Yager and Harry, 1964). 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 acute values for cadmium are available for species in 44 genera and range from 1.0 µg/L for rainbow trout to 28,000 µg/L for a mayfly. The antagonistic effect of hardness on acute toxicity has been demonstrated with five species. Chronic tests have been conducted on cadmium with twelve freshwater fish species and four invertebrate species with chronic values ranging from 0.15 µg/L for *Daphnia magna* to 156 µg/L for the Atlantic salmon. Acute-chronic ratios are available for eight 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 7,400 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 fresh water range from 164 to 4,190 for invertebrates and from 3 to 2,213 for fishes.

Saltwater acute values for cadmium and five species of fishes range from 577 µg/L for larval Atlantic silverside to 114,000 µg/L for juvenile mummichog. Acute values for thirty species of invertebrates range from 15.5 µg/L for a mysid to 135,000 µg/L for an oligochaete worm. The acute toxicity of cadmium generally increases as salinity decreases. The effect of temperature seems to be species-specific. Two life-cycle tests with *Mysidopsis bahia* under different test conditions resulted in similar chronic values of 8.2 and 7.1 µg/L, but the acute-chronic ratios were 1.9 and 15, respectively. The acute values appear to reflect effects of salinity and temperature, whereas the few available chronic values apparently do not. A life-cycle test with *Mysidopsis bigelowi* also resulted in a chronic value of

7.1 μg/L and an acute-chronic ratio of 15. Studies with microalgae and macroalgae revealed effects at 22.8 to 860 μg/L.

BCFs determined with a variety of saltwater invertebrates range from 5 to 3,160. BCFs for bivalve molluscs were above 1,000 in long exposures, with no indication that steady-state had been reached. Cadmium mortality is cumulative for exposure periods beyond four days. Chronic cadmium exposure resulted in significant effects on the growth of bay scallops at 78 μg/L and on reproduction of a copepod at 44 μg/L.

National Criteria

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 very sensitive, freshwater aquatic organisms and their uses should not be affected unacceptably if the four-day average concentration (in μg/L) of cadmium does not exceed the numerical value given by $e^{(0.7852[\ln(\text{hardness})]-3.490)}$ more than once every three years on the average and if the one-hour average concentration (in μg/L) does not exceed the numerical value given by $e^{(1.128[\ln(\text{hardness})]-3.828)}$ 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 concentrations of cadmium are 0.66, 1.1, and 2.0 μg/L, respectively, and the one-hour average concentrations are 1.8, 3.9, and 8.6 μg/L. If brook trout, brown trout, and striped bass are as sensitive as some data indicate, they might not be protected by this criterion.

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 very sensitive, saltwater aquatic organisms and their uses should not be affected unacceptably if the four-day average concentration of cadmium does not exceed 9.3 ug/L more than once every three years on the average and if the one-hour average concentration does not exceed 43 μg/L more than once every three years on the average. The little information that is available concerning the sensitivity of the American lobster to cadmium indicates that this important species might not be protected by this criterion. In addition, data suggest that the acute toxicity of cadmium is salinity-dependent; therefore the one-hour average concentration might be underprotective at low salinities and overprotective at high salinities.

EPA believes that a measurement such as "acid-soluble" would provide a more scientifically correct basis upon which to establish criteria for metals. The criteria were developed on this basis. However, at this time, no EPA approved methods for such a measurement are available to implement the criteria through the regulatory programs of the Agency and the States. The Agency is considering development and approval of methods for a measurement such as "acid-soluble". Until available, however, EPA recommends applying the criteria using the total recoverable method. This has two impacts: (1) certain species of some metals cannot be analyzed directly because the total recoverable method does not distinguish between individual oxidation states, and (2) these criteria may be overly protective when based on the total recoverable method.

The recommended exceedence frequency of three years is the Agency's best scientific judgment of the average amount of time it will take an unstressed system to recover from a pollution event in which exposure to cadmium exceeds the criterion. Stressed systems, for example, one in which several outfalls occur in a limited area, would be expected to require more time for recovery. 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, 1985).

Table 1. Acute Toxicity of Cadmium to Aquatic Animals

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
			FRESHWATER SPECIES			
Tubificid worm, *Branchiura sowerbyi*	S, M	Cadmium sulfate	5.3	240	3,018	Chapman, et al. 1982a
Tubificid worm, *Limnodrilus hoffmeisteri*	S, M	Cadmium sulfate	5.3	170	2,137	Chapman, et al. 1982a,b
Tubificid worm, *Quistadrilus multisetosus*	S, M	Cadmium sulfate	5.3	320	4,024	Chapman, et al. 1982a
Tubificid worm, *Rhyacodrilus montana*	S, M	Cadmium sulfate	5.3	630	7,921	Chapman, et al. 1982a
Tubificid worm, *Spirosperma ferox*	S, M	Cadmium sulfate	5.3	350	4,401	Chapman, et al. 1982a
Tubificid worm, *Spirosperma nikolskyi*	S, M	Cadmium sulfate	5.3	450	5,658	Chapman, et al. 1982a
Tubificid worm, *Stylodrilus heringianus*	S, M	Cadmium sulfate	5.3	550	6,915	Chapman, et al. 1982a
Tubificid worm, *Tubifex tubifex*	S, M	Cadmium sulfate	5.3	320	4,024	Chapman, et al. 1982a,b
Tubificid worm, *Varichaeta pacifica*	S, M	Cadmium sulfate	5.3	380	4,778	Chapman, et al. 1982a
Worm, *Nais* sp.	S, U	-	50	1,700	1,700	Rehwoldt, et al. 1973
Snail (embryo), *Amnicola* sp.	S, U	-	50	3,800	-	Rehwoldt, et al. 1973
Snail (adult), *Amnicola* sp.	S, U	-	50	8,400****	3,800	Rehwoldt, et al. 1973
Snail, *Aplexa hypnorum*	FT, M	Cadmium chloride	45.3	93	104.0	Holcombe, et al. 1984
Snail (adult), *Physa gyrina*	S, M	-	200	1,370	-	Wier & Walter, 1976

Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Snail (immature), Physa gyrina	S, M	-	200	410	156.9	Wier & Walter, 1976
Cladoceran, Ceriodaphnia reticulata	S, U	-	45	66	-	Mount & Norberg, 1984
Cladoceran, Ceriodaphnia reticulata	S, M	Cadmium chloride	55-79	129	83.02	Spehar & Carlson, 1984a,b
Cladoceran, Daphnia magna	S, U	Cadmium chloride	-	<1.6	-	Anderson, 1948
Cladoceran, Daphnia magna	S, U	Cadmium chloride	45	65*****	-	Biesinger & Christensen, 1972
Cladoceran, Daphnia magna	FT, M	Cadmium chloride	130	58*****	-	Attar & Maly, 1982
Cladoceran, Daphnia magna	S, M	Cadmium chloride	51	9.9	-	Chapman, et al. Manuscript
Cladoceran, Daphnia magna	S, M	Cadmium chloride	104	33	-	Chapman, et al. Manuscript
Cladoceran, Daphnia magna	S, M	Cadmium chloride	105	34	-	Chapman, et al. Manuscript
Cladoceran, Daphnia magna	S, M	Cadmium chloride	197	63	-	Chapman, et al. Manuscript
Cladoceran, Daphnia magna	S, M	Cadmium chloride	209	49	-	Chapman, et al. Manuscript
Cladoceran, Daphnia magna	R, M	Cadmium chloride	100	30*****	-	Canton & Slooff, 1982
Cladoceran, Daphnia magna	S, M	Cadmium chloride	55-79	166*****	-	Spehar & Carlson, 1984a,b
Cladoceran, Daphnia magna	S, U	Cadmium nitrate	-	27.07*****	-	Canton & Adema, 1978
Cladoceran, Daphnia magna	S, U	Cadmium nitrate	-	28.04*****	-	Canton & Adema, 1978

Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Cladoceran, *Daphnia magna*	S, U	Cadmium nitrate	-	35.13*****	-	Canton & Adema, 1978
Cladoceran, *Daphnia magna*	S, U	-	45	118*****	12.19	Mount & Norberg, 1984
Cladoceran, *Daphnia pulex*	S, U	Cadmium nitrate	-	93.45	-	Canton & Adema, 1978
Cladoceran, *Daphnia pulex*	S, U	-	45	68	-	Mount & Norberg, 1984
Cladoceran, *Daphnia pulex*	S, U	Cadmium chloride	57	47	55.72	Bertram & Hart, 1979
Cladoceran, *Moina macrocopa*	S, U	Cadmium chloride	80-84	71.25	40.78	Hatakeyama & Yasuno, 1981b
Cladoceran, *Simocephalus serrulatus*	S, M	Cadmium chloride	11.1	7.0	-	Giesy, et al. 1977
Cladoceran, *Simocephalus serrulatus*	S, M	Cadmium chloride	55-79	123†	-	Spehar & Carlson, 1984a,b
Cladoceran, *Simocephalus serrulatus*	S, M	Cadmium chloride	39-48	24.5	45.93	Spehar & Carlson, 1984a,b
Cladoceran, *Simocephalus vetulus*	S, U	-	45	24	-	Mount & Norberg, 1984
Cladoceran, *Simocephalus vetulus*	S, M	Cadmium chloride	55-79	89.3	41.65	Spehar & Carlson, 1984a,b
Isopod, *Asellus bicrenata*	FT, M	Cadmium chloride	220	2,130††	400.5	Bosnak & Morgan, 1981
Isopod, *Lirceus alabamae*	FT, M	Cadmium chloride	152	150††	42.80	Bosnak & Morgan, 1981
Amphipod, *Gammarus pseudolimnaeus*	S, M	Cadmium chloride	55-79	54.4	-	Spehar & Carlson, 1984a,b
Amphipod, *Gammarus pseudolimnaeus*	S, M	Cadmium chloride	39-48	68.3	55.90	Spehar & Carlson, 1984a,b

Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Amphipod, *Gammarus* sp.	S, U	-	50	70	70.00	Rehwoldt, et al. 1973
Amphipod, *Hyalella azteca*	S, M	Cadmium chloride	55-79	285	204.9	Spehar & Carlson, 1984a,b
Crayfish, *Orconectes limosus*	S, M	Cadmium chloride	-	400	-	Boutet & Chaisemartin, 1973
Mayfly, *Paraleptophlebia praepedita*	S, M	Cadmium chloride	55-79	449	322.8	Spehar & Carlson, 1984a,b
Mayfly, *Ephemerella grandis*	FT, M	Cadmium chloride	-	28,000	-	Clubb, et al. 1975
Mayfly, *Ephemerella grandis*	S, U	Cadmium sulfate	44	2,000	2,310	Warnick & Bell, 1969
Damselfly, (Unidentified)	S, U	-	50	8,100	8,100	Rehwoldt, et al. 1973
Stonefly, *Pteronarcella badia*	FT, M	Cadmium chloride	-	18,000	-	Clubb, et al. 1975
Caddisfly, (Unidentified)	S, U	-	50	3,400	3,400	Rehwoldt, et al. 1973
Midge, *Chironomus* sp.	S, U	-	50	1,200	1,200	Rehwoldt, et al. 1973
Bryozoan, *Pectinatella magnifica*	S, U	-	190-220	700	142.5	Pardue & Wood, 1980
Bryozoan, *Lophopodella carteri*	S, U	-	190-220	150	30.54	Pardue & Wood, 1980
Bryozoan, *Plumatella emarginata*	S, U	-	190-220	1,090	221.9	Pardue & Wood, 1980
American eel, *Anguilla rostrata*	S, M	-	55	820	736.4	Rehwoldt, et al. 1972
Coho salmon (adult), *Oncorhynchus kisutch*	FT, M	Cadmium chloride	23	17.5****	-	Chapman, 1975

Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Coho salmon (parr), Oncorhynchus kisutch	FT, M	Cadmium chloride	23	2.7	-	Chapman, 1975
Coho salmon (1 year), Oncorhynchus kisutch	S, U	Cadmium chloride	90	10.4	5.894	Lorz, et al. 1975
Chinook salmon (alevin), Oncorhynchus tshawytscha	FT, M	Cadmium chloride	23	>26****	-	Chapman, 1975, 1978
Chinook salmon (swim-up), Oncorhynchus tshawytscha	FT, M	Cadmium chloride	23	1.8	-	Chapman, 1975, 1978
Chinook salmon (parr), Oncorhynchus tshawytscha	FT, M	Cadmium chloride	23	3.5	-	Chapman, 1975, 1978
Chinook salmon (smolt), Oncorhynchus tshawytscha	FT, M	Cadmium chloride	23	>2.9†††	-	Chapman, 1975, 1978
Chinook salmon (juvenile), Oncorhynchus tshawytscha	FT, M	Cadmium chloride	25	1.41	-	Chapman, 1982
Chinook salmon (juvenile), Oncorhynchus tshawytscha	FT, M	Cadmium sulfate	20-22	1.1	4.254	Finlayson & Verrue, 1982
Rainbow trout (alevin), Salmo gairdneri	FT, M	Cadmium chloride	23	>27****	-	Chapman, 1975, 1978
Rainbow trout (swim-up), Salmo gairdneri	FT, M	Cadmium chloride	23	1.3	-	Chapman, 1975, 1978
Rainbow trout (parr), Salmo gairdneri	FT, M	Cadmium chloride	23	1.0	-	Chapman, 1978
Rainbow trout (smolt), Salmo gairdneri	FT, M	Cadmium chloride	23	4.1 >2.9†††		Chapman, 1975 Chapman, 1978
Rainbow trout (2-mos), Salmo gairdneri	FT, M	Cadmium nitrate	-	6.6	-	Hale, 1977
Rainbow trout, Salmo gairdneri	FT, M	Cadmium sulfate	31	1.75	-	Davies, 1976

Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Rainbow trout, *Salmo gairdneri*	S, U	-	-	6	-	Kumada, et al. 1973
Rainbow trout, *Salmo gairdneri*	S, U	-	-	7	-	Kumada, et al. 1973
Rainbow trout, *Salmo gairdneri*	S, U	Cadmium chloride	-	6.0	-	Kumada, et al. 1980
Rainbow trout, *Salmo gairdneri*	S, M	Cadmium chloride	55-79	10.2†	-	Spehar & Carlson, 1984a,b
Rainbow trout, *Salmo gairdneri*	S, M	Cadmium chloride	39-48	2.3	3.589	Spehar & Carlson, 1984a,b
Brown trout, *Salmo trutta*	S, M	Cadmium chloride	55-79	15.1†	-	Spehar & Carlson, 1984a,b
Brown trout, *Salmo trutta*	S, M	Cadmium chloride	39-48	1.4	1.638	Spehar & Carlson, 1984a,b
Brook trout, *Salvelinus fontinalis*	FT, M	Cadmium chloride	47.4	5,080	-	Holcombe, et al. 1983
Brook trout, *Salvelinus fontinalis*	S, M	Cadmium sulfate	42	<1.5	††††	Carroll, et al. 1979
Goldfish, *Carassius auratus*	S, U	Cadmium chloride	20	2,340	-	Pickering & Henderson, 1966
Goldfish, *Carassius auratus*	S, M	Cadmium chloride	20	2,130	-	McCarty, et al. 1978
Goldfish, *Carassius auratus*	S, M	Cadmium chloride	140	46,800	8,325	McCarty, et al. 1978
Common carp, *Cyprinus carpio*	S, M	-	55	240	215.5	Rehwoldt, et al. 1972
Fathead minnow, *Pimephales promelas*	S, U	Cadmium chloride	20	1,050****	-	Pickering & Henderson, 1966

Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Fathead minnow, *Pimephales promelas*	S, U	Cadmium chloride	20	630****	-	Pickering & Henderson, 1966
Fathead minnow, *Pimephales promelas*	S, U	Cadmium chloride	360	72,600****	-	Pickering & Henderson, 1966
Fathead minnow, *Pimephales promelas*	S, U	Cadmium chloride	360	73,500****	-	Pickering & Henderson, 1966
Fathead minnow, *Pimephales promelas*	FT, M	Cadmium sulfate	201	11,200****	-	Pickering & Gast, 1972
Fathead minnow, *Pimephales promelas*	FT, M	Cadmium sulfate	201	12,000****	-	Pickering & Gast, 1972
Fathead minnow, *Pimephales promelas*	FT, M	Cadmium sulfate	201	6,400****	-	Pickering & Gast, 1972
Fathead minnow, *Pimephales promelas*	FT, M	Cadmium sulfate	201	2,000****	-	Pickering & Gast, 1972
Fathead minnow, *Pimephales promelas*	FT, M	Cadmium sulfate	201	4,500****	-	Pickering & Gast, 1972
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 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Fathead minnow (adult), *Pimephales promelas*	S, M	Cadmium chloride	103	3,060****	-	Birge, et al. 1983
Fathead minnow (adult), *Pimephales promelas*	S, M	Cadmium chloride	103	2,900****	-	Birge, et al. 1983
Fathead minnow (adult), *Pimephales promelas*	S, M	Cadmium chloride	103	3,100****	-	Birge, et al. 1983
Fathead minnow (adult), *Pimephales promelas*	S, M	Cadmium chloride	254-271	7,160****	-	Birge, et al. 1983
Fathead minnow, *Pimephales promelas*	S, M	Cadmium chloride	55-79	3,390****	-	Spehar & Carlson, 1984a,b
Fathead minnow, *Pimephales promelas*	S, M	Cadmium chloride	39-48	1,280****	-	Spehar & Carlson, 1984a,b
Fathead minnow, *Pimephales promelas*	FT, M	Cadmium chloride	55-79	1,830****	30.50	Spehar & Carlson, 1984a,b
Northern squawfish, *Ptychocheilus oregonensis*	FT, M	Cadmium chloride	20-30	1,092	-	Andros & Garton, 1980
Northern squawfish, *Ptychocheilus oregonensis*	FT, M	Cadmium chloride	20-30	1,104	2,400	Andros & Garton, 1980
White sucker, *Catostomus commersoni*	FT, M	Cadmium chloride	18	1,110	3,514	Duncan & Klaverkamp, 1983
Channel catfish, *Ictalurus punctatus*	S, M	Cadmium chloride	55-79	7,940	5,708	Spehar & Carlson, 1984a,b
Banded killifish, *Fundulus diaphanus*	S, M	-	55	110	98.79	Rehwoldt, et al, 1972
Flagfish, *Jordanella floridae*	FT, M	Cadmium chloride	44	2,500	2,888	Spehar, 1976a,b
Mosquitofish, *Gambusia affinis*	FT, M	Cadmium chloride	11.1	900	-	Giesy, et al. 1977

Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Mosquitofish, <u>Gambusia affinis</u>	FT, M	Cadmium chloride	11.1	2,200	7,685	Giesy, et al. 1977
Guppy, <u>Poecilia reticulata</u>	S, U	Cadmium chloride	20	1,270	3,570	Pickering & Henderson, 1966
Threespine stickleback, <u>Gasterosteus aculeatus</u>	S, U	Cadmium chloride	115	6,500	-	Pascoe & Cram, 1977
Threespine stickleback, <u>Gasterosteus aculeatus</u>	R, M	Cadmium chloride	103-111	23,000	4,977	Pascoe & Mattey, 1977
White perch, <u>Morone americana</u>	S, M	-	55	8,400	7,544	Rehwoldt, et al. 1972
Striped bass, <u>Morone saxatilis</u>	S, M	-	55	1,100	-	Rehwoldt, et al. 1972
Striped bass (larva), <u>Morone saxatilis</u>	S, U	Cadmium chloride	34.5	1	-	Hughes, 1973
Striped bass (fingerling), <u>Morone saxatilis</u>	S, U	Cadmium chloride	34.5	2	††††	Hughes, 1973
Green sunfish, <u>Lepomis cyanellus</u>	S, U	Cadmium chloride	20	2,840	-	Pickering & Henderson, 1966
Green sunfish, <u>Lepomis cyanellus</u>	S, U	Cadmium chloride	360	66,000	-	Pickering & Henderson, 1966
Green sunfish, <u>Lepomis cyanellus</u>	FT, M	Cadmium chloride	335	20,500	5,147	Jude, 1973
Pumpkinseed, <u>Lepomis gibbosus</u>	S, M	-	55	1,500	1,347	Rehwoldt, et al. 1972
Bluegill, <u>Lepomis macrochirus</u>	S, U	Cadmium chloride	20	1,940	-	Pickering & Henderson, 1966
Bluegill, <u>Lepomis macrochirus</u>	FT, M	Cadmium chloride	207	21,100	-	Eaton, 1980

Table I. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Bluegill, *Lepomis macrochirus*	S, M	Cadmium chloride	18	3,860	-	Bishop & McIntosh, 1981
Bluegill, *Lepomis macrochirus*	S, M	Cadmium chloride	18	2,800	-	Bishop & McIntosh, 1981
Bluegill, *Lepomis macrochirus*	S, M	Cadmium chloride	18	2,260	-	Bishop & McIntosh, 1981
Bluegill, *Lepomis macrochirus*	S, M	Cadmium chloride	55-79	8,810	6,961	Spehar & Carlson, 1984a,b
		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	12,250	Reish, et al. 1976
Sand worm, *Nereis virens*	S, U	Cadmium chloride	-	9,300	-	Eisler & Hennekey, 1977
Polychaete worm, *Nereis virens*	S, U	Cadmium chloride	-	11,000	10,110	Eisler, 1971
Polychaete worm (adult), *Capitella capitata*	S, U	Cadmium chloride	-	7,500****	-	Reish, et al. 1976
Polychaete worm (larva), *Capitella capitata*	S, U	Cadmium chloride	-	200	200	Reish, et al. 1976
Oligochaete worm, *Limnodriloides verrucosus*	R, U	Cadmium sulfate	-	10,000	10,000	Chapman, et al. 1982a
Oligochaete worm, *Monophylephorus cuticalatus*	R, U	Cadmium sulfate	-	135,000	135,000	Chapman, et al. 1982a
Oligochaete worm, *Tubificoides gabriellae*	R, U	Cadmium sulfate	-	24,000	24,000	Chapman, et al. 1982a

Table 1. (Continued)

Species	Method*	Chemical	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Oyster drill, *Urosalpinx cinerea*	S, U	Cadmium chloride	6,600	6,600	Eisler, 1971
Mud snail, *Nassarius obsoletus*	S, U	Cadmium chloride	35,000	-	Eisler & Hennekey, 1977
Mud snail, *Nassarius obsoletus*	S, U	Cadmium chloride	10,500	19,170	Eisler, 1971
Blue mussel, *Mytilus edulis*	S, U	Cadmium chloride	25,000	-	Eisler, 1971
Blue mussel (embryo), *Mytilus edulis*	S, U	Cadmium chloride	1,200	-	Martin, et al. 1981
Blue mussel, *Mytilus edulis*	S, M	Cadmium chloride	1,620	-	Ahsanullah, 1976
Blue mussel, *Mytilus edulis*	FT, M	Cadmium chloride	3,600	-	Ahsanullah, 1976
Blue mussel, *Mytilus edulis*	FT, M	Cadmium chloride	4,300	3,934	Ahsanullah, 1976
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	2,500	-	Eisler & Hennekey, 1977
Soft-shell clam, *Mya arenaria*	S, U	Cadmium chloride	2,200	-	Eisler, 1971

Table 1. (Continued)

Species	Method*	Chemical	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Soft-shell clam, *Mya arenaria*	S, U	Cadmium chloride	850	1,672	Eisler, 1977
Copepod, *Pseudodiaptomus coronatus*	S, U	Cadmium chloride	1,708	1,708	Gentile, 1982
Copepod, *Eurytemora affinis*	S, U	Cadmium chloride	1,080	-	Gentile, 1982
Copepod (nauplius), *Eurytemora affinis*	S, U	Cadmium chloride	147.7	399.4	Sullivan, et al. 1983
Copepod, *Acartia clausi*	S, U	Cadmium chloride	144	144	Gentile, 1982
Copepod, *Acartia tonsa*	S, U	Cadmium chloride	90	-	Sosnowski & Gentile, 1978
Copepod, *Acartia tonsa*	S, U	Cadmium chloride	122	-	Sosnowski & Gentile, 1978
Copepod, *Acartia tonsa*	S, U	Cadmium chloride	220	-	Sosnowski & Gentile, 1978
Copepod, *Acartia tonsa*	S, U	Cadmium chloride	337	168.9	Sosnowski & Gentile, 1978
Copepod, *Nitocra spinipes*	S, U	Cadmium chloride	1,800	1,800	Bengtsson, 1978
Mysid, *Mysidopsis bahia*	FT, M	Cadmium chloride	15.5	-	Nimmo, et al. 1977a
Mysid, *Mysidopsis bahia*	FT, M	Cadmium chloride	110	41.29	Gentile, et al. 1982; Lussier, et al. Manuscript
Mysid, *Mysidopsis bigelowi*	FT, M	Cadmium chloride	110	110	Gentile, et al. 1982
Amphipod (adult), *Ampelisca abdita*	FT, M	Cadmium chloride	2,900	2,900	Scott, et al. Manuscript

Table 1. (Continued)

Species	Method*	Chemical	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Amphipod (young), Marinogammarus obtusatus	S, M	Cadmium chloride	3,500	-	Wright & Frain, 1981
Amphipod (adult), Marinogammarus obtusatus	S, M	Cadmium chloride	13,000****	3,500	Wright & Frain, 1981
Pink shrimp, Penaeus duorarum	FT, M	Cadmium chloride	3,500	3,500	Nimmo, et al. 1977b
Grass shrimp, Palaemonetes vulgaris	S, U	Cadmium chloride	420	-	Eisler, 1971
Grass shrimp, Palaemonetes vulgaris	FT, 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 & Gentile, 1979
Hermit crab, Pagurus longicarpus	S, U	Cadmium chloride	320	-	Eisler, 1971
Hermit crab, Pagurus longicarpus	S, U	Cadmium chloride	1,300	645	Eisler & Hennekey, 1977
Rock crab (zoea), Cancer irroratus	FT, M	Cadmium chloride	250	250	Johns & Miller, 1982
Dungeness crab (zoea), Cancer magister	S, U	Cadmium chloride	247	247	Martin, et al. 1981
Blue crab (juvenile), Callinectes sapidus	S, U	Cadmium chloride	11,600	-	Frank & Robertson, 1979
Blue crab (juvenile), Callinectes sapidus	S, U	Cadmium chloride	4,700	7,384	Frank & Robertson, 1979
Green crab, Carcinus maenas	S, U	Cadmium chloride	4,100	4,100	Eisler, 1971

Table 1. (Continued)

Species	Method*	Chemical	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Fiddler crab, <u>Uca pugilator</u>	S, U	Cadmium chloride	46,600	-	O'Hara, 1973a
Fiddler crab, <u>Uca pugilator</u>	S, U	Cadmium chloride	37,000	-	O'Hara, 1973a
Fiddler crab, <u>Uca pugilator</u>	S, U	Cadmium chloride	32,300	-	O'Hara, 1973a
Fiddler crab, <u>Uca pugilator</u>	S, U	Cadmium chloride	23,300	-	O'Hara, 1973a
Fiddler crab, <u>Uca pugilator</u>	S, U	Cadmium chloride	10,400	-	O'Hara, 1973a
Fiddler crab, <u>Uca pugilator</u>	S, U	Cadmium chloride	6,800	21,240	O'Hara, 1973a
Starfish, <u>Asterias forbesi</u>	S, U	Cadmium chloride	7,100	-	Eisler & Hennekey, 1977
Starfish, <u>Asterias forbesi</u>	S, U	Cadmium chloride	820	2,413	Eisler, 1971
Sheepshead minnow, <u>Cyprinodon variegatus</u>	S, U	Cadmium chloride	50,000	50,000	Eisler, 1971
Mummichog (adult), <u>Fundulus heteroclitus</u>	S, U	Cadmium chloride	49,000	-	Eisler, 1971
Mummichog (adult), <u>Fundulus heteroclitus</u>	S, U	Cadmium chloride	22,000	-	Eisler & Hennekey, 1977
Mummichog (juvenile), <u>Fundulus heteroclitus</u>	S, U	Cadmium chloride	114,000	-	Voyer, 1975
Mummichog (juvenile), <u>Fundulus heteroclitus</u>	S, U	Cadmium chloride	92,000	-	Voyer, 1975
Mummichog (juvenile), <u>Fundulus heteroclitus</u>	S, U	Cadmium chloride	78,000	-	Voyer, 1975

Table 1. (Continued)

Species	Method*	Chemical	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	73,000	-	Voyer, 1975
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	63,000	-	Voyer, 1975
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	31,000	-	Voyer, 1975
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	30,000	-	Voyer, 1975
Mummichog (juvenile), *Fundulus heteroclitus*	S, U	Cadmium chloride	29,000	50,570	Voyer, 1975
Striped killifish (adult), *Fundulus majalis*	S, U	Cadmium chloride	21,000	21,000	Eisler, 1971
Atlantic silverside (adult), *Menidia menidia*	S, U	Cadmium chloride	2,032****	-	Cardin, 1982
Atlantic silverside (juvenile), *Menidia menidia*	S, U	Cadmium chloride	28,532****	-	Cardin, 1982
Atlantic silverside (juvenile), *Menidia menidia*	S, U	Cadmium chloride	13,652****	-	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
Winter flounder (larva), *Pseudopleuronectes americanus*	S, U	Cadmium chloride	602†††††	-	Cardin, 1982

Table 1. (Continued)

Species	Method*	Chemical	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Winter flounder (larva), *Pseudopleuronectes americanus*	S, U	Cadmium chloride	14,297	14,297	Cardin, 1982

* S = static, R = renewal, FT = flow-through, M = measured, U = unmeasured.

** Results are expressed as cadmium, not as the chemical.

*** Freshwater Species Mean Acute Values are calculated at a hardness of 50 mg/L using the pooled slope.

**** Not used in calculations because data are available for a more sensitive life stage.

***** Not used in calculations (see text).

† Not used in calculations because this higher value was obtained in river water.

†† Average of values calculated using two different methods.

††† "Greater than" values were not used in calculations.

†††† No Species Mean Acute Value calculated because acute values are too divergent for this species.

††††† Not used in calculations because this lower value was obtained in artificial sea water.

Table 1. (Continued)

Results of Covariance Analysis of Freshwater Acute Toxicity versus Hardness

Species	n	Slope	95% Confidence Limits	Degrees of Freedom
Daphnia magna (all data)	10	-0.14[illegible]	-1.171, 0.881	8
Daphnia magna (Chapman, et al. Manuscript)	5	1.182	0.519, 1.846	3
Goldfish	3	1.564	1.032, 2.095	1
Fathead minnow	16	1.239	0.780, 1.698	14
Green sunfish	3	0.905	-3.352, 5.162	1
Bluegill	6	0.868	0.516, 1.220	4
Four fishes	28	1.125*	0.853, 1.397	2[illegible]
All of above using all data for *D. magna*	38	0.975**	0.672, 1.278	3[illegible]
All of above using only data from Chapman, et al. (Manuscript) for *D. magna*	33	1.128***	0.883, 1.373	27

* P=0.44 for equality of slopes.

** P=0.04 for equality of slopes.

***P=0.54 for equality of slopes.

Table 2. Chronic Toxicity of Cadmium to Aquatic Animals

Species	Test*	Chemical	Hardness (mg/L as $CaCO_3$)	Limits (µg/L)**	Chronic Value (µg/L)**	Adjusted Chronic Value (µg/L)***	Reference
			FRESHWATER SPECIES				
Snail, *Aplexa hypnorum*	LC	Cadmium chloride	45.3	4.41-7.63	5.801	6.269	Holcombe, et al. 1984
Snail, *Aplexa hypnorum*	LC	Cadmium chloride	45.3	2.50-4.79	3.460	3.739	Holcombe, et al. 1984
Cladoceran, *Ceriodaphnia reticulata*	LC	Cadmium chloride	55-79	3.4-7.2	4.948†	3.932†	Spehar & Carlson, 1984a,b
Cladoceran, *Daphnia magna*	LC	Cadmium chloride	53	0.08-0.29	0.1523	0.1455	Chapman, et al. Manuscript
Cladoceran, *Daphnia magna*	LC	Cadmium chloride	103	0.16-0.28	0.2117	0.1200	Chapman, et al. Manuscript
Cladoceran, *Daphnia magna*	LC	Cadmium chloride	209	0.21-0.91	0.4371	0.1422	Chapman, et al. Manuscript
Cladoceran, *Moina macrocopa*	LC	Cadmium chloride	80-84	0.2-0.4	0.2828	0.1918	Hatakeyama & Yasuno, 1981b
Coho salmon (Lake Superior), *Oncorhynchus kisutch*	ELS	Cadmium chloride	44	1.3-3.4	2.102	2.324	Eaton, et al. 1978
Coho salmon (West Coast), *Oncorhynchus kisutch*	ELS	Cadmium chloride	44	4.1-12.5	7.159	7.915	Eaton, et al. 1978
Chinook salmon, *Oncorhynchus tshawytscha*	ELS	Cadmium chloride	25	1.3-1.88	1.563	2.694	Chapman, 1975
Atlantic salmon, *Salmo salar*	ELS	Cadmium chloride	19-28	90-270 (5 C) 2.5-8.2 (9.6 C)	155.9 4.528	282.0†† 8.192	Rombough & Garside, 1982
Brown trout, *Salmo trutta*	ELS	Cadmium chloride	44	3.8-11.7	6.668	7.372	Eaton, et al. 1978

Table 2. (Continued)

Species	Test*	Chemical	Hardness (mg/L as $CaCO_3$)	Limits (µg/L)**	Chronic Value (µg/L)**	Adjusted Chronic Value (µg/L)***	Reference
Brook trout, *Salvelinus fontinalis*	ELS	Cadmium chloride	44	1.1-3.8	2.045	2.261	Eaton, et al. 1978
Brook trout, *Salvelinus fontinalis*	LC	Cadmium chloride	44	1.7-3.4	2.404	2.658	Benoit, et al. 1976
Brook trout, *Salvelinus fontinalis*	ELS	Cadmium chloride	37	1-3	1.732	2.194	Sauter, et al. 1976
Lake trout, *Salvelinus namaycush*	ELS	Cadmium chloride	44	4.4-12.3	7.357	8.134	Eaton, et al. 1978
Northern pike, *Esox lucius*	ELS	Cadmium chloride	44	4.2-12.9	7.361	8.138	Eaton, et al. 1978
Fathead minnow, *Pimephales promelas*	LC	Cadmium sulfate	201	37-57	45.92	15.40	Pickering & Gast, 1972
Fathead minnow, *Pimephales promelas*	ELS	Cadmium chloride	55-79	13.4-26.7	18.92†	15.04†	Spehar & Carlson, 1984a,b
White sucker, *Catostomus commersoni*	ELS	Cadmium chloride	44	4.2-12.0	7.099	7.849	Eaton, et al. 1978
Flagfish, *Jordanella floridae*	LC	Cadmium chloride	44	4.1-8.1	5.763	6.371	Spehar, 1976a
Flagfish, *Jordanella floridae*	LC	Cadmium chloride	44-51	3.0-6.5	4.416	4.597	Carlson, et al. 1982
Flagfish, *Jordanella floridae*	LC	Cadmium chloride	44-51	3.4-7.3	4.982	5.187	Carlson, et al. 1982
Bluegill, *Lepomis macrochirus*	LC	Cadmium sulfate	207	31-80	49.80	16.32	Eaton, 1974
Smallmouth bass, *Micropterus dolomieui*	ELS	Cadmium chloride	44	4.3-12.7	7.390	8.170	Eaton, et al. 1978

Table 2. (Continued)

Species	Test*	Chemical	Hardness (mg/L as $CaCO_3$)	Limits (μg/L)**	Chronic Value (μg/L)**	Adjusted Chronic Value (μg/L)***	Reference
			SALTWATER SPECIES				
Mysid, *Mysidopsis bahia*	LC	Cadmium chloride	-	6.4-10.6	8.237	-	Nimmo et al. 1977a
Mysid, *Mysidopsis bahia*	LC	Cadmium chloride	-	5.1-10	7.141	-	Gentile, et al. 1982; Lussier, et al. Manuscript
Mysid, *Mysidopsis bigelowi*	LC	Cadmium chloride	-	5.1-10	7.141	-	Gentile, et al. 1982

* ELS = early life stage, LC = life cycle or partial life cycle.

** Results are expressed as cadmium, not as the chemical.

***Adjusted to a hardness of 50 mg/L using a slope of 0.7852 (see text).

† Test was conducted in river water.

†† Not used in calculations (see text).

Acute-Chronic Ratio

Species	Hardness (mg/L as $CaCO_3$)	Acute Value (μg/L)	Chronic Value (μg/L)	Ratio
Snail, *Aplexa hypnorum*	45.3	93	5.801	16.03
Snail, *Aplexa hypnorum*	45.3	93	3.460	26.88
Cladoceran, *Moina macrocopa*	80-84	71.25	0.2828	251.9
Cladoceran, *Ceriodaphnia reticulata*	55-79	129*	4.948*	26.07*

Table 2. (Continued)

Acute-Chronic Ratio

Species	Hardness (mg/L as $CaCO_3$)	Acute Value (µg/L)	Chronic Value (µg/L)	Ratio
Cladoceran, *Daphnia magna*	53	9.9	0.1523	65.00
Cladoceran, *Daphnia magna*	103	33	0.2117	155.9
Cladoceran, *Daphnia magna*	209	49	0.4371	112.1
Chinook salmon, *Oncorhynchus tshawytscha*	25	1.41	1.563	0.9021
Fathead minnow, *Pimephales promelas*	201	5,995**	45.92	130.6
Fathead minnow, *Pimephales promelas*	55-79	1,830*	18.92*	96.72*
Flagfish, *Jordanella floridae*	44	2,500	5.763	433.8
Bluegill, *Lepomis macrochirus*	207	21,100	49.80	423.7
Mysid, *Mysidopsis bahia*	-	15.5	8.237	1.882
Mysid, *Mysidopsis bahia*	-	110	7.141	15.40
Mysid, *Mysidopsis bigelowi*	-	110	7.141	15.40

* Acute and chronic tests were conducted in river water (Spehar and Carlson, 1984a,b).

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

Table 2. (Continued)

Ranked Freshwater Genus Mean Chronic Values

Rank*	Genus Mean Chronic Value (µg/L)**	Species	Species Mean Chronic Value (µg/L)**	Species Mean Acute-Chronic Ratio
13	16.32	Bluegill, *Lepomis macrochirus*	16.32	423.7
12	15.22	Fathead minnow, *Pimephales promelas*	15.22***	112.4***
11	8.170	Smallmouth bass, *Micropterus dolomieui*	8.170	-
10	8.138	Northern pike, *Esox lucius*	8.138	-
9	7.771	Atlantic salmon, *Salmo salar*	8.192	-
		Brown trout, *Salmo trutta*	7.372	-
8	7.849	White sucker, *Catostomus commersoni*	7.849	-
7	5.336	Flagfish, *Jordanella floridae*	5.336†	433.8
6	4.841	Snail, *Aplexa hypnorum*	4.841***	20.76***
5	4.383	Brook trout, *Salvelinus fontinalis*	2.362†	-
		Lake trout, *Salvelinus namaycush*	8.134	-
4	3.932	Cladoceran, *Ceriodaphnia reticulata*	3.932	26.07

Table 2. (Continued)

Rank*	Genus Mean Chronic Value (µg/L)**	Species	Species Mean Chronic Value (µg/L)**	Species Mean Acute-Chronic Ratio
3	3.399	Coho salmon, *Oncorhynchus kisutch*	4.289***	-
		Chinook salmon, *Oncorhynchus tshawytscha*	2.694	0.9021
2	0.1918	Cladoceran, *Moina macrocopa*	0.1918	251.9
1	0.1354	Cladoceran, *Daphnia magna*	0.1354	104.3

* Ranked from most resistant to most sensitive based on Genus Mean Chronic Value.

** Genus Mean Chronic Values and Species Mean Chronic Values are at a hardness of 50 mg/L.

***Geometric mean of two values.

† Geometric mean of three values.

At a hardness of 50 mg/L:

Freshwater Final Chronic Value = 0.0405 µg/L (using N = 13)

Freshwater Final Chronic Value = 0.6582 µg/L (using N = 44; see text)

Slope = 0.7852 (see text)

ln (Final Chronic Intercept) = ln(0.6582) - [slope x ln(50)]

= -0.4182 - (0.7852 x 3.912) = -3.490

Freshwater Final Chronic Value = $e^{(0.7852[\ln(\text{hardness})]-3.490)}$

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

Rank*	Genus Mean Acute Value (µg/L)**	Species	Species Mean Acute Value (µg/L)**	Species Mean Acute-Chronic Ratio
		FRESHWATER SPECI...		
44	8,325	Goldfish, *Carassius auratus*	8,325	-
43	8,100	Damselfly, (Unidentified)	8,100	-
42	7,921	Tubificid worm, *Rhyacodrilus montana*	7,921	-
41	7,685	Mosquitofish, *Gambusia affinis*	7,685	-
40	7,544	White perch, *Morone americana*	7,544	-
39	6,915	Tubificid worm, *Stylodrilus heringianus*	6,915	-
38	5,708	Channel catfish, *Ictalurus punctatus*	5,708	-
37	4,990	Tubificid worm, *Spirosperma ferox*	4,401	-
		Tubificid worm, *Spirosperma nikolskyi*	5,658	-
36	4,977	Threespine stickleback, *Gasterosteus aculeatus*	4,977	-
35	4,778	Tubificid worm, *Varichaeta pacifica*	4,778	-
34	1,024	Tubificid worm, *Tubifex tubifex*	4,024	-
33	4,024	Tubificid worm, *Quistradilus multisetosus*	4,024	-

Table 3. (Continued)

Rank*	Genus Mean Acute Value (µg/L)**	Species	Species Mean Acute Value (µg/L)**	Species Mean Acute-Chronic Ratio
32	3,800	Snail, *Amnicola* sp.	3,800	-
31	3,641	Green sunfish, *Lepomis cyanellus*	5,147	-
		Pumpkinseed, *Lepomis gibbosus*	1,347	-
		Bluegill, *Lepomis macrochirus*	6,961	423.7
30	3,570	Guppy, *Poecilia reticulata*	3,570	-
29	3,514	White sucker, *Catostomus commersoni*	3,514	-
28	3,400	Caddisfly, (Unidentified)	3,400	-
27	3,018	Tubificid worm, *Branchiura sowerbyi*	3,018	-
26	2,888	Flagfish, *Jordanella floridae*	2,888	433.8
25	2,400	Northern squawfish, *Ptychocheilus oregonensis*	2,400	-
24	2,310	Mayfly, *Ephemerella grandis*	2,310	-
23	2,137	Tubificid worm, *Limnodrilus hoffmeisteri*	2,137	-
22	1,700	Worm, *Nais* sp.	1,700	-

Table 3. (Continued)

Rank*	Genus Mean Acute Value (µg/L)**	Species	Species Mean Acute Value (µg/L)**	Species Mean Acute-Chronic Ratio
21	1,200	Midge, *Chironomus* sp.	1,200	-
20	736.4	American eel, *Anguilla rostrata*	736.4	-
19	400.5	Isopod, *Asellus bicrenata*	400.5	-
18	322.8	Mayfly, *Paraleptophlebia praepedita*	322.8	-
17	221.9	Bryozoan, *Plumatella emarginata*	221.9	-
16	215.5	Common carp, *Cyprinus carpio*	215.5	-
15	204.9	Amphipod, *Hyalella azteca*	204.9	-
14	156.9	Snail, *Physa gyrina*	156.9	-
13	142.5	Bryozoan, *Pectinatella magnifica*	142.5	-
12	104.0	Snail, *Aplexa hypnorum*	104.0	20.76***
11	98.79	Banded killifish, *Fundulus diaphanus*	98.79	-
10	83.02	Cladoceran, *Ceriodaphnia reticulata*	83.02	26.07
9	62.55	Amphipod, *Gammarus pseudolimnaeus*	55.90	-
		Amphipod, *Gammarus* sp.	70.00	-

Table 3. (Continued)

Rank*	Genus Mean Acute Value (µg/L)**	Species	Species Mean Acute Value (µg/L)**	Species Mean Acute-Chronic Ratio
8	43.74	Cladoceran, *Simocephalus serrulatus*	45.93	-
		Cladoceran, *Simocephalus vetulus*	41.65	-
7	42.80	Isopod, *Lirceus alabamae*	42.80	-
6	40.78	Cladoceran, *Moina macrocopa*	40.78	251.9
5	30.54	Bryozoan, *Lophopodella carteri*	30.54	-
4	30.50	Fathead minnow, *Pimephales promelas*	30.50	112.4***
3	26.06	Cladoceran, *Daphnia magna*	12.19	104.3****
		Cladoceran, *Daphnia pulex*	55.72	-
2	5.007	Coho salmon, *Oncorhynchus kisutch*	5.894	-
		Chinook salmon, *Oncorhynchus tshawytscha*	4.254	0.9021
1	2.425	Rainbow trout, *Salmo gairdneri*	3.589	-
		Brown trout, *Salmo trutta*	1.638	-
		SALTWATER SPECIES		
33	135,000	Oligochaete worm, *Monopylephorus cuticalatus*	135,000	-

Table 3. (Continued)

Rank*	Genus Mean Acute Value (µg/L)**	Species	Species Mean Acute Value (µg/L)**	Species Mean Acute-Chronic Ratio
32	50,000	Sheepshead minnow, *Cyprinodon variegatus*	50,000	-
31	32,590	Mummichog, *Fundulus heteroclitus*	50,570	-
		Striped killifish, *Fundulus majalis*	21,000	-
30	24,000	Oligochaete worm, *Tubificoides gabriellae*	24,000	-
29	21,240	Fiddler crab, *Uca pugilator*	21,240	-
28	19,170	Mud snail, *Nassarius obsoletus*	19,170	-
27	14,297	Winter flounder, *Pseudopleuronectes americanus*	14,297	-
26	12,250	Polychaete worm, *Neanthes arenaceodentata*	12,250	-
25	10,110	Sand worm, *Nereis virens*	10,110	-
24	10,000	Oligochaete worm, *Limnodriloides verrucosus*	10,000	-
23	7,384	Blue crab, *Callinectes sapidus*	7,384	-
22	6,600	Oyster drill, *Urosalpinx cinerea*	6,600	-
21	4,100	Green crab, *Carcinus maenas*	4,100	-
20	3,934	Blue mussel, *Mytilus edulis*	3,934	-

Table 3. (Continued)

Rank*	Genus Mean Acute Value (µg/L)**	Species	Species Mean Acute Value (µg/L)**	Species Mean Acute-Chronic Ratio
19	3,500	Amphipod, *Marinogammarus obtusatus*	3,500	-
18	3,500	Pink shrimp, *Penaeus duorarum*	3,500	-
17	2,900	Amphipod, *Ampelisca abdita*	2,900	-
16	2,413	Starfish, *Asterias forbesi*	2,413	-
15	1,800	Copepod, *Nitocra spinipes*	1,800	-
14	1,708	Copepod, *Pseudodiaptomus coronatus*	1,708	-
13	1,672	Soft-shell clam, *Mya arenaria*	1,672	-
12	1,480	Bay scallop, *Argopecten irradians*	1,480	-
11	930.6	Pacific oyster, *Crassostrea gigas*	227.9	-
		Eastern oyster, *Crassostrea virginica*	3,800	-
10	779.8	Atlantic silverside, *Menidia menidia*	779.8	-
9	760	Grass shrimp, *Palaemonetes vulgaris*	760	-
8	645	Hermit crab, *Pagurus longicarpus*	645	-
7	399.4	Copepod, *Eurytemora affinis*	399.4	-

Table 3. (Continued)

Rank*	Genus Mean Acute Value (µg/L)**	Species	Species Mean Acute Value (µg/L)**	Species Mean Acute-Chronic Ratio
6	320	Sand shrimp, *Crangon septemspinosa*	320	-
5	248.5	Rock crab, *Cancer irroratus*	250	-
		Dungeness crab, *Cancer magister*	247	-
4	200	Polychaete worm, *Capitella capitata*	200	-
3	156	Copepod, *Acartia clausi*	144	-
		Copepod, *Acartia tonsa*	168.9	-
2	78	American lobster, *Homarus americanus*	78	-
1	67.39	Mysid, *Mysidopsis bahia*	41.29	5.384***
		Mysid, *Mysidopsis bigelowi*	110	15.40

Table 3. (Continued)

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* Ranked from most resistant to most sensitive based on Genus Mean Acute Value.

** Freshwater Genus Mean Acute Values and Species Mean Acute Values are at a hardness of 50 mg/L.

*** Geometric mean of two values in Table 2.

****Geometric mean of three values in Table 2 from Chapman, et al. (Manuscript).

Fresh water

Final Acute Value = 8.917 µg/L (calculated at a hardness of 50 mg/L from Genus Mean Acute Values)

Final Acute Value = 3.589 µg/L (lowered to protect rainbow trout at a hardness of 50 mg/L; see text)

Criterion Maximum Concentration = (3.589 µg/L) / 2 = 1.7945 µg/L (at a hardness of 50 mg/L)

Pooled Slope = 1.128 (see Table 1)

ln (Criterion Maximum intercept) = ln(1.7945) - [slope x ln(50)]

= 0.5847 - (1.128 x 3.912) = -3.828

Criterion Maximum Concentration = $e^{(1.128[\ln(\text{hardness})]-3.828)}$

Salt water

Final Acute Value = 85.09 µg/L

Criterion Maximum Concentration = (85.09 µg/L) / 2 = 42.54 µg/L

Final Acute-Chronic Ratio = 9.105 (see text)

Final Chronic Value = (85.09 µg/L) / 9.105 = 9.345 µg/L

Table 4. Toxicity of Cadmium to Aquatic Plants

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Effect	Result (µg/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 & 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, 1980
Green alga, *Ankistrodesmus falcatus*	Cadmium chloride	-	58% reduction in growth	2,500	Devi Prasad & Devi Prasad, 1982
Blue alga, *Microcystis aeruginosa*	Cadmium nitrate	-	Incipient inhibition	70	Bringmann, 1975; Bringmann & Kuhn, 1976, 1978a,b
Green alga, *Scenedesmus quadricauda*	Cadmium nitrate	-	Incipient inhibition	310	Bringmann & Kuhn, 1977a, 1978a,b, 1979, 1980b
Green alga, *Chlorella saccharophila*	Cadmium chloride	-	96-hr EC50	105	Rachlin, et al. 1984
Alga, *Chlorococcum* spp.	Cadmium chloride	-	42% reduction in growth	2,500	Devi Prasad & Devi Prasad, 1982

Table 4. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Effect	Result (µg/L)*	Reference
Green alga, *Chlorella pyrenoidosa*	-	-	Reduction in growth	250	Hart & Scaife, 1977
Green alga, *Chlorella vulgaris*	-	-	Reduction in growth	50	Hutchinson & Stokes, 1975
Green alga, *Chlorella vulgaris*	Cadmium chloride	-	50% reduction in growth	60	Rosko & Rachlin, 1977
Green alga, *Chlorella vulgaris*	Cadmium chloride	50	96-hr EC50 (growth inhibition)	3,700	Canton & 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
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 & Czyrska, 1972
Eurasian watermilfoil, *Myriophyllum spicatum*	-	-	32-day EC50 (root weight)	7,400	Stanley, 1974
Duckweed, *Lemna valdiviana*	Cadmium nitrate	-	Reduction in number of fronds	10	Hutchinson & Cyrska, 1972

Table 4. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Effect	Result (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 & Jones, 1981
Diatom, *Ditylum brightwellii*	Cadmium chloride	-	5-day EC50 (growth)	60	Canterford & Canterford, 1980
Diatom, *Thalassiosira pseudonana*	Cadmium chloride	-	96-hr EC50 (growth rate)	160	Gentile & Johnson, 1982
Diatom, *Skeletonema costatum*	Cadmium chloride	-	96-hr EC50 (growth rate)	175	Gentile & Johnson, 1982
Red alga, *Champia parvula*	Cadmium chloride	-	Reduced tetra-sporophyte growth	24.9	Steele & Thursby, 1983
Red alga, *Champia parvula*	Cadmium chloride	-	Reduced tetra-sporangia production	>189	Steele & Thursby, 1983
Red alga, *Champia parvula*	Cadmium chloride	-	Reduced female growth	22.8	Steele & Thursby, 1983
Red alga, *Champia parvula*	Cadmium chloride	-	Stopped sexual reproduction	22.8	Steele & Thursby, 1983

* Results are expressed as cadmium, not as the chemical.

Table 5. Bioaccumulation of Cadmium by Aquatic Organisms

Species	Tissue	Chemical	Duration (days)	Bioconcentration Factor*	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 & Czyrska, 1972
Fern, *Salvinia natans*	Whole plant	Cadmium nitrate	21	960	Hutchinson & Czyrska, 1972
Snail, *Physa integra*	Whole body	Cadmium chloride	28	1,750	Spehar, et al. 1978
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**	Winner, 1984
Crayfish, *Orconectes propinquus*	Whole body	-	8	184	Gillespie, et al. 1977
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

Table 5. (Continued)

Species	Tissue	Chemical	Duration (days)	Bioconcentration Factor*	Reference
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**	Dressing, et al. 1982
Biting midge, Ceratopogonidae	Whole body	Cadmium chlorde	365	936	Giesy, et al. 1979
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
Rainbow trout, *Salmo gairdneri*	Whole body	-	140	540	Kumada, et al. 1973
Rainbow trout, *Salmo gairdneri*	Whole body	Cadmium chloride	70	33	Kumada et al. 1980
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

Table 5. (Continued)

Species	Tissue	Chemical	Duration (days)	Bioconcentration Factor[a]	Reference
Brook trout, *Salvelinus fontinalis*	Muscle	Cadmium chloride	93	22	Sangalang & 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 & Slooff, 1982
African clawed frog, *Xenopus laevis*	Whole body	-	100	130	Canton & Slooff, 1982
		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 & Coombs, 1977
Blue mussel, *Mytilus edulis*	Soft parts	Cadmium chloride	35	306	Phillips, 1976
Bay scallop, *Argopecten irradians*	Muscle	Cadmium chloride	42	2,040	Pesch & Stewart, 1980
Eastern oyster, *Crassostrea virginica*	Soft parts	Cadmium chloride	280	2,150	Zaroogian & 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 & Pringle, 1969
Soft-shell clam, *Mya arenaria*	Soft parts	Cadmium nitrate	70	160	Pringle, et al. 1968

Table 5. (Continued)

Species	Tissue	Chemical	Duration (days)	Bioconcentration Factor*	Reference
Pink shrimp, *Penaeus duorarum*	Whole body	Cadmium chloride	30	57	Nimmo, et al. 1977b
Grass shrimp, *Paleomonetes puglo*	Whole body	Cadmium chloride	42	22	Pesch & Stewart, 1980
Grass shrimp, *Palaemonetes puglo*	Whole body	Cadmium chloride	28	203	Nimmo, et al. 1977b
Grass shrimp, *Palaemonetes vulgaris*	Whole body	Cadmium chloride	28	307	Nimmo, et al. 1977b
Green crab, *Carcinus maenas*	Muscle	Cadmium chloride	68	5	Wright, 1977
Green crab, *Carcinus maenas*	Muscle	Cadmium chloride	40	7	Jennings & Rainbow, 1979a

* Results are based on cadmium, not the chemical.

**Bioconcentration factor was converted from dry weight to wet weight basis.

Maximum Permissible Tissue Concentration

Consumer	Effect	Concentration	Reference
Mallard, *Anas platyrhynchos*	Kidney tubule degeneration; significant testis weight reduction; evidence of inhibited spermatozoa production	200 mg/kg in food for 90 days	White & Finley, 1978a,b; White, et al. 1978
Man	Emetic threshold	13 to 15 mg/kg (based on weight of human consumer)	Anon., 1950

Table 5. (Continued)

Fresh water

Geometric mean of all whole body and whole plant BCFs (weighted by species) = 648.6

Final Residue Value = (200 mg/kg) / 648.6 = 0.3084 mg/kg = 308.4 µg/L

Salt water

Geometric mean of all BCFs (weighted by species) = 225.7

Final Residue Value = (200 mg/kg) / 225.7 = 0.8861 mg/kg = 886.1 µg/L

Table 6. Other Data on Effects of Cadmium on Aquatic Organisms

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)*	Reference
		FRESHWATER SPECIES				
Mixed natural fungi and bacterial colonies on leaf litter	Cadmium chloride	10.7	28 wks	Inhibition of leaf decompositon	5	Giesy, 1978
Plankton	-	-	2 wks	Reduced crustacean, zooplankton, and rotifers	1-3	Marshall, et al. 1981, 1983
Green alga, *Scenedesmus quadricauda*	Cadmium chloride	-	96 hrs	Incipient inhibition (river water)	100	Bringmann & Kuhn, 1959a,b
Bacteria, *Escherichia coli*	Cadmium chloride	-	-	Incipient inhibition	150	Bringmann & Kuhn, 1959a
Bacteria, *Salmonella typhimurium*	Cadmium chloride	50	8 hrs	EC50 (growth inhibition)	10,400	Canton & Slooff, 1982
Bacteria, *Pseudomonas putida*	Cadmium chloride	-	16 hrs	Incipient inhibition	80	Bringmann & Kuhn, 1976, 1977a, 1979, 1980b
Bacteria, (6 species)	Cadmium chloride	-	18 hrs	Reduced growth	5,000-100,000	Seyfried & Horgan, 1983
Protozoan, *Entosiphon sulcatum*	Cadmium nitrate	-	72 hrs	Incipient inhibiton	11	Bringmann, 1978; Bringmann & Kuhn, 1979, 1980b, 1981
Protozoan, *Microregma heterostoma*	Cadmium chloride	-	28 hrs	Incipient inhibition	100	Bringmann & Kuhn, 1959b
Protozoan, *Chilomonas paramecium*	Cadmium nitrate	-	48 hrs	Incipient inhibition	160	Bringmann, et al. 1980, 1981
Protozoan, *Uronema parduezi*	Cadmium nitrate	-	20 hrs	Incipient inhibition	26	Bringmann & Kuhn, 1980a, 1981
Hydra, *Hydra oligactis*	Cadmium nitrate	-	48 hrs	LC50	583	Slooff, 1983; Slooff, et al. 1983
Hydra, *Hydra littoralis*	Cadmium chloride	70	12 days	Reduced growth	20	Santiago-Faudino, 1983

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)*	Reference
Planarian, _Dugesia lugubris_	Cadmium nitrate	-	48 hrs	LC50	>20,000	Slooff, 1983
Mixed macroinvertebrates	Cadmium chloride	11.1	52 wks	Reduced taxa	5	Giesy, et al. 1979
Tubificid worm, _Tubifex tubifex_	Cadmium chloride	224	48 hrs	LC50	320,000	Qureshi, et al. 1980
Worm, _Pristina_ sp.	Cadmium chloride	11.1	52 wks	Population reduction	5	Giesy, et al. 1979
Snail, _Lymnaea stagnalis_	Cadmium nitrate	-	48 hrs	LC50	583	Slooff, 1983; Slooff, et al. 1983
Snail, _Physa integra_	Cadmium chloride	44-58	28 days	LC50	10.4	Spehar, et al. 1978
Cladoceran, _Daphnia galeata mendotae_	Cadmium chloride	-	22 wks	Reduced biomass	4.0	Marshall, 1978a
Cladoceran, _Daphnia galeata mendotae_	Cadmium chloride	-	15 days	Reduced rate of increase	5.0	Marshall, 1978b
Cladoceran, _Daphnia magna_	Cadmium chloride	-	48 hrs	EC50 (river water)	100	Bringmann & Kuhn, 1959a,b
Cladoceran, _Daphnia magna_	Cadmium chloride	45	21 days	Reproductive impairment	0.17	Biesinger & Christensen, 1972
Cladoceran, _Daphnia magna_	Cadmium chloride	163	72 hrs	LC50	14-17	Debelak, 1975
Cladoceran, _Daphnia magna_	Cadmium sulfate	-	24 hrs	LC50	600	Bringmann & Kuhn, 1977b
Cladoceran (3-5 days), _Daphnia magna_	Cadmium sulfate	-	72 hrs	LC50 (10 C) (15 C) (25 C) (30 C)	224 224 12 0.1	Braginskiy & Shcherban, 1978
Cladoceran (adult), _Daphnia magna_	Cadmium sulfate	-	72 wks	LC50 (10 C) (15 C) (25 C) (30 C)	479 187 10.2 2.4	Braginskiy & Shcherban, 1978

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)[a]	Reference
Cladoceran, *Daphnia magna*	Cadmium nitrate	200	24 hrs	EC50	160	Bellavera & Gorbi, 1981
Cladoceran, *Daphnia magna*	Cadmium chloride	130	96 hrs	EC50	5	Attar & Maly, 1982
Cladoceran, *Daphnia magna*	Cadmium chloride	200	20 days	LC50	670	Canton & Slooff, 1982
Cladoceran, *Daphnia pulex*	Cadmium chloride	57	140 days	Reduced reproduction	1	Bertram & Hart, 1979
Cladoceran, *Daphnia pulex*	Cadmium chloride	110	48 hrs	LC50 (fed)	104-127	Ingersoll & Winner, 1982
Cladoceran, *Daphnia pulex*	Cadmium chloride	110	21 days	MATC	5-10	Ingersoll & Winner, 1982
Cladoceran, *Daphnia pulex*	Cadmium sulfate	100	72 hrs	LC50 (fed)	80-92	Winner, 1984
Cladoceran, *Moina macrocopa*	Cadmium chloride	80-84	20 days	Reduced survival	0.2	Hatakeyama & Yasuno, 1981b
Copepod, *Acanthocyclops viridis*	Cadmium sulfate	-	72 hrs	LC50	0.5	Braginskiy & Shcherban, 1978
Copepod, *Eucyclops agilis*	Cadmium chloride	11.1	52 wks	Population reduction	5	Giesy, et al. 1979
Crayfish, *Cambarus latimanus*	Cadmium chloride	11.1	5 mo	Significant mortality	5	Thorp, et al. 1979
Mayfly, *Cloeon dipterum*	Cadmium sulfate	-	72 hrs	LC50 (10 C) (15 C) (25 C) (30 C)	70,600 28,600 6,990 930	Braginskiy & Shcherban, 1978
Mayfly, *Cloeon dipterum*	Cadmium nitrate	-	48 hrs	LC50	56,000	Slooff, et al. 1983
Mayfly, *Ephemerella* sp.	Cadmium chloride	44-48	28 days	LC50	<3.0	Spehar, et al. 1978

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)*	Reference
Mayfly, *Hexagenia rigida*	Cadmium nitrate	79.1	96 hrs	LC50	>1,000	Leonhard, et al. 1980
Mosquito, *Aedes aegypti*	Cadmium nitrate	-	48 hrs	LC50	4,000	Slooff, et al. 1983
Mosquito, *Culex pipiens*	Cadmium nitrate	-	48 hrs	LC50	765	Slooff, et al. 1983
Midge, *Tanytarsus dissimilis*	Cadmium chloride	47	10 days	LC50	3.8	Anderson, et al. 1980
Coho salmon (juvenile), *Oncorhynchus kisutch*	Cadmium chloride	22	217 hrs	LC50	2.0	Chapman & Stevens, 1978
Coho salmon (adult), *Oncorhynchus kisutch*	Cadmium chloride	22	215 hrs	LC50	3.7	Chapman & Stevens, 1978
Chinook salmon (alevin), *Oncorhynchus tshawytscha*	Cadmium chloride	23	200 hrs	LC10	18-26	Chapman, 1978
Chinook salmon (swim-up), *Oncorhynchus tshawytscha*	Cadmium chloride	23	200 hrs	LC10	1.2	Chapman, 1978
Chinook salmon (parr), *Oncorhynchus tshawytscha*	Cadmium chloride	23	200 hrs	LC10	1.3	Chapman, 1978
Chinook salmon (smolt), *Oncorhynchus tshawytscha*	Cadmium chloride	23	200 hrs	LC10	1.5	Chapman, 1978
Rainbow trout, *Salmo gairdneri*	Cadmium stearate	-	96 hrs	LC50	6.0	Kumada, et al. 1980
Rainbow trout, *Salmo gairdneri*	Cadmium acetate	-	96 hrs	LC50	6.2	Kumada, et al. 1980
Rainbow trout, *Salmo gairdneri*	Cadmium chloride	112	80 min	Significant avoidance	52	Black & Birge, 1980
Rainbow trout, *Salmo gairdneri*	-	112	18 mos	Reduced survival	0.2	Birge, et al. 1981

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)*	Reference
Rainbow trout (embryo, larva), *Salmo gairdneri*	Cadmium chloride	104	28 days	EC50 (death and deformity)	140	Birge, 1978; Birge, et al. 1980
Rainbow trout, *Salmo gairdneri*	-	-	240 hrs	LC50	7 5	Kumada, et al. 1973
Rainbow trout (adult), *Salmo gairdneri*	Cadmium chloride	54	408 hrs	LC50	5.2	Chapman & Stevens, 1978
Rainbow trout (alevin), *Salmo gairdneri*	Cadmium chloride	23	186 hrs	LC10	>6	Chapman, 1978
Rainbow trout (swim-up), *Salmo gairdneri*	Cadmium chloride	23	200 hrs	LC10	1.0	Chapman, 1978
Rainbow trout (parr), *Salmo gairdneri*	Cadmium chloride	23	200 hrs	LC10	0.7	Chapman, 1978
Rainbow trout (smolt), *Salmo gairdneri*	Cadmium chloride	23	200 hrs	LC10	0.8	Chapman, 1978
Rainbow trout, *Salmo gairdneri*	Cadmium sulfate	326	96 hrs	LC20	20	Davies, 1976
Rainbow trout, *Salmo gairdneri*	Cadmium stearate	-	10 wks	BCF=27 BCF=40	-	Kumada, et al. 1980
Rainbow trout, *Salmo gairdneri*	Cadmium acetate	-	10 wks	BCF=63	-	Kumada, et al. 1980
Rainbow trout, *Salmo gairdneri*	Cadmium chloride	125	10 days	LC50 (18 C) (12 C) (6 C)	10-30 30 10-30	Roch & Maly, 1979
Rainbow trout, *Salmo gairdneri*	Cadmium sulfate	240	234 days	Increased gill diffusion	2	Hughes, et al. 1979
Rainbow trout, *Salmo gairdneri*	Cadmium chloride	320	4 mos	Physiological effects	10	Arillo, et al. 1982, 1984
Rainbow trout, *Salmo gairdneri*	Cadmium chloride	98.6	47 days	Reduced growth and survival	100	Woodworth & Pascoe, 1982

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)*	Reference
Rainbow trout (*embryo, larva*), <u>Salmo gairdneri</u>	Cadmium sulfate	100	62 days	Reduced survival	<5	Dave, et al. 1981
Rainbow trout (larva), <u>Salmo gairdneri</u>	Cadmium chloride	89-107	7 days	LC50	700	Birge, et al. 1983
Rainbow trout (larva), <u>Salmo gairdneri</u>	Cadmium chloride	89-107	7 days	LC50 after 24 days acclimated to 5.9 µg/L	1,590	Birge, et al. 1983
Rainbow trout, <u>Salmo gairdneri</u>	Cadmium nitrate	-	48 hrs	LC50	55	Slooff, et al. 1983
Rainbow trout, <u>Salmo gairdneri</u>	Cadmium chloride	82	11 days	LC50 (10 C)	16.0	Majewski & Giles, 1984
Rainbow trout, <u>Salmo gairdneri</u>	Cadmium chloride	82	8 days	LC50 (15 C)	16.6	Majewski & Giles, 1984
Rainbow trout, <u>Salmo gairdneri</u>	Cadmium chloride	82	178 days	Physiological effects	3.6-6.4	Majewski & Giles, 1984
Atlantic salmon, <u>Salmo salar</u>	Cadmium chloride	13	70 days	Reduced growth	2	Peterson, 1983
Brook trout, <u>Salvelinus fontinalis</u>	Cadmium chloride	10	21 days	Testicular damage	10	Sangalang & O'Halloran, 1972, 1973
Goldfish (embryo, larva), <u>Carassius auratus</u>	Cadmium chloride	195	7 days	EC50 (death and (deformity)	170	Birge, 1978
Goldfish, <u>Carassius auratus</u>	-	-	50 days	Reduced plasma sodium	44.5	McCarty & Houston, 1976
Common carp (embryo), <u>Cyprinus carpio</u>	Cadmium sulfate	360	-	EC50 (hatch)	2,094	Kapur & Yadav, 1982
Fathead minnow, <u>Pimephales promelas</u>	Cadmium chloride	63	96 hrs	LC50	80.8	Spehar, 1982

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)*	Reference
Fathead minnow, *Pimephales promelas*	Cadmium chloride	55	96 hrs	LC50	40.9	Spehar, 1982
Fathead minnow, *Pimephales promelas*	Cadmium chloride	59	96 hrs	LC50	64.8	Spehar, 1982
Fathead minnow, *Pimephales promelas*	Cadmium chloride	66	96 hrs	LC50	135	Spehar, 1982
Fathead minnow, *Pimephales promelas*	Cadmium chloride	65	96 hrs	LC50	120	Spehar, 1982
Fathead minnow, *Pimephales promelas*	Cadmium chloride	74	96 hrs	LC50	86.3	Spehar, 1982
Fathead minnow, *Pimephales promelas*	Cadmium chloride	79	96 hrs	LC50	86.6	Spehar, 1982
Fathead minnow, *Pimephales promelas*	Cadmium chloride	62	96 hrs	LC50	114	Spehar, 1982
Fathead minnow, *Pimephales promelas*	Cadmium chloride	63	96 hrs	LC50	80.8	Spehar, 1982
Fathead minnow, *Pimephales promelas*	Cadmium nitate	-	48 hrs	LC50	2,200	Sloof, et al. 1983
Fathead minnow, *Pimephales promelas*	Cadmium chloride	103	6.8 hrs	LT50	6,000	Birge, et al. 1983
Fathead minnow, *Pimephales promelas*	Cadmium chloride	254-271	3.7 hrs	LT50	16,000	Birge, et al. 1983
Fathead minnow (larva), *Pimephales promelas*	Cadmium chloride	89-107	7 days	LC50	200	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	Birge, et al. 1983

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)[a]	Reference
Fathead minnow, *Pimephales promelas*	Cadmium chloride	-	4 days	Histological effects	12,000	Stromberg, et al. 1983
Fathead minnow, *Pimephales promelas*	Cadmium nitrate	209	48 hrs	LC50	802	Slooff, et al. 1983
Brown bullhead, *Ictalurus nebulosus*	Cadmium chloride	-	2 hrs	Affected gills and kidney	61,300	Bilckens, 1978; Garofano, 1979
Channel catfish, *Ictalurus punctatus*	Cadmium chloride	-	-	Increased albinism	0.5	Westerman & Birge, 1978
Channel catfish, *Ictalurus punctatus*	Cadmium chloride	-	-	BCF=4.0-6.7	-	Birge, et al. 1979
Mosquitofish, *Gambusia affinis*	Cadmium chloride	-	8 wks	BCF=6,100 at 0.02 µg/L & 1.13 ppm added to food	-	Williams & Giesy, 1978
Mosquitofish, *Gambusia affinis*	Cadmium chloride	29	8 wks	BCF=1,430 at 10 µg/L & 1.13 ppm added to food	-	Williams & Giesy, 1978
Guppy, *Poecilia reticulata*	Cadmium nitrate	209	48 hrs	LC50	41,900	Slooff, et al. 1983
Bluegill, *Lepomis macrochirus*	Cadmium chloride	112	80 min	Significant avoidance	>41.1	Black & Birge, 1980
Bluegill, *Lepomis macrochirus*	Cadmium chloride	340-360	3 days	Increased cough rate	50	Bishop & McIntosh, 1981
Largemouth bass, *Micropterus salmoides*	Cadmium chloride	112	80 min	Significant avoidance	8.83	Black & Birge, 1980

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)*	Reference
Largemouth bass (embryo, larva), *Micropterus salmoides*	Cadmium chloride	99	8 days	EC50 (death and deformity)	1,640	Birge, et al. 1978
Largemouth bass, *Micropterus salmoides*	-	-	24 hrs	Affected opercular activity	150	Morgan, 1979
Narrow-mouthed toad (embryo, larva), *Gastrophyryne carolinensis*	Cadmium chloride	195	7 days	EC50 (death and deformity)	40	Birge, 1978
African clawed frog, *Xenopus laevis*	Cadmium nitrate	209	48 hrs	LC50	11,700	Slooff & Baerselman, 1980; Slooff, et al. 1983
African clawed frog, *Xenopus laevis*	-	170	48 hrs	LC50	3,200	Canton & Slooff, 1982
African clawed frog, *Xenopus laevis*	-	170	100 days	Inhibited development	650	Canton & Slooff, 1982
Marbled salamander (embryo, larva), *Ambystoma opacum*	Cadmium chloride	99	8 days	EC50 (death and deformity)	150	Birge, et al. 1978
			SALTWATER SPECIES			
Natural phytoplankton population	Cadmium chloride	-	4 days	Reduced biomass	112	Hollibaugh, et al. 1980
Hydroid, *Campanularia flexuosa*	-	-	-	Enzyme inhibition	40-75	Moore & Stebbing, 1976
Hydroid, *Campanularia flexuosa*	-	-	11 days	Growth rate	110-280	Stebbing, 1976

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)*	Reference
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. 1978
Polychaete worm, *Capitella capitata*	Cadmium chloride	-	28 days	LC50	700	Reish, et al. 1976
Blue mussel, *Mytilus edulis*	Cadmium EDTA	-	28 days	BCF=252	-	George & Coombs, 1977
Blue mussel, *Mytilus edulis*	Cadmium alginate	-	28 days	BCF=252	-	George & Coombs, 1977
Blue mussel, *Mytilus edulis*	Cadmium humate	-	28 days	BCF=252	-	George & Coombs, 1977
Blue mussel, *Mytilus edulis*	Cadmium pectate	-	28 days	BCF=252	-	George & Coombs, 1977
Blue mussel, *Mytilus edulis*	Cadmium chloride	-	21 days	BCF=710	-	Janssen & Scholz, 1979
Bay scallop, *Argopecten irradians*	Cadmium chloride	-	42 days	EC50 (growth reduction)	78	Pesch & 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 & 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 & Morrison, 1981
Pacific oyster, *Crassostrea gigas*	Cadmium chloride	-	6 days	50% reduction in settlement	20-25	Watling, 1983b

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)*	Reference
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 & 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, *Tisbe holothuriae*	Cadmium chloride	-	48 hrs	LC50	970	Moraitou-Apostolopoulou & Verriopoulos, 1982
Mysid, *Mysidopsis bahia*	-	-	17 days	LC50 (15-23 g/kg salinity)	11	Nimmo, et al. 1977a
Mysid, *Mysidopsis bahia*	Cadmium chloride	-	16 days	LC50 (30 g/kg salinity)	28	Gentile, et al. 1982
Mysid, *Mysidopsis bahia*	Cadmium chloride	-	8 days	LC50	60	Gentile, et al. 1982
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	-	5 days	LC50 (3 g/kg salinity)	10,000	Jones, 1975

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)*	Reference
Isopod, *Idotea baltica*	Cadmium sulfate	-	3 days	LC50 (21 g/kg salinity)	10,000	Jones, 1975
Isopod, *Idotea baltica*	Cadmium sulfate	-	1.5 days	LC50 (14 g/kg salinity)	10,000	Jones, 1975
Pink shrimp, *Penaeus duorarum*	Cadmium chloride	-	30 days	LC50	720	Nimmo, et al. 1977b
Grass shrimp, *Palaemonetes pugio*	Cadmium chloride	-	42 days	LC50	300	Pesch & Stewart, 1980
Grass shrimp, *Palaemonetes pugio*	Cadmium chloride	-	21 days	LC25 (5 g/kg salinity)	50	Vernberg, et al. 1977
Grass shrimp, *Palaemonetes pugio*	Cadmium chloride	-	21 days	LC10 (10 g/kg salinity)	50	Vernberg, et al. 1977
Grass shrimp, *Palaemonetes pugio*	Cadmium chloride	-	21 days	LC5 (20 g/kg salinity)	50	Vernberg, et al. 1977
Grass shrimp, *Palaemonetes pugio*	Cadmium chloride	-	6 days	LC75 (10 g/kg salinity)	300	Middaugh & Floyd, 1978
Grass shrimp, *Palaemonetes pugio*	Cadmium chloride	-	6 days	LC50 (15 g/kg salinity)	300	Middaugh & Floyd, 1978
Grass shrimp, *Palaemonetes pugio*	Cadmium chloride	-	6 days	LC25 (30 g/kg salinity)	300	Middaugh & Floyd, 1978
Grass shrimp, *Palaemonetes pugio*	Cadmium chloride	-	21 days	BCF=140	-	Vernberg, et al. 1977
Grass shrimp, *Palaemonetes vulgaris*	Cadmium chloride	-	29 days	LC50	120	Nimmo, et al. 1977b
American lobster, *Homarus americanus*	Cadmium chloride	-	21 days	BCF=25	-	Eisler, et al. 1972

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)*	Reference
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 & Hennekey, 1977
Hermit crab, *Pagurus longicarpus*	Cadmium chloride	-	60 days	LC56	70	Pesch & Stewart, 1980
Rock crab, *Cancer irroratus*	Cadmium chloride	-	96 hrs	Enzyme activity	1,000	Gould, et al. 1976
Rock crab (larva), *Cancer irroratus*	Cadmium chloride	-	28 days	Delayed development	50	Johns & Miller, 1982
Blue crab, *Callinectes sapidus*	Cadmium nitrate	-	7 days	LC50 (10 g/kg salinity)	50	Rosenberg & Costlow, 1976
Blue crab, *Callinectes sapidus*	Cadmium nitrate	-	7 days	LC50 (30 g/kg salinity)	150	Rosenberg & Costlow, 1976
Blue crab (juvenile), *Callinectes sapidus*	Cadmium chloride	-	4 days	LC50 (1 g/kg salinity)	320	Frank & Robertson, 1979
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 harrisii*	Cadmum nitrate	-	11 days	LC80 (10 g/kg salinity)	50	Rosenberg & Costlow, 1976
Mud crab, *Rhithropanopeus harrisii*	Cadmium nitrate	-	11 days	LC75 (20 g/kg salinity)	50	Rosenberg & Costlow, 1976
Mud crab, *Rhithropanopeus harrisii*	Cadmium nitrate	-	11 days	LC40 (30 g/kg salinity)	50	Rosenberg & Costlow, 1976
Fiddler crab, *Uca pugilator*	-	-	10 days	LC50	2,900	O'Hara, 1973a

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)[a]	Reference
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 & Hennekey, 1977
Herring (larva), *Clupea harengus*	Cadmium chloride	-	-	100% embryonic survival	5,000	Westernhagen, et al. 1979
Pacific herring (embryo), *Clupea harengus pallasi*	Cadmium chloride	-	<24 hrs	17% reduction in volume	10,000	Alderdice, et al. 1979a
Pacific herring (embryo), *Clupea harengus pallasi*	Cadmium chloride	-	96 hrs	Decrease in capsule strength	1,000	Alderdice, et al. 1979b
Pacific herring (embryo), *Clupea harengus pallasi*	Cadmium chloride	-	48 hrs	Reduced osmolality of perivitelline fluid	1,000	Alderdice, et al. 1979c
Mummichog (adult), *Fundulus heteroclitus*	Cadmium chloride	-	48 hrs	LC50 (20 g/kg salinity)	60,000	Middaugh & Dean, 1977
Mummichog (adult), *Fundulus heteroclitus*	Cadmium chloride	-	48 hrs	LC50 (30 g/kg salinity)	43,000	Middaugh & Dean, 1977
Mummichog, *Fundulus heteroclitus*	Cadmium chloride	-	21 days	BCF=48	-	Eisler, et al. 1972
Mummichog (larva), *Fundulus heteroclitus*	Cadmium chloride	-	48 hrs	LC50 (20 g/kg salinity)	32,000	Middaugh & Dean, 1977
Mummichog (larva), *Fundulus heteroclitus*	Cadmium chloride	-	48 hrs	LC50 (30 g/kg salinity)	7,800	Middaugh & Dean, 1977
Atlantic silverside (adult), *Menidia menidia*	Cadmium chloride	-	48 hrs	LC50 (20 g/kg salinity)	13,000	Middaugh & Dean, 1977
Atlantic silverside (adult), *Menidia menidia*	Cadmium chloride	-	48 hrs	LC50 (30 g/kg salinity)	12,000	Middaugh & Dean, 1977

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)*	Reference
Atlantic silverside, *Menidia menidia*	Cadmium chloride	-	19 days	LC50 (12 g/kg salinity)	<160	Voyer, et al. 1979
Atlantic silverside, *Menidia menidia*	Cadmium chloride	-	19 days	LC50 (20 g/kg salinity)	540	Voyer, et al. 1979
Atlantic silverside, *Menidia menidia*	Cadmium chloride	-	19 days	LC50 (30 g/kg salinity)	>970	Voyer, et al. 1979
Atlantic silverside (larva), *Menidia menidia*	Cadmium chloride	-	48 hrs	LC50 (20 g/kg salinity)	2,200	Middaugh & Dean, 1977
Atlantic silverside (larva), *Menidia menidia*	Cadmium chloride	-	48 hrs	LC50 (30 g/kg salinity)	1,600	Middaugh & Dean, 1977
Striped bass (juvenile), *Morone saxatilis*	Cadmium choride	-	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, et al. 1975
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 hrs	Decreased enzyme activity	3,000	Gould & Karolus, 1974
Winter flounder, *Pseodopleuronectes americanus*	Cadmium chloride	-	8 days	50% viable hatch	300	Voyer, et al. 1977

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)*	Reference
Winter flounder, *Pseodopleuronectes americanus*	Cadmium chloride	-	60 days	Increased gill tissue respiration	5	Calabrese, et al. 1975
Winter flounder, *Pseudopleuronectes americanus*	Cadmium chloride	-	17 days	Reduction of viable hatch	586	Voyer, et al. 1982

* Results are expressed as cadmium, not as the chemical.

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