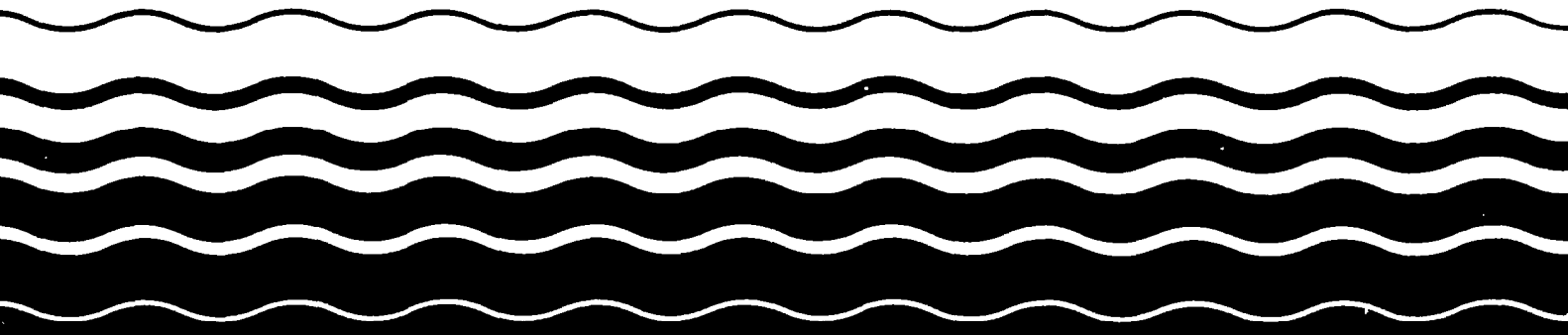




Water

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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  $\text{pH} = 1.5$  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  $\text{pH} = 1.5$  to  $2.0$  than it does from  $\text{pH} = 4$  to  $9$  (Weber and Scumm, 1963).
9. Differences in  $\text{pH}$  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  $\mu\text{g/L}$  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  $\mu\text{g/L}$ . This Final Acute Value is slightly above the Species Mean Acute Value of 78  $\mu\text{g/L}$  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  $\mu\text{g/L}$ . Bertram and Hart (1979) and Ingersoll and Winner (1982) found chronic toxicity to Daphnia pulex at less than 1 and 10  $\mu\text{g/L}$ , respectively. The 200-hr LC10 of 0.7  $\mu\text{g/L}$  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  $\mu\text{g/L}$  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  $0.6582 \mu\text{g/L}$  at a hardness of  $50 \text{ mg/L}$ , and the Final Chronic Value (in  $\mu\text{g/L}$ ) =  $e^{(0.7852[\ln(\text{hardness})]-3.490)}$ . At a hardness of  $50 \text{ mg/L}$  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  $10.6 \mu\text{g/L}$ , 84% at the next lower test concentration of  $6.4 \mu\text{g/L}$ , and 95% in the controls. No unacceptable effects were observed at  $6.4 \mu\text{g/L}$  or any lower concentration. The chronic toxicity limits, therefore, are 6.4 and  $10.6 \mu\text{g/L}$ , with a chronic value of  $8.237 \mu\text{g/L}$ . The 96-hr LC50 was  $15.5 \mu\text{g/L}$ , 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  $23 \mu\text{g/L}$ . At  $10 \mu\text{g/L}$  a series of morphological aberrations occurred at the onset of sexual maturity. External genitalia in males were aberrant, 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  $\mu\text{g/L}$ . Thus, the chronic limits for this study are 5.1 and 10  $\mu\text{g/L}$  for a chronic value of 7.141  $\mu\text{g/L}$ . The LC50 at 21 C and salinity of 30 g/kg was 110  $\mu\text{g/L}$  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  $\mu\text{g/L}$  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  $\mu\text{g/L}$  is divided by the mean acute-chronic ratio of 9.105, a saltwater Final Chronic Value of 9.345  $\mu\text{g/L}$  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  $\mu\text{g/L}$  for Dicylum brightwelli to 175  $\mu\text{g/L}$  for Skeletonema costatum. The brown macroalga (kelp) was the least sensitive to cadmium with an EC50 of 860  $\mu\text{g/L}$ . 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  $\mu\text{g/L}$ . 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 (Zarogian 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  $\mu\text{g/L}$  in order to reach the emetic threshold.

#### Other Data

Cadmium-binding proteins were isolated from Amoeba proteus (Al-ata, 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  $\mu\text{g/L}$  (Table 1) and a 17-day LC50 of 11  $\mu\text{g/L}$  (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  $\mu\text{g/L}$  (Table 1) and the 28-day LC50 was 16  $\mu\text{g/L}$  (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  $\mu\text{g/L}$  (MacInnes, et al. 1977). Dawson, et al. (1977) also reported a significant decrease in gill-tissue respiration of striped bass at 0.5  $\mu\text{g/L}$  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  $\mu\text{g/L}$ .

#### 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 Dechlefsen (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 Macete, 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 Saurer, 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; Gearley 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; Pecon 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 Utte, 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<sub>3</sub> 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

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

Table 1. (Continued)

<u>Species</u>	<u>Method<sup>a</sup></u>	<u>Chemical</u>	<u>Hardness (mg/L as CaCO<sub>3</sub>)</u>	<u>LC50 or EC50 (µg/L)**</u>	<u>Species Mean Acute Value (µg/L)***</u>	<u>Reference</u>
<u>Snail (Immature), Physa gyrina</u>	S, M	-	200	410	156.9	Wier & Walter, 1976
<u>Cladoceran, Ceriodaphnia reticulata</u>	S, U	-	45	66	-	Mount & Norberg, 1984
<u>Cladoceran, Ceriodaphnia reticulata</u>	S, M	Cadmium chloride	55-79	129	83.02	Spehar & Carlson, 1984 a,b
<u>Cladoceran, Daphnia magna</u>	S, U	Cadmium chloride	-	<1.6	-	Anderson, 1948
<u>Cladoceran, Daphnia magna</u>	S, U	Cadmium chloride	45	65*****	-	Biesinger & Christensen, 1972
<u>Cladoceran, Daphnia magna</u>	FT, M	Cadmium chloride	130	58*****	-	Attar & Maly, 1982
<u>Cladoceran, Daphnia magna</u>	S, M	Cadmium chloride	51	9.9	-	Chapman, et al. Manuscript
<u>Cladoceran, Daphnia magna</u>	S, M	Cadmium chloride	104	33	-	Chapman, et al. Manuscript
<u>Cladoceran, Daphnia magna</u>	S, M	Cadmium chloride	105	34	-	Chapman, et al. Manuscript
<u>Cladoceran, Daphnia magna</u>	S, M	Cadmium chloride	197	63	-	Chapman, et al. Manuscript
<u>Cladoceran, Daphnia magna</u>	S, M	Cadmium chloride	209	49	-	Chapman, et al. Manuscript
<u>Cladoceran, Daphnia magna</u>	R, M	Cadmium chloride	100	30*****	-	Canton & Slooff, 1982
<u>Cladoceran, Daphnia magna</u>	S, M	Cadmium chloride	55-79	166*****	-	Spehar & Carlson, 1984 a,b
<u>Cladoceran, Daphnia magna</u>	S, U	Cadmium nitrate	-	27.07*****	-	Canton & Adema, 1978
<u>Cladoceran, Daphnia magna</u>	S, U	Cadmium nitrate	-	28.04*****	-	Canton & Adema, 1978



Table 1. (Continued)

<u>Species</u>	<u>Method</u> <sup>a</sup>	<u>Chemical</u>	<u>Hardness</u> (mg/L as CaCO <sub>3</sub> )	<u>LC50</u> or <u>EC50</u> (µg/L)**	<u>Species Mean</u> <u>Acute Value</u> (µg/L)***	<u>Reference</u>
<u>Cladoceran,</u> <u>Daphnia magna</u>	S, U	Cadmium nitrate	-	35.13*****	-	Canton & Adema, 1978
<u>Cladoceran,</u> <u>Daphnia magna</u>	S, U	-	45	118*****	12.19	Mount & Norberg, 1984
<u>Cladoceran,</u> <u>Daphnia pulex</u>	S, U	Cadmium nitrate	-	93.45	-	Canton & Adema, 1978
<u>Cladoceran,</u> <u>Daphnia pulex</u>	S, U	-	45	68	-	Mount & Norberg, 1984
<u>Cladoceran,</u> <u>Daphnia pulex</u>	S, U	Cadmium chloride	57	47	55.72	Bertram & Hart, 1979
<u>Cladoceran,</u> <u>Moina macrocopa</u>	S, U	Cadmium chloride	80-84	71.25	40.78	Hatakeyama & Yasuno, 1981b
<u>Cladoceran,</u> <u>Simocephalus serrulatus</u>	S, M	Cadmium chloride	11.1	7.0	-	Glesy, et al. 1977
<u>Cladoceran,</u> <u>Simocephalus serrulatus</u>	S, M	Cadmium chloride	55-79	123 <sup>†</sup>	-	Spehar & Carlson, 1984a,b
<u>Cladoceran,</u> <u>Simocephalus serrulatus</u>	S, M	Cadmium chloride	39-48	24.5	45.93	Spehar & Carlson, 1984a,b
<u>Cladoceran,</u> <u>Simocephalus vetulus</u>	S, U	-	45	24	-	Mount & Norberg, 1984
<u>Cladoceran,</u> <u>Simocephalus vetulus</u>	S, M	Cadmium chloride	55-79	89.3	41.65	Spehar & Carlson, 1984a,b
<u>Isopod,</u> <u>Asellus bicrenata</u>	FT, M	Cadmium chloride	220	2,130 <sup>††</sup>	400.5	Bosnak & Morgan, 1981
<u>Isopod,</u> <u>Lirceus alabamæ</u>	FT, M	Cadmium chloride	152	150 <sup>††</sup>	42.80	Bosnak & Morgan, 1981
<u>Amphipod,</u> <u>Gammarus pseudolimnaeus</u>	S, M	Cadmium chloride	55-79	54.4	-	Spehar & Carlson, 1984a,b
<u>Amphipod,</u> <u>Gammarus pseudolimnaeus</u>	S, M	Cadmium chloride	39-48	68.3	55.90	Spehar & Carlson, 1984a,b

Table 1. (Continued)

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

Table 1. (Continued)

<u>Species</u>	<u>Method*</u>	<u>Chemical</u>	<u>Hardness (mg/L as CaCO<sub>3</sub>)</u>	<u>LC50 or EC50 (µg/L)**</u>	<u>Species Mean Acute Value (µg/L)***</u>	<u>Reference</u>
<u>Coho salmon (parr), Oncorhynchus kisutch</u>	FT, M	Cadmium chloride	23	2.7	-	Chapman, 1975
<u>Coho salmon (1 year), Oncorhynchus kisutch</u>	S, U	Cadmium chloride	90	10.4	5.894	Lorz, et al. 1975
<u>Chinook salmon (alevin), Oncorhynchus tshawytscha</u>	FT, M	Cadmium chloride	23	>26****	-	Chapman, 1975, 1978
<u>Chinook salmon (swim-up), Oncorhynchus tshawytscha</u>	FT, M	Cadmium chloride	23	1.8	-	Chapman, 1975, 1978
<u>Chinook salmon (parr), Oncorhynchus tshawytscha</u>	FT, M	Cadmium chloride	23	3.5	-	Chapman, 1975, 1978
<u>Chinook salmon (smolt), Oncorhynchus tshawytscha</u>	FT, M	Cadmium chloride	23	>2.9†††	-	Chapman, 1975, 1978
<u>Chinook salmon (juvenile), Oncorhynchus tshawytscha</u>	FT, M	Cadmium chloride	25	1.41	-	Chapman, 1982
<u>Chinook salmon (juvenile), Oncorhynchus tshawytscha</u>	FT, M	Cadmium sulfate	20-22	1.1	4.254	Finlayson & Verrue, 1982
<u>Rainbow trout (alevin), Salmo gairdneri</u>	FT, M	Cadmium chloride	23	>27****	-	Chapman, 1975, 1978
<u>Rainbow trout (swim-up), Salmo gairdneri</u>	FT, M	Cadmium chloride	23	1.3	-	Chapman, 1975, 1978
<u>Rainbow trout (parr), Salmo gairdneri</u>	FT, M	Cadmium chloride	23	1.0	-	Chapman, 1978
<u>Rainbow trout (smolt), Salmo gairdneri</u>	FT, M	Cadmium chloride	23	4.1 >2.9†††	-	Chapman, 1975 Chapman, 1978
<u>Rainbow trout (2-mos), Salmo gairdneri</u>	FT, M	Cadmium nitrate	-	6.6	-	Hale, 1977
<u>Rainbow trout, Salmo gairdneri</u>	FT, M	Cadmium sulfate	31	1.75	-	Davies, 1976

Table 1. (Continued)

<u>Species</u>	<u>Method<sup>a</sup></u>	<u>Chemical</u>	<u>Hardness (mg/L as CaCO<sub>3</sub>)</u>	<u>LC50 or EC50 (µg/L)**</u>	<u>Species Mean Acute Value (µg/L)***</u>	<u>Reference</u>
<u>Rainbow trout, Salmo gairdneri</u>	S, U	-	-	6	-	Kumada, et al. 1973
<u>Rainbow trout, Salmo gairdneri</u>	S, U	-	-	7	-	Kumada, et al. 1973
<u>Rainbow trout, Salmo gairdneri</u>	S, U	Cadmium chloride	-	6.0	-	Kumada, et al. 1980
<u>Rainbow trout, Salmo gairdneri</u>	S, M	Cadmium chloride	55-79	10.2 <sup>†</sup>	-	Spehar & Carlson, 1984a,b
<u>Rainbow trout, Salmo gairdneri</u>	S, M	Cadmium chloride	39-48	2.3	3,589	Spehar & Carlson, 1984a,b
<u>Brown trout, Salmo trutta</u>	S, M	Cadmium chloride	55-79	15.1 <sup>†</sup>	-	Spehar & Carlson, 1984a,b
<u>Brown trout, Salmo trutta</u>	S, M	Cadmium chloride	39-48	1.4	1,638	Spehar & Carlson, 1984a,b
<u>Brook trout, Salvelinus fontinalis</u>	FT, M	Cadmium chloride	47.4	5,080	-	Holcombe, et al. 1983
<u>Brook trout, Salvelinus fontinalis</u>	S, M	Cadmium sulfate	42	<1.5	†††	Carroll, et al. 1979
<u>Goldfish, Carassius auratus</u>	S, U	Cadmium chloride	20	2,340	-	Pickering & Henderson, 1966
<u>Goldfish, Carassius auratus</u>	S, M	Cadmium chloride	20	2,130	-	McCarty, et al. 1978
<u>Goldfish, Carassius auratus</u>	S, M	Cadmium chloride	140	46,800	8,325	McCarty, et al. 1978
<u>Common carp, Cyprinus carpio</u>	S, M	-	55	240	215.5	Rehwoidt, et al. 1972
<u>Fathead minnow, Pimephales promelas</u>	S, U	Cadmium chloride	20	1,050****	-	Pickering & Henderson, 1966

Table 1. (Continued)

<u>Species</u>	<u>Method*</u>	<u>Chemical</u>	<u>Hardness (mg/L as CaCO<sub>3</sub>)</u>	<u>LC50 or EC50 (µg/L)**</u>	<u>Species Mean Acute Value (µg/L)***</u>	<u>Reference</u>
<u>Fathead minnow, Pimephales promelas</u>	S, U	Cadmium chloride	20	630****	-	Pickering & Henderson, 1966
<u>Fathead minnow, Pimephales promelas</u>	S, U	Cadmium chloride	360	72,600****	-	Pickering & Henderson, 1966
<u>Fathead minnow, Pimephales promelas</u>	S, U	Cadmium chloride	360	73,500****	-	Pickering & Henderson, 1966
<u>Fathead minnow, Pimephales promelas</u>	FT, M	Cadmium sulfate	201	11,200****	-	Pickering & Gast, 1972
<u>Fathead minnow, Pimephales promelas</u>	FT, M	Cadmium sulfate	201	12,000****	-	Pickering & Gast, 1972
<u>Fathead minnow, Pimephales promelas</u>	FT, M	Cadmium sulfate	201	6,400****	-	Pickering & Gast, 1972
<u>Fathead minnow, Pimephales promelas</u>	FT, M	Cadmium sulfate	201	2,000****	-	Pickering & Gast, 1972
<u>Fathead minnow, Pimephales promelas</u>	FT, M	Cadmium sulfate	201	4,500****	-	Pickering & Gast, 1972
<u>Fathead minnow (fry), Pimephales promelas</u>	S, M	Cadmium chloride	40	21.5	-	Spehar, 1982
<u>Fathead minnow (fry), Pimephales promelas</u>	S, M	Cadmium chloride	48	11.7	-	Spehar, 1982
<u>Fathead minnow (fry), Pimephales promelas</u>	S, M	Cadmium chloride	39	19.3	-	Spehar, 1982
<u>Fathead minnow (fry), Pimephales promelas</u>	S, M	Cadmium chloride	45	42.4	-	Spehar, 1982
<u>Fathead minnow (fry), Pimephales promelas</u>	S, M	Cadmium chloride	47	54.2	-	Spehar, 1982
<u>Fathead minnow (fry), Pimephales promelas</u>	S, M	Cadmium chloride	44	29.0	-	Spehar, 1982

Table 1. (Continued)

<u>Species</u>	<u>Method*</u>	<u>Chemical</u>	<u>Hardness (mg/L as CaCO<sub>3</sub>)</u>	<u>LC50 or EC50 (µg/L)**</u>	<u>Species Mean Acute Value (µg/L)***</u>	<u>Reference</u>
<u>Fathead minnow (adult), Pimephales promelas</u>	S, M	Cadmium chloride	103	3,060****	-	Birge, et al. 1983
<u>Fathead minnow (adult), Pimephales promelas</u>	S, M	Cadmium chloride	103	2,900****	-	Birge, et al. 1983
<u>Fathead minnow (adult), Pimephales promelas</u>	S, M	Cadmium chloride	103	3,100****	-	Birge, et al. 1983
<u>Fathead minnow (adult), Pimephales promelas</u>	S, M	Cadmium chloride	254-271	7,160****	-	Birge, et al. 1983
<u>Fathead minnow, Pimephales promelas</u>	S, M	Cadmium chloride	55-79	3,390****	-	Spehar & Carlson, 1984a,b
<u>Fathead minnow, Pimephales promelas</u>	S, M	Cadmium chloride	39-48	1,280****	-	Spehar & Carlson, 1984a,b
<u>Fathead minnow, Pimephales promelas</u>	FT, M	Cadmium chloride	55-79	1,830****	30,50	Spehar & Carlson, 1984a,b
<u>Northern squawfish, Ptychocheilus oregonensis</u>	FT, M	Cadmium chloride	20-30	1,092	-	Andros & Garton, 1980
<u>Northern squawfish, Ptychocheilus oregonensis</u>	FT, M	Cadmium chloride	20-30	1,104	2,400	Andros & Garton, 1980
<u>White sucker, Catostomus commersoni</u>	FT, M	Cadmium chloride	18	1,110	3,514	Duncan & Klaverkamp, 1983
<u>Channel catfish, Ictalurus punctatus</u>	S, M	Cadmium chloride	55-79	7,940	5,708	Spehar & Carlson, 1984a,b
<u>Banded killifish, Fundulus diaphanus</u>	S, M	-	55	110	98.79	Rehboldt, et al, 1972
<u>Flagfish, Jordanella floridae</u>	FT, M	Cadmium chloride	44	2,500	2,888	Spehar, 1976a,b
<u>Mosquitofish, Gambusia affinis</u>	FT, M	Cadmium chloride	11.1	900	-	Glesy, et al. 1977

Table I. (Continued)

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

Table 1. (Continued)

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



Table 1. (Continued)

<u>Species</u>	<u>Method<sup>a</sup></u>	<u>Chemical</u>	<u>LC50 or EC50 (<math>\mu\text{g/L}</math>)<sup>b,c</sup></u>	<u>Species Mean Acute Value (<math>\mu\text{g/L}</math>)<sup>d,e</sup></u>	<u>Reference</u>
<u>Oyster drill, Urosalpinx cinerea</u>	S, U	Cadmium chloride	6,600	6,600	Eisler, 1971
<u>Mud snail, Nassarius obsoletus</u>	S, U	Cadmium chloride	35,000	-	Eisler & Hennekey, 1977
<u>Mud snail, Nassarius obsoletus</u>	S, U	Cadmium chloride	10,500	19,170	Eisler, 1971
<u>Blue mussel, Mytilus edulis</u>	S, U	Cadmium chloride	25,000	-	Eisler, 1971
<u>Blue mussel (embryo), Mytilus edulis</u>	S, U	Cadmium chloride	1,200	-	Martin, et al. 1981
<u>Blue mussel, Mytilus edulis</u>	S, M	Cadmium chloride	1,620	-	Ahsanullah, 1976
<u>Blue mussel, Mytilus edulis</u>	FT, M	Cadmium chloride	3,600	-	Ahsanullah, 1976
<u>Blue mussel, Mytilus edulis</u>	FT, M	Cadmium chloride	4,300	3,934	Ahsanullah, 1976
<u>Bay scallop (juvenile), Argopecten irradians</u>	S, U	Cadmium chloride	1,480	1,480	Nelson, et al. 1976
<u>Pacific oyster (embryo), Crassostrea gigas</u>	S, U	Cadmium chloride	611	-	Martin, et al. 1981
<u>Pacific oyster (larva), Crassostrea gigas</u>	S, U	Cadmium chloride	85	227.9	Watling, 1982
<u>Eastern oyster (larva), Crassostrea virginica</u>	S, U	Cadmium chloride	3,800	3,800	Calabrese, et al. 1973
<u>Soft-shell clam, Mya arenaria</u>	S, U	Cadmium chloride	2,500	-	Eisler & Hennekey, 1977
<u>Soft-shell clam, Mya arenaria</u>	S, U	Cadmium chloride	2,200	-	Eisler, 1971

Table 1. (Continued)

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

Table 1. (Continued)

<u>Species</u>	<u>Method<sup>a</sup></u>	<u>Chemical</u>	<u>LC50 or EC50 (<math>\mu\text{g/L}</math>)<sup>***</sup></u>	<u>Species Mean Acute Value (<math>\mu\text{g/L}</math>)<sup>***</sup></u>	<u>Reference</u>
<u>Amphipod (young), Marinogammarus obtusatus</u>	S, M	Cadmium chloride	3,500	-	Wright & Fraai, 1981
<u>Amphipod (adult), Marinogammarus obtusatus</u>	S, M	Cadmium chloride	13,000****	3,500	Wright & Fraai, 1981
<u>Pink shrimp, Penaeus duorarum</u>	FT, M	Cadmium chloride	3,500	3,500	Nimmo, et al. 1977b
<u>Grass shrimp, Palaemonetes vulgaris</u>	S, U	Cadmium chloride	420	-	Eisler, 1971
<u>Grass shrimp, Palaemonetes vulgaris</u>	FT, M	Cadmium chloride	760	760	Nimmo, et al. 1977b
<u>Sand shrimp, Crangon septemspinosa</u>	S, U	Cadmium chloride	320	320	Eisler, 1971
<u>American lobster (larva), Homarus americanus</u>	S, U	Cadmium chloride	78	78	Johnson & Gentile, 1979
<u>Hermit crab, Pagurus longicarpus</u>	S, U	Cadmium chloride	320	-	Eisler, 1971
<u>Hermit crab, Pagurus longicarpus</u>	S, U	Cadmium chloride	1,300	645	Eisler & Hennekey, 1977
<u>Rock crab (zoea), Cancer irroratus</u>	FT, M	Cadmium chloride	250	250	Johns & Miller, 1982
<u>Dungeness crab (zoea), Cancer magister</u>	S, U	Cadmium chloride	247	247	Martin, et al. 1981
<u>Blue crab (juvenile), Callinectes sapidus</u>	S, U	Cadmium chloride	11,600	-	Frank & Robertson, 1979
<u>Blue crab (juvenile), Callinectes sapidus</u>	S, U	Cadmium chloride	4,700	7,384	Frank & Robertson, 1979
<u>Green crab, Carcinus maenas</u>	S, U	Cadmium chloride	4,100	4,100	Eisler, 1971

Table 1. (Continued)

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

Table 1. (Continued)

<u>Species</u>	<u>Method</u> <sup>#</sup>	<u>Chemical</u>	<u>LC50 or EC50 (µg/L)</u> <sup>**</sup>	<u>Species Mean Acute Value (µg/L)</u> <sup>***</sup>	<u>Reference</u>
<u>Mummichog (juvenile), Fundulus heteroclitus</u>	S, U	Cadmium chloride	73,000	-	Voyer, 1975
<u>Mummichog (juvenile), Fundulus heteroclitus</u>	S, U	Cadmium chloride	63,000	-	Voyer, 1975
<u>Mummichog (juvenile), Fundulus heteroclitus</u>	S, U	Cadmium chloride	31,000	-	Voyer, 1975
<u>Mummichog (juvenile), Fundulus heteroclitus</u>	S, U	Cadmium chloride	30,000	-	Voyer, 1975
<u>Mummichog (juvenile), Fundulus heteroclitus</u>	S, U	Cadmium chloride	29,000	50,570	Voyer, 1975
<u>Striped killifish (adult), Fundulus majalis</u>	S, U	Cadmium chloride	21,000	21,000	Eisler, 1971
<u>Atlantic silverside (adult), Menidia menidia</u>	S, U	Cadmium chloride	2,032****	-	Cardin, 1982
<u>Atlantic silverside (juvenile), Menidia menidia</u>	S, U	Cadmium chloride	28,532****	-	Cardin, 1982
<u>Atlantic silverside (juvenile), Menidia menidia</u>	S, U	Cadmium chloride	13,652****	-	Cardin, 1982
<u>Atlantic silverside (larva), Menidia menidia</u>	S, U	Cadmium chloride	1,054	-	Cardin, 1982
<u>Atlantic silverside (larva), Menidia menidia</u>	S, U	Cadmium chloride	577	779.8	Cardin, 1982
<u>Winter flounder (larva), Pseudopleuronectes americanus</u>	S, U	Cadmium chloride	602†††††	-	Cardin, 1982

Table 1. (Continued)

<u>Species</u>	<u>Method</u> <sup>*</sup>	<u>Chemical</u>	<u>LC50 or EC50 (<math>\mu\text{g/L}</math>)<sup>**</sup></u>	<u>Species Mean Acute Value (<math>\mu\text{g/L}</math>)<sup>***</sup></u>	<u>Reference</u>
Winter flounder (larva), <u>Pseudopleuronectes americanus</u>	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

<u>Species</u>	<u>n</u>	<u>Slope</u>	<u>95% Confidence Limits</u>	<u>Degrees of Freedom</u>
<u>Daphnia magna</u> (all data)	10	-0.14	-1.171, 0.881	8
<u>Daphnia magna</u> (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*
All of above using all data for <u>D. magna</u>	38	0.975**	0.672, 1.278	30
All of above using only data from Chapman, et al. (Manuscript) for <u>D. magna</u>	33	1.128***	0.883, 1.373	27

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\* 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

<u>Species</u>	<u>Test<sup>a</sup></u>	<u>Chemical</u>	<u>Hardness (mg/L as CaCO<sub>3</sub>)</u>	<u>Limits (µg/L)<sup>bb</sup></u>	<u>Chronic Value (µg/L)<sup>bb</sup></u>	<u>Adjusted Chronic Value (µg/L)<sup>bbb</sup></u>	<u>Reference</u>
<u>FRESHWATER SPECIES</u>							
<u>Snail, Aplexa hypnorum</u>	LC	Cadmium chloride	45.3	4.41-7.63	5.801	6.269	Holcombe, et al. 1984
<u>Snail, Aplexa hypnorum</u>	LC	Cadmium chloride	45.3	2.50-4.79	3.460	3.739	Holcombe, et al. 1984
<u>Cladoceran, Ceriodaphnia reticulata</u>	LC	Cadmium chloride	55-79	3.4-7.2	4.948 <sup>†</sup>	3.932 <sup>†</sup>	Spehar & Carlson, 1984a,b
<u>Cladoceran, Daphnia magna</u>	LC	Cadmium chloride	53	0.08-0.29	0.1523	0.1455	Chapman, et al. Manuscript
<u>Cladoceran, Daphnia magna</u>	LC	Cadmium chloride	103	0.16-0.28	0.2117	0.1200	Chapman, et al. Manuscript
<u>Cladoceran, Daphnia magna</u>	LC	Cadmium chloride	209	0.21-0.91	0.4371	0.1422	Chapman, et al. Manuscript
<u>Cladoceran, Moina macrocopa</u>	LC	Cadmium chloride	80-84	0.2-0.4	0.2828	0.1918	Hatakeyama & Yasuno, 1981b
<u>Coho salmon (Lake Superior), Oncorhynchus kisutch</u>	ELS	Cadmium chloride	44	1.3-3.4	2.102	2.324	Eaton, et al. 1978
<u>Coho salmon (West Coast), Oncorhynchus kisutch</u>	ELS	Cadmium chloride	44	4.1-12.5	7.159	7.915	Eaton, et al. 1978
<u>Chinook salmon, Oncorhynchus tshawytscha</u>	ELS	Cadmium chloride	25	1.3-1.88	1.563	2.694	Chapman, 1975
<u>Atlantic salmon, Salmo salar</u>	ELS	Cadmium chloride	19-28	90-270 (5 C) 2.5-8.2 (9.6 C)	155.9 4.528	282.0 <sup>††</sup> 8.192	Rombough & Garside, 1982
<u>Brown trout, Salmo trutta</u>	ELS	Cadmium chloride	44	3.8-11.7	6.668	7.372	Eaton, et al. 1978



Table 2. (Continued)

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

Table 2. (Continued)

<u>Species</u>	<u>Test*</u>	<u>Chemical</u>	<u>Hardness (mg/L as CaCO<sub>3</sub>)</u>	<u>Limits (µg/L)**</u>	<u>Chronic Value (µg/L)**</u>	<u>Adjusted Chronic Value (µg/L)***</u>	<u>Reference</u>
<u>SALTWATER SPECIES</u>							
<u>Mysid, Mysidopsis bahia</u>	LC	Cadmium chloride	-	6.4-10.6	8.237	-	Nimmo et al. 1977a
<u>Mysid, Mysidopsis bahia</u>	LC	Cadmium chloride	-	5.1-10	7.141	-	Gentile, et al. 1982; Lussler, et al. Manuscript
<u>Mysid, Mysidopsis bigelowi</u>	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).

<u>Species</u>	<u>Acute-Chronic Ratio</u>			
	<u>Hardness (mg/L as CaCO<sub>3</sub>)</u>	<u>Acute Value (µg/L)</u>	<u>Chronic Value (µg/L)</u>	<u>Ratio</u>
<u>Snail, Aplexa hypnorum</u>	45.3	93	5.801	16.03
<u>Snail, Aplexa hypnorum</u>	45.3	93	3.460	26.88
<u>Cladoceran, Moina macrocopa</u>	80-84	71.25	0.2828	251.9
<u>Cladoceran, Ceriodaphnia reticulata</u>	55-79	129*	4.948*	26.07*

Table 2. (Continued)

<u>Species</u>	<u>Acute-Chronic Ratio</u>			<u>Ratio</u>
	<u>Hardness (mg/L as CaCO<sub>3</sub>)</u>	<u>Acute Value (µg/L)</u>	<u>Chronic Value (µg/L)</u>	
<u>Cladoceran, Daphnia magna</u>	53	9.9	0.1523	65.00
<u>Cladoceran, Daphnia magna</u>	103	33	0.2117	155.9
<u>Cladoceran, Daphnia magna</u>	209	49	0.4371	112.1
<u>Chinook salmon, Oncorhynchus tshawytscha</u>	25	1.41	1.563	0.9021
<u>Fathead minnow, Pimephales promelas</u>	201	5,995**	45.92	130.6
<u>Fathead minnow, Pimephales promelas</u>	55-79	1,830*	18.92*	96.72*
<u>Flagfish, Jordanella floridae</u>	44	2,500	5.763	433.8
<u>Bluegill, Lepomis macrochirus</u>	207	21,100	49.80	423.7
<u>Mysid, Mysidopsis bahia</u>	-	15.5	8.237	1.882
<u>Mysid, Mysidopsis bahia</u>	-	110	7.141	15.40
<u>Mysid, Mysidopsis bigelowi</u>	-	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)

<u>Ranked Freshwater Genus Mean Chronic Values</u>				
<u>Rank<sup>#</sup></u>	<u>Genus Mean Chronic Value (µg/L)<sup>**</sup></u>	<u>Species</u>	<u>Species Mean Chronic Value (µg/L)<sup>**</sup></u>	<u>Species Mean Acute-Chronic Ratio</u>
13	16.32	Bluegill, <u>Lepomis macrochirus</u>	16.32	423.7
12	15.22	Fathead minnow, <u>Pimephales promelas</u>	15.22 <sup>***</sup>	112.4 <sup>***</sup>
11	8.170	Smallmouth bass, <u>Micropterus dolomieu</u>	8.170	-
10	8.138	Northern pike, <u>Esox lucius</u>	8.138	-
9	7.771	Atlantic salmon, <u>Salmo salar</u>	8.192	-
		Brown trout, <u>Salmo trutta</u>	7.372	-
8	7.849	White sucker, <u>Catostomus commersoni</u>	7.849	-
7	5.336	Flagfish, <u>Jordanella floridae</u>	5.336 <sup>†</sup>	433.8
6	4.841	Snail, <u>Aplexa hypnorum</u>	4.841 <sup>***</sup>	20.76 <sup>***</sup>
5	4.383	Brook trout, <u>Salvelinus fontinalis</u>	2.362 <sup>†</sup>	-
		Lake trout, <u>Salvelinus namaycush</u>	8.134	-
4	3.932	Cladoceran, <u>Ceriodaphnia reticulata</u>	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, <u>Oncorhynchus kisutch</u>	4.289***	-
		Chinook salmon, <u>Oncorhynchus tshawytscha</u>	2.694	0.9021
2	0.1918	Cladocaran, <u>Molna macrocopa</u>	0.1918	251.9
1	0.1354	Cladocaran, <u>Daphnia magna</u>	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)

$\ln(\text{Final Chronic Intercept}) = \ln(0.6582) - (\text{slope} \times \ln(50))$

$= -0.4182 - (0.7852 \times 3.912) = -3.490$

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

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

Table 3. (Continued)

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

Table 3. (Continued)

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



Table 3. (Continued)

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

Table 3. (Continued)

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

Table 3. (Continued)

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

Table 3. (Continued)

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

Table 3. (Continued)

\* 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  $\mu\text{g/L}$  (calculated at a hardness of 50 mg/L from Genus Mean Acute Values)

Final Acute Value = 3.589  $\mu\text{g/L}$  (lowered to protect rainbow trout at a hardness of 50 mg/L; see text)

Criterion Maximum Concentration = (3.589  $\mu\text{g/L}$ ) / 2 = 1.7945  $\mu\text{g/L}$  (at a hardness of 50 mg/L)

Pooled Slope = 1.128 (see Table 1)

$\ln(\text{Criterion Maximum Intercept}) = \ln(1.7945) - (\text{slope} \times \ln(50))$

$$= 0.5847 - (1.128 \times 3.912) = -3.828$$

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

Salt water

Final Acute Value = 85.09  $\mu\text{g/L}$

Criterion Maximum Concentration = (85.09  $\mu\text{g/L}$ ) / 2 = 42.54  $\mu\text{g/L}$

Final Acute-Chronic Ratio = 9.105 (see text)

Final Chronic Value = (85.09  $\mu\text{g/L}$ ) / 9.105 = 9.345  $\mu\text{g/L}$

Table 4. Toxicity of Cadmium to Aquatic Plants

<u>Species</u>	<u>Chemical</u>	<u>Hardness (mg/L as CaCO<sub>3</sub>)</u>	<u>Effect</u>	<u>Result (µg/L)*</u>	<u>Reference</u>
<u>FRESHWATER SPECIES</u>					
Diatom, <u>Asterionella formosa</u>	-	-	Factor of 10 growth rate decrease	2	Conway, 1978
Diatom, <u>Scenedesmus quadricauda</u>	Cadmium chloride	-	Reduction in cell count	6.1	Kloss, et al. 1974
Diatom, <u>Nitzschia costerium</u>	Cadmium chloride	-	96-hr EC50	480	Rachlin, et al. 1982
Diatom, <u>Navicula incerta</u>	Cadmium chloride	-	96-hr EC50	310	Rachlin, et al. 1982
Green alga, <u>Scenedesmus obliquus</u>	Cadmium chloride	-	39% reduction in growth	2,500	Devi Prasad & Devi Prasad, 1982
Alga, <u>Euglena gracilis</u>	Cadmium chloride	-	Morpho- logical abnor- malities	5,000	Nakano, et al. 1980
Alga, <u>Euglena gracilis anabaena</u>	Cadmium nitrate	-	Cell divi- sion inhibi- tion	20,000	Nakano, 1980
Green alga, <u>Ankistrodesmus falcatus</u>	Cadmium chloride	-	58% reduction in growth	2,500	Devi Prasad & Devi Prasad, 1982
Blue alga, <u>Microcystis aeruginosa</u>	Cadmium nitrate	-	Incipient inhibition	70	Bringmann, 1975; Bringmann & Kuhn, 1976, 1978a,b
Green alga, <u>Scenedesmus quadricauda</u>	Cadmium nitrate	-	Incipient inhibition	310	Bringmann & Kuhn, 1977a, 1978a,b, 1979, 1980b
Green alga, <u>Chlorella saccharophila</u>	Cadmium chloride	-	96-hr EC50	105	Rachlin, et al. 1984
Alga, <u>Chlorococcum spp.</u>	Cadmium chloride	-	42% reduction in growth	2,500	Devi Prasad & Devi Prasad, 1982

Table 4. (Continued)

<u>Species</u>	<u>Chemical</u>	<u>Hardness (mg/L as CaCO<sub>3</sub>)</u>	<u>Effect</u>	<u>Result (µg/L)*</u>	<u>Reference</u>
Green alga, <u>Chlorella pyrenoidosa</u>	-	-	Reduction in growth	250	Hart & Scalfe, 1977
Green alga, <u>Chlorella vulgaris</u>	-	-	Reduction in growth	50	Hutchinson & Stokes, 1975
Green alga, <u>Chlorella vulgaris</u>	Cadmium chloride	-	50% reduction in growth	60	Rosko & Rachlin, 1977
Green alga, <u>Chlorella vulgaris</u>	Cadmium chloride	50	96-hr EC50 (growth inhibi- tion)	3,700	Canton & Slooff, 1982
Green alga, <u>Selenastrum capricornutum</u>	Cadmium chloride	-	Reduction in growth	50	Bartlett, et al. 1974
Green alga, <u>Selenastrum capricornutum</u>	Cadmium nitrate	-	Reduction in growth	255	Slooff, et al. 1983
Alga, <u>Anabaena flos-aquae</u>	Cadmium chloride	-	96-hr EC50	120	Rachlin, et al. 1984
Algae (mixed spp.)	Cadmium chloride	11.1	Significant reduction in population	5	Glesy, et al. 1979
Fern, <u>Salvinia natans</u>	Cadmium nitrate	-	Reduction in number of fronds	10	Hutchinson & Cyrska, 1972
Eurasian watermilfoil, <u>Myriophyllum spicatum</u>	-	-	32-day EC50 (root weight)	7,400	Stanley, 1974
Duckweed, <u>Lemna valdiviana</u>	Cadmium nitrate	-	Reduction in number of fronds	10	Hutchinson & Cyrska, 1972

Table 4. (Continued)

<u>Species</u>	<u>Chemical</u>	<u>Hardness (mg/L as CaCO<sub>3</sub>)</u>	<u>Effect</u>	<u>Result (µg/L)*</u>	<u>Reference</u>
<u>SALTWATER SPECIES</u>					
<u>Kelp, Laminana saccharina</u>	Cadmium chloride	-	8-day EC50 (growth rate)	860	Markham, et al. 1980
<u>Diatom, Asterionella japonica</u>	Cadmium chloride	-	72-hr EC50 (growth rate)	224.8	Fisher & Jonas, 1981
<u>Diatom, Ditylum brightwellii</u>	Cadmium chloride	-	5-day EC50 (growth)	60	Canterford & Canterford, 1980
<u>Diatom, Thalassiosira pseudonana</u>	Cadmium chloride	-	96-hr EC50 (growth rate)	160	Gentile & Johnson, 1982
<u>Diatom, Skeletonema costatum</u>	Cadmium chloride	-	96-hr EC50 (growth rate)	175	Gentile & Johnson, 1982
<u>Red alga, Champia parvula</u>	Cadmium chloride	-	Reduced tetra- sporophyte growth	24.9	Steele & Thursby, 1983
<u>Red alga, Champia parvula</u>	Cadmium chloride	-	Reduced tetra- sporangia production	>189	Steele & Thursby, 1983
<u>Red alga, Champia parvula</u>	Cadmium chloride	-	Reduced female growth	22.8	Steele & Thursby, 1983
<u>Red alga, Champia parvula</u>	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

<u>Species</u>	<u>Tissue</u>	<u>Chemical</u>	<u>Duration (days)</u>	<u>Bioconcentration Factor<sup>a</sup></u>	<u>Reference</u>
<u>FRESHWATER SPECIES</u>					
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, <u>Lemna valdiviana</u>	Whole plant	Cadmium nitrate	21	603	Hutchinson & Czyrska, 1972
Fern, <u>Salvinia natans</u>	Whole plant	Cadmium nitrate	21	960	Hutchinson & Czyrska, 1972
Snail, <u>Physa integra</u>	Whole body	Cadmium chloride	28	1,750	Spehar, et al. 1978
Asiatic clam, <u>Corbicula fluminea</u>	Whole body	Cadmium sulfate	28	3,770	Graney, et al. 1983
Asiatic clam, <u>Corbicula fluminea</u>	Whole body	Cadmium sulfate	28	1,752	Graney, et al. 1983
Cladoceran, <u>Daphnia magna</u>	Whole body	Cadmium sulfate	2-4	320	Poldoski, 1979
Cladoceran, <u>Daphnia magna</u>	Whole body	Cadmium sulfate	7	484**	Winner, 1984
Crayfish, <u>Orconectes propinquus</u>	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, <u>Pantala hymenea</u>	Whole body	Cadmium chloride	365	736	Giesy, et al. 1979
Dragonfly, <u>Pantala hymenea</u>	Whole body	Cadmium chloride	365	680	Giesy, et al. 1979

Table 5. (Continued)

<u>Species</u>	<u>Tissue</u>	<u>Chemical</u>	<u>Duration (days)</u>	<u>Bioconcentration Factor<sup>a</sup></u>	<u>Reference</u>
Damselfly, <u>Ischnura</u> sp.	Whole body	Cadmium chloride	365	1,300	Glesy, et al. 1979
Damselfly, <u>Ischnura</u> sp.	Whole body	Cadmium chloride	365	928	Glesy, et al. 1979
Stonefly, <u>Pteronarcys dorsata</u>	Whole body	Cadmium chloride	28	373	Spehar, et al. 1978
Beetle, Dytiscidae	Whole body	Cadmium chloride	365	164	Glesy, et al. 1979
Beetle, Dytiscidae	Whole body	Cadmium chloride	365	260	Glesy, et al. 1979
Caddisfly, <u>Hydropsyche betteni</u>	Whole body	Cadmium chloride	28	4,190	Spehar, et al. 1978
Caddisfly, <u>Hydropsyche</u> sp.	Whole body	Cadmium chloride	2-8	228.2**	Dressing, et al. 1982
Biting midge, Ceratopogonidae	Whole body	Cadmium chloride	365	936	Glesy, et al. 1979
Biting midge, Ceratopogonidae	Whole body	Cadmium chloride	365	662	Glesy, et al. 1979
Midge, Chironomidae	Whole body	Cadmium chloride	365	2,200	Glesy, et al. 1979
Midge, Chironomidae	Whole body	Cadmium chloride	365	1,830	Glesy, et al. 1979
Rainbow trout, <u>Salmo gairdneri</u>	Whole body	-	140	540	Kumada, et al. 1973
Rainbow trout, <u>Salmo gairdneri</u>	Whole body	Cadmium chloride	70	33	Kumada et al. 1980
Brook trout, <u>Salvelinus fontinalis</u>	Muscle	Cadmium chloride	490	3	Benolt, et al. 1976
Brook trout, <u>Salvelinus fontinalis</u>	Muscle	Cadmium chloride	84	151	Benolt, et al. 1976

Table 5. (Continued)

<u>Species</u>	<u>Tissue</u>	<u>Chemical</u>	<u>Duration (days)</u>	<u>Bioconcentration Factor<sup>a</sup></u>	<u>Reference</u>
<u>Brook trout, Salvelinus fontinalis</u>	Muscle	Cadmium chloride	95	22	Sangalang & Freeman, 1979
<u>Mosquitofish, Gambusia affinis</u>	Whole body (estimated steady state)	Cadmium chloride	180	2,213	Glesy, et al. 1979
<u>Mosquitofish, Gambusia affinis</u>	Whole body (estimated steady state)	Cadmium chloride	180	1,891	Glesy, et al. 1979
<u>Guppy, Poecilia reticulata</u>	Whole body	-	32	280	Canton & Slooff, 1982
<u>African clawed frog, Xenopus laevis</u>	Whole body	-	100	130	Canton & Slooff, 1982
<u>SALTWATER SPECIES</u>					
<u>Polychaete worm, Ophryotrocha diadema</u>	Whole body	Cadmium chloride	64	3,160	Klockner, 1979
<u>Blue mussel, Mytilus edulis</u>	Soft parts	Cadmium chloride	28	113	George & Coombs, 1977
<u>Blue mussel, Mytilus edulis</u>	Soft parts	Cadmium chloride	35	306	Phillips, 1976
<u>Bay scallop, Argopecten irradians</u>	Muscle	Cadmium chloride	42	2,040	Pesch & Stewart, 1980
<u>Eastern oyster, Crassostrea virginica</u>	Soft parts	Cadmium chloride	280	2,150	Zarogian & Cheer, 1976
<u>Eastern oyster, Crassostrea virginica</u>	Soft parts	Cadmium chloride	280	1,830	Zarogian, 1979
<u>Eastern oyster, Crassostrea virginica</u>	Soft parts	Cadmium nitrate	98	1,220	Schuster & Pringle, 1969
<u>Soft-shell clam, Mya arenaria</u>	Soft parts	Cadmium nitrate	70	160	Pringle, et al. 1968

Table 5. (Continued)

<u>Species</u>	<u>Tissue</u>	<u>Chemical</u>	<u>Duration (days)</u>	<u>Bioconcentration Factor*</u>	<u>Reference</u>
<u>Pink shrimp, Penaeus duorarum</u>	Whole body	Cadmium chloride	30	57	Nimmo, et al. 1977b
<u>Grass shrimp, Palaemonetes pugio</u>	Whole body	Cadmium chloride	42	22	Pesch & Stewart, 1980
<u>Grass shrimp, Palaemonetes pugio</u>	Whole body	Cadmium chloride	28	203	Nimmo, et al. 1977b
<u>Grass shrimp, Palaemonetes vulgaris</u>	Whole body	Cadmium chloride	28	307	Nimmo, et al. 1977b
<u>Green crab, Carcinus maenas</u>	Muscle	Cadmium chloride	68	5	Wright, 1977
<u>Green crab, Carcinus maenas</u>	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

<u>Consumer</u>	<u>Effect</u>	<u>Concentration</u>	<u>Reference</u>
<u>Mallard, Anas platyrhynchos</u>	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)

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Fresh water

Geometric mean of all whole body and whole plant BCFs (weighted by species) = 648,6

Final Residue Value =  $(200 \text{ mg/kg}) / 648,6 = 0,3084 \text{ mg/kg} = 308,4 \text{ } \mu\text{g/L}$

Salt water

Geometric mean of all BCFs (weighted by species) = 225,7

Final Residue Value =  $(200 \text{ mg/kg}) / 225,7 = 0,8861 \text{ mg/kg} = 886,1 \text{ } \mu\text{g/L}$

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

<u>Species</u>	<u>Chemical</u>	<u>Hardness (mg/L as CaCO<sub>3</sub>)</u>	<u>Duration</u>	<u>Effect</u>	<u>Result (µg/L)*</u>	<u>Reference</u>
<u>FRESHWATER SPECIES</u>						
Mixed natural fungi and bacterial colonies on leaf litter	Cadmium chloride	10.7	28 wks	Inhibition of leaf decomposition	5	Glesy, 1978
Plankton	-	-	2 wks	Reduced crusta- cean, zooplankton, and rotifers	1-3	Marshall, et al. 1981, 1983
Green alga, <u>Scenedesmus quadricauda</u>	Cadmium chloride	-	96 hrs	Incipient inhibition (river water)	100	Bringmann & Kuhn, 1959a,b
Bacteria, <u>Escherichia coli</u>	Cadmium chloride	-	-	Incipient inhibition	150	Bringmann & Kuhn, 1959a
Bacteria, <u>Salmonella typhimurium</u>	Cadmium chloride	50	8 hrs	EC50 (growth inhibition)	10,400	Canton & Slooff, 1982
Bacteria, <u>Pseudomonas putida</u>	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, <u>Entosiphon sulcatum</u>	Cadmium nitrate	-	72 hrs	Incipient inhibition	11	Bringmann, 1978; Bringmann & Kuhn, 1979, 1980b, 1981
Protozoan, <u>Microcystis heterostoma</u>	Cadmium chloride	-	28 hrs	Incipient inhibition	100	Bringmann & Kuhn, 1959b
Protozoan, <u>Chlamydomonas paramecium</u>	Cadmium nitrate	-	48 hrs	Incipient inhibition	160	Bringmann, et al. 1980, 1981
Protozoan, <u>Uronema parduezi</u>	Cadmium nitrate	-	20 hrs	Incipient inhibition	26	Bringmann & Kuhn, 1980a, 1981
Hydra, <u>Hydra oligactis</u>	Cadmium nitrate	-	48 hrs	LC50	583	Slooff, 1983; Slooff, et al. 1983
Hydra, <u>Hydra littoralis</u>	Cadmium chloride	70	12 days	Reduced growth	20	Santiago-Faudino, 1983

Table 6. (Continued)

<u>Species</u>	<u>Chemical</u>	<u>Hardness (mg/L as CaCO<sub>3</sub>)</u>	<u>Duration</u>	<u>Effect</u>	<u>Result (µg/L)<sup>a</sup></u>	<u>Reference</u>
<u>Planarian, Dugesia lugubris</u>	Cadmium nitrate	-	48 hrs	LC50	>20,000	Slooff, 1983
Mixed macroinvertebrates	Cadmium chloride	11.1	52 wks	Reduced taxa	5	Giesy, et al. 1979
<u>Tubificid worm, Tubifex tubifex</u>	Cadmium chloride	224	48 hrs	LC50	320,000	Qureshi, et al. 1980
<u>Worm, Pristina sp.</u>	Cadmium chloride	11.1	52 wks	Population reduction	5	Giesy, et al. 1979
<u>Snail, Lymnaea stagnalis</u>	Cadmium nitrate	-	48 hrs	LC50	583	Slooff, 1983; Slooff, et al. 1983
<u>Snail, Physa integra</u>	Cadmium chloride	44-58	28 days	LC50	10.4	Spehar, et al. 1978
<u>Cladoceran, Daphnia galeata mendotae</u>	Cadmium chloride	-	22 wks	Reduced biomass	4.0	Marshall, 1978a
<u>Cladoceran, Daphnia galeata mendotae</u>	Cadmium chloride	-	15 days	Reduced rate of increase	5.0	Marshall, 1978b
<u>Cladoceran, Daphnia magna</u>	Cadmium chloride	-	48 hrs	EC50 (river water)	100	Bringmann & Kuhn, 1959a,b
<u>Cladoceran, Daphnia magna</u>	Cadmium chloride	45	21 days	Reproductive impairment	0.17	Blesinger & Christensen, 1972
<u>Cladoceran, Daphnia magna</u>	Cadmium chloride	163	72 hrs	LC50	14-17	Debelak, 1975
<u>Cladoceran, Daphnia magna</u>	Cadmium sulfate	-	24 hrs	LC50	600	Bringmann & Kuhn, 1977b
<u>Cladoceran (3-5 days), Daphnia magna</u>	Cadmium sulfate	-	72 hrs	LC50 (10 C) (15 C) (25 C) (30 C)	224 224 12 0.1	Braginskiy & Shcherban, 1978
<u>Cladoceran (adult), Daphnia magna</u>	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)

<u>Species</u>	<u>Chemical</u>	<u>Hardness (mg/L as CaCO<sub>3</sub>)</u>	<u>Duration</u>	<u>Effect</u>	<u>Result (µg/L)<sup>a</sup></u>	<u>Reference</u>
<u>Cladoceran, Daphnia magna</u>	Cadmium nitrate	200	24 hrs	EC50	160	Bellavera & Gorbi, 1981
<u>Cladoceran, Daphnia magna</u>	Cadmium chloride	130	96 hrs	EC50	5	Attar & Maly, 1982
<u>Cladoceran, Daphnia magna</u>	Cadmium chloride	200	20 days	LC50	670	Canton & Slooff, 1982
<u>Cladoceran, Daphnia pulex</u>	Cadmium chloride	57	140 days	Reduced reproduction	1	Bertram & Hart, 1979
<u>Cladoceran, Daphnia pulex</u>	Cadmium chloride	110	48 hrs	LC50 (fed)	104-127	Ingersoll & Winner, 1982
<u>Cladoceran, Daphnia pulex</u>	Cadmium chloride	110	21 days	MATC	5-10	Ingersoll & Winner, 1982
<u>Cladoceran, Daphnia pulex</u>	Cadmium sulfate	100	72 hrs	LC50 (fed)	80-92	Winner, 1984
<u>Cladoceran, Moina macrocopa</u>	Cadmium chloride	80-84	20 days	Reduced survival	0.2	Hatakeyama & Yasuno, 1981b
<u>Copepod, Acanthocyclops vernalis</u>	Cadmium sulfate	-	72 hrs	LC50	0.5	Braglinskiy & Shcherban, 1978
<u>Copepod, Eucyclops agilis</u>	Cadmium chloride	11.1	52 wks	Population reduction	5	Giesy, et al. 1979
<u>Crayfish, Cambarus latimanus</u>	Cadmium chloride	11.1	5 mo	Significant mortality	5	Thorp, et al. 1979
<u>Mayfly, Cloeon dipterum</u>	Cadmium sulfate	-	72 hrs	LC50 (10 C) (15 C) (25 C) (30 C)	70,600 28,600 6,990 930	Braglinskiy & Shcherban, 1978
<u>Mayfly, Cloeon dipterum</u>	Cadmium nitrate	-	48 hrs	LC50	56,000	Slooff, et al. 1983
<u>Mayfly, Ephemera sp.</u>	Cadmium chloride	44-48	28 days	LC50	<3.0	Spehar, et al. 1978



Table 6. (Continued)

<u>Species</u>	<u>Chemical</u>	<u>Hardness (mg/L as CaCO<sub>3</sub>)</u>	<u>Duration</u>	<u>Effect</u>	<u>Result (µg/L)<sup>#</sup></u>	<u>Reference</u>
<u>Mayfly, Hexagenia rigida</u>	Cadmium nitrate	79.1	96 hrs	LC50	>1,000	Leonhard, et al. 1980
<u>Mosquito, Aedes aegypti</u>	Cadmium nitrate	-	48 hrs	LC50	4,000	Slooff, et al. 1983
<u>Mosquito, Culex pipiens</u>	Cadmium nitrate	-	48 hrs	LC50	765	Slooff, et al. 1983
<u>Widge, Tanytarsus dissimilis</u>	Cadmium chloride	47	10 days	LC50	3.8	Anderson, et al. 1980
<u>Coho salmon (juvenile), Oncorhynchus kisutch</u>	Cadmium chloride	22	217 hrs	LC50	2.0	Chapman & Stevens, 1978
<u>Coho salmon (adult), Oncorhynchus kisutch</u>	Cadmium chloride	22	215 hrs	LC50	3.7	Chapman & Stevens, 1978
<u>Chinook salmon (alevin), Oncorhynchus tshawytscha</u>	Cadmium chloride	23	200 hrs	LC10	18-26	Chapman, 1978
<u>Chinook salmon (swim-up), Oncorhynchus tshawytscha</u>	Cadmium chloride	23	200 hrs	LC10	1.2	Chapman, 1978
<u>Chinook salmon (parr), Oncorhynchus tshawytscha</u>	Cadmium chloride	23	200 hrs	LC10	1.3	Chapman, 1978
<u>Chinook salmon (smolt), Oncorhynchus tshawytscha</u>	Cadmium chloride	23	200 hrs	LC10	1.5	Chapman, 1978
<u>Rainbow trout, Salmo gairdneri</u>	Cadmium stearate	-	96 hrs	LC50	6.0	Kumada, et al. 1980
<u>Rainbow trout, Salmo gairdneri</u>	Cadmium acetate	-	96 hrs	LC50	6.2	Kumada, et al. 1980
<u>Rainbow trout, Salmo gairdneri</u>	Cadmium chloride	112	80 min	Significant avoidance	52	Black & Birge, 1980
<u>Rainbow trout, Salmo gairdneri</u>	-	112	18 mos	Reduced survival	0.2	Birge, et al. 1981

Table 6. (Continued)

<u>Species</u>	<u>Chemical</u>	<u>Hardness (mg/L as CaCO<sub>3</sub>)</u>	<u>Duration</u>	<u>Effect</u>	<u>Result (µg/L)*</u>	<u>Reference</u>
<u>Rainbow trout (embryo, larva), Salmo gairdneri</u>	Cadmium chloride	104	28 days	EC50 (death and deformity)	140	Birge, 1978; Birge, et al. 1980
<u>Rainbow trout, Salmo gairdneri</u>	-	-	240 hrs	LC50	7 5	Kumada, et al. 1973
<u>Rainbow trout (adult), Salmo gairdneri</u>	Cadmium chloride	54	408 hrs	LC50	5.2	Chapman & Stevens, 1978
<u>Rainbow trout (alevin), Salmo gairdneri</u>	Cadmium chloride	23	186 hrs	LC10	>6	Chapman, 1978
<u>Rainbow trout (swim-up), Salmo gairdneri</u>	Cadmium chloride	23	200 hrs	LC10	1.0	Chapman, 1978
<u>Rainbow trout (parr), Salmo gairdneri</u>	Cadmium chloride	23	200 hrs	LC10	0.7	Chapman, 1978
<u>Rainbow trout (smolt), Salmo gairdneri</u>	Cadmium chloride	23	200 hrs	LC10	0.8	Chapman, 1978
<u>Rainbow trout, Salmo gairdneri</u>	Cadmium sulfate	326	96 hrs	LC20	20	Davies, 1976
<u>Rainbow trout, Salmo gairdneri</u>	Cadmium stearate	-	10 wks	BCF=27 BCF=40	-	Kumada, et al. 1980
<u>Rainbow trout, Salmo gairdneri</u>	Cadmium acetate	-	10 wks	BCF=63	-	Kumada, et al. 1980
<u>Rainbow trout, Salmo gairdneri</u>	Cadmium chloride	125	10 days	LC50 (18 C) (12 C) (6 C)	10-30 30 10-30	Roch & Maly, 1979
<u>Rainbow trout, Salmo gairdneri</u>	Cadmium sulfate	240	234 days	Increased gill diffusion	2	Hughes, et al. 1979
<u>Rainbow trout, Salmo gairdneri</u>	Cadmium chloride	320	4 mos	Physiological effects	10	Arillo, et al. 1982, 1984
<u>Rainbow trout, Salmo gairdneri</u>	Cadmium chloride	98.6	47 days	Reduced growth and survival	100	Woodworth & Pascoe, 1982

Table 6. (Continued)

<u>Species</u>	<u>Chemical</u>	<u>Hardness (mg/L as CaCO<sub>3</sub>)</u>	<u>Duration</u>	<u>Effect</u>	<u>Result (µg/L)<sup>a</sup></u>	<u>Reference</u>
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	LD50 (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)

<u>Species</u>	<u>Chemical</u>	<u>Hardness (mg/L as CaCO<sub>3</sub>)</u>	<u>Duration</u>	<u>Effect</u>	<u>Result (µg/L)*</u>	<u>Reference</u>
<u>Fathead minnow, Pimephales promelas</u>	Cadmium chloride	55	96 hrs	LC50	40.9	Spehar, 1982
<u>Fathead minnow, Pimephales promelas</u>	Cadmium chloride	59	96 hrs	LC50	64.8	Spehar, 1982
<u>Fathead minnow, Pimephales promelas</u>	Cadmium chloride	66	96 hrs	LC50	135	Spehar, 1982
<u>Fathead minnow, Pimephales promelas</u>	Cadmium chloride	65	96 hrs	LC50	120	Spehar, 1982
<u>Fathead minnow, Pimephales promelas</u>	Cadmium chloride	74	96 hrs	LC50	86.3	Spehar, 1982
<u>Fathead minnow, Pimephales promelas</u>	Cadmium chloride	79	96 hrs	LC50	86.6	Spehar, 1982
<u>Fathead minnow, Pimephales promelas</u>	Cadmium chloride	62	96 hrs	LC50	114	Spehar, 1982
<u>Fathead minnow, Pimephales promelas</u>	Cadmium chloride	63	96 hrs	LC50	80.8	Spehar, 1982
<u>Fathead minnow, Pimephales promelas</u>	Cadmium nitrate	-	48 hrs	LC50	2,200	Sloof, et al. 1983
<u>Fathead minnow, Pimephales promelas</u>	Cadmium chloride	103	6.8 hrs	LT50	6,000	Birge, et al. 1983
<u>Fathead minnow, Pimephales promelas</u>	Cadmium chloride	254-271	3.7 hrs	LT50	16,000	Birge, et al. 1983
<u>Fathead minnow (larva), Pimephales promelas</u>	Cadmium chloride	89-107	7 days	LC50	200	Birge, et al. 1983
<u>Fathead minnow (larva), Pimephales promelas</u>	Cadmium chloride	89-107	7 days	LC50 after 4 days acclimated to 5.6 µg/L	540	Birge, et al. 1983

Table 6. (Continued)

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

Table 6. (Continued)

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

Table 6. (Continued)

<u>Species</u>	<u>Chemical</u>	<u>Hardness (mg/L as CaCO<sub>3</sub>)</u>	<u>Duration</u>	<u>Effect</u>	<u>Result (µg/L)*</u>	<u>Reference</u>
<u>Polychaete worm, Neanthes arenaceodentata</u>	Cadmium chloride	-	28 days	LC50	3,000	Relsh, et al. 1976
<u>Polychaete worm, Capitella capitata</u>	Cadmium chloride	-	28 days	LC50	630	Relsh, et al. 1978
<u>Polychaete worm, Capitella capitata</u>	Cadmium chloride	-	28 days	LC50	700	Relsh, et al. 1976
<u>Blue mussel, Mytilus edulis</u>	Cadmium EDTA	-	28 days	BCF=252	-	George & Coombs, 1977
<u>Blue mussel, Mytilus edulis</u>	Cadmium alginate	-	28 days	BCF=252	-	George & Coombs, 1977
<u>Blue mussel, Mytilus edulis</u>	Cadmium humate	-	28 days	BCF=252	-	George & Coombs, 1977
<u>Blue mussel, Mytilus edulis</u>	Cadmium pectate	-	28 days	BCF=252	-	George & Coombs, 1977
<u>Blue mussel, Mytilus edulis</u>	Cadmium chloride	-	21 days	BCF=710	-	Janssen & Scholz, 1979
<u>Bay scallop, Argopecten irradians</u>	Cadmium chloride	-	42 days	EC50 (growth reduction)	78	Pesch & Stewart, 1980
<u>Bay scallop, Argopecten irradians</u>	Cadmium chloride	-	21 days	BCF=168	-	Elsler, et al. 1972
<u>Eastern oyster, Crassostrea virginica</u>	Cadmium iodide	-	40 days	BCF=677	-	Kerfoot & Jacobs, 1976
<u>Eastern oyster, Crassostrea virginica</u>	Cadmium chloride	-	21 days	BCF=149	-	Elsler, et al. 1972
<u>Eastern oyster, Crassostrea virginica</u>	Cadmium chloride	-	2 days	Reduction in embryonic development	15	Zaroglian & Morrison, 1981
<u>Pacific oyster, Crassostrea gigas</u>	Cadmium chloride	-	6 days	50% reduction in settlement	20-25	Watling, 1983b

Table 6. (Continued)

<u>Species</u>	<u>Chemical</u>	<u>Hardness (mg/L as CaCO<sub>3</sub>)</u>	<u>Duration</u>	<u>Effect</u>	<u>Result (µg/L)*</u>	<u>Reference</u>
<u>Pacific oyster, Crassostrea glgas</u>	Cadmium chloride	-	14 days	Growth reduction	10	Watling, 1983b
<u>Pacific oyster, Crassostrea glgas</u>	Cadmium chloride	-	23 days	LC50	50	Watling, 1983b
<u>Soft-shell clam, Mya arenaria</u>	Cadmium chloride	-	7 days	LC50	150	Eisler, 1977
<u>Soft-shell clam, Mya arenaria</u>	Cadmium chloride	-	7 days	LC50	700	Eisler & Hennekey, 1977
<u>Copepod (nauplius), Eurytemora affinis</u>	Cadmium chloride	-	1 day	Reduction in swimming speed	130	Sullivan, et al. 1983
<u>Copepod (nauplius), Eurytemora affinis</u>	Cadmium chloride	-	2 days	Reduction in development rate	116	Sullivan, et al. 1983
<u>Copepod, Tisbe holothuriae</u>	Cadmium chloride	-	48 hrs	LC50	970	Moral tou-Apostolopoulou & Verriopoulos, 1982
<u>Mysid, Mysidopsis bahia</u>	-	-	17 days	LC50 (15-23 g/kg salinity)	11	Nimmo, et al. 1977a
<u>Mysid, Mysidopsis bahia</u>	Cadmium chloride	-	16 days	LC50 (30 g/kg salinity)	28	Gentile, et al. 1982
<u>Mysid, Mysidopsis bahia</u>	Cadmium chloride	-	8 days	LC50	60	Gentile, et al. 1982
<u>Mysid, Mysidopsis bigelowi</u>	Cadmium chloride	-	8 days	LC50	70	Gentile, et al. 1982
<u>Mysid, Mysidopsis bigelowi</u>	Cadmium chloride	-	28 days	LC50	18	Gentile, et al. 1982
<u>Isopod, Idotea baltica</u>	Cadmium sulfate	-	5 days	LC50 (3 g/kg salinity)	10,000	Jones, 1975



Table 6. (Continued)

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

Table 6. (Continued)

<u>Species</u>	<u>Chemical</u>	<u>Hardness (mg/L as CaCO<sub>3</sub>)</u>	<u>Duration</u>	<u>Effect</u>	<u>Result (µg/L)*</u>	<u>Reference</u>
<u>American lobster, Homarus americanus</u>	Cadmium chloride	-	30 days	Increase in ATPase activity	6	Tucker, 1979
<u>Hermit crab, Pagurus longicarpus</u>	Cadmium chloride	-	7 days	25% mortality	270	Elsler & Hennekey, 1977
<u>Hermit crab, Pagurus longicarpus</u>	Cadmium chloride	-	60 days	LC56	70	Pesch & Stewart, 1980
<u>Rock crab, Cancer irroratus</u>	Cadmium chloride	-	96 hrs	Enzyme activity	1,000	Gould, et al. 1976
<u>Rock crab (larva), Cancer irroratus</u>	Cadmium chloride	-	28 days	Delayed development	50	Johns & Miller, 1982
<u>Blue crab, Callinectes sapidus</u>	Cadmium nitrate	-	7 days	LC50 (10 g/kg salinity)	50	Rosenberg & Costlow, 1976
<u>Blue crab, Callinectes sapidus</u>	Cadmium nitrate	-	7 days	LC50 (30 g/kg salinity)	150	Rosenberg & Costlow, 1976
<u>Blue crab (juvenile), Callinectes sapidus</u>	Cadmium chloride	-	4 days	LC50 (1 g/kg salinity)	320	Frank & Robertson, 1979
<u>Mud crab (larva), Eurypanopeus depressus</u>	Cadmium chloride	-	8 days	LC50	10	Mirkes, et al. 1978
<u>Mud crab (larva), Eurypanopeus depressus</u>	Cadmium chloride	-	44 days	Delay in metamorphosis	10	Mirkes, et al. 1978
<u>Mud crab, Rhithropanopeus harrisi</u>	Cadmium nitrate	-	11 days	LC80 (10 g/kg salinity)	50	Rosenberg & Costlow, 1976
<u>Mud crab, Rhithropanopeus harrisi</u>	Cadmium nitrate	-	11 days	LC75 (20 g/kg salinity)	50	Rosenberg & Costlow, 1976
<u>Mud crab, Rhithropanopeus harrisi</u>	Cadmium nitrate	-	11 days	LC40 (30 g/kg salinity)	50	Rosenberg & Costlow, 1976
<u>Fiddler crab, Uca pugilator</u>	-	-	10 days	LC50	2,900	O'Hara, 1975a

Table 6. (Continued)

<u>Species</u>	<u>Chemical</u>	<u>Hardness (mg/L as CaCO<sub>3</sub>)</u>	<u>Duration</u>	<u>Effect</u>	<u>Result (µg/L)<sup>a</sup></u>	<u>Reference</u>
<u>Fiddler crab, Uca pugilator</u>	Cadmium chloride	-	-	Effect on respiration	1.0	Vernberg, et al. 1974
<u>Starfish, Asterias forbesi</u>	Cadmium chloride	-	7 days	25% mortality	270	Eisler & Hennekey, 1977
<u>Herring (larva), Clupea harengus</u>	Cadmium chloride	-	-	100% embryonic survival	5,000	Westernhagen, et al. 1979
<u>Pacific herring (embryo), Clupea harengus pallasii</u>	Cadmium chloride	-	<24 hrs	17% reduction in volume	10,000	Alderdice, et al. 1979a
<u>Pacific herring (embryo), Clupea harengus pallasii</u>	Cadmium chloride	-	96 hrs	Decrease in capsule strength	1,000	Alderdice, et al. 1979b
<u>Pacific herring (embryo), Clupea harengus pallasii</u>	Cadmium chloride	-	48 hrs	Reduced osmo- lality of perivitelline fluid	1,000	Alderdice, et al. 1979c
<u>Mummichog (adult), Fundulus heteroclitus</u>	Cadmium chloride	-	48 hrs	LC50 (20 g/kg salinity)	60,000	Middaugh & Dean, 1977
<u>Mummichog (adult), Fundulus heteroclitus</u>	Cadmium chloride	-	48 hrs	LC50 (30 g/kg salinity)	43,000	Middaugh & Dean, 1977
<u>Mummichog, Fundulus heteroclitus</u>	Cadmium chloride	-	21 days	BCF=48	-	Eisler, et al. 1972
<u>Mummichog (larva), Fundulus heteroclitus</u>	Cadmium chloride	-	48 hrs	LC50 (20 g/kg salinity)	32,000	Middaugh & Dean, 1977
<u>Mummichog (larva), Fundulus heteroclitus</u>	Cadmium chloride	-	48 hrs	LC50 (30 g/kg salinity)	7,800	Middaugh & Dean, 1977
<u>Atlantic silverside (adult), Menidia menidia</u>	Cadmium chloride	-	48 hrs	LC50 (20 g/kg salinity)	13,000	Middaugh & Dean, 1977
<u>Atlantic silverside (adult), Menidia menidia</u>	Cadmium chloride	-	48 hrs	LC50 (30 g/kg salinity)	12,000	Middaugh & Dean, 1977

Table 6. (Continued)

<u>Species</u>	<u>Chemical</u>	<u>Hardness (mg/L as CaCO<sub>3</sub>)</u>	<u>Duration</u>	<u>Effect</u>	<u>Result (µg/L)*</u>	<u>Reference</u>
<u>Atlantic silverside, Menidia menidia</u>	Cadmium chloride	-	19 days	LC50 (12 g/kg salinity)	<160	Voyer, et al. 1979
<u>Atlantic silverside, Menidia menidia</u>	Cadmium chloride	-	19 days	LC50 (20 g/kg salinity)	540	Voyer, et al. 1979
<u>Atlantic silverside, Menidia menidia</u>	Cadmium chloride	-	19 days	LC50 (30 g/kg salinity)	>970	Voyer, et al. 1979
<u>Atlantic silverside (larva), Menidia menidia</u>	Cadmium chloride	-	48 hrs	LC50 (20 g/kg salinity)	2,200	Middaugh & Dean, 1977
<u>Atlantic silverside (larva), Menidia menidia</u>	Cadmium chloride	-	48 hrs	LC50 (30 g/kg salinity)	1,600	Middaugh & Dean, 1977
<u>Striped bass (juvenile), Morone saxatilis</u>	Cadmium chloride	-	90 days	Significant de- crease in enzyme activity	5	Dawson, et al. 1977
<u>Striped bass (juvenile), Morone saxatilis</u>	Cadmium chloride	-	30 days	Significant de- crease in oxygen consumption	0.5-5.0	Dawson, et al. 1977
<u>Spot (larva), Leiostomus xanthurus</u>	Cadmium chloride	-	9 days	Incipient LC50	200	Middaugh, et al. 1975
<u>Cunner (adult), Tautoglabrus adspersus</u>	Cadmium chloride	-	60 days	37.5% mortality	100	MacInnes, et al. 1977
<u>Cunner (adult), Tautoglabrus adspersus</u>	Cadmium chloride	-	30 days	Depressed gill tissue oxygen consumption	50	MacInnes, et al. 1977
<u>Cunner (adult), Tautoglabrus adspersus</u>	Cadmium chloride	-	96 hrs	Decreased en- zyme activity	3,000	Gould & Karolus, 1974
<u>Winter flounder, Pseudopleuronectes americanus</u>	Cadmium chloride	-	8 days	50% viable hatch	300	Voyer, et al. 1977

Table 6. (Continued)

<u>Species</u>	<u>Chemical</u>	<u>Hardness (mg/L as CaCO<sub>3</sub>)</u>	<u>Duration</u>	<u>Effect</u>	<u>Result (µg/L)*</u>	<u>Reference</u>
<u>Winter flounder, Pseudopleuronectes americanus</u>	Cadmium chloride	-	60 days	Increased gill tissue respiration	5	Calabrese, et al. 1975
<u>Winter flounder, Pseudopleuronectes americanus</u>	Cadmium chloride	-	17 days	Reduction of viable hatch	586	Voyer, et al. 1982

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

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