AMBIENT AQUATIC LIFE WATER QUALITY CRITERIA FOR

LEAD

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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*

Because of the variety of forms of lead (Boggess, 1977; 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 lead. Previous aquatic life criteria for lead (U.S. EPA, 1980) were expressed in terms of total recoverable lead (U.S. EPA, 1983a), but this measurement is probably too rigorous in some situations. Acid-soluble lead (operationally defined as the lead that passes through a 0.45 μm membrane filter after the sample is acidified to pH = 1.5 to 2.0 with nitric acid) is probably the best measurement at the present for the following reasons:

1. This measurement is compatible with nearly all available data concerning toxicity of lead to, and bioaccumulation of lead by, aquatic organisms. Very few 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 lead. For example, results reported in terms of dissolved lead were not used if the concentration of precipitated lead was substantial.
2. On samples of ambient water, measurement of acid-soluble lead should measure all forms of lead 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 lead that is occluded in minerals, clays, and sand or is strongly sorbed to

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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.

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 lead, such as the EDTA complex of lead, 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 lead in aqueous effluents. Measurement of acid-soluble lead should be applicable to effluents because it will measure precipitates, such as carbonate and hydroxide precipitates of lead, that might exist in an effluent and dissolve when the effluent is diluted with receiving water. If desired, dilution of effluent with receiving water before measurement of acid-soluble lead might be used to determine whether the receiving water can decrease the concentration of acid-soluble lead because of sorption.
4. The acid-soluble measurement should be useful for most metals, thus minimizing the number of samples and procedures that are necessary.
5. The acid-soluble measurement does not require filtration at the time of collection, as does the dissolved measurement.
6. The only treatment required at the time of collection is preservation by acidification to pH = 1.5 to 2.0, similar to that required for the total recoverable measurement.
7. Durations of 10 minutes to 24 hours between acidification and filtration probably will not affect the result substantially.
8. The carbonate system has a much higher buffer capacity from pH = 1.5 to 2.0 than it does from pH = 4 to 9 (Weber and Stumm, 1963).
9. Differences in pH within the range of 1.5 to 2.0 probably will not affect the result substantially.

10. The acid-soluble measurement does not require a digestion step, as does the total recoverable measurement.
11. After acidification and filtration of the sample to isolate the acid-soluble lead, the analysis can be performed using either atomic absorption spectroscopy or ICP-atomic emission spectroscopy (U.S. EPA, 1983a), as with the total recoverable measurement.

Thus, expressing aquatic life criteria for lead 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 lead or for measuring lead in ambient water or aqueous effluents, measurement of both acid-soluble lead and total recoverable lead in ambient water or effluent or both might be useful. For example, there might be cause for concern if total recoverable lead is much above an applicable limit, even though acid-soluble lead is below the limit.

Unless otherwise noted, all concentrations reported herein are expected to be essentially equivalent to acid-soluble lead concentrations. All concentrations are expressed as lead, not as the chemical tested. The criteria presented herein supersede previous aquatic life water quality criteria for lead (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

Acute tests were conducted at three different levels of water hardness with *Daphnia magna* (Chapman, et al. Manuscript), demonstrating that daphnids were three times more sensitive to lead in soft than in hard water (Table 1). The value in soft water agrees closely with the value in Table 6 for the same species in soft water (Biesinger and Christensen, 1972). Data in Table 1 also indicate that lead was more toxic to the rainbow trout, fathead minnow, and bluegill in soft than in hard water. The results of the acute tests conducted by Davies, et al. (1976) with rainbow trout in hard water are reported as unmeasured values in Table 1, because total lead concentrations were not measured, even though the dissolved concentrations were. Hale (1977) conducted an acute exposure of rainbow trout to lead and obtained an LC50 of 8,000 µg/L. This value is almost seven times greater than the LC50 obtained for rainbow trout in soft water by Davies, et al. (1976). Hale did not report water hardness; however, alkalinity and pH were reported to be 105 mg/L and 7.3, respectively, which suggests that this water was probably harder than the soft water used by Davies, et al. (1976).

Amphipods were reported by Spehar, et al. (1978) and Call, et al. (1983) to be more sensitive to lead than any other freshwater animal species thus far tested. Also, in exposures lasting up to 28 days the amphipod was far more sensitive to lead than a snail, cladoceran, chironomid, mayfly, stonefly, and caddisfly (Table 6) (Anderson, et al. 1980; Biesinger and Christensen, 1972; Nehring, 1976; Spehar, et al. 1978). Although results of tests on lead acetate were placed in Table 6 because of the possible effect of acetate on the toxicity of lead, Pickering and Henderson (1966) found that lead chloride (Table 1) and lead acetate (Table 6) were about equally toxic to the fathead minnow in static tests in soft water. Wallen, et al. (1957) reported that

lead oxide (Table 6) is much less acutely toxic than lead nitrate (Table 1) to the mosquitofish in water containing a high concentration of suspended clay particles.

Different species exhibit different sensitivities to lead, and many other factors might affect the results of tests of the toxicity of lead 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 lead, although the observed effect is probably 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 lead. 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 the 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 four 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 at least 100 mg/L higher than the lowest. An F-test showed that, under the assumption of equality of slopes, the probability of obtaining four slopes as dissimilar as these is P=0.03. This was interpreted as indicating that it is unreasonable to assume that the slopes for these four species are the same. The slopes for Daphnia magna, fathead minnow, and bluegill (see end of Table 1) were close to the slope of 1.0 that is expected on the basis that lead, calcium, magnesium, and carbonate all have

a charge of two. The slope for rainbow trout was 2.475 and therefore was not used. A test of equality of slopes showed that P=0.16, indicating that it is not unreasonable to assume that the slopes for the three species are the same.

The pooled slope of 1.273 was used with the data in Table 1 to calculate Species Mean Acute Values at a hardness of 50 mg/L (Table 1). Genus Mean Acute Values (Table 3) were then calculated as geometric means of the available freshwater Species Mean Acute Values. Of the ten genera for which acute values are available, the most sensitive genus, Gammarus, was 1,650 times more sensitive than the most resistant, Tanytarsus. The freshwater Final Acute Value of 67.54 µg/L was calculated at a hardness of 50 mg/L from the Genus Mean Acute Values in Table 3 using the procedure described in the Guidelines. Thus, the freshwater Criterion Maximum Concentration (in µg/L) = $e^{(1.273[\ln(\text{hardness})]-1.460)}$.

Tests of the acute toxicity of lead to saltwater organisms have been conducted with nine species of invertebrates and four species of fish (Table 1). In flow-through toxicity tests with two fish species, less than 50 percent of the test organisms were killed at 3,140 µg/L, which is the solubility of lead in sea water under the test conditions, but the acute value for the mummichog is 315 µg/L. The range of sensitivities of bivalve molluscs is also great, probably reflecting differences in life stage. The adult soft-shell clam had an LC50 of 27,000 µg/L, whereas the acute values with larvae of four species ranged from 476 to 2,450 µg/L. Of the eleven saltwater genera for which acute values are available, the most sensitive genus, Fundulus, was 85 times more sensitive than the most resistant, Mya (Table 3). The sensitivities of the six most sensitive genera differed by only a factor of 2.5, even though these six lowest Genus Mean Acute Values are from tests

conducted with a variety of species and life stages. The saltwater Final Acute Value was calculated to be 287.4 µg/L.

Chronic Toxicity to Aquatic Animals

Chapman, et al. (Manuscript) studied the chronic toxicity of lead to Daphnia magna at three different hardnesses (Table 2). The daphnids were nearly 11 times more sensitive to lead in soft water than in hard water. The value in soft water was about one-fourth that obtained by Biesinger and Christensen (1972) with the same species in a different soft water in a test in which the concentrations of lead were not measured (Table 6). The chronic values of Chapman, et al. were regressed against hardness; the slope was 2.328, but the 95% confidence limits were -8.274 and 12.931.

A life-cycle test on lead in hard water was conducted by Borgmann, et al. (1978) with a snail. These authors used biomass as their endpoint and reported that lead concentrations as low as 19 µg/L significantly decreased survival, but not growth or reproduction. It is not clear, however, how these investigators arrived at such a low effect concentration. This publication did, however, contain suitable information for determining a chronic value. Chronic limits were taken directly from the cumulative percent survival figure which showed no observed effect on survival at 12 µg/L and almost complete mortality at 54 µg/L. The chronic value (geometric mean of the lower and upper limits) for snails was therefore established at 25.46 µg/L (Table 2).

Davies, et al. (1976) published results of an early life-stage test with rainbow trout in soft water (Table 2). Even though this test was started with embryos and continued for 19 months after hatch, it could not be considered a life-cycle test because no reproduction occurred. Davies, et al. (1976)

selected chronic limits based on a very low incidence of black-colored tails and spinal deformities (4.7 and 0.7 percent, respectively). For the purposes of deriving water quality criteria, such low percentages of such effects were not considered unacceptable. The concentration of 27 µg/L was selected as the upper limit because it caused spinal curvature in 32.2 percent of the fish, whereas 13.2 µg/L only caused curvature in 3.6 percent of the fish. The occurrence of black tails was not considered to be an unacceptable effect.

Spinal deformities were also caused by lead in a life-cycle test with brook trout (Holcombe, et al. 1976) and in an early life-stage test with rainbow trout (Sauter, et al. 1976). Results of tests by Sauter, et al. (1976) with the northern pike, walleye, lake trout, channel catfish, white sucker, and bluegill were not included in Tables 2 or 6 because of excessive mortality in the controls. Even though the hardnesses were similar, the chronic value obtained for rainbow trout by Sauter, et al. (1976) is higher than the chronic value derived from Davies, et al. (1976), possibly because Sauter, et al. exposed the fish for 2 months, whereas Davies, et al. exposed the fish for 19 months.

Davies, et al. (1976) described the long-term effects on rainbow trout fry and fingerlings exposed to various concentrations of lead for 19 months in hard and soft water (Table 6). Although these tests were neither life-cycle (no natural reproduction) nor early life-stage (no embryos exposed), they do provide information concerning the relationship between water hardness and the chronic toxicity of lead to fish. In the test in hard water, only 0 and 10 percent of the trout developed spinal deformities at measured lead concentrations of 190 and 380 µg/L, respectively. In soft water 44 and 97

percent of the trout developed spinal deformities at measured lead concentrations of 31 and 62 µg/L, respectively. These results strongly demonstrate that lead is more chronically toxic in soft water than in hard water.

The mysid, Mysidopsis bahia, is the only saltwater species with which a chronic test has been conducted on lead (Table 2). The most sensitive observed adverse effect was reduced spawning and the resulting chronic value was 25.08 µg/L. The 96-hr LC50 for this same species in the same study was 3,130 µg/L, producing an acute-chronic ratio of 124.8.

The range of the available acute-chronic ratios (Table 3) is small enough that all four can be used to calculate the geometric mean ratio of 51.29. When this ratio is used with the freshwater Final Acute Value and the pooled slope (Table 3), the resulting freshwater Final Chronic Value (in µg/L) = $e^{(1.273[\ln(\text{hardness})]-4.705)}$. Similarly, the saltwater Final Chronic Value is 5.603 µg/L (Table 3).

Toxicity to Plants

The effects of lead on various species of algae have been studied in tests which lasted from 4 to 10 days (Table 4). All authors except Rachlin, et al. (1982, 1983) used nominal concentrations. The adverse effect concentrations from these tests ranged from 500 to 63,800 µg/L. It would appear therefore that adverse effects of lead on freshwater plants are unlikely at concentrations protective of chronic effects on freshwater animals.

The saltwater alga, Champia parvula, is quite sensitive to lead and a diatom is only slightly less sensitive (Table 4). The saltwater alga, Dunaliella tertiolecta, is 10 times more sensitive to tetraethyl lead than to tetramethyl lead (Table 6).

Bioaccumulation

Four freshwater invertebrate species have been exposed to lead (Borgmann, et al. 1978; Spehar, et al. 1978) and the bioconcentration factors (BCFs) ranged from 499 to 1,700 (Table 5). BCFs obtained with brook trout and bluegills were 42 and 45, respectively, (Atchison, et al. 1977; Holcombe, et al. 1976).

BCFs reported for lead from tests with saltwater bivalve molluscs and diatoms range from 17.5 from a 56-day exposure of the quahog clam to 2,570 from a 130-day exposure of the blue mussel (Table 5). The difference in BCFs might be a difference between species or might be due to the difference in the duration of the tests.

Neither a freshwater nor a saltwater Final Residue Value can be calculated because no maximum permissible tissue concentration is available for lead.

Other Data

Many of the values in Table 6 have already been discussed. Spehar, et al. (1978) found no adverse effects on a freshwater snail, stonefly, and caddisfly in 28 days at 565 µg/L. Anderson, et al. (1980) obtained a 10-day LC50 of 258 µg/L for the midge, Tanytarsus dissimilis (Table 6), which is much lower than the 48-hr acute value of 224,000 µg/L obtained by Call, et al. (1983) with the same species. The 10-day exposure includes most of its life cycle and several of the presumably sensitive molts, and so should probably be considered as useful as the early life-stage test with fish. Merlini and Pozzi (1977a) conducted a pH acclimation and lead bioconcentration study with bluegills collected from a lake contaminated with lead.

A variety of effects on saltwater organisms have been observed. Gray and Ventilla (1973) observed a reduction in growth rate in a ciliate protozoan after 12-hr exposures to lead concentrations of 150 and 300 µg/L. Woolery and Lewin (1976) observed a reduction in photosynthesis and respiration in the diatom, Pheodactylum tricornutum, at concentrations of lead ranging from 100 to 10,000 µg/L. However, Hannan and Patouillet (1972) obtained no inhibition of growth of the same species at a concentration of 1,000 µg/L after 72 hours. Rivkin (1979), using growth rate to determine toxicity to the diatom, Skeletonema costatum, reported a 12-day EC50 of 5.1 µg/L. Hessler (1974) observed delayed cell division in the phytoplankton, Platymonas subcordiformus, during exposure to 2,500 µg/L for 72 hours. At 60,000 µg/L, however, Hessler (1974) reported not only growth retardation but also death. Benijts-Claus and Benijts (1975) observed delayed larval development in the mud crab, Rhithropanopeus harrisii, during exposure to 50 µg/L. Weis and Weis (1977) observed depressed axis formation in developing embryos of Fundulus heteroclitus at lead concentrations of 100 µg/L. Reish and Carr (1978) found that 1,000 µg/L suppressed reproduction of two polychaete species, Ctenodriluis serratus and Ophryotrocha diadema, in a 21-day test.

Unused Data

Some data on the effects of lead on aquatic organisms were not used because the studies were conducted with species that are not resident in North America. Jennett, et al. (1981) did not identify their test animals beyond common names such as "algae, crayfish, and minnows". Nehring, et al. (1979) did not identify their organisms to species, so it is not known if

[illegible], which were collected in Iran, are also found in North America. Brown and Ahsanullah (1971) conducted tests with brine shrimp, which species is too atypical to be used in deriving national criteria.

Data were not used if lead was a component of a mixture (Hedtke and Puglisi, 1980; Heisey and Damman, 1982; Jana and Choudhuri, 1984; Wong, et al. 1982). Reviews by Chapman, et al. (1968), Demayo, et al. (1980, 1982), Eisler (1981), Eisler, et al. (1979), North, et al. (1972), Phillips and Russo (1978), and Thompson, et al. (1972) only contain data that have been published elsewhere.

Many studies dealing with toxicity or physiological effects could not be used because the authors did not report clearly defined endpoints (i.e., LC50, EC50, statistically significant adverse effects): Apostol (1973), Baker, et al. (1983), Behan, et al. (1979), Belding (1927), Carpenter (1925), Crandall and Goodnight (1962), Dawson (1935), Dilling, et al. (1926), Dilling and Healy (1927), Ellis (1937), Ferguson and Bubela (1974), Fujiya (1961), Jackim (1973), Jackim, et al. (1970), Johnson and Eaton (1980), Jones (1935, 1947a,b), Laube, et al. (1980), Lloyd (1961), Lu, et al. (1975), Manalis and Cooper (1973), Manalis, et al. (1984), Merlini and Pozzi (1977b), Metayer, et al. (1982), Narbonne, et al. (1973), O'Neill (1981), Overnell (1975), Phillips (1980), Rao and Subramanian (1982), Rathore and Swarup (1978), Rice, et al. (1973), Ruthven and Cairns (1973), Ryck and Whitley (1974), Schulze and Brand (1978), Stratford, et al. (1984), Thomas, et al. (1980), Tucker and Matte (1980), Van der Werff and Pruyt (1982), Varansai and Gmur (1978), Varansai, et al. (1975), Watling (1981), Westfall (1945), and Wiener and Giesy (1979).

Some results were not used because the test was either improperly designed for deriving criteria or important details were omitted from the

report: Ferard, et al. (1982), Foster (1982a,b), Gentile, et al. (1982), Marion and Denizeau (1983), Passino and Cotant (1979), Say and Whitton (1983), Vighi (1981), Wehr and Whitton (1983a,b), and Whitton, et al. (1982). Dorfman and Whitworth (1969) exposed brook trout to lead only on week days and the concentrations were not measured during tests lasting up to 38 days. These authors and Carpenter (1927), Rushton (1922), and Tarzwell and Henderson (1960) conducted tests with only one or two fish at a time. Rainbow trout tested by Hodson, et al. (1978b) were not acclimated to abrupt changes in pH before stressing them with lead. Experiments reported by Hodson, et al. (1982) were designed to measure lead uptake in opercular bone and formation of black tails correlated to different growth rates of rainbow trout; however, these fish were only exposed to one sublethal concentration of lead. No data are available on the concentrations of lead in water during the studies reported by Hodson, et al. (1983a). Sicko-Goad (1982), Sicko-Goad and Lazinsky (1981, 1982), and Sicko-Goad and Stoermer (1979) exposed algae to only one sublethal concentration of lead. The 96-hr values reported by Buikema, et al. (1974a,b) were subject to error because of possible reproductive interactions (Buikema, et al. 1977). Clarke and Clarke (1974) reported that their test water was contaminated with lead leached from plastic exposure tanks. Exposure times were not reported by Brown (1976) and Haider (1964). Kariya, et al. (1969) and Turnbull (1954) failed to report the number of fish tested. High control mortalities occurred in all except one test reported by Sauter, et al. (1976). Control mortality exceeded 10 percent in two tests by Mount and Norberg (1984).

English, et al. (1963) published results based on volume dilutions instead of nominal or measured concentrations. Brown (1968), Garavini and

Martelli (1979), Pawlaczyk-Szpilowa and Slowik (1981), Rao and Saxena (1980), and Rolfe, et al. (1977) exposed algae, invertebrates, and fish to lead but failed to adequately describe their test methods. Carpenter (1926, 1930), Carter and Cameron (1973), Ellgaard and Rudner (1982), Ellis (1940), Grande and Andersen (1983), Jones (1938, 1939), Nyman (1981), Ozoh (1979), Rathore, et al. (1979), Shaw and Grushkin (1957), Shaw and Lowrance (1956), Vijaymadhavan and Iwai (1975), Wang (1959), and Weir and Hine (1970) conducted tests in distilled, deionized, chlorinated, or "tap" water.

Biegert and Valkovic (1980) expressed their acute data in hours to death and concentrations were a factor of ten apart. The concentrations of lead overlapped in the tests by Sparks, et al. (1983). Tests on the toxicity of lead to algae were not used if the medium contained too much of a complexing agent such as EDTA (Davis, 1978).

Results of laboratory bioconcentration tests were not used if the test was not flow-through (Montgomery, et al. 1978; Watling, 1983), if the test did not last long enough (Wong, et al. 1981), if no soft tissues were analyzed (Sturesson, 1978), if the concentration in water was not known (Ray, et al. 1981) or was not measured often enough (Freeman, 1978, 1980), or if control mortalities were high (Valiela, et al. 1974). Studies such as those by Ancellin, et al. (1973), Aubert, et al. (1974), and Nash, et al. (1981), which used radioactive isotopes of lead, were not used because of the possibility of isotope discrimination. Newman and McIntosh (1983b) conducted a depuration study, but not an uptake study.

A large number of reports on lead toxicity and residues in wild aquatic organisms could not be used for the calculation of bioaccumulation factors or toxicity due to an insufficient number of measurements of the concentration

of lead in the water: Anderson (1977), Badsha and Goldspink (1982), Brezina and Arnold (1977), Brezina, et al. (1974), Brown and Chow (1977), Eide and Myklestad (1980), Enk and Mathis (1977), Evans and Lasenby (1983), Gale, et al. (1973a,b, 1982), Gordon, et al. (1980), Holm (1980), Kharkar, et al. (1976), Knowlton, et al. (1983), Leland and McNurney (1974), Lucus and Edgington (1970), Martin and Mudre (1982), Martin, et al. (1984), Mathis and Cummings (1973), Mathis and Kevern (1975), May and McKinney (1981), Mehrle, et al. (1982), Newman and McIntosh (1983a), Pagenkopf and Newman (1974), Pakkala, et al. (1972), Pennington, et al. (1982), Popham and D'Auria (1981), Price and Knight (1978), Randall, et al. (1981), Ray (1978), Sidwell, et al. (1978), Simpson (1979), Smith, et al. (1981), Tong, et al. (1974), Trollope and Evans (1976), Tsui and McCart (1981), Uthe and Bligh (1971), Vinikour, et al. (1980), Wachs (1982), Walsh, et al. (1977), Welsh and Denny (1980), Wixson and Bolter (1972), and Wren, et al. (1983).

Summary

The acute toxicity of lead to several species of freshwater animals has been shown to decrease as the hardness of water increases. At a hardness of 50 mg/L the acute sensitivities of ten species range from 142.5 µg/L for an amphipod to 235,900 µg/L for a midge. Data on the chronic effects of lead on freshwater animals are available for two fish and two invertebrate species. The chronic toxicity of lead also decreases as hardness increases and the lowest and highest available chronic values (12.26 and 128.1 µg/L) are both for a cladoceran, but in soft and hard water, respectively. Acute-chronic ratios are available for three species and range from 18 to 62. Freshwater algae are affected by concentrations of lead above 500 µg/L, based

on data for four species. Bioconcentration factors are available for four invertebrate and two fish species and range from 42 to 1,700.

Acute values are available for 13 saltwater animal species and range from 315 µg/L for the mummichog to 27,000 µg/L for the soft-shell clam. A chronic toxicity test was conducted with a mysid; unacceptable effects were observed at 37 µg/L but not at 17 µg/L and the acute-chronic ratio for this species is 124.8. A species of macroalgae was affected at 20 µg/L. Available bioconcentration factors range from 17.5 to 2,570.

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 lead does not exceed the numerical value given by $e^{(1.273[\ln(hardness)]-4.705)}$ more than once every three years on the average and if the one-hour average concentration (in ug/L) does not exceed the numerical value given by $e^{(1.273[\ln(hardness)]-1.460)}$ more than once every three years on the average. For example, at hardnesses of 50, 100, and 200 mg/L as $CaCO_3$ the four-day average concentrations of lead are 1.3, 3.2, and 7.7 µg/L, respectively, and the one-hour average concentrations are 34, 82, and 200 ug/L.

The procedures described in the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" indicate that, except possibly where a locally important species is very sensitive, saltwater aquatic organisms and their uses should not be affected unacceptably if the four-day average concentration of lead does not

exceed 5.6 µg/L more than once every three years on the average and if the one-hour average concentration does not exceed 140 µg/L more than once every three years on the average.

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 lead 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 Lead to Aquatic Animals

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
			FRESHWATER SPECIES			
Snail, *Aplexa hypnorum*	FT, M	Lead nitrate	61	1,340	1,040	Call, et al. 1981
Cladoceran, *Daphnia magna*	S, U	Lead chloride	-	931	-	Anderson, 1948
Cladoceran, *Daphnia magna*	S, U	Lead nitrate	-	5,000****	-	Bringmann & Kuhn, 1959a,b
Cladoceran, *Daphnia magna*	R, M	Lead nitrate	54	612	-	Chapman, et al. Manuscript
Cladoceran, *Daphnia magna*	R, M	Lead nitrate	110	952	-	Chapman, et al. Manuscript
Cladoceran, *Daphnia magna*	R, M	Lead nitrate	152	1,910	447.8	Chapman, et al. Manuscript
Cladoceran, *Daphnia pulex*	S, U	Lead nitrate	45	5,100*****	-	Mount & Norberg, 1984
Cladoceran, *Simocephalus vetulus*	S, U	Lead nitrate	45	4,500*****	-	Mount & Norberg, 1984
Amphipod, *Gammarus pseudolimnaeus*	FT, M	Lead nitrate	46	124	-	Spehar, et al. 1978
Amphipod, *Gammarus pseudolimnaeus*	FT, M	Lead nitrate	48	140	142.6	Call, et al. 1983
Crayfish, *Orconectes limosus*	S, M	Lead chloride	-	3,300	-	Boutet & Chaisemartin, 1973
Midge, *Tanytarsus dissimilis*	FT, M	Lead nitrate	48	224,000	235,900	Call, et al. 1983
Rainbow trout (2 mos), *Salmo gairdneri*	FT, M	Lead nitrate	-	8,000	-	Hale, 1977

Table 1. (Continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)[aa]	Species Mean Acute Value (µg/L)[aaa]	Reference
Rainbow trout, *Salmo gairdneri*	S, U	Lead nitrate	290	542,000	-	Goetti, et al. 1972; Davies & Everhart, 1973; Davies, et al. 1976
Rainbow trout, *Salmo gairdneri*	S, U	Lead nitrate	353	471,000	-	Goetti, et al. 1972; Davies & Everhart, 1973; Davies, et al. 1976
Rainbow trout, *Salmo gairdneri*	FT, U	Lead nitrate	28	1,170	2,448[†]	Goetti, et al. 1972; Davies & Everhart, 1973; Davies, et al. 1976
Brook trout (18 mos), *Salvelinus fontinalis*	FT, M	Lead nitrate	44	4,100	4,820	Holcombe, et al. 1976
Goldfish, *Carassius auratus*	S, U	Lead chloride	20	31,500	101,100	Pickering & Henderson, 1966
Fathead minnow, *Pimephales promelas*	S, U	Lead chloride	20	5,580	-	Pickering & Henderson, 1966
Fathead minnow, *Pimephales promelas*	S, U	Lead chloride	20	7,330	-	Pickering & Henderson, 1966
Fathead minnow, *Pimephales promelas*	S, U	Lead chloride	360	482,000	25,440	Pickering & Henderson, 1966
Mosquitofish (adult), *Gambusia affinis*	S, U	Lead nitrate	-	240,000[††]	-	Wallen, et al. 1957
Guppy (6 mos), *Poecilia reticulata*	S, U	Lead chloride	20	20,600	66,140	Pickering & Henderson, 1966
Bluegill, *Lepomis macrochirus*	S, U	Lead chloride	20	23,800	-	Pickering & Henderson, 1966
Bluegill, *Lepomis macrochirus*	S, U	Lead chloride	360	442,000	52,310	Pickering & Henderson, 1966

Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
			SALTWATER SPECIES			
Blue mussel (larva), *Mytilus edulis*	S, U	Lead nitrate	-	476		Martin, et al. 1981
Pacific oyster (larva), *Crassostrea gigas*	S, U	Lead nitrate	-	758	758	Martin, et al. 1981
Eastern oyster (larva), *Crassostrea virginica*	S, U	Lead nitrate	-	2,450	2,450	Calabrese, et al. 1973
Quahog clam (larva), *Mercenaria mercenaria*	S, U	Lead nitrate	-	780	780	Calabrese & Nelson, 1974
Soft-shell clam (adult), *Mya arenaria*	S, U	Lead nitrate	-	27,000	27,000	Eisler, 1977
Copepod, *Acartia clausi*	S, U	Lead nitrate	-	668	668	Gentile, 1982
Mysid, *Mysidopsis bahia*	FT, M	Lead nitrate	-	3,130	3,130	Lussier, et al. Manuscript
Amphipod, *Ampelisca abdita*	R, U	Lead nitrate	-	547	547	Scott, et al. Manuscript
Dungeness crab, *Cancer magister*	S, U	Lead nitrate	-	575	575	Martin, et al. 1981
Sheepshead minnow, *Cyprinodon variegatus*	FT, M	Lead nitrate	-	>3,140	>3,140	Cardin, 1981
Mummichog, *Fundulus heteroclitus*	S, U	Lead nitrate	-	315	315	Dortman, 1977
Inland silverside, *Menidia beryllina*	FT, M	Lead nitrate	-	>3,140	>3,140	Cardin, 1981
Atlantic silverside, *Menidia menidia*	S, U	Lead nitrate	-	>10,000	>10,000	Berry, 1981

Table 1. (Continued)

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

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

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

**** In river water.

***** Not used in calculations because the values in Mount and Norberg (1984) are much higher than values for other species in the same genus and family.

† Calculated from acute value of 1,170 µg/L using pooled slope (see text).

†† High turbidity.

Results of Covariance Analysis of Freshwater Acute Toxicity versus Hardness

Species	n	Slope	95% Confidence Limits	Degrees of Freedom
Daphnia magna	3	1.021	-3.592, 5.634	1
Rainbow trout	3	2.475	-0.357, 5.308	1
Fathead minnow	3	1.495	0.458, 2.533	1
Bluegill	2	1.011	(cannot be calculated)	0
All of above	11	1.608*	1.014, 2.202	6
All of above except rainbow trout	8	1.273**	0.909, 1.637	4

* P=0.03 for equality of slopes.

** P=0.16 for equality of slopes.

Table 2. Chronic Toxicity of Lead to Aquatic Animals

Species	Test*	Chemical	Hardness (mg/L as $CaCO_3$)	Limits (µg/L)**	Chronic Value (µg/L)**	Reference
			FRESHWATER SPECIES			
Snail, *Lymnaea palustris*	LC	Lead nitrate	139	12-54	25.46	Borgmann, et al. 1978
Cladoceran, *Daphnia magna*	LC	Lead nitrate	52	9-16.7	12.26	Chapman, et al. Manuscript
Cladoceran, *Daphnia magna*	LC	Lead nitrate	102	78-181	118.8	Chapman, et al. Manuscript
Cladoceran, *Daphnia magna*	LC	Lead nitrate	151	85-193	128.1	Chapman, et al. Manuscript
Rainbow trout, *Salmo gairdneri*	ELS	Lead nitrate	28	13.2-27	18.88	Goettl, et al. 1972; Davies & Everhart, 1973; Davies, et al. 1976
Rainbow trout, *Salmo gairdneri*	ELS	Lead nitrate	35	71-146	101.8	Sauter, et al. 1976
Brook trout, *Salvelinus fontinalis*	LC	Lead nitrate	44	58-119	83.08	Holcombe, et al. 1976
			SALTWATER SPECI			
Mysid, *Mysidopsis bahia*	LC	Lead nitrate	-	17-37	25.08	Lussier, et al. Manuscript

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

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

Results of Regression Analysis of Freshwater Chronic Toxicity versus Hardness

Species	n	Slope	95% Confidence Limits	Degrees of Freedom
Daphnia magna	3	2.328	-8.274, 12.931	1

Table 2. (Continued)

Acute-Chronic Ratio

Species	Hardness (mg/L as $CaCO_3$)	Acute Value (µg/L)	Chronic Value (µg/L)	Ratio	
Cladoceran, *Daphnia magna*	52-54	612	12.26	49.92	
Cladoceran, *Daphnia magna*	102-110	952	118.8	8.013	18.13
Cladoceran, *Daphnia magna*	151-152	1,910	128.1	14.91	
Rainbow trout, *Salmo gairdneri*	28	1,170	18.88	61.97	61.97
Brook trout, *Salvelinus fontinalis*	44	4,100	83.08	49.35	49.35
Mysid, *Mysidopsis bahia*	-	3,130	25.08	124.8	124.8

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

Rank*	Genus Mean Acute Value (µg/L)**	Species	Species Mean Acute Value (µg/L)**	Species Mean Acute-Chronic Ratio	
		FRESHWATER SPECIES			
10	235,900	Midge, *Tanytarsus dissimilis*	235,900	-	Insect
9	101,100	Goldfish, *Carassius auratus*	101,100	-	
8	66,140	Guppy, *Poecilia reticulata*	66,140	-	
7	52,310	Bluegill, *Lepomis macrochirus*	52,310	-	
6	25,440	Fathead minnow, *Pimephales promelas*	25,440	-	
5	4,820	Brook trout, *Salvelinus fontinalis*	4,820	49.35	
4	2,448	Rainbow trout, *Salmo gairdneri*	2,448	61.97	Salmonid
3	1,040	Snail, *Aplexa hypnorum*	1,040	-	-
2	447.8	Cladoceran, *Daphnia magna*	447.8	18.13***	plankton c
1	142.6	Amphipod, *Gammarus pseudolimnaeus*	142.6	-	benthic
		SALTWATER SPECIES			
11	27,000	Soft-shell clam, *Mya arenaria*	27,000	-	

Table 3. (Continued)

Rank*	Genus Mean Acute Value (µg/L)**	Species	Species Mean Acute Value (µg/L)**	Species Mean Acute-Chronic Ratio
10	>5,604	Inland silverside, *Menidia beryllina*	>3,140	-
		Atlantic silverside, *Menidia menidia*	>10,000	-
9	>3,140	Sheepshead minnow, *Cyprinodon variegatus*	>3,140	-
8	3,130	Mysid, *Mysidopsis bahia*	3,130	124.8
7	1,363	Pacific oyster, *Crassostrea gigas*	758	-
		Eastern oyster, *Crassostrea virginica*	2,450	-
6	780	Quahog clam, *Mercenaria mercenaria*	780	-
5	668	Copepod, *Acartia clausi*	668	-
4	575	Dungeness crab, *Cancer magister*	575	-
3	547	Amphipod, *Ampelisca abdita*	547	-
2	476	Blue mussel, *Mytilus edulis*	476	-
1	315	Mummichog, *Fundulus heteroclitus*	315	-

Table 3. (Continued)

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

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

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

Fresh water

Final Acute Value = 67.54 µg/L (at a hardness of 50 mg/L)

Criterion Maximum Concentration = (67.54 µg/L) / 2 = 33.77 µg/L (at a hardness of 50 mg/L)

Pooled Slope = 1.273 (see Table 1)

ln(Criterion Maximum Intercept) = ln(33.77) - [slope x ln(50)]

= 3.520 - (1.273 x 3.912) = -1.460

Criterion Maximum Concentration = $e^{(1.273[\ln(\text{hardness})]-1.460)}$

Final Acute-Chronic Ratio = 51.29 (see text)

Final Chronic Value = (67.54 µg/L) / 51.29 = 1.317 µg/L (at a hardness of 50 mg/L)

ln(Final Chronic Intercept) = ln(1.317) - [slope x ln(50)]

= 0.2754 - (1.27 x 3.912) = -4.705

Final Chronic Value = $e^{(1.273[\ln(\text{hardness})]-4.70}$

Salt water

Final Acute Value = 287.4 µg/L

Criterion Maximum Concentration = (287.4 µg/L) / 2 = 143.7 µg/L

Final Acute-Chronic Ratio = 51.29 (see text)

Final Chronic Value = (287.4 µg/L) / 51.29 = 5.603 µg/L

Table 4. Toxicity of Lead to Aquatic Plants

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Effect	Result (µg/L)*	Reference
			FRESHWATER SPECIES		
Alga, *Ankistrodesmus* sp.	Lead chloride	-	24% growth inhibition	1,000	Monahan, 1976
Alga, *Ankistrodesmus falcatus*	Lead chloride	-	60% growth inhibition	2,500	Devi Prasad & Devi Prasad, 1982
Alga, *Chlorella* sp.	Lead chloride	-	53% growth inhibition	500	Monahan, 1976
Alga, *Chlorella saccharophila*	Lead chloride	-	EC50	63,800	Rachlin, et al. 1982
Alga, *Chlorococcum* sp.	Lead chloride	-	71% growth inhibition	2,500	Devi Prasad & Devi Prasad, 1982
Alga, *Scenedesmus* sp.	Lead chloride	-	35% growth inhibition	500	Monahan, 1976
Alga, *Scenedesmus obliquus*	Lead chloride	-	72% growth inhibition	2,500	Devi Prasad & Devi Prasad, 1982
Alga, *Selenastrum* sp.	Lead chloride	-	52% growth inhibition	500	Monahan, 1976
Diatom, *Navicula incerta*	Lead chloride	-	EC50	10,960	Rachlin, et al. 1983
Eurasian watermilfoil, *Myriophyllum spicatum*	-	-	32-day EC50 (root growth)	363,000	Stanley, 1974
			SALTWATER SPECIES		
Alga, *Champia parvula*	Lead nitrate	-	Stopped sexual reproduction	20.3	Steele & Thursby, 1983
Alga, *Champia parvula*	Lead nitrate	-	Reduced female growth	20.3	Steele & Thursby, 1983

Table 4. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Effect	Result (µg/L)*	Reference
Alga, *Champia parvula*	Lead nitrate	-	Reduced tetrasporangia production	23.3	Steele & Thursby, 1983
Alga, *Champia parvula*	Lead nitrate	-	Reduced tetrasporophyte growth	23.3	Steele & Thursby, 1983
Alga, *Dunaliella salina*	Lead nitrate	-	65% growth reduction	900	Pace, et al. 1977
Diatom, *Ditylum brightwelli*	Lead chloride	-	EC50	40	Canterford & Canterford, 1980
Diatom, *Asterionella japonica*	Lead nitrate	-	EC50	207	Fisher & Jones, 1981

* Results are expressed as lead, not as the chemical. All results are based on unmeasured concentrations.

Table 5. Bioaccumulation of Lead by Aquatic Organisms

Species	Tissue	Chemical	Duration (days)	Bioconcentration Factor[a]	Reference
		FRESHWATER SPECIES			
Snail, *Lymnaea palustris*	Whole body	Lead nitrate	120	1,700**	Borgmann, et al. 1978
Snail, *Physa integra*	Whole body	Lead nitrate	28	738**	Spehar, et al. 1978
Stonefly, *Pteronarcys dorsata*	Whole body	Lead nitrate	28	1,120**	Spehar, et al. 1978
Caddisfly, *Brachycentrus* sp.	Whole body	Lead nitrate	28	499**	Spehar, et al. 1978
Brook trout (embryo-3 mos), *Salvelinus fontinalis*	Whole body	Lead nitrate	140	42**	Holcombe, et al. 1976
Bluegill, *Lepomis macrochirus*	Whole body	-	-***	45**	Atchison, et al. 1977
		SALTWATER SPECIES			
Diatom, *Ditylum brightwellii*	Cells	Lead chloride	14	725**	Canterford, et al. 1978
Blue mussel, *Mytilus edulis*	Soft parts	Lead nitrate	40	650**	Schulz-Baldes, 1974
Blue mussel, *Mytilus edulis*	Soft parts	Lead chloride	37	200**	Talbot, et al. 1976
Blue mussel, *Mytilus edulis*	Soft parts	Lead nitrate	130	2,570**	Schulz-Baldes, 1972
Blue mussel, *Mytilus edulis*	Soft parts	Lead nitrate	130	2,080**	Schulz-Baldes, 1972
Blue mussel, *Mytilus edulis*	Soft parts	Lead nitrate	130	796**	Schulz-Baldes, 1972
Eastern oyster, *Crassostrea virginica*	Soft parts	Lead nitrate	140	536	Zaroogian, et al. 1979

Table 5. (Continued)

Species	Tissue	Chemical	Duration (days)	Bioconcentration Factor*	Reference
Eastern oyster, *Crassostrea virginica*	Soft parts	Lead nitrate	49	68**	Pringle, et al. 1968
Eastern oyster, *Crassostrea virginica*	Soft parts	Lead nitrate	70	1,400	Shuster & Pringle, 1969
Quahog clam, *Mercenaria mercenaria*	Soft parts	Lead nitrate	56	17.5**	Pringle, et al. 1968

* Results are based on lead, not the chemical.

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

***This field study was conducted with a natural population of bluegills living in a small lake which was extensively analyzed for lead, zinc, and cadmium.

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

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)[a]	Reference
			FRESHWATER SPECIES			
Green alga, *Scenedesmus quadricauda*	Lead nitrate	-	96 hrs	Incipient inhibition	2,500[aa]	Bringmann & Kuhn, 1959a,b
Blue alga, *Microcystis aeruginosa*	Lead acetate	-	8 days	Incipient inhibition	450	Bringmann, 1975; Bringmann & Kuhn, 1976, 1978a,b
Green alga, *Scenedesmus quadricauda*	Lead acetate	-	8 days	Incipient inhibition	3,700	Bringmann & Kuhn, 1977a, 1978a,b, 1979, 1980b
Alga, *Anabaena* sp.	Lead nitrate	-	24 hrs	50% reduction of $^{14}CO_2$ fixation	15,000 26,000 15,000	Malanchuk & Gruendling, 1973
Alga, *Chlamydomonas* sp.	Lead nitrate	-	24 hrs	50% reduction of $^{14}CO_2$ fixation	17,000 17,000	Malanchuk & Gruendling, 1973
Angiosperm, *Potamogeton pectinatus*	Lead acetate	-	3 days	Reduced respiration	325,200	Jana & Choudhuri, 1982
Angiosperm, *Vallisneria spiralis*	Lead acetate	-	3 days	Reduced respiration	3,252,000	Jana & Choudhuri, 1982
Desmid, *Cosmarium* sp.	Lead nitrate	-	24 hrs	50% reduction of $^{14}CO_2$ fixation	5,000 5,000 5,000	Malanchuk & Gruendling, 1973
Diatom, *Navicula* sp.	Lead nitrate	-	24 hrs	50% reduction of $^{14}CO_2$ fixation	17,000 28,000 17,000	Malanchuk & Gruendling, 1973
Bacterium, *Escherichia coli*	Lead nitrate	-	-	Incipient inhibition	1,300	Bringmann & Kuhn, 1959a
Bacterium, *Pseudomonas putida*	Lead acetate	-	16 hrs	Incipient inhibition	1,800	Bringmann & Kuhn, 1976, 1977a, 1979, 1980b
Protozoan, *Entosiphon sulcatum*	Lead acetate	-	72 hrs	Incipient inhibition	20	Bringmann, 1978; Bringmann & Kuhn, 1979, 1980b, 1981

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)[a]	Reference
Protozoan, *Microregma heterostoma*	Lead nitrate	-	28 hrs	Incipient inhibition	1,250	Bringmann & Kuhn, 1959b
Protozoan, *Chilomonas paramecium*	Lead acetate	-	48 hrs	Incipient inhibition	220	Bringmann, et al. 1980, 1981
Protozoan, *Uronema parduezi*	Lead acetate	-	20 hrs	Incipient inhibition	70	Bringmann & Kuhn, 1980a, 1981
Tubificid worm, *Tubifex tubifex*	Lead nitrate	224	48 hrs	LC50	450,000	Qureshi, et al. 1980
Tubificid worm, *Tubifex* sp.	Lead nitrate	-	24 hrs	LC50	49,000	Whitley, 1968
Tubificid worm, *Tubifex* sp.	Lead nitrate	-	24 hrs	LC50	27,500	Whitley, 1968
Snail, *Goniobasis livescens*	Lead acetate	-	48 hrs	LC50	71,000	Cairns, et al. 1976
Snail, *Lymnaea emarginata*	Lead acetate	-	48 hrs	LC50	14,000	Cairns, et al. 1976
Snail, *Physa integra*	Lead nitrate	46	28 days	No effect on survival	565	Spehar, et al. 1978
Cladoceran, *Daphnia magna*	Lead chloride	45	48 hrs	EC50 (fed) (immobilization)	450	Biesinger & Christensen, 1972
Cladoceran, *Daphnia magna*	Lead chloride	45	21 days	Reproductive impairment	30	Biesinger & Christensen, 1972
Cladoceran, *Daphnia magna*	Lead acetate	-	24 hrs	LC50	2,500	Bringmann & Kuhn, 1977b
Natural copepod assemblages	Lead nitrate	-	7 days	Reduced growth rate	2,320	Borgmann, 1980
Amphipod, *Gammarus pseudolimnaeus*	Lead nitrate	46	28 days	LC50	28.4	Spehar, et al. 1978
Crayfish, *Orconectes virilis*	Lead acetate	-	40 days	Increase in ventilation rate	500	Anderson, 1978

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)[a]	Reference
Mayfly, *Ephemerella grandis*	Lead nitrate	50	14 days	LC50	3,500	Nehring, 1976
Mayfly (nymph), *Ephemerella grandis*	Lead nitrate	50	14 days	BCF = 2,366	-	Nehring, 1976
Mayfly, *Ephemerella subvaria*	Lead sulfate	44	7 days	LC50	16,000	Warnick & Bell, 1969
Stonefly, *Pteronarcys californica*	Lead nitrate	50	14 days	BCF = 86	-	Nehring, 1976
Stonefly, *Pteronarcys dorsata*	Lead nitrate	46	28 days	No effect on survival	565	Spehar, et al. 1978
Caddisfly, *Hydropsyche betteni*	Lead sulfate	44	7 days	LC50	32,000	Warnick & Bell, 1969
Caddisfly, *Brachycentrus* sp.	Lead nitrate	46	28 days	No effect on survival	565	Spehar, et al. 1978
Midge, (embryo - 3rd instar), *Tanytarsus dissimilis*	Lead nitrate	47	10 days	LC50	258	Anderson, et al. 1980
Rainbow trout, *Salmo gairdneri*	Lead nitrate	135	28 days	Inhibition of ALA-D activity	13	Hodson, 1976
Rainbow trout (12 mos), *Salmo gairdneri*	-	135	14 days	Inhibition of ALA-D activity	10	Hodson, et al. 1977
Rainbow trout, *Salmo gairdneri*	Lead nitrate	135	21 days	LC50	2,400	Hodson, et al. 1978a
Rainbow trout, *Salmo gairdneri*	Lead nitrate	135	32 wks	Black-tails in 3 of 10 remaining fish	120	Hodson, et al. 1978a; Sippel, et al. 1983
Rainbow trout, *Salmo gairdneri*	Lead nitrate	135	32 wks	Affected RBC, iron content, and ALA-D in blood	13	Hodson, et al. 1978a

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)[a]	Reference
Rainbow trout, *Salmo gairdneri*	-	135	29 wks	All fish had black tails and decrease in ALA-D in blood	87	Hodson, et al. 1979a, 1980
Rainbow trout, *Salmo gairdneri*	Lead nitrate	135	30 wks	64% inhibition of ALA-D activity and black tails in 88% of fish	65	Hodson, et al. 1979b
Rainbow trout, *Salmo gairdneri*	Lead nitrate	135	20 days	45% inhibition of ALA-D activity	25	Hodson, et al. 1983b
Rainbow trout (embryo, larva), *Salmo gairdneri*	Lead chloride	101	28 days	EC50 (death and deformity)	220	Birge, et al. 1980
Rainbow trout (embryo, larva), *Salmo gairdneri*	Lead chloride	101	28 days	EC1 (death and deformity)	10.3	Birge, et al. 1980, 1981
Rainbow trout (fingerling), *Salmo gairdneri*	Lead nitrate	353	19 mos	Lordoscoliosis	850	Goetti, et al. 1972; Davies, et al. 1976
Rainbow trout (sac fry), *Salmo gairdneri*	Lead nitrate	28	19 mos	Lordoscoliosis	31	Goetti, et al. 1972; Davies, et al. 1976
Brook trout, *Salvelinus fontinalis*	-	-	21 days	Stamina	14	Adams, 1975
Brook trout (12 mos), *Salvelinus fontinalis*	Lead nitrate	135	14 days	Inhibition of ALA-D activity	90	Hodson, et al. 1977
Brook trout (embryo - 21 day), *Salvelinus fontinalis*	Lead chloride	44	38 days	Elevation of ALP and ACH activity	525	Christensen, 1975
Brook trout (12 mos), *Salvelinus fontinalis*	Lead chloride	44	56 days	Decrease of hemoglobin and inhibition of GOT activity	58	Christensen, et al. 1977
Goldfish (embryo, larva), *Carassius auratus*	Lead chloride	195	7 days	EC50 (death and deformity)	1,660	Birge, 1978
Goldfish (<12 mos), *Carassius auratus*	Lead nitrate	135	14 days	Inhibition of ALA-D activity	470	Hodson, et al. 1977

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)[a]	Reference
Common carp, *Cyprinus carpio*	Lead acetate	360	6 days	50% reduction in hatch	13,350	Kapur & Yadav, 1982
Red shiner, *Notropis lutrensis*	Lead nitrate	-	48 hrs	LC50 (high turbidity)	630,000	Wallen, et al. 1957
Fathead minnow, *Pimephales promelas*	Lead acetate	20	96 hrs	LC50	7,480	Pickering & Henderson, 1966
Fathead minnow, *Pimephales promelas*	Lead acetate	44	96 hrs	LC50	27,800	Curtis & Ward, 1981
Fathead minnow, *Pimephales promelas*	Lead fluoroborate	44	96 hrs	LC50	12,000	Curtis & Ward, 1981
Channel catfish (1.6 g), *Ictalurus punctatus*	Lead arsenate	45	96 hrs	LC50	>100,000	Johnson & Finley, 1980
Mosquitofish (adult), *Gambusia affinis*	Lead oxide	-	96 hrs	LC50 (high turbidity)	>56,000,000	Wallen, et al. 1957
Pumpkinseed (>12 mos), *Lepomis gibbosus*	Lead nitrate	135	14 days	Inhibition of ALA-D activity	90	Hodson, et al. 1977
Largemouth bass (embryo, larva), *Micropterus salmoides*	Lead chloride	99	8 days	EC50 (death and deformity)	240	Birge, et al. 1978
Largemouth bass, *Micropterus salmoides*	-	-	24 hrs	Affected opercular rhythm	1,050	Morgan, 1979
Leopard frog (adult), *Rana pipiens*	Lead nitrate	-	30 days	Death	100	Kaplan, et al. 1967
Narrow-mouthed toad (embryo, larva) *Gastrophryne carolinenis*	Lead chloride	195	7 days	EC50 (death and deformity)	40	Birge, 1978
Marbled salamander (embryo, larva), *Ambystoma opacum*	Lead chloride	99	8 days	EC50 (death and deformity)	1,460	Birge, et al. 1978

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)[a]	Reference
			SALTWATER SPECIES			
Alga, *Laminaria digitata*	-	-	30-31 days	50-60% reduction in growth	1,000	Bryan, 1976
Diatom, *Phaeodactylum tricornutum*	Lead chloride	-	24 hrs	Completely inhibited photosynthesis	10,000	Woolery & Lewin, 1976
Diatom, *Phaeodactylum tricornutum*	Lead chloride	-	48-72 hrs	Reduced photosynthesis and respiration by 25-50%	100	Woolery & Lewin, 1976
Diatom, *Phaeodactylum tricornutum*	-	-	72 hrs	No growth inhibition	1,000	Hannan & Patouillet, 1972
Diatom, *Phaeodactylum tricornutum*	Lead chloride	-	1 hr	BCF = 1,050	-	Schulz-Baldes & Lewin, 1976
Diatom, *Skeletonema costatum*	Lead nitrate	-	12 days	EC50 (growth rate)	5.1	Rivkin, 1979
Diatom, *Skeletonema costatum*	Lead nitrate	-	12 days	EC50 (growth rate)	3.7	Rivkin, 1979
Phytoplankton, *Platymonas subcordiformis*	Lead chloride	-	72 hrs	Retarded population growth by delaying cell division	2,500	Hessler, 1974
Phytoplankton, *Platymonas subcordiformis*	Lead chloride	-	1 hr	BCF = 933	-	Schulz-Baldes & Lewin, 1976
Phytoplankton, *Platymonas subcordiformis*	Lead chloride	-	72 hrs	Death and inhibition of growth	60,000	Hessler, 1974
Phytoplankton, *Platymonas subcordiformis*	Lead chloride	-	2 days	48% of cells in culture died	2,500	Hessler, 1974
Phytoplankton, *Platymonas subcordiformis*	Lead chloride	-	6 days	98% of cells in culture died	60,000	Hessler, 1975

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)[a]	Reference
Alga, *Dunaliella tertiolecta*	Tetramethyl lead	-	96 hrs	EC50	1,650	Marchetti, 1978
Alga, *Dunaliella tertiolecta*	Tetraethyl lead	-	96 hrs	EC50	150	Marchetti, 1978
Alga, *Chlorella stigmatophora*	Lead acetate	-	21 days	50% growth inhibition	700	Christensen, et al. 1979
Natural phytoplankton populations	Lead chloride	-	5 days	Reduced chlorophyll a	207	Hollibaugh, et al. 1980
Natural phytoplankton populations	Lead chloride	-	4 days	Reduced biomass	21	Hollibaugh, et al. 1980
Macroalga, *Fucus serratus*	Lead acetate	-	-	45% growth inhibition	810	Stromgren, 1980
Ciliate protozoa, *Cristigera* sp.	Lead nitrate	-	12 hrs	Reduced growth rate by 8.5%	150	Gray & Ventilla, 1973
Ciliate protozoa, *Cristigera* sp.	Lead nitrate	-	12 hrs	Reduced growth rate by 11.7%	300	Gray & Ventilla, 1973
Polychaete worm, *Ophryotrocha diadema*	Lead acetate	-	96 hrs	LC50	14,100	Reish, et al. 1976
Polychaete worm, *Ophryotrocha diadema*	Lead acetate	-	21 days	Suppressed reproduction	1,000	Reish & Carr, 1978
Polychaete worm, *Ophryotrocha diadema*	Lead chloride	-	48 hrs	LC50	100,000	Parker, 1984
Polychaete worm, *Ctenodrilus serratus*	Lead acetate	-	21 days	Suppressed reproduction	1,000	Reish & Carr, 1978
Polychaete worm, *Capitella capitata*	Lead acetate	-	96 hrs	LC50	1,200	Reish, et al. 1976

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)[a]	Reference
Red abalone, *Haliotis rufescens*	Lead chloride	-	6 mos	Accumulated 21 µg/g wet w[illegible] while [illegible] laevi- [illegible] was [illegible] with [illegible] /L	-	Stewart & Schulz-Baldes, 1976
Blue mussel, *Mytilus edulis*	Lead chloride	-	40 days	LC50	30,000	Talbot, et al. 1976
Blue mussel, *Mytilus edulis*	Lead nitrate	-	150 days	LT50	500	Schulz-Baldes, 1972
Eastern oyster, *Crassostrea virginica*	Field study	-	1 yr	BCF = 326	-	Kopfler & Mayer, 1973
Oyster, Unspecified	Lead acetate	-	14 days	BCF = 1044	-	Stone, et al. 1981
Soft-shell clam, *Mya arenaria*	Lead nitrate	-	168 hrs	LC50	8,800	Elsler, 1977
American lobster, *Homarus americanus*	Lead nitrate	-	30 days	Reduced enzyme activity	50	Gould & Greig, 1983
Mud crab, *Rhithropanopeus harrisii*	Lead chloride	-	-	Delayed larval development	50	Benijts-Claus & Benijts, 1975
Fiddler crab, *Uca pugilator*	Lead nitrate	-	[illegible] wks	BCF = 20	-	Weis, 1976
Sea urchin, *Arbacia punctulata*	Lead nitrate	-	-	Few gastrula developed	14	Waterman, 1937
Mummichog (embryo), *Fundulus heteroclitus*	Lead nitrate	-	-	Depressed axis formation	100	Weis & Weis, 1977
Mummichog (embryo), *Fundulus heteroclitus*	Lead nitrate	-	-	Retarded hatching	10,000	Weis & Weis, 1982

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)*	Reference
Shiner perch, *Cymatogaster aggregata*	Lead nitrate	-	-	27% inhibition of brain cholinesterase	7.8	Abou-Donia & Menzel, 1967

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

** In river water.

REFERENCES

Abou-Donia, M.B. and D.B. Menzel. 1967. Fish brain cholinesterase: its inhibition by carbamates and automatic assay. Comp. Biochem. Physiol. 21: 99.

Adams, E.S. 1975. Effect of lead and hydrocarbons from snowmobile exhaust on brook trout (Salvelinus fontinalis). Trans. Am. Fish. Soc. 104: 363.

Ancellin, J., et al. 1973. Aspects of biologiques et physico-chimiques de la contamination radioactive d'especes et de sediments marins. In: Radioactive Contamination of the Marine Environment. International Atomic Energy Agency, Vienna, Austria. p. 225.

Anderson, B.G. 1948. The apparent thresholds of toxicity to Daphnia magna for chlorides of various metals when added to Lake Erie water. Trans. Am. Fish. Soc. 78: 96.

Anderson, R.L., et al. 1980. Survival and growth of Tanytarsus dissimilis (Chironomidii) exposed to copper, cadmuim, zinc, and lead. Arch. Environ. Contam. Toxicol. 9: 329.

Anderson, R.V. 1977. Concentration of cadmium, copper, lead and zinc in six species of freshwater clams. Bull. Environ. Contam. Toxicol. 18: 492.

Anderson, R.V. 1978. The effects of lead on oxygen uptake in the crayfish, Orconectes virilis (Hagen). Bull. Environ. Contam. Toxicol. 20: 394.

Apostol, S. 1973. A bioassay of toxicity using protozoa in the study of aquatic environment pollution and its prevention. Environ. Res. 6: 365.

Atchison, G.J., et al. 1977. Trace metal contamination of bluegill (Lepomis macrochirus) from two Indiana lakes. Trans. Am. Fish. Soc. 106: 637.

Aubert, M., et al. 1974. Utilisation du'une chaine trophyodynamique de type pelagique pour l'etude des transferts des pollutions metallique. Rev. Int. Oceanogr. Med. 28: 27.

Badsha, K.S. and C.R. Goldspink. 1982. Preliminary observations on the heavy metal content of four species of freshwater fish in NW England. Jour. Fish Biol. 21: 251.

Baker, M.D., et al. 1983. Toxicity of pH, heavy metals and bisulfite to a freshwater green alga. Chemosphere 12: 35.

Behan, M.J., et al. 1979. Lead accumulation in aquatic plants from metallic sources including shot. Jour. Wildl. Manage. 43: 240.

Belding, D.L. 1927. Toxicity experiments with fish in reference to trade waste pollution. Trans. Am. Fish. Soc. 57: 100.

Benijts-Claus, C. and F. Benijts. 1975. The effect of low lead and zinc concentrations on the larval development of the mud crab, Rhithropanopeus

harrisii. In: J.H. Koeman and J.J. Strik (eds.), Sublethal Effects of Toxic Chemicals on Aquatic Animals. Elsevier, Amsterdam. p. 43.

Berry, W.J. 1981. Memorandum to John H. Gentile. U.S. EPA, Narragansett, Rhode Island.

Biegert, E.K. and V. Valkovic. 1980. Acute toxicity and accumulation of heavy metals in aquatic animals. Period. Biol. 82: 25.

Biesinger, K.E. and G.M. Christensen. 1972. Effect of various metals on survival, growth, reproduction, and metabolism of Daphnia magna. Jour. Fish. Res. Board Can. 29: 1691.

Birge, W.J. 1978. Aquatic toxicology of trace elements of coal and fly ash. In: J.H. Thorpe and J.W. Gibbons (eds.), Energy and Environmental Stress in Aquatic Systems. CONF-771114. National Technical Information Service, Springfield, Virginia. p. 219.

Birge, W.J., et al. 1978. Embryo-larval bioassays on inorganic coal elements and in situ biomonitoring of coal-waste effluents. In: D.E. Samuel, et al. (eds.), Surface Mining and Fish/Wildlife Needs in the Eastern United States. PB 298353. National Technical Information Service, Springfield, Virginia. p. 97.

Birge, W.J., et al. 1980. Aquatic toxicity tests on inorganic elements occurring in oil shale. In: C. Gale (ed.), Oil Shale Symposium: Sampling,

Analysis and Quality Assurance. EPA-600/9-80-022. National Technical Information Service, Springfield, Virginia. p. 519.

Birge, W.J., et al. 1981. The reproductive toxicology of aquatic contaminants. In: J. Saxena and F. Fisher (eds.), Hazard Assessment of Chemicals: Current Developments. Vol. I. Academic Press, New York. p. 59.

Boggess, W.R. (ed.). 1977. Lead in the environment. PB 278278. National Technical Information Service, Springfield, Virginia.

Borgmann, U., et al. 1978. Rates of mortality, growth, and biomass production of Lymnaea palustris during chronic exposure to lead. Jour. Fish. Res. Board Can. 35: 1109.

Borgmann, U. 1980. Interactive effects of metals in mixtures on biomass production kinetics of freshwater copepods. Can. Jour. Fish. Aquat. Sci. 37: 1295.

Boutet, C. and C. Chaisemartin. 1973. Specific toxic properties of metallic salts in Austropotamobius pallipes pallipes and Orconectes limosus. C.R. Soc. Biol. 167: 1933.

Brezina, E.R. and M.Z. Arnold. 1977. Levels of heavy metals in fishes from selected Penna. waters. Publication No. 50. Bureau of Water Quality Management, Pennsylvania Department of Environmental Resources, Harrisburg, Pennsylvania.

Brezina, E.R., et al. 1974. Schuylkill river basin water quality. Publication No. 34. Bureau of Water Quality Management, Pennsylvania Department of Environmental Resources, Harrisburg, Pennsylvania.

Bringmann, G. 1975. Determination of the biologically harmful effect of water pollutants by means of the retardation of cell proliferation of the blue algae Microcystis. Gesundheits-Ing. 96: 238.

Bringmann, G. 1978. Determination of the biological toxicity of waterbound substances towards protozoa. I. bacteriovorous flagellates (model organism: Entosiphon sulcatum Stein). Z. Wasser Abwasser Forsch. 11: 210.

Bringmann, G. and R. Kuhn. 1959a. The toxic effects of waste water on aquatic bacteria, algae, and small crustaceans. Gesundheits-Ing. 80: 115.

Bringmann, G. and R. Kuhn. 1959b. Water toxicology studies with protozoans as test organisms. Gesundheits-Ing. 80: 239.

Bringmann, G. and R. Kuhn. 1976. Comparative results of the damaging effects of water pollutants against bacteria (Pseudomonas putida) and blue algae (Microcystis aeruginosa). Gas-Wasserfach, Wasser-Abwasser 117: 410.

Bringmann, G. and R. Kuhn. 1977a. Limiting values for the damaging action of water pollutants to bacteria (Pseudomonas putida) and green algae (Scenedesmus quadricauda) in the cell multiplication inhibition test. Z. Wasser Abwasser Forsch. 10: 87.

Bringmann, G. and R. Kuhn. 1977b. Results of the damaging effect of water pollutants on Daphnia magna. Z. Wasser Abwasser Forsch. 10: 161.

Bringmann, G. and R. Kuhn. 1978a. Limiting values for the noxious effects of water pollutant material to blue algae (Microcystis aeruginosa) and green algae (Scenedesmus quadricauda) in cell propagation inhibition tests. Vom Wasser 50: 45.

Bringmann, G. and R. Kuhn. 1978b. Testing of substances for their toxicity threshold: model organisms Microcystis (Diplocystis) aeruginosa and Scenedesmus quadricauda. Mitt. Int. Ver. Theor. Angew. Limnol. 21: 275.

Bringmann, G. and R. Kuhn. 1979. Comparison of toxic limiting concentrations of water contaminations toward bacteria, algae, and protozoa in the cell-growth inhibiton test. Haustech. Bauphys. Umwelttech. 100: 249.

Bringmann, G. and R. Kuhn. 1980a. Determination of the harmful biological effect of water pollutants on protozoa. II. bacteriovorous ciliates. Z. Wasser Abwasser Forsch. 13: 26.

Bringmann, G. and R. Kuhn. 1980b. Comparison of the toxicity threshold of water pollutants to bacteria, algae, and protozoa in the cell multiplication inhibition test. Water Res. 14: 231.

Bringmann, G. and R. Kuhn. 1981. Comparison of the effects of harmful substances on flagellates as well as ciliates and on halozoic bacteriophagous and saprozoic protozoa. Gas-Wasserfach, Wasser-Abwasser 122: 308.

Bringmann, G., et al. 1980. Determination of biological damage from water pollutants to protozoa. III. saprozoic flagellates. Z. Wasser Abwasser Forsch. 13: 170.

Brown, B. and M. Ahsanullah. 1971. Effect of heavy metals on mortality and growth. Mar. Pollut. Bull. 2: 182.

Brown, G.W. 1976. Effects of polluting substances on enzymes of aquatic organisms. Jour. Fish. Res. Board Can. 33: 2018.

Brown, J.R. and L.Y. Chow. 1977. Heavy metal concentration in Ontario fish. Bull. Environ. Contam. Toxicol. 17: 190.

Brown, V.M. 1968. Calculation of the acute toxicity of mixtures of poisons to rainbow trout. Water Res. 2: 723.

Bryan, G.W. 1976. Heavy metal contamination in the sea. In: R. Johnson (ed.), Marine Pollution. Academic Press, New York. p. 185.

Buikema, A.L., Jr., et al. 1974a. Rotifers as monitors of heavy metal pollution in water. Bulletin 71. Virginia Water Resources Research Center, Blacksburg, Virginia.

Buikema, A.L., Jr., et al. 1974b. Evaluation of Philodina acuticornis (Rotifera) as a bioassay organism for heavy metals. Water Resources Bull. 10 648.

Buikema, A.L., Jr., et al. 1977. Rotifer sensitivity to combinations of inorganic water pollutants. Bulletin 92. Virginia Water Resources Research Center, Blacksburg, Virginia.

Cairns, J., et al. 1976. Invertebrate response to thermal shock following exposure to acutely sub-lethal concentrations of chemicals. Arch. Hydrobiol. 77: 164.

Calabrese, A. and D.A. Nelson. 1974. Inhibition of embryonic development of the hard clam, Mercenaria mercenaria, by heavy metals. Bull. Environ. Contam Toxicol. 11: 92.

Calabrese, A., et al. 1973. The toxicity of heavy metals to embryos of the American oyster Crassostrea virginica. Mar. Biol. 18: 162.

Call, D.J., et al. 1981. Aquatic pollutant hazard assessments and developme of a hazard prediction technology by quantitative structure-activity relationships. First Quarterly Report to EPA. Center for Lake Superior Environmental Studies. University of Wisconsin-Superior, Superior, Wisconsin.

Call, D.J., et al. 1983. Toxicity and metabolism studies with EPA priority pollutants and related chemicals in freshwater organisms. PB83-263665. National Technical Information Service, Springfield, Virginia.

Callahan, M.A., et al. 1979. Water-related environmental fate of 129 priority pollutants. Vol. I. EPA-440/4-79-029a. National Technical Information Service, Springfield, Virginia.

Canterford, G.S. and D.R. Canterford. 1980. Toxicity of heavy metals to the marine diatom Ditylum brightwellii (West) Grunow: correlation between toxicity and metal speciation. Jour. Mar. Biol. Assoc. U.K. 60: 227.

Canterford, G.S., et al. 1978. Accumulation of heavy metals by the marine diatom Ditylum brightwellii (West) Grunow. Aust. Jour. Mar. Freshwater Res. 29: 613.

Cardin, J.A. 1981. Memorandum to John H. Gentile. U.S. EPA, Narragansett, Rhode Island.

Carpenter, K.E. 1925. On the biological factors involved in the destruction of river-fisheries by pollution due to lead-mining. Ann. Appl. Biol. 12: 1.

Carpenter, K.E. 1926. The lead mine as an active agent in river pollution. Ann. Appl. Biol. 13: 395.

Carpenter, K.E. 1927. The lethal action of soluble metallic salts of fishes. Br. Jour. Exp. Biol. 4: 378.

Carpenter, K.E. 1930. Further researches on the action of metallic salts on fishes. Jour. Exp. Zool. 56: 407.

Carter, J.W. and I.L. Cameron. 1973. Toxicity bioassay of heavy metals in water using Tetrahymena pyriformis. Water Res. 7: 951.

Chapman, G.A., et al. Manuscript. Effects of water hardness on the toxicity of metals to Daphnia magna. U.S. EPA, Corvallis, Oregon.

Chapman, W.H., et al. 1968. Concentration factors of chemical elements in edible aquatic organisms. UCRL-50564. National Technical Information Service, Springfield, Virginia.

Christensen, E.R., et al. 1979. Effects of manganese, copper and lead on Selenastrum capricornutum and Chlorella stigmatophora. Water Res. 13: 79.

Christensen, G.M. 1975. Biochemical effects of methylmercuric chloride, cadmium chloride and lead nitrate on embryos and alevins of the brook trout. Toxicol. Appl. Pharmacol. 32: 191.

Christensen, G., et al. 1977. The effect of methylmercuric chloride, cadmium chloride, and lead nitrate on six biochemical factors of the brook trout (Salvelinus fontinalis). Toxicol. Appl. Pharmacol. 42: 523.

Clarke, A.M. and J.H. Clarke. 1974. A static monitor for lead in natural and waste waters. Environ. Letters 7: 251.

Crandall, C.A. and C.J. Goodnight. 1962. Effects of sublethal concentrations of several toxicants on growth of the common guppy Lebistes reticulatus. Limnol. Oceanogr. 7: 233.

Curtis, M.W. and C.H. Ward. 1981. Aquatic toxicity of forty industrial chemicals: testing in suport of hazardous substance spill prevention regulation Jour. Hydrol. 51: 359.

Davies, P.H. and W.E. Everhart. 1973. Effects of chemical variations in aquatic environments: lead toxicity to rainbow trout and testing application factor concept. EPA-R3-73-011C. National Technical Information Service, Springfield, Virginia.

Davies, P.H., et al. 1976. Acute and chronic toxicity of lead to rainbow trout (Salmo gairdneri) in hard and soft water. Water Res. 10: 199.

Davis, G.A. 1978. Pollution studies with marine plankton. Part II. heavy metals. Adv. Mar. Biol. 15: 381.

Dawson, A.B. 1935. The hemopoietic response in the catfish, Ameivrus nebulosus, to chronic lead poisoning. Biol. Bull. 68: 335.

Demayo, A., et al. 1980. Guidelines for surface water quality: inorganic chemical substances - lead. Inland Waters Directorate, Water Quality Branch, Ottawa, Canada.

Demayo, A., et al. 1982. Toxic effects of lead and lead compounds on human health, aquatic life, wildlife, plants and lifestock. CRC Crit. Rev. Environ. Control 12: 257.

Devi Prasad, P.V. and P.S. Devi Prasad. 1982. Effect of cadmium, lead and nickel on three freshwater green algae. Water Air Soil Pollut. 17: 263.

Dilling, W.J. and C.W. Healy. 1927. Influence of lead on the metallic ions of Cu, Zn, thorium, beryllium and thallium on the germination of frogs' spawn and the growth of tadpoles. Ann. Appl. Biol. 13: 177.

Dilling, W.J., et al. 1926. Experiments on the effects of lead on the growth of plaice (Pleuronectes platessa). Ann. Appl. Biol. 13: 168.

Dixon, W.J. and M.B. Brown, eds. 1979. BMDP Biomedical Computer Programs, P-series. University of California, Berkeley, California. p. 521.

Dorfman, D. 1977. Tolerance of Fundulus heteroclitus to different metals in saltwaters. Bull. New Jersey Acad. Sci. 22: 21.

Dorfman, D. and W.R. Whitworth. 1969. Effects of fluctuations of lead, temperature, and dissolved oxygen on the growth of brook trout. Jour. Fish. Res. Board Can. 26: 2493.

Eide, I. and S. Myklestad. 1980. Long-term uptake and release of heavy metals by Ascophyllum nodosum (L.) Le Jol (Phaeophyceae) in situ. Environ. Pollut. (Series A) 23: 19.

Eisler, R. 1977. Acute toxicities of selected heavy metals to the soft-shell clam, Mya arenaria. Bull. Environ. Contam. Toxicol. 17: 137.

Eisler, R. 1981. Trace Metal Concentrations in Marine Organisms. Pergamon Press, New York.

Eisler, R., et al. 1979. Fourth annotated bibliography on biological effects of metals in aquatic environments. EPA-600/3-79-084. National Technical Information Service, Springfield, Virginia.

Ellgaard, E.G. and T.W. Rudner. 1982. Lead acetate: toxicity without effects on the locomotor activity of the bluegill sunfish. Jour. Fish Biol. 21: 411.

Ellis, M.M. 1937. Detection and measurement of stream pollution. (Bulletin No. 22, U.S. Bureau of Fisheries) Bull. Bureau Fish. 48: 365.

Ellis, M.M. 1940. Pollution of the Coeur d'Alene River and adjacent waters by mine wastes. Special Scientific Report No. 1. U.S. Fish and Wildlife Service. p. 61.

English, J.N., et al. 1963. Pollutional effects of outboard motor exhaust - laboratory studies. Jour. Water Pollut. Control Fed. 35: 923.

Enk, M.D. and B.J. Mathis. 1977. Distribution of cadmium and lead in a stream ecosystem. Hydrobiologia 52: 153.

Evans, R.D. and D.C. Lasenby. 1983. Relationship between body-lead concentration of Mysis relicta and sediment-lead concentration in Kootenary, B.C. Can. Jour. Fish. Aquat. Sci. 40: 78.

Ferard, J.F., et al. 1982. Value of dynamic tests in acute ecotoxicity assessment in algae. In: W.C. McKay (ed.), Proceedings of the Ninth Annual Aquatic Toxicity Workshop. Can. Tech. Rept. Fish. Aquat. Sci. No. 1163. University of Alberta, Edmonton, Alberta. p. 38.

Ferguson, J. and B. Bubela. 1974. The concentration of Cu(II), Pb(II), and Zn(II) from aqueous solution by particulate algal matter. Chem. Geol. 13: 163.

Fisher, N.S. and G.J. Jones. 1981. Heavy metals and marine phytoplankton: correlation of toxicity and sulfhydryl-binding. Jour. Phycol. 17: 108.

Foster, P.L. 1982a. Species association and metal contents of algae from rivers polluted by heavy metals. Freshwater Biol. 12: 17.

Foster, P.L. 1982b. Metal resistances of chlorophyta from rivers polluted by heavy metals. Freshwater Biol. 12: 41.

Freeman, B.J. 1978. Accumulation of cadmium, chromium, and lead by bluegill sunfish (Lepomis macrochirus Rafinesque) under temperature and oxygen stress. SRO-757-6. National Technical Information Service, Springfield, Virginia.

Freeman, B.J. 1980. Accumulation of cadmium, chromium, and lead by bluegill sunfish (Lepomis macrochirus Rafinesque) under temperature and oxygen stress. Thesis. University of Georgia, Athens, Georgia.

Fujiya, M. 1961. Use of electrophoretic serum separation in fish studies. Jour. Water Pollut. Control Fed. 33: 250.

Gale, N.L., et al. 1973a. Transport of trace pollutants in lead mining wastewaters. In: D.D. Hemphill (ed.), Trace Substances in Environmental Health-VI. University of Missouri, Columbia, Missouri. p. 95.

Gale, N.L., et al. 1973b. Aquatic organisms and heavy metals in Missouri's new lead belt. Water Resources Bull. 9: 673.

Gale, N.L., et al. 1982. Lead concentrations in edible fish filets collected from Missouri's old lead belt. In: D.D. Hemphill (ed.), Trace Substances in Environmental Health-XVI. University of Missouri, Columbia, Missouri. p. 12.

Garavini, C. and P. Martelli. 1979. Effect of lead acetate on erythropoiensis and ultrastructural changes of erythroblasts in the catfish. Monitore Zool. Italy 13: 83.

Gentile, J.H., et al. 1982. The use of life-tables for evaluating the chronic toxicity of pollutants to Mysidopsis bahia. Hydrobiologia 93: 179.

Gentile, S.M. 1982. Memorandum to John H. Gentile. U.S. EPA, Narragansett, Rhode Island.

Goettl, J.P., et al. 1972. Laboratory water pollution studies. Colorado Fisheries Research Review.

Gordon, M., et al. 1980. Mytilus californianus as a bioindicator of trace metal pollution: variability and statistical considerations. Mar. Pollut. Bull. 11: 193.

Gould, E. and R.A. Greig. 1983. Short-term low salinity response in lead-exposed lobsters, Homarus americanus (Milne Edwards). Jour. Exp. Mar. Biol. Ecol. 69: 283.

Grande, M. and S. Andersen. 1983. Lethal effects of hexavalent chromium, lead and nickel on young stages of Atlantic salmon (Salmo salar L.) in soft water. Vatten 39: 405.

Gray, J.S. and R.J. Ventilla. 1973. Growth rates of sediment-living marine protozoan as a toxicity indicator for heavy metals. Ambio 2: 118.

Haider, G. 1964. Studies on the heavy metal poisoning of fishes. I: lead poisoning of rainbow trout. Z. Angew. Zool. 51: 347.

Hale, J.G. 1977. Toxicity of metal mining wastes. Bull. Environ. Contam. Toxicol. 17: 66.

Hannan, P.J. and C. Patouillet. 1972. Effect of mercury on algal growth rates. Biotechnol. Bioeng. 14: 93.

Hedtke, S.F. and F.A. Puglisi. 1980. Effects of waste oil on the survival and reproduction of the American flagfish. Can. Jour. Fish. Aquat. Sci. 37: 757.

Heisey, R.M. and A.H. Damman. 1982. Copper and lead uptake by aquatic macrophytes in eastern Connecticut, U.S.A. Aquat. Bot. 14: 213.

Hessler, A. 1974. Effects of lead on algae. I. effects of Pb on viability and motility of Platymonas subcordiformis (Chlorophyta:volvocales). Water Air Soil Pollut. 3: 371.

Hessler, A. 1975. Effects of lead on algae. Mutagenesis experiments on Platymonas subcordiformis (Chlorophyta:valvocales). Mutat. Res. 31: 43.

Hodson, P.V. 1976. Delta-amino levulinic acid dehydratase activity of fish blood as an indictor of a harmful exposure to lead. Jour. Fish. Res. Board Can. 33: 268.

Hodson, P.V., et al. 1977. Evaluation of erythrocyte delta-amino levulinic acid dehydratase activity as a short-term indicator in fish of a harmful exposure to lead. Jour. Fish. Res. Board Can. 34: 501.

Hodson, P.V., et al. 1978a. Chronic toxicity of water-borne and dietary lead to rainbow trout (Salmo gairdneri) in Lake Ontario water. Water Res. 12: 869.

Hodson, P.V., et al. 1978b. pH-induced changes in blood lead of lead-exposed rainbow trout. Jour. Fish. Res. Board Can. 35: 437.

Hodson, P.V., et al. 1979a. Effects of increasing dietary ascorbic acid on chronic lead toxicity in rainbow trout. Am. Jour. Clin. Nutrition 32: R28.

Hodson, P.V., et al. 1979b. Effect of fish age on predicted and observed chronic toxicity of lead to rainbow trout in Lake Ontario water. Int. Assoc. Great Lakes Res. 1: 84.

Hodson, P.V., et al. 1980. Effects of dietary ascorbic acid on chronic lead toxicity to young rainbow trout (Salmo gairdneri). Can. Jour. Fish. Aquat. Sci. 37: 170.

Hodson, P.V., et al. 1982. Effect of growth and size of fish on rate of intoxication of waterborne lead. Can. Jour. Fish. Aquat. Sci. 39: 1243.

Hodson, P.V., et al. 1983a. Suitability of a biochemical method for assessing the exposure of feral fish to lead. In: W.E. Bishop, et al. (eds.), Aquatic Toxicology and Hazard Assessment. ASTM STP 802. American Society for Testing and Materials, Philadelphia, Pennsylvania. p. 389.

Hodson, P.V., et al. 1983b. Effect of fluctuating lead exposures in lead accumulation by rainbow trout. Environ. Toxicol. Chem. 2: 225.

Holcombe, G.W., et al. 1976. Long term effects of lead exposure on three generations of brook trout (Salvelinus fontinalis). Jour. Fish. Res. Board Can. 33: 1731.

Hollibaugh, J.T., et al. 1980. A comparison of the acute toxicities of ten heavy metals to phytoplankton from Saanich Inlet, B. C. Canada. Estuarine Coastal Mar. Sci. 10: 93.

Holm, J. 1980. Lead, Cd, As and Zn contents in fish from uncontaminated and contaminated inland waters. Sonderdruck aus Fleishwirtschaft 5: 1076.

Jackim, E. 1973. Influence of lead and other metals on fish delta-aminolevulinate dehydrase activity. Jour. Fish. Res. Board Can. 30: 560.

Jackim, E., et al. 1970. Effects of metal poisoning on five liver enzymes in the killifish (Fundulus heteroclitus). Jour. Fish. Res. Board Can. 27: 383.

Jana, S. and M.A. Choudhuri. 1982. Senescence in submerged aquatic angiosperms: effects of heavy metals. New Phytol. 90: 477.

Jana, S. and M.A. Choudhuri. 1984. Synergistic effects of heavy metal pollutants on senescence of submerged aquatic plants. Water Air Soil Pollut. 21: 351.

Jennett, J.C., et al. 1981. Some effects of century old abandoned lead mining operations on streams in Missouri, U.S.A. Minerals and the Environment 3: 17.

Johnson, M.S. and J.W. Eaton. 1980. Environmental contamination through residual trace metal dispersal from a derelict lead-zinc mine. Jour. Environ. Qual. 9: 175.

Johnson, W.W. and M.T. Finley. 1980. Handbook of acute toxicity of chemicals to fish and aquatic invertebrates. Resource Publication 137. U.S. Fish and Wildlife Service, Washington, D.C.

Jones, J.R.E. 1935. The toxic action of heavy metal salts on the three-spined stickleback. Jour. Exp. Biol. 12: 165.

Jones, J.R. 1938. The relative toxicity of salts of Pb, Zn, and Cu to the stickleback and the effects of calcium on the toxicity of lead and zinc salts. Jour. Exp. Biol. 15: 394.

Jones, J.R.E. 1939. The relation between the electrolytic solution pressures of the metals and their toxicity to the stickleback (Gasterosteus aculeatus L.). Jour. Exp. Biol. 16: 425.

Jones, J.R.E. 1947a. The oxygen consumption of Gasterosteus aculeatus L. in toxic solutions. Jour. Exp. Biol. 23: 298.

Jones, J.R. 1947b. A further study of the reactions of fish to toxic solutions. Jour. Exp. Biol. 24: 22.

Kaplan, H.M., et al. 1967. Toxicity of lead nitrate solutions for frogs (Rana pipiens). Lab. Animal Care 17: 240.

Kapur, K. and N.A. Yadav. 1982. The effect of certain heavy metal salts on the development of eggs of common carp. Acta Hydrochim. Hydrobiol. 10: 517.

Kariya, T., et al. 1969. Studies of the post-mortem identification of the pollutant in fish killed by water pollution-X: acute poisoning with lead. Bull. Jap. Soc. Sci. Fish. 35: 1167.

Kharhar, D.P., et al. 1976. Uranium and thorium decay series nuclides in plankton from the Caribbean. Limnol. Oceanogr. 21: 294.

Knowlton, M.K., et al. 1983. Uptake of lead from aquatic sediment by submerged macrophytes and crayfish. Arch. Environ. Contam. Toxicol. 12: 535.

Kopfler, F.C. and J. Mayer. 1973. Concentration of five trace metals in the waters and oysters (Crassostrea virginica) of Mobile Bay, Alabama. Proc. Natl. Shellfish Assoc. 63: 27.

Laube, V.M., et al. 1980. Strategies of response to copper, cadmium and lead by a blue green and a green alga. Can. Jour. Microbiol. 26: 1300.

Leland, H.V. and J.M. McNurney. 1974. Lead transport in a river ecosystem. In: Proceedings of the International Conference on Transport of Persistent Chemicals in Aquatic Ecosystems. Part III. National Research Council of Canada, Ottawa. p. 17.

Lloyd, R. 1961. Effects of dissolved oxygen concentrations on the toxicity of several poisons to rainbow trout (Salmo gairdneri). Jour. Exp. Biol. 38: 447.

Lu, P., et al. 1975. Model ecosystems studies of lead and cadmium of urban sewage sludge containing these elements. Jour. Environ. Qual. 4: 505.

Lucus, H.F. and D.N. Edgington. 1970. Concentration of trace elements in Great Lakes fishes. Jour. Fish. Res. Board Can. 27: 677.

Lussier, S.M., et al. Manuscript. Acute and chronic effects of heavy metals and cyanide on Mysidopsis bahia (Crustacea: Mysidacea). U.S. EPA, Narragansett, Rhode Island.

Malanchuk, J.L. and G.K. Gruendling. 1973. Toxicity of lead nitrate to algae. Water Air Soil Pollut. 2: 181.

Manalis, R. and G. Cooper. 1973. Presynaptic and postsynaptic effects of lead at the frog neuromuscular junction. Nature 243: 354.

Manalis, R.S., et al. 1984. Effects of lead on neuromuscular transmission in the frog. Brain Res. 294: 95.

Marchetti, R. 1978. Acute toxicity of alkyl lead to some marine organisms. Mar. Pollut. Bull. 9: 206.

Marion, M. and F. Denizeau. 1983. Rainbow trout and human cells in culture for the evaluation of the toxicity of aquatic pollutants: a study with lead. Aquat. Toxicol. 3: 47.

Martin, M.G. and J.M. Mudre. 1982. Patterns of bioaccumulation of heavy metals in stream fishes. Virginia Jour. Sci. 33: 116.

Martin, M., et al. 1981. Toxicities of ten metals to Crassostrea gigas and Mytilus edulis embryos and Cancer magister larvae. Mar. Pollut. Bull. 12: 305.

Martin, M., et al. 1984. Relationships between physiological stress and trace toxic substances in the bay mussel, Mytilus edulis, from San Francisco Bay, California. Mar. Environ. Res. 11: 91.

Mathis, B.J. and T.F. Cummings. 1973. Selected metals in sediments, water, and biota in the Illinois River. Jour. Water Pollut. Control Fed. 45: 1573.

Mathis, B.J. and N.R. Kevern. 1975. Distribution of mercury, cadmium, lead and thallium in [illegible]trophic lake. Hydrobiologia 46: 207.

May, T.W. and G.L. McKinney. 1981. Cadmium, lead, mercury, arsenic and selenium concentrations in freshwater fish, 1976-77 - National Pesticide Monitoring Program. Pestic. Monit. Jour. 15: 14.

Mehrle, P.M., et al. 1982. Relationship between body contaminants and bone development in East-Coast striped bass. Trans. Am. Fish. Soc. 111: 231.

Merlini, M. and G. Pozzi. 1977a. Lead and freshwater fishes: Part I - lead accumulation and water pH. Environ. Pollut. 12: 167.

Merlini, M. and G. Pozzi. 1977b. Lead and freshwater fishes: Part II - ionic lead accumulation. Environ. Pollut. 13: 119.

Metayer, C., et al. 1982. Accumulation of some trace metals (cadmium, lead, copper and zinc) in sole (Solea solea) and flounder (Platichthys flesus):

changes as a function of age and organotropism. Rev. Int. Oceanogr. Med. 66-67: 33.

Monahan, T.J. 1976. Lead inhibition of chlorophycean microalgae. Jour. Phycol. 12: 358.

Montgomery, J.R., et al. 1978. Biological availability of pollutants to marine organisms. EPA-600/3-78-035. National Technical Information Service, Springfield, Virginia.

Morgan, W.S.C. 1979. Fish locomotor behavior patterns as a monitoring tool. Jour. Water Pollut. Control Fed. 51: 580.

Mount, D.I. and T.J. Norberg. 1984. A seven-day life-cycle cladoceran toxicity test. Environ. Toxicol. Chem. 3: 425.

Narbonne, J.F., et al. 1973. Toxicity of lead nitrate to carp - data on modifications of nuceloprotein and glucide metabolism. Compt. Rend. Soc. Biol. 167: 572.

Nash, W.W., et al. 1981. The uptake and cellular distribution of lead in developing sea urchin embryos. Comp. Biochem. Physiol. 69C: 205.

Nehring, R.B. 1976. Aquatic insects as biological monitors of heavy metal pollution. Bull. Environ. Contam. Toxicol. 15: 147.

Nehring, R.B., et al. 1979. Reliability of aquatic insects versus water samples as measures of aquatic lead pollution. Bull. Environ. Contam. Toxicol. 22: 103.

Neter, J. and W. Wasserman. 1974. Applied Linear Statistical Models. Irwin, Inc., Homewood, Illinois.

Newman, M.C. and A.W. McIntosh. 1983a. Slow accumulation of lead from contaminated food sources by the freshwater gastropods, Physa integra and Campeloma decisum. Arch. Environ. Contam. Toxicol. 12: 685.

Newman, M.C. and A.W. McIntosh. 1983b. Lead elimination and size effects on accumulation by two freshwater gastropods. Arch. Environ. Contam. Toxicol. 12: 25.

North, W.F., et al. 1972. Marine algae and their relations to pollution problems. In: M. Ruivo (ed.), Marine Pollution and Sea Life. Fishing Trading News Ltd., London. p. 330.

Nyman, H.G. 1981. Sublethal effects of lead on size selective predation by fish-application in the ecosystem level. Verh. Int. Ver. Limnol. 21: 1126.

O'Neill, J.G. 1981. Effects of intraperitoneal lead and cadmium on the humoral immune response of Salmo trutta. Bull. Environ. Contam. Toxicol. 27: 42.

Overnell, J. 1975. The effect of some heavy metal ions on photosynthesis in freshwater algae. Pestic. Biochem. Physiol. 5: 19.

Ozoh, P.T. 1979. Studies on intraperitoneal toxicity of lead to Cichlasoma nigrofasciatum development. Bull. Environ. Contam. Toxicol. 21: 676.

Pace, F., et al. 1977. Effects of sublethal doses of copper sulphate and lead nitrate on growth and pigment composition of Dunaliella salina Teod. Bull. Environ. Contam. Toxicol. 17: 679.

Pagenkopf, G.K. and D.R. Newman. 1974. Lead concentrations in native trout. Bull. Environ. Contam. Toxicol. 12: 70.

Pakkala, I.S., et al. 1972. Residues in fish, wildlife and estuaries. Pestic. Monit. Jour. 5: 348.

Parker, J.G. 1984. The effects of selected chemicals and water quality on the marine polychaete, Ophryotrocha diadema. Water Res. 18: 865.

Passino, D.R. and C.A. Cotant. 1979. Allantoinase in lake trout: in vitro effects of PCB, DDT and metals. Comp. Biochem. Physiol. 62C: 71.

Pawlaczyk-Szpilowa, M. and J. Slowik. 1981. The biocumulation of copper and lead by Scenedesmus obliquus. Acta Microbiol. Pol. 30: 79.

Pennington, C.H., et al. 1982. Contaminant levels in fishes from Brown's Lake, Mississippi. Jour. Mississippi Acad. Sci. 27: 139.

Phillips, G.R. 1980. Accumulation of selected elements (As, Cu, Hg, Pb, Se and Zn) by northern pike reared in surface coal mine decant water. Proc. Montana Acad. Sci. 39: 44.

Phillips, G.R. and R.C. Russo. 1978. Metal bioaccumulation in fishes and aquatic invertebrates: a literature review. EPA-600/3-78-103. National Technical Information Service, Springfield, Virginia.

Pickering, Q.H. and C. Henderson. 1966. The acute toxicity of some heavy metals to different species of warmwater fishes. Air Water Pollut. Int. Jour. 10: 453.

Popham, J.D. and J.M. D'Auria. 1981. Statistical models for estimating seawater metal concentrations from metal concentrations in mussels (Mytilus edulis). Bull. Environ. Contam. Toxicol. 27: 660.

Price, R.E. and L.A. Knight. 1978. Hg, Cd, Pb and As in sediment, plankton and clams from Lake Washington and Sardis Reservoir, Mississippi. Pestic. Monit. Jour. 4: 182.

Pringle, B.H., et al. 1968. Trace metal accumulation by estuarine mollusks. Am. Soc. Civil. Eng., Jour. Sanit. Eng. Div. 94: 455.

Qureshi, S.A., et al. 1980. Acute toxicity of four heavy metals to benthic fish food organisms from River Khan, Vjjain. Int. Jour. Environ. Studies 15: 59.

Rachlin, J.W., et al. 1982. The growth response of the green alga (Chlorella saccharophila) to selected concentrations of heavy metals Cd, Cu, Pb and Zn. In: D.D. Hemphill (ed.), Trace Substances in Environmental Health-XVI. University of Missouri, Columbia, Missouri. p. 145.

Rachlin, J.W., et al. 1983. The growth response of the diatom Navicula incerta to selected concentrations of the metals cadmium, copper, lead and zinc. Bull. Torrey Bot. Club 110: 217.

Randall, G.W., et al. 1981. The significance of heavy metals in urban runoff entering the Occoquan Reservoir. Bulletin 132. Virginia Water Resources Research Center, Blacksburg, Virginia.

Rao, D.S. and A.B. Saxena. 1980. Acute toxicity of Hg, Zn, Pb, Cd and Mn to Chironomus sp. Int. Jour. Environ. Studies 16: 227.

Rao, V.N.R. and S.K. Subramanian. 1982. Metal toxicity tests on growth of some diatoms. Acta Bot. Indica 10: 274.

Rathore, H.S. and H. Swarup. 1978. A short note on the pollution ecology of Chironomus tentans larvae in a river. Natl. Acad. Sci. Letters 1: 235.

Rathore, H.S., et al. 1979. Toxicity of cadmium chloride and lead nitrate to Chironomus tentans larvae. Environ. Pollut. 18: 173.

Ray, S. 1978. Bioaccumulation of lead in Atlantic salmon. Bull. Environ. Contam. Toxicol. 19: 631.

Ray, S., et al. 1981. Accumulation of copper, zinc, cadmium and lead from two contaminated sediments by three marine invertebrates--a laboratory study. Bull. Environ. Contam. Toxicol. 26: 315.

Reish, D.J. and R.S. Carr. 1978. The effect of heavy metals on the survival, reproduction, development and life cycles for two species of polychaetous annelids. Mar. Pollut. Bull. 9: 24. (Table 3 available from author.)

Reish, D.J., et al. 1976. The effect of heavy metals on laboratory populations of two polychaetes with comparisons to the water quality conditions and standards in Southern California marine waters. Water Res. 10: 299.

Rice, H., et al. 1973. The effects of some trace metals on marine phytoplankton. CRC Crit. Rev. Microbiol. 3: 27.

Rivkin, R.B. 1979. Effects of lead on growth of the marine diatom Skeletonema costatum. Mar. Biol. 50: 239.

Rolfe, G.L., et al. 1977. Environmental contamination by lead and other heav metals. Vol. 2: ecosystem analysis. Institute for Environmental Studies, University of Illinois at Urbana, Champaign, Illinois.

Rushton, W. 1922. Biological notes. Salmon and Trout Magazine 28: 42.

Ruthven, J.A. and J. Cairns, Jr. 1973. Response of fresh-water protozoan artificial communities to metals. Jour. Protozool. 20: 127.

Ryck, F.M. and J.R. Whitley. 1974. Pollution abatement in the lead mining districts of Missouri. Missouri Department of Conservation, Columbia, Missouri.

Sauter, S., et al. 1976. Effects of exposure to heavy metals on selected freshwater fish. Toxicity of copper, cadmium, chromium and lead to eggs and f of seven fish species. EPA 600/3-76-105. National Technical Information Service, Springfield, Virginia.

Say, P.J. and B.A. Whitton. 1983. Accumulation of heavy metals by aquatic mosses. 1: Fontinalis antipyretica. Hydrobiologia 100: 245.

Schulz-Baldes, M. 1972. Toxizitat und anreicherung von blei bei der mies-muschel Mytilis edulis im laborexperiment. Mar. Biol. 16: 266.

Schulz-Baldes, M. 1974. Lead uptake from seawater and food, and lead loss in the common mussel Mytilis edulis. Mar. Biol. 25: 177.

Schulz-Baldes, M. and R.A. Lewin. 1976. Lead uptake in two marine phytoplankton organisms. Biol. Bull. 150: 118.

Schulze, H. and J. Brand. 1978. Lead toxicity and phosphate deficiency in chlamydomonas. Plant Physiol. 62: 727.

Scott, K.J., et al. Manuscript. Toxicological methods using the benthic amphipod Ampelisca abdita Mills. U.S. EPA, Narragansett, Rhode Island.

Shaw, W.H. and B. Grushkin. 1957. The toxicity of metal ions to aquatic organisms. Arch. Biochem. Biophys. 67: 447.

Shaw, W.H.R. and B.R. Lowrance. 1956. Bioassay for the estimation of metal ions. Anal. Chem. 28: 1164.

Shuster, C.N. and B.H. Pringle. 1969. Trace metal accumulation by the American Eastern oyster, Crassostrea virginica. Proc. Natl. Shellfish Assoc. 59: 91.

Sicko-Goad, L. 1982. A morphometric analysis of algal response to low dose short term heavy metal exposure. Protoplasma 110: 75.

Sicko-Goad, L. and D. Lazinsky. 1981. Accumulation and cellular effects of heavy metals in benthic and planktonic algae. Micron Microscopia Acta 22: 289.

Sicko-Goad, L. and D. Lazinsky. 1982. Polyphosphate body formation and degradation in Plectonema boryanum. Micron Microscopia Acta 13: 459.

Sicko-Goad, L. and E.F. Stoermer. 1979. A morphometric study of lead and copper effects on Diatoma tenue. Jour. Phycol. 15: 316.

Sidwell, V.D., et al. 1978. Composition of the edible portion of raw (fresh or frozen) crustaceans, finfish and mollusks. III. microelements. Mar. Fish. Res. 40: 1.

Simpson, R.D. 1979. Uptake and loss of zinc and lead by mussels (Mytilis edulis) and relationships with body weight and reproductive cycle. Mar. Pollut Bull. 10: 74.

Sippel, A.J.A., et al. 1983. Histopathological and physiological responses of rainbow trout to sublethal levels of lead. Water Res. 17: 1115.

Smith, D.J., et al. 1981. Distribution and significance of copper, lead, zinc and cadmium in the Corio Bay ecosystem. Aust. Jour. Mar. Freshwater Res. 32: 151.

Sparks, R.E., et al. 1983. Identification of the water quality factors which prevent fingernail clams from recolonizing the Illinois River. Research Report No. 179. Water Resources Center, University of Illinois, Urbana, Illinois.

Spehar, R.L., et al. 1978. Toxicity and bioaccumulation of cadium and lead in aquatic invertebrates. Environ. Pollut. 15: 195.

Stanley, R.A. 1974. Toxicity of heavy metals and salts to Eurasian watermilfoil (Myriophyllum spicatum L.). Arch. Environ. Contam. Toxicol. 2: 331.

Steele, R.L. and G.B. Thursby. 1983. A toxicity test using life stages of Champia parvula (Rhodophyta). In: W.E. Bishop, et al. (eds.), Aquatic Toxicology and Hazard Assessment. ASTM STP 802. American Society for Testing and Materials, Philadelphia, Pennsylvania. p. 73.

Stephan, C.E., et al. 1985. Guidelines for deriving numerical national water quality criteria for the protection of aquatic organisms and their uses. National Technical Information Service, Springfield, Virginia.

Stewart, J. and M. Schulz-Baldes. 1976. Long-term lead accumulation in abalone (Haliotus sp.) fed on lead-treated brown algae (Egregia laevigata). Mar. Biol. 36: 19.

Stone, C.L., et al. 1981. Bioavailability of lead in oysters fed to young Japanese quail. Environ. Res. 26: 409.

Stratford, H.K., et al. 1984. Effects of heavy metals on water hyacinths. Aquat. Toxicol. 5: 117.

Stromgren, T. 1980. The effect of lead, cadmium, and mercury on the increase in length of five intertidal fucales. Jour. Exp. Mar. Biol. Ecol. 43: 107.

Sturesson, U. 1978. Cadmium enrichment in shells of Mytilus edulis. Ambio 7: 122.

Talbot, V., et al. 1976. Lead in Port Phillip bay mussels. Mar. Pollut. Bull. 7: 234.

Tarzwell, C.M. and C. Henderson. 1960. Toxicity of less common metals to fishes. Ind. Wastes 5: 12.

Thomas, W. H., et al. 1980. Effects of heavy metals on the morphology of some marine phytoplankton. Phycologia 19: 202.

Thompson, S.E., et al. 1972. Concentration factors of chemical elements in edible aquatic organisms. UCRL-50564. Rev. 1. National Technical Information Service, Springfield, Virginia.

Tong, S.S.C., et al. 1974. Trace metals in Lake Cayuga lake trout (Salvelinus namaycush) in relation to age. Jour. Fish. Res. Board Can. 31: 238.

Trollope, D.R. and B. Evans. 1976. Concentrations of copper, iron, lead, nickel and zinc in freshwater algae blooms. Environ. Pollut. 11: 109.

Tsui, P.T.P. and P.J. McCart. 1981. Chlorinated hydrocarbon residues and heav metals in several fish species from the Cold Lake area in Alberta, Canada. Int Jour. Environ. Anal. Chem. 10: 277.

Tucker, R.K. and A. Matte. 1980. In vitro effects of cadmium and lead in ATPase in the gill of the rock crab, Cancer irroratus. Bull. Environ. Contam. Toxicol. 24: 847.

Turnbull, H., et al. 1954. Toxicity of various refinery materials to freshwater fish. Ind. Eng. Chem. 46: 324.

U.S. EPA. 1976. Quality criteria for water. EPA-440/9-76-023. National Technical Information Service, Springfield, Virginia.

U.S. EPA. 1980. Ambient water quality criteria for lead. EPA-440/4-80-057. National Technical Information Service, Springfield, Virginia.

U.S. EPA. 1983a. Methods for chemical analysis of water and wastes. EPA-600/4-79-020 (Revised March 1983). National Technical Information Service, Springfield, Virginia.

U.S. EPA. 1983b. Water quality standards regulation. Federal Register 48: 51400. November 8.

U.S. EPA. 1983c. Water quality standards handbook. Office of Water Regulations and Standards, Washington, D.C.

U.S. EPA. 1985. Technical support document for water quality-based toxics control. Office of Water, Washington, D.C.

Uthe, J.F. and E.G. Bligh. 1971. Preliminary survey of heavy metal contamination of Canadian freshwater fish. Jour. Fish. Res. Board Can. 28: 786.

Valiela, I., et al. 1974. Response of salt marsh bivalves to enrichment with metal-containing sewage sludge and retention of lead, zinc and cadmium by marsh sediment. Environ. Pollut. 7: 149.

Van der Werff, M. and M.J. Pruyt. 1982. Long-term effects of heavy metals on aquatic plants. Chemosphere 11: 727.

Varanasi, U. and D.J. Gmur. 1978. Influence of water-borne and dietary calcium on uptake and retention of lead by coho salmon. Toxicol. Appl. Pharmacol. 46: 65.

Varansai, U., et al. 1975. Structural alterations in fish epidermal mucus produced by water-borne lead and mercury. Nature 258: 431.

Vighi, M. 1981. Lead uptake and release in an experimental trophic chain. Ecotoxicol. Environ. Safety 5: 177.

Vijaymadhavan, K.T. and T. Iwai. 1975. Histochemical observations on the permeation of heavy metals into taste buds of goldfish. Bull. Jap. Soc. Sci. Fish. 41: 631.

Vinikour, W.S., et al. 1980. Bioconcentration patterns of zinc, copper, cadmium and lead in selected fish species from the Fox River, Illinois. Bull. Environ. Contam. Toxicol. 24: 727.

Wachs, B. 1982. Concentration of heavy metals in fishes from the river Danube. Z. Wasser Abwasser Forsch. 15: 43.

Wallen, I.E., et al. 1957. Toxicity to Gambusia affinis of certain pure chemicals in turbid waters. Sew. Ind. Wastes 29: 695.

Walsh, D.F., et al. 1977. Residues in fish, wildlife and estuaries. Pestic. Monit. Jour. 11: 5.

Wang, H. 1959. Analyses of a toxic factor, lethal to paramecium present in non-glass-distilled water. Proc. Soc. Exp. Biol. Med. 101: 682.

Warnick, S.L and H.L. Bell. 1969. The acute toxicity of some heavy metals to different species of aquatic insects. Jour. Water Pollut. Control Fed. 41: 280.

Waterman, A.J. 1937. Effects of salts of heavy metals on development of the sea urchin, Arbacia punctulata. Biol. Bull. 73: 401.

Watling, H.R. 1981. Effects of metals on the development of oyster embryos. South African Jour. Sci. 77: 134.

Watling, H.R. 1983. Accumulation of seven metals by Crassostrea gigas, Crassostrea margaritacea, Perna perna, and Choromytilus meridionalis. Bull. Environ. Contam. Toxicol. 30: 317.

Weber, W.J., Jr., and W. Stumm. 1963. Mechanism of hydrogen ion buffering in natural waters. Jour. Am. Water Works Assoc. 55: 1553.

Wehr, J.D. and B.A. Whitton. 1983a. Accumulation of heavy metals by aquatic mosses. 2: Rhynchostegium riparioides. Hydrobiologia 100: 261.

Wehr, J.D. and B.A. Whitton. 1983b. Accumulation of heavy metals by aquatic mosses. 3: seasonal changes. Hydrobiologia 100: 285.

Weir, P.A. and C.H. Hine. 1970. Effects of various metals on behavior of conditioned goldfish. Arch. Environ. Health. 20: 45.

Weis, J.S. 1976. Effects of mercury, cadmium, and lead salts on regeneration and ecdysis in the fiddler crab, Uca pugilator. Fish. Bull. 74: 464.

Weis, J.S. and P. Weis. 1977. Effect of heavy metals on development of the killifish, Fundulus heteroclitus. Jour. Fish Biol. 11: 49.

Weis, P. and J.S. Weis. 1982. Toxicity of methyl mercury, mercuric chloride, and lead in killifish (Fundulus heteroclitus) from Southampton, New York. Environ. Res. 28: 364.

Welsh, R.P. and P. Denny. 1980. The uptake of lead and copper by submerged aquatic macrophytes in two English lakes. Jour. Ecol. 68: 443.

Westfall, B.A. 1945. Coagulation film anoxia in fishes. Ecology 26: 283.

Whitley, L.S. 1968. The resistance of tubificid worms to three common pollutants. Hydrobiologia 32: 193.

Whitton, B.A., et al. 1982. Accumulation of zinc, cadmium, and lead by the aquatic liverwort Scapania. Environ. Pollut. (Series B) 3: 299.

Wiener, J.G. and J.P. Giesy. 1979. Concentration of Cd, Cu, Mn, Pb and Zn in fishes of a highly organic softwater pond. Jour. Fish. Res. Board Can. 36: 270.

Wixson, B.G. and E. Bolter. 1972. Evaluations of stream pollution and trace substances in the new lead belt of Missouri. In: D.D. Hemphill (ed.), Trace Substances in Environmental Health-V. University of Missouri, Columbia, Missouri. p. 143.

Wong, P.T.S., et al. 1981. Accumulation and depuration of tetramethyllead by rainbow trout. Water Res. 15: 621.

Wong, P.T.S., et al. 1982. Physiological and biochemical responses of several freshwater algae to a mixture of metals. Chemosphere 11: 367.

Woolery, M.L. and R.A. Lewin. 1976. The effects of lead on algae. IV. effects of lead on respiration and photosynthesis of Phaeodactylum tricornutum (Bacillariophyceae). Water Air Soil Pollut. 6: 25.

Wren, C.D., et al. 1983. Examination of bioaccumulation and biomagnification of metals in a precambrian shield lake. Water Air Soil Pollut. 19: 277.

Zaroogian, G.E., et al. 1979. Crassostrea virginica as an indicator of lead pollution. Mar. Biol. 52: 189.