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Ambient Water Quality Criteria for

Cyanide - 1984

AMBIENT AQUATIC LIFE WATER QUALITY CRITERIA FOR

CYANIDE

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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*

Compounds containing the cyanide group (CN) are used and readily formed in many industrial processes and can be found in a variety of effluents, such as those from the steel, petroleum, plastics, synthetic fibers, metal plating, mining, and chemical industries. Cyanide occurs in water as hydrocyanic acid (HCN), the cyanide ion (CN^-), simple cyanides, metallocyanide complexes, and as simple chain and complex ring organic compounds (Callahan, et al. 1979). "Free cyanide" is defined as the sum of the cyanide present as HCN and as CN^-, and the relative concentrations of these two forms depend mainly on pH and temperature. When pH is below 8 and temperature is below 25 C, at least 94 percent of the free cyanide exists as HCN. When pH or temperature or both are higher, a greater percentage of free cyanide exists as CN^-. For example, when pH is 9 and temperature is 30 C, about 55 percent of the free cyanide exists as HCN.

Although simple cyanides such as sodium cyanide and potassium cyanide readily dissociate and hydrolyze to form CN^- and HCN, the metallocyanide complex anions have a wide range of stabilities. Zinc and cadmium cyanide complexes dissociate rapidly and nearly completely in dilute solutions, whereas the stability of the copper and nickel metallocyanide anions are pH-dependent. Cyanide complexes of iron dissociate very little, but they are subject to photolysis by natural light. Release of cyanide ion by photodecomposition might be important in relatively clear receiving waters.

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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.

The apparent toxicity to aquatic organisms of most simple cyanides and metallocyanide complexes is due mainly to the presence of HCN derived from dissociation, photodecomposition, and hydrolysis (Doudoroff, et al. 1966; Smith, et al. 1979), although CN^- is apparently also toxic (Broderius, et al. 1977). Most metallocyanide complexes are not very toxic. The available literature on the toxicity of cyanides and related compounds to fish was critically reviewed by Doudoroff (1976, 1980). Additional reviews on the environmental effects of cyanides have been prepared by Leduc (1984), Leduc, et al. (1982), and Towill, et al. (1978).

Because (a) both HCN and CN^- are toxic to aquatic life, (b) the vast majority of free cyanide usually exists as the more toxic HCN, and (c) CN^- can be readily converted to HCN at pH values that commonly exist in surface waters, cyanide criteria will be stated in terms of free cyanide expressed as CN. Free cyanide is a much more reliable index of toxicity to aquatic life than total cyanide because total cyanide can include nitriles (organic cyanides) and relatively stable metallocyanide complexes. In highly alkaline waters a criterion that takes into account the relative toxicities of HCN and CN^- may be appropriate due to the dependence of the form of free cyanide on pH.

If performed often enough over a wide enough geographical area, measurement of free cyanide (ASTM, 1984; Broderius, 1981) should be adequate for monitoring cyanide in a body of water. However, because dissociation of several metallocyanide complexes is very dependent on pH in the range that commonly occurs in many water bodies, a measurement such as (a) free cyanide at the lowest pH occurring in the receiving water or (b) cyanide amenable to chlorination or total cyanide (U.S. EPA, 1983a) is probably more appropriate if only a few measurements are made on a water body and whenever measurements are made on an effluent. Dilution of an effluent with receiving water before measuring cyanide should demonstrate whether the receiving water can decrease the cyanide of concern because of sorption or complexation. Some measurements of total cyanide in the receiving water or effluent or both are desirable because if total cyanide is much higher than free cyanide or cyanide amenable to chlorination, the importance of release of cyanide from metallocyanide complexes by photolysis should receive consideration.

All cyanide concentrations reported herein are in terms of free cyanide expressed as CN. Thus, data reported in the original literature in terms of free cyanide expressed as CN did not have to be adjusted. However, when free cyanide was expressed as HCN, KCN, etc., the results were adjusted using the molecular weights of the compound and CN. When data were reported in the original literature in terms of HCN, rather than in terms of free cyanide, the data were converted from molecular HCN to free cyanide as CN as follows:

$$(\mu g \text{ of free cyanide as CN/L}) = (\mu g \text{ of HCN/L})\ (1 + 10^{pH-pK_{HCN}}) \times \frac{\text{mol. wt. CN}}{\text{mol. wt. HCN}}$$

where $pK_{HCN} = 1.3440 + \frac{2347.2}{T + 273.16}$ (Izatt, et al. 1962)

and T = degrees Celsius. The criteria presented herein supersede previous aquatic life water quality criteria for cyanide (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

Most of the invertebrate species tested were considerably more resistant than fishes, but Daphnia sp. and Gammarus pseudolimnaeus were comparable to fishes in sensitivity. On the other hand, about half of the tests with invertebrate species were static and the test concentrations were not measured, whereas many of the tests with fish were flow-through tests in which free cyanide concentrations were measured (Table 1).

Certain life stages and species of fish appear to be more sensitive to cyanide than others. Embryos, sac fry, and warmwater species tended to be the most resistant. Free cyanide concentrations from about 50 to 200 μg/L eventually were fatal to juveniles of most of the more sensitive fish species, with concentrations much above 200 μg/L being rapidly fatal to most juvenile fish. Thus, there is a relatively narrow range of species sensitivity for fish. A comparison of acute toxicity values for fishes (Table 1) supports the conclusion (Doudoroff, 1976) that results of static toxicity tests tend to be somewhat higher than results of renewal or flowthrough tests of equal, fairly prolonged duration.

The toxicity of cyanide increases with reduction in dissolved oxygen below the saturation level (Doudoroff, 1976; Smith, et al. 1978) and the resistances of fishes to cyanide solutions that are rapidly lethal decreases with an increase in temperature. Long-term lethality tests, however, have demonstrated that juvenile fishes are more sensitive to cyanide with a reduction in temperature (Doudoroff, 1980; Leduc, et al. 1982; Smith, et al.

1978). No pronounced relationship has been observed between the acute toxicity of cyanide to fishes and alkalinity, hardness, or pH below about 8.3.

Genus Mean Acute Values (Table 3) were calculated as the geometric means of the available Species Mean Acute Values (Table 1). Data are available for more than one species in two genera and the Species Mean Acute Values in each are within a factor of 2. Of the 15 genera the most sensitive, Salmo, is 39 times more sensitive than the most resistant, Tanytarsus (Table 3). A freshwater Final Acute Value of 62.68 µg/L was calculated from the Genus Mean Acute Values using the calculation procedure described in the Guidelines. However, the Species Mean Acute Value for the important rainbow trout is 44.73 µg/L. Because this value is based on the results of flow-through tests in which the concentrations were measured, it replaces the calculated freshwater Final Acute Value (Table 3). At low temperatures acute effects on rainbow trout have been observed (Kovacs, 1979; Kovacs and Leduc, 1982b) at concentrations below the Final Acute Value (Table 1).

Data are available on the acute toxicity of cyanide to saltwater species in three fish genera and five invertebrate genera (Tables 1 and 3). Species Mean Acute Values for invertebrates ranged from 4.893 µg/L for larvae of the rock crab, Cancer irroratus, to over 10,000 µg/L for larvae of the common Atlantic slippershell, Crepidula fornicata. C. irroratus is six times more sensitive to cyanide than the next most sensitive species, the calanoid copepod, Acartia tonsa. Acute values for fishes only ranged from 59 µg/L to 372 µg/L. Only the genus Mysidopsis contained more than one species and the Species Mean Acute Values were within a factor of 1.1. The saltwater Final Acute Value calculated from the Genus Mean Acute Values in Table 3 is 2.030 µg/L, which is approximately one-half the Species Mean Acute Value of the most sensitive of the nine species for which acute values are available.

Chronic Toxicity to Aquatic Animals

The long-term survival and growth of various freshwater fish species were observed to be substantially reduced at free cyanide concentrations of about 20 to 50 µg/L (Tables 2 and 5). Based on reduced long-term survival in an early life-stage test with the bluegill, and reduced reproduction by the brook trout and fathead minnow in a partial life-cycle and life-cycle test, the chronic values were 13.57, 7.849, and 16.39 µg/L, respectively. Life-cycle tests (Table 2) have been conducted with two freshwater invertebrates. The chronic values were 34.06 µg/L for the isopod, *Asellus communis*, and 18.33 µg/L for the amphipod, *Gammarus pseudolimnaeus*.

Four of the freshwater acute-chronic ratios are between 7 and 11, whereas the one for the resistant isopod is 68.29 (Tables 2 and 3). It seems reasonable to use the geometric mean of the four as the freshwater Final Acute-Chronic Ratio. Division of the Final Acute Value by the Final Acute-Chronic Ratio results in a freshwater Final Chronic Value of 5.221 µg/L (Table 3).

Data are available on the chronic toxicity of cyanide to the saltwater fish, *Cyprinodon variegatus*, and the mysid, *Mysidopsis bahia* (Table 2). The early life-stage test with the sheepshead minnow, *C. variegatus*, showed that growth was not significantly reduced at a cyanide concentration of 462 µg/L. Survival, however, was significantly reduced at cyanide concentrations ≥45 µg/L but not at ≤29 µg/L. Thus, the chronic value for sheepshead minnow is 36.12 µg/L. A life-cycle test with the mysid, *M. bahia*, showed that growth and survival were not affected at cyanide concentrations ≤43 µg/L. Acute toxicity, however, occurred at 113 µg/L. The chronic limits for this species were defined, therefore, as 43 and 113 µg/L. The geometric mean of these limits results in a chronic value of 69.71 µg/L.

The two acute-chronic ratios available from tests with saltwater species are 8.306 and 1.621 (Table 3), but both of these species are relatively resistant to cyanide and the acute values in those ratios were obtained with juveniles of the fish and mysid. On the other hand, the acute value for the sensitive rock crab was obtained using larvae of that species. Thus, this acute value for the rock crab is probably a better indication of the chronic sensitivity of this species than would be obtained by dividing this acute value by an acute-chronic ratio. Therefore, it seems reasonable to set the saltwater Final Chronic Value equal to the Criterion Maximum Concentration of 1.015 µg/L (Table 3). Division of the geometric mean of the two saltwater acute-chronic ratios into the Species Mean Acute Values of all saltwater species except the rock crab results in values that are at least 1.6 times greater than this Final Chronic Value.

Toxicity to Aquatic Plants

Data on the toxicity of free cyanide to freshwater and saltwater plant species are presented in Table 4. Both freshwater and saltwater plants show a wide range of sensitivities to cyanide, and the saltwater red macroalga, *Champia parvula*, is extremely sensitive to cyanide poisoning with growth and reproductive effects occurring at 11 to 25 µg/L. Adverse effects of cyanide on plants are unlikely, however, at concentrations which do not cause chronic effects on most freshwater and saltwater animal species.

Bioaccumulation

No studies have been reported showing a biomagnification of cyanide in the food chain (Towill, et al. 1978). Pennington, et al. (1982) found no detectable levels of cyanide in four species of fish from a Mississippi lake.

Murachi, et al. (1978) and Holden and Marsden (1964) measured the concentration of cyanide in various tissues of fish exposed to very rapidly lethal cyanide levels. It is obvious from such experiments that cyanide does penetrate aquatic organisms but bioaccumulation cannot be demonstrated because it is readily metabolized.

Other Data

Embryos of the fathead minnow are possibly slightly less sensitive to cyanide than fry and juveniles, whereas embryos of yellow perch are about as sensitive as fry, but less sensitive than juveniles (Tables 1 and 5) (Broderius, et al. 1977; Smith, et al. 1978). Several authors (Broderius, 1970; Dixon and Leduc, 1981; Kovacs, 1979; Kovacs and Leduc, 1982a; Leduc, 1977, 1978; Leduc and Chan, 1975; Lesniak, 1977; McCracken and Leduc, 1980; Neil, 1957; Oseid and Smith, 1979; Ruby, et al. 1979) reported adverse effects due to cyanide concentrations as low as 10 μg/L. In another study, Kimball, et al. (1978) reported that no reproduction occurred among adult bluegills when exposed for 289 days to the lowest concentration tested (5.2 μg of HCN/L = 5.4 μg of free cyanide as CN/L). During this period, however, only a total of 13 spawnings occurred in two controls and no concentration-effect relationship was observed. Because of reservations regarding the spawning data, the chronic value for the bluegill was based on long-term fry survival. On the other hand, the most sensitive adverse effect of cyanide on both the fathead minnow and brook trout was reduced reproduction.

Unused Data

Some data on the effects of cyanide on aquatic organisms were not used because the studies were conducted with species that are not resident in

North America (Abram, 1964; Brockway, 1963; Costa, 1966; Lomte and Jadhav, 1982; Woker and Wuhrmann, 1950). Data were not used if cyanide was a component of a complex cyanide (Doudoroff, 1976) or an effluent (Lloyd and Jordan, 1964; Shelford, 1917).

Some data were not used because the results were only presented graphically (Downing, 1954; Renn, 1955; Smith and Heath, 1979). Studies conducted using inadequate dilution water (Jones, 1941) or without controls (Bridges, 1958; Costa, 1965a,b,c) were also not used. Bringmann and Kuhn (1982) cultured Daphnia magna in one water but conducted tests in another water. Data in some papers were not used because either the test conditions were not clearly stated (Burdick and Lipschuetz, 1950; Ishio, 1965; Lewis and Tarrant, 1960; Whittingham, 1952) or the test procedures were considered inadequate (Lund, 1918; Moore and Kin, 1968; Summerfelt and Lewis, 1967; Washburn, 1948). The 96-hr values reported by Buikema, et al. (1977) were subject to error because of possible reproductive interactions.

Summary

Data on the acute toxicity of free cyanide (the sum of cyanide present as HCN and CN^-, expressed as CN) are available for a wide variety of freshwater species that are involved in diverse community functions. The acute sensitivities ranged from 44.73 µg/L to 2,490 µg/L, but all of the species with acute sensitivities above 400 µg/L were invertebrates. A long-term survival, and a partial and life-cycle test with fish gave chronic values of 13.57, 7.849, and 16.39 µg/L, respectively. Chronic values for two freshwater invertebrate species were 18.33 and 34.06 µg/L. Freshwater plants were affected at cyanide concentrations ranging from 30 µg/L to 26,000 µg/L.

The acute toxicity of free cyanide to saltwater species ranged from 4.893 µg/L to >10,000 µg/L and invertebrates were both the most and least sensitive species. Long-term survival in an early life-stage test with the sheepshead minnow gave a chronic value of 36.12 µg/L. Long-term survival in a mysid life-cycle test resulted in a chronic value of 69.71 µg/L. Tests with the red macroalga, Champia parvula, showed cyanide toxicity at 11 to 25 µg/L, but other species were affected at concentrations up to 3,000 µg/L.

National Criteria

The procedures described in the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" indicate that, except possibly where a locally important species is very sensitive, freshwater aquatic organisms and their uses should not be affected unacceptably if the four-day average concentration of cyanide does not exceed 5.2 µg/L more than once every three years on the average and if the one-hour average concentration does not exceed 22 µg/L more than once every three years on the average.

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 one-hour average concentration of cyanide does not exceed 1.0 µg/L more than once every three years on the average.

EPA believes that a measurement such as free cyanide would provide a more scientifically correct basis upon which to establish criteria for cyanide. 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 free cyanide. Until available, however, EPA recommends applying the criteria using the total cyanide method. These criteria may be overly protective when based on the total cyanide 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 cyanide 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 Cyanide to Aquatic Animals

Species	Method*	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)**	Reference
		FRESHWATER SPECIES		
Snail, *Physa heterostropha*	S, U	432	432	Cairns & Scheier, 1958; Patrick, et al. 1968
Cladoceran, *Daphnia magna*	S, U	<1,800	-	Anderson, 1946
Cladoceran, *Daphnia magna*	S, U	160	160	Dowden & Bennett, 1965
Cladoceran, *Daphnia pulex*	S, U	83	-	Lee, 1976
Cladoceran, *Daphnia pulex*	S, M	110	95.55	Cairns, et al. 1978
Isopod, *Asellus communis*	FT, M	2,326	2,326	Oseid & Smith, 1979
Amphipod, *Gammarus pseudolimnaeus*	FT, M	167	167	Oseid & Smith, 1979
Stonefly, *Pteronarcys dorsata*	FT, M	426	426	Call & Brooke, 1982
Midge, *Tanytarsus dissimilis*	S, M	2,490	2,490	Call, et al. 1983
Rainbow trout (fry), *Salmo gairdneri*	S, U	90	-	Bills, et al. 1977
Rainbow trout (juvenile), *Salmo gairdneri*	S, U	97	-	Skibba, 1981
Rainbow trout (juvenile), *Salmo gairdneri*	S, U	46.3	-	Marking, et al. 1984
Rainbow trout (juvenile), *Salmo gairdneri*	S, U	52.1	-	Marking, et al. 1984
Rainbow trout (juvenile), *Salmo gairdneri*	S, U	54.1	-	Marking, et al. 1984

Table 1. (Continued)

Species	Method*	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)**	Reference
Rainbow trout (juvenile), <u>Salmo gairdneri</u>	S, U	62.1	-	Marking, et al. 1984
Rainbow trout (juvenile), <u>Salmo gairdneri</u>	S, U	74.8	-	Marking, et al. 1984
Rainbow trout (juvenile), <u>Salmo gairdneri</u>	FT, M	57	-	Smith, et al. 1978; Broderius & Smith, 1979
Rainbow trout (juvenile), <u>Salmo gairdneri</u>	FT, M	27	-	Kovacs, 1979; Kovacs & Leduc, 1982b
Rainbow trout (juvenile), <u>Salmo gairdneri</u>	FT, M	40	-	Kovacs, 1979; Kovacs & Leduc, 1982b
Rainbow trout (juvenile), <u>Salmo gairdneri</u>	FT, M	65	44.73	Kovacs, 1979; Kovacs & Leduc, 1982b
Atlantic salmon (juvenile), <u>Salmo salar</u>	R, M	90	90	Tryland and Grande, 1983
Brook trout (sac fry), <u>Salvelinus fontinalis</u>	FT, M	105***	-	Smith, et al. 1978
Brook trout (sac fry), <u>Salvelinus fontinalis</u>	FT, M	342***	-	Smith, et al. 1978
Brook trout (sac fry), <u>Salvelinus fontinalis</u>	FT, M	507***	-	Smith, et al. 1978
Brook trout (sac fry), <u>Salvelinus fontinalis</u>	FT, M	252***	-	Smith, et al. 1978
Brook trout (swim-up fry), <u>Salvelinus fontinalis</u>	FT, M	84	-	Smith, et al. 1978
Brook trout (swim-up fry), <u>Salvelinus fontinalis</u>	FT, M	54.4	-	Smith, et al. 1978
Brook trout (swim-up fry), <u>Salvelinus fontinalis</u>	FT, M	86.5	-	Smith, et al. 1978

Table 1. (Continued)

Species	Method*	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)**	Reference
Brook trout (swim-up fry), *Salvelinus fontinalis*	FT, M	104	-	Smith, et al. 1978
Brook trout (swim-up fry), *Salvelinus fontinalis*	FT, M	90.3	-	Smith, et al. 1978
Brook trout (juvenile), *Salvelinus fontinalis*	FT, M	73.5	-	Smith, et al. 1978
Brook trout (juvenile), *Salvelinus fontinalis*	FT, M	83	-	Smith, et al. 1978
Brook trout (juvenile), *Salvelinus fontinalis*	FT, M	75	-	Smith, et al. 1978
Brook trout (juvenile), *Salvelinus fontinalis*	FT, M	86.4	-	Smith, et al. 1978
Brook trout (juvenile), *Salvelinus fontinalis*	FT, M	91.9	-	Smith, et al. 1978
Brook trout (juvenile), *Salvelinus fontinalis*	FT, M	99	-	Smith, et al. 1978
Brook trout (juvenile), *Salvelinus fontinalis*	FT, M	96.7	-	Smith, et al. 1978
Brook trout (juvenile), *Salvelinus fontinalis*	FT, M	112	-	Smith, et al. 1978
Brook trout (juvenile), *Salvelinus fontinalis*	FT, M	52	-	Smith, et al. 1978
Brook trout (juvenile), *Salvelinus fontinalis*	FT, M	60.2	-	Smith, et al. 1978
Brook trout (juvenile), *Salvelinus fontinalis*	FT, M	66.8	-	Smith, et al. 1978
Brook trout (juvenile), *Salvelinus fontinalis*	FT, M	71.4	-	Smith, et al. 1978

Table 1. (Continued)

Species	Method*	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)**	Reference
Brook trout (juvenile), *Salvelinus fontinalis*	FT, M	97	-	Smith, et al. 1978
Brook trout (juvenile), *Salvelinus fontinalis*	FT, M	143	-	Smith, et al. 1978
Brook trout (adult), *Salvelinus fontinalis*	FT, M	156	85.80	Cardwell, et al. 1976
Goldfish (juvenile), *Carassius auratus*	FT, M	318	318	Cardwell, et al. 1976
Fathead minnow (juvenile), *Pimephales promelas*	S, U	230	-	Doudoroff, 1956
Fathead minnow, *Pimephales promelas*	S, M	350	-	Henderson, et al. 1961
Fathead minnow, *Pimephales promelas*	S, M	230	-	Henderson, et al. 1961
Fathead minnow (fry), *Pimephales promelas*	FT, M	120	-	Smith, et al. 1978
Fathead minnow (fry), *Pimephales promelas*	FT, M	98.7	-	Smith, et al. 1978
Fathead minnow (fry), *Pimephales promelas*	FT, M	81.8	-	Smith, et al. 1978
Fathead minnow (fry), *Pimephales promelas*	FT, M	110	-	Smith, et al. 1978
Fathead minnow (fry), *Pimephales promelas*	FT, M	116	-	Smith, et al. 1978
Fathead minnow (juvenile), *Pimephales promelas*	FT, M	119	-	Smith, et al. 1978
Fathead minnow (juvenile), *Pimephales promelas*	FT, M	126	-	Smith, et al. 1978

Table 1. (Continued)

Species	Method*	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)**	Reference
Fathead minnow (juvenile), Pimephales promelas	FT, M	81.5	-	Smith, et al. 1978
Fathead minnow (juvenile), Pimephales promelas	FT, M	124	-	Smith, et al. 1978; Broderius & Smith, 1979
Fathead minnow (juvenile), Pimephales promelas	FT, M	137	-	Smith, et al. 1978
Fathead minnow (juvenile), Pimephales promelas	FT, M	131	-	Smith, et al. 1978
Fathead minnow (juvenile), Pimephales promelas	FT, M	105	-	Smith, et al. 1978
Fathead minnow (juvenile), Pimephales promelas	FT, M	119	-	Smith, et al. 1978
Fathead minnow (juvenile), Pimephales promelas	FT, M	131	-	Smith, et al. 1978
Fathead minnow (juvenile), Pimephales promelas	FT, M	122	-	Smith, et al. 1978
Fathead minnow (juvenile), Pimephales promelas	FT, M	161	-	Smith, et al. 1978
Fathead minnow (juvenile), Pimephales promelas	FT, M	188	-	Smith, et al. 1978
Fathead minnow (juvenile), Pimephales promelas	FT, M	175	-	Smith, et al. 1978
Fathead minnow (juvenile), Pimephales promelas	FT, M	163	-	Smith, et al. 1978
Fathead minnow (juvenile), Pimephales promelas	FT, M	169	-	Smith, et al. 1978
Fathead minnow (juvenile), Pimephales promelas	FT, M	120	-	Broderius, et al. 1977

Table 1. (Continued)

Species	Method*	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)**	Reference
Fathead minnow (juvenile), *Pimephales promelas*	FT, M	113	-	Broderius, et al. 1977
Fathead minnow (juvenile), *Pimephales promelas*	FT, M	128	-	Broderius, et al. 1977
Fathead minnow (juvenile), *Pimephales promelas*	FT, M	128	125.1	Broderius, et al. 1977
Guppy (adult), *Poecilia reticulata*	FT, M	147	147	Anderson & Weber, 1975
Bluegill (juvenile), *Lepomis macrochirus*	S, U	180	-	Cairns & Scheier, 1958, 1968; Patrick, et al. 1968
Bluegill, *Lepomis macrochirus*	S, M	220	-	Cairns & Scheier, 1959
Bluegill, *Lepomis macrochirus*	S, M	180	-	Cairns & Scheier, 1959
Bluegill, *Lepomis macrochirus*	S, M	230	-	Cairns & Scheier, 1959
Bluegill (juvenile), *Lepomis macrochirus*	S, M	150	-	Henderson, et al. 1961
Bluegill (juvenile), *Lepomis macrochirus*	S, M	160	-	Cairns & Scheier, 1963
Bluegill (fry), *Lepomis macrochirus*	FT, M	364***	-	Smith, et al. 1978
Bluegill (fry), *Lepomis macrochirus*	FT, M	232***	-	Smith, et al. 1978
Bluegill (fry), *Lepomis macrochirus*	FT, M	279***	-	Smith, et al. 1978
Bluegill (fry), *Lepomis macrochirus*	FT, M	273***	-	Smith, et al. 1978

Table 1. (Continued)

Species	Method*	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)**	Reference
Bluegill (juvenile), *Lepomis macrochirus*	FT, M	81	-	Smith, et al. 1978
Bluegill (juvenile), *Lepomis macrochirus*	FT, M	85.7	-	Smith, et al. 1978
Bluegill (juvenile), *Lepomis macrochirus*	FT, M	74	-	Smith, et al. 1978
Bluegill (juvenile), *Lepomis macrochirus*	FT, M	100	-	Smith, et al. 1978
Bluegill (juvenile), *Lepomis macrochirus*	FT, M	107	-	Smith, et al. 1978
Bluegill (juvenile), *Lepomis macrochirus*	FT, M	99	-	Smith, et al. 1978
Bluegill (juvenile), *Lepomis macrochirus*	FT, M	113	-	Smith, et al. 1978
Bluegill (juvenile), *Lepomis macrochirus*	FT, M	121	-	Smith, et al. 1978
Bluegill (juvenile), *Lepomis macrochirus*	FT, M	126	99.28	Smith, et al. 1978
Largemouth bass (juvenile), *Micropterus salmoides*	FT, M	102	102	Smith, et al. 1979
Black crappie, *Pomoxis nigromaculatus*	FT, M	102	102	Smith, et al. 1979
Yellow perch (embryo), *Perca flavescens*	FT, M	281***	-	Smith, et al. 1978
Yellow perch (fry), *Perca flavescens*	FT, M	288***	-	Smith, et al. 1978
Yellow perch (fry), *Perca flavescens*	FT, M	330***	-	Smith, et al. 1978

Table 1. (Continued)

Species	Method*	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)**	Reference
Yellow perch (juvenile), *Perca flavescens*	FT, M	88.9	-	Smith, et al. 1978
Yellow perch (juvenile), *Perca flavescens*	FT, M	93	-	Smith, et al. 1978
Yellow perch (juvenile), *Perca flavescens*	FT, M	74.7	-	Smith, et al. 1978
Yellow perch (juvenile), *Perca flavescens*	FT, M	94.7	-	Smith, et al. 1978
Yellow perch (juvenile), *Perca flavescens*	FT, M	101	-	Smith, et al. 1978
Yellow perch (juvenile), *Perca flavescens*	FT, M	107	92.64	Smith, et al. 1978
		SALTWATER SPECIES		
Common Atlantic slippershell, *Crepidula fornicata*	S, U	>10,000	>10,000	Gardner & Nelson, 1981
Copepod, *Acartia clausi*	S, U	30	30	Gentile, 1980
Mysid, *Mysidopsis bahia*	S, U	93	-	Gentile, 1980
Mysid, *Mysidopsis bahia*	FT, M	113	113	Lussier, et al. Manuscript
Mysid, *Mysidopsis bigelowi*	S, U	124	124	Gentile, 1980
Amphipod, *Ampelisca abdita*	S, U	1,220	-	Scott, et al. Manuscript
Amphipod, *Ampelisca abdita*	S, U	1,150	-	Scott, et al. Manuscript

Table 1. (Continued)

Species	Method*	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)**	Reference
Amphipod, *Ampelisca abdita*	S, U	704	995.9	Scott, et al. Manuscript
Rock crab (larva), *Cancer irroratus*	FT, M	4.2	-	Johns & Gentile, 1981
Rock crab (larva), *Cancer irroratus*	FT, M	5.7	4.893	Johns & Gentile, 1981
Sheepshead minnow, *Cyprinodon variegatus*	FT, M	300	300	Schimmel, et al. 1981
Atlantic silverside, *Menidia menidia*	FT, M	59	59	Gardner & Berry, 1981
Winter flounder, *Pseudopleuronectes americanus*	S, U	372	372	Cardin, 1980

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

** Results are expressed as free cyanide as CN.

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

Table 2. Chronic Toxicity of Cyanide to Aquatic Animals

Species	Test*	Limits (µg/L)**	Chronic Value (µg/L)**	Reference
		FRESHWATER SPECIES		
Isopod, *Asellus communis*	LC	29-40	34.06	Oseid & Smith, 1979
Amphipod, *Gammarus pseudolimnaeus*	LC	16-21	18.33	Oseid & Smith, 1979
Brook trout, *Salvelinus fontinalis*	LC	5.6-11.0	7.849	Koenst, et al. 1977
Fathead minnow, *Pimephales promelas*	LC	13.3-20.2	16.39	Lind, et al. 1977
Bluegill, *Lepomis macrochirus*	ELS	9.3-19.8	13.57	Kimball, et al. 1978
		SALTWATER SPECIES		
Mysid, *Mysidopsis bahia*	LC	43-113	69.71	Lussier, et al. Manuscript
Sheepshead minnow, *Cyprinodon variegatus*	ELS	29-45	36.12	Schimmel, et al. 1981

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

**Results are expressed as free cyanide as CN.

Acute-Chronic Ratio

Species	Acute Value (µg/L)	Chronic Value (µg/L)	Ratio
Isopod, *Asellus communis*	2,326	34.06	68.29
Amphipod, *Gammarus pseudolimnaeus*	167	18.33	9.111

Table 2. (Continued)

Acute-Chronic Ratio

Species	Acute Value (µg/L)	Chronic Value (µg/L)	Ratio
Brook trout, *Salvelinus fontinalis*	83.14***	7.849	10.59
Fathead minnow, *Pimephales promelas*	125.1****	16.39	7.633
Bluegill, *Lepomis macrochirus*	99.28*****	13.57	7.316
Mysid, *Mysidopsis bahia*	113	69.71	1.621
Sheepshead minnow, *Cyprinodon variegatus*	300	36.12	8.306

*** Geometric mean of 19 values from Smith, et al. (1978) in Table 1.

**** Geometric mean of 24 values from Smith, et al. (1978) and Broderius, et al. (1977) in Table 1.

***** Geometric mean of 9 values from Smith, et al. (1978) in Table 1.

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		
15	2,490	Midge, *Tanytarsus dissimilis*	2,490	-
14	2,326	Isopod, *Asellus communis*	2,326	68.29
13	432	Snail, *Physa heterostropha*	432	-
12	426	Stonefly, *Pteronarcys dorsata*	426	-
11	318	Goldfish, *Carassius auratus*	318	-
10	167	Amphipod, *Gammarus pseudolimnaeus*	167	9.111
9	147	Guppy, *Poecilia reticulata*	147	-
8	125.1	Fathead minnow, *Pimephales promelas*	125.1	7.633
7	123.6	Cladoceran, *Daphnia magna*	160	-
		Cladoceran, *Daphnia pulex*	95.55	-
6	102	Largemouth bass, *Micropterus salmoides*	102	-
5	102	Black crappie, *Pomoxis nigromaculatus*	102	-
4	99.28	Bluegill, *Lepomis macrochirus*	99.28	7.316

Table 3. (Continued)

Rank*	Genus Mean Acute Value (µg/L)	Species	Species Mean Acute Value (µg/L)	Species Mean Acute-Chronic Ratio
3	92.64	Yellow perch, *Perca flavescens*	92.64	-
2	85.80	Brook trout, *Salvelinus fontinalis*	85.80	10.59
1	63.45	Rainbow trout, *Salmo gairdneri*	44.73	-
		Atlantic salmon, *Salmo salar*	90.00	-
		SALTWATER SPECIES		
8	>10,000	Common Atlantic slippershell, *Crepidula fornicata*	>10,000	-
7	995.9	Amphipod, *Ampelisca abdita*	995.9	-
6	372	Winter flounder, *Pseudopleuronectes americanus*	372	-
5	300	Sheepshead minnow, *Cyprinodon variegatus*	300	8.306
4	118.4	Mysid, *Mysidopsis bahia*	113	1.621
		Mysid, *Mysidopsis bigelowi*	124	-
3	59	Atlantic silverside, *Menidia menidia*	59	-
2	30	Copepod, *Acartia clausi*	30	-
1	4.893	Rock crab, *Cancer irroratus*	4.893	-

Table 3. (Continued)

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

Fresh water

Final Acute Value = 62.68 µg/L (calculated from Genus Mean Acute Values)

Final Acute Value = 44.73 µg/L (lowered to protect rainbow trout - see text)

Criterion Maximum Concentration = (44.73 µg/L) / 2 = 22.36 µg/L

Final Acute-Chronic Ratio = 8.568 (see text)

Final Chronic Value = (44.73 µg/L) / 8.568 = 5.221 µg/L

Salt water

Final Acute Value = 2.030 µg/L

Criterion Maximum Concentration = (2.030 µg/L) / 2 = 1.015 µg/L

Final Chronic Value = 1.015 µg/L (see text)

Table 4. Toxicity of Cyanide to Aquatic Plants

Species	Effect	Result (µg/L)*	Reference
	FRESHWATER SPECIES		
Blue-green alga, *Microcystis aeruginosa*	90% kill	8,000	Fitzgerald, et al. 1952
Blue alga, *Microcystis aeruginosa*	Incipient inhibition	75	Bringmann, 1975; Bringmann & Kuhn, 1976, 1978a,b
Green alga, *Scenedesmus quadricauda*	Incipient inhibition	30	Bringmann & Kuhn, 1977a, 1978a,b, 1979, 1980b
Diatom, *Navicula seminulum*	50% reduction in division	277-491	Academy of Natural Sciences, 1960
Volvocales, *Chlamydomones* sp.	No effect on mean or maximum growth rate	10-100	Cairns, et al. 1978
Duckweed, *Lemna gibba* G3	Decreased potassium uptake	26,000	Kondo & Tsudzuki, 1980
Eurasian watermilfoil, *Myriophyllum spicatum*	32-day EC50 (root weight)	22,400	Stanley, 1974
	SALTWATER SPECIES		
Green alga, *Prototheca zopfi*	Respiration inhibition	3,000	Webster & Hackett, 1965
Green alga, *Chlorella* sp.	Enzyme inhibition	30,000	Nelson & Tolbert, 1970
Red alga, *Champia parvula*	Reduced tetrasporophyte growth	16	Steele & Thursby, 1983
Red alga, *Champia parvula*	Reduced tetrasporangia production	25	Steele & Thursby, 1983
Red alga, *Champia parvula*	Reduced female growth	11	Steele & Thursby, 1983

Table 4. (Continued)

Species	Effect	Result (µg/L)*	Reference
Red alga, *Champia parvula*	Stopped sexual reproduction	11	Steele & Thursby, 1983

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* Results are expressed as free cyanide as CN.

Table 5. Other Data on Effects of Cyanide on Aquatic Organisms

Species	Duration	Effect	Result (µg/L)*	Reference
		FRESHWATER SPECIES		
Green alga, *Scenedesmus quadricauda*	96 hr	Incipient inhibition	160**	Bringmann & Kuhn, 1959a,b
Bacteria, *Escherichia coli*	-	Incipient inhibition	400-800	Bringmann & Kuhn, 1959a
Bacteria, *Pseudomonas putida*	16 hrs	Incipient inhibition	1	Bringmann & Kuhn, 1976, 1977a, 1979, 1980b
Protozoan, *Entosiphon sulcatum*	72 hrs	Incipient inhibition	1,800	Bringmann, 1978; Bringmann & Kuhn, 1979, 1980b, 1981
Protozoan, *Microregma heterostoma*	28 hrs	Incipient inhibition	40	Bringmann & Kuhn, 1959b
Protozoan, *Chilomonas paramecium*	48 hrs	Incipient inhibition	1,200	Bringmann, et al. 1980, 1981
Protozoan, *Uronema parduezi*	20 hrs	Incipient inhibition	270	Bringmann & Kuhn, 1980a, 1981
Rotifer, *Philodina acuticornis*	48 hrs	LC50	20,000-145,000	Cairns, et al. 1978
Worm, *Aeolosoma headleyi*	48 hrs	LC50 (5 C)	10,000	Cairns, et al. 1978
		(10 C)	9,000	
		(15 C)	120,000	
		(20 C)	160,000	
		(25 C)	160,000	
Snail, *Goniobasis livescens*	48 hrs	LC50	760,000	Cairns, et al. 1976
Snail, *Nitocris* sp.	48 hrs	LC50 (5 C)	13,600	Cairns, et al. 1978
		(10 C)	12,800	
		(15 C)	10,000	
		(20 C)	8,000	
		(25 C)	7,000	

Table 5. (Continued)

Species	Duration	Effect	Result (µg/L)*	Reference
Snail, *Lymnaea emarginata*	48 hrs	LC50	3,300	Cairns, et al. 1976
Snail (embryo), *Lymnaea* sp.	96 hrs	LC50	52,000	Dowden & Bennett, 1965
Snail, *Physa heterostropha*	96 hrs	LC50 (periodic low D.O.)	190	Cairns & Scheier, 1958
Snail, *Physa integra*	48 hrs	LC50	1,350	Cairns, et al. 1976
Cladoceran, *Daphnia magna*	48 hrs	EC50	800**	Bringmann & Kuhn, 1959a,b
Cladoceran, *Daphnia magna*	24 hrs	LC50	530	Bringmann & Kuhn, 1977b
Cladoceran, *Daphnia pulex*	48 hrs	LC50 (5 C)	330	Cairns, et al. 1978
		(10 C)	330	
		(15 C)	180	
		(25 C)	1	
Amphipod, *Gammarus pseudolimnaeus*	98 days	Competition with *Asellus* affects HCN toxicity	9	Oseid & Smith, 1979
Mayfly, *Stenonema rubrum*	48 hrs	LC50	500	Roback, 1965
Caddisfly (larva), *Hydropsyche* sp.	48 hrs	LC50	2,000	Roback, 1965
Midge, *Tanytarsus dissimilis*	48 hrs	EC50	<880	Call, et al. 1979
Coho salmon, *Oncorhynchus kisutch*	2 hrs	Swimming speed reduced	10	Broderius, 1970
Coho salmon (juvenile), *Oncorhynchus kisutch*	36 days	Reduction in growth	77	Leduc, 1966

Table 5. (Continued)

Species	Duration	Effect	Result (µg/L)*	Reference
Chinook salmon (juvenile), *Oncorhynchus tshawytscha*	64 days	27% reduction in biomass	20	Negilski, 1973
Rainbow trout (juvenile), *Salmo gairdneri*	250 min	Approximate median survival time	200	Dep. Sci. Ind. Res., 1956
Rainbow trout (adult), *Salmo gairdneri*	2 min	Mean survival time	2,000	Herbert & Merkens, 1952
Rainbow trout (adult), *Salmo gairdneri*	8 min	Mean survival time	300	Herbert & Merkens, 1952
Rainbow trout (adult), *Salmo gairdneri*	12 min	Mean survival time	250	Herbert & Merkens, 1952
Rainbow trout (adult), *Salmo gairdneri*	12 min	Mean survival time	200	Herbert & Merkens, 1952
Rainbow trout (adult), *Salmo gairdneri*	24 min	Mean survival time	180	Herbert & Merkens, 1952
Rainbow trout (adult), *Salmo gairdneri*	72 min	Mean survival time	160	Herbert & Merkens, 1952
Rainbow trout (adult), *Salmo gairdneri*	90 min	Mean survival time	140	Herbert & Merkens, 1952
Rainbow trout (adult), *Salmo gairdneri*	2,525 min	Mean survival time	100	Herbert & Merkens, 1952
Rainbow trout (adult), *Salmo gairdneri*	1,617 min	Mean survival time	90	Herbert & Merkens, 1952
Rainbow trout (adult), *Salmo gairdneri*	3,600 min	Mean survival time	80	Herbert & Merkens, 1952
Rainbow trout (adult), *Salmo gairdneri*	4,441 min	Mean survival time	70	Herbert & Merkens, 1952
Rainbow trout, *Salmo gairdneri*	48 hrs	LC50	68	Brown, 1968

Table 5. (Continued)

Species	Duration	Effect	Result (µg/L)*	Reference
Rainbow trout (juvenile), *Salmo gairdneri*	18 days	Weight gain reduced	9.6	Dixon & Leduc, 1981
Rainbow trout (juvenile), *Salmo gairdneri*	4 days	Increased respiration rate	9.6	Dixon & Leduc, 1981
Rainbow trout (juvenile), *Salmo gairdneri*	18 days	Liver damage (necrobiosis)	9.6	Dixon & Leduc, 1981
Rainbow trout (juvenile), *Salmo gairdneri*	18 days	Reduction in fat content	19	Dixon & Leduc, 1981
Rainbow trout (juvenile), *Salmo gairdneri*	18 days	Higher relative body water content	9.6	Dixon & Leduc, 1981
Rainbow trout (yearling), *Salmo gairdneri*	21 days	65% reduction in weight gain	19	Speyer, 1975
Rainbow trout (yearling), *Salmo gairdneri*	21 days	75% reduction in swimming ability	19	Speyer, 1975
Rainbow trout (yearling), *Salmo gairdneri*	21 days	Higher relative body water content	19	Speyer, 1975
Rainbow trout (juvenile), *Salmo gairdneri*	28 days	Altered blood chloride and osmolarity	9.6	Leduc & Chan, 1975
Rainbow trout (yearling), *Salmo gairdneri*	20 days	Abnormal oocyte development	9.6	Lesniak, 1977; Lesniak & Ruby, 1982
Rainbow trout (juvenile), *Salmo gairdneri*	18 days	Production of dividing spermatogonia reduced by 13%	9.6	Ruby, et al. 1979
Rainbow trout (juvenile), *Salmo gairdneri*	18 days	Production of dividing spermatogonia reduced by 50%	29	Ruby, et al. 1979
Rainbow trout (yearling), *Salmo gairdneri*	7 days	Serum calcium reduced; hepatosomatic indices declined	9.6 19	Costa & Ruby, 1984

Table 5. (Continued)

Species	Duration	Effect	Result (µg/L)*	Reference
Rainbow trout (juvenile), *Salmo gairdneri*	24 hrs	LC50 (5 C) (12 C) (18 C)	90 98 92	Cairns, et al. 1978
Rainbow trout (juvenile), *Salmo gairdneri*	21 days	No effect on dry weight gain	33	Dixon & Sprague, 1981
Rainbow trout (juvenile), *Salmo gairdneri*	21 days	Kidney damage	33	Dixon & Sprague, 1981
Rainbow trout (juvenile), *Salmo gairdneri*	144 hrs	LC50	93	Dixon & Sprague, 1981
Rainbow trout (juvenile), *Salmo gairdneri*	20 days	Reduction in swimming ability (6-18 C)	4.8-43	Kovacs, 1979; Kovacs & Leduc, 1982a
Rainbow trout (juvenile), *Salmo gairdneri*	20 days	Threshold concentration (6-18 C) for reduction of relative: wet weight gain dry weight gain fat gain	 9.6-29 <4.8-29 <4.8-24	Kovacs, 1979; Kovacs & Leduc, 1982a
Rainbow trout (juvenile), *Salmo gairdneri*	20 days	Increase in relative water content (6-18 C)	4.8-43	Kovacs, 1979; Kovacs & Leduc, 1982a
Rainbow trout (juvenile), *Salmo gairdneri*	20 days	No effect on wet or dry weight relative growth rate or fat weight change for 8 g fish forced to swim at 12 cm/sec and 10 C	9.6	McCracken & Leduc, 1980
Rainbow trout (juvenile), *Salmo gairdneri*	20 days	Increased food maintenance requirements, decreased wet and dry weight relative growth rate and fat weight change for 18 g fish forced to swim at 12 cm/sec and 10 C	13	McCracken & Leduc, 1980

Table 5. (Continued)

Species	Duration	Effect	Result (μg/L)*	Reference
Rainbow trout (juvenile), *Salmo gairdneri*	20 days	Decreased wet weight gain for 27 g fish forced to swim at 12 cm/sec and 10 C	9.6	McCracken & Leduc, 1980
Atlantic salmon (larva), *Salmo salar*	58 days	Abnormal embryo and larval development	9.6	Leduc, 1978
Atlantic salmon (smolt), *Salmo salar*	24 hrs	LC50 (10 mg D.O./L) (3.5 mg D.O./L)	70 23	Alabaster, et al. 1983
Brown trout (fry), *Salmo trutta*	8.2 min	Death	8,030	Karsten, 1934
Brown trout (fry), *Salmo trutta*	8.9 min	Death	4,140	Karsten, 1934
Brown trout (fry), *Salmo trutta*	8.2 min	Death	2,070	Karsten, 1934
Brown trout (fry), *Salmo trutta*	140 min	Death	217	Karsten, 1934
Brown trout (juvenile), *Salmo trutta*	6.58 min	Geometric mean time to death	1,006	Burdick, et al. 1958
Brown trout (juvenile), *Salmo trutta*	15 min	Geometric mean time to death	510	Burdick, et al. 1958
Brown trout (juvenile), *Salmo trutta*	30.1 min	Geometric mean time to death	320	Burdick, et al. 1958
Brown trout (juvenile), *Salmo trutta*	5 hrs	Oxygen uptake inhibited	25	Carter, 1962
Brook trout (fry), *Salvelinus fontinalis*	15.2 min	Death	8,640	Karsten, 1934
Brook trout (fry), *Salvelinus fontinalis*	10.8 min	Death	4,290	Karsten, 1934
Brook trout (fry), *Salvelinus fontinalis*	11.7 min	Death	2,130	Karsten, 1934

Table 5. (Continued)

Species	Duration	Effect	Result (µg/L)*	Reference
Brook trout (fry), *Salvelinus fontinalis*	26 min	Death	853	Karsten, 1934
Brook trout (fry), *Salvelinus fontinalis*	58 min	Death	392	Karsten, 1934
Brook trout (fry), *Salvelinus fontinalis*	210 min	Death	217	Karsten, 1934
Brook trout (fry), *Salvelinus fontinalis*	130 hrs	Death	50	Karsten, 1934
Brook trout (fry), *Salvelinus fontinalis*	27 days	100% survival	20	Karsten, 1934
Brook trout (juvenile), *Salvelinus fontinalis*	3.6 days	Death	80	Neil, 1957
Brook trout (juvenile), *Salvelinus fontinalis*	40 days	No death	50	Neil, 1957
Brook trout (juvenile), *Salvelinus fontinalis*	25.5 min	75% reduction in swimming endurance	10	Neil, 1957
Brook trout (juvenile), *Salvelinus fontinalis*	90 days	Reduced growth	33	Koenst, et al. 1977
Goldfish (juvenile), *Carassius auratus*	336 hrs	LC50	261	Cardwell, et al. 1976
Goldfish (juvenile), *Carassius auratus*	24 hrs	LC50 (5 C)	3,250	Cairns, et al. 1978
		(15 C)	440	
		(30 C)	280	
Golden shiner (juvenile), *Notemigonus crysoleucas*	24 hrs	LC50 (5 C)	540	Cairns, et al. 1978
		(15 C)	310	
		(30 C)	300	
Fathead minnow, *Pimephales promelas*	48 hrs	LC50	240	Black, et al. 1957
Fathead minnow (juvenile), *Pimephales promelas*	5 days	LC50	120	Cardwell, et al. 1976

Table 5. (Continued)

Species	Duration	Effect	Result (µg/L)*	Reference
Fathead minnow (juvenile), *Pimephales promelas*	10 days	LC50	114	Cardwell, et al. 1976
Fathead minnow (juvenile), *Pimephales promelas*	28 days	Reduced increase in length	35	Lind, et al. 1977
Fathead minnow (juvenile), *Pimephales promelas*	56 days	Reduced increase in length and weight	62	Lind, et al. 1977
Fathead minnow (embryo), *Pimephales promelas*	96 hrs	LC50	347	Smith, et al. 1978
Fathead minnow (embryo), *Pimephales promelas*	96 hrs	LC50	272	Smith, et al. 1978
Fathead minnow (embryo), *Pimephales promelas*	96 hrs	LC50	201	Smith, et al. 1978
Fathead minnow (embryo), *Pimephales promelas*	96 hrs	LC50	123	Smith, et al. 1978
Fathead minnow (embryo), *Pimephales promelas*	96 hrs	LC50	186	Smith, et al. 1978
Fathead minnow (embryo), *Pimephales promelas*	96 hrs	LC50	200	Smith, et al. 1978
Fathead minnow (embryo), *Pimephales promelas*	96 hrs	LC50	206	Smith, et al. 1978
Blacknose dace, *Rhinichthys atratulus*	24 hrs	LC50	220	Lipschuetz & Cooper, 1955
Channel catfish (juvenile), *Ictalurus punctatus*	26 hrs	LC50	161	Cardwell, et al. 1976
Channel catfish (juvenile), *Ictalurus punctatus*	24 hrs	LC50 (5 C) (15 C) (30 C)	200 310 230	Cairns, et al. 1978
Flagfish, *Jordanella floridae*	10 days exposure	Reduced fecundity and hatching	63	Cheng & Ruby, 1981

Table 5. (Continued)

Species	Duration	Effect	Result (µg/L)*	Reference
Mosquitofish, *Gambusia affinis*	96 hrs	LC50 (high turbidity)	640	Wallen, et al. 1957
Guppy (juvenile), *Poecilia reticulata*	120 hrs	Threshold concentration	236	Chen & Selleck, 1969
Threespine stickleback, *Gasterosteus aculeatus*	90 min	Depressed respiration rate to 32% of normal	1,040	Jones, 1947
Threespine stickleback (adult), *Gasterosteus aculeatus*	824 min	Median survival time	134	Broderius, 1973
Threespine stickleback (adult), *Gasterosteus aculeatus*	642 min	Median survival time	170	Broderius, 1973
Threespine stickleback (adult), *Gasterosteus aculeatus*	412 min	Median survival time	237	Broderius, 1973
Bluegill (juvenile), *Lepomis macrochirus*	202 min	Median survival time	198	Broderius, 1973
Bluegill (juvenile), *Lepomis macrochirus*	260 min	Median survival time	194	Broderius, 1973
Bluegill (juvenile), *Lepomis macrochirus*	351 min	Median survival time	165	Broderius, 1973
Bluegill (juvenile), *Lepomis macrochirus*	258 min	Median survival time	165	Broderius, 1973
Bluegill (juvenile), *Lepomis macrochirus*	352 min	Median survival time	144	Broderius, 1973
Bluegill (juvenile), *Lepomis macrochirus*	655 min	Median survival time	127	Broderius, 1973
Bluegill (juvenile), *Lepomis macrochirus*	48 hrs	LC50	134	Cardwell, et al. 1976

Table 5. (Continued)

Species	Duration	Effect	Result (µg/L)*	Reference
Bluegill (juvenile), *Lepomis macrochirus*	48 hrs	LC50	280	Turnbull, et al. 1954
Bluegill (juvenile), *Lepomis macrochirus*	50 min	Median resistance time	960	Doudoroff, et al. 1966
Bluegill (juvenile), *Lepomis macrochirus*	91 min	Median resistance time	720	Doudoroff, et al. 1966
Bluegill (juvenile), *Lepomis macrochirus*	129 min	Median resistance time	540	Doudoroff, et al. 1966
Bluegill (juvenile), *Lepomis macrochirus*	700 min	Median resistance time	170	Doudoroff, et al. 1966
Bluegill (juvenile), *Lepomis macrochirus*	72 hrs	LC50	154	Doudoroff, et al. 1966
Bluegill (juvenile), *Lepomis macrochirus*	24 hrs	LC50 (5 C) (15 C) (30 C)	240 160 190	Cairns, et al. 1978
Bluegill (juvenile), *Lepomis macrochirus*	96 hrs	LC50 (periodic low D.O.)	48	Cairns & Scheier, 1958
Bluegill (adult), *Lepomis macrochirus*	48 hrs	LC50	160	Cairns, et al. 1965
Bluegill (adult), *Lepomis macrochirus*	289 days	Survival reduced	67.8	Kimball, et al. 1978
Bluegill (adult), *Lepomis macrochirus*	289 days	No reproduction	5.4	Kimball, et al. 1978
Smallmouth bass (juvenile), *Micropterus dolomieui*	7.8 min	Geometric mean time to death	1,900	Burdick, et al. 1958
Smallmouth bass (juvenile), *Micropterus dolomieui*	12.4 min	Geometric mean time to death	1,430	Burdick, et al. 1958

Table 5. (Continued)

Species	Duration	Effect	Result (µg/L)*	Reference
Smallmouth bass (juvenile), <u>Micropterus dolomieui</u>	15.4 min	Geometric mean time to death	978	Burdick, et al. 1958
Smallmouth bass (juvenile), <u>Micropterus dolomieui</u>	30.6 min	Geometric mean time to death	755	Burdick, et al. 1958
Smallmouth bass (juvenile), <u>Micropterus dolomieui</u>	42.8 min	Geometric mean time to death	478	Burdick, et al. 1958
Smallmouth bass (juvenile), <u>Micropterus dolomieui</u>	80.5 min	Geometric mean time to death	338	Burdick, et al. 1958
Smallmouth bass (juvenile), <u>Micropterus dolomieui</u>	122 min	Geometric mean time to death	243	Burdick, et al. 1958
Smallmouth bass (juvenile), <u>Micropterus dolomieui</u>	290 min	Geometric mean time to death	175	Burdick, et al. 1958
Largemouth bass (juvenile), <u>Micropterus salmoides</u>	2 days	Significant increases in opercular rate	40	Morgan & Kuhn, 1974
Largemouth bass (juvenile), <u>Micropterus salmoides</u>	24 hrs	Affected opercular rhythm	10	Morgan, 1979
		<u>SALTWATER SPECIES</u>		
Oyster, <u>Crassostrea</u> sp.	10 min	Suppressed ciliary activity	150	Usuki, 1956
Oyster, <u>Crassostrea</u> sp.	3 hrs	Inhibited ciliary activity	30,000	Usuki, 1956

Table 5. (Continued)

Species	Duration	Effect	Result (µg/L)*	Reference
Atlantic salmon, *Salmo salar*	24 hrs	LC50	20-75	Alabaster, et al. 1983
Pinfish, *Lagodon rhomboides*	24 hrs	LC50	69	Daugherty & Garrett, 1951

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* Results are expressed as free cyanide as CN.

**In river water.

REFERENCES

Abram, F.S.H. 1964. An application of harmonics to fish toxicology. Int. Jour. Air Water Pollut. 8: 325.

Academy of Natural Sciences. 1960. The sensitivity of aquatic life to certain chemicals commonly found in industrial wastes. Philadelphia, Pennsylvania.

Alabaster, J.S., et al. 1983. The acute lethal toxicity of mixtures of cyanide and ammonia to smolts of salmon, Salmo salar L. at low concentrations of dissolved oxygen. Jour. Fish Biol. 22: 215.

Anderson, B.G. 1946. The toxicity thresholds of various sodium salts determined by the use of Daphnia magna. Sew. Works Jour. 18: 82.

Anderson, P. and L. Weber. 1975. Toxic response as a quantitative function of body size. Toxicol. Appl. Pharmacol. 33: 471.

ASTM. 1984. Test method for determination of free cyanide in water and wastewater by microdiffusion. Standard D 4282. Annual Book of ASTM Standards, Vol. 11.02. American Society for Testing and Materials, Philadelphia, Pennsylvania. p. 137.

Bills, T.D., et al. 1977. Effects of residues of the polychlorinated biphenyl Aroclor 1254 on the sensitivity of rainbow trout to selected environmental contaminants. Prog. Fish-Cult. 39: 150.

Black, H.H., et al. 1957. Industrial wastes guide--by-product coke industry. Sew. Ind. Wastes 29: 53.

Bridges, W.R. 1958. Sodium cyanide as a fish poison. Special Scientific Report - Fisheries No. 253. U.S. Fish and Wildlife Service, Washington, D.C.

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. and R. Kuhn. 1982. Results of toxic action of water pollutants on Daphnia magna Straus tested by an improved standardized procedure. Z. Wasser Abwasser Forsch. 15: 1.

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

Brockway, D.L. 1963. Some effects of sub-lethal levels of pentachlorophenol and cyanide on the physiology and behavior of a cichlid fish, Cichlasoma bimaculatum (Linnaeus). M.S. Thesis. Oregon State University, Corvallis, Oregon.

Broderius, S.J. 1970. Determination of molecular hydrocyanic acid in water and studies of the chemistry and toxicity to fish of the nickelocyanide complex. M.S. Thesis. Oregon State University, Corvallis, Oregon.

Broderius, S.J. 1973. Determination of molecular hydrocyanic acid in water and studies of the chemistry and toxicity to fish of metal-cyanide complexes. Ph.D. Thesis. Oregon State University, Corvallis, Oregon.

Broderius, S.J. 1981. Determination of hydrocyanic acid and free cyanide in aqueous solution. Anal. Chem. 53: 1472.

Broderius, S.J. and L.L. Smith, Jr. 1979. Lethal and sublethal effects of binary mixtures of cyanide and hexavalent chromium, zinc, or ammonia to the fathead minnow (Pimephales promelas) and rainbow trout (Salmo gairdneri). Jour. Fish. Res. Board Can. 36: 164.

Broderius, S., et al. 1977. Relative toxicity of free cyanide and dissolved sulfide forms to the fathead minnow, Pimephales promelas. Jour. Fish. Res. Board Can. 34: 2323.

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

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

Burdick, G.E. and M. Lipschuetz. 1950. Toxicity of ferro- and ferricyanide solutions to fish, and determination of the cause of mortality. Trans. Am. Fish. Soc. 78: 192.

Burdick, G.E., et al. 1958. Toxicity of cyanide to brown trout and smallmouth bass. New York Fish Game Jour. 5: 133.

Cairns, J., Jr., and A. Scheier. 1958. The effect of periodic low oxygen upon toxicity of various chemicals to aquatic organisms. Proc. 12th Ind. Waste Conf., Purdue Univ., Eng. Ext. Ser. No. 94, Eng. Bull. 42: 165.

Cairns, J., Jr., and A. Scheier. 1959. The relationship of bluegill sunfish body size to tolerance for some common chemicals. Proc. 13th Ind. Waste Conf., Purdue Univ., Eng. Ext. Ser. No. 95, Eng. Bull. 43: 243.

Cairns, J., Jr., and A. Scheier. 1963. Environmental effects upon cyanide toxicity to fish. Notulae Naturae, No. 361.

Cairns, J., Jr., and A. Scheier. 1968. A comparison of the toxicity of some common industrial waste components tested individually and combined. Prog. Fish-Cult. 30: 3.

Cairns, J., Jr., et al. 1965. A comparison of the sensitivity to certain chemicals of adult zebra danios Brachydanio rerio (Hamilton-Buchanan) and zebra danio eggs with that of adult bluegill sunfish Lepomis macrochirus Raf. Notulae Naturae, No. 381.

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

Cairns, J., Jr., et al. 1978. Effects of temperature on aquatic organism sensitivity to selected chemicals. Bulletin 106. Virginia Water Resorces Research Center, Blacksburg, Virginia.

Call, D. and L. Brooke. 1982. Memorandum to Richard E. Siefert. University of Wisconsin-Superior, Superior, Wisconsin. March 3.

Call, D.J., et al. 1979. Toxicity, bioconcentration, and metabolism of selected chemicals in aquatic organisms. Third Quarterly Progress Report. 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.

Cardin, J.A. 1980. Memorandum to John H. Gentile. U.S. EPA, Narragansett, Rhode Island.

Cardwell, R., et al. 1976. Acute toxicity of selected toxicants to six species of fish. EPA-600/3-76-008. National Technical Information Service, Springfield, Virginia.

Carter, L. 1962. Bioassay of trade wastes. Nature 196: 1304.

Chen, C.W. and R.E. Selleck. 1969. A kinetic model of fish toxicity threshold. Jour. Water Pollut. Control Fed. 41: R294.

Cheng, S.K. and S.M. Ruby. 1981. Effects of pulse exposure to sublethal levels of hydrogen cyanide on reproduction of American flagfish. Arch. Environ. Contam. Toxicol. 10: 105.

Costa, H.D. and S.M. Ruby. 1984. The effect of sublethal cyanide on vitellogenic parameters in rainbow trout *Salmo gairdneri*. Arch. Environ. Contam. Toxicol. 13: 101.

Costa, H.H. 1965a. Responses of freshwater animals to sodium cyanide solutions. I. fish. Ceylon Jour. Sci. 5: 41.

Costa, H.H. 1965b. Responses of freshwater animals to sodium cyanide solutions. II. *Gammarus pulex*. Ceylon Jour. Sci. 5: 88.

Costa, H.H. 1965c. Responses of freshwater animals to sodium cyanide solutions. III. tadpoles of *Rana temporaria*. Ceylon Jour. Sci. 5: 97.

Costa, H.H. 1966. The effect of exercise on the survival of *Phoxinus phoxinus* L. in sodium cyanide solutions. Hydrobiologia 28: 241.

Daugherty, F.M., Jr., and J.T. Garrett. 1951. Toxicity levels of hydrocyanic acid and some industrial by-products. Texas Jour. Sci. 3: 391.

Department of Scientific and Industrial Research. 1956. Water Pollution Research 1955. London. p. 37.

Dixon, D.G. and G. Leduc. 1981. Chronic cyanide poisoning of rainbow trout and its effects on growth, respiration, and liver histopathology. Arch. Environ. Contam. Toxicol. 10: 117.

Dixon, D.G. and J.B. Sprague. 1981. Acclimation-induced changes in toxicity of arsenic and cyanide to rainbow trout, *Salmo gairdneri* Richardson. Jour. Fish Biol. 18: 579.

Doudoroff, P. 1956. Some experiments on the toxicity of complex cyanides to fish. Sew. Ind. Wastes 28: 1020.

Doudoroff, P. 1976. Toxicity to fish of cyanides and related compounds: a review. EPA-600/3-76-038. National Technical Information Service, Springfield, Virginia.

Doudoroff, P. 1980. A critical review of recent literature on the toxicity of cyanides to fish. American Petroleum Institute, Washington, D.C.

Doudoroff, P., et al. 1966. Acute toxicity to fish of solutions containing complex metal cyanides, in relation to concentrations of molecular hydrocyanic acid. Trans. Am. Fish. Soc. 95: 6.

Dowden, B.F. and H.J. Bennett. 1965. Toxicity of selected chemicals to certain animals. Jour. Water Pollut. Control Fed. 37: 1308.

Downing, K.M. 1954. The influence of dissolved oxygen on the toxicity of potassium cyanide to rainbow trout. Jour. Exp. Biol. 31: 161.

Fitzgerald, G.P., et al. 1952. Studies on chemicals with selective toxicity to blue-green algae. Sew. Ind. Wastes 24: 888.

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

Gardner, G. and W. Nelson. 1981. Memorandum to John H. Gentile. U.S. EPA, Narragansett, Rhode Island.

Gentile, S.L. 1980. Memorandum to John H. Gentile. U.S. EPA, Narragansett, Rhode Island.

Henderson, C., et al. 1961. The effects of some organic cyanides (nitriles) on fish. Proc. 15th Ind. Waste Conf., Purdue Univ., Eng. Ext. Ser. No. 106., Eng. Bull. 45: 120.

Herbert, D.W.M. and J.C. Merkens. 1952. The toxicity of potassium cyanide to trout. Jour. Exp. Biol. 29: 632.

Holden, A.V. and K. Marsden. 1964. Cyanide in salmon and brown trout. No. 33. Freshwater and Salmon Fisheries Research, Department of Agriculture and Fisheries for Scotland, Edinburgh.

Ishio, S. 1965. Behavior of fish exposed to toxic substances. *In*: O. Jaag (ed.), Advances in Water Pollution Research. Pergamon Press, New York. p. 19.

Izatt, R.M., et al. 1962. Thermodynamics of metal-cyanide coordination. I. pK, H^o, and S^o values as a function of temperature for hydrocyanic acid dissociation in aqueous solution. Inorg. Chem. 1: 828.

Johns, M. and S.L. Gentile. 1981. Memorandum to John H. Gentile. U.S. EPA, Narragansett, Rhode Island.

Jones, J.R.E. 1941. A study of the relative toxicity of anions, with *Polycelis nigra* as test animals. Jour. Exp. Biol. 18: 170.

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

Karsten, A. 1934. Investigations of the effect of cyanide on Black Hills trout. Black Hills Eng. 22: 145.

Kimball, G., et al. 1978. Chronic toxicity of hydrogen cyanide to bluegills. Trans. Am. Fish. Soc. 107: 341.

Koenst, W., et al. 1977. Effect of chronic exposure of brook trout to sublethal concentrations of hydrogen cyanide. Environ. Sci. Technol. 11: 883.

Kondo, T. and T. Tsudzuki. 1980. Energy supply for potassium uptake rhythm in a duckweed *Lemna gibba* G-3. Plant Cell Physiol. 21: 433.

Kovacs, T.G. 1979. The effect of temperature on cyanide toxicity to rainbow trout (*Salmo gairdneri*). Part I: acute toxicity. Part II: sub-lethal toxicity. M.S. Thesis. Concordia University, Montreal, Quebec.

Kovacs, T.G. and G. Leduc. 1982a. Sublethal toxicity of cyanide to rainbow trout (*Salmo gairdneri*) at different temperatures. Can. Jour. Fish. Aquat. Sci. 39: 1389.

Kovacs, T.G. and G. Leduc. 1982b. Acute toxicity of cyanide to rainbow trout (*Salmo gairdneri*) acclimated at different temperatures. Can. Jour. Fish. Aquat. Sci. 39: 1426.

Leduc, G. 1966. Some physiological and biochemical responses of fish to chronic poisoning by cyanide. Ph.D. Thesis. Oregon State University, Corvallis, Oregon.

Leduc, G. 1977. The role of cyanide as an ecological stressing factor to fish. In: R.A. Tubb (ed.), Recent Advances in Fish Toxicology. EPA-600/3-77-085. National Technical Information Service, Springfield, Virginia.

Leduc, G. 1978. Deleterious effects of cyanide on early life stages of Atlantic salmon (Salmo salar). Jour. Fish. Res. Board Can. 35: 166.

Leduc, G. 1984. Cyanides in water: toxicological significance. In: L.J. Weber (ed.), Aquatic Toxicology. Vol. 2. Raven Press, New York. p. 153.

Leduc, G. and K.K.S. Chan. 1975. The effects of chronic cyanide poisoning on the tolerance of rainbow trout to varying salinity. In: Water Pollution Research in Canada. 1975. Proc. 10th Canadian Symp. Water Pollut. Res. p. 118.

Leduc, G., et al. 1982. The effects of cyanides on aquatic organisms with emphasis upon freshwater fishes. NRCC No. 19246. National Research Council of Canada, NRCC Associate Committee on Scientific Criteria for Environmental Quality.

Lee, D. 1976. Development of an invertebrate bioassay to screen petroleum refinery effluents discharged into freshwater. Ph.D. Thesis. Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Lesniak, J.A. 1977. A histological approach to the study of sublethal cyanide effects on rainbow trout ovaries. M.S. Thesis. Concordia University, Montreal.

Lesniak, J.A. and S.M. Ruby. 1982. Histological and quantitative effects of sublethal cyanide exposure on oocyte development in rainbow trout. Arch. Environ. Contam. Toxicol. 11: 343.

Lewis, W.M. and R.M. Tarrant, Jr. 1960. Sodium cyanide in fish management and culture. Prog. Fish-Cult. 22: 177.

Lind, D., et al. 1977. Chronic effects of hydrogen cyanide on the fathead minnow. Jour. Water Pollut. Control Fed. 49: 262.

Lipschuetz, M. and A.L. Cooper. 1955. Comparative toxicities of potassium cyanide and potassium cuprocyanide to the western blacknosed dace (Rhinichtys atratulus meleagris). New York Fish Game Jour. 2: 194.

Lloyd, R. and D.H.M. Jordan. 1964. Predicted and observed toxicities of several sewage effluents to rainbow trout: a further study. Inst. Sew. Purif., Jour. Proc. 1964 (Pt. 2): 183.

Lomte, V.S. and M.L. Jadhav. 1982. Effects of toxic compounds on oxygen consumption in the fresh water bivalve, Corbicula regularis (Prime, 1860). Comp. Physiol. Ecol. 7: 31.

Lund, B.L. 1918. The toxic action of KCN and its relation to the state of nutrition and age of the cell as shown by *Paramecium* and *Didinium*. Biol. Bull. 35: 211.

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.

Marking, L.L., et al. 1984. Effects of five diets on sensitivity of rainbow trout to eleven chemicals. Prog. Fish-Cult. 46: 1.

McCracken, I.R. and G. Leduc. 1980. Allometric growth response of exercised rainbow trout to cyanide poisoning. *In*: J.G. Eaton, et al. (eds.), Aquatic Toxicology. ASTM STP 707. American Society for Testing and Materials, Philadelphia, Pennsylvania. p. 303.

Moore, S.L. and S.R. Kin. 1968. Cyanide pollution and emergency duty: train wreck, Dunreith, Indiana. Proc. 23rd Ind. Waste Conf., Purdue Univ., Eng. Ext. Series No. 132 (Pt. 1), Eng. Bull. 53: 583.

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

Morgan, W.S.G. and P.C. Kuhn. 1974. A method to monitor the effects of toxicants upon breathing rates of largemouth bass (*Micropterus salmoides* Lacepede). Water Res. 8: 67.

Murachi, S., et al. 1978. Relation between the concentration of cyanide ion detected in carp and that in environmental water. Jour. Fac. Fish. Anim. Husb., Hiroshima Univ. (Japan) 17: 199.

Negilski, D.S. 1973. Individual and combined effects of cyanide, pentachlorophenol and zinc on juvenile chinook salmon and invertebrates in model stream communities. M.S. Thesis. Oregon State University, Corvallis, Oregon.

Neil, J.H. 1957. Some effects of potassium cyanide on speckled trout (*Salvelinus fontinalis*). 4th Ontario Industrial Waste Conference. Ontario Water Resources Commission, Toronto. p. 74.

Nelson, E.B. and N.E. Tolbert. 1970. Glycolate dihydrogenase in green algae. Arch. Biochem. Biophys. 141: 102.

Oseid, D. and L.L. Smith, Jr. 1979. The effects of hydrogen cyanide on *Asellus communis* and *Gammarus pseudolimnaeus* and changes in their competitive response when exposed simultaneously. Bull. Environ. Contam. Toxicol. 21: 439.

Patrick, R., et al. 1968. The relative sensitivity of diatoms, snails, and fish to twenty common constituents of industrial wastes. Prog. Fish-Cult. 30: 137.

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

Renn, C.E. 1955. Biological properties and behaviors of cyanogenic wastes. Sew. Ind. Wastes 27: 297.

Roback, S.S. 1965. Environmental requirements of Trichoptera. *In*: C.M. Tarzwell (ed.), Biological Problems in Water Pollution. Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio. p. 118.

Ruby, S.M., et al. 1979. Inhibition of spermatogensis in rainbow trout during chronic cyanide poisoning. Arch. Environ. Contam. Toxicol. 8: 533.

Schimmel, S., et al. 1981. Memorandum to John H. Gentile. U.S. EPA, Narragansett, Rhode Island.

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

Shelford, V.E. 1917. An experimental study of the effects of gas waste upon fishes, with especial reference to stream pollution. Bull. Illinois State Laboratory Nat. History Vol. XI, Article VI. p. 381.

Skibba, W.D. 1981. Trout test with *Salmo gairdneri* Richardson for determining the acute toxicity of pollutants and test measurements for sodium cyanide, a cyanidic copper electrolyte and azaplant. Acta Hydrochim. Hydrobiol. 9: 3.

Smith, L.L., Jr., et al. 1978. Acute toxicity of hydrogen cyanide to freshwater fishes. Arch. Environ. Contam. Toxicol. 7: 325.

Smith, L.L., Jr., et al. 1979. Acute and chronic toxicity of HCN to fish and invertebrates. EPA-600/3-79-009. National Technical Information Service, Springfield, Virginia.

Smith, M.J. and A.G. Heath. 1979. Acute toxicity of copper, chromate, zinc and cyanide to freshwater fish: effect of different temperatures. Bull. Environ. Contam. Toxicol. 22: 113.

Speyer, M.R. 1975. Some effects of chronic combined arsenic and cyanide poisoning on the physiology of rainbow trout. M.S. Thesis. Concordia University, Montreal.

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: Sixth Symposium. 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.

Summerfelt, R.C. and W.M. Lewis. 1967. Repulsion of green sunfish by certain chemicals. Jour. Water Pollut. Control Fed. 39: 2030.

Towill, L.E., et al. 1978. Reviews of the environmental effects of pollutants: V. cyanide. EPA-600/1-78-027. National Technical Information Service, Springfield, Virginia.

Tryland, Ø. and M. Grande. 1983. Removal of cyanide from scrubber effluents and its effect on toxicity to fish. Vatten 39: 168.

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 cyanides. EPA-440/5-80037. 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.

Usuki, I. 1956. A comparison of the effects of cyanide and azide on the ciliary activity of the oyster gill. Sci. Rept. Tohoku University, Fourth Sci. 22: 137.

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

Washburn, G.N. 1948. The toxicity to warm-water fishes of certain cyanide plating and carburizing salts before and after treatment by the alkali-chlorination method. Sew. Works Jour. 20: 1074.

Webster, D.A. and D.P. Hackett. 1965. Respiratory chain of colorless algae. I. *Chlorophyta* and *Euglenophyta*. Plant Physiol. Lancaster 40: 1091.

Whittingham, C.P. 1952. Inhibition of photosynthesis by cyanide. Nature 169: 838.

Woker, H. and K. Wuhrmann. 1950. Contributions to fish toxicology. VI. the sensitivity of different species of fish to ammonia, hydrocyanic acid, and phenol. Rev. Suisse Zool. 57: 548.