440 5 88 093

Draft
8/30/88

AMBIENT AQUATIC LIFE WATER QUALITY CRITERIA FOR ANTIMONY(III)

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RESEARCH AND DEVELOPMENT
ENVIRONMENTAL RESEARCH LABORATORIES
DULUTH, MINNESOTA
NARRAGANSETT, RHODE ISLAND

NOTICES

This document has been reviewed by the Criteria and Standards Division, Office of Water Regulations and Standards, U.S. Environmental Protection Agency, and approved for publication.

Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

This document is available to the public through the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161.

FOREWORD

Section 304(a)(1) of the Clean Water Act requires the Administrator of the Environmental Protection Agency to publish water quality criteria that accurately reflect the latest scientific knowledge on the kind and extent of all identifiable effects on health and welfare that might be expected from the presence of pollutants in any body of water. Pursuant to that end, this document proposes water quality criteria for the protection of aquatic life. These criteria do not involve consideration of effects on human health.

This document is a draft, distributed for public review and comment. After considering all public comments and making any needed changes, EPA will issue the criteria in final form, at which time they will replace any previously published EPA aquatic life criteria for the same pollutant.

The term "water quality criteria" is used in two sections of the Clean Water Act, section 304(a)(1) and section 303(c)(2). In section 304, the term represents a non-regulatory, scientific assessment of effects. Criteria presented in this document are such scientific assessments. If water quality criteria associated with specific stream uses are adopted by a State as water quality standards under section 303, then they become maximum acceptable pollutant concentrations that can be used to derive enforceable permit limits for discharges to such waters.

Water quality criteria adopted in State water quality standards could have the same numerical values as criteria developed under section 304. However, in many situations States might want to adjust water quality criteria developed under section 304 to reflect local environmental conditions before incorporation into water quality standards. Guidance is available from EPA to assist States in the modification of section 304(a)(1) criteria, and in the development of water quality standards. It is not until their adoption as part of State water quality standards that the criteria become regulatory.

Martha G. Prothro
Director
Office of Water Regulations and Standards

ACKNOWLEDGMENTS

Loren J. Larson
(freshwater author)
University of Wisconsin-Superior
Superior, Wisconsin

Robert S. Carr
(saltwater author)
Battelle Ocean Sciences
Duxbury, Massachusetts

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

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

CONTENTS

TABLES

Introduction

Antimony occurs naturally in the environment. Geologic formations and minerals such as stibnik, kermesite, senarmonite, and jamesonite are comprised in part of antimony. Water-borne antimony can result from natural weathering of these formations or from anthropogenic sources such as effluents of mining, manufacturing and municipal wastes. Important uses of antimony, as antimony oxide, include its incorporation into various materials as a flame retardant. There are no known biological functions for antimony (Wood and Wang 1985).

Oxidation states of antimony include -3, 0, +3, and +5. According to Callahan et al. (1979), the +3 state occurs under "moderately oxidizing conditions," whereas +5 predominates in highly oxidizing environments. Field data from Andreae et al. (1981) indicated that in natural waters antimony(V) greatly predominates, although their samples appear to have been taken from well-oxygenated waters. The possible effect of dissolved oxygen levels approaching or entering anoxia on the ratio of Sb(III)/Sb(V) is unknown.

Callahan et al. (1979) stated that important processes influencing the fate of antimony in the aquatic environment include chemical speciation (determined by ambient oxygen levels), volatilization, and sorption to sediments. Andreae et al. (1981) indicated that biomethylation is also an important process which may, in addition to the volatilization of stibine (SbH_3) from reducing sediments, act to remobilize antimony from bed sediments. These processes and reactions are similar to those found for certain other metals and metalloids (e.g., arsenic, selenium, mercury) and are important in assessing environmental impacts (Wood and Wang 1985).

Precipitation of antimony, primarily as antimony trioxide (Sb_2O_3) or antimony oxychloride (SbOCl) can be an important factor in limiting soluble antimony levels in natural waters, and can influence the results of toxicity tests. Antimony(III) does not occur as a free ion, Sb^{+3}. In solution, antimony(III) will occur as the cation antimony oxide (SbO^{+}) or as antimony oxychloride (SbOCl) (Burns et al. 1981), with the former predominating. Soluble antimony will be the total antimony occurring in solution in either of these forms. Antimony oxychloride transforms to antimony trioxide (Sb_2O_3) which precipitates, becoming less available to aquatic organisms. Brooke et al. (1986) conducted a study of the effect of chloride enrichment on maintaining dissolved antimony concentrations in solutions. When the chloride concentration was low, dissolved antimony concentrations in static exposures were reduced by as much as 76% in 96 hours. When solutions were enriched with sodium chloride, adjusting the chloride ion concentration to 1000 mg/L, the maximum reduction in dissolved antimony in 96 hours was 13%.

Working with antimony trioxide, soluble antimony concentrations do not reach levels high enough to produce mortalities for most aquatic organisms, due to the low solubility of antimony trioxide. The highest dissolved antimony concentration attained by Brooke et al. (1986) was 3,300 μg/L when antimony trioxide was added to lab water at a nominal concentration of 110,000 μg/L. When antimony trichloride ($SbCl_3$) is used, higher soluble antimony levels can be obtained, but this is limited by the transformation of antimony oxychloride (SbOCl) to antimony trioxide (Sb_2O_3). Ambient chloride levels will have a strong influence on this precipitation and in turn will influence the maximum soluble antimony levels which can be maintained.

Because antimony trioxide will not produce dissolved antimony(III) concentrations high enough to result in acute mortality, toxicity tests using this compound were not used in derivation of national freshwater criteria for antimony(III). Results from studies on freshwater organisms in which antimony trioxide was used were placed in Table 6, if otherwise acceptable. In all cases, toxicity tests utilizing antimony trioxide produced "greater than" values. Only acute toxicity tests utilizing antimony trichloride were included in the freshwater section of Table 1 and used to derive freshwater criteria. Data from acceptable tests on both antimony trichloride and antimony trioxide were used in the derivation of the saltwater criterion.

Unless otherwise noted, all concentrations of antimony(III) in water reported herein from toxicity and bioconcentration tests are expected to be essentially equivalent to acid-soluble antimony(III) concentrations. All concentrations are expressed as antimony, not as the chemical tested. Although antimony(V) is expected to be the predominant oxidation state at chemical equilibrium in oxygenated alkaline water (Andreae et al. 1981), it was assumed that when antimony(III) was introduced into stock or test solutions, it would persist as the predominate state throughout the test, even if no analyses specific for the antimony(III) oxidation state were performed.

A comprehension of the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" (Stephan et al. 1985), hereinafter referred to as the Guidelines, and the response to public comment (U.S. EPA 1985a) is necessary in order to understand the following text, tables, and calculations. Results of such intermediate calculations as recalculated LC50s and Species Mean Acute Values are given to four significant figures to prevent round-off error in subsequent calculations, not to reflect the precision of the value. The criteria presented herein supersede the aquatic life information in the previous criteria document for antimony (U.S. EPA 1980a) because these criteria were derived using improved procedures and additional information. The latest comprehensive literature search for information for this document was conducted in July, 1986; some more recent information was also included.

Acute Toxicity to Aquatic Animals

Acceptable data on the acute toxicity of antimony(III) to freshwater organisms are available for seven species (Table 1). Five of those species, an annelid, amphipod, caddisfly, the rainbow trout, and the bluegill, have reported LC50s greater than the highest soluble antimony(III) levels attained. These values were greater than about 26,000 μg/L (Brooke et al. 1986; Spehar 1987).

Finite LC50s were reported by Brooke et al. (1986), Kimball (Manuscript), and Spehar (1987) for the fathead minnow, *Pimephales promelas*, the cladocerans *Daphnia magna* and *Ceriodaphnia dubia* and a hydra, *Hydra oligactis*. The minnow and cladoceran Species Mean Acute Values were 21,800 μg/L, 18,140 μg/L, and 3,470 μg/L, respectively. The hydra was considerably more sensitive to antimony(III) with a 96-hr LC50 of 500 μg/L. Antimony(III) was more toxic to *D. magna* in tests in which the organisms were fed. The 48-hr EC50 was 33% lower when the cladoceran was fed.

Freshwater Species Mean Acute Values (Table 1) were calculated as geometric means of the available acute values, and then Genus Mean Acute Values (Table 3) were calculated as geometric means of the available Species Mean Acute Values. Of the nine freshwater genera for which mean acute values are available, the most sensitive genus, *Hydra*, is at least 51 times more sensitive than the most resistant genus. The freshwater Final Acute Value for antimony(III) was calculated to be 175.0 μg/L, using the procedure described in the Guidelines. The Final Acute Value is lower than the lowest freshwater Species Mean Acute Value.

The acute toxicity of antimony(III) to saltwater animals has been determined with seven invertebrate and four fish species (Table 1). The range of acute values extends from 3,780 μg/L for adult sea urchins, Hytechinus pictus (Bettelle Ocean Sciences 1987) to > 1,000,000 μg/L for the mummichog, Fundulus heteroclitus (Dorfman 1977). Acute values were similar from tests with antimony trichloride and antimony trioxide with the sheepshead minnow, Cyprinodon variegatus, and possibly with the mysid, Mysidopsis bahia (Battelle Ocean Sciences 1987; Heitmuller et al. 1981; U.S. EPA 1978). Hughes and Boothman (1987) reported unstable antimony in flow-through tests with Menidia beryllina caused by the hydrolysis of antimony trichloride to antimony oxychloride. The acute value of 7,830 μg/L from their test differed little from the acute value of 21,900 μg/L from a static test with the same species (Battelle Ocean Sciences 1987), probably because most of the mortality in both tests occurred during the first 24 hours of the 96-hr tests.

Acute values for the seven most sensitive species, four invertebrate species from three phyla, and three fish species, differed by only a factor of 3.4. The saltwater Final Acute Value is 2,934 μg/L, which is lower than the lowest saltwater Species Mean Acute Value. The saltwater Final Acute Value is much higher than the freshwater Final Acute Value, probably because chloride reduces the toxicity of antimony(III).

Chronic Toxicity to Aquatic Animals

The available data that are usable according to the Guidelines concerning the chronic toxicity of antimony(III) are summarized in Table 2. Kimball (Manuscript) conducted a life-cycle test with a cladoceran, Daphnia magna. In relatively hard water (220 mg/L as $CaCO_3$), survival of the cladoceran was reduced to 40% at a concentration of 4,160 μg/L, although reproduction of the survivors was equal or better than that of the controls. Survival of cladocerans exposed to 2,490 µg/L was equal to that of the controls. The chronic value for this test was 3,218 µg/L and the acute-chronic ratio was 5.633. The 28-day LC50 was 4,510 µg/L.

An early life-stage chronic exposure with the fathead minnow (Pimephales promelas) was also conducted by Kimball (Manuscript). Growth of juveniles was the most sensitive effect, and was reduced at a concentration of 2,310 µg/L. No significant reduction in survival or growth was observed at 1,130 µg/L. The resulting chronic value and acute-chronic ratio were 1,616 µg/L and 13.51, respectively.

The chronic toxicity of antimony(III) has been determined in two early life-stage tests with a saltwater fish, the inland silverside, Menidia beryllina (Hughes and Boothman 1987). Results from the tests were similar, with concentrations ≥ 8,770 µg/L reducing survival, and concentrations ≥ 4,030 µg/L reducing weights of surviving fish. No effects were detected at ≤ 2,230 µg/L. Chronic values for the two tests were 2,874 and 3,016 µg/L; the acute-chronic ratios were 2.724 and 2.596, respectively.

The available Species Mean Acute-Chronic Ratios are 5.633, 13.51, and 2.659 (Table 3). The geometric mean of these three values is 5.871, which is the Final Acute-Chronic Ratio. Division of the freshwater and saltwater Final Acute Values by 5.871 results in freshwater and saltwater Final Chronic Values of 29.81 and 499.7 µg/L, respectively.

Toxicity to Aquatic Plants

Data on the effects of antimony(III) on aquatic plants are summarized in Table 4. In a 4-day exposure with the green alga Selenastrum capricornutum, the EC50 (chlorophyll a) was 610 µg/L (U.S. EPA 1978). Within the obvious limitations of this restricted data set, this might indicate a high relative toxicity of antimony(III) to freshwater algae compared to other freshwater organisms. Brooke et al. (1986) reported the EC50 for duckweed (Lemna minor) to be greater than solubility. No effects were observed at the highest concentration attainable, 25,200 μg/L.

Information on the toxicity of antimony(III) to saltwater plants is limited to one 96-hr test with the diatom, Skeletonema costatum (U.S. EPA 1978). No effect was observed on chlorophyll a at 4,200 μg/L.

A Final Plant Value, as defined by the Guidelines, cannot be obtained because no test has been conducted with a sensitive aquatic plant species in which the concentration of antimony(III) was measured.

Bioaccumulation

Barrows et al. (1980) studied uptake of antimony(III) in bluegills (Table 5). In a 28-day exposure, no antimony residues significantly greater than those of the controls were found. Antimony is known to occur in the tissues of saltwater organisms (Hall et al. 1978; Goldberg 1972; Chattopadhyay et al. 1979; Greig and Jones 1976). No data are available on the magnitude of bioconcentration of antimony(III) in salt water. Antimony is one of several elements known to form methyl-metal compounds in environmental exposures which readily bioaccumulate (Wood and Wang 1985).

No U.S. FDA action level or other maximum acceptable concentration in tissue, as defined in the Guidelines, is available for antimony(III), and, therefore, no Final Residue Value can be calculated.

Other Data

Additional data concerning the lethal and sublethal effects of antimony(III) on aquatic species are presented in Table 6. Birge (1978) and Birge et al. (1979,1980) conducted studies on the mortality and teratogenic effects of antimony trichloride on embryo-larval stages of rainbow trout (Salmo gairdneri), goldfish (Carassius auratus), and a toad (Gastrophyrne carolinensis). EC50s (death and deformity) were calculated at 4 days post-hatch. The goldfish was significantly more resistant to antimony(III), with an EC50 of 11,300 µg/L, than the rainbow trout and the toad, which had EC50s of 660 and 300 µg/L, respectively.

Also included in Table 6 are results of toxicity tests on antimony trioxide (Sb_2O_3). Results are available for a cladoceran (Daphnia magna), fathead minnow (Pimephales promelas) and a bluegill (Lepomis macrochirus). Presumably due to the low solubility of this salt, all results were reported as "greater than" values. Independent of nominal concentrations, soluble antimony(III) levels in all these tests were probably about 4,000 µg/L (Brooke et al. 1986), which is below the known acute sensitivity of most freshwater fish and invertebrates to antimony(III).

Unused Data

Some data on the effects of antimony on aquatic organisms were not used because the studies were conducted with species that are not resident in North America (e.g., Juhnke and Ludemann 1978). Results were not used when the test procedures (e.g., Amiard 1976; Knie et al. 1983) or test material (e.g., Woodiwiss and Fretwell 1974) were not adequately described. Results by Tamulinus (1979) were not used because the dilution water was renewed only once a week. Data were not used when antimony was a component of an effluent mixture, or sediment (e.g., Hildebrand and Carter 1976; Jay and Muncy 1979; Payer and Runkel 1978; Seeleye et al. 1982; Thomas et al. 1980b). Tests conducted with too few test organisms (e.g., Tarzwell and Henderson 1960) were not used. Results of tests conducted on antimony(V) were not used (e.g., Hollibaugh et al. 1980; Thomas et al. 1980a).

Reports of the concentrations of antimony in wild aquatic organisms (e.g., Brezina and Arnold 1977; Chassard-Bouchard and Balvay 1978; Chattopadhyay et al. 1979; Cherry et al. 1979,1980; DeGoey et al. 1974; Friant and Koerner 1981; Friant and Sherman 1980; Goldberg 1972; Greig and Jones 1976; Hall et al. 1978; Hert and Klusek 1985; Korda et al. 1977; Lucas et al. 1970; Moller et al. 1983; Payer et al. 1976; Shuman et al. 1977; Smock 1983a,b; Telitchenko et al. 1970; Tong et al. 1974; Uthe and Bligh 1971) were not used to calculate bioaccumulation factors when the number of measurements of the concentration in water was too small.

Summary

Acute toxicity of antimony(III) to several freshwater species did not occur below the limits of solubility of antimony salts. These species included an annelid, an amphipod, a caddisfly, and rainbow trout. Four species were reported to be acutely sensitive to antimony(III). Mean acute values for the fathead minnow, _Daphnia magna_, _Ceriodaphnia dubia_, and a hydra were 21,800, 18,140, 3,470, and 500 μg/L, respectively. Chronic toxicity of antimony(III) to _Daphnia magna_ and the fathead minnow has been studied. Chronic values were 3,218 and 1,616 μg/L, respectively.

The freshwater alga _Selenastrum capricornutum_ had an EC50 of 610 μg/L in a 4-day exposure to antimony(III). There was no effect on a freshwater vascular plant, _Lemna minor_, at the highest concentration attainable in

water. Negligible uptake of antimony(III) was reported in the bluegill (Lepomis macrochirus).

Acute toxicity tests have been conducted on antimony(III) with eleven genera of saltwater animals and the acute values range from 3,780 μg/L for the sea urchin, Lytechinus pictus, to > 1,000,000 μg/L for the mummichog, Fundulus heteroclitus. The values for the seven most sensitive genera, including representatives of four phyla, differed by only a factor of 3.4. The chronic values from two early life-stage tests with the inland silverside, Menidia beryllina, were 2,874 and 3,016 μg/L; the acute-chronic ratios were 2.724 and 2.596, respectively. The diatom, Skeletonema costatum, was not affected by 4,200 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 antimony(III) does not exceed 30 μg/L more than once every three years on the average and if the one-hour average concentration does not exceed 88 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 four-day average concentration of antimony(III) does not exceed 500 µg/L more than once every three years on the average and if the one-hour average concentration does not exceed 1,500 µg/L more than once every three years on the average. Because sensitive saltwater animals appear to have a narrow range in susceptibilities to antimony(III), this criterion will probably be as protective as intended only when the magnitudes and/or duration of excursions are appropriately small.

Implementation

Because of the variety of forms of antimony(III) in ambient water and the lack of definitive information about their relative toxicities to aquatic species, no available analytical measurement is known to be ideal for expressing aquatic life criteria for antimony(III). Previous aquatic life criteria for metals and metalloids (U.S. EPA 1980b) were expressed in terms of the total recoverable measurement (U.S. EPA 1983a), but newer criteria for metals and metalloids have been expressed in terms of the acid-soluble measurement (U.S. EPA 1985b). Acid-soluble antimony(III) (operationally defined as the antimony(III) that passes through a 0.45 µm membrane filter after the sample has been acidified to a pH between 1.5 and 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 antimony(III) to, and bioaccumulation of antimony(III) by, aquatic organisms. It is expected that the results of tests used in the derivation of the criteria would not have been substantially different if they had been reported in terms of acid-soluble antimony(III).
2. On samples of ambient water, measurement of acid-soluble antimony(III) will probably measure all forms of antimony(III) that are toxic to

aquatic life or can be readily converted to toxic forms under natural conditions. In addition, this measurement probably will not measure several forms, such as antimony(III) that is occluded in minerals, clays, and sand or is strongly sorbed to particulate matter, that are not toxic and are not likely to become toxic under natural conditions.

3. Although water quality criteria apply to ambient water, the measurement used to express criteria is likely to be used to measure antimony(III) in aqueous effluents. Measurement of acid-soluble antimony(III) is expected to be applicable to effluents. If desired, dilution of effluent with receiving water before measurement of acid-soluble antimony(III) might be used to determine whether the receiving water can decrease the concentration of acid-soluble antimony(III) because of sorption.

4. The acid-soluble measurement is expected to be useful for most metals and metalloids, thus minimizing the number of samples and procedures that are necessary.

5. The acid-soluble measurement does not require filtration of the sample at the time of collection, as does the dissolved measurement.

6. For the measurement of total acid-soluble antimony, the only treatment required at the time of collection is preservation by acidification to a pH between 1.5 and 2.0, similar to that required for the total recoverable measurement.

7. Durations of 10 minutes to 24 hours between acidification and filtration of most samples of ambient water probably will not substantially affect the result of the measurement of total acid-soluble antimony. However, acidification might not prevent oxidation or reduction of antimony(III) and antimony(V). Therefore, measurement of acid-soluble antimony(III)

and/or antimony(V) might require separation or measurement at the time of collection of the sample or special preservation to prevent conversion of one oxidation state of antimony to the other.

8. Ambient waters have much higher buffer intensities at a pH between 1.5 and 2.0 than they do at a pH between 4 and 9 (Stumm and Morgan 1981).
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 antimony, the analysis for total acid-soluble antimony can be performed using either atomic absorption spectrophotometric or ICP-atomic emission spectrometric analysis (U.S. EPA 1983a), as with the total recoverable measurement. It might be possible to separately measure acid-soluble antimony(III) and acid-soluble antimony(V) using the methods described by Andreae et al. (1981).

Expressing aquatic life criteria for antimony(III) in terms of the acid-soluble measurement has both toxicological and practical advantages. The U.S. EPA is considering development and approval of just such a method.

Metals and metalloids might be measured using the total recoverable method (U.S. EPA 1983a). This would have two major impacts because this method includes a digestion procedure. First, certain species of some metals and metalloids cannot be measured because the total recoverable method cannot distinguish between individual oxidation states. Second, in some cases these criteria would be overly protective when based on the total recoverable method because the digestion procedure might dissolve antimony that is not toxic and cannot be converted to a toxic form under natural conditions. Because no measurement is known to be ideal for expressing aquatic life criteria for antimony(III) or for measuring antimony(III) in ambient water or aqueous effluents, measurement of acid-soluble antimony(III), acid-soluble antimony, and total recoverable antimony in ambient water or effluent or both might be useful. For example, there might be cause for concern when total recoverable antimony is much above an applicable limit, even though acid-soluble antimony(III) is below the limit.

In addition, metals and metalloids might be measured using the dissolved method, but this would also have several impacts. First, whatever analytical method is specified for measuring antimony(III) in ambient surface water will probably also be used to monitor effluents. If effluents are monitored by measuring only the dissolved metals and metalloids, the effluents might contain some antimony(III) that would not be measured but might dissolve, due to dilution or change in pH or both, when the effluent is mixed with receiving water. Second, measurement of dissolved antimony(III) requires filtration of the sample at the time of collection. Third, the dissolved measurement is especially inappropriate for use with such metals as aluminum that can exist as hydroxide and carbonate precipitates in toxicity tests and in effluents. Use of different methods for different metals and metalloids would be unnecessarily complicated. For these reasons, it is recommended that aquatic life criteria for antimony(III) not be expressed as dissolved antimony(III).

As discussed in the Water Quality Standards Regulation (U.S. EPA 1983b) and the Foreword to this document, a water quality criterion for aquatic life has regulatory impact only after it has been adopted in a state water quality standard. Such a standard specifies a criterion for a pollutant that is consistent with a particular designated use. With the concurrence of the U.S.

EPA, states designate one or more uses for each body of water or segment thereof and adopt criteria that are consistent with the use(s) (U.S. EPA 1983c,1987). In each standard a state may adopt the national criterion, if one exists, or, if adequately justified, a site-specific criterion.

Site-specific criteria may include not only site-specific criterion concentrations (U.S. EPA 1983c), but also site-specific, and possibly pollutant-specific, durations of averaging periods and frequencies of allowed excursions (U.S. EPA 1985c). The averaging periods of "one hour" and "four days" were selected by the U.S. EPA on the basis of data concerning how rapidly some aquatic species react to increases in the concentrations of some pollutants, and "three years" is the Agency's best scientific judgment of the average amount of time aquatic ecosystems should be provided between excursions (Stephan et al. 1985; U.S. EPA 1985c). However, various species and ecosystems react and recover at greatly differing rates. Therefore, if adequate justification is provided, site-specific and/or pollutant-specific concentrations, durations, and frequencies may be higher or lower than those given in national water quality criteria for aquatic life.

Use of criteria, which have been adopted in state water quality standards, for developing water quality-based permit limits and for designing waste treatment facilities requires selection of an appropriate wasteload allocation model. Although dynamic models are preferred for the application of these criteria (U.S. EPA 1985c), limited data or other considerations might require the use of a steady-state model (U.S. EPA 1986). Guidance on mixing zones and the design of monitoring programs is also available (U.S. EPA 1985c,1987).

Table 1. Acute Toxicity of Antimony(III) to Aquatic Animals

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)[b]	Species Mean Acute Value (µg/L)	Reference
			FRESHWATER SPECIES			
Hydra, *Hydra oligactis*	S, M	Antimony trichloride	46.9	500	500	Brooke et al. 1986
Annelid, *Lumbriculus variegatus*	S, M	Antimony trichloride	52.2	> 25,700	> 25,700	Brooke et al. 1986
Cladoceran, *Ceriodaphnia dubia*	S, M	Antimony trichloride	-	3,470	3,470	Spehar 1987
Cladoceran (< 8 hr), *Daphnia magna*	S, U	Antimony trichloride	-	15,640	-	Anderson 1948
Cladoceran (< 24 hr), *Daphnia magna*	R, M	Antimony trichloride	220[c]	14,500	-	Kimball, Manuscript
Cladoceran (< 24 hr), *Daphnia magna*	R, M	Antimony trichloride	220[c]	23,500	18,140	Kimball, Manuscript
Amphipod, *Gammarus pseudolimnaeus*	S, M	Antimony trichloride	52.2	> 25,700	> 25,700	Brooke et al. 1986
Caddisfly (larva), *Pycnopsyche* sp.	S, M	Antimony trichloride	52.2	> 25,700	> 25,700	Brooke et al. 1986
Rainbow trout (fry), *Salmo gairdneri*	S, M	Antimony trichloride	52.2	> 25,700	> 25,700	Brooke et al. 1986
Fathead minnow (8 wk), *Pimephales promelas*	F, M	Antimony trichloride	220[c]	22,700	-	Kimball, Manuscript
Fathead minnow (8 wk), *Pimephales promelas*	F, M	Antimony trichloride	220[c]	21,000	-	Kimball, Manuscript

Table 1. (continued)

Species	Method[a]	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)[b]	Species Mean Acute Value (µg/L)	Reference
Fathead minnow (fry), *Pimephales promelas*	S, M	Antimony trichloride	48.5	14,400	21,800	Brooke et al. 1986
Bluegill, *Lepomis macrochirus*	S, M	Antimony trichloride	44-46	> 25,800	> 25,800	Spehar 1987
			SALTWATER SPECIES			
Archiannelid (immature), *Dinophilus gyrociliatus*	S, U	Antimony trichloride	31[d]	4,310	4,310	Battelle Ocean Sciences 1987
Sandworm (adult), *Nereis virens*	S, U	Antimony trichloride	30[d]	12,800	12,800	Battelle Ocean Sciences 1987
Mysid (juvenile), *Mysidopsis bahia*	S, U	Antimony trichloride	30[d]	8,320	8,320	Battelle Ocean Sciences 1987
Mysid (juvenile), *Mysidopsis bahia*	S, U	Antimony trioxide	-	> 5,000	-	U.S. EPA 1978
Isopod (adult), *Idothea resecata*	S, U	Antimony trichloride	30[d]	> 53,400	> 53,400	Battelle Ocean Sciences 1987
Amphipod (adult), *Rhepoxynius abronius*	S, U	Antimony trichloride	30[d]	> 53,400	> 53,400	Battelle Ocean Sciences 1987
Coon stripe shrimp (juvenile), *Pandalus danae*	S, U	Antimony trichloride	30[d]	46,200	46,200	Battelle Ocean Sciences 1987

Table 1. (continued)

Species	Method[a]	Chemical	Salinity (g/kg)	LC50 or EC50 (µg/L)[b]	Species Mean Acute Value (µg/L)	Reference
Sea urchin (adult), _Lytechinus pictus_	S, U	Antimony trichloride	30	3,780	3,780	Battelle Ocean Sciences 1987
Pacific herring (juvenile), _Clupea harengas pallisai_	S, U	Antimony trichloride	30	4,800	4,800	Battelle Ocean Sciences 1987
Mummichog, _Fundulus heterclitus_	S, U	Antimony trioxide	6	> 1,000,000	-	Dorfman 1977
Mummichog, _Fundulus heterclitus_	S, U	Antimony trioxide	21.6	> 1,000,000	> 1,000,000	Dorfman 1977
Sheepshead minnow (juvenile), _Cyprinodon variegatus_	S, U	Antimony trioxide	-	> 6,200, < 8,300	-	Heitmuller et al. 1981; U.S. EPA 1978
Sheepshead minnow (juvenile), _Cyprinodon variegatus_	S, U	Antimony trichloride	30	7,380	7,380	Battelle Ocean Sciences 1987
Inland silverside (juvenile), _Menidia beryllina_	S, U	Antimony trichloride	31	21,900	-	Battelle Ocean Sciences 1987
Inland silverside (juvenile), _Menidia beryllina_	F, M	Antimony trichloride	30	7,830	7,830	Hughes and Boothman 1987

[a] S = static; R = renewal; F = flow-through; M = measured; U = unmeasured.

[b] As antimony(III), not as chemical.

[c] From Smith et al. (1976).

[d] Salinity (g/kg), not hardness.

Table 2. Chronic Toxicity of Antimony(III) to Aquatic Animals

Species	Test[a]	Chemical	Hardness (mg/L as $CaCO_3$)	Chronic limits (µg/L)[b]	Chronic Value (µg/L)	Reference
FRESHWATER SPECIES						
Cladoceran, <u>Daphnia magna</u>	LC	Antimony trichloride	220[c]	2,490-4,160	3,218	Kimball, Manuscript
Fathead minnow, <u>Pimephales promelas</u>	ELS	Antimony trichloride	220[c]	1,130-2,310	1,616	Kimball, Manuscript
SALTWATER SPECIES						
Inland silverside, <u>Menidia beryllina</u>	ELS	Antimony trichloride	30[d]	2,230-4,080	3,016	Hughes and Boothman 1987
Inland silverside, <u>Menidia beryllina</u>	ELS	Antimony trichloride	30[d]	2,050-4,030	2,874	Hughes and Boothman 1987

[a] LC = life-cycle or partial life-cycle; ELS = early life-stage.

[b] Results are based on measured concentrations of antimony.

[c] From Smith et al. (1976).

[d] Salinity (g/kg), not hardness.

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*	220	18,138	3,218	5.633
Fathead minnow, *Pimephales promelas*	220	21,833	1,616	13.51
Inland silverside, *Menidia beryllina*	30[a]	7,830	3,016	2.596
Inland silverside, *Menidia beryllina*	30[a]	7,830	2,874	2.724

[a] Salinity (g/kg), not hardness.

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

Rank[a]	Genus Mean Acute Value (µg/L)	Species	Species Mean Acute Value (µg/L)[b]	Species Mean Acute-Chronic Ratio[c]
		FRESHWATER SPECIES		
9	> 25,800	Bluegill, *Lepomis macrochirus*	> 25,800	-
8	> 25,700	Annelid, *Lumbriculus variegatus*	> 25,700	-
	> 25,700	Amphipod, *Gammarus pseudolimnaeus*	> 25,700	-
	> 25,700	Caddisfly, *Pycnopschye* sp.	> 25,700	-
	> 25,700	Rainbow trout, *Salmo gairdneri*	> 25,700	-
4	21,800	Fathead minnow, *Pimephales promelas*	21,800	13.51
3	18,140	Cladoceran, *Daphnia magna*	18,140	5.633
2	3,470	Cladoceran, *Ceriodaphnia dubia*	3,470	-
1	500	Hydra, *Hydra oligactis*	500	-

Table 3. (continued)

Rank[a]	Genus Mean Acute Value (μg/L)	Species	Species Mean Acute Value (μg/L)[b]	Species Mean Acute-Chronic Ratio[c]
		SALTWATER SPECIES		
11	> 1,000,000	Mummichog, *Fundulus heteroclitus*	> 1,000,000	-
10	> 53,400	Amphipod, *Rhepoxynius abronius*	> 53,400	-
9	> 53,400	Isopod, *Idothea resecata*	> 53,400	-
8	> 46,200	Coon stripe shrimp, *Pandalus danae*	> 46,200	-
7	12,800	Sandworm, *Nereis virens*	12,800	-
6	8,320	Mysid, *Mysidopsis bahia*	8,320	-
5	7,830	Inland silverside, *Menidia beryllina*	7,830	2.659[d]
4	7,380	Sheepshead minnow, *Cyprinodon variegatus*	7,380	-
3	4,800	Pacific herring, *Clupea harengas pallisai*	4,800	-
2	4,310	Archiannelid, *Dinophilus gyrociliatus*	4,310	-
1	3,780	Sea urchin, *Lytechinus pictus*	3,780	-

Table 3. (continued)

[a] Ranked from most resistant to most sensitive based on Genus Mean Acute Value. Inclusion of "greater than" values does not necessarily imply a true ranking, but does allow use of all genera for which data are available so that the Final Acute Value is not unnecessarily lowered.

[b] From Table 1.

[c] From Table 2.

[d] Geometric mean of two values in Table 2.

<u>Fresh water</u>

Final Acute Value = 175.0 µg/L

Criterion Maximum Concentration = (175.0 µg/L) / 2 = 87.50 µg/L

Final Acute-Chronic Ratio = 5.871 (see text)

Final Chronic Value = (175.0 µg/L) / 5.871 = 29.81 µg/L

<u>Salt water</u>

Final Acute Value = 2,934 µg/L

Criterion Maximum Concentration = (2,934 µg/L) / 2 = 1,467 µg/L

Final Acute-Chronic Ratio = 5.871 (see text)

Final Chronic Value = (2,934 µg/L) / 5.871 = 499.7 µg/L

Table 4. Toxicity of Antimony(III) to Aquatic Plants

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration (days)	Effect	Concentration (µg/L)[a]	Reference
			FRESHWATER SPECIES			
Green alga, *Selenastrum capricornutum*	Antimony trioxide	-	4	EC50 (chlorophyll *a*)	610	U.S. EPA 1978
Duckweed, *Lemna minor*	Antimony trichloride	60.5	4	EC50	> 25,200	Brooke et al. 1986
			SALTWATER SPECIES			
Diatom, *Skeletonema costatum*	Antimony trioxide	-	4	EC50 (chlorophyll *a*)	> 4,200	U.S. EPA 1978

[a] Concentration of antimony, not the chemical.

Table 5. Bioaccumulation of Antimony(III) by Aquatic Organisms

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Concentration in Water (µg/L)[a]	Duration (days)	Tissue	BCF or BAF[b]	Reference
			FRESHWATER SPECIES				
Bluegill (juvenile), *Lepomis macrochirus*	Antimony trioxide	-	-	28	Whole body	No significant accumulation	Barrows et al. 1980

[a] Measured concentration of antimony.

[b] Bioconcentration factors (BCFs) and bioaccumulation factors (BAFs) are based on measured concentrations of antimony(III) in water and in tissue.

Table 6. Other Data on Effects of Antimony(III) on Aquatic Organisms

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration (µg/L)[a]	Reference
FRESHWATER SPECIES						
Cladoceran (< 24 hr), *Daphnia magna*	Antimony trioxide	72	48 hr	EC50	> 443,000	LeBlanc 1980
Cladoceran, *Daphnia magna*	Antimony trichloride	220[b]	48 hr	EC50 (fed)	12,100	Kimball, Manuscript
Cladoceran, *Daphnia magna*	Antimony trichloride	220[b]	96 hr	EC50 (fed)	12,100	Kimball, Manuscript
Rainbow trout (embryo/larva), *Salmo gairdneri*	Antimony trichloride	195	27 days (4 days post-hatch)	EC50 (death and deformity)	660	Birge et al. 1980
Goldfish (embryo/larva), *Carassius auratus*	Antimony trichloride	195	7 days (4 days post-hatch)	EC50 (death and deformity)	11,300	Birge 1978
Fathead minnow, *Pimephales promelas*	Antimony trioxide	40-48	96 hr	LC50	> 695,800	Curtis and Ward 1981
Fathead minnow (fry), *Pimephales promelas*	Antimony trioxide	-	96 hr	LC50	> 4.500	Brooke et al. 1986
Fathead minnow (embryo), *Pimephales promelas*	Antimony trioxide	28-40	96 hr	LC50	> 7.5	LeBlanc and Dean 1984
Fathead minnow (embryo/larva), *Pimephales promelas*	Antimony trioxide	28-40	30 day	Chronic value	> 7.5	LeBlanc and Dean 1984
Fathead minnow (juvenile), *Pimephales promelas*	Antimony trichloride	220[b]	8 days	LC50 (fed)	20,200	Kimball, Manuscript

Table 6. (continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Concentration (μg/L)[a]	Reference
Bluegill (0.3-1.2 g), *Lepomis macrochirus*	Antimony trioxide	32-48	96 hr	LC50	> 443,000	Buccafusco et al. 1981
Narrow-mouthed toad (embryo/larva), *Gastrophryne carolinensis*	Antimony trichloride	195	7 days (4 days post-hatch)	EC50 (death and deformity)	300	Birge 1978; Birge et al. 1979

[a] Concentration of antimony, not the chemical.

[b] From Smith et al. (1976)

REFERENCES

Amiard, J.C. 1976. Experimental study of the toxicity of salts of cobalt, antimony, strontium and silver with some crustaceans and their larvae and some teleosts. Rev. Intern. Oceanogr. Med. 43:79-95

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. 78:96-113.

Andreae, M.O., J.F. Asmode, P. Foster and L. Vantdack. Determination of antimony(III), antimony(V), and methylantimony species in natural waters by atomic absorption spectrometry with hydride generation. Anal. Chem. 53:1766-1771.

Barrows, M.E., S.R. Petrocelli and K.J. Macek. 1980. Bioconcentration and elimination of selected water pollutants by bluegill sunfish (Lepomis macrochirus) In: Dynamics, exposure and hazard assessment of toxic chemicals. Hague, R. (Ed.). Ann Arbor Science, Ann Arbor, MI. pp. 379-390.

Battelle Ocean Sciences. 1987. Acute toxicity of antimony(III) to saltwater organisms. Report to U.S. EPA, Criteria and Standards Division, Washington, DC.

Birge, W.J. 1978. Aquatic toxicology of trace elements of coal and fly ash. In: Energy and environmental stress in aquatic systems. Thorp, J.H. and J. Gibbons (Eds.). CONF-771114. National Technical Information Service, Springfield, VA. pp. 219-240.

Birge, W.J., J.A. Black and A.G. Westerman. 1979. Evaluation of aquatic pollutants using fish and amphibian eggs as bioassay organisms. In: Animals as monitors of environmental pollutants. Nielson, S.W., G. Migaki and D.G. Scarrelli (Eds.). National Academy of Sciences, Washington, DC. pp. 108-118.

Birge, W.J., J.A. Black, A.G. Westerman and J.E. Hudson. 1980. Aquatic toxicity tests on inorganic elements occurring in oil shale. In: Oil shale symposium: Sampling, analysis and quality assurance. Gale, C. (Ed.). EPA-600/9-80-022 or PB80-221435. National Technical Information Service, Springfield, VA. pp. 519-534.

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

Brooke, L.T., D.J. Call, C.A. Lindberg and T.P. Markee. 1986. Acute toxicity of antimony(III) to several species of freshwater organisms. Center for Lake Superior Environmental Studies, University of Wisconsin-Superior, WI.

Buccafusco, R.J., S.J. Ells and G.A. LeBlanc. 1981. Acute toxicity of priority pollutants to bluegill (Lepomis macrochirus). Bull. Environ. Contam. Toxicol. 26:446-452.

Burns, D.T., A. Townshend and A.H. Carter. 1981. Inorganic reaction chemistry. Vol. 2. Reactions of the elements and their compounds. Part A. Alkali metals to nitrogen. Ellis Horwood Ltd., Chichester, U.K.

Callahan, M.A., M.W. Slimak, N.W. Gabel, I.P. May, C.F. Fowler, J.R. Freed, P. Jennings, R.L. Durfee, F.C. Whitmore, B. Maestri, W.R. Mabey, B.R. Holt and C. Gould. 1979. Water-related environmental fate of 129 priority pollutants. Vol. I. EPA-440/4-79-029a. pp. 5-1 to 5-8.

Chassard-Bouchard, C. and G. Balvay. 1978. Application of electron probe x-ray microanalysis to the detection of metal pollutants in freshwater zooplankton. Microsc. Acta (Suppl.) 2:185-192.

Chattopadhyay, A., K.M. Ellis and K. Desilva. 1979. Determination of trace elements in fisheries samples by instrumental neutron and photon activation analysis. Nucl. Act. Tech. Life Sci. Proc. Int. Symp. pp. 667-683.

Cherry, D.S., R.K. Guthrie, F.F. Sherberger and S.R. Larrick. 1979. The influence of coal ash and thermal discharges upon the distribution and bioaccumulation of aquatic organisms. Hydrobiologia 62:257-267.

Cherry, D.S., J.H. Rodgers, Jr., R.L. Graney and J. Cairns, Jr. 1980. Dynamics and control of the asiatic clam in the New River, Virginia. Bulletin No. 123. Virginia Water Resources Research Center, Blacksburg, VA.

Crecelius, E.A., M.H. Bothner and R. Carpenter. 1975. Geochemistries of arsenic, antimony, mercury, and related elements in sediments of Puget Sound. Environ. Sci. Technol. 9:325-333.

Curtis, M.W. and C.H. Ward. 1981. Aquatic toxicity of forty industrial chemicals: Testing in support of hazardous substance spill prevention regulation. J. Hydrol. (Amst.) 51:359-367.

DeGoey, J.J.M., V.P. Guinn, D.R. Young and A.J. Mearns. 1974. Neutron activation analysis trace-element studies of Dover sole liver and marine sediments. Nucl. Sci. Abstr. 29:189-200.

Dorfman, D. 1977. Tolerance of _Fundulus_ _heteroclitus_ to different metals in salt waters. Bull. N. J. Acad. Sci. 22:21-23.

Friant, S.L. and H. Koerner. 1981. Use of an in-situ artificial substrate for biological accumulation and monitoring of aqueous trace metals. A preliminary field investigation. Water Res. 15:161-167.

Friant, S.L. and J.W. Sherman. 1980. The use of algae as biological accumulators for monitoring aquatic pollutants. In: 2nd interagency workshop on in-situ water quality sensing: Biological sensing. National Marine Pollution Program Office, National Oceanic and Atmospheric Administration, Rockville, MD. pp. 185-206.

Goldberg, E.D. (Ed.). 1972. Baseline studies of pollutants in the marine environment and research recommendations. NSF-IDOE-74-26. pp. 231-273.

Greig, R.A. and J. Jones. 1976. Nondestructive neutron activation analysis of marine organisms collected from ocean dump sites of the middle eastern United States. Arch. Environ. Contam. Toxicol. 4:420-434.

Hall, R.A., E.G. Zook and O.M. Meaberm. 1978. National Marine Fisheries Service survey of trace elements in the fisheries resource. NOAA Technical Report NMFS SSRF-721.

Heit, M. and C.S. Klusek. 1985. Trace element concentrations in the dorsal muscle of white suckers and brown bullheads from two acidic Adirondack lakes. Water Air Soil Pollut. 25:87-96.

Heitmuller, P.T., T.A. Hollister and P.R. Parrish. 1981. Acute toxicity of 54 industrial chemicals to sheepshead minnow (Cyprinodon variegatus). Bull. Environ. Contam. Toxicol. 27:596-604.

Hildebrand, S.G. and J.A. Carter. 1976. The potential toxicity and bioaccumulation in aquatic systems of trace elements present in aqueous coal conversion effluents. In: Trace substances in environmental health - X. Hemphill, D.D. (Ed.). University of Missouri, Columbia, MO. pp. 305-312.

Hollibaugh, J.T., D.L. Seibert and W.H. Thomas. 1980. A comparison of the acute toxicities of ten heavy metals to phytoplankton from Saanich Inlet, B.C., Canada. Estuarine Coastal Sci. 10:93-105.

Hughes, M.M. and W.S. Boothman. 1987. SAI Corp., Narragansett, RI. (Memorandum to D.J. Hansen, U.S. EPA, Narragansett, RI. April 28.)

Jay, F.B. and R.J. Muncy. 1979. Toxicity to channel catfish of wastewater from an Iowa coal beneficiation plant. Iowa State J. Res. 54:45-50.

Juhnke, I. and D. Ludemann. 1978. Results of the investigation of 200 chemical compounds for acute fish toxicity with the golden orfe test. Z. Wasser Abwasser Forsch. 11:161-164.

Kimball, G. Manuscript. The effects of lesser known metals and one organic to fathead minnows (Pimephales promelas) and Daphnia magna. Available from: Charles E. Stephan, U.S. EPA, Duluth, MN.

Knie, J., A. Halke, I. Juhnke and W. Schiller. 1983. Results of studies of chemical substances using four biotests. Dtsch. Gewasserkd. Mitt. 27:77-79.

Korda, R.J., T.E. Henzler, P.A. Helmke, M.M. Jimenez, L.A. Haskin and E.M. Larsen. 1977. Trace elements in samples of fish, sediment and taconite from Lake Superior. J. Great Lakes Res. 3:148-154.

LeBlanc, G.A. 1980. Acute toxicity of priority pollutants to water flea (Daphnia magna). Bull. Environ. Contam. Toxicol. 24:684-691.

LeBlanc, G.A. and J.W. Dean. 1984. Antimony and thallium toxicity to embryos and larvae of fathead minnows (Pimephales promelas). Bull. Environ. Contam. Toxicol. 32:565-569.

Lucas, H.F., Jr., D.N. Edgington and P.J. Colby. 1970. Concentrations of trace elements in Great Lakes fishes. J. Fish. Res. Board Can. 27:677-684.

Moller, H., R. Schneider and C. Schnier. 1983. Trace metal and PCB content of mussels (Mytilus edulis) from the southwestern Baltic Sea. Int. Revue ges. Hydrobiol. 68:633-647.

Parrish, P.R., K.S. Buxton and J.R. Gibson. 1976. Oysters (Crassostrea virginica) exposed to a complex industrial waste survival growth and uptake of antimony compounds. Proc. Natl. Shellfish Assoc. pp. 104.

Payer, H.D. and K.H. Runkel. 1978. Environmental pollutants in freshwater algae from open-air mass cultures. Arch. Hydrobiol. 11:184-198.

Payer, H.D., K.H. Runkel, P. Schramel, E. Stengel, A. Bhumiratana and C.J. Soeder. 1976. Environmental influences on the accumulation of lead, cadmium, mercury, antimony, arsenic, selenium, bromine and tin in unicellular algae cultivated in Thailand and in Germany. Chemosphere 5:413-418.

Seelye, J.G., R.J. Hesselberg and M.J. Mac. 1982. Accumulation by fish of contaminants released from dredge and sediments. Environ. Sci. Technol. 16:459-464.

Shuman, M.S., L.A. Smock and C.L. Haynie. 1977. Metals in the water, sediments and biota of the Haw and New Hope Rivers, North Carolina. UNC-WRRI-77-124. Water Resources Institute, University of North Carolina, Chapel Hill, NC.

Smith, L.L., Jr., D.M. Oseid, G.L. Kimball and E.M. El-Kandelgy. 1976. Toxicity of hydrogen sulfide to various life history stages of bluegill (Lepomis macrochirus). Trans. Am. Fish. Soc. 105:442-449.

Smock, L.A. 1983a. The influence of feeding habits on whole body metal concentrations in aquatic insects. Freshwater Biol. 13:301-311.

Smock, L.A. 1983b. Relationships between metal concentrations and organism size in aquatic insects. Freshwater Biol. 13:313-321.

Spehar, R.L. 1987. U.S. EPA, Duluth, MN. (Memorandum to C. Stephan, U.S. EPA, Duluth, MN. August 27.)

Stephan, C.E., D.I. Mount, D.J. Hansen, J.H. Gentile, G.A. Chapman and W.A. Brungs. 1985. Guidelines for deriving numerical national water quality criteria for the protection of aquatic organisms and their uses. PB85-227049. National Technical Information Service, Springfield, VA.

Stumm, W. and J.J. Morgan. 1982. Aquatic chemistry. Wiley, New York, N. Y. pp. 176-177.

Tamulinus, S.H. 1979. The effects of antimony trioxide on channel catfish Ictalurus punctatus. Ph.D. thesis. Texas A & M University, Bryan, TX. University Microfilms, Ann Arbor, MI. Order No. 80-12005.

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

Telitchenko, M.M., G.V. Tsytsarin and Y.L. Shirokova. 1970. Trace elements and algal "bloom." Hydrobiol. J. (Engl. Transl. Gidrobiol Zh.) 6(6):1-6.

Thomas, W.H., J.T. Hollibaugh and D.L.R. Seibert. 1980a. Effects of heavy metals on the morphology of some marine phytoplankton. Phycologia 19:202-209.

Thomas. W.H., J.T. Hollibaugh, D.L.R. Seibert and G.T. Wallace, Jr. 1980b. Toxicity of a mixture of ten metals to phytoplankton. Mar. Ecol. Prog. Ser. 2:213-220.

Tong, S.S., W.D. Youngs, W.H. Gutenmann and D.J. Lisk. 1974. Trace metals in Lake Cayuga lake trout (Salvelinus namaycush) in relation to age. J. Fish. Res. Board Can. 31:238-239.

U.S. EPA. 1978. In-depth studies on health and environmental impacts of selected water pollutants. (Table of data available from Charles E. Stephan, U.S. EPA, Duluth, MN.)

U.S. EPA. 1980a. Ambient water quality criteria for antimony. EPA-440/5-80-020. National Technical Information Service, Springfield, VA.

U.S. EPA. 1980b. Water quality criteria documents. Federal Regist. 45:79318-79379. November 28.

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, VA.

U.S. EPA. 1983b. Water quality standards regulation. Federal Regist. 48:51400-51413. November 8.

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

U.S. EPA. 1985a. Appendix B - Response to public comments on "Guidelines for deriving numerical national water quality criteria for the protection of aquatic organisms and their uses." Federal Regist. 50:30793-30795. July 29.

U.S. EPA. 1985b. Water quality criteria. Federal Regist. 50:30784-30792. July 29.

U.S. EPA. 1985c. Technical support document for water quality-based toxics control. EPA-440/4-85-032 or PB86-150067. National Technical Information Service, Springfield, VA.

U.S. EPA. 1986. Chapter I - Stream design flow for steady-state modeling. In: Book VI - Design conditions. In: Technical guidance manual for performing waste load allocation. Office of Water, Washington, DC. August.

U.S. EPA. 1987. Permit writer's guide to water quality-based permitting for toxic pollutants. EPA-440/4-87-005. Office of Water, Washington, DC.

Uthe, J.F. and E.G. Bligh. 1971. Preliminary survey of heavy metal contamination of Canadian freshwater fish. J. Fish. Res. Board Can. 28:786-788.

Walz, F. 1979. Uptake and elimination of antimony in the mussel, Mytilus edulis. Veroff. Inst. Meersforsch. Bremerh. 18:203-215.

Wood, J.M. and H.K. Wang. 1985. Strategies for microbial resistance to heavy metals. In: Chemical processes in lakes. Stumm, W. (Ed.). John Wiley and Sons Publishers, New York. pp. 81-98.

Woodiwiss, F.S. and G. Fretwell. 1974. The toxicities of sewage effluents, industrial discharges and some chemical substances to brown trout (Salmo trutta) in the Trent River Authority Area. Water Pollut. Control 73:396-405.