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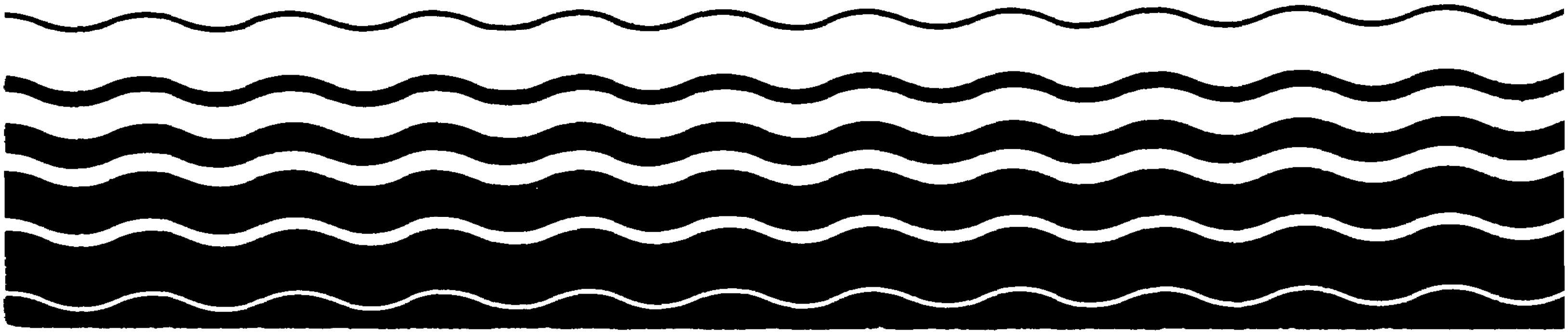

AMBIENT AQUATIC LIFE WATER QUALITY CRITERIA FOR
CHLORINE

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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*

Discharges of chlorine are common because it is used to disinfect effluents, to control fouling organisms in cooling water systems, and in industrial processes, particularly in the food and paper industries. These discharges may be quite toxic to aquatic organisms, but the complexity of the reactions of chlorine (Jolley and Carpenter, 1981, 1982) increases the difficulty of assessing the impact of chlorine. When chlorine is added to fresh water, the solution will usually contain two forms of free chlorine: hypochlorous acid (HOCl) and the hypochlorite ion (OCl^-). If the water contains ammonia, the solution will probably also contain two forms of combined chlorine: monochloramine and dichloramine. Because all four of these are quite toxic to aquatic organisms, the term "total residual chlorine" is used to refer to the sum of free chlorine and combined chlorine in fresh water. However, because salt water contains bromide, addition of chlorine also produces hypobromous acid (HOBr), hypobromous ion (OBr^-), and bromamines (Dove, 1970; Johnson, 1977; Macalady, et al. 1977; Sugam and Helz, 1977). The term "chlorine-produced oxidants" is used to refer to the sum of these oxidative products in salt water (Burton, 1977). Consequently, the freshwater and saltwater data herein will be expressed as total residual chlorine (TRC) and chlorine-produced oxidants (CPO), respectively, although both terms are intended to refer to the sum of free and combined chlorine and bromine as measured by the methods for "total residual chlorine" (U.S. EPA,

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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.

1983a). Chlorinated organic compounds resulting from aqueous chlorination are not addressed herein.

The complexity of the reactions of chlorine in fresh and salt water makes it important that studies of the effects of chlorine on aquatic organisms be appropriately designed and that concentrations of TRC or CPO be adequately measured. Because the half-lives of TRC and CPO are short in most waters, usually tests must be flow-through and the concentrations must be measured often enough to demonstrate that substantial reduction in concentration is not occurring. Also, the measurements must usually be performed using a method (e.g., amperometric, iodometric, or potentiometric titration, or DPD) that measures TRC or CPO and not just one or more components, such as free, but not combined, chlorine.

Numerous toxicity tests have been conducted using very short (i.e., less than 3-hour) exposures (e.g., Basch and Truchan, 1976; Brooks and Seegert, 1977a,b; Brooks, et al. 1982; Capuzzo, 1979a,b; Capuzzo, et al. 1976; Fandrei and Collins, 1979; Goldman and Davidson, 1977; Latimer, et al. 1975; Mattice, et al. 1981b; Stober, et al. 1980; Thomas, et al. 1980), intermittent exposures (Brooks and Seegert, 1977a,b; Thomas, et al. 1980), or triangular (increasing-decreasing) exposures (Heath, 1977; Trotter, et al. 1978) to simulate discharges that could result from specially controlled chlorination of cooling water systems. Although such data may be useful for modelling purposes (Murray, et al. 1984) and for making decisions concerning this particular application, results of such tests are not used herein for deriving water quality criteria. These criteria are intended to apply to situations of continuous exposure, whether the concentrations are fluctuating or constant, but not to situations of specially controlled intermittent exposures when more appropriate data are available. However, the effects of short exposures will probably be underestimated if the observation period is not extended to take into account delayed effects (Brooks and Seegert, 1977a; Latimer, et al. 1975).

The criteria presented herein supersede previous aquatic life water quality criteria for chlorine (U.S. EPA, 1976) 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

Toxicity of TRC to freshwater aquatic life is dependent on a variety of factors. Alkalinity did not affect toxicity in the single study conducted (Larson, et al. 1978), but almost all other factors studied did influence toxicity in this or other studies (e.g., Fandrei and Collins, 1979). The form of TRC (free versus combined) affects toxicity in short exposures of a few minutes to 4 hours (Beeton, et al. 1976; Mattice, et al. 1981b), but there are few data comparing the relative toxicities of the various components of TRC under continuous exposure for 48 or more hours. Merkens (1958) found that free chlorine was more toxic than combined chlorine. In addition, the 96-hr LC50s of some salmonid species are quite consistent between tests conducted in chlorinated sewage, in which chloramines predominated, and in clean water, in which there was a high proportion of free chlorine. It is possible that the toxicities of the various chemical forms of TRC are inherently different, but it is also possible that they only have different rates of toxicity. Thus, the differences in toxicity between components of TRC under very short exposure conditions (a few minutes to a few hours) could be rate dependent.

Temperature has been frequently demonstrated to affect TRC toxicity in very short tests simulating condenser cleaning operations. However, only a few 96-hr exposures have been conducted to evaluate the effect of temperature. Thatcher, et al. (1976) exposed juvenile brook trout to TRC at 10, 15 and 20 C. The 96-hr LC50s at 20 C were about one-third lower than those at 10 and 15 C. The bluegill and channel catfish were exposed to monochloramine at 20 and 30 C (Roseboom and Richey, 1977a,b). The bluegill, but not the channel catfish, was more sensitive at 30 C. Larson, et al. (1977b) exposed brook trout alevins, fry, and juveniles and the range of the five 96-hr LC50s was only 82 to 106 μg/L, indicating no large difference in sensitivities of these life stages. Even though many factors may occasionally affect TRC toxicity slightly, no pattern is consistent or great enough to justify criteria being dependent on any such factor.

In general, the rate of lethality due to TRC is rapid. Arthur, et al. (1975) published 1-, 4-, and 7-day LC50s for 7 species of freshwater fish in 5 different families. The mean 24-hr LC50 was only 1.4 times the 96-hr LC50; the mean 7-day LC50 was 0.87 of the 96-hr LC50. Other studies indicate that nearly half of the mortalities in a 96-hr exposure occur in the first 12 hours. Not only is the lethality rate rapid, the toxicity slope is steep. Lamperti (1976) observed that the lowest concentration of TRC causing 100 percent mortality of coho salmon was only about three times the highest concentration that did not kill any coho salmon. Mattice and Zittel (1976) derived a numerical relationship between 50 percent mortality and 0 percent mortality for 14 species. This relationship was $y = 0.37x$, where x is the time in minutes to yield 50 percent mortality and y is the maximum time in minutes which caused no mortality. For 30-min exposures Brooks and Seegert (1977a) observed a ratio of about 0.65 between the concentrations causing 50 percent mortality and concentrations causing no mortality for both yellow perch and rainbow trout. They recommended 0.5 of the LC50 as an estimate of non-lethal concentrations for short exposure periods.

There is a wide range in relative sensitivities among freshwater invertebrate species; a crayfish, stonefly, and amphipod had Species Mean Acute Values from 266 and 673 μg/L, whereas those for two gastropods, two copepods, and _Daphnia magna_ ranged from 27 to 80 μg/L. Ward, et al. (1976) and Ward and DeGrave (1980) reported acute values of 17 μg/L and 45 μg/L, respectively, for _Daphnia magna_. In addition, Ward, et al. (1976) summarized the results of a test from which an LC50 could not be calculated; they observed 100 percent mortality of 3-day-old _Daphnia magna_ in 10.5 hours at 70 μg/L. Arthur, et al. (1975) presented 7-day survival data from their two chronic tests with _Daphnia magna_ (Table 4). One 7-day LC50 was 2 μg/L and the other was between 4 and 14 μg/L during those tests in which the organisms were fed. Together, these data consistently indicate that _Daphnia magna_ is the most sensitive tested species to TRC.

Freshwater fishes demonstrated about the same range of sensitivities as the invertebrates. A darter and a stickleback had LC50s of 390 μg/L and 710 μg/L, respectively, whereas acute values for two trouts, two shiners, and the channel catfish were between 45 μg/L and 90 μg/L.

Acceptable acute values are available for freshwater fish and invertebrate species in 28 genera (Tables 1 and 3). Acute values are available for more than one species in each of three genera, and the range of Species Mean Acute Values within each genus is less than a factor of 4. The freshwater Final Acute Value of 38.32 µg/L was calculated from the Genus Mean Acute Values (Table 3) using the procedure described in the Guidelines. The acute value of 27.66 µg/L for the genus Daphnia is lower than the Final Acute Value.

It appears that saltwater species are more sensitive to CPO when simultaneously subjected to thermal stress. This trend has been observed for saltwater invertebrate species (Capuzzo, 1979b; Capuzzo, et al. 1976, 1977a; Gibson, et al. 1976; Goldman, et al. 1978) and fishes (Capuzzo, et al. 1977b; Goldman, et al. 1978; Stober, et al. 1980). Moreover, saltwater invertebrate species are more sensitive to CPO resulting from combined chlorine (chloramine) than free chlorine (sodium hypochlorite); the opposite is true for fishes (Capuzzo, 1979a,b; Capuzzo, et al. 1977b; Goldman, et al. 1978).

Acute toxicity values are available for a variety of saltwater invertebrate species (Table 1). Adult blue crabs were relatively insensitive to CPO with LC50s ranging from 700 to 860 µg/L (Laird and Roberts, 1980; Vreenegoor, et al. 1977). A mixture of two species of shore crabs was also insensitive with an LC50 of 1,418 µg/L (Thatcher, 1978). Several other invertebrate species including amphipods, hermit crabs, and shrimp showed intermediate sensitivities to CPO with LC50s ranging from 90 to 687 µg/L (Thatcher, 1978). In contrast, larvae of the eastern oyster and a saltwater copepod were very sensitive (Roberts and Gleeson, 1978); the respective Species Mean Acute Values were 26 and 29 µg/L.

The eleven species of saltwater fish had acute values ranging from 37 to 270 µg/L. The coho salmon (with a Species Mean Acute Value of 47 µg/L), the tidewater silverside (54 µg/L), and the Atlantic silverside (37 µg/L) were especially sensitive to CPO (Buckley, 1976; Goodman, et al. 1983; Roberts, et al. 1975; Thatcher, 1978).

Twenty-one Genus Mean Acute Values are available for saltwater organisms (Table 3). Acute values are available for more than one species in each of two genera and the range of Species Mean Acute Values within each genus is less than a factor of 2.2. The most sensitive genus, Crassostrea, is 54 times more sensitive than the most resistant, Hemigrapsus. Nine of the eleven most resistant genera are invertebrates. In contrast, seven of the ten most sensitive genera are fishes. The four most sensitive genera include such economically and ecologically important species as the coho salmon, tidewater silverside, Atlantic silverside, Acartia tonsa, and eastern oyster. These data result in a saltwater Final Acute Value of 25.24 µg/L (Table 3).

Chronic Toxicity to Aquatic Animals

Life-cycle tests have been conducted with two freshwater invertebrate species and one freshwater fish species. Arthur, et al. (1975) conducted two 2-week tests beginning with 16- to 24-hr-old Daphnia magna. Flow-through tests were conducted with nominal sewage concentrations of 1.2 to 20 percent; untreated Lake Superior water was the dilution water. The secondary sewage was chlorinated just before entering the diluter systems, and the probable predominant form of TRC was monochloramine. The TRC concentrations ranged from control to 114 µg/L in one test and control to 136 µg/L in the second. Daphnids did not survive the 2-week exposure to the three highest chlorinated effluent concentrations (14 to 114 µg/L in the first test and 7 to 136 µg/L in the second). Daphnids that survived to adulthood reproduced successfully. In the first test, therefore, the lowest unacceptable concentration was 14 µg/L and the highest acceptable concentration was 4 ug/L, resulting in a chronic value of 7.483 µg/L for that test (Table 2).

The results of the second test are more difficult to interpret. At the test concentration of 7 µg/L, all daphnids died in seven days in both test chambers. At the next lower concentration of 2 µg/L, all daphnids died in one test chamber in seven days, but 50 percent of the daphnids in the duplicate chamber survived and reproduced successfully. Two of the four controls from both tests had survival as low as 70 percent. Based on the probable comparability of test procedures, the total mortality in one test chamber at 2 µg/L will be considered an anomaly, and that concentration will be considered to be the highest acceptable concentration in the second test. This results in a chronic value of 3.742 µg/L for that test (Table 2).

Arthur, et al. (1975) also conducted a life-cycle test with the amphipod, *Gammarus pseudolimnaeus*, in chlorinated secondary sewage effluent. No test animals survived in either test chamber at a TRC concentration of 123 µg/L. Survival after 16 weeks of the test was reduced at 54 µg/L. The number of spawns per female was significantly reduced at a TRC concentration of 19 µg/L, the lowest unacceptable concentration. The highest acceptable concentration was 12 µg/L, resulting in a chronic value of 15.10 µg/L (Table 2). Earlier, Arthur and Eaton (1971) conducted a life-cycle test on TRC with *Gammarus pseudolimnaeus*. Amphipods were exposed for 15 weeks to Lake Superior water to which both ammonia and free chlorine had been added to provide TRC concentrations from control to 163 µg/L. Adult survival was markedly less at concentrations of 35 µg/L and higher, and no young were produced by the survivors. The number of young per female at TRC concentrations of 3.4 and 16 µg/L was only about one-tenth of the duplicate control values of 27.8 and 21.0 young per female. In the absence of an acceptable TRC concentration, the chronic value must be less than the lowest test concentration of 3.4 µg/L. No explanation can be given for the difference in results between the two life-cycle tests. Both were conducted in the same laboratory with the same dilution water by basically the same group of researchers, and chloramines were the dominant components of TRC in both tests.

Fathead minnow life-cycle tests were conducted by both Arthur and Eaton (1971) and Arthur, et al. (1975), and the two tests produced comparable results (Table 2). Arthur and Eaton (1971) began their test with 3-month-old juveniles under conditions of constant temperature (23 ± 1 C) and photoperiod (16 hr of light per day). Test fish were exposed for 21 weeks to chloramine concentrations in tap water from control to 154 µg/L for the adult fish and control to 212 µg/L for their progeny. Only one spawning occurred in the duplicate chambers at 85 µg/L. The number of spawnings per female was significantly reduced at 43 µg/L and fewer eggs were produced per female at this concentration. No toxicant related effects were observed on embryo incubation or hatching, and no reductions in growth or survival of the progeny were observed during the 30-day exposure. Consequently, the chronic value for this test is the geometric mean (26.22 µg/L) of the upper (43 µg/L) and the lower (16 µg/L) chronic limits (Table 2).

No spawning occurred at 100 µg/L in the fathead minnow life-cycle test conducted by Arthur, et al. (1975). As with the amphipod and *Daphnia magna*, this test was conducted with secondary sewage effluent that was chlorinated just before entering the test system. The exposure began with 1- to 20-day-old larvae. No spawning differences were observed at TRC concentrations up to and including 42 µg/L. Mortality of adults during the 43-week exposure at 24 C was significantly increased at 42 and 110 µg/L. No adverse effect on the adults was observed at a concentration of 14 µg/L. In a different test system several exposures of progeny at each concentration demonstrated reduced survival at a mean concentration of 21 µg/L. No growth or survival effects on the progeny were observed at a TRC concentration of 6 µg/L. Unlike the life-cycle test conducted by Arthur and Eaton (1971), the progeny were more sensitive. Progeny survival was reduced at 21 µg/L. No adverse effects on adults were observed at 14 µg/L, but since no progeny were exposed at that TRC concentration, it cannot be assumed that there would not have been an effect on the progeny. Consequently, the lower chronic limit for the total test would be 6 µg/L, where no progeny effects were observed. The chronic value for this test is, therefore, 11.22 µg/L (Table 2).

Embryos and young of the tidewater silverside, Menidia peninsulae, were exposed continuously to CPO in a 28-day early life-stage test (Goodman, et al. 1983) at a salinity of 15 to 22 g/kg and a temperature of 25 ± 2 C. CPO concentrations were measured using amperometric titration. Although 200 µg/L had no effect on hatching success of the embryos, all fry died at this concentration. At the next lower concentration of 40 µg/L, the exposed fish weighed 10 percent less than the control fish, but the difference was not statistically significant. In a related acute toxicity test, the 96-hr LC50 was 54 µg/L (Goodman, et al. 1983), which will be used as the upper limit on the chronic value. The chronic value for this species is 46.48 µg/L and the acute-chronic ratio is 1.162 (Table 2).

The species mean acute-chronic ratios of two of the more sensitive freshwater species and the one sensitive saltwater species are all between 1.0 and 6.2 (Table 3). The ratio for the more resistant scud is greater than 37. Thus it seems reasonable to calculate the Final Acute-Chronic Ratio as the geometric mean of the three lower ratios, resulting in a value of 3.345. The resulting freshwater and saltwater Final Chronic Values are 11.46 µg/L and 7.546 µg/L, respectively (Table 3). All three freshwater species with which chronic tests have been conducted have at least one chronic value below the freshwater Final Chronic Value.

Toxicity to Aquatic Plants

Numerous studies (e.g., Betzer and Kott, 1969; Brook and Baker, 1972; Murray, 1980; Schmager, 1979; Toetz, et al. 1977) have been conducted on the effects of TRC on morphology, growth, biomass (in terms of chlorophyll a and/or phaeophyton a), photosynthesis, trophic state, respiration, ammonia or nitrate uptake, and community structure of algae. In most of these studies the exposures were of short duration and in most the concentration of TRC was not adequately measured. Such studies do indicate, however, that exposure in fresh water to mean TRC concentrations of 1,000 µg/L or less for periods of one hour or less can reduce survival and inhibit physiological processes. Although there are substantial interspecies differences, diatoms tend to be more sensitive than green algae, which are generally more sensitive than blue-green algae. After an initial effect of a short exposure to TRC, algal growth and photosynthesis often recover to control levels.

In the study of Brooks and Seegert (1977b) phytoplankton were exposed for 30 minutes under static conditions. TRC analyses at the beginnings and endings of the exposures indicated that the exposures were predominantly to free chlorine and that the concentrations did not decline significantly. Studies were conducted in each of the four seasons by exposing natural phytoplankton communities from Lake Michigan and comparing their chlorophyll a and phaeophyton a contents and ^{14}C uptake rates with those for the controls for each of the four seasons (Table 4). The EC50s based on ^{14}C uptake ranged from 160 to 760 μg/L.

Continuous exposure of Eurasian watermilfoil, Myriophyllum spicatum, to a concentration of 50 μg TRC/L resulted in significant reductions in weight gain of shoots and of the total plant, but not in dry weight of the root or the chlorphyll a index (Table 4). Watkins and Hammerschlag (1984) concluded that the impact of TRC on vascular aquatic plants appears to be subtle and would likely occur only in conjunction with other environmental stresses.

Several studies have been conducted to determine the effect of brief exposure to CPO on natural assemblages or single species of saltwater phytoplankton. As was true in fresh water, most of these studies were designed to simulate the effects of power plant entrainment and most included simultaneous exposure to temperature change as a part of the experimental design. Effects were determined by measurement of parameters such as growth rate, generation time, ATP activity, ^{14}C uptake, and biomass. In general, brief exposure to CPO did not cause substantial long-term damage to phytoplankton. Goldman and Quinby (1979) measured delays in attainment of peak ATP after 2- to 3-hr exposures of natural phytoplankton assemblages to 20 to 80 μg CPO/L in combination with an increase in temperature of 10 to 17.5 C; several of their individual observations are summarized in Table 4. No change was found in species composition between samples taken before and after chlorination. They concluded that entrained phytoplankton subjected to temperature stress and CPO recovered and that there was no prolonged effect on growth rates of natural populations. However, Sanders and Ryther (1980) observed that continuous chlorination at measured concentrations of 50 to 150 µg/L resulted in shifts in species composition of phytoplankton communities (Table 4), suggesting that chlorination could have detrimental effects, especially in areas with restricted flow.

Bioaccumulation

No freshwater or saltwater data on the bioconcentration of TRC or CPO were found, or expected.

Other Data

Most of the freshwater data in Table 4 have been discussed previously. The most important generalities that can be drawn from these additional data are that a variety of lethal and sublethal effects can occur at concentrations that are not too much higher than the calculated criteria. For example, the 24-hr LC50 for a rotifer is 13 µg/L (Grossnickle, 1974). In addition, Larson, et al. (1977a) observed a decrease in growth rate of juvenile coho salmon at a TRC concentration of 11 µg/L for 21 days, and the 21-week LC10 for the fathead minnow is 43 µg/L (Arthur and Eaton, 1971).

The 96-hr LC50s for the crayfish, Orconectes nais, ranged from 470 to 960 µg/L (Table 1), but Larson, et al. (1978) reported a 365-day LC50 of 31 µg/L (Table 4) for a different crayfish, Pacifastacus trowbridgii. Larson, et al. (1978) observed that chronic mortality was related to the periods of molting, which, apparently, are quite sensitive to TRC. Typically, a 96-hr exposure would not incorporate the molting cycle for crayfish.

Two studies have characterized fish populations below chlorinated sewage outfalls. Seegert (1979) studied streams in the Upper Passaic River Basin in New Jersey above and below 11 wastewater treatment plants. He observed fish only where TRC concentrations were equal to or less than 100 µg/L. Tsai (1973) conducted comparative studies of water quality on fish species diversity in streams above and below 149 chlorinated secondary sewage treatment plants. None of 45 fish species was observed at TRC concentrations above approximately 400 µg/L. Ten species, mostly salmonids and cyprinids, were not found at concentrations above 40 µg/L (Table 4).

The sensitivity ranking of genera in Tsai's (1973) study was compared with Genus Mean Acute Values (Table 3). Estimates were made from Figure 8 (Tsai, 1973) of the concentrations above which each of 45 species of fish avoided TRC. The species data were then combined as to genus and mean avoidance concentrations were calculated for the 10 genera for which data were available. Twenty-three of the 45 species in the avoidance list were represented in the 10 genera. A correlation coefficient of 0.40 was obtained for all the data. One potential outlier was the genus Etheostoma. If the data for this genus are not used, the correlation coefficient for the other nine genera is 0.74. Considering the very different sources of the data, the coefficient is quite good, implying that the genus sensitivity ranking is similar for field-observed avoidance and laboratory-derived LC50s.

Other saltwater data summarized in Table 4 provide an overview of various effects of CPO on invertebrates and fishes. Several 30-min exposures to CPO, resulting from free chlorine (sodium hypochlorite) or combined chlorine (chloramines), have been conducted with rotifers and the eastern oyster. These tests indicated that rotifers were more sensitive to combined chlorine (LC50 of 20 µg/L) than free chlorine (LC50 of 180 µg/L). When a 5 C increase in temperature was added, respective LC50s for combined and free chlorine decreased to 10 µg/L and 90 µg/L (Capuzzo, 1979b). A similar trend was noted in tests conducted by Capuzzo (1979a) with larval eastern oysters. Larvae were very sensitive to CPO applied as combined chlorine; the 30-min LC50 was 10 µg/L. When a 5 C increase in temperature was added, the LC50 was less than 10 µg/L. Larvae were considerably more resistant to free chlorine, with 30-min LC50s of 120 µg/L (delta t of 0 C) and 80 µg/L (delta t of 5 C).

Roberts, et al. (1975) and Roberts and Gleeson (1978) demonstrated that copepods were sensitive to CPO in flow-through tests. The 24- and 48-hr LC50s ranged from 50 µg/L to 29 µg/L (Table 4). Capuzzo (1979a) found that copepods were not very sensitive to CPO in short-term toxicity tests. However, the trend of greater sensitivity to combined chlorine (chloramines) was apparent. The same trend was noted by Goldman, et al. (1978) in tests with American lobster larvae. The 60-min LC50 for free chlorine was 3,950 µg/L; in contrast, combined chlorine resulted in a LC50 of 1,300 µg/L.

Sand dollar sperm proved to be very sensitive to CPO (Table 4). Exposure of sperm to a concentration of 2 µg/L for 5 minutes resulted in a 50 percent reduction in egg fertilization (Dinnel, et al. 1981).

Several studies with commercially important saltwater fishes have demonstrated toxicological and behavioral effects at low CPO concentrations. For example, striped bass larvae had 48-hr LC50s ranging from 40 to 70 µg CPO/L (Middaugh, et al. 1977a). Juvenile spot showed a temperature dependent avoidance of CPO; at 10 C a concentration of 180 µg/L resulted in consistent avoidance whereas 50 µg/L was avoided at 15 C (Middaugh, et al. 1977b). Absence or presence of food also has been shown to influence the avoidance of

CPO by fish. Blacksmith avoided 162 µg/L in the absence of food. However, a concentration of 203 µg/L was required to elicit avoidance when food was present. Moreover, a concentration of 327 µg CPO/L was needed to cause total avoidance by blacksmith which had been starved for 24 hours prior to tests in which food was present. Fish fed to satiation prior to exposure to CPO avoided 175 µg/L (Hose and Stoffel, 1980).

Unused Data

Some data on the effects of chlorine on aquatic organisms were not used because the studies were conducted with species that are not resident in North America. In addition, much of the available information on the effects of chlorine on aquatic animals and plants is concerned with the control of nuisance species in ponds, reservoirs, and cooling towers (e.g., Courchene and Chapman, 1975; Mangum and McIlhenny, 1975; Mattice, et al. 1981a), and is not useful for deriving water quality criteria. Brungs (1973, 1976) and Hall, et al. (1981) only present data that have been published elsewhere.

Because of the short half-life of TRC and CPO in most waters, results were not used if the test concentrations were not measured (e.g., Bringmann and Kuhn, 1959; Brook and Baker, 1972; Cole, 1978; Kaniewska-Prus, 1982; Marking, et al. 1984; Osborne, 1982) or were not measured often enough or did not demonstrate that the concentrations were nearly uniform during the exposure (e.g., Cairns, et al. 1978; Heath, 1977; Servizi and Martens, 1974; Videau, et al. 1979).

Also, results were not used if the analytical method measured only free chlorine rather than TRC or CPO (e.g., Betzer and Kott, 1969; Carpenter, et al. 1972; Learner and Edwards, 1963; Stober and Hanson, 1974) or if the analytical method used was not identified (e.g., Arora, et al. 1970; Bills, et al. 1977; Davies and Jensen, 1975; James, 1967). Too few test organisms were used in some tests (Scheuring and Stetter, 1951), and some tests did not provide clearly defined endpoints (Mitchell and Cech, 1983).

Summary

Thirty-three freshwater species in 28 genera have been exposed to TRC and the acute values range from 28 μg/L for *Daphnia magna* to 710 μg/L for the threespine stickleback. Fish and invertebrate species had similar ranges of sensitivity. Freshwater chronic tests have been conducted with two invertebrate and one fish species, and the chronic values for these 3 species ranged from less than 3.4 to 26 μg/L, with acute-chronic ratios from 3.7 to greater than 78.

The acute sensitivities of 24 species of saltwater animals in 21 genera have been determined for CPO, and the LC50s range from 26 μg/L for the eastern oyster to 1,418 μg/L for a mixture of two shore crab species. This range is very similar to that observed with freshwater species, and fish and invertebrate species had similar sensitivities. Only one chronic test has been conducted with a saltwater species, *Menidia peninsulae*, and in this test the acute-chronic ratio was 1.162.

The available data indicate that aquatic plants are more resistant to chlorine than fish and invertebrate species.

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 total residual chlorine does not exceed 11 μg/L more than once every three years on the average and if the one-hour average concentration does not exceed 19 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 chlorine-produced oxidants does not exceed 7.5 μg/L more than once every three years on the average and if the one-hour average concentration does not exceed 13 μg/L more than once every three years on the average.

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 chlorine 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 Chlorine to Aquatic Animals

Species	Method*	LC50 or EC50 (μg/L)**	Species Mean Acute Value (μg/L)**	Reference
		FRESHWATER SPECIES		
Snail (adult), *Goniobasis virginica*	FT, M	110	-	Gregg, 1975
Snail (adult), *Goniobasis virginica*	FT, M	44	69.57	Gregg, 1975
Snail (adult), *Nitocris carinata*	FT, M	141	-	Gregg, 1975
Snail (adult), *Nitocris carinata*	FT, M	86	-	Gregg, 1975
Snail (adult), *Nitocris carinata*	FT, M	42	79.86	Gregg, 1975
Snail (adult), *Physa heterostropha*	FT, M	258	-	Gregg, 1975
Snail (adult), *Physa heterostropha*	FT, M	221	238.8	Gregg, 1975
Cladoceran (1-day-old), *Daphnia magna*	FT, M	17	-	Ward, et al. 1976; Ward & DeGraeve, 1978
Cladoceran (1-day-old), *Daphnia magna*	FT, M	45	27.66	Ward & DeGraeve, 1980
Copepod, *Epischura lacustris*	FT, M	63	63	Ward & DeGraeve, 1980
Copepod, *Cyclops bicuspidatus*	FT, M	84	-	Beeton, et al. 1976
Copepod, *Cyclops bicuspidatus*	FT, M	69	76.13	Beeton, et al. 1976
Isopod, *Caecidotea bicrenata*	FT, M	147.5***	147.5	Bosnak & Morgan, 1981
Isopod, *Lirceus alabamae*	FT, M	150***	150	Bosnak & Morgan, 1981

Table 1. (Continued)

Species	Method*	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)**	Reference
Amphipod, *Gammarus pseudolimnaeus*	FT, M	330	-	Arthur, et al. 1975
Amphipod, *Gammarus pseudolimnaeus*	FT, M	215	266.4	Arthur, et al. 1975
Crayfish (adult), *Orconectes nais*	FT, M	960	-	Ludwig, 1979
Crayfish (adult), *Orconectes nais*	FT, M	472	673.1	Hazel, et al. 1979
Mayfly (nymph), *Stenonema ithaca*	FT, M	102	102	Gregg, 1975
Stonefly (nymph), *Pteronarcys* sp.	FT, M	400	400	Arthur, et al. 1975
Coho salmon, *Oncorhynchus kisutch*	FT, M	102	-	Arthur, et al. 1975
Coho salmon (fry), *Oncorhynchus kisutch*	FT, M	69	-	Lamperti, 1976
Coho salmon (juvenile), *Oncorhynchus kisutch*	FT, M	57	-	Lamperti, 1976
Coho salmon (juvenile), *Oncorhynchus kisutch*	FT, M	62	-	Lamperti, 1976
Coho salmon (juvenile), *Oncorhynchus kisutch*	FT, M	72	-	Lamperti, 1976
Coho salmon (juvenile), *Oncorhynchus kisutch*	FT, M	64	-	Lamperti, 1976
Coho salmon (juvenile), *Oncorhynchus kisutch*	FT, M	72	-	Lamperti, 1976
Coho salmon (juvenile), *Oncorhynchus kisutch*	FT, M	74	-	Lamperti, 1976

Table 1. (Continued)

Species	Method*	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)**	Reference
Coho salmon (juvenile), *Oncorhynchus kisutch*	FT, M	82	-	Lamperti, 1976
Coho salmon (juvenile), *Oncorhynchus kisutch*	FT, M	82	-	Lamperti, 1976
Coho salmon (juvenile), *Oncorhynchus kisutch*	FT, M	81	-	Lamperti, 1976
Coho salmon (juvenile), *Oncorhynchus kisutch*	FT, M	71	-	Lamperti, 1976
Coho salmon (juvenile), *Oncorhynchus kisutch*	FT, M	59	-	Ward, et al. 1976; Ward & DeGraeve, 1978
Coho salmon, *Oncorhynchus kisutch*	FT, M	123	74.79	Rosenberger, 1972
Cutthroat trout (juvenile), *Salmo clarki*	FT, M	75	-	Larson, et al. 1978
Cutthroat trout (juvenile), *Salmo clarki*	FT, M	82	-	Larson, et al. 1978
Cutthroat trout (juvenile), *Salmo clarki*	FT, M	83	-	Larson, et al. 1978
Cutthroat trout (juvenile), *Salmo clarki*	FT, M	95	-	Larson, et al. 1978
Cutthroat trout (juvenile), *Salmo clarki*	FT, M	94	85.46	Larson, et al. 1978
Rainbow trout, *Salmo gairdneri*	FT, M	110****	-	Merkens, 1958

Table 1. (Continued)

Species	Method*	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)**	Reference
Rainbow trout (sac fry), *Salmo gairdneri*	FT, M	52	-	Wolf, et al. 1975
Rainbow trout (fry), *Salmo gairdneri*	FT, M	47	-	Wolf, et al. 1975
Rainbow trout (fry), *Salmo gairdneri*	FT, M	40	-	Wolf, et al. 1975
Rainbow trout (fry), *Salmo gairdneri*	FT, M	84	-	Wolf, et al. 1975
Rainbow trout (fry), *Salmo gairdneri*	FT, M	56	-	Wolf, et al. 1975
Rainbow trout (juvenile), *Salmo gairdneri*	FT, M	69	61.92	Ward, et al. 1976; Ward & DeGraeve, 1978
Brook trout (sac fry), *Salvelinus fontinalis*	FT, M	65	-	Wolf, et al. 1975
Brook trout (sac fry), *Salvelinus fontinalis*	FT, M	90	-	Wolf, et al. 1975
Brook trout (sac fry), *Salvelinus fontinalis*	FT, M	85	-	Wolf, et al. 1975
Brook trout (fry), *Salvelinus fontinalis*	FT, M	60	-	Wolf, et al. 1975
Brook trout (juvenile), *Salvelinus fontinalis*	FT, M	133	-	Wolf, et al. 1975
Brook trout (juvenile), *Salvelinus fontinalis*	FT, M	135	-	Wolf, et al. 1975
Brook trout (juvenile), *Salvelinus fontinalis*	FT, M	175	-	Wolf, et al. 1975
Brook trout (juvenile), *Salvelinus fontinalis*	FT, M	130	-	Thatcher, et al. 1976

Table 1. (Continued)

Species	Method*	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)**	Reference
Brook trout (juvenile), Salvelinus fontinalis	FT, M	146	-	Thatcher, et al. 1976
Brook trout (juvenile), Salvelinus fontinalis	FT, M	179	-	Thatcher, et al. 1976
Brook trout (juvenile), Salvelinus fontinalis	FT, M	146	-	Thatcher, et al. 1976
Brook trout (juvenile), Salvelinus fontinalis	FT, M	163	-	Thatcher, et al. 1976
Brook trout (juvenile), Salvelinus fontinalis	FT, M	160	-	Thatcher, et al. 1976
Brook trout (juvenile), Salvelinus fontinalis	FT, M	150	-	Thatcher, et al. 1976
Brook trout (juvenile), Salvelinus fontinalis	FT, M	146	-	Thatcher, et al. 1976
Brook trout (juvenile), Salvelinus fontinalis	FT, M	150	-	Thatcher, et al. 1976
Brook trout (juvenile), Salvelinus fontinalis	FT, M	131	-	Thatcher, et al. 1976
Brook trout (juvenile), Salvelinus fontinalis	FT, M	107	-	Thatcher, et al. 1976
Brook trout (juvenile), Salvelinus fontinalis	FT, M	115	-	Thatcher, et al. 1976
Brook trout (alevin), Salvelinus fontinalis	FT, M	106	-	Larson, et al. 1977b
Brook trout (alevin), Salvelinus fontinalis	FT, M	91	-	Larson, et al. 1977b
Brook trout (fry), Salvelinus fontinalis	FT, M	82	-	Larson, et al. 1977b

Table 1. (Continued)

Species	Method*	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)**	Reference
Brook trout (juvenile), *Salvelinus fontinalis*	FT, M	91	-	Larson, et al. 1977b
Brook trout (juvenile), *Salvelinus fontinalis*	FT, M	102	-	Thatcher, et al. 1976
Brook trout (juvenile), *Salvelinus fontinalis*	FT, M	88	-	Larson, et al. 1977b
Brook trout (juvenile), *Salvelinus fontinalis*	FT, M	135	-	Nolan & Johnson, 1977
Brook trout (juvenile), *Salvelinus fontinalis*	FT, M	135	117.4	Arthur, et al. 1975
Lake trout (juvenile), *Salvelinus namaycush*	FT, M	60	60	Ward, et al. 1976; Ward & DeGraeve, 1978
Goldfish (adult), *Carassius auratus*	FT, M	153	-	Ward, et al. 1976; Ward & DeGraeve, 1978
Goldfish (adult), *Carassius auratus*	FT, M	210	-	Ward, et al. 1976; Ward & DeGraeve, 1978
Goldfish, *Carassius auratus*	FT, M	350	224.0	Tsai & McKee, 1980
Golden shiner (adult), *Notemigonus crysoleucas*	FT, M	40	-	Ward, et al. 1976; Ward & DeGraeve, 1978
Golden shiner, *Notemigonus crysoleucas*	FT, M	180	-	Finlayson & Hansen, 1979
Golden shiner, *Notemigonus crysoleucas*	FT, M	190	-	Esvelt, et al. 1971
Golden shiner, *Notemigonus crysoleucas*	FT, M	190	127.0	Stone, et al. 1973
Pugnose shiner (adult), *Notropis anogenus*	FT, M	45	45	Ward, et al. 1976; Ward & DeGraeve, 1978

Table 1. (Continued)

Species	Method*	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)**	Reference
Common shiner (adult), *Notropis cornutus*	FT, M	51	51	Ward, et al. 1976; Ward & DeGraeve, 1978
Red shiner, *Notropis lutrensis*	FT, M	169	169	Hazel, et al. 1979
Fathead minnow, *Pimephales promelas*	FT, M	130	-	Arthur, et al. 1975
Fathead minnow, *Pimephales promelas*	FT, M	86	-	Arthur, et al. 1975
Fathead minnow, *Pimephales promelas*	FT, M	130	-	Finlayson & Hansen, 1979
Fathead minnow (adult), *Pimephales promelas*	FT, M	95	-	Ward, et al. 1976; Ward & DeGraeve, 1978
Fathead minnow (adult), *Pimephales promelas*	FT, M	82	-	Ward, et al. 1976; Ward & DeGraeve,1978
Fathead minnow (adult), *Pimephales promelas*	FT, M	120	105.2	Ward & DeGraeve, 1980
White sucker, *Catostomus commersoni*	FT, M	138	138	Arthur, et al. 1975
Channel catfish, *Ictalurus punctatus*	FT, M	90	-	Roseboom & Richey, 1977a,b
Channel catfish, *Ictalurus punctatus*	FT, M	90	90	Roseboom & Richey, 1977a,b
Threespine stickleback, *Gasterosteus aculeatus*	FT, M	710	710	Esvelt, et al. 1971
Bluegill, *Lepomis macrochirus*	FT, M	330	-	Roseboom & Richey, 1977a,b
Bluegill, *Lepomis macrochirus*	FT, M	250	-	Roseboom & Richey, 1977a,b

Table 1. (Continued)

Species	Method*	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)**	Reference
Bluegill, *Lepomis macrochirus*	FT, M	180	245.8	Roseboom & Richey, 1977a,b
Sunfish, *Lepomis* sp.	FT, M	278	-	Ward, et al. 1976; Ward & DeGraeve, 1978
Sunfish, *Lepomis* sp.	FT, M	195	232.8†	Ward, et al. 1976; Ward & DeGraeve, 1978
Largemouth bass, *Micropterus salmoides*	FT, M	295	-	Arthur, et al. 1975
Largemouth bass (juvenile), *Micropterus salmoides*	FT, M	241	266.6	Ward, et al. 1976; Ward & DeGraeve, 1978
Crappie, *Pomoxis* sp.	FT, M	127	127†	Ward, et al. 1976; Ward & DeGraeve, 1978
Orangethroat darter, *Etheostoma spectabile*	FT, M	390	390	Ludwig, 1979
Yellow perch, *Perca flavescens*	FT, M	205	205	Arthur, et al. 1975
Walleye, *Stizostedion vitreum vitreum*	FT, M	150	-	Arthur, et al. 1975
Walleye, *Stizostedion vitreum vitreum*	FT, M	108	127.3	Ward, et al. 1976; Ward & DeGraeve, 1978
		SALTWATER SPECIES		
Eastern oyster (larva), *Crassostrea virginica*	FT, M	26	26	Roberts & Gleeson, 1978
Copepod, *Acartia tonsa*	FT, M	29	29	Roberts & Gleeson, 1978

Table 1. (Continued)

Species	Method*	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)**	Reference
Mysid, Neomysis sp.	FT, M	162	162	Thatcher, 1978
Amphipod, Pontogeneia sp.	FT, M	687	687	Thatcher, 1978
Amphipod, Anonyx sp.	FT, M	145	145	Thatcher, 1978
Grass shrimp, Palaemonetes pugio	FT, M	220	220	Roberts, et al. 1975
Coon stripe shrimp, Pandalus danae	FT, M	210	-	Gibson, et al. 1976
Coon stripe shrimp, Pandalus danae	FT, M	295	-	Gibson, et al. 1976
Coon stripe shrimp, Pandalus danae	FT, M	178	-	Gibson, et al. 1976
Coon stripe shrimp, Pandalus danae	FT, M	133	-	Gibson, et al. 1976
Coon stripe shrimp, Pandalus danae	FT, M	178	192.0	Thatcher, 1978
Shrimp, Pandalus goniurus	FT, M	90	90	Thatcher, 1978
Shrimp, Crangon nigricauda	FT, M	134	134	Thatcher, 1978
Hermit crab (larva), Pagurus longicarpus	FT, M	102	-	Roberts, 1978
Hermit crab (larva), Pagurus longicarpus	FT, M	211	146.7	Roberts, 1978
Blue crab, Callinectes sapidus	FT, M	700	-	Vreenegoor, et al. 1977

Table 1. (Continued)

Species	Method*	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)**	Reference
Blue crab (adult male), *Callinectes sapidus*	FT, M	840	-	Laird & Roberts, 1980
Blue crab (adult female), *Callinectes sapidus*	FT, M	860	796.7	Laird & Roberts, 1980
Shore crab, *Hemigrapsus nudus* and *H. oregonensis*	FT, M	1,418	1,418†	Thatcher, 1978
Pacific herring (juvenile), *Clupea harengus pallasi*	FT, M	65	65	Thatcher, 1978
Coho salmon, *Oncorhynchus kisutch*	FT, M	70	-	Buckley, 1976
Coho salmon (juvenile), *Oncorhynchus kisutch*	FT, M	32	47.33	Thatcher, 1978
Atlantic silverside, *Menidia menidia*	FT, M	37	37	Roberts, et al. 1975
Tidewater silverside (juvenile), *Menidia peninsulae*	FT, M	54	54	Goodman, et al. 1983
Threespine stickleback, *Gasterosteus aculeatus*	FT, M	167	167	Thatcher, 1978
Northern pipefish, *Syngnathus fuscus*	FT, M	270	270	Roberts, et al. 1975
Spot, *Leiostomus xanthurus*	FT, M	90	90	Bellanca & Bailey, 1977
Shiner perch (juvenile and adult), *Cymatogaster aggregata*	FT, M	71	71	Thatcher, 1978

Table 1. (Continued)

Species	Method*	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)**	Reference
Pacific sand lance (juvenile and adult), Ammodytes hexapterus	FT, M	82	82	Thatcher, 1978
Naked goby (juvenile), Gobiosoma bosci	FT, M	80	80	Roberts, et al. 1975
English sole (juvenile), Parophrys vetulus	FT, M	73	73	Thatcher, 1978

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* FT = flow-through, M = measured.

** Results are expressed as total residual chlorine for freshwater species and chlorine-produced oxidants for saltwater species.

*** Average of values calculated using two different methods.

****96-hr LC50 was obtained by interpolation from Figure 4 in Merkens (1958).

† A mixture of two species was used in the test.

Table 2. Chronic Toxicity of Chlorine to Aquatic Animals

Species	Test*	Limits (µg/L)**	Chronic Value (µg/L)**	Reference
		FRESHWATER SPECIES		
Cladoceran, *Daphnia magna*	LC	4-14	7.483	Arthur, et al. 1975
Cladoceran, *Daphnia magna*	LC	2-7	3.742	Arthur, et al. 1975
Amphipod, *Gammarus pseudolimnaeus*	LC	12-19	15.10	Arthur, et al. 1975
Amphipod, *Gammarus pseudolimnaeus*	LC	<3.4***	<3.4	Arthur & Eaton, 1971
Fathead minnow, *Pimephales promelas*	LC	16-43	26.23	Arthur & Eaton, 1971
Fathead minnow, *Pimephales promelas*	LC	6-21	11.22	Arthur, et al. 1975
		SALTWATER SPECIES		
Tidewater silverside, *Menidia peninsulae*	ELS	40-54	46.48	Goodman, et al. 1983

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

** Results are expressed as total residual chlorine for freshwater species and chlorine-produced oxidants for saltwater species.

***Adverse effects occurred at all concentrations tested.

Table 2. (Continued)

	Acute-Chronic Ratio		
Species	Acute Value (µg/L)	Chronic Value (µg/L)	Ratio
Cladoceran, *Daphnia magna*	27.66*	7.483	3.696
Cladoceran, *Daphnia magna*	27.66*	3.742	7.392
Amphipod, *Gammarus pseudolimnaeus*	266.4**	15.10	17.64
Amphipod, *Gammarus pseudolimnaeus*	266.4**	<3.4	>78.35
Fathead minnow, *Pimephales promelas*	105.7**	26.23	4.030
Fathead minnow, *Pimephales promelas*	105.7**	11.22	9.421
Tidewater silverside, *Menidia peninsulae*	54	46.48	1.162

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* The Species Mean Acute Value was used here because the only acute values reported by Arthur, et al. (1975) were for 7-day exposures. This value of 27.66 µg/L is not inconsistent with the 7-day values (see Table 4) and the resulting acute-chronic ratios are comparable to those for the fathead minnow and tidewater silverside.

**Geometric mean of two values from Arthur, et al. (1975) 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		
28	710	Threespine stickleback, *Gasterosteus aculeatus*	710	-
27	673.1	Crayfish, *Orconectes nais*	673.1	-
26	400	Stonefly, *Pteronarcys* sp.	400	-
25	390	Orangethroat darter, *Etheostoma spectabile*	390	-
24	266.6	Largemouth bass, *Micropterus salmoides*	266.6	-
23	266.4	Amphipod, *Gammarus pseudolimnaeus*	266.4	>37.18**
22	239.2	Bluegill, *Lepomis macrochirus*	245.8	-
		Sunfish, *Lepomis* sp.	232.8	-
21	238.8	Snail, *Physa heterostropha*	238.8	-
20	224.0	Goldfish, *Carassius auratus*	224.0	-
19	205	Yellow perch, *Perca flavescens*	205	-
18	150	Isopod, *Lirceus alabamae*	150	-
17	147.5	Isopod, *Caecidotea bicrenata*	147.5	-
16	138	White sucker, *Catostomus commersoni*	138	-

Table 3. (Continued)

Rank*	Genus Mean Acute Value (µg/L)	Species	Species Mean Acute Value (µg/L)	Species Mean Acute-Chronic Ratio
15	127.3	Walleye,, *Stizostedion vitreum vitreum*	127.3	-
14	127	Crappie, *Pomoxis* sp.	127	-
13	127.0	Golden shiner, *Notemigonus crysoleucas*	127.0	-
12	105.2	Fathead minnow, *Pimephales promelas*	105.2	6.162**
11	102	Mayfly, *Stenonema ithaca*	102	-
10	90	Channel catfish, *Ictalurus punctatus*	90	-
9	83.93	Brook trout, *Salvelinus fontinalis*	117.4	-
		Lake trout, *Salvelinus namaycush*	60	-
8	79.86	Snail, *Nitocris carinata*	79.86	-
7	76.13	Copepod, *Cyclops bicuspidatus*	76.13	-
6	74.79	Coho salmon, *Oncorhynchus kisutch*	74.79	-
5	72.93	Pugnose shiner, *Notropis anogenus*	45	-
		Common shiner, *Notropis cornutus*	51	-
		Red shiner, *Notropis lutrensis*	169	-

Table 3. (Continued)

Rank*	Genus Mean Acute Value (µg/L)	Species	Species Mean Acute Value (µg/L)	Species Mean Acute-Chronic Ratio
4	72.74	Cutthroat trout, *Salmo clarki*	85.46	-
		Rainbow trout, *Salmo gairdneri*	61.92	-
3	69.57	Snail, *Goniobasis virginica*	69.57	-
2	63	Copepod, *Epischura lacustris*	63	-
1	27.66	Cladoceran, *Daphnia magna*	27.66	5.227**
		SALTWATER SPECIES		
21	1,418	Shore crab, *Hemigrapsus nudus* and *H. oregonensis*	1,418	-
20	796.7	Blue crab, *Callinectes sapidus*	796.7	-
19	687	Amphipod, *Pontogenia* sp.	687	-
18	270	Northern pipefish, *Syngnathus fuscus*	270	-
17	220	Grass shrimp, *Palaemonetes pugio*	220	-
16	167	Threespine stickleback, *Gasterosteus aculeatus*	167	-

Table 3. (Continued)

Rank*	Genus Mean Acute Value (µg/L)	Species	Species Mean Acute Value (µg/L)	Species Mean Acute-Chronic Ratio
15	162	Mysid, *Neomysis* sp.	162	-
14	146.7	Hermit crab, *Pagurus longicarpus*	146.7	-
13	145	Amphipod, *Anonyx* sp.	145	-
12	134	Shrimp, *Crangon nigricauda*	134	-
11	131.5	Coon stripe shrimp, *Pandalus danae*	192.0	-
		Shrimp, *Pandalus goniurus*	90	-
10	90	Spot, *Leiostomus xanthurus*	90	-
9	82	Pacific sand lance, *Ammodytes hexapterus*	82	-
8	80	Naked goby, *Gobiosoma bosci*	80	-
7	73	English sole, *Parophrys vetulus*	73	-
6	71	Shiner perch, *Cymatogaster aggregata*	71	-
5	65	Pacific herring, *Clupea harengus pallasi*	65	-
4	47.33	Coho salmon, *Oncorhynchus kisutch*	47.33	-
3	44.70	Atlantic silverside, *Menidia menidia*	37	-
		Tidewater silverside, *Menidia peninsulae*	54	1.162

Table 3. (Continued)

Rank*	Genus Mean Acute Value (µg/L)	Species	Species Mean Acute Value (µg/L)	Species Mean Acute-Chronic Ratio
2	29	Copepod, *Acartia tonsa*	29	-
1	26	Eastern oyster, *Crassostrea virginica*	26	-

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

**Geometric mean of two values in Table 2.

Fresh water

Final Acute Value = 38.32 µg/L

Criterion Maximum Concentration = (38.32 µg/L) / 2 = 19.16 µg/L

Final Acute-Chronic Ratio = 3.345 (see text)

Final Chronic Value = (38.32 µg/L) / 3.345 = 11.46 µg/L

Salt water

Final Acute Value = 25.24 µg/L

Criterion Maximum Concentration = (25.24 µg/L) / 2 = 12.62 µg/L

Final Acute-Chronic Ratio = 3.345 (see text)

Final Chronic Value = (25.24 µg/L) / 3.345 = 7.546 µg/L

Table 4. Other Data on Effects of Chlorine on Aquatic Organisms

Species	Duration	Effect	Result (µg/L)*	Reference
		FRESHWATER SPECIES		
Lake Michigan phytoplankton	30 min	EC50 (^{14}C uptake)	275**	Brooks & Seegert, 1977b; Brooks & Liptak, 1979
Lake Michigan phytoplankton	30 min	EC50 (^{14}C uptake)	160**	Brooks & Seegert, 1977b; Brooks & Liptak, 1979
Lake Michigan phytoplankton	30 min	EC50 (^{14}C uptake)	620**	Brooks & Seegert, 1977b; Brooks & Liptak, 1979
Lake Michigan phytoplankton	30 min	EC50 (^{14}C uptake)	760**	Brooks & Seegert, 1977b; Brooks & Liptak, 1979
Eurasian watermilfoil, *Myriophyllum spicatum*	96 hrs	Reduced growth	50	Watkins & Hammerschlag, 1984
Rotifer, *Keratella cochlearis*	24 hrs	LC50	13	Grossnickle, 1974
Cladoceran, *Daphnia magna*	7 days	LC50	4-14	Arthur, et al. 1975
Cladoceran, *Daphnia magna*	7 days	LC50	2	Arthur, et al. 1975
Crayfish (adult), *Pacifastacus trowbridgii*	365 days	LC50***	31	Larson, et al. 1978
Coho salmon (alevin), *Oncorhynchus kisutch*	21 days	Decrease in growth	23	Larson, et al. 1977a
Coho salmon (juvenile), *Oncorhynchus kisutch*	21 days	Decrease in growth	11	Larson, et al. 1977a
Fathead minnow (fry), *Pimephales promelas*	30 days	LC50	45	Ward, et al. 1976
Fathead minnow (adult), *Pimephales promelas*	21 wks	LC45	85	Arthur & Eaton, 1971
Fathead minnow (adult), *Pimephales promelas*	21 wks	LC10	43	Arthur & Eaton, 1971

Table 4. (Continued)

Species	Duration	Effect	Result (µg/L)*	Reference
Ten fish species	-	Avoidance of chlorinated sewage effluent in field	50	Tsai, 1973
Fish	-	Avoidance of chlorinated sewage effluent in field	100	Seegert, 1979
		SALTWATER SPECIES		
Phytoplankton	2-3 hrs (10 C delta t)	2-3 day delay in peak ATP	20	Goldman & Quinby, 1979
Phytoplankton	2-3 hrs (11 C delta t)	2-3 day delay in peak ATP	60	Goldman & Quinby, 1979
Phytoplankton	2-3 hrs (17.5 C delta t)	5 day delay in peak ATP	80	Goldman & Quinby, 1979
Phytoplankton	30-60 days	Shifts in composition of phytoplankton community	50-100	Sanders & Ryther, 1980
Rotifer, *Brachionus plicatilis*	30 min (0 C delta t)	LC50	180****	Capuzzo, 1979b
Rotifer, *Brachionus plicatilis*	30 min (0 C delta t)	LC50	20*****	Capuzzo, 1979b
Rotifer, *Brachionus plicatilis*	30 min (5 C delta t)	LC50	90*****	Capuzzo, 1979b
Rotifer, *Brachionus plicatilis*	30 min (5 C delta t)	LC50	<10*****	Capuzzo, 1979b
Eastern oyster (larvae), *Crassostrea virginica*	30 min (0 C delta t)	LC50	120****	Capuzzo, 1979a
Eastern oyster (larvae), *Crassostrea virginica*	30 min (0 C delta t)	LC50	10****	Capuzzo, 1979a

Table 4. (Continued)

Species	Duration	Effect	Result (µg/L)*	Reference
Eastern oyster (larva), *Crassostrea virginica*	30 min (5 C delta t)	LC50	80****	Capuzzo, 1979a
Eastern oyster (larva), *Crassostrea virginica*	30 min (5 C delta t)	LC50	<10****	Capuzzo, 1979a
Copepod, *Acartia tonsa*	24 hrs	LC50	<50	Roberts, et al. 1975
Copepod, *Acartia tonsa*	48 hrs	LC50	<50	Roberts, et al. 1975
Copepod, *Acartia tonsa*	48 hrs	LC50	29	Roberts & Gleeson, 1978
Copepod, *Acartia tonsa*	30 min (0 C delta t)	LC50	820****	Capuzzo, 1979a
Copepod, *Acartia tonsa*	30 min (0 C delta t)	LC50	320*****	Capuzzo, 1979a
Copepod, *Acartia tonsa*	30 min (5 C delta t)	LC50	860****	Capuzzo, 1979a
Copepod, *Acartia tonsa*	30 min (5 C delta t)	LC50	320*****	Capuzzo, 1979a
American lobster (larva), *Homarus americanus*	60 min	LC50	2,900****	Goldman, et al. 1978
American lobster (larva), *Homarus americanus*	60 min	LC50	300*****	Goldman, et al. 1978
American lobster (larva), *Homarus americanus*	60 min	LC50	3,950****	Goldman, et al. 1978
American lobster (larva), *Homarus americanus*	60 min	LC50	1,300*****	Goldman, et al. 1978
Sand dollar (sperm), *Dendraster excentricus*	5 min	EC50 (egg fertilization)	2	Dinnel, et al. 1981
Sand dollar (sperm), *Dendraster excentricus*	5 min	EC50 (egg fertilization)	13	Dinnel, et al. 1981

Table 4. (Continued)

Species	Duration	Effect	Result (µg/L)*	Reference
Striped bass (larva), *Morone saxatilis*	48 hrs	Incipient LC50	40	Middaugh, et al. 1977a
Striped bass (larva), *Morone saxatilis*	48 hrs	Incipient LC50	70	Middaugh, et al. 1977a
Spot (juvenile), *Leiostomus xanthurus*	30 min (10 C)	Avoidance	180	Middaugh, et al. 1977b
Spot (juvenile), *Leiostomus xanthurus*	30 min	Avoidance	50	Middaugh, et al. 1977b
Blacksmith (juvenile), *Chromis punctipinnis*	Short term	Total avoidance (food absent)	162	Hose & Stoffel, 1980
Blacksmith (juvenile), *Chromis punctipinnis*	Short term	Total avoidance (food present)	203	Hose & Stoffel, 1980
Blacksmith (juvenile), *Chromis punctipinnis*	Short term (satiated prior to test)	Total avoidance (food present)	175	Hose & Stoffel, 1980
Blacksmith (juvenile), *Chromis punctipinnis*	Short term (starved for 24 hr prior to test)	Total avoidance (food present)	327	Hose & Stoffel, 1980

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* Results are expressed as total residual chlorine for freshwater species and chlorine-produced oxidants for saltwater species.

** Exposure was to predominantly free residual chlorine; results are for spring, summer, fall, and winter, respectively.

*** LC50 was not reported by authors, but was calculated from their data.

**** Applied as free chlorine, measured as CPO.

*****Applied as chloramine, measured as CPO.

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