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Ambient Water Quality Criteria for Chromium - 1984

AMBIENT AQUATIC LIFE WATER QUALITY CRITERIA FOR

CHROMIUM

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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*

Significant quantities of chromium(III) or chromium(VI) or both exist in various bodies of water, and either can be converted to the other under appropriate natural conditions (Callahan, et al. 1979; Jan and Young, 1978; Smillie, et al. 1981). Because the chemical and toxicological properties of the two oxidation states appear to be quite different and the toxicities of the two states have not been shown to be additive, chromium(III) and chromium(VI) will be treated as separate materials herein.

Because of the variety of forms of chromium(III) and chromium(VI) and lack of definitive information about their relative toxicities, no available analytical measurement is known to be ideal for expressing aquatic life criteria for chromium. Previous aquatic life criteria for chromium (U.S. EPA, 1980) were expressed in terms of total recoverable chromium(III) and total recoverable chromium(VI), but the individual oxidation states cannot be distinguished by this method. Acid-soluble chromium(III) (operationally defined as the chromium(III) that passes through a 0.45 μm membrane filter after the sample is acidified to pH = 1.5 to 2.0 with nitric acid) and acid-soluble chromium(VI) are probably the best measurements at the present for the following reasons:

1. These measurements are compatible with all available data concerning toxicity of chromium to, and bioaccumulation of chromium by, aquatic organisms. No test results were rejected just because it was likely that

*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.

they would have been substantially different if they had been reported in terms of acid-soluble chromium. For example, results reported in terms of dissolved chromium(III) would not have been used if the concentration of precipitated chromium was substantial.

2. On samples of ambient water, measurement of acid-soluble chromium(III) and chromium(VI) should measure all forms of chromium that are toxic to aquatic life or can be readily converted to toxic forms under natural conditions. In addition, these measurements should not measure several forms, such as chromium that is occluded in minerals, clays, and sand or is strongly sorbed to particulate matter, that are not toxic and are not likely to become toxic under natural conditions. Although this measurement (and many others) will measure soluble, complexed forms of chromium, such as the EDTA complex of chromium(III), that probably have low toxicities to aquatic life, concentrations of these forms probably are negligible in most ambient water.

3. Although water quality criteria apply to ambient water, the measurements used to express criteria are likely to be used to measure chromium in aqueous effluents. Measurements of acid-soluble chromium(III) and chromium(VI) should be applicable to effluents because they will measure precipitates, such as carbonate and hydroxide precipitates of chromium(III), that might exist in an effluent and dissolve when the effluent is diluted with receiving water. If desired, dilution of effluent with receiving water before measurement of acid-soluble chromium might be used to determine whether the receiving water can decrease the concentration of acid-soluble chromium because of sorption. However, the relationship between what is in an effluent and what will occur in the

receiving water should take into account the possibility of conversion of one oxidation state of chromium to the other.

4. The acid-soluble measurement should be useful for most metals, thus minimizing the number of samples and procedures that are necessary.
5. The acid-soluble measurement does not require filtration at the time of collection, as does the dissolved measurement.
6. For the measurement of total acid-soluble chromium the only treatment required at the time of collection is preservation by acidification to pH = 1.5 to 2.0, similar to that required for the measurement of total recoverable chromium. Durations of 10 minutes to 24 hours between acidification and filtration probably will not affect the measurement of total acid-soluble chromium substantially. However, acidification might not prevent conversion of chromium(III) to chromium(VI) or vice versa. Therefore, measurement of acid-soluble chromium(III) or acid-soluble chromium(VI) or both will probably require separation or measurement at the time of collection of the sample or special preservation to prevent conversion of one oxidation state of chromium to the other.
7. The carbonate system has a much higher buffer capacity from pH = 1.5 to 2.0 than it does from pH = 4 to 9 (Weber and Stumm, 1963).
8. Differences in pH within the range of 1.5 to 2.0 probably will not affect the result substantially.
9. The acid-soluble measurement does not require a digestion step, as does the total recoverable measurement.
10. After acidification and filtration of the sample to isolate the acid-soluble chromium, the analysis can be performed using either atomic absorption spectroscopy or ICP-emission spectroscopy for total

acid-soluble chromium or a chelation-extraction or coprecipitation procedure for chromium(VI) (U.S. EPA, 1983a).

11. It is not possible to separately measure total recoverable chromium(III) and total recoverable chromium(VI).

Thus, expressing aquatic life criteria for chromium in terms of the acid-soluble measurement has both toxicological and practical advantages. On the other hand, because no measurement is known to be ideal for expressing aquatic life criteria for chromium or for measuring chromium in ambient water or aqueous effluents, measurement of both total acid-soluble chromium and total recoverable chromium in ambient water or effluent or both might be useful. For example, there might be cause for concern if total recoverable chromium is much above an applicable limit, even though total acid-soluble chromium is below the limit.

Unless otherwise noted, all concentrations reported herein are expected to be essentially equivalent to acid-soluble chromium. All concentrations are expressed as chromium, not as the chemical tested. The criteria presented herein supersede previous aquatic life water quality criteria for chromium (U.S. EPA, 1976, 1980) because these new criteria were derived using improved procedures and additional information. Whenever adequately justified, a national criterion may be replaced by a site-specific criterion (U.S. EPA, 1983b), which may include not only site-specific criterion concentrations (U.S. EPA, 1983c), but also site-specific durations of averaging periods and site-specific frequencies of allowed exceedences (U.S. EPA, 1985). The latest literature search for information for this document was conducted in May, 1984; some newer information was also used.

Acute Toxicity to Aquatic Animals

Chromium(VI)

Muller (1980, 1982) studied the influence of hardness, alkalinity, and calcium-magnesium ratio on the 24-hr LC50s for *Daphnia magna*, and found that potassium dichromate was more toxic at lower hardness and alkalinity. In addition, dichromate was less toxic at a 4:1 calcium-magnesium ratio than when the hardness was due only to calcium or magnesium. Call, et al. (1981) determined the acute toxicity of four chromium(VI) salts to *Daphnia magna* in static tests (Tables 1 and 6). They conducted toxicity tests on each salt in hard (185 to 213 mg/L) water at pH = 7.5 to 7.6 and at pH = 8.2 to 8.4, and in Lake Superior water (hardness = 50 mg/L and pH = 7.5). In these three tests the animals were not fed and a 48-hr EC50 was determined. In addition, both 48-hr and 96-hr EC50s were determined in Lake Superior water in tests in which the animals were fed. Concentrations of chromium were measured in all tests and there were only minor differences in the toxicities of the four salts. Test concentrations of both the dichromates and chromates had but a small influence on the pH of the test solutions. In hard water all four salts were less toxic at the higher pH. All four were 5 to 9 times more toxic in soft Lake Superior water than in the hard water at a pH of 7.5 to 7.6. The presence of food had little effect on the results at 48 hours, and in the tests with food, the 48- and 96-hr EC50s were about the same. Stephenson and Watts (1984) studied the effect of diet and temperature on the toxicity of chromium(VI) to *Daphnia magna*.

Wallen, et al. (1957) studied the toxicity of chromium(VI) to mosquitofish in turbid water using potassium and sodium salts of both dichromate and chromate (Table 6) but the effect of turbidity on toxicity was not studied.

The dichromate salts were slightly more toxic than the chromate salts. Trama and Benoit (1960) compared the toxicities of dichromate and chromate to the bluegill in soft water. The 96-hr LC50s were 110,000 μg/L for dichromate and 170,000 μg/L for chromate. They concluded that the acidic dichromate was more toxic than the basic chromate because the greatest part of the chromium(VI) was in the form of the hydrochromate ion at the lower pH of the dichromate solutions, whereas at the higher pH of the chromate solutions most of the chromium(VI) was in the form of the chromate ion.

The toxicity of chromium(VI) to the bluegill in soft and hard water was determined at 18 C and 30 C (Academy of Natural Sciences, 1960). At 18 C the 96-hr LC50s were 113,000 μg/L in soft water and 135,000 μg/L in hard water. Similar results were obtained at 30 C with the 96-hr LC50s being 113,000 μg/L in soft water and 130,400 μg/L in hard water. Pickering and Henderson (1966) tested the toxicity of potassium dichromate to the fathead minnow and bluegill in soft and hard water. The 96-hr LC50s for the fathead minnow in soft and hard water were 17,600 and 27,300 μg/L, respectively. The corresponding values for the bluegill were 118,000 μg/L and 133,000 μg/L.

Hogendoorn-Roozemond, et al. (1978) reported on the acute toxicity of sodium chromate to the rainbow trout at two pH levels. Methods for the study were not given so the values are not listed in Table 1 or Table 6. They reported that young rainbow trout were much more sensitive to sodium chromate at pH = 6.9 than at pH = 7.9 and concluded that chromic acid was the most probable chromium compound or ion responsible for chromium(VI) toxicity. van der Putte, et al. (1982) found that chromium(VI) is more toxic at pH = 6.5 than at pH = 7.8 (Table 6).

Adelman and Smith (1976) found that the threshold lethal concentration for chromium(VI) does not occur within 96 hours (Tables 1 and 6). For 16 tests the average ratio of 11-day to 96-hr LC50s was 0.37 for the fathead minnow and 0.27 for the goldfish. White (Manuscript) conducted static tests with measured concentrations to determine the 96-hr LC50s for eleven fish species and three invertebrate species (Table 1). These acute values ranged from 36,300 μg/L for the yellow perch to 1,870,000 μg/L for a stonefly. This value for the stonefly is the highest acute value for any aquatic animal.

The toxicity of chromium(VI) apparently increases as pH is lowered or as hardness is lowered or both. Although there are exceptions, softer surface waters usually have a lower pH than harder surface waters. However, the available data are insufficient to develop criteria on the basis of water quality characteristics. The Species Mean Acute Values of the five most sensitive animals were determined in soft water.

Genus Mean Acute Values were calculated (Table 3) as the geometric means of the available Species Mean Acute Values (Table 1). Of the 27 genera for which data are available, the most sensitive, Daphnia, is 64,600 times more sensitive than the most resistant, Neophasganophora. Acute values are available for more than one species in each of five genera, and the range of Species Mean Acute Values within each genus is less than a factor of 2. Both the eight most sensitive and the three most resistant genera are invertebrates. A freshwater Final Acute Value of 31.49 μg/L was calculated from the Genus Mean Acute Values using the procedure described in the Guidelines; this value is slightly above that for the genus Daphnia.

Dorfman (1977), Fales (1978), Frank and Robertson (1979), and Olson and Harrell (1973) reported that the toxicity of chromium(VI) to a fish, shrimp, crab, and clam increased as salinity decreased (Tables 1 and 6). The change was usually less than a factor of two, except when salinity was about 1 g/kg.

Data from tests at such very low salinities are in Table 6 and were not used in deriving criteria. Fales (1978) also found that toxicity was greater at 25 C than at 10 C.

Of the 21 saltwater genera for which acute values are available, the most sensitive, Nereis, is about 52 times more sensitive than the most resistant, Nassarius (Table 3). This range is surprisingly small compared to the very large range of sensitivities of freshwater animals to chromium(VI). Both the twelve most sensitive and two most resistant genera are invertebrates. Acute values are available for two 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 saltwater Final Acute Value of 2,158 μg/L for chromium(VI) was calculated from the Genus Mean Acute Values in Table 3.

Chromium(III)

Chapman, et al. (Manuscript) measured the acute toxicity of chromium(III) to Daphnia magna at three hardnesses and the 48-hr acute values ranged from 16,800 μg/L in soft water to 58,700 μg/L in hard water. Pickering and Henderson (1966) obtained 96-hr LC50s of 5,070 and 67,400 μg/L with the fathead minnow in soft and hard water, respectively. The corresponding values for the bluegill were 7,460 and 71,900 μg/L.

Different species exhibit different sensitivities to chromium(III), and many other factors might affect the results of tests of the toxicity of chromium(III) to aquatic organisms. Criteria can quantitatively take into account such a factor, however, only if enough data are available to show that the factor similarly affects the results of tests with a variety of species. Hardness is often thought of as having a major effect on the toxicity of chromium(III), although the observed effect is probably due to one or more of a number of usually interrelated ions, such as hydroxide, carbonate, calcium, and magnesium. Hardness is used here as a surrogate for the ions which affect the results of toxicity tests on chromium(III). An analysis of covariance (Dixon and Brown, 1979; Neter and Wasserman, 1974) was performed using the natural logarithm of the acute value as the dependent variable, species as the treatment or grouping variable, and the natural logarithm of hardness as the covariate or independent variable. This analysis of covariance model was fit to the data in Table 1 for the three species for which acute values are available over a range of hardness such that the highest hardness is at least three times the lowest and the highest is at least 100 mg/L higher than the lowest. The slopes for all three species are between 0.78 and 0.89 (see end of Table 1) and are close to the slope of 0.667 which is expected on the basis that calcium, magnesium, and carbonate have a charge of two, whereas chromium(III) has a charge of three. An F-test showed that, under the assumption of equality of slopes, the probability of obtaining three slopes as dissimilar as these is P=0.82. This was interpreted as indicating that it is reasonable to assume that the slopes for these three species are the same.

The pooled slope of 0.8190 was then used with the data in Table 1 to calculate Species Mean Acute Values at a hardness of 50 mg/L. Genus Mean Acute Values (Table 3) were then calculated as geometric means of the available Species Mean Acute Values. 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 1.3. The most sensitive genus, Ephemerella, is about 32 times more sensitive than the most resistant genus, Hydropsyche; interestingly, both of these are insects. The freshwater Final Acute Value of 1,968 μg/L was calculated at a hardness of 50 mg/L from the Genus Mean Acute Values in Table 3 using the procedure described in the Guidelines. Thus, the freshwater Criterion Maximum Concentration (in μg/L) = $e^{(0.8190[\ln(\text{hardness})]+3.688)}$.

The acute toxicity of chromium(III) in salt water has been determined with only two species (Table 1). The acute value for the eastern oyster is 10,300 μg/L, whereas that for the mummichog is 31,500 μg/L.

Chronic Toxicity to Aquatic Animals

Chromium(VI)

Benoit (1976) studied the chronic effects of chromium(VI) on brook trout and rainbow trout. For both species the most sensitive effect was mortality, the chronic limits were 200 and 350 μg/L, and the resulting chronic value was 264.6 μg/L. Although growth during the first eight months was retarded at all test concentrations, this effect was temporary and was not used to establish the chronic limits. In an early life-stage test with rainbow trout, Sauter, et al. (1976) found chronic limits of 51 and 105 μg/L, resulting in a chronic value of 73.18 μg/L. These limits were based on a reduction in growth 60 days after hatch and this chronic value was about one-fourth the chronic value of 264.6 μg/L from the chronic test reported by Benoit (1976). The species mean acute-chronic ratios for brook trout and rainbow trout, calculated from the data of Benoit (1976) are 223.0 and 260.8, respectively (Table 3). Sauter, et al. (1976) provided no acute data in their study with which to calculate an acute-chronic ratio.

The limits of 1,000 and 3,950 μg/L in a life-cycle test with the fathead minnow (Pickering, 1980) were based on survival. As with the trout, an early retardation of growth was only temporary. The chronic value of 1,987 µg/L is much higher than that for the trout but the acute-chronic ratio of 18.55 is much lower.

Six chronic values are available for five species of daphnids and they range from less than 2.5 to 40 µg/L (Table 2). The results of Trabalka and Gehrs (1977) support those of Mount (1982). The five species mean acute-chronic ratios range from 1.13 to >6.957 (Table 3). The species mean acute-chronic ratio for chromium(VI) seems to be lower for sensitive species so the four known acute-chronic ratios for daphnids were used to calculate the freshwater Final Acute-Chronic Ratio of 2.917 (Table 3). Division of the Final Acute Value by the Final Acute-Chronic Ratio results in a freshwater Final Chronic Value of 10.80 µg/L, which is in the range of the chronic values for the cladocerans.

Results of life-cycle tests with the saltwater polychaete, *Neanthes arenaceodentata*, and the mysid, *Mysidopsis bahia*, are reported in Table 2. Other life-cycle data on the polychaetes, *Capitella capitata* and *Ophryotrocha diadema*, were placed in Table 6 because exposure concentrations were not adequately measured. Chronic values for *N. arenaceodentata* ranged from less than 13 to 36.74 µg/L depending upon the generation tested, whereas that for the mysid was 132 µg/L. Reduction in the number of young per brood was the most sensitive effect for both species (Table 3). The acute-chronic ratios were 121.8 for the polychaete and 15.38 for the mysid, and these two species were among the most acutely sensitive to chromium(VI). If the geometric mean of these two ratios is used as the saltwater Final Acute-Chronic Ratio, division of the saltwater Final Acute Value for chromium(VI) by the Final Acute-Chronic Ratio results in a saltwater Final Chronic Value of 49.86 µg/L.

However, reproduction of Neanthes arenaceodentata was affected at concentrations ranging from <13 to 54 μg/L.

Chromium(III)

Chapman, et al. (Manuscript) studied the chronic toxicity of chromium(III) to Daphnia magna at three hardnesses (Table 2). The daphnids were about three times as sensitive at a hardness of 52 mg/L as at a hardness of 100 mg/L. At a hardness of 200 mg/L, however, chromium(III) was more toxic than at 52 mg/L. They speculated that ingested precipitated chromium contributed to toxicity in the hard water exposure. The chronic values of Chapman, et al. (Manuscript) were regressed against hardness but the slope was not significant. Biesinger and Christensen (1972) studied the chronic toxicity of chromium(III) to Daphnia magna in soft water but did not measure the chromium concentrations (Table 6). Their chronic value of 330 μg/L was about five times greater than the value obtained by Chapman, et al. (Manuscript) in soft water.

The chronic toxicity of chromium(III) to fish has been studied in a life-cycle test with the fathead minnow in hard water and in an early life-stage test with rainbow trout in soft water. Pickering (Manuscript) found that the upper chronic limit for the fathead minnow was based on survival of both first and second generation fish. Stevens and Chapman (1984) found that this limit for trout was based on survival. Trout in soft water were much more sensitive chronically than the fathead minnow in hard water, and the acute-chronic ratio for trout was about two times greater than that for the minnow.

Both the freshwater chronic values and acute-chronic ratios for chromium(III) range from about 27 to about 1,300. A chronic value of 68.63

μg/L is available for the rainbow trout. Because this is an important and relatively sensitive species, it seems reasonable to base the Final Chronic Value on this datum. Although hardness did not have a consistent relationship to the chronic toxicity of chromium(III) to Daphnia magna, a filter feeder, it does not seem unreasonable to assume that hardness relates to chronic toxicity to rainbow trout about the same way it related, on the average, to acute toxicity to Daphnia magna, the fathead minnow, and the bluegill. Thus, 0.8190 is used as the chronic slope (Table 3) and the freshwater Final Chronic Value (in μg/L) = $e^{(0.8190[\ln(\text{hardness})]+1.561)}$.

A life-cycle test has been conducted on chromium(III) with the saltwater polychaete worm, Neanthes arenaceodentata. A concentration of 50,400 μg/L, which is above the acute values obtained with the eastern oyster and the mummichog, did not substantially affect the test species.

Toxicity to Aquatic Plants

Chromium(VI)

Tests have been conducted with a wide variety of freshwater plants (Table 4) and the effect concentrations of chromium(VI) range from 2 μg/L for the blue alga, Microcystis aeruginosa, to 7,800 μg/L for the diatom, Nitzschia linearis. Toxicity of chromium(VI) to the diatom, Navicula seminulum, was tested at three temperatures and two hardnesses (Academy of Natural Sciences, 1960). The geometric mean of the concentrations causing a 50 percent reduction in growth was 245 μg/L at the lower water hardness and 335 μg/L at the higher hardness. The diatom was more sensitive to chromium(VI) at 22 C than at 30 C.

Toxicity studies were performed with the saltwater macroalga, Macrocystis pyrifera, to investigate the effect of chromium(VI) on photosynthesis

(Table 4). The 96-hr EC50 reported by Clendenning and North (1959) was 5,000 µg/L, whereas 20 percent inhibition was noted after five days at 1,000 µg/L by Bernhard and Zattera (1975). These plants are almost as sensitive to chromium(VI) as the most sensitive animal species.

Chromium(III)

Toxicity tests on chromium(III) have only been conducted with two freshwater plant species (Table 4). Richter (1982) studied the toxicity of chromium(III) to Selenastrum capricornutum and calculated the results from initial measured concentrations. Chromium(III) was less toxic than chromium(VI) to this green alga. The algistatic concentration was >1000 µg/L, and the concentration that caused a 50% reduction in growth was 397 µg/L. No toxicity tests have been conducted on chromium(III) with a salt-water plant.

Bioaccumulation

Chromium(VI)

The three bioconcentration factors (BCFs) determined with the rainbow trout are less than three (Table 5). Apparently, algae accumulate chromium to a much greater extent, because Patrick, et al. (1975) found a BCF of 8,500 for an algal community (Table 6). The BCFs determined with a saltwater polychaete, mussel, and oyster range from 125 to 200 (Table 5).

Chromium(III)

No data are available concerning the bioaccumulation of chromium(III) by freshwater organisms. Bioconcentration tests on chromium(III) in salt water with the blue mussel, soft-shell clam, and oyster resulted in BCFs from 86 to 153 (Table 5). These BCFs are similar to those for chromium(VI).

Other Data

Chromium(VI)

Zarafonetis and Hampton (1974) reported inhibition of photosynthesis of a natural population of river algae exposed to 20 μg/L (Table 6). Olson and Foster (1956) reported a ten percent reduction in growth of chinook salmon and rainbow trout at 16 and 21 μg/L, respectively. As noted earlier, Benoit (1976) and Pickering (1980) also reported effects on growth of fishes exposed to low concentrations, but in these life-cycle tests the effect was temporary and was not used to establish chronic limits. A 7-day EC50 of 30 μg/L was reported for the narrow-mouthed toad (Birge, 1978).

Exposures of the saltwater polychaete, Neanthes arenaceodentata, to chromium(VI) for 56 and 59 days resulted in LC50s of 200 μg/L (Table 6) compared to the 96-hr LC50 of 3,100 μg/L (Table 1). Sublethal effects reported for this species show inhibition of tube building at 79 μg/L. Holland, et al. (1960) reported toxicity to salmon at a concentration of 31,800 μg/L, which is similar to the Species Mean Acute Value for the speckled sanddab but twice as high as that reported for the Atlantic silverside (Table 1).

Chromium(III)

Embryos of a freshwater snail are rather insensitive to chromium(III) (Table 6). Oshida, et al. (1976, 1981) were able to kill a saltwater polychaete worm with chromium(III) by adding 50,400 μg/L, probably because the pH dropped to 4.5. When the pH was raised to about 7.9 by adding sodium hydroxide, the worms not only survived for at least 160 days, but also reproduced (Table 6).

Unused Data

Some data on the effects of chromium on aquatic organisms were not used because the studies were conducted with species that are not resident in North America (e.g., Ahsanullah, 1982; Baudouin and Scoppa, 1974; Cairns and Loos, 1967; Lee and Xu, 1984; Moshe, et al. 1972; Okubo and Okubu, 1962; Pagano, et al. 1983; Ramusino, et al. 1981; Ravera, 1977; Srivastava, et al. 1979) or because the test species was not obtained in North America and was not identified well enough to determine if it is resident in North America (e.g., van Weerett, et al. 1984). Data were not used if chromium was a component of an effluent (Klassen, et al. 1949), drilling mud (Bookhout, et al. 1982; Carr, et al. 1982; Conklin, et al. 1983), or a mixture (Wong, et al. 1982b). Reviews by Chapman, et al. (1968), Eisler (1981), Eisler, et al. (1979), European Inland Fisheries Advisory Commission (1983), National Research Council of Canada (1976), Phillips and Russo (1978), and Thompson, et al. (1972) only contain data that have been published elsewhere.

Some data, such as those in Babich, et al. (1982), Bovee (1976), Brkovic-Popovic and Popovic (1977a,b), Draggan (1977), Grande and Andersen (1983), Schaefer and Pipes (1973), and Sudo and Aiba (1973), were not used because the tests were conducted in distilled, deionized, chlorinated, or "tap" water. Algal tests were not used if they were not conducted in an appropriate medium (Stary and Kratzer, 1982). Smith and Heath (1979) only presented results graphically. Data reported by Frey, et al. (1983), Gentile, et al. (1982), Ten Holder, et al. (1978), and Verriopoulos (1980) were not used because either the methods or results were not adequately presented. Bringmann and Kuhn (1982) cultured Daphnia magna in one water and conducted tests in another. High control mortalities occurred in all except two tests reported by Sauter, et al. (1976). The 96-hr values reported by Buikema, et al. (1974a,b) were subject to error because of possible reproductive interactions (Buikema, et al. 1977). Berglind and Dave (1984) cultured and tested their organisms in different waters. Dowden and Bennett (1965), Freeman and Fowler (1953), and Wong, et al. (1982a) did not report the hydration of the chemical used.

Elwood, et al. (1980), Giesy and Wiener (1977), Gordon (1980), Lucus and Edgington (1970), Martin (1984), Mathis and Cummings (1973), Pearce, et al. (1971), and Tong, et al. (1974) did not report sufficient measurements of chromium concentrations in water to allow use of results of their field studies. The significance of physiological effects due to in vitro exposures could not be determined to allow use of studies by Christensen and Tucker (1976), Hoffert and Fromm (1964), and van der Putte and Part (1982).

Results of bioconcentration tests were not used if the tests were conducted in distilled water, were not long enough, or were not flow-through, or if the concentration of chromium in the test solution was not adequately measured (e.g., Flos, et al. 1983; Freeman, 1978, 1980; Smock, 1983; Stary, et al. 1982; Walting, 1981b). Shuster and Pringle (1969) and Sklar (1980) did not report whether their bioconcentration tests were conducted on chromium(III) or chromium(VI).

Summary

Chromium(VI)

Acute toxicity values for chromium(VI) are available for freshwater animal species in 27 genera and range from 23.07 μg/L for a cladoceran to 1,870,000 μg/L for a stonefly. These species include a wide variety of animals that perform a wide spectrum of ecological functions. All five tested species of daphnids are especially sensitive. The few data that are available indicate that the acute toxicity of chromium(VI) decreases as hardness and pH increase.

The chronic value for both rainbow trout and brook trout is 264.6 μg/L, which is much lower than the chronic value of 1,987 μg/L for the fathead minnow. The acute-chronic ratios for these three fishes range from 18.55 to 260.8. In all three chronic tests a temporary reduction in growth occurred at low concentrations. Six chronic tests with five species of daphnids gave chronic values that range from <2.5 to 40 μg/L and the acute-chronic ratios range from 1.130 to >9.680. Except for the fathead minnow, all the chronic tests were conducted in soft water. Green algae are quite sensitive to chromium(VI). The bioconcentration factor obtained with rainbow trout is less than three. Growth of chinook salmon was reduced at a measured concentration of 16 μg/L.

The acute toxicity of chromium(VI) to 23 saltwater vertebrate and invertebrate species ranged from 2,000 μg/L for a polychaete worm and a mysid to 105,000 μg/L for the mud snail. The chronic values for a polychaete ranged from <13 to 36.74 μg/L, whereas that for a mysid was 132 μg/L. The acute-chronic ratios ranged from 15.38 to >238.5. Toxicity to macroalgae was reported at 1,000 and 5,000 μg/L. Bioconcentration factors for chromium(VI) range from 125 to 236 for bivalve molluscs and polychaetes.

Chromium(III)

Acute values for chromium(III) are available for 20 freshwater animal species in 18 genera ranging from 2,221 µg/L for a mayfly to 71,060 µg/L for a caddisfly. Hardness has a significant influence on toxicity, with chromium(III) being more toxic in soft water.

A life-cycle test with Daphnia magna in soft water gave a chronic value of 66 µg/L. In a comparable test in hard water the lowest test concentration of 44 µg/L inhibited reproduction of Daphnia magna, but this effect may have been due to ingested precipitated chromium. In a life-cycle test with the fathead minnow in hard water the chronic value was 1,025 µg/L. Toxicity data are available for only two freshwater plant species. A concentration of 9,900 µg/L inhibited growth of roots of Eurasian watermilfoil. A freshwater green alga was affected by a concentration of 397 µg/L in soft water. No bioconcentration factor has been measured for chromium(III) with freshwater organisms.

Only two acute values are available for chromium(III) in salt water - 10,300 µg/L for the eastern oyster and 31,500 µg/L for the mummichog. In a chronic test effects were not observed on a polychaete worm at 50,400 µg/L at pH = 7.9, but acute lethality occurred when pH = 4.5. Bioconcentration factors for saltwater organisms and chromium(III) range from 86 to 153, which are similar to the bioconcentration factors for chromium(VI) and saltwater species.

National Criteria

Chromium(VI)

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 chromium(VI) 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 16 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 chromium(VI) does not exceed 50 μg/L more than once every three years on the average and if the one-hour average concentration does not exceed 1,100 μg/L more than once every three years on the average. Data suggest that the acute toxicity of chromium(VI) is salinity-dependent; therefore the one-hour average concentration might be underprotective at low salinities.

Chromium(III)

The procedures described in the "Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses" indicate that, except possibly where a locally important species is very sensitive, freshwater aquatic organisms and their uses should not be affected unacceptably if the four-day average concentration (in μg/L) of chromium(III) does not exceed the numerical value given by $e^{(0.8190[\ln(\text{hardness})]+1.561)}$ more than once every three years on the average and if the one-hour average concentration (in μg/L) does not exceed the numerical value given by $e^{(0.8190[\ln(\text{hardness})]+3.688)}$ more than once every three years on the average. For example, at hardnesses of 50, 100, and 200 mg/L as $CaCO_3$ the four-day average concentrations of chromium(III) are 120, 210, and 370 µg/L, respectively, and the one-hour average concentrations are 980, 1,700, and 3,100 µg/L.

No saltwater criterion can be derived for chromium(III), but 10,300 µg/L is the EC50 for eastern oyster embryos, whereas 50,400 µg/L did not affect a polychaete worm in a life-cycle test.

EPA believes that a measurement such as "acid-soluble" would provide a more scientifically correct basis upon which to establish criteria for metals. The criteria were developed on this basis. However, at this time, no EPA approved methods for such a measurement are available to implement the criteria through the regulatory programs of the Agency and the States. The Agency is considering development and approval of methods for a measurement such as "acid-soluble". Until available, however, EPA recommends applying the criteria using the total recoverable method. This has two impacts: (1) certain species of some metals cannot be analyzed directly because the total recoverable method does not distinguish between individual oxidation states, and (2) these criteria may be overly protective when based on the total recoverable method.

The recommended exceedence frequency of three years is the Agency's best scientific judgment of the average amount of time it will take an unstressed system to recover from a pollution event in which exposure to chromium 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 Chromium to Aquatic Animals

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
			FRESHWATER SPECIES			
			Chromium(VI)			
Snail, *Physa heterostropha*	S, U	Potassium dichromate	43	16,800	-	Patrick, et al. 1968
Snail, *Physa heterostropha*	S, U	Potassium chromate	45	17,300	-	Academy of Natural Sciences, 1960; Patrick, et al. 1968
Snail, *Physa heterostropha*	S, U	Potassium chromate	45	17,300	-	Academy of Natural Sciences, 1960
Snail, *Physa heterostropha*	S, U	Potassium chromate	171	40,600	-	Academy of Natural Sciences, 1960
Snail, *Physa heterostropha*	S, U	Potassium chromate	171	31,600	23,010	Academy of Natural Sciences, 1960
Cladoceran, *Ceriodaphnia reticulata*	FT, M	Sodium dichromate	45	45.2	-	Mount, 1982
Cladoceran, *Ceriodaphnia reticulata*	FT, M	-	45	45	45.10	Mount & Norberg, 1984
Cladoceran, *Daphnia magna*	S, U	Sodium chromate	-	<103	-	Anderson, 1946
Cladoceran, *Daphnia magna*	S, U	Sodium dichromate	-	<123	-	Anderson, 1946
Cladoceran, *Daphnia magna*	S, U	Potassium dichromate	-	141	-	Dowden & Bennett, 1965
Cladoceran, *Daphnia magna*	S, U	Sodium dichromate	-	3,490	-	Dowden & Bennett, 1965
Cladoceran, *Daphnia magna*	S, M	Potassium dichromate	213	212[†]	-	Call, et al. 1981
Cladoceran, *Daphnia magna*	S, M	Potassium dichromate	196	85.7[††]	-	Call, et al. 1981

Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Cladoceran, *Daphnia magna*	S, M	Potassium dichromate	50	19.9[†††]	-	Call, et al. 1981
Cladoceran, *Daphnia magna*	S, M	Potassium dichromate	45	900	-	Cairns, et al. 1978
Cladoceran, *Daphnia magna*	S, M	Sodium chromate	-	50	-	Trabalka & Gehrs, 1977
Cladoceran, *Daphnia magna*	S, M	Potassium dichromate	100	175	-	White, 1979
Cladoceran, *Daphnia magna*	S, M	Potassium dichromate	92	157	-	White, 1979
Cladoceran, *Daphnia magna*	S, M	Sodium dichromate	185	131[†]	-	Call, et al. 1981
Cladoceran, *Daphnia magna*	S, M	Sodium dichromate	196	73.6[††]	-	Call, et al. 1981
Cladoceran, *Daphnia magna*	S, M	Sodium dichromate	50	21.3[†††]	-	Call, et al. 1981
Cladoceran, *Daphnia magna*	S, M	Potassium chromate	212	137[†]	-	Call, et al. 1981
Cladoceran, *Daphnia magna*	S, M	Potassium chromate	188	66.7[††]	-	Call, et al. 1981
Cladoceran, *Daphnia magna*	S, M	Potassium chromate	50	15.3[†††]	-	Call, et al. 1981
Cladoceran, *Daphnia magna*	S, M	Sodium chromate	185	164[†]	-	Call, et al. 1981
Cladoceran, *Daphnia magna*	S, M	Sodium chromate	213	75.8[††]	-	Call, et al. 1981
Cladoceran, *Daphnia magna*	S, M	Sodium chromate	50	20.6[†††]	-	Call, et al. 1981

Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Cladoceran, *Daphnia magna*	S, U	Potassium dichromate	240	81	-	Stephenson & Watts, 1984
Cladoceran, *Daphnia magna*	S, U	Potassium dichromate	240	110	-	Stephenson & Watts, 1984
Cladoceran, *Daphnia magna*	S, U	Potassium dichromate	240	35	-	Stephenson & Watts, 1984
Cladoceran, *Daphnia magna*	FT, M	Sodium dichromate	45	24.2	-	Mount, 1982
Cladoceran, *Daphnia magna*	FT, M	-	45	22	23.07	Mount & Norberg, 1984
Cladoceran, *Daphnia pulex*	S, M	Potassium dichromate	45	760	-	Cairns, et al. 1978
Cladoceran, *Daphnia pulex*	S, U	-	45	48	-	Mount & Norberg, 1984
Cladoceran, *Daphnia pulex*	FT, M	Sodium dichromate	45	36.3	36.3	Mount, 1982
Cladoceran, *Simocephalus serrulatus*	FT, M	Sodium dichromate	45	40.9	40.9	Mount, 1982
Cladoceran, *Simocephalus vetulus*	S, U	-	45	50	-	Mount & Norberg, 1984
Cladoceran, *Simocephalus vetulus*	FT, M	Sodium dichromate	45	32.3	32.3	Mount, 1982
Amphipod, *Gammarus pseudolimnaeus*	S, M	Potassium chromate	50	101	-	Call, et al. 1981
Amphipod, *Gammarus pseudolimnaeus*	S, U	Potassium dichromate	48	94.1	-	Call, et al. 1983
Amphipod, *Gammarus pseudolimnaeus*	FT, M	Potassium dichromate	48	67.1	67.1	Call, et al. 1983

Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Amphipod, *Hyalella azteca*	S, M	Potassium chromate	50	630	630	Call, et al. 1981
Crayfish, *Orconectes rusticus*	S, M	Potassium dichromate	120-160	176,000	176,000	White, Manuscript
Damselfly, *Enallagma aspersum*	S, M	Potassium dichromate	120-160	140,000	140,000	White, Manuscript
Stonefly, *Neophasganophora capitata*	S, M	Potassium dichromate	120-160	1,870,000	1,870,000	White, Manuscript
Midge, *Chironomus tentans*	S, M	Potassium dichromate	101	61,000	61,000	Batac-Catalan & White, 1983
Midge, *Tanytarsus dissimilis*	FT, M	Potassium dichromate	47	57,300	57,300	Call, et al. 1983
Bryozoan, *Pectinatella magnifica*	S, U	Potassium chromate	205	1,440	1,440	Pardue & Wood, 1980
Bryozoan, *Lophopodella carteri*	S, U	Potassium chromate	205	1,560	1,560	Pardue & Wood, 1980
Bryozoan, *Plumatella emarginata*	S, U	Potassium chromate	205	650	650	Pardue & Wood, 1980
Rainbow trout, *Salmo gairdneri*	FT, M	Sodium dichromate	45	69,000	69,000	Benoit, 1976
Brook trout, *Salvelinus fontinalis*	FT, M	Sodium dichromate	45	59,000	59,000	Benoit, 1976
Central stoneroller, *Campostoma anomalum*	S, M	Potassium dichromate	120-160	51,250	51,250	White, Manuscript
Goldfish, *Carassius auratus*	S, U	Potassium dichromate	20	37,500	-	Pickering & Henderson, 1966

Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Goldfish, *Carassius auratus*	S, U	Potassium dichromate	-	110,000	-	Riva, et al. 1981
Goldfish, *Carassius auratus*	FT, M	Potassium dichromate	220	123,000	-	Adelman & Smith, 1976
Goldfish, *Carassius auratus*	FT, M	Potassium dichromate	220	123,000	-	Adelman & Smith, 1976
Goldfish, *Carassius auratus*	FT, M	Potassium dichromate	220	90,000	-	Adelman & Smith, 1976
Goldfish, *Carassius auratus*	FT, M	Potassium dichromate	220	125,000	-	Adelman & Smith, 1976
Goldfish, *Carassius auratus*	FT, M	Potassium dichromate	220	109,000	-	Adelman & Smith, 1976
Goldfish, *Carassius auratus*	FT, M	Potassium dichromate	220	135,000	-	Adelman & Smith, 1976
Goldfish, *Carassius auratus*	FT, M	Potassium dichromate	220	110,000	-	Adelman & Smith, 1976
Goldfish, *Carassius auratus*	FT, M	Potassium dichromate	220	129,000	-	Adelman & Smith, 1976
Goldfish, *Carassius auratus*	FT, M	Potassium dichromate	220	98,000	-	Adelman & Smith, 1976
Goldfish, *Carassius auratus*	FT, M	Potassium dichromate	220	133,000	-	Adelman & Smith, 1976
Goldfish, *Carassius auratus*	FT, M	Potassium dichromate	220	102,000	-	Adelman & Smith, 1976
Goldfish, *Carassius auratus*	FT, M	Potassium dichromate	220	133,000	-	Adelman & Smith, 1976
Goldfish, *Carassius auratus*	FT, M	Potassium dichromate	220	126,000	-	Adelman & Smith, 1976

Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Goldfish, _Carassius auratus_	FT, M	Potassium dichromate	220	126,000	-	Adelman & Smith, 1976
Goldfish, _Carassius auratus_	FT, M	Potassium dichromate	220	133,000	-	Adelman & Smith, 1976
Goldfish, _Carassius auratus_	FT, M	Potassium dichromate	220	126,000	-	Adelman & Smith, 1976
Goldfish, _Carassius auratus_	FT, M	Potassium dichromate	220	124,000	119,500	Adelman & Smith, 1976
Silverjaw minnow, _Ericymba buccata_	S, M	Potassium dichromate	120-160	49,600	49,600	White, Manuscript
Emerald shiner, _Notropis atherinoides_	S, M	Potassium dichromate	120-160	48,400	48,400	White, Manuscript
Striped shiner, _Notropis chrysocephalus_	S, M	Potassium dichromate	120-160	85,600	85,600	White, Manuscript
Sand shiner, _Notropis stramineus_	S, M	Potassium dichromate	120-160	74,600	74,600	White, Manuscript
Bluntnose minnow, _Pimephales notatus_	S, M	Potassium dichromate	120-160	54,225	54,225	White, Manuscript
Fathead minnow, _Pimephales promelas_	S, M	Potassium dichromate	120-160	58,000	-	White, Manuscript
Fathead minnow, _Pimephales promelas_	S, U	Potassium dichromate	209	39,700	-	Pickering, 1980
Fathead minnow, _Pimephales promelas_	S, U	Potassium dichromate	209	32,700	-	Pickering, 1980
Fathead minnow, _Pimephales promelas_	S, U	Potassium dichromate	20	17,600	-	Pickering & Henderson, 1966
Fathead minnow, _Pimephales promelas_	S, U	Potassium dichromate	360	27,300	-	Pickering & Henderson, 1966

Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Fathead minnow, *Pimephales promelas*	S, U	Potassium chromate	20	45,600	-	Pickering & Henderson, 1966
Fathead minnow, *Pimephales promelas*	FT, M	Potassium dichromate	220	56,000	-	Adelman & Smith, 1976
Fathead minnow, *Pimephales promelas*	FT, M	Potassium dichromate	220	51,000	-	Adelman & Smith, 1976
Fathead minnow, *Pimephales promelas*	FT, M	Potassium dichromate	220	53,000	-	Adelman & Smith, 1976
Fathead minnow, *Pimephales promelas*	FT, M	Potassium dichromate	220	49,000	-	Adelman & Smith, 1976
Fathead minnow, *Pimephales promelas*	FT, M	Potassium dichromate	220	48,000	-	Adelman & Smith, 1976
Fathead minnow, *Pimephales promelas*	FT, M	Potassium dichromate	220	60,000	-	Adelman & Smith, 1976
Fathead minnow, *Pimephales promelas*	FT, M	Potassium dichromate	220	50,000	-	Adelman & Smith, 1976
Fathead minnow, *Pimephales promelas*	FT, M	Potassium dichromate	220	53,000	-	Adelman & Smith, 1976
Fathead minnow, *Pimephales promelas*	FT, M	Potassium dichromate	220	49,000	-	Adelman & Smith, 1976
Fathead minnow, *Pimephales promelas*	FT, M	Potassium dichromate	220	37,000	-	Adelman & Smith, 1976
Fathead minnow, *Pimephales promelas*	FT, M	Potassium dichromate	220	66,000	-	Adelman & Smith, 1976
Fathead minnow, *Pimephales promelas*	FT, M	Potassium dichromate	220	55,000	-	Adelman & Smith, 1976
Fathead minnow, *Pimephales promelas*	FT, M	Potassium dichromate	220	38,000	-	Adelman & Smith, 1976

Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Fathead minnow, *Pimephales promelas*	FT, M	Potassium dichromate	220	34,000	-	Adelman & Smith, 1976
Fathead minnow, *Pimephales promelas*	FT, M	Potassium dichromate	220	29,000	-	Adelman & Smith, 1976
Fathead minnow, *Pimephales promelas*	FT, M	Potassium dichromate	220	34,000	-	Adelman & Smith, 1976
Fathead minnow, *Pimephales promelas*	FT, M	Potassium dichromate	220	26,000	-	Adelman & Smith, 1976
Fathead minnow, *Pimephales promelas*	FT, M	Sodium dichromate	220	33,200	-	Broderius & Smith, 1979
Fathead minnow, *Pimephales promelas*	FT, M	Potassium dichromate	209	37,700	-	Pickering, 1980
Fathead minnow, *Pimephales promelas*	FT, M	Potassium dichromate	209	37,000	-	Pickering, 1980
Fathead minnow, *Pimephales promelas*	FT, M	Potassium dichromate	209	35,900	-	Pickering, 1980
Fathead minnow, *Pimephales promelas*	FT, M	-	-	52,000	-	Ruesink & Smith, 1975
Fathead minnow, *Pimephales promelas*	FT, M	-	-	37,000	-	Ruesink & Smith, 1975
Fathead minnow, *Pimephales promelas*	FT, M	Potassium dichromate	400	24,140	-	Waheda, 1977
Fathead minnow, *Pimephales promelas*	FT, M	Potassium dichromate	400	22,580	41,050	Waheda, 1977
Guppy, *Poecilia reticulata*	S, U	Potassium dichromate	20	30,000	30,000	Pickering & Henderson, 1966
Striped bass, *Morone saxatilis*	S, U	Potassium dichromate	35	35,000	-	Hughes, 1973

Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Striped bass, *Morone saxatilis*	S, U	Potassium dichromate	35	26,500	30,450	Hughes, 1973
Green sunfish, *Lepomis cyanellus*	FT, M	Potassium dichromate	400	89,160	-	Waheda, 1977
Green sunfish, *Lepomis cyanellus*	FT, M	Potassium dichromate	400	147,560	114,700	Waheda, 1977
Bluegill, *Lepomis macrochirus*	S, U	Potassium dichromate	20	118,000	-	Pickering & Henderson, 1966
Bluegill, *Lepomis macrochirus*	S, U	Potassium dichromate	360	133,000	-	Pickering & Henderson, 1966
Bluegill, *Lepomis macrochirus*	S, U	Potassium dichromate	45	110,000	-	Trama & Benoit, 1960
Bluegill, *Lepomis macrochirus*	S, U	Potassium chromate	45	170,000	-	Trama & Benoit, 1960
Bluegill, *Lepomis macrochirus*	S, U	Potassium dichromate	44	113,000	-	Cairns & Scheier, 1958, 1959, 1968; Patrick, et al. 1968
Bluegill, *Lepomis macrochirus*	S, U	Potassium dichromate	44	113,000	-	Cairns & Scheier, 1959
Bluegill, *Lepomis macrochirus*	S, U	Potassium dichromate	44	113,000	-	Cairns & Scheier, 1959
Bluegill, *Lepomis macrochirus*	S, U	Potassium chromate	44	120,000	-	Cairns & Scheier, 1959
Bluegill, *Lepomis macrochirus*	S, U	Potassium chromate	44	168,800	-	Cairns & Scheier, 1959; Patrick, et al. 1968
Bluegill, *Lepomis macrochirus*	S, U	Potassium chromate	44	147,000	-	Cairns & Scheier, 1959

Table I. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Bluegill, *Lepomis macrochirus*	S, U	Potassium dichromate	171	135,000	-	Academy of Natural Sciences, 1960
Bluegill, *Lepomis macrochirus*	S, U	Potassium dichromate	171	130,400	-	Academy of Natural Sciences, 1960
Bluegill, *Lepomis macrochirus*	S, M	Potassium dichromate	120-160	144,500	-	White, Manuscript
Bluegill, *Lepomis macrochirus*	FT, M	Potassium dichromate	20-44	132,890††††	132,900	Cairns, et al. 1981
White crappie, *Pomoxis annularis*	S, M	Potassium dichromate	120-160	72,600	72,600	White, Manuscript
Johnny darter, *Etheostoma nigrum*	S, M	Potassium dichromate	120-160	46,000	46,000	White, Manuscript
Yellow perch, *Perca flavescens*	S, M	Potassium dichromate	120-160	36,300	36,300	White, Manuscript
			Chromium(III)			
Worm, *Nais* sp.	S, M	-	50	9,300	9,300	Rehwoldt, et al. 1973
Snail (embryo), *Amnicola* sp.	S, M	-	50	12,400	-	Rehwoldt, et al. 1973
Snail (adult), *Amnicola* sp.	S, M	-	50	8,400	10,210	Rehwoldt, et al. 1973
Cladoceran, *Daphnia magna*	S, U	Chromic chloride	-	1,200	-	Anderson, 1948
Cladoceran, *Daphnia magna*	S, M	Chromic nitrate	52	16,800	-	Chapman, et al. Manuscript
Cladoceran, *Daphnia magna*	S, M	Chromic nitrate	99	27,400	-	Chapman, et al. Manuscript

Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Cladoceran, *Daphnia magna*	S, M	Chromic nitrate	110	26,300	-	Chapman, et al. Manuscript
Cladoceran, *Daphnia magna*	S, M	Chromic nitrate	195	51,400	-	Chapman, et al. Manuscript
Cladoceran, *Daphnia magna*	S, M	Chromic nitrate	215	58,700	16,010	Chapman, et al. Manuscript
Amphipod, *Gammarus* sp.	S, M	-	50	3,200	3,200	Rehwoldt, et al. 1973
Crayfish, *Orconectes limosus*	S, M	Chromium chloride	-	6,600	-	Boutet & Chaisemartin, 1973
Mayfly, *Ephemerella subvaria*	S, U	Chromic chloride	44	2,000	2,221	Warnick & Bell, 1969
Damselfly, (Unidentified)	S, M	-	50	43,100	43,100	Rehwoldt, et al. 1973
Caddisfly, *Hydropsyche betteni*	S, U	Chromic chloride	44	64,000	71,060	Warnick & Bell, 1969
Caddisfly, (Unidentified)	S, M	-	50	50,000	50,000	Rehwoldt, et al. 1973
Midge, *Chironomus* sp.	S, M	-	50	11,000	11,000	Rehwoldt, et al. 1973
American eel, *Anguilla rostrata*	S, M	-	55	13,900	12,860	Rehwoldt, et al. 1972
Rainbow trout (2 mos), *Salmo gairdneri*	FT, M	Chromic nitrate	-	24,100	-	Hale, 1977
Rainbow trout, *Salmo gairdneri*	S, U	Chromium Chloride	44	11,200	-	Bills, et al. 1977; Marking, 1982
Rainbow trout, *Salmo gairdneri*	FT, M	Chromium nitrate	26	4,400	9,669	Stevens & Chapman, 1984
Goldfish, *Carassius auratus*	S, U	Chromium potassium sulfate	20	4,100	8,684	Pickering & Henderson, 1966

Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Common carp, Cyprinus carpio	S, M	-	55	14,300	13,230	Rehwoldt, et al. 1972
Fathead minnow, Pimephales promelas	S, U	Chromium potassium sulfate	20	5,070	-	Pickering & Henderson, 1966
Fathead minnow, Pimephales promelas	S, U	Chromium potassium sulfate	360	67,400	-	Pickering & Henderson, 1966
Fathead minnow, Pimephales promelas	FT, M	Chromium potassium sulfate	203	29,000	-	Pickering, Manuscript
Fathead minnow, Pimephales promelas	FT, M	Chromium potassium sulfate	203	27,000	10,320	Pickering, Manuscript
Banded killifish, Fundulus diaphanus	S, M	-	55	16,900	15,630	Rehwoldt, et al. 1972
Guppy, Poecilia reticulata	S, U	Chromium potassium sulfate	20	3,330	7,053	Pickering & Henderson, 1966
White perch, Morone americana	S, M	-	55	14,400	13,320	Rehwoldt, et al. 1972
Striped bass, Morone saxatilis	S, M	-	55	17,700	16,370	Rehwoldt, et al. 1972
Pumpkinseed, Lepomis gibbosus	S, M	-	55	17,000	15,720	Rehwoldt, et al. 1972
Bluegill, Lepomis macrochirus	S, U	Chromium potassium sulfate	20	7,460	-	Pickering & Henderson, 1966
Bluegill, Lepomis macrochirus	S, U	Chromium potassium sulfate	360	71,900	15,020	Pickering & Henderson, 1966
			SALTWATER SPECIES			
			Chromium(VI)			
Polychaete worm, Neanthes arenaceodentata	S, M	Potassium dichromate	-	3,100	3,100	Mearns, et al. 1976

Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Sand worm, *Nereis virens*	S, U	Potassium chromate	-	2,000	2,000	Eisler & Hennekey, 1977
Polychaete worm, *Ophryotrocha diadema*	S, U	Chromium trioxide	-	7,500	7,500	Reish & Carr, 1978
Polychaete worm, *Ctendrilus serratus*	S, U	Chromium trioxide	-	4,300	4,300	Reish & Carr, 1978
Polychaete worm (larva), *Capitella capitata*	S, U	Chromium trioxide	-	8,000	-	Reish, et al. 1976
Polychaete worm (adult), *Capitella capitata*	S, U	Chromium trioxide	-	5,000	6,325	Reish, et al. 1976
Mud snail, *Nassarius obsoletus*	S, U	Potassium chromate	-	105,000	105,000	Eisler & Hennekey, 1977
Blue mussel (embryo), *Mytilus edulis*	S, U	Potassium dichromate	-	4,469	4,469	Martin, et al. 1981
Pacific oyster, *Crassostrea gigas*	S, U	Potassium dichromate	-	4,538	4,538	Martin, et al. 1981
Common rangia, *Rangia cuneata*	S, U	Potassium dichromate	-	14,000	-	Olson & Harrel, 1973
Common rangia, *Rangia cuneata*	S, U	Potassium dichromate	-	35,000	22,140	Olson & Harrel, 1973
Soft-shell clam, *Mya arenaria*	S, U	Potassium chromate	-	57,000	57,000	Eisler & Hennekey, 1977
Copepod, *Pseudodiaptomus coronatus*	S, U	Potassium dichromate	-	3,650	3,650	Gentile, 1982
Copepod, *Acartia clausi*	S, U	Potassium dichromate	-	6,600	6,600	Gentile, 1982
Mysid, *Mysidopsis bahia*	S, M	Potassium dichromate	-	2,030	2,030	Lussier, et al. Manuscript

Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Mysid, *Mysidopsis bigelowi*	S, M	Potassium dichromate	-	4,400	4,400	Gentile, 1982
Hermit crab, *Pagurus longicarpus*	S, U	Potassium chromate	-	10,000	10,000	Eisler & Hennekey, 1977
Dungeness crab, *Cancer magister*	S, U	Potassium dichromate	-	3,440	3,440	Martin, et al. 1981
Blue crab, *Callinectes sapidus*	S, U	Potassium dichromate	-	89,000	-	Frank & Robertson, 1979
Blue crab, *Callinectes sapidus*	S, U	Potassium dichromate	-	98,000	93,390	Frank & Robertson, 1979
Starfish, *Asterias forbesi*	S, U	Potassium chromate	-	32,000	32,000	Eisler & Hennekey, 1977
Mummichog, *Fundulus heteroclitus*	S, U	Potassium chromate	-	91,000	-	Eisler & Hennekey, 1977
Mummichog, *Fundulus heteroclitus*	S, U	Potassium chromate	-	55,000	-	Dorfman, 1977
Mummichog, *Fundulus heteroclitus*	S, U	Potassium chromate	-	81,000	74,010	Dorfman, 1977
Atlantic silverside (larva), *Menidia menidia*	S, U	Potassium dichromate	-	12,400	-	Cardin, 1982
Atlantic silverside (larva), *Menidia menidia*	S, U	Potassium dichromate	-	14,300	-	Cardin, 1982
Atlantic silverside (juvenile), *Menidia menidia*	S, U	Potassium dichromate	-	20,100	15,280	Cardin, 1982
Tidewater silverside, *Menidia peninsulae*	S, U	Potassium dichromate	-	22,000	22,000	Hansen, 1983

Table 1. (Continued)

Species	Method*	Chemical	Hardness (mg/L as $CaCO_3$)	LC50 or EC50 (µg/L)**	Species Mean Acute Value (µg/L)***	Reference
Spot, *Leiostomus xanthurus*	S, U	Potassium dichromate	-	27,000	27,000	Hansen, 1983
Speckled sanddab, *Citharichthys stigmaeus*	S, U	Potassium dichromate	-	31,000	-	Sherwood, 1975
Speckled sanddab, *Citharichthys stigmaeus*	S, U	Potassium dichromate	-	30,000	30,500	Mearns, et al. 1976
		Chromium(III)				
Eastern oyster, *Crassostrea virginica*	S, U	Chromium chloride	-	10,300	10,300	Calabrese, et al. 1973
Mummichog, *Fundulus heteroclitus*	S, U	Chromium chloride	-	31,500	-	Dorfman, 1977
Mummichog, *Fundulus heteroclitus*	S, U	Chromium chloride	-	31,500	31,500	Dorfman, 1977

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

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

*** For chromium(III) in fresh water, Species Mean Acute Values are calculated for a hardness of 50 mg/L using the pooled slope.

† pH = 8.2 to 8.4.

†† pH = 7.5 to 7.6.

††† pH = 7.5.

†††† Published as average of results of two tests, one at hardness of 20-22 mg/L and one at 42-44 mg/L.

Table 1. (Continued)

Results of Covariance Analysis of Freshwater Acute Toxicity of Chromium(III) versus Hardness

Species	n	Slope	95% Confidence Limits	Degrees of Freedom
Daphnia magna	5	0.8872	0.6073, 1.1671	3
Fathead minnow	4	0.8304	0.3641, 1.2968	2
Bluegill	2	0.7839	(cannot be calculated)	0
All of above	11	0.8190*	0.7088, 0.9290	7

* P=0.82 for equality of slopes.

Table 2. Chronic Toxicity of Chromium to Aquatic Animals

Species	Test*	Chemical	Hardness (mg/L as $CaCO_3$)	Limits (µg/L)**	Chronic Value (µg/L)**	Reference
			FRESHWATER SPECIES			
			Chromium(VI)			
Cladoceran, *Ceriodaphnia reticulata*	LC	Sodium dichromate	45	25-64	40.00	Mount, 1982
Cladoceran, *Daphnia magna*	LC	Sodium chromate	-	<10***	<10	Trabalka & Gehrs, 1977
Cladoceran, *Daphnia magna*	LC	Sodium dichromate	45	<2.5***	<2.5	Mount, 1982
Cladoceran, *Daphnia pulex*	LC	Sodium dichromate	45	4.7-8.0	6.132	Mount, 1982
Cladoceran, *Simocephalus serrulatus*	LC	Sodium dichromate	45	13.9-28.5	19.90	Mount, 1982
Cladoceran, *Simocephalus vetulus*	LC	Sodium dichromate	45	4.7-8.0	6.132	Mount, 1982
Rainbow trout, *Salmo gairdneri*	ELS	Chromium trioxide	34	51-105	73.18	Sauter, et al. 1976
Rainbow trout, *Salmo gairdneri*	ELS	Sodium dichromate	45	200-350	264.6	Benoit, 1976
Brook trout, *Salvelinus fontinalis*	LC	Sodium dichromate	45	200-350	264.6	Benoit, 1976
Fathead minnow, *Pimephales promelas*	LC	Potassium dichromate	209	1,000-3,950	1,987	Pickering, 1980
			Chromium(III)			
Cladoceran, *Daphnia magna*	LC	Chromic nitrate	52	47-93	66.11	Chapman, et al. Manuscript
Cladoceran, *Daphnia magna*	LC	Chromic nitrate	100	129-291	193.7	Chapman, et al. Manuscript
Cladoceran, *Daphnia magna*	LC	Chromic nitrate	206	<44***	<44	Chapman, et al. Manuscript
Rainbow trout, *Salmo gairdneri*	ELS	Chromium nitrate	26	30-157	68.63	Stevens & Chapman, 1984

Table 2. (Continued)

Species	Test*	Chemical	Hardness (mg/L as $CaCO_3$)	Limits (µg/L)**	Chronic Value (µg/L)**	Reference
Fathead minnow, *Pimephales promelas*	LC	Chromium potassium sulfate	203	750-1,400	1,025	Pickering, Manuscript
		SALTWATER SPECIES				
		Chromium(VI)				
Polychaete worm (parental generation), *Neanthes arenaceodentata*	LC	Potassium dichromate	-	16.6-38.2	25.18	Oshida & Word, 1982
Polychaete worm (F_1 generation), *Neanthes arenaceodentata*	LC	Potassium dichromate	-	16.6-38.2	25.18	Oshida & Word, 1982
Polychaete worm (parental generation), *Neanthes arenaceodentata*	LC	Potassium dichromate	-	<13***	<13	Oshida, et al. 1976, 1981
Polychaete worm (F_1 generation), *Neanthes arenaceodentata*	LC	Potassium dichromate	-	13-25	18.03	Oshida, et al. 1976, 1981
Polychaete worm (F_2 generation), *Neanthes arenaceodentata*	LC	Potassium dichromate	-	25-54	36.74	Oshida, et al. 1976, 1981
Mysid, *Mysidopsis bahia*	LC	Potassium dichromate	-	88-198	132.0	Lussier, et al. Manuscript
		Chromium(III)				
Polychaete worm (parental and F_1 generations), *Neanthes arenaceodentata*	LC	Chromium chloride	-	>50,400	>50,400	Oshida, et al. 1976, 1981

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

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

***Adverse effects occurred at all concentrations tested.

Table 2. (Continued)

Acute-Chronic Ratio

Species	Hardness (mg/L as $CaCO_3$)	Acute Value (µg/L)	Chronic Value (µg/L)	Ratio
		Chromium(VI)		
Cladoceran, *Ceriodaphnia reticulata*	45	45.2	40.00	1.130
Cladoceran, *Daphnia magna*	-	50	<10	>5.000
Cladoceran, *Daphnia magna*	45	24.2	<2.5	>9.680
Cladoceran, *Daphnia pulex*	45	36.3	6.132	5.920
Cladoceran, *Simocephalus serrulatus*	45	40.9	19.90	2.055
Cladoceran, *Simocephalus vetulus*	45	32.3	6.132	5.267
Rainbow trout, *Salmo gairdneri*	45	69,000	264.6	260.8
Brook trout, *Salvelinus fontinalis*	45	59,000	264.6	223.0
Fathead minnow, *Pimephales promelas*	209	36,860†	1,987	18.55
Polychaete worm, *Neanthes arenaceodentata*	-	3,100	25.18	123.1
Polychaete worm, *Neanthes arenaceodentata*	-	3,100	25.18	123.1
Polychaete worm, *Neanthes arenaceodentata*	-	3,100	<13	>238.5
Polychaete worm, *Neanthes arenaceodentata*	-	3,100	18.03	171.9

Table 2. (Continued)

Acute-Chronic Ratio

Species	Hardness (mg/L as $CaCO_3$)	Acute Value (μg/L)	Chronic Value (μg/L)	Ratio
Polychaete worm, *Neanthes arenaceodentata*	-	3,100	36.74	84.38
Mysid, *Mysidopsis bahia*	-	2,030	132.0	15.38
		Chromium(III)		
Cladoceran, *Daphnia magna*	52	16,800	66.11	254.1
Cladoceran, *Daphnia magna*	100	27,400	193.7	141.5
Cladoceran, *Daphnia magna*	206	55,380[††]	<44	>1,259
Rainbow trout, *Salmo gairdneri*	26	4,400	68.63	64.11
Fathead minnow, *Pimephales promelas*	203	27,980[†††]	1,025	27.30

† Geometric mean of values from three flow-through tests from Pickering (1980) in Table 1.

†† Calculated by log-log interpolation between results of acute tests at hardnesses of 195 and 215 μg/L from Chapman, et al. (Manuscript) in Table 1.

††† Geometric mean of two values from Pickering (Manuscript) 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		
		Chromium(VI)		
27	1,870,000	Stonefly, Neophasganophora capitata	1,870,000	-
26	176,000	Crayfish, Orconectes rusticus	176,000	-
25	140,000	Damselfly, Enallagma aspersum	140,000	-
24	123,500	Green sunfish, Lepomis cyanellus	114,700	-
		Bluegill, Lepomis macrochirus	132,900	-
23	119,500	Goldfish, Carassius auratus	119,500	-
22	72,600	White crapple, Pomoxis annularis	72,600	-
21	69,000	Rainbow trout, Salmo gairdneri	69,000	260.8
20	67,610	Emerald shiner, Notropis atherinoides	48,400	-
		Striped shiner, Notropis chrysocephalus	85,600	-
		Sand shiner, Notropis stramineus	74,600	-
19	61,000	Midge, Chironomus tentans	61,000	-

Table 3. (Continued)

Rank*	Genus Mean Acute Value (µg/L)**	Species	Species Mean Acute Value (µg/L)**	Species Mean Acute-Chronic Ratio
18	59,000	Brook trout, *Salvelinus fontinalis*	59,000	223.0
17	57,300	Midge, *Tanytarsus dissimilis*	57,300	-
16	51,250	Central stoneroller, *Campostoma anomalum*	51,250	-
15	49,600	Silverjaw minnow, *Ericymba buccata*	49,600	-
14	47,180	Bluntnose minnow, *Pimephales notatus*	54,225	-
		Fathead minnow, *Pimephales promelas*	41,050	18.55
13	46,000	Johnny darter, *Etheostoma nigrum*	46,000	-
12	36,300	Yellow perch, *Perca flavescens*	36,300	-
11	30,450	Striped bass, *Morone saxatilis*	30,450	-
10	30,000	Guppy, *Poecilia reticulata*	30,000	-
9	23,010	Snail, *Physa heterostropha*	23,010	-
8	1,560	Bryozoan, *Lophopodella carteri*	1,560	-

Table 3. (Continued)

Rank*	Genus Mean Acute Value (µg/L)**	Species	Species Mean Acute Value (µg/L)**	Species Mean Acute-Chronic Ratio
7	1,440	Bryozoan, *Pectinatella magnifica*	1,440	-
6	650	Bryozoan, *Plumatella emarginata*	650	-
5	630	Amphipod, *Hyalella azteca*	630	-
4	67.1	Amphipod, *Gammarus pseudolimnaeus*	67.1	-
3	45.10	Cladoceran, *Ceriodaphnia reticulata*	45.10	1.130
2	36.35	Cladoceran, *Simocephalus serrulatus*	40.9	2.055
		Cladoceran, *Simocephalus vetulus*	32.3	5.267
1	28.94	Cladoceran, *Daphnia magna*	23.07	>6.957†
		Cladoceran, *Daphnia pulex*	36.3	5.920
		Chromium(III)		
18	71,060	Caddisfly, *Hydropsyche betteni*	71,060	-
17	50,000	Caddisfly, (Unidentified)	50,000	-
16	43,100	Damselfly, (Unidentified)	43,100	-

Table 3. (Continued)

Rank*	Genus Mean Acute Value (µg/L)**	Species	Species Mean Acute Value (µg/L)**	Species Mean Acute-Chronic Ratio
15	16,010	Cladoceran, *Daphnia magna*	16,010	>356.4[††]
14	15,630	Banded killifish, *Fundulus diaphanus*	15,630	-
13	15,370	Pumpkinseed, *Lepomis gibbosus*	15,720	-
		Bluegill, *Lepomis macrochirus*	15,020	-
12	14,770	White perch, *Morone americana*	13,320	-
		Striped bass, *Morone saxatilis*	16,370	-
11	13,230	Common carp, *Cyprinus carpio*	13,230	-
10	12,860	American eel, *Anguilla rostrata*	12,860	-
9	11,000	Midge, *Chironomus* sp.	11,000	-
8	10,320	Fathead minnow, *Pimephales promelas*	10,320	27.30
7	10,210	Snail, *Amnicola* sp.	10,210	-
6	9,669	Rainbow trout, *Salmo gairdneri*	9,669	64.11
5	9,300	Worm, *Nais* sp.	9,300	-
4	8,684	Goldfish, *Carassius auratus*	8,684	-

Table 3. (Continued)

Rank*	Genus Mean Acute Value (µg/L)**	Species	Species Mean Acute Value (µg/L)**	Species Mean Acute-Chronic Ratio
3	7,053	Guppy, *Poecilia reticulata*	7,053	-
2	3,200	Amphipod, *Gammarus* sp.	3,200	-
1	2,221	Mayfly, *Ephemerella subvaria*	2,221	-
		SALTWATER SPECIES		
		Chromium(VI)		
21	105,000	Mud snail, *Nassarius obsoletus*	105,000	-
20	93,390	Blue crab, *Callinectes sapidus*	93,390	-
19	74,010	Mummichog, *Fundulus heteroclitus*	74,010	-
18	57,000	Soft-shell clam, *Mya arenaria*	57,000	-
17	32,000	Starfish, *Asterias forbesi*	32,000	-
16	30,500	Speckled sanddab, *Citharichthys stigmaeus*	30,500	-
15	27,000	Spot, *Leiostomus xanthurus*	27,000	-
14	22,140	Common rangia, *Rangia cuneata*	22,140	-

Table 3. (Continued)

Rank*	Genus Mean Acute Value (µg/L)**	Species	Species Mean Acute Value (µg/L)**	Species Mean Acute-Chronic Ratio
13	18,330	Atlantic silverside, *Menidia menidia*	15,280	-
		Tidewater silverside, *Menidia peninsulae*	22,000	-
12	10,000	Hermit crab, *Pagurus longicarpus*	10,000	-
11	7,500	Polychaete worm, *Ophryotrocha diadema*	7,500	-
10	6,600	Copepod, *Acartia clausi*	6,600	-
9	6,325	Polychaete worm, *Capitella capitata*	6,325	-
8	4,538	Pacific oyster, *Crassostrea gigas*	4,538	-
7	4,469	Blue mussel, *Mytilus edulis*	4,469	-
6	4,300	Polychaete worm, *Ctenodrilus serratus*	4,300	-
5	3,650	Copepod, *Pseudodiaptomus coronatus*	3,650	-
4	3,440	Dungeness crab, *Cancer magister*	3,440	-
3	3,100	Polychaete worm, *Neanthes arenaceodentata*	3,100	121.8†††

Table 3. (Continued)

Rank*	Genus Mean Acute Value (µg/L)**	Species	Species Mean Acute Value (µg/L)**	Species Mean Acute-Chronic Ratio
2	2,989	Mysid, *Mysidopsis bahia*	2,030	15.38
		Mysid, *Mysidopsis bigelowi*	4,400	-
1	2,000	Polychaete worm, *Nereis virens*	2,000	-

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

** Freshwater Genus Mean Acute Values and Species Mean Acute Values for chromium(III) are at a hardness of 50 mg/L.

† Geometric mean of two values in Table 2.

†† Geometric mean of three values in Table 2.

††† Geometric mean of four values in Table 2.

<u>Chromium(VI)</u>

<u>Fresh water</u>

Final Acute Value = 31.49 µg/L

Criterion Maximum Concentration = (31.49 µg/L) / 2 = 15.74 µg/L

Final Acute-Chronic Ratio = 2.917 (see text)

Final Chronic Value = (31.49 µg/L) / 2.917 = 10.80 µg/L.

<u>Salt water</u>

Final Acute Value = 2,158 µg/L

Criterion Maximum Concentration = (2,158 µg/L) / 2 = 1,079 µg/L

Final Acute-Chronic Ratio = 43.28 (see text)

Final Chronic Value = (2,158 µg/L) / 43.28 = 49.86 µg/L

Table 3. (Continued)

<u>Chromium(III)</u>

<u>Fresh water</u>

Final Acute Value = 1,968 µg/L (at a hardness of 50 mg/L)

Criterion Maximum Concentration = (1,968 µg/L) / 2 = 984.0 µg/L (at a hardness of 50 mg/L)

Pooled Slope = 0.8190 (see Table 1)

ln(Criterion Maximum Intercept) = ln(984.0) - [slope x ln(50)]

= 6.892 - (0.8190 x 3.912) = 3.688

Criterion Maximum Concentration = $e^{(0.8190[\ln(\text{hardness})]+3.688)}$

Final Chronic Value = 68.63 µg/L (at a hardness of 26 mg/L) (see text)

Assumed Chronic Slope = 0.8190 (see text)

ln(Final Chronic Intercept) = ln(68.63) - [slope x ln(26)]

= 4.229 - (0.8190 x 3.258) = 1.561

Final Chronic Value = $e^{(0.8190[\ln(\text{hardness})]+1.561)}$

Table 4. Toxicity of Chromium to Aquatic Plants

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Effect	Result (µg/L)*	Reference
		FRESHWATER SPECIES			
		Chromium(VI)			
Green alga, *Chlamydomonas reinhardi*	Potassium dichromate	-	Reduction in growth	10	Zarafonetis & Hampton, 1974
Green alga, *Chlorella pyrenoidosa*	-	-	50% inhibition of growth	5,000	Wium-Anderson, 1974
Green alga, *Scenedesmus* sp.	Potassium dichromate	-	Inhibition of growth	500	Staub, et al. 1973
Blue alga, *Microcystis aeruginosa*	Sodium dichromate	-	Incipient inhibition	2	Bringmann, 1975; Bringmann & Kuhn, 1976, 1978a,b
Green alga, *Scenedesmus quadricauda*	Sodium dichromate	-	Incipient inhibition	580	Bringmann & Kuhn, 1977a, 1978a,b, 1979, 1980b
Green alga, *Scenedesmus quadricauda*	Potassium dichromate	45	Inhibition of growth	500	Cairns, et al. 1978
Green alga, *Selenastrum capricornutum*	Sodium chromate	-	Inhibition of growth	62	Garton, 1973
Green alga, *Selenastrum capricornutum*	Sodium dichromate	53	50% inhibition of growth in 4 days	183	Richter, 1982
Green alga, *Selenastrum capricornutum*	Sodium dichromate	53	**	>1,050	Richter, 1982
Euglena, *Euglena gracilis*	Potassium dichromate	-	Abnormal growth	1,500	Fasulo, et al. 1983
Diatom, *Cyclotella meneghiniana*	Potassium dichromate	45	Growth inhibition	500	Cairns, et al. 1978
Diatom, *Navicula seminulum*	Potassium dichromate	45	50% growth reduction	187	Academy of Natural Sciences, 1960
Diatom, *Navicula seminulum*	Potassium dichromate	45	50% growth reduction	230	Academy of Natural Sciences, 1960
Diatom, *Navicula seminulum*	Potassium dichromate	45	50% growth reduction	251	Academy of Natural Sciences, 1960

Table 4. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Effect	Result (µg/L)*	Reference
Diatom, <u>Navicula seminulum</u>	Potassium dichromate	45	50% growth reduction	272	Academy of Natural Sciences, 1960
Diatom, <u>Navicula seminulum</u>	Potassium dichromate	45	50% growth reduction	308	Academy of Natural Sciences, 1960
Diatom, <u>Navicula seminulum</u>	Potassium dichromate	45	50% growth reduction	237	Academy of Natural Sciences, 1960
Diatom, <u>Navicula seminulum</u>	Potassium dichromate	171	50% growth reduction	254	Academy of Natural Sciences, 1960
Diatom, <u>Navicula seminulum</u>	Potassium dichromate	171	50% growth reduction	254	Academy of Natural Sciences, 1960
Diatom, <u>Navicula seminulum</u>	Potassium dichromate	171	50% growth reduction	343	Academy of Natural Sciences, 1960
Diatom, <u>Navicula seminulum</u>	Potassium dichromate	171	50% growth reduction	343	Academy of Natural Sciences, 1960
Diatom, <u>Navicula seminulum</u>	Potassium dichromate	171	50% growth reduction	424	Academy of Natural Sciences, 1960
Diatom, <u>Navicula seminulum</u>	Potassium dichromate	171	50% growth reduction	442	Academy of Natural Sciences, 1960
Diatom, <u>Nitzschia linearis</u>	Potassium dichromate	295	LC50 (120 hrs)	208	Patrick, et al. 1968
Diatom, <u>Nitzschia linearis</u>	Potassium chromate	295	LC50 (120 hrs)	7,800	Patrick, et al. 1968
Diatom, <u>Nitzschia palea</u>	-	-	50% of photosynthesis	800	Wium-Anderson, 1974
Diatom, <u>Nitzschia palea</u>	-	-	Inhibition of growth	150	Wium-Anderson, 1974
Eurasian watermilfoil <u>Myriophyllum spicatum</u>	Dichromate***	-	32-day EC50 (root weight)	910	Stanley, 1974

Table 4. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Effect	Result (µg/L)*	Reference
		Chromium(III)			
Green alga, *Selenastrum capricornutum*	Chromium chloride	53	50% inhibition of growth in 4 days	397	Richter, 1982
Green alga, *Selenastrum capricornutum*	Chromium chloride	53	**	>1,000	Richter, 1982
Eurasian watermilfoil, *Myriophyllum spicatum*	-	-	32-day EC50 (root weight)	9,900	Stanley, 1974
		SALTWATER SPECIES			
		Chromium(VI)			
Alga, *Macrocystis pyrifera*	-	-	50% inhibition of photosynthesis in 4 days	5,000	Clendenning & North, 1959
Alga, *Macrocystis pyrifera*	Potassium dichromate	-	10 - 20% inhibition of photosynthesis in 5 days	1,000	Bernhard & Zattera, 1975

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

** Highest concentration that would not have killed a significant number of cells in 5 days.

***Cation not specified.

Table 5. Bioaccumulation of Chromium by Aquatic Organisms

Species	Tissue	Chemical	Duration (days)	Bioconcentration Factor*	Reference
FRESHWATER SPECIES					
Chromium(VI)					
Rainbow trout, *Salmo gairdneri*	Muscle	Sodium dichromate	22	<1	Buhler, et al. 1977
Rainbow trout, *Salmo gairdneri*	Whole body	Potassium chromate	30	1	Fromm & Stokes, 1962
Rainbow trout, *Salmo gairdneri*	Muscle	Potassium dichromate	180	2.8	Calamari, et al. 1982
SALTWATER SPECIES					
Chromium(VI)					
Polychaete worm, *Neanthes arenaceodentata*	-	-	150	200**	Mearns & Young, 1977
Polychaete worm, *Neanthes arenaceodentata*	-	-	146-163	236	Oshida & Word, 1982
Blue mussel, *Mytilus edulis*	Soft parts	Sodium dichromate	84	192**	Zaroogian & Johnson, 1983
Eastern oyster, *Crassostrea virginica*	Soft parts	Sodium dichromate	84	125**	Zaroogian & Johnson, 1983
Chromium(III)					
Blue mussel, *Mytilus edulis*	Soft parts	Chromic chloride	168	86**	Capuzzo & Sasner, 1977
Eastern oyster, *Crassostrea virginica*	Soft parts	Chromic nitrate	140	116	Shuster & Pringle, 1969
Soft-shell clam, *Mya arenaria*	Soft parts	Chromic chloride	168	153**	Capuzzo & Sasner, 1977

* Results are based on chromium, not the chemical.

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

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

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)*	Reference
			FRESHWATER SPECIES			
			Chromium(VI)			
Algal community	Potassium dichromate	-	1 mo	Diatoms reduced blue green algae dominant	400	Patrick, et al. 1975
Algal community	Potassium dichromate	-	1 mo	Diversity of diatoms reduced	100	Patrick, et al. 1975
Algal community	Potassium dichromate	-	1 mo	BCF=8,500	-	Patrick, et al. 1975
Algal community	Potassium dichromate	-	25 hrs	32% inhibition of photosynthesis	20	Zarafonetis & Hampton, 1974
Green alga, *Scenedesmus quadricauda*	Potassium dichromate	-	96 hrs	Incipient inhibition (river water)	700	Bringmann & Kuhn, 1959a,b
Bacteria, *Escherichia coli*	Potassium dichromate	-	-	Incipient inhibition	700	Bringmann & Kuhn, 1959a
Bacteria, *Pseudomonas putida*	Sodium dichromate	-	16 hrs	Incipient inhibition	380	Bringmann & Kuhn, 1976, 1977a, 1979, 1980b
Protozoan, *Entosiphon sulcatum*	Sodium dichromate	-	72 hrs	Incipient inhibition	9,600 20,000	Bringmann, 1978; Bringmann & Kuhn, 1979, 1980b, 1981
Protozoan, *Microregma heterostoma*	Potassium dichromate	-	28 hrs	Incipient inhibition	210	Bringmann & Kuhn, 1959b
Protozoan, *Chilomonas paramecium*	Sodium dichromate	-	48 hrs	Incipient inhibition	0.12	Bringmann, et al. 1980, 1981
Protozoan, *Uronema parduezi*	Sodium dichromate	-	20 hrs	Incipient inhibition	2,100	Bringmann & Kuhn, 1980a, 1981
Protozoa, *Blepharisma* sp.	Potassium dichromate	-	3 hrs	Some living	32,000	Ruthven & Cairns, 1973

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)*	Reference
Euglena, *Euglena gracilis*	Chromium trioxide	-	3 hrs	Tolerated	1,000	Yongue, et al. 1979
Rotifer, *Philodina acuticornis*	Potassium dichromate	45	48 hrs	LC50 (5 C) (10 C) (15 C) (20 C) (25 C)	54,000 50,600 39,200 31,000 29,000	Cairns, et al. 1978
Worm, *Aeolosoma headleyi*	Potassium dichromate	45	48 hrs	LC50 (5 C) (10 C) (15 C) (20 C) (25 C)	12,100 10,000 8,600 7,000 4,800	Cairns, et al. 1978
Snail, *Goniobasis livescens*	Potassium dichromate	154	48 hrs	LC50	2,400	Cairns, et al. 1976
Snail, *Nitocris* sp.	Potassium dichromate	45	48 hrs	LC50 (5 C) (10 C) (15 C) (20 C) (25 C)	9,100 7,800 3,700 1,200 800	Cairns, et al. 1978
Snail, *Lymnaea emarginata*	Potassium dichromate	154	48 hrs	LC50	34,800	Cairns, et al. 1976
Snail, *Physa integra*	Potassium dichromate	154	48 hrs	LC50	660	Cairns, et al. 1976
Cladoceran, *Daphnia magna*	Potassium dichromate	200	24 hrs	EC50	1,570	Bellavere & Gorbi, 1981
Cladoceran, *Daphnia magna*	Potassium dichromate	86	72 hrs	EC50	31-44	Debelak, 1975
Cladoceran, *Daphnia magna*	Potassium dichromate	163	72 hrs	EC50	64-81	Debelak, 1975
Cladoceran, *Daphnia magna*	Potassium dichromate	45	48 hrs	LC50 (5 C) (10 C) (15 C) (25 C)	7,600 5,600 4,300 560	Cairns, et al. 1978

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)*	Reference
Cladoceran, *Daphnia magna*	Chromium trioxide	-	16 hrs	LC50	<312	Anderson, 1944
Cladoceran, *Daphnia magna*	Potassium dichromate	-	16 hrs	LC50	<212	Anderson, 1944
Cladoceran, *Daphnia magna*	Potassium dichromate	50	48 hrs	EC50 (fed)	21.6	Call, et al. 1981
Cladoceran, *Daphnia magna*	Potassium dichromate	50	96 hrs	EC50 (fed)	16.9	Call, et al. 1981
Cladoceran, *Daphnia magna*	Sodium dichromate	50	48 hrs	EC50 (fed)	19.9	Call, et al. 1981
Cladoceran, *Daphnia magna*	Sodium dichromate	50	96 hrs	EC50 (fed)	24.5	Call, et al. 1981
Cladoceran, *Daphnia magna*	Potassium chromate	50	48 hrs	EC50 (fed)	19.2	Call, et al. 1981
Cladoceran, *Daphnia magna*	Potassium chromate	50	96 hrs	EC50 (fed)	7.39	Call, et al. 1981
Cladoceran, *Daphnia magna*	Sodium chromate	50	48 hrs	EC50 (fed)	21.1	Call, et al. 1981
Cladoceran, *Daphnia magna*	Sodium chromate	50	96 hrs	EC50 (fed)	17.8	Call, et al. 1981
Cladoceran, *Daphnia magna*	Potassium dichromate	-	48 hrs	EC50 (river water)	700	Bringmann & Kuhn, 1959a,b
Cladoceran, *Daphnia magna*	Sodium dichromate	288	24 hrs	LC50	1,400	Bringmann & Kuhn, 1977b
Cladoceran, *Daphnia pulex*	Potassium dichromate	45	48 hrs	LC50 (5 C) (10 C) (15 C) (25 C)	4,800 3,200 900 400	Cairns, et al. 1978

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)*	Reference
Cladoceran, *Daphnia pulex*	Potassium chromate	44	2 hrs	Death (after 22 hours)	100	Lee & Bulkema, 1979
Midge, *Chironomus tentans*	Potassium dichromate	101	1.5 hrs	Supressed respiration	100	Batac-Catalan & White, 1983
Coho salmon, *Oncorhynchus kisutch*	Potassium chromate	-	13 days	LC50	25,000	Holland, et al. 1960
Coho salmon, *Oncorhynchus kisutch*	Potassium dichromate	90	144 hrs	100% survival	5,000	Lorz, et al. 1978
Coho salmon, *Oncorhynchus kisutch*	Sodium dichromate	60	14 days	Mortality after transfer to 30 g/kg seawater	520	Sugatt, 1980a
Coho salmon, *Oncorhynchus kisutch*	Sodium dichromate	60	14 days	Mortality after transfer to 20 g/kg seawater	480	Sugatt, 1980a
Coho salmon, *Oncorhynchus kisutch*	Sodium dichromate	60	28 days	Mortality after transfer to 20 g/kg seawater	230	Sugatt, 1980a
Coho salmon, *Oncorhynchus kisutch*	Sodium dichromate	60	2 wks	Decreased disease resistance	500	Sugatt, 1980b
Coho salmon, *Oncorhynchus kisutch*	Sodium dichromate	60	2 wks	Immunosuppresion	470	Sugatt, 1980b
Chinook salmon, *Oncorhynchus tshawytscha*	Sodium dichromate	70	7 mos	Reduced growth	16	Olson & Foster, 1956
Chinook salmon, *Oncorhynchus tshawytscha*	Potassium dichromate	-	12 wks	Reduced growth and survival	200	Olson, 1958
Chinook salmon (embryo, fingerling), *Oncorhynchus tshawytscha*	Sodium dichromate	70	42 days	No effect on survival in 22 wks	174	Olson & Foster, 1957

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)*	Reference
Chinook salmon (fingerling), Oncorhynchus tshawytscha	Sodium dichromate	70	74 days	47% reduction in growth at 10°C	95	Olson & Foster, 1957
Chinook salmon (fingerling), Oncorhynchus tshawytscha	Sodium dichromate	70	74 days	40% reduction in growth at 5°C	91	Olson & Foster, 1957
Rainbow trout (embryo, larva), Salmo gairdneri	Chromium trioxide	101	28 days	EC50 (death and deformity)	190	Birge, et al. 1980
Rainbow trout (embryo, larva), Salmo gairdneri	Chromium trioxide	101	28 days	EC10 (death and deformity)	56.9	Birge, et al. 1981
Rainbow trout, Salmo gairdneri	Potassium dichromate	36	24 hrs	LC50 (5 C) (15 C) (30 C)	58,900 141,000 95,500	Cairns, et al. 1978
Rainbow trout, Salmo gairdneri	Potassium dichromate	70	7 days	Plasma "cortisol"	20	Hill & Fromm, 1968
Rainbow trout, Salmo gairdneri	Hexavalent chromium	-	2 days	Inhibited Na/K-ATPase	2,500	Kuhnert, et al. 1976
Rainbow trout (larva, fingerling), Salmo gairdneri	Sodium dichromate	70	16 wks	Reduced growth	21	Olson & Foster, 1956
Rainbow trout, Salmo gairdneri	Potassium chromate	334	24 hrs	Hematocrits	2,000	Schiffman & Fromm, 1959
Rainbow trout, Salmo gairdneri	Potassium chromate	334	24 hrs	LC50	100,000	Schiffman & Fromm, 1959
Rainbow trout, Salmo gairdneri	Potassium dichromate	-	15 days	Death	10,000	Strik, et al. 1975
Rainbow trout, Salmo gairdneri	Potassium dichromate	27	15 days	25% mortality	10,000	Strik, et al. 1975
Rainbow trout, Salmo gairdneri	Potassium dichromate	27	15-22 days	Alteration of some blood parameters	10,000	Strik, et al. 1975
Rainbow trout (adult), Salmo gairdneri	Potassium dichromate	320	6 mos	Decrease of total liver glucides in males	200	Arillo, et al. 1982

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)*	Reference
Rainbow trout (adult), *Salmo gairdneri*	Potassium dichromate	320	6 mos	Increase in liver proteolytic activity of males	200	Arillo, et al. 1982
Rainbow trout (yearling), *Salmo gairdneri*	Sodium chromate	80	96 hrs	25% survival (pH 6.5)	16,500	van der Putte, et al. 1981
Rainbow trout (yearling), *Salmo gairdneri*	Sodium chromate	80	96 hrs	63% survival (pH 7.8)	16,500	van der Putte, et al. 1981
Rainbow trout (yearling), *Salmo gairdneri*	Sodium chromate	80	96 hrs	0% survival (pH 6.5)	50,000	van der Putte, et al. 1981
Rainbow trout (yearling), *Salmo gairdneri*	Sodium chromate	80	96 hrs	50% survival (pH 7.8)	50,000	van der Putte, et al. 1981
Rainbow trout (eyed embryo, juvenile), *Salmo gairdneri*	Sodium chromate	80	32 wks	0% survival (pH 6.5)	2,000	van der Putte, et al. 1982
Rainbow trout (eyed embryo, juvenile), *Salmo gairdneri*	Sodium chromate	80	32 wks	32% survival (pH 7.8)	2,000	van der Putte, et al. 1982
Rainbow trout (eyed embryo, juvenile), *Salmo gairdneri*	Sodium chromate	80	32 wks	40% survival (pH 6.5)	200	van der Putte, et al. 1982
Rainbow trout (eyed embryo, juvenile), *Salmo gairdneri*	Sodium chromate	80	32 wks	76% survival (pH 7.8)	200	van der Putte, et al. 1982
Rainbow trout (alevin, juvenile), *Salmo gairdneri*	Sodium chromate	80	32 wks	0% survival (pH 6.5)	2,000	van der Putte, et al. 1982
Rainbow trout (alevin, juvenile), *Salmo gairdneri*	Sodium chromate	80	32 wks	44% survival (pH 7.8)	2,000	van der Putte, et al. 1982

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)*	Reference
Rainbow trout (alevin, juvenile), *Salmo gairdneri*	Sodium chromate	80	32 wks	72% survival (pH 6.5)	200	van der Putte, et al. 1982
Rainbow trout (alevin, juvenile), *Salmo gairdneri*	Sodium chromate	80	32 wks	76% survival (pH 7.8)	200	van der Putte, et al. 1982
Rainbow trout, *Salmo gairdneri*	-	-	4 mos	No effect on immune response	200	Viale & Calamari, 1984
Rainbow trout, *Salmo gairdneri*	Sodium chromate	80	11 days	Induced hyperplasia	3,200	Temmink, et al. 1983
Brown trout (yearling), *Salmo trutta*	Potassium dichromate	207	38 wks	Suppression of immune response	1,010	O'Neill, 1981
Goldfish, *Carassius auratus*	Potassium dichromate	220	11 days	LC50	30,400	Adelman & Smith, 1976
Goldfish (embryo, larva), *Carassius auratus*	Chromium trioxide	195	7 days	EC50 (death and deformity)	660	Birge, 1978
Goldfish (juvenile), *Carassius auratus*	Potassium dichromate	36	24 hrs	LC50 (5 C) (15 C) (30 C)	354,000 213,000 109,000	Cairns, et al. 1978
Goldfish (juvenile), *Carassius auratus*	Potassium dichromate	-	24 hrs	LC50	249,000	Dowden & Bennett, 1965
Common carp (adult), *Cyprinus carpio*	Potassium dichromate	207	38 wks	Suppression of immune response	1,010	O'Neill, 1981
Golden shiner, *Notemigonus crysoleucas*	Potassium dichromate	36	24 hrs	LC50 (5 C) (15 C) (30 C)	151,000 109,000 104,000	Cairns, et al. 1978
Fathead minnow, *Pimephales promelas*	Potassium dichromate	220	11 days	LC50	17,300	Adelman & Smith, 1976

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)*	Reference
Channel catfish (juvenile), *Ictalurus punctatus*	Potassium dichromate	36	24 hrs	LC50 (5 C) (15 C) (30 C)	50,000 58,000	Cairns, et al. 1978
Mosquitofish, *Gambusia affinis*	Potassium dichromate	-	96 hrs	LC50 (high turbidity)	99,000	Wallen, et al. 1957
Mosquitofish, *Gambusia affinis*	Sodium dichromate	-	96 hrs	LC50 (high turbidity)	92,000	Wallen, et al. 1957
Mosquitofish, *Gambusia affinis*	Potassium chromate	-	96 hrs	LC50 (high turbidity)	107,000	Wallen, et al. 1957
Mosquitofish, *Gambusia affinis*	Sodium chromate	-	96 hrs	LC50 (high turbidity)	135,000	Wallen, et al. 1957
Bluegill, *Lepomis macrochirus*	Potassium dichromate	36	24 hrs	LC50 (5 C) (15 C) (30 C)	228,000 280,000 214,000	Cairns, et al. 1978
Bluegill, *Lepomis macrochirus*	Potassium dichromate	-	24 hrs	LC50	261,000	Dowden & Bennett, 1965
Bluegill, *Lepomis macrochirus*	Potassium dichromate	43	96 hrs	LC50 (low dissolved oxygen)	113,000	Cairns & Scheier, 1958
Bluegill, *Lepomis macrochirus*	Potassium dichromate	43	48 hrs	LC50	155,500	Cairns, et al. 1965
Bluegill, *Lepomis macrochirus*	Sodium dichromate	120	48 hr	LC50	213,000	Turnbull, et al. 1954
Bluegill, *Lepomis macrochirus*	Potassium dichromate	105	2 wks	Increased locomotor activity	50	Ellgaard, et al. 1978
Largemouth bass (embryo, larva), *Micropterus salmoides*	Chromium trioxide	99	8 days	EC50 (death and deformity)	1,170	Birge, et al. 1978
Largemouth bass (juvenile), *Micropterus salmoides*	Potassium chromate	334	36 hrs	Pathology of intestine	94,000	Fromm & Schiffman, 1958

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)*	Reference
Largemouth bass (juvenile), *Micropterus salmoides*	Potassium chromate	334	48 hrs	LC50	195,000	Fromm & Schiffman, 1958
Narrow-mouthed toad (embryo, larva), *Gastrophryne carolinensis*	Chromium trioxide	195	7 days	EC50 (death and deformity)	30	Birge, 1978
Marbled salamander (embryo, larva), *Ambystoma opacum*	Chromium trioxide	99	8 days	EC50 (death and deformity	2,130	Birge, et al. 1978
			Chromium(III)			
Green alga, *Scenedesmus quadricauda*	Potassium chromium sulfate	-	96 hrs	Incipient inhibition (river water)	5,000	Bringmann & Kuhn, 1959a,b
Protozoan, *Microregma heterostoma*	Potassium chromium sulfate	-	28 hrs	Incipient inhibition	37,000	Bringmann & Kuhn, 1959b
Cladoceran, *Daphnia magna*	Potassium chromium sulfate	-	48 hrs	EC50 (river water)	42,000	Bringmann & Kuhn, 1959a,b
Cladoceran, *Daphnia magna*	Potassium chloride sulfate	-	24 hrs	LC50		Bringmann & Kuhn, 1977b
Cladoceran, *Daphnia magna*	Chromium chloride	45	3 wks	LC50	2,000	Biesinger & Christensen, 1972
Cladoceran, *Daphnia magna*	Chromium chloride	45	3 wks	Impaired reproduction	330	Biesinger & Christensen, 1972
Rainbow trout, *Salmo gairdneri*	Chromium chloride	-	30 days	No effect on gill AChE activity	1,000	Smissaert, et al. 1975
Rainbow trout, *Salmo gairdneri*	-	-	56 days	None	6 mg/kg in food	Tacon and Beveridge, 1982

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)*	Reference
Common carp, *Cyprinus carpio*	Chromium sulfate	-	48 hrs	60% mortality	2,900	Muramoto, 1981
Common carp, *Cyprinus carpio*	Chromium chloride	-	24 hrs	100% mortality	3,900	Muramoto, 1981
			SALTWATER SPECIES			
			Chromium(VI)			
Polychaete worm (juvenile), *Neanthes arenaceodentata*	Chromium trioxide	-	28 days	LC50	700	Reish, et al. 1976
Polychaete worm (adult), *Neanthes arenaceodentata*	Chromium trioxide	-	28 days	LC50	550	Reish, et al. 1976
Polychaete worm, *Neanthes arenaceodentata*	Potassium dichromate	-	7 days	LC50	1,460-1,770	Oshida, et al. 1976, 1981
Polychaete worm, *Neanthes arenaceodentata*	Potassium dichromate	-	56 days	LC50	200	Oshida & Reish, 1975
Polychaete worm, *Neanthes arenaceodentata*	Potassium dichromate	-	14 days	Inhibition-tube building	79	Oshida & Reish, 1975
Polychaete worm, *Neanthes arenaceodentata*	Potassium dichromate	-	59 days	LC50	200	Mearns, et al. 1976
Polychaete worm, *Neanthes arenaceodentata*	Potassium dichromate	-	350 days	Brood size decrease	12.5	Mearns, et al. 1976
Polychaete worm, *Nereis virens*	Sodium chromate	-	21 days	LC50	1,000	Raymont & Shields, 1963
Polychaete worm, *Nereis virens*	Potassium chromate	-	7 days	LC50	700	Eisler & Hennekey, 1977
Polychaete worm, *Ophryotrocha diadema*	Chromium trioxide	-	21 days	100% mortality	50,000	Reish & Carr, 1978

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)*	Reference
Polychaete worm, Ophryotrocha diadema	Chromium trioxide	-	28 days	Brood size decrease	500-1,000	Reish & Carr, 1978
Polychaete worm, Ophryotrocha diadema	Potassium dichromate	-	48 hrs	LC50	1,000-3,300	Parker, 1984
Polychaete worm, Ctenodrilus serratus	Chromium trioxide	-	21 days	100% mortality	50,000	Reish & Carr, 1978
Polychaete worm (adult), Capitella capitata	Chromium trioxide	-	28 days	LC50	280	Reish, et al. 1976
Polychaete worm (adult), Capitella capitata	Potassium dichromate	-	5 mos	Brood size decrease	50-100	Reish, 1977
Mud snail, Nassarius obsoletus	Potassium chromate	-	7 days	LC50	10,000	Eisler & Hennekey, 1977
Pacific oyster, Crassostrea gigas	Sodium dichromate	-	48 hrs	No effect	100	Watling, 1981a
Common rangia, Rangia cuneata	Potassium dichromate	-	96 hrs	LC50 (<1 g/kg salinity)	210	Olson & Harrel, 1973
Soft-shell clam, Mya arenaria	Potassium chromate	-	7 days	LC50	8,000	Eisler & Hennekey, 1977
Copepod, Acartia clausi	Sodium chromate	-	48 hr	LC50	13,700	Moraitou-Apostolopoulou & Verriopoulos, 1982b
Copepod, Acartia clausi	Sodium chromate	-	7 days	Decreased life span	4,000 (14 C) 5,000 (22 C)	Moraitou-Apostolopoulou & Verriopoulos, 1982b
Copepod, Tisbe holothuriae	Sodium chromate	-	48 hrs	LC50	8,140	Moraitou-Apostolopoulou & Verriopoulos, 1982a
Grass shrimp, Palaemonetes pugio	Potassium chromate	-	48 hrs	LC50 (10 C, 10 g/kg salinity)	81,000	Fales, 1978
Grass shrimp, Palaemonetes pugio	Potassium chromate	-	48 hrs	LC50 (15 C, 10 g/kg salinity)	39,000	Fales, 1978

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)*	Reference
Grass shrimp, *Palaemonetes pugio*	Potassium chromate	-	48 hrs	LC50 (20 C, 10 g/kg salinity)	37,000	Fales, 1978
Grass shrimp, *Palaemonetes pugio*	Potassium chromate	-	48 hrs	LC50 (25 C, 10 g/kg salinity)	21,000	Fales, 1978
Grass shrimp, *Palaemonetes pugio*	Potassium chromate	-	48 hrs	LC50 (10 C, 20 g/kg salinity)	147,000	Fales, 1978
Grass shrimp, *Palaemonetes pugio*	Potassium chromate	-	48 hrs	LC50 (15 C, 20 g/kg salinity)	107,000	Fales, 1978
Grass shrimp, *Palaemonetes pugio*	Potassium chromate	-	48 hrs	LC50 (20 C, 20 g/kg salinity)	78,000	Fales, 1978
Grass shrimp, *Palaemonetes pugio*	Potassium chromate	-	48 hrs	LC50 (25 C, 20 g/kg salinity)	77,000	Fales, 1978
Grass shrimp, *Palaemonetes pugio*	Sodium chromate	-	28 days	Cuticular lesions; pereiopod loss	500-4,000	Doughtie, et al. 1983
Hermit crab, *Pagurus longicarpus*	Potassium chromate	-	7 days	LC50	2,700	Eisler & Hennekey, 1977
Blue crab (larva), *Callinectes sapidus*	Sodium chromate	-	40 days	Reduced survival	1,500	Bookhout, et al. 1984
Blue crab, *Callinectes sapidus*	Potassium dichromate	-	96 hr	LC50 (1 g/kg salinity)	34,000	Frank & Robertson, 1979
Green crab, *Carcinus maenas*	Sodium chromate	-	12 days	LC50	60,000	Raymont & Shields, 1963
Mud crab (larva), *Rhithropanopeus harrisii*	Sodium chromate	-	19 days	Reduced survival; affected swimming	2,290	Bookhout, et al. 1984

Table 6. (Continued)

Species	Chemical	Hardness (mg/L as $CaCO_3$)	Duration	Effect	Result (µg/L)*	Reference
Starfish, *Asterias forbesi*	Potassium chromate	-	7 days	LC50	10,000	Eisler & Hennekey, 1977
Brittle star, *Ophiothrix spiculata*	-	-	7 days	LC50	1,700	Oshida & Wright, 1978
Coho salmon, *Oncorhynchus kisutch*	Potassium chromate	-	5 days	33% mortality	31,800	Holland, et al. 1960
Coho salmon, *Oncorhynchus kisutch*	Potassium chromate	-	11 days	100% mortality	31,800	Holland, et al. 1960
Mummichog, *Fundulus heteroclitus*	Potassium chromate	-	7 days	LC50	44,000	Eisler & Hennekey, 1977
Speckled sanddab, *Citharichthys stigmaeus*	Potassium dichromate	-	21 days	LC50	5,400	Sherwood, 1975
Speckled sanddab, *Citharichthys stigmaeus*	Potassium dichromate	-	21 days	EC50 (fed)	2,200	Sherwood, 1975
Speckled sanddab, *Citharichthys stigmaeus*	Potassium dichromate	-	21 days	LC50	5,000	Mearns, et al. 1976
			Chromium(III)			
Polychaete worm, *Neanthes arenaceodentata*	Chromium chloride	-	<24 hrs	100% mortality (pH=4.5)	50,400	Oshida, et al. 1976, 1981
Polychaete worm, *Neanthes arenaceodentata*	Chromium chloride	-	160 days	Reproduction occurred (pH=7.9)	50,400	Oshida, et al. 1976, 1981
Polychaete worm, *Ophryotrocha diadema*	Chromium trichloride	-	48 hrs	LC50	100,000	Parker, 1984

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

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