Chlorine Water Quality Guidelines (Reformatted Guideline from 1989)

Technical Appendix

Ministry of Environment and Climate Change Strategy
Water Protection & Sustainability Branch

The Water Quality Guideline Series is a collection of British Columbia (B.C.) Ministry of Environment and Climate Change Strategy water quality guidelines. Water quality guidelines are developed to protect a variety of water values and uses: aquatic life, drinking water sources, recreation, livestock watering, irrigation, and wildlife. The Water Quality Guideline Series focuses on publishing water quality guideline technical reports and guideline summaries using the best available science to aid in the management of B.C.'s water resources. For additional information on B.C.'s approved water quality parameter specific guidelines, visit:

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Sections of this report on industrial water use, drinking water and recreation have been removed. B.C. adopts Health Canada drinking water and recreation guidelines and no longer develops or supports guidelines for industrial water use.

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1. INTRODUCTION

This document discusses the effects of total residual chlorine on the various water use categories which include drinking water, aquatic life, wildlife, livestock watering, irrigation, recreation and aesthetics, and industrial water supplies. Halogenated organic compounds, including those produced by oxidation of organic matter by residual chlorine, are beyond the scope of this report and will be addressed in separate criteria documents published in this series. It is “total residual chlorine”, as defined in Section 2, upon which this document will focus.

Aquatic organisms are particularly sensitive to residual chlorine, and therefore a large portion of this document focuses on the toxicity of residual chlorine to aquatic life. Because of the extensive amount of literature on residual chlorine, much of the information presented in this document has been extracted from recent reviews documenting the numerous toxicological studies pertaining to this contaminant. The purpose of this document is not to re-review the extensive amount of original material already addressed in recent publications, but instead, to focus on the most applicable information which could be used to formulate appropriate criteria for British Columbia waters.

Where applicable, or where sufficient information exists, criteria are recommended to protect water users from the deleterious effects of residual chlorine. As part of this criteria development process, water quality standards, objectives, and criteria and accompanying rationales from other jurisdictions are reviewed and their suitability for British Columbia waters are considered.

2. FORMS AND TRANSFORMATIONS

2.1 Chlorine in Freshwater

Chlorine is a powerful oxidizing agent with a high solubility in water. When elemental chlorine (Cl_2) or hypochlorite compounds (e.g. calcium hypochlorite) are added to freshwater at about pH 5 or greater, chlorine hydrolyzes rapidly and completely to form hypochlorous acid according to the reaction:

$$\mathrm{Cl2 + H2O \rightarrow HCl + HOCl}$$

The HOCl is a weak acid and partially dissociates to form hypochlorite ions which are in equilibrium with HOCl according to the equation:

$$\mathrm{HOCl \rightleftharpoons H^{+} + OC^{-}}$$

That portion of chlorine present as HOCl and OCl^- in aqueous solution is referred to as “free available chlorine” which is often abbreviated to “free chlorine”. The ratio between HOCl and OCl^- is primarily a function of pH with a dissociation constant of 3.3×10^{-8} at 20°C (McKee and Wolf, 1963). For example, 96 percent of the free available chlorine is present as HOCl at pH 6, 75 percent at pH 7, 22 percent at pH 8, and only about 3 percent at pH 9. The normal temperature range of ambient water affects this ratio only slightly (Alabaster and Lloyd, 1982; McKee and Wolf, 1963).

If chlorine is added to water which contains ammonia, such as sewage effluent, then the combination will form chloramines (mono-, di-, tri-), nitrogenous compounds (e.g., N-chloramides), or a mixture of these compounds (Alabaster and Lloyd, 1982; Pierce, 1978; Brungs, 1973). The relative concentrations of these compounds are dependent primarily upon the initial chlorine: ammonia ratio and the pH of the solution (Pierce, 1978). The portion of the chlorine that is present as chloramines (with the exception of trichloramine) or combined with other nitrogenous compounds (with an N-Cl link) is referred to as “combined available chlorine” (Alabaster and Lloyd, 1982; Pierce, 1978; Brungs, 1973).

"Total residual chlorine" (often abbreviated to "residual chlorine" or simply "TRC" and sometimes referred to as "total available chlorine") is the sum of the "free available chlorine" plus the "combined available chlorine". This includes all the forms of chlorine which are able to act as an oxidant (Alabaster and Lloyd, 1982; Pierce, 1978; Brungs, 1973).

Initial loss of chlorine disinfectant is due to reaction with easily oxidized organic compounds, and with readily oxidized inorganic ions including ferrous ion, sulphide, nitrite, and other reducing agents. By definition, chlorine demand is the sum of the reducing agents available to react with free available chlorine in a given time. After the demand is satisfied, combined available chlorine is formed that is primarily monochloramine (NH_2Cl), as follows:

$$HOCl + NH_3 \rightleftharpoons NH_2Cl + H_2O$$

As additional chlorine is added beyond that needed to react with ammonia-nitrogen (5 mg/L for each 1 mg/L of $NH_3^{-}N$), dichloramine ($NHCl_2$) begins to form and decompose as follows:

$$HOCl + NH_2Cl \rightleftharpoons NHCl_2 + H_2O$$

This decomposition results in the loss of residual combined available chlorine, until breakpoint chlorination occurs (near 8 mg/L Cl 2 for each mg N) as the ammonia present in the combined available chlorine is oxidized to N 2 and the chlorine becomes chloride (Cl^-) as follows:

$$2NHCl_2 + H_2O \rightleftharpoons N_2 + H^{3+} + 3Cl^- + HOCl$$

The breakpoint represents the minimal concentration of both residual chlorine and ammonia. Beyond the breakpoint, excess free available chlorine remains in solution except as it is consumed by difficult to oxidize organic and inorganic compounds (Pierce, 1978; Johnson, 1978). Tri chloramine (NCl_3), or nitrogen trichloride as it is sometimes called, may be formed beyond breakpoint by reaction of the excess hypochlorous acid with dichloramine as follows:

$$HOCl + NHCl_2 \rightleftharpoons NHCl_3 + H_2O$$

As noted in Section 1, halogenated organic compounds, including those produced by oxidation of organic matter by residual chlorine are beyond the scope of this report and will be addressed in separate criteria documents published in this series.

2.2 Chlorine in Seawater

Chlorine reacts differently in seawater than in freshwater because of the relatively high concentrations of bromide (67 mg/L Br^-) naturally present in seawater (salinity of 35 ppt) compared to the amount of chlorine (0.5 to 10 mg/L) typically introduced from anthropogenic sources (Pierce, 1978). At pH 8 (typical pH of seawater), the addition of chlorine to seawater, or any water high in bromide, results in the rapid formation of hypobromous acid (HOBr) in equilibrium with hypobromite ions (OBr^-) and all the chlorine would be reduced to chloride ions (Cl^-) according to the reactions:

$$HOCl + Br^- \rightleftharpoons HOBr + Cl^-$$
$$OCl^- + Br^- \rightleftharpoons OBr^- + Cl^-$$
$$HOBr^- \rightleftharpoons OBr^- + H^+$$

According to Pierce (1978), both HOBr and OBr^- are unstable and undergo further decay to bromate (BrO_3^-) and bromide ions (Br^-) as follows:

$$2HOBr \rightleftharpoons 2H^+ + 2\ Br^- + O_2$$

$$2OBr^- \rightleftharpoons 2Br^- + O_2$$

$$3HOBr \rightleftharpoons 3H^+ + 2Br^- + BrO_3^-$$

$$30Br^- \rightleftharpoons 2Br^- + BrO_3^-$$

If ammonia is present in the chlorinated seawater, then the hypobromous acid will react with the ammonia to form bromamines (mono-, di-, tri-) as follows:

$HOBr + NH_3 \rightleftharpoons NH\ 2\ Br + H_2O$ monobromamine
$HOBr + NH_2Br \rightleftharpoons NHBr_2 + H_2O$ dibromamine
$HOBr + NHBr_2 \rightleftharpoons NBr_3 + H_2O$ tribromamine

The relative concentrations of mono-, di-, and tribromamines are dependent upon the ammonia:bromide ratio and the pH of the solution. Monobromamine formation is favoured by high ammonia:bromide ratio at alkaline pH. Dibromamine formation is favoured at pH 6 to 9 range with ammonia:bromide ratio of 5 to 20. Tribromamine formation is favoured in more acid solutions (Pierce, 1978).

Like aqueous chlorine, aqueous bromine will participate in a breakpoint reaction with ammonia as follows:

$$3HOBr + 2NH_3 \rightarrow N_2 + 3H_2O + 3Br^- + 3H^+$$

$$30Br^- + 2NH_3 \rightarrow N_2 + 3H_2O + 3Br^-$$

To indicate that bromine is involved in the reaction when chlorine is added to seawater, the term "chlorine-produced oxidants", often abbreviated to "CPO", is used to refer to the sum of these oxidative products in seawater (U.S. EPA, 1985). Thus, this term will be used to describe the seawater data presented herein.

Similar to reactions with chlorine, bromine can also participate in the oxidation of organic matter to form brominated organic compounds. As noted in Section 1, halogenated organic compounds, including those produced by oxidation of organic matter by the introduction of residual chlorine, will be addressed in separate criteria documents published in this series.

2.3 Analytical Techniques

While there are a number of analytical tests for aqueous chlorine and its inorganic products, a review of the literature indicated that it is generally agreed that the amperometric titration technique is the preferred analytical method. The American Public Health Association (APHA), the American Water Works Association (AWWA), and the Water Pollution Control Federation (WPCF) (1985) state that for the measurement of TRC (or CPO) in natural or treated waters the amperometric method is the method of choice because it provides the greatest sensitivity and is not subject to interference from colour, turbidity, iron, manganese or nitrite nitrogen.

For toxicological concerns, it is important that the method measures TRC (in freshwater) or CPO (in seawater) and not just one or more components, such as free, but not combined chlorine. Furthermore, because of the reactivity of chlorine and the inability to preserve the sample adequately, the measurement must be performed on-site, immediately after sample collection. Given a portable power supply, amperometric titration can be performed in the field; however, APHA et al. (1985) state that this technique requires a higher degree of skill and care than the colourimetric methods.

Improvements to amperometric titration techniques for TRC (or CPO) have increased the reliability and sensitivity of the measurements. For example, Marinenko et al. (1976) developed an amperometer with internal calibration which improved the sensitivity from a few tenths of a mg/L to a few µg/L of TRC.

Stockmeier et al. (1987) modified the amperometric back-titration technique by using a more diluted iodine titrant solution, and by using a microburette (0.01 ml divisions) with a screw advance device allowing continuous control of titrant delivery within a few microlitres. The delivery tip of the microburette is immersed in the titration solution and designed so that unintended diffusion of the titrant into the solution is negligible. This eliminates the errors associated with estimating the volume of discrete droplets.

A number of toxicological studies (Arthur and Eaton, 1971; Latimer et al., 1975; Dinnel et al., 1981; Roberts et al., 1975; Larson, Hutchins, and Lamperti, 1977; Larson, Hutchins, and Schlesinger, 1977; Stober et al., 1980; Thatcher et al., 1976) which involve the measurement of TRC, CPO or their components by amperometric titration reported that detection levels as low as 0.5 to 2 µg/L have been attained.

3. OCCURRENCE IN THE ENVIRONMENT

3.1 Natural Sources

Not to be confused with chlorides which are ubiquitous throughout the environment and present in almost all natural waters, chlorine in its “free available” form (Section 2.1) does not occur naturally except under unique circumstances. According to Duce (1969, as cited in U.S. EPA, 1981) and the National Research Council (1976, as cited in U.S. EPA, 1981, 1986) there are data indicating that chlorine is formed in the stratosphere by the action of ozone on aqueous aerosol particles of chloride released to the atmosphere from ocean spray, volcanoes, and forest fires. However, it is doubtful that this natural source of chlorine would have a measurable effect on ambient waters. For the purpose of this document, it is assumed that any total residual chlorine measured in ambient waters is the product of anthropogenic activities which are discussed in the following section.

3.2 Anthropogenic Sources

Chlorine is produced in British Columbia through the electrolytic decomposition of seawater. The major producer in British Columbia is Canadian Occidental Petroleum with plants located in Vancouver, Harmac, and Squamish. Combined, these plants have the capacity to produce up to 237 kilotonnes of chlorine per year which is about 15 to 20 percent of the national production level (Environment Canada, 1984).

3.2.1 *Municipal and Domestic Uses*

The primary municipal uses of chlorine include the disinfection of drinking water supplies, sewage treatment, and swimming pool treatment. As a disinfectant, the bactericidal properties of chlorine are well known and it has proven to be an effective agent for destroying or deactivating disease-producing organisms (APHA, AWWA, and WPCF, 1985). A secondary benefit of chlorine is the overall improvement of water quality by controlling nuisance organisms, reducing taste and odour, removing colour, iron and manganese, and destroying hydrogen sulphide and cyanides (Pierce, 1978). These multi-purpose treatment capabilities of chlorine are due to its powerful oxidizing property.

For domestic uses, there are a wide range of commercial products available with chlorine as the active ingredient for cleaning, disinfecting, and bleaching in the household, and for disinfection and algae control in private swimming pools.

Since most of the chlorine used for domestic or municipal purposes enters the aquatic environment via municipal sewers which contain ammonia, almost all of the total residual chlorine discharged is in the "combined available" form (see Section 2).

3.2.2 *Industrial Uses*

Chlorine has a wide variety of industrial uses throughout the Province. Based on the total quantities of chlorine used for various purposes across Canada (Pierce, 1978), it is estimated that industry accounts for over 90 percent of the chorine used in British Columbia for the following purposes:

i) disinfection
ii) bleaching
iii) control of nuisance organisms
iv) oxidation of waste products
v) manufacture of chlorinated and non-chlorinated products.

As a disinfectant, chlorine is used in certain food and beverage processing industries such as fruit and vegetable processing, cottage cheese processing, poultry processing, shellfish processing, fish packing, and the brewing and malting industries (Pierce, 1978). However, in some food processing industries, chlorine may cause undesirable tastes in canned or frozen products, or may cause corrosion in cans (McKee and Wolf, 1963).

For bleaching purposes, chlorine is used in the pulp and paper industry and textile industry to remove wanted colour from the products. Chlorine dioxide, a bleaching and delignifying agent, is produced on-site in some pulpmills and does not dissociate or form chloramines or nitrogenous organic compounds but instead it is reduced to chlorite (Pierce, 1978). Chlorine is also used for its bleaching property to remove intense colour from wastewaters such as by the textile industry (Pierce, 1978).

For the control of nuisance organisms such as slime growths, barnacles, mussels, and algae, chlorine is used in the cooling water systems of industrial facilities to prevent biofouling. This may be accomplished by a continuous low dose of chlorine to the intake water or by intermittent higher doses (Pierce, 1978; Mattice and Zittel, 1976). Chlorine is also used in the processing systems of pulp and paper mills to prevent slime growths from developing (Pierce, 1978).

Chlorine is used in the treatment of some industrial wastewaters to destroy certain harmful waste products by oxidation (Pierce, 1978). Examples of this form of treatment are as follows:

i) alkaline chlorination which is used in the mining and smelting industry to destroy cyanides;
ii) chloroxidation for phenol removal in wastewaters from coking operations, petrochemical refining, plastics manufacture, steel mills, foundries, and various chemical industries;
iii) oxidation of hydrogen sulphide to form sulphates in pulp and paper mill and petroleum refinery effluents; and
iv) oxidation of iron and manganese to form precipitates.

Chlorine is used in the manufacture of a vast array of organochlorine products such as polymers used in paints, adhesives, packaging films, synthetic textiles, laminates, wire and cable covering, hoses, belting, and fire-resistant materials, and in solvents, pesticides, and aerosol propellants.

Although chlorine is used widely in industry, as outlined above, only a few industries are likely to be a source of residual chlorine entering the aquatic environment. According to McKee and Wolf (1963), the industrial processes most likely to contain residual chlorine are those employing bleaching operations such as textile mills or paper pulping operations, or those using chlorine in cooling waters.

3.3 Chlorine Requirements for Domestic and Industrial Waters

The chlorine dosage used to treat domestic or industrial waters varies widely and depends upon the type and degree of treatment required. Some typical chlorine dosages for domestic and industrial waters have been compiled from White (1972, as cited in Pierce, 1978) and Palin (1974, as cited in Pierce, 1978) in a table by Pierce (1978) which is reproduced in Table 1.

3.4 Residual Chlorine Concentrations in Receiving Waters

When considering the toxicological effects of residual chlorine in ambient waters, the amount of chlorine normally added to domestic or industrial waters (Table 1) has little bearing on the residual chlorine concentrations· that will occur in the environment. For example, Jolley (1975) reported that 99 percent of the chlorine dose used to disinfect secondary treatment sewage is reduced to harmless chloride. Servizi (1979) noted that chlorine residuals in municipal sewage effluent commonly range between 0.5 and 2.0 mg/L. In a 1975 survey of total residual chlorine in the final effluent of selected sewage treatment facilities throughout British Columbia, Cook and Trasolini (1977) reported that out of 11 facilities studied, 5 exceeded 1.0 mg/L in more than 40 percent of the samples, 9 exceeded 0.02 mg/L in 50 percent of the samples and 4 exceeded 0.02 mg/L in 90 percent of the samples. At two sites, total residual chlorine concentrations of 0.17 mg/L (15 m downstream from the outfall) and 0.41 mg/L (25 m downstream) were measured in the receiving waters.

Servizi (1979) reported that chlorine residuals decrease as a consequence of reaction with a wide variety of substances in sewage, but a significant amount may persist for long periods. This persistence is likely due to the formation of monochloramine which, according to Johnson (1978), may persist in natural waters for days. Similarly, from a review of the literature, Brungs (1973) also concluded that residual chlorine persists for periods longer than the few minutes or hours indicated by some authorities. For example, Esvelt et al. (1973) reported that chlorine residuals in chlorinated sewage gradually decreased with time but persisted for at least 3 days.

Martens and Servizi (1975) measured the rate of decay of residual chlorine in unaerated and aerated sewage. Initial chlorine residuals of 1.2 to 1.1 mg/L in unaerated and aerated samples declined to 0.02 and <0.02 mg/L, respectively, in approximately 13 hours. About 75 percent of the initial chlorine residuals were lost within the first 3 to 4 hours. In similar tests, Servizi and Martens (1974) reported that approximately 50 hours were required for residual chlorine in primary sewage plant effluent and in aerated lagoon effluent to decay from 2.6 to 1.2 mg/Land from 0.2 to 0.12 mg/L, respectively. In the same study, when chlorinated sewage was mixed with the receiving river water in a 5 percent v/v mixture, a chlorine residual of 0.12 mg/L was measured after 9 hours, but no residual was detected after 24 hours. In another study, Baker and Cole (1974, as cited in Servizi, 1979) noted an almost complete absence of chlorine demand of receiving waters. Based on a review of the literature, Servizi (1979) concluded that there was no evidence of accelerated decay in chlorine residual when chlorinated sewage was mixed with receiving waters. However, it would seem likely that the chlorine demand of ambient waters may vary with the waterbody and that the rate of decay would be dependent upon the water quality characteristics of that waterbody. Mattice and Zittel (1976) indicate the need for caution in predicting the toxicity of an effluent in the receiving water because of the uncertainties regarding results of interaction of chlorine with natural waters.

According to the Journal of Hazardous Materials (1977 as cited in Environment Canada, 1984), experiments have shown that seawater typically has a 30-rninute chlorine demand of 1.5 mg/L and a 2-day chlorine demand of about 3 mg/L.

Based on decay rates of chlorine at varying concentrations in natural and artificial seawater, Goldman et al. (1979) confirmed the results of other researchers that showed losses of residual chlorine in seawater occur in two distinct phases. First, a very rapid and significant demand attributed to a true organic demand, followed by a continuous loss at a reduced rate which does not appear to approach a saturation limit, even after 10 days. The fate of the residual chlorine lost in the second phase has not as yet been satisfactorily explained, but the Goldman et al. (1979) study indicated that it is associated with the bromine chemical system in seawater. The authors (Goldman et al. (1979) recommended that until the lost chlorine, which is not recoverable by current techniques, is clearly identified, it must remain suspect as a potential biocide.

3.5 Concentrations in Biological Tissues

A recent review of the literature by the U.S. EPA (1985) stated that no freshwater or saltwater data on the bioconcentration of total residual chlorine or chlorine-produced oxidants were found, or expected.

In terms of uptake by ingestion, McKee and Wolf (1963) noted that it is generally agreed that the small amounts of chlorine present in chlorinated water are dissipated by reaction with saliva and gastric juices as soon as the water is swallowed.

4. AQUATIC LIFE

The following discussion regarding the effects of chlorine on aquatic life (Sections 5.2 to 5.5 inclusive) will focus upon the relevant data produced from the more sensitive tests taking into consideration the relationship between exposure periods and concentrations which may influence the determination of criteria levels. A more complete survey of the available toxicological data is presented in Tables 2 and 2a for freshwater organisms and Tables 3 and 3a for marine and estuarine organisms. Graphical representations of the data in these tables (harmful concentrations as a function of exposure periods) are presented in Figures and 2, respectively.

Furthermore, for the purpose of this discussion, the boundaries between acute and chronic exposures are 120 hours for freshwater organisms and 2 hours for marine and estuarine organisms as determined by Mattice and Zittel (1976). (Figures 1 and 2).

4.1 Mode of Toxic Action

The chemical mechanism by which residual chlorine incapacitates aquatic life is not completely understood. Some researchers (Green and Stumpf, 1946, as cited in Alabaster and Lloyd, 1982; Albert, 1965, as cited in Alabaster and Lloyd, 1982) reported that intracellular enzymes containing sulphydryl (-SH) groups, which are essential to cellular metabolism, become oxidized almost immediately by residual chlorine in both plants and animals. Because of the strength of the covalent bond formed, enzymatic activity is irreversibly terminated which may explain why fish exposed to residual chlorine usually do not recover once equilibrium has been lost (Albert, 1965, as cited in Alabaster and Lloyd, 1982).

In fish, gills have been suggested as the primary site of residual chlorine toxicity based on the damage observed to gill epitheleum following exposure (Penzes, 1971, as cited in Alabaster and Lloyd, 1982; Valenzuela, 1976, as cited in Alabaster and Lloyd, 1982; Bass et al., 1977, as cited in Alabaster and Lloyd, 1982). Bass and Heath (1977) and Cairns et al. (1975) concluded that the primary mode of toxic action of residual chlorine to fish was acute gill tissue damage coupled with mucous accumulation in the gills which inhibited oxygen uptake resulting in death by asphyxiation. On the other hand, Fobes (1971, as cited in Alabaster and Lloyd, 1982) reported no change in the respiration rate of excised fish gill tissue following exposure to 1 mg/L residual chlorine.

Acutely toxic concentrations of residual chlorine have been shown to alter the blood chemistry in fish. Zeithoun et al. (1977) measured increases in phosphorus, magnesium, iron, copper, zinc, and potassium levels and decreases in sodium levels in the blood plasma of 3-year old rainbow trout (*Oncorhynchus mykiss*). They concluded that chlorine toxicity appeared to disturb the mineral hemeostasis in the blood.

Groethe and Eaton (1975) attributed the acute toxicity of monochloramine to anoxia (severe oxygen deficiency) caused by the oxidation of haemoglobin to methaemoglobin in the blood. Similarly, Buckley (1976a) noted a slight increase in methaemoglobin, a slight decrease in haemoglobin, and a temporary reduction in the percentage of immature erythrocytes in the blood of young coho salmon (*Oncorhynchus kisutch*) when exposed to 0.07 mg/L residual chlorine in a mixture of sewage and seawater. In another study, Buckley (1976b) reported that concentrations of 3 to 50 µg/L residual chlorine in a mixture of sewage and river water caused mild to severe symptoms of haemolytic anaemia. The haematological changes were attributed to the oxidative nature of residual chlorine.

4.2 Effects on Algae

4.2.1 *Freshwater Algae*

The available data indicate a wide range in the sensitivity of algae to residual chlorine.

Carlson (1976, as cited in Brungs, 1976) performed long-term (3.5 months) multi species bioassays investigating the effects of chloramine on fish reproduction, invertebrates and algae. Chloramine concentrations of 1, 4.3, and 11.4 µg/L had no apparent effect upon the reproductive behaviour of the fish, or upon the standing crop of invertebrates. However, growth of peri phyton on the walls of the test chamber were delayed in all three test concentrations when compared to controls, and periphyton standing crop decreased in biomass with increasing chloramine concentration (Pt. 113, Figure 1).

Trotter et al. (1987) exposed attached, filamentous, green algae (*Stigeoclonium subsecundum*) to intermittent (6 hours/week) doses of chlorine. The toxicity was found to be dependent upon the algal biomass. If sufficient biomass was present, then an initial peak of 500 µg/L residual chlorine had no effect upon the final biomass. If, however, an insufficient biomass was present, all the algal cells would be killed within a week. Microscopic observations revealed that, compared to controls, the larger algal cultures adjusted to the chlorine doses by producing a shorter and denser filament growth. This change in morphology protected the basal algae by reducing the circulation of chlorine-laden water through the thick algal mat while the terminal cells of longer filaments were killed (Pt. 110, Figure 1).

Eiler and Delfino (1974) studied the biological effects of chlorinated cooling water discharged to the Mississippi River from a nuclear power station. They concluded that the periodic concentrations of chlorine in the heated effluent appeared to have a more significant impact on the biotic communities in the river than the increased water temperature. Productivity of periphytic algae was reduced at times downstream from the plant. Residual chlorine concentrations measured weekly in the river over a one-year period were always below the analytical detection limit of 10 µg/L.

For phytoplankton, Toetz et al. (1977) reported that an initial chlorine concentration of 28 µg/L depressed uptake of nitrates by 50 percent after 24 hours (Pt. 111, Figure 1). Since the concentration reported was that measured initially, the actual concentration of residual chlorine during incubation was probably lower. The authors suggested that residual chlorine may destroy or inactivate enzymes in the cell membrane that are responsible for the uptake of nitrate.

Brooks and Liptak (1979) exposed Lake Michigan phytoplankton to different concentrations of chlorine (0 to 1.5 mg/L) in separate tests for a single 20-minute period. Below 100 µg/L residual chlorine, only slight reductions in chlorophyll *a* were noted, and following an initial decrease, carbon uptake rates achieved nearly complete recovery after 24 hours. At or above 1 000 µg/L residual chlorine, the photosynthetic system of the algae was irreversibly destroyed. Between 100 and 1 000 µg/L, intermediate effects were observed (Pt. 112, Figure 1).

Brook and Baker (1972, as cited in Alabaster and Lloyd, 1982) reported an EC50 of 320 µg/L residual chlorine for reduction of photosynthesis and respiration of phytoplankton.

4.2.2 *Marine and Estuarine Algae*

A review of the available literature indicated that marine and estuarine algae generally demonstrated a similar wide range of sensitivity to residual chlorine as freshwater algae. The lowest residual chlorine concentration reported to have a harmful effect on marine. and estuarine algae was 9 µg/L. Davis and Coughlan (1978, as cited in Ho and Roberts, 1985), and Roberts and Illowsky (n.d., as cited in Ho and Roberts, 1985) reported 2 or 3 h EC50's (photosynthetic inhibition) of 9 to 100 µg/L residual chlorine for mixed phytoplankton communities (Pt. 70, Figure 2).

Eppley et al. (1976) observed decreases in marine phytoplankton photo- synthesis after 20 hours of exposure to power plant chlorination at a concentration as low as 10 µg/L total residual chlorine (Pt. 71, Figure 2). Similarly, Bender et al. (1977, as cited in Ho and Roberts, 1985) reported that over a range of three salinities and three temperatures, four estuarine species of nanoplankton in unialgal cultures exhibited 4-h EC50's (inhibition of carbon uptake) of 10 to 470 µg/L residual chlorine (Pt. 69, Figure 2).

Ho and Roberts (1985) exposed indigenous phytoplankton populations of the lower James River in Virginia to mixtures of chlorinated sewage and estuarine river water. Based on the chlorine residual measured in the sewage, an EC50 of 70 µg/L residual chlorine was calculated as the average concentration which inhibited photosynthetic activity in the mixtures. The exposure period was not reported.

Gentile et al. (1974, as cited in Brungs, 1976) reported that the growth rates of 11 species of marine phytoplankton were decreased by 50 percent on exposure to residual chlorine concentrations which ranged between 76 and 330 µg/L for 24 hours (Pt. 10, Figure 2).

Carpenter et al. (1972) exposed marine phytoplankton to several continuously maintained residual chlorine concentrations. The lowest concentration tested, which was less than the detection limit of 100 µg/L, reduced productivity by 79 percent.

Stone et al. (1973, as cited in Brungs, 1976) tested the long-term effects of chlorinated municipal wastewater upon San Francisco Bay biota (composed of decomposers, producers and herbivores). An average residual chlorine concentration of 60 µg/L in a mixture of one percent wastewater in seawater reduced biomass accumulation to less than 30 percent of that produced in unchlorinated wastewater/ seawater mixtures. At this same concentration, chlorophyll was reduced to 50 percent of that measured in the controls. No biota survived in bioassays receiving residual chlorine concentrations higher than 60 µg/L.

Goldman and Quinby (1979) measured the recovery rates of marine phytoplankton entrained in the chlorinated cooling water of two power plants. Chlorination of the cooling water was intermittent (15 or 30 minutes, twice daily) and the residual chlorine at discharge ranged from 80 to 110 µg/L at one plant and from 20 to 80 µg/L at the other plant. At both pl ants, regrowth of phytoplankton entrained in the heated, chlorinated cooling water after discharge was virtually identical (as measured by cell number, ATP, or chlorophyll *a*) to the intake control samples within a few days which indicated that phytoplankton surviving chlorination are capable of quickly re-establishing prechlorination growth rates (Pts. 72, 73, 74, Figure 2).

4.3 Effects on Aquatic Macrophytes

Very few data were available regarding the toxic effects of residual chlorine to vascular aquatic macrophytes. Interest in this topic was generated by field observations during related studies.

Whigham and Simpson (1978, as cited in Watkins and Hammerschlag, 1984) noted reductions in macrophyte biomass, changes in species composition, and elimination of species in freshwater tidal wetlands receiving chlorinated sewage effluent. The authors attributed these changes to chlorine in the effluent; however, no chlorine measurements were made to confirm their suspicions. Similar changes were noted by Wester and Rawles (1979, as cited in Watkins and Hammerschlag, 1984) in selected areas of the upper Potomac and Anacostia estuaries and appeared to be associated with electric generating and waste treatment plant outfalls, both of which are potential sources of residual chlorine. However, the numerous confounding factors common to field observations made meaningful conclusions difficult regarding the cause of the changes.

In laboratory tests, Watkins and Hammerschlag (1984) exposed Eurasian water milfoil (*Myriophylum spicatum*) to a series of intermittent and continuous concentrations of total residual chlorine over 96 hours. A continuous 96-hour exposure to 50 µg/L total residual chlorine significantly reduced shoot length growth by 16.2 percent and dry weights by 30 percent when compared to control plants (Pt. 114, Figure 1). Concentrations required to achieve a 50 percent reduction in the growth under continuous chlorination occurred in the 100 to 400 µg/L range. Results from the intermittent chlorination tests indicated an insensitivity of growth reduction at all concentrations below 1 000 µg/L during the 96-hour test period.

4.4 Effects on Invertebrates

4.4.1 *Freshwater Invertebrates*

4.4.1.1 *Acute Toxicity*

There is a considerable range in the acute toxicity of residual chlorine to invertebrates. The large range seems dependent on a number of factors including the exposure period, the species tested, and variations in test procedures. Also, some of the data are questionable due to conflicting results, mortality in control tests or unverified results.

The lowest total residual chlorine concentration reported in the literature to be acutely toxic to freshwater invertebrates was 1 µg/L. This chloramine concentration, cited by Arthur and Eaton (1971) as a personal communication with K.E. Biesinger, was reported to kill all *Daphnia magna* individuals in 3 to 5 days (Pt. 118, Figure 1). However, the original study does not appear to have been published to verify these results.

Ward et al. (1976) studied the effects of chlorinated municipal wastewater, primarily of domestic origin, upon *Daphnia magna*. The authors reported 100 percent mortality of 3-day-old *D. magna* exposed to 70 µg/L residual chlorine for 10.5 hours (Pt. 119, Figure 1). One-day-old *D. magna* suffered 30 percent mortality at 11 µg/L after 48 hours yielding a 48-h LC50 of 17 µg/L (Pt. 120, Figure 1). However, control test mortalities revealed that inherent properties of the unchlorinated effluent were toxic to this species.

Arthur et al. (1975) performed two separate tests, each with duplicates (i.e., total of 4 tests) at various residual chlorine concentrations using *Daphnia magna* exposed to secondary-treated sewage. After 7 days exposure at 2 µg/L, both duplicates in test No. 1 had only 1 mortality each out of 10 individuals which was similar to the mortality rate in each of the unchlorinated control tests. At 4 µg/L, 50 percent of the individuals survived after 7 days, but the duplicate showed 90 percent survival which exceeded the 70 percent survival in the corresponding unchlorinated control test. In test No. 2 at 2 µg/L residual chlorine, the survival rate after 7 days was zero percent and 50 percent in each of the duplicates, compared to 70 and 90 percent survival, respectively, in the controls. At total residual chlorine concentrations of 7 µg/L or greater, no *Daphnia* survived. In view of the inconsistencies in these data, the 7-day LC50 would appear to lie somewhere between 2 and 7 µg/L total residual chlorine (Pt. 117, Figure 1).

Grossnickle (1974, as cited in Brungs, 1976) exposed rotifers (*Keratella cochlearis*) to total residual chlorine continuously for periods of 1, 4, and 24 hours. The 1, 4, and 24-h LC50's were 32, 27, and 13.5 µg/L, respectively (Pt. 127, Figure 1). Similarly, Beeton et al. (1976, as cited in Brungs, 1976) exposed the same species of rotifer to a mixture of hypochlorite and monochloramine. The 4-h LC50 was 19 µg/L total residual chlorine (Pt. 128, Figure 1).

Ward and DeGraeve (1980) measured the acute toxicity of chlorinated effluent from a treatment plant receiving both domestic and industrial wastewaters. The 48-h LC50's for various invertebrate species, including aquatic insect larvae, ranged from 41 µg/L total residual chlorine for copepods to 1 120 µg/L for the amphipod *Gammarus* sp. (Pt. 126, Figure 1). When compared to tests using unchlorinated wastewater, the authors concluded that the majority of the toxicity measured was associated with chlorination and not merely the inherent toxicity of the unchlorinated effluent.

Arthur and Eaton (1971) exposed the amphipod *Gammarus pseudolimnaeus* to various chloramine concentrations under continuous flow conditions. The 96-h LC50 for this species was 220 µg/L total residual chlorine (Pt. 21, Figure 1).

Arthur et al. (1975) reported a 7-day LC50 for caddisfly (*Tricoptera*) larvae of 550 µg/L total residual chlorine and a 3-day LC50 of 480 µg/L for stonefly (*Plecoptera*) larvae tested in chlorinated sewage (Pts. 32 and 36, Figure 1).

Latimer et al. (1975) investigated the effects of a single 30-minute dose of chlorine at different temperatures on two species of copepods (*Limnocalanus macrurus* and *Cyclops bicuspidatus thomasi*) to simulate the effect of intermittent chlorination of power plant cooling water. The 0.5-h LC5's (concentration causing 5 percent mortality over the 30-minute exposure period) were used to predict “safe” concentrations. The “safe” 30-minute total residual chlorine concentrations predicted for *L. macrurus* and *C. b. thomasi* were 900 and 500 µg/L, respectively (Pts. 124 and 125, Figure 1).

Greg (1974, as cited in Brungs, 1976) reported that temperature exerted an influence on residual chlorine toxicity but the degree varied widely depending upon the species tested. Generally, 2 and 4-day LC50 values for a variety of freshwater invertebrates and aquatic insect larvae exposed continuously to residual chlorine ranged between 10 and 100 µg/L (Pts. 28, 30, 31, 33, 34, 35, 37, 44, 45, 47, Figure 1). However, it was suspected that. nearly lethal temperatures may have played a major role in some of the tests, as indicated by high control mortalities.

4.4.1.2 *Chronic Toxicity*

A review of the few available studies investigating the chronic effects of residual chlorine to freshwater invertebrates indicated a wide range of sensitivities depending on the species, the effect studied, and the exposure period.

Arthur et al. (1975) noted decreased reproduction in *Daphnia magna* after 2 weeks exposure to 2 µg/L total residual chlorine in secondary treated municipal sewage, although duplicate tests at this concentration yielded somewhat inconsistent results. When compared to unchlorinated control tests, obvious decreases in reproduction occurred at 4 µg/L and greater (Pt. 117, Figure 1). Decreased reproduction in the amphipod *Gammarus pseudolimnaeus* was noted at 19 µg/L total residual chlorine after 20 weeks exposure and decreased survival of adults occurred at 54 µg/L after 16 weeks exposure (Pts. 23 and 24, Figure 1). The authors concluded that the highest mean total residual chlorine concentrations having no long-term adverse effects on amphipods and *Daphnia* were 12 µg/L and 2 to 4 µg/L, respectively.

Arthur and Eaton (1971) exposed *G. pseudolimnaeus* to chloramine for periods up to 15 weeks. While the 96-h LC50 for this species was 220 µg/L, 80 percent mortality occurred at 35 µg/L after 15 weeks and reproductive success was markedly reduced in chloramine concentrations of 3.4 to 16 µg/L after 15 weeks (Pts, 20, 21, 22, Figure 1).

The U.S. EPA (1985) calculated a 365-day LC50 of 31 µg/L total residual chlorine for the crayfish *Pacifastacus trowbridgii* based on studies performed by Larson et al. (1978) (Pt. 129, Figure 1).

4.4.2 *Marine Invertebrates*

4.4.2.1 *Acute Toxicity*

A review of the toxicological data has revealed that, generally invertebrates are the most sensitive marine organisms to short-term exposures of chlorine-produced oxidants (CPO).

Dinel et al. (1981) demonstrated that egg fertilization success in sand dollars (*Dendraster excentricus*) and sea urchins (*Strongylocentrotus droebachiensis*) was reduced by 50 percent when exposed to CPO concentrations as low as 2 to 13 µg/L for 5 minutes (Pt. 121 and 122, Figure 2). In an earlier study, Muchmore and Epel (1973) showed that the CPO concentration required to reduce egg fertilization success of another sea urchin species (*Strongylocentrotus purpuratus*) to 1 to 6 percent after 5 minutes exposure was 125 µg/L. Mattice and Zittel (1976) assessed this earlier data (Pt. 41, Figure 2) and determined an acute toxicity threshold of 67 µg/L for an exposure period of 5 minutes.

Of the various species of marine arthropods tested, rotifers (*Brachionus plicatilis*) have shown the greatest sensitivity to CPO. Capuzzo (1979) determined a 30-minute LC50 of <10 µg/L CPO for rotifers exposed to chloramine in a test with a 5°C temperature increase. Under the same test conditions, but using free chlorine, the 30-minute LC50 was 90 µg/L. Similar tests with no temperature change produced 30-minute LC50’s of 20 and 180 µg/L CPO when exposed to chloramines or free chlorine, respectively. (Pts. 93 to 96, Figure 2). It is apparent from these tests that rotifers are more sensitive to chloramines than to free chlorine, especially when exacerbated with temperature increases. This same trend of sensitivity was noted for other marine invertebrates including copepods, lobsters, and oysters.

Capuzzo (1979) showed that 30-minute LC50's for the eastern oyster (*Crassostrea virginica*) exposed to chloramine during no temperature change and a 5°C temperature change of the test water were 10 µg/L or less. When exposed to free chlorine under the same temperature conditions, the LC50's were 120 and 80 µg/L CPO, respectively, especially at increased temperatures (Pts. 86 and 87, Table 3a). It should be noted that several other studies (Roberts et al., 1975; Scott and Middaugh, 1977; U.S. EPA, 1981; Roosenburg, Rhoderick, Block, Kennedy, Gullans, et al., 1980) using the eastern oyster have indicated that this species may not be as sensitive to chlorine as indicated by Capuzzo (1979), even after longer exposures, This eastern oyster species is not found in British Columbia waters. The species of oyster common in British Columbia coastal waters is *Crassostrea gigas* which was introduced from Japan many years ago. While the two species are closely related, no toxicological data were available for the effects of chlorine on *C. gigas*.

Lobster (*Homarus americanus*) larvae have shown a considerable range of sensitivity to CPO depending upon the form of chlorine (chloramine or free chlorine) introduced and upon the particular response tested. The lowest concentration found to have a deleterious effect was 30 µg/L CPO on exposure to chloramine for 60 minutes which reduced the respiration rate by 50 percent (Capuzzo, 1977) (Pt. 117, Figure 2). Under identical test conditions, but using free chlorine, the 60-minute EC50 for the same response was 80 µg/L indicating a greater sensitivity to chloramine (Pt. 118, Figure 2). Lobsters are not indigenous to British Columbia coastal waters and attempts to introduce them here have proven unsuccessful.

4.4.2.2 *Chronic Toxicity*

The toxicological data indicate that invertebrates are the most sensitive marine organisms to chronic exposures of CPO. This high sensitivity of invertebrates was also noted for acute exposures (Section 4.4.2.1).

The lowest CPO concentration reported to have a detrimental effect on marine invertebrates was a 48-h LC50 of 1 µg/L (Pt. 91, Figure 2), calculated by Roberts et al. (1975) for the hard clam (*Mercenaria mercenaria*). However, it should be noted that due to the limitations of analytical detection of the study, this was an extrapolated value and therefore may be somewhat questionable. This same study (Roberts et al., 1975) also reported that the 48-h LC50 for retarded hinge development in hard clam larvae was 6 µg/L CPO (Pt. 90, Figure 2). In addition, Roberts et al. (1975) noted reduced shell deposition in juvenile eastern oysters exposed to CPO for 96 hours. An extrapolated 96-h EC50 of 23 µg/L was derived because the lowest concentration tested was 40 µg/L (Pt. 78, Figure 2).

Hawk and Block (in press, as cited in Scott, 1981) noted reduced glycogen levels in the adductor muscles of adult oysters (*C. virginica*) exposed to 4 µg/L CPO for 96 hours (Pt. 85, Figure 2). However, it is unclear if this response is harmful to the animals in terms of survival, growth, longevity or reproductive success.

Roberts and Gleeson (1978) determined 48-h LC50's of 26 and 29 µg/L CPO for eastern oyster larvae (Pt. 77, Figure 2), and for the copepod *Acartia tonsa* (Pt. 98, Figure 2), respectively, in constant addition systems.

Hillman et al. (1979) showed inhibited shell growth in adult littleneck clams (*Protothaca staminea*) exposed to 25 µg/L CPO for 8 months (Pt. 92, Figure 2).

Roberts (1977) reported a 96-h LC50 of 24 µg/L CPO for intertidal mud crab (*Panopeus herbstii*) larvae (Pt. 110, Figure 2) while the lowest 120-h LC50 for the larvae of a species of hermit crab (*Pagurus longicarpus*) was 54 µg/L CPO (Pt. 111, Figure 2).

All other long-term (>2-hour exposure period} toxicological results for marine invertebrates exceed a CPO concentration of 30 µg/L (Figure 2).

4.5 Effects on Fish

Due to the large amount of data pertaining to the toxicological effects of residual chlorine on fish, the following discussion will focus upon the relevant data produced from the more sensitive tests taking into account the relationship between exposure period and concentration, and any other factors which may influence the determination of criteria levels.

4.5.1 *Freshwater Fish*

4.5.1.1 *Acute Toxicity*

In an extensive review of the literature regarding the toxicity of chlorine to aquatic organisms, Brungs (1976) concluded that most of the 96-h LC50 values for the more sensitive freshwater fish (trout, salmon, and minnows) ranged between 40 and 80 µg/L total residual chlorine.

Other data, not included in the review by Brungs (1976) have indicated that. concentrations of total residual chlorine less than 40 µg/L are acutely toxic to fish. For example, Cairns and Conn (1979, as cited in Servizi, 1979) produced minimum and average 96-h LC50‘s of 10 and 40 µg/L, respectively, for rainbow trout (*Oncorhynchus mykiss*) exposed to residual chlorine in secondary-treated municipal sewage using continuous-flow bioassays (Pt. 140, Figure 1).

Rosenberger (1972, as cited in Mattice and Zittel, 1976) determined mortality thresholds for coho salmon (*Oncorhynchus kisutch*) of 16 and 4 µg/L for exposure periods of 24 and 96 hours, respectively (Pt. 50, Figure 1). These data were included in the review by Mattice and Zittel (1976) who rated the results as "good" in terms of their overall scientific validity, based upon the experimental procedure, analytical technique, and reporting of the data.

Truchan and Basch (1971, as cited in Mattice and Zittel, 1976) reported some mortality of the gizzard shad (*Dorosoma cepedianum*) exposed to 620 µg/L total residual chlorine in a power plant discharge after 10 minutes (Pt. 49, Figure 1). Mattice and Zittel (1976) evaluated this study and rated the data as good.

Holland et al. (1960, as cited in Mattice and Zittel, 1976) reported 100 percent mortality of coho fingerlings exposed to 150 µg/L monochloramine (measured as total residual chlorine) for less than 48 minutes (Pt. 51, figure 1). This result was rated good by Mattice and Zittel (1976).

Hubbs (1930, as cited in Mattice and Zittel, 1976) reported 100 percent mortality of roseyface shiners (*Notropis rubellus*) exposed to 70 µg/L total residual chlorine for 180 minutes (Pt. 83, Figure 1). This result was also rated good by Mattice and Zittel (1976).

Pike (1971, as cited in Mattice and Zittel, 1976) reported 50 percent mortality to brown trout (*Salmo trutta*) exposed to 90, 50, and 20 µg/L free chlorine for periods of 180, 360 and 660 minutes, respectively (Pt. 63, Figure 1). It should be noted that the measurement of free chlorine (orthotolidine method) may have under estimated the concentration of total residual chlorine required to cause mortality (i.e., the free chlorine measurement may have been conservative with respect to environmental protection in this particular context).

In field studies, Basch et al. (1971, as cited in Basch and Truchan, 1974) placed caged rainbow trout upstream (control site) and at various locations downstream from four Michigan municipal wastewater treatment plants while the plants were chlorinating at normal levels. In three of these caged fish studies, average concentrations of total residual chlorine as low as 20 µg/L were lethal to rainbow trout after 96 hours. The lowest 96-h LC50 reported was 14 µg/L (Pt. 54, Figure 1). On request, the plants stopped chlorinating and new fish were placed in the cages. During the discharge of unchlorinated effluent, the trout survived exposure to undiluted effluent indicating that residual chlorine was the toxic constituent. Mattice and Zittel (1976) rated these results as good.

Similarly, in British Columbia. Servizi and Martens (1974) placed young sockeye salmon (*Oncorhynchus nerka*) in cages at various locations downstream from three chlorinated domestic wastewater discharges. At a residual chlorine concentration of 1 000 µg/L, 100 percent mortality was recorded in 18 minutes. When the total residual chlorine ranged between 200 and 220 µg/L, 50 percent of the fish died after 3 to 4 hours of exposure. The authors concluded that mortality of so eke ye salmon and rainbow trout was likely when total residual chlorine in the receiving water was 20 µg/L or greater.

Tsai (1973) studied fish species diversity and occurrence above and below 149 domestic wastewater treatments in Virginia, Pennsylvania, and Maryland. No fish were found in water containing residual chlorine which exceeded 370 µg/L. Tsai's graphically presented data indicated that brown trout (*Salmo trutta*) and brook trout (*Salvenlinus fontinalis*) did not occur where total residual chlorine concentrations exceeded about 20 µg/L.

DeGraeve and Ward (1977) studied the ability of fathead minnows (*Pimephales promelas*) and lake trout (*Salvelinus narnaycush*) to acclimate to residual chlorine. The authors found that fish previously exposed to sublethal chlorine concentrations for longer than about 2 hours were capable of tolerating higher levels of total residual chlorine for longer periods of time when compared to control fish that were not previously exposed.

4.5.1.2 *Chronic Toxicity*

The lowest concentration of total residual chlorine shown to produce harmful effects to freshwater fish on long-term exposure was 3 µg/L, Buckley (1976b) demonstrated that fingerling coho salmon, exposed for 12 weeks to mixtures of secondary-treated domestic wastewater and river water diluent containing 3 to 50 µg/L total residual chlorine, developed mild to severe symptoms of haemolytic anemia (Pt. 132, Figure 1).

Dandy (1972) reported depressed locomotory activity of brook trout exposed to 5 µg/L total residual chlorine for 7 days. The 7-day lethal threshold for brook trout was reported as 10 µg/L total residual chlorine (Pt. 65, Figure 1). These results were rated as good by Mattice and Zittel (1976) whereas the. results of an earlier (1935) study by Coventry et al. (1935, as cited in Mattice and Zittel, 1976), which reported the same 7-day lethal threshold concentration (10 µg/L) for brook trout was considered questionable (Pt. 66, Figure 1).

Larson, Hutchins, and Lamperti (1977) reported a decrease in the growth of juvenile coho salmon, when compared to controls, at chloramine concentrations of 22 to 23 µg/L (measured as total residual chlorine) after 3 weeks exposure (Pt. 133, Figure 1). Growth and food conversion efficiency in test fish were not affected at a total residual chlorine concentration of 5 µg/L. The authors concluded that the threshold concentration for reduction in growth occurred between 11 and 23 µg/L, but this was probably influenced by fish size, history of exposure to the toxicant, and the age-season complex.

The avoidance of total residual chlorine by fish was highly variable and dependent on a number of factors including the total residual chlorine concentration, water temperature, and the species tested.

Giattina et al. (1981) studied the avoidance of total residual chlorine by fish in field surveys and laboratory tests. Whitetail shiners (*Notropis galacturus*) avoided 40 µg/L total residual chlorine (intermittent chlorination) when field temperatures ranged between 30 and 35°C. When field temperatures were falling from 26 to 7°C, the fish avoided 230 to 420 µg/L. Based on published acute toxicity tests using intermittent chlorination, the authors concluded that most fish species generally avoided chlorine residuals of 50 percent or less of the median lethal concentrations.

From field studies using caged rainbow trout, data obtained by Osborne et al. (1981) indicate that, contrary to popular belief, fish do not congregate below sewage outfalls, but instead they avoid chlorinated sewage. However, fish moved in and out of the chlorinated sewage, presumably to feed.

Sprague and Drury (1969, as cited in Katz and Harder, 1976) found that salmon avoided total residual chlorine concentrations of 1, 10, and 1 000 µg/L, but seemed to be attracted to 100 µg/L. The authors interpreted this phenomenon as a “physiological trap” involving the sense organs. Katz and Harder (1976) offered another interpretation of this particular phenomenon. Since chlorine reacts with ammonia (excreted from the gills of fish) to form chloramines, it is possible that at the 100 µg/L concentration, breakpoint chlorination (Section 2) occurred at the gills. At the breakpoint, no chlorine residuals are present which indicate chlorine-free water to the fish and thus misleads them into turning around and re-entering the chlorinated water.

4.5.2 *Marine Fish*

While there is a considerable amount of data regarding the toxicity of CPO to marine fish, the majority of the studies focus upon lethal responses. Few data were available regarding sublethal responses in marine fish. Furthermore, there was a paucity of data regarding exposure periods exceeding 96 hours.

4.5.2.1 *Acute Toxicity*

A review of the available toxicological data indicated that marine fish generally appear to be more tolerant to acute exposures of CPO than marine invertebrates or phytoplankton.

The lowest concentration of CPO reported to have a lethal effect on marine fish after acute exposure (less than 2 hours) was 75 µg/L. Alderson (1970, as cited in Mattice and Zittel, 1976) reported 50 percent mortality to plaice (*Pleuronectes platessa*) larvae exposed to 75 µg/L CPO (introduced as free chlorine) for 75 minutes (Pt. 47, Figure 2). Mattice and Zittel (1976) rated the results of this study as good. While plaice are not indigenous to British Columbia coastal waters, there are several closely related species which do inhabit these waters.

Other available data regarding lethal concentrations of CPO to marine fish exposed for 2 hours or less were all greater than 100 µg/L, regardless of the life state, or whether the fish were exposed to free chlorine or chloramine, or of any temperature change during the test.

Less severe effects such as avoidance or di stress were noted at much lower concentrations. For example, Stober et al. (1980) determined an avoidance threshold of 2 µg/L CPO for coho salmon. While an exposure period is not given, a response, such as avoidance, usually occurs quickly, Avoidance is not a severe effect and thus, is not likely to have an immediately harmful effect on fish. Nevertheless, avoidance may disturb migration patterns, such as inhibiting or stalling the passage of salmon through estuaries on their return to spawn. On the other hand, avoidance may be merely an initial response which may be overcome by gradual acclimation.

Avoidance of CPO by other marine fish species occurred at higher levels. Middaugh et al. (1977) reported avoidance of spot (*Leiostomus xanthurus*) to 50 and 180 µg/L CPO after 30 minutes exposure (Pt, 159, Figure 2), and Stober et al. (1980) reported an avoidance threshold of 175 µg/L for shiner perch (*Cymatogastor aggregata*). Hose and Stoffel (1980) found that avoidance of chlorinated seawater by the blacksmith (*Chromis punctipinnis*), indigenous to warm temperate waters, was significant at CPO concentrations of 80 to 1 00 µg/L.

Holland et al. (1960, as cited in Mattice and Zittel, 1976) observed signs of distress, but no mortality, in Chinook salmon (*Oncorhynchus tshawytscha*) exposed to 100 µg/L for 60 minutes (Pt, 54, Figure 2).

4.5.2.2 *Chronic Toxicity*

The lowest CPO concentration reported in the literature to have a harmful effect on marine fish after an exposure period of more than 2 hours was >23 µg/L. Thatcher (1977) reported 96-h LC50's of >23 µg/L for juvenile pink salmon (*Oncorhynchus gorbuscha*) and 32 µg/L CPO for juvenile coho salmon (*O. kisutch*) in laboratory bioassays designed to simulate chlorinated cooling water in seawater (Pts. 132 and 131, Figure 2).

On the other hand, Buckley (1976a) reported a 96-h LC50 of 70 µg/L CPO for juvenile coho salmon exposed to a mixture of chlorinated sewage and seawater diluent (Pt. 128, Figure 2). However, in a previous study which investigated changes in blood chemistry and blood cell morphology, Buckley et al. (1976) determined a maximum safe concentration of between 3 and 9 µg/L CPO for yearling coho salmon exposed to chlorinated sewage and seawater for 12 weeks (Pt. 129, Figure 2).

Alderson (1970, as cited in Mattice and Zittel, 1976) noted 50 percent mortality to plaice larvae on exposure to 28 µg/L CPO introduced as free chlorine) for 96 hours (Pt. 47, Figure 2).

Esvelt et al. (1973) reported 50 percent mortality to golden shiners (*Notemigonus chrysoleucas*) exposed to between 30 and 230 µg/L for 96 hours (Pt. 65, Figure 2).

Roberts et al. (1975) reported 48 and 96-h LC50's of 38 and 37 µg/L CPO, respectively, for Atlantic silversides (*Menida menida*) in estuarine water (Pts. 134, Figure 2). The ambient ammonia levels (100 to 300 µg/L) in the diluent water indicated that only combined chlorine, primarily as monochloramine, should be present. However, no monochloramine was detected at the detection limit of 20 µg/L.

4.6 Criteria from the Literature

Criteria, objectives, and standards to protect aquatic life from TRC (in freshwater) or CPO (in seawater) have been compiled from a number of jurisdictions and tabulated in Tables 4 and 5, respectively.

4.6.1 *Continuous Exposure*

Recent criteria to protect freshwater aquatic life from continuous exposure to TRC generally range between about 2 and 20 µg/L. For continuous exposure of marine and estuarine aquatic life, a similar range of CPO concentrations has been recommended by various jurisdictions over the years.

The most recent (1985) U.S. EPA (1985) criteria to protect freshwater aquatic life from continuous exposure to TRC specify that the 1-hour average concentration should not exceed 19 ug/L and the 4-day average should not exceed 11 µg/L, To protect marine aquatic life, the U.S. EPA (1985) criteria specify a 1-hour average of 13 µg/L CPO and a 4-day average of 7.5 µg/L CPO. These criteria do not apply to situations of specifically controlled intermittent exposures.

The U.S. EPA (1985) has introduced a new concept to its most recent aquatic life criteria. It permits the criteria to be exceeded an average of once every three years. The reasoning behind this concept is based on the U.S. EPA's best scientific judgement that three years is the average amount of time it would take to an unstressed system to recover from a pollution event (Stephan et al., 1985).

The U.S. EPA criteria were derived using a somewhat complex statistical procedure developed by Stephan et al. (1985) and are intended to protect at least 95% of a group of diverse genera. If a sensitive species Ls economically, recreationally, or socially important, then the criterion is based on toxicity data for that sensitive species. The U.S. EPA criterion to protect aquatic life from acute toxicity is based on the “Final Acute Value” (a Genus Mean Acute Value derived using statistical procedures based on 96-h LC50' s). In the case of an important sensitive species, the criterion is based upon the “Species Mean Acute Value” which becomes the “Final Acute Value” The “Final Acute Value” is divided by a safety factor of two to determine the “Criterion Maximum Concentration”, which is the criterion level (specified as a 1-hour average) designed to protect aquatic life from acute effects.

The U.S. EPA 4-day average criterion level, which is designed to protect organisms from the chronic effects of chlorine, is derived by dividing the “Final Acute Value” by the geometric mean of the acute-chronic ratios (inverse of the application factor) for sensitive organisms. This value has been called the “Criterion Continuous Concentration” by the U.S. EPA.

The most recent Canadian criterion for total residual chlorine was determined by the Canadian Council of Resource and Environment Ministers (CCREM) (1987) in 1987. It recommends that the concentration of TRC, as measured by the amperometric (or equivalent) method, should not exceed 2 µg/L. This criterion applies only to freshwater. It is not clear whether the criterion applies to controlled intermittent exposures as well as continuous exposure.

The use of separate criteria for warm and cold freshwater aquatic life by some jurisdictions is considered no longer valid. Brungs (1976) reported that additional data for some warm-water fish no longer support this distinction.

The British Columbia Pollution Control Objectives for Municipal Waste Discharges (B.C. Ministry of Environment, 1979), Forest Products Industries (B.C. Ministry of Environment, 1977), Chemical and

Petroleum Industries (B.C. Ministry of Environment, 1980), and Food-Processing, Agriculture and Other Miscellaneous Industries (B.C. Ministry of Environment, 1980) specify that TRC should not be detectable (as measured by the amperometric method) outside the initial dilution zone. As noted in Section 2.3, detection limits for the amperometric titration technique can vary depending upon improvements to the technique and operator skill. This “non-detectable” approach could result in the uneven application of criteria throughout the Province and, in some cases, result in criteria that may be underprotective or overprotective.

4.6.2 *Intermittent Exposure*

The popular approach to protect aquatic life from controlled, intermittent exposures to TRC or CPO is to base the criteria on an exposure time- concentration relationship. This approach which was first introduced by Mattice and Zittel (1976) in 1976 and later recommended by the American Fisheries Society (DeGraeve et al., 1979), is demonstrated in Figures 1 and 2, where the safe level can be obtained directly from the “Acute Toxicity Threshold”. A modification to their concept by Brungs (1977) has refined the criteria to take into account the additive toxic effect of intermittent exposures. To accomplish this, the exposure time over a 24-hour period was totalled and the acceptable toxicant concentration was read from time-concentration graphs (Figures 1 and 2) for freshwater or marine situations as appropriate.

This additive approach may be, at times, overprotective. Brooks et al. (1982) showed that totalled intermittent exposures were often less toxic than continuous exposures of similar duration. This indicated that sane recovery occurred during the intervals between exposures. However, in some cases, totalled intermittent exposures yielded similar, and at times, identical results to continuous exposures of the same duration (Pts. 152, Table 2a). These latter data support the additive concept conceived by Brungs (1977).

The U.S. EPA has recently (1988) reviewed applications for two electric generating plants to intermittently discharge TRC at levels beyond the “best available technology economically achievable” requirements of the Clean Water Act. To discharge concentrations of contaminants which exceed maximum concentrations specified under the Act, a variance must be obtained by the applicant. To grant a variance for any applicant, the U.S. EPA must ensure that State Water Quality Standards are met and that the proposed concentrations will not be detrimental to water uses in the area.

The two applications reviewed by the U.S. EPA include a freshwater discharge to the Mississippi River in the State of Mississippi (U.S. EPA, 1988a), and a marine discharge to an estuary in California (U.S. EPA, 1988b). The Mississippi discharge has been officially approved and the California discharge has been tentatively approved pending the outcome of a 30-day public comment and notice period. Since Water Quality Standards for the two states are different, the impact assessments and the determination of receiving water objectives have been approached in a different manner for each discharge. Mississippi requires that the concentration of toxic pollutants shall not exceed 0.1 of the 96-h LC50 based on available data. The U.S. EPA interpreted the 96-h LC50 as 38 µg/L TRC which is the “Final Acute Value” derived by the U.S. EPA for continuous exposure (Section 4.6.1). Thus, it was established that a level of 3.8 µg/L TRC may not be exceeded at the edge of the initial dilution zone. An additional condition of the variance stipulated that intermittent chlorine discharges are restricted to a maximum total duration of 2 hours per day (U.S. EPA, 1988a).

For the marine discharge in California, the California Ocean Plan standard for intermittent discharges of TRC had to be considered before a variance could be granted by the U.S. EPA. The California standard is based on the duration of chlorination as outlined in the beginning of this Section (4.6.2) and is derived by the equation:

$$\log y = -0.33 (\log x) + 2.1$$

where x is the duration of uninterrupted chlorine discharge in minutes and y is the water quality objective for TRC (in µg/L) to apply at the edge of the mixing zone when chlorine is being discharged. This standard is similar to, and appears to be taken from, the acute toxicity threshold derived by Mattice and Zittel (1976) (Figure 2). Under the conditions of the California Ocean Plan, intermittent discharges of chlorine are limited to a maximum total duration of 2 hours per day per outfall (U.S. EPA, 1988b).

4.7 Recommended Criteria

Criteria to protect aquatic life from the harmful effects of TRC in freshwater, and CPO in estuarine and coastal marine waters of British Columbia, are modified from criteria developed by other sources and take into account appropriate toxicological data to tailor the criteria for aquatic life found in local waters. These criteria are designed to protect aquatic life from both continuous and controlled, intermittent exposures.

4.7.1 *Freshwater Aquatic Life*

"Total residual chlorine" is the sum of the "free available chlorine" plus the "combined available chlorine". This includes all the forms of chlorine which are able to act as an oxidant.

4.7.1.1 *Continuous Exposure*

(a) The average concentration of total residual chlorine should not exceed 2 µg/L. This is the threshold of chronic toxicity. The averaging period should not be less than 4 days nor more than 30 days. A minimum of 5 samples, equally spaced in time, should be used to calculate the average.

4.7.1.2 *Controlled Intermittent Exposures*

(a) The total residual chlorine concentration should be time-related and should not exceed the numerical value (in µg/L) given by the formula ($1074(\text{duration})^{-0.74}$), where duration is the uninterrupted exposure period (in minutes). This is the threshold of acute toxicity.

(b) The total duration of exposure in any consecutive 24-hour period should not exceed 2 hours.

(c) The maximum concentration of total residual chlorine should not exceed 100 µg/L regardless of the exposure period.

Examples based on these criteria (rounded to nearest µg/L) are as follows:

Duration of Exposure (minutes)	**TRC Concentration µg/L**
≤25	100 [as per 4.7.1.2(c)]
30	87
45	64
60	52
90	38
120	31
>120	apply continuous exposure criterion (4.7.1.1)

4.7.2 *Marine and Estuarine Aquatic Life*

In marine or estuarine waters, the term "chlorine-produced oxidants" is used because of the high levels of bromide naturally present in seawater. Bromide, in the presence of residual chlorine, forms "free available bromine" or "combined available bromine" which are able to act as oxidants.

4.7.2.1 *Continuous Exposure*

(a) The average concentration of chlorine-produced oxidants should not exceed 3 µg/L. This is the threshold of chronic toxicity. The averaging period should not be less than 2 hours nor more than 30 days. A minimum of 5 samples, equally spaced in time, should be used to calculate the average.

4.7.2.2 *Controlled Intermittent Exposures*

(a) The chlorine-produced oxidant concentration should be time-related and should not exceed the numerical value (in µg/L) given by the formula ($20.36(\text{duration})^{-0.4}$), where duration is the uninterrupted exposure period (in minutes). This is the threshold of acute toxicity. The total duration of exposure in any consecutive 24-hour period should not exceed 2 hours.

(b) The maximum concentration of chlorine-produced oxidants should not exceed 40 µg/L regardless of the exposure period.

Examples based on these criteria (rounded to nearest µg/L) are as follows:

Duration of Exposure (minutes)	**TRC Concentration µg/L**
≤0.2	40 [as per 5.7.2.2(c)]
5	11
10	8
15	7
30	5
60	4
90	3
>120	apply continuous exposure criterion (5.7.2.1)

4.7.3 *Application of Criteria*

The lower limits for the duration of the averaging periods for continuous exposure and time-related concentrations for intermittent exposures specified in the criteria imply a requirement for frequent monitoring. However, longer averaging periods are acceptable because beyond the acute- chronic intercepts (Fig. 1 and Fig. 2) harmful effects are no longer time dependent. Thus, to allow flexibility in monitoring programs, the averaging period could be as long as 30 days. Such monitoring is necessary only if dilution calculations indicate that the criteria might possibly be exceeded at the edge of the initial dilution zone of a discharge containing chlorine.

To determine whether monitoring is necessary, a worst-case scenario should be formulated using site-specific information which include the effluent concentration of TRC and the minimum dilution available at the edge of the site-specific initial dilution zone. If the average criterion value for continuous exposure is not exceeded by the calculated estimate under worst-case conditions, then monitoring is unnecessary regardless of whether the exposure is intermittent or continuous. If calculations show that the average criterion value for continuous exposure could be exceeded, for freshwater or seawater as. Appropriate, then monitoring should be initiated.

When monitoring for TRC or CPO is necessary, the amperometric method of analysis, using modifications to improve the detection limit (discussed in Section 2.3), is the recommended method. Furthermore, it is recommended that an individual, experienced in the operation of an amperometer, be designated to perform the analyses (see Research and Development Needs, Section 6). While frequent monitoring may be necessary to determine if criteria are being met, usually only a short-term monitoring program is necessary. Such a monitoring program should be performed at times when minimum dilution is available, in keeping with the worst-case scenario.

An initial assessment should be made to determine whether exposure at the edge of the initial dilution zone is continuous or intermittent. In some situations, this determination may be obvious. For example, if a discharge is continuously chlorinated then, in all likelihood, the exposure will be continuous, and the appropriate criteria will apply. However, if a discharge is intermittently chlorinated it does not necessarily follow that exposure is intermittent. For example, if the discharge is to a moving body of water such as a river then, in all likelihood, exposure will be intermittent. On the other hand, if TRC is discharged intermittently to a relatively motionless body of water such as a lake, exposure may be intermittent or continuous depending upon whether residuals persist between the chlorination periods. If residuals do persist through the periods of non-chlorination, then the situation should be treated as continuous exposure and the continuous exposure criteria should apply. If residuals do not persist at the edge of the initial dilution zone, then the intermittent exposure criteria should apply.

While the monitoring schedule should be somewhat flexible to determine if criteria are being met, enough samples should be taken to provide a relatively accurate profile of the exposure characteristics. For continuous exposure situations, at least 5 samples, equally spaced in time, are recommended to determine an average concentration over the averaging periods. The minimum duration of the averaging periods is 4 days for fresh- water and only 2 hours for marine or estuarine waters but may be as long as 30 days as noted earlier in this Section.

For an intermittent exposure situation, some knowledge of the chlorination schedule, including the start times, duration of the chlorination period, and daily frequency, would be helpful prior to monitoring. This prior knowledge would provide an indication of when to start monitoring so that samples could be collected over the entire exposure period. Monitoring should be continued as frequently as possible over the chlorination period and until the concentration at the edge of the initial dilution zone drops below the continuous exposure criterion (i.e., 2 or 3 µg/L for fresh or marine water as appropriate). The concentrations measured over the uninterrupted duration of exposure should be averaged and the average value should not exceed the appropriate freshwater (5.7.1.2(a)) or marine and estuarine (5.7.2.2(b)) criterion. No individual sample should exceed 100 µg/L TRC in freshwater or 40 µg/L CPO in marine or estuarine water, as per Sections 5.7.1.2(c) or 5.7.2.2(c). Since the intermittent exposure criteria formulae [5.7,1.2(a) or 5.7.2.2(a)] are based on the acute toxicity threshold, application of these criteria at the edge of the initial dilution zone could lead to acutely toxic conditions for a short time within the initial dilution zone, depending upon the dilution available and upon the exposure time of organisms in the initial dilution zone. These items should be considered on a site-specific basis.

It should be noted that while intermittent exposures are not restricted by a lower average criterion, they are restricted in terms of a maximum exposure period of 2 hours in any consecutive 24-hour period. If the duration of exposure at the edge of the initial dilution zone exceeds 2 hours in any consecutive 24-hour period, then the continuous criterion should be applied.

In situations where the criteria have not been met, then one or more of the following corrective measures should be taken:

i) reduce the chlorine discharge rate,
ii) use an alternative form of treatment,
iii) dechlorinate the effluent.

4.7.4 *Rationale*

The criteria recommended in this document for the protection of marine, estuarine and freshwater aquatic life in British Columbia have been based, in part, upon the exposure duration-concentration concept originally developed by Mattice and Zittel (1976). Certain modifications have been made to provide a more appropriate level of protection to aquatic life in British Columbia. The addition of more recent toxicological data has allowed a greater refinement of the threshold levels as shown in the exposure duration-concentration relationships (Figures 1 and 2). These graphs serve as the basis upon which the criteria were derived.

The toxicity threshold lines were drawn to enclose valid data points so that concentrations above the threshold lines would be harmful while concentrations below the threshold lines would be acceptable from a toxicological perspective. Thus, these threshold lines are a graphical representation of the criteria. While these graphs may be open to different interpretations, it is believed that the approach used here will provide adequate protection to aquatic organisms without being too restrictive.

The criteria are expressed in terms of total residual chlorine for freshwater aquatic life and chlorine-produced oxidants for marine and estuarine aquatic life. A review of the toxicological data failed to support any justification for separating the chemical components of TRC or CPO.

4.7.4.1 *Averaging Periods*

The averaging periods for the continuous exposure criteria were determined directly from the exposure duration-concentration graphs (Figures and 2) for freshwater or marine water as appropriate. The point of intersect between the acute and chronic thresholds was chosen as the minimum duration for the averaging periods for continuous exposure. For freshwater, this intersect occurs at 5 000 minutes (Figure 1) and the averaging period was rounded off to 4 days (5 760 minutes). For marine and estuarine waters, the intersect for the minimum duration of the averaging period occurs at 2 hours (Figure 2). Beyond the acute-chronic intercepts harmful effects are no longer time-dependent. Thus, to provide some flexibility in monitoring programs, averaging periods of up to 30 days were considered acceptable. The most recent criteria developed by the U.S. EPA (1985) for continuous exposure specify averaging periods of 4 days and 1 hour for both freshwater and seawater situations. These U.S. EPA averaging periods have been based on philosophical assumptions and apply to all contaminants whereas the British Columbia averaging periods are tailored specifically for chlorine.

4.7.4.2 *Continuous Exposure Criteria*

a) Freshwater Aquatic Life

The chronic toxicity threshold for freshwater organisms (Figure 1) was increased slightly (to 2.0 µg/L) from that (1.5 µg/L) originally determined by Mattice and Zittel (1976). Close scrutiny of the studies upon which the original limit was based indicated that there was little justification for such a low value. Nevertheless, given the high margin of error likely in analytical precision at such low values, there is probably little difference between the two values. The U.S. EPA (1985) 4-day average criterion of 11 µg/L TRC for continuous exposure was not considered protective enough given the numerous data points, some of which include economically and recreationally important species, which occur below that concentration (see Figure 1). On the other hand, the CCREM (1987) criterion of 2 µg/L TRC, specified as a maximum, is more restrictive than the British Columbia average criterion because, by definition, a maximum does not allow for any excursions beyond that limit. In view of the relationship between safe concentrations and the duration of exposure as shown in Figure 1, it is not unreasonable to assume that occasional minor fluctuations over the criterion average concentration would be acceptable, provided that:

i) the duration and magnitude of the increases do not exceed the acute threshold value given by the formula in Section 4.7.1.2(a), and;
ii) the average criterion is met over the duration of the averaging period.

Because the average criterion concentration for TRC in freshwater is at or near the minimum detectable concentration (MDC), a maximum criterion concentration was considered unnecessary for continuous exposure situations. The low average criterion and its proximity to the MDC would limit the magnitude and number of fluctuations over the average criterion value because, when calculating an average concentration, the MDC should be used for all samples in which TRC is not detected. A maximum criterion concentration (i.e., the formula for the acute toxicity threshold given in Section 4.7.1.2(a)) would only be necessary if the MDC was considerably lower than the average criterion which, for TRC, is unlikely given the present analytical capabilities.

b) Marine and Estuarine Aquatic Life

The chronic toxicity threshold for marine and estuarine aquatic life has been readjusted considerably from that originally determined by Mattice and Zittel (1976). The addition of more recent data to the exposure duration- concentration relationship (Figure 2) indicates that marine and estuarine organisms are considerably more sensitive to CPO than originally believed. As noted in Figure 2, the chronic toxicity threshold which represents the British Columbia criteria has been reduced from 20 µg/L to 3 µg/ L to take into account most of the recent data. While one data point (91) is below the chronic toxicity threshold (continuous criterion) for British Columbia waters, this value was extrapolated from tests using higher concentrations. As an extrapolated value, this result was considered questionable because it was outside the limits of the test. One data point (129) situated on the chronic toxicity threshold was determined by one researcher to be the no-effect level for coho salmon.

The U.S. EPA (1985) 4-day average criterion of 7.5 µg/L CPO for continuous exposure was not considered protective enough in view of the lower concentrations which have been shown to be detrimental to economically or recreationally important species. The CCREM (1987) has not recommended criteria for marine or estuarine aquatic life.

4.7.4.3 *Intermittent Exposure Criteria*

These criteria were derived by enclosing the valid data points by the acute toxicity thresholds and determining the formulae for these thresholds for freshwater (Figure 1) and marine and estuarine organisms (Figure 2) as appropriate. The formulae are designed for use in situations that involve the discharge of non-recycled cooling water from industries that use “shock chlorination” to prevent bio-fouling of the heat exchangers. “Shock chlorination” is the term used to describe intermittent chlorination at elevated concentrations as opposed to low-dose chlorination delivered on a continuous basis.

This exposure time-concentration approach for setting criteria for intermittent discharges of TRC was first introduced by Mattice and Zittel (1976) in 1976 and recommended later by the American Fisheries Society (DeGraeve et al., 1979) in 1979. Recently the U.S. EPA (1988b) has adopted this time-related approach for an intermittent TRC discharge in California (see Section 4.6.2).

To address the problem of toxic carry-over effects between intermittent exposures, the approach used by the U.S. EPA (1988a, 1988b) was adopted whereby the exposure was limited to a maximum total duration of 2 hours per day. This limit should allow enough time between exposures for complete recovery of aquatic organisms and thus prevent toxic carry-over. For continuous exposure situations, a time-related maximum criterion was unnecessary because the average criterion limits the magnitude and duration of any fluctuations (see Section 4.7.4.2(a)).

a) Freshwater Aquatic Life

The acute toxicity threshold upon which the British Columbia criterion was derived is basically the same as that originally determined by Mattice and Zittel (1976) (see Figure 1). The addition of more recent data did not warrant readjustment of the threshold. While three new data points were addressed at or below the acute toxicity threshold indicating possible toxic conditions, two of these data points (127, 128) were considered questionable because other tests using the same organism over a similar exposure period showed less toxicity. The other data point (118) was secondarily referenced as a personal communication, but the original data were never published to verify this result.

Since it is not unreasonable to assume that there is probably an upper TRC concentration which will be toxic to aquatic organisms regardless of the exposure duration, and because few data were available for exposure periods less than about 30 minutes, a maximum criterion of 100 µg/L TRC, regardless of the exposure period, was specified for freshwater situations.

b) Marine and Estuarine Aquatic Life

The acute toxicity threshold for British Col um bi a marine and estuarine aquatic life has been reduced considerably from that originally determined by Mattice and Zittel (1976) to take into account more recent data. Only two data points (121, 122) were excluded from the acute toxicity threshold which represents the British Columbia criterion. While no irregularities regarding test procedures for these two values were noted, the results were considered anomalous because other tests using the same organisms over the same exposure period showed less toxicity.

For marine and estuarine situations, the acute toxicity threshold was well defined for exposure periods of less than one minute. Nevertheless, to protect against the occurrence of any individual sample from exceeding a concentration that may be harmful, a maximum criterion of 40 µg/L CPO, regardless of the exposure period, was specified.

5. OTHER WATER-USE CATEGORIES

A search of the literature indicated that total residual chlorine criteria, developed specifically for the protection of other water-use categories which include wildlife, livestock watering, irrigation, recreation and aesthetics, and industry have been established only in a few instances. The small amount of information pertaining to the toxic effects of TRC on water users in these categories generally indicates a high tolerance to TRC. Moreover, the presence of small to moderate amounts of TRC may actually be beneficial in some cases because of its bactericidal qualities.

In practice, most waterbodies which are used for other purposes in addition to aquatic life will be protected by the criteria for aquatic life because, in the case of multi-use waters, the criteria for the most sensitive designated use will apply. For TRC, aquatic life is by far the most sensitive of the various water-use categories.

5.1 Wildlife and Livestock Watering

No known TRC criteria have been established for these particular categories by other jurisdictions. Recent U.S. EPA (1981, 1986) reviews of toxicological studies which used experimental animals to investigate possible harmful effects to humans of TRC in drinking water generally indicate a high tolerance to TRC. The U.S. EPA (1981, 1986) concluded that TRC is not bioaccumulated, nor is there any substantive evidence that it is mutagenic, teratogenic or carcinogenic. In 1982, the U.S. EPA (1981) proposed an upper limit of 10 mg/L TRC in drinking water for humans, based primarily on taste considerations. A similar concentration likely would be acceptable for wildlife or livestock. However, because a concentration of this magnitude would be extremely unlikely in ambient waters, TRC criteria for wildlife and livestock watering are considered unnecessary.

5.2 Irrigation Water

A search of the literature revealed that criteria for TRC in irrigation water has been recommended by only .one jurisdiction. In 1979, Manitoba (Manitoba Clean Environment Commission, 1979) recommended acceptable limits of <50 µg/L TRC to protect crops and provide good quality irrigation water, and 50 µg/L to protect against significant crop damage and provide acceptable quality irrigation water. It is not clear how these levels were derived, as no rationale for these criteria was provided. Nevertheless, in 1983, Manitoba (Manitoba Department of Environment and Workplace Safety and Health, 1983) dropped these TRC requirements for irrigation water.

In a 1963 review of the literature, McKee and Wolf (1963) noted that no injury to terrestrial plants occurs when irrigation water contains 50 µg/L TRC or less. However, they also reported that while roots from tomato cuttings in chlorinated water were not affected by 5.0 mg/L TRC, growth was retarded at 10 mg/L.

In a more recent (1987) study, Frink and Bugbee (1987) exposed 11 species of potted foliage plants, 8 species of potted flowering plants, and 4 species of vegetable seedlings, in soilless media to irrigation water containing 0, 2, 8, 18, 37 or 77 mg/L TRC. Growth and appearance were determined after 12 weeks for potted plants and 6 weeks for seedlings. When compared to controls, growth of *Pelargonium hortorum* (geranium) and begonia declined at 2 mg/L, *capsicum* (pepper) and tomato at 8 mg/L, *Kalanchoe blossfeldiana*, lettuce, and *Tradescantia albiflora* at 18 mg/L, broccoli, *Tagetes erecta* (marigold), and petunia at 37 mg/L, and *Plectranthus coleoides* (Swedish Ivy), *Impatiens walleriana*, *Chrysalidocarpus lutescens* (Madagascar palm), and *Hedera helix* (English Ivy) at 77 mg/L. Germination of vegetable seeds was not affected by any of the chlorine treatments. It was suggested that TRC was more likely a system! C poison than a contact poison because chlorosis was general and not pronounced where water remained on the foliage. The authors concluded that a TRC concentration of 1 mg/L should not adversely affect the growth or appearance of most potted plants and vegetable seedlings grown in soilless media.

Based on these findings, it appears that there is considerable interspecies variation in the sensitivity of plants to TRC. Furthermore, it seems likely that plants grown in soil are more tolerant to TRC than those grown in soilless media, As compared to the more inert components of soilless media, the reducing agents of natural soil probably provide protection to plants by consuming much of the TRC thus preventing uptake by the roots.

While a TRC concentration as high as 1 mg/L TRC in ambient waters is unlikely, it seems appropriate that this concentration be considered a guideline for irrigation waters used for plants grown hydroponically or in soilless media. Since plants grown in soil appear to be considerably more tolerant to TRC coupled with the unlikely occurrence of TRC concentrations in the mg/L range in ambient waters, a criterion or guideline for TRC in irrigation water was considered unnecessary for crops grown in soil.

6. RESEARCH AND DEVELOPMENT NEEDS

- To improve the minimum detectable concentration for TRC and CPO to at least the criterion levels and preferably below by modifying the amperometric technique as outlined in Section 2.3.
- To have individuals, experienced in the amperometric technique, on hand to perform on-site TRC analyses when required.
- To obtain more toxicological data regarding the chronic exposure (>96 hours) of marine and freshwater organisms to residual chlorine.

Table 1. Chlorine requirements for various waters (White, 1972, as cited in Pierce, 1978; Palin, 1974, as cited in Pierce, 1978).

Application	**Probable chlorine requirement (mg/l)**
Algae control	3-5
Bacterial slime prevention	3-5
BOD reduction	10-20
Color removal	5-100 (or more depending upon type of wastewater)
Cyanide destruction	6.8 times cyanide content
Hydrogen sulfide removal	8.4 times H 2 S content (oxidation to sulfate)
Iron bacteria control	2 -10
Iron precipitation	0.63 times iron content
Manganese precipitation	1.3 times manganese content
Sewage – disinfection	
Raw fresh domestic waste	8-15
Raw septic domestic waste	15-30
Primary sedimentation effluent	8-15
Recirculated biofilter effluent	5-8
Secondary biofilter effluent	3-8
Trickling filter effluent	3-10
Activated sludge effluent	2-8
Sand filtered effluent	2-5
Septic tank effluent	30-45
Water – disinfection	
Cooling (once-through)	5-15 (intermittent)
Cooling (open recirculation)	3-5
Chilling	20
Washdown	50
Disinfection (tanks and mains)	10-50

Reproduced from Pierce (1978)

Table 2. Summary of Toxicity of Chlorine to Freshwater Organisms

Data Point and Scientific Name	**Descriptive Name**	**Concentration (mg/l)***	**Duration (min)**	**Effect**	**Reference**
Plants:					
Chlorophyta					
1. *Chlorella pyrenoidosa*		0.18	1,440	50% decrease in growth	National Research Council, 1976, as cited in U.S. EPA, 1981
2. *Chlorella pyrenoidosa*		0.4	300	50% decrease in growth	Les, 1968, as cited in U.S. EPA, 1981
3. *Chlorella pyrenoidosa*		0.6	1,200	43% mortality	Les, 1968, as cited in U.S. EPA, 1981
4. *Chlorella variegata*		2	4,320	Decreased growth	U.S. EPA, 1973
5. *Scenedesmus obliquus*		2	4,320	Decreased growth	U.S. EPA, 1973
6. *Scenedesmus* sp.		10	5,760	Mortality threshold	Knox et al., 1948, as cited in U.S. EPA, 1986
Chrysophyta					
7. *Gomphonema parvulum*		2	4,320	Decreased growth	U.S. EPA, 1973
8. *Nitzschia palea*		2	4,320	Decreased growth	U.S. EPA, 1973
Cyanophyta					
9. *Cylindrospermum licheniforme*		2	4,320	Decreased growth	U.S. EPA, 1973
10. *Microcystis aeruginosa*		2	4,320	Decreased growth	U.S. EPA, 1973
Miscellaneous N.G. †		0.4	N.G.	Stops Growth	Servizi and Martens, 1974
Invertebrate animals:					
Protozoa (many species)		2-8	<1	Some mortality	Cohen, 1933, as cited in U.S. EPA, 1986
Arthropoda-crustacea					
11. *Asellus aquaticus*	Water louse	0.5	60	No reproduction	Gottlieb et al., 1981, as cited in U.S. EPA, 1986
12. *Asellus racovitzas*	Isopod	0.613	1,440	50% mortality (15°C)	Crump and Guess, 1980, as cited in U.S. EPA, 1981
13. *Cyclops* sp.		1	30	Some mortality	Chang et al., 1981, as cited in U.S. EPA, 1986
14. *Daphnia magna*	Water flea	4	2,880	Mortality threshold	Knox et al., 1948, as cited in U.S. EPA, 1986
15. *Daphnia magna*	Water flea	0.125	240	100% mortality	EPA unpub., as cited in Alabaster and Lloyd, 1982
16. *Daphnia magna*	Water flea	0.002	20,160	Decreased reproduction ‡	Done, 1961, as cited in U.S. EPA, 1986
17. *Daphnia magna*	Water flea	0.5	4,320	100% mortality	U.S. EPA, 1981

Data Point and Scientific Name	**Descriptive Name**	**Concentration (mg/l)***	**Duration (min)**	**Effect**	**Reference**
18. *Daphna* sp.	Water flea	0.5	60	Some mortality	Chang et al., 1981, as cited in U.S. EPA, 1986
19. *Gammarus minus*	Scud	0.023	2,880	50% mortality (15°C)	Crump and Guess, 1980, as cited in U.S. EPA, 1981
20. *Gammarus pseudolimnaeus*	Scud	0.035	151,200	80% mortality	Vogt et al., 1982, as cited in U.S. EPA, 1986
21. *Gammarus pseudolimnaeus*	Scud	0.22	5,760	50% mortality	Vogt et al., 1982, as cited in U.S. EPA, 1986
22. *Gammarus pseudolimnaeus*	Scud	0.0034	151,200	Almost 0 reproduction	Vogt et al., 1982, as cited in U.S. EPA, 1986
23. *Gammarus pseudolimnaeus*	Scud	0.054	161,280	Decreased survival ‡	Done, 1961, as cited in U.S. EPA, 1986
24. *Gammarus pseudolimnaeus*	Scud	0.019	201,600	Decreased reproduction ‡	Done, 1961, as cited in U.S. EPA, 1986
25. *Gammarus pseudolimnaeus*	Scud	0.135	43,200	No effect ‡	Done, 1961, as cited in U.S. EPA, 1986
26. *Gammarus pseudolimnaeus*	Scud	0.900	1,440	50% mortality ‡	Done, 1961, as cited in U.S. EPA, 1986
27. Orconectes virilis	Crayfish	0.780	10,080	50% mortality ‡	Done, 1961, as cited in U.S. EPA, 1986
Arthropoda-insecta					
28. *Centroptilum* sp.	Mayfly	0.071	1,440	50% mortality (6°C)	Crump and Guess, 1980, as cited in U.S. EPA, 1981
29. *Chironomus* sp.	Midge larvae	7	1,440	80% mortality	National Research Council, 1976, as cited in U.S. EPA, 1981, 1986
30. *Ephemerella lata*	Mayfly	0.027	2,880	50% mortality (15°C)	Crump and Guess, 1980, as cited in U.S. EPA, 1981
31. *Hydropsyche binda*	Caddisfly	0.396	482	50% mortality (25°C)	Crump and Guess, 1980, as cited in U.S. EPA, 1981
32. Hydropsyche sp.	Caddisfly	0.55	10,080	50% mortality ‡	Done, 1961, as cited in U.S. EPA, 1986
33. *Iron humeralis*	Mayfly	0.046	480	50% mortality (15°C)	Crump and Guess, 1980, as cited in U.S. EPA, 1981
34. *Isonychia* sp.	Mayfly	0.0093	2,880	50% mortality (6°C)	Crump and Guess, 1980, as cited in U.S. EPA, 1981
35. *Peltoperla maria*	Stonefly	0.020	2,880	50% mortality (15°C)	Crump and Guess, 1980, as cited in U.S. EPA, 1981
36. Pteronarcys sp.	Stonefly	0.480	4,320	50% mortality ‡	Done, 1961, as cited in U.S. EPA, 1986
37. Stenonema ithaca	Mayfly	0.502	480	50% mortality (25°C)	Crump and Guess, 1980, as cited in U.S. EPA, 1981
Annelida					

Data Point and Scientific Name	Descriptive Name	Concentration (mg/l)*	Duration (min)	Effect	Reference
38. *Nais communis*	Oligochaete worm	1.0	35	95% mortality	Moore and Calabrese, 1980
39. *Nais* sp.	Oligochaete worm	1.0	34	100% mortality	Hoyano et al., 1973, as cited in U.S. EPA, 1986
40. *Nais* sp.	Oligochaete worm	0.5	30	Disintegration	Kanarek and Young, 1982, as cited in U.S. EPA, 1986
Nematoda					
Cheilobus quadrilabiatus	Nematode worm	91	30	50% mortality	Patton et al., 1972, as cited in U.S. EPA, 1986
41. *Diplogaster nudicapitatus*	Nematode worm	13.0	120	50% mortality	Patton et al., 1972, as cited in U.S. EPA, 1986
42. *Trilobus gracilis*	Nematode	20.0	150	100% mortality	Hoyano et al., 1973, as cited in U.S. EPA, 1986
42. *Trilobus gracilis*	Nematode (immature)	3.0	90	100% mortality	Hoyano et al., 1973, as cited in U.S. EPA, 1986
Mollusca					
43. *Campeloma decisum*	Operculate snail	>0.810	20,160	50% mortality ‡	Done, 1961, as cited in U.S. EPA, 1986
44. *Goniobasis virginica*	Operculate snail	0.044	5,760	50% mortality (25°C)	Crump and Guess, 1980, as cited in U.S. EPA, 1981
45. *Nitocris (Anculosa) carinata*	Operculate snail	0.086	5,760	50% mortality (25°C)	Crump and Guess, 1980, as cited in U.S. EPA, 1981
46. *Physa inlegra*	Pulmonate snail	>0.810	20,160	50% mortality ‡	Done, 1961, as cited in U.S. EPA, 1986
47. *Physa heterostropha*	Pulmonate snail	0.258	5,760	50% mortality (25°C)	Crump and Guess, 1980, as cited in U.S. EPA, 1981
Vertebrate animals:					
Amphibia					
48. *Rana catesbeiana*	Tadpole	2.4	510	100% mortality	Muegge, 1956, as cited in U.S. EPA, 1986
Fish:					
Clupeidae					
49. *Dorosoma cepedianum*	Gizzard shad	0.62	10	Some mortality	Goldman et al., 1979
Salmonidae					
50. *Oncorhynchus kisutch*	Coho salmon	0.016	1,440	Mortality threshold	Groethe and Eaton, 1975
50. *Oncorhynchus kisutch*	Coho salmon	0.004	5,760	Mortality threshold	Groethe and Eaton, 1975
Fish:					

Data Point and Scientific Name	Descriptive Name	Concentration (mg/l)*	Duration (min)	Effect	Reference
51. *Oncorhynchus kisutch*	Coho salmon fingerlings	0.2	1,152	76% mortality (free Ocl)	Jacangelo and Olivieri, 1985
51. *Oncorhynchus kisutch*	Coho salmon fingerlings	0.75	180	100% mortality (NH_2Cl)	Jacangelo and Olivieri, 1985
51. *Oncorhynchus kisutch*	Coho salmon fingerlings	0.15	<48	100% mortality ($NHCl_2$)	Jacangelo and Olivieri, 1985
51. *Oncorhynchus kisutch*	Coho salmon fingerlings	0.2	<1	Immediate distress	Jacangelo and Olivieri, 1985
52. *Oncorhynchus kisutch*	Coho salmon	0.230	720	50% mortality ‡	Done, 1961, as cited in U.S. EPA, 1986
53. *Oncarhynchus tshawytscha*	Chinook salmon fry	1.0	12	100% mortality	Dennis et al., 1978, as cited in U.S. EPA, 1986
54. *Salmo gairdneri*	Rainbow trout	0.02	7,200	50% mortality ‡	Strange et al., 1951, as cited in U.S. EPA, 1986
54. *Salmo gairdneri*	Rainbow trout	0.014	5,760	50% mortality ‡	Strange et al., 1951, as cited in U.S. EPA, 1986
54. *Salmo gairdneri*	Rainbow trout	0.029	5,760	50% mortality ‡	Strange et al., 1951, as cited in U.S. EPA, 1986
55. *Salmo gairdneri*	Rainbow trout	0.7	2,220	100% mortality	Mickey and Holden, 1971, as cited in U.S. EPA, 1981
56. *Salmo gairdneri*	Rainbow trout	0.2	300	50% mortality	Valenzuela, 1976, as cited in Alabaster and Lloyd, 1982
56. *Salmo gairdneri*	Rainbow trout	0.5	50	50% mortality	Valenzuela, 1976, as cited in Alabaster and Lloyd, 1982
57. *Salmo gairdneri*	Rainbow trout	0.108	672	60% mortality	Baker and Cole, 1974, as cited in Servizi, 1979
57. *Salmo gairdneri*	Rainbow trout	0.354	330	40% mortality	Baker and Cole, 1974, as cited in Servizi, 1979
58. *Salmo gairdneri*	Rainbow trout	0.4	120	100% mortality	Eichelsdoerfer et al., 1975, as cited in Moore and Calabrese, 1980
59. *Salmo gairdneri*	Rainbow trout	0.04	5,760	50% mortality (20-80mm)	British Columbia Ministry of Health, 1982
60. *Salmo gairdneri*	Rainbow trout fingerlings	0.2	240	100% mortality	Eichelsdoerfer et al., 1975, as cited in Moore and Calabrese, 1980
61. *Salmo trutta*	Brown trout	0.35	1,440	Mortality §	Urbach and Gottlieb, 1946, as cited in U.S. EPA, 1981
62. *Salmo trutta*	Brown trout	0.5	120	50% mortality	Watson and Kibler, 1933, as cited in U.S. EPA, 1986
63. *Salmo trutta*	Brown trout	0.09	180	50% mortality	Watson and Kibler, 1933, as cited in U.S. EPA, 1986

Data Point and Scientific Name	Descriptive Name	Concentration (mg/l)*	Duration (min)	Effect	Reference
63. *Salmo trutta*	Brown trout	0.05	360	50% mortality	Watson and Kibler, 1933, as cited in U.S. EPA, 1986
63. *Salmo trutta*	Brown trout	0.02	660	50% mortality	Watson and Kibler, 1933, as cited in U.S. EPA, 1986
64. *Salmo trutta*	Brown trout fingerlings	0.5	90	50% mortality	Sheldon and Lovell, 1949, as cited in U.S. EPA, 1986
65. *Salvelinus fontinalis*	Brook trout	0.01	10,080	Mortality threshold	Wlodkowski and Rosenkranz, 1975, as cited in U.S. EPA, 1986
65. *Salvelinus fontinalis*	Brook trout	0.005	10,080	Activity depressed	Wlodkowski and Rosenkranz, 1975, as cited in U.S. EPA, 1986
66. *Salvelinus fontinalis*	Brook trout	0.01	10,080	Mortality threshold	Rosenkranz, 1973, as cited in U.S. EPA, 1986
66. *Salvelinus fontinalis*	Brook trout	0.05	2880	100% mortality	Rosenkranz, 1973, as cited in U.S. EPA, 1986
67. *Salvelinus fontinalis*	Brook trout	0.06	5,760	50% mortality	British Columbia Ministry of Health, 1982
68. *Salvelinus fontinalis*	Brook trout	10.0	1,440	100% mortality	Muhlendahl et al., 1978, as cited in U.S. EPA, 1986
69. *Salvelinus fontinalis*	Brook trout	0.360	720	50% mortality ‡	Done, 1961, as cited in U.S. EPA, 1986
70. *Salvelinus fontinalis*	Brook trout	0.102	5,760	50% mortality (20°C)	Vogt et al., 1979, as cited in U.S. EPA, 1986
Esocidae					
71. *Esox lucius*	Northern pike	0.7	1,800	100% mortality (temp 4.5°-7°C)	Mickey and Holden, 1971, as cited in U.S. EPA, 1981
72. *Esox vermiculatus*	Grass pickerel	1	60	100% mortality (after 24 hr)	Wilkins et al., 1979, as cited in U.S. EPA, 1986
Catastomidae					
73. *Catostomus commersonii*	White sucker	1	60	100% mortality	Shy and Struba, 1980, as cited in U.S. EPA, 1981
74. *Catostomus commersonii*	White sucker	0.248	720	50% mortality ‡	Done, 1961, as cited in U.S. EPA, 1986
Cyprinidae					
75. *Carassius auratus*	Goldfish	1.6	240	100% mortality	Muegge, 1956, as cited in U.S. EPA, 1986
76. N.G.	Goldfish	1.0	480	Some mortality	Bass and Heath, 1977
77. N.G.	Goldfish	0.3	1440	100% mortality	Kjellstrand et al., 1974, as cited in Moore and Calabrese, 1980
78. *Carassius auratus*	Goldfish	1.0	5760	100% mortality	U.S. EPA, 1981

Data Point and Scientific Name	**Descriptive Name**	**Concentration (mg/l)***	**Duration (min)**	**Effect**	**Reference**
79. *Cyprinus carpio*	Carp	0.72	65	Some mortality	Goldman et al., 1979
80. *Cyprinus carpio*	Carp	0.7	6000	80% mortality	Mickey and Holden, 1971, as cited in U.S. EPA, 1981
Notemigonus crysoleucas	Golden shiner	>3,000	0.17	Death	Eaton et al., 1973, as cited in Moore and Calabrese, 1980
81. *Notemigonus crysoleucas*	Golden shiner	0.8	240	100% mortality	Muegge, 1956, as cited in U.S. EPA, 1986
82. *Notropis cornutus*	Common shiner	0.7	76	100% mortality	Wilkins et al., 1979, as cited in U.S. EPA, 1986
83. *Notropis rubellus*	Roseyface shiner	0.07	180	100% mortality	Wilkins et al., 1979, as cited in U.S. EPA, 1986
84. *Notropis rubellus*	Roseyface shiner	0.7	79	100% mortality	Wilkins et al., 1979, as cited in U.S. EPA, 1986
85. *Pimephales notatus*	Minnow bluntnose	0.7	61	100% mortality	Johnson, 1978
86. *Pimephales promelas*	Fathead minnow larvae	0.108	43,200	60% mortality	Vogt et al., 1982, as cited in U.S. EPA, 1986
87. *Pimephales promelas*	Fathead minnow larvae	0.108	43,200	68% decreased growth	Vogt et al., 1982, as cited in U.S. EPA, 1986
88. *Pimephales promelas*	Fathead minnow	0.043	10,080	50% decreased spawning	Vogt et al., 1982, as cited in U.S. EPA, 1986
89. *Pimephales promelas*	Fathead minnow	0.08-0.19	5,760	50% mortality	Duce, 1969, as cited in U.S. EPA, 1981
90. *Pimephales promelas*	Fathead minnow	0.05	5,760	Threshold mortality	Duce, 1969, as cited in U.S. EPA, 1981
91. *Pimephales promelas*	Fathead minnow	0.02	7,200	50% mortality	Strange et al., 1951, as cited in U.S. EPA, 1986
92. *Pimephales promelas*	Fathead minnow	0.185	720	50% mortality ‡	Done, 1961, as cited in U.S. EPA, 1986
93. *Pimephales promelas*	Fathead minnow	0.110	100,800	No spawning ‡	Done, 1961, as cited in U.S. EPA, 1986
94. *Rhinichthys atronaus*	Minnow	0.7	79	100% mortality	Wilkins et al., 1979, as cited in U.S. EPA, 1986
95. *Scardinius erythrophthalmus*	Rudd	0.7	2,460	100% mortality	Mickey and Holden, 1971, as cited in U.S. EPA, 1981
96. *Tinca tinca*	Tench	0.7	6,000	20% mortality	Mickey and Holden, 1971, as cited in U.S. EPA, 1981
Ictaluridae					
97. *Ictalurus melas*	Black bullhead	~4.5	1,440	50% mortality	Muegge, 1956, as cited in U.S. EPA, 1986
98. *Ictalurus melas*	Black bullhead	1.36	25	Some mortality	Goldman et al., 1979
Anguillidae					

Data Point and Scientific Name	**Descriptive Name**	**Concentration (mg/l)***	**Duration (min)**	**Effect**	**Reference**
99. *Anguilla anguilla*	Eel	0.7	6,000	Mortality threshold	Mickey and Holden, 1971, as cited in U.S. EPA, 1981
Poeciliidae					
100. *Gambusia affinis*	Mosquitofish	0.5-1.0	4,320	Mortality threshold	Crump and Guess, 1982, as cited in U.S. EPA, 1986
Serranidae					
101. *Morone saxatilis*	Striped bass	0.3	1,440	50% mortality	Druckrey, 1968, as cited in U.S. EPA, 1981
101. *Morone saxatilis*	Striped bass	0.25	2,880	50% mortality	Druckrey, 1968, as cited in U.S. EPA, 1981
Centrarchidae					
102. *Lepomis cyanellus*	Green sunfish	2	1,440	60% mortality	Muegge, 1956, as cited in U.S. EPA, 1986
Lepomis cyanellus	Green sunfish	0.4	N.G.	Eventual mortality	Rosenkranz, 1973, as cited in U.S. EPA, 1986
103. *Micropterus dolomieui*	Smallmouth bass	0.5	900	50% mortality	Sheldon and Lovell, 1949, as cited in U.S. EPA, 1986
104. *Micropterus salmoides*	Largemouth bass	0.494	1,440	50% mortality ‡	Done, 1961, as cited in U.S. EPA, 1986
105. *Pomoxis nigromaculatus*	Black crappie	1.36	25	Some mortality	Goldman et al., 1979
Percidae					
106. *Perca flavescens*	Yellow perch	0.72	65	Some mortality	Goldman et al., 1979
107. *Perca flavescens*	Yellow perch	0.365	720	50% mortality ‡	Done, 1961, as cited in U.S. EPA, 1986
108. *Stizostedion vitreum vitreum*	Walleye	0.267	720	50% mortality ‡	Done, 1961, as cited in U.S. EPA, 1986
Miscellaneous					
109. N.G.	Freshwater minnows, “killies”	0.3	120	No distress	Eun et al., 1984, as cited in U.S. EPA, 1986

Reproduced from Mattice and Zittel (1976)

* Mg/l and ppm were treated as equivalent units.
† Not given
‡ Wastewater chlorination.
† Measured time of first “agitation.” But death occurred about 1 min later.

Table 2a. Toxicity of Chlorine to Freshwater Organisms, Not Included in Review by Mattice and Zittel (1976)

Data Point and Scientific Name	**Descriptive Name**	**Concentration (µg/L)***	**Duration (min)**	**Effect**	**Reference**
Plants:					
Chlorophyta					
110. *Stigeoclonium subsecundum*		500	10080	100% mortality	Trotter et al., 1987
Miscellaneous:					
111. N.G.	Phytoplankton	28	1440	50% reduction in NO_3 uptake	Toetz et al., 1977
112. N.G.	Phytoplankton	275	30	EC50 ^{14}C uptake spring	Brooks and Liptak, 1979
112. N.G.	Phytoplankton	160	30	EC50 ^{14}C uptake summer	Brooks and Liptak, 1979
112. N.G.	Phytoplankton	620	30	EC50 ^{14}C uptake fall	Brooks and Liptak, 1979
112. N.G.	Phytoplankton	760	30	EC50 ^{14}C uptake winter	Brooks and Liptak, 1979
113. N.G.	Periphyton	1	151200	Decrease in biomass	Carlson, 1976, as cited in Brungs, 1976
113. N.G.	Periphyton	4	151200	Decrease in biomass	Carlson, 1976, as cited in Brungs, 1976
113. N.G.	Periphyton	11	151200	Decrease in biomass	Carlson, 1976, as cited in Brungs, 1976
Magnoliaphyta:					
114. *Myriophyllum spicatum*	Eurasion watermilfoil	50	5760	Reduced growth	Watkins and Hammerschlag, 1984
115. *Cabomba caroliniana*	Fanwort	150-3000	8640	Slight chlorosis	Zimmerman and Berg, 1934, as cited in Alabaster and Lloyd, 1982
115. *Elodea canadensis*		150-3000	8640	Slight chlorosis	Zimmerman and Berg, 1934, as cited in Alabaster and Lloyd, 1982
Invertebrates:					
Protozoa					
116. Many species		500	60	Reduced community respiration	Osborne, 1982
Arthropoda-crustacea:					
117. *Daphnia magna*	Water flea	2	10080	LC50	Arthur et al., 1975
117. *Daphnia magna*	Water flea	4-14	10080	LC50	Arthur et al., 1975
118. *Daphnia magna*	Water flea	1	4320	100% mortality	Arthur and Eaton, 1971

Data Point and Scientific Name	Descriptive Name	Concentration (µg/L)*	Duration (min)	Effect	Reference
119. *Daphnia magna*	Water flea	70	630	100% mortality	Ward et al., 1976
120. *Daphnia magna*	Water flea	17	2880	LC50	Ward et al., 1976
120. *Daphnia magna*	Water flea	11	2880	30% mortality	Ward et al., 1976
121. *Daphnia magna*	Water flea	45	2880	LC50	Ward and DeGraeve, 1980
122. *Gammarus sp.*	Amphipod	1102	2880	LC50	Ward and DeGraeve, 1980
123. *Epischura lacustris*	Copepod	63	2880	LC50	Ward and DeGraeve, 1980
Arthropoda-crustacea:					
124. *Limnocalanus macrurus*	Copepod	900	30	5% mortality	Latimer et al., 1975
125. *Cyclops bicuspidatus thomasi*	Copepod	500	30	5% mortality	Latimer et al., 1975
126	Ass't copepod	41	2880	LC50	Ward and DeGraeve, 1980
127. *Keratella cochlearis*	Rotifer	32	60	LC50	Grossnickle, 1974, as cited in Brungs, 1976
127. *Keratella cochlearis*	Rotifer	27	240	LC50	Grossnickle, 1974, as cited in Brungs, 1976
127. *Keratella cochlearis*	Rotifer	1 3	1440	LC50	Grossnickle, 1974, as cited in Brungs, 1976
128. *Keratella cochlearis*	Rotifer	19	240	LC50	Beeton et al., 1976, as cited in Brungs, 1976
129. *Pacifastacus trowbridgii*	Crayfish	31	525600	LC50 (Calculated)	Larson et al., 1978
Anthropoda-insecta:					
130. *Hexaginia sp.*	Mayfly larvae	357	2880	LC50	Ward and DeGraeve, 1980
131. Order Plecoptera	Stonefly larvae	781	2880	LC50	Ward and DeGraeve, 1980
Vertebrate Animals:					
Fish:					
Salmonidae					
132. *Oncorhynchus kisutch*	Coho salmon	3	120960	mild haematological changes	Buckley, 1976b
132. *Oncorhynchus kisutch*	Coho salmon	50	120960	severe haematological changes	Buckley, 1976b
133. *Oncorhynchus kisutch*	Coho salmon	23	30240	decrease in growth	Larson, Hutchins, and Lamperti, 1977
133. *Oncorhynchus kisutch*	Coho salmon	11	30240	decrease in growth	Larson, Hutchins, and Lamperti, 1977

Data Point and Scientific Name	**Descriptive Name**	**Concentration (µg/L)***	**Duration (min)**	**Effect**	**Reference**
134. *Oncorhynchus kisutch*	Coho salmon	57	5760	LC50	Lamperti, 1976, as cited in U.S. EPA, 1985
135. *Oncorhynchus kisutch*	Coho salmon	59	5760	LC50	Ward and DeGraeve, 1978
136. *Oncorhynchus nerka*	Sockeye salmon	1000	18	100% mortality LC50	Servizi and Martens, 1974
136. *Oncorhynchus nerka*	Sockeye salmon	200	180	LC50	Servizi and Martens, 1974
Vertebrate Animals:					
Fish:					
Salmonidae**					
137. *Salmo gairdneri*	Rainbow trout	69	5760	LC50	Ward and DeGraeve, 1978
138. *Salmo gairdneri*	Rainbow trout	440	1440	LC50	Osborne et al., 1981
139. *Salmo gairdneri*	Rainbow trout	3860	8	Change in blood characteristics	Zeithoun et al., 1977
139. *Salmo gairdneri*	Rainbow trout	2470	19	Change in blood characteristics	Zeithoun et al., 1977
139. *Salmo gairdneri*	Rainbow trout	2750	20	Change in blood characteristics	Zeithoun et al., 1977
139. *Salmo gairdneri*	Rainbow trout	1090	29	Change in blood characteristics	Zeithoun et al., 1977
140. *Salmo gairdneri*	Rainbow trout	10	5760	LC50 (minimum)	Cairns and Conn, 1979, as cited in Servizi, 1979
140. *Salmo gairdneri*	Rainbow trout	40	5760	LC50 (average)	Cairns and Conn, 1979, as cited in Servizi, 1979
141. *Salmo gairdneri*	Rainbow trout	990	30	LC50 (10°C)	Brooks and Seegert, 1977
141. *Salmo gairdneri*	Rainbow trout	940	30	LC50 (15°C)	Brooks and Seegert, 1977
142. *Salmo gairdneri*	Rainbow trout	132	5760	LC50	Marking et al., 1984
143. *Salmo clarki*	Cutthroat trout (juv.)	75	5760	LC50	Larson et al., 1978
143. *Salmo clarki*	Cutthroat trout (juv.)	82	5760	LC50	Larson et al., 1978
143. *Salmo clarki*	Cutthroat trout (juv.)	83	5760	LC50	Larson et al., 1978
143. *Salmo clarki*	Cutthroat trout (juv.)	95	5760	LC50	Larson et al., 1978
143. *Salmo clarki*	Cutthroat trout (juv.)	94	5760	LC50	Larson et al., 1978
144. *Salvelinus fontinalis*	Brook trout	107	5760	LC50	Larson, Hutchins, and Schlesinger, 1977
144. *Salvelinus fontinalis*	Brook trout (al.)	91	5760	LC50	Larson, Hutchins, and Schlesinger, 1977
144. *Salvelinus fontinalis*	Brook trout (fry)	82	5760	LC50	Larson, Hutchins, and Schlesinger, 1977

Data Point and Scientific Name	Descriptive Name	Concentration (µg/L)*	Duration (min)	Effect	Reference
144. *Salvelinus fontinalis*	Brook trout (juv.)	91	5760	LC50	Larson, Hutchins, and Schlesinger, 1977
144. *Salvelinus fontinalis*	Brook trout (juv.)	88	5760	LC50	Larson, Hutchins, and Schlesinger, 1977
145. *Salvelinus namaycush*	Lake trout	60	5760	LC50	Ward and DeGraeve, 1978
Cyprindinae:					
146. *Carassius auratus*	Goldfish	153	5760	LC50	Ward and DeGraeve, 1978
146. *Carassius auratus*	Goldfish	210	5760	LC50	Ward and DeGraeve, 1978
147. *Carassius auratus*	Goldfish	490	1 lJ40	LC50*	Tsai and McKee, 1980
147. *Carassius auratus*	Goldfish	390	2880	LC50*	Tsai and McKee, 1980
147. *Carassius auratus*	Goldfish	360	4320	LC50*	Tsai and McKee, 1980
147. *Carassius auratus*	Goldfish	350	5760	LC50*	Tsai and McKee, 1980
148. *Notemigonus crysoleucas*	Golden shiner	40	5760	LC50	Ward and DeGraeve, 1978
149. *Notropis anogenus*	Pugnose shiner	45	5760	LC50	Ward and DeGraeve, 1978
149. *Notropis anogenus*	Pugnose shiner	29	5760	100% mortality	Ward and DeGraeve, 1980
150. *Notropis cornutus*	Common shiner	51	5760	LC50	Ward and DeGraeve, 1978
151. *Notropis atherinoides*	Emerald shiner	350	40	LC50*	Seegert et al., 1979
152. *Notropis atherinoides*	Emerald shiner	260	15	LC50	Brooks et al., 1982
152. *Notropis atherinoides*	Emerald shiner	180	30	LC50	Brooks et al., 1982
152. *Notropis atherinoides*	Emerald shiner	100	120	LC50	Brooks et al., 1982
152. *Notropis atherinoides*	Emerald shiner	100	30x4	LC50	Brooks et al., 1982
153. *Notropis atherinoides*	Emerald shiner	230	30	LC50	Fandrei and Collins, 1979
154. *Pimephales promelas*	Fatheat minnow	95	5760	LC50	Seegert et al., 1979
154. *Pimephales promelas*	Fatheat minnow	82	5760	LC50	Seegert et al., 1979
155. *Pimephales promelas*	Fatheat minnow	45	43200	LC50	Ward et al., 1976
156. *Pimephales promelas*	Fatheat minnow	120	5760	LC50	Ward and DeGraeve, 1980
Ictaluridae:					
157. *Ictalurus punctatus*	Channel catfish	90	5760	LC50	Roseboom and Richey, 1977, as cited in U.S. EPA, 1985
158. *Ictalurus punctatus*	Channel catfish	70	50400	Gill hyperplasia*	Mitchell and Cech, 1983
Poeciliidae:					
159. *Gambusia affinis*	Mosquitofish	410	60	LC50	Mattice et al., 1981
Centrarchidae:					

Data Point and Scientific Name	Descriptive Name	Concentration (µg/L)*	Duration (min)	Effect	Reference
160. *Lepomis macrochirus*	Bluegill	330	5760	LC50	Roseboom and Richey, 1977, as cited in U.S. EPA, 1985
160. *Lepomis macrochirus*	Bluegill	250	5760	LC50	Roseboom and Richey, 1977, as cited in U.S. EPA, 1985
160. *Lepomis macrochirus*	Bluegill	180	5760	LC50	Roseboom and Richey, 1977, as cited in U.S. EPA, 1985
161. *Lepomis sp.*	Sunfish	278	5760	LC50	Ward and DeGraeve, 1978
161. *Lepomis sp.*	Sunfish	195	5760	LC50	Ward and DeGraeve, 1978
162. Micropterus salmoides	Largemouth bass	241	5760	LC50	Ward and DeGraeve, 1978
163. *Pomoxis sp.*	Crappie	127	5760	LC50	Ward and DeGraeve, 1978
Percidae:					
164. *Stizostedion vitreum*	Walleye	108	5760	LC50	Ward and DeGraeve, 1978
165. *Perca flavescens*	Yellow perch	700	30	LC50 (30°C)	Brooks and Seegert, 1977
165. *Perca flavescens*	Yellow perch	8000	30	LC50 (10°C)	Brooks and Seegert, 1977

N.G.	Not Given
*	Chloramines tested or suspected
**	Taxonomic classifications for rainbow trout (*Salmo gairdneri*) and cutthroat trout (*Salmo clarki*) recently have been changed to *Oncorhynchus mykiss* and *Oncorhynchus clarki*, respectively.
juv.	Juvenile
Al.	Alevin

Table 3. Summary of Data on Toxicity of Chlorine to Marine Organisms

Data Point and Scientific Name	**Descriptive Name**	**Concentration (mg/l)***	**Duration (min)**	**Effect**	**Reference**
Plants:					
1. N.G.†	Phytoplankton	<0.1	240	71% decrease in productivity	Johnson, 1978
N.G.	Phytoplankton	0.03	N.G.	50% decrease in photosynthesis ‡	Latimer et al., 1975
Chlorophyta					
2. *Chlamydomonas* sp.		1.5	5-10	Decreased growth	Beeton et al., 1976, as cited in Brungs, 1976
3. *Dunaliella tertiolecta*		0.11	1,440	50% decrease in growth	Ward et al., 1976
Chrysophyta					
4. *Asterionella japonica*		0.4	0.27	50% decrease in growth	Esvelt et al., 1973
4. *Asterionella japonica*		0.2	2	50% decrease in growth	Esvelt et al., 1973
5. *Chaetoceros decipiens*		0.14	1,440	50% decrease in growth	Ward et al., 1976
6. *Chaetoceros didymum*		0.125	1,440	50% decrease in growth	Ward et al., 1976
7. *Detonula confervacea*		0.8	0.6	50% decrease in growth	Esvelt et al., 1973
8. *Skeletonema costatum*		0.095	1,440	50% decrease in growth	Ward et al., 1976
8. *Skeletonema costatum*		0.6	1.7	50% decrease in growth	Esvelt et al., 1973
9. Thalassiosira nordenskioeldii		0.195	1,440	50% decrease in growth	Ward et al., 1976
10. *Thalassiosira pseudonana*		0.075	1,440	50% decrease in growth	Ward et al., 1976
10. *Thalassiosira pseudonana*		0.2	6.8	50% decrease in growth	Ward et al., 1976
10. *Thalassiosira pseudonana*		0.5	0.3	50% decrease in growth	Esvelt et al., 1973
11. *Thalassiosira rotula*		0.33	1,440	50% decrease in growth	Bass and Heath, 1977)

Data Point and Scientific Name	Descriptive Name	Concentration (mg/l)*	Duration (min)	Effect	Reference
Chrysophyceae					
12. *Monochrysis lutheri*		0.2	1,440	50% decrease in growth	Ward et al., 1976
13. *Rhodomonas baltica*		0.11	1,440	50% decrease in growth	Ward et al., 1976
Phaeophyta					
14. *Macrocystis pyrifera*	Giant kelp	5-10	5,760	50% decrease in photosynthesis	Wester and Rawles, 1979, as cited in Watkins and Hammerschlag, 1984
Invertebrate animals:					
Cnidaria					
N.G.	Sea anemone	1.0	21,600	No effect	Capuzzo, Goldman, et al., 1977
15. *Bimeria franciscana*	Hydroid	2.5	180	Slight decrease in growth	Larson et al., 1978
Annelida					
16. *Phragmatopoma californica*	Polychaete worm	0.2	5	17% decrease in sperm motility ‡	Capuzzo, 1979
17. *Phragmatopoma californica*	Polychaete worm	0.4	5	70% decrease in sperm motility ‡	Capuzzo, 1979
Mollusca					
Crassostrea virginica	Oyster	0.2	N.G.	~46% decrease in ciliary beat rate	Arthur and Eaton, 1971
18. *Crassostrea virginica*	Oyster	1.0	20-90	Pumping threshold	Arthur and Eaton, 1971
19. *Crassostrea virginica*	Oyster	0.18	4,320	50% decrease in time open	Roberts et al., 1975
20. *Ostrea edulis*	Oyster larvae	0.5	2	Swimming stopped	Hawk and Block, in press, as cited in Scott, 1981
N.G.	Oysters	2.5	10	No effect (30°C)	Whigham and Simpson, 1978, as cited in Watkins and Hammerschlag, 1984
21. *Mytilus edulis*	Mussel	1.0	21,600	100% mortality	Capuzzo, Goldman, et al., 1977
21. *Mytilus edulis*	Mussel	2.5	7,200	100% mortality	Capuzzo, Goldman, et al., 1977
Mytilus edulis	Mussel	0.02-0.05	N.G.	Young won't attach-attached ones will move	Mattice and Zittel, 1976
Crepidula and Littorina	Gastropods	0.2	N.G.	Stops growth	Roberts and Gleeson, 1978
22. *Acartia tonsa*	Copepod	0.75	2	30% mortality @ 25°C after 96 hr	Dychdala, 1977, as cited in U.S. EPA, 1986

Data Point and Scientific Name	**Descriptive Name**	**Concentration (mg/l)***	**Duration (min)**	**Effect**	**Reference**
23. *Acartia tonsa*	Copepod	0.75	2	70% mortality @ 25°C after 96 hr	Dychdala, 1977, as cited in U.S. EPA, 1986
24. *Acartia tonsa*	Copepod	1	120	50% mortality	Ward et al., 1976
24. *Acartia tonsa*	Copepod	10.0	0.7	50% mortality	Ward et al., 1976
25. *Acartia tonsa*	Copepod	2.5	5	90% mortality-after 3 hr	Dinnel et al., 1981
26. *Eurytemora affinis*	Copepod	1	360	50% mortality	Ward et al., 1976
26. *Eurytemora affinis*	Copepod	10.0	2	50% mortality	Ward et al., 1976
27. *Pseudodiaptomus coronatus*	Copepod	2.5	45	50% mortality	Ward et al., 1976
27. *Pseudodiaptomus coronatus*	Copepod	10	5	50% mortality	Ward et al., 1976
28. *Balanus improvisus*	Barnacle larvae	2.5	5	80% mortality-after 3 hr	Dinnel et al., 1981
29. *N.G.*	Barnacles	1.0	21,600	Most dead	Capuzzo, Goldman, et al., 1977
30. *Elminius modestus*	Barnacle nauplii	0.5	10	Threshold mortality	Hawk and Block, in press, as cited in Scott, 1981
31. *Elminius modestus*	Barnacle nauplii	1	10	Heavy losses-no growth	Hawk and Block, in press, as cited in Scott, 1981
32. *Corophium* sp.	Tube dwelling amphipod	10	410	No mortality after 24 hr	Esvelt et al., 1973
33. *Gammarus tigrinus*	Amphipod	2.5	180	25% mortality after 96 hr	Dinnel et al., 1981
34. *Melita nitida*	Amphipod	2.5	120	50% mortality	Dinnel et al., 1981
35. *Melita nitida*	Amphipod	2.5	5	Some mortality	Dinnel et al., 1981
36. *Callinectes sapidus*	Blue crab	10	1,140	50% mortality	Roberts et al., 1975
36. *Callinectes sapidus*	Blue crab	0.1	5,760	50% mortality	Roberts et al., 1975
37. *Crangon septemspinosus*	Sand shrimp	0.15	900	50% mortality	Roberts et al., 1975
38. *Crangon septemspinosus*	Sand shrimp larvae	5	10	42% mortality	Ward et al., 1976
38. *Crangon septemspinosus*	Sand shrimp larvae	10	5	55% mortality	Ward et al., 1976
39. *Palaemonetes pugio*	Grass shrimp	2.5	180	98% mortality-after 96 hr	Dinnel et al., 1981
Ectoprocta					
40. *Bugula* sp.		2.5	2,880	100% mortality	Capuzzo, Goldman, et al., 1977
40. *Bugula* sp.		10	1,440	100% mortality	Capuzzo, Goldman, et al., 1977
Echinodermata					

Data Point and Scientific Name	**Descriptive Name**	**Concentration (mg/l)***	**Duration (min)**	**Effect**	**Reference**
41. *Strongylocentrotus purpuratus*	Sea urchin	0.125	5	1-6% fertilization success ‡	Capuzzo, 1979
42. *Urechis caupo*	Echiuroid	0.2	5	78% fertilization success‡	Capuzzo, 1979
43. *Urechis caupo*	Echiuroid	0.4	5	0% fertilization success‡	Capuzzo, 1979
Chordata					
44. *Botryllus* sp.		10	1,440	100% mortality	Capuzzo, Goldman, et al., 1977
45. *Molgula* sp.		1	4,320	100% mortality	Capuzzo, Goldman, et al., 1977
Vertebrate animals:					
Pleuronectidae					
46. *Limanda ferruginea*	Yellowtail flounder	0.1	1,440	50% mortality	Ward et al., 1976
47. *Pleuronectes platessa*	Plaice larvae	0.028	5,760	50% mortality	Cairns et al., 1975
47. *Pleuronectes platessa*	Plaice larvae	0.05	460	50% mortality	Cairns et al., 1975
47. *Pleuronectes platessa*	Plaice larvae	0.075	75	50% mortality	Cairns et al., 1975
48. *Pleuronectes platessa*	Plaice larvae	0.25	4,320	Mortality threshold	Cairns et al., 1975
49. *Pseudopleuronectes americanus*	Winter flounder	2.5	15	50% mortality	Ward et al., 1976
49. *Pseudopleuronectes americanus*	Winter flounder	10	0.3	50% mortality	Ward et al., 1976
50. *Pseudopleuronectes americanus*	Winter flounder eggs	10	20	No mortality	Ward et al., 1976
Salmonidae					
51. *Oncorhynchus gorbuscha*	Pink salmon	0.05	5,760	50% mortality	Jacangelo and Olivieri, 1985
52. *Oncorhynchus gorbuscha*	Pink salmon	0.5	7.5	50% mortality (13.6°C)	U.S. EPA, 1981
52. *Oncorhynchus gorbuscha*	Pink salmon	0.25	15	50% mortality (13.6°C)	U.S. EPA, 1981
53. *Oncorhynchus kisutch*	Coho salmon	0.08	<7,200	50% mortality	Jacangelo and Olivieri, 1985
54. *Oncorhynchus tshawytscha*	Chinook salmon	0.1	60	Distressed-no mortality	Jacangelo and Olivieri, 1985
55. *Oncorhynchus tshawytscha*	Chinook salmon	0.25	130	Mortality threshold	Jacangelo and Olivieri, 1985
55. *Oncorhynchus tshawytscha*	Chinook salmon	1	23	Mortality threshold	Jacangelo and Olivieri, 1985
56. *Oncorhynchus tshawytscha*	Chinook salmon	0.5	7.5	50 % mortality (11.7°C)	U.S. EPA, 1981
56. *Oncorhynchus tshawytscha*	Chinook salmon	0.25	30	50 % mortality (11.7°C)	U.S. EPA, 1981

Data Point and Scientific Name	**Descriptive Name**	**Concentration (mg/l)***	**Duration (min)**	**Effect**	**Reference**
57. *N.G.*	Young salmon	0.05	33,123	Threshold mortality	Jacangelo and Olivieri, 1985
Atherinidae					
58. *Menidia menidia*	Atlantic silverside	0.58	90	50% mortality	Goldman and Quinby, 1979
58. *Menidia menidia*	Atlantic silverside	1.2	30	50% mortality	Goldman and Quinby, 1979
Clupeidae					
59. *Alosa aestivalis*	Blueback herring	0.67	60	50% mortality	Goldman and Quinby, 1979
59. *Alosa aestivalis*	Blueback herring	1.2	15	50% mortality	Goldman and Quinby, 1979
60. *Brevoortia tyrannus*	Atlantic menhaden	0.22	60	50% mortality	Brungs, 1973
60. *Brevoortia tyrannus*	Atlantic menhaden	0.7	10	50% mortality	Brungs, 1973
61. *Brevoortia tyrannus*	Atlantic menhaden	0.21	300	50% mortality	Goldman and Quinby, 1979
61. *Brevoortia tyrannus*	Atlantic menhaden	1.2	30	50% mortality	Goldman and Quinby, 1979
62. *Brevoortia tyrannus*	Atlantic menhaden larvae	0.5	3	0 mortality	Ward and DeGraeve, 1980
Gasterosteidae					
63. *Gasterosteus aculeatus †*	Threespine stickle-back	0.09-0.13	5,760	50% mortality	Watkins and Hammerschlag, 1984
Ameiuridae					
64. *Ameiurus catus*	White catfish	0.1	2,880	50% mortality	Watkins and Hammerschlag, 1984
Cyprinidae					
65. *Notemigonus chrysoleucas*	Golden shiner	0.03-0.23	5,760	50% mortality	Watkins and Hammerschlag, 1984
Bothidae					
66. *Paralichthys* sp.	Flounder	0.3	5	Threshold mortality	Ward and DeGraeve, 1980
Mugilidae					
67. *Mugil cephalus*	Striped mullet juveniles	0.3	5	Threshold mortality	Ward and DeGraeve, 1980
Miscellaneous					
68. N.G.	Marine fish	1.0	<1	Slight irritant response	Grossnickle, 1974, as cited in Brungs, 1976

Reproduced from Mattice and Zittel (1976)

mg/l and ppm were treated as equivalent units.
† Not given.
‡ Wastewater chlorination.

Table 3a. Toxicity of Chlorine to Marine Organisms, Not Included in Review by Mattice and Zittel (1976)

Data Point and Scientific Name	**Descriptive Name**	**Concentration (µg/L)**	**Duration (Min.)**	**Effect**	**Ref.**
Plants:					
Miscellaneous:					
69. N.G	Nanoplankton	10	240	EC50 (inhibition of carbon uptake	Bender et al., 1977, as cited in Ho and Roberts, 1985
70. N.G.	Phytoplankton	9	120	EC50 (photosynthetic inhibition)	Davis and Coughlan, 1978, as cited in Ho and Roberts, 1985; Roberts and Illowsky, n.d., as cited in Ho and Roberts, 1985
71. N.G.	Phytoplankton	10	1440	EC50 (photosynthetic inhibition)	Eppley et al., 1976
71. N.G.	Phytoplankton	70	N.G.	photosynthetic inhibition	Ho and Roberts, 1985
71. N.G.	Phytoplankton	60	N.G.	50% chlorophyll reduction	Stone et al., 1973, as cited in Brungs, 1976
72. N.G.	Phytoplankton	20	120-180	2-3 day delay in peak ATP (10°CΔT)	Goldman and Quinby, 1979
73. N.G.	Phytoplankton	60	120-180	2-3 day delay in peak ATP (11°CΔT)	Goldman and Quinby, 1979
74. N.G.	Phytoplankton	80	120-180	5 day delay in peak ATP (17.5°CΔT)	Goldman and Quinby, 1979
75. N.G.	Phytoplankton	50-100	43200-86400	shifts in composition of phyto community	Sanders and Ryther, 1979
Invertebrates:					
Mollusca:					
76. *Crassostrea virginica*	E. Oyster (larvae)	750	120	LC50	Roberts et al., 1975
76. *Crassostrea virginica*	E. Oyster (larvae)	270	1440	LC50	Roberts et al., 1975
76. *Crassostrea virginica*	E. Oyster (larvae)	110	2880	LC50	Roberts et al., 1975
77. *Crassostrea virginica*	E. Oyster (larvae)	26	2880	LC50	Roberts and Gleeson, 1978
78. *Crassostrea virginica*	E. Oyster (spat)	23	5760	EC50 (extrapolated)	Roberts et al., 1975
79. *Crassostrea virginica*	E. Oyster (adult)	140	36000	LC10 (fall)	Scott and Middaugh, 1977
80. *Crassostrea virginica*	E. Oyster (adult)	140	64800	LC10 (winter)	Scott and Middaugh, 1977
81. *Crassostrea virginica*	E. Oyster (adult)	650	21600	LC10 (spring)	Scott and Middaugh, 1977

Data Point and Scientific Name	Descriptive Name	Concentration (µg/L)	Duration (Min.)	Effect	Ref.
82. *Crassostrea virginica*	E. Oyster (spat)	250	120960	LC80	U.S. EPA, 1981
83. *Crassostrea virginica*	E. Oyster (spat)	125	120960	Retarded growth	U.S. EPA, 1981
84. *Crassostrea virginica*	E. Oyster (larvae)	300	2880	LC50	Roosenburg, Rhoderick, Block, Kennedy, Gullans, et al., 1980
84. *Crassostrea virginica*	E. Oyster (larvae)	80	4320	LC50	Roosenburg, Rhoderick, Block, Kennedy, Gullans, et al., 1980
84. *Crassostrea virginica*	E. Oyster (larvae)	60	5760	LC50	Roosenburg, Rhoderick, Block, Kennedy, Gullans, et al., 1980
85. *Crassostrea virginica*	E. Oyster (adult)	4	5760	Reduced adductor muscle glycogen	Hawk and Block, in press, as cited in Scott, 1981
86. *Crassostrea virginica*	E. Oyster (larvae)	120	30	LC50 (0°CΔT)	Capuzzo, 1979
86. *Crassostrea virginica*	E. Oyster (larvae)	10	30	LC50 (0°CΔT)*	Capuzzo, 1979
87. *Crassostrea virginica*	E. Oyster (larvae)	80	30	LC50 (5°CΔT)	Capuzzo, 1979
87. *Crassostrea virginica*	E. Oyster (larvae)	<10	30	LC50 (5°CΔT)*	Capuzzo, 1979
88. *Mya arenaria*	Soft clam (larvae)	350	720	LC50 (approximate)	Roosenburg, Rhoderick, Block, Kennedy, and Vreenegoor, 1980
88. *Mya arenaria*	Soft clam (larvae)	270	960	LC50 (approximate)	Roosenburg, Rhoderick, Block, Kennedy, and Vreenegoor, 1980
89. *Mya arenaria*	Soft clam (pediveligers)	500	1440	LC50 (approximate)	Roosenburg, Rhoderick, Block, Kennedy, and Vreenegoor, 1980
89. *Mya arenaria*	Soft clam (pediveligers)	250	2880	LC50 (approximate)	Roosenburg, Rhoderick, Block, Kennedy, and Vreenegoor, 1980
89. *Mya arenaria*	Soft clam (pediveligers)	165	4320	LC50 (approximate)	Roosenburg, Rhoderick, Block, Kennedy, and Vreenegoor, 1980
89. *Mya arenaria*	Soft clam (pediveligers)	125	5760	LC50 (approximate)	Roosenburg, Rhoderick, Block, Kennedy, and Vreenegoor, 1980
90. *Mercenaria mercenaria*	Hard clam (larvae)	6	2880	EC50 (retarded development)	Roberts et al., 1975
91. *Mercenaria mercenaria*	Hard clam (larvae)	1-5	2880	LC50 (extrapolated)	Roberts et al., 1975
92. *Protothaca staminea*	Littleneck clam (adult)	25	345600	Inhibition of shell growth	Hillman et al., 1979
Arthropoda crustacea:					
93. *Brachionus plicatilis*	Rotifer	180	30	LC50 (0°CΔT)	Capuzzo, 1979
94. *Brachionus plicatilis*	Rotifer	20	30	LC50 (0°CΔT)*	Capuzzo, 1979
95. *Brachionus plicatilis*	Rotifer	90	30	LC50 (5°CΔT)*	Capuzzo, 1979

Data Point and Scientific Name	Descriptive Name	Concentration (µg/L)	Duration (Min.)	Effect	Ref.
96. *Brachionus plicatilis*	Rotifer	<10	30	LC50 (5°CΔT)*	Capuzzo, 1979
97. *Acartia tonsa*	Copepod	<50	1440	LC50*	Roberts et al., 1975
97. *Acartia tonsa*	Copepod	<50	2880	LC50*	Roberts et al., 1975
98. *Acartia tonsa*	Copepod	29	2880	LC50	Roberts and Gleeson, 1978
98. *Acartia tonsa*	Copepod	67	2880	LC50	Roberts and Gleeson, 1978
99. *Acartia tonsa*	Copepod	820	30	LC50 (0°CΔT)	Capuzzo, 1979
100. *Acartia tonsa*	Copepod	320	30	LC50 (0°CΔT)*	Capuzzo, 1979
101. *Acartia tonsa*	Copepod	860	30	LC50 (5°CΔT)	Capuzzo, 1979
102. *Acartia tonsa*	Copepod	320	30	LC50 (5°CΔT)*	Capuzzo, 1979
103. *Palaemonetes pugio*	Glass shrimp	380	1440	LC50*	Roberts et al., 1975
103. *Palaemonetes pugio*	Glass shrimp	220	5760	LC50*	Roberts et al., 1975
104. *Crangon nigricauda*	Shrimp (adult)	134	5760	LC50	Thatcher, 1977
105. *Pandalus goniurus*	Shrimp (adult)	90	5760	LC50	Thatcher, 1977
106. *Pandalus danae*	Shrimp (juv. & adult)	178	5760	LC50	Thatcher, 1977
107. *Anonyx sp.*	Amphipod (adult)	145	5760	LC50	Thatcher, 1977
108. *Pontogeneia sp.*	Amphipod (juv.)	687	5760	LC50	Thatcher, 1977
109. *Neomysis sp.*	Mysid (adult)	162	5760	LC50	Thatcher, 1977
110. *Panopeus herbstii*	Crab (larvae)	24	5760	LC50	Roberts, 1977
111. *Pagurus longicarpus*	Crab (larvae)	<400	1440	LC50	Roberts, 1977
111. *Pagurus longicarpus*	Crab (larvae)	160	2880	LC50	Roberts, 1977
111. *Pagurus longicarpus*	Crab (larvae)	62	5760	LC50	Roberts, 1977
111. *Pagurus longicarpus*	Crab (larvae)	54	7200	LC50	Roberts, 1977
112. *Hemigrapsus nudus*	Crab (juv. & adult)	1418	5760	LC50	Thatcher, 1977
113. *Hemigrapsus oregonsis*	Crab (juv. & adult)	1418	5760	LC50	Thatcher, 1977
114. Cancer productus	Crab (adult)	690	5760	Disruption of Mg regulation	Roesijadi et al., 1979
115. *Hornarus americanus*	Lobster (larvae)	300	30	LC50*	Capuzzo, 1977
116. *Hornarus americanus*	Lobster (larvae)	2900	30	LC50	Capuzzo, 1977
117. *Hornarus americanus*	Lobster (larvae)	30	60	EC50 reduced respiration rate*	Capuzzo, 1977
118. *Hornarus americanus*	Lobster (larvae)	80	60	EC50 reduced respiration rate	Capuzzo, 1977
119. *Homarus americanus*	Lobster (larvae)	2900	60	LC50	Goldman et al., 1977

Data Point and Scientific Name	Descriptive Name	Concentration (µg/L)	Duration (Min.)	Effect	Ref.
119. *Homarus americanus*	Lobster (larvae)	3950	60	LC50	Goldman et al., 1977
120. *Homarus americanus*	Lobster (larvae)	300	60	LC50*	Goldman et al., 1977
120. *Homarus americanus*	Lobster (larvae)	1300	60	LC50*	Goldman et al., 1977
Echinodermata:					
121. *Dendraster excentricus*	Sand dollar	2	5	EC50 (egg fertilization success)	Dinnel et al., 1981
121. *Dendraster excentricus*	Sand dollar	13	5	EC50 (egg fertilization success)	Dinnel et al., 1981
122. *Strongylocentrotus droebachiensis*	Sea urchin	5	5	EC50 (egg fertilization success)	Dinnel et al., 1981
Vertebrates:					
Fish:					
Pleuronectidae:					
123. *Pseudopleuronectes americanus*	Winter flounder (juv.)	550	30	100% mortality	Capuzzo, Davidson, et al., 1977
124. *Pseudopleuronectes americanus*	Winter flounder (juv.)	2550	30	100% mortality*	Capuzzo, Davidson, et al., 1977
125. *Pseudopleuronectes americanus*	Winter flounder (juv.)	200	30	Stress	Capuzzo, Davidson, et al., 1977
126. *Pseudopleuronectes americanus*	Winter flounder (juv.)	1500	30	Stress*	Capuzzo, Davidson, et al., 1977
127. *Parophrys vetulus*	English sole. (juv.)	73	5760	LC50	Thatcher, 1977
Salmonidae:					
128. *Oncorhynchus kisutch*	Coho salmon (juv.)	70	5760	LC50*	Buckley, 1976a
129. *Oncorhynchus kisutch*	Coho salmon (juv.)	3-9	120960	Maximum safe concentration*	Buckley et al., 1976
130. *Oncorhynchus kisutch*	Coho salmon (smolts)	270	7.5	LC50 (7.3°CΔT)	Stober et al., 1980
130. *Oncorhynchus kisutch*	Coho salmon (smolts)	179	15	LC50 (7.3°CΔT)	Stober et al., 1980
130. *Oncorhynchus kisutch*	Coho salmon (smolts)	129	30	LC50 (7.3°CΔT)	Stober et al., 1980
130. *Oncorhynchus kisutch*	Coho salmon (smolts)	130	60	LC50 (7.3°CΔT)	Stober et al., 1980
- Oncorhynchus kisutch	Coho salmon (smolts)	2	N.G.	Avoidance threshold	Stober et al., 1980
131. *Oncorhynchus kisutch*	Coho salmon (juv.)	32	5760	LC50 (5°CΔT)	Thatcher, 1977
132. *Oncorhynchus gorbuscha*	Pink salmon (juv.)	>23	5760	LC50	Thatcher, 1977
133. *Oncorhynchus tshawytscha*	Chinook salmon (juv.)	>38	5760	LC50	Thatcher, 1977

Data Point and Scientific Name	Descriptive Name	Concentration (µg/L)	Duration (Min.)	Effect	Ref.
Antherinidae:					
134. *Menidia menidia*	Atlantic silverside	95	1440	LC50	Roberts et al., 1975
134. *Menidia menidia*	Atlantic silverside	38	2880	LC50	Roberts et al., 1975
134. *Menidia menidia*	Atlantic silverside	37	5760	LC50	Roberts et al., 1975
135. *Menidia menidia*	Atlantic silversides (egg)	120	1440	LC5	Morgan and Prince, 1977
135. *Menidia menidia*	Atlantic silversides (egg)	160	2880	LC5	Morgan and Prince, 1977
136. *Menidia menidia*	Atlantic silversides (egg)	380	1440	LC50	Morgan and Prince, 1977
136. *Menidia menidia*	Atlantic silversides (egg)	300	2880	LC50	Morgan and Prince, 1977
137. *Menida beryllina*	Tidewater silversides (egg)	150	1440	LC5	Morgan and Prince, 1977
137. *Menida beryllina*	Tidewater silversides (egg)	140	2880	LC5	Morgan and Prince, 1977
138. *Menida beryllina*	Tidewater silversides (egg)	230	1440	LC50	Morgan and Prince, 1977
138. *Menida beryllina*	Tidewater silversides (egg)	250	2880	LC50	Morgan and Prince, 1977
Percichthyidae:					
139. *Morone saxatilis*	Striped bass (larvae)	40	2880	Incipient LC50	Middaugh et al., 1977, as cited in U.S. EPA, 1985
139. *Morone saxatilis*	Striped bass (larvae)	70	2880	Incipient LC50	Middaugh et al., 1977, as cited in U.S. EPA, 1985
140. *Morone saxatilis*	Striped bass (eggs)	270	120	LC50	Burton et al., 1979
141. *Morone saxatilis*	Striped bass (prolarvae)	160	5	LC50	Burton et al., 1979
141. *Morone saxatilis*	Striped bass (prolarvae)	190	240	LC50	Burton et al., 1979
141. *Morone saxatilis*	Striped bass (prolarvae)	120	120	LC50	Burton et al., 1979
142. *Morone saxatilis*	Striped bass (egg)	48	2880	LC50	Morgan and Prince, 1977
142. *Morone saxatilis*	Striped bass (egg)	60	1440	LC50	Morgan and Prince, 1977
143. *Morone saxatilis*	Striped bass (egg)	220	2880	LC50	Morgan and Prince, 1977
144. *Morone saxatilis*	Striped bass (larvae)	68	1440	LC50	Morgan and Prince, 1977
145. *Morone americana*	White perch (egg)	150	4560	LC50	Morgan and Prince, 1977
146. *Morone americana*	White perch (larvae)	200	1440	LC50	Morgan and Prince, 1977
147. *Morone americana*	White perch (egg)	270	4560	LC50	Morgan and Prince, 1977
148. *Morone americana*	White perch (larvae)	310	1440	LC50	Morgan and Prince, 1977
Clupeidae:					
149. *Alosa aestivalis*	Blueback herring (egg)	150	4800	LC50	Morgan and Prince, 1977
150. *Alosa aestivalis*	Blueback herring (egg)	330	4800	LC50	Morgan and Prince, 1977

Data Point and Scientific Name	**Descriptive Name**	**Concentration (µg/L)**	**Duration (Min.)**	**Effect**	**Ref.**
151. *Alosa aestivalis*	Blueback herring (larvae)	75	2880	LC50	Morgan and Prince, 1977
152. *Alosa aestivalis*	Blueback herring (larvae)	250	2880	LC50	Morgan and Prince, 1977
153. *Clupea harengus*	Pacific herring (juv)	65	5760	LC50	Thatcher, 1977
Embiotocidae:					
154. *Cymatogaster aggregata*	Shiner perch (juv.)	664	7.5	LC50 (7.5°CΔT)	Stober et al., 1980
154. *Cymatogaster aggregata*	Shiner perch (juv.)	220	60	LC50 (7.5°CΔT)	Stober et al., 1980
155. *Cymatogaster aggregata*	Shiner perch (juv.)	410	15	LC50 (3.2°CΔT)	Stober et al., 1980
155. *Cymatogaster aggregata*	Shiner perch (juv.)	302	30	LC50 (3.2°CΔT)	Stober et al., 1980
- Cymatogaster aggregata	Shiner perch (juv.)	175	N.G.	Avoidance threshold	Stober et al., 1980
156. *Cymatogaster aggregata*	Shiner perch (juv & adult)	71	5760	LC50	Thatcher, 1977
Gobiidae:					
157. *Gobiosoma bosci*	Naked gody	640	120	LC50	Roberts et al., 1975
157. *Gobiosoma bosci*	Naked goby	80	1440	LC50	Roberts et al., 1975
157. *Gobiosoma bosci*	Naked goby	80	2880	LC50	Roberts et al., 1975
157. *Gobiosoma bosci*	Naked goby	80	5760	LC50	Roberts et al., 1975
Syngnathidae:					
158. Syngnathus fuscus	N. pipefish	280	1440	LC50	Roberts et al., 1975
158. Syngnathus fuscus	N. pipefish	270	2880	LC50	Roberts et al., 1975
158. Syngnathus fuscus	N. pipefish	270	5760	LC50	Roberts et al., 1975
Sciaenidae:					
159. Leiostanus xanthurus	Spot (juv.)	180	30	Avoidance	Middaugh et al., 1977
159. Leiostomus xanthurus	Spot (juv.)	50	30	Avoidance	Middaugh et al., 1977
160. Leiostomus xanthurus	Spot (juv.)	140	1440	LC50	Bellanca and Bailey, 1977
160. Leiostomus xanthurus	Spot (juv.)	90	5760	LC50	Bellanca and Bailey, 1977
Cyprinodontidae:					
161. Fundulus heteroclitus	Mummichog	650	30	100% mortality, 25°c	Capuzzo, Davidson, et al., 1977
162. Fundulus heteroclitus	Mummichog	1200	30	100% mortality 25°C*	Capuzzo, Davidson, et al., 1977
163. Fundulus heteroclitus	Mummichog	250	30	100% mortality 30°c	Capuzzo, Davidson, et al., 1977

Data Point and Scientific Name	**Descriptive Name**	**Concentration (µg/L)**	**Duration (Min.)**	**Effect**	**Ref.**
164. Fundulus heteroclitus	Mummichog	850	30	100% mortality 30°C*	Capuzzo, Davidson, et al., 1977
165. Fundulus heteroclitus	Mummichog	400	30	100% mortality 25°C	Capuzzo, Goldman, et al., 1977
166. Fundulus heteroclitus	Mummichog	300	30	100% mortality 25°C*	Capuzzo, Goldman, et al., 1977
167. Fundulus heteroclitus	Mummichog	300	30	Initial respiratory stress*	Capuzzo, Goldman, et al., 1977
Sparidae:					
168. Stenotomus versicolor	Scup	650	30	100% mortality	Capuzzo, Davidson, et al., 1977
169. Stenotomus versicolor	Scup	3100	30	100% mortality*	Capuzzo, Davidson, et al., 1977
170. Stenotomus versicolor	Scup	500	30	Stress	Capuzzo, Davidson, et al., 1977
171. Stenotomus versicolor	Scup	2200	30	Stress*	Capuzzo, Davidson, et al., 1977
Gasterosteidae:					
172. Gasterosteus aculeatus	3-spine Stickleback (juv.& adult)	167	5760	LC50	Thatcher, 1977
Ammodytidae:					
173. Ammodytes hexapterus	Pac. sand lance (juv. & adult)	82	5760	LC50	Thatcher, 1977

N.G.	Not Given
*	Chloramines tested or suspected
juv.	Juvenile
Δ	Temperature change

Table 4. Chlorine Criteria for Freshwater Aquatic Life

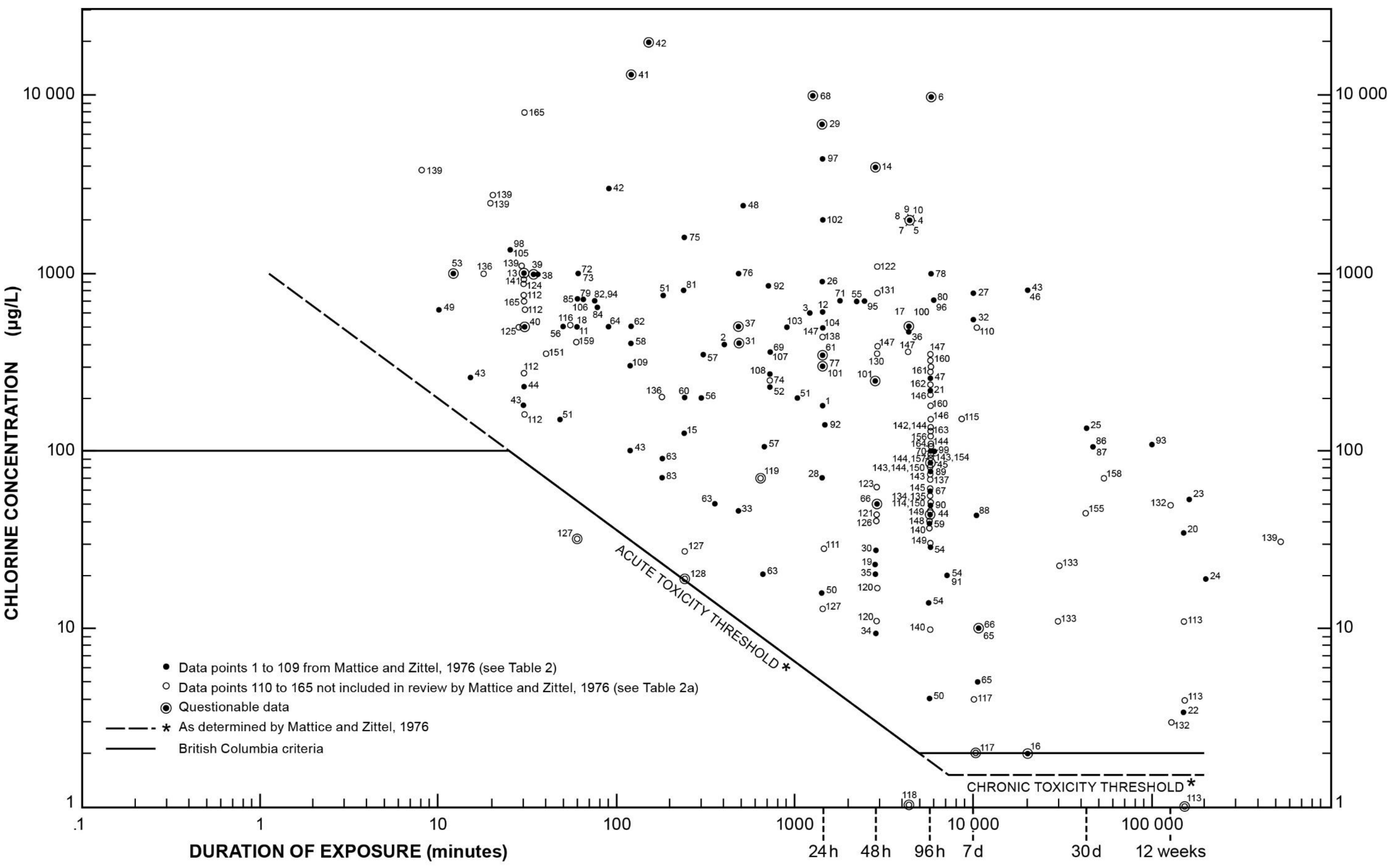
Criteria Statements	**Criteria Values**	**Jurisdiction or Author**	**Date**
Aquatic life should be protected where the concentration of residual chlorine in the receiving system does not exceed 3 µg/L at any time or place. Aquatic organisms will tolerate short-term exposure to high levels of chlorine. Until more is known about the short-term effects, it is recommended that total chlorine should not exceed 50 µg/L for a period up to 30-minutes in any 24-hour period.	3-50 µg/L	U.S. EPA	1973
Concentration of total residual chlorine not to exceed 10 µg/L when discharged continuously. This concentration would not protect trout and salmon and some important fish-food organisms; it could be partially lethal to sensitive life stages of sensitive fish species.	10 µg/L	Brungs	1973
Concentration of total residual chlorine not to exceed 2 µg/L when discharged continuously. This concentration should protect most aquatic organisms.	2 µg/L	Brungs	1973
Concentration of total residual chlorine not to exceed 200 µg/L when discharged intermittently for a period of 2 h/day. This concentration would not protect trout and salmon.	200 µg/L for 2h/day	Brungs	1973
Concentration of total residual chlorine not to exceed 40 µg/L when discharged intermittently for a period of 2 h/day. This concentration should protect most species of fish.	40 µg/L for 2h/ day	Brungs	1973
An upper limit of 4 µg/L HOCl should afford sufficient protection of fish stocks and other aquatic organisms.	4 µg/L HOCL	EIFAC Alabaster and Lloyd	1973 1984
Safe values for continuous exposure are 5 µg/L and 20 µg/L TRC for coldwater and warmwater intolerant fish, respectively.	5 µg/L and 10 µg/L	Basch and Truchan	1974
Safe values for intermittent exposure to chlorine are 40 µg/L and 200 µg/L for coldwater and warmwater intolerant fish, respectively. These intermittent safe concentrations are to apply to a 30-minute exposure period with a number of 30-minute exposures allowable/day to be determined on a case-by-case basis for each plant.	40 µg/L and 200 µg/L	Basch and Truchan	1974
Total residual chlorine should not exceed (a) 2.0 µg/L for the protection of salmonid fish; and (b) should not exceed 1 O. 0 µg/L for other freshwater organisms.	2.0 µg/L and 10.0 µg/L	U.S. EPA Alaska	1976 1979

Criteria Statements	Criteria Values	Jurisdiction or Author	Date
A single criterion for total residual chlorine of 3 µg/L for fresh water aquatic life continuously exposed to total residual chlorine.	3 µg/L	Brungs	1976
Criteria for intermittent exposure of aquatic organisms to total residual chlorine should be time-related as proposed by Mattice and Zittel (1976).	Time-related	Brungs	1976
The chronic (>5 days) toxicity threshold for freshwater aquatic life is 1.5µg/L total residual chlorine.	1. 5 µg/L	Mattice and Zittel	1976
The acute (<5 days) toxicity threshold for freshwater aquatic life exposed to intermittent discharges is 1 000 µg/L for 1 minute. time-related and ranges from 1.5 µg/L total residual chlorine for 5 days to	Time-related	Mattice and Zittel	1976
Objective for residual chlorine in receiving waters outside the initial dilution zone is below detectable limits as measured by amperometric method.	Below detection	British Columbia	1977 1979 1980 1980
Total residual chlorine, as measured by the amperometric (or equivalent) method, should not exceed 2 µg/L to protect aquatic life.	2 µg/L	International Joint Commission Ontario	1978 1984
A single criterion of 3 to 5 µg/L total residual chlorine (measured by amperometric titration in conjunction with a polarograph). Separate criteria should be established for intermittent discharges based on an exposure time versus chlorine concentration curve.	3 to 5 µg/L Time-related	American Fisheries Society	1979
Total residual chlorine must not exceed 2 µg/L for cold water biota and 1 0 µg/L for warm water biota.	2 µg/L and 10 µg/L	Idaho	1980
For continuous exposure, the total residual chlorine should be less than 2 µg/L.	2 µg/L	Canada Dept. of Fisheries and Oceans	1983
For intermittent exposure, the total residual chlorine should be less than 40 µg/L for 2 hours/day.	40 µg/L	Canada Dept. Fisheries and Oceans	1983
Maximum acceptable concentration of total residual chlorine for cold water aquatic life is 2 µg/L.	2 µg/L	Manitoba	1983
Maximum acceptable concentration of total residual chlorine for cool water aquatic life is 10 µg/L	10 µg/L	Manitoba	1983
To protect freshwater aquatic life and its uses, in each 30 consecutive days: (a) the average concentration of total	8.3 and 14 µg/L	U.S. EPA	1983 (Draft)

Criteria Statements	Criteria Values	Jurisdiction or Author	Date
residual chlorine should not exceed 8.3 µg/L; (b) the maximum concentration should not exceed 14 µg/L; and (c) the concentration may be between 0.3 and 14 µg/L for up to 96 hours.			
Freshwater aquatic organisms and their uses should not be affected unacceptably if the -day average concentration of total residual chlorine does not exceed 11 µg/L more than once every 3 years on the average and if the 1-hour average concentration does not exceed 19 µg/L more than once every 3 years on the average.	11 and 19 µg/L	U.S. EPA	1985
The concentration of residual chlorine, as measured by the amperometric (or equivalent) method, should not exceed 2.0 µg/L.	2 µg/L	CCREM	1987

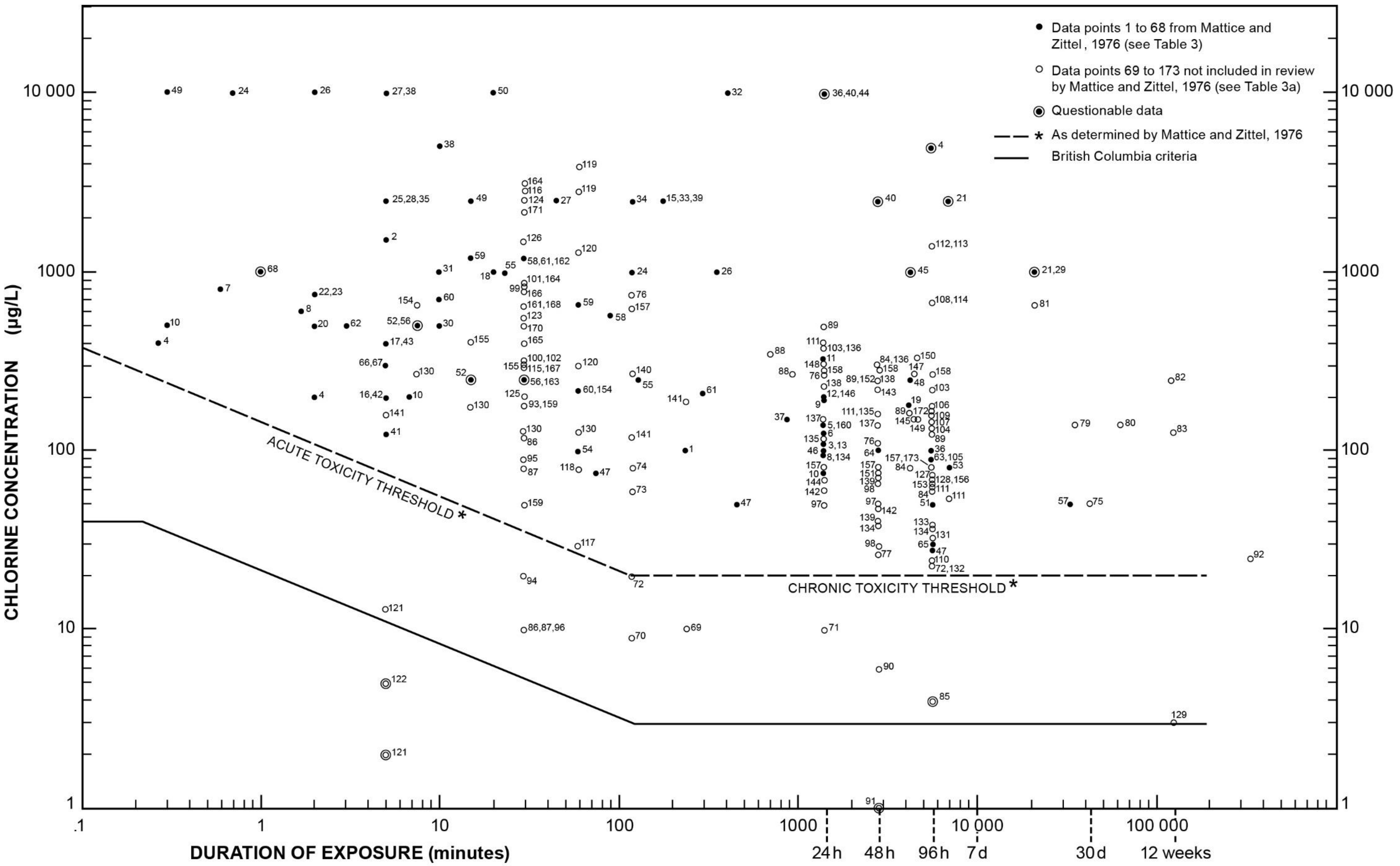
Table 5. Chlorine Criteria for Marine Aquatic Life

Criteria Statements	**Criteria Values**	**Jurisdiction or Author**	**Date**
It is recommended that an application factor of 0.1 be used with 96-h LC50 data from seawater bioassays for the most sensitive species to be protected.	0.1 of 96-h LC50	U.S. EPA	1972
However, it is suggested that free residual chlorine in seawater in excess of 10 µg/L can be hazardous to marine life.	10 µg/L	U.S. EPA	1972
Total residual chlorine concentration of 10 µg/L for marine organisms.	10 µg/L	U.S. EPA	1976
The chronic toxicity threshold for saltwater is 20 µg/L.	20 µg/L	Mattice and Zittel	1976
The acute toxicity threshold for marine aquatic life exposed to intermittent discharges is time-related and ranges from 20 µg/L total residual chlorine for 2 hours to 300 µg/L for 10 seconds.	Time-related	Mattice and Zittel	1976
Objective for residual chlorine in receiving waters outside the initial dilution zone is below detectable limits as measured by amperometric method.		British Columbia	1977 1979 1980
The best criterion available for marine organisms at present is 20 µg/L (as oxidant species).	20 µg/L	American Fisheries Society	1979
Total residual chlorine shall not exceed 2.0 µg/L for salmonid fish, or 10.0 µg/L for other organisms. For harvesting for consumption of raw mollusks or other raw aquatic life, total residual chlorine shall not exceed 1 000 µg/L at any time.	2 and 10 µg/L 1 000 µg/L	Alaska	1979
To protect saltwater aquatic life and its uses, in each 30 consecutive days: (a) the average concentration of chlorine-produced oxidants should not exceed 7.4 µg/L; (b) the maximum should not exceed 13 µg/L; and (c) the concentration may be between 7.4 and 13 µg/L for up to 96 hours.	7.4 and 1 3 µg/L	U.S. EPA	1983 (Draft)
Saltwater aquatic organisms and their uses should not be affected unacceptably if the 4-day average concentration of chlorine-produced oxidants does not exceed 7.5 µg/L more than once every 3 years on the average and if the 1-hour average concentration does not exceed 13 µg/L more than once every 3 years on the average.	7.5 and 13 µg/L	U.S. EPA	1985



modified after Mattice and Zittel, 1976

Figure 1. Toxicity of Chlorine to Freshwater Organisms



modified after Mattice and Zittel, 1976

Figure 2. Toxicity of Chlorine to Marine Organisms

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