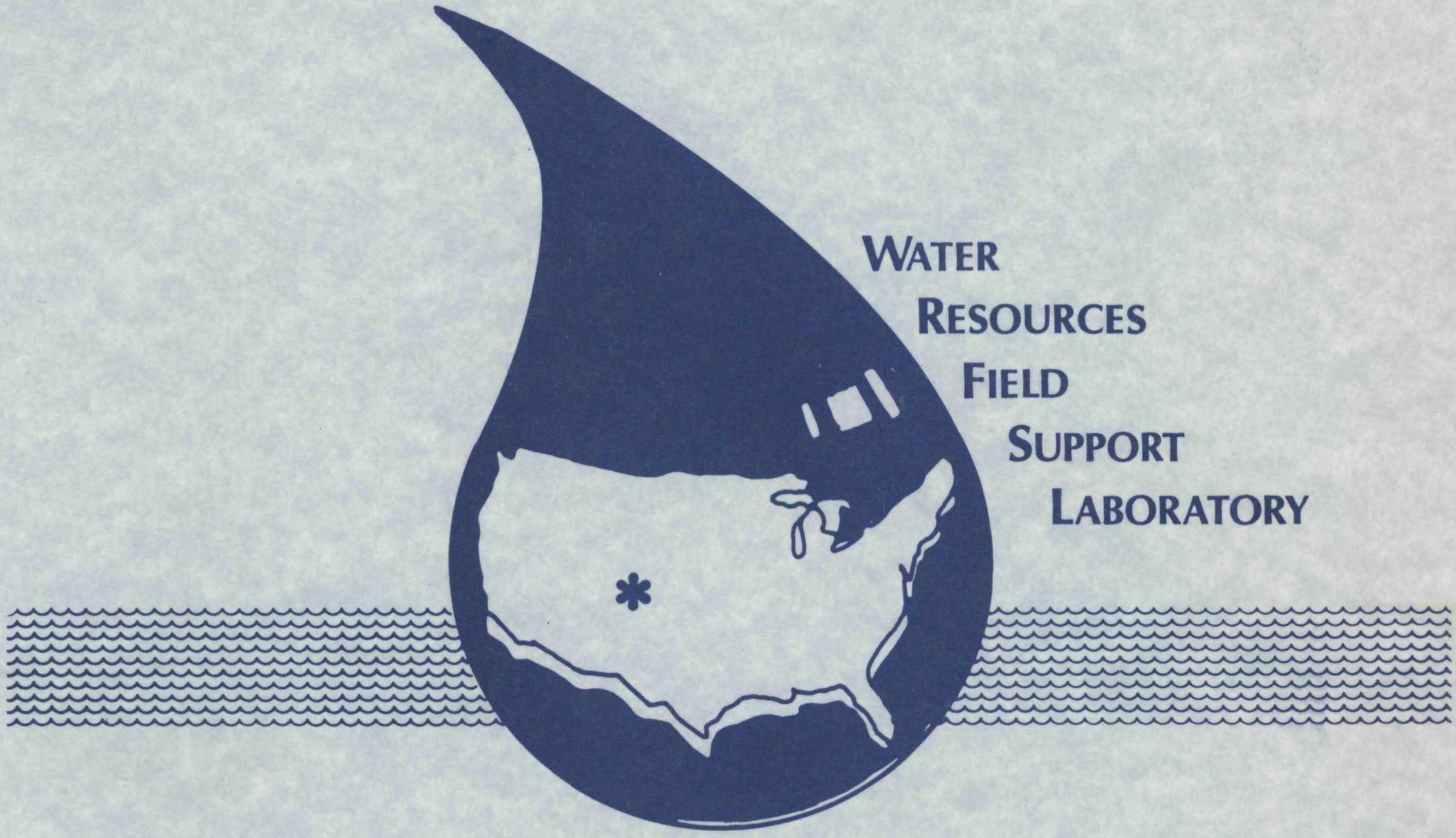
WATER QUALITY CRITERIA: AN OVERVIEW FOR PARK NATURAL RESOURCE SPECIALISTS



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WATER RESOURCES FIELD SUPPORT LABORATORY
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WRFSL Report No. 84-4

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INTRODUCTION

In response to numerous requests for advice on interpreting water quality data, Water Quality Criteria: An Overview for Park Natural Resource Specialists has been compiled by the staff of the Water Resources Branch to serve as a training document and an introduction to water quality criteria. As such, this report has been designed 1) to provide the basic information needed to determine from water quality data whether a pollution problem exists in a watercourse, and 2) to suggest references providing more specific information about each constituent. The 39 water quality constituents discussed are those that NPS personnel are likely to encounter when reviewing and interpreting water quality data.

It should be stressed that a water quality criterion is "a description of certain maximum or minimum physical, chemical and biological characteristics of water which reflect tolerances and requirements of the aquatic biota, human health considerations, and man's sense of aesthetics, which, when incorporated into standards, will protect defined uses of the nation's waters with an adequate degree of safety" (AFS, 1979). A water quality standard, on the other hand, "connotes a legal entity for a particular reach of waterway or for an effluent" (U.S. EPA, 1976). Thus, the criteria listed in this report are not legal water quality standards. Water quality standards are adopted on a state-by-state basis (under guidelines promulgated by the U.S. Environmental Protection Agency) and are located within the statutes and regulations of each individual state. In addition, most states have developed systems of stream classification for surface waters within their states, including those waters of NPS units. Because of this variation among states, it is each resource manager's responsibility to become familiar with the classification of waters and the applicable water quality standards within his or her local area.

It is important to note that, as more is learned about the impacts of different chemical constituents on the aquatic environment, the federal and state standards and criteria continue to be modified. Especially likely candidates for such modification are those chemicals whose impacts and presence in water we are still learning to assess. Up-to-date information on water quality standards are directly available from the agency responsible for water quality management within each state. In addition, the Environment Reporter is a useful reference for current information pertaining to state water quality standards. Three volumes of this publication are devoted to state water quality standards and contain applicable regulations, water quality standards and National Pollutant Discharge Elimination System permit regulations (where applicable) for all 50 states, the District of Columbia and Puerto Rico. This reference, available in the libraries of most academic institutions, is continuously updated as changes take place.

It is our hope that this compilation of existing water quality criteria will serve as a useful primer for resource managers and others charged with the responsibility of managing and monitoring water resources.

CONSTITUENT	BACKGROUND	DRINKING WATER STANDARD	AQUATIC LIFE REQUIREMENTS/RESTRICTIONS	COMMENTS
ALKALINITY	Alkalinity is defined as the the quantitative capacity of water to react with hydrogen ions to a preselected pH end-point (AFS, 1979). As such, alkalinity is a measure of the buffering capacity of the water. Because pH affects organisms as well as the toxicity of certain pollutants in water, the buffering capacity is important to water quality (US EPA, 1976).	Naturally occurring levels up to 400 mg/ℓ as $CaCO_3$ are not a health hazard (NAS, 1973).	Alkalinity is important to fish and wildlife because it will buffer both natural pH change and human-induced change such as the impact of acid deposition. For fish and wildlife, the recommended minimum alkalinity is 20 mg/ℓ (as $CaCO_3$) (NAS, 1973) and assumes natural alkalinity is not reduced or increased by more than 25% (AFS, 1979). Resource managers should work to assure that changes in alkalinity are kept to a minimum. This is because the alkalinity of a system not only influences the suitability of the system for biological activity, but it influences the composition of the biological community as well (AFS, 1979).	While the EPA recommends a minimum criterion for alkalinity, some researchers feel this rationale is faulty. They feel that minimizing change in alkalinity is more important than the establishment of a minimum criterion (AFS, 1979).

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ALUMINUM	Aluminum in natural waters appears in a wide array of forms, including organic complexes, fluoride complexes, and aluminum hydroxide. The toxicity of aluminum depends on how it is complexed. For example, organically-bound forms of aluminum generally are less toxic than the inorganic forms (Grahn, 1980). The speciation of aluminum is pH-dependent, and higher aluminum toxicities also occur at lower pH levels. Because of the many species of aluminum found in water, the precise relationships of aluminum concentrations to toxicity still are not well understood.	Aluminum has a low toxicity to humans, and levels 5 to 50 times the normal daily intake do not appear harmful to humans (Sorenson et al., 1974; Phillips and Russo, 1978). Furthermore, aluminum compounds are commonly used in treating drinking water and in the processing of food. Thus, aluminum is not normally considered a problem in public water supplies (NAS, 1982).	Data presented in McKee and Wolf (1963) indicate that an upper limit of 0.25 mg/ℓ aluminum would protect most aquatic life, while lower limits may be required for a few more sensitive species. Some researchers have found toxicity values as low as 0.1 mg/ℓ at pH values of 5.5 (U.S. Fish and Wildlife Service, Columbia National Fisheries Research Lab, personal communication).	Since aluminum is generally a minor constituent in irrigation waters, it has little effect on irrigation. However, a limit of 5.0 mg/ℓ is suggested if irrigation is to continue permanently (NAS, 1982). Swimming pools with an alum concentration of 0.1 mg/ℓ aluminum may cause human eye irritation; a concentration equivalent to 0.5 mg/ℓ causes acute eye irritation (McKee and Wolf, 1963).

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AMMONIA	Ammonia is a biologically active nutrient that is present in most waters as a normal biological degradation product of nitrogenous organic matter. It may also enter water as a byproduct of industrial wastes, as sewage effluent or as agricultural runoff. As a macronutrient, it is important to monitor in system productivity/eutrophication assessment. The toxicity of ammonia is strongly affected by pH as well as its concentration in solution. Two important factors affecting the concentration of NH_3 are temperature and ionic strength. An increase in temperature will bring about an increase in NH_3 concentration, but with an increase in ionic strength the NH_3 concentration will decrease (US EPA, 1976).	No domestic drinking water standard for ammonia has been established (McKee and Wolf, 1963). However, the WHO European Drinking-Water Standards set a recommended limit of 0.050 mg/ℓ of ammonia (as NH_4) (WHO, 1970).	To protect freshwater aquatic life, the criteria for ammonia are based upon ambient water temperature and pH with maximum concentration and 30-day average values provided by the US EPA. Tables of suggested criteria for un-ionized ammonia and total ammonia have been published in the Federal Register (US EPA, 1984) and are reproduced in Appendix A.	The US EPA is presently considering the development of implementation guidelines to accompany the revised ammonia criteria.

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ARSENIC	Arsenic is an element which exhibits both metallic and non-metallic properties. Its compounds, found everywhere in nature, may be organic or inorganic and occur mostly as arsenides and arsenopyrites. Four arsenic species common in natural waters are arsenate (+5), arsenite (+3), methanearsonic acid and dimethylarsinic acid. The chemical and toxicological properties of the forms appear to be quite different. Since the toxicities of these forms have not been shown to be additive, these compounds should be treated separately. In fact, trivalent inorganic arsenicals are more toxic to mammals and aquatic species than the pentavalent forms. Arsenicals are used widely in industry and are a constitutent of herbicides used in forest management and agriculture (US EPA, 1976; US EPA, 1983a).	An arsenic concentration not greater than 0.05 mg/ℓ is recommended for the domestic drinking water supply (NAS, 1982; CFR, 1983a). A concentration not greater than 0.05 mg/ℓ is also recommended by the World Health Organization as the international standard for drinking water (WHO, 1971).	Although arsenic can be concentrated in aquatic organisms, it apparently does not become progressively concentrated along the food chain (US EPA, 1976). Fresh water: For the protection of freshwater aquatic life the average concentration of dissolved trivalent inorganic arsenic (operationally defined as the trivalent inorganic arsenic that passes through a 0.45 micron membrane filter) should not exceed 0.072 mg/ℓ in any 30 consecutive days, nor should the concentration exceed 0.14 mg/ℓ for more than 96 consecutive hours. Pentavalent inorganic arsenic is actively toxic to freshwater aquatic animals at concentrations as low as 0.850 mg/ℓ. Pentavalent arsenic at concentrations as low as 0.048 mg/ℓ may be toxic to freshwater aquatic plants (US EPA, 1984). Salt water: For the protection of saltwater aquatic life the average concentration of dissolved trivalent inorganic arsenic should not exceed 0.063 mg/ℓ in any 30 consecutive days, nor should the concentration exceed 0.12 mg/ℓ for more than 96 consecutive hours. Pentavalent inorganic arsenic is acutely toxic to saltwater animals at concentrations as low as 2.319 mg/ℓ and may be toxic to saltwater plants at 0.005-0.050 mg/ℓ (US EPA, 1984).	A maximum arsenic concentration of 0.100 mg/ℓ is recommended as a limit for irrigation water. It is suggested that a maximum concentration of 0.100 mg/ℓ be observed for the protection of aquatic vegetation (US EPA, 1976).

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BARIUM	A malleable, ductile metal, barium is most often found in nature as barite ($BaSO_4$) and witherite ($BaCO_3$), both of which are highly insoluble salts. However, many other salts of barium are soluble both in water and in acid and are poisonous. Barium enters the body primarily through air and water; appreciable amounts are not contained in foods. Its ions are thought to be rapidly precipitated or removed from solution by adsorption and sedimentation (US EPA, 1976).	In domestic drinking water supplies, concentrations of barium generally range from less than 0.0006 mg/ℓ to approximately 0.010 mg/ℓ (US EPA, 1976). A maximum limit of 1 mg/ℓ is recommended for barium in domestic water supplies (CFR, 1983a; US EPA, 1976). Recent information indicates that the basis on which the original and current drinking water standards (1 mg/ℓ) were established may have been in error. The oral intake limit (maximum allowable concentration) may be increased from 1 mg/ℓ to 4.7 mg/ℓ. Therefore, there are recommendations to re-evaluate the current drinking water standard (NAS, 1982).	Both in fresh and marine waters, the concentration of soluble barium would have to exceed 50 mg/ℓ before it would be likely to have a toxic effect on aquatic life. In the majority of natural waters, there is ample sulfate or carbonate to precipitate the barium present in the water as a virtually insoluble, non-toxic compound. Restrictive criteria for aquatic life appears unjustified under usual marine and freshwater conditions because the physical and chemical properties of barium generally will preclude the existence of the toxic soluble form (US EPA, 1976).	Because of the increased activity in offshore drilling and the wide use of drilling fluids (barite) which contain a high percentage of barium sulfate, the need for a better understanding of the real or potential toxicity of $BaSO_4$ has increased. Information about the toxicity of drilling fluids to marine organisms is given by Land (1974) and Grantham and Sloane (1975) (AFS, 1979).

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BERYLLIUM	The probability of beryllium occurring at significantly toxic levels in ambient natural waters is minimal. The chloride and nitrate salts of beryllium are very soluble in water, the sulfate is only moderately so, and the carbonate and hydroxide are virtually insoluble in cold water. Beryllium can enter waters in effluents from certain metallurgical plants, but the inhalation of beryllium-containing fumes and dust originating from processing and fabrication operations poses the most serious health hazard to humans (US EPA, 1976).	There are no applicable drinking water standards for beryllium.	For soft fresh water the criterion for the protection of aquatic life is established at 0.011 mg/ℓ. The criterion for the protection of aquatic life in hard fresh water is established at 1.10 mg/ℓ. As can be seen from these criteria, beryllium is considerably (100 times) more toxic in soft water than in hard-water. In marine organisms, beryllium has been reported to be concentrated as much as 1000 times the ambient concentration (McKee and Wolf, 1963; US EPA, 1976).	Because of its toxicity in nutrient solutions in acid soils, the criterion for beryllium in irrigation waters is 0.50 mg/ℓ for use on neutral to alkaline fine-textured soils and 0.10 mg/ℓ for use on all other soils (US EPA, 1976).

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BIOCHEMICAL OXYGEN DEMAND (B.O.D.)	Biochemical oxygen demand determination does not reveal the concentration of a specific substance, but it does measure the effect of a combination of substances and conditions. B.O.D. is not a pollutant itself and causes no direct harm. Only by lowering the dissolved oxygen content to levels that are threatening to fish life and other beneficial uses does B.O.D. exert a potentially harmful effect (McKee and Wolf, 1963).	There are no applicable B.O.D. drinking water standards.	While B.O.D does not affect aquatic life directly, it has the indirect effect of influencing the dissolved oxygen of the system. B.O.D. standards for effluent discharge will vary depending upon the condition of the receiving water. In a slow-moving stream, a 5-day B.O.D. of 5 mg/ℓ may be enough to produce deoxygenation, which results in anaerobic conditions. On the other hand, a rapid mountain stream may have the capacity to assimilate an effluent with a B.O.D. of 50 mg/ℓ without appreciable depletion of the dissolved oxygen (McKee and Wolf, 1963).	The input of natural organic matter (i.e., leaf fall in autumn) also exerts an increase in the BOD of the receiving water.

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BORON	Boron does not occur in nature in its elemental state but instead is found as sodium or calcium borate salt. Boron salts have a variety of uses, including fire retardants, leather tanning, and high-energy rocket fuels. In addition, sodium borohydride is used by the pulp and paper industry in the production of the whitening agent sodium dithionite, and borax has long been used in detergents (AFS, 1979). Elemental boron is frequently used for neutron absorption in nuclear reactors. Boron is essential for plant growth, but apparently is not required by animals (US EPA, 1976).	In general, boron in drinking water is not regarded as being hazardous to human health. It has been reported that in drinking water, boron concentrations up to 30 mg/ℓ have no detrimental health effects (McKee and Wolf, 1963). However, the Merck Index (1974) states that the lethal dose of boric acid for adult humans varies from 5 to 20 g.	Seawater has a boron concentration of 4.5 mg/ℓ in the form of borate. Naturally occurring concentrations of boron do not appear to have an adverse effect on aquatic life. The EPA (1976) notes that the minimum lethal dose for minnows exposed to boric acid at 20°C for 6 hours has been reported as 18,000 to 19,000 mg/ℓ in distilled water and 19,000 to 19,500 mg/ℓ in hard water (US EPA, 1976). The American Fisheries Society task force (AFS, 1979) suggested the following maximum criteria: 1 mg/ℓ for discharge to marine waters; 10 mg/ℓ for discharge to freshwater.	It is believed that a criterion of 0.750 mg/ℓ will protect sensitive crops during long-term irrigation. The lethal dose of boric acid for animals varies according to species from 1.2 to 3.45 grams per kilogram of body weight. One study reports that, in the dairy cow, 16 to 20 g/day of boric acid in a 40-day period produced no ill effects (McKee and Wolf, 1963; US EPA, 1976). It should also be noted that no simple methods are available for the field determination of boron (AFS, 1979).

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CADMIUM	Cadmium is a soft metal which is readily soluble in mineral acids. It is a biologically nonessential, nonbeneficial element which can be highly toxic. Cadmium usually is found in nature as a sulfide salt, often in association with zinc and lead ores. In the vicinity of mines and smelters, cadmium accumulations in the soil can result in high local concentrations in adjacent waters. When ingested or inhaled, cadmium is toxic to humans. Fish and other specified invertebrates have been found to be sensitive to low levels of cadmium in waters (US EPA, 1976; US EPA, 1983b).	Assuming a 2-liter daily consumption of water, the recommended maximum concentration in drinking water is 0.01 mg/ℓ. The maximum daily intake of cadmium should not exceed 0.02 mg from water (NAS, 1982; CFR, 1983a). A maximum concentration of 0.01 mg/ℓ is recommended in the World Health Organization's International Standards for Drinking Water (WHO, 1971).	It has been demonstrated that increased hardness and/or alkalinity can decrease the toxicity of cadmium in acute freshwater mortality tests (US EPA, 1976). Fresh water: Since the acute and chronic toxicities of cadmium to sensitive freshwater species are approximately the same, to protect freshwater aquatic life the concentration (in μg/ℓ) of active cadmium should not exceed the numerical value given by $e^{[1.16[\ln(\text{hardness})]-3.841]}$. For example, at hardnesses of 50 and 250 mg/ℓ as $CaCO_3$, the maximum allowable concentrations of active cadmium are 2.0 and 12.97 μg/ℓ (0.002 and 0.01297 mg/ℓ), respectively. It is noted that very sensitive species may not be protected by this criterion (US EPA, 1984). Salt water: For the protection of saltwater aquatic life and its uses, the average concentration of active cadmium should not exceed 0.012 mg/ℓ in any 30 consecutive days; the concentration may be between 0.012 and 0.038 mg/ℓ for no longer than 96 consecutive hours (US EPA, 1984).	

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CALCIUM	Because it readily oxidizes in air and reacts with water to release hydrogen gas, calcium does not occur in nature as a pure element. Even so, calcium salts and calcium ions are among the most commonly encountered substances in water. Calcium ions can result from the leaching of soil and other natural sources, or they may be contained in sewage and various industrial wastes. A direct relationship exists between calcium and water hardness, such that an increase in calcium ions will increase the hardness (McKee and Wolf, 1963).	The USPHS Drinking Water Standards set no limits for calcium in drinking water (McKee and Wolf, 1963). However, the World Health Organization's International Standards set as "permissible" a limit of 75 mg/ℓ and as "excessive" a limit of 200 mg/ℓ for drinking water (WHO, 1971).	Calcium in water decreases the toxicity of many chemical compounds to a variety of fish. In fact, in most cases calcium is beneficial and thus is not a concern (McKee and Wolf, 1963).	For livestock the recommended threshold limit of calcium in water is 1000 mg/ℓ. As calcium is an essential element for the normal growth of plants, it is a desirable constituent of irrigation water (McKee and Wolf, 1963).

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CHLORIDES	In natural waters, chlorides can be considered ubiquitous. They may originate naturally from minerals or derive from seawater contamination of ground water, salts spread on fields for agricultural purposes, human or animal waste, or various industrial effluents. Because chlorides are more of an aesthetic than a health concern (although high concentrations can be harmful to those with heart or kidney ailments), restrictions on chloride concentrations in drinking water are founded on taste considerations rather than health concerns (McKee and Wolf, 1963).	Chloride concentration in drinking water may be particularly important to persons on low salt diets. The maximum contaminant level for public water supplies is 250 mg/ℓ (CFR, 1983b).	Because the concentration of chlorides is closely related to total salinity and its effects on osmosis, excessive changes in salinity are not tolerated by freshwater fish. By the same token, saltwater fish are vulnerable to waters with low salinity. Since each mixture of chlorides with other salts must be treated separately, and since different species respond variously to certain concentrations, it is difficult to generalize about the effects of chlorides on aquatic life. However, some data indicate that among U.S. fresh waters supporting a good fish fauna, the chloride concentration is below 170 mg/ℓ in 95 percent of such waters (McKee and Wolf, 1963).	It has been determined that the following concentrations of chlorides will not be detrimental to these beneficial uses: irrigation.... 100 mg/ℓ; stock and wildlife........1500 mg/ℓ (McKee and Wolf, 1963). Chloride buildup in soils in arid or semi-arid environments is an important concern in some areas.

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CHLORINE (gas)	A highly soluble gas, elemental chlorine reacts readily with many inorganic substances and all animal and plant tissues. Chlorine has a denaturing effect on animal and plant tissues which renders it an effective disinfectant for water treatment. Although chlorine is not a natural constituent of water, it can appear in surface or ground water from domestic sewage disinfection and from industrial processes which use chlorine for bleaching operations or for controlling organism growth. When chlorine in its free form (HOCl and OCl^-) reacts with nitrogenous organic material, it forms chloramines, which are toxic to fish (US EPA, 1976; US EPA, 1983c).	While no maximum concentration criterion for chlorine has been established, a concentration of above 5 mg/ℓ in drinking water causes taste and odor problems (NAS, 1982). Also, chlorination of water containing high levels of natural or man-made organic compounds leads to the formation of trihalomethanes, which recently have received much attention as potential carcinogens.	The degree of chlorine toxicity to aquatic life depends on the total residual chlorine, which is defined as the amount of free chlorine plus chloramines. Freshwater fish and marine aquatic life in most cases should be protected if residual chlorine concentrations are kept below 0.010 mg/ℓ, although the more sensitive salmonids require a criterion of 0.0020 mg/ℓ (US EPA, 1976). Fresh water: For the protection of freshwater aquatic life, the average concentration of total residual chlorine should not exceed 0.0083 mg/ℓ over any 30-day period, nor should the maximum concentration exceed 0.014 mg/ℓ for more than 96 consecutive hours (US EPA, 1984). Salt water: For the protection of saltwater aquatic life, the average concentration of chlorine-produced oxidants should not exceed 0.0074 mg/ℓ over any 30-day period; the maximum concentration should not exceed 0.013 mg/ℓ for more than 96 consecutive hours (US EPA, 1984).	

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CHROMIUM	In the earth's crust, chromium is ranked as the 17th most abundant nongaseous element. Oxidation states of chromium range from Cr^{-2} to Cr^{-6}, but the form most commonly found in nature is the trivalent form. Though chromium is rarely found in natural waters, it is found in air, soil, some foods, and most biological systems. Chromium has been recognized as an essential trace element for humans (US EPA, 1976).	To avoid any potential human health hazard, a maximum chromium concentration of 0.050 mg/ℓ in domestic water supplies should be observed (CFR, 1983a).	Toxicity of chromium varies with the species type, chromium oxidation state, and pH. In general, freshwater fish seem to be relatively tolerant of chromium, although some aquatic invertebrates are very sensitive (US EPA, 1976). Fresh water: For the protection of freshwater aquatic life, the average concentration of dissolved hexavalent chromium should not exceed 0.0072 mg/ℓ over any 30-day period or 0.011 mg/ℓ for more than 96 consecutive hours. The average concentration (in µg/ℓ) of active trivalent chromium should not exceed the numerical value given by $e^{(0.819[\ln(\text{hardness})]+3.568)}$, although it may be between $e^{(0.819[\ln(\text{hardness})]+0.537)}$ and $e^{(0.819[\ln(\text{hardness})]+3.568)}$ for up to 96 consecutive hours. For example, at hardnesses of 50 and 250 mg/ℓ as $CaCO_3$, the maximum allowable concentrations of trivalent chromium are 873 and 3262 µg/ℓ (0.873 and 3.262 mg/ℓ), respectively (US EPA, 1983d; US EPA, 1984). Salt water: For the protection of saltwater aquatic life, the average concentration of dissolved hexavalent chromium should not exceed 0.054 mg/ℓ in any 30-day period; the concentration may be between 0.054 and 1.200 mg/ℓ for up to 96 hours. No saltwater criteria exist for trivalent chromium, but levels of 10.30 mg/ℓ were lethal to the eastern oyster (US EPA, 1983d; US EPA, 1984).	Chromium salts can impart color to water at concentrations above 1.5 mg/ℓ (McKee and Wolf, 1963).

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COLIFORM BACTERIA (Fecal and total)	Since the time when the relationship between fecally-associated microbes and disease transmission was established in the late 1800's, use of biological indicator organisms in defining water quality has become a common practice. They are used to identify environmental changes, to quantify pollution levels, and to study, under controlled laboratory conditions, phenomena which could occur in the natural environment. Microbiological indicators have been used to determine a water's safety for drinking, swimming, and shellfish harvesting. Coliform bacteria are considered to be the primary indicators of fecal contamination, and as such are some of the most frequently applied indicators of water quality (US EPA, 1976).	Drinking water standards are based on total coliform bacteria and are usually regulated by the state. The National Academy of Science (1973) recommended a limit of 2000 coliforms/100 ml for raw water prior to treatment. Drinking water must be free of coliform organisms at the time of consumption. Normally this is accomplished via disinfection (chlorine, ozonation, etc.) as part of the water treatment process.	Though state standards vary, fecal coliform limitations for non-contact recreational waters generally range from a geometric mean of 100 to 1000 organisms per 100 ml, with not more than 10% of the samples exceeding twice the adopted standard (US EPA, 1979).	The EPA (1976) recommends that for contact recreation waters, based on a minimum of five samples taken over a 30-day period, the fecal coliform bacterial level should not exceed a log mean of 200 organisms per 100 ml, nor should more than 10 percent of the total samples taken during any 30-day period exceed 400 organisms per 100 ml.

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COLOR	The degradation process in a natural environment results in the color of the water. The most common cause of color in water is complex organic compounds originating from the decomposition of natural organic matter. However, colloidal forms of iron and/or manganese can also create color in water. The color itself is a result of light scattering and fluorescence and not light energy absorption. Color intensity and the particle size of color-causing colloids are both affected by pH. Color is measured by the platinum-cobalt method and is reported in color "units" (US EPA, 1976).	For domestic water supplies it is recommended that the color of acceptable water should not exceed 15 units on the platinum-cobalt scale (CFR, 1983b). Water can be treated using standard coagulation and filtration processes. These processes will reduce the color below 15 color units if the original water source does not exceed 75 color units (US EPA, 1979).	Light penetration is reduced by the presence of color, so that photosynthesis by phytoplankton is also reduced. As a result, the zone for growth of vascular plants is likewise restricted. The depth of the compensation point for photosynthetic activity should not be reduced by increasing the color (combined with turbidity) by more than 10 percent from the seasonally established norm for aquatic life (US EPA, 1976).	Reid (1976) is suggested as a reference for an excellent discussion of color.

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COPPER	Copper occurs as a pure metal and in various mineral forms such as cuprite and malachite. In addition to mining activities, heat exchangers and other industrial uses may release copper into the environment. Copper has also received widespread usage in high concentrations as an herbicide to control algal blooms and some usage agriculturally as a fungicide. In lakes where it has been used to control algal blooms, it is not uncommon to find major changes in the overall food chain.	A recommended maximum limit of 1.0 mg/ℓ of copper is recommended for drinking water due to the possibility of undesirable taste (US EPA, 1976; CFR, 1983b).	A water's alkalinity directly affects the toxicity of copper to aquatic life, which generally is augmented at lower alkalinities. As most adult fish are able to tolerate relatively high concentrations of copper for short periods of time, the critical effect of copper is its greater toxicity to younger fish (US EPA, 1976). Fresh water: For the protection of freshwater aquatic life, the average concentration of active copper should not exceed, over any 30-day period, the numerical value given by $e^{(0.905[\ln(\text{hardness})]-1.785)}$; the concentration (in µg/ℓ) may be between $e^{(0.905[\ln(\text{hardness})]-1.785)}$ and $e^{(0.905[\ln(\text{hardness})]-1.413)}$ for up to 96 hours. For example, at hardnesses of 50 and 250 mg/ℓ as $CaCO_3$, the maximum allowable concentrations of copper are 5.8 and 24.8 µg/ℓ (0.0058 and 0.0248 mg/ℓ), respectively (US EPA, 1983e; US EPA, 1984). Salt water: For the protection of saltwater aquatic life, the average concentration of active copper should not exceed 0.002 mg/ℓ for any 30-day period; the concentration may be between 0.002 and 0.0032 mg/ℓ for up to 96 hours (US EPA, 1983e; US EPA, 1984).	The American Fisheries Society task force (AFS, 1979) suggests that a criterion in the range of .005 mg/ℓ to .015 mg/ℓ would protect entire ecosystems.

CONSTITUENT	BACKGROUND	DRINKING WATER STANDARD	AQUATIC LIFE REQUIREMENTS/RESTRICTIONS	COMMENTS
CYANIDE	Cyanide and its compounds are prevalent wherever life and industry are found. Simple hydrocyanic acid (HCN) and alkali metal salts such as potassium cyanide (KCN) and sodium cyanide (NaCN) are common forms and sources of cyanide. The most toxic form of cyanide in water is probably hydrocyanic acid. Under natural conditions, the ratio of hydrocyanic acid to total cyanide fluctuates frequently due to changes in pH caused by acid wastewater discharges or by photosynthetic and respiration cycles of aquatic plant life (US EPA, 1976).	The WHO International Drinking Water Standards set a tentative upper limit of 0.05 mg/ℓ for cyanides as CN^- (WHO, 1971).	The toxicity of cyanides to fish is dependent on the pH, temperature, dissolved oxygen, and concentration of minerals. An increase in temperature increases the toxicity of cyanide, and an increase of 10°C will produce a two- to threefold increase in the rate of lethal action of cyanide (US EPA, 1976). <u>Fresh water</u>: For the protection of freshwater aquatic life, the average concentration of free cyanide (the sum of cyanide present as HCN and CN^-, expressed as CN) should not exceed 0.0042 mg/ℓ for any 30-day period; the concentration may be between 0.0042 and 0.022 mg/ℓ for up to 96 consecutive hours (US EPA, 1984). <u>Salt water</u>: For the protection of saltwater aquatic life, the average concentration of free cyanide should not exceed 0.00057 mg/ℓ for any 30-day period; the concentration may be between 0.00057 and 0.001 mg/ℓ for up to 96 consecutive hours (US EPA, 1984).	Cyanide seems not to have any direct effect on recreational uses of water other than its effect on aquatic life. No information is available on adverse effects of cyanide in agricultural practices (US EPA, 1976).

CONSTITUENT	BACKGROUND	DRINKING WATER STANDARD	AQUATIC LIFE REQUIREMENTS/RESTRICTIONS	COMMENTS
DISSOLVED OXYGEN (D.O.)	Dissolved oxygen is an important constituent in the overall determination of the quality of water. It is generally considered to be a factor in the protection of aesthetic qualities of water and in the maintenance of aquatic life and fish diversity (US EPA, 1976). The ability of water to hold oxygen decreases with increases in temperature and/or salinity. In a stream system, the dissolved oxygen concentration will depend on such conditions as organic waste loading (biochemical oxygen demand), the rate of atmospheric reaeration, photosynthesis, and respiration. Insufficient dissolved oxygen can lead to unsuitable conditions for aquatic life, and its absence can result in the unpleasant odors associated with anaerobic decomposition. Furthermore, the presence of toxic substances such as cyanides and some metals can exacerbate the lethal effects of low concentrations of dissolved oxygen (McKee and Wolf, 1963).	Treated drinking water supplies are frequently aerated prior to distribution for better taste and odor consistency. Since dissolved oxygen concentration in drinking water is not health related, there are no established criteria.	The minimum dissolved oxygen concentration required to support fish varies because the oxygen requirements of fish vary with a number of factors, including the species and age of the fish, prior acclimatization, temperature, and concentration of other substances in the water. In average stream conditions, a concentration of 3.0 mg/ℓ of dissolved oxygen or less should be regarded as hazardous or lethal to fish life. In order to maintain a varied and healthy fish population, the dissolved oxygen concentration should remain at 5.0 mg/ℓ or higher. For more sensitive species such as trout, the lower limit in soft water has been set at 6.0 mg/ℓ (McKee and Wolf, 1963).	It is essential that consideration of natural regimes of dissolved oxygen be included in applying criteria to specific water bodies. A management objective for NPS areas is to ensure the nondegradation of the natural regime.

CONSTITUENT	BACKGROUND	DRINKING WATER STANDARD	AQUATIC LIFE REQUIREMENTS/RESTRICTIONS	COMMENTS
DISSOLVED SOLIDS	The dissolved solids in natural waters primarily include carbonates, bicarbonates, chlorides, sulfates, and phosphates, and may also include nitrates of calcium and potassium. All dissolved salts change the physical and chemical nature of the water and will exert osmotic pressure. Some of the salts have toxic or other physiological effects as well. McKee and Wolf (1963) point out the possibility of synergistic or antagonistic interactions between mixed salts in solution, which may render the effects of salts in combination different from those of salts separately.	The drinking water criterion for domestic water supplies should not exceed 500 mg/ℓ dissolved solids (CFR, 1983b).	Due to the antagonistic effect of hardness on metals, dissolved solids can alter the toxicity of organic compounds and heavy metals to aquatic life. For freshwater fish the tolerance levels for different concentrations of dissolved solids are not definitely known but have been found to range from 5000 to 10,000 mg/ℓ, according to species and prior acclimatization. Some species of fish are adapted to living in more saline waters; however, a few species of freshwater fish have existed in natural waters with salt concentrations of 15,000 to 20,000 mg/ℓ. Fish have the capacity to slowly adapt to higher salinities than those to which they are accustomed, but the sudden introduction of high salinities, such as from oil field brines, can be deadly. One study reports that 95% of inland waters in the U.S. supporting varied fish fauna have dissolved solid concentrations below 400 mg/ℓ (McKee and Wolf, 1963).	The concentrations of dissolved solids up to the following limits should not adversely affect these uses: irrigation...700 mg/ℓ; stock watering...2500 mg/ℓ (McKee and Wolf, 1963). Highly mineralized waters are also unsuitable for many industrial applications (APHA, 1980).

CONSTITUENT	BACKGROUND	DRINKING WATER STANDARD	AQUATIC LIFE REQUIREMENTS/RESTRICTIONS	COMMENTS
FLUORIDES	Fluoride is the most reactive nonmetal, and as such is never found free in nature but is a constituent of fluorite or fluorospar in sedimentary rocks and cryolite in igneous rocks. In natural surface waters, fluorides in high concentrations are uncommon. However, they may occur in detrimental concentrations in ground waters. Among other things, fluorides are employed in chemical industries, in water treatment, and in disinfecting brewery apparatus, and they are effective insecticides. In sufficient amounts fluorides are toxic to humans; doses of 250 to 450 mg can cause severe harm, and 4.0 g can be fatal (McKee and Wolf, 1963).	A fluoride concentration of approximately 1 mg/ℓ in drinking water effectively reduces dental cavities without harmful effects on health (APHA, 1980). For domestic water supplies, research in McKee and Wolf (1963) suggests that fluoride concentrations between 0.7 and 1.2 mg/ℓ will not interfere with beneficial uses, although mild mottling of teeth may occur at concentrations between 0.8 and 1.5 mg/ℓ.	Fluoride ions appear to be directly toxic to aquatic life; in addition, there seems to be a relationship between fluorides in water and the condition of the teeth of fish. The concentration of fluorides should not exceed 1.5 mg/ℓ in waters inhabited by aquatic life (McKee and Wolf, 1963).	The maximum recommended concentrations of fluorides are as follows for these uses: irrigation water......10 mg/ℓ; stock watering.........1.0 mg/ℓ (McKee and Wolf, 1963).

CONSTITUENT	BACKGROUND	DRINKING WATER STANDARD	AQUATIC LIFE REQUIREMENTS/RESTRICTIONS	COMMENTS
HARDNESS	Water hardness is a measure of bivalent metallic ions dissolved in water (AFS, 1979). In fresh waters these ions are primarily calcium and magnesium, although other metals, such as iron and manganese, may be present in appreciable concentrations. Hardness is commonly expressed as an equivalent concentration of calcium carbonate ($CaCO_3$). In fresh water, hardness is distinguished as carbonate and noncarbonate fractions. The carbonate hardness fraction is equivalent to the sum of the bicarbonate and carbonate components in alkalinity. If total hardness exceeds alkalinity, the excess is reported as "noncarbonate" hardness (AFS, 1979). Hardness in nature usually results from rainwater percolating through carbonate rocks. Otherwise, the inorganic chemical industry and discharges from both operating and abandoned mines contribute to the hardness of nearby waters (US EPA, 1976).	The EPA guidelines (1976) note that because hardness concentrations in water have not been related to health problems, and due to treatment processes used to reduce hardness, a criterion for public water supplies is not practical or necessary.	Water hardness may limit the growth of fish. On the other hand, soft water solutions increase the sensitivity of fish to toxic metals, whereas in hard waters toxic metals may be less dangerous (McKee and Wolf, 1963). The effects of hardness on freshwater fish and other aquatic life appear to be related to the ions causing the hardness rather than the hardness itself (US EPA, 1976).	In general, hardness helps reduce metal toxicity effects (US EPA, 1976).

CONSTITUENT	BACKGROUND	DRINKING WATER STANDARD	AQUATIC LIFE REQUIREMENTS/RESTRICTIONS	COMMENTS
IRON	By weight, iron is the fourth most abundant element in the earth's crust. It is an important constituent of many soils, especially clay soils, and may be present in water in varying quantities, depending upon the geology of the area and the chemical makeup of the water. Iron is an essential trace element required by plants and animals alike, and in all vertebrates and some invertebrates it is a critical transport mechanism in the blood. The forms of major interest in the aquatic environment are the ferrous (Fe^{++}) and ferric (Fe^{+++}) forms. The ferrous form, usually resulting from the pumping of ground waters or the draining of mines, can persist in waters devoid of dissolved oxygen. The ferric form, on the other hand, is for all practical purposes insoluble (US EPA, 1976).	A criterion of 0.3 mg/ℓ for iron is the recommended limit for domestic water supplies, primarily because of the taste threshold of iron in water (US EPA, 1976; CFR, 1983b).	The iron concentration in fresh water should not exceed 1.0 mg/ℓ to be protective of aquatic life. Certain conditions (e.g., alkalinity, pH, hardness, temperature) in ambient natural waters can change the valence state and solubility of iron, and thus affect its toxicity. Although the effects of iron on marine life have not been sufficiently investigated for establishing a criterion, there is concern that iron flocs, which are precipitated from dissolved iron in alkaline seawaters, can settle and adversely affect shellfish populations (US EPA, 1976).	At exceptionally high concentrations, iron has been reported to be toxic to livestock (US EPA, 1976). Elevated iron concentrations in water often result from acid mine drainage. An imported source of iron pollution may result from the lowering of redox potential due to the input of organic matter or other reducing substances in a particular region (AFS, 1979).

CONSTITUENT	BACKGROUND	DRINKING WATER STANDARD	AQUATIC LIFE REQUIREMENTS/RESTRICTIONS	COMMENTS
LEAD	Although primarily found as lead sulfite (galena), lead occurs in several common forms in nature, including lead carbonate, lead sulfate, and lead chlorophosphate. As with other heavy metals, the toxicity of lead is affected by such conditions as pH, hardness, the organic materials present, and the presence of other metals. The solubility of most lead salts is low, ranging from 0.50 mg/ℓ in soft water to 0.0030 mg/ℓ in hard water. Precipitation, lead dust fallout, erosion and leaching of soil, municipal and industrial waste discharges, and runoff from streets and other surfaces serve as sources of lead in natural waters. It is estimated that as much as 5000 tons of lead per year nationwide may be added to the aquatic environment as a result of urban runoff (US EPA, 1976).	Because lead is a cumulative poison, lead concentrations in drinking water should be kept to a minimum; a criterion of 0.050 mg/ℓ is attainable and protective (US EPA, 1976; CFR, 1983a).	<u>Fresh water</u>: For the protection of freshwater aquatic life, the average concentration (in µg/ℓ) of active lead (operationally defined as the lead that passes through a 0.45 µm membrane filter after the sample is acidified to pH 4 with nitric acid) should not exceed the numerical value given by $e^{(1.34[\ln(\text{hardness})]-5.245)}$ in any 30 consecutive days; the concentration may be between $e^{(1.34[\ln(\text{hardness})]-5.245)}$ and $e^{(1.34[\ln(\text{hardness})]-2.014)}$ for up to 96 consecutive hours but should never exceed the latter value. For example, at hardnesses of 50 and 250 mg/ℓ as $CaCO_3$, the maximum allowable concentrations of active lead are 25.2 and 218.0 µg/ℓ (0.0252 and 0.218 mg/ℓ), respectively (US EPA, 1984). <u>Salt water</u>: To protect saltwater aquatic life, the average concentration of active lead should not exceed 0.0086 mg/ℓ in any 30 consecutive days; the concentration may be between 0.0086 and 0.220 mg/ℓ for up to 96 consecutive hours (US EPA, 1984).	

CONSTITUENT	BACKGROUND	DRINKING WATER STANDARD	AQUATIC LIFE REQUIREMENTS/RESTRICTIONS	COMMENTS
MAGNESIUM	Magnesium is one of the most common elements found in the earth's crust and occurs in many ores and minerals. It is found as a constituent of the ferromagnesian minerals of igneous rock as well as in metamorphic and sedimentary rock. Due to its chemically active nature, it forms highly soluble salts and is not found in the elemental form. Magnesium is used in making light alloys and in other metallurgical processes. Because magnesium ions occur in significant concentrations in natural waters, they are an important factor in water quality and along with calcium form the major portion of the hardness reaction. Magnesium is considered relatively nontoxic to humans since it becomes unpalatable before dangerous concentrations are reached (McKee and Wolf, 1963; Hem, 1970).	In 1946, the USPHS standards recommended a limit of 125 mg/ℓ for drinking water, but the 1962 standards set no limit. The 1958 WHO International Standards set a "permissible limit" of 50 mg/ℓ and an "excessive limit" of 150 mg/ℓ, but no maximum allowable limit is given. A limit of 125 mg/ℓ is recommended in the 1961 WHO European Standards, unless sulfates exceed 250 mg/ℓ; in that case, the magnesium is limited to 30 mg/ℓ (McKee and Wolf, 1963).	At concentrations between 100 and 400 mg/ℓ, magnesium chloride and nitrate can be toxic to fish in distilled water or tap water. However, at concentrations between 1000 and 3000 mg/ℓ, magnesium chloride, nitrate, and sulfate have been tolerated for 2-11 days. A concentration of 300 mg/ℓ of magnesium has been reported to be toxic to the stickleback. Magnesium salts in water can also affect the toxicity of copper to fish. In short, the effects of different magnesium salts on different species can vary considerably (McKee and Wolf, 1963). Determining limits of magnesium salt concentrations in a body of water will depend on the specific salts present and the biota living there.	The taste threshold for magnesium has been reported to be 100 mg/ℓ, but for the average individual, taste is noticeable at about 500 mg/ℓ (McKee and Wolf, 1963).

CONSTITUENT	BACKGROUND	DRINKING WATER STANDARD	AQUATIC LIFE REQUIREMENTS/RESTRICTIONS	COMMENTS
MANGANESE	Manganese occurs in nature as a component of various salts and minerals and is often found in association with iron compounds. It occurs in both bivalent and trivalent states and is highly soluble in its chloride, nitrate, and sulfate forms. The oxides of manganese are only slightly soluble, so that in natural surface waters, manganic or manganous ions are rarely found in concentrations greater than 1.0 mg/ℓ (McKee and Wolf, 1963). Natural changes in redox potential, dissolved oxygen, pH, and seasonal leaf fall may cause pronounced changes in dissolved manganese concentrations in streams (AFS, 1979). Industrial and mining wastes can also increase manganese above low natural levels in receiving waters.	A concentration less than 0.05 mg/ℓ is recommended for domestic water supplies (CFR, 1983b).	The US EPA (1976) established a criterion of 0.1 mg/ℓ manganese for the protection of consumers of marine molluscs. The American Fisheries Society task force (AFS, 1979) felt that the lack of knowledge on chronic toxicity made further research necessary before a realistic criterion could be established. The National Academy of Sciences (1973) suggests that manganese levels above 0.1 mg/ℓ constitute a hazard to marine life.	Metal mining wastes discharged into the environment have contained as much as 8.2 mg/ℓ manganese (Clarke, 1974).

CONSTITUENT	BACKGROUND	DRINKING WATER STANDARD	AQUATIC LIFE REQUIREMENTS/RESTRICTIONS	COMMENTS
MERCURY	A highly toxic metal which accumulates in living systems, mercury can occur in nature in several forms, including its elemental form and various dissolved organic and inorganic species. Because certain microorganisms are known to convert the soluble forms into highly toxic methyl or dimethyl mercury, any form of mercury must be considered potentially hazardous to the environment. Human poisoning by mercury can be either acute or chronic; a fatal dose of mercuric salts ranges from 20 mg to 3.0 g. Mercurous salts are less soluble, and therefore less toxic, than mercuric salts. Alkyl compounds, the derivatives of mercury most toxic to humans, produce illness or death from the ingestion of amounts in milligrams (US EPA, 1976).	For domestic water supplies, it is recommended that the mercury concentration not exceed 0.002 mg/ℓ (CFR, 1983a). The World Health Organization's International Standards for Drinking Water recommends a maximum limit of 0.001 mg/ℓ (WHO, 1971).	Fresh water: For the protection of freshwater aquatic life and its uses, the average concentration of active mercury (operationally defined as the mercury that passes through a 0.45 µm membrane filter after the sample is acidified to pH 4 with nitric acid) should not exceed 0.0002 mg/ℓ, nor should the maximum exceed 0.0011 mg/ℓ in any 30 consecutive days; the concentration may be between 0.0002 and 0.0011 mg/ℓ for up to 96 consecutive hours. Because these values are based on tests on bivalent organic mercury, they will be too high if a substantial portion of the active mercury is methylmercury or if bioaccumulation is greater in a field situation than in laboratory tests (US EPA, 1984). Salt water: For the protection of saltwater aquatic life and its uses, the average concentration of active mercury should not exceed 0.0001 mg/ℓ, nor should the maximum exceed 0.0019 mg/ℓ in any 30 consecutive days; the concentration may be between 0.0001 and 0.0019 mg/ℓ for up to 96 consecutive hours. Here again, these values are based on bivalent organic mercury and will be too high if a substantial portion of the active mercury is methylmercury (US EPA, 1984).	The levels of mercury in livestock consumed by humans should not exceed 0.5 mg/kg. The established guideline for mercury in edible fish is 0.5 mg/kg (US EPA, 1976).

CONSTITUENT	BACKGROUND	DRINKING WATER STANDARD	AQUATIC LIFE REQUIREMENTS/RESTRICTIONS	COMMENTS
NICKEL	Nickel is a metal which seldom occurs as a pure element, but its compounds are common in ores and minerals. The soluble nickel salts can leach from nickel-bearing ores or be discharged into natural waters from metal-plating works (US EPA, 1976). Nickel is *considered nontoxic to humans*, although nickel ions can be detrimental to beneficial uses of water (McKee and Wolf, 1963).	There is no established drinking water criterion for nickel (US EPA, 1976).	The EPA (1976) reports that, in bioassay tests designed to determine chronic effects on aquatic life, it has been demonstrated that nickel concentrations of 0.380 mg/ℓ and lower in hard water did not adversely affect survival, growth, or reproduction of the fathead minnow. However, reproduction is *hindered at concentrations of 0.730* mg/ℓ or greater in the fathead minnow and at concentrations as low as 0.095 mg/ℓ in a *Daphnia* species (US EPA, 1976). The American Fisheries Society task force (AFS, 1979) states that a suggested criterion of 0.1 mg/ℓ is not adequate for protecting freshwater organisms. They further maintain that sufficient data are not available for determining water quality requirements for estuarine and marine life.	At concentrations as low as 0.50 mg/ℓ, nickel in water can be toxic to plant life (US EPA, 1976).

CONSTITUENT	BACKGROUND	DRINKING WATER STANDARD	AQUATIC LIFE REQUIREMENTS/RESTRICTIONS	COMMENTS
NITRATES (NO_3^-) and NITRITES (NO_2^-)	Nitrogen occurs in freshwater systems in several forms, including dissolved molecular nitrogen, ammonia, nitrate, nitrite, and numerous organic forms. Sources of nitrogen include: atmospheric inputs (precipitation and fallout); biological fixation; inputs by ground water; and such man-made influences as the effluent from sewage treatment plants, or runoff from agricultural and residential areas where nitrogen compounds are commonly applied as fertilizers. Since nitrogen compounds are important macronutrients in aquatic systems, they are important to monitor in system productivity and eutrophication assessment.	The EPA (1976) reports that, because of the potential risk of methemoglobinemia in bottle-fed infants, and in view of an absence of substantiated physiological effects at nitrate concentrations below 10 mg/ℓ, 10 mg/ℓ (as N) is the accepted criterion for nitrates in domestic water supplies. Water with nitrite nitrogen concentrations greater than 1.0 mg/ℓ should not be used for infant feeding (US EPA, 1976; CFR, 1983a).	Nitrate and nitrite nitrogens are important nutrients which influence the overall trophic state of the aquatic system. High nitrate concentrations in wastewater effluents or from agricultural runoff can affect primary productivity and community structure. Most states have criteria for nitrate, nitrite, and other nutrients which are dependent upon the degree of protection being afforded the water. Most NPS waters are accorded the highest degree of protection. An example is Everglades National Park, which has a maximum nitrate standard of 0.7 mg/ℓ and nitrite standard of 0.04 mg/ℓ (Rosendahl and Rose, 1979).	Waters with significant nitrate and nitrite concentrations are probably heavily polluted and possibly bacteriologically unacceptable (US EPA, 1976).

CONSTITUENT	BACKGROUND	DRINKING WATER STANDARD	AQUATIC LIFE REQUIREMENTS/RESTRICTIONS	COMMENTS
pH	The unit "pH" is used to designate the logarithm (base 10) of the reciprocal of the hydrogen ion concentration, expressed by the equation $pH = -\log_{10}[H^+]$ (McKee and Wolf, 1963). Thus, pH is a measure of hydrogen ion activity in a water sample. As it can directly or indirectly affect the concentrations or activity of other constituents present, pH is an important description of the chemical and biological systems of natural waters. Changes in pH affect the degree of dissociation of weak acids or bases, which in turn affects the toxicity of many compounds. For example, hydrogen cyanide toxicity to fish increases with lowered pH; rapid increases in pH increase NH_3 concentrations; and the solubilities of metal compounds are affected by pH. The pH of a water does not indicate its "buffering capacity," which is controlled by the amounts of alkalinity and acidity present (McKee and Wolf, 1963; US EPA, 1976).	Because pH can be adjusted prior to and during water treatment, a rather wide range is acceptable for water serving as a public water supply. Treated drinking water (with a few exceptions) should have a pH of between 6.5 and 8.5 (CFR, 1983b).	The permissible range of pH for fish depends upon many other factors such as temperature, dissolved oxygen, and the content of various anions and cations. A pH range of 6.5-9.0, with no change greater than 0.5 unit outside the natural seasonal maximum or minimum, is protective of freshwater aquatic life and is considered harmless to fish (US EPA, 1976; AFS, 1979). Because of the large concentrations of salts and the natural buffering system present in seawater, the naturally occurring variability of pH is less than in fresh water. Normal pH values in marine waters are 8.0 to 8.2 at the surface and decrease to 7.7 or 7.8 with increasing depth. The EPA (1976) states that, in open ocean waters where the depth is substantially greater than that of the euphotic zone, "the pH should not be changed more than 0.2 units from the naturally occurring variation or in any case outside the range of 6.5 to 8.5." It is pointed out, however, that due to photosynthesis, large diurnal pH changes can occur as a natural condition in shallow, biologically active waters in tropical and subtropical zones. Here, the pH can vary from 9.5 during the day to 7.3 just before dawn (US EPA, 1976).	To avoid undesirable effects in irrigation waters, the pH should not fall outside a range of 4.5 to 9.0 (US EPA, 1976).

CONSTITUENT	BACKGROUND	DRINKING WATER STANDARD	AQUATIC LIFE REQUIREMENTS/RESTRICTIONS	COMMENTS
PHOSPHORUS (Soluble reactive phosphate and total phosphorus)	Phosphorus in water may occur in several forms, including soluble reactive phosphate (SRP) and total phosphorus. Phosphates in wastes are the primary source of excess amounts of nutrients in water. Artificially nutrient-enriched waters quite often are biologically altered, creating problems with algal blooms, stimulated growth of aquatic weeds, and the replacement of desirable fish species by less desirable ones. Lake Erie is a classic example of this problem.	No drinking water criterion for phosphorus has been established.	Standards for phosphorus are usually established according to the degree of protection a state wishes to afford a particular water. The State of California has established a mean annual concentration of soluble phosphorus for Lake Tahoe (a very clean lake) at 0.007 mg/ℓ, while mean annual concentrations for soluble phosphorus in other state waters in California are as high as 0.100 mg/ℓ (NAS, 1973). The maximum allowable mean annual concentration for soluble phosphorus in the delivery water to Everglades National Park is 0.020 mg/ℓ (Rosendahl and Rose, 1979).	It is appropriate to adopt a phosphorus standard for both soluble reactive phosphate and total phosphorus in waters of critical concern. Excellent discussions of phosphorus chemistry and its ecological impacts can be found in Wetzel (1983) and Strickland and Parsons (1972).

CONSTITUENT	BACKGROUND	DRINKING WATER STANDARD	AQUATIC LIFE REQUIREMENTS/RESTRICTIONS	COMMENTS
POTASSIUM	As one of the more common elements, potassium occurs in many minerals. Because it is one of the most active metals and readily reacts with oxygen and water, it is found only in the ionized or molecular form in nature. Potassium and sodium share a number of the same properties, so that potassium salts can be substituted for sodium salts in many industrial applications; however, for some uses, such as fertilizers, potassium is indispensable. Due to the high solubility of common salts of potassium, even the carbonate and the hydroxide, evaporation is the only natural process by which potassium is readily separated from water (McKee and Wolf, 1963).	A concentration of 1000 to 2000 mg/ℓ is regarded as the extreme limit of potassium permissible in drinking water. The taste threshold for potassium is 340 mg/ℓ from potassium chloride and 680 mg/ℓ from potassium acetate (McKee and Wolf, 1963).	The toxicity of potassium to fish is reduced by calcium and to a lesser extent by sodium. Potassium is more toxic to fish and shellfish than calcium, magnesium, or sodium. Potassium in chloride and nitrate forms has been found by several investigators to be toxic to fish in soft or distilled waters at concentrations of 50-200 mg/ℓ. The threshold concentration of potassium for fish in different kinds of water is about 400 mg/ℓ when potassium chloride, nitrate, or sulfate is used (McKee and Wolf, 1963).	

CONSTITUENT	BACKGROUND	DRINKING WATER STANDARD	AQUATIC LIFE REQUIREMENTS/RESTRICTIONS	COMMENTS
SELENIUM	In trace amounts, selenium is an essential, beneficial element in that it is a metabolic requirement for animals; but it becomes toxic if it is ingested in amounts ranging from about 0.1 to 10 mg/kg of food. In humans, the symptoms of selenium poisoning are similar to those of arsenic poisoning. Selenium occurs in the soil as basic ferric selenite, calcium selenate, and as elemental selenium, which must be oxidized to the selenite or selenate form before it has appreciable solubility in water (US EPA, 1976).	In view of both dietary and health concerns, a concentration of no more than 0.01 mg/ℓ is recommended for domestic water supplies (CFR, 1983a).	Selenium in water is toxic to a few species at concentrations of 2.5 mg/ℓ or less. Marine and freshwater aquatic life should not be exposed to water containing more than 0.01 of the 96 consecutive-hour LC_{50} as determined through bioassay using a sensitive resident species (US EPA, 1976).	

CONSTITUENT	BACKGROUND	DRINKING WATER STANDARD	AQUATIC LIFE REQUIREMENTS/RESTRICTIONS	COMMENTS
SILVER	Silver occurs both as a pure element and as a component of various ores. Biologically it is neither essential nor beneficial, and it is toxic to aquatic life. In humans, ingestion of silver or silver salts can cause discoloration in skin, eyes, and mucous membranes. Though there is no apparent systemic reaction, a concentration limit for drinking water was established due to evidence that silver, once absorbed, is held indefinitely in body tissues, apparently without loss through normal means of elimination or reduction. Because silver is strongly bactericidal, it has been used as a water disinfectant. Dosages of 1×10^{-6} to 0.500 mg/ℓ of silver have been used to sterilize water without apparent risk to human health (US EPA, 1976).	A concentration limit of 0.050 mg/ℓ is recommended for domestic water supplies (CFR, 1983a).	In differing concentrations of silver nitrate, average survival times of the stickleback were: 1 week at 0.004 mg/ℓ; 4 days at 0.01 mg/ℓ; and only 1 day at 0.10 mg/ℓ. There is a wide variation in the toxicity of silver compounds to aquatic life. Further, their toxicity is affected by the degrees of dissociation particular to those compounds. Since the movement and chemical stability of silver compounds in the aquatic environment is not well known, a silver criterion must be based on the total silver concentration. This criterion should be established at 0.01 of the 96 consecutive-hour LC_{50} as determined through bioassay using a sensitive resident species (US EPA, 1976).	A task force convened by the American Fisheries Society (AFS, 1979) is critical of the criterion established by the US EPA (US EPA, 1976). They suggest alternate criteria for freshwater systems based upon water hardness. These are: Hardness (mg/ℓ as $CaCO_3$) — Silver conc. (mg/ℓ) 0-150 — 0.00010 150-300 — 0.00015 300-400 — 0.00020 >400 — 0.00025 (AFS, 1979).

CONSTITUENT	BACKGROUND	DRINKING WATER STANDARD	AQUATIC LIFE REQUIREMENTS/RESTRICTIONS	COMMENTS
SODIUM	A highly reactive metal, sodium does not occur in nature in its elemental form, but its compounds constitute 2.8 percent of the earth's crust. Sodium salts are extremely soluble in water; thus, any sodium that is leached from soil or discharged into streams with industrial waste will remain in solution. The passage of water through certain soils can remove some sodium by an ion-exchange phenomenon. Because sodium is the cation of numerous salts used industrially, its ions are among the most common in process wastes (McKee and Wolf, 1963).	Sodium in drinking water can be harmful to persons suffering from cardiac, renal, and circulatory diseases. Due to the association of sodium intake with hypertension, the American Heart Association suggests a maximum sodium concentration of 20 mg/ℓ in drinking water (NAS, 1980).	It has been reported that 500-1000 mg/ℓ of sodium was toxic to fish in distilled and soft waters when sodium chloride or nitrate was tested. Other data show variance in the effects of sodium on fish. It appears that the toxicity of sodium salts depends on the particular anion involved, e.g., the chromate is highly toxic and the sulfate is much less so. It is possible that moderate amounts of sodium in water will reduce the toxic effects of potassium and ammonium salts on fish (McKee and Wolf, 1963).	Since excess concentrations of sodium salts in drinking water have been shown to be harmful to a variety of animals, a threshold limit of 2000 mg/ℓ of sodium in water for livestock has been suggested (McKee and Wolf, 1963).

CONSTITUENT	BACKGROUND	DRINKING WATER STANDARD	AQUATIC LIFE REQUIREMENTS/RESTRICTIONS	COMMENTS
SPECIFIC CONDUCTANCE	Small quantities of mineral salts are usually contained in natural inland waters, but in waters polluted by brines and various chemical wastes, salt concentrations may rise to levels harmful to living organisms due to the increase in osmotic pressure. Salinity is often expressed as specific electrical conductance in studies of waters used for irrigation and fish production. Thus, the determination of conductivity is a measure of the total ionic concentration of water. Specific conductance is expressed as reciprocal ohms (mhos) at 25°C (McKee and Wolf, 1963). In many basically unpolluted streams, specific conductance is also an indicator of the total dissolved solids (TDS) content since TDS are composed primarily of ionic substances.	No criterion exists for specific conductance in drinking water.	Collectively, all substances in solution exert osmotic pressure on the organisms living in it, which in turn adapt to the condition imposed upon the water by its dissolved constituents. With excessive salts in solution, osmotic pressure becomes so high that water may be drawn from gills and other delicate external organs, resulting in cell damage or death of the organism. Good mixed fish fauna have not often been found in waters with a specific conductance greater than 2000 µmhos at 25°C. A specific conductance of 4000 µmhos at 25°C is the approximate upper limit of ionizable salts tolerated by fish in mixtures of sodium, magnesium, and calcium compounds. It has been reported that in U.S. waters supporting a good fish fauna, approximately 95 percent have a conductivity reading (at 25°C) of under 1100 µmhos (McKee and Wolf, 1963).	

CONSTITUENT	BACKGROUND	DRINKING WATER STANDARD	AQUATIC LIFE REQUIREMENTS/RESTRICTIONS	COMMENTS
SULFATES (SO_4)	The sulfate form of sulfur is found almost universally in natural waters in concentrations ranging from a few tenths up to several thousand mg/ℓ. H_2SO_4 occurs frequently in rainfall (acid rain), sometimes at concentrations greater than 10 mg/ℓ (NAS, 1977). Sulfates appear in natural waters as leachate from gypsum and other prevalent minerals, particularly in the western U.S. They can result from the oxidation of sulfides, sulfites, and thiosulfites. Many industries may also discharge wastes containing sulfates (McKee and Wolf, 1963), and human waste impacts add sulfates to water as well.	For domestic water supplies it is recommended that sulfate concentrations should not exceed 250 mg/ℓ. This limit appears to be based less on taste or physiological effects than on the laxative action toward new users (McKee and Wolf, 1963; NAS, 1977). The absolute level recommended for avoiding any adverse health effects is 500 mg/ℓ (NAS, 1982). The taste threshold for sulfate in water is about 300-400 mg/ℓ (NAS, 1977).	McKee and Wolf (1963) report that, of U.S. waters that support good game fish, 5 percent contain less than 11 mg/ℓ of sulfates, 50 percent less than 32 mg/ℓ, and 95 percent less than 90 mg/ℓ. Some research indicates that water containing less than 0.50 mg/ℓ of sulfate will not support growth of algae (McKee and Wolf, 1963).	It has been determined that the following concentrations of sulfate will not be detrimental for these uses: irrigation....200 mg/ℓ; stock watering...500 mg/ℓ (McKee and Wolf, 1963).

CONSTITUENT	BACKGROUND	DRINKING WATER STANDARD	AQUATIC LIFE REQUIREMENTS/RESTRICTIONS	COMMENTS
SUSPENDED SOLIDS	Most suspended solids in natural waters are composed of erosion silt, organic detritus, and plankton. However, human activity creates impacts which both alter and increase these constituents. Primary sources of such effects are the discharge of liquid wastes, erosion from deforested and cultivated areas, gravel washings and mine tailings, steel mill wastes, and dust that is blown into waterways (McKee and Wolf, 1963).	There is no specified limit for suspended solids in drinking water, although one researcher cited in McKee and Wolf (1963) suggests a maximum limit of 0.10 mg/ℓ for drinking water of ideal quality.	Apart from possible toxic effects attributable to substances leached out by water, suspended solids may kill fish and shellfish by causing abrasive injuries, clogging the gills and respiratory passages of various aquatic species, killing eggs, and destroying spawning beds. Further, and more indirectly, suspended solids can be harmful when they screen out light or trap bacteria and detritus on the bottom, resulting in oxygen depletion (McKee and Wolf, 1963).	

CONSTITUENT	BACKGROUND	DRINKING WATER STANDARD	AQUATIC LIFE REQUIREMENTS/RESTRICTIONS	COMMENTS
TURBIDITY	Turbidity is attributable to suspended and colloidal matter that can cloud water and diminish light penetration. Turbidity is defined as an expression of the optical property that causes light to be scattered and absorbed rather than transmitted in straight lines through the sample (APHA, 1980). The degree of turbidity is not equal to the concentration of suspended solids; rather it is an expression of just one effect of suspended solids upon a water's character. Turbidity is measured in units known as nephelometric turbidity units (NTU) or Jackson turbidity units (JTU) (APHA, 1980).	For domestic water supplies turbidity should not exceed 1.0 unit after treatment (CFR, 1983a).	Excessive turbidity caused by abiotic factors such as increased sediment lead, may affect fish by interfering with the penetration of light so that photosynthesis is diminished, which in turn decreases the primary productivity upon which the food chain depends. By the same token, the decreased light makes it difficult for fish to find food, although smaller fish may be protected from predators. In some ponds, turbidity lowers the bottom temperature which can result in lowered productivity. Turbidities as high as 200 units should be tolerable to fish. Waters with turbidities of 3000 units are considered dangerous to fish when maintained over a 10-day period (McKee and Wolf, 1963).	The capacity of water treatment processes to remove suspended matter to achieve acceptable final turbidities is a function of the composition of the material as well as the concentration. The desirability of water for swimming and other water sports increases as turbidity decreases (US EPA, 1976).

CONSTITUENT	BACKGROUND	DRINKING WATER STANDARD	AQUATIC LIFE REQUIREMENTS/RESTRICTIONS	COMMENTS
ZINC	Zinc usually occurs in nature as a sulfide, often in association with sulfides of other metals, especially lead, copper, cadmium, and iron. Most other zinc minerals represent only minor sources of zinc and are probably oxidation products of the sulfide. As a metal, zinc is most often used in galvanizing. Since zinc is oxidized preferentially when in contact with iron, it protects the metal it coats and retards corrosion. Industrial sources of zinc also include power plant condensor tubes and fly ash from coal-burning power plants (EPA, 1976; AFS, 1979).	For domestic water supplies the concentration of zinc should be below 5.0 mg/ℓ to protect against undesirable aesthetic effects (US EPA, 1976; CFR, 1983b).	The toxicity of zinc compounds to aquatic animals is significantly affected by several environmental factors, notably hardness, dissolved oxygen, and temperature. The EPA (1976) cites evidence that salts of alkaline earth metals are antagonistic to the action of zinc salts, and that salts of certain heavy metals are synergistic in soft water. An increase in temperature or a reduction in dissolved oxygen will increase the toxicity of zinc. In toxic concentrations, zinc compounds can have a variety of deleterious effects on both the morphology and physiology of fish. To protect freshwater aquatic life, 0.01 of the 96 consecutive-hour LC_{50} as determined through bioassay using a sensitive resident species is recommended (US EPA, 1976). The American Fisheries Society task force (AFS, 1979) recommend criteria for total zinc in fresh waters based on a sliding scale for hardness. These criteria are: Hardness (mg/ℓ as $CaCO_3$) — Zn (mg/ℓ total Zn) 0-150 — 0.05 150-300 — 0.10 300-400 — 0.30 >400 — 0.60 (AFS, 1979).	

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APPENDIX A

FEDERAL REGISTER, VOL. 49 No. 26
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REQUEST FOR COMMENTS: EPA PROPOSED WATER QUALITY CRITERIA FOR AMMONIA

(1) MAXIMUM ALLOWED CONCENTRATIONS FOR AMMONIA[1,2]

pH	0 C	5 C	10 C	15 C	20 C	25 C	30 C
Un-ionized Ammonia (mg/liter NH_3)							
6.50	0.008	0.013	0.019	0.019	0.019	0.019	0.019
6.75	0.014	0.021	0.031	0.031	0.031	0.031	0.031
7.00	0.021	0.032	0.048	0.048	0.048	0.048	0.048
7.25	0.030	0.046	0.069	0.069	0.069	0.069	0.069
7.50	0.040	0.061	0.091	0.091	0.091	0.091	0.091
7.75	0.049	0.074	0.110	0.110	0.110	0.110	0.110
8.00	0.056	0.084	0.125	0.125	0.125	0.125	0.125
8.25	0.061	0.091	0.135	0.135	0.135	0.135	0.135
8.50	0.065	0.096	0.141	0.141	0.141	0.141	0.141
8.75	0.068	0.100	0.145	0.145	0.145	0.145	0.145
9.00	0.071	0.104	0.147	0.147	0.147	0.147	0.147
Total Ammonia (mg/liter NH_3)							
6.50	31.9	31.9	31.9	21.8	15.0	10.5	7.41
6.75	29.5	29.5	29.5	20.1	13.9	9.69	6.86
7.00	25.7	25.7	25.7	17.6	12.1	8.48	6.00
7.25	20.8	20.8	20.8	14.2	9.84	6.89	4.88
7.50	15.5	15.5	15.5	10.6	7.34	5.15	3.66
7.75	10.6	10.6	10.6	7.29	5.06	3.56	2.55
8.00	6.84	6.84	6.84	4.71	3.28	2.33	1.68
8.25	4.22	4.22	4.22	2.92	2.05	1.47	1.08
8.50	2.54	2.54	2.54	1.78	1.27	0.93	0.70
8.75	1.53	1.53	1.53	1.09	0.80	0.60	0.47
9.00	0.94	0.94	0.94	0.69	0.52	0.41	0.33

(2) 30-DAY AVERAGE ALLOWED CONCENTRATIONS FOR AMMONIA[1,2]

pH	0 C	5 C	10 C	15 C	20 C	25 C	30 C
Un-ionized Ammonia (mg/liter NH_3)							
6.50	0.0018	0.0027	0.0040	0.0040	0.0040	0.0040	0.0040
6.75	0.0027	0.0041	0.0061	0.0061	0.0061	0.0061	0.0061
7.00	0.0042	0.0063	0.0094	0.0094	0.0094	0.0094	0.0094
7.25	0.0064	0.0096	0.0144	0.0144	0.0144	0.0144	0.0144
7.50	0.0098	0.0148	0.0220	0.0220	0.0220	0.0220	0.0220
7.75	0.0138	0.0208	0.0310	0.0310	0.0310	0.0310	0.0310
8.00	0.0139	0.0209	0.0310	0.0310	0.0310	0.0310	0.0310
8.25	0.0140	0.0210	0.0310	0.0310	0.0310	0.0310	0.0310
8.50	0.0142	0.0211	0.0310	0.0310	0.0310	0.0310	0.0310
8.75	0.0145	0.0214	0.0310	0.0310	0.0310	0.0310	0.0310
9.00	0.0150	0.0219	0.0310	0.0310	0.0310	0.0310	0.0310
Total Ammonia (mg/liter NH_3)							
6.50	6.82	6.82	6.83	4.65	3.21	2.24	1.58
6.75	5.87	5.87	5.89	4.01	2.76	1.93	1.37
7.00	5.06	5.06	5.07	3.45	2.38	1.67	1.18
7.25	4.36	4.36	4.37	2.98	2.06	1.44	1.02
7.50	3.77	3.77	3.78	2.58	1.78	1.25	0.89
7.75	2.99	2.99	3.00	2.05	1.42	1.00	0.72
8.00	1.70	1.70	1.70	1.17	0.81	0.58	0.42
8.25	0.97	0.97	0.97	0.67	0.47	0.34	0.25
8.50	0.56	0.56	0.56	0.39	0.28	0.20	0.15
8.75	0.33	0.33	0.33	0.23	0.17	0.13	0.10
9.00	0.20	0.20	0.20	0.14	0.11	0.09	0.07

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[1] To convert these values to mg/liter N, multiply by 0.822.

[2] Taken from: U.S. Environmental Protection Agency. 1984. Water quality criteria. Federal Register, Feb. 7, 1984, p. 4551. Proposed criteria for ammonia. (As proposed criteria, these figures may be modified by E.P.A. officials. However, changes should be slight, and the criteria in their present form can be used as a guideline.)

March 3, 1849

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environment and cultural value of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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