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Committee on Water Quality Criteria

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PREFACE

In 1971, at the request of the United States Environmental Protection Agency, the National Academy of Sciences-National Academy of Engineering undertook the revision of WATER QUALITY CRITERIA, the 1968 Report of the National Technical Advisory Committee (NTAC) to the Secretary of the Interior. The Academies appointed a Committee on Water Quality Criteria and six Panels, and the responsibility for overseeing their activities was assigned to the Environmental Studies Board, a joint body of the Academies.

The guidelines for the Academies' Committee were similar to those followed by the NTAC. The Federal Water Pollution Control Act of 1948, as amended by the Water Quality Act of 1965, authorized the states and the federal government to establish water quality standards for interstate and coastal waters. Paragraph 3, Section 10 of the 1965 Act reads as follows:

Standards of quality established pursuant to this subsection shall be such as to protect the public health or welfare, enhance the quality of water and serve the purposes of this Act. In establishing such standards the Secretary, the Hearing Board, or the appropriate state authority shall take into consideration their use and value for public water supplies, propagation of fish and wildlife, recreational purposes, and agricultural, industrial, and other legitimate uses.

Because of the vast amount of material that falls into the rubric of fish and wildlife, the Academies established separate Panels for freshwater and marine aquatic life and wildlife. Thus the Committee's six Panels were: (1) Recreation and Aesthetics, (2) Public Water Supplies, (3) Freshwater Aquatic Life and Wildlife, (4) Marine Aquatic Life and Wildlife, (5) Agricultural Uses of Water, and (6) Industrial Water Supplies.

The members of the Committee and its Panels were scientists and engineers expert and experienced in the various disciplines associated with the subject of water quality. The Panels also drew upon special advisors for specific water quality concerns, and in addition were aided by Environmental Protection Agency experts as liaison at the Panel meetings. This arrangement with EPA facilitated the Panels' access to EPA data on water quality. Thirty-nine meetings were held by the Committee and its Panels resulting in an interim report to the Academies and the Environmental Studies Board on December 1, 1971. This was widely circulated, and comments on it were solicited from many quarters. The commentaries were then considered for inclusion by the Committee and the appropriate Panels. This volume, submitted for publication in August 1972, within eighteen months of the inception of the task, is the final version of the Committee's report.

The 1972 Report is vastly more than a revision of the NTAC Report. To begin with, it is nearly four times longer. Many new subjects are discussed in detail, among them: the recreational impact of boating, levels of use, disease vectors, nuisance organisms, and aquatic vascular plants; viruses in relation to public water supplies; effects of total dissolved gases on aquatic life; guidelines for toxicological research on pesticides and uses of toxicants in fisheries management; disposal of solid wastes in the ocean; use of waste water for irrigation; and industrial water treatment processes

and resultant wastes. Many toxic or potentially toxic substances not considered by the NTAC are discussed including polychlorinated biphenyls, phthalate esters, nitrilotriacetate (NTA), numerous metals, and chlorine. The additional length also reflects the greater current awareness of how various characteristics of water affect its quality and use; and the expansion of the information base of the NTAC Report through new data from recent research activities and the greater capabilities of information processing, storage, and retrieval—especially evident in the three appendixes—have made their impact on the increase in size. In spite of these additions, however, the 1972 Report differs from the NTAC Report in that its six Sections do not provide summaries. The Committee agreed that an understanding of how the recommendations should be interpreted and used can be gained only by a thorough reading of the rationale and the evaluation of criteria preceding the recommendations.

Although each Section was prepared by its appropriate Panel, some discussions reflect the joint effort of two or more Panels. These combined discussions attempt to focus attention where desirable on such subjects as radioactivity, temperature, nutrient enrichment, and growths of nuisance organisms. However, the majority of topics were most effectively treated by individual Panel discussions, and the reader is encouraged to make use of the Tables of Contents and the index in assessing the full range of the Report's coverage of the many complex aspects of water quality.

Water quality science and its application have expanded rapidly, but much work remains to be done. In the course of this revision, the Committee and its Panels have identified many areas where further knowledge is needed, and these findings, now in preparation, will be published separately by the National Academy of Sciences-National Academy of Engineering as a report on research needs.

Social perspectives and policies for managing, enhancing, and preserving water resources are undergoing rapid and pervasive change. Because of the stipulations of the 1965 Water Quality Act, interstate water resources are currently categorized by use designation, and standards to protect those uses are developed from criteria. It is in this context that the Report of the NAS-NAE Committee, like that of the NTAC, was prepared. Concepts of managing water resources are subject to social, economic, and political decisions and will continue to evolve; but the Committee believes that the criteria and recommendations in this Report will be of value in the context of future as well as current approaches that might be taken to preserve and enhance the quality of the nation's water resources.

GERARD A. ROHLICH

Chairman, Committee on Water Quality Criteria

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in water at a temperature above 34–35 C (93–95 F), depends on his tolerance to the elevation of his internal temperature, and there is a real risk of injury with prolonged exposure (Table I-3). Water ranging in temperature from 26–30 C (78–86 F) is comfortable to most swimmers throughout prolonged periods of moderate physical exertion (Bullard and Rapp 1970).²⁰⁶ Although data are limited, natural surface waters do not often exceed skin temperature, but water at 32 C (90 F) is not unusual for rivers and estuaries (Public Works 1967).²²⁵

Recommendation

In recreational waters used for bathing and swimming, the thermal characteristics should not cause an appreciable increase or decrease in the deep body temperature of bathers and swimmers. One hour of continuous immersion in waters colder than 15 C (59 F) may cause the death of some swimmers and will be extremely stressful to all swimmers who are not garbed in underwater protective cold-clothing. Scientific evidence suggests that prolonged immersion in water warmer than 34–35 C (93–94 F) is hazardous. The degree of hazard varies with water temperature, immersion time, and metabolic rate of the swimmer.

pH Characteristics

Some chemicals affect the pH of water. Many saline, naturally alkaline, or acidic fresh waters may cause eye irritation because the pH of the water is unfavorable. Therefore, special requirements concerning the pH of recreational waters may be more restrictive than those established for public water supplies.

The lacrimal fluid of the human eye has a normal pH of approximately 7.4 and a high buffering capacity due primarily to the presence of complex organic buffering agents. As is true of many organic buffering agents, those of the lacrimal fluid are able to maintain the pH within a narrow range until their buffering capacity is exhausted. When the lacrimal fluid, through exhaustion of its buffering capacity, is unable to adjust the immediate contact layer of another fluid to a pH of 7.4, eye irritation results. A deviation of no more than 0.1 unit from the normal pH of the eye may result in discomfort, and appreciable deviation will cause severe pain (Mood 1968).²²¹

Ideally, the pH of swimming water should be approximately the same as that of the lacrimal fluid, i.e., 7.4. However, since the lacrimal fluid has a high buffering capacity, a range of pH values from 6.5 to 8.3 can be tolerated under average conditions. If the water is relatively free of dissolved solids and has a very low buffering capacity, pH values from 5.0 to 9.0 may be acceptable to most swimmers.

Conclusion

For most bathing and swimming waters, eye irritation is minimized and recreational enjoyment enhanced by maintaining the pH within the range of 6.5 and 8.3 except for those waters with a low buffer capacity where a range of pH between 5.0 and 9.0 may be tolerated.

Clarity Considerations

It is important that water at bathing and swimming areas be clear enough for users to estimate depth, to see subsurface hazards easily and clearly, and to detect the submerged bodies of swimmers or divers who may be in difficulty. Aside from the safety factor, clear water fosters enjoyment of the aquatic environment. The clearer the water, the more desirable the swimming area.

The natural turbidity of some bathing and swimming waters is often so high that visibility through the water is dangerously limited. If such areas are in conformance with all other requirements, they may be used for bathing and swimming, provided that subsurface hazards are removed and the depth of the water is clearly indicated by signs that are easily readable.

Conclusion

Safety and enhancement of aesthetic enjoyment is fostered when the clarity of the water in designated bathing and swimming areas allows the detection of subsurface hazards or submerged bodies. Where such clarity is not attainable, clearly readable depth indicators are desirable.

Chemical Considerations

It is impossible to enumerate in specific terms all the specialized requirements that pertain to the chemical quality of bathing and swimming waters. In general, these requirements may be quantified by analyzing the conditions stipulated by two kinds of human exposure, i.e., ingestion and contact. A bather involuntarily swallows only a small amount of water while swimming, although precise data on this are lacking.

Recommendation

Prolonged whole body immersion in the water is the principal activity that influences the required chemical characteristics of recreational waters for bathing and swimming.

The chemical characteristics of bathing and swimming waters should be such that water is nontoxic and nonirritating to the skin and the mucous membranes of the human body. (See also the Recommendations on p. 30.)

Section II PUBLIC WATER SUPPLIES

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pH

The pH of a raw water supply is significant because it affects water treatment processes and may contribute to corrosion of waterworks structures, distribution lines, and household plumbing fixtures. This corrosion can add such constituents as iron, copper, lead, zinc, and cadmium to the water. Most natural waters have pH values within the range of 5.0 to 9.0. Adjustment of pH within this range is relatively simple, and the variety of anticorrosion pro-

cedures currently in use make it unnecessary to recommend a more narrow range.

Recommendation

Because the defined treatment process can cope with natural waters within the pH range of 5.0 to 9.0 but becomes less economical as this range is extended, it is recommended that the pH of public water supply sources be within 5.0 to 9.0.

PHENOLIC COMPOUNDS

Phenolic compounds are defined (Standard Methods 1971)³⁰¹ as hydroxy derivatives of benzene and its condensed nuclei. Sources of phenolic compounds are industrial waste water discharges (Faust and Anderson 1968),²⁹² domestic sewage (Hunter 1971),²⁹⁶ fungicides and pesticides (Frear 1969),²⁹⁴ hydrolysis and chemical oxidation of organophosphorus pesticides (Gomaa and Faust 1971),²⁹⁵ hydrolysis and photochemical oxidation of carbamate pesticides (Aly and El-Dib 1971),²⁸⁹ microbial degradation of phenoxyalkyl acid herbicides (Menzie 1969),²⁹⁸ and naturally occurring substances (Christman and Ghassemi 1966).²⁹¹ Some phenolic compounds are sufficiently resistant to microbial degradation to be transported long distances by water.

Phenols affect water quality in many ways. Perhaps the greatest effect is noticed in municipal water systems where trace concentrations of phenolic compounds (usually less than 1.0 mg/l) affect the organoleptic properties of the drinking water. For example, p-cresol has a threshold order concentration of 0.055 mg/l, m-cresol 0.25 mg/l, and o-cresol 0.26 mg/l (Rosen et al. 1962).³⁰⁰ Phenol has a threshold odor concentration of 4.2 mg/l (Rosen et al. 1962),³⁰⁰ whereas the values for the chlorinated phenols are: 2-chlorophenol, 2.0 µg/l; and 4-chlorophenol, 250 µg/l (Burttschell et al. 1959).²⁹⁰ Generally, phenolic compounds

are not removed efficiently by the defined treatment process. Furthermore, municipal waters are postchlorinated to insure disinfection. If phenolic compounds are present in waters that are chlorinated for disinfection, chlorophenols may be formed. The kinetics of this reaction are such that chlorophenols may not appear until the water has been distributed from the treatment plant (Lee and Morris 1962).²⁹⁷ 2,4-dinitrophenol has been shown to inhibit oxidative phosphorylation at concentrations of 184 and 278 mg/l (Pinchot 1967).²⁹⁹

The development of criteria for phenolic compounds is hampered by the lack of sensitive standard analytical techniques for the detection of specific phenolic compounds. Some of the more odorous compounds are the para substituted halogenated phenols. These escape detection by the methodology suggested by Standard Methods (1971)³⁰¹ unless the analytical conditions are precisely set (Faust et al. 1971).²⁹³

Recommendation

Because the defined treatment process may severely increase the odor of many phenolic compounds, it is recommended that public water supply sources contain no more than 1 µg/l phenolic compounds.

Section III—FRESHWATER AQUATIC LIFE AND WILDLIFE

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ACIDITY, ALKALINITY, AND pH

NATURAL CONDITIONS AND SIGNIFICANCE

Acidity in natural waters is caused by carbon dioxide, mineral acids, weakly dissociated acids, and the salts of strong acids and weak bases. The alkalinity of a water is actually a measure of the capacity of the carbonate-bicarbonate system to buffer the water against change in pH. Technical information on alkalinity has recently been reviewed by Kemp (1971).¹⁶²

An index of the hydrogen ion activity is pH. Even though pH determinations are used as an indication of acidity or alkalinity or both, pH is not a measure of either. There is a relationship between pH, acidity, and alkalinity (Standard Methods 1971):¹⁶⁴ water with a pH of 4.5 or lower has no measurable alkalinity, and water with a pH of 8.3 or higher has no measurable acidity. In natural water, where the pH may often be in the vicinity of 8.3, acidity is not a factor of concern. In most productive fresh waters, the pH falls in a range between 6.5 and 8.5 (except when increased by photosynthetic activity). Some regions have soft waters with poor buffering capacity and naturally low pH. They tend to be less productive. Such conditions are found especially in dark colored waters draining from coniferous forests or muskegs, and in swampy sections of the Southeast. For a variety of reasons, some waters may exhibit quite extreme pH values. Before these are considered natural conditions, it should be ascertained that they have not actually resulted from man-made changes, such as stripping of ground cover or old mining activities. This is important because the recommendations refer to estimated natural levels.

TOXICITY TO AQUATIC LIFE

Some aquatic organisms, especially algae, have been found to live at pH 2 and lower, and others at pH 10 and higher; however, such organisms are relatively few. Some natural waters with a pH of 4 support healthy populations of fish and other organisms. In these cases the acidity is due primarily to carbon dioxide and natural organic acids, and the water has little buffering capacity. Other natural waters with a pH of 9.5 also support fish but are not usually highly productive.

The effects of pH on aquatic life have been reviewed in detail in excellent reports by the European Inland Fisheries Advisory Commission (1969)¹⁶⁰ and Katz (1969).¹⁶¹ Interpretations and summaries of these reviews are given in Table III-6.

ADVERSE INDIRECT EFFECTS OR SIDE EFFECTS

Addition of either acids or alkalies to water may be harmful not only by producing acid or alkaline conditions, but also by increasing the toxicity of various components in the waters. For example, acidification of water may release free carbon dioxide. This exerts a toxic action additional to that of the lower pH. Recommendations for pH are valid if carbon dioxide is less than 25 mg/l (see the discussion of Carbon Dioxide, p. 139).

A reduction of about 1.5 pH units can cause a thousand-fold increase in the acute toxicity of a metalocyanide complex (Doudoroff et al. 1966).¹⁶⁹ The addition of strong alkalies may cause the formation of undissociated NH_4OH or un-ionized NH_3 in quantities that may be toxic (Lloyd 1961,¹⁶³ Burrows 1964).¹⁶⁸ Many other pollutants may change their toxicity to a lesser extent. It is difficult to predict whether toxicity will increase or decrease for a given direction of change in pH.

Weakly dissociated acids and bases must be considered in terms of their toxicities, as well as their effects on pH and alkalinity.

The availability of many nutrient substances varies with the hydrogen ion concentration. Some trace metals become more soluble at low pH. At higher pH values, iron tends to become unavailable to some plants, and hence the production of the whole aquatic community may be affected.

The major buffering system in natural waters is the carbonate system that not only neutralizes acids and bases to reduce the fluctuations in pH, but also forms a reservoir of carbon for photosynthesis. This process is indispensable, because there is a limit on the rate at which carbon-dioxide can be obtained from the atmosphere to replace that in the water. Thus the productivity of waters is closely correlated to the carbonate buffering system. The addition of mineral acids preempts the carbonate buffering capacity, and the

TABLE III-6—A Summary of Some Effects of pH on Freshwater Fish and Other Aquatic Organisms

pH	Known effects
11.5-12.0	Some caddis flies (Trichoptera) survive but emergence reduced.
11.0-11.5	Rapidly lethal to all species of fish.
10.5-11.0	Rapidly lethal to salmonids. The upper limit is lethal to carp (<i>Cyprinus carpio</i>), goldfish (<i>Carassius auratus</i>), and pike. Lethal to some stoneflies (Plecoptera) and dragonflies (Odonata). Caddis fly emergence reduced.
10.0-10.5	Withstood by salmonids for short periods but eventually lethal. Exceeds tolerance of bluegills (<i>Lepomis macrochirus</i>) and probably goldfish. Some typical stoneflies and mayflies (<i>Ephemera</i>) survive with reduced emergence.
9.5-10.0	Lethal to salmonids over a prolonged period of time and no viable fishery for coldwater species. Reduces populations of warmwater fish and may be harmful to development stages. Causes reduced emergence of some stoneflies.
9.0-9.5	Likely to be harmful to salmonids and perch (<i>Perca</i>) if present for a considerable length of time and no viable fishery for coldwater species. Reduced populations of warmwater fish. Carp avoid these levels.
8.5-9.0	Approaches tolerance limit of some salmonids, whitefish (<i>Coregonus</i>), catfish (<i>Ictaluridae</i>), and perch. Avoided by goldfish. No apparent effects on invertebrates.
8.0-8.5	Motility of carp sperm reduced. Partial mortality of burbot (<i>Lota lota</i>) eggs.
7.0-8.0	Full fish production. No known harmful effects on adult or immature fish, but 7.0 is near low limit for <i>Gammarus</i> reproduction and perhaps for some other crustaceans.
6.5-7.0	Not lethal to fish unless heavy metals or cyanides that are more toxic at low pH are present. Generally full fish production, but for fathead minnow (<i>Pimephales promelas</i>), frequency of spawning and number of eggs are somewhat reduced. Invertebrates except crustaceans relatively normal, including common occurrence of mollusks. Microorganisms, algae, and higher plants essentially normal.
6.0-6.5	Unlikely to be toxic to fish unless free carbon dioxide is present in excess of 100 ppm. Good aquatic populations with varied species can exist with some exceptions. Reproduction of <i>Gammarus</i> and <i>Daphnia</i> prevented, perhaps other crustaceans. Aquatic plants and microorganisms relatively normal except fungi frequent.
5.5-6.0	Eastern brook trout (<i>Salvelinus fontinalis</i>) survive at over pH 5.5. Rainbow trout (<i>Salmo gairdneri</i>) do not occur. In natural situations, small populations of relatively few species of fish can be found. Growth rate of carp reduced. Spawning of fathead minnow significantly reduced. Mollusks rare.
5.0-5.5	Very restricted fish populations but not lethal to any fish species unless CO ₂ is high (over 25 ppm), or water contains iron salts. May be lethal to eggs and larvae of sensitive fish species. Prevents spawning of fathead minnow. Benthic invertebrates moderately diverse, with certain black flies (<i>Simuliidae</i>), mayflies (<i>Ephemerella</i>), stoneflies, and midges (<i>Chironomidae</i>) present in numbers. Lethal to other invertebrates such as the mayfly. Bacterial species diversity decreased; yeasts and sulfur and iron bacteria (<i>Thiobacillus-Ferrobacillus</i>) common. Algae reasonably diverse and higher plants will grow.
4.5-5.0	No viable fishery can be maintained. Likely to be lethal to eggs and fry of salmonids. A salmonid population could not reproduce. Harmful, but not necessarily lethal to carp. Adult brown trout (<i>Salmo trutta</i>) can survive in peat waters. Benthic fauna restricted, mayflies reduced. Lethal to several typical stoneflies. Inhibits emergence of certain caddis fly, stonefly, and midge larvae. Diatoms are dominant algae.
4.0-4.5	Fish populations limited; only a few species survive. Perch, some coarse fish, and pike can acclimate to this pH, but only pike reproduce. Lethal to fathead minnow. Some caddis flies and dragonflies found in such habitats; certain midges dominant. Flora restricted.
3.5-4.0	Lethal to salmonids and bluegills. Limit of tolerance of pumpkinseed (<i>Lepomis gibbosus</i>), perch, pike, and some coarse fish. All flora and fauna severely restricted in number of species. Cattail (<i>Typha</i>) is only common higher plant.
3.0-3.5	Unlikely that any fish can survive for more than a few hours. A few kinds of invertebrates such as certain midges and alderflies, and a few species of algae may be found at this pH range and lower

original biological productivity is reduced in proportion to the degree that such capacity is exhausted. Therefore, the minimum essential buffering capacity and tolerable pH limits are important water quality considerations.

Because of this importance, there should be no serious depletion of the carbonate buffering capacity, and it is recommended that reduction of alkalinity of natural waters should not exceed 25 per cent.

Recommendations

Suggested maximum and minimum levels of protection for aquatic life are given in the following recommendations. A single range of values could not apply to all kinds of fish, nor could it cover the different degrees of graded effects. The selection of the level of protection is a socioeconomic decision, not a biological one. The levels are defined in Table III-3 (see the discussion of Dissolved Oxygen).

Nearly Maximum Level of Protection

- pH not less than 6.5 nor more than 8.5. No change greater than 0.5 units above the estimated natural seasonal maximum, nor below the estimated natural seasonal minimum.

High Level of Protection

- pH not less than 6.0 nor more than 9.0. No change greater than 0.5 units outside the estimated natural seasonal maximum and minimum.

Moderate Level of Protection

- pH not less than 6.0 nor more than 9.0. No change greater than 1.0 units outside the estimated natural seasonal maximum and minimum.

Low Level of Protection

- pH not less than 5.5 nor more than 9.5. No change greater than 1.5 units outside the estimated natural seasonal maximum and minimum.

Additional Requirements for All Levels of Protection

- If a natural pH is outside the stated range of pH for a given level of protection, no further change is desirable.
- The extreme range of pH fluctuation in any location should not be greater than 2.0 units. If natural fluctuation exceeds this, pH should not be altered.
- The natural daily and seasonal patterns of pH variation should be maintained, although the absolute values may be altered within the limits specified.
- The total alkalinity of water is not to be decreased more than 25 per cent below the natural level.

WILDLIFE

In this report, wildlife is defined as all species of vertebrates other than fish and man. To assure the short-term and long-term survival of wildlife, the water of the aquatic ecosystem must be of the quality and quantity to furnish the necessary life support throughout the life-cycle of the species involved. In addition to the quantity, the quality of food substances produced by the aquatic environment must be adequate to support the long-term survival of the wildlife species.

Many species of wildlife require the existence of specific, complex, and relatively undisturbed ecosystems for their continued existence. Aquatic ecosystems, such as bogs, muskegs, seepages, swamps, and marshes, can exhibit marked fragility under the influence of changing water levels, various pollutants, fire, or human activity. Changes in the abundance of animal populations living in such aquatic communities can result in reactions and altered abundance of plant life, which in turn will have repercussions of other species of animal life. In general, these transitional ecosystems between land and water are characterized by very high productivity and importance for wildlife, and they should thus be maintained in that state to the greatest possible extent.

In many instances, criteria to protect fish and invertebrates or to provide water suitable for consumption by man or domestic animals will also provide the minimal requisites for some species of wildlife. This would be true for species that use water only for direct consumption or that feed on aquatic organisms to only a minor extent. For many species of wildlife, however, the setting of water quality criteria is complicated by their ecological position at the apex of complex food webs, and also by the extreme mobility of some wildlife, especially birds.

Those substances which are concentrated via food chains, such as many chlorinated hydrocarbons, present special problems for those species that occupy the apex of long food chains. In those instances, environmental levels which are safe for fish, do not necessarily convey safety to predators or even to scavengers that consume fish.

PROTECTION OF FOOD AND SHELTER FOR WILDLIFE

A number of factors can be identified that can affect specific components of the ecosystem and cause reduced food and shelter for wildlife. These factors also affect fish and other aquatic life and therefore are discussed in greater detail in appropriate related subtopics.

pH

In bioassays with aquatic plants, Sincock (1968)⁵⁹³ found that when the pH of the water in test vessels dropped to 4.5, reedhead-grass (*Potamogeton perfoliatus*), a valuable waterfowl food plant, died within a few days. Similarly, in Back Bay, Virginia, between August and November, 1963, the aquatic plant production declined from 164 to 13 pounds per acre. This atypical decline was immediately preceded by a decline in pH to 6.5 compared to previous midsummer readings of 7.7 to 9.2. (U.S. Bureau of Sport Fisheries and Wildlife).⁶⁰¹

Recommendation

Aquatic plants of greatest value as food for waterfowl thrive best in waters with a summer pH range of 7.0 to 9.2.

ALKALINITY

Generally, waters with reasonably high bicarbonate alkalinity are more productive of valuable waterfowl food plants than are waters with low bicarbonate alkalinity. Few waters with less than 25 mg/l bicarbonate alkalinity can be classed among the better waterfowl habitats. Many waterfowl habitats productive of valuable foods, such as sago pondweed (*Potamogeton pectinatus*), widgeongrass (*Ruppia maritima* and *R. occidentalis*), banana waterlily (*Castalia flava*), wild celery, (*Vallisneria americana*), and others have a bicarbonate alkalinity range of 35 to 200 mg/l.

Definitive submerged aquatic plant communities develop in waters with different concentrations of bicarbonate

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Section IV—MARINE AQUATIC LIFE AND WILDLIFE

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important behavioral reactions stimulated by low concentrations of some of the metals.

In the following review of different inorganic constituents, the total amount of each element is considered in the discussion and recommendation, unless otherwise stated. Whereas some of the methods of analysis for constituents recommended for fresh water and waste water can also be used in marine environments, the interference from salt demands other specialized techniques for many elements (Strickland and Parsons 1968,²⁷³ Food and Agriculture Organization 1971¹⁶⁴).

Not only has the recent literature been reviewed in this examination of the properties and effects of inorganic constituents, but various bibliographic and other standard references have been liberally consulted (The Merck Index 1960,²²⁸ McKee and Wolf 1963,²²⁶ Wilber 1969,²⁹⁹ NRC Committee on Oceanography 1971,²³⁷ U.S. Department of the Interior Federal Water Pollution Control Administration 1968,²⁸⁷ Canada Interdepartmental Committee on Water 1971¹³⁶).

Alkalinity or Buffer Capacity, Carbon Dioxide, and pH

The chemistry of sea water differs from that of fresh water largely because of the presence of salts, the major constituents of which are present in sea water in constant proportion. The weak-acid salts, such as the carbonates, bicarbonates, and borates, contribute to the high buffering capacity or alkalinity of sea water. This buffering power renders many wastes of a highly acidic or alkaline nature, which are often highly toxic in fresh water, comparatively innocuous after mixing with sea water.

The complex carbon dioxide-bicarbonate-carbonate system in the sea is described in standard textbooks (Sverdrup et al. 1946,²⁷⁶ Skirrow 1965²⁶⁴). Alkalinity and the hydrogen-ion concentration, as expressed by pH (Strickland and Parsons 1968),²⁷³ are the best measure of the effects of highly acidic or highly alkaline wastes.

European Inland Fisheries Advisory Commission (1969)¹⁵⁸ and Kemp (1971)²⁰² reviewed the pH requirements of freshwater fishes. Because of the large difference in buffer capacities, techniques for measurement and definitions of alkalinity are quite different for marine and fresh waters. The normal range of pH encountered in fresh water is considerably wider than that found in sea water, and for this reason, freshwater communities are adapted to greater pH extremes than are marine communities.

Sea water normally varies in pH from surface to bottom because of the carbon dioxide-bicarbonate-carbonate equilibria. Photosynthetic and respiratory processes also contribute to variations in pH. At the sea surface, the pH normally varies from 8.0 to 8.3, depending on the partial pressure of carbon dioxide in the atmosphere and the salinity and temperature of the water. A large uptake of carbon dioxide during photosynthesis in the euphotic zone leads to high pH values exceeding 8.5 in exceptional cases.

Release of carbon dioxide during decomposition in intermediate and bottom waters results in a lowering of pH. In shallow, biologically-active waters, particularly in warm tropical and subtropical areas, there is a large diurnal variation in pH with values ranging from a high of 9.5 in the daytime to a low of 7.3 at night or in the early morning.

The toxicity of most pollutants increases as the pH increases or decreases from neutral (pH 7). This is true for complex mixtures, such as pulp mill effluents (Howard and Walden 1965),¹⁸³ for constituents which dissociate at different pH (e.g., H₂S and HCN), and for heavy metals. The toxicity of certain complexes can change drastically with pH. Nickel cyanide exhibits a thousandfold increase in toxicity with a 1.5 unit decrease in pH from 8.0 to 6.5 (Robert A. Taft Sanitary Engineering Center 1953,²⁵⁵ Doudoroff et al. 1966¹⁵²). pH may also determine the degree of dissociation of salts, some of which are more toxic in the molecular form than in the ionic form. Sodium sulfide is increasingly toxic with decreasing pH as S⁼ and HS⁻ ions are converted to H₂S (Jones 1948).²⁰⁰ The tolerance of fish to low concentrations of dissolved oxygen, high temperatures, cations, and anions varies with pH. Therefore, non-injurious pH deviations and ranges depend on local conditions.

There are large fluctuations in natural pH in the marine environment. Changes in pH indicate that the buffering capacity of the sea water has been altered and the carbon dioxide equilibria have shifted. The time required for mixing of an effluent with a large volume of sea water is exceedingly important. When the pH of the receiving sea water undergoes an increase or decrease, its duration can be important to the survival of organisms. At present, there are not sufficient data with which to assign time limits to large departures of pH.

Fish tolerate moderately large pH changes in the middle of their normal pH ranges. Small pH changes at the limits of their ranges and also in the presence of some pollutants can have significant deleterious effects.

Plankton and benthic invertebrates are probably more sensitive than fish to changes in pH. Oysters appear to perform best in brackish waters when the pH is about 7.0. At a pH of 6.5 and lower, the rate of pumping decreases notably, and the time the shells remain open is reduced by 90 per cent (Loosanoff and Tommers 1948,²¹⁹ Korringa 1952²⁰⁷). Oyster larvae are impaired at a pH of 9.0 and killed at 9.1 in a few hours (Gaarder 1932).¹⁶⁷ The upper pH limit for crabs is 10.2 (Meinck et al. 1956).²²⁷

Recommendation

Changes in sea water pH should be avoided. The effects of pH alteration depend on the specific conditions. In any case, the normal range of pH in either direction should not be extended by more than 0.2 units. Within the normal range, the pH should not vary by more than 0.5 pH units. Ad-

dition of foreign material should not drop the pH below 6.5 or raise it above 8.5.

Aluminum

Aluminum, one of the most abundant elements in the earth's crust, does not occur in its elemental form in nature. It is found as a constituent in all soils, plants, and animal tissues. Aluminum is an amphoteric metal; it may be in solution as a weak acid, or it may assume the form of a flocculent hydroxide, depending on the pH. In the aluminum sulfate form (alum), it is used in water treatment as a coagulant for suspended solids, including colloidal materials and microorganisms.

Aluminum may be adsorbed on plant organisms, but very little ingested by animals is absorbed through the alimentary canal. Goldberg et al. (1971)¹⁷² reported an aluminum concentration factor for phytoplankton (*Sargassum*) ash of 65 and for zooplankton ash of 300. However, Lowman et al. (1971),²²¹ in their compilation of concentration factors for various elements, noted that aluminum was reported to be concentrated 15,000 times in benthic algae, 10,000 times in plankton (phyto- and zoo-), 9,000 times in the soft parts of molluscs, 12,000 times in crustacean muscle, and 10,000 times in fish muscle.

In fresh water, the toxicity of aluminum salts varies with hardness, turbidity, and pH. Jones (1939)¹⁹⁸ found the lethal threshold of aluminum nitrate for stickleback (*Gasterosteus aculeatus*) in very soft water to be 0.07 mg/l. Using tap water with the same compound tested on the same species, Anderson (1948)¹¹² reported a toxic threshold of less than 5×10^{-5} molar aluminum chloride (1.35 mg/l Al). Average survival times of stickleback in different concentrations of aluminum in the nitrate form have been reported as one day at 0.3 mg/l and one week at 0.1 mg/l (Doudoroff and Katz 1953).¹⁵⁰ It was noted by the same authors that 0.27 mg/l aluminum in the nitrate form did not apparently harm young eels in 50 hours' exposure.

Because of the slightly basic nature of sea water, aluminum salts tend to precipitate in the marine environment. These salts have exhibited comparatively low toxicities with 96-hour LC50's of 17.8 mg/l for redfish tested in sea water with aluminum chloride (Pulley 1950).²⁵² Concentrations of 8.9 mg/l of aluminum (from $AlCl_3$) did not have a lethal effect on marine fish and oysters tested (*Cynoscion nebulosus*, *Sciaenops ocellatus*, *Fundulus grandis*, *Fundulus similis*, *Cyprindon variegatus*, *Ostrea virginica*) (Pulley 1950).²⁵² The flocs of precipitated aluminum hydroxide may affect rooted aquatics and invertebrate benthos. Wilder (1952)³⁰⁰ noted no significant effect on lobsters (*Homarus americanus*) of a tank lined with an aluminum alloy (Mn, 1 to 1.5 per cent; Fe, 0.7 per cent; Si, 0.6 per cent; Cu, 0.2 per cent, and Zn, 0.1 per cent).

Aluminum hydroxide can have an adverse effect on bottom communities. Special precautions should be taken to avoid disposal of aluminum-containing wastes in water

supporting commercial populations of clams, scallops, oysters, shrimps, lobsters, crabs, or bottom fishes.

Recommendation

Because aluminum tends to be concentrated by marine organisms, it is recommended that an application factor of 0.01 be applied to marine 96-hour LC50 data for the appropriate organisms most sensitive to aluminum. On the basis of data available at this time, it is suggested that concentrations of aluminum exceeding 1.5 mg/l constitute a hazard in the marine environment, and levels less than 0.2 mg/l present minimal risk of deleterious effects.

Ammonia

Most of the available information on toxicity of ammonia is for freshwater organisms. For this reason, the reader is referred to the discussion of ammonia in Section III on Freshwater Aquatic Life and Wildlife (p. 186). Because of the slightly higher alkalinity of sea water and the larger proportion of un-ionized ammonium hydroxide, ammonia may be more toxic in sea water than in fresh water (Doudoroff and Katz 1961).¹⁵¹ Holland et al. (1960)¹⁸² noted a reduction in growth and a loss of equilibrium in chinook salmon (*Oncorhynchus tshawytscha*) at concentrations 3.5 to 10 mg/l of ammonia. Dissolved oxygen and carbon dioxide decrease the toxicity of ammonia (U.K. Department of Science and Research 1961).²⁸⁴ Lloyd and Orr (1969),²¹⁷ in their studies on the effect of un-ionized ammonia at a pH of 8 to 10, found 100 per cent mortality with 0.44 mg/l NH_3 in 3 hours for rainbow trout (*Salmo gairdneri*). This confirmed earlier results of 100 per cent mortality in 24 hours at 0.4 mg/l. The toxicity increased with pH between 7.0 and 8.2.

Recommendation

It is recommended that an application factor of 0.1 be applied to marine 96-hour LC50 data for the appropriate organisms most sensitive to ammonia. On the basis of freshwater data available at this time, it is suggested that concentrations of un-ionized ammonia equal to or exceeding 0.4 mg/l constitute a hazard to the marine biota, and levels less than 0.01 mg/l present minimal risk of deleterious effects.

Antimony

Antimony occurs chiefly as sulfide (stibnite) or as the oxides cervantite (Sb_2O_4) and valentinite (Sb_2O_3) and is used for alloys and other metallurgical purposes. It has also been used in a variety of medicinal preparations and in numerous industrial applications. Antimony salts are used in the fireworks, rubber, textile, ceramic, glass and paint industries.

Section V—AGRICULTURAL USES OF WATER

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dispersal, unless leaching is accomplished by adding calcium or calcium-producing amendments.

Adsorption of sodium from a given irrigation water is a function of the proportion of sodium to divalent cations (calcium and magnesium) in that water. To estimate the degree to which sodium will be adsorbed by a soil from a given water when brought into equilibrium with it, the Salinity Laboratory (1954)³³⁵ proposed the sodium adsorption ratio (SAR):

$$\frac{\text{Na}^+}{\sqrt{\frac{\text{Ca}^{++} + \text{Mg}^{++}}{2}}} \quad \text{Expressed as me/l}$$

As soils tend to dry, the SAR value of the soil solution increases even though the relative concentrations of the cations remain the same. This is apparent from the SAR equation, where the denominator is a square-root function. This is a significant factor in estimating sodium effects on soils.

The SAR value can be related to the amount of exchangeable cation content. This latter value is called the exchangeable sodium percentage (ESP). From empirical determinations, the U. S. Salinity Laboratory (1954)³³⁵ obtained an equation for predicting a soil ESP value based on the SAR value of a water in equilibrium with it. This is expressed as follows:

$$\text{ESP} = \frac{[100 a + b(\text{SAR})]}{[1 + a + b(\text{SAR})]}$$

The constants "a" (intercept representing experimental error) and "b" (slope of the regression line) were determined statistically by various investigators who found "a" to be in the order of -0.06 to 0.01 and "b" to be within the range of 0.014 to 0.016. This relationship is shown in the nomogram (Figure V-4) developed by the U. S. Salinity Laboratory (1954).³³⁵ For sensitive fruits, the tolerance limit for SAR of irrigation water is about four. For general crops, a limit of eight to 18 is generally considered within a usable range, although this depends to some degree on the type of clay mineral, electrolyte concentration in the water, and other variables.

The ESP value that significantly affects soil properties varies according to the proportion of swelling and non-swelling clay minerals. An ESP of 10 to 15 per cent is considered excessive, if a high percentage of swelling clay minerals such as montmorillonite are present. Fair crop growth of alfalfa, cotton, and even olives, have been observed in soils of the San Joaquin Valley (California) with ESP values ranging from 60 to 70 percent (Schoonover 1963).³³⁶

Prediction of the equilibrium ESP from SAR values of irrigation waters is complicated by the fact that the salt content of irrigation water becomes more concentrated in the soil solution. According to the U. S. Salinity Laboratory

(1954),³³⁵ shallow ground waters 10 times as saline as the irrigation waters may be found within depths of 10 feet, and a salt concentration two to three times that of irrigation water may be reasonably expected in the first-foot depth. Under conditions where precipitation of salts and rainfall may be neglected, the salt content of irrigation water will increase to higher concentrations in the soil solution without change in relative composition. The SAR increases in proportion to the square root of the concentration; therefore, the SAR applicable for calculating equilibrium ESP in the upper root zone may be assumed to be two to three times that of the irrigation water.

Recommendation

To reduce the sodium hazard in irrigation water for a specific crop, it is recommended that the SAR value be within the tolerance limits determined by the U.S. Soil Salinity Laboratory Staff.

Biochemical Oxygen Demand (BOD) and Soil Aeration

The need for adequate oxygen in the soil for optimum plant growth is well recognized. To meet the oxygen requirement of the plant, soil structure (porosity) and soil water contents must be adequate to permit good aeration. Conditions that develop immediately following irrigation are not clearly understood.

Soil aeration and oxygen availability normally present no problem on well-structured soils with good quality water. Where drainage is poor, oxygen may become limiting. Utilization of waters having high BOD or Chemical Oxygen Demand (COD) values could aggravate the condition by further depleting available oxygen. Aside from detrimental effects of oxygen deficiency for plant growth, reduction of elements such as iron and manganese to the more soluble divalent forms may create toxic conditions. Other biological and chemical equilibria may also be affected.

There is very little information regarding the effect of using irrigation waters with high BOD values on plant growth. Between source of contamination and point of irrigation, considerable reduction in BOD value may result. Sprinkler irrigation may further reduce the BOD value of water. Infiltration into well-drained soils can also decrease the BOD value of the water without serious depleting the oxygen available for plant growth.

Acidity and Alkalinity

The pH of normal irrigation water has little direct significance. Since water itself is unbuffered, and the soil is a buffered system (except for extremely sandy soils low in organic matter), the pH of the soil will not be significantly affected by application of irrigation water. There are, however, some extremes and indirect effects.

Water having pH values below 4.8 applied to acid soils over a period of time may possibly render soluble iron,

aluminum, or manganese in concentrations large enough to be toxic to plant growth. Similarly, additions of saline waters to acid soils could result in a decrease in soil pH and an increase in the solubility of aluminum and manganese. In some areas where acid mine drainage contaminates water sources, pH values as low as 1.8 have been reported. Waters having unusually low pH values such as this would be strongly suspect of containing toxic quantities of certain heavy metals or other elements.

Waters having pH values in excess of 8.3 are highly alkaline and may contain high concentrations of sodium, carbonates, and bicarbonates. These constituents affect soils and plant growth directly or indirectly, (see "Effects on Plant Growth" above).

Recommendation

Because most of the effects of acidity and alkalinity in irrigation waters on soils and plant growth are indirect, no specific pH values can be recommended. However, water with pH values in the range of 4.5 to 9.0 should be usable provided that care is taken to detect the development of harmful indirect effects.

Suspended Solids

Deposition of colloidal particles on the soil surface can produce crusts that inhibit water infiltration and seedling emergence. This same deposition and crusting can reduce soil aeration and impede plant development. High colloidal content in water used for sprinkler irrigation could result in deposition of films on leaf surfaces that could reduce photosynthetic activity and thereby deter growth. Where sprinkler irrigation is used for leafy vegetable crops such as lettuce, sediment may accumulate on the growing plant affecting the marketability of these products.

In surface irrigation, suspended solids can interfere with the flow of water in conveyance systems and structures. Deposition of sediment not only reduces the capacity of these systems to carry and distribute water but can also decrease reservoir storage capacity. For sprinkler irrigation, suspended mineral solids may cause undue wear on irrigation pumps and sprinkler nozzles (as well as plugging up the latter), thereby reducing irrigation efficiency.

Soils are specifically affected by deposition of these suspended solids, especially when they consist primarily of clays or colloidal material. These cause crust formations that reduce seedling emergence. In addition, these crusts reduce infiltration and hinder the leaching of saline soils. The scouring action of sediment in streams has also been found to affect soils adversely by contributing to the dissolution and increase of salts in some areas (Pillsbury and Blaney 1966).³³¹ Conversely, sediment high in silt may improve the texture, consistency, and water-holding capacity of a sandy soil.

Effect on Animals or Humans

The effects of irrigation water quality on soils and plants has been discussed. However, since the quality of irrigation water is variable and originates from different sources, there may be natural or added substances in the water which pose a hazard to animals or humans consuming irrigated crops. These substances may be accumulated in certain cereals, pasture plants, or fruit and vegetable crops without any apparent injury. Of concern, however, is that the concentration of these substances may be toxic or harmful to humans or animals consuming the plants. Many substances in irrigation waters such as inorganic salts and minerals, pesticides, human and animal pathogens have recommendations to protect the desired resource. For radionuclides no such recommendation exists.

Radionuclides

There are no generally accepted standards for control of radioactive contamination in irrigation water. For most radionuclides, the use of federal Drinking Water Standards, should be reasonable for irrigation water.

The limiting factor for radioactive contamination in irrigation is its transfer to foods and eventual intake by humans. Such a level of contamination would be reached long before any damage to plants themselves could be observed. Plants can absorb radionuclides from irrigation water in two ways: direct contamination of foliage through sprinkler irrigation, and indirectly through soil contamination. The latter presents many complex problems since eventual concentration in the soil will depend on the rate of water application, the rate of radioactive decay, and other losses of the radionuclide from the soil. Some studies, relating to these factors have been reported (Menzel et al. 1963,³²⁶ Moorby and Squire 1963,³²⁸ Perrin 1963,³²⁹ Menzel 1965,³²⁵ Milbourn and Taylor 1965³²⁷).

It is estimated that concentrations of strontium-90 and radium-226 in fresh produce would approximate those in the irrigation water for the crop if there was negligible uptake of these radionuclides from the soil. With flood or furrow irrigation only, one or more decades of continuous irrigation with contaminated water would be required before the concentrations of strontium-90 or radium-226 in the produce equalled those in the water (Menzel *personal communication* 1972).³³⁹

Recommendation

In view of the lack of experimental evidence concerning the long-term accumulation and availability of strontium-90 and radium-226 in irrigated soils and to provide an adequate margin of safety, it is recommended that Federal Drinking Water Standards be used for irrigation water.

Section VI—INDUSTRIAL WATER SUPPLIES

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INTRODUCTION

WATER USE

Since the advent of the industrial era, the use and availability of water has been of primary concern to industry both in the selection and design of plant sites and in plant operation. By 1968 the water withdrawal of industry—including both industrial manufacturing plants and investor-owned thermal electric utilities—had reached a total of approximately 84,000 billion gallons per year (bgy). Of these, about 93 per cent or 78,000 bgy was used for cooling or condensing purposes; 5 per cent or nearly 4,300 bgy was used for processing, including water that came in contact with the product as steam or coolant; and less than 2 per cent or 1,000 bgy was used as boiler-feed water (U. S. Department of Commerce, Bureau of the Census 1971¹⁹ hereafter referred to as Bureau of the Census 1971).^{5 *}

Of the total intake nearly 30 per cent or 25,000 bgy was brackish water containing more than 1,000 milligrams per liter (mg/l) of dissolved solids. The freshwater intake amounted to 59,000 bgy; 56,000 of these took the form of surface water delivered by water systems owned by the user

company. Groundwater amounted to 2,300 bgy, a relatively small percentage of the total intake, but its significance and importance cannot be overlooked in view of the number of industrial plants that use it for part or all of their supply.

Thirty per cent of the approximately 4,000 bgy used by the manufacturing processes in 1968 was treated or secured from a public water supply. Ninety per cent of all the water the manufacturing industry used for boiler feed and processing was represented in this figure. Water for cooling or condensing represented over 90 per cent of total industrial water use. The largest part of this was on a once-through basis where only a minimum of treatment was economically feasible.

Table VI-1 summarizes the information on water intake, recycling, and consumption for each industrial group considered in this Section. Recycling may include reuse for different cooling or process systems, recirculation through cooling towers or cooling ponds, recharge of water to an underground aquifer, or reuse of effluents from sewage or waste treatment plants.

TABLE VI-1—Industrial Plant and Investor-Owned Thermal Electric Plant Water Intake, Reuse, and Consumption, 1968

SIC	Industrial group	Water intake (bgy)				Water recycled (bgy)	Gross water use, including recycling (bgy)	Water consumed (bgy)	Water discharged (bgy)
		Purpose			Total				
		Cooling and condensing	Boiler feed, sanitary service, etc.	Process					
20	Food and kindred products.....	427	93	290	810	535	1,345	57	753
22	Textile mill products.....	24	22	109	155	174	329	19	136
24	Lumber and wood products.....	62	20	37	119	87	206	26	93
26	Paper and allied products.....	652	123	1,478	2,253	4,270	6,523	175	2,078
28	Chemicals and allied products.....	3,533	210	733	4,476	4,940	9,416	301	4,175
29	Petroleum and coal products.....	1,230	111	95	1,436	5,855	7,291	219	1,217
31	Leather and leather products.....	1	1	14	16	4	20	1	15
33	Primary metal industry.....	3,632	165	1,207	5,004	2,780	7,784	308	4,696
	Subtotal.....	9,561	745	3,963	14,269	18,645	32,914	1,106	13,163
	Other Industries.....	574	291	332	1,197	1,589	2,786	84	1,113
	Total Industry.....	10,135	1,036	4,295	15,466	20,234	35,700	1,190	14,276
	Thermal electric plants.....	68,200	(a)	68,200	8,525	76,725	100	68,100
	TOTAL.....	78,335	1,036 (b)	4,295	83,666	28,759	112,425	1,290	82,376

^a Boiler-feed water use by thermal electric plants estimated to be equivalent to industrial sanitary service, etc., water use.

^b Total boiler-feed water.
Bureau of the Census 1971⁵

* Literature citations appear at the end of the Section. They can be located alphabetically or by superscript number.

SCOPE

After describing industry's use of water in steam generation and cooling, the panel on Industrial Water Supplies examined ten groups of one or more industries as defined by the Standard Industrial Classification (SIC) coding used by the Bureau of the Census (U. S. Executive Office of the President, Bureau of the Budget 1967).²²

The industries included textile mills (SIC 22), lumber and wood (SIC 24), pulp and paper (SIC 26), chemical and allied products (SIC 28), petroleum refining (SIC 2911), primary metals (SIC 33), food canning (SIC 2032 and 2033), bottled and canned soft drinks (SIC 2086), tanning (SIC 3111), and mining and cement (SIC 10). Only the

major users of water were included, representing a variety of industries in order to insure that a wide cross section of water qualities would be described.

Industrial effluents cause water quality changes in the receiving systems, but consideration of these changes was not part of the charge to the Panel on Industrial Water Supplies. The other Sections in this Report include consideration of the effects of many specific constituents of such effluents as related to various water uses.

WATER QUALITY REQUIREMENTS

Water quality requirements differ widely for the broad variety of industrial uses, but modern water treatment tech-

TABLE VI-2—Summary of Specific Quality Characteristics of Surface Waters That Have Been Used as Sources for Industrial Water Supplies

(Unless otherwise indicated, units are mg/l and values are maximums. No one water will have all the maximum values shown)

Characteristics	Boiler Makeup water		Cooling Water				Process Water										
	Industrial 0 to 1,500 psig	Utility 700 to 5,000 psig	Fresh		Brackish ^a		Textile Industry SIC-22	Lumber Industry SIC-24	Pulp and Paper Industry SIC-26	Chemical Industry SIC-28	Petroleum Industry SIC-29	Prim. Metals Industry SIC-33	Mining Industry		Oil Recovery Injection Waters		
			Once through	Makeup recycle	Once through	Makeup recycle							Copper Sulfide Concentra- tor Process Water	Copper Leach Solution	Sea Water	Formation Water	
Silica (SiO ₂)	150	150	50	150	25	25			50		85						
Aluminum (Al)	3	3	3	3										12,000			
Iron (Fe)	80	80	14	80	1.0	1.0	0.3		2.6	10	15			12,000 ^b	0.2		13
Manganese (Mn)	10	10	2.5	10	0.02	0.02	1.0			2							
Copper (Cu)							0.5										
Calcium (Ca)			500	500	1,200	1,200				250	220		1,510		400		2,727
Magnesium (Mg)										100	85		(CaCO ₃)	12,000	1,272		655
Sodium & potassium (Na+K)											230				10,840		42,000
Ammonia (NH ₃)											40						
Bicarbonate (HCO ₃)	600	600	600	600	180	180				600	480						
Sulfate (SO ₄)	1,400	1,400	680	680	2,700	2,700				850	900		1,634	64,000	2,560		42
Chloride (Cl)	19,000	19,000	600	500	22,000	22,000			200 ^c	500	1,600	500	12		18,980		72,782
Fluoride (F)											1.2						
Nitrate (NO ₃)			30	30							8						
Phosphate (PO ₄)		50	4	4	5	5											
Dissolved Solids	35,000	35,000	1,000	1,000	35,000	35,000	150		1,080	2,500	3,500	1,500	2,100		34,292		118,524
Suspended Solids	15,000	15,000	5,000	15,000	250	250	1,000	(^e)		10,000	5,000	3,000					
Hardness (CaCO ₃)	5,000	5,000	850	850	7,000	7,000	120		475	1,000	900	1,000	1,530				
Alkalinity (CaCO ₃)	500	500	500	500	150	150				500	500	200	415				
Acidity (CaCO ₃)	1,000	1,000	0	200	0	0						75					
pH, units			5.0-8.9	3.5-9.1	5.0-8.4	5.0-8.4	6.0-8.0	5-9	4.6-9.4	5.5-9.0	6.0-9.0	3-9	to 11.7	3-3.5			to 6.5
Color, units	1,200	1,200		1,200					360	500	25						
Organics:																	
Methylene blue ac- tive substances	2 ^d	10	1.3	1.3		1.3											
Carbon tetrachloride extract	100	100	(^e)	100	(^e)	100						30					
Chemical oxygen de- mand (COD)	100	500		100		200											
Hydrogen sulfide (H ₂ S)					4	4					20						
Temperature, F.	120	120	100	120	100	120			95 ^f			100					

^a Water containing in excess of 1,000 mg/l dissolved solids.

^b May be \leq 1,000 for mechanical pulping operations.

^c No particles \geq 3 mm diameter.

^d One mg/l for pressures above 700 psig.

^e No floating oil.

^f Applies to bleached chemical pulp and paper only.

^g 12,000 mg/l Fe includes 6,000 Fe⁺; and 6,000 Fe⁺⁺.

ASTM Standards 1970⁺ or Standard Methods 1971¹⁶

nology is capable of treating almost any raw water to render it suitable for any industrial use. The treatment may be costly, and may require large ground space not always available at otherwise suitable plant locations. Sometimes the substitution of a more expensive alternative supply is necessary. Nevertheless, in most cases, the costs involved are but a small part of the total production and marketing costs of the industrial product in question.

It is evident that the more nearly the composition of an available water supply approaches the particular composition needed, the more desirable that water is, and, conversely, the more such compositions differ, the more difficult and expensive it is to modify the water for use. Improper operation or malfunction of control instruments or water treating equipment may cause a deterioration of the treated water, and this, in turn, can cause deterioration or loss of product and damage to equipment. The poorer the quality of the raw water, the more serious the consequences of such malfunctions.

Improving the quality of a given water supply will only incrementally decrease the cost of treatment for an industrial installation, because it is often too late to make economical alterations in the existing water treatment facilities. For the same reason, if the quality characteristics of the water supply are allowed to deteriorate from their usual range, the cost for treatment can be substantially increased. On the other hand, improved water supply characteristics at a given site may mean lower water treatment costs for other industries subsequently established there.

Table VI-2 summarizes quality characteristics of surface waters at the point of intake that have been used as sources of boiler makeup, cooling, and process water.

CONCLUSIONS

- Industry is diversified in kind, size, and product. It incorporates many processes, including different

ones to achieve the same ends. Water quality requirements for different industries, for various industrial processes within a single plant, and for the same process in different plants vary widely.

- Water quality requirements at *point of use*, as distinguished from requirements at *point of intake*, are established for a number of industrial processes but are inadequately defined or nonexistent for others.
- Modern water treatment technology permits water of virtually any quality to be treated to provide the characteristics desired by industry at point of use. Occasionally, this may be costly; but in general the cost of treating water for specific processes is acceptable to industry, because it is only a small part of total production and marketing costs.
- Although water quality at *point of use* is critical for many industrial processes, industry's *intake water* quality requirements are not as stringent as those for public water supplies, recreational or agricultural use, or support of aquatic life.
- Because of the diversity of industrial water quality requirements, it is not possible to state specific values for intake water quality characteristics for industrial use. Ordinarily these values lie between those that have been used by industries for sources of water (Table VI-2) and the quality recommended for other uses in other sections of this book.

Recommendations

Desirable intake water quality characteristics for industrial water supplies can be meaningfully designated as a range lying between the values that have been used by industry for sources of water (Table VI-2) and the quality characteristics recommended for other water uses in other chapters of this Section. Values that exceed those in Table VI-2 would ordinarily not be acceptable to industry.