Water Quality

Water Quality Criteria for Aluminum

Overview Report

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Summary

This report is one in a series which establishes water quality criteria for the province. The report sets criteria for aluminum to protect a number of uses. These include drinking water, freshwater aquatic life, wildlife, livestock, irrigation and recreation.

The criteria are set as either maximum concentrations of total and dissolved aluminum which must be met any time, or average concentrations which should not be exceeded over a 30-day period. Actual values are summarized in the Tables and show that criteria for aquatic life vary according to the pH of the water.

Except for aquatic life, the criteria are consistent with Canadian Water Quality Guidelines drafted by the CCREM Task Force on Water Quality Guidelines (1987). For aquatic life in water with pH below 6.5, the criteria are less restrictive than the CCREM guidelines which are considered overprotective for BC conditions in the low pH range.

The major use of the criteria is as a guideline for assessments of water quality conditions. They are thus one of the factors considered when water quality objectives for a specific body of water are being set.

Tables

Table 1. Summary of Water Quality Criteria for Aluminum

Water Use	Maximum Aluminum in mg/L (use instantaneous pH value)	30-Day Mean Aluminum in mg/L (use median pH value)
Drinking Water Supply	0.2 mg/L dissolved Al	None proposed
Fresh Water Aquatic Life (pH greater than or equal to 6.5)	0.1 mg/L dissolved Al	0.05 mg/L dissolved Al
Fresh Water Aquatic Life (pH less than 6.5)	dissolved Al = $_e(1.209 - 2.426\ (pH) + 0.286\ K)$ where $K = (pH)^2$	dissolved Al = $_e(1.6 - 3.327\ (median\ pH) + 0.402\ K)$ where $K = (median\ pH)^2$
Wildlife Water Supply	5 mg/L total Al	None proposed
Livestock Water Supply	5 mg/L total Al	None proposed
Marine and Estuarine Aquatic Life	None proposed	None proposed
Irrigation Water Supply	5 mg/L total Al	None proposed
Recreation and Aesthetics	0.2 mg/L dissolved Al	None proposed

1. When detailed knowledge of the bioavailable forms of aluminum is available, the form of aluminum in the criteria for aquatic life can be modified, as justified by the data.

2. The average is calculated from at least 5 weekly samples

taken in a period of 30 days.

3. Table 2 and Table 3 give maximum and 30-day average criteria specified by the regression equations. (If the natural levels exceed the criteria, the increase in aluminum levels above background to be allowed, if any, should be based on site-specific data).

Table 2. Maximum Dissolved Aluminum Concentration (mg/L) at pH LESS THAN 6.5

pH	Maximum	pH	Maximum	pH	Maximum
pH 4.0-4.6	0.020 mg/L	pH 5.3	0.027 mg/L	pH 5.9	0.043 mg/L
pH 4.7-4.8	0.021 mg/L	pH 5.4	0.029 mg/L	pH 6.0	0.047 mg/L
pH 4.9	0.022 mg/L	pH 5.5	0.031 mg/L	pH 6.1	0.052 mg/L
pH 5.0	0.023 mg/L	pH 5.6	0.033 mg/L	pH 6.2	0.059 mg/L
pH 5.1	0.024 mg/L	pH 5.7	0.036 mg/L	pH 6.3	0.066 mg/L
pH 5.2	0.025 mg/L	pH 5.8	0.039 mg/L	pH 6.4	0.074 mg/L

Table 3. 30-Day Average Dissolved Aluminum Concentration (mg/L) at pH LESS THAN 6.5

Median pH	30-day mean	Median pH	30-day mean	Median pH	30-day mean
pH 4.0-4.5	0.005 mg/L	pH 5.5	0.011 mg/L	pH 6.0	0.020 mg/L
pH 4.6-4.9	0.006 mg/L	pH 5.6	0.012 mg/L	pH 6.1	0.024 mg/L
pH 5.0-5.1	0.007 mg/L	pH 5.7	0.013 mg/L	pH 6.2	0.028 mg/L

pH 5.2	0.008 mg/L	pH 5.8	0.015 mg/L	pH 6.3	0.033 mg/L
pH 5.3	0.009 mg/L	pH 5.9	0.018 mg/L	pH 6.4	0.040 mg/L
pH 5.4	0.010 mg/L	—	—	—	—

Preface

THE MINISTRY OF ENVIRONMENT, LANDS AND PARKS (now called Ministry of Water, Land and Air Protection) develops province-wide ambient water quality guidelines for variables that are important in the surface waters of British Columbia. This work has the following goals:

1. to provide guidelines for the evaluation of data on water, sediment, and biota
2. to provide guidelines for the establishment of site-specific ambient water quality objectives

Ambient water quality objectives for specific waterbodies will be based on the guidelines and also consider present and future uses, waste discharges, hydrology/limnology/oceanography, and existing background water quality. The process for establishing water quality objectives is more fully outlined in *Principles for Preparing Water Quality Objectives in British Columbia*, copies of which are available from the Water Quality Section of the Environmental Quality Branch.

Neither guidelines nor objectives which are derived from them, have any legal standing. The objectives, however, can be used to calculate allowable limits or levels for contaminants in waste discharges. These limits are set out in waste management permits and thus have legal standing. The objectives are not usually incorporated as conditions of the permit.

The definition adopted for a guideline is:

> ***A maximum and/or a minimum value for a physical, chemical or biological characteristic of water, sediment or biota, which should not be exceeded to prevent specified detrimental effects from occurring to a water use, including aquatic life, under specified environmental conditions.***

The guidelines are province-wide in application, are use-specific, and are designed for some or all of the following specific water uses:

- raw drinking, public water supply and food processing
- aquatic life and wildlife
- agriculture (livestock watering and irrigation)
- recreation and aesthetics
- industrial (water supplies)

The guidelines are set after considering the scientific literature, guidelines from other jurisdictions, and general conditions in British Columbia. The scientific literature gives information on the effects of toxicants on various life forms. This information is not always conclusive because it is usually based on laboratory work which, at best, only approximates actual field conditions. To compensate for this uncertainty, guidelines have built-in safety factors which are conservative but reflect natural background conditions in the province.

The site-specific water quality objectives are, in most cases, the same as guidelines. However, in some cases, such as when natural background levels exceed the guidelines, the objectives could be less stringent than the guidelines. In relatively rare instances, for example if the resource is unusually valuable or of special provincial significance, the safety factor could be increased by using objectives which are more stringent than the guidelines. Another approach in such special cases is to develop site-specific guidelines by carrying out toxicity experiments in the field. This approach is costly and time-consuming and therefore seldom used.

Guidelines are subject to review and revision as new information becomes available, or as other circumstances dictate.

The guidelines apply to the ambient raw water source before it is diverted or treated for domestic use.

The Ministry of Health regulates the quality of water for domestic use after it is treated and delivered by a water purveyor.

Guidelines relating to public health at bathing beaches are the same as those used by the Ministry of Health which regulates the recreation and aesthetic use.

Recommended Guidelines

These criteria are based on a detailed analysis given in a technical appendix and are summarized in the Tables. The criteria are consistent with the Canadian Water Quality Guidelines (CCREM guidelines) issued by the Canadian Council of Resource and Environment Ministers (1987), except as noted.

1. DRINKING WATER (INCLUDES FOOD PROCESSING WATER)

A drinking water quality criterion for aluminum based on aesthetic considerations is recommended to be 0.2 mg/L dissolved aluminum (maximum at any time).

This criterion would apply to both untreated raw water and raw water treated to remove suspended solids. While there is presently no health evidence upon which to base a drinking water criterion, this level is considered to provide consumers with a margin of safety from potential health risks associated with aluminum ingestion.

There are no Health and Welfare Canada guidelines and no CCREM guidelines for aluminum in drinking water.

2. AQUATIC LIFE

The criteria are expressed in terms of dissolved aluminum which provides the most general application in the absence of detailed site-specific information. When detailed knowledge of the bio-available forms of aluminum in a waterbody is available, the form of aluminum in the criteria may be modified, as justified by the data (see Application of Criteria).

2.1 Freshwater Aquatic Life

The 30-day average concentration of dissolved aluminum (based on a minimum of 5 approximately weekly samples) should not exceed:

1. 0.05 mg/L when the median pH over 30 days is greater than or equal to 6.5
2. the value determined by the following relationship at median pH less than 6.5

$$\text{Dissolved Aluminum} = {}_{e}e(1.6-3.327\ (\text{median pH}) + 0.402\ K)$$
$$\text{where } k = (\text{median pH})^2$$

Examples based on this formula are found in Table 2.

The maximum concentration of dissolved aluminum at any time should not exceed:

1. 0.10 mg/L when the pH is greater than or equal to 6.5
2. the value determined by the following relationship at median pH less than 6.5

$$\text{Dissolved Aluminum} = {}_{e}e(1.6-3.327\ (\text{median pH}) + 0.402\ K)$$
$$\text{where } k = (\text{pH})^2$$

Examples based on this formula are found in Table 3.

If natural background levels exceed the 30-day average or maximum as shown above, then the increase in dissolved aluminum above background to be allowed, if any, should be based on site-specific conditions.

The 30-day average criteria recommended for freshwater aquatic life at pH less than 5.4 are presently below the limit detectable by the Provincial Environmental Laboratory. The minimum detectable concentration for dissolved aluminum is 10 ug/L at this time, and until the detection limit can be improved measurements reported as less than 10 ug/L will be considered acceptable. However, receiving water aluminum concentrations calculated from waste loadings should not exceed the recommended criteria or site-specific objective at appropriate locations in the waterbody.

For water with pH below 6.5, these criteria are less restrictive than the CCREM guidelines which were considered overprotective for BC conditions over most of the low pH range.

2.2 Estuarine and Marine Aquatic Life

No criteria recommended.

3. WILDLIFE

The concentration of total aluminum in waters frequented by wildlife should not exceed 5 mg/L at any time.

There are no CCREM guidelines for wildlife.

4. LIVESTOCK

The concentration of total aluminum in livestock drinking water should not exceed 5 mg/L at any time.

5. IRRIGATION

The concentration of total aluminum in irrigation waters for continuous use on all soils should not exceed 5 mg/L at any time.

6. RECREATION AND AESTHETICS

A drinking water quality criterion for aluminum based on aesthetic considerations is recommended to be 0.2 mg/L dissolved aluminum (maximum at any time).

The drinking water criterion (for untreated raw water) given in this document is adopted as the criterion to protect waterbodies used for recreational activities.

There are no CCREM guidelines for recreation and aesthetics.

Application of the Guidelines

APPLICATION OF THE CRITERIA FOR AQUATIC LIFE

1. ANALYTICAL TECHNIQUES

The criteria recommended here have two applications: for assessing existing water quality data, and for setting water quality objectives. The application will determine how the criteria should be used. In assessing existing water quality data or in setting water quality objectives, there are advantages and disadvantages to using any one of the analytical techniques that are presently available and that can be performed on a routine, province-wide basis. The advantages and disadvantages of these techniques are reviewed below.

1.1 Total Aluminum

The advantage of total aluminum is that all the aluminum that may potentially be toxic is included in the measurement (i.e., if the total aluminum concentration measured in a waterbody is within the criteria limits, then it can be concluded with confidence that no aluminum problems exist). Another advantage of total aluminum is that, for comparative purposes, there is sometimes a considerable amount of historical background data available. Furthermore, total aluminum is a relatively inexpensive measurement and can be easily monitored on a routine basis.

The main disadvantage of using total aluminum to assess water quality is that a large fraction of the total aluminum may be in forms that are not biologically reactive (e.g., organically complexed or sorbed by particulates). Therefore, total aluminum usually overestimates toxicity to a considerable extent, especially in a turbid waterbody with high complexing capacity.

1.2 Dissolved Aluminum

The main advantage of dissolved aluminum is that most of the bio-reactive aluminum is likely to be in the dissolved fraction. The measurement excludes particulate aluminum which is less likely to be biologically reactive. Another advantage of dissolved aluminum is that, for comparative purposes, there is sometimes a considerable amount of historical background data available. Furthermore, dissolved aluminum is a relatively inexpensive measurement and can easily be monitored on a routine basis.

A disadvantage of using dissolved aluminum is that as an operationally defined measurement, it does not indicate the species of aluminum included, and it includes all that can pass through a 0.45 micron filter. It could include aluminum-containing particulates that are retained by a 0.01-0.1 micron filter. In addition, a portion of the dissolved aluminum fraction may be complexed with soluble organic ligands and not biologically active. Thus, dissolved aluminum may overestimate the bio-available aluminum.

It is also possible that dissolved aluminum could underestimate the bio-available toxic aluminum. In some cases, biologically available aluminum may be weakly adsorbed to the filter or large organic macromolecules, and hence be retained in the non-filterable fraction. The extent of this underestimation has not been described adequately in the literature.

1.3 Extractable Aluminum

The advantage of extractable aluminum is that it includes both the weakly-sorbed aluminum in the particulate fraction which may be biologically reactive, and the dissolved aluminum fraction which is likely to contain most of the bio-reactive aluminum.

The disadvantage of extractable aluminum is that, like dissolved aluminum, it can include aluminum complexed with soluble organic ligands, and the bio-reactive aluminum may be overestimated. Also, extractable aluminum, like dissolved aluminum, is an operationally defined measurement, and therefore is subject to the same uncertainties. Another disadvantage of extractable aluminum is that the analytical technique, as presently defined by the Inland Waters Directorate, is not restrictive enough (i.e., no standard time period between sample collection and analysis) to ensure reproducible results. Caution should be exercised when comparing historical levels of extractable metals because no time restriction on sample storage was specified in the past. Furthermore, there are a number of different "extractable" procedures in the literature, sufficiently different that the results are not comparable to each other. A measurement for extractable aluminum will likely be between total and dissolved aluminum for a particular waterbody. In eutrophic waters, extractable aluminum is likely to be closer to total aluminum values than dissolved aluminum values, whereas in oligotrophic waters, extractable, dissolved and total aluminum values are likely to be similar.

1.4 Inorganic Aluminum

The inorganic monomeric fraction of aqueous aluminum has shown strong association with toxicity to aquatic life and is considered by various investigators to be the bioavailable fraction. Total and dissolved aluminum, in contrast, may not correlate well with toxicity because of particulate matter and the varying complexing capacities of natural water.

Methods for the fractionation of aluminum exist, but are at an early stage of development and are both expensive and laborious. Improvements are needed before they can be applied routinely to general water quality monitoring programs. The speciation methods cannot measure aluminum species directly but rather define the aluminum species operationally so that minor differences in methodology (e.g. dialysis time) can result in different degrees of aluminum species separation. There is also considerable uncertainty as to what aluminum species really exist in solution, and there is still a lack of definitive characterization of the relative toxicities of the aluminum species. The Provincial Environmental Laboratory does not, at this time, have the capability to fractionate aqueous aluminum. However, as more knowledge on the bioavailable forms of aluminum becomes available and as speciation methods are developed, the form of aluminum specified in the criteria may be modified.

2. ASSESSMENT OF EXISTING WATER QUALITY DATA

The criteria recommended in this document are based predominantly on laboratory bioassays, which usually have been performed using dilution waters with low complexing capacities. The criteria are therefore likely to be overprotective for many waterbodies, especially for those in a eutrophic condition in which aluminum complexes may form. Therefore, based on the analysis of dissolved aluminum, it cannot be concluded with certainty that an aluminum problem exists in a waterbody if measurements exceed the criteria. If any of these measurements suggest that a problem exists by exceeding the criteria, and if aluminum is anthropogenically generated, then a more intensive investigation employing other techniques would have to be used to confirm that a problem exists. Other methods may include one or more assessment techniques such as aluminum speciation methods, measuring the complexing capacity, bioassays on sensitive resident species using local water, and population studies on biota (fish, benthos, algae, etc.). Because of the complexity and cost of these alternative methods, they should be reserved for waterbodies with high fisheries values, which are threatened by a controllable aluminum input.

3. SETTING WATER QUALITY OBJECTIVES

In setting water quality objectives for waterbodies which exceed the aluminum criteria as a result of existing discharges, it would be necessary to determine the form of discharged aluminum (particulate, organically complexed, soluble). Also, in view of the dependence of aluminum toxicity on ambient hardness, pH, and organic carbon, an assessment would have to be performed on a site-specific basis to determine if the biota are being harmed. The use of alum in the treatment of certain municipal effluents results in the discharge of residual aluminum. Further work will be needed to determine whether such discharges are toxic to aquatic life.

For undeveloped waterbodies, two situations could exist: natural concentrations (i.e., non-anthropogenic) either meet the criteria or they do not. At any location, both cases may occur depending upon the time of year. When natural concentrations in water equal or exceed the criteria, the objectives should be based on the natural levels and any increase in dissolved aluminum to be allowed should be based on site-specific investigations. Even though dissolved aluminum can in theory underestimate the bio-reactive aluminum, the use of dissolved aluminum for objectives is recommended because it more closely represents the bio-reactive aluminum than either extractable or total aluminum.

When natural concentrations of dissolved aluminum in undeveloped waterbodies are less than the criteria levels, then the criteria, or more stringent values if justified, should apply. In some cases, socioeconomic factors may justify objectives which are less stringent than the criteria. Site-specific impact studies would be required in such cases.