Water Quality

Ambient Water Quality Criteria for Fluoride

Overview Report

Prepared pursuant to Section 2(e) of the
Environment Management Act, 1981

Original signed by J. O'Riordan
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Summary

This document is one in a series that establishes ambient water quality criteria for British Columbia. It includes an overview which is followed by the main body of the report. This document sets criteria for fluoride to protect habitat for freshwater and marine aquatic life, drinking water for wildlife, livestock and man, irrigation water for crops and water for industrial food processing.

Criteria were not set for recreational waters since there were no suitable data documenting the effects of fluoride for this use and any such criteria would be higher than the aquatic life criteria and therefore redundant. The criteria are interim until suitable controlled experiments can determine the appropriate levels of fluoride under various combinations of water temperature and hardness.

Fluoride is most toxic to freshwater aquatic life and to people undergoing dialysis. Fluoride accumulates, permanently, in the long bones of vertebrates, causing fluorosis, when present in excessive amounts. Fluoride criteria are summarized in the section on Recommended Criteria. A more detailed discussion of the criteria is presented in the full report.

Tables

Table 1: Summary Table of Recommended Criteria for Fluoride

WATER USE	CRITERIA (in mg/L as total F)

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Raw Drinking Water	1.0 mg/L as a 30-day mean —— 1.5 mg/L as a maximum
Fresh Water Aquatic Life	0.4 as a maximum where the water hardness is 10 mg/L $CaCO_3$ otherwise use the equation: LC_{50} fluoride = $-51.73 + 92.57 \log_{10}$ (Hardness) and multiply by 0.01
Marine Aquatic Life	1.5 mg/L maximum
Wildlife	1.0 mg/L as a 30-day mean —— 1.5 mg/L as a maximum
Dairy Cows, Breeding Stock - long-lived animals	1.0 mg/L as a 30-day mean —— 1.5 mg/L as a maximum
Livestock - high fluoride diets - mineral or bone meal feed additives	1.0 mg/L as a 30-day mean —— 2.0 mg/L as a maximum
All Other Livestock - normal diet	2.0 mg/L as a 30-day mean —— 4.0 mg/L as a maximum
Irrigation - all soils	1.0 mg/L as a 30-day mean —— 2.0 mg/L as a maximum
Recreation	No criterion set
Industrial - beer - beverages - processed foods	1.0 mg/L as a 30-day mean —— 1.5 mg/L as a maximum

1. Table values are in mg/L of total fluoride.
2. This is an interim criterion until carefully controlled experiments can determine the appropriate levels of fluoride under various combinations of water temperature and hardness, measured as calcium carbonate.
3. The Okanagan Valley is the only area of the Province where background values generally exceed 0.2 and even there levels do not generally exceed 0.3.

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 Water Quality Section of the Water Management 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 developed 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.

Introduction

Fluoride Toxicity

A natural or man-made chemical present in the environment does not always lead to human or animal exposure. Exposure requires contact with substances containing the chemical. Exposure itself is not necessarily harmful; several other factors determine whether contact leads to harmful effects and the type and severity of these effects. These factors include the dose (how much), the duration (how long), the timing (when in the life cycle), the route of exposure (injection, inhalation, ingestion, contact) and individual characteristics and lifestyles (sex, age, health, habits, fitness, genetic predisposition).

Populations that are unusually susceptible to toxic effects from fluoride are those human populations undergoing dialysis due to malfunction or loss of their kidneys and those freshwater wildlife populations in very soft water. Livestock receiving high-fluoride feed supplements are also at risk of fluorosis from fluoride pollution of their pastures or high fluoride in their drinking water.

Some portions of the population are more at risk from high fluoride levels than others; they include: workers in welding, aluminum smelter and phosphate fertilizer industries; people living near such industries where water and air are subject to pollution: people living in areas where goiter is endemic; people with kidney disfunction, polydipsia or diabetes insipidus; those whose diets are deficient in iodine, calcium, manganese or vitamin-C; and those with low calcium to phosphorus ratios in their diet.

Fluoride Contamination

Wastewater from aluminum, steel and phosphate fertilizer plants are the major sources of fluoride contamination. Glass. tile, brick, adhesives, ceramics, herbicides, insecticides metal fluxes, brazing, welding, plating and smelting industries also produce fluoride waste.

The main sources of fluoride contamination in BC are the Alcan aluminum smelter in Kitimat and the Cominco fertilizer plants in Trail and Kimberley.

Recommended Guidelines

A summary of the water quality criteria for fluoride is given in Table 1. The criteria are based on a detailed analysis given in a full report. The criteria are consistent with the Canadian Water Quality Guidelines (CCREM Guidelines) issued by the Canadian Council of Resource and Environment Ministers (1997), except as noted (the CCREM is now known as the CCME, or Canadian Council of Ministers of the Environment).

RAW DRINKING WATER

> ***Total fluoride should not exceed 1.0 mg/L as a 30-day mean, in raw drinking water in British Columbia. The maximum value is 1.5 mg/L. The mean is based on a minimum of five samples.***

These criteria meet CCREM guidelines and the water will meet British Columbia Water Quality Standards (1982) without further treatment. Normal water treatment processes will not substantially affect fluoride levels.

AQUATIC LIFE

In fresh water total fluoride should not exceed 0.4 as a maximum where the water hardness is 10 mg/L $CaCO_3$otherwise use the equation: LC_{50} fluoride = -51.73 + 92.57 $\log_{10}$ (Hardness) and multiply by 0.01

Fluoride should not exceed 1.5 mg/L in marine or estuarine waters used by aquatic life. There is no CCREM guideline for aquatic life.

LIVESTOCK

The total fluoride recommendation for dairy cows, breeding stock and other long-lived animals is 1.0 mg/L as a 30-day mean and 1.5 mg/L as a maximum. Total fluoride should not exceed 2.0 mg/L as a 30-day mean or 4.0 mg/L maximum in the drinking water of all other types of livestock, unless fluoride is provided in the diet by bone meal or mineral additives, in which case 1.0 mg/L as a 30-day mean and 2.0 mg/L maximum is recommended.

The CCREM guidelines are maximums of 1.0 mg/L when fluoride supplements are fed and 2.0 mg/L otherwise.

WILDLIFE

Total fluoride should not exceed 1.0 mg/L as a 30-day average or 1.5 mg/L as a maximum in fresh water used by wildlife.

There is no CCREM guideline for wildlife.

IRRIGATION

Total fluoride in irrigation water should not exceed 1.0 mg/L as a 30-day average or a maximum of 2.0 mg/L.

The CCREM guideline is a maximum of 1 mg/L.

RECREATION

No criterion for fluoride is set for recreational waters nor is any set by CCREM.

INDUSTRIAL

Drinking water criteria are recommended, primarily for the beer, beverage and processed foods industries.

No CCREM guideline exists for this water use.

Application of the Guidelines

Some natural supplies exceed the fluoride drinking water objective of 1.0 mg/L, they need to be treated to remove excess fluoride. Other supplies are below the objective and need to have fluoride added since too little has detrimental effects on teeth.

Water supplies which have excessive fluoride levels need to be reduced before delivery to the consumer. There are a number of processes which will do this, but all are expensive and few jurisdictions carry them out. Precipitation of calcium fluoride by adding calcium salts such as calcium hydroxide, calcium sulphate or calcium chloride is one method and adsorption to the insoluble aluminum hydroxide is another method. Ion exchange and sorption on bone char, synthetic ion exchange media and activated alumina are also practiced.

Fluoride is added to water as sodium fluoride, sodium silicofluoride or fluorosilicic acid where water fluoridation is practiced In 1985, only 11% of British Columbia's population received fluoridated water. The fluoride content of natural water supplies in Canada varies between 0.01 and 4.5 milligrams per litre (mg/L). Ground water infiltration is suspected of being the major source of fluoride in surface water with high fluoride concentrations.

High dental caries levels may occur if fluoride levels are below 0.5 mg/L. Small amounts of fluoride reduce dental caries while excessive levels cause mottling of teeth. Water with less than 1.0 mg/L fluoride will seldom cause mottled tooth enamel in children. There is abundant literature to show the advantages of maintaining a fluoride level of about 1 mg/L. In adults less than 3.0 or 4.0 mg/L causes no skeletal effects and up to 5.0 mg/L causes only mottling of tooth enamel.

The fluoride criteria are temperature dependent. The lowest isotherms used are 12 degrees C or 10 degrees C and in both these cases the optimum fluoride level is 1.2 mg/L. In British Columbia the mean annual daily maximum temperature is below the 10 degrees C isotherm, except for two areas which may reach 10 degrees C or 11 degrees C some years, but never reach the 12 degrees C isotherm. The areas where the mean may be this high are, however, the most highly populated areas of southeastern Vancouver Island, the lower Fraser Valley and the Okanagan Valley. In these areas, the optimum level of fluoride would be 1.0 mg/L or 1.2 mg/L but in all other areas of British Columbia the optimum level would be 1.2 mg/L. The maximum acceptable level is 1.5 mg/L or 1.7 mg/L.

Only a few areas in British Columbia reach the 10 degrees C isotherm and these isotherms are not always reached. These areas are thus marginal cases. It is not judged that any harm would result from using the 1.2 mg/L criterion uniformly throughout British Columbia especially since the peak summer temperatures in the Victoria and Vancouver areas are relatively low and the main reason the mean reaches 10 degrees C is due to relatively high winter temperatures. Thus, summer water consumption would not be inordinately high. However, the 1.0 mg/L fluoride concentration is recommended since it should adequately protect teeth and allows a little more safety margin between the therapeutic dose and harmful levels.

The fluoride criterion is unique in this regard since most other criteria have at least a ten-fold safety factor between the criterion and any known effect levels. This is not possible with fluoride and in any case the first "harmful" effects to appear are cosmetic and not functional.

Fluoride ions are directly toxic to aquatic life, and accumulate in the tissues, at concentrations where absorption rates exceed excretion rates. Some accumulation occurs in all tissues, but in most tissues subsequent losses may occur when ambient fluoride levels decrease. However, in bone, tooth and scales, accumulation is permanent and cumulative. Temperature affects fluoride toxicity, in part because metabolic rates and thus uptake rates double for every 10 degree C rise in temperature. The duration of exposure also affects toxicity. The fluoride level necessary to cause death of half a population decreases as the time of exposure increases.

Water hardness, mostly calcium, also affects fluoride toxicity; however, there exists considerable confusion in this area. The solubility of calcium fluoride is 16 mg/L (7.8 mg/L fluoride and 8.2 mg/L calcium). When high fluoride levels are used in experiments with hard water, both the hardness and the fluoride level of the solution drop rapidly due to precipitation of the calcium fluoride. If additional fluoride is added to try and maintain a fluoride level, precipitation will continue as long as free calcium is available.

One can eventually achieve a high fluoride solution but only after most calcium and magnesium have been reacted. This means that the water is no longer hard, but soft. Thus, one can not carry out an experiment on the effects of high fluoride in hard water, and if hardness is maintained, fluoride levels will be driven down to less than 10 mg/L.

Of the natural fluoride level in the ocean, 1.2 to 1.4 mg/L, only about half is in the biologically available fluoride ion form; the rest is present as a relatively insoluble magnesium fluoride complex. Thus the effects on marine organisms noted for ambient fluoride levels are essentially due to actual levels of about 0.6 to 0.7 mg/L of available fluoride.

Fluoride accumulates in hard or mineralized tissues such as bones, teeth and invertebrate exoskeletons. In bone, the presumed process is fluoride ion exchange in the hydroxyapatite complex. In the amorphous crustacean skeletons, most fluoride is likely to be simply calcium fluoride precipitated in the open matrix. Dietary studies have shown that fish accumulate fluoride in hard tissues and in parts of South-East Asia this results in some human populations having a high fluoride diet. Marine mammals and birds which live on fish can also receive excessive fluoride in their diets from this source. Those parts of the fish in contact with the water, such as scales, fins and gills, have the highest fluoride levels. Skin is very high in fluoride and predators consuming the whole fish are subject to much higher fluoride levels than man who often removes the skin first. Canned salmon and mackerel have high fluoride levels in the bones and some prepared feeds containing fish meal also have high fluoride levels.

Dairy feed and mineral supplements may contain high levels of fluoride, up to 200 mg/kg, though most are under 30 mg/kg. Cows may thus get more than their recommended daily dose of fluoride from this source before water and forage are even considered. Bone meal supplements can be very high in fluoride since cattle grazing contaminated pastures may accumulate 10 g fluoride/kg of bone; the normal level is around 1.5 g fluoride/kg. It is recommended that such products not be marketed if their fluoride levels exceed 5 to 10 mg fluoride/kg of product. Levels in excess of this put severe restrictions on the levels of fluoride which can be accepted in forage and water, if the acceptable total fluoride dose in the diet is not to be exceeded.

The toxic effects of fluoride can be affected in several ways. Alternating high and low fluoride levels have been shown to be more toxic than a steady dose of the same total amount over a period of time. Fluoride toxicosis is reduced if the diet is high in calcium, sodium chloride, aluminum oxide, calcium carbonate, aluminum sulphate, aluminum chloride or aluminum acetate. Aluminum salts must be fed simultaneously; they will not deplete already deposited fluoride. Aluminum compounds may, however, affect dietary phosphorus retention and, if used to alleviate fluoride toxicosis, supplemental phosphorus may have to be fed as well.

Effects on livestock, wildlife and people are basically the same and occur at about the same fluoride levels. Aesthetics of mottled teeth are considered when people are concerned, but only function is considered when livestock and wildlife are concerned. Thus slightly higher levels of fluoride can be tolerated by livestock and wildlife.

Dairy cattle appear to be the most sensitive livestock to fluoride toxicity. They have high food and water uptake rates and long productive lives which leads to maximal opportunity for fluoride to accumulate to harmful levels in the bones and teeth. Most livestock is slaughtered well before fluoride accumulation would become a problem and can be exposed to higher levels of fluoride than breeding stock, laying hens or dairy cows.

Most plants do not take up much fluoride from the soil or from irrigation water; the major fluoride source is airborne deposition. Neutral and alkaline soils deactivate fluoride or restrict its uptake. Lower fluoride levels may be required for hydroponically-grown plants, but there are insufficient data to set a criterion for this use at present. Much of the total fluoride on a forage crop likely comes from the soil in which it is growing, not by uptake through the roots, but by deposition of soil particles on the surface of the plant. This deposition may be due to splashing during irrigation or rainfall or due to dust and particle suspension caused by cultivation and harvesting.

Fluoride toxicity in aquatic organisms is known to be affected by water hardness and temperature. Other constituents of the water, such as chloride, may also affect fluoride toxicity. A single multifactorial

experiment is needed to determine values for rainbow trout at various combinations of water hardness and temperature at which half the population dies. Such experiments would be expected to yield a single equation from which one would be able to derive the criteria for fluoride for any combination of water temperature and hardness.

Little is known about fluoride levels and availability in forage, crops and agricultural soils throughout British Columbia. A survey of crops, forage and soil fluoride levels should be conducted and the agricultural areas grouped into regions based upon fluoride levels found in forage and crops. This would allow region-specific fluoride levels to be determined for drinking, livestock watering and irrigation waters, and would maintain an acceptable total fluoride dose in the typical diet.

Almost nothing is known about synergistic effects of fluoride with other compounds. The specific cation associated with a fluoride salt may effect fluoride toxicity. Suitable experiments need to be carried out to determine if such effects do occur, and if so, the level at which they occur and the nature of the effect.

Research is needed on the chronic effects of various fluoride levels on salmonid eggs and larvae, and on *Daphnia* growth and reproduction, especially for soft waters. The effects of low-fluoride levels on food organisms must also take into account in predators as the fluoride moves up the food chain to longer-lived, bony, top predators. Levels not affecting prey may be unacceptable due to accumulation.