Water Quality

Ambient Water Quality Criteria for Dissolved Oxygen

Overview Report

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

Original signed by Don Fast
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Summary

This report is one in a series which establishes ambient water quality criteria for British Columbia. It includes an overview which is followed by the main body of the report. This report sets criteria for dissolved oxygen to protect aquatic life and discusses appropriate levels established elsewhere for drinking water, recreation and some industry.

Oxygen is the single most important component of surface water for self-purification processes and the maintenance of aquatic organisms which utilize aerobic respiration. The focus of this document is on the effects of minimum oxygen levels on aquatic life. Dissolved oxygen is not a known concern for other water uses other than for some industries, where corrosion can be a concern.

Dissolved oxygen standards and criteria from other agencies and jurisdictions are reviewed in the main body of the report along with information available from the literature. The objective of the review was to incorporate the most applicable information which could be used to formulate defensible criteria to protect aquatic life in British Columbia waters.

Tables

Table 1: Recommended Criteria for the Protection of Aquatic Life

Life Stages	All Life Stages Other Than Buried Embryo / Alevin	Buried Embryo / Alevin Life Stages	Buried Embryo / Alevin Life Stages
Dissolved Oxygen	Water Column	Water Column	Interstitial Water

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- concentration	mg/L O_2	mg/L O_2	mg/L O_2
Instantaneous Minimum	5	9	6
30-day Mean	8	11	8

1. For the buried embryo / alevin life stages these are in-stream concentrations from spawning to the point of yolk sac absorption or 30 days post-hatch for fish; the water column concentrations recommended to achieve interstitial dissolved oxygen values when the latter are unavailable. Interstitial oxygen measurements would supersede water column measurements in comparing to criteria.
2. The instantaneous minimum level is to be maintained at all times.
3. The mean is based on at least five approximately evenly spaced samples. If a diurnal cycle exists in the water body, measurements should be taken when oxygen levels are lowest (usually early morning).

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

Oxygen is the most abundant element of the earth's crust and waters combined. It is the single most important component of surface water for self-purification processes and the maintenance of aquatic organisms which utilize aerobic respiration.

The combination of the divalent oxygen atom with single valent hydrogen atom comprises the extremely stable H_2O molecule. Under natural conditions water exists in several physical states, but the molecule itself dissociates to a very limited extent as ions (H+ and OH-). Two OH- molecules can, by covalent bonding, combine to form H_2O_2 or hydrogen peroxide.

The double bonded, two-atom molecule is the single form of oxygen which has relevance to this discussion. Air contains approximately 20.9 percent oxygen gas by volume; however, the proportion of dissolved oxygen in air dissolved in water is about 35 percent, because nitrogen (the remainder) is less soluble in water. Oxygen is considered to be moderately soluble in water. This solubility is governed by a complex set of physical conditions that include atmospheric and hydrostatic pressure, turbulence, temperature and salinity .

In British Columbia surface waters, dissolved oxygen levels are usually high, close to saturation levels, and often greater than 10 mg/L. The amount of oxygen in marine water is naturally about 20% less than in freshwater. In lakes, oxygen levels depend primarily on seasonal temperature variation, depth, and trophic status.

Recommended Guidelines

The following criteria are based on information presented in the main body of the report, and are summarized in this overview.

Aquatic Life

Life Stages	All Life Stages Other Than Buried Embryo / Alevin	Buried Embryo / Alevin Life Stages	Buried Embryo / Alevin Life Stages
Dissolved Oxygen - concentration	Water Column mg/L O_2	Water Column mg/L O_2	Interstitial Water mg/L O_2
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2. The instantaneous minimum level is to be maintained at all times.
3. The mean is based on at least five approximately evenly spaced samples. If a diurnal cycle exists in the water body, measurements should be taken when oxygen levels are lowest (usually early morning).

Wildlife, Livestock, Raw Drinking Water and Irrigation

Dissolved oxygen criteria for the protection of wildlife, livestock, raw drinking water supplies and irrigation are not considered necessary at this time.

Recreation and Aesthetics

Dissolved oxygen criteria for recreation and aesthetics are not deemed necessary for British Columbia, as the criteria for aquatic life can be protective of virtually all waters where aesthetic considerations such as hydrogen sulphide generation could be an issue.

Industrial Water Uses

With the exception of the food and beverage industries (using production water) and aquaculture, the presence of natural levels of dissolved oxygen in water for industrial operations generally is undesirable. It is accepted that industries incorporate conditioning processes to provide the quality levels necessary for the water supply, based on their own needs. Therefore, dissolved oxygen criteria for industrial water uses have not been developed.

Application of Guidelines

Dissolved oxygen is more reactive and variable in the short-term than most chemical constituents of water. Special considerations are necessary when designing a monitoring program and applying criteria.

Oxygen Cycles and Monitoring Frequency

Dissolved oxygen cycles in productive waters are common, and site-specific details must be taken into account when designing a sampling strategy. Diurnal oxygen fluctuations typically result in sub-optimal conditions for at least brief periods, therefore the timing of measurements is very important. It is the intent of two-number criteria proposed that these fluctuations do not go lower than the instantaneous minimum criterion. In natural waters influenced by oxygen generation from primary production, daily cycles usually are sinusoidal with a maximum concentration reached late in the day and a minimum concentration in early morning. Whether a cycle exists naturally or is the result of a manipulated discharge (e.g., a hypolimnetic withdrawal from a reservoir), it is necessary to determine a reasonable average of the extreme high and low concentrations once the shape of the oxygen curve is determined (i.e., at least two measurements must be taken). Cycles are more likely to be non-sinusoidal in manipulated flows, and the USEPA recommends that time-weighted averages be used in these circumstances. In addition, maximum dissolved oxygen concentrations used in calculating daily averages should not exceed the known saturation limit.

The required frequency of sampling can be based on a number of circumstances (e.g., known variability of oxygen levels in the source water, the most sensitive species / life stages present and their duration, and logistical constraints such as cost or distance between sample sites). For normal ambient monitoring, five measurements taken weekly within 30 days is a minimum frequency. As mentioned earlier, daily average values have to be used where cycles exist. Additional sampling is recommended where ambient levels are known to vary over time or are close to criteria values. A few excursions below the mean can easily result in non-attainment. In such cases, additional sampling over a 7-day averaging period would be prudent to check for anomalies and determine the extent of low dissolved oxygen concentrations.

Temperature Considerations

Although it was decided there were insufficient data to incorporate a temperature component into broad aquatic life criteria, it should be recognized that the effects of hypoxia likely are more severe under the added stress of higher temperatures. If the presence of early life stages (prone to highest mortality) coincides with high seasonal summer temperatures, special attention should be given to the attainment of criteria.

Multiple Toxicity Considerations

The dissolved oxygen criteria are sufficiently conservative so that multiple toxicity generally will not be a cause for concern. With the exception of ammonia, there is limited opportunity in the literature to develop quantitative relationships between dissolved oxygen and potential toxicants. It is recommended that multiple toxicity be dealt with on a site-specific basis where, in the presence of known contaminants (e.g., cyanide, un-ionized ammonia), the criteria for dissolved oxygen and the other contaminants may have to be modified to provide the appropriate level of protection for aquatic life. Where literature studies lack sufficient detail to accomplish this, bioassays could be performed on sensitive local species for the range of expected conditions.

Interstitial Considerations

It is incumbent on resource managers to have a reasonable understanding of the aquatic life resources being protected. For example, in salmonid-bearing waters, embryos and alevins typically are buried in the stream bottom or shallow lake bed for several months each year. Due to the variety of salmonids endemic to British Columbia, there may only be a limited time that early life stages are not present in spawning media. As discussed previously, the criteria for early life and mature life stages are the same when interstitial measurements are being used for the buried early life stages. If surface water is being tested, a 3 mg/L differential is assumed, wherein the instantaneous minimum and mean criteria values are raised to 9 and 11 mg/L, respectively, for the buried early life stages. Interstitial data clearly represent a more direct measure of available oxygen; however, the increased complexity of sampling may not be practical for routine field monitoring.

Natural Oxygen Levels That Do Not Meet Criteria

Studies of dissolved oxygen levels in spawning media have determined that, under normal circumstances, concentrations may not meet provincial criteria. Typical survival rates of incubating salmonids from egg deposition through to emergence are known to be relatively low due to a combination of stressors, and lack of oxygen commonly is cited. Based on works which detail the elevated oxygen requirements near the time of hatch, it is apparent that hypoxic stress, particularly in the interstitial environment, is not uncommon during early development.

In cases where natural dissolved oxygen concentrations in surface waters or sub-surface waters do not meet criteria, no statistically significant reduction below natural levels should be permitted. An accurate determination of natural ambient conditions, including temporal variability, would be critical in such an assessment. Statistical comparison of background levels (e.g., for lakes) or upstream / downstream measurements in relation to a perturbation such as a discharge should use a one-tailed, two-sample t-test, at the 0.05 probability level. The minimum sampling requirement is five measurements collected weekly in 30 days. The two-sample t-test requires the different stations to have similar variances (use the F-test). If, at the affected site, data from a discharge event are pooled with steady-state data, the variance may increase and become dissimilar to the ambient site invalidating the two-sample t-test. Data from the steady state and the event should be treated independently to reduce variance.