Water Quality

Water Quality Guidelines for Temperature

Overview Report

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Summary

This document is one in a series which establishes ambient water quality guidelines for British Columbia. It is based on a report prepared by G. G. Oliver and L. E. Fidler of Aspen Applied Sciences Ltd. under contract to the Water Management Branch. The Consultant's report, Towards a Water Quality Guideline for Temperature in the Province of British Columbia, provides the scientific background information, recommends guidelines and provides the supporting documentation.

The guidelines are safe conditions or levels of a variable which have province-wide application and are set to protect various water uses. This report sets guidelines for temperature, as appropriate, to protect

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drinking water, freshwater and marine aquatic life, wildlife, recreation and aesthetics, irrigation, livestock watering, and industrial water uses. The guidelines recommended by the consultants were adopted by the province, except where certain adjustments were deemed necessary as follows:

- For recreation and aesthetics, the guidelines recommended by the consultants were replaced by the Guidelines for Canadian Recreational Water Quality, which are used by the BC Ministry of Health Services. Guidelines relating to public health at bathing beaches fall under the authority of the BC Ministry of Health Services.

The guidelines are summarized in Table 1.

A major use of the guidelines is to set ambient water quality objectives. The objectives are the guidelines modified or adopted to protect the most sensitive designated water use in a particular body of water. The objectives are used in the preparation of waste management plans, pollution prevention plans, waste management permits, orders or approvals. These waste management permits, orders and approvals are the only documents that have legal standing.

Tables

Table 1: Summary of Water Quality Guidelines for Temperature

Water Use	Recommended Guideline
Drinking Water Supply	15 degrees Celsius maximum
Freshwater Aquatic Life - streams with bull trout and/or Dolly Varden	Maximum Daily Temperature is 15 degrees Celsius Maximum Incubation Temperature is 10 degrees Celsius Minimum Incubation Temperature is 2 degrees Celsius Maximum Spawning Temperature is 10 degrees Celsius
Freshwater Aquatic Life - streams with known fish distribution	+ or - 1 degree Celsius change beyond optimum temperature range as shown in Table 2 for each life history phase of the most sensitive salmonid species present Hourly rate of change not to exceed 1 degree Celsius
Freshwater Aquatic Life - streams with unknown fish distribution	MWMT = 18 degrees Celsius (Maximum Daily Temperature = 19 degrees Celsius) Hourly rate of change not to exceed1 degree Celsius Maximum Incubation Temperature = 12 degrees Celsius (in the spring and fall)
Freshwater Aquatic Life - lakes and impoundments	+ or - 1 degree Celsius change from natural ambient background
Marine and Estuarine Aquatic Life	+ or - 1 degree Celsius change from natural ambient

	background the hourly rate of change up to 0.5 degrees Celsius see narrative in footnote
Wildlife and Livestock Watering Irrigation and Industrial Water Supplies	+ or - 1 degree Celsius change from natural ambient background the hourly rate of change should not exceed 0.5 degrees Celsius
Recreation and Aesthetics	30 degrees Celsius maximum see narrative in footnote

1. The MWMT, mean weekly maximum temperature is defined as the average of the warmest daily maximum temperatures for seven consecutive days.
2. The natural temperature cycle characteristic of the site should not be altered in amplitude or frequency by human activities.
3. The thermal characteristics of waters used for bathing and swimming should not cause an appreciable increase or decrease in the deep body temperature of bathers and swimmers.

Table 2: Optimum Temperature Ranges of Specific Life History Stages of Salmonids and Other Coldwater Species for Guideline Application

Species	Incubation	Rearing	Migration	Spawning
Salmon				
Chinook	5.0-14.0	10.0-15.5	3.3-19.0	5.6-13.9
Chum	4.0-13.0	12.0-14.0	8.3-15.6	7.2-12.8
Coho	4.0-13.0	9.0-16.0	7.2-15.6	4.4-12.8
Pink	4.0-13.0	9.3-15.5	7.2-15.6	7.2-12.8
Sockeye	4.0-13.0	10.0-15.0	7.2-15.6	10.6-12.8
Trout				
Brown	1.0-10.0	6.0-17.6	—	7.2-12.8
Cutthroat	9.0-12.0	7.0-16.0	—	9.0-12.0
Rainbow	10.0-12.0	16.0-18.0	—	10.0-15.5

Char				
Arctic Char	1.5-5.0	5.0-16.0	—	4.0
Brook Trout	1.5-9.0	12.0-18.0	—	7.1-12.8
Bull Trout	2.0-6.0	6.0-14.0	—	5.0-9.0
Dolly Varden	—	8.0-16.0	—	—
Lake Trout	5.0	6.0-17.0	—	10.0
Grayling				
Arctic Grayling	7.0-11.0	10.0-12.0	—	4.0-9.0
Whitefish				
Lake Whitefish	4.0-6.0	12.0-16.0	—	greater than 8.0
Mountain Whitefish	less than 6.0	9.0-12.0	—	less han 6.0
Other Species				
Burbot	4.0-7.0	15.6-18.3	—	0.6-1.7
White Sturgeon	14.0-17.0	—	—	14.0

Preface

THE 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 Services regulates the quality of purveyed water.***
>
> ***Guidelines relating to public health at bathing beaches are the same as those used by the Ministry of Health Services***

which regulates the recreation and aesthetic use.

Recommended Guidelines

These guidelines are based on information presented in a consultant's technical report and are summarized in Table 1. Some changes have been made and are identified in the Summary at the beginning of this overview.

1.0 RAW DRINKING WATER SUPPLY

The aesthetic objective for temperature of less than or equal to 15 degrees Celsius in water to be used for drinking is adopted from the 'Guidelines for Canadian Drinking Water', which has been accepted by the Ministry of Health Services for application in British Columbia.

2.0 AQUATIC LIFE

These guidelines are designed to protect aquatic life in fresh, estuarine and coastal marine waters from excessive temperature fluctuations that are influenced by anthropogenic activities during sensitive periods. Given the large variation in water temperatures throughout British Columbia due both to the geographical range of the province as well as the large differences in elevation, ambient temperatures are factored into the guidelines so that they adhere closely to the natural temperature regime to which sensitive organisms have adapted through evolutionary processes. In addition, special recognition in terms of more restrictive guidelines have been recommended for streams and rivers frequented by bull trout *Salvelinus confluentus*. Dolly Varden *Salvelinus malma*, once thought to be the same species of char as bull trout, have also been afforded this same special protection because of their close relationship which suggests that both species may be equally sensitive to thermal variations.

To protect freshwater aquatic life, the Canadian Council of Ministers of the Environment (CCME) set a series of complex, narrative guidelines for temperature in 1987. They are appended at the end of this document. The guidelines recommended for British Columbia attempt to remove some of this complexity with more useable, practical guidelines.

2.1 Streams Frequented by Bull Trout *Salvelinus confluentus* and/or Dolly Varden *Salvelinus malma*

- the Maximum Daily Temperature should not exceed 15 degrees Celsius
- maximum spawning temperature should not exceed 10 degrees Celsius
- preferred incubation temperatures should range from 2 to 6 degrees Celsius

Rationale

Bull trout have demonstrated the highest thermal sensitivity of native BC fish species tested. Hence, more restrictive guidelines specific to streams frequented by this species and their close relative, Dolly Varden, have been recommended to reflect their sensitivity. The recommended maximum spawning temperature recognizes the lower thermal tolerance of adults to elevated temperatures during the fall spawning period and provides protection from short-term extreme temperature exposures.

2.2 All Other Streams

Streams with Unknown Fish Distribution

- the mean weekly maximum temperature (MWMT) = 18 degrees Celsius
- the maximum daily temperature = 19 degrees Celsius
- maximum daily incubation temperature (Spring and Fall) = 12 degrees Celsius

Streams with Known Fish Distribution

- + or - 1 degree Celsius beyond the optimum temperature range (see Table 2) for each life history phase of the most sensitive salmonid species present
- hourly rate of change = 1 degree Celsius

Rationale

The guidelines for streams and rivers other than those frequented by bull trout and Dolly Varden are based on temperature tolerance data for salmonids. Salmonids are cold-water dependent and prefer a narrow range of water temperatures during critical periods to meet their life history requirements. Temperature tolerance for juvenile salmonids has been determined under laboratory conditions but adults are more sensitive to elevated temperatures. This thermal sensitivity of adults has been taken into consideration by the recommended guidelines. The use of the MWMT is an approach designed to reduce the risk of cumulative stress leading to death, disease, poor reproductive success or poor growth and is consistent with guidelines specified by Oregon, Washington and Idaho. The recommended maximum temperature guideline is expected to support the maximum productive capacity of stream environments for salmonids in British Columbia. Failure of some egg development has been experimentally determined where incubation temperatures exceed 13 degrees Celsius for sensitive species.

2.3 Lakes

- + or - 1 degree Celsius change from the natural condition

Rationale

The guideline for lakes are based on natural ambient conditions so that temperatures adhere closely to regimes which organisms have adapted through evolutionary processes.

2.4 Marine and Estuarine

- + or - 1 degree Celsius change from the natural condition
- the natural temperature cycle characteristic of the site should not be altered in amplitude or frequency by human activities
- the maximum rate of any human-induced temperature change should not exceed 0.5 degrees Celsius per hour

Rationale

The guideline for marine and estuarine waters are based on natural ambient conditions so that temperatures adhere closely to regimes which organisms have adapted through evolutionary processes. Insufficient data are available to set specific limits. These guidelines are consistent with those recommended by CCME and other jurisdictions in the Pacific Northwest (e.g., Alaska).

3.0 WILDLIFE, LIVESTOCK WATERING, IRRIGATION AND INDUSTRIAL WATER SUPPLIES

An interim guideline to protect wildlife, livestock watering, irrigation and industry from excessive temperature changes in British Columbia waters is based on natural background levels.

- + or - 1 degree Celsius change from the natural condition

Rationale

The guideline for wildlife, livestock watering, and irrigation are based on natural ambient conditions so that temperatures adhere closely to regimes which plants and animals have adapted through evolutionary processes. The same guideline has been specified for industrial water supplies to ensure that temperature regimes are close to that which could have been expected under natural situations.

4.0 RECREATION AND AESTHETICS

The guidelines for temperature in water to be used for recreational activities are adopted from the 'Guidelines for Canadian Recreational Water Quality', which has been accepted by the Ministry of Health Services for application in British Columbia as follows:

- the thermal characteristics of waters used for bathing and swimming should not cause an appreciable increase or decrease in the deep body temperature of bathers and swimmers
- the upper recommended limit of temperature is 30 degrees Celsius

Rationale

Health and Welfare Canada reports that scientific evidence suggests that prolonged immersion in water warmer than 34 to 35 degrees Celsius is hazardous. The degree of hazard varies with the water temperature, immersion time and the metabolic rate of the swimmer.

Application of the Guidelines

Application of Guidelines for Aquatic Life

The guidelines can be used to assess water quality impacts or as starting points to develop site-specific objectives. It is recommended that the user be familiar with the concepts and guidelines detailed in the supporting technical report "Towards a Water Quality Guideline for Temperature in the Province of British Columbia" prepared by Aspen Applied Sciences Ltd. for the Ministry Of Environment, Lands and Parks, prior to making comparisons between monitoring results and guidelines. To assist in designing monitoring programs "Statistical Designs and Sampling Protocols for Monitoring Attainment of Temperature Guidelines", a section of the consultant's report without the cited references is summarized here.

Statistical Designs

The choice of an appropriate test to reliably detect environmental disturbance due to human activities is often difficult if the magnitude of the impact is small relative to natural background parameter variability. As demonstrated for stream environments, the temperature regime varies longitudinally with stream order, width and elevation and can often be modified by land management activities that influence channel width, riparian canopy cover, pool volume, run-off timing and in-stream flow. Moreover, stream temperature varies daily and seasonally and can be further modified by small-scale (wildfires, floods) and large-scale (global warming) disturbances. Therefore, the challenge exists to select a sampling design that can detect unusual patterns of change in a very interactive and variable measurement.

Paired studies represent the most robust means of comparing the effects of disturbance. The use of paired lakes or paired watersheds is most desirable among any sampling design, but it is often difficult to establish suitable pairs given the ubiquity of land development. As an alternative, sampling designs have evolved to contrast differences in parameters between disturbed and undisturbed sites within the same basin.

In its simplest form in stream environments, environmental monitoring to detect change from a given disturbance has been facilitated by comparison of a measurement upstream and downstream from a known point source. An early environmental sampling design employed measurements before and after the initiation of a disturbance at control and impact locations; the design was originally referred to as Before-After-Control-Impact (BACI). This design has been criticized for its failure to account for measurement differences before and after the disturbance and directly related to an impact that could otherwise be explained by natural variation in space and time. The problem is quickly overcome with suitable replication of control and impact locations sampled over time, but may be restrictive due to the number of samples required. The application of this design to rivers, lakes and streams is highly adaptable to the measurement of a variety of disturbances from human activity, but exceedingly more difficult in marine environments where replication of representative habitats or site conditions are required.

The procedure is relatively straightforward where a single putative impact occurs within a basin and becomes progressively more difficult where cumulative effects result from a variety of point and non-point sources, each with its own level of impact. In the simpler cases, application of a BACI design with paired sampling or an asymmetrical design is recommended for statistical comparisons. In the latter instance, additional control locations are incorporated into the design together with a single impact location to account for variability in nature and to detect impacts reliably at either spatial or temporal scales. As with all statistical designs, the rules of representativeness and randomness must apply, and therefore in the case of single point source assessment, control and impact sites should be restricted to the same stream reach and located in similar habitat units. In the more difficult examples where multiple non-point sources occur, it may be more instructive to monitor temperature change at strategic points throughout the basin to determine where temperature maxima may limit the distribution and abundance of biota or impose restrictions on other beneficial uses. In this instance, strategic monitoring locations would likely correspond to areas of increasing stream order from headwaters to confluence. Locations would necessarily correspond to stream reaches above and below land-based developments within the basin. This approach would be highly consistent with ecosystem-level monitoring (i.e., holistic approach) upon which informed management decisions could be based.

Sampling Protocols

The issue of sampling protocols for temperature collection seems relatively clear. In light of today's technologies, there is little question that continuous temperature records should be maintained. Continuous data loggers not only provide seasonality to temperature collections, but also provide the added advantage of identifying the frequency and duration of temperature extremes. In consideration of their cost relative to the quality and quantity of information provided, continuous records should become the standard with individual measurements collected at hourly intervals. The placement of temperature recorders within the thalweg (the line of maximum depth and velocity in a stream) and at near-shore margins would provide a more reasonable estimate of average temperature within the cross-section at each site. The three stations at each site would also serve as replicates for statistical analysis. The combined procedure would greatly assist calculations of mean weekly maximum temperatures (MWMT) for future enforcement of the recommended guidelines. The incorporation of a temperature recurrence interval during temperature analysis would be beneficial in estimating the probability of exceedence of fixed temperature thresholds throughout the year that coincide with specific life history activities of individual fish species. Calculation of the cumulative probability of a sequence of events within a specified duration is also recommended. Application of this information would suggest periods where fish may be at risk if the cumulative effects of consecutive days of sub-lethal temperatures impart negative

biological responses (e.g, increased susceptibility to disease or poor growth). The output of this approach would certainly aid the decision-making process relative to adjudication's on future land-based developments.

Appendix: Canadian (CCME) Environmental Guidelines for Aquatic Life

FRESHWATER

1. Thermal Stratification

Thermal additions to receiving waters should be such that thermal stratification and subsequent turnover dates are not altered from those existing prior to the addition of heat from artificial origins.

2. Maximum Weekly Average Temperatures (MWAT)

Thermal additions to receiving waters should be such that the MWAT is not exceeded.

a. In the warmer months, the MWAT is determined by adding to the physiological optimum temperature (usually for growth) a factor calculated as one-third of the difference between the ultimate upper incipient lethal temperature and the optimum temperature for the most appropriate life stage of the sensitive important species that normally is found at that location and time. Some MWAT values are shown in US EPA (1976).
b. In the colder months, the MWAT is an elevated temperature that would still ensure that important species would survive if the temperature suddenly dropped to the normal ambient temperature. The limit is the acclimation temperature minus 2 degrees Celsius when the lower lethal threshold temperature equals the ambient water temperature.
c. During reproductive seasons, the MWAT meets specific site requirements for successful migration, egg incubation, fry rearing, and other reproductive functions of important species.
d. At a specific site, the MWAT preserves normal species diversity or prevents undesirable growths of nuisance organisms.

3. Short-term Exposure to Extreme Temperature

Thermal additions to receiving waters should be such that the maximum temperatures as calculated in "a" and "b" are not exceeded. Exposures should not be so lengthy or frequent as to adversely affect the important species.

a. For growth, the short-term maximum temperature is the 24-h median tolerance limit, minus 2 degrees Celsius at an acclimation temperature approximating the MWAT for that month.

b. The short-term maximum temperature for the season of reproduction should not exceed the maximum incubation temperature for successful embryo survival, or the maximum temperature for spawning.

MARINE

Not to exceed a 1 degree Celsius change from natural background temperature.