Towards a Water Quality Guideline for Temperature in the Province of British Columbia

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EXECUTIVE SUMMARY

The Ministry of Environment, Lands and Parks, Water Management Branch (Water Quality Section) recognizes the need to update water quality guidelines for temperature to protect water uses in British Columbia. Specific water uses include drinking water, recreation and aesthetics, freshwater and marine life, wildlife, agriculture (*i.e.*, irrigation and livestock watering) and industry. To facilitate this need, Aspen Applied Sciences Ltd. was contracted to update the current literature on factors that determine temperature in ambient water and recommend guidelines that provide adequate protection for all beneficial uses. More specifically, the guidance document was to provide numerical values for the protection of aquatic life and other uses that would assist government staff with regulatory functions. To this end, a literature search was conducted on the more recent subject matter and a review completed of temperature guidelines presently in use by other jurisdictions in North America and Europe. With respect to aquatic life, salmonid fishes were selected as sentinel species for which guidelines were developed to safeguard the aquatic environment from the adverse effects of human activities. The document provides general, interim guidelines for the protection of all beneficial uses and recommends future development of water use classifications based on a range of environmental temperature quality that varies with provincial geography. Consistent with the classification system, the development of region-specific temperature guidelines is advocated to reflect differences in environmental conditions throughout the province. Using an ecosystem-based approach, guidelines for the protection of individual water uses within each classification should be developed in support of the minimum temperature requirements of the specific use most sensitive to temperature change. Methods for the derivation of water use classifications are discussed and sampling protocols for temperature monitoring and compliance are recommended.

SPECIAL NOTE

An addendum has been added to the end of the document that reviews the recent study, ***The Mediated Associations and Preferences of Native Bull Trout and Rainbow Trout With Respect to Maximum Water Temperature, its Measurements Standards, and Habitat.*** This new study was brought to our attention after completion of the Technical Appendix. To ensure all key data was considered, the study was reviewed for its relevance to the recently developed British Columbia Water Quality Guideline for Temperature. The review concluded that no changes to the Guidelines were necessary.

1.0 Introduction

The Ministry of Environment Lands and Parks, Water Management Branch, (*i.e.*, Water Quality Section) has identified the need to upgrade existing water quality guidelines (WQG) for temperature to protect water uses in British Columbia. A key requirement of this review was the need to replace narrative statements for some water uses in the existing guideline with numerical values derived for practical application. Water uses include drinking water, recreation and aesthetics, aquatic life (freshwater and marine), wildlife, industrial and agriculture (both irrigation and livestock watering). The intent of this initiative is to develop a guidance document that will safeguard water quality from a variety of human activities that could lead to adverse temperature effects on specific uses in aquatic environments throughout the province. Although generic in nature, the recommended guidelines are further intended to provide a baseline for setting water quality objectives within specific aquatic environments where extraordinary natural resource values warrant special consideration.

The nature of any adverse effect of human activity on water quality will depend on both temporal and spatial scales of that activity relative to the size of a given watershed, water body or receiving environment. To this end, adverse temperature effects may arise from a single activity or reflect a cumulative outcome from a variety of activities over a much larger geographical area. Similarly, a variety of guideline recommendations for individual water uses may be easily derived or difficult to establish, depending upon ecosystem complexity or the social, economic and cultural needs of society. The challenge, then, is to provide realistic measures of protection to each water use, in the face of burgeoning water and land-based developments and global climatic change, at a provincial scale.

A difficulty within the guideline development process concerns the trade-off between maximizing benefits and minimizing impacts of competing uses. The guideline could range between the extremes of full protection and full utilization of each use. There is little doubt that maximizing all designated uses will impose conflicting impacts on certain uses that cannot tolerate wide temperature variation. A further challenge, then, is to reach a balance that does not compromise resource values yet offers some flexibility for individual uses.

The purpose of this report is to review and incorporate recent literature related to temperature that will add to or improve on the current BC guidelines; applicable changes should focus on environmental conditions and organisms specific to the province of British Columbia.

In that context, the terms of reference for the work were very specific, requiring only the most recent updates in the literature. To this end, the last ten years was considered most relevant, although some papers back to the early 1970's were reviewed, where appropriate. In the review, it was recognized that the foundation of the existing BC guideline and those of most other jurisdictions, along with much of our understanding of temperature effects on fish in general, are based on the early work of Brett (1952; 1956) and others (*e.g.*, Fry 1947; 1967). Rather than re-examining these works, the goal was is to expand on the most recent information that would improve the overall knowledge base.

The review also explored guidelines used by other jurisdictions in Canada and the United States. The intent was to develop a document with guideline recommendations supported, in part, by the expertise and knowledge that has been developed in other jurisdictions to effectively protect water uses from adverse effects of temperature from a variety of human activities. Numerical values to establish temperature maxima and minima for individual uses were considered where feasible.

It is important to note that temperature plays an important role in the response of aquatic organisms to a wide range of physical, chemical, and biological stresses. For example, increasing temperature accelerates the rate of uptake of chemical toxicants through increased cardiovascular and respiration function. Elevated temperatures increase the oxygen demand for most aquatic organisms while at the same time reducing the availability of dissolved oxygen in the environmental water. High water temperature degrades the ability of organisms to cope with swimming demands, while compounding the effects of biological stresses such as predation and disease. When dissolved gas supersaturation is present, accompanied by elevated temperatures, the effects of gas bubble trauma in fish are much more severe (Nebeker *et al..* 1979, Birtwell et al 2000). These factors, while associated with temperature, cannot all be dealt with explicitly in this document. Such a task would essentially involve developing individual water quality guidelines for each stressor with temperature as an ancillary factor. The Province of British Columbia, the Canadian Council of Resource and Environment Ministers (CCRME - 1987), and the Canadian Council of Ministers of Environment (CCME - 1999) have developed guidelines for a wide range of chemical and physical stressors (see Section 1.1) and the effects of temperature are incorporated into those guidelines. Therefore, this guideline upgrade will examine the effects of water temperature on aquatic organisms in the absence of other physical and chemical stress issues.

Finally, this work identifies future research needs and presents data gaps, as well as provides guidance on the most appropriate temperature monitoring methods (*i.e.*, sampling protocols) to assess compliance with the recommended guidelines.

1.1 Background

Water quality guidelines to assess water quality problems or manage competing uses of water resources in inland waters were initially developed on behalf of the Task Force for Water Quality Guidelines for the Canadian Council of Resource and Environment Ministers (CCRME) in 1987.
The guidelines were developed for use by Canadian provincial, territorial and federal agencies to establish certain protective guidelines that were relevant to Canadian conditions; guidelines that were considered general in nature and subject to modification where local conditions dictated. Water uses considered at that time included drinking water, recreation and aesthetics, freshwater aquatic life, industrial and agricultural uses. Updates to the initial document have occurred since 1989 as information on the effects of particular water quality indicators have become available to support recommendations that minimize adverse effects on specific uses.

The most recent guideline document was issued in 1999 on behalf of the Canadian Council of Ministers of the Environment (CCME). With respect to temperature, the most recent guidelines have been expanded to include the marine environment.

Canadian water quality guidelines have been formulated on the basis of the effects of water quality indicators on specific uses reported in the scientific literature. With respect to aquatic life, a number of protocols (*i.e.*, minimum data set requirements and standards for toxicity testing) have been adopted to facilitate the guideline development process.

Following an extensive literature review of the properties, effective concentration and toxicity of a selected indicator, the guideline derivation approach considers all trophic levels of the aquatic ecosystem where data are available. The protection of all life history stages for all forms of aquatic life is a key element of the derivation process, and for most indicators a single maximum value is recommended based on a long-term no-effect concentration (*i.e.*, the lowest-observable-effects level (LOEL) from a chronic exposure study using a non-lethal endpoint for the most sensitive life stage of the most sensitive aquatic species investigated (CCME 1999)).

In the absence of this information, acute exposure data have been substituted by adjusting short-term median lethal (LC_{50}) or median effective (EC_{50}) concentrations to long-term no-effect concentrations. When available, acute/chronic ratios (ACRs) are employed by dividing the median lethal or effective concentration by the no-observed-effect level (NOEL). When ACR's are unavailable, guidelines are derived from acute short-term study data by applying a universal application factor (AF) to each value (*i.e.*, 0.05 for non-persistent variables and 0.01 for persistent variables (CCME 1999)).

Protocol procedures, however, recognize certain limitations that hamper guideline utility (CCME 1999). Data are seldom available to generate guidelines for all species present in the receiving environment. Extrapolation of toxicological data from one species to another may not reflect actual differences in sensitivities between species and, hence, may generate guidelines that are incapable of providing adequate protection for all species. Similarly, the extrapolation of laboratory results to natural aquatic ecosystems may not be truly representative of the expected response of individual organisms due to existing background environmental conditions (*i.e.*, potential cumulative effects of physical and chemical constituents), acclimation processes or the population dynamics of representative biota (*i.e.*, compensatory processes in the wild).

To date, the Ministry of Environment, Lands and Parks in the Province of British Columbia has adopted water temperature guidelines for drinking water and recreation provided by Health and Welfare Canada (BCMOELP 1998) and included additional working criteria for the protection of aquatic life in freshwater (Nagpal *et al.*. 1998). Of the specified uses identified above, the development of guideline information for the protection of aquatic life should receive the highest degree of scrutiny, given the more serious implications of water temperature fluctuations and extremes on aquatic biota.

Relative to this document, the selection of salmonid fishes as sentinel species in freshwater environments is intended to provide an acceptable benchmark for the protection of all aquatic life forms within distinct trophic levels. The use of salmonids as indicator species of ecosystem health is encouraged given their economic and recreational value province-wide. The development of temperature guidelines within an ecosystem context is intended to provide criteria that are compatible with ambient temperature regimes and the native fish complex. Water uses other than aquatic life are not expected to be seriously affected by a guideline that recognizes fisheries resources as the most sensitive use.

Beyond the protocols established in the CCME document, this report will attempt to address the effects of rate of temperature change on life history stages, in addition to identifying acceptable temperature maxima or minima for specific life history stages of individual species.

1.2 Literature search

The primary database search was conducted with the assistance of the National Research Council, Canadian Institute for Scientific and Technical Information (CISTI). The following resources were consulted during the water temperature search: Aquatic Sciences and Fisheries Abstracts, Biosis Previews, CAB Abstracts, EI Compendex, Enviroline, Oceanic Abstracts, Pollution Abstracts, Water Resources Abstracts, and Waternet. Information sources available through government services included the British Columbia, Ministry of Environment, Lands and Parks library catalogue, the British Columbia, Ministry of Environment, Lands and Parks web site, the Canada Department of Fisheries and Oceans library catalogue, the United States Environmental Protection Agency (EPA) library catalogue and the United States Environmental Protection Agency web site.

In addition, a request for current guideline information and supporting documents was issued to provincial agencies across Canada, as well as federal agencies (Environment Canada). EPA surface water quality standards for individual states in the Pacific Northwest (Washington, Idaho, Montana, Oregon and Alaska) were also reviewed at their respective web sites. A request for information was also sent to the Department of the Environment, Transport and the Region of Great Britain.

1.2 Definitions

For the sake of clarity, the following definitions are provided for specific terms used in this document (after MacDonald *et al..* 1992):

a) Criteria - scientific data that are evaluated from specific studies designed to establish the lethal limit of a given parameter on a particular species or life stage (*e.g.*, maximum upper tolerance temperature of developing rainbow trout embryos.

b) Guidelines - recommended numerical concentrations or narrative statements to protect specific water uses (*e.g.*, no measurable change from natural conditions; lakes)

c) Objectives - numerical concentrations or narrative statements established to protect specific water uses at a specified site (*e.g.*, 2.2 degrees C change; maximum increase for receiving waters)

d) Standards - objectives that are enforceable within environmental control laws of a level of government (*e.g.*, 15 degrees C; maximum; for food processing)

2.0 Land development or industrial activities affecting water temperature in BC

A variety of land-based developments or industrial activities in British Columbia have the potential to affect the temperature of surface or ground water supplies through either direct or indirect means. Freshwater is utilized in various process applications in industry (Manahan 1991) and, following treatment, effluent can be released as a point source discharge to surface waters. As part of the treatment process, waste water is often stored in lagoons or settling basins for the purpose of aeration, filtration and clarification. Depending on time of year, the treated effluent may be warmer than its attendant receiving environment and hence, the downstream zone of influence may be altered spatially on a seasonal basis. Monitoring activities to date however, have concentrated on toxic constituents in effluents rather than temperature effects due to the dilution characteristics of most receiving environments relative to the rate of effluent input (L. E. McDonald, Environmental Protection, Cranbrook, BC; pers. comm.). Industrial and municipal examples include smelting, chemical manufacturing, petrochemical refining, pulp and paper processing, thermal power generation, underground and surface mining, and sewage treatment. With respect to the pulp and paper industry, research has traditionally focused on the lethal and sub-lethal effects of pulp mill effluent on aquatic biota; exposure studies on fish have been directed toward the secondary effect of effluent on high temperature tolerance ability among salmonids under ambient conditions (Thut and Schmiege 1991). It is important to recognize that storage of untreated effluent in lagoons following initial discharge from the plant effectively reduces high temperatures normally associated with process water. Thermal shock to biota in receiving waters has only been reported under conditions of an accidental spill (Walden and Howard 1974). Alternatively, the direct discharge of cooling water associated with certain industrial activities may effect the zone of influence over short time intervals since the rate of temperature change may be much more dramatic due to the greater temperature differential between the effluent and the environment. The degree of impact on the receiving environment is again dependent upon the size of the water body and time of year. Heat exchange processes are more commonly associated with the smelting and thermal-electric generation industries.

Non-point source temperature effects are encountered at a much larger spatial scale and are generally associated with natural resource development activities that alter ecosystem structure and function. Examples include forestry, mining, and hydro-electric and community water supply development. Water temperature in streams can be affected by forestry operations in two principal ways: 1) removal of streamside shading that increases direct solar heating (Beschta *et al.* 1987) and 2) modification of hydrologic processes that regulate the quantity and timing of streamflow (*i.e.*, precipitation, infiltration, evapotranspiration, storage and run-off; Swanston 1991). Heat transfer occurs in direct proportion to the amount of solar radiation reaching the water surface and as a function of a stream's channel geometry (Chamberlin *et al.* 1991). Although volume and turbulence can affect temperature, depth has been shown to have an over-riding influence relative to basin elevation (Adams and Sullivan 1989; Caldwell *et al.* 1991 cited in Teti 1998). Partial stratification of deep pools helps moderate heat transfer and the combination of overstream cover and deep pool habitat help determine the magnitude of diurnal or seasonal temperature fluctuation. A lower channel stability following riparian harvesting is manifested through increased width:depth ratios due to channel widening and increased sediment input, as well as reduced pool to riffle ratios as structural elements become depleted (Bisson *et al.* 1987; Chamberlin *et al.* 1991). In the absence of shade and large residual pool volumes, summer stream temperatures have increased (Holtby 1988; Brownlee *et al.* 1988). Increased stream temperature effects are expected to occur in the mid to lower reaches of a watershed since water temperature maxima are strongly influenced by elevation; further increases above a maximum equilibrium temperature in headwater areas are unobserved despite higher ambient air temperature (Caldwell *et al.* 1991 cited in Teti 1998). As a consequence, timber harvest-related temperature effects within first order headwater streams are expected to have minimal impact on downstream higher order stream reaches (Doughty and Sullivan 1991; Caldwell *et al.* 1991 cited in Teti 1998).

Timber harvesting has been linked to changes in water quality, water quantity and timing of streamflow with a wide degree of variation in hydrologic responses that can be related to the method and extent of harvesting within a particular basin. The effects of forest practices can influence snow accumulation and melt rate, evapotranspiration and soil water, as well as water infiltration into, and transmission rate through, forest soils (Chamberlin *et al.* 1991). With a higher accumulation of snow and faster rate of melt contributing to a higher run-off from cut-blocks (Toews and Gluns 1986), the degree of ground water recharge has been shown to increase or decrease depending upon the amount soil compaction associated with harvesting activities that affect its infiltration capacity. (Greacen and Sands 1980; Hetherington 1988; Hartman and Scrivener 1990). Since stream temperature can be moderated by ground water input, changes in ground water supply can either stabilize or alter the thermal regime.

Similar changes in the water balance have been attributed to surface mining operations owing to largescale landscape modification (*i.e.*, vegetation removal and soil disturbance). Stream temperature can be affected by interception and redirection of surface flows or disruption of entire aquifers (Nelson *et al.* 1991). Moreover, both non-metallic or metallic ores require large volumes of water for processing and depending upon availability from surface supplies, potential dewatering of channels during periods of low summer flow can elevate stream temperatures dramatically. Effluents from smelters or concentrators or shallow tailings ponds and settling basins may be considerably warmer than attendant receiving waters; particularly in settling ponds where fine (black) sediments absorb heat. The downstream zone of influence is again variable depending on the rate of discharge relative to the size of the receiving body.

The impoundment of large or small rivers and streams for the purpose of hydro-electric development or community water supply can effect the thermal regime of the systems' pre-impoundment condition and potentially alter the thermal regime of downstream reaches. Seasonal temperature profiles in reservoirs are highly variable and dependent upon complex hydrodynamics relative to tributary inflow, basin morphometry, drawdown and discharge characteristics (Wetzel 1975), as well as degree of stratification. In summer, elevated temperatures in epiliminial waters released through a spillway can increase downstream river temperatures, whereas a decrease can be expected if cooler hypolimnial waters are released through turbines or sluice gates. The opposite effect is generally observed in winter due to density/temperature gradients associated with the degree of limnetic stratification. Conversely, run-of-the-river type reservoirs that typically display much shorter retention times, are less susceptible to stratification and often parallel temperature characteristics of upstream reservoir releases (US Army Corps of Engineers 1999). Diurnal or seasonal differences in the thermal regime of downstream reaches are therefore strongly related to operational regimes of individual dams in response to hydro-electric demand, storage for flood control/water supply or demand for downstream water use. Both daily and seasonal dynamics in dam operations have the potential to alter background temperature patterns associated with the river's pre-impoundment condition (Oliver and MacDonald 1995).

Agricultural use of water or rangeland use associated with small streams and their riparian areas is widespread throughout the province. Water extraction during the period of low summer flow and unrestricted livestock grazing in streamside environments have also been shown to have indirect effects on stream temperature (Platts 1991; Rinne 1999). Small streams that support the irrigation needs of adjacent croplands can often lead to lowering of stream flow and elevated temperatures in summer, particularly where irrigation demand is high, water supply is limited and over-licensing has occurred. Improper range management practices that have led to over-grazing of riparian areas have ultimately been responsible for changing, reducing or eliminating vegetation or modifying stream banks (*i.e.*, trampling by livestock). The removal of overstream (vegetation) and degradation of instream (undercut banks) cover have reduced the amount of shading and led to increased solar heating (Armour 1977; Benke and Zarn 1976; and Platts 1983 cited in Platts 1991). In British Columbia, the most sensitive stream ecosystems affected by range management practices are likely associated with arid regions of the south and central interior where thin soils and sparse grasslands are easily disturbed and recovery periods are long.

3.0 Effects of temperature on aquatic biota

Temperature has long been recognized as an important environmental factor in both terrestrial and aquatic ecosystems in regard to its pivotal role over biological activity (development, growth and reproduction). Seasonal temperature differences strongly influence the biological activity of aquatic organisms and establish cyclical patterns that often mediate the scope of each activity. Over the long-term, changes to the thermal regime of the surrounding environment can effect the evolutionary, physiological and behavioural responses of individual organisms (Begon *et al.* 1990).

Thermal regimes can be expected to vary with latitude but, in general, vary daily and on a seasonal basis; the cyclical pattern of diel variation in temperate regimes demonstrates an early morning low and a mid-afternoon high with mean daily temperatures reaching a maximum during summer. Moreover, the amplitude of diel variation (*i.e.* delta T degrees C) is also greatest during summer and may be affected by the degree of riparian development (vegetation removal that promotes channel widening or reduces channel shading). To this end, local adaptation to thermal regimes by aquatic organisms can also be expected to vary over a species geographical distribution (*i.e.* latitude) and as a function of environmental condition (*i.e.* the basin's development history).

The causes of temperature increases in aquatic ecosystems due to human activities in British Columbia, then, are associated with either active or passive heating of the receiving environment. The response of aquatic biota to physical changes in light or photoperiod, nutrients, temperature and flow can often lead to profound changes in individual development and survival or community structure across each trophic level (Barnes and Minshall 1983; Resh and Rosenberg 1984; Stevenson, Bothwell and Lowe 1996). The response of marine and freshwater algae to temperature change have been summarized by DeNicola (1996) and include a variety of effects that have been studied at the cellular, population and community level. Individual responses are highly dependent upon the variability in the physicochemical environment and spatio-temporal pattern in species distribution. Physiological responses to temperature include changes in concentrations of photosynthetic and respiratory enzymes, changes in cell quota and nutrient uptake, as well as alterations in fatty acids and proteins. Individual populations have been shown to exhibit minimum, maximum and optimal temperatures for growth that contribute to species composition and diversity and eventually lead to seasonal succession. Several broad generalizations concerning periphyton responses to temperature have been summarized by DeNicola as follows: 1) as temperature increases, there is a shift in the dominance of algal classes from diatoms (<20 degrees C) to green algae (15-30 degrees C) to blue-green algae (>30 degrees C). 2) species diversity increases from approximately 0 to 25 degrees C and decreases at temperatures > 30 degrees C. 3) the degree to which community composition changes with thermal input depends on the initial ambient temperature. Increases in temperature in environments near 25-30 degrees C usually cause greater changes in community structure than in environments <25 degrees C. 4) community structure usually recovers rapidly (< 1 yr) when temperature stress is discontinued. 5) biomass increases with temperature from approximately 0-30 degrees C, and decreases at 30-40 degrees C. 6) in many natural communities, temperature does not usually limit biomass and primary productivity, but it does set an upper limit for production when other factors are optimal. Maximum areal productivity of lotic periphyton increases exponentially with temperature for temperatures <30 degrees C. 7) the degree to which primary productivity is limited by factors such as light, nutrients, and grazing depends on temperature.

With respect to aquatic insect community response, temperature fluctuations beyond threshold levels can have a dramatic effect on diapause induction (*i.e.*, as a function of endocrine processes; Vannote and Sweeney 1980), hatching success (*i.e.*, decreases at low or high extremes; Elliott and Humpesch 1980), larval growth, adult size and fecundity (*i.e.*, both temperature and nutrition influence on the rate of feeding, assimilation and respiration, food conversion efficiencies and enzymatic kinetics; Anderson and Cummins 1979; Vannote and Sweeney 1980; Sweeney and Vannote 1981), voltinism (*i.e.*, number of generations per year based on larval growth rate; Newell and Minshall 1978) and timing of adult emergence (*i.e.*, premature or delayed depending on temperature increase or decrease; Sweeney and Vannote 1981).

In regard to salmonid community response, increases in surface water temperature beyond diurnal or seasonal averages, have the potential to accelerate embryo development, alter the timing of emergence, growth and downstream migration of juveniles, reduce metabolic efficiencies of food conversion into growth (*i.e.*, due to thermal stress and oxygen deficiency), alter adult spawning migration and spawning timing, increase susceptibility to disease and shift the competitive advantage of salmonids over non-salmonid species (Hicks *et al.* 1991; De Staso III and Rahel 1994; Flebbe 1994; Dickerson and Vinyard 1999). Sub-lethal temperature effects are also related to metabolic inefficiencies, susceptibility to disease and toxic effects of pollutants, behavioural patterns, intra- and inter-specific competition, predator-prey relationships, community composition and parasite-host relationships.

The negative effects of thermal regime modification are not restricted to temperature increases alone. Temperature reductions to stream environments in winter may result from the loss of insulation of the forest canopy under clear-cut conditions in combination with increased radiant cooling; accelerated freezing may lead to anchor ice formation and minimize interstitial habitat for juvenile fish (Hicks *et al.* 1991).

The physiological effects of extremely high as well as extremely low temperatures on aquatic organisms are reviewed in CCME (1999). From that document, "...potential effects of extremely low water temperatures on aquatic organisms include insufficient integration of nervous and metabolic processes, insufficient rates of energy liberation, changes in water and mineral balance, increase in osmoconcentration resulting from extracellular freezing followed by the dehydration of cells, liquefaction of cortical protoplasm and gelation of the cell interior...the effects of extremely high temperatures include insufficient supply of oxygen, failures in process integration, desiccation (inter-tidal organisms), enzyme inactivation, change in lipid state, increase in protoplasmic viscosity, increase in cell membrane permeability, protein denaturation, and release of toxic substances from damaged cells...Death can result from exposure to either extremely high or extremely low water temperatures..."

The apparent benefits of increased light and temperature in affected streams that contribute to improved embryo development (shorter incubation time, earlier fry emergence) and juvenile growth rates (longer growing season, greater food availability) in salmonids may have negative long-term implications on later life history stages (Hartman and Scrivener 1990). For example, anadromous species such as chum salmon that migrate to the ocean following an earlier spring emergence, may be at a disadvantage if the timing of food availability in the marine/estuarine environment is lagging. Similarly, early emergence of coho fry that leads to a longer period of summer growth may increase under-yearling size and improve over-winter survival, but may induce a higher emigration of 1+ smolts the following spring that exhibit a lower ocean survival. A lower survival for stream resident trout may also occur if the period of tributary rearing is reduced by accelerated growth, yet the habitat requirements of smaller-sized fish are unavailable in mainstem channels. The greater dilemma for stream resident species may be related to summer temperatures near their upper tolerance limits that force individuals to seek cooler refuges in headwater areas that exhibit a lower capability for food and shelter when compared to the more productive downstream reaches (Vannote *et al.* 1980).

A comprehensive review of the biological effects of water temperature on marine and brackish water organisms has been summarized in the CCME-Canadian Water Quality Guidelines for the Protection of Aquatic Life, Temperature (CCME; 1999). Sub-lethal temperature effects are similarly related to metabolic inefficiencies, susceptibility to disease and toxic effects of pollutants, behavioural patterns, intra- and inter-specific competition, predator-prey relationships, community composition and parasite-host relationships.

4.0 Literature update on water temperature criteria for the protection of salmonid resources

Temperature change beyond the range of thermal regimes observed in natural waters in British Columbia is expected to have the most serious impact on salmonid fisheries in freshwater environments in comparison to other water uses. To this end, an updated review of the available scientific literature on temperature criteria for individual life history stages of native species is provided to establish acceptable limits. Minimum and maximum endpoint values are tabulated for embryo/alevin, juvenile and adult stages with temperature criteria provided for incubation, rearing, migration and spawning activities. The summary borrows heavily from an extensive literature review and synthesis of freshwater temperature alterations on salmonid life history stages after McCullough (1999) and incorporates effects of rate of change (*i.e.*, increase or decrease) where data are currently available for individual species.

4.1 Incubation

The rate of embryo and alevin development is strongly influenced by water temperature and the time to emergence is governed by changes in ambient conditions. In general terms, the higher the temperature within acceptable limits, the faster the rate of embryogenesis (Bjornn and Reiser 1991). Salmonids have evolved to complete certain life history functions within the range of ambient temperatures provided in nature. In this regard, the eggs of fall spawners experience a slower rate of development through the winter while the eggs of spring spawners experience a faster rate of development during late spring-early summer. A critical requirement of embryo development, however, involves a stable temperature regime immediately following spawning since eggs are highly temperature-sensitive soon after fertilization (Peterson et al 1977). For example, cutthroat trout eggs initially fertilized at a temperature of 7 degrees C and cooled at a rate of 1 degrees C/h had a significantly lower survival in less than or equal to 11 d than control eggs reared at 7 degrees C (Hubert and Gern 1995). More importantly, the same experiment repeated 13 d after fertilization (*i.e.*, a stage in development following the period of neural tube closure) revealed no difference in survival between control and treatment groups. Notwithstanding, the rate of temperature decrease does not seem to be as important as the endpoint temperature value. In a related study on temperature reduction during early cutthroat, rainbow and brown trout egg incubation, a thermal shock applied at a rate of 0.25, 1, 5 and 20 degrees C/h, that lowered the initial incubation temperature from 7 to 2 degrees C, showed little difference in embryo survival among the experimental rates of adjustment tested (Stonecypher *et al.* 1994). The final endpoint of 2 degrees C caused the highest mortality observed as late as the eyed stage of development. Heat shock of +6.8 degrees C to incubating coho eggs acclimated to 1.5, 3.5, 4.0, 6.1 and 10.2 degrees C, over an 8 h period, only caused a reduction in survival to 50% hatching by egg batches cultured at 10.2 degrees C (Tang *et al.* 1987). The thermal shock applied to egg batches incubated at 10.2 degrees C was the only test case where eggs were exposed to temperatures well above their threshold (*i.e.*, 17 degrees C versus a threshold of 13 degrees C). Despite returning individual egg batches to their original incubation temperature after the 8 h exposure, the highest endpoint was implicated as the causitive factor in reduced survival irrespective of developmental stage. Optimum, maximum and minimum incubation temperatures for native salmonids (and eastern brook trout) are provided in Table 1.

4.2 Juvenile rearing

Juvenile salmonid rearing environments are highly variable throughout their early life history stages and individual species have adapted a variety of life history strategies to facilitate survival that include lotic, lentic and estuarine habitats. Individual species occupy aquatic environments with thermal regimes that vary daily, seasonally, annually and spatially, and each species has demonstrated well-defined temperature preferences and tolerances (Bjornn and Reiser 1991). The majority of juvenile salmonids display an optimum growth zone between 10 and 15 degrees C while positive growth is maintained from about 4-19 degrees C (Armour 1991). Optimal growth temperatures of 19 degrees C with continued feeding up to 23 degrees C have been demonstrated for some species in response to an unlimited food supply but food conversion efficiencies were maximized at ~19.6 degrees C (*e.g.*, chinook salmon, Brett *et al.* 1982). When food is limited however, the optimum growth zone is reduced to lower temperatures to compensate for elevated respiration/growth ratios (Elliott 1981 cited in McCullough 1999). Temperature extremes as high as 22-24 degrees C and as low as 0 degrees C are considered life-threatening for salmon species (Walthers and Nener 1997) or have been shown to alter growth in other salmonid species due to differences in metabolic efficiencies at high or low temperatures (McCullough 1999). A rise in the metabolic rate of cold-blooded aquatic organisms occurs when optimum temperatures are exceeded, which in turn, increases their energy requirements. A higher food requirement for juvenile salmonids may increase the risk of predation due to increased foraging.

Behavioural changes have been most notable in response to annual temperature variation: salmonids have demonstrated an avoidance reaction to high temperatures by seeking a variety of thermal refugia (deep pools (Matthews and Berg 1997), areas of ground water intrusion (Bisson *et al.* 1988; Nielsen *et al.* 1994), cooler tributaries (Mabbot 1982), or cooler headwater reaches (Rahel and Hubert 1991). It is important to note, however, that salmonids cannot always avoid elevated temperature conditions in the wild which places individuals at higher risk to multiple stressors that can reduce the performance capacity of the fish; metabolic energy is diverted from investment activities such as growth and reproduction and directed toward activities that restore homeostasis (*i.e.* respiration, locomotion, hydromineral regulation and tissue repair; Wendelaar Bonga 1997). Alternatively, fish that move from coldwater refugia to warm water feeding areas may experience a temperature shock during the transition between holding and feeding stations (and vice-versa) that could increase the risk of predation during recovery (Coutant 1973).

For juvenile salmonids in stream environments however, temperature avoidance may require certain life stages to occupy sub-optimal habitat. Under high temperature extremes, juvenile salmonids become lethargic (McCullough 1999) or may display

Table 1. Optimum water temperatures and threshold levels for eggs/alevins of salmonids species in British Columbia. (summaries after Bjornn and Reiser 1991 and McCullough 1999).

Species	Optimum water temperature range (C)	Upper or lower limit of water temperature (C) allowing >50% egg survival	Maximum or minimum tolerance temperature (≤25% survival)	Reference
Chinook	5-14.4			Reiser and Bjornn 1979
	6-10			Heming 1982
	5.8-14.2			Slater 1963
	5-14.4			Bell 1986
		3		Beacham and Murray 1990
		14.4		Bell 1991
		12.8-14.2		CDWR 1988
		11 and 5	16 and 1	Murray and McPhail 1988
			15	Garling and Masterson 1985
			15.6-16.1	Healy 1979
Coho	5-11; optimum 8		13.5 and 1	Murray and McPhail 1988
	4.4-13.3			Bell 1986
			12.4 and 1.3	Tang et al. 1987
Sockeye	2-14; optimum 8	15.5 and 1		Murray and McPhail 1988
	4.4-12.8			Combs 1965
	4.4-13.3			Bell 1986
			15.6	Andrew and Green 1960
			15.6	Mead and Woodall 1968
			15.6	Withler and Morley 1970
Chum	optimum 8	>16 and 2.5		Murray and McPhail 1988
	4-12			Beacham and Murray 1985
	4.4-13.3			Bell 1986
Pink	4.4-13.3			Bell 1986
odd year	optimum 8	15.5 and 4.5		Murray and McPhail 1988
even year	optimum 8	>15 and 3.5		Murray and McPhail 1988
Brown trout	1-10		15 (0% survival) and <1	Humpesch 1985
Cutthroat trout	<10; oogenesis and ovulation		>10; 40% survival	Smith et al. 1983
	12-14 (hatchery)			P.Brown (pers. comm.)
	10.0		tolerance=6-12	Ford et al. 1995
Rainbow trout	10-12		18.5 and 3; 0% survival	Humpesch 1985
	11			Ford et al. 1995
Arctic char	1.5-5		12.5 (0% survival) and <1	Humpesch 1985
Brook trout	6-8			Hokanson et al. 1973
	1.5-9		15 (0% survival) and <1	Humpesch 1985
	6		tolerance=0-12	Ford et al. 1995
Bull trout	2-6; optimum 2-4		8-10	McPhail and Murray 1979
	4-6			Weaver and White 1985
Lake trout	5		tolerance=0.3-10	Ford et al. 1995
Arctic grayling	7-11		3	Humpesch 1985
	10.7			Stuart and Chislett 1979
	9			McPhail and Lindsay 1970
	10			Beauchamp 1981 cited in Northcote 1993
	6-10		tolerance=2-16	Ford et al. 1995
Lake whitefish	4-6		tolerance=0-12	Ford et al. 1995
Mountain whitefish	upper limit=6		tolerance=0-12	Ford et al. 1995
Other species				
Burbot	4-7		tolerance=1-7	Ford et al. 1995
White sturgeon	14-17		tolerance up to 20	Ford et al. 1995

erratic behaviour prior to loss of equilibrium (Elliott and Elliott 1995), are unable to defend individual territories (McCullough 1999) and become more vulnerable to predation (Coutant 1973).

Due to lower metabolic activity at extremely low temperatures, salmonids also exhibit reduced activity.

Under low temperature extremes, stream-rearing juvenile salmonids seek out cover in interstitial areas of the channel bed (*i.e.* both large rivers and small streams) or alternative habitats associated with off-channel areas (Bjornn and Reiser 1991).

In nature, diurnal temperature fluctuations are generally greatest under hot summer, low flow conditions. Temperature shifts of 15 degrees C have been reported in small streams of low volume and limited riparian cover without high juvenile mortality, if maximum daily temperatures approaching upper incipient lethal levels are short-lived and temperatures are restored within the optimal range for growth (Bjornn and Reiser 1991). Notwithstanding, a large amplitude of diel variation can be considered a threat to fish health particularly where individuals are subjected to repeated exposure to resistance temperatures over a lengthy interval. Cyclical patterns of resistance temperature exposure can lead to chronic stress that manifests in reduced overall vigor, lower disease resistance, reduced growth, impaired maturation, poor reproductive success or altered behaviour (Wendelaar Bonga 1997). Depending on the rate of temperature change that may induce a temperature shock, individuals may be at a higher predation risk during the recovery period (Coutant 1973).

The determination of lethal temperatures has largely been laboratory-derived using two distinct methods: 1) the direct transfer of fish from an acclimation temperature to high or low endpoints to establish incipient lethal temperatures (ILT) or 2) gradual heating or cooling under specified rates of temperature change from an initial period of acclimation to yield critical thermal maxima or minima (CTM;McCullough 1999). A rapid increase or decrease in temperature can result in high mortality. The severity of temperature shocks however, are directly related to the acclimation temperature preceding the change, the magnitude of the temperature change and the period of exposure (Tang *et al.* 1987). Experimental evidence suggests that most fish can tolerate temperature shifts of 15-18 degrees C if exposure temperatures fall within the tolerance range of individual species (Hokanson 1977 cited in McCullough 1999). Under laboratory conditions, salmonids have shown different responses to rates of temperature change. Under a declining regime, slower rates of change have allowed individuals to achieve lower temperatures prior to loss of equilibrium, suggesting that partial acclimation occurs with a more gradual rate of cooling (Becker *et al.* 1977). Conversely, higher resistance temperatures are achieved with a higher rate of heating prior to loss of equilibrium or death, but exposure times are accordingly reduced (examples cited in McCullough 1999). It is important to note that heat exchange is a function of body size wherein a slower rate of heat transfer occurs in larger fish owing to their larger body volume. Regardless of mass, the body temperature of fish cools more quickly than it warms and juvenile salmonids may be more vulnerable to a 1-2 degrees C decrease near temperature minima compared to a 5-10 degrees C increase that approaches temperature maxima (examples provided in McCullough 1999). In general, adult fish are much more sensitive to temperature extremes than juveniles of the same species (Spigarelli *et al.* 1983 cited in McCullough 1999) and both preferred temperatures and tolerance limits are lower for adults than juveniles (McCauley and Huggins 1979)

Although variable rates of temperature change together with high endpoint values have demonstrated both sub-lethal and lethal effects, it is important to recognize the effects of a cyclic regime of diel fluctuations where some part of the fluctuation extends beyond tolerance temperature ranges over a period of weeks. To this end, the thermal exposure history may induce a cumulative response that ends in mortality where fish are subjected to unusual stress loading (DeHart 1975; Golden 1976 cited in McCullough 1999).

From a seasonal perspective, temperature fluctuations above background may have an inhibitory influence on physiological processes associated with the smoltification of anadromous salmonids. Either seaward migration or smoltification can be blocked if spring temperatures exceed a threshold of 12-14 degrees C established for most native species (Hoar 1988; Johnston and Saunders 1981).

Given that temperature thresholds for salmonids have largely been derived under a controlled environment in the laboratory, the applicability of threshold values to the wild may have its limitations where artificial conditions fail to integrate a variety of dynamic processes found in nature. The interaction of a variety of environmental effects (*i.e.* water quality, habitat quality, inter-specific competition or predation that manifest in physiological stress) may therefore impose constraints that lower temperature tolerance limits derived under more controlled circumstances.

In consideration of the types of land or water-based developments in BC, the effects of rapid (point-source heated effluents) or gradual (passive solar heating) temperature increases in receiving environments are more likely to be observed than rapid cooling events. The degree to which passive rates of temperature change occur in the province will likely vary according to geographical location and climate; higher rates of change expected in southern latitudes and lower rates in latitudes that are more northerly.

A summary of incipient lethal temperatures and critical thermal maxima for native salmonids are provided in Tables 2 and 3, respectively.

4.3 Adult migration

Water temperature provides a physical cue to adult spawners in spring, summer or fall to signal entry into natal streams. A variety of migration strategies are exhibited among anadromous salmonids that may involve a period of summer or winter holding in large river environments prior to immigration into natal spawning tributaries. Individual species show specific temperature preferences during seasonal migrations. Preferred upstream migration temperatures for salmon are particularly important given the limited energy reserves and allotted time requirements for both migration and spawning activities. Although individual populations have evolved to compensate for annual variation in climatic conditions, prolonged high temperatures can increase the rate at which energy stores are depleted for standard metabolism (Fry 1971 cited in McCullough 1999). Thermal blockages that delay migration and exhaust energy reserves can result in complete reproductive failure; elevated stream temperatures that are sub-lethal can indirectly influence spawning success by increasing metabolic stress (*i.e.*, reduced oxygen levels) or reducing resistance to disease (McCullough 1999; Gilhousen 1990). Susceptibility to disease among spawners has been reported when water temperatures exceed 16 degrees C (Walthers and Nener 1997). A summary of preferred migration temperatures and tolerance limits is provided in Table 4.

Table 2. Optimum growth and upper and lower incipient lethal temperatures of juvenile salmonids in selected states and provinces of the Pacific Northwest (after Bjornn and Reiser 1991; McCullough 1999).

Species	Location	Optimum growth temperature (C)	Acclimation temperature (C)	ILT (C) Lower/Upper	Reference
Chinook	*United States*	15.5 (10-18)			cited in Hillman and Essig 1998
	Alaska	10.5			Wilson et al. 1987
	California	13-16			Marine and Cech 1998
		10-15.6 (4.5-19.1 limit)	15.6	24.8	Armour 1991
	Washington	12-13	20 / 24	25.1	Brett 1952
		15			Banks 1971 cited in McCullough 1999
		14.6			Reiser and Bjornn 1979
		12-14		0.8/26.2	Bjornn and Reiser 1991
	British Columbia	14.8; 60% feeding ration			Brett et al. 1982
	Bear River		14	22.4; 87% mort in 1.9 d	Beacham and Withler 1991
	Robertson Ck		14	22; 74% mort in 18 d	
Chum	*British Columbia*	14.1	20	23.7	Brett 1952
	Nile Ck		23	23.8	
		12-14		0.5 / 25.4	Bjornn and Reiser 1991
		13 (13-14.1)			cited in Hillman and Essig 1998
Coho	*British Columbia*				
	Nile Ck		20 / 23	25.0	Brett 1952
		12-14		1.7 / 26.0	Bjornn and Reiser 1991
		14.8 (9-16.6)		short exposure=24	cited in Hillman and Essig 1998
Pink	*Washington*		20	23.9	Brett 1952
	Dungeness R		24	23.9	
		12-14			Brett 1952
		15.5 (9.3-15.5)			cited in Hillman and Essig 1998
Sockeye	*Washington*				
	Issaquah R		20	23.5	McConnell and Blahm 1970 cited in McCullough 1999
		14.5	20	24.8	Brett 1952
			23	24.3	
		12-14		3.1 / 25.8	Bjornn and Reiser 1991
		15 (10-15)		short exposure=22	cited in Hillman and Essig 1998
Brown trout	*England*		20	23.5	Bishai 1960
			23	25.3	Frost and Brown 1967
			20	26.3	Alabaster and Downing 1966 cited in McCullough 1999
		17.6		upper avoidance = 20	Coutant 1977
		10.0-15.5 (6-20)		short exposure=24	cited in Hillman and Essig 1998
Cutthroat trout				0.6 / 22.8	Bjornn and Reiser 1991
		7-16			McIntyre and Rieman 1995
		12-15			cited in Hillman and Essig 1998
		9-13		tolerance=0-22	Ford et al. 1995
Rainbow trout		16.5-17.2 (10-22)		short exposure=24	cited in Hillman and Essig 1998
	Ontario				
	Lake Superior	16-18	16	25.6	Hokanson et al. 1977
	Lake Erie, Huron, Superior		15	25-26	Bidgood and Berst 1969
			24	25	Cherry et al. 1977
			24?	26	Stauffer et al. 1984
			20	25.9	Threader and Houston 1983
			20	26.7	Alabaster 1964 cited in McCullough 1999
		18-19		upper avoidance=22 lower avoidance=14	Coutant 1977
	British Columbia				
	Summerland Hatchery		11	24	Black 1953
		10-14		tolerance=0-24	Ford et al. 1995
	Arizona		10	28.4	Lee and Rinne 1980
			20	29.35	
	Montana				
	Firehole R		24.5	26.2	Kaya 1978
	Ennis Hatchery		24.5	26.2	Kaya 1978
	Winthrop Hatchery		24.5	26.2	Kaya 1978
	Oregon		max <16.5		Wurtsbaugh and Davis 1977

Species	Location	Optimum growth temperature (C)	Acclimation temperature (C)	ILT (C) Lower/Upper	Reference
		BT Presence		BT Distribution limits	
Arctic char		14 (5-16)			cited in Hillman and Essig 1998
Brook trout			20	25.3	Fry et al. 1946
			24	25.5	
		14-16		25.8	Bjornn and Reiser 1991
		15			Beamish 1964
		16-18		upper avoidance = 20	Coutant 1977
		13.0-16.1 (7-20.3)		short exposure=24	cited in Hillman and Essig 1998
		12-15		tolerance=0-24	Ford et al. 1995
Bull trout	*Montana*				
	NF Flathead R	12		temperature limit = 18	Shepard et al. 1989
	NF Flathead R	12.6-12.8		daily maximums=14.1-18.9	Graham et al. 1980; Fraley et al. 1981
	Idaho				
	Weiser R drainage	2.5-19.5		temperature limit= 20.5	Adams 1994
	Lake Pend Oreille tributaries	7.8-13.9			Saffel and Scarnecchia 1995
	SF Salmon R	8.5-19.5		temperature limit= 19.5	Thurow 1987
	EF Salmon R	9-13.5			Thurow and Schill 1996
	Oregon				
	Klamath R	6.9		low density at 9.4	Ziller 1992
	Metolius R	5.7-8.2		low density at 18.2	Ratliff 1992
	Malheur R	6.7-7.8		low density at 11.1-12.2	Buckman et al. 1992
	Washington				
	Tucannon R	13-16		daily maximums=19.0	Martin et al. 1992
	British Columbia				
	Wigwam R			daily maximums=11	Oliver 1979
	Salmo R			daily maximums=14-16	Baxter unpublished data
		12-14			Hillman and Essig 1998
		<12		tolerance=0-18	Ford et al. 1995
Dolly Varden	*Japan*	8-12; > 16, appetite reduced	8	26 mortality initiated at 20	Takami et al. 1997
Lake trout	*Ontario*		20	24-24.5	Fry and Gibson 1953
		10-15.5		upper avoidance = 15	Coutant 1977
				25	Bjornn and Reiser 1991
		6-13		tolerance=-0.8-23.5	Ford et al. 1995
Grayling and whitefish					
Arctic grayling	*Montana*		20	25	Lohr et al. 1996
	Alaska		?	24.5	LaPerriere and Carlson 1973 cited in McCullough 1999
		<18			Coutant 1977
		10-12		tolerance=2-24.5	Ford et al. 1995
Whitefish					
Lake whitefish		12-16		upper avoidance=19 lower avoidance=12	Coutant 1977
		14		tolerance=2-26.6	Ford et al. 1995
Mountain whitefish		9-12		tolerance=0-20.6	Ford et al. 1995
Other species					
Burbot		15.6-18.3		tolerance=8-23.3	Ford et al. 1995
White sturgeon					

Table 3. Critical thermal maxima for juvenile salmonids reported in McCullough 1999.

Species	Origin	Acclimation Temperature (C)	Heating Rate (C/hr)	CTM (C)	Reference
Chinook	Grande Ronde R, Oregon	diel cycle (16.1-25.6)		0% surv. in 24 h	Burck 1994
		maxima 23.9-25.6		20% surv. in 4 d	
		minima 11.1-13.3			
		maxima 19.4-22.2		100% surv. in 4 d	
Coho		15	1	27.65[a]	Becker and Genoway 1979
				27.56[b]	
			18	28.7[a]	
				29.72[b]	
			60	29.63[a]	
				31.15[b]	
	6 BC hatcheries Chilliwack, Quinsam, Eagel River, Tenderfoot)	6	1	23.8-24.4[a c b]	McGeer et al. 1991
	Bingham Ck, WA	11.5c	20	28.2	Konecki et al. 1993 and
	Bockman Ck, WA	16.6c	20	29.1	Konecki et al. 1995
	Snow Ck, WA	14.6c	20	29.2	
	Bingham Ck, WA	11+ 1	20	27.6	Konecki et al. 1993 and
		11± 1	20	27.9	Konecki et al. 1995
Brown trout	age 1+ and 2+	20	0.01	24.8 (±1.56)	Elliott and Elliott 1995
			1	29.58 (±0.63)	
			18	29.98 (+1.44)	
	Ord Ck, Fort Apache Indian Res., Arizona	20	1.2	29.85 (+0.58[a]	Lee and Rinne 1980
Cutthroat trout	Oregon	23	?	30.57	Golden 1976
		13-23 cycle		29.82	
Rainbow trout	(2-3 mo old)	17	0.04-0.08	26.3	Grande and Anderson 1991
	Williams Ck NFH, Arizona	20	1.2	29.35 (±0.58)[a]	Lee and Rinne 1980
Brook trout	3-4 mo. old	17	0.08	27.2	Grande and Anderson 1991
	Ord Ck, Fort Apache Indian Res., Arizona	20	1.2	29.76 (±0.35)[a]	Lee and Rinne 1980
Lake trout	2-3 mo. old	17	0.04-0.08	25.9b	Grande and Anderson 1991
	3-4 mo. old	17	0.08	25.9b	
Arctic grayling	Big Hole R, Montana	20	24	29.3	Lohr et al. 1996

[a]=CTM determined to loss of equilibrium temperature; [b]=CTM determined to death temperature; [c]=ambient field temperature

Table 4. Preferred migration water temperatures and upper thermal tolerances for selected salmonids in streams (after Bjornn and Reiser 1991; Mc Cullough 1999).

Species	Preferred migration temperatures (C)	Upper thermal tolerance (C)	Location	Reference
Chinook		21-22	Columbia R	Becker 1973
		19	Yakima R WA	Berman 1990
		21.1	Tucannon R WA	Bumgarner et al. 1997
		>21	Clearwater R ID	Stabler 1981
		21-25	Willamette R OR	Schreck et al. 1997
Fall chinook	10.6-19.4			Bjornn and Reiser 1991
Spring chinook	3.3-13.3			Bjornn and Reiser 1991
Summer chinook	13.9-20.0			Bjornn and Reiser 1991
Chum	8.3-15.6			Bjornn and Reiser 1991
Coho	7.2-15.6			Bjornn and Reiser 1991
		>20	Lake Erie	Flett 1996
Pink	7.2-15.6			Bjornn and Reiser 1991
Sockeye	7.2-15.6			Bjornn and Reiser 1991
		22.2	Okanagan R WA	Quinn et al. 1997
Cutthroat trout		<10		Smith et al. 1983
Steelhead (rainbow)		21	Columbia R	Coutant 1970

4.4 Spawning

Although a period of holding of up to several months can occur between initial migration and spawning, the timing of the spawning period is inextricably linked to water temperatures conducive to incubation. Declining fall temperatures usually trigger the onset of spawning, however, sufficient time must follow to ensure that an adequate period of egg development precedes winter minima. Suitable fall temperatures oscillate around 10 degrees C for most salmonid species (Bjornn and Reiser 1991). Rising water temperatures similarly provide a physical cue for spring spawners with optimum incubation temperatures remaining less than 12 degrees C during the period of embryogenesis (refer to Table 1).

Pre-spawning water temperatures within acceptable levels are highly important with respect to egg viability prior to ovulation and maternal care following egg deposition. The viability of eggs within a maturing female is often reduced if holding temperatures exceed temperature tolerances of individual species prior to spawning (*e.g.*, 15-16 degrees C for salmon; 13-15 degrees C for trout; McCullough 1999). Alternatively, the period of nest guarding by females, that prevents the potential re-excavation of the redd by later spawning runs, may be reduced if limited energy stores are used up prematurely in response to higher metabolic costs associated with high stream temperatures. A summary of observed spawning temperatures for the majority of salmonids present in coastal and interior watersheds is provided in Table 5.

Table 5. Observed spawning temperatures and thermal tolerances of selected salmonids in streams (after Bjornn and Reiser 1991; McCullough 1999).

Species	Spawning Temperatures (C)	Upper thermal tolerance (C)	References
Chinook	5.6-12.8	13.3-15.6	McCullough 1999
	5.6-14.2		Bell 1991
		15-17	Marine 1992
Fall chinook	5.6-13.9		Bjornn and Reiser 1991
Spring chinook	5.6-13.9		Bjornn and Reiser 1991
Summer chinook	5.6-13.9		Bjornn and Reiser 1991
Chum	7.2-12.8		Bjornn and Reiser 1991
Coho	4.4-9.4		Bjornn and Reiser 1991
	10.6-12.8		McCullough 1999
Pink	7.2-12.8		Bjornn and Reiser 1991
Sockeye	10.6-12.2		Bjornn and Reiser 1991
	10.6-12.8	14.4-16.1	McCullough 1999
Brown trout	7.2-12.8		Bjornn and Reiser 1991
Cutthroat trout	6.1-17.2		Bjornn and Reiser 1991
	10.0		McIntyre and Rieman 1995
	10.0		Scott and Crossman 1973
Steelhead	3.9-9.4		Bjornn and Reiser 1991
Rainbow trout	2.2-20.0		Bjornn and Reiser 1991
	10.0-15.5		Scott and Crossman 1973
	7.2-13.3		Ford et al. 1995
Arctic char	4.0		Scott and Crossman 1973
Brook trout	7.1-12.8	16-19	Hokanson et al. 1973
	9.0		Ford et al. 1995
Bull trout	5.0-9.0		Shepard et al. 1984; McPhail and Murray 1979
Lake trout	10		Ford et al. 1995
Arctic grayling	4.0 (southerly)		Northcote 1993
	5.0-9.0 (northerly)		
	7-10		Ford et al. 1995
Lake whitefish	>8		Ford et al. 1995
Mountain whitefish	<6.0		Ford et al. 1995
Other species			
Burbot	0.6-1.7		Ford et al. 1995
White sturgeon	14		Ford et al. 1995

5.0 Review of existing temperature guidelines

A summary of water temperature guidelines for beneficial uses (domestic, recreational, agricultural and industrial) is provided in Appendix 1. The summary borrows from a recently completed compendium of environmental quality benchmarks (MacDonald *et al.*. 1999) and includes updates from the present literature search. The summary provides guideline, standard and criterion information for Canadian, American and European jurisdictions at the federal, provincial or state level. Certain jurisdictions have identified surface water uses (water supply, aquatic life, recreation, etc.) that apply to specific surface water classifications. Classification standards include water quality characteristics that are arranged from the highest to the lowest (*e.g.*, Class AA to Class C) within individual jurisdictions and include designated uses applicable to the water quality standard. The number of beneficial or designated uses usually decreases with declining water temperature quality. Within some jurisdictions, sub-classes may be designated (*e.g.*, B1, B2, or B3). Surface water quality temperature criteria or narrative statements are assigned to specific classifications for protective purposes. In certain instances, exceedance levels due to human activities are specified by formulae that allow incremental increases beyond ambient conditions. In regard to point-source activities, maximum permissible temperature increases are calculated using the highest ambient water temperature at a point or points unaffected by the discharge for a given period. In some instances, the amount of change above background or allowable rate of change in temperature is also specified. A list of acronyms and classification details for individual jurisdictions associated with guideline summaries are appended in a glossary at the end of the document.

With respect to characteristic uses, water supply designations are sub-divided into domestic, agricultural or industrial uses, while recreation designations are sub-divided into primary contact (*i.e.*, ingestion possible) or secondary contact (*i.e.*, ingestion not possible) uses. Aquatic life designations may include a sub-division between cold water (*i.e.*, <18 degrees C) and warm water (*i.e.*, >18 degrees C) biota or specify temperature criteria for fish life history activities that include migration, spawning, incubation and rearing. Similarly, specific water temperature criteria may be provided for the protection of threatened and endangered species.

5.1 Drinking water

Of eleven jurisdictions reported in North America and Europe, guideline values range from 12-15 degrees C and water quality standards range from 16-28.3 degrees C, depending on geographic location. The upper values are associated with the eastern seaboard states of the continental United States (refer to Appendix 1-1). Temperature guideline recommendations in the Pacific Northwest (PNW) range from less than or equal to 15-18 degrees C. Maximum temperature change, above ambient conditions, range from 0.3-2.8 degrees C across four surface water classifications. Temperature changes in the PNW range from 0.3-0.6 degrees C. Criteria have been established for aesthetic purposes or to accommodate thermal requirements of cold water or warm water fisheries. Narrative statements are provided to limit temperature change in lakes from background conditions.

5.2 Recreation and aesthetics

Of twelve jurisdictions reported in North America, water quality standards for primary contact use range from 13-32.2 degrees C and from 19-32.2 degrees C for secondary contact use in fresh, salt or estuarine waters (refer to Appendix 1-2). Maximum temperature criteria for secondary use such as angling include numeric values up to 23.9 degrees C for cold water fisheries and up to 28.3 degrees C for warm water fisheries. Maximum allowable increases over ambient conditions extend from 0.3-3.0 degrees C for all uses. Within the PNW, Washington and Montana have the most stringent permissible increases within individual classifications when natural conditions are exceeded (0.3-0.6 degrees C). Narrative statements are provided to minimize temperature change from background levels for lake classifications or provide guidelines for swimmers and bathers.

5.3 Aquatic life and wildlife

Of 20 jurisdictions reported, freshwater temperature guidelines are defined for general or specific life history activities or species within classifications or individual basins that distinguish cold water and warm water fisheries (refer to Appendix 1-3). For cold water designations, temperature criteria range from 8-24 degrees C with specific designations defined for salmonid spawning, incubation, rearing and migration. Listed species with special restrictions include bull trout and white sturgeon. Adopted protocols to establish numeric values are based on mean weekly average temperatures, maximum daily average temperatures or maximum daily temperatures. Maximum allowable temperature increases above ambient conditions range from 0.3-1.7 degrees C. The numeric values and allowances established by Washington, Oregon, Idaho, Montana, Alaska, Virginia, Massachusetts and Europe provide a level of protection that fit the range of environmental conditions observed for cold water fisheries in British Columbia. Temperature criteria for warm water designations range from 10-29.4 degrees C with allowable increases up to 3 degrees C. In a few cases, narrative statements are provided to limit alterations to natural thermal regimes or identify conditions under which further temperature increases are unacceptable.

Water quality standards for the protection of aquatic life in marine or estuarine waters are generally specified for water quality classifications (refer to Appendix 1-4). The standards show wide variation over geographical areas ranging from 13-39.4 degrees

C. Temperature changes above ambient conditions are also variable within applicable beneficial use designations (0.3-2.8 degrees C). Narrative statements are provided within certain jurisdictions to address maximum rates of temperature change or alterations in amplitude or frequency of daily temperature cycles. The standards are generally expressed as maximum values or maximum daily means. Standards with the greatest applicability to cold water biota in British Columbia are derived from Washington State guidelines where numeric values range from 13-22 degrees C.

Of nine jurisdictions reported, water quality standards or criteria for wildlife use are specified within water use classifications that range from 13.0-32.2 degrees C (refer to Appendix 1-5). Water quality standards or criteria are provided as maximum or maximum daily mean temperature values. Maximum allowable increases above ambient water temperature range from 0.3-3.0 degrees C. Narrative statements include allowable changes from natural conditions for lakes, the amount of allowable weekly average increases, and the maximum hourly rate of change. Allowable alterations to daily temperature cycles are also included for some jurisdictions. Standards with the greatest applicability to wildlife in British Columbia are again likely derived from numeric values provided from Washington State guidelines (13-21 degrees C).

5.4 Irrigation and livestock watering

Of six jurisdictions reported, water quality standards for irrigation uses identified within classifications range from 16-30 degrees C (refer to Appendix 1-6). Water quality standards are provided as maximum temperature values. Maximum allowable increases above ambient water temperature range from 0.3-2.8 degrees C. Narrative statements reflect allowable changes from natural conditions for lakes.

Of five jurisdictions reported, water quality standards for the protection of livestock within water use classifications range from 16-30 degrees C (refer to Appendix 1-7). Water quality standards are listed as maximum temperatures for all categories. Maximum allowable increases above ambient water temperature range from 0.3-2.8 degrees C. Narrative statements include allowable changes from natural conditions for lakes.

5.5 Industrial use

Of seven jurisdictions reported, water quality standards for the protection of industrial uses within water use classifications range from 13-29.4 degrees C (refer to Appendix 1-8). Water quality standards or criteria reflect maximum temperatures for all categories. Maximum allowable increases above ambient temperature range from 0.3-

2.8 degrees C. Narrative statements include allowable changes from natural conditions for lakes.

6.0 Recommended guidelines and rationale for the protection of water uses in BC

The derivation of water quality guidelines for temperature, based on a single numeric value that provides adequate protection for a designated water use, is extremely challenging given the diversity of aquatic environments in BC that vary with elevation and latitude. Both ecological communities and environmental factors vary widely throughout the province and therefore application of uniform water quality guidelines should not be expected to provide complete protection for all species at all locations. Given the overall size and geography of the province, it is unreasonable to consider that a "one size fits all" approach would adequately address the needs of society or the environment. To this end, a two-tiered approach to guideline development is recommended: 1) province-wide, interim numeric temperature guidelines are suggested to provide generic/conservative protection to designated uses until such time as 2) a surface water use classification is completed at a regional scale. The water use classification approach is recommended to distinguish differences in temperature quality among the diversity of aquatic environments throughout the province. The process should further distinguish what water uses are practical and what level of temperature modification is acceptable within the diversity of existing temperature regimes provided in nature. The procedure for developing a classification system will be expanded upon in greater detail in Section 8.

In consideration of the protection requirements of specific water uses, guideline development should adopt an ecosystem-based approach wherein the array of potential designated water uses complement or support the single use with the most stringent temperature criteria applied to each classification. That is, allowable temperature modifications from human activities associated with one use should not compromise the protective needs of an alternative use within the same classification. Moreover, it is critically important that cumulative effects of human activities/uses on water temperature be considered holistically and not individually. This is particularly important in light of management decisions to allow future developments to proceed if existing uses already compromise the attainment of a desired guideline. If guidelines are to be considered within an ecosystem context, then all beneficial uses should be accommodated within the temperature regimes provided in nature.

6.1 Drinking water

The numerical guideline value (less than or equal to 15 degrees C) prescribed by Health and Welfare Canada (1998) and adopted by the Ministry of Environment, Lands and Parks (1998) should be maintained as an aesthetic objective. To date, guideline improvement based on evidence in the scientific literature has not been shown and the current guideline is consistent with other jurisdictions in the Pacific Northwest.

6.2 Recreation and aesthetics

The numerical guideline (15-30 degrees C) provided on behalf of Health and Welfare Canada (1992) is recommended on an interim basis in place of the narrative statement provided on behalf of Ministry of Environment, Lands and Parks (1998; after CCME 1999) which states, "the thermal characteristics of water should not cause an appreciable increase or decrease in the deep body temperature of bathers and swimmers". Elevated temperatures in excess of 30 degrees C provide optimal conditions for blue-green algal blooms; toxins produced by certain strains of blue-green algae have been linked to illness in humans (CCREM 1987). Future recreation guidelines should consider primary and secondary contact criteria (*e.g.*, Washington State 1997) following the development of water use classifications.

6.3 Aquatic life

6.3.1 Freshwater

Current BC temperature guidelines for the protection of freshwater aquatic life specify an allowable increase or decrease of 1 degrees C from seasonal, background conditions in the environment (Nagpal *et al.* 1998). Temperature guidelines are further included to protect specific life history stages of salmonids: juvenile and adult rearing, 18 to 19 degrees C (maximum weekly average); maximum water temperatures between 22 and 24 degrees C; adult spawning, 8 to 10 degrees C (maximum weekly average); and egg incubation, 13 to 15 degrees C (maximum). In keeping with the lowest-observable-effects level protocol (CCME 1999), the process of setting temperature guidelines necessarily involves satisfying the needs of the most sensitive species. As outlined above, salmonids are cold-water dependent and exhibit a narrow range of cold temperatures to meet their life history requirements. Accordingly, the range of water temperatures encountered in the wild play a critical role in determining their overall distribution and abundance. Of the native species described, rainbow trout are considered to have the lowest thermal sensitivity and bull trout the highest. Given the current BC guidelines, existing temperature criteria are not considered optimal to meet the protective needs of all life stages or all fish species. Specifically, maximum temperature allowances for juvenile exposure in the range of 22-24 degrees C and incubation temperatures up to 15 degrees C are considered inappropriate.

Temperatures in the range of 22-24 degrees C represent the thermal limits to salmonid distribution and acceptance of these threshold values place individual species at much higher risk. As demonstrated above, criteria that exceed optimum temperatures have serious implications on growth/development, disease resistance, reproduction and species interactions. Based on the review of the literature to date, maximum temperature allowances between optimum and incipient lethal levels suggest that individual species will experience an impairment threshold (*i.e.* net zero growth or cumulative effects leading to death; McCullough 1999). Biophysical surveys documenting fish distribution in the wild suggest that maximum temperature tolerances are always less than the upper incipient lethal level (Eaton *et al.* 1995). Allowances set beyond optimum temperatures, therefore, will likely affect fish production by forcing species to utilize less productive environments (*i.e.*, headwaters) in their search for temperature preferences. Consequently, regulations designed to accommodate tolerance limits will ultimately force fish production well below maximum population density.

Given the range of temperatures for specific life history stages among all salmonid species encountered in British Columbia, the selection of a single criterion to meet the temperature requirements of all species is considered exceedingly difficult. Moreover, for any one species, physiological optima occur over a range of temperatures rather than at a single value. Therefore, temperature guidelines that closely follow the physiological optima of a particular life stage for an individual specie will likely provide maximum protection where a species presence has been previously determined. Based on the availability of fish presence/absence information throughout the province, a known versus unknown fish distribution approach to guideline development is recommended: As an interim measure for streams where fish presence is suspected but unconfirmed, summer rearing conditions should not exceed a mean weekly maximum temperature (MWMT - see below) of 18 degrees C and the maximum daily temperature should not exceed 19 degrees C. Similarly, incubation temperatures for eggs deposited in late spring and early fall should not exceed 12 degrees C. Where fish distribution information is available, then mean weekly maximum water temperatures should only vary + or - 1 degrees C beyond the optimum temperature range of each life history phase (incubation, rearing, migration and spawning) for the most sensitive salmonid species present (refer to Table 6). The proposed general guideline lies within the temperature tolerance limits for salmonids (refer to Table 2), extends to the upper temperature limit for positive growth (Armour 1991) and minimizes the period of exposure at the boundary limit (average maximum temperature over 7 consecutive days). The upper limit of 12 degrees C for incubation lies below the tolerance limit for those species having incubation periods that overlap either early or late summer when embryos are potentially at highest risk. Failure of complete egg development has been experimentally determined where temperatures exceed 13 degrees C for the more sensitive species (refer to Table 1). The general guideline is only intended for use as a default when fish presence is unknown. The majority of watersheds supporting industrial activities that could otherwise alter background temperature regimes in streams have resource inventory information presently available. Alternatively, new industrial projects would require a full environmental assessment that would provide a complete listing of aquatic resources. The specie-specific guideline variance of 1 degrees C places an upper and lower limit at the boundary of the optimum temperature range for each life history stage, allows for seasonality by encompassing temperature optima for individual life stages and avoids tolerance limits that could otherwise

Table 6. 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		>8.0
Mountain whitefish	<6.0	9.0-12.0		<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

contribute to chronic sub-lethal effects during summer maxima. The guideline offers consistency in its approach by recognizing the most sensitive species in the stream ecosystem. Moreover, the guideline is highly amenable to regional adjustments in species-specific temperature optima owing to differences in latitude or elevation across the province that may influence a species' local adaptation to ambient temperature regimes. Finally, because of the close relationship between behavioural thermoregulation in fish and thermal optima, the incorporation of optimum temperatures as a guideline seems highly appropriate since final temperature preferenda often coincide with temperature optima for a variety of species and age classes within a species (Kellogg and Gift 1983; Jobling 1981; Brett 1971). Thermal optimization has been shown to confer a selective advantage (*i.e.* capacity adaptation) whereby salmonids that occupy discrete thermal gradients maximize their scope for activity and ultimately enhance survival (Evans 1990; Bryan *et al.* 1990).

The choice of mean weekly maximum temperature as the most appropriate temperature metric is further recommended since fluctuating temperature regimes that exceed incipient lethal levels may place populations at further risk where maximum limits are calculated from maximum weekly average temperatures (MWAT). Although MWAT has been widely used in previous guideline documents (Nagpal *et al.* 1998; CCME 1999), the application of this metric can be biologically criticized for the peak temperatures that they average away (McCullough 1999). The MWAT calculation has been shown to sacrifice some level of production and not provide adequate protection (Hokanson *et al.* 1977 cited in McCullough 1999). For example, a recommended MWAT of 17 + or - 2 degrees C for rainbow trout was insufficient to facilitate maximum yield; a reduction of ~27% of the normal production was observed under conditions of a fluctuating temperature regime. Use of the 7-day average maximum temperature (or the average of the warmest daily maximum temperatures for 7 consecutive days (MWMT)) is recommended since the 7-d average maximum is generally 0.5 to 2.0 degrees C lower than the highest daily maximum temperature in summer (Buchanan and Gregory 1997) and the mean difference between MWMT and MWAT is about 3 degrees C based on a comparison of metrics conducted on 73 streams in Idaho and Montana (Hillman and Essig 1998). This consideration is particularly important relative to cumulative effects if fish are repeatedly exposed to maximum temperatures above critical limits over brief periods. To this end, an allowance for the frequency of exceedence must be taken into consideration to reduce the risk of cumulative stress leading to death, disease, poor reproductive success or poor growth. The 7-day average maximum is consistent with protocols established by Oregon (ODEQ 1996), and the approach is consistent with guidelines specified by Oregon, Washington and Idaho (refer to Appendix 1-3). The MWMT has been recently supported by the US Environmental Protection Agency (EPA 1997) and the US Forest Service Inland Native Fish Strategy (USFS 1995). Since the downstream limits to fish distribution are linked to maximum temperatures attained within specific reaches, the recommended maximum temperature guideline is expected to support the maximum productive capacity of stream environments for salmonids in British Columbia. The interim guidelines recommended above are not considered fully adequate for the protection of bull trout. In consideration of their blue-listed status in BC, specific temperature guidelines are recommended for waters frequented by bull trout. To this end, maximum daily temperatures should not exceed 15 degrees C, maximum spawning temperatures should not exceed 10degrees C, and incubation temperatures should not exceed 6 degrees C or fall below 2 degrees C. The sensitivity of survival rate to a 1 degrees C decrease in winter is much greater than a corresponding increase in summer, when temperatures lie at the extreme of optimum seasonal ranges (McCullough 1999). Therefore, no measurable temperature modification (*i.e.*, increase or decrease) during the period of incubation should be allowed. Optimum juvenile rearing temperatures fall within the range of 6-14 degrees C. While bull trout distributional information for daily maximum temperature exceeding 20 degrees C exist for watersheds in their southerly range in North America (Adams 1994; Gamett 1998), short-term exposures to these critical levels are not considered conducive to normal growth or survival. These recommendations are consistent with the range of temperature criteria specified for bull trout in Oregon (ODEQ 1996) and Idaho (IDH&W 1998; refer to Appendix 1-3).

The justification for special guidelines for bull trout has been aptly summarized by Buchanan and Gregory (1997) and is highly applicable to regions of British Columbia affected by hydro-electric development:

"Most cold-water species such as bull trout were distributed more widely during previous glacial periods of lower temperatures across the North American continent. Current populations commonly are patchy and restricted to cold water refuges. Gene flow between populations is minimal, and local populations are easily isolated by impacts on stream flows and temperatures. The extreme temperature constraints on cold water species limit them to restricted or marginal habitats in the headwaters of river drainages and scattered outlets of deep cold water aquifers. To protect these species, water temperature standards must be substantially lower than traditional criteria, and must accommodate seasonal requirements of specific life history stages." This same approach is recommended for British Columbia to protect cold-water species at all stages of their development.

Dolly Varden (*Salvelinus malma*), once thought to be the same species of char as bull trout, display similarities to bull trout in their choice of habitat within British Columbia. Temperature preferences for rearing also show a close parallel (Tables 2 and 6). Based on these similarities, it is recommended that Dolly Varden be afforded the same special protection as bull trout, since their close relationship suggests that both species may be equally sensitive to thermal variations.

Much of the rationale for a temperature guideline to protect aquatic life has centered on the avoidance of temperature extremes that have either acute or chronic consequences. Equally important, however, is the need to identify an acceptable rate of temperature change that does not invoke a physiological response that contributes to mortality. The experimental evidence suggests that the response to thermal shock is highly dependent on the acclimation temperature (both constant and cyclic), the magnitude of the temperature shift and the final endpoint value (Threader and Houston 1983; Thomas *et al.* 1986; Tang *et al.* 1987). Beyond the obvious consequences of an instantaneous temperature change that leads to death within minutes, experimental designs that impose a large amplitude of diel variation can also have lethal effects when fluctuations lead to increased widening of the diel range (Thomas *et al.* 1986). Sub-lethal effects over a narrower range in delta T that lead to either heat shock or cold shock (*i.e.* rapid increase or decrease) can include physiological stress leading to metabolic dysfunction (Wedemeyer 1973), growth inhibition and disease initiation (Wedemeyer and McLeay 1981) or increased predation (Coutant 1973). Slower rates of heating or cooling expose fish to temperatures within their tolerance range and provide a period of acclimation to facilitate physiological adjustment (McCullough 1999).

Rapid increases associated with diel fluctuation would not be expected to occur in nature since daily variation in temperature of about 3 degrees C has been reported for streams in an undisturbed old growth forest (Thomas *et al.* 1986); a diel fluctuation (minimum to maximum) which is equivalent to about a 0.4degrees C change per hour. In the same study, a higher rate of heating of about 1.95 degrees C/h was observed for streams associated with clear-cuts. The fact that salmonids have adapted to small rates of change in natural ecosystems suggests that alterations in stream temperature imposed by anthropogenic sources should follow the same template provided in nature. To this end, a rate of temperature change in the order of 0.5 to 1.0 degrees C/h is recommended for guideline purposes. Experimental support for this recommendation is further provided from a study on the effect of rate of temperature increase on salmonid parr (Elliott and Elliott 1995). In a series of tests to determine the CTM at nine different rates of temperature increase (*i.e.* 0.0104 - 18 degrees C/h), rapid recovery of fish, returned to suitable temperatures before death occurred, was only observed for rates up to 2 degrees C/h.

Continued application of the + or - 1 degrees C change from natural conditions is expected to meet the protection needs of aquatic life in natural lake environments. The availability of water temperature in a range, which is physiologically optimal, has also been demonstrated to contribute strongly to a species productive capacity within a lake environment (Christie and Regier 1988). Further definition is required on the size of acceptable mixing zones associated with point-source discharges to lakes or rivers before temperature guidelines are formalized. Mixing zone boundary considerations should be resolved with future deliberations aimed at water use classifications.

In summary, recommended guideline changes for the protection of aquatic life in streams include:

· temperature metrics to be described by the 7-d average maximum temperature or mean weekly maximum temperature (MWMT)

· where fish presence is unknown, salmonid rearing not to exceed MWMT of 18 degrees C; maximum daily temperature not to exceed 19 degrees C and;

· maximum temperature for salmonid incubation from June until August not to exceed 12 degrees C;

· where fish presence is known, mean weekly maximum water temperatures should not exceed + or - 1 degrees C beyond the optimum temperature range for each life history phase of the most sensitive salmonid species present (refer to Table 6 for temperature optima)

· the rate of temperature change in natural water bodies not to exceed 1 degrees C/h.

Specific to bull trout and Dolly Varden in streams:

· maximum daily temperatures for rearing should not exceed 15 degrees C;

· maximum spawning temperature should not exceed 10 degrees C;

· preferred incubation temperatures should range from 2- 6 degrees C In lakes:

· + or - 1 degrees C change from natural condition

6.3.2 Marine

The numerical standard (+ or - 1 degrees C from natural background condition) recommended by CCME (1999) and cited as a working guideline by the Ministry of Environment, Lands and Parks (Nagpal 1998), should be maintained to minimize impacts on marine resources. The following narrative statements included in the CCME (1999) recommendation should also apply, "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 C per hour". To date, guideline improvement based on evidence in the scientific literature has not been shown and the current guideline is consistent with other jurisdictions in the Pacific Northwest (*e.g.*, Alaska; refer to Appendix 1-4).

6.4 Wildlife

At present, there is no guideline value or narrative statement for the protection of wildlife in British Columbia. As an interim measure, the numerical guideline of + or - 1 degrees C from natural background condition should apply until the recommended water use classification (section 8) is completed. Future recommendations for the protection of wildlife should be considered within an ecosystem context; recommendations should complement temperature guidelines developed for the most sensitive use within specific classifications. A scaled model of temperature criteria for the protection of wildlife is provided by Washington State, where increasing temperature allowances mirror the shift from cold water to cool water environments (refer to Appendix 1-7).

6.5 Irrigation and livestock watering

At present there is no guideline value or narrative statement for the protection of irrigation or livestock in British Columbia. As an interim measure, the numerical guideline of + or - 1 degrees C from natural background condition should apply until the recommended water use classification (section 8) is completed. Future recommendations for the protection of irrigation or livestock should be considered within an ecosystem context; recommendations should complement temperature guidelines developed for the most sensitive use within specific classifications. A scaled model of temperature criteria for the protection of irrigation and livestock is provided by Washington State where increasing temperature allowances mirror the shift from cold water to cool water environments (refer to Appendices 1-5 and 1-6).

6.6 Industrial use

At present there is no guideline value or narrative statement for the protection of industrial use in British Columbia. As an interim measure, the numerical guideline of + or - 1 degrees C from natural background condition should apply until the recommended water use classification is completed. Future recommendations for the protection of industrial use should be considered within an ecosystem context; recommendations should complement temperature guidelines developed for the most sensitive use within specific classifications. A scaled model of temperature criteria for the protection of industrial use is provided by Washington State where increasing temperature allowances mirror the shift from cold water to cool water environments (refer to Appendix 1-8).

7.0 Statistical designs and sampling protocols for monitoring attainment of temperature guidelines

7.1 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 instream flow (Rhodes *et al.* 1994 cited in McCullough 1999). 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 (Underwood 1994).

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 BACI (Before-After-Control-Impact; Green 1979). The 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 (*i.e.*, the "pseudoreplication" argument advanced by Hurlbert 1984). 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 (Stewart-Oaten *et al.* 1986; Underwood 1991, 1992 and 1994; Osenberg *et al.* 1994). 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 (Osenberg *et al.* 1994) or an asymmetrical design (Underwood 1994) is recommended for statistical comparisons. In the latter instance, additional control locations are incorporated into the design along with a single impact location to account for variability in nature and reliably detect impacts 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.

7.2 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 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 (Bartholow 1989 cited in McCullough 1999) 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. Bartholow (1989) also recommended calculation of the cumulative probability of a sequence of events within a specified duration. 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.

8.0 Water use classification

A review of the guideline approach in the majority of jurisdictions in the PNW has revealed that most US states have opted for a water use classification system that recognizes the diversity of water resource values provided in nature, identifies what beneficial uses are appropriate for each classification, and assigns specific guidelines for their individual protection. The same approach is recommended for British Columbia to offer greater flexibility in the designation of beneficial uses by fine-tuning guidelines that provide appropriate levels of protection to water resources of varying environmental quality. An ecosystem-based model for the derivation of classifications is similarly recommended to ensure that individual designated uses complement and support the most sensitive use.

The classification of watersheds across the province is in no way a small task. The challenge to such an undertaking is to apply a classification system that is simple, cost-effective and region-specific. Consistent with other jurisdictions, the classification approach could employ a series of classes based on environmental quality (*e.g.*, Class AA (extraordinary), A (excellent), B (good) or C (fair); Washington State) or adopt a cold water (up to 20 degrees C), cool water (up to 25 degrees C), and warm water (up to 30 degrees C) designation.

The characterization of streams and rivers of variable size throughout the province could be accomplished by a variety of means. In consideration of the existing temperature records available through federal and provincial programs or local community watershed or stewardship groups, it may be possible to categorize a number of streams based on previously recorded summer maxima. In areas where water temperature information is lacking, estimates could be derived from air temperature records. For example, based on field studies of the air-water relationship, Stefan and Preud'homme (1993) found weekly water temperature changes to average 0.86 of the weekly air temperature changes for streams of various sizes in southern and northern US states (Eaton and Scheller 1996). The method could be applied to unrecorded streams where air temperature data from nearby climate stations are available. Accuracy of the estimate could be further improved by a simple field measurement. Stoneman and Jones (1996) were able to classify representative streams in Ontario by simply comparing water temperature to air temperature at 16:00 h on hot summer days. Maximum daily water temperatures corrected with air temperature were highly effective in establishing the thermal stability of selected streams and separating observations into discrete classifications with limited overlap. The same process could be duplicated in BC with the assistance of seasonal staff or stewardship groups, particularly in community watersheds. A third method that would lend itself to development of specific temperature guidelines for streams characteristic of different fish guilds, is the field information-based system for estimating fish temperature tolerances (Eaton *et al.* 1995). The method involves a technique for spatial and temporal matching of stream temperature records and fish sampling events to establish annual temperature regimes for freshwater fish (*i.e.*, the Fish and Temperature Database Matching System (FTDMS)). The 95th percentile of the weekly mean temperatures is used to estimate the maximum temperatures tolerated by a particular species in nature (Eaton *et al.* 1995). This same approach could be used to separate cold water salmonid streams from other cool water or warm water streams colonized by non-salmonid fish species. Datasets for fish/temperature series could be accessed from the BC Fisheries Branch Fish Information Summary System (FISS) to determine species presence/absence throughout the year. The number of stream records in the FISS database has increased dramatically in most regions since promulgation of the Forest Practices Code. Maximum temperature estimates could be acquired from sources identified above. The technique has two principal benefits: 1) it allows temperature tolerance guidelines to be based on temperature preferential displayed by representative fish species in nature and avoids reliance on incipient lethal limits determined under laboratory conditions and 2) it lends itself to an ecosystem-based approach wherein temperature guidelines are developed in consideration of the most sensitive use. Guidelines for temperature would therefore follow the temperature tolerances of representative fish guilds within discrete classifications; other beneficial water uses would be included within the same temperature range to complement the most sensitive use (*i.e.*, fish). The development of class-specific temperature guidelines and inclusion of designated uses within each class are therefore derived from the variation of environmental qualities provided in nature and is consistent with classification systems adopted in Washington, Oregon, Idaho and Montana.

The future development of temperature-specific guidelines for water use classifications across the province is paramount given the threat of surface water temperature increases due to global warming. Historical summaries comparing the effect of climatic condition on annual growth (King *et al.* 1999), experimental manipulations of the thermal regime of stream environments (Hogg *et al.* 1995; Hetrick *et al.* 1998), or the application of simulation models (Van Winkle *et al.* 1997), suggest that the effects of temperature increase on annual temperature cycles will have positive and negative impacts on aquatic biota relative to growth, reproductive success, physiological condition and population genetics. Negative impacts in aquatic environments are anticipated with temperature shifts as little as 2 to 4 degrees C. These events place a larger burden on management agencies to minimize temperature perturbations associated with smaller-scale human activities within individual basins. It is suggested that the water use classification approach is an important step in improving the temperature guideline process and deriving region-specific guidelines that provide adequate levels of protection throughout the province. To facilitate the guideline development process, it is further recommended that the utility of derivation methods such as the air-water relationship or FTDMS be tested for ease of application over a smaller geographical area before it is given province-wide application. Vancouver Island seems a logical choice in consideration of the diversity of anadromous and resident fish species present, diversity of development activities in watersheds, expected diversity of stream temperature regimes due to latitudinal position and elevation, and temperature data records. Following the development of a classification system, temperature guidelines should be developed for individual beneficial uses within each classification. Guideline examples provided by PNW jurisdictions are highly recommended to facilitate this process.

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APPENDIX 1. A Summary of the Available Water Quality Criteria and Guidelines for the Protection of Water Uses

Appendix 1-1. A Summary of the Available Water Quality Criteria and Guidelines for the Protection of Human Health (Water Supplies).

Parameter	Water Type	Guideline	Units	Application	Jurisdiction	Reference
Temperature	FW	12	°C	Guide level	Europe	CEC 1988
	FW	<=15	°C	Guideline; Aesthetic Objective	Canada	Health Canada 1998
	FW	<=15	°C	Guideline; Aesthetic Objective	British Columbia	BCMOELP 1998
	FW	15	°C	Standard; Maximum	Alaska	ADEC 1998a
	FW	15	°C	Maximum desirable; Related to aesthetic	Ontario	Environment Ontario 1983
	FW	16.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=23/ [T+5] at any time; Class AA (extraordinary)	Washington	Washington State 1997
	FW	18.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=28/ [T+7] at any time; Class A (excellent)	Washington	Washington State 1997
	FW	20	°C	Criterion; Use IIIp waters; (68 F); Outside mixing zone; Or may not exceed ambient temperature, whichever is greater	Maryland	MDOE 1997
	FW	20	°C	Standard; For Class A; Maximum in cold water fisheries (or 68 F)	Massachusetts	COM 1996
	FW	22	°C	Guide level for all categories	Europe	CEC 1988
	FW	25	°C	Imperative values for all categories	Europe	CEC 1988
	FW	25	°C	Maximum admissible	Europe	CEC 1988
	FW	28.3	°C	Criterion; Maximum; Class A, B, B1, C; (83 F)	Rhode Island	RIDEM 1997
	FW	28.3	°C	Standard; For Class A; Maximum in warm water fisheries (or 83 F)	Massachusetts	COM 1996
Temperature (change)	FW	0.3	°C	Standard; Maximum allowable increase when natural conditions exceed 16.0 C; Class AA (extraordinary)	Washington	Washington State 1997
	FW	0.3	°C	Standard; Secondary Upper Limit for A-1, B-1 and C-1 Classifications; (0.5 F)	Montana	USEPA 1988a
	FW	0.6	°C	Standard; Upper value for A-1, B-1 and C-1 Classifications; (1 F)	Montana	USEPA 1988a
	FW	0.83	°C	Standard; For Class A; (1.5 F)	Massachusetts	COM 1996

Parameter	Water Type	Guideline	Units	Application	Jurisdiction	Reference
Temperature (change; cont.)	FW	1.7	°C	Standard; Secondary Upper Limit; After disinfection; Class AA; (3 F)	Maine	USEPA 1988b
	FW	1.7	°C	Standard; Secondary Upper Limit; After disinfection; Class A; (3 F)	Maine	USEPA 1988b
	FW	1.7	°C	Standard; Secondary Upper Limit; After disinfection; Class B; (3 F)	Maine	USEPA 1988b
	FW	1.7	°C	Standard; Secondary Upper Limit; After disinfection; Class C; (3 F)	Maine	USEPA 1988b
	FW-Lakes	1.7	°C	Standard; Secondary Upper Limit; After disinfection; Class GPA - Lakes and Ponds; (3 F)	Maine	USEPA 1988b
	FW	2.2	°C	Criterion; Maximum increase for receiving waters; Class A, B, B1, C; (4 F)	Rhode Island	RIDEM 1997
	FW	2.8	°C	Standard; Upper value; After disinfection; Class AA; (5 F)	Maine	USEPA 1988b
	FW	2.8	°C	Standard; Upper value; After disinfection; Class A; (5 F)	Maine	USEPA 1988b
	FW	2.8	°C	Standard; Upper value; After disinfection; Class B; (5 F)	Maine	USEPA 1988b
	FW	2.8	°C	Standard; Upper value; After disinfection; Class C; (5 F)	Maine	USEPA 1988b
	FW-Lakes	2.8	°C	Standard; Upper value; After disinfection; Class GPA - Lakes and Ponds; (5 F)	Maine	USEPA 1988b
	FW-Lakes	Narrative		Standard; No measurable change from natural conditions; Lake Class	Washington	Washington State 1997

Appendix 1-2. A Summary of the Available Water Quality Criteria and Guidelines for the Protection of Recreation and Aesthetics.

Parameter	**Water Type**	**Guideline**	**Units**	**Application**	**Jurisdiction**	**Reference**
Temperature	SW	13.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=8/ [T-4] at any time; Class AA (extraordinary); Primary contact	Washington	Washington State 1997
	FW	15–30	°C	Range for bathing	Canada	H&WC 1983
	FW	16.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=23/ [T+5] at any time; Class AA (extraordinary); Primary contact	Washington	Washington State 1997
	SW	16.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=12/ [T-2] at any time; Class A (excellent); Primary contact	Washington	Washington State 1997
	FW	18.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=28/ [T+7] at any time; Class A (excellent); Primary contact	Washington	Washington State 1997
	SW	19.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=16/[T]; Class B (good); Secondary contact	Washington	Washington State 1997
	FW	20	°C	Standard; For Class A; Maximum in cold water fisheries (or 68 F)	Massachusetts	COM 1996
	FW	20	°C	Standard; For Class B; Maximum in cold water fisheries; (or 68 F)	Massachusetts	COM 1996
	FW	21.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=34/ [T+9]; Class B (good); Secondary contact	Washington	Washington State 1997
	SW	22.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=20/ [T+2]; Class C (fair); Secondary contact	Washington	Washington State 1997
	FW	23.9	°C	Criterion; Use IV - Recreational trout waters; (75 F); Outside mixing zone; Or may not exceed ambient temperature, whichever is greater	Maryland	MDOE 1997
	EST/SW	26.7	°C	Standard; For Class SA; Maximum daily mean (or 80 F)	Massachusetts	COM 1996
	EST/SW	26.7	°C	Standard; For Class SB; Maximum daily mean (or 80 F)	Massachusetts	COM 1996
	FW	28.3	°C	Criterion; Maximum; Primary or Secondary contact; Class A, B, B1, C; (83 F)	Rhode Island	RIDEM 1997

Parameter	Water Type	Guideline	Units	Application	Jurisdiction	Reference
Temperature (cont.)	FW	28.3	°C	Standard; For Class A; Maximum in warm water fisheries (or 83 F)	Massachusetts	COM 1996
	FW	28.3	°C	Standard; For Class B; Maximum in warm water fisheries; (or 83 F)	Massachusetts	COM 1996
	SW	28.3	°C	Criterion; Maximum; Primary and secondary contact; Class SA, SB, SB1,and SC; (83 F)	Rhode Island	RIDEM 1997
	FW	29.4	°C	Standard; For Class C; At any time (or 85 F); Secondary recreation	Massachusetts	COM 1996
	FW/SW	29.4	°C	Standard; Upper value; Primary and secondary contact and water of exceptional recreation or ecological significance; (85 F)	Delaware	USEPA 1988d
	EST/SW	29.4	°C	Standard; For Class SA; Maximum at any time (or 85 F)	Massachusetts	COM 1996
	EST/SW	29.4	°C	Standard; For Class SB; Maximum at any time (or 85 F)	Massachusetts	COM 1996
	EST/SW	29.4	°C	Standard; For Class SC; Maximum at any time (or 85 F); Secondary recreation	Massachusetts	COM 1996
	FW	30	°C	Standard; Maximum, For contact recreation	Alaska	ADEC 1998a
	FW/EST	32.2	°C	Standard; Upper value; Secondary contact	District of Columbia	USEPA 1988d
	FW/SW	32.2	°C	Criterion; Use I waters - Primary contact (90 F); Outside mixing zone; Or may not exceed ambient temperature, whichever is greater	Maryland	MDOE 1997
	FW	Narrative		Guideline; Should not cause an appreciable increase or decrease in deep body temperature for swimmers and bathers	British Columbia	BCMOELP 1998
Temperature (change)	FW	0.3	°C	Standard; Secondary Upper Limit for A-1, B-1 and C-1 Classifications; (0.5 F)	Montana	USEPA 1988a
	FW	0.3	°C	Standard; Secondary Upper Limit for B-2, B-3, C-2 and C-3 Classifications; (0.5 F)	Montana	USEPA 1988a
	FW/SW	0.3	°C	Standard; Maximum allowable increase when natural conditions exceed 16.0 C / 13.0 C for FW/SW respectively; Class AA (extraordinary); Primary contact	Washington	Washington State 1997
	FW/SW	0.3	°C	Standard; Maximum allowable increase when natural conditions exceed 21.0 C / 19.0 C for FW/SW respectively; Class B (good); Secondary contact	Washington	Washington State 1997

Parameter	Water Type	Guideline	Units	Application	Jurisdiction	Reference
Temperature (change; cont.)	FW/SW	0.3	°C	Standard; Maximum allowable increase when natural conditions exceed guideline; Class A (excellent); Primary contact	Washington	Washington State 1997
	SW	0.3	°C	Standard; Maximum allowable increase when natural conditions exceed 22.0 C for SW; Class C (fair); Secondary contact	Washington	Washington State 1997
	FW	0.6	°C	Standard; Upper value for A-1, B-1 and C-1 Classifications; (1 F)	Montana	USEPA 1988a
	FW	0.6	°C	Standard; Upper value for B-2 and C-2 Classifications; (1 F)	Montana	USEPA 1988a
	FW	0.83	°C	Standard; For Class A; (or1.5 F)	Massachusetts	COM 1996
	EST/SW	0.83	°C	Standard; Secondary Upper value; Class SA; (1.5 F)	Maine	USEPA 1988b
	EST/SW	0.83	°C	Standard; Secondary Upper value; Class SB; (1.5 F)	Maine	USEPA 1988b
	EST/SW	0.83	°C	Standard; Secondary Upper value; Class SC; (1.5 F)	Maine	USEPA 1988b
	EST/SW	0.83	°C	Standard; For Class SA; (or 1.5 F)	Massachusetts	COM 1996
	EST/SW	0.83	°C	Standard; For Class SB; (or 1.5 F); During summer months	Massachusetts	COM 1996
	SW	0.89	°C	Criterion; Maximum increase above normal temperature; Primary and secondary contact; Class SA, SB, SB1, and SC; (1.6 F)	Rhode Island	RIDEM 1997
	FW-Lakes	1.7	°C	Standard; Secondary Upper Limit; Class GPA - Lakes and Ponds; (3 F)	Maine	USEPA 1988b
	FW	1.7	°C	Standard; Upper value for B-3 and C-3 Classifications; (3 F)	Montana	USEPA 1988a
	FW	1.7	°C	Standard; Secondary Upper Limit; Class AA; (3 F)	Maine	USEPA 1988b
	FW	1.7	°C	Standard; Secondary Upper Limit; Class A; (3 F)	Maine	USEPA 1988b
	FW	1.7	°C	Standard; Secondary Upper Limit; Class B; (3 F)	Maine	USEPA 1988b
	FW	1.7	°C	Standard; Secondary Upper Limit; Class C; (3 F)	Maine	USEPA 1988b
	FW	1.7	°C	Standard; For Class B; Maximum in cold water fisheries; (or 3 F)	Massachusetts	COM 1996
	FW	1.7	°C	Standard; For Class B; Maximum for lakes and ponds; (or 3 F)	Massachusetts	COM 1996
	FW	2.2	°C	Criterion; Maximum increase for receiving waters; Primary and secondary contact; Class A, B, B1, C; (4 F)	Rhode Island	RIDEM 1997

Parameter	Water Type	Guideline	Units	Application	Jurisdiction	Reference
Temperature (change; cont.)	FW/SW	2.2	°C	Standard; Secondary Upper Limit; Primary and secondary contact and water of exceptional recreation or ecological significance; (4 F)	Delaware	USEPA 1988d
	EST/SW	2.2	°C	Standard; Upper value; Class SA; (4 F)	Maine	USEPA 1988b
	EST/SW	2.2	°C	Standard; Upper value; Class SB; (4 F)	Maine	USEPA 1988b
	EST/SW	2.2	°C	Standard; Upper value; Class SC; (4 F)	Maine	USEPA 1988b
	EST/SW	2.2	°C	Standard; For Class SB; (or 4 F); During winter months	Massachusetts	COM 1996
	FW-Lakes	2.8	°C	Standard; Upper value; Class GPA - Lakes and Ponds; (5 F)	Maine	USEPA 1988b
	FW	2.8	°C	Standard; Upper value; Class AA; (5 F)	Maine	USEPA 1988b
	FW	2.8	°C	Standard; Upper value; Class A; (5 F)	Maine	USEPA 1988b
	FW	2.8	°C	Standard; Upper value; Class B; (5 F)	Maine	USEPA 1988b
	FW	2.8	°C	Standard; Upper value; Class C; (5 F)	Maine	USEPA 1988b
	FW	2.8	°C	Standard; For Class B; Maximum in warm water fisheries; (or 5 F)	Massachusetts	COM 1996
	FW	2.8	°C	Standard; For Class C; (or 5 F); Secondary recreation	Massachusetts	COM 1996
	FW/EST	2.8	°C	Standard; Upper value for Temperature Change	District of Columbia	USEPA 1988d
	FW/SW	2.8	°C	Standard; Upper value; Primary and secondary contact and water of exceptional recreation or ecological significance; (5 F)	Delaware	USEPA 1988d
	EST/SW	2.8	°C	Standard; For Class SC; (or 5 F); Secondary recreation	Massachusetts	COM 1996
	FW	3	°C	Maximum increase above ambient conditions	Alberta	AEP 1997
	FW-Lakes	Narrative		Standard; No measurable change from natural conditions; Lake Class; Primary contact	Washington	Washington State 1997

Appendix 1-3. A Summary of the Available Water Quality Criteria and Guidelines for the Protection of Freshwater Aquatic Life.

Parameter	Water Type	Guideline	Units	Application	Jurisdiction	Reference
Temperature	FW	8-10	°C	Criterion; Maximum weekly average; adult salmonid spawning	British Columbia	BCMOELP 1998
	FW	9	°C	Criterion; Maximum daily average for bull trout spawning (Sept and Oct.)	Idaho	IDH&W 1998
	FW	10	°C	Basin level criteria; no measureable (0.25F) increase from anthropogenic activities when 10 C is exceeded to maintain viability of native bull trout	Oregon	ODEQ 1996
	FW	10 – 21.5	°C	Imperative for salmonid waters; Downstream of the point of thermal discharge (edge of mixing zone); weekly sampling upstream and downstream of point of thermal discharge	Europe	CEC 1988
	FW	10 – 28	°C	Imperative for cyprinid waters; Downstream of the point of thermal discharge (edge of mixing zone); weekly sampling upstream and downstream of point of thermal discharge	Europe	CEC 1988
	FW	12	°C	Criterion; Maximum daily average for juvenile bull trout rearing	Idaho	IDH&W 1998
	FW	12.8	°C	Basin level criteria; no measureable (0.25F) increase from anthropogenic activities when 12.8 C is exceeded to support native salmonid spawning, egg incubation and fry emergence	Oregon	ODEQ 1996
	FW	13	°C	Standard; For spawning areas and egg & fry incubation; Includes aquaculture	Alaska	ADEC 1998a
	FW	13	°C	Criterion; Maximum for water-column spawning salmon; And maximum daily average <= 9 °C	Idaho	IDH&W 1998
	FW	13-15	°C	Criterion; Maximum for salmonid embryo survival	British Columbia	BCMOELP 1998
	FW	14	°C	Criterion; Kootenai R sturgeon; 7 d average not to exceed 14 C; Bonner's Ferry to Shorty's Island; May 1 to July 1	Idaho	IDH&W 1999
	FW	15	°C	Standard; For migration routes and rearing areas; Includes aquaculture	Alaska	ADEC 1998a
	FW	16.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=23/ [T+5] at any time; Class AA (extraordinary)	Washington	Washington State 1997

Parameter	Water Type	Guideline	Units	Application	Jurisdiction	Reference
Temperature (cont.)	FW	17.8	°C	Basin level criteria; no measureable (0.25F) increase from anthropogenic activities where salmonid rearing is a designated beneficial use	Oregon	ODEQ 1996
	FW	18.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=28/ [T+7] at any time; Class A (excellent)	Washington	Washington State 1997
	FW	18-19	°C	Criterion; Maximum weekly average; adult and juvenile salmonid rearing	British Columbia	BCMOELP 1998
	FW	19	°C	Criterion; Maximum daily average for waters 22 °C or less; Cold Water Biota	Idaho	IDH&W 1998
	FW	20	°C	Columbia R criteria; no measureable (0.25F) increase from anthropogenic activities when 20 C is exceeded	Oregon	ODEQ 1996
	FW	20	°C	Standard; Maximum; Natural trout waters	Virginia	COV 1997
	FW	20	°C	Standard; Maximum; Includes aquaculture	Alaska	ADEC 1998a
	FW	20	°C	Standard; For Class A; Maximum in cold water fisheries (or 68 F)	Massachusetts	COM 1996
	FW	20	°C	Standard; For Class B; Maximum in cold water fisheries; (or 68 F)	Massachusetts	COM 1996
	FW/SW	20	°C	Criterion; (68 F); Outside mixing zone; Or may not exceed ambient temperature, whichever is greater; Use III and IV waters - Natural trout waters	Maryland	MDOE 1997
	FW	21	°C	Standard; Maximum; Stockable trout waters	Virginia	COV 1997
	FW	21.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=34/ [T+9]; Class B (good)	Washington	Washington State 1997
	FW	22	°C	Standard; Maximum due to human activities; No increase shall exceed t=20/ [T+2]; Class C (fair)	Washington	Washington State 1997
	FW	22-24	°C	Criterion; Maximum; adult and juvenile salmonids	British Columbia	BCMOELP 1998
	FW	28.3	°C	Criterion; Maximum; Class A, B, B1, C; (83 F)	Rhode Island	RIDEM 1997
	FW	28.3	°C	Standard; For Class B; Maximum in warm water fisheries; (or 83 F)	Massachusetts	COM 1996
	FW	28.3	°C	Standard; For Class A; Maximum in warm water fisheries (or 83 F)	Massachusetts	COM 1996
	FW	29	°C	Criterion; Maximum daily average for waters 33 °C or less; Warm Water Biota	Idaho	IDH&W 1998

Parameter	**Water Type**	**Guideline**	**Units**	**Application**	**Jurisdiction**	**Reference**
Temperature (cont.)	FW	29.4	°C	Standard; For Class C; At any time (or 85 F)	Massachusetts	COM 1996
	FW/SW	29.4	°C	Standard; Upper value; Coldwater fish (put-and-take); Water of exceptional recreation or ecological significance; And shellfish waters; (85 F)	Delaware	USEPA 1988d
	FW	31	°C	Standard; Maximum; Mountainous	Virginia	COV 1997
	FW	32	°C	Standard; Maximum; Nontidal waters	Virginia	COV 1997
	FW/EST	32.2	°C	Standard; Upper value	District of Columbia	USEPA 1988d
	FW/SW	32.2	°C	Criterion; Use I waters - Primary contact (90 F); Outside mixing zone; Or may not exceed ambient temperature, whichever is greater	Maryland	MDOE 1997
	FW	Narrative		Objective; The natural thermal regime of any body of water shall not be altered so as to impair the quality of the natural environment. In particular, the diversity, distribution and abundance of plant and animal life shall not be significantly changed	Ontario	Environment Ontario 1989a
	FW	Narrative		Guideline; Thermal additions should not alter thermal stratification or turnover dates, exceed maximum weekly average temperatures; Nor exceed maximum short-term	Canada	Environment Canada 1999
	FW	Narrative		Interim Guideline; Thermal additions should not alter thermal stratification or turnover dates, exceed maximum weekly average temperatures; Nor exceed maximum short-term	Nova Scotia	NSDOE 1998
Temperature (change)	FW	0.25	°F	Basin level criteria; no measureable increase from anthropogenic activities; ecologically significant coldwater refugia; stream segments containing Federally listed threatened and endangered species; dissolved oxygen within 0.5 mg/l or 10 % saturation of the water column; natural lakes	Oregon	ODEQ 1996
	FW/SW	0.3	°C	Standard; Maximum allowable increase when natural conditions exceed 21.0 C / 19.0 C for FW/SW respectively; Class B (good)	Washington	Washington State 1997

Parameter	Water Type	Guideline	Units	Application	Jurisdiction	Reference
Temperature (change; cont.)	FW/SW	0.3	°C	Standard; Maximum allowable increase when natural conditions exceed 16.0 C / 13.0 C for FW/SW respectively; Class AA (extraordinary)	Washington	Washington State 1997
	FW/SW	0.3	°C	Standard; Maximum allowable increase when natural conditions exceed 18.0C / 16 C for FW/SW, respectively; Class A (excellent)	Washington	Washington State 1997
	FW	0.3	°C	Standard; Maximum allowable increase when natural conditions exceed 22.0C; Class C (fair)	Washington	Washington State 1997
	FW	0.3	°C	Standard; Secondary Upper Limit for B-2, B-3, C-2 and C-3 Classifications; (0.5 F)	Montana	USEPA 1988a
	FW	0.3	°C	Standard; Secondary Upper Limit for A-1, B-1 and C-1 Classification; (0.5 F)	Montana	USEPA 1988a
	FW	0.5	°C	Criterion; Maximum for bull trout waters (See reference)	Idaho	IDH&W 1998
	FW	0.6	°C	Standard; Upper value for A-1, B-1 and C-1 Classification; (1 F)	Montana	USEPA 1988a
	FW	0.6	°C	Standard; Upper value for B-2 and C-2 Classifications; (1 F)	Montana	USEPA 1988a
	FW	0.83	°C	Standard; For Class A; (or 1.5 F)	Massachusetts	COM 1996
	FW	1	°C	Standard; freshwater aquatic life; +/- 1 C from natural background condition	British Columbia	BCMOELP 1998
	FW	1.5	°C	Maximum increase; Imperative for salmonid waters; Weekly measurements taken both upstream and downstream of the point of thermal discharge (edge of mixing zone)	Europe	CEC 1988
	FW	1.7	°C	Standard; For Class B; Maximum for lakes and ponds; (or 3 F)	Massachusetts	COM 1996
	FW	1.7	°C	Standard; For Class B; Maximum in cold water fisheries; (or 3 F)	Massachusetts	COM 1996
	FW	1.7	°C	Standard; Secondary Upper Limit; Class A; (3 F)	Maine	USEPA 1988b
	FW	1.7	°C	Standard; Upper value for B-3 and C-3 Classifications; (3 F)	Montana	USEPA 1988a
	FW	1.7	°C	Standard; Secondary Upper Limit; Class B; (3 F)	Maine	USEPA 1988b
	FW	1.7	°C	Standard; Secondary Upper Limit; Class C; (3 F)	Maine	USEPA 1988b
	FW	1.7	°C	Standard; Secondary Upper Limit; Class AA; (3 F)	Maine	USEPA 1988b

Parameter	Water Type	Guideline	Units	Application	Jurisdiction	Reference
Temperature (change; cont.)	FW-Lakes	1.7	°C	Standard; Secondary Upper Limit; Class GPA - Lakes and Ponds; (3 F)	Maine	USEPA 1988b
	FW/SW	2	°C	Guideline; Maximum increase	Australia	ANZECC 1992
	FW	2.2	°C	Criterion; Maximum increase for receiving waters; Class A, B, B1, C; (4 F)	Rhode Island	RIDEM 1997
	FW/SW	2.2	°C	Standard; Secondary Upper Limit; Coldwater fish (put-and-take); Water of exceptional recreation or ecological significance; And shellfish waters; (4 F)	Delaware	USEPA 1988d
	FW	2.8	°C	Standard; Upper value; Class C; (5 F)	Maine	USEPA 1988b
	FW	2.8	°C	Standard; For Class B; Maximum in warm water fisheries; (or 5 F)	Massachusetts	COM 1996
	FW/EST	2.8	°C	Standard; Upper value for Temperature Change	District of Columbia	USEPA 1988d
	FW	2.8	°C	Standard; Upper value; Class A; (5 F)	Maine	USEPA 1988b
	FW	2.8	°C	Standard; Upper value; Class AA; (5 F)	Maine	USEPA 1988b
	FW	2.8	°C	Standard; Upper value; Class B; (5 F)	Maine	USEPA 1988b
	FW	2.8	°C	Standard; For Class C; (or 5 F)	Massachusetts	COM 1996
	FW	2.8	°C	Standard; For Class AA, A and B; non-point source discharges; change above ambient	Washington	Washington State 1997
	FW/SW	2.8	°C	Standard; Upper value; Coldwater fish (put-and-take); Water of exceptional recreation or ecological significance; And shellfish waters; (5 F)	Delaware	USEPA 1988d
	FW-Lakes	2.8	°C	Standard; Upper value; Class GPA - Lakes and Ponds; (5 F)	Maine	USEPA 1988b
	FW	3	°C	Objective; Maximum increase above ambient water temperature	Saskatchewan	SDEPS1988
	FW	3	°C	Maximum increase, imperative for cyprinid waters, weekly measurements taken both upstream and downstream of the point of thermal discharge (edge of mixing zone)	Europe	CEC 1988
	FW	3	°C	Interim Guideline; Maximum increase above ambient conditions	Alberta	AEP 1997
	FW-Lakes	Narrative		Standard; No measurable change from natural conditions; Lake Class	Washington	Washington State 1997

Appendix 1-4. A Summary of the Available Water Quality Criteria and Guidelines for the Protection of Marine and Estuarine Aquatic Life.

Parameter	Water Type	Guideline	Units	Application	Jurisdiction	Reference
Temperature	SW	13	°C	Standard; Maximum due to human activities; No increase shall exceed t = 8/ [T-4] at any time; Class AA (extraordinary)	Washington	Washington State 1997
	SW	16	°C	Standard; Maximum due to human activities; No increase shall exceed t = 12/ [T-2] at any time; Class A (excellent)	Washington	Washington State 1997
	SW	19	°C	Standard; Maximum due to human activities; No increase shall exceed t = 16/[T]; Class B (good)	Washington	Washington State 1997
	FW/SW	20	°C	Criterion; (68 F); Outside mixing zone; Or may not exceed ambient temperature, whichever is greater; Use III and IV waters - Natural trout waters	Maryland	MDOE 1997
	SW	22	°C	Standard; Maximum due to human activities; No increase shall exceed t = 20/ [T+2]; Class C (fair); For salmonid and other fish migration	Washington	Washington State 1997
	EST/SW	26.7	°C	Standard; For Class SA; Maximum daily mean (or 80 F)	Massachusetts	COM 1996
	EST/SW	26.7	°C	Standard; For Class SB; Maximum daily mean (or 80 F)	Massachusetts	COM 1996
	SW	28.3	°C	Criterion; Maximum; Class SA, SB, SB1,and SC; (83 F)	Rhode Island	RIDEM 1997
	EST/SW	29.4	°C	Standard; For Class SB; Maximum at any time (or 85 F)	Massachusetts	COM 1996
	EST/SW	29.4	°C	Standard; For Class SC; Maximum at any time (or 85 F)	Massachusetts	COM 1996
	FW/SW	29.4	°C	Standard; Upper value; Coldwater fish (put-and-take); Water of exceptional recreation or ecological significance; And shellfish waters; (85 F)	Delaware	USEPA 1988d
	FW/EST	32.2	°C	Standard; Upper value	District of Columb	USEPA 1988d
	FW/SW	32.2	°C	Criterion; Use I waters - Primary contact (90 F); Outside mixing zone; Or may not exceed ambient temperature, whichever is greater	Maryland	MDOE 1997
	EST/SW	39.4	°C	Standard; For Class SA; Maximum at any time (or 85 F)	Massachusetts	COM 1996

Parameter	Water Type	Guideline	Units	Application	Jurisdiction	Reference
Temperature (change)	FW/SW	0.3	°C	Standard; Maximum allowable increase when natural conditions exceed 16.0 C / 13.0 C for FW/SW respectively; Class AA (extraordinary)	Washington	Washington State 1997
	FW/SW	0.3	°C	Standard; Maximum allowable increase when natural conditions exceed 21.0 C / 19.0 C for FW/SW respectively; Class B (good)	Washington	Washington State 1997
	FW/SW	0.3	°C	Standard; Maximum allowable increase when natural conditions exceed guideline; Class A (excellent)	Washington	Washington State 1997
	SW	0.3	°C	Standard; Maximum allowable increase when natural conditions exceed 22.0 C for SW; Class C (fair); For salmonid and other fish migration	Washington	Washington State 1997
	EST/SW	0.83	°C	Standard; Secondary Upper value; Class SA; For aquaculture, propagation and harvesting of shellfish and as habitat; (1.5 F)	Maine	USEPA 1988b
	EST/SW	0.83	°C	Standard; Secondary Upper value; Class SB; For aquaculture, propagation and harvesting of shellfish and as habitat; (1.5 F)	Maine	USEPA 1988b
	EST/SW	0.83	°C	Standard; Secondary Upper value; Class SC; For aquaculture, propagation and restricted harvesting of shellfish and as habitat; (1.5 F)	Maine	USEPA 1988b
	EST/SW	0.83	°C	Standard; For Class SA; (or 1.5 F)	Massachusetts	COM 1996
	EST/SW	0.83	°C	Standard; For Class SB; (or 1.5 F); During summer months	Massachusetts	COM 1996
	SW	0.89	°C	Criterion; Maximum increase above normal temperature; Class SA, SB, SB1, and SC; (1.6 F)	Rhode Island	RIDEM 1997
	SW	1	°C	Standard; marine aquatic life; +/-1 C from natural background condition	British Columbia	BCMOELP 1998
	FW/SW	2	°C	Guideline; Maximum increase	Australia	ANZECC 1992
	SW	2	°C	Maximum increase above natural conditions; Guideline for shellfish waters	Europe	CEC 1988
	EST/SW	2.2	°C	Standard; Upper value; Class SA; For aquaculture, propagation and harvesting of shellfish and as habitat; (4 F)	Maine	USEPA 1988b

Parameter	Water Type	Guideline	Units	Application	Jurisdiction	Reference
Temperature (change; cont.)	EST/SW	2.2	°C	Standard; Upper value; Class SB; For aquaculture, propagation and harvesting of shellfish and as habitat; (4 F)	Maine	USEPA 1988b
	EST/SW	2.2	°C	Standard; Upper value; Class SC; For aquaculture, propagation and restricted harvesting of shellfish and as habitat; (4 F)	Maine	USEPA 1988b
	EST/SW	2.2	°C	Standard; For Class SB; (or 4 F); During winter months	Massachusetts	COM 1996
	FW/SW	2.2	°C	Standard; Secondary Upper Limit; Coldwater fish (put-and-take); Water of exceptional recreation or ecological significance; And shellfish waters; (4 F)	Delaware	USEPA 1988d
	FW/EST	2.8	°C	Standard; Upper value for temperature change	District of Columb	USEPA 1988d
	EST/SW	2.8	°C	Standard; For Class SC; (or 5 F)	Massachusetts	COM 1996
	FW/SW	2.8	°C	Standard; Upper value; Coldwater fish (put-and-take); Water of exceptional recreation or ecological significance; And shellfish waters; (5 F)	Delaware	USEPA 1988d
	SW	Narrative		Interim Guideline; Not to exceed +/-1 C and the maximum rate of temperature change should not exceed 0.5C per hour	Canada	Environment Canada 1999
	SW	Narrative		Guideline; Not to exceed +/-1 C and the maximum rate of temperature change should not exceed 0.5C per hour	Nova Scotia	NSDOE 1998
	SW	Narrative		Standard; May not cause the weekly average temperature to increase more than 1 C. The maximum rate of change may not exceed 0.5 C per hour; Normal daily temperature cycles may not be altered in amplitude or frequency	Alaska	ADEC 1998a

Appendix 1-5. A Summary of the Available Water Quality Criteria and Guidelines for the Protection of Wildlife (Water Consumption).

Parameter	Water Type	Guideline	Units	Application	Jurisdiction	Reference
Temperature	SW	13.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=8/ [T-4] at any time; Class AA (extraordinary)	Washington	Washington State 1997
	FW	16.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=23/ [T+5] at any time; Class AA (extraordinary)	Washington	Washington State 1997
	SW	16.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=12/ [T-2] at any time; Class A (excellent)	Washington	Washington State 1997
	FW	18.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=28/ [T+7] at any time; Class A (excellent)	Washington	Washington State 1997
	SW	19.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=16/[T]; Class B (good)	Washington	Washington State 1997
	FW	20	°C	Standard; Maximum	Alaska	ADEC 1998a
	FW	20	°C	Standard; For Class A; Maximum in cold water fisheries (or 68 F)	Massachusetts	COM 1996
	FW	20	°C	Standard; For Class B; Maximum in cold water fisheries; (or 68 F)	Massachusetts	COM 1996
	FW	21.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=34/ [T+9]; Class B (good)	Washington	Washington State 1997
	EST/SW	26.7	°C	Standard; For Class SA; Maximum daily mean (or 80 F)	Massachusetts	COM 1996
	EST/SW	26.7	°C	Standard; For Class SB; Maximum daily mean (or 80 F)	Massachusetts	COM 1996
	FW	28.3	°C	Criterion; Maximum; Class A, B, B1, C; (83 F)	Rhode Island	RIDEM 1997
	FW	28.3	°C	Standard; For Class A; Maximum in warm water fisheries (or 83 F)	Massachusetts	COM 1996
	FW	28.3	°C	Standard; For Class B; Maximum in warm water fisheries; (or 83 F)	Massachusetts	COM 1996
	SW	28.3	°C	Criterion; Maximum; Class SA, SB, SB1,and SC; (83 F)	Rhode Island	RIDEM 1997

Parameter	Water Type	Guideline	Units	Application	Jurisdiction	Reference
Temperature (cont.)	EST/SW	29.4	°C	Standard; For Class SA; Maximum at any time (or 85 F)	Massachusetts	COM 1996
	EST/SW	29.4	°C	Standard; For Class SB; Maximum at any time (or 85 F)	Massachusetts	COM 1996
	EST/SW	29.4	°C	Standard; For Class SC; Maximum at any time (or 85 F)	Massachusetts	COM 1996
	FW	29.4	°C	Standard; For Class C; At any time (or 85 F)	Massachusetts	COM 1996
	FW/SW	29.4	°C	Standard; Upper value; (85 F)	Delaware	USEPA 1988d
	FW/EST	32.2	°C	Standard; Upper value	District of Columb	USEPA 1988d
Temperature (change)	FW/SW	0.3	°C	Standard; Maximum allowable increase when natural conditions exceed 16.0 C / 13.0 C for FW/SW respectively; Class AA (extraordinary)	Washington	Washington State 1997
	FW/SW	0.3	°C	Standard; Maximum allowable increase when natural conditions exceed 21.0 C / 19.0 C for FW/SW respectively; Class B (good)	Washington	Washington State 1997
	FW/SW	0.3	°C	Standard; Maximum allowable increase when natural conditions exceed guideline; Class A (excellent)	Washington	Washington State 1997
	FW	0.3	°C	Standard; Secondary Upper Limit for A-1, B-1 and C-1 Classifications; (0.5 F)	Montana	USEPA 1988a
	FW	0.3	°C	Standard; Secondary Upper Limit for B-2, B-3, C-2 and C-3 Classifications; (0.5 F)	Montana	USEPA 1988a
	FW	0.6	°C	Standard; Upper value for A-1, B-1 and C-1 Classifications; (1 F)	Montana	USEPA 1988a
	FW	0.6	°C	Standard; Upper value for B-2 and C-2 Classifications; (1 F)	Montana	USEPA 1988a
	EST/SW	0.83	°C	Standard; For Class SA; (or 1.5 F)	Massachusetts	COM 1996
	EST/SW	0.83	°C	Standard; For Class SB; (or 1.5 F); During summer months	Massachusetts	COM 1996
	FW	0.83	°C	Standard; For Class A; (or 1.5 F)	Massachusetts	COM 1996

Parameter	Water Type	Guideline	Units	Application	Jurisdiction	Reference
Temperature (change; cont.)	SW	0.89	°C	Criterion; Maximum increase above normal temperature; Class SA, SB, SB1, and SC; (1.6 F)	Rhode Island	RIDEM 1997
	FW	1.7	°C	Standard; Upper value for B-3 and C-3 Classifications; (3 F)	Montana	USEPA 1988a
	FW	1.7	°C	Standard; For Class B; Maximum in cold water fisheries; (or 3 F)	Massachusetts	COM 1996
	FW	1.7	°C	Standard; For Class B; Maximum for lakes and ponds; (or 3 F)	Massachusetts	COM 1996
	EST/SW	2.2	°C	Standard; For Class SB; (or 4 F); During winter months	Massachusetts	COM 1996
	FW	2.2	°C	Criterion; Maximum increase for receiving waters; Class A, B, B1, C; (4 F)	Rhode Island	RIDEM 1997
	FW/SW	2.2	°C	Standard; Secondary Upper Limit; (4 F)	Delaware	USEPA 1988d
	FW/EST	2.8	°C	Standard; Upper value for Temperature Change	District of Columb	USEPA 1988d
	EST/SW	2.8	°C	Standard; For Class SC; (or 5 F)	Massachusetts	COM 1996
	FW	2.8	°C	Standard; For Class B; Maximum in warm water fisheries; (or 5 F)	Massachusetts	COM 1996
	FW	2.8	°C	Standard; For Class C; (or 5 F)	Massachusetts	COM 1996
	FW/SW	2.8	°C	Standard; Upper value; (5 F)	Delaware	USEPA 1988d
	FW	3	°C	Objective; Maximum increase above ambient water temperature	Saskatchewan	SDEPS1988
	FW-Lakes	Narrative		Standard; No measurable change from natural conditions; Lake Class	Washington	Washington State 1997
	SW	Narrative		Standard; May not cause the weekly average temperature to increase more than 1 C; Maximum rate of change may not exceed 0.5 C per hour; Normal daily temperature cycles may not be altered in amplitude or frequency	Alaska	ADEC 1998a

Appendix 1-6. A Summary of the Available Water Quality Criteria and Guidelines for the Protection of Irrigation.

Parameter	Water Type	Guideline	Units	Application	Jurisdiction	Reference
Temperature	FW	16.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=23/ [T+5] at any time; Class AA (extraordinary)	Washington	Washington State 1997
	FW	18.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=28/ [T+7] at any time; Class A (excellent)	Washington	Washington State 1997
	FW	20	°C	Standard; For Class B; Maximum in cold water fisheries; (or 68 F)	Massachusetts	COM 1996
	FW	21.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=34/ [T+9]; Class B (good)	Washington	Washington State 1997
	FW	28.3	°C	Standard; For Class B; Maximum in warm water fisheries; (or 83 F)	Massachusetts	COM 1996
	FW	29.3	°C	Criterion; Maximum; Class A, B, B1, C; (83 F)	Rhode Island	RIDEM 1997
	FW	29.4	°C	Standard; Upper value; Value applies to general agricultural uses; (85 F)	Delaware	USEPA 1988d
	FW	29.4	°C	Standard; For Class C; At any time (or 85 F); After cooking	Massachusetts	COM 1996
	FW	30	°C	Standard; Maximum	Alaska	ADEC 1998a
Temperature (change)	FW	0.3	°C	Standard; Maximum allowable increase when natural conditions exceed 16.0 C / 13.0 C for FW/SW respectively; Class AA (extraordinary)	Washington	Washington State 1997
	FW	0.3	°C	Standard; Maximum allowable increase when natural conditions exceed 21.0 C / 19.0 C for FW/SW respectively; Class B (good)	Washington	Washington State 1997
	FW	0.3	°C	Standard; Maximum allowable increase when natural conditions exceed guideline; Class A (excellent)	Washington	Washington State 1997
	FW	0.3	°C	Standard; Secondary Upper Limit for A-1, B-1 and C-1 Classifications; Value applies to general agricultural uses; (0.5 F)	Montana	USEPA 1988a
Temperature (change; cont.)	FW	0.3	°C	Standard; Secondary Upper Limit for B-2, B-3, C-2 and C-3 Classifications; Value applies to general agricultural uses; (0.5 F)	Montana	USEPA 1988a
	FW	0.6	°C	Standard; Upper value for A-1, B-1 and C-1 Classifications; Value applies to general agricultural uses; (1 F)	Montana	USEPA 1988a
	FW	0.6	°C	Standard; Upper value for B-2 and C-2 Classifications; Value applies to general agricultural uses; (1 F)	Montana	USEPA 1988a
	FW	1.7	°C	Standard; Upper value for B-3 and C-3 Classifications; Value applies to general agricultural uses; (3 F)	Montana	USEPA 1988a
	FW	1.7	°C	Standard; For Class B; Maximum in cold water fisheries; (or 3 F)	Massachusetts	COM 1996
	FW	1.7	°C	Standard; For Class B; Maximum for lakes and ponds; (or 3 F)	Massachusetts	COM 1996
	FW	2.2	°C	Standard; Secondary Upper Limit; Value applies to general agricultural uses; (4 F)	Delaware	USEPA 1988d
	FW	2.2	°C	Criterion; Maximum increase for receiving waters; Class A, B, B1, C; (4 F)	Rhode Island	RIDEM 1997
	FW	2.8	°C	Standard; Upper value; Value applies to general agricultural uses; (5 F)	Delaware	USEPA 1988d
	FW	2.8	°C	Standard; For Class B; Maximum in warm water fisheries; (or 5 F)	Massachusetts	COM 1996
	FW	2.8	°C	Standard; For Class C; (or 5 F); After cooking	Massachusetts	COM 1996
	FW-Lakes	Narrative		Standard; No measurable change from natural conditions; Lake Class	Washington	Washington State 1997

Appendix 1-7. A Summary of the Available Water Quality Criteria and Guidelines for the Protection of Livestock.

Parameter	Water Type	Guideline	Units	Application	Jurisdiction	Reference
Temperature	FW	16.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=23/ [T+5] at any time; Class AA (extraordinary)	Washington	Washington State 1997
	FW	18.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=28/ [T+7] at any time; Class A (excellent)	Washington	Washington State 1997
	FW	21.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=34/ [T+9]; Class B (good)	Washington	Washington State 1997
	FW	28.3	°C	Criterion; Maximum; Class A, B, B1, C; Value applies to general agricultural uses; (83 F)	Rhode Island	RIDEM 1997
	FW	29.4	°C	Standard; Upper value; Value applies to general agricultural uses; (85 F)	Delaware	USEPA 1988d
	FW	30	°C	Standard; Maximum	Alaska	ADEC 1998a
Temperature (change)	FW	0.3	°C	Standard; Maximum allowable increase when natural conditions exceed 16.0 C; Class AA (extraordinary)	Washington	Washington State 1997
	FW	0.3	°C	Standard; Maximum allowable increase when natural conditions exceed 21.0 C / 19.0 C for FW/SW respectively; Class B (good)	Washington	Washington State 1997
	FW	0.3	°C	Standard; Maximum allowable increase when natural conditions exceed guideline; Class A (excellent)	Washington	Washington State 1997
	FW	0.3	°C	Standard; Secondary Upper Limit for B-2, B-3, C-2 and C-3 Classifications; Value applies to general agricultural uses; (0.5 F)	Montana	USEPA 1988a
	FW	0.3	°C	Standard; Secondary Upper Limit for A-1, B-1 and C-1 Classifications; Value applies to general agricultural uses; (0.5 F)	Montana	USEPA 1988a
	FW	0.6	°C	Standard; Upper value for B-2 and C-2 Classifications; Value applies to general agricultural uses; (1 F)	Montana	USEPA 1988a
	FW	0.6	°C	Standard; Upper value for A-1, B-1 and C-1 Classifications; Value applies to general agricultural uses; (1 F)	Montana	USEPA 1988a

Parameter	Water Type	Guideline	Units	Application	Jurisdiction	Reference
Temperature (change; cont.)	FW	1.7	°C	Standard; Upper value for B-3 and C-3 Classifications; Value applies to general agricultural uses; (3 F)	Montana	USEPA 1988a
	FW	2.2	°C	Criterion; Maximum increase for receiving waters; Class A, B, B1, C; Value applies to general agricultural uses; (4 F)	Rhode Island	RIDEM 1997
	FW	2.2	°C	Standard; Secondary Upper Limit; Value applies to general agricultural uses; (4 F)	Delaware	USEPA 1988d
	FW	2.8	°C	Standard; Upper value; Value applies to general agricultural uses; (5 F)	Delaware	USEPA 1988d
	FW-Lakes	Narrative		Standard; No measurable change from natural conditions; Lake Class	Washington	Washington State 1997

Appendix 1-8. A Summary of the Available Water Quality Criteria and Guidelines for the Protection of Industrial Uses.

Parameter	Water Type	Guideline	Units	Application	Jurisdiction	Reference
Temperature	SW	13.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=8/ [T-4] at any time; Class AA (extraordinary)	Washington	Washington State 1997
	FW	15	°C	Standard; Maximum; For food processing	Alaska	ADEC 1998a
	SW	15	°C	Standard; Maximum; For seafood processing	Alaska	ADEC 1998a
	FW	16.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=23/ [T+5] at any time; Class AA (extraordinary)	Washington	Washington State 1997
	SW	16.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=12/ [T-2] at any time; Class A (excellent)	Washington	Washington State 1997
	FW	18.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=28/ [T+7] at any time; Class A (excellent)	Washington	Washington State 1997
	SW	19.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=16/[T]; Class B (good)	Washington	Washington State 1997
	FW	20	°C	Standard; For Class B; Maximum in cold water fisheries; (or 68 F)	Massachusetts	COM 1996
	FW	21.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=34/ [T+9]; Class B (good)	Washington	Washington State 1997
	SW	22.0	°C	Standard; Maximum due to human activities; No increase shall exceed t=20/ [T+2]; Class C (fair)	Washington	Washington State 1997
	FW/SW	25	°C	Standard; Maximum	Alaska	ADEC 1998a
	FW	28.3	°C	Criterion; Maximum; Class A, B, B1, C; (83 F)	Rhode Island	RIDEM 1997
	FW	28.3	°C	Standard; For Class B; Maximum in warm water fisheries; (or 83 F)	Massachusetts	COM 1996
	SW	28.3	°C	Criterion; Maximum; Class SA, SB, SB1,and SC; (83 F)	Rhode Island	RIDEM 1997
	EST/SW	29.4	°C	Standard; For Class SC; Maximum at any time (or 85 F)	Massachusetts	COM 1996
	FW	29.4	°C	Standard; Upper value; (85 F)	Delaware	USEPA 1988d
	FW	29.4	°C	Standard; For Class C; At any time (or 85 F)	Massachusetts	COM 1996

Parameter	Water Type	Guideline	Units	Application	Jurisdiction	Reference
Temperature (change)	FW/SW	0.3	°C	Standard; Maximum allowable increase when natural conditions exceed 16.0 C / 13.0 C for FW/SW respectively; Class AA (extraordinary)	Washington	Washington State 1997
	FW/SW	0.3	°C	Standard; Maximum allowable increase when natural conditions exceed 21.0 C / 19.0 C for FW/SW respectively; Class B (good)	Washington	Washington State 1997
	SW	0.3	°C	Standard; Maximum allowable increase when natural conditions exceed 22.0 C for SW; Class C (fair)	Washington	Washington State 1997
	FW/SW	0.3	°C	Standard; Maximum allowable increase when natural conditions exceed 18.0 C / 16.0 C for FW/SW respectively; Class A (excellent)	Washington	Washington State 1997
	FW	0.3	°C	Standard; Secondary Upper Limit for A-1, B-1 and C-1 Classifications; (0.5 F)	Montana	USEPA 1988a
	FW	0.3	°C	Standard; Secondary Upper Limit for B-2, B-3, C-2 and C-3 Classifications; (0.5 F)	Montana	USEPA 1988a
	FW	0.6	°C	Standard; Upper value for A-1, B-1 and C-1 Classifications; (1 F)	Montana	USEPA 1988a
	FW	0.6	°C	Standard; Upper value for B-2 and C-2 Classifications; (1 F)	Montana	USEPA 1988a
	EST/SW	0.83	°C	Standard; Secondary Upper value; Class SB; (1.5 F)	Maine	USEPA 1988b
	EST/SW	0.83	°C	Standard; Secondary Upper value; Class SC; (1.5 F)	Maine	USEPA 1988b
	SW	0.89	°C	Criterion; Maximum increase above normal temperature; Class SA, SB, SB1, and SC; (1.6 F)	Rhode Island	RIDEM 1997
	FW	1.7	°C	Standard; Upper value for B-3 and C-3 Classifications; (3 F)	Montana	USEPA 1988a
	FW	1.7	°C	Standard; Secondary Upper Limit; Class A; (3 F)	Maine	USEPA 1988b
	FW	1.7	°C	Standard; Secondary Upper Limit; Class B; (3 F)	Maine	USEPA 1988b
	FW	1.7	°C	Standard; Secondary Upper Limit; Class C; (3 F)	Maine	USEPA 1988b
	FW	1.7	°C	Standard; For Class B; Maximum in cold water fisheries; (or 3 F)	Massachusetts	COM 1996
	FW	1.7	°C	Standard; For Class B; Maximum for lakes and ponds; (or 3 F)	Massachusetts	COM 1996

Parameter	Water Type	Guideline	Units	Application	Jurisdiction	Reference
Temperature (change; cont.)	FW-Lakes	1.7	°C	Standard; Secondary Upper Limit; Class GPA - lakes and ponds; (3 F)	Maine	USEPA 1988b
	EST/SW	2.2	°C	Standard; Upper value; Class SB; (4 F)	Maine	USEPA 1988b
	EST/SW	2.2	°C	Standard; Upper value; Class SC; (4 F)	Maine	USEPA 1988b
	FW	2.2	°C	Standard; Secondary Upper Limit; (4 F)	Delaware	USEPA 1988d
	FW	2.2	°C	Criterion; Maximum increase for receiving waters; Class A, B, B1, C; (4 F)	Rhode Island	RIDEM 1997
	EST/SW	2.8	°C	Standard; For Class SC; (or 5 F); Secondary recreation	Massachusetts	COM 1996
	FW	2.8	°C	Standard; Upper value; (5 F)	Delaware	USEPA 1988d
	FW	2.8	°C	Standard; Upper value; Class A; (5 F)	Maine	USEPA 1988b
	FW	2.8	°C	Standard; Upper value; Class B; (5 F)	Maine	USEPA 1988b
	FW	2.8	°C	Standard; Upper value; Class C; (5 F)	Maine	USEPA 1988b
	FW	2.8	°C	Standard; For Class B; Maximum in warm water fisheries; (or 5 F)	Massachusetts	COM 1996
	FW	2.8	°C	Standard; For Class C; (or 5 F)	Massachusetts	COM 1996
	FW-Lakes	2.8	°C	Standard; Upper value; Class GP A - lakes and ponds; (5 F)	Maine	USEPA 1988b
	FW-Lakes	Narrative		Standard; No measurable change from natural conditions; Lake Class	Washington	Washington State 1997

Glossary of Acronyms and Terms

C - Degrees Celsius
°C - Degrees Celsius
d - Day
EST - Estuary
F - Degrees Fahrenheit
°F - Degrees Fahrenheit
FW - Freshwater
hr - Hour
L - Litre
LC_{50} - Lethal Concentration affecting 50 percent of the population
m - Metre
mg/L - Milligrams per litre (mg/kg, micrograms/g or ppm)
SW - Saltwater

t - Maximum permissible temperature increase measured at a dilution zone boundary
T Background temperature as measured at a point(s) unaffected by the discharge and representative of the highest ambient water temperature in the vicinity of the discharge

WQ - Water Quality

Classification Definitions (by Jurisdiction)

Europe

Category A1 - Surface water. Simple physical treatment and disinfection, *e.g.* rapid filtration and disinfection.

Category A2 - Surface water. Normal physical treatment, chemical treatment and disinfection, *e.g.* pre-chlorination, coagulation, flocculation, decantation, filtration, disinfection (final chlorination).

Category A3 - Surface water. Intensive physical and chemical treatment, extended treatment and disinfection, *e.g.* chlorination to break-point, coagulation, flocculation, decantation, filtration, adsorption (activated carbon), disinfection (ozone, final chlorination).

Maine

Class AA Fresh surface waters. Drinking water after disinfection, fishing, recreation in and on the water and navigation and as habitat for fish and other aquatic life.

Class A Fresh surface waters. Drinking water after disinfection, fishing, recreation in and on the water, industrial processes and cooling water supply, hydroelectric power generation, except as prohibited under Title 12, section 403, and navigation, and as habitat for fish and other aquatic life.

Class B Fresh surface waters. Drinking water after disinfection, fishing, recreation in and on the water, industrial processes and cooling water supply, hydroelectric power generation, except as prohibited under Title 12, section 403, and navigation, and as habitat for fish and other aquatic life.

Class C - Fresh surface waters. Drinking water after disinfection, fishing, recreation in and on the water, industrial processes and cooling water supply, hydroelectric power generation, except as prohibited under Title 12, section 403, and navigation, and as habitat for fish and other aquatic life.

Class GPA - Lakes and ponds. Drinking water after disinfection, fishing, recreation in and on the water, industrial processes and cooling water supply, hydroelectric power generation and navigation, and as habitat for fish and other aquatic life.

Class SA - Estuarine and marine waters. Recreation in and on the water, fishing, aquaculture, propagation and harvesting of shellfish and navigation, and as habitat for fish and other estuarine and marine life.

Class SB - Estuarine and marine waters. Recreation in and on the water, fishing, aquaculture, propagation and harvesting of shellfish, industrial process and cooling water supply, hydroelectric power generation and navigation and as habitat for fish and other estuarine and marine life.

Class SC - Estuarine and marine waters. Fishing, aquaculture, propagation and restricted harvesting of shellfish, industrial processes and cooling water supply, hydroelectric power generation and navigation and as habitat for fish and other estuarine and marine life.

Class GW-A - Public water supplies.

Class GW-B - All other uses other than public water supplies.

Maryland

Use I - Water Contact Recreation, and Protection of Aquatic Life. This use designation includes waters which are suitable for water contact sports; play and leisure time activities where individuals may come in direct contact with the surface water; fishing; the growth and propagation of fish (other than trout), other aquatic life, and wildlife; agricultural water supply; and industrial water supply.

Use II - Shellfish Harvesting Waters. This use designation include waters where shellfish are propagated, stored, or gathered for marketing purposes, and there are actual or potential areas for the harvesting of oysters, soft-shell clams, hard-shell clams, and brackish water clams.

Use III - Natural Trout Waters. This use designation includes waters which have the potential for or are suitable for the growth and propagation of trout and capable of supporting self-sustaining trout populations and their associated food organisms.

Use IIIp - Natural Trout Waters and Public Water Supply. This use designation includes all uses identified for Use III waters, and use as a public water supply.

Use IV - Recreational Trout Waters. This use designation includes cold or warm waters which have the potential for or are capable of holding or supporting adult trout for put-and-take fishing, and managed as a special fishery by periodic stocking and seasonal catching.

Massachusetts

Class A - Freshwater. These waters are designated as a source of public water supply. To the extent compatible with this use they shall be an excellent habitat for fish, other aquatic life and wildlife, and suitable for primary and secondary contact recreation. These waters shall have excellent aesthetic value. These waters are designated for protection as Outstanding Resource Waters under 314 CMR 4.04(3).

Class B - Freshwater. These waters are designated as a habitat for fish, other aquatic life, and wildlife, and for primary and secondary contact recreation. Where designated they shall be suitable as a source of public water supply with appropriate treatment. They shall be suitable for irrigation and other agricultural uses and for compatible industrial cooling and process uses. These waters shall have consistently good aesthetic value.

Class C - These waters are designated as a habitat for fish, other aquatic life and wildlife, and for secondary contact recreation. These waters shall be suitable for the irrigation of crops used for consumption after cooking and for compatible industrial cooling and process uses. These waters shall have good aesthetic value.

Class SA - Freshwater. These waters are designated as an excellent habitat for fish, other aquatic life and wildlife and for primary and secondary contact recreation. In approved areas they shall be suitable for shellfish harvesting without depuration (Restricted Shellfish Areas). These waters shall have excellent aesthetic value.

Class SB - Coastal and Marine. These waters are designated as a habitat for fish, other aquatic life and wildlife and for primary and secondary contact recreation. In approved areas they shall be suitable for shellfish harvesting without depuration (Open Shellfish Areas). These waters shall have consistently good aesthetic value.

Class SC - Coastal and Marine. These waters are designated as a habitat for fish, other aquatic life and wildlife and for secondary contact recreation. They shall also be suitable for certain industrial cooling and process uses. These waters shall have good aesthetic value.

Montana

Class A-1 - Suitable for drinking, culinary and food processing purposes after conventional treatment for removal of naturally present impurities. Water quality must be suitable for bathing, swimming and recreation; growth and propagation of salmonid fishes and associated aquatic life, waterfowl and furbearers; and agricultural and industrial water supply.

Class B-1 - Suitable for drinking, culinary and food processing purposes after conventional treatment; bathing, swimming and recreation; growth and propagation of salmonid fishes and associated aquatic life, waterfowl and furbearers; and agricultural and industrial water supply.

Class B-2 - Suitable for drinking, culinary and food processing purposes after conventional treatment; bathing, swimming and recreation; growth and marginal propagation of salmonid fishes and associate aquatic life, waterfowl and furbearers; and agricultural and industrial water supply.

Class B-3 - Suitable for drinking, culinary and food processing purposes after conventional treatment; bathing, swimming and recreation; growth and propagation of non-salmonid fishes and associated aquatic life, waterfowl and furbearers; and agricultural and industrial water supply.

Class C-1 - Suitable for bathing, swimming and recreation; growth and propagation of salmonid fishes and associated aquatic life, waterfowl and furbearers; and agricultural and industrial water supply.

Class C-2 - Suitable for bathing, swimming and recreation; growth and marginal propagation of salmonid fishes and associated aquatic life, waterfowl and furbearers; and agricultural and industrial water supply.

Class C-3 - Suitable for bathing, swimming and recreation; growth and propagation of non-salmonid fishes and associated aquatic life, waterfowl and furbearers; and agricultural and industrial water supply.

Rhode Island

Class A - Freshwater. These waters are designated as a source of public drinking water supply, for primary and secondary contact recreational activities and for fish and wildlife habitat. They shall be suitable for compatible industrial processes and cooling, hydropower, aquaculture uses, navigation, and irrigation and other agricultural uses. These waters shall have good aesthetic value.

Class B - Freshwater. These waters are designated for fish and wildlife habitat and primary and secondary contact recreational activities. They shall be suitable for compatible industrial processes and cooling, hydropower, aquaculture uses, navigation, and irrigation and other agricultural uses. These waters shall have good aesthetic value.

Class B1 - Freshwater. These waters are designated for primary and secondary contact recreational activities and fish and wildlife habitat. They shall be suitable for compatible industrial processes and cooling, hydropower, aquacultural uses, navigation, and irrigation and other agricultural uses. These waters shall have good aesthetic value. Primary contact recreational activities may be impacted due to pathogens from approved wastewater discharges, however, all Class B criteria must be met.

Class C - Freshwater. These waters are designated for secondary contact recreational activities and fish and wildlife habitat. They shall be suitable for compatible industrial processes and cooling, hydropower, aquaculture uses, navigation, and irrigation and other agricultural uses. These waters shall have good aesthetic value.

Class SA - Saltwater. These waters are designated for shellfish harvesting for direct human consumption, primary and secondary contact recreational activities, and fish and wildlife habitat. They shall be suitable for aquacultural uses, navigation and industrial cooling. These waters shall have good aesthetic value.

Class SB - Saltwater. These waters are designated for primary and secondary contact recreational activities; shellfish harvesting for controlled relay and depuration; and fish and wildlife habitat. They shall be suitable for aquacultural uses, navigation, and industrial cooling. These waters shall have good aesthetic value.

Class SB1 - Saltwater. These waters are designated for primary and secondary contact recreational activities and fish and wildlife habitat. They shall be suitable for aquaculture use, navigation, and industrial cooling. These waters shall have good aesthetic value. Primary contact recreational activities may be impacted due to pathogens from approved wastewater discharges. However, all Class SB criteria must be met.

Class SC - Saltwater. These waters are designated for secondary contact recreational activities, and fish and wildlife habitat. They shall be suitable for aquacultural uses, navigation, and industrial cooling. These waters shall have good aesthetic value.

Class GAA - Ground Water. Those ground water resources which the Director has designated to be suitable for public drinking water use without treatment and which are located within the following areas: Ground water reservoirs and portions of their recharge areas, Wellhead protection areas, and Ground water dependent areas.

Class GA - Ground Water. Those ground water resource which the Director has desisted to be suitable for public or private drinking water without treatment and which are not described in class GAA

Washington

Class AA - Extraordinary. Water quality of this class shall markedly and uniformly exceed the requirements for all or substantially all uses. Characteristic uses shall include, but not be limited to, the following:
i) Water supply (domestic, industrial, agricultural);
ii) Stock watering;

iii) Fish and shellfish;

- Salmonid migration, rearing, spawning, and harvesting,
- Other fish migration, rearing, spawning, and harvesting,
- Clam, oyster, and mussel rearing, spawning, and harvesting,
- Crustaceans and other shellfish (crabs, shrimp, crayfish, scallops, etc.) Rearing, spawning, and harvesting,

iv) Wildlife habitat;
v) Recreation (primary contact recreation, sport fishing, boating, and aesthetic enjoyment); and,
vi) Commerce and navigation.

Class A - Excellent. Water quality of this class shall meet or exceed the requirements for all or substantially all uses. Characteristic uses shall include, but not be limited to, the following:
i) Water supply (domestic, industrial, agricultural);
ii) Stock watering;

iii) Fish and shellfish;

- Salmonid migration, rearing, spawning, and harvesting,
- Other fish migration, rearing, spawning, and harvesting,
- Clam, oyster, and mussel rearing, spawning, and harvesting,
- Crustaceans and other shellfish (crabs, shrimp, crayfish, scallops, etc.) rearing, spawning, and harvesting,

iv) Wildlife habitat;
v) Recreation (primary contact recreation, sport fishing, boating, and aesthetic enjoyment); and,
vi) Commerce and navigation.

Class B - Good. Water quality of this class shall meet or exceed the requirements for most uses. Characteristic uses shall include, but not be limited to, the following:
i) Water supply (industrial and agricultural);
ii) Stock watering;

iii) Fish and shellfish;

- Salmonid migration, rearing, and harvesting,
- Other fish migration, rearing, spawning, and harvesting,
- Clam, oyster, and mussel rearing and spawning,
- Crustaceans and other shellfish (crabs, shrimp, crayfish, scallops, etc.) rearing, spawning, and harvesting,

iv) Wildlife habitat;
v) Recreation (secondary contact recreation, sport fishing, boating, and aesthetic enjoyment); and,
vi) Commerce and navigation.

Class C - Fair. Water quality of this class shall meet or exceed the requirements of selected and essential uses. Characteristic uses shall include, but not be limited to, the following:
i) Water supply (industrial);
ii) Fish (salmonid and other fish migration);
iii) Recreation (secondary contact recreation, sport fishing, boating, and aesthetic enjoyment); and,

iv) Commerce and navigation.

Lake Class - Water quality of this class shall meet or exceed the requirements for all or substantially all uses. Characteristic uses shall include, but not be limited to, the following:
i) Water supply (domestic, industrial, agricultural);
ii) Stock watering;

iii) Fish and shellfish;

- Salmonid migration, rearing, spawning, and harvesting,
- Other fish migration, rearing, spawning, and harvesting,
- Clam and mussel rearing, spawning, and harvesting,
- Crayfish rearing, spawning, and harvesting,

iv) Wildlife habitat; and,

v) Recreation (primary contact recreation, sport fishing, boating, and aesthetic enjoyment).