Preliminary Review Draft
Discussion Paper

WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

Evaluating Standards for Protecting Aquatic Life In Washington's Surface Water Quality Standards

Temperature Criteria

Water Quality Program
Watershed Management Section
Olympia, Washington 98504-7710

April, 2000

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Sponsored by the
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Abstract

Maintaining proper temperatures in our natural waterways is vital to the long-term health of fish and other aquatic life. This paper examines the temperature requirements of aquatic species indigenous to the State of Washington to determine if the existing state standards provide full and effective protection. It is the conclusion of the author, that the existing state temperature criteria as currently established and applied are inadequate to fully protect sensitive stream dwelling amphibians and our native char; and allows temperature regimes to be developed that have the potential to cause slight to moderate impairment of Pacific salmon, steelhead, and cutthroat trout. The existing standards also fail to adequately recognize natural warm water fish habitats that are not used by salmon or trout. It is recommended that the existing temperature standards be revised, and that replacement criteria be established that more explicitly consider and incorporate the specific life-history patterns and temperature requirements of our indigenous aquatic life communities.

Rather than specifying only summer maximum criteria as currently exists, the proposed criteria define optimal temperature regimes for both individuals and groups of key species. These optimal regimes recognize how temperature requirements change as species pass through specific life-history stages across the seasons. Five separate temperature regimes are recommended. These regimes were developed in consideration of the direct, indirect, lethal, and sublethal effects that may interfere with the long-term health of Washington's aquatic communities. Specific considerations include the effect of temperature on increasing the incidence of disease; spawner egg quality; incubation survival; juvenile rearing; competition and genetic hybridization; adult migration; and short-term lethality. Temperature criteria recommendations include two values, a running 7-day average of the daily maximum temperatures and a limit on individual daily maximum temperatures. The average daily maximum criteria ensures that conditions remain within the overall optimal range for the preponderance of each life-history stage, while the single daily maximum limit ensures that acute lethality and does not occur.

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I. Introduction

1. Background Discussion

The Washington State Department of Ecology administers the state's surface water quality standards regulations (Chapter 173-201A WAC). These regulations establish minimum requirements for the quality of water that must be maintained in lakes, rivers, streams, and marine waters. This is done to ensure that all the beneficial uses associated with these waterbodies are protected. Examples of protected beneficial uses include: aquatic life and wildlife habitat, fishing, shellfish collection, swimming, boating, aesthetic enjoyment, and domestic and industrial water supplies.

As part of a public review of its water quality standards, the State of Washington Department of Ecology convened a technical work-group to evaluate the water quality criteria established to protect freshwater aquatic communities. The work-group recommended that Ecology:

1) Re-evaluate the existing criteria for temperature and dissolved oxygen; and
2) Develop criteria to protect channel stability and substrate quality.

This document addresses one of those recommendations, the re-evaluation of the state's current temperature criteria for freshwater aquatic life. The primary goal of this project is to recommend temperature criteria that will fully protect Washington's freshwater aquatic communities. Full protection includes the prevention of both lethal and sublethal effects that may detrimentally affect the health, fecundity, and ultimate wellbeing of naturally balanced indigenous populations. As such, it uses the available technical literature to determine the temperature optima and timing of occurrence for individual life-history stages for key species, then combines this information into stream-wide temperature standards that will protect entire communities of aquatic life. To the extent consistent with the primary project goal, the criteria recommendations are designed to avoid unnecessary impact on human economic activities. This has primarily been accomplished by selecting criteria from the upper end of the suspected optimal temperature range where doing so seemed fully defensible, and by not taking the most restrictive approach possible in setting application periods.

2. Report Format

This report is organized in a manner that allows several different levels of public and technical review:

- Persons who <u>just want to see the recommendations</u> should only read sections I-II.
- Persons who <u>want to understand the overall basis</u> for the recommendations should review the entire body of this paper, while skipping the appendices.

- Persons who need or want to know all of the details sufficient to determine if they would reach the same conclusions should also review the separate document containing the appendices. The information and reference citations contained therein allows the reader to go to greater depth in reviewing the basis for the recommendations proposed in this paper, without having to personally obtain and review each article in length.

II. Criteria Recommendations

The existing Washington State surface water quality standards contain three separate maximum temperature criteria limits that can be applied to rivers (16°C, 18°C, and 21°C), and requires that temperatures be maintained at natural levels in lakes. This paper proposes to change the state's temperature criteria based on a review of the available technical literature.

Through a formal public process governing how state regulations on water quality standards may be changed, waterbodies would be assigned to the appropriate use-category for protection. When applied to protect the designated key species (as indicated below), these new temperature standards will provide full and protection for the entire aquatic community.

There are three alternative recommendations provided below for establishing statewide temperature criteria. The first two alternatives take more generalized and less complicated approaches to setting water quality criteria, and assume that by maintaining optimal peak summer temperatures the natural fall cooling pattern will protect spawning and incubation. Both also work to maintain overall temperature regimes lower than the maximum allowed. The first alternative does this by including a cooler criteria as a 7-day average value and the second alternative does this by reducing the allowable single daily maximum. The third alternative establishes more detailed seasonal-based criteria that are tied directly to protecting the individual life-cycle requirements of key fish and amphibian species. It should be noted, however, that the state has been unable to identify any waterbodies where the sole use is as a migration corridor, thus the provision of Alternative 3(e) seems to have little practical value.

Alternative 1:

a) Char Spawning, Rearing, and Adult Holding. Waters used for the spawning, rearing, and summer or fall holding by adult or juvenile bull trout or Dolly Varden. Temperatures shall be maintained below 10°C as a moving 7-day average of the daily maximum temperatures, with no single daily maximum temperature greater than 13°C.

b) <u>Salmon Spawning, Rearing, and Adult Holding</u>. **Waters used for the spawning, rearing, and summer or fall holding by adult or juvenile Pacific salmon, steelhead trout, or cutthroat trout.** Temperatures shall be maintained below 15°C as a moving 7-day average of the daily maximum temperatures, with no single daily maximum temperature greater than 20°C.

c) <u>Non-anadromous Rainbow Trout</u>. **Waters where the only salmonid present is a non-anadromous form of naturalized rainbow or redband trout.** Temperatures shall be maintained below 18°C as a moving 7-day average of the daily maximum temperatures, with no single daily maximum greater than 22°C.

d) <u>Warm Water Species Spawning, Rearing, and Holding</u>. **Waters without naturalized populations of indigenous salmonid or char species, or that serve as migration corridors for such species; where the dominant species under natural conditions would be temperature tolerant indigenous non-salmonid species such as dace, redside shiner, chiselmouth, sucker, and northern squawfish.** Temperatures shall be maintained below 20°C as a moving 7-day average of the daily maximum temperatures, with no single daily maximum temperature greater than 25°C from June 1 to September 1; and below 15°C as a moving 7-day average of the daily maximum temperatures, with no single daily maximum temperature greater than 20°C between September 1 and June 1; in waters where the dominant species under natural conditions would be temperature tolerant indigenous non-salmonid species such as dace, redside shiner, chiselmouth, sucker, and northern squawfish. This criteria is not acceptable where naturalized populations of indigenous salmonid or char species exist, or in waters that serve as migration corridors for such species.

Alternative 2:

a) <u>Char Spawning, Rearing, and Adult Holding</u>. **Waters used for the spawning, rearing, and summer or fall holding by adult or juvenile bull trout or Dolly Varden.** Temperatures shall not exceed 12.5°C as a single daily maximum.

b) <u>Salmon Spawning, Rearing, and Adult Holding</u>. **Waters used for the spawning, rearing, and summer or fall holding by adult or juvenile Pacific salmon, steelhead trout, or cutthroat trout.** Temperatures shall not exceed 17.5°C as a single daily maximum.

c) <u>Non-anadromous Rainbow Trout</u>. **Waters where the only salmonid present is a non-anadromous form of naturalized rainbow or redband trout.** Temperatures shall not exceed 20.5°C.

d) <u>Warm Water Species Spawning, Rearing, and Holding</u>. **Waters without naturalized populations of indigenous salmonid or char species, or that serve as**

migration corridors for such species; where the dominant species under natural conditions would be temperature tolerant indigenous non-salmonid species such as dace, redside shiner, chiselmouth, sucker, and northern squawfish. Temperatures shall not exceed 22.5°C as a single daily maximum in waters where the dominant species under natural conditions would be temperature tolerant indigenous non-salmonid species such as dace, redside shiner, chiselmouth, sucker, and northern squawfish. This criteria is not acceptable where naturalized populations of indigenous salmonid or char species exist, or in waters that serve as migration corridors for such species.

Alternative 3:

a) Native Char and Tailed Frog. **Waters used for spawning, or tributary rearing for the first years of life, by any species of native char or tailed frog.** Not to exceed 10°C as a 7-day average of the daily maximum temperatures year-round, with no single daily maximum temperature exceeding 13°C.

b) Resident Cutthroat Trout, Torrent Salamanders, Subadult Char, and Tailed Frog. **Waters used for spawning or rearing by non-migratory forms of cutthroat trout or torrent salamanders, used for rearing by subadult char or tailed frog.** Not to exceed 12°C as a 7-day average of the daily maximum temperatures, with no single daily maximum temperature greater than 14°C.

c) Salmonids. **Waters used for spawning or rearing by naturalized populations of indigenous salmon or trout.** Not to exceed 15°C as a 7-day average of the daily maximum temperatures from June 1 to September 1, with no single daily maximum temperature exceeding 20°C. Not to exceed 12°C a 7-day average of the daily maximum temperatures after September 1 and prior to June 1; with no single daily maximum temperature exceeding 14.5°C.

d) Non-Anadromous Rainbow and Redband Trout. **Waters where the only salmonid present is a non-anadromous form of naturalized rainbow or redband trout**. Not to exceed 18°C as a 7-day average of the daily maximum temperatures from June 1 to October 1, with no single daily maximum temperature exceeding 22°C. Not to exceed 12°C a 7-day average of the daily maximum temperatures after October 1 and prior to June 1; with no single daily maximum temperature exceeding 14.5°C.

e) Anadromous Salmonids and Char. **Where lower mainstem reaches are used exclusively as a migration corridor for the in-going and out-going saltwater migration of salmonids or char.** Not to exceed 17°C as a 7-day average of the daily maximum temperatures from June 1-September 1, with no single daily maximum greater than 21°C. Not to exceed 13°C as a 7-day average of the daily maximum temperatures between September 1 and June 1, with no single daily maximum greater than 16°C.

f) **<u>Warm Water Fish Communities</u>. Waters without naturalized populations of indigenous salmonid or char species, or that serve as migration corridors for such species; where the dominant species under natural conditions would be temperature tolerant indigenous non-salmonid species such as dace, redside shiner, chiselmouth, sucker, and northern squawfish.** Not to exceed 20°C as a 7-day average of the daily maximum temperatures from June 1 to October 1, with no single daily maximum temperature greater than 25°C. Between October 1 and June 1 the 7-day average of the daily maximum temperatures is not to exceed 15°C, with no single daily maximum temperature greater than 20°C.

Regulatory Notes to Support Temperature Criteria:

The following statements should be included in the water quality standards regulation to serve as mandatory guidelines for the implementation of the temperature criteria:

1. **<u>Insufficient Averaging Data.</u>** Where data is not sufficient to directly calculate, or reasonably estimate compliance with the criteria established as a running 7-day average of the daily maximum temperatures, the seven-day average criteria value must be used as a single daily maximum criteria limit.

2. **<u>Natural Exceedences.</u>** When temperatures naturally exceed the assigned criteria for a waterbody, no actions alone or in combination can be allowed that would raise the receiving water temperature by greater than 0.3°C above the estimated natural condition.

3. **<u>Measuring Temperature.</u>** Temperature measurements used to assess compliance with the recommended temperature criteria should be taken so as to generally represent the habitat as a whole within a segment of a waterbody. Measurements taken from shallow stagnant backwater areas, within isolated thermal refuges, at the surface, or at the waters edge should generally not to be compared with the criteria proposed in this paper. In reservoirs and lakes, temperature measurements can be taken from the cooler portion of a thermocline in the summer period, if the spatial extent and oxygen content of that cooler water would otherwise be sufficient to support fish populations.

4. **<u>Boundary Areas.</u>** Temperatures must be maintained such that the water quality criteria of downstream waters are fully protected. An area of mixing, and localized non-attainment, however, can be allowed in the vicinity of where an upstream waterbody segment having less stringent criteria enters a downstream waterbody segment having more stringent criteria. This mixing proviso is allowed only where

the localized change in quality would not have a likely potential to block or otherwise impair the aquatic life of the downstream waters.

5. **<u>Waterbody-Specific Application Dates</u>**. Salmonid stocks known to have incubation or marine smoltification periods that are not reasonably described by the timeframes established in the state-wide temperature criteria recommendations should be protected by setting waterbody specific application dates under the water quality standards regulation.

III. Considerations in Establishing Criteria

This section discusses the methodology used and some of the underlying thoughts and concerns that went into establishing the temperature criteria recommendations contained in this paper.

1. Adjusting Laboratory Data to for Application to Natural Waters

Laboratory tests do not represent the full range of conditions that an organism will face in the natural environment. In most laboratory tests fish are exposed to a constant temperature environment, while in natural waters the temperature fluctuates during each day, between days, and in seasonal trends of spring warming and fall cooling. In natural waters fish must actively maintain position and seek food and shelter in the currents of rivers, succeed in the face of inter- and intra-species competition for both food and shelter, avoid predation, and resist disease. In laboratory studies, however, the fish are often in test chambers without substantial currents, fed food in pellet form, treated to prevent disease, and seldom need to compete or avoid predation. On the other hand, in laboratory tests, fish are often crowded into very small unnatural spaces, even styrofoam cups, and forced to perform using electrical stimulation or prodding, subject to laminar artificial flows; and often fed unusual rations with large time intervals of starvation.

Because of the differences between laboratory conditions and the environmental conditions that fish face in the natural world, we must use caution in how we apply laboratory-derived data in setting ambient water criteria. We must ensure that the temperature regimes used in the laboratory tests are considered in any application to natural streams, and where appropriate adjust the laboratory-based data to account for any changes in performance expected in response to natural stressors such as currents, competition, predation, and natural food shortages.

In this paper both laboratory and field-based data are converted to approximate daily maximum temperatures. By standardizing and applying this approach to each life-history stage as it occurs over the seasons we can create a hypothetical thermograph that represents the seasonal pattern of maximum daily temperatures that will allow for the optimal health and survival of a fish species. Then by considering together the needs of multiple species within watersheds, we can make recommendations for surface water quality criteria that will provide full protection for entire communities of aquatic organisms. This is the approach and basis for the specific criteria recommendations established in this paper. The criteria are established as the warmest average temperature created by taking the arithmetic average of seven consecutive daily maximum temperatures. In this document this criteria form will be referred to as the 7-day average of the daily maximum temperatures (or 7-DADM). A seven day period is used since it represents a period of time in which any unhealthy condition will likely express itself in a fish population. Organisms may pass through critical life history stages such as out-migration, spawning, and egg incubation to epiboly, in short windows of time; often on the order of one to two weeks. A criteria could be based on other averaging periods (e.g., daily, monthly) and also be defensible, so long as attention is paid to setting complementary limits on single daily maximum temperature values so that unhealthy effects will be unlikely to occur within portions of the averaging period.

In this paper adjustments were made to the results of growth, incubation, and lethality studies conducted at constant temperature exposures. These adjustments were made to make the results more applicable to natural fluctuating stream environments. No adjustment was made to try and standardize test feeding regimes or to translate test results to match the feeding regimes expected in natural waters. The basis for making or not making these adjustments are described below.

Growth Studies:

Most of the research on optimal growth temperatures is conducted with water kept at a constant temperature. Water quality standards, however, must apply to naturally fluctuating thermal environments. Since temperature directly effects the metabolism of the fish, a fish kept continuously in warm water will experience more metabolic enhancement than one which only experiences that same temperature for one or two hours per day. Thus constant test results can not be reasonably applied directly to the daily maximum temperature in a fluctuating stream environment. While the constant temperature test results could be used to represent daily mean temperatures, it is believed that the daily maximum temperature is more influential to the biology and should be the focus of any standards developed. In this paper an adjustment is made to the results of constant exposure growth tests to convert them to approximate daily maximum stream temperatures. This is done in two steps: first it is assumed that the constant test temperature is equal to a the daily mean of a fluctuating environment, then a modest (2°C) increase is added to convert the approximate daily mean value into a daily maximum value that would achieve the same level of growth performance. The research reviewed for this paper generally supports both steps.

Summer stream temperatures will generally fluctuate at least 2°C above their daily mean during the summer season, so this level of fluctuation is common in nature. It is also consistent with the relationships (1.5-2.5°C) found in the literature (Hokanson et al., 1977) between daily maximum temperatures and constant test temperatures producing similar growth responses. The following citations are provided in support of taking this adjustment and in support of the need to keep daily maximum temperatures below stressful levels.

Clarke (1978) studied individual specific growth rates of under-yearling sockeye salmon after 42 days at five constant temperatures ranging from 7.5°C to 17.5 and two diel cycles of 7-13°C and 5-15°C. At constant temperature, there was a linear increase in growth rate over the range 7.5-17.5°C. Both thermocycles had a mean of 10°C, but growth was greater on the 5-15°C cycle. The author notes that the equivalent constant temperature for specific growth rate in length on the 7-13°C cycle was increased significantly from 10°C in one replicate (12.3°C), but not in the other (10.8°C). Specific growth rate in length on the 5-15°C cycle was equivalent to that on a constant temperature of 15.3°C. Specific growth rate in weight on the 7-13°C cycle was equivalent to that on a constant 11.4°C; on the 5-15°C cycle it was the equivalent of a constant 13.9°C. This study concludes that underyearling sockeye salmon exposed to diel thermocycles are able to acclimate their growth rates to a temperature above the mean of the cycle.

Dickerson, Vinyard, and Weber (1999 and unpublished data, as cited in Dunham, 1999) conducted experiments with hatchery-reared Pyramid Lake strain Lahontan cutthroat trout. Fish were exposed to one week fluctuating temperatures (20-26°C; mean = 23°C), and to constant temperatures of 13, 20, 23°C. Growth rates in the fluctuating temperature tests were lower than for fish exposed to constant temperatures of 13 and 20°C, but were similar to groups of fish held at a constant 23°C.

Hahn (1977) investigated the effects of fluctuating (8-19°C) and constant temperatures (8.5, 13.5, 18.5°C) on steelhead trout fry and yearlings. He found that as many fish remained in the fluctuating regime as in the constant 13.5°C temperature water; twice as many remained in fluctuating temperature regime as remained in the constant 18.5°C temperatures; and twice as many fish remained in constant 8.5°C water as in the fluctuating temperature regime. By inference, Hahn found the relationship between the three constant temperatures were the same as the relationship of each to the fluctuating temperature: twice as many fish in 13.5°C compared to 18.5°C, twice as many fish at 8.5°C as in 13.5°C, and four times as many fish in 8.5°C as in 18.5°C. One can conclude from Hahn's work that juveniles equally preferred the constant 13.5°C water as well as the fluctuating (8-19°C) water which had a mean of 13.5°C. While not a growth test, the work of Hahn supports the general premise that daily mean temperatures are reasonable approximations of constant exposure test temperatures.

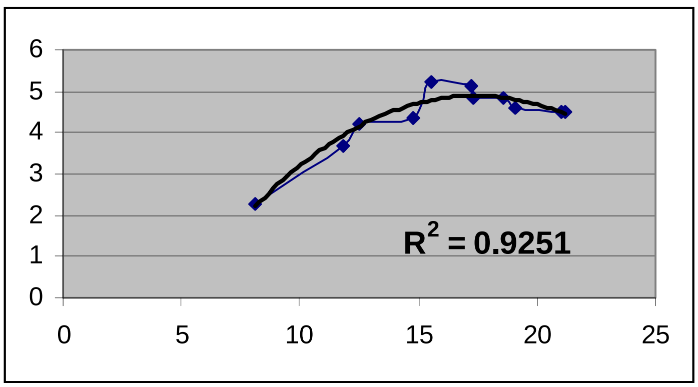
Grabowski (1973) conducted growth experiments using steelhead trout. Fish were fed a percentage of body weight according to feeding charts twice per day based on temperature and changes in body weight. To evaluate growth, fish were subjected to four test temperatures for eight weeks. These four regimes were a fluctuating test from 8 to 18°C (mean 13°C), and constant tests held at 8, 15, and 18°C. Steelhead grew better at 15°C than at other temperatures. Fish in the fluctuating test had the second highest growth rate and actual weight gain. Growth rate in the fluctuating test was only 13% less than that at the constant test of 15°C, while growth rates at 8 and 18°C were 47% and 21% less, respectively. Plotting the data using the midpoint in the fluctuating test as a surrogate for a constant test condition creates near linear growth from 8 to 15°C with a steep drop as temperature progresses to 18°C. Thus the mean of the fluctuating treatment appears generally comparable to a constant test temperature of the same value.

Hokanson et al. (1977) compared specific growth and mortality rates of juvenile rainbow trout for 50 days at seven constant temperatures between 8°C and 22°C and six diel temperature fluctuations (sine curve of amplitude +/- 3.8°C about mean temperatures from 12°C to 22°C). Thus in the fluctuating tests, temperatures fluctuated 7.6°C each day from the daily low to the daily high temperature.

Constant Test Mean	Growth Rate	**Fluctuating Test Mean**	Daily Maximum	Growth Rate
C-11.8	3.66	F-12.5	16.3	4.23
C-14.8	4.36	F-15.5**a**	19.3	5.24
C-17.2**a**	5.12	F-17.3**a**	21.1	4.86
C-18.6**a**	4.83	F-19.1	22.9	4.58
C-21.2	4.49	F-21.0	24.8	4.48
C-22.3	3.94	F-22.2	26	-2.12

a = Slope not statistically different from optimum at F-15.5°C

Growth rates at the fluctuating 17.3°C and the constant 18.6 and 17.2°C treatments were not statistically different than the growth in the fluctuating 15.5°C test. Plotting the growth rates against the mean temperatures for both the constant and fluctuating tests produces the following characteristic normal distribution for growth rate and temperature.



Thus a strong relationship appears to exist with growth between the daily mean temperatures in fluctuating tests and those in the constant tests. A pattern was demonstrated, however, where daily mean temperatures in the fluctuating tests at 12.5 and 15.5°C produced greater growth rates than comparable constant temperatures at 11.8 and 14.8°C. At the constant optimal temperature of 17.2°C and above, however, this pattern was reversed. This pattern led Hokanson et al. to suggest that the growth of rainbow trout appears to be accelerated at fluctuating treatments when the mean temperature is below the constant temperature optimum for growth and retarded by mean fluctuating temperatures above the constant temperature optimum. Hokanson et al. suggested that water quality standards (based on weekly mean values) should be set such that the average weekly temperature is below the constant test temperature producing maximum growth. They determined that rainbow trout do not respond to mean temperature, but they acclimate to some value between the mean and maximum daily temperatures. Looked at another way, the optimal fluctuating regime had a mean of 15.5°C with a range of 11.7 to 19.3°C; and the optimal constant test temperature of 17.2°C fell approximately midway between the daily mean and the daily maximum of the optimal fluctuating test. While the work of Hokanson et al. generally supports the relationship between fluctuating mean temperatures and constant test temperatures, it also suggests this relationship may change with the relative temperatures. This is similar to the results found by Everson (1973) (discussed below). At and above the constant temperature that produced the optimal growth, a daily mean temperature is equal to or slightly above the constant test temperature. But below the constant test temperature that produced optimal growth, a daily mean temperature is not equal to the constant temperature but is below the constant test temperature.

Thomas et al. (1986) investigated the effects of diel temperature cycles on coho salmon. Temperature cycles (10-13, 9-15, 8-17, and 6.5-20°C) were used to simulate observed temperatures in clear cuts of southeastern Alaska. Different levels of feeding, including starvation were used in each of the tests. Cyclic temperatures for 40 days, averaging 11°C daily, did not influence growth of age-0 fish on any ration in comparison to the controls (kept at a constant 11°C). Plasma cortisol and glucose concentrations were significantly greater in fish maintained for 20 days in the 6.5-20°C cycle, which may be an indicator of long-term stress. Thus in the work by Thomas et al. (1986) the daily mean of the fluctuating test and the constant test exposures produced essentially equivalent results, but stress conditions were noted to occur in cycles with daily peak temperatures of 20°C.

Everson (1973) used the data of Averett (1969) to show that growth rates and gross efficiencies of food conversion of fish kept at moderate constant temperatures (15.5°C) were somewhat greater than those of fish exposed to temperatures that fluctuated about a similar mean value (15.6°C); whereas, at higher average temperatures the fluctuation of temperature markedly benefited the growth and food conversion efficiency of the fish. Thus Everson showed support for the assumption that fluctuating temperatures can produce greater benefits to growth as compared to higher constant temperatures.

Variable Feeding Regimes:

Growth rates are related to both temperature and food rates. As temperature goes up, more food is necessary to supply basic physiological needs but also the efficiency goes up for utilizing excess foods. This relationship results in a situation where at maximum feeding rates fish will grow the largest in warmer water, but at reduced feeding rates in the warmer water growth rates will suffer. In cooler waters maximum growth rates are achieved at feeding rates well below those that produced maximum growth in the warmer waters. This relationship between feeding rates and temperature means that at least in theory laboratory test results should be modified to account for the feeding regimes present in natural stream environments.

As an example of the influence of feeding rates, **McMahon, Zale, and Selong (1999)** tested bull trout growth and found that at satiation (maximum) and 66% satiation ration levels growth was highest at 16°C, whereas at a 33% satiation ration growth rate was maximized at 12°C. Thus in waters of lower productivity maximum growth may occur at temperatures 4°C less than what occurred at high rations. When the authors plotted calorie availability in a hypothetical high versus low productivity system, the curves showed a shift to maximal growth at even lower temperatures (8 and 12°C).

While the basic relationship between feeding rates and growth at various temperatures is well established, there is a problem with trying to apply an adjustment factor to laboratory test results. In the laboratory tests reviewed for this paper, feeding rates and regimes varied significantly. Fish were fed one to three times per day all they could eat in some tests, in others a percentage of body weight was fed one to several times per day that could vary by over 100% between researchers, or the fish might be fed according to optimal hatchery-based feeding charts that vary the quantity and frequency of feeding by fish age, and mean size, and water temperature. More troublesome is that some authors only noted that they “fed to satiation”, or “fed to repletion” without providing any more specifics on the feeding amount or frequency. A final issue is that feed type will also influence growth rates. In addition to the nutritional value differences between feeds, the size and type of food influences the ability and voracity to which the fish will feed.

Given that many if not a majority of the growth tests were not actually representative of maximum feeding regimes, and that the feeding regimes were so highly variable, trying to make a standard adjustment to laboratory test results to try and match natural feeding regimes would be problematic. Though no adjustment is made to try and mimic natural feeding regimes, there are a couple of factors that reduce any risks of not making an adjustment. One, is that the highest growth temperatures generally are above the temperature thresholds that trigger increased disease risks, and thus criteria recommendations are often not based on the highest growth rates found in laboratory tests. Second, the temperature criteria are applied as the warmest 7-day period of the summer and most years will need to be cooler even during the warmest period to be in compliance with the criteria during the warmer climatic periods, thus feeding will almost always be occurring at much cooler temperatures.

Incubation Studies:

Specific studies were not found that compared the effects of constant to fluctuating incubation environments. However, it is assumed in this paper that that incubating fish generally respond to the daily mean temperature. This seems warranted given the strong basis for use of the standardized temperature unit calculations in hatchery operations and in fisheries science in general. It is fortunate that many of the incubation studies were conducted at fluctuating water temperatures (highlighted in the discussion on individual species). This provided a good opportunity to check the effect of making adjustments to the temperatures considered optimal for incubation for specific fish species. A 2°C upward adjustment was made to constant incubation exposure test results, but only overtly in the discussion portion of each section. In other words, the values ascribed to specific authors have not been altered, only after all of the constant exposure tests were evaluated together and a general conclusion noted was an adjustment made. This was then generally compared separately to any tests conducted in fluctuating thermal environments.

A natural safety factor often exists to protect egg incubation. Since salmonids bury their eggs in the gravels of the stream bed, they are buffered slightly from both daily maximum and daily minimum stream temperatures. The buffering of the stream bed gravels can effectively reduce the daily maximum temperature by at least 1-1.5°C (Crisp, 1990). While this natural safety factor is not accounted for in laboratory tests it is also not dependable. Therefore, in the recommendations of this paper no adjustment is made to account for this often occurring buffering effect. It is useful however to recognize that sudden and unseasonable rises in stream temperature during incubation will often not cause similar temperature exchanges in the egg pockets situated in the gravels.

Lethality and Acute Effects:

The water quality standards must be set so as to consider a broad range of human activities and how those activities influence the health of the aquatic system. Water quality standards must protect against both gradual and basin-wide increases in peak temperature, as well as phase-shifts of the daily maximum temperature. The standards must also be applicable to protecting organisms from rapid or site-specific changes in temperature that can be caused by unique human activities (e.g., cooling waters, process wastewaters, and releases from dams). While localized extreme changes in water temperature are not as widespread or common as the gradual basin-wide changes, they do exist, and their regulation through discharge permits and water quality certification programs require careful application of biologically-based temperature standards. These localized point sources of temperature change are also the most capable of creating short-term lethality to aquatic life as they may discharge water significantly hotter or colder than the ambient water to which organisms are acclimated.

In establishing daily maximum temperature limits that will prevent any direct mortality statewide, it is recommended that the incipient lethal level representing acclimation at a low temperature minus a 2°C safety factor be used as the daily maximum temperature limit. Since this value is determined with cold acclimated fish, it will protect fish populations during winter from any unseasonable discharges, protect fish migrating from cooler ocean waters during the spring and summer, and provide an undefined additional level of protection for well acclimated migratory and non-migratory fish during the summer. The exception to this approach would occur where testing has shown a separate life stage, such as embryonic development, to be more susceptible to thermal effects, in which case that value should be used minus the 2°C adjustment factor.

Since the incipient lethal level is one with a calculated 50% mortality of test fish, it needs to be adjusted to a level that would not be expected to cause any mortality. The National Academy of Sciences (1972; as cited in Dunham, 1999) and Coutant (1973; as cited in Hokanson et al., 1977) recommend subtracting 2°C from the LT50 value to determine a safe short-term temperature limit. This seems reasonable in recognition that time above lethal levels appears cumulative (DeHart, 1974, 1975, and Golden, 1978), since adults may be more sensitive than the juveniles which are most commonly tested (Coutant, 1970; Becker, 1973; Bouck and Chapman, 1975), since individual stocks possess slightly different tolerance levels (Beacham and Withler, 1991), and since the range between no mortality and high mortality rates is often described by as little as 0.5°C (Charlon, Barbier, and Bonnet, 1970).

In setting single daily maximum temperature limits to protect juvenile or adult rearing, the Incipient Lethal Level (ILL) determined using fish that were held at an acclimation temperature which is near the lower end of a species' health optimum was generally used. This helps account for sudden or localized changes in water temperature that may occur from discrete human activities. A more protective approach would be to always assume the coolest acclimation temperature exists when setting a daily maximum criteria, and the warmest acclimation temperature exists when determining if a cold water discharge would be acceptable. A further adjustment is made to the ILL determined from laboratory testing. With most species examined a 0.5-1.0°C reduction in temperature from the ILL will result in complete survival of the test fish (instead of the 50% or greater mortality rate that is described by the ILL). Thus the ILL is reduced by 1.0°C to change it to an approximate value which is absent the potential to cause lethal effects even with a sudden exposure lasting up to 7 days. This approach also recognizes that as we get close to lethal limits an unexpected increase of 1-2°C above what was modeled as acceptable in a pollution control program could create serious damage to a local population. Research has demonstrated that once temperatures reach levels which cause death within 1-7 days of constant exposure, increases of only 0.3-1.0°C can be associated with significant increases in the mortality rate. This suggests extra caution is warranted anytime temperatures enter or approach lethal levels.

Though test results that determine lethal threshold temperatures are used as a primary basis for recommendations on daily maximum water temperatures for specific life stages, such as juvenile rearing, the final recommendations are seldom based on just avoiding lethality. Temperatures that would result in any detrimental acute effect such as causing a barrier to adult fish spawning or migration, or that are directly linked to the ability of a species to inhabit a waterbody, or in some other way be indicative of unhealthy habitat conditions typically take precedence in the recommendations. Thus, while a species may be able to survive in a laboratory environment at a given temperature, research may show that the temperature maximum is rarely if ever found in natural waters that contain healthy populations of the species.

Most tests of short-term lethality have focused on the juvenile life stage for salmon, and few studies have examined the affect of short-term peaks in temperature to egg-bearing adults. These data gaps are troublesome to setting water quality criteria, particularly in light of the results of the few studies that have been done to determine the effects on these other life stages. To ensure that the criteria recommended are fully protective, where data is available that pertains to a particular life-stage of one species it will be applied to other species that lack such specific data, unless some direct and convincing evidence exists to defend doing otherwise. Thus, if the only data on the effects of short-term increases in temperature on fish egg development is for chinook salmon, it is assumed to apply to the egg development stage for all the other salmonids where such information is otherwise absent.

2. <u>Additional Concerns with Using Laboratory Results</u>

In addition to the issues discussed above, there are numerous other considerations that exist with converting laboratory-based data to ambient water criteria. Where possible each of these issues has been addressed in establishing the final recommendations for water quality criteria. These include:

- Prior acclimation temperatures affect the test results;
- Significant increases in predation may occur before direct lethality occurs from high temperatures;
- Test endpoints vary from physical disorganization to complete mortality;
- Cumulative effects occur from multiple exposures to temperatures above the incipient lethal level;
- Risk of catastrophic population mortality exists if the daily maximum criteria is exceeded by only several degrees;
- Mortality must be above 50% to set a standardized critical thermal maximum or incipient lethal level estimate; and
- Tests seldom examine delayed mortality or exposures longer than 7 days.

The general approach to incorporating these concerns is to assume adverse prior acclimation temperatures, use any endpoints that would indirectly or indirectly harm a species, set daily maximum temperatures that consider the time and frequency of exposure at that temperature, and apply a safety factor to bring lethal endpoints down to levels at which no lethality would be expected. Each of these issues is discussed as these issues are considered for the individual species (Sections IV-VII) or in the synthesis stage (Section VIII) of making the criteria recommendations.

3. Minimum Temperature Criteria

One issue not directly included in the criteria recommendations at this time is minimum temperature limits. It is well documented that unseasonably cold waters can be as detrimental, and lethal, to aquatic organisms as unseasonably warm waters. Sudden releases of very cold water can cause rapid lethality to unacclimated organisms, and waters substantially colder than what is optimal can decrease survival of eggs and embryos as well as detrimentally depress juvenile growth rates. Human activities, such as the removal of overhead vegetative canopies will increase long-wave radiative cooling causing potentially harmful drops in the natural winter low temperatures. This may encourage anchor ice, a result of streams freezing, that may cause additional damage to fish and their habitat as it scours the channel during spring break-up. It is recommended that criteria for low temperature limits be considered at some point in the future, and information is included in this paper sufficient to assist in setting site-specific limits for individual activities. However, to keep the focus of this paper on the area of greatest perceived concern, that of high water temperatures, the issue of cold water limits is not being addressed at this time.

4. Application of Spawning and Incubation Criteria

Literature on spawning periods was used, where possible, to set two time markers for applying protective criteria. The first is the point in time after which typically 98% of a species is known to first initiate spawning. The second, is the point in time after which occurs the midpoints in the spawning ranges of about 98% of a species. This may be a good surrogate for the period of peak spawning activity. These two time periods are used generally to establish points in time at which incubation-based temperature criteria should be applied statewide.

Since a few spawners may begin to spawn long before most of the stocks begin in the same river, and since the literature dates may be influenced by seasonal climatic patterns, there are some difficult decisions associated with applying optimal incubation criteria using the dates cited in the literature. Perhaps the most important is whether to apply the optimal incubation temperature at the point where the earliest fish begins spawning on during the coolest year on record, or whether to apply the value at a time where there is greater confidence fish would be spawning most years. In general the approach recommended is to use early spawning dates for most species and to formally allow that the timing for applying incubation criteria should be adjusted formerly within the water quality standards regulation where site-specific information demonstrates a more technically accurate period of application. This issue is discussed further in Section VIII, Synthesis.

5. Criteria for Incremental Temperature Change

The existing water quality standards set a limit on the amount of change in temperature that is allowed from any single human activity. For point sources a mathematical equation is used to determine how much change in temperature any single source can cause. For nonpoint sources a fixed allowable change of 2.8°C is established. Within the range of temperatures that are allowed under the current standards, point sources are typically allowed to increase water temperatures anywhere from about 1 to 1.5°C. The basis for allowing nonpoint sources to increase temperatures by 2.8°C is not known and cannot be found in departmental files or archives. It appears to be a modification of a staff suggestion that all sources combined should be limited to a 2.5°C change in ambient water temperatures.

The recorded staff recommendation appears generally sound, as a change of 2.5°C can certainly be detrimental to the biology. Species genetically evolve and adjust their life histories to match the temperature regime of their home waters. Changes to the temperature regime run the risk of creating detrimental effects to the species and communities of species that have spent centuries adapting to them. While it is at least theoretically desirable to limit the amount of change in a waterbody to avoid complex and potentially detrimental biological consequences, retaining a criteria on incremental change is not recommended in this paper.

The criteria recommendations in this paper include upper optimal criteria that are to be applied across specific periods of time where critical life-history-stages typically occur. The recommendations also include single daily maximum criteria designed to prevent detrimental effects from extreme, or unseasonable, changes in temperature. When combined these criteria act to preserve an optimal thermal regime both for sympatric communities of salmon, as well as for aquatic communities of resident char and cutthroat trout that rely on cold waters to provide them a competitive edge against other salmonids.

6. Allowing Temperature Increases to Naturally Warm Waters

The existing water quality standards include a provision that allows a total 0.3°C increase in the maximum temperature of a waterbody when that waterbody naturally exceeds its assigned criteria. This increase is provided to allow for some economic activity that may cause very minor increases in temperature above the level established to protect aquatic life. This provision does not allow individual sources to each increase the temperature, but instead just moves up the established standard. For example in our existing Class AA waters the maximum temperature is 16°C. If a waterbody exceeds 16°C naturally, let's say it has a maximum of 17.7°C, then this provision states that all human sources combined are only allowed to raise the water 0.3°C to a new maximum of 18°C. This allowance provides some regulatory flexibility without seriously increasing the risk to aquatic life. Care must be exercised in allowing increases in temperature above the recommendations made in this paper. Even very small increases (0.3-0.5°C) can cause significant increases in mortality or other effects if the natural conditions are near a biological threshold. Given this fact, and that naturally warm waters can be very high, an allowance for a further warming of naturally warm waters should kept minimal. Any allowance should be at a level that would not be easily discernable in the waterbody as a whole. It is recommended, therefore, that the provision to allow a total 0.3°C increase be retained in the water quality standards.

7. Protection of Untested Species

The criteria recommendations made in this paper are primarily based on data obtained on the temperature requirements of our two native char, the five Pacific salmon, rainbow and cutthroat trout, smelt, and several amphibian and insect species. Rigorous scientific testing generally has not been done on most of the other aquatic species indigenous to Washington's waters. What references have been found for these other species tends to be more of an anecdotal nature; noting what the temperature is when spawning has been observed, or indicating the temperature of a waterbody where a species has been found. Although, for some of these less well known indigenous species direct testing of their temperature optima and lethal limits has occurred. Based on what temperature information has been found, both direct and indirect, these species do not appear to possess more sensitive temperature requirements than the char, salmonids, and stream breeding amphibians and insects used to make the temperature criteria recommendations in this paper.

Many of the less well known aquatic species, which often occur together as a community, appear to thrive in waters which are at the upper margin of what is optimal for salmonids, and represent warm water fish communities indigenous to Washington. Recognition of these species has resulted in the recommendation that the state establish a unique level of use-support that can be assigned to our naturally warmer waters. It has also resulted in a specific recommendation on applying the criteria (i.e., taking measurements) that acknowledges unique species exist and thrive in the warmer backwaters of many of our cold water rivers and lakes.

The warm waters that occur in the margins and slack-water areas of many rivers serve as important habitat to many species that prefer summer water temperatures somewhat warmer than what is optimal for the state's indigenous salmonids. These other species also commonly serve as food fish for salmonids and are important to the overall health of the system. Thus, these warmer marginal regions should not be viewed as lost or unhealthy habitat, but as a necessary and natural adjunct to a healthy aquatic system.

8. Application of the Temperature Criteria

The temperature criteria recommended in this paper are not intended to apply to every portion of every waterbody. The warmer water caused by solar heating in the uppermost surface layer of a waterbody, over shallow sand bars, or in back-water areas effectively separated from the main channel should not to be compared with these recommended criteria. Similarly, temperature measurements should not represent isolated thermal refuges associated with emerging ground waters or cold water springs. While these areas are often vital to both winter and summer survival of many species, the criteria proposed herein refer to the conditions found generally throughout a waterbody or reach. Temperature measurements typically should be taken between 1/3 and 2/3 the depth in the mid-portion of runs and riffles of streams and rivers. In reservoirs and lakes, temperature measurements can be taken from the cooler portion of a thermocline in the summer period, so long as the spacial extent and oxygen content of that cooler water would otherwise be sufficient to support fish populations.

IV. Temperature Requirements of Char and Salmonid Species

In this section, the temperature requirements of the char and salmonid species indigenous to Washington are examined. Whenever there was sufficient data, two temperature values are provided for each species' key life stages to define the end of its upper optimal temperature range. It is intended that these values be compared against the 7- day average of the daily maximum temperature values. An upper endpoint range is also provided for setting a single daily maximum temperature for each life stage and species examined.

The optimal range defined by the recommended temperatures is intended to clearly protect each species to its fullest natural potential from any detrimental effects of increasing temperatures. The single daily maximum value is based on avoiding both lethal and sublethal impacts (such as migration blockage or spawning inhibition) that may occur from acute (short-term exposure) temperature exposures.

In the following section, for each species a summary chart is first presented, followed by a specific recommendation for that species, and then by brief discussion on the findings in the literature. Refer to the appendices appropriate to the individual species to find more details on the specific literature references used.

1. Native Char

Upper End of Optimal Temperature Range by Life Stage:

General Limitations	**7-DAM**	**1-DM**
Incubation	5.5-6.5	7-8
Rearing	10–12	13-14
Fry/smolt migration	11-12	13-14
Adult migration only	14-17	19.5-20

Point Limitations	**1-DM**	**Instant Mix**
Acute threshold	19.5-20	30-31
Acute threshold (alevins)	16.5-17.5	Insuf. Data

Notes: 7-DAM refers to the rolling arithmetic average of seven consecutive daily maximum temperatures; 1-DM refers to the highest daily maximum temperature outside of an authorized mixing zone; Instant Mix refers to any place within a river where adult or juvenile fish may become fully entrained in a warm water plume, and typically applies within the established acute exceedence area of an established mixing zone.

Species-Specific Recommendations:

The following two alternatives show what temperature criteria would be recommended if this were the only species of concern. They also may be further modified in the Section VIII, Synthesis to account for other species in the stream complex and to remove unreasonable risks from warm water diseases. Thus the recommendations below for this species may not correspond directly with the final recommendations of this paper.

- In waters used for the spawning, rearing, and summer or fall holding by adult or juvenile char, temperatures should not exceed 10°C as a 7-DADM with no single daily maximum greater than 13.

- In the waters used for the spawning and tributary rearing of for the first years of life by native char, temperatures should not exceed 10°C as a 7-day average daily maximum temperatures (7-DADM); with no single daily maximum temperature greater than 13°C.   In mainstem waters used for rearing habitat only by subadult char summer temperatures should not exceed 12°C as a 7-day average daily maximum temperatures (7-DADM); with no single daily maximum temperature greater than 14°C

Summary Discussion

General Life History:

Native char in Washington consist of Dolly Varden (*Salvelinus malma*) and bull trout (*Salvelinus confluentus*). These two closely related species are difficult to taxonomically identify from one another in the field (Hass and McPhail, 1991). Cavender (1978; as cited in Goetz, 1989) is credited with recognizing that what had previously been considered an interior form of Dolly Varden was in fact a distinct species, now referred to as the bull trout. He further suggested the bull trout may be more directly related to the arctic char (*Salvelinus alpinus*), and in fact a sister to the arctic char-Dolly Varden group. Spalding (1997) found that for the Olympic Peninsula many of the anadromous char previously assumed to be Dolly Varden keyed out to bull trout using the Hass linear discrimination function. Dolly Varden and bull trout are generally considered to have very similar biological requirements, and the management measures needed to protect both Dolly Varden and bull trout may be identical (WSDFW, 1994). The Washington State Department of Fish and Wildlife considers the majority of native char stocks in the state as being "Vulnerable Populations" requiring special protection. Bull trout in particular have received considerable publicity in recent years because of the U.S. Fish and Wildlife Service's proposed listing as an endangered species. The results of a 12-month study evaluating stock status by U.S. Fish and Wildlife Service noted serious declines of bull trout populations statewide (USFWS, 1997).

Spawning Requirements:

Bull trout (*Salvelinus confluentus)* and Dolly Varden (*Salvelinus malma*) are the two species of char native to the State of Washington (Hass and McPhail, 1991). Perhaps more than any other species, cold waters are critical to maintaining healthy populations of our native char. Maximum temperatures should generally be below 12°C (Fraley and Shepard, 1989) and on a Fall season cooling trend at the time char enter their spawning streams. The daily maximum temperature may need to fall below 9-11°C (WSDFW, 1994), or the daily average temperature maintained between about 6.8 to 8.1°C (Reiser et al., 1997), for redd construction to begin. No authors have been found that suggest spawning will begin at daily maximum temperatures above 10°C. Many place the temperature that triggers spawning below 9°C (Goetz, 1989; Pratt, 1992; Kramer, 1991; Fraley and Shepard, 1989), and suggest the peak of spawning activity does not occur until the stream temperatures fall below 7°C (James and Sexauer, 1997; Wydoski and Whitney, 1979). In a study in Idaho, pairing behavior was noted to begin after average water temperatures dropped from 10 to 6.5°C **(Schill, Thurow, and Kline, 1994).** Although, in the same river **Elle, Thurow and Lamansky (1994)** found that water temperatures below the spawning areas were just dropping below 10°C at the time when most spawners were out-migrating. **Gillet (1991; as cited in Baroudy and Elliott, 1994)** found that ovulation in char was inhibited above 11°C and slowed down above 8°C. Temperatures above 8°C were noted by **Kramer (1994)** as appearing to cause spawning activity to temporarily cease in char in northwest Washington streams.

Bull trout are noted to begin spawning as soon as conditions are suitable and redds are constructed; and temperature may be the primary cue used by the fish to determine when to initiate spawning **(Kramer, 1994).** It is important that temperatures be within a range that would not hinder ovulation and would not cause obvious harm to offspring of any early spawning individuals.

Incubation through Early Fry Development:

Research suggesting that spawning does not peak until temperatures fall to below 7°C, and that ovulation and spawning activity may be impaired above 8°C is consistent with the results of studies determining temperatures necessary for the successful incubation of char eggs. These studies show that char require temperatures below 7°C to achieve optimal survival rates. It is generally agreed that poor survival occurs at temperatures above 7-8°C. Under test conditions where temperatures were held constant, 8-10°C resulted in very poor survival of eggs (0-20%) in a test by McPhail and Murry, (1979), and test temperatures in the range of 7-11°C were reported to result in poor survival in hatchery culture by Brown (1985). McPhail and Murry (1979) found a temperature of 6°C to produce variable survival rates(60-90%), while **Fredenberg, Dwyer, and Barrows (1992, and 1995)** found a temperature of 6.5°C (minor diel fluctuations) produced excellent survival (95.5%) and reported that incubation results at 5.8°C also appeared normal.

In studies on the related species of Arctic char, Humpesch (1985) reported optimal incubation to occur at 5°C. Incubation of bull trout eggs at 4.0 and 3.1°C produced excellent survivals (93-95% and 97.1%) in studies by McPhail and Murry (1979) and **Fredenberg, Dwyer, and Barrows (1992, 1995).** McPhail and Murry (1979) cited that the range of 2-4°C produced good survival (80-90%).

While not shown directly for char species, other salmonids have been shown to undergo some conditioning in the early stage of incubation that allows excellent survival at very low temperatures. Where the conditioning does not occur, and the eggs are incubated at an early stage at very low temperatures, significant reductions in survival have been noted (Murry and Beacham, 1986; Seymour, 1956). Thus even if 2°C is suboptimal at a constant incubation temperature, natural seasonal declines in temperature down to 2°C in the incubation period may not decrease survival. This assumption is supported by work showing that newly hatched bull trout alevins are tolerant of temperatures near 0°C **(Baroudy and Elliott, 1985)** and that the lower limit for hatching in Arctic char is less than 1°C.

Based on the information examined, the initiation of spawning behavior and invivo egg development will be fully supported by keeping maximum temperatures in the spawning areas below 7-8°C during the spawning season. Given that excellent survival has been noted in spring water tests at 6.5°C, which fluctuated in semi-natural manner, and that a variety of impacts to spawning have been noted above 7°C, it is recommended that temperatures be kept generally below 5.5-6.5°C at the early portion of a known spawning period. Temperatures should be allowed to continue to drop towards 3-5°C as the spawning season progresses. **In consideration of the above information, the highest staff recommendation is that the 7-day average daily maximum temperature remain below 6.5° and/or no single daily maximum should exceed 8° C to protect the spawning and incubation of char.**

Spawning initiation dates will vary to some extent from year to year based on the climatic patterns; being earlier in cooler years and later in warmer years **(Kramer, 1994).** Establishing a date of application for a state-wide criteria based on the earliest recorded date of spawning would be most protective, but not necessarily appropriate or realistic. Some cautious consideration of the natural variation in spawning activity both geographically and annually seems warranted.

River temperatures typically remain near their seasonal maximum values throughout most of the month of August. Beginning in late August to early September the temperatures in the upper watersheds where char stocks spawn typically experience a constant and often rapid decline in temperature. Setting optimal criteria that cover every stock assessed would mean applying the spawning criteria as early as mid August statewide. This would result in many waters being treated as not protecting their indigenous stocks of char, when in fact they are meeting the temperature criteria when the spawning would normally occur in that waterbody. Additionally, populations of char which spawn in mid-August are likely to be at high altitudes in headwater rivers heavily influenced by cold glacial or groundwater source waters. It is recommended that early spawning stocks be considered for site-specific criteria designations at a later time, rather than using them as the basis for establishing char spawning criteria statewide.

There are numerous approaches that could be used to establish a date to apply spawning criteria, each would have its strengths and weaknesses. Perhaps the best would be to know at what date spawning has historically begun on average and use that date as the basis for setting criteria. Given that water quality criteria would apply to climatically warm years, using the average start date would be a reasonable yet protective approach that would also help maintain the typical timing of spawning activity and thus also maintain the typical dates of fry emergence in the Spring. Such detailed information is not available, however, and will be unlikely to be available in the future. Thus another approach must be taken. Data that is available suggests that in Washington, 31 of the 35 char stocks assessed begin spawning after September 1, and 32 of 35 stocks have midpoints in their spawning periods that fall after September 15 (Appendix D). **It is recommended that any statewide spawning criteria for char be set between September 1 and September 15.**

Juvenile Rearing:

Upon hatch, char fry will either remain in the localized area or move downstream to larger stream reaches or lakes to rear (Goetz, 1989; Williams and Mullen, 1992). **Unless**

information clearly demonstrates that a stretch of water would not be used for summer rearing even under natural conditions, temperature criteria assigned to the migration paths should be set to protect rearing.

Some research suggests that age 0-1 juvenile char have cooler temperature preferences than age 1+ juveniles; however, there is little consistency in the values identified. The preference values for age 0-1 bull trout range from an average of 4.5°C (Ratliff, 1992), to maximum stream temperatures of 10°C and 13°C (Ratliff, 1987, as cited in WSDFW, 1994; and Martin et al., 1991). It is known that resident forms of bull trout remain in or near their natal streams for their entire life. Fluvial and adfluvial forms may remain in the area of their natal stream for 1 to 3 years and then migrate significant distances to more productive waters for juvenile growth (Pratt, 1992; Ratliff, 1992; Riehle et al., 1997; Fraley and Shepard, 1989; Goetz, 1989); although, some stocks have also been observed to migrate to lakes or reservoirs immediately after hatching (Reiser et al., 1997). Sea-run (anadromous) forms will migrate hundreds of miles to take advantage of productive near-shore marine habitat (Goetz, 1989). Temperature standards would ideally be set in consideration of these various life-strategies. The needs of resident forms may be slightly different from the various migratory forms. A non-migratory resident bull trout, must remain in and defend their natal habitat for their entire life. Temperatures here should clearly favor bull trout over competing species such as chinook salmon, rainbow trout, and brook trout (Martin et al., 1991; Mullan et al., 1992; Ziller, 1992; Adams and Bjornn, 1997; WSDFW, 1994).

Juvenile bull trout and Dolly Varden have difficulty competing with several common salmonid species in warmer waters. This may provide an explanation for why researchers have observed young juvenile fish remaining in their natal stream for the first several years before moving downstream to warmer and more productive waters. The lack of significant competitors in their cold natal streams may more than compensate for the reduced productivity of these pristine environments. **Willams and Mullen (1992; as cited in Adams, 1999)** found that rainbow trout excluded the first two age classes of bull trout at weekly average temperatures above approximately 11-12°C. And in a study by **McMahon, Zale and Selong (1999),** it was found that the presence of brook trout in sympatry with bull trout resulted in significantly greater growth of brook trout and significantly lower growth for bull trout than occurred with either species in allopatry, especially at water temperatures equal to or greater than 12°C. However, it may be worth noting that temperature alone is unlikely to eliminate the presence of competing species. **Kitana et al. (1994)** for example found that brook trout and cutthroat trout coexisted with bull trout in waters with early September temperatures of 5.3-8.9°C. Once juvenile fish are of sufficient size to defend themselves and their feeding territories, migration to warmer and more productive stream reaches and reservoirs may then have survival value as it allows for a more rapid increase in body weight.

Saffel and Scarnecchia (1999) examined 18 reaches of 6 streams during a one year period. They found that two variables, maximum summer temperature and number of pocket pools/100 m, were significantly related with density of juvenile bull trout. The density of bull trout increased with increasing maximum temperature below 14°C (range 7.8-13.9°C) and decreased with increasing temperature above 18°C (range 18.3-23.3°C). The highest densities were found in reaches with a high number of pocket pools and maximum summer temperatures between 10-13.9°C. There were no study streams with temperatures between 14-18.3°C. Thus while it may in fact be true that younger fish require cooler water, the relative preference seems somewhat obscured by the available range of stream temperatures in the various study streams.

The temperature conditions of streams having 100% char or that are dominated by char may help describe conditions that clearly favor char over competing species. Streams having 100% char have been reported to have summer averages typically below 7.2°C (Ratliff, 1992), and summer maximum temperatures of 11-11.5°C (Ziller, 1992) to less than 13°C (Martin et al., 1991; and Goetz, 1989, 1997a). Summer average temperatures above 7.9°C have been associated with some loss in bull trout dominance (11 to 86%) (Ziller, 1992; Ratliff, 1992).

Numerous authors have studied the general distributional patterns of char in relation to temperature in the field. Any study of an single basin or stream needs to be kept in that limited context; however, the wealth of studies across the Northwest when considered in combination create some strong patterns of occurrence. For example, while in the cold groundwater dominated Metolius River system in Oregon Ratliff (1987) reported that bull trout were rarely found at temperatures above 10°C, it is important to recognize that this watershed does not generally contain waters with warmer summer temperatures. Numerous authors have, however, examined the patterns of occurrence in more heterogeneous environments and have specifically tried to answer the question of when summer temperatures appear to be a limiting factor for char. It is only by combining the results of all these various studies and recognizing their general limitations that allows a pattern to emerge.

Sexauer and James (1997) studied four bull trout streams in the Yakima and Wenatchee River Watershed of central Washington that were considered healthy. They found that summer maximum temperatures ranged from 9-12.5°C. **Adams (1999)** in reviewing this work noted that in the highest 7-day average daily maximum value was 12°C. **Williams and Mullan (1992; as cited in Adams, 1999)** found that bull trout growth in the Early Winters Creek basin of northwest Washington increased with increasing temperature. Maximum growth occurred in the stream with the maximum temperature of 13.1°C (7-day average of the daily maximums). **Adams (1999) also cites unpublised work by Gordon Hass** as showing the highest densities of bull trout occurring in the range of 11.2-12.3°C (7-day average of daily maximums) with the single highest daily temperature of 13.6°C. Between 10.1-11.2°C and 12.3-13.9°C the densities were comparable (highest daily maximum of 15.1°C but most below 14.1°C). **Rieman and Chandler (1999)** found that 95% of the bull trout found occurred at summer maximum temperatures less than 18°C, with most occurring below 14°C. They noted that the juvenile or small bull trout were most likely to occur at summer maximum temperatures of 11-14°C. Goetz (1997b) surveyed 13 drainages in Washington and Oregon and were unable to find juvenile bull in streams with temperatures above 14°C, and Jensen (1981; as cited in Pratt, 1992) noted that 14°C appears to create a thermal barrier to the distribution of the related Arctic char. **Hass (pers. com., in Adams, 1999)** is reported to have found that in his studies the warmest stream containing bull trout had a maximum daily temperature of 16.3°C. This is similar to other authors who found temperatures of 15-16°C set the limits for streams that contain bull trout (Fraley and Shepard, 1989; Shepard, 1985; Goetz, 1989; Pratt, 1992; Martin et al., 1991; and **Rieman et al., 1997, as cited in McMahon, Zale, and Selong, 1999**), and that a temperature of 15°C can trigger the out-migration of char from otherwise suitable habitat (Goetz, 1997). It is also noteworthy that temperatures above 15-16°C have been associated with increased metabolic stress and swimming impairment (Bonneau and Scarnecchia, 1996).

Rieman and Chandler (1999), in perhaps the most comprehensive statistical evaluation to date, examined distribution and temperature data from 581 sites. They concluded that 95% of the observations of juvenile bull trout were from waters with summer maximums less than 18°C; and the majority were from waters with maximum summer temperatures less than 14°C. It was concluded that juvenile/small bull trout are most likely to be found in streams with summer maximum temperatures of 11-14°C.

As noted in the work of **Riemen and Chandler (1999),** char can be found in streams with temperatures well in excess of 15-16°C, with some researchers citing 17.2-20.5°C as the limit for finding bull trout (Brown, 1992; Goetz, 1989; Adams and Bjornn, 1997). In the study by Adams and Bjornn (1997) both adult and juvenile bull trout were found in a segment of stream having a temperature of 20.5°C; however, the fish were found holding at the bottom of a pool where ground water flows kept the water below 17.2°C. In a review of this same study, **Adams (1999)** noted that the author thought the bull trout holding in this warm water looked physically unhealthy.

In growth studies, **Fredenberg, Dwyer, and Barrows (1995)** found that 8.3°C produced greater growth at maximum rations than at lower test temperatures. **McMahon, Zale and Selong (1998)** found that growth was highest at 12°C, but non-significantly less at 14 and 16°C at maximum rations. Growth declined sharply at temperatures greater than 18 and less than 10°C. In follow-up tests, **(McMahon, Zale and Selong, 1999)** the authors found that growth at maximum and 66% of maximum rations were highest at 16°C, but that at 33% of maximum ration growth was maximized at 12°C. In modeling the available calories in low productivity streams against the growth observed in their tests, the authors suggested the optimum growth range of 12-16°C would shift to 8-12°C. Similar findings were produced using Arctic Char **(Swift, 1975, and Jensen, 1990; as cited in Jensen, 1995)** where maximum growth occurred at about 12-14°C (at likely maximum or near maximum rations). These recent growth studies may help explain why Shepard et al. (1984; as cited in Pratt, 1992) found that bull trout growth was slower in the middle fork of the Flathead River, Montana, even though it was warmer and more productive.

In summarizing the key findings, daily maximum temperatures between 11-14°C are most widely cited as the upper limits to finding populations of char, but within the range of 11-13°C researchers have often noted the highest densities and greatest growth. So, while temperatures above a typical summer maximum of about 13-14° seem to define the upper temperature for finding healthy char populations, temperatures just below this upper limit may often define some of the best native char habitat. The growth of char under both satiation and subsistence rations can be maximized at a constant temperature of 12°C, thus it is reasonable to assume that summer stream temperatures which seldom exceed 13-14°C would be physiologically beneficial to bull trout under a variety of feeding regimes. The recommendation by **Adams (1999)** that bull trout waters not exceed 12°C as a 7-day average of the daily maximum temperatures seems well supported by the literature, and should be incorporated in the recommendations for char for the state of Washington.

In consideration of the above information, it is recommended that the 7-day average of the daily maximum temperatures not exceed 10-12.5°C in streams used for summer rearing by char, and/or single daily maximum temperatures not exceed 13-14°C. To provide greater confidence that resident stocks and young juveniles (first year or two) of migratory stocks will be fully protected, consideration should be given to establishing even cooler temperatures in natal streams than in non-natal waters used for rearing.

It is intended that rearing criteria be applied to waters where char are found during the peak of summer, thus where sound scientific investigation shows a natural pattern of use only over the winter and early spring in mainstem rivers the rearing criteria is not intended to be applied. Reasonable alternatives approaches include, a) setting only a single daily maximum temperature of 12° in natal streams and 14°C elsewhere within their range; b) setting 12° C as a 7-day average of the daily maximum temperatures to be applied to all waters used for either spawning or rearing by native char; or c) any compatible combination of the above recommendations.

Lethality to Adults and Juveniles:

While having relatively sensitive optimal temperature limits, adult and juvenile char do not appear unusually sensitive to acute temperature limits. With acclimation, juvenile and adult char are very tolerant of temperature extremes in a laboratory environment – capable of withstanding temperatures of –1.2°C for up to 5 continuous days and having upper lethal temperature limits similar to, but on the lower end, of that for the Pacific salmon.

Lethal temperatures change depending upon the background temperature at which the fish have been acclimated to. In general, as the acclimation temperature increases so does the ability to survive potentially lethal temperatures. The estimated 7-day LT50 (lethal to

50% of test population within 7 days) for char at acclimations of 5-20°C generally group between 21.5-24° **(McMahon, Zale, and Selong, 1999**; Lohr et al, 1996; Brett, 1956; **Lyytikainen, Koskela, and Rissanen, 1997; Baroudy and Elliott, 1994).** In work done on the alevin life stage, however, acclimations of 5 and 20°C produced 7-day LT50 values of 18.7 and 20.8°C, respectively **(Baroudy and Elliott, 1994)**. In 60-day lethality tests, **MacMahon, Zale and Selong (1998, 1999)** calculated a 60-day LT50 of 20.8°C; and found that survival was 98% at temperatures between 7.5-18°C. Mortality was 100% within 10 days at 24°C and within 38 days at 22°C. It should be noted that in the tests of MacMahon, Zale and Selong the water temperature was gradually raised at 1°C/day to the test temperature, allowing for some additional acclimation prior to subjecting the fish to a constant exposure at the test temperature in an effort to come close to replicating natural warming and allow for some reasonable level of acclimation. At full acclimation to temperatures from 15-20°C, sudden exposure to 29 and 30°C water produced LT50 values within 2-4 minutes (Lohr et al., 1996; and **Lyytikainen, Koskela, and Rissanen, 1997).** At an acclimation of 6°C a test temperature of 24°C produced LT50 results in juveniles in only 1-hour. When alevins were acclimated to 5°C, however, 50% mortality occurred in less than 10 minutes at 23.3°C **(Baroudy and Elliott, 1994).**

Based on the literature reviewed, temperatures of 21.5-24°C should be considered capable of producing LT50-type effects within an exposed population of juvenile fish given exposure time is comparable to the test conditions. For alevin, this range would be lowered to 18.7-20.8°C. A safety factor of 2°C is recommended for application to these numbers to bring them down to levels that will ensure that neither individuals nor sensitive subgroups within natural populations will be harmed.

As discussed previously in this section, daily maximum temperatures well below those posing a threat of acute lethality are important to the health of our native char. Thus in general, daily maximum criteria are not recommended to be set primarily to avoid lethal temperatures. However, for evaluating special projects, and the size and siting conditions for mixing zones for point source dischargers, knowledge of acutely lethal levels is very important. Additionally, we may want to consider the relative safety of char passing through mainstem rivers during anadromous migrations or when leaving winter holding areas. In such cases it will be important to ensure criteria set primarily for other salmonids are not too warm for the appropriate level use by char.

In consideration of the above information, it is recommended daily maximum temperatures are established to avoid lethality, criteria be set no higher than 19.5-20°C to protect juvenile and adult char. In evaluating projects that may raise temperatures to waters containing incubating char, it should be assumed that daily maximum temperatures should remain below 16.7-17.3°C to prevent direct mortality. Further, when authorizing thermal discharges, it is recommended that conditions not be permitted that would have a reasonable potential of allowing juvenile or adult char to be fully entrained at temperatures greater than 30-31°C for more than a brief second.

2. Chinook Salmon

Upper End of Optimal Temperature Range by Life Stage

General Limitations	7-DAM	1-DM
Incubation	11-12	13.5-14.5
Juvenile rearing	14.2-16.8	20-21
Smoltification	12.0-13.8	20-21
Adult holding	14.2-15.6	20-21
Adult migration only	14.2-16.8	20-21

Point Limitations	1-DM	Instant Mix
Acute threshold	20-21	30-32
Acute threshold (embryos)	13.5-14.5	Insuf. Data

Notes: 7-DAM refers to the rolling arithmetic average of seven consecutive daily maximum temperatures; 1-DM refers to the highest daily maximum temperature outside of an authorized mixing zone; Instant Mix refers to any place within a river where adult or juvenile fish may become fully entrained in a warm water plume, and typically applies within the established acute exceedence area of an established mixing zone.

Species-Specific Recommendations:

The following two alternatives show what temperature criteria would be recommended if this were the only species of concern. They also may be further modified in the Section VIII, Synthesis to account for other species in the stream complex and to remove unreasonable risks from warm water diseases. Thus the recommendations below for this species may not correspond directly with the final recommendations of this paper.

- Waters used for spawning and rearing by chinook salmon should not exceed a 7-day average of the daily maximum temperatures (7-DADM) greater than 15.6°C, with no single daily maximum temperature greater than 20°C.

- By August 1, the typical date when most stocks begin spawning, the 7-DADM should be at or below 12.5°C, with no single daily maximum exceeding 18°C. By August 23, the midpoint of spawning for most stocks, the 7-DADM should be at or below 11.5°C, with no single daily maximum exceeding 17°C. Portions of streams used for juvenile rearing should not exceed 16.5°C. Areas used for adult holding by spring-run stocks must provide for optimal protection against chronic sublethal effects. As such, temperatures in these stream segments should not exceed 15.6°C as a 7-DADM, with no single daily maximum greater than 20°C. Out-migrating smolts should not experience temperatures generally above 13.5°C. Stream segments used by chinook salmon only as adult migration corridors should not exceed 16.5°C as a 7-DADM, with no single daily temperature maximum greater than 20°C.

Summary Discussion

General Life History:

Chinook salmon (*Oncorhynchus tshawytscha*) are found in most of the larger streams of the upper and lower Columbia River drainage, and the coastal and Puget Sound drainages. Juvenile chinook salmon spend about a year in fresh water before smolting and migrating to the Pacific, where they generally remain from 3-4 years before returning to their natal streams to spawn. Adults begin the ascent of coastal streams in late May and early June. The principal spawning months are July through September. Chinook salmon are primarily divided into two stock types, based on the season they initially return to fresh waters. These are spring run and fall run stocks, but in some areas a third summer run stock may be identified. Fall chinook migrate up the streams in August and September and spawn as soon as the spawning grounds are reached, when water temperatures are between 5.6-14.4°C. Eggs hatch in about 2 months and the young remain in the gravel for 2-3 weeks prior to emerging. Juveniles remain in freshwater from a few days to 3 years. Usually, juvenile fall chinook feed for a short time and then migrate to the ocean, whereas most juvenile spring chinook remain in the stream for one year before migrating (Wydoski and Whitney, 1979).

Spawning Requirements:

Regardless of when the fish enter fresh waters, all chinook spawn in fall. Spring run fish begin entering freshwaters from May through June, and typically hold in deep pools and at the mouths of cool tributaries until the fall rains begin and stream levels go up sufficiently to allow them to reach their upriver spawning sites. These spring run fish tend to spawn higher in the watersheds than the fall run stocks. Fall chinook tend to migrate in August and September and spawn as soon as they reach their spawning grounds (Wydoski and Whitney, 1979). In Washington, 96 of the 98 chinook stocks assessed began spawning after August 1, and 96 of 98 had midpoints in their spawning periods that were after August 23 (Appendix D). It is recommended that these dates be considered when establishing statewide temperature criteria that will protect chinook salmon.

The technical literature reviewed for this paper notes a wide range of temperatures associated with the spawning of chinook salmon (5.6-17.7°C) (Seymour, 1956). The majority of these temperature observations, however, cite a maximum temperature below 14.5°C (Bell, 1986; Piper et al., 1982; Beschta et al., 1987; Wydoski and Whitney).

Several researchers have examined the effects of holding mature adult chinook prior to spawning at warm temperatures. It has been found that temperature can effect both the health of the spawners and their potential reproductive success prior to the act of spawning. One of the ways in which temperature affects the health of spawners is by increasing the risk of mortality from warm water diseases **(Schreck et al., 1994;**

Bumgarner et al., 1997; and ODFW, 1992) prior to spawning (disease is discussed separately in this paper). Another way that warm water affects the success of spawners is through its effect on the health of the unfertilized eggs as well as maturation timing of adult salmon. Holding mature adults at warm temperatures has been found to result in the reduced survival of eggs **(Hinze, 1959; as cited in CDWR, 1988). Rice (1960)** found that holding broodstock at temperatures above 15.6°C reduced survival of eggs to the eyed stage by 12.7% as compared to holding broodstock at 8.3-15.6°C. Adult immigrants held at temperatures greater than 15.6 or less than 3.3°C were also found to produce eggs that are less viable in a study by **Hinze, Culver, and Rice (1956; as cited in CDWR, 1988).** The greatest survival was from adults taken at temperatures in the range of 11.7-12.2°C. Berman and Quinn (1989) cite a personal communication with the manager of the Kalama State Fish Hatchery as finding egg mortalities of 50% or more from adults held in river waters fluctuating from 14.4-19.4°C. The current supervisor of the Kalama Falls Hatchery, **Ron Castaneda,** notes that they still attribute some increased losses to holding temperature around 15.6-17.8°C; although, they have not had conditions of mortality as high as 50%.

Incubation and Early Fry Development:

Once spawning has taken place, the eggs of chinook salmon hatch in about 2 months and the young remain in the gravel for 2-3 weeks prior to emerging. Many researchers have tested incubation survival at constant exposure to various test temperatures. Complete mortality (100%) has been noted at incubation temperatures from 13.9 to 19.4°C (Donaldson, 1955; Garling and Masterson, 1985; Seymour, 1956; **Eddy, 1972, as cited in Raleigh, Miller, and Nelson, 1986**). Significant mortality (over 50%) has been noted at constant incubation temperatures from 9.9 to 16.7°C (Donaldson, 1955; Seymour, 1956; **Burrows, 1963, and Bailey and Evans, 1971; as cited in Alderdice and Velsen, 1978; Hinze, 1959; as cited in Healy, 1979**). A constant incubation temperature of 8°C produced more robust alevin and fry than constant exposure to either 4 or 12°C in a study by Murry and Beacham (1986), and Velesen (1987) compiled data showing that the best survival (>92.9%) occurred between 7.2-9.6°C. Heming (1982), however, found good survival at both 10°C and 12°C. Heming tested the survival in both incubation trays and artificial redds. Survival rates declined as the temperatures increased from 6 to 8, 10, and 12°C. The greatest survival (91.7-98%) occurred at 6 and 8°C, but it was still very good (90.2-95.9%) at 10°C. Incubation at 12°C consistently had the lowest survival (84.6-89.3%). Heming also tested survival rates from incubation to hatching against survival rates from hatching through complete yolk absorption. His work suggests higher incubation temperatures may create a metabolic energy deficit for pre-emergent salmon that increases mortality. Once alevin have hatched and absorbed their yolk sacs they will need to make a transition to active feeding. Heming and McInery (1982) found that temperatures of 6, 8, and 10°C resulted in an average survival of 98.4% during this transitional period, while 12°C was associated with a decrease in survival to 89.2%. The maximum conversion of yolk to tissue weight was cited by Beacham and Murray (1986) as occurring at 6°C or below. Seymour (1956) noted a 9 fold increase in abnormalities in fry incubated at 15.6°C and higher when compared to those incubated between 4.4-12.8°C. Seymour also noted that fry incubated at 4.4°C emerged larger than those reared at higher temperatures, however, subsequent fry growth was maximized at 12.8°C. Considered together, the work of the authors cited above most strongly suggest that constant temperatures above 9-10°C and below 5°C may reduce the survival of chinook salmon embryos and alevins. While constant temperatures of 11-12°C can still result in good success, the results are consistently less than what is produced at lower temperatures. As discussed previously in this paper, constant laboratory test temperatures of 9-10°C should be considered roughly equivalent to naturally fluctuating stream temperatures with daily maximums of 11-12°C.

Some researchers have tried to mimic the naturally fluctuating and falling temperatures actually experienced by incubating eggs, or have stepwise reduced the incubation temperatures as incubation progressed. Initial incubation temperatures from 15.6-16.7°C have been associated with significant to total losses of young fish through the incubation to early fry development phase **(Healy; 1979; Brice, 1953; CDWR, 1988; Jewett, 1970; as cited in CDWR, 1988). Rice (1960)** found that source waters declining from 15.6-8.3°C resulted in satisfactory egg development, though did not provide survival rates or clearly consider survival through to the fry stage. **Johnson and Brice (1953)** found survival to often exceed 90% where initial water temperatures (as a daily mean) were below 12.2°C. **Healy (1979)** found that highest survival (97%) occurred in creek water where the daily maximum reached 12.8°C only a few times during the first two weeks of development; but also noted that survival was still very good (90-94%) where the initial temperatures were between 12.8-14.2°C. Olson and Nakatani (1969) found 53.7-88% survival in egg lots started at 12.5°C, experiencing a brief increase to 14.7°C in the first week, and then quickly dropping back to 12-12.5°C and assuming a seasonal downward trend in temperature (test water paralleled both diel and seasonal fluctuations). Olson and Foster (1955) found the greatest survival at an initial test temperature of 11.6°C (92.2%), but reported no appreciable differences in survival rates at initial test temperatures of 13.8, 15, and 16°C (89.9-83.9%) (test water paralleled seasonal daily average temperatures). Seymour (1956) tested four geographically distinct stocks of chinook. Taking into consideration both mortality and growth rate, the optimum temperature was estimated as 11.1°C for eggs and fry. The mortality rate was considered low at all stages of development for lots reared between 4.4°C and 12.8°C. Lots with initial temperatures of 18.3° had the highest mortality (11, 24, 40, and 100%). In the cyclic and fluctuating temperature tests reviewed here, having temperatures at the beginning of incubation that are below 11-12.8° are typically associated with optimal survival rates. This compares well with the adjusted optimal range of 11.5-12.5°C suggested above based on examining the constant temperature exposure studies. This range also compares well with the optimal temperature range of 8-12°C recommended by the **Independent Scientific Group (1996)** study.

Donaldson (1955) transferred eggs to more optimal (10-12.8°C) incubation temperatures after various periods of exposure to higher temperatures. He found that tolerance to temperature exposure varies with the stage of development. He also found 20% mortality could be induced by exposing eggs to 19.4°C for one day, 18.3°C for thee days and 17.2°C for less than ten days. Donaldson's work lends further support of the observations made by other authors such as Jewett (1970; as cited in CDWR,1988) that the latent effects of holding eggs at higher than optimal temperatures continues through the period of absorption of the yolk sac, thus using mortality estimates at the time of hatching underestimate the total temperature induced mortality. Donaldson found the developmental stages associated with the greatest percentages of temperature induced mortality were: 1) the time up until the closure of the blastopore (200 T.U.); 2) the period just previous to and during hatching; and 3) when fry are adapting themselves to feeding. He also found that when eggs were exposed to test temperatures (17.2, 18.3, and 19.4°C) past the eye pigmentation stage (350 T.U.) the time necessary for complete hatching doubled, and the frequency of common abnormalities increased with both the higher temperatures and longer exposures. Murry and Beacham (1986) found that initial incubation at 4°C reduced survival even with later transfer (at completion of epiboly) to warmer waters (8°C and 12°C). Transfers after ebiboly or completion of eye pigmentation from 4 to 12°C and from 12 to 4°C also caused an increase in alevin mortality. The authors also found that a decreasing temperature regime produced longer and heavier alevins and fry. Combs (1965) found that eggs developed to the 128-cell stage at 5.8°C could then tolerate 1.7°C for the remainder of the incubation period with only moderate losses. Mortality of 14.5% was observed with a transfer time of 72 hours, while only 3.3% mortality occurred with a transfer at 144 hours. These three works taken together suggest that the effects of suboptimal initial incubation temperatures may not be nullified by later changes in the temperature regime to more optimal levels; that sudden changes in temperature at either early or later stages of development, regardless of the direction of that change, can be harmful to pre-emergent life stages; and that initial incubation at optimal temperatures may condition eggs and embryos such that they can withstand very low winter temperature regimes.

In addition to the work done by Donaldson (1955), Neitzel and Becker (1985) also conducted work on the effects of short-term increases in temperature that can be used to support daily maximum temperature criteria. Neitzel and Becker (1985) used chinook salmon to try and determine the effects of short term dewatering of redds by hydropower facilities. Neitzel and Becker found that sudden increases in temperatures from 10°C to above 22°C for 1-8 hours significantly reduced survival of cleavage eggs in chinook salmon. Controls held at 10°C experienced very low mortalities (less than 2%). Mortality in treatment groups was 8-10% at 22°C after 2 hours exposure, and was 22% after a one hour exposure at 23.5°C. They further found that decreasing the temperature from 10°C to near freezing (0.0°C) for up to 24 hours did not increase mortality in eggs, embryos, or alevin. Considering the work of and Nietzel and Becker (1985) it would appear that chinook salmon eggs and embryos are relatively tolerant of short-term increases in temperature up to 22°C. However, since Donaldson (1955) found that

19.4°C produced 20% mortality in one day and 18.3°C produced 20% in three days, setting a more restrictive single daily maximum temperature limit is certainly warranted. If a 2°C safety factor is applied to the lower effects range of 17.2-18.3°C determined by Donaldson, it would result in a recommendation that daily maximum temperatures not exceed 15.2-16.3°C during incubation. However, as described above, incubation conditions where daily maximum temperatures were in the range of 14.4-15.6 produced reduced survival rates, so it is recommended that daily maximum temperatures during incubation not exceed 13.5-14.5°C.

While there is some disagreement, the literature is very consistent overall regarding the optimal incubation requirements for chinook salmon. **To provide for optimal protection from fertilization through initial fry development it is recommended that 7-day average of the daily maximum temperatures at the time of fertilization of chinook salmon eggs not exceed 11-12°C; and that individual daily maximum temperatures not exceed 13.5-14.5°C**.

Juvenile Rearing:

After emerging from the gravels, chinook fry may remain in freshwater from just a few days to up to 3 years. Usually, fall chinook feed for a short time and then migrate to the ocean, whereas most juvenile spring chinook remain in the stream for one year before migrating to the ocean (Wydoski and Whitney, 1979). In examining temperatures optimal for juvenile chinook salmon, it is important to note that disease, predation, and smoltification concerns (all discussed and incorporated separately in the recommendations of this paper) are all issues that need to be considered in addition to growth rates. Additionally, in considering growth rates, it is important to distinguish between studies conducted under constant and cyclic temperature regimes, and to recognize that the feeding rates used in testing will affect the results of the test. As food becomes scarce, the temperature which provides for optimal growth declines. As food becomes more plentiful fish can grow larger in warmer waters. Most tests are conducted at high to very high rations and it is an important question as to how well the results can be applied to natural stream environments where food availability can be more limiting.

In constant temperature experiments conducted at high feeding rates, maximum growth tends to be associated with temperatures in the range of 18.3-19°C **(Brett et al., 1982; Banks, Fowler, and Elliott, 1971, as cited in CDWR)**. A rearing temperature of 15.6°C was found to produce insignificantly less growth as compared to 18.3°C and temperatures above 19°C were associated with reduced feeding and growth, and increased problems with disease. Brett (1982) estimated that under natural ration levels the optimum of 19°C would be reduced to 14.8°C and no growth would be possible at 21.4°C. Seymour (1956) studied three Washington and one California stock of chinook salmon and concluded that the general optimum temperature for growth and survival of chinook fingerlings was 14.4°C. **Zaugg and Wagner (1973)** found that at the end of a 16 month test growth was roughly 27% greater at 12°C than at 8°C. In studying growth in a natural stream, **Bisson and Davis (1976; as cited in ODFW, 1992)** reported that juvenile chinook grew faster in a stream where temperatures peaked at 16°C compared with a stream where temperatures peaked at 20°C. **Neilson and Green (1985)** interestingly found that in comparing fluctuating to constant test conditions, that growth was enhanced through naturally cyclic temperature regimes, suggesting that food utilization in fluctuating environments may be higher.

The **Independent Scientific Group (1996)** study concluded that juvenile chinook salmon rearing is optimal where temperatures are maintained in the range of 12-17°C; and suggests 15°C is most optimal. Beschta et al. (1987; based on the work of Reiser and Bjornn, 1979) recommended a juvenile rearing temperature range of 7.3-14.6°C and suggests optimal juvenile rearing occurs at 12.2°C. Brett (1951; as cited in Ferguson, 1958) reportedly found that the final preferendum temperature for chinook is 11.7°C. The general range for chinook salmon has been suggested as extending from 0.0-0.6°C to 25°C, with an optimal or preferred range extending from 6.7-10°C to 13.9-14.4°C (Bell, 1986; Piper et al., 1982).

There is a great amount of variability in the research and recommendations for chinook rearing temperatures. Optimal temperature regimes generally encapsulate the range of 7-17°C, but efforts to provide specific optimum temperature recommendations to natural feeding regimes tend to narrow the range to 12.2-14.8°C. Recommendations in this range remain connected to studies conducted at constant temperatures, and some minor adjustment to account for fluctuating natural environments seems warranted. As discussed previously in this paper, constant laboratory test temperatures of 12.2-14.8°C should be considered roughly equivalent to naturally fluctuating stream temperatures with daily maximums of 14.2-16.8°C. While the concern for disease and smoltification capabilities may warrant further reduction (and is discussed and incorporated separately), **it is recommended that to provide for optimal growth conditions that the 7-day average of the daily maximum temperatures not exceed 14.2-16.8°C during the peak of summer.**

Juvenile Winter Holding:

Temperature declines below 1.1-5°C can cause fish to become dormant and move into the substrate. Once fish have initiated hiding behavior, it may take temperatures rising again to above 7°C to bring them back out (Chapman and Bjornn, 1969). While this natural behavior is a healthy response for winter survival, unseasonably cold discharges causing water temperatures to unseasonably fall below 5-7°C need to be avoided. Dropping the temperature to 2.5°C for even a few days may result in mortality to chinook that were acclimated to a river temperature of 15°C (Brett, 1956). To avoid initiating unseasonable hiding behavior, to avoid lethal effects, and to encourage strong growth rates the daily low temperature should typically exceed 7°C during the growing season.

Smoltification:

As described previously, once juvenile chinook grow to an appropriate size they will migrate to the ocean (**Ewing et al., 1979; Clarke and Shelborn, 1985)**. Out-going migrations typically occur during the first and second years of life (Wydoski and Whitney, 1979) but since success is related to smolt size, some fish will not be ready until their third year. Temperature is known to affect the ability of smolts to transition to and grow in a saline environment. The physiological preparation of juvenile fish for life at seas is commonly referred to as smoltification. Perhaps the greatest concerns at this stage are that fish will not be able to fully adapt to saline water, and that delays in adaptation will cause extensive losses in the estuarine areas. The literature on the effects of temperature on smoltification of juvenile chinook salmon is not as extensive as for coho salmon and steelhead trout, and direct lethality due to inadequate smoltification is not well established for chinook. However, **Sauter and Maule (1997)** reported cessation of feeding as well as thermoregulatory behavior in subyearling fall chinook held between 18-20°C. Exposure to water temperatures of 20°C for several hours induced heat shock proteins (Sauter et al., in review, and M. Hargis, personal comm.; as cited in Sauter and Maule, 1997). **Zaug and McLain (1976)** found decreased (Na+K)-ATPase activity (a measure of sea water adaptability) at 12°C as compared to 8°C, and **Clarke and Shelbourn (1985)** found that optimum regulation of plasma sodium concentrations occurred with transfer of fish from 13.8°C fresh water to 10.2°C sea water. They also noted that severe descaling in their freshwater holding tanks occurred in groups of smolts reared at 16 or 17°C, as well as with groups transferred from 8-12°C freshwater to 14°C seawater. While the research on impairment to smoltification is rather scant, what has been reviewed suggests that **temperatures should be generally maintained below 12-13.8°C during out-migration of chinook smolts.**

Adult Migration:

After spending 3-4 years in the ocean mature chinook salmon begin their return migrations to freshwaters to spawn. Temperatures can create serious problems for migrating salmon. In addition to posing the threat of direct lethality to adult spawners, temperatures can create blockages that stop migrating fish, create conditions that result in high mortality of spawners from disease, and reduce the overall fitness of migrants. Since migrating salmon do not feed in freshwaters they must enter freshwater with sufficient fat and muscle reserves to supply their metabolic requirements up to and through the act of spawning. The increased active and basal metabolic demands caused by travelling and holding in warmer waters uses up stored energy reserves at a more rapid rate. This can result in a decrease the quality and quantity of eggs as well as an overall reduction in the fitness of the adult fish who need to migrate and negotiate obstacles, excavate and guard redds, and complete the act of spawning. Berman and Quinn (1991) demonstrated that in the months prior to spawning, spring run chinook actively sought out cool water refuges in the Yakima River, in Washington. These fish were able to maintain average internal temperatures 2-5°C below the ambient river condition, which may have reduced their metabolic demand by 12-20%. A summary on the energetics requirements of salmon is provided in Appendix C. The most widespread concern with warm temperatures is from prespawning mortality due to an increased incidence of diseases. These diseases can directly kill or impair healthy fish, or act secondarily through infection of the minor wounds that normally occur in migrating fish. Disease is a serious concern and is discussed and incorporated separately in the recommendations of this paper. The focus of the following literature citations is on conditions that result in the blockage of migrating adults. Direct lethality, an additional concern regarding migration, will be discussed subsequently.

Daily maximum temperatures rising above 21°C are widely cited as causing barriers to migrating chinook **salmon (Stabler, 1981; Bumgarner et al., 1997; Hallock, Elwell, and Fry, 1970;** Thompson, 1945, as cited in Snyder and Blahm, 1971; **Don Raliff, 1977, as cited in Stabler, 1981; Fish and Hanavan, 1948, and Major and Mighell, 1967, as cited in USEPA, 1971)**. **Hallock, Elwell, and Fry (1970)** suggested that maximum temperatures of 18.9°C in association with low dissolved oxygen levels (5 ppm) created a partial block of migrating chinook salmon. However, some authors note chinook not showing avoidance for temperatures as high as 24.4°C (Gray, 1990; **Dunham, 1968; as cited in CDWR, 1988**). Thompson (1945; as cited in Snyder and Blahm, 1971) suggested that it was the difference in temperatures that stopped chinook from migrating from the Columbia to the Snake River. Differences were 17.2:21.7°C and 22.2:26.1°C when blockages occurred, with migration resuming when the difference approached 1.6°C. Similarly Gray (1990) suggested that incremental increases of 9-11°C formed a barrier to migration. **Sauter and Maule (1997)** reported cessation of feeding as well as thermoregulatory behavior in subyearling fall chinook held between 18-20°C, with exposure to 20°C for several hours inducing heat shock proteins (**Sauter et al., in review, and M. Hargis, personal comm.; as cited in Sauter and Maule, 1997**). In a field study by Frissel, Nawa, and Liss (1992), it was found that maximum water temperatures in a coastal river system in Oregon were linked to the presence or absence of various species of salmonids. While it was noted that cutthroat were absent and coho salmon rare or absent in segments exceeding 21°C, chinook dropped out completely only at 23°C; although, there presence in such waters was associated with positioning in small cool pockets in otherwise warm reaches. Some authors have suggested criteria for the protection of migrating chinook salmon. Piper et al. (1982) considering this important life stage suggested that 7.2-15.6°C was necessary to protect upstream migration and maturation. Bell (1973; as cited by Everest et al., 1985) suggested that temperatures should be within the range of 3.3-13.3°C for spring chinook, 13.9-20°C for summer chinook, and 10.6-19.4°C for fall chinook. **Based on the technical literature, it is recommended that to prevent a serious risk of causing blockage of migrating chinook salmon daily maximum temperatures should not exceed 20-21°C.**

Support for assuming a general 20-21°C threshold for salmon migration can also be found in the technical literature on lethality studies. As summarized below, temperatures of 20-22°C, particularly at lower prior acclimation temperatures, can be directly lethal to chinook salmon (Brett, 1956; Brett et al., 1982; Coutant, 1970; Beacham and Withler, 1991; **Becker, 1973; Orsi, 1971; as cited in CDWR, 1988**). It also appears from the available evidence that adults may be more sensitive than the juveniles which are most typically tested (**Becker, 1973**).

Many runs of chinook will need to hold or travel during the summer when stream temperatures are at a maximum in the lower and mid elevation rivers. Therefore, criteria to protect migration should be set to protect against chronic sublethal effects as well as acute effects such as blockages and lethality. While chinook adults can almost certainly withstand occasional daily peak temperature cycles up to 22°C, the general condition encountered by these migrating fish should approach more optimal conditions. While concern for disease may warrant further reduction (and will be discussed and incorporated as appropriate later), **it is broadly recommended that summer daily maximum temperatures during migration generally remain within or below the range of 14.2-16.8°C, identified previously as optimal for juvenile chinook salmon growth**.

Where fish may hold for in waterbody segments for long periods of time prior to spawning, as is commonly the case for spring chinook, it is recommended that daily maximum temperatures not exceed the range created by using the final preferendum value for chinook adjusted for fluctuating environments, and the highest temperature associated with having no invivo impairment to eggs in ripe females (as discussed previously). Taking this approach, **it is recommended that areas used for the long-term holding by chinook salmon should at a minimum be protected by maintaining average daily maximum temperatures below 14.2-15.6°C.**

Lethality to Adults and Juveniles:

Beacham and Withler (1991) moved juvenile chinook salmon from 14°C saline water to a series of test temperatures and noted genetic differences in the resistance times of from southern versus northern stocks. They also found that 55% mortality occurred within three days after transfers to saline waters with temperatures as low as 20.3-21.5°C. They found 87% mortality occurred within 2 days at 22.4°C. In tests using adult “jack” chinook salmon the authors established an upper incipient lethal temperature of 21-22°C. **Orsi (1971; as cited in CDWR, 1988)** found that 50% mortality in fingerlings acclimated to 15.6°C occurred within 48 hours at 21.1°C, however, by slowly acclimating fish to 21.1°C the author raised the lethal endpoint to 24.7°C. **Becker (1973)** noted that tests conducted with Jack chinook salmon produced 50% mortality near 21-22°C (this was likely the same tests conducted in Coutant, 1970, in which case the acclimation was at the prevailing summer temperature of the Columbia River). Brett found that 21.5°C was the lethal limit of spring chinook acclimated previously at 10°C and that minor increases in mortality (up to 5%) occurred at 20°C. Snyder and Blahm (1971), however, reported no mortality in chinook subjected to a change from 10 to 21.1°C over a 72-hour test. Temperatures in the range of what has been found to cause lethality have also been associated with sublethal effects. For example, Brett et al., (1982) estimated that at 21.4°C growth would cease under natural food rations. As demonstrated by the aforementioned research, there is very good support for assuming that temperatures in the range of 20-22°C can produce significant stress, and sometimes lethality, in chinook salmon even at acclimation temperatures that are likely to naturally occur in Washington's waters.

Apart from the studies cited above, however, most researchers have found that lethal levels in chinook occur slightly above 25°C when fish have been acclimated carefully to warmer temperatures. **Orsi (1971; as cited in CDWR, 1988)** found that fish acclimated to 21.1°C had an lethal limit of 24.7. Brett (1956) found that acclimations of 5, 10, 15, and 20°C produced 50% mortality at test temperatures of 21.5, 24.3, 25, and 25.1°C. Brett et al (1982) established the lethal level to be 25°C at an acclimation of 20°C.

The previously mentioned studies of lethality were all conducted in a laboratory environment. Baker et al. (1995), however, modeled the escapement of smolts from the lower Sacramento River and determined an upper lethal temperature of 23.01°C. Burck (1993) used live-box tests with juvenile chinook salmon. Burck found that daily maximum temperatures in the range of 25.5-26.6°C were lethal to all of the test fish after a single daily cycle of exposure (daily minimums ranged from 13.3-16.1°C). Daily maximums in the range of 23.8 to 25.5°C (minimums ranging from 11.1-13.3°C) resulted in 80% mortality over the four day test period. No mortality occurred in the three controls which had daily maximum temperatures from 14.4-17.2°C, 50% mortality occurred in one treatment with maximums of 20.5-21.6°C, but no mortality occurred in four other treatments with daily maximums in the range of 20.0-22.7°C. We can roughly compare Burck's data with values found in standardized laboratory tests using chinook salmon. If we assume the temperature midway between the daily maximum and the daily average is the acclimation temperature, then these live-box tests generally demonstrated that at an acclimation temperature of 20.6°C the lethal temperature was 25.6°C, and at an acclimation of 18.3°C the lethal level was 24.7°C. At an acclimation temperature of 16.5°C, however, there was inconsistent but typically complete survival at up to 21.6°C.

Some authors have noted temperatures that result in almost instantaneous lethality to chinook salmon. **Orsi (1971; as cited in CDWR, 1988)** found that fingerlings acclimated to 21.1°C suffered complete mortality when exposed to 31.1°C water for 4-6 minutes, and 50% mortality occurred in fish acclimated to 18.3°C and exposed to 28.3°C from 4-6 minutes. In a study by Snyder and Blahm (1971) a temperature of 26.7°C has resulted in mortalities beginning after just 100 seconds of exposure and complete mortality after 4 minutes, while at 32.2°C it only takes 4 seconds for mortality to begin and complete mortality after 11 seconds. Further, Gray (1990) found that temperature plumes above 25.1°C caused spasmodic muscle contractions in passing chinook salmon.

Additionally, Gray (1990) cited research showing that juvenile salmonids are more susceptible to predation at 10-20% of the thermal dose causing loss of equilibrium.

The laboratory data considered independently would suggest constant exposure to temperatures of 21-22°C carries a risk of causing direct lethality to migrating chinook salmon. With thorough acclimation, however, consistent exposure to temperatures of at 23-24°C would be necessary to produce a real risk of direct mortality to chinook salmon. These values correspond reasonable well with the results of field studies. In the Baker et al. (1995) model, a lethal level of 23.1°C at a prior acclimation of 20°C was estimated. In the live box studies by Burck (1993) it was found that daily maximum temperatures of 23.8-25.5°C were substantially lethal with a single day's exposure, and that mortality can occur when daily maximum temperatures occurred between 20.5-21.6°C; though consistent mortality seems to require that daily maximum temperatures be above 22°C. Considering that adult fish have been suggested to have lower lethal thresholds than juvenile fish, and that migrating salmon are coming from the cooler waters of the ocean, it may not be wise to rely too strongly on results using juvenile fish acclimated to warmer temperatures. If we use 22-23°C as a reasonable representation of the LT50 and subtract a 2°C safety factor (as discussed previously), it would produce a recommended maximum criteria of 20-21°C to prevent acute lethality. Considering all of the above mentioned factors together and recognizing the importance of preventing direct lethality, **it is recommended that to protect fish from acute lethality that daily maximum temperatures be maintained below 20-21°C.** In recognition that extremely warm temperatures can cause almost instantaneous mortality to passing fish, **it is further recommended that thermal plumes not be allowed such that fish could become entrained for more than an instant in water of greater than 30-32°C.**

3. <u>Coho Salmon</u>

Upper End of Optimal Temperature Range by Life Stage

General Limitations	**7-DAM**	**1-DAM**
Incubation	9-12	13.5-14.5
Juvenile rearing	14-17	20-21
Adult migration only	14-17	20-21

Point Limitations	**1-DM**	**Instant Mix**
Acute threshold	20-21	Insuf. Data
Acute threshold (embryos)	13.5-14.5	Insuf. Data

Notes: <u>7-DAM</u> refers to the rolling arithmetic average of seven consecutive daily maximum temperatures; <u>1-DM</u> refers to the highest daily maximum temperature outside of an authorized mixing zone; <u>Instant Mix</u> refers to any place within a river where adult or juvenile fish may become fully entrained in a warm water plume, and typically applies within the established acute exceedence area of an established mixing zone.

Species-Specific Recommendations:

The following two alternatives show what temperature criteria would be recommended if this were the only species of concern. They also may be further modified in the Section VIII, Synthesis to account for other species in the stream complex and to remove unreasonable risks from warm water diseases. Thus the recommendations below for this species may not correspond directly with the final recommendations of this paper.

- Waters used for spawning and rearing by chinook salmon should not exceed a 7-day average of the daily maximum temperatures (7-DADM) greater than 17°C, with no single daily maximum temperature greater than 21°C.

- By September 22, the typical date when most stocks begin spawning, 7-DADM should be at or below 13°C, with no single daily maximum temperature exceeding 17.5°C. By November 1, the midpoint of spawning for most stocks, the 7-DADM should be at or below 9.5°C, with no single daily maximum exceeding 17.5°C. To fully protect areas used for juvenile rearing by coho, the 7-DADM should be at or below 17°C, with no single daily maximum exceeding 21°C. Sections of rivers used only for adult migration should not exceed 17.5°C as a 7-DADM, with no single daily maximum temperature exceeding 21°C.

Summary Discussion

General Life History:

Coho salmon occur all along the Pacific coast. While fourth in abundance of the Pacific salmon, coho provide the dominant harvest of sport fisherman (Wydoski and Whitney, 1979). In Washington, spawning adults are found in most streams of the upper and lower Columbia River drainage, and in the coastal and Puget Sound drainages. Coho spend their first 1 to 2 years in freshwater before becoming smolts and migrating to the ocean. Spawning generally occurs from September through December; although, a late run of large fish spawns is known to spawn in January in the Satsop River. Like all Pacific salmon, adult coho die after spawning. Young hatch in 6-8 weeks depending on water temperature and emerge in about 2-3 weeks. Fry congregate in schools in the pools of the stream. Ruggels (1966; as cited by Chapman and Bjornn, 1969) found that coho did not use substrate as cover in the winter, and Hartman (1965) found that coho tended to lie near or on pool bottoms in aggregations.

Spawning Requirements:

Coho salmon (*Oncorhynchus kisutch*) tend to spawn later and at lower water temperatures than the other Pacific salmon. In Washington, 79 of the 82 stocks of coho salmon assessed begin spawning after September 22, and 80 of 82 have midpoints in their spawning periods that occur after November 1 (Appendix D). It is recommended that these dates be considered when establishing statewide temperature criteria that will protect coho salmon.

Spawning activity in coho may typically occur in the range of 4.4-13.3°C (Bell, 1986; Beschta et al., 1987; Piper et al., 1982; **Chambers, 1956, as cited in Andrew and Green, 1960; Gribanov, 1948, and Briggs, 1953, as cited in Sandercock, 1991**). However, **Bell (1973; as cited in Everest et al., 1985)** suggested that for successful spawning of coho temperatures should be within the range of 7.2-15.6°C.

Incubation through Early Fry Development:

Embryo survival is consistently maximized in tests at constant temperature exposures between 2.5-6.5°C, and is only slightly less successful between 1.3-10.9°C (Dong, 1981; Tang et al., 1987; Murry et al., 1988; Velsen, 1987). **Davidson and Hutchinson (1938; as cited in Sandercock, 1991)** suggested the optimum temperature for egg incubation is from 4-11°C. Mortalities tend to become moderate (74-79%) between 11-12.5°C, and between 12.5°C and 13.5°C mortalities of 50% can be expected. Above 14-14.4°C, tests commonly report at or near 100% mortality. Alevin survival may be excellent (97%) between 1.3-10.9°C (Dong, 1981; Tang et al., 1987), and the most robust fry are at incubation temperatures between 4-8°C (Dong, 1981; Murry et al., 1988). Alevin mortalities of 51-59% occur at 12.5°C (Dong, 1981), and 100% mortality occurs at 14-14.4°C (Dong, 1981; Murry et al., 1988).

From the studies discussed above we can be relatively confident that egg survival would be consistently maximized at exposure to constant temperatures between 2.5-6.5°C, but may still be excellent for many stocks at temperatures between 1.3-10.9°C. Alevin and fry survival and health may be optimized at exposure to constant temperatures between 4-8°C, but survival may remain excellent up to 10.9°C. This review of the available literature suggests that a constant 7-10°C may form the upper threshold for optimal development of coho salmon eggs and alevin. Adjusting this laboratory-based naturally fluctuating stream environments (as discussed previously) results in the recommendation that **to fully support the pre-emergent stages of coho development that the 7-day average of the daily maximum temperatures should not exceed 9-12°C**.

There is no information available that suggests coho salmon embryos and alevin would be more sensitive to short term (daily peak) increases in temperature than any other Pacific salmon. The one study reviewed that looks at short term temperature changes for coho was that by Tang et al. (1987). In that study, incubation temperatures were increased from 10.2 to 17°C and lowered from 10.2 to 4°C for eight hours. In neither test did these modest changes result in any statistically significant increase in mortality. Additionally, one field study reported coho alevins surviving very “substantial” daily peak temperatures with no clear change in later juvenile abundance (summer peak stream temperatures of 24 and 30°C were noted) (Hall and Lantz, 1969). Since no clear basis has been found for setting a daily peak temperature specific to coho incubation, it is recommended that the daily maximum value chosen for chinook (13.5-14.5°C) be used for coho salmon as well.

Juvenile Rearing:

While incubating eggs are optimally protected at very cool temperatures, juvenile coho salmon do not appear particularly sensitive to stream temperatures. Maximum temperatures between 9.4-14.4°C are generally suggested as optimal or selectively preferred by juvenile coho (Beschta et al., 1987; Piper et al., 1982); however, Bell (1986) suggested the preferred range for coho is 4.4-9.4°C. **Konnecki, Woody and Quinn (1995)** studied two groups of coho and found that the preference temperature changed with the parental stock used. Coho from parental stock originating from cold ground water supplied streams preferred 9.6°C (range 6-16°C), while those from stock originating from warmer streams preferred 11.6°C (range 7-21°C).

Maximum growth of coho fed to satiation in the laboratory occurred at 17°C (Shelbourn, 1980). Averett (1969) as cited by Everson (1973) proposed that August-September stream temperatures should fluctuate between 11-17°C (median 14°C) for optimal growth. In a controlled study by Everson (1973), test fish were subjected to different fluctuating temperature regimes. The greatest growth occurred at the lowest test regime of 12.1-20.8°C (median 16.5°C). Everson also found that juveniles fed moderate rations and subjected to higher fluctuating test temperatures did not reach sizes typical of smolts at the time of downstream migration. Holtby (1988) reviewing a long term study of coho in an experimentally harvested watershed determined that coho had likely benefited from changes in maximum stream temperature from 12°C to 15°C. Similarly, **Thedinga and Koski (1984)** found that smolt size and condition factor was greater in years in which stream temperatures fluctuating annually from 4-13.5°C than in years with temperatures of near 0-11 to12°C. They associated greater smolt return rates with this greater growth. Servizi and Martens (1991) found that susceptibility to sediment toxicity increased by 33% at 18°C), and Shelbourn (1980) determined that hypoosmoregulatory capacity is optimized at 14°C.

In a field study by Martin et al. (1984) the stream having the lowest growth was the warmest surveyed, and had average monthly temperatures of 12 to 17°C and peak monthly temperatures of 21-26 through the summer months. In trying to determine the cause for coho losses from streams on the west side of Mount St. Helens, Martin et al. (1986) found that summer mortality was correlated with both high monthly average temperatures and maximum August diel fluctuations. One creek experiencing high mortality exceeded 25°C for 10 days in one year and 30 days in the next. Bisson et al. (1988) found that growth remained positive in streams that exceeded 24.5°C, but that at about 22°C the coho seek out cool water areas. Hall and Lantz (1969) found no statistically significant change in coho abundance in a clear-cut test stream where maximum summer temperatures were increased from 16.1-16.6°C to 24-30°C, even though cutthroat trout populations experienced a decline of 75%. In a study of salmonid distributions in a coastal Oregon river drainage, **Frissell, Nawa, and Liss (1992)** found that cutthroat, coho, and chinook salmon dropped out in sequence as daily maximum temperatures increased, with rainbow trout being the only species found in waters exceeding 23°C. An abrupt loss of coho and chinook was found to occur between 21 and 23°C, and while small numbers of coho were found in the warmer waters, they always found in association with small cool pockets of otherwise warm reaches.

In tests on swimming performance, **Griffiths, and Alderdice (1972)** and **Brett, Hollands and Alderdice (1958)** found that optimum swimming performance in juvenile coho salmon occurred at a combination of acclimation and test temperatures near 20°C. Griffiths, and Alderdice reported that above 20°C swimming performance experienced a marked reduction. **Delacy, Felton and Paulik (1956) and Paulik, Delacy, and Stacy (1957**) also studied the swimming performance of coho salmon. They found that coho could recover to approximately to 31% after a one-hour rest and to 70% within three hours of exhaustive swimming effort, and recover fully overnight. They also noted that eggs taken from coho salmon repeatedly fatigued in their testing exhibited normal fertility and survival. A significant swimming performance decrement was associated with pre-test activity of the salmon, and salmon that swam longer before fatigue required more recuperation time; suggesting that the salmon are highly susceptible to fatigue.

In the field and laboratory research and recommendation reviewed here for coho salmon, average or constant temperatures of 12-15°C probably best characterize optimal rearing conditions. Considering all of these factors, and adjusting the optimal range for a naturally fluctuating stream environment (as discussed previously) results in the recommendation that **to fully protect juvenile coho salmon rearing the 7-day average of the daily maximum temperatures should remain below 14-17°C**.

Adult Migration:

While adults can migrate through waters warmer than considered optimal for juvenile rearing, the same thresholds which produce metabolic stress with juveniles is likely to produce stress in adults that can lead to lethal and sublethal effects. Beschta et al. (1987) suggested as a basis for water quality criteria that upstream migration occurs between 7.2-15.6°C. Studies with other species support the work of Thomas et al. (1986) with coho in showing that adults may actually be somewhat more temperature sensitive than juveniles. Sensitivity is enhanced in adults through the fact that they do not feed during their freshwater migration and must rely on their stored fat and muscle reserves to see them through the spawning process. The stress of higher temperatures not only influences the health of the spawner, but to some extent it also can effect the quality of unfertilized eggs carried by the hen salmon. In tests evaluating the effects of holding migrating adult coho at warm temperatures, **Bouck et al. (1970; as cited in USEPA, 1971)** found no apparent adverse effects to eggs in utero caused by prolonged exposure to 16.7°C. **Flett et al. (1996)** found that adults migrating through waters often warmer than 20°C experienced reduced quality and more rapid deterioration of eggs. For these reasons it would be prudent to maintain typical daily maximum temperatures close to the range considered optimal for juvenile coho (14-17°C) over the migration routes used by adult spawners.

Lethality to Adults and Juveniles:

In constant exposure tests, the upper lethal levels producing 50% mortality in juvenile coho was 25°C at an acclimation temperature of 20°C (DeHart,1974; Brett, 1956), but at an acclimation of 5°C Brett (1956) found the lethal level declined to 22.9°C. **McGeer, Baranyi, and Iwama (1991)** exposed stocks from six hatcheries to a 1°C/hour increase in temperature and found the point of 50% mortality ranged from 23.8-24.4°C. While all test fish survived up to 23°C none survived beyond 25.5°C. DeHart (1974) reported that a cyclic temperature regime having 6 hours a day over 25°C produced 50% mortality in 1.5 cycles. In a 20 day test with highly fluctuating daily temperatures (5-23°C) having an average of 11°C, Thomas et al. (1986) found no increase in mortality. Acclimated age 0 and age II fish did not begin dying until the diel temperature range reached 4-25°C. Thomas et al. also reported that juvenile coho were able to feed and grow in fluctuating temperatures that approached their upper lethal limits. While juvenile coho are reasonably tolerant to short-term peaks in temperature, adults may be far less tolerant. Using migrating adult fish taken during the summer from the Columbia River, **Coutant (1970, and Becker, 1973)** determined the lethal limit to be at 21-22°C.

In considering the literature, it appears constant exposure to temperatures in the range of 22-23°C poses a risk of causing direct lethality to coho salmon. Subtracting the 2°C safety factor (discussed previously) results in the recommendation that **to avoid direct lethality to adult and juvenile coho salmon daily maximum temperatures should not exceed 20-21°C.** It is reasonably clear that temperatures at the upper end of this range would not pose a significant risk of any acute mortality occurring in acclimated juvenile coho, but could be a cause mortality of some of the more sensitive adults migrants.

4. <u>Chum Salmon</u>

Upper End of Optimal Temperature Range by Life Stage

General Limitations	**7-DAM**	**1-DM**
Incubation	10.5-12	13.5-14.5
Juvenile rearing	N.A.	N/A
Smoltification	N/A	N/A
Adult migration only	Insuf. Data.	Insuf. Data

Point Limitations	**1-DM**	**Instant Mix**
Acute threshold	20-21	33-34
Acute threshold (embryos)	13.5-14.5	Insuf. Data

Notes: 7-DAM refers to the rolling arithmetic average of seven consecutive daily maximum temperatures; 1-DM refers to the highest daily maximum temperature outside of an authorized mixing zone; Instant Mix refers to any place within a river where adult or juvenile fish may become fully entrained in a warm water plume, and typically applies within the established acute exceedence area of an established mixing zone.

Species-Specific Recommendations:

The following two alternatives show what temperature criteria would be recommended if this were the only species of concern. They also may be further modified in the Section VIII, Synthesis to account for other species in the stream complex and to remove unreasonable risks from warm water diseases. Thus the recommendations below for this species may not correspond directly with the final recommendations of this paper.

- By October 8 through June 1, the 7-day average of the daily maximum temperatures (7-DADM) should be at or below 10.5°C, with no single daily maximum exceeding 17.5°C.

- By October 8, the 7-DADM should be at or below 12°C, with no single daily maximum exceeding 17.5°C.

Summary Discussion

General Life History:

Chum salmon are found in streams of the Puget Sound and coastal drainages, and up the Columbia to the Wind River (upstream from the Bonneville Dam). Spawning often occurs just at the head of tidewater. Upon emergence from the stream gravel, chum salmon fry begin to migrate to the ocean. Juveniles migrate to the ocean between March and June where they spend 6 months to 4 years. In Washington, chum salmon spawn primarily from October to December. Redds occur in medium or fine gravel in the stream riffles. Most of the high mortality from the fertilized egg to early fry state (70 to over 90%) occurs during the embryonic stage due to suffocation from silt. Eggs hatch in 2 weeks to 4.5 months depending upon the temperature. Newly hatched fry (alevins) absorb their yolk sac in 30-50 days, again depending on temperature. Fry are usually in fresh water for only a few days after emerging from the gravel. They migrate downstream at night from April through June (Wydoski and Whitney, 1979).

Spawning Requirements:

Chum salmon are reported to spawn between 1-12.8°C, with a range of 7-10.5°C being most consistently identified (Beschta et al., 1987; Bell, 1986; Beacham and Murray, 1986). In Washington, 65 of the 68 stocks of chum salmon (*Oncorhynchus keta*) assessed begin spawning after September 1, and 65 of the 68 stocks have midpoints in their spawning ranges that occur after October 8. It is recommended that these dates be considered when establishing state-wide spawning criteria.

Incubation through Early Fry Development:

Incubation survival from fertilization to emergence is variable, but can be excellent anywhere from 4-12°C (Murray and Beacham, 1986; Beacham and Murray, 1985). In the initial period of embryonic development temperatures in the range of 8-12°C produce the highest survival. However in later stages of incubation temperatures in the range of 5-8°C produce the best survival as well as the largest and heaviest alevin and fry (Beacham and Murray, 1986). Temperatures of 12°C in the later developmental stages can result in heavy losses in some stocks (Beacham and Murray, 1985; Beacham and Murray, 1986). The optimal temperature range for conversion of yolk to tissue weight was estimated to be from 6-10°C (Beacham and Murray, 1986), and optimal respiration efficiency has been estimated to range from 11-12.5°C for prolarvae and larvae (Zinichev and Zotin, 1988). Constant incubation at temperatures of 14°C and 16°C as well as at 2.5°C have been associated with embryonic mortalities of 50% (Beacham and Murray, 1990). The alevin stage of development (late), however, were shown to have very high survival rates when exposed to temperatures as low as 2°C.

Based on the literature reviewed, constant incubation temperatures from 4-12°C commonly produce excellent and incubation results; however, some researchers have noted less than optimal survival occurring at the ends of this range. It appears that constant initial incubation temperatures in the range 8-10°C would be most consistently optimal for chum salmon. Adjusting the constant exposure data to fit a fluctuating stream environment, results in the recommendation that **the 7-day average of the daily maximum temperatures not exceed 10-12°C from fertilization through fry**

emergence. Given that constant temperature exposures throughout the entire development period have commonly produced survivals in the 96-100% range, it appears safe and appropriate to select a final criterion from the upper end of this range. There is no specific basis for setting a daily peak temperature for incubating chum; therefore, the daily maximum value used with chinook salmon (13.5-14.5°C) is recommended for chum as well.

Juvenile Rearing:

Little information was found on which to base a recommendation for juvenile rearing temperature limits for chum salmon; however, this is not a major concern. Considering that juvenile chum may only spend a few days in freshwaters, the criteria established for the pre-emergent stages of development should result in cool waters remaining during the out-migration period. Thus even without a specific juvenile rearing criterion the freshwater portion of the juvenile life-stage will be fully protected. If unique situations appear to demand that a separate rearing standard be applied, it is recommended that criteria to protect other Pacific salmon smolts during sea-water adaptation be applied.

While juvenile and adult chum salmon have been observed in waters with temperatures ranging from 0-25.6°C (Bell, 1986), the literature reviewed for this paper is more definitive in suggesting that optimal rearing occurs between about 13-14.5°C. Juvenile chum salmon reportedly prefer temperatures between 11-14.6°C, and are considered to be optimally maintained at 13-13.5°C (Beschta et al., 1987; **Kepshire, 1971; as cited in Brett, 1979**). Ferguson (1958) suggests that the final temperature preferendum for chum salmon is 14.1°C.

Adult Migration:

Studies were not found that establishes a specific basis for setting adult upstream migration criteria. Beschta et al. (1987) has suggested as a basis for establishing water quality criteria that upstream migration is protected by keeping water temperatures in the range of 8.3-15.6°C. While adults can certainly withstand much higher temperatures for short periods of exposure without directly lethal effects, the potential of warm waters (above 14°C) to reduce the number of viable eggs, as shown in other fish species, should be cause for some caution. Since chum salmon spawn just above tidewater and have very short migrations in most watersheds, their time in migration and thus the potential to have sublethal effects appears at least somewhat naturally mitigated in most cases. Recommendations for protecting other mature Pacific salmon spawners ripe with eggs, should also be applied for chum salmon.

Lethality to Adults and Juveniles:

Chum acclimated to cold waters (5°C) have an upper lethal temperature of 21.8°C, which increases to 22.6 and 23.1°C at acclimation temperatures of 10 and 15°C (Brett, 1956). Beschta et al. (1987) suggested that the upper lethal temperature for chum is 25.8°C. In work by Snyder and Blam (1971), it was found that 50% mortality occurred in less than 50 minutes to a test population transferred from 15.6°C to 26.7°C. A transfer from 15.6°C to 29.4°C resulted in 50% mortality in only 60 seconds, and at 32.2°C it only required 15 seconds to cause 100% mortality. Lethal low temperatures range from 6.5°C and 4.7°C at acclimation temperatures of 20°C and 15°C, to 0.5°C at a 10°C acclimation.

Based on the studies examined, it should be assumed that constant exposure to 22-23°C can result in significant lethality to chum salmon. Subtracting a 2°C safety factor (discussed previously) results in the recommendation that to prevent direct lethality to juvenile and adult chum salmon **daily maximum temperatures should not exceed 20--21°C. Further, conditions should not exist within mixing zones that would allow full entrainment of adult or juvenile fish for more than a brief second at temperatures greater than 33-34°C**

5. <u>Pink Salmon</u>

Upper End of Optimal Temperature Range by Life Stage

<u>General Limitations</u>	**<u>7-DAM</u>**	**<u>1-DM</u>**
Incubation	10-12	13.5-14.5
Juvenile rearing	12.5-14.5.	19-20.5
Adult migration only	12.5-14.5	19-20.5

<u>Point Limitations</u>	**<u>1-DM</u>**	**<u>Instant Mix</u>**
Acute threshold	19-20.5	Insuf. Data
Acute threshold (embryos)	13.5-14.5	Insuf. Data

Notes: <u>7-DAM</u> refers to the rolling arithmetic average of seven consecutive daily maximum temperatures; <u>1-DM</u> refers to the highest daily maximum temperature outside of an authorized mixing zone; <u>Instant Mix</u> refers to any place within a river where adult or juvenile fish may become fully entrained in a warm water plume, and typically applies within the established acute exceedence area of an established mixing zone.

Species-Specific Recommendations:

The following two alternatives show what temperature criteria would be recommended if this were the only species of concern. They also may be further modified in the Section VIII, Synthesis to account for other species in the stream complex and to remove unreasonable risks from warm water diseases. Thus the recommendations below for this species may not correspond directly with the final recommendations of this paper.

- Waters used for spawning and rearing by Pink salmon should not exceed 14°C as a 7-day average of the daily maximum temperatures (7-DADM) between September 1 and May 1.

- By September 22 the 7-DADM should not exceed 12°C, with no single daily maximum temperature greater than 13.5°C. Waters used for juvenile rearing should not exceed a 7-DADM greater than 14°C, with no single daily maximum greater than 21°C. Sections of rivers used only for adult spawning migration by pink salmon should not exceed 14°C as a 7-DADM, with no single daily maximum temperature greater than 21°C.

Summary Discussion

General Life History:

Pink salmon are the most abundant of the Pacific Salmon. Pink salmon ascend rivers along the Pacific coast; and in Washington, the Stillaguamish, Skagit, Snohomish, Puyallup, and Nooksack are the top producing watersheds. Pink salmon are similar to chum salmon in spending only a brief time in fresh water as juveniles and adults. Spawning in Washington occurs chiefly during August and September, usually near the mouths of streams, but sometimes spawning occurs far up into large rivers, such as the Skagit. Females usually dig redds in a riffle area with small to medium size gravel, but they occasionally spawn in the tail section of pools. In Alaska, a large percentage of pink salmon spawn in the intertidal areas. Eggs usually hatch in 3-5 months, depending upon water temperature. The alevins and fry remain in the gravel for as long as several months at low temperatures in northern waters before emerging (Wydoski and Whitney, 1979). Washington state appears to be at the southern end of the range for streams that support consistently exploitable spawning runs of pink salmon. Pink salmon have a 2 year life cycle which is so invariable that fish running in odd-numbered calendar years are effectively genetically isolated from those that run in even years (Bonar et al., 1989).

Spawning Requirements:

In Washington, 10 of the 12 pink salmon (*Oncorhynchus gorbuscha*) stocks assessed begin spawning after September 1, and 10 of 12 have midpoints in their spawning periods which occur after September 22. It is recommended that these dates be considered when establishing statewide temperature criteria that will protect pink salmon.

Spawning typically occurs between 7.2-14°C (Bonar et al., 1989), and may be optimally supported at temperatures from 7-12.8°C (Sheridan, 1962; Bell, 1986; Beschta et al., 1987). This potential optimum range coincides well with an identified peak in spawning activity at 10°C identified by Sheridan (1962).

Incubation through Early Fry Emergence:

The range for successful incubation has been suggested to be from 4.4°C to 13.3°C (Beschta et al., 1987; Bonar et al., 1989). Murray and Beacham (1986) reported excellent survival (91-97%) with initial fertilization occurring at 14°C and a 0.5°C drop in temperature every three days down to 5°C. When they allowed temperatures to drop further to 4 and 2°C survival was reduced. Murray and McPhail found survival of 94% from fertilization to emergence at 5°C, and Beacham and Murray (1986) found the greatest survival for 5 stocks and 21 families of pink salmon tested at 8°C. Velsen (1987) compiled data that showed the best, though highly variable, survival (generally >89.5%) occurred between 8-13°C. Survival decreased at an incubation temperature of 11°C in a test by Murray and McPhail (1988), and was 50% at 15-15.5°C (Beacham and Murray, 1990). Temperatures of 5-8°C produced the largest alevins in a study by Murray and McPhail (1988), and 8°C produced the longest (Beacham and Murray, 1986) and fry heaviest (Murray and McPhail, 1988).

Survival of the alevin life-stage was found to be generally excellent (>97%) for 21 families of pink salmon tested at temperatures ranging from 4-12°C (Beacham and Murray, 1986). Survival to emergence was reported as low at 14°C (Murray and McPhail, 1988).

Examining low incubation temperatures, Beacham and Murray (1986) found that temperatures of 4°C consistently resulted in the lowest survival for 5 stocks and 21 families of pink salmon, and in a 1990 study found 50% mortality at 5°C. Murray and McPhail (1988) and Beacham and Murray (1990) and **Bailey and Evans (1971)** found 100% mortality at incubation temperatures of 2°C. Murray and Beacham (1986) transferred embryos in a late stage of development from 8°C to 1°C and found that while northern stocks had 100% survival, southern stocks experienced moralities ranging from 38-60%.

Based on the research cited above, constant temperatures in the range of 4.5-12°C, and a constantly declining temperature regime beginning at 14°C are capable of producing excellent and perhaps optimal survival rates of incubating pink salmon. However, a constant temperature of 8°C appears to produce the most consistently optimal results; and while tests up to 12-13.3°C were found to produce optimal results, several tests found temperatures of 11-12 (as well as ones conducted at 4.5-5°C) to produce less survival and smaller fry. Further, in natural streams the temperatures will not dependably decline at a steady rate, and temperatures of 15-16°C have resulted in high mortality. In consideration of all of these issues it should be assumed that constant temperatures in the range of 8-10°C represent optimal conditions for embryonic development. Adjusting this range to apply to a naturally fluctuating stream environment (as discussed previously) results in the recommendation that **to fully protect the embryonic development of pink salmon the 7-day average of the daily maximum temperatures should not exceed 10-12°C**. No specific information was reviewed that examined the effect of short-term and infrequent peaks of temperature on developing pink salmon. It recommended, therefore, that the daily peak temperature criteria limit recommended for chinook salmon incubation (13.5-14.5°C) also be applied to pink salmon.

Juvenile Rearing and Smoltification:

Pink salmon are noted as being found in temperatures ranging from 0-25.6°C (Bell, 1986), while Sheridan (1962) has stated that the range in Alaskan waters as extends from 7.2-18.3°C. Bell (1986) and Bonar et al. (1989) suggest pink salmon prefer waters in the range of about 5.6-14.5°C, while Ferguson sets the final perferendum at 11.7°C and Brett (1952) determined pink salmon acclimated to temperatures below 15°C select temperatures in the range of 12-14°C. Bonar et al. (1989) considered 10.1°C to be the optimal temperature for adults, and Beacham and Murray (1987) found that 10°C resulted in higher growth and survival (96%) of fry. Welch et al. (1995) determined that the upper thermal boundary for the offshore marine occurrence of pink salmon was 10.4°C. In the work of Beacham and Murray (1987), fry survival rates were 62% at 13°C, and 73% at 16°C.

Pink salmon fry migrate to the sea soon after emergence in April or May. This practice allows the fry to avoid the high summer temperatures which are a typical concern for most of the other Pacific salmon. Since they most commonly spawn near tidewaters, their migration journeys in freshwater are commonly short, helping to reduce the time they may need to travel through warmer mainstem rivers. Temperatures maintained to protect incubation will generally result in full protection of outgoing fry since these fry will travel predominately short distances and at night (Bonar et al., 1989; Wydoski and Whitney, 1979). However, in situations where juveniles hatch farther distances upstream, consideration of a separate standard to protect out-migration in the lower reaches of major rivers may be appropriate. Beacham and Murray (1987) found that both fry survival and growth rates were optimized at 10°C as compared with either 13 or 16°C. Beschta et al (1987) used the work of Reiser and Bjornn (1979) to suggest that preferred rearing occurs between 5.6-14.6°C with and optimum at 10°C. Pink salmon have been generally shown to prefer temperatures in the range of 11.7-14°C in studies by Brett (1951; as cited in Ferguson, 1958) and Brett (1952). Based on the above works, it appears that constant temperatures in the range of 10-12°C are optimal and most commonly preferred by juvenile, as well as generally by adult pink salmon. Adjusting this constant temperature range for a fluctuating stream environment results in the recommendation that **to protect juvenile rearing the 7-day average of the daily maximum temperatures should not exceed 12-14°C**.

Adult Migration:

Unlike most Pacific Salmon, the pink salmon that occur in Washington exhibit relatively short migrations and concerns over disease and over depleting energy reserves is less than with the other salmon. However, migrating adults will pass through the lower reaches of major rivers near the period of maximum seasonal temperatures and disease is still a concern that should be considered in setting any final temperature recommendations (discussed and incorporated separately). **It is recommended that the criteria range determined optimal for juveniles (12-14°C) be applied to protect the migrating adult pink salmon**.

Lethality to Adults and Juveniles:

The lethal temperature limit for pink salmon was suggested to be 25.8°C by Beschta et al. (1987); however, in the studies conducted by Brett (1952) pink salmon could not be acclimated to 24°C and were unable to survive for one week at 25°C. Brett (1952) found that at acclimations of 5°C the LT50 occurred within one hour of exposures to 22.5°C and 23°C. With acclimation to 10°C the LT50 occurred at 22.5°C, and at an acclimation of 20°C, it occurred at 23.9. Based on the works cited above, it should be assumed that constant temperatures as low as 21-22.5°C are capable of producing acutely lethal conditions for pink salmon. Applying a 2°C safety factor (discussed previously) to translate it to a level at which no mortality should occur, results in the recommendation **that to prevent acute lethality in adult and juvenile pink salmon, daily maximum temperatures should not exceed 19-20.5°C.**

6. Sockeye Salmon

Upper End of Optimal Temperature Range by Life Stage

General Limitations	7-DAM	1-DM
Incubation	10.5-12	13.5-14.5
Juvenile rearing	12-16	20-21
Adult migration only	13-14.5	20-21

Point Limitations	1-DM	Instant Mix
Acute threshold	20-21	Insuf. Data
Acute threshold (embryos)	13.5-14.5	Insuf. Data

Notes: 7-DAM refers to the rolling arithmetic average of seven consecutive daily maximum temperatures; 1-DM refers to the highest daily maximum temperature outside of an authorized mixing zone; Instant Mix refers to any place within a river where adult or juvenile fish may become fully entrained in a warm water plume, and typically applies within the established acute exceedence area of an established mixing zone.

Species-Specific Recommendations:

The following two alternatives show what temperature criteria would be recommended if this were the only species of concern. They also may be further modified in the Section VIII, Synthesis to account for other species in the stream complex and to remove unreasonable risks from warm water diseases. Thus the recommendations below for this species may not correspond directly with the final recommendations of this paper.

- In waters used for spawning and rearing by sockeye salmon the 7-day average of the daily maximum temperatures (7-DADM) should not exceed 15.5°C, with no single daily maximum greater than 21°C.

- To fully protect the spawning and embryonic development of sockeye salmon, waters used for spawning should not exceed 12.5°C as a 7-DADM after September 7, with no single daily maximum temperature greater than 17.5°C. In waters used for juvenile rearing, the 7-DADM should not exceed 15.5°C, with no single daily maximum value above 21°C. In waters used by sockeye salmon only for spawning migration corridors, the 7-DADM should not exceed 14.5°, with no single daily maximum value above 21°C.

Summary Discussion

General Life History:

In Washington, populations of sockeye travel up the Columbia River to the headwaters of the Salmon River in Central Idaho. Populations also use Quinalt Lake on the Olympic Peninsula, Baker Lake, lakes Washington and Sammamish in the Puget Sound drainage, and Osoyoos Lake and Lake Wenatchee east of the Cascade Mountains. Kokanee, the land-locked version of sockeye, were introduced into the lakes of Washington, with some of the larger populations found in Banks Lake on the Columbia and Loon Lake in eastern Washington. Sockeye differ from the other species of salmon because they require a lake environment for part of their life cycle. Although spawning typically occurs in the gravel of streams some may spawn along lake shores in areas where ground water percolates through the gravel. Eggs hatch in 6-9 weeks. The young remain in the gravel for another 2-3 weeks. Newly emerged fry move from the spawning stream into the lake associated with the stream. Young sockeye live in the pelagic zone of the lake for 1-2 years before migrating to sea where they will remain for two years before returning to freshwaters to spawn (Wydoski and Whitney, 1979).

Spawning Requirements:

In Washington, 8 of the 8 stocks of sockeye salmon (*Oncorhynchus nerka*) assessed begin spawning after September 7, and 8 of 8 have midpoints in their spawning ranges that occur after October 3. These dates should be considered in establishing temperature criteria requirements for sockeye.

Temperatures to support spawning activity in sockeye salmon have been identified as ranging from 7.2-12.2°C (Piper et al, 1982), with a preferred range between 10.6-12.2°C (Bell, 1986; Beschta et al., 1987). **Chambers (1956; as cited in Andrew and Geen, 1960)** reported that sockeye spawn on the falling portion of the cycle at 12.8 to 8.3°C. **Andrew and Geen (1960)** reported that spawning temperature of sockeye in the Fraser River range from 12.8 to 7.2°C with a peak at about 10°C. The authors noted that average daily temperatures in excess of 12.8°C during the spawning period appear to increase the numbers of females that die unspawned. In one year when the average daily water temperatures at the peak of spawning ranged from 12.8-15.6°C, spawning success was only 45%.

Incubation through Early Fry Development:

Murray and McPhail (1988) and Combs (1965) report that sockeye salmon are more tolerant of low incubation temperatures and less tolerant of high incubation temperatures than the other Pacific Salmon. At constant exposure, Combs (1965) reported that temperatures within the range of 4.4-12.7°C produced similarly high survival rates (85.8-90.9%), with the highest occurring at 5.8°C. Combs found incremental increases in mortality of 53-67% occurred when the temperature was lowered from 5.8 to 4.4°C or raised from 12.7 to 14.2°C. Velsen (1987) found that while survival rates were highly inconsistent between 1.1-15°C, that the best survival generally occurred between 3.1-5.8 (generally >90%), with fair survival (>70%) occurring in the range of 2.1-12.7°C, and survival rates consistently poor (17-76%) above 14°C. Murray and McPhail (1988) found that survival was highest at 8°C (79%) but only 40% at both 11 and 5°C. **Andrew and Geen (1960)** reported that in the first two years or a four year field study, the Salmon Commission found that eggs initially incubated at temperatures of 7.2°C had lower survival than those initially incubated at 10, 12.8, and 15.6°C. In a follow-up experiment the following two years, they found that eggs exposed to temperatures of 15.6 to 16.7°C for short periods of time suffered severe losses during the period of exposure, and that temperatures of 16.7-18.3°C caused extensive losses both during and following exposure. In a study by Craig et al. (1996) the temperature range of 8-10°C resulted in the optimum 1:1 male to female sex ratio in offspring, though the study design really only allows the conclusion that temperature in the early stage of development affects sex determination.

The data on sockeye incubation survival is highly variable. Overall, however, it can be said that constant temperatures in the range of 4-12.5°C produce variable but oftentimes excellent survival rates in sockeye salmon; but that the range 8-10°C appears most consistently optimum. In consideration of the above factors, and after making some adjustments to account for naturally fluctuating stream conditions (as discussed previously), it is recommended that **to fully protect sockeye salmon from fertilization through fry emergence the 7-day average of the daily maximum temperatures should not exceed 10.5-12°C**. No specific studies have been found to suggest a basis for a single daily maximum temperature limit during the incubation period; therefore, it is recommended that the value recommended for chinook (13.5-14.5°C) also be applied to sockeye salmon.

Juvenile Rearing:

Attaining good growth rates is very important to the survival of young sockeye salmon. In a study by Burrows (1963) it was found that doubling the weight of fingerlings released from a hatchery resulted in a tripling of the adult return rate. While sockeye salmon are noted to occur within the range of 0.6-21°C (Piper et al., 1982), the range of temperatures under which they perform optimally may be more restricted. The optimal temperature for juvenile rearing was identified 10-15°C by Piper et al. (1982), 10.6-12.2°C by Bell (1986), and 11.2-14.6°C by Beschta et al. (1987). Temperatures in the range of 4-7°C have been associated with poor growth (Brett, 1956). Ferguson (1958) used earlier work by Brett (1951) to determine that the final preferendum for sockeye was 14.5°C.

In a 1952 study, Brett found that juvenile sockeye avoided temperatures above 15°C and selected 12-14°C when provided an opportunity. Brett (1967; and **Brett et al. 1969, as cited in Brett 1979**) found that sockeye fed an unrestricted ration had optimal growth at 15°C. However, a temperature of 10°C was found to result in the highest growth and most efficient use of food by Brett (1956), and was also determined to create 33% less demand for food energy compared to 15°C (Brett and Glass, 1973). **Clarke (1978)** found that under-yearling sockeye salmon exposed to diel thermocycles are able to acclimate their growth to a temperature above the mean of the cycle. Specific growth in weight on the 7-13°C cycle was equivalent to that on a constant 11.4°C, and on the 5-15°C cycle it was equivalent to a constant 13.9°C. Clarke found that growth was greater at a 5-15°C cycle than at a 7.5-17.5°C cycle. In constant exposure testing on maximum rations, growth was linear over the range of 7.5-17.5°C. **Brett and Groves (1979)** note that at temperatures below 10°C food conversion efficiency rises most rapidly from the base level (maintenance ration) and reaches peak efficiency at an intermediate ration. This relation changes progressively with rising temperature such that at 17°C and above the highest efficiency occurs on a maximum ration diet. They note that for sockeye salmon, over the complete range of tolerable temperatures maximum food conversion efficiency occurs at 11°C. **Donaldson and Foster (1941; as cited in Brett, Hollands, and Alderdice, 1958)** discovered that growth in young sockeye tends to be poor to none-at-all at temperatures above 21°C and below 4°C. Brett (1956) noted that sockeye juveniles may cease feeding entirely when temperatures reach 21°C.

In tests on physiological performance, juveniles sockeye reach their maximum swimming speed at 15°C (Brett and Glass, 1973; **Brett, Hollands, and Alderdice, 1958**). **Brett, Hollands, and Alderdice, 1958** noted that the capacity of young sockeye to stem a normal river current of 1.0 ft/sec. for more than an hour is limited to a relatively small temperature range of 12.5-17.5°C. **Brett (1983)** in discussing the energetic needs of sockeye suggested that the protected environment of a growth-metabolism tank or hatchery pond may not correspond well with the search-attack-avoid-escape patterns of real life. An attack or escape episode involving 20 second burst speed was shown, in terms of energy expended, to be equal to that of 15 minutes of active metabolism (maximum sustained swimming speed) or about 3 hours of basal metabolism (cites Brett and Groves, 1979). Brett suggests the additional energy requirements of real life cannot be disregarded; nor can it be conceived as incessantly present.

Based on the research reviewed above, constant temperatures in the range of 10-14°C appear optimal for the rearing conditions for juvenile sockeye salmon. Although growth may be optimized at constant temperatures from 15-17.5°C on maximum diets, under natural conditions, where food may be more limiting, temperatures within this higher range may reduce potential growth and the overall carrying capacity of the rearing stream **(Kalleberg, 1958; as cited in Burrows, 1963)**. Adjusting the constant temperature range (10-14°C) for a naturally fluctuating stream environment (as discussed previously) results in the recommendation that **to optimally support juvenile sockeye salmon rearing,**

temperatures should not exceed a 7-day average of the daily maximum temperatures greater than 12-16°C.

Adult Migration:

Migration exerts a tremendous strain on salmon. **Idler and Clemens (1959)** found that female sockeye salmon in the Fraser River may use between 91.4-96% of their body fat reserves, and 53-61% of their protein reserves from the time of entrance to completion of spawning. As noted by Brett (1983), migration and egg production uses up most of the energy stored from ocean feeding and leaves "all too slim a safe margin of energy reserves".

Linley (1993; as cited in Quinn, Hodgson, and Peven, 1997) reportedly found that populations with arduous migrations show lower levels of reproductive output (ovary weight) than populations with shorter migrations. At a constant 16.2°C, depletion of fat reserves and reproductive organ abnormalities were noted by Bouk (1977), and Gilhousen (1990) found that high prespawning mortalities were associated with adult salmon migrating through waters having daily maximum temperatures between 17.5-19°C. Temperatures above 15.5°C (as an apparent daily average value) were also noted by Gilhousen (1990) as being linked to higher prespawning mortality from columnaris disease in adult Fraser River sockeye salmon.

Paulik (1960) found that sockeye subjected to daily swimming tests did not live as long as control fish, and postulated that as migrating salmon move upstream their swimming capacity declines such that performance is progressively reduced. **DeLacy, Felton, and Paulik (1956)** found, however, using eggs from coho salmon and steelhead trout that the viability of sex products did not seem to be affected by repeated exhaustive testing.

Welch et al. (1995) found that the upper thermal limit to the off-shore occurrence of sockeye salmon was 8.9°C, and 8.9°C was found to be the maximum holding temperature in lakes by migrating adults (Wydoski and Whitney, 1979).

Quinn and Adams, 1996; as cited in Quinn, Hodgson, and Peven, 1997) note that in the Columbia River, based on passage data at Ice Harbor Dam, migration usually ceases at temperatures above 21°C. **Fish and Hanava, (1948; as cited by USEPA, 1971)** found that during an extremely warm year (1941) sockeye were observed congregating in small previously unused cold tributary creeks when the temperature in the Columbia rose to 21.7-23.9°C. **Major and Mighell (1966)** noted that entry of sockeye from the Columbia River into the Okanogan River, was blocked when rising or stable daily average temperatures were above 21.1°C, but that migration would resume if temperatures were falling. Hatch et al. (1992) found that when water temperatures reached daily average temperatures of 22.8°C, all migration of sockeye salmon ceased, that the bulk of the migration occurred below 22.2°C, and that surges of migration occurred when temperatures fell to below 21.1°C. Based on the research reviewed above, **7-day average daily maximum temperatures below 13-14.5°C would be optimal for migrating adult sockeye salmon.** This temperature range is generally associated with an absence of prespawning mortality and will avoid high losses of stored energy reserves. Further, daily maximum temperatures above 22-23°C should be considered to have a high potential of causing blockages to migrating fish.

Lethality to Adults and Juveniles:

Brett (1952) determined the lower acutely lethal temperatures for juvenile sockeye salmon. He found that at acclimations of 15 and 20°C the temperatures that produced 50% mortality of a one week test were 4.1 and 4.7°C, and that fish acclimated to 10°C had a lower lethal level of 3.1°C. Bouck and Chapman (1975) found that adult sockeye could not survive long periods at 20°C or 22°C, and determined that the LT50 for these temperatures occurred at 11.7 days and 3.2 days, respectively. At the lower acclimation temperatures of 5 and 10°C Brett found that juvenile sockeye had lethal levels of 22.2°C and 23.4°C in a week-long test. At acclimations between 15-23°C, the LT50s for juvenile sockeye were variable within the range of 24-24.8°C (Brett, 1952; Bescta et al., 1987; Servizi and Jensen, 1977). In consideration of this information should be assumed that constant exposure to temperatures of 22-23°C pose a risk of direct lethality to sockeye salmon. Applying a 2°C safety factor (as discussed previously) results in the recommendation that **to prevent direct mortality to adult and juvenile sockeye salmon, single daily maximum temperatures should not exceed 20-21°C**.

7. Steelhead Trout

Upper End of Optimal Temperature Range by Life Stage

General Limitations	7-DAM	1-DM
Incubation	13-14	13.5-14.5
Juvenile rearing	16.5-17.5	21-23
Smoltification	13.3-14.3	21-23
Adult migration only	16-17	21-23

Point Limitations	1-DM	Instant Mix
Acute threshold	13.5-14.5	Insuf. Data
Acute threshold (embryos)	Insuf. Data	Insuf. Data

Notes: 7-DAM refers to the rolling arithmetic average of seven consecutive daily maximum temperatures; 1-DM refers to the highest daily maximum temperature outside of an authorized mixing zone; Instant Mix refers to any place within a river where adult or juvenile fish may become fully entrained in a warm water plume, and typically applies within the established acute exceedence area of an established mixing zone.

Species-Specific Recommendations:

The following two alternatives show what temperature criteria would be recommended if this were the only species of concern. They also may be further modified in the Section VIII, Synthesis to account for other species in the stream complex and to remove unreasonable risks from warm water diseases. Thus the recommendations below for this species may not correspond directly with the final recommendations of this paper.

- Waters used for spawning or rearing shall be maintained below a 7-day average daily maximum temperatures (7-DADM) of 16.5°C, with no single daily maximum temperature greater than 21°C. Waters used only for the in-migration of adult spawners and the out-migration of juvenile steelhead the 7-DADM should not exceed 16°C, with no single daily maximum greater than 21°C.

- Waters used for spawning shall be maintained below a 7-DADM of 16.5°C from June 15-September 30, with no single daily maximum temperature greater than 21°C. From October 1-June 14, the 7-DADM shall not exceed 13.5°C as a 7-DADM, with no single daily maximum temperature greater than 14.5°C. All other waters used for either rearing or juvenile and adult migration shall not exceed 17°C as a 7-DADM from June 15-September 30, with no single daily maximum of 21°C. At all other times these waters shall be maintained below 14.5°C as a 7-DADM, with no single daily maximum temperature greater than 21°C.

Summary Discussion

General Life History:

Steelhead is the popular name given to the anadromous form of *O. mykiss*. The anadromous form is found in coastal rainbow and interior redband trout groups and occurs from southern California to Alaska (Behnke, 1992). Steelhead populations can be broadly divided into spring-, summer-, fall- and winter-run stocks, depending upon the time the fish re-enters freshwater. Spring and summer-run fish enter fresh waters typically from May through August and move upstream to hold over until the following spring to spawn. Fall runs typically enter from September through November and spawn in the spring. Winter-run (December-March) steelhead may spawn soon after entering fresh waters. In general, summer-run steelhead spawn further upstream in the watershed than the fall- or winter-run fish. With a spring spawning stock, protection is achieved by not encouraging spring water temperatures to warm above optimal levels during the spawning and incubation periods.

Spawning Requirements:

In Washington, 101 of the 105 spring spawning steelhead stocks assessed begin spawning before July 1 (91 of the 105 begin prior to June 15), and 101 of 105 have midpoints in their spawning periods that occur before May 7. Thus May 7 is recommended for representing the peak spawning period. One challenge in setting criteria to protect spring spawning species such as *O. mykiss* is that the time of spawning may be more directly tied to the specific temperature regime of the waterbody than it is to a calendar date. Late spring and early summer spawners are waiting until very cold headwater streams warm sufficient enough to support spawning. There may also somewhat less urgency in the spawning and incubation of *O. mykiss*, compared with the Pacific salmon, since they are not faced with impending winter temperatures that are unhealthy for their developing embryos and may continue to feed up until the point where spawning occurs. Setting a statewide criteria to protect the spawning of *O. mykiss* based on the characteristics of a minority of stocks that are actually being constrained by cold water temperatures may add an unnecessary level of stringency. It is recommended, therefore, that any proposal to set a default statewide criteria for spring spawning species such as steelhead be based more on the midpoint of the spawning period rather than on the latest spawning dates observed. **For establishing criteria to protect the incubation success of *O. mykiss*, it is recommended that a temperature in the middle of the optimal range be applied prior to May 7, the period of peak spawning activity, and that a temperature that represents the upper end of the optimal incubation range be applied five to six weeks later (approximately June 15) to provide time for most fry to emerge under optimal conditions.**

One fall spawning steelhead stock was assessed, and that stock began spawning as early as August 15 and had a midpoint within the spawning period of September 15. With only one stock assessed, and that one stock spawning in the early fall when temperatures will be falling from their summer highs, the issue of providing specific protection for fall spawning steelhead is not considered important to establishing the final criteria recommendations.

Spawning occurs primarily in the spring as water temperatures are rising. Bell (1986) noted that spawning has been observed at temperatures ranging from 3.9-21.1°C. **Hunter (1973; as cited in Swift, 1976)** noted the preferred temperatures for spawning to range from 4.4-12.8°C. Beschta et al. (1987; using the work of Reiser and Bjornn, 1979, and **Bell, 1973, as cited by Everest et al., 1985**) after reviewing the literature suggested that 3.9-9.4°C should form the basis for spawning standards. Warmer temperatures have been associated with reduced fecundity in Pacific salmon, and constant temperatures of 12.2-13.3°C have been shown to be detrimental to the eggs of in non-anadromous forms of *O. mykiss* (Piper et al., 1982; Smith et al., 1983). Thus the temperatures of the water holding steelhead ripe with eggs also can affect the subsequent survival of their offspring. However, since steelhead are spring spawners, to maintain optimal temperatures throughout embryonic development will require that temperatures experienced by spawners be substantially lower during spawning than would cause invivo effects to unfertilized eggs.

Incubation through Early Fry Development:

In establishing a state standard to protect spawning, it is important to consider temperature recommendations established to protect embryonic development. Fuss (1998) considered the range 5.6-11.1°C as being optimal for steelhead egg survival in the Washington State hatchery program, and Bell (1986) suggests that 10°C is the preferred hatching temperature for steelhead eggs. **Rombough (1988)** found less than 4% embryonic mortality at 6, 9, and 12°C, but noted an increase to 15% mortality at 15°C. Alevin mortality was less than 5% at all temperatures tested, but alevins hatching at 15°C were considerably smaller and appeared less well developed than those incubated at the lower test temperatures. Redding and **Schreck (1979)** similarly found that emergent fry were larger at 12°C than at 16°C.

Based on the works reviewed above, it appears that an optimal constant incubation temperature occurs below 11-12°C. Adjusting the constant laboratory condition for a natural fluctuating river environment (as discussed previously) results in the recommendation that **average daily maximum temperatures from fertilization through hatching should remain below 13-14°C.**

No specific research results were found that could be used to suggest a single daily maximum temperature limit for waters containing incubating steelhead. **It is recommended, therefore, that the single daily maximum temperature limit of 13.5-**

14.5°C recommended for chinook salmon also be applied to protect incubating steelhead.

Juvenile Growth:

After steelhead fry emerge from the gravels they move to the slow moving waters of the stream margins, shifting to faster and deeper waters as they grow larger (Chapman and Bjornn, 1969). Martin et al. (1991) and Wydoski and Whitney (1979) note the importance of cover to juvenile steelhead. Large woody debris, substrate, and turbulence are all identified as important habitat for young juveniles. Temperature is believed to affect the habitat selection and migration of juveniles. Mullan et al. (1992) found that fry emigrate from cold headwater streams to down-stream reaches to rear in warmer waters. Chapman and Bjornn (1969) found that young steelhead may move downstream in the fall to over-winter in larger streams. Chapman and Bjornn (1969) found that 5-5.5°C marked the boundary between activity and inactivity in steelhead, with fish entering the substrate. They found that steelhead emigration could be stopped by warming the water from 7.2°C to 11-12.2°C. Mullan et al. (1992) suggest that while steelhead juveniles may reside in the dark frozen snow covered tributaries near 0°C for up to 5 months, 6°C may form the boundary that allows winter growth to occur.

Juvenile steelhead may remain in freshwaters for 1-7 years before emigrating to sea, depending upon the stream temperature and the latitude, although, most stay in fresh water for 2 years (Wydoski and Whitney, 1979; Mullan et al., 1992). Mullan et al. (1992) note that summer-run stocks tend to remain longer in freshwater than winter run steelhead, presumably because the colder temperatures of the headwaters streams preferred by summer-run steelhead retards their growth rate.

Grabowski (1973) tested three constant temperatures (8, 15, and 18°C) and one fluctuating (8-18°C) over eight weeks with juvenile steelhead on maximum rations. The author found that steelhead grew best at the constant 15°C and second best in the fluctuating with its mean of 13°C. When the author plotted the data using the midpoint of the fluctuating test as a surrogate for a constant test condition, it showed almost linear growth from 8 to 15°C with a steep drop as the temperature approached 18°C. The percentage weight gains at 8 and 18°C were very similar and both substantially lower than the similar gains obtained at 13(mean) and 15°C. **Olson and Tempelton (undated manuscript; as cited in USEPA)** reportedly found that the most favorable range for growth was between 5-17°C, with a physiological optimum in the vicinity of 15°C. The amount of food necessary to maintain the fishes' weight increased rapidly as temperatures rose above 12°C with no growth occurring at approximately 23°C despite the presence of excess food. It was suggested that the most efficient growth, within the consumption ranges believed to occur in nature, is at the temperature of 5-14°C in the early spring, 11-14°C in early summer, 14-17°C in late summer, 11-17°C in fall, and 5-8°C in winter.

Hahn (1977) compared the preference decisions of fry and yearling steelhead exposed to three constant (8.5°C, 13.5°C, and 18.5°C) and one fluctuating (8-19°C) temperature regime. Hahn found that as many fish remained in the fluctuating regime (which has a mean of 13.5°C) as in the constant 13.5°C regime; twice as many fish remained in the fluctuating regime compared with the constant 18.5°C; and twice as many remained in the constant 8.5°C as in the fluctuating regime. By inference, Hahn concluded that twice as many fish preferred a constant 13.5°C to a constant 18.5°C, and twice as many preferred a constant 8.5°C to a constant 13.5°C. Hahn's work suggests that juvenile steelhead may have a preference for water temperatures between 8.5-13.5°C. It also suggests that the daily average temperature may roughly equal a constant exposure test scenario for the purpose of translating laboratory tests into water quality criteria. The work of Hahn also generally supports the recommendations of Beschta et al. (1987) and Bell (1986) based on their review of the literature that temperatures should generally be maintained in the range of 7.3-14.5°C for optimal rearing of juvenile steelhead.

The general consensus of the literature reviewed is that constant temperatures in the range of 14-15°C appear to provide for optimal growth of juvenile steelhead. Adjusting these results for natural fluctuating stream environments (discussed previously) results in the recommendation that **to optimally protect juvenile rearing of steelhead trout the 7-day average of the daily maximum temperatures should not exceed 16-17°C.** The upper end of this range remains below the high end of the ranges used by **Grabowski (1973)** and Hahn (1977) which were cooler regimes than what produced the maximum growth, and is slightly higher than the range recommended by **Olson and Tempelton** based on their attempt to modify constant test results at maximum feed to natural stream environments.

Juvenile competition, particularly with warm water and non-salmonid species, is a concern that is sometimes expressed in association with warm summer rearing temperatures. Reeves et al. (1987) found that steelhead production was decreased by 54% in the presence of redside shiner in waters in the range of 19-22°C, but was not reduced in cooler waters (12-15°C). They also noted that production of steelhead in a fluctuating 19-22°C waterway was less than half of that in a fluctuating 12-15°C waterway. While warmer waters favor redside shiner over steelhead, colder waters may favor other species. It has been suggested, for example, that in cooler waters brook trout can out-compete juvenile steelhead. In trying to explain the patterns of species distributions observed in the upper Columbia river tributaries, Mullan et al. (1992; using the work of Cherry et al., 1975) note that sympatry occurs between *O. mykiss* and brook trout in the range of 15-18°C, that temperatures above 18°C favors *O. mykiss*, and that temperatures less than 15°C favors brook trout. They also note, however, that under natural food rations, the level of optimal competition is likely to be lower.

The works of Reeves (1987) and Mullan et al. (1992) provide no basis for suggesting that the recommended rearing criteria of 16.5-17.5°C should be restricted further. In fact their works help substantiate that this temperature range is generally very favorable to steelhead. Disease and outgoing smoltification concerns (discussed and incorporated elsewhere) may, however, warrant restricting temperatures below that recommended here for rearing based primarily on feeding and competitive performance work.

Smoltification:

In Washington, migratory smolts usually move to sea during April through June, with a peak about mid April (Wydoski and Whitney, 1979). Wedemeyer and Goodyear (1984) used the work of Zaugg and McLain (1976), Zaugg and Wagner (1973), and Clarke et al. (1981) to conclude that water temperature alterations can adversely affect the ability of steelhead smolts to make the physiological adaptations necessary to survive in marine waters. They noted that the physiological effects may express themselves as delayed or accelerated smolt development or parr reversion, depending upon whether the temperature regime was too warm or too cold. The effect on the smoltification process was considered more severe for steelhead than for other anadromous salmonids, and the upper limit for normal ATPase development was cited to be 13°C, below the temperature (>15°C) considered to produce accelerated growth in fish hatcheries.

Temperatures of 11.3-12.3 are consistently cited as uppermost constant temperature exposures that will not interfere with smoltification (Zaugg et al.,1972; Zaugg and Wagner, 1973; Zaugg,1981; Adams, Zaugg, and McLain, 1975) in steelhead trout. Detrimental effects were noted by these authors in tests with steelhead at constant temperatures at 12.7, 13.6, 14, 15 and 15.8°C. Temperatures warmer than 12-13°C may encourage parr to remain for an additional year in freshwaters prior to attempting to migrate to the sea, or to hold for longer periods in the estuaries while completing their parr-smolt transformation. There is some concern that spring flow-induced out-migrations of parr that are not fully transformed for life in marine water may result in increased predation and direct mortality in the estuarine environment.

It is important to note that the above referenced research on saltwater adaptation were conducted using constant exposure tests, and no defined periods of exposure necessary to induce a detrimental effect were determined. Adjusting the constant temperature test range to apply to a fluctuating stream environment (as discussed previously) results in the recommendation that **the 7-day average of the daily maximum water temperatures experienced by outgoing steelhead smolts should not exceed 13.3-14.3°C**.

In considering the literature recommendations and research results on juvenile rearing, competition, and smoltification **it is specifically recommended that the water temperatures be maintained below 14.3°C prior to July 1, and maintained below 16°C for the remainder of the summer**. Applying this temperature regime should ensure juveniles are exposed to an optimal range for overall health and growth over the bulk of the growing season. This regime applied state-wide will well accommodate the naturally broad periods of out-migration observed for steelhead smolts. As discussed below, juveniles should be able to withstand peak temperatures as high as 21-22°C for several consecutive days, as long as the typical daily maximum temperature remains in the optimal range.

Adult Migration:

Most fish returning to Washington's streams are believed to have been at sea for 2 years. Fish that have been at sea for three years make up 18.5-33% of the returning fish, and only a few are at sea for 4 years (1-3.9%). The largest steelhead are generally those with the longest oceanic phase (Wydoski and Whitney, 1979).

Snyder and Blahm (**1971; as cited in Monan, Johnson, and Esterberg, 1975**) found that temperatures of 23.9°C created a barrier to the migration of steelhead trout from the Columbia to the Snake River that remained until temperatures declined to nearly 21.1°C. **Strickland (1967; as cited in Stabler, 1981)also** noted that steelhead destined for the Snake River do not leave the cooler waters of the Columbia River until the Snake cools to 21°C or lower. **Fish and Hanavan (1948; as cited in Stabler, 1981 and USEPA, 1971)** reported that steelhead trout entered minor typically unused tributaries and died there when the temperatures in the Columbia River ranged from 21.6 to 23.8°C. On the Deschutes River in Oregon, nearly all steelhead reportedly stopped migrating the fish hatchery on Pelton Dam when the water in the ladder averaged between 20-21°C and the water below the dam was 13-14°C **(Don Ratliff, personal communication, as cited in Stabler, 1981).** Stabler (1981) also notes that Fessler (1977) and Everest (1973) have reported that steelhead halt their migration and will enter nonparent streams when water temperatures exceed 21°C. While not a study on migration, Nielsen, Lisle, and Ozaki (1994) found temperatures of 22°C elicited an avoidance reaction in steelhead trout. They noted that foraging began to decline and antagonistic behavior when stream temperatures reached approximately 22°C; although, it was noted that juvenile steelhead were seen actively feeding in surface waters with ambient temperatures up to 24°C. Fish moved to cool portions of stratified pools when temperatures exceeded 22°C, but not at or below 22°C, and would return to their original stream territories once ambient stream temperatures fell to about 23°C. **Based on the consistency of the above referenced studies, it is recommended that temperatures above 21-22°C be avoided so as to prevent any barrier to migrating steelhead trout.**

Support for assuming 21-22°C creates significant enough stress in steelhead as to create a potential barrier to migration is also found in lethality studies of Coutant (1970) and Becker (1973). Citing what appears to be a single study, these authors concluded that the incipient lethal temperature for migrating adult steelhead was near 21-22°C. They noted that adults appear to be more susceptible to high temperatures than are juvenile which are typically used in lethality studies.

Concerns over disease may warrant restricting temperatures to levels well below that which would result in direct barriers to migrating steelhead. Diseases of native fishes is discussed and incorporated separately in this paper. In setting a criteria for the full protection of migration, it is also important to consider chronic and sublethal effects caused by warm waters. Migrating spring and summer steelhead will be passing through during the peak temperatures of summer as they move upstream to holding areas where they will wait until the following stream. While often repeat spawners, steelhead still rely on their muscle and fat reserves to hold them over through to the completion of spawning and return to the ocean. In addition to concerns over disease, the metabolic demands of swimming, negotiating obstacles, and supplying the basal metabolic requirements while holding leaves little reserves left for digging redds and spawning once they reach their spawning streams. The warmer the water the more energy will be required to survive until spawning is completed and thus the greater chance that fitness will be affected and that higher pre- and post-spawning mortalities will occur. For these reasons it would be unwise to assume that any temperature regime that does not form a blockage to migration or cause direct lethality will protect migrating steelhead.

Where fish may hold in waterbody segments for long periods of time prior to spawning, as is common for spring and summer run steelhead, it is recommended that daily maximum temperatures not exceed the range previously identified for optimal for juvenile rearing (16.5-17.5°C). At this point in the life-stage of the adults when feeding is not occurring, even cooler waters would likely be more preferable.
In summary, **it is recommended that waters used for migration and holding by steelhead trout not exceed weekly average daily maximum temperatures of 16-17°C, with single daily maximum temperatures below 20-21°C.**

Lethality to Adults and Juveniles:

In evaluating the affect of high water temperature on steelhead, Beschta et al. (1987) concluded that the upper lethal temperature is 24.1°C. **Redding and Schreck (1979)** subjected juvenile steelhead acclimated to 12°C to a rapid rise (6.25 hours) to 26.5°C where it was maintained for the duration of the test. All fish died within 20.5 hours. In a separate test the temperature was held at 26°C, and all fish died within 31 hours. Coutant (1970), however, examined the upper lethal temperatures for adult steelhead taken at peak migrating temperatures from the Columbia River in Washington. Coutant concluded from his work that the incipient lethal temperature for migrating adult steelhead was closer to 21-22°C (this research also appears to be that used in **Becker, 1973**). Most laboratory studies use juveniles of the larger species of fish due to the difficulty of handling adult salmon and steelhead in laboratory tanks. It has been noted previously that adult Pacific salmon may have lower incipient lethal levels than that for juveniles, and it could be that this relationship may hold true for steelhead as well. To fully protect steelhead from acutely lethal temperature effects, water temperatures should seldom rise above 21-22°C in areas and at times that adult steelhead are migrating.

There is less information than is desirable with which to set lethal limits for steelhead. Since the data produced by Coutant (1970) was for a stock from and acclimated to prevailing summer temperatures of the Columbia River it will form the basis for recommending acute temperature limits. After applying a safety factor of 2°C (discussed previously) results in the recommendation **that daily maximum temperatures remain below 19-20°C to prevent directly lethal conditions to steelhead trout**. Steelhead juveniles, however, can likely withstand single daily maximum as high as 23-24°C °C without any direct mortality (Nielsen, Lisle, and Ozaki, 1994).

8. <u>Rainbow Trout (non-anadromous)</u>

Upper End of Optimal Temperature Range by Life Stage

General Limitations	**7-DAM**	**1-DM**
Incubation	9-12	13.5-14.5
Juvenile Rearing	15.5-18	21-23

Point Limitations	**1-DM**	**Instant Mix**
Acute Threshold	21-23	Insuf. Data
Acute Threshold (embryos)	Insuf. Data	Insuf. Data

Notes: <u>7-DAM</u> refers to the rolling arithmetic average of seven consecutive daily maximum temperatures; <u>1-DM</u> refers to the highest daily maximum temperature outside of an authorized mixing zone; <u>Instant Mix</u> refers to any place within a river where adult or juvenile fish may become fully entrained in a warm water plume, and typically applies within the established acute exceedence area of an established mixing zone.

Species-Specific Recommendations:

The following two alternatives show what temperature criteria would be recommended if this were the only species of concern. They also may be further modified in the Section VIII, Synthesis to account for other species in the stream complex and to remove unreasonable risks from warm water diseases. Thus the recommendations below for this species may not correspond directly with the final recommendations of this paper.

- Waters used for spawning and rearing by rainbow trout should not exceed a 7-day average of the daily maximum temperatures (7-DADM) of 18°C, with no single daily maximum greater than 22°C.

- Waters used for spawning and rearing by non-anadromous forms of rainbow trout should not exceed 18°C as a 7-DADM, with no single daily maximum temperature exceeding 22°C from May 8 to November 1; and not exceed 12°C as a 7-DADM between November 1 and May 8, with no single daily maximum temperature exceeding 14.5°C.

Summary Discussion

General Life History:

The name rainbow trout is commonly applied to represent any or all of the members of *Oncorhynchus mykiss*. However, *O. mykiss* in Washington can be further divided into resident coastal rainbow trout; resident interior redband trout; and steelhead, the anadromous form of the coastal rainbow and redband trout. Coastal rainbow trout populations extend from Alaska to Mexico, and non-anadromous, or resident, populations occur throughout the entire range (Behnke, 1992). Redband trout are found east of the Cascades and in the Columbia River basin, and Behnke suggests that that the native redband trout of each basin has its own peculiarities and could probably be separated into several new subspecies. Behnke also notes that in the desert basins of the western states, the redband trout has evolved adaptations to live in extremely harsh environments characterized by great extremes in water temperature and flow.

Spawning Requirements:

Both the coastal rainbow and the redband trout spawn in the spring, stimulated by rising water temperatures. Behnke (1992) suggests that along the Pacific coast a water temperature of about 3-6°C may initiate spawning activity, but that actual spawning does not occur until the temperatures reach 6-9°C. While this spawning activity would typically occur from late December through April, in some very cold headwater streams local temperatures may delay spawning until July or August for some stocks. Beschta et al. (1987) suggests that spawning of rainbow trout occurs between 2.2-20°C; Bell (1986) set the range for spawning at 2.2-18.9°C; and Piper et al. (1982) concluded that rainbow trout spawning should occur between 10-12.8°C. Smith et al. (1983) and Piper et al. (1982) cite work demonstrating that adult brood-fish should be held at temperatures below 12.2-13.3°C prior to spawning to produce good quality eggs, while holding temperatures above 13°C have been found to reduce invivo post-ovulatory egg survival (Flett et al., 1996, and **Billard and Gillet, 1981; as cited in Billard, 1985**). Temperatures of 18°C or higher have been found to reduce the volume of male sperm, and a temperature of 20°C has found to cause a drop in egg fertility invivo to 5% after a four and one-half days (**Billard and Breton, 1977**). At 10°C, fertility of the eggs held in the hen trout remained high. Saki et al. (1975; as cited in De Gaudemar and Beal, 1998) found that embryonic and post hatching survival in *O. mykiss* decreased significantly if they remained ripe in the body cavity for more than 5-7 days after ovulation, and fertility could approach zero after two weeks (Stein and Hochs, 1979; as cited in De Gaudemar and Beal, 1998).

Incubation through Early Fry Development:

Kamler and Kato (1993) tested incubation survival at 9, 10, 12, 14, and 16°C. They found the highest survival of eggs at 10°C and 12°C, slightly lower survival at 14°C, and abrupt drops in survival at both 9°C and 16°C. Velsen (1987) compiled data on the incubation survival of both rainbow trout and steelhead trout that showed survival was consistently high (>92%) between 4-9°C, and fair (>78%) between 3-15°C, but very poor (7%) above 16°C. Survival to the swim-up stage in two strains of rainbow trout had 94-98% survival at 7°C, 72-95% at 4°C, and <12-41% survival at 2°C (**Stonecypher and Hubert, 1994**). **Kwain (1975)** found the lowest mortalities occurred at 7 and 10°C, and

Billard and Breton (1977) found a drop in fertility at temperatures higher than 10°C, and **Kashiwagi et al. (1987; as cited in Taylor and Barton, 1992)** found optimal hatching occurred at 10°C. Humpesh (1985) found that optimal hatching (>90%) occurred between 7-11°C, and **Alekseeva (1987; as cited in Taylor and Barton, 1992)** suggested that optimal incubation occurs with temperatures rising from 5.3-10.5°C. **Rombough (1988; as cited in Taylor and Barton, 1992)** found that temperatures less than 12°C had less than 4% mortality. Constant temperatures above 12°C have produced variable, but generally lower survival during incubation temperatures, with often severe losses occurring at temperatures of 15-16°C (Velsen, 1987; **Billard and Breton, 1977**; Kwain, 1975; Kamler and Kato, 1983; **Rombough, 1988; as cited in Taylor and Barton**).

Based on the literature cited above, it can be generally concluded that constant temperatures in the range of 7-10°C are optimal for the incubation and embryonic development of rainbow trout. Adjusting this constant temperature range to fit a naturally fluctuating stream environment (discussed previously) results in the recommendation that **the 7-day average of the daily maximum temperatures not exceed 9-12°C from spawning through fry emergence.** No specific studies have been found that test the ability of *O. mykiss* eggs or alevin to survive high single daily maximum temperatures; therefore, the value recommended for chinook salmon incubation (13.5-14.5) should also be applied to rainbow trout.

Statewide spawning dates were not found for non-anadromous rainbow trout. However, May 7 has been identified as the peak spawning date for the anadromous steelhead form and June 15 was generally assumed to represent the period of peak emergence. It is recommended that these dates be considered in setting criteria to protect non-anadromous rainbow trout, at least until more specific statewide stock estimates become available.

Juvenile Rearing:

Final preferred and optimal temperatures for rainbow trout sometimes cited as occurring in the range of 12-19°C (Bell, 1992; **Taylor and Barton, 1992**), and scope of activity and growth for juvenile fish are commonly cited to be optimized between 15-21°C on a satiation diet (Moyle, 1976; **McCauley and Pond, 1971; Dickson and Kramer, 1971; Kwain and McCauley, 1978; and Huggins (1978; as cited in Kwain and McCauley, 1978**). However, some authors have suggested lower temperature ranges as being optimal. Piper et al. (1982) set the optimal at 10-16.7°C; although, **Sadler, Friars, and Ihssen (1986)** found that growth and food conversion efficiency were greater at 16°C as compared with 10°C. **McCauley and Huggins (1975)** found that five large (150-250 grams) rainbow trout had a preferred mean temperature of 16.7°C, and that the fish actively cycled between 13.8°C and 18°C. Behnke (1992) suggests that the optimum temperature for the growth and food assimilation in salmonids occurs between 13-16°C. Ferguson (1958) cites 13.6°C as the final preferendum temperature for rainbow trout, and Mckee and Wolf (1963; cited in Wedemeyer et al., date absent from paper) are reported to have found 13°C to be optimum. **Kwain and McCauley, 1978** suggest that over-yearling fish may have a final preferenda centering on 13°C (citing the works of **Garside and Tait, 1958, Christie as reported in Fry, 1971, and McCauley et al., 1977; as cited in Kwain and McCauley, 1978**), although, as noted above the work of McCauley and Huggins (1975) suggest older fish sometimes demonstrate more intermediate temperature preferences.

Dockray, Reid, and Wood (1996) found that in a fluctuating temperatures environment temperature increase were beneficial to growth up to daily maximum temperatures of 18°C, after which it inhibited long term growth. De Leeuw (1982) found that stream temperature increases that raised the summer time maximum temperature from 12°C to 16.5°C were associated with an increase in growth rates in three streams in British Columbia, Canada. Hokanson et al. (1997) found that a constant exposure to 17.2°C produced the greatest growth rates in trout fed to satiation over a 30 day test period. Increased mortality was observed in temperatures in excess of this growth optimum. They also noted that in fluctuating temperature experiments that growth was accelerated where the mean temperature is below the constant temperature optimum (17.2°C), and growth was retarded by mean fluctuating temperatures above this optimum. The highest growth rate in the fluctuating temperature environment occurred at a mean of 15.5°C (range of 11.7-19.3°C). A statistically non-significant decrease occurred at a mean of 17.3°C (range of 13.5-21.1°C). Through their work the authors also concluded that rainbow trout acclimate to some value between the mean and the maximum daily temperatures. Sometimes warmer waters may provide secondary benefits to rainbow trout. **Cunjak and Green (1986)** found that rainbow trout were able to compete better with brook trout at 19°C than at either 8 or 13°C.

Bisson and Davis (1976; as cited in Li et al., 1994) found that streams with daily maximum temperatures in the range of 16-23°C had greater standing crops of trout than streams with warmer maximum temperatures (26-31°C). **Frissel, Nawa, and Liss (1992)** studied the distribution of rainbow trout and found that while they could be found in water temperatures over 23°C, there was a general threshold response for age 1+ fish above 22°C and for age 2+ fish above 21°C. Consistent with these results, **Li et al. (1993; and 1994) and Li et al. (1991; as cited in Spence et al., 1996)** note suggest that while rainbow trout may show no avoidance reactions when stream temperatures were below 20°C, they actively avoided staying in waters warmer than 23-25°C. Linton et al. (1997) noted that rainbow trout fed to satiation continued to feed at grow at a mean temperature of 20.5°C, that a 30% reduction in food intake occurred at 22°C, and that juvenile fish continued to feed near their thermal maximum. Linton et al. (1997) found that increasing the temperature regime by 2°C over the natural (base) level for Lake Ontario trout resulted in increased spring and early summer growth, that was lost in the latter part of the summer due to suppression of appetite and growth. Mortality rates increased from 6 to 13.1% in the warmer test water during the late summer in the first summer of testing when the mean monthly base temperature in August was 23°C. Mortality was almost nonexistent through the following summer which had a mean

August base temperature of 18°C (the test waters should have had a mean of 20°C). The threshold temperature for the cessation of feeding, and subsequently growth, differed from >20°C to <20°C over the two summers, and thus also fish size and age. Behnke (1992) cites work showing that trout reduce and finally cease feeding as temperatures rise to between 22-25°C, often well below the lethal temperature.

While the works of Le et al. (1991, 1993, and 1994) cited above were conducted on interior forms of rainbow trout, Behnke (1992) reported finding redband trout in the desert basins of southern Oregon and northern Nevada that regularly encounter temperatures that kill other trout. Trout in these intermittent desert streams were found actively feeding in water of 28.3°C. Behnke suggests that redband trout from an Oregon desert basin have been demonstrated to have an optimum feeding temperature at some untested temperature higher than 19°C. He suggests that these desert redband have a functional feeding temperature that is higher than rainbow trout that have evolved in less harsh environments of temperature and water flow. A test was evaluated that compared an introduced population of rainbow trout in the Firehole River in Montana to two hatchery stocks. Temperatures in the Firehole River at times reach summer maximums as high as 29.5°C due to thermal springs. The planted stock has been living in the river for approximately 20 generations, yet it was found that neither the functional feeding temperature or the upper incipient lethal temperature had increased in comparison to the hatchery stocks. The author concluded that thousands of years of adaptation to a desiccating environment have enabled the Oregon desert redband trout to feed at high temperatures, but 60-70 years seem too few to have allowed the planted rainbow trout to expand their functional feeding temperature in the Firehole River. Kaya et al. (1977) found that daily maximum temperatures exceeding 25°C caused rainbow trout to move out of the mainstem of the Firehole River in Montana. These fish would move into tributary streams that averaged 6-10°C lower in temperature.

As obvious from the above cited research, there is a wide range in the estimates of temperature optimal for the rearing of rainbow trout. This wide range may reflect the individual subspecies and stocks that have evolved to fit the characteristics of their home streams, as well as the relative ages and sizes of the fish used in the research. Recognizing that criteria must protect both adult and juvenile forms of rainbow trout, an optimal constant temperature regime seems to most consistently occur in the range of 13-16°C. Adjusting this range to apply to a natural fluctuating environment (discussed previously) results in the recommendation that **to protect the juvenile rearing of rainbow trout, the 7-day average of the daily maximum temperatures should not exceed 15-18°C**. It is also suggested, based on the results of the fluctuating laboratory tests and field studies, that water quality criteria selected towards or at the upper end of this range will be fully protective of non-anadromous rainbow trout.

Lethality to Adults and Juveniles:

Temperatures as low as 23°C have been found to produce 50% mortality (LT50) with a week's constant exposure in fish previously acclimated to very cold (4°C) waters (**Sonski, 1982; Threader and Houston, 1983, as cited in Taylor and Barton, 1992)**, with the lethal temperature rising to 24°C in moderately cold water (6-11°C) acclimated fish (**Black, 1953; Stauffer et al., 1984; Bidgood, 1980, as cited in Taylor and Barton, 1992**). However, at most acclimation temperatures likely to be encountered during the spring through fall seasons (12-20°C) lethal levels are consistently in the range of 25-26°C (**Bidgood and Berst, 1969**; Hokanson et al., 1987). With cautious acclimation to temperatures in the range of 23-24°C, fish may not experience LT50 level effects until temperatures are held for a week at 26°C (Charlon et al., 1970, as cited in Grande and Anderson, 1991). Even with careful acclimation, 27°C results in high or complete mortality in less than 24 hours (**Charlon, Barbier, and Bonnet, 1970**), and temperatures of 29-30°C result in 50% mortality in periods of 1-2 hours (Kaya, 1978; **Craigie, 1963, and Alabaster and Welcomme, 1962, as cited in Taylor and Barton, 1992**).

Under fluctuating temperature test conditions, rainbow trout have been found to experience 50% mortality in a week of daily cycles from 21-27°C (**Lee, 1980**). **Sonski (1983)**, however, notes success with culturing rainbow trout at in ponds that that reached 28.9°C, and **Chandrasekaran and Subb Rao (1979)** noted that rainbow trout were largely able to survive in rearing ponds with months of daily maximum temperatures in the range of 26-29°C.

The literature clearly indicates under scenarios of both sudden and dramatic change in temperature and under slow acclimation to up to 20°C , rainbow trout are at risk of serious lethality (50%) with constant temperature exposures of 23-25°C for up to one week. After subtracting a 2°C safety factor (discussed previously) from this range it results in the recommendation that **the 7-day average of the daily maximum temperatures during the summer not exceed 21-23°C**. Given feeding is commonly reported to cease at 22-25°C and that at a very low acclimation (4°C) even 23°C was lethal, it is recommended that the lower portion of this range be considered the acute limit for rainbow trout.

9. <u>Cutthroat Trout</u>

Upper End of Optimal Temperature Range by Life Stage

General Limitations	**7-DAM**	**1-DM**
Incubation	10-11	13.5-14.5
Juvenile rearing	13-15.5	19-20
Anadromous migration	14.5-17.5	19-20

Point Limitations	**1-DM**	**Instant Mix**
Acute threshold	19-20	Insuf. Data
Acute threshold (embryos)	Insuf. Data	Insuf. Data

Notes: <u>7-DAM</u> refers to the rolling arithmetic average of seven consecutive daily maximum temperatures; <u>1-DM</u> refers to the highest daily maximum temperature outside of an authorized mixing zone; <u>Instant Mix</u> refers to any place within a river where adult or juvenile fish may become fully entrained in a warm water plume, and typically applies within the established acute exceedence area of an established mixing zone.

Staff Recommendations

The many life strategies and subspecies of cutthroat trout make establishing recommended criteria problematic. In order of preference, it is recommended that Ecology establish criteria to protect steelhead trout as follows:

- Waters used for the spawning and rearing of cutthroat trout should not exceed a 7-day average of the daily maximum temperatures (7-DADM) greater than15.5°C with no single daily maximum greater than 20°C.

- In waters used for spawning by any form of cutthroat trout, or used for rearing by non-sea run forms, the 7-DADM shall remain below 13°C from April 1 – October 1, with no single daily maximum temperatures greater than 19°C. During the remainder of the year, the 7-DADM shall remain below 10°C, with no single daily maximum greater than 13.5°C.

Summary Discussion

General Life History:

In Washington, native cutthroat trout can be separated into coastal cutthroat (*Oncorhynchus clarki clarki*) and west-slope cutthroat trout (*Oncorhynchus clarki lewisi)*. Coastal cutthroat exhibit anadromous, potamodromous stream dwelling, potamodromous lake-dwelling, and headwater stream-resident life-history forms; while west-slope cutthroat exclude anadromous populations (Trotter, 1998). Behnke (1992) suggests that cutthroat trout enjoy a selective advantage over non-native trout in many high-altitude headwaters; presumably because they function better in colder waters. He notes that native cutthroat are quickly eliminated from waters where non-native trout become established. Cutthroat are displaced from preferred habitat in the presence of rainbow trout and coho salmon. The aggressive interaction of these other species may be heightened by warmer water temperatures and thus the displacement of cutthroat is lessened by cooler water temperatures (Pauley et al., 1989; Trotter, 1989; and Mullan et al., 1992).

The coastal cutthroat trout (*Oncorhynchus clarki clarki*) occurs all along the Pacific coast from southern California to Alaska. Though rarely found more than 16 km inland, it is considered the most abundant of the cutthroat subspecies (Trotter, 1998). Sea-run cutthroat live to a maximum age of about 10 years, as compared to resident forms which may live for only 4 to 5 years (Behnke, 1992).

In Washington, sea-run cutthroat may re-enter fresh water for spawning anytime from July through March (Pauley et al., 1989). Early-entering stocks in Puget Sound and Hood Canal typically occur from July through November with the peak in September and October. Late-entering migration peaks in December and January but continues through March (Trotter, 1989; Pauley et al., 1989). In southeast Alaska, Jones (1977; as cited in Pauley et al., 1989) found that migration began at 10-12°C and peaked at 9-10°C.

Stream resident forms of coastal cutthroat spend most or all of their life in or very near their natal streams (Trotter, 1989). In spring when water temperatures reach 5-6°C, mature resident cutthroat move onto the spawning gravel. Trotter (1989) suggests that potamodromous forms of coastal cutthroat do not move into spawning tributaries until very late winter or spring rather than in autumn to early winter as for anadromous fish. Similar to stream resident forms, they are reported to begin spawning as the water temperature increases to 5-6°C, which may occur from February through June. Lake-dwelling potamadromous coastal cutthroat first spawn at age 3 or 4, and then spawn almost every year thereafter for the remainder of their lives in the inlet and outlet streams of the lake (Trotter, 1989).

West-slope cutthroat trout, the interior form, has been found to spawn in April and early May with a peak around mid-April in Montana (Fraley et al., 1981). Trotter (1999) found an introduced population of west-slope cutthroat initiating spawning around June 1 at a temperature of 7°C in the Tolt River in Washington, and a natural population initiating spawning on June 29 at a temperature of 11°C in a stream in the upper Yakima River basin in Washington.

Spawning Requirements:

Varley and Gresswell (1988) suggested that the optimum water temperature for cutthroat trout is from 5.5-15.5°. Beschta et al. (1987) suggests that spawning temperatures should be 7.2-12.8°C, and Bell (1986) has suggested that the spawning range is 6.1-17.2°C. Fraely et al. (1981) evaluated the spawning habitat of west-slope cutthroat trout in Montana. They found that the better spawning streams had maximum temperatures of 11-13°C and mean monthly maximum temperatures that exceeded 10°C only during July and August. The poorer quality spawning streams had higher maximum summer temperatures, with two having 18°C and 19°C as the average maximum temperatures during July.

Few sea-run cutthroat trout sexually mature before age 4, and not all returning fish spawn their first year back in freshwater (Trotter, 1989). Fish that do spawn, may return (39-41%) to spawn a second time, and some (12%) may return for a third spawning (Trotter, 1989; Pauley et al., 1989). Cutthroat trout spawn in the spring, stimulated by a rising water temperature. While temperatures of 3-6°C may initiate spawning activity by coastal cutthroat from late December through April, actual spawning may not occur until temperatures reach 6-9°C. Spawning may extend from December through May in Washington, but peaks in February (Trotter, 1989; Wydoski and Whitney, 1979; Pauley et al., 1989; Behnke, 1992). Sea-run cutthroat tend to spawn close to deep pools (Pauley et al., 1989) in low gradient areas of small tributaries (Wydoski and Whitney, 1979; Trotter, 1989) where they may avoid competition for rearing area with steelhead and coho salmon. Pauley et al. (1989) suggest that cutthroat travel farther upstream to spawn than either steelhead or coho salmon where they rear sympatric with resident cutthroat populations. While cutthroat home very precisely to their natal streams to spawn, immature fish may migrate from marine waters to non-natal areas to feed (Pauley et al., 1989).

Incubation through Early Fry Development:

Eggs of sea-run cutthroat incubate for 6-7 weeks before they hatch and the alevin remain in the gravel for about another 2 weeks before they emerge (Trotter, 1989; Pauley et al. 1989). Fry may emerge from March through June, depending on the location and time of spawning, but peak emergence occurs in mid April (Trotter, 1989; Wydoski and Whitney, 1979). Pauley et al. (1989) cite studies demonstrating that the optimum temperature for incubation is 10-11°C. Bell (1986) has suggested that the range for hatching of cutthroat trout eggs is from 4.4-12.8°C. Smith et al. (1983) found that west-slope cutthroat trout eggs held in creek water with a fluctuating temperature of 2-10°C had significantly better survival than eggs held at a constant 10°C.

Hubert and Gern (1995) found 68.6% in a control population held at 7°C when testing the effects of lowering incubation temperatures in the early stage of development. Mortality rates were no different from controls when temperatures were lowered to 3°C at least 13-15 days after fertilization but were higher if the cooling took place sooner. **Stonecypher and Hubert (1994)** found that survival to swim-up stage in Snake River cutthroat trout was 95% at 7°C, approximately 87% at 4°C, and less than 16% at 2°C.

It is somewhat problematic to set standards to protect the incubation of cutthroat trout which can be reasonably applied statewide. As a spring spawning species that often spawns high in the watershed, cutthroat trout have a very broad period of spawning when examined statewide. Stocks that exist in lower or warmer watersheds will spawn as early as February when temperatures rise above 6°C, while stocks that exist in high elevation snow fed streams may need to wait until late June or July for waters to be sufficiently warm (6-11°C) to allow successful spawning. Were it not for risk of egg loss due to late winter and spring freshets, one could suggest that the spring spawning strategy is relatively unencumbered by changes in the temperature regime. While earlier spawning subjects cutthroat eggs to higher risks of physical damage, the earlier hatch also places surviving resident fry in a good position to maximize summer growth and thus increase their survival opportunities over the following winter. It may well be that the superior growth obtained in the oceanic phase of anadromous forms may make increases in weight gains from earlier emergence of less value, but this relationship remains to be tested. In general, specific stocks will have tailored their spawning and emergence periods to optimize both incubation survival and early fry growth. Significant changes in the temperature regime, such as earlier spring warming will bring unknown risks to individual populations. Therefore, while an optimal temperature regime is recommended in this paper for cutthroat trout, it would be best tailored to the historic patterns of spawning found in specific stocks. To initiate spawning in most stocks the water temperatures must at least warm to daily maximums of 6-7°C, though some stocks may not begin spawning until temperatures reach 11°C. Specific studies on incubation survival suggest that incubation may be optimized with constant temperature exposures in the range of 7-10°C. Adjusting this for a fluctuating stream environment (as discussed previously), would produce a recommendation of 9-12°C. Statewide, most cutthroat spawn in mid-February and hatch by the end of March. It is recommended that the incubation criteria be applied prior to April 1 to protect the full pre-emergent period of most of the sensitive stocks. Given that the studies reviewed create some contradictions, it is recommended that the middle portion of the possible optimal range be used for the final recommendation. Therefore, **it is recommended that the 7-day average daily maximum temperature in waters used for spawning by cutthroat trout not exceed 10-11°C prior to April 1**. No specific basis is provided in the literature for setting single daily maximum criteria for the incubation of cutthroat trout; therefore, **it is further recommended that the value used for chinook salmon incubation (13.5-14.5°C) also be applied to cutthroat trout.**

Juvenile Rearing:

Newly emerged fry move to low velocity stream margins, backwaters, and side channels adjacent to the main-channel pools and riffles (Pauley et al., 1989; Trotter, 1989). Trotter (1989) suggests that these young fish, as early as the winter of their first year but more generally in the spring, may move downstream to the main stem. With the onset of winter freshets, the fish may again move back into the tributaries. Older fish may migrate to sea where they will remain for 2-5 months concentrating in bays, and estuaries along the coast gaining weight before returning to fresh waters. It is considered unusual for cutthroat to over-winter in salt waters. (Pauley et al., 1989). Fry of potamadromous forms may spend the first 1-3 years in the tributaries before commencing a lake-ward migration. These potamadromous fish may over-winter in the lower main-stem of the river while anadromous fish are in the marine waters (Trotter, 1989). Pauley et al. (1989) cite research showing that while in freshwaters, cutthroat adults are associated with the deeper pools and slower velocity waters, while the fry are found in shallower, faster areas.

Beschta et. al. (1987) suggest that the preferred juvenile rearing temperature is 9.5-12.9°C. Bell (1986) used a review of the literature to conclude that the range for cutthroat trout was from 0.6-22.7°C, and the preferred range was from 9.4-12.7°C.

Hall and Lantz (1969) found a 75% reduction in a cutthroat trout population in response to experimental logging of riparian canopies in three coastal streams. Prior to treatment, these streams had monthly average temperatures ranging from 6.1-12.8°C and maximum temperatures ranging from 16.1-16.6°C. In the treatment stream experiencing the greatest canopy removal, daily maximum temperatures increased to 24 and 30°C in the two years following treatment. These results compared well with the work of **Frissell, Nawa, and Liss (1992)** who studied the distribution of salmonids in a small coastal river system in southwest Oregon. They found that cutthroat , coho, and chinook salmon dropped out in sequence as maximum temperatures increased, with rainbow trout the only species present in waters exceeding 23°C. Cutthroat were absent, and coho salmon rare in segments exceeding 21°C. **Dunham et al. (unpub.; as cited in Dunham, 1999)** found Lahontan cutthroat appear to have distributional limits that correspond closely to maximum water temperatures of 26°C, and while **Varely and Gresswell (1988; as cited in Gresswell, 1995)** reported that Yellowstone cutthroat are found in geothermally heated streams with ambient temperatures of 27°C, they report these fish are found associated with cooler thermal refuges. **Kelly (1993: as cited in Gresswell, 1995),** however, reportedly found that cutthroat were excluded from a tributary to the Yellowstone River because summer water temperatures often exceeded 22°C. **Dickerson, Vinyard, and Weber (1999, and unpub. Data; as cited in Dunham, 1999)** found that growth rates in a test with temperatures fluctuating from 20-26°C (mean of 23°C) were similar to groups of fish held at a constant 23°C, and after two weeks not significantly different from fish held at a constant 20°C.

Temperature increases, however, are not always found to restrict cutthroat populations. Aho (1976) found coastal cutthroat preferring an unshaded section of stream in the Cascade mountains of Oregon. Density was twice as high and biomass was 49-65% greater in the unshaded section. He suggested that earlier fry emergence in the warmer unshaded section probably played a role in creating the greater fish weights. The highest weekly mean temperature was 14°C in the unshaded area, with the highest one hour temperature being 17°C. This compared to a maximum daily temperature of 14°C in the shaded section. Cutthroat were the only fish species present in the study stream so any relationship to potential competition could not be evaluated. Martin (1985) studied the affect of removing the vegetative canopy along a 1000 meter section of a third order stream on the Olympic Peninsula used only by cutthroat trout. Fish density increased in the upper 500 meter treatment reach in comparison to the 200 meter control section established just above the treatment reach. Summer daily maximum temperatures in this upper treatment ranged from 13.8°C at the boundary with the control section to about 16.1°C at the bottom of this upper treatment section 500 meters downstream. In the second treatment reach, which extended from 500 to 1000 meters below the control section, the average fish weight increased but density went down. Temperatures in this reach changed from 16.1°C at the upper boundary of the treatment reach to 17.3°C at the lower boundary of the lower treatment reach. The daily maximum temperature was 15.2°C in the midpoint of the upper treatment reach where fish density increased.

Consistent with the results of the above field studies, Pauley et al. (1989) cites research concluding that the optimal temperature for juveniles is 15°C, and that equilibrium and ability to swim is lost between 28-30°C. They further suggest that cutthroat trout are not usually found in waters where the maximum temperature exceeds 22°C even though they may tolerate brief periods of temperatures as high as 26°C. **Hickman and Raleigh (1982; as cited in Dunham, 1999)** suggested that the optimal temperature for cutthroat is 15°C, and **Dwyer, and Kramer (1975; as cited in Dunham, 1999, and Gresswell, 1995)** found the greatest scope for activity to be 15°C. Data reviewed by **Carlander (1969; as cited in Gresswell, 1995)** suggest optimum water temperatures between 4.4 and 15.5°C for Yellowstone cutthroat trout.

Martin (1984) in studying a small upper watershed creek on the Olympic Peninsula found that higher water temperatures during the summer caused metabolism and thus food consumption to increase in a population of cutthroat trout. He found that growth rates declined from a spring high to a low in the winter, and was below the maximum possible during periods of optimum water temperature. Food consumption followed the seasonal trend in food abundance and was limited by the available food supply.

DeStaso and Rahel (1994; as cited in Dunham, 1999) found that Colorado cutthroat trout competed nearly equally with brook trout at 10°C, but at 20°C the brook trout were dominant. **Schroeter (1988; as cited in Dunham, 1999)** found that Lahontant cutthroat equal competitors with brook trout at 15°C. **Nilsson and Northcote (1981)** found interestingly enough that in sympatry the presence of more aggressive rainbow trout actually resulted in higher growth rates in cutthroat trout than the growth rates shown by the cutthroat in allopatry.

The key to protecting the rearing of cutthroat trout may not so much in maintaining a temperature regime that is at their biological optimum, but in ensuring that the temperature regime is lower than the biological optimum of competing species, such as *O. mykiss*, *O. tshawytsha*, and *O. kisutch*. An isolated population of cutthroat will thrive in water which is optimum for these other salmonids, but when these other species are present cutthroat will be subject to displacement from the higher quality habitats and crossbreeding with *O. mykiss* or *S. fontinalis*. So, for cutthroat trout it may be most appropriate to recommend temperatures that are below the upper end of their zone of optima to minimize harmful interactions with other species. Where cutthroat are not faced with competition, optimal rearing is likely to occur in streams with daily maximum temperatures in the summer that typically range from 14.5-16.5°C. Preferred juvenile rearing habitat and high quality cutthroat streams, however, are often cited as having maximum summer temperatures of 9.5-13°C, well below the potential optimal growth range. In consideration of all of these factors **it is recommended that juvenile rearing habitat not exceed 13-15.5°C as a 7-day average of the daily maximum temperatures during the summer period**.

Smoltification:

Pauley et al. (1989) suggests that prior to smolting and entering saltwater, sea run cutthroat juveniles may migrate up and downstream several times. They further suggest that in Washington and Oregon, downstream movement is reported to take place from March to June, but peaks in mid-May. They note that in southeast Alaska, juveniles have been reported to experience a peak of out-migration when water temperatures are between 4-6°C. Cutthroat parr may migrate to sea from age 1-age 6 but age 2-4 may be most common (Trotter, 1989; Pauley et al., 1989).

Adult Migration:

Gresswell (1995) suggests that cutthroat generally migrate when temperatures approach 5°C **(citing Varely and Gresswell, 1988, Byorth, 1990, and Thurow and King, 1994).** For 13 years maximum daily water temperatures at the time of peak spawning in one cutthroat stream into Yellowstone Lake ranged from 10-14.2°C **(USFWS, unpubl. Data; as cited in Gresswell, 1995).**

Migrations of resident and potamadromous cutthroat trout occupy largely the same habitat used for juvenile rearing. Thus for these forms, there is little specific basis for establishing a specific migration criteria higher than the optimal range identified for juvenile rearing. The anadromous forms of cutthroat, unlike the Pacific salmon, may make numerous journeys to the marine waters and back again. Thus they may need to repeatedly pass through any suboptimal temperature regime, however, since they may feed on their return migrations through fresh waters, they may be subject to less sublethal stress effects than the Pacific salmon. Considering these factors and noting that cutthroat are not more sensitive to acutely lethal temperatures, it is recommended that any standard applied to protect the anadromous migration of the Pacific salmon also be applied to cutthroat trout. Such a criteria would likely be protective if the typical daily maximum temperature seldom exceeded 17-18°C and the daily maximum temperature rarely exceeded 20-21°C. For anadromous cutthroat the temperatures during the spawning migration do not need to be as cool as that needed to support rearing populations since the concerns over competition for rearing habitat do not exist. The primary concerns for this life-stage would be to ensure temperatures are not conducive to disease outbreaks, cause direct lethality, interfere with swimming ability, or impair egg quality. Early-sea-run cutthroat populations may have peak migrations in Washington in September and October; although, individual cutthroat may enter freshwater anytime from July through March. For establishing statewide criteria, **it is recommended that portions of streams used only as migration corridors for spawning migrations not exceed 14.5-17.5°C** as a 7-day average of the daily maximum temperatures. This range should allow for optimal swimming and growth to occur on the migratory runs and avoid substantially increasing the risk of disease outbreaks.

Lethality to Adults and Juveniles:

Golden (1976) tested the temperature tolerance of zero age coastal cutthroat stocks from western Oregon. It was found that seven diel cycles of 13-27°C resulted in from 0-20% mortality. However, by increasing the peak temperature in the cycle 0.5°C (13-27.5°C) mortalities increased to 50-90% within 1 to 1.5 cycles. In critical thermal maximum tests (CTM) where the temperature is rapidly increased until the fish die or loose equilibrium, acclimation to 10 and 23°C yielded CTM values of 28.03 and 30.62°C. At a fluctuating equilibriums of 7.8-10°C and 13-23°C the CTM values were 27.64 and 30.31°C. Golden (1978) tested the lethality of significantly fluctuating temperature regimes with cutthroat trout. Incipient lethal levels were 25.5°C and 25.7°C for fish acclimated to 23°C and a fluctuating regime of 13-23°C. Golden estimated losses in one week of 10% or less at a fluctuating cycle of 13-27°C. Heath (1963) subjected sea-run cutthroat to a cyclic temperature regime of 10-20°C and found a CTM of 29.77. At constant acclimations of 10, 15, and 20°C, the corresponding CTM values were 27.63, 29.06, and 29.88°C. Beschta et al. (1987) has suggested that the upper lethal temperature for cutthroat trout is 24.1°C, and Pauley et al. (1989) cite research concluding that equilibrium and ability to swim is lost with a rise in temperature to 28-30°C.

Vigg and Koch (1980) measured the lethal limits to two stocks of Lahontan cutthroat in three water types and found that alkalinity profoundly influences the results. In waters with alkalinity of 1,487 mg/l the lethal range was 18.5-20.2°C, in waters with alkalinity of 357 mg/l the range was 20.2-21.1°C, and at an alkalinity of 69 mg/l the lethal range was 21.8-23.0°C for the two species. Kramer (1975; as cited in Vigg and Koch, 1980) found they were able to hold a Humboldt River strain of cutthroat at 24°C for two weeks without any mortality, but only feeding inhibition.

Dickerson, Vinyard, and Weber (1999, and unpublished data, as cited in Dunham, 1999) tested the lethal tolerance levels of Lahontan cutthroat. Survival was 100% at 24°C but declined to 35% at 26°C. At 28°C mortality was complete in 48 hours. In a separate test of fluctuating (20-26°C) and constant (13, 20, and 23°C) temperatures no mortality occurred. Dunham (1999) concluded from a review of the literature that Lahontan cutthroat can survive weekly exposure to daily temperature fluctuations of 20-26°C, including 1-hour exposures to temperatures of up to 26°C.

Titus and Vanicek (1988; as cited in Muoneke and Childress, 1994) reported that mortality of cutthroat trout caught and released by angling was less than 2% at temperatures below 17°C but rose to 49% as the temperature neared 21°C.

Were it not for the studies of Lahontan cutthroat trout by **Vigg and Koch (1980)**, it would be easy to conclude that cutthroat trout should be expected to have 50% mortality (LT50) over a one week's exposure to constant temperatures above 24°C. While it is clear that in many cases no mortality would occur as a consequence of short term exposure to infrequent daily maximum temperatures as high as 26°C, the data of **Vigg and Koch (1980)** suggest more caution may be warranted. They calculated LT50 values of 20.2-21.1°C and 22-23°C using two stocks of cutthroat and two water sources with alkalinity levels comparable to what we could regularly find in Washington. Thus for the purpose of setting a protective water quality criteria it is recommended that we assume LT50 level results could occur at constant temperatures ranging as low as 20.5-22°C. Subtracting a 2°C safety factor (as discussed previously) to convert these results to safe short-term temperature levels results in the recommendation that **to prevent direct mortality to juvenile and adult cutthroat trout single daily maximum temperatures should not exceed 19-20°C.**

V. Temperature Influenced Fish Diseases

Temperature affects both the occurrence and severity of many diseases and infections important to fish and other aquatic life. While some diseases are associated with holding fish at very cold temperatures, and some are prevalent at across the full spectrum of temperatures occurring in Washington's waters, many are facilitated by temperatures within or slightly above the optimal temperature range for the growth of our native fishes. The focus of this discussion is on those diseases that are known or likely to cause illness in populations of wild fish that are facilitated by temperatures at the upper end of the physiologically optimal range of our indigenous fish. The intent is to identify where a stream temperature standard may need to be set below this upper end to prevent, or at least reduce the severity of, disease outbreaks in natural fish populations. It must be recognized, however, that temperature standards by themselves will not eliminate the risk of disease in fish. Besides warm water diseases, native fishes are harmed by numerous very important cold water fish diseases, such as bacterial kidney disease and the parasite *Ceratomyxiasis Shasta* (See appendix J for information on these coldwater diseases). It is of course reasonable that most fish pathogens thrive in cold waters here in the northwest as the pathogens themselves have evolved along with our native fishes.

Fish diseases can be divided into four types of infections: 1) bacterial, 2) viral, 3) fungal, and 4) parasitic. Regardless of the type of infection, temperature affects both the virulence of the disease as well as the immune system of the host fish. When environmental conditions are optimal for the disease it grows more rapidly and is often more virulent. If the environmental conditions are more optimal for the disease then they are for the fish, then there is a greater likelihood that the disease will be able to overcome the host's defense systems and create serious illness (Wedemeyer and Goodyear, 1984). Just as each disease causing organism has an optimum temperature range, they also have lethal boundaries or limits of activity. If the temperature is above or below these thresholds, the disease causing organism will be unable to reproduce or grow, and thus unable to affect disease in fish. Catastrophic outbreaks of many bacterial diseases are associated with water temperatures that are optimal for the bacterium but above the optimal temperature for the fish.

While some diseases will have thresholds of temperature above or below which the disease organism is unable to grow, most diseases are able to grow at some temperature that occurs during the year in Washington's waters. The primary goal, therefore, cannot be to set standards at which diseases organisms will not exist. A complicating factor in evaluating diseases is that most have multiple, sometimes hundreds, of strains. Individual strains can have significantly different characteristics for optimal infection and virulence. Since researchers often do not specify specific strains examined, this creates variability in research results that may very well just be the consequence of testing different strains**.**

The focus of this effort is to identify pathogens that: 1) occur in freshwaters; 2) are enhanced by increasing water temperatures in the upper optimal range of our native fishes (roughly 14-18°C); and 3) have been associated with serious outbreaks of disease in indigenous wild fish populations.

In reviewing the literature, only two diseases appear to meet all three criteria, these are columnaris disease and the parasite Ichthyophthiriasis. While numerous other diseases are documented to be influenced by warming temperatures, these others tend to primarily be problems associated with intensive fish culturing facilities, or are associated with species and temperatures not common in our natural waters. Since there is little suggestion that any of these other diseases pose a significant threat to the welfare of our native fishes, they will be used only broadly to discuss how temperatures influence the health of fish and in support of the findings for the two specific diseases discussed below. Appendix J describes research findings for 33 fish pathogens identified in the literature as having relationships with temperature. The reader should refer to the appendix for more details on individual fish diseases and in regards to the general findings noted in this discussion.

Ichthyophthiriasis. Post (1987) notes that the etiological agent for ichthyophthiriasis is *Ichthyophthirius multifillis*, the largest protozoan found on fishes. Occurring on both hatchery and wild fish (Bell, 1986), Ichthyophthiriasis is considered one of the most prevalent diseases of fishes (Post, 1987). Bell (1986) notes that outbreaks in fingerlings often occur at temperatures above 15.5°C, and the optimum temperature for the organisms is 25-27°C. Post (1987) notes that temperatures over 12-15°C are more suitable for reproduction, and that disastrous losses have occurred in trout culture where water warms to near 20°C.

Columnaris Disease. There is little doubt that columnaris disease is the most important warm-water disease for our native salmonid populations. Frequent and catastrophic losses to natural populations throughout the Pacific northwest are well document throughout the literature. For this reason, the prevention of human-caused additional losses from columnaris disease should be considered a critical element in setting temperature standards for the state of Washington.

In evaluating the research it is important to recognize that there are probably at least 1,200 strains of columnaris in Washington, and that strains can be categorized as possessing low, medium, and high levels of virulence (Pacha, 1961). High virulence strains are infective and capable of producing high rates of mortality at low temperatures, while low virulence strains are problematic only at higher temperatures (Bell, 1986). Since only a handful of authors categorized the strains they were evaluating, care must be exercised in broadly applying the conclusions of any one study. Table J-1 below summarizes the results noted in the literature.

The milestones of 12-13, 15-16, 18-20°C are cited extensively in both field and laboratory research, and show generally consistent levels of increasing risk of columnaris disease. In field studies it has been noted that as river temperatures rise to about 10-12.8°C, researchers begin isolating columnaris strains from water (Fujihara and Nakatani, 1970). Temperatures above 13°C were associated with the occurrence columnaris in thirteen species of fish collected from the Columbia River watershed (Fujihara and Huntgate, 1970). In the Fraser River in Canada it was found that prespawning mortality of sockeye was eliminated by maintaining average temperatures on the spawning grounds of 12.8°C (Colgrove and Wood, 1966). This finding was generally supported by the work of Johnson and Brice (1952, as cited in Colgrove and Wood, 1966) who exposed four species of salmonids to columnaris for six months and found that no mortalities developed when daily maximum temperatures were 12.8°C or less. At maximum temperatures of 15.6-18.3°C, mortalities increased to 0.7-15.5% in three species but remained zero in the fourth, and at maximum temperatures 18.3-21.1°C all four species showed high mortalities (37.5-82%). These results are supported by other researchers studying columnaris under natural environmental conditions.

The spread of columnaris throughout the Columbia River basin has been noted to be linked to the water temperatures occurring during individual years. In warmer years, columnaris disease is widespread throughout the entire basin, but in cooler years, the first major exposure occurred at McNary Dam and the warmer tributaries (Pacha and Ordal, 1970). A difference of heating or cooling natural river water 2.2°C from its natural (17.7-21.7°C) condition was shown to increase and decrease mortality rates in naturally exposed fish (Fujihara, Olson, and Nakatani, 1971). While the decrease resulted in only a modest decrease (4.2%) in mortality (6.2 versus 10.4%), the increase resulted in a more substantial increase (19.5%) in mortality (29.9 versus 10.4%).

At river temperatures of about 15°C isolation of columnaris cultures is typically quite successful (Ordal and Pacha, 1963; Pacha and Ordal, 1970), with 15°C found also to be a demarcation point between high (54%) and moderate (22%) levels of infection in the crowded spawning channels of the Columbia River. Scrapfish collected from waters throughout the Columbia River basin were found to exhibit the disease when warmed to 16.7°C (Pacha and Ordal, 1970). At river temperatures above 18.8°C strains of low and intermediate virulence can be readily isolated from fish (Pacha, 1961; Bell, 1986). Major outbreaks are said to almost always occur during periods in which the water temperature was 18.3-21.1°C (Pacha, 1961), and an average mid-summer river temperature of 20.3°C was associated with a catastrophic outbreak in sockeye salmon in the Columbia River (Fish, 1948).

Laboratory tests generally confirm what has been found through these field or controlled channel studies. A complication is created by looking strictly at mortality rates from these laboratory tests. Fish are generally injected with or exposed to high doses of the pathogen, and some are inoculated with high virulent strains while others with low or intermediate virulent strains. Putting aside these general problems with comparing laboratory test results we can see the same basic patterns emerge as were found in field research. Constant temperatures of less than 12°C result in low to no infections or mortalities (Fryer and Pilcher, 1974; Post, 1987; Fujihara and Nakatani, 1970; Ordal and

Pacha, 1963). Constant temperatures of 15-18°C have produced a wide range of mortalities, but is most characterized by moderate (typically 20-60%) to heavy (80-100%) mortality. In this range, authors that have made the distinction have shown high virulence strains to be commonly associated with the highest mortality (see table J-1 for references). At constant temperature exposures of 20-23.6°C, mortalities of infected fish are consistently very high (70-100%) (Ordal and Rucker, 1944; Fryer and Picher, 1974; Fish and Rucker, 1943; as cited in Ordal and Pacha, 1963; Holt et. al., 1975).

Based on a review of the available literature, it is concluded that for columnaris and *Ichthyophthiriasis*, as well as for warm-water induced diseases in general (see Appendix J for information on diseases not discussed in this section), the following general statements hold true:

1. Average temperatures below 12-13°C significantly and often completely eliminate both infection and mortality;
2. Average temperatures above 15-16°C are associated with often serious rates of infection and noticeable mortality; and
3. Average temperatures above 18-20°C are commonly associated with very severe infections and often catastrophic outbreaks of many fish diseases.

For the purpose of setting water quality criteria, it should be assumed that a weekly average temperature of less than 12-13°C will provide optimal relief from fish diseases by discouraging further infection and transmission, and eliminating any significant risk of mortality in fish that may already be infected. Based on the work of Colgrove and Wood (1966) and in an effort to translate this weekly average value to a general daily maximum, **it is recommended that the 7-day average of the daily maximum temperatures not exceed 14-15°C to ensure optimal relief from disease. This level of protection should be applied at a minimum to waters used for holding, rearing, or spawning by native salmonids.** Doing so will provide safe harbor not only for resident species and critical life stages, but will also serve to reduce or eliminate prespawning mortalities in migrating fish.

It should also be assumed that average temperatures regimes above 16°C will result in a predictable increase in the transmission, infection, mortality level in native fish populations. Based on the work of Pacha (1961) and others and in an effort to translate this weekly average value to a general daily maximum, it is recommended that average daily maximum temperatures of 17-18°C be assumed to be the upper range to prevent substantial risks from disease. This level of protection may be appropriate in lower mainstem river reaches where salmonids, which are the species most identified at risk of mortality in the literature, will not be residing for any significant period of time and will be able to find otherwise safe-haven in colder upstream tributaries. However, if fish are forced to hold behind dams, or will be migrating through these temperatures for more than about a week these temperatures may still allow for some prespawning mortality to occur.

When weekly average river temperatures exceed 20°C, or average daily maximum temperatures exceed 22°C, explosive infection rates and the risk of catastrophic population-level outbreaks in natural populations become a serious concern. This level of risk is very high and should not be permitted to occur in natural waters used as habitat by any of our native salmon.

The research evaluated in this paper has focused on protecting cold-water fish communities, the above recommendations may not be applicable, and are therefore not recommended for application to any designated habitat for warm water fish-species. Information on the disease threats to native warm water fishes was not discovered during the review of the available literature. For warm water fish habitat it is recommended that temperatures be maintained well into the optimum zone for the fish community to maintain the health and thus resistance to potential diseases.

Table J-1 Summary of literature findings for columnaris disease. Detailed discussions are provided in appendix J.

Approximate Temperature Range or Direction	Categories of Effects of Interest noted in the literature associated with the temperature range	Citation from the Literature
< --- 12	Seldom infectious; difficult to isolate in the field; and low (0-8%) fatalities experimentally infected fish.	Fryer and Pilcher, 1974; Post, 1987; Fujihara and Nakatani, 1970; Ordal and Pacha, 1963
13	Organism begins to be to isolate in the water and fish; not associated with measurable prespawning mortality; moderate (0-20%) to high (20-100%) mortality in experimentally infected fish;	Holt et al., 1975; Fryer and Pilcher, 1974; Fujihara and Nakatani, 1970; Johnson and Brice, 1952 as cited in Pacha, and Colgrove and Wood, 1966; Fish, 1944; USEPA, 1976; Fujihara and Huntgate, 1970; Colgrove and Wood, 1966
14.4	Ave. river temperature not leading to disease.	Colgrove and Wood, 1966
< --- 15-15.6	Rarely a problem; mortality from low virulence strains decline; incidence of disease in river declines to 22%	Amend, 1970; as cited in Austin and Austin; Johnson and Brice, 1952 and Rucker, 1944 as cited in Pacha, 1961; Garnjobst, 1945, as cited in Colgrove and Wood, 1966; Fujihara and Olson, 1962, as cited in Colgrove and Wood, 1966
15-16.7	Moderate (31-56%) mortalities become more consistent in infected test fish; disease appears in Scrapfish after temperature elevation; epizootics in aquarium.	Holt et al., 1975; USEPA, 1976; Fryer and Pilcher, 1974; Pacha and Ordal; Colgrove and Wood, 1966, as cited in Pacha and Ordal, 1970; Post, 1987
15.6-16	Moderate (60%) mortality of injured fish; high mortality (80-100%) from high virulence strains; prespawning mortality 63-81%, two week average temperature necessary to initiate pathological effects in river; moderately high (30-64%) mortality in infected test fish	Post, 1987; Pacha and Ordal, 1970; Colgrove and Wood, 1966; Fish, 1944; Ordal and Pacha, 1963; Ordal and Rucker, 1944, as cited in Pacha and Ordal, 1970
15-15.6 --- >	Easy to isolate in the field; associated with seasonal .mortality in hatcheries; mortality and morbidity become factors in natural waters; outbreaks of high virulence strains; initiated mortalities in migrating sockeye; disease incidence in river becomes high (54%)	Ordal and Pacha, 1963; Fujihara and Nakatani, 1970; Post, 1987; Bell, 1986; Colgrove and Wood, as cited by Gilhousen, 1970; Fujihara and Olson, 1962, as cited in Colgrove and Wood, 1966

13-18	Low (0.6-7.7%) moderate (20-50%) and high (60-100%) mortality in exposed test fish. Known virulent strains resulting in highest mortality.	Fryer and Pilcher, 1974; Johnson and Brice, 1952, as cited in Pacha, 1961; Pacha and Ordal, 1970
15.6-18.3	Low (0.7-15.5%) mortality in three species of salmonids	Johnson and Brice, 1952, as cited in Colgrove and Wood, 1966
15.9-19.9	Fluctuating river temp with low (6.2%) mortality	Fujihara, Olson, and Nakatani, 1971
17-18	Mortality sometimes moderate (37- 50%) but mostly very high (99-100%) in infected test fish; explosive infections; high mortality from all strain types	Fryer and Pilcher, 1974; Holt et al., 1975; USEPA, 1976; Pacha and Ordal, 1970
17-21.7	Fluctuating river temp with 10.4% mortality	Fujihara, Olson and Nakatani, 1971
< --- 18	Deaths greatly diminish	Ordal and Pacha, 1963
18 --- >	Mortality high from all strains, low and moderate strains isolated	Johnson and Brice, 1952, and Rucker, 1944, as cited in Pacha, 1961
18-22	Mortalities moderate to high (37.5-82%) in infected fish; most outbreaks; fish found releasing columnaris; Epizootics	Johnson and Brice, 1952, as cited in Colgrove and Wood, 1966, and as cited in Pacha, 1961; Fujihara and Nakatani, 1970; Amend, 1970, as cited in Austin and Austin, 1987; and Davis, 1922, Nigrelli and Hunter, 1945, Isom, 1960, and Johnson and Brice, 1952, as cited in Pacha, 1961
19.9 –23.9	Fluctuating river temp with 29% mortality	Fujihara, Olson and Nakatani, 1971
20-21	Outbreaks of low virulence strains; mortality high (70-100%) in infected test fish, catastrophic outbreak, 28-75% morbidity in river population; outbreaks in physically stressed fish; serious epidemics	Bell, 1986; Ordal and Pacha, 1963; Pacha and Ordal, 1970; Fish, 1948; Holt et. al., 1948; Fryer and Pilcher, 1974; Post, 1987; Fish, 1944
22.2-23.6	Mortality 100% in infected test fish, summer maximum associated with devastating outbreak	Ordal and Rucker, 1944, as cited in Pacha and Ordal, 1970; Fish, 1948; Fryer and Pilcher, 1974
25-37	Optimum growth temperature for organism	Garnjobst, 1945, as cited in Colgrove and Wood, 1966; Pacha, 1961; Post, 1987

VI. Miscellaneous Indigenous Species

With the possible exception of two amphibian species, the tailed frog and the torrent salamander, and one fish species, the smelt, no other aquatic organisms have been identified that appear as sensitive to temperature increases as the native salmonids and char (see Appendices G and H). This paper has focused on protecting species sensitive to temperature increases, however, it is important to remember that some of our native populations thrive in waters warmer than what is optimal for salmonids.

For the water quality standards to be fully protective in the ecological sense, they must recognize the continuum of temperature changes from upstream to downstream and between ecoregions and waterbody forms. The water quality standards should acknowledge that certain waters that are naturally not optimal for salmonids may be ideally suited for other native species. It is appropriate that some of these naturally warmer waters have separate standards that consider more accurately the warm water tolerant communities that have historically existed.

1. Sensitive Amphibians

Three stream dwelling amphibians are of concern when it comes to temperature alterations (Appendix H). These are the *Rhycotriton* species (3 species of torrent salamanders), the *Dicamptodon* species (Pacific and Copes giant salamanders), and *Ascaphus truei* (tailed frog).

Rhyacotriton species are found in temperatures ranging from 5.9-10.9°C, and eggs have been found at 8-9°C then taken to the lab and incubated successfully at 8-9°C. Like most amphibians, *Rhyacotriton* can withstand high daily peak temperatures. When acclimated in a laboratory to temperatures of 13-14°C, *Rhycotriton* has a critical thermal maximum (CTM) of 27.8-29°C.

Dicamptodon species have larvae noted to develop at 12-16°C in the field. Larvae may develop for 2 years prior to becoming adult salamanders. Adults spawn in the spring when waters are warming, but may also spawn in the fall. While the Pacific giant salamander becomes a terrestrial salamander, the Copes giant salamander does not.

Ascaphys truei is typically found in waters from 4.4-14°C. Embryonic development can occur between 5-18°C. Tadpoles from 1-2 years old prefer waters around 5-8°C, but 3-4 year olds prefer waters of 12-16°C. *A. truei* larvae have a critical thermal maximum of 28.9-30.1°C and adults of 23-24°C; when both are acclimated at 23°C. The nine day LT50 for tailed frog larvae was determined to be 23°C. Tadpoles may develop from 1 to 4 years, depending on the individual stream, before metamorphosis.

Larvae of all of these stream breeding amphibians rely primarily on the perennial flows of 1st and 2nd order streams (mostly Type 4 and 5, but also some smaller Type 3 streams). Their rates of growth, and thus time prior to metamorphosis, is affected by temperature and food. Warmer waters within their tolerance range may speed up development.

Sensitive stream breeding amphibians would not be fully protected at temperatures acceptable to some salmon and trout. However, these amphibians often occur high in the drainages often above the upper limits of many fish species. Though these species can withstand daily peak temperatures from 22-27°C their optimal limits are much lower. The giant salamanders are typically found only in streams with temperatures below 16-17°C, torrent salamanders are typically found below 11°C, and the young embryos of the tailed frog prefer temperatures below 8°C.

2. Other Sensitive Fish Species

Smelt were identified through the literature as possessing sensitive temperature limits. The studies on smelt indicate they have a lower lethal temperature limit than do the salmonids and a lower optimum temperature preferendum. Longfin smelt (*Spirinchus thaleichthys*) was identified as having a limit of occurrence of 18.3°C by Wydoski and Whitney (1979). This corresponds well to acute exposure testing using the Eulachon smelt (*Thaleichthys pacificus*) by Snyder and Blahm (1971) who found a change from 10 to 18°C resulted in 50% mortality to adults in less than one hour, and 50% mortality occurring in 26 minutes at an exposure of 21°C. While temperature increases from 10°C to 13°C and 15°C, did not induce mortality over a 50-hour holding time, none of the females exposed to the higher test temperatures deposited their eggs. **USEPA (1971)** notes that in temperature studies on the eulachon, **Smith and Saalfeld (1955; as cited in USEPA, 1971)** reported the fish entered the Columbia River when the temperature was between 2 and 10°C but they migrate up to and beyond the Cowlitz River (RM 68) when the Columbia is approximately 4.4°C. The smelt run was delayed five weeks from entering the Cowlitz River because of low water temperatures during December 1968 and January 1969 **(Snyder, 1970; as cited in USEPA, 1971).** Eulachon eggs appear to be more tolerant than adults to temperature increases. The eggs can withstand a temperature of 14°C from a base temperature of 4 to 8°C without appreciable mortalities **(Parente and Ambrogetti, 1970; as cited in USEPA, 1971)**, but a 3°C increase halts maturation of adult females. In tests in 1968 and again in 1969, it was observed that female smelt exposed to water heated 3.89°C above river temperatures were reluctant to spawn. Adult female smelt are less tolerant of temperature changes than other fish. Bell (1986) in a general review on the temperature requirements of fish suggested that the range for smelt was 3.8-12.7°C, and the preferred spawning range was 7.2-8.3°C. The spawning range identified by Bell, closely matches that observed for longfin smelt in the Cedar River in Washington. Wydoski and Whitney (1979) suggest that spawning occurs primarily in late February (with a range of mid-January to mid-April) when the river was between 4.4-7.2°C. They also note a British Columbia stock that hatches at 9.4-10.6°C approximately

25 days after spawning. Given that adult spawners and outgoing juveniles may be in fresh waters as late as March to mid-April, and their temperature requirements may be more strict than most salmonids, the protection of smelt is an important consideration in setting water quality standards. **In waters supporting smelt, it is recommended that the 7-day average of the daily maximum temperatures not exceed 12-14°C prior to May 1; with no single daily maximum temperature greater than 16°C.** This will allow most stocks to spawn and have the newly hatched juveniles return to the sea (or lake where a landlocked population) under tolerable temperature conditions.

3. Stream Macroinvertebrates

Only a relatively small number of studies were found that tested the thermal tolerance of stream macroinvertebrates (Appendix H). Most of the species examined have thermal limits as higher than the Pacific salmon and trout species found in Washington (**Sprague, 1963; Nebeker and Lemke, 1968; Moulton et al., 1993; Sherberger et al., 1977, as cited in Beschta et al., 1987; Craddock, 1970 and Hair, 1971, as cited in USEPA, 1971**). However, two sets of studies were found that suggest individual species may sometimes as sensitive, and in some cases more sensitive, as our indigenous salmonids.

Gaufin and Hern (1971; as cited in Moulton et al., 1993) reported a range of 21.7 to 30.1ºC in mean TL_m for six species of caddisflies held at 6.4ºC. The lowest TL_m (21.7ºC) was observed for *Parapsyche elsis* Milne, (Hydropsychidae) an inhabitant of cold, fast-flowing mountain streams while the highest TL_m (30.1ºC) was recorded for *Hydropsyche sp.* collected from a marsh-lake outflow.

USEPA (1971) conducted 96-hour lethality studies to examine the heat tolerance of late instar larvae of 15 species of aquatic insects and one species of amphipod. USEPA reported that a marked difference in sensitivity was apparent in the different species. A mayfly, *Cinygmula par* Eaton, died at 11.7°C and was the most sensitive of all the species tested. This species is found in very cold clear mountain streams. The freshwater shrimp, *Gammarus limnaeus* Smith, proved to be surprisingly sensitive to temperature increases, with 50% lethality at 14.5°C. *Ephemerella doddsi* Needham, a small, widely distributed mayfly characteristic of cold turbulent streams in the Intermountain Region, was also very sensitive with a TLm value of 15.4°C. A lotic species of mayfly, *Hexagenia limbata* Guerin, was much more tolerant than other mayflies tested with a TLm of 26.6°C. Considerable difference existed between the three stoneflies tested. *Isogenus aestivalis* (Needham and Claassen) was quite sensitive, 50% dying at 16°C, while *Pteronarcella badia* (Hagen) and *Pteronarcys californica* Newport, two closely related species survived increases to 24.6 and 26.6°C, respectively. Six species of caddis flies were tested and clearly reflected thermal differences in their habitat requirements. *Parapsyche elsis* Milne, which is largely restricted to cold, fast flowing mountain streams, had a TLm of 21.8°C while *Hydropsyche* sp. Taken from a slow flowing stream draining a marshy lake was very tolerant with a TLm of 30.1°C. In long-term (12-30 days) thermal bioassays of five aquatic insects, the stonefly *Pternorcella badi* was most sensitive with 50% mortality occurring at 18.1-20.5°C within 24-30 days (its 96-hour TLm was 22.55°C). *Ephemerlla grandis* Eaton experienced 50% mortality in 12 days at 21.5°C (its 96-hour TLm was also 21.5°C). *Pteronarcys californica* Newport experienced 50% mortality in 25 days at 20°C (its 96-hour TLm was 27°C). None of the three most sensitive species tested in the 96-hour tests (*C. par, E. doddsi, and G. limnaeus*) were included in these long-term tests.

It does not seem appropriate to establish specific temperature criteria for the more sensitive macroinvertebrates, since the values were based on a single test results. However, **to confidently protect all species of macroinvertebrates in cold water stream assemblages require temperatures be maintained towards the lower end of the upper optimal range established for the fish communities**.

VII. Miscellaneous Indigenous Fish Species

The following graphical summary includes only those species for which temperature information was available. Appendix G includes a discussion of these and all other indigenous fish species not discussed previously, though in many cases the information pertains only to their general habitat associations and life-history traits. Information is not adequate to propose temperature criteria for any of these species; however, the information is useful in evaluating whether the criteria recommended to protect the native salmonids and char will also be protective of these other species.

Western Brook Lamprey **10** (Spawn peak, May)

Pacific Lamprey **12.8** (Too cold for incubation)
15.6 (Successful incubation)
15---------------------------------25 (Successful incubation)

White Sturgeon **8.9---------------------------17.2** (Spawn, May-July)
10---------------------------18 (Spawning)
14 (Optimal Incubation)
14 (Most spawning occurred)
17.2-17.8 (summer occupation)
18 (Elevated embryonic mortality)
18------20 (Limited spawning occurs)
20 (Complete embryonic mortality)

Eulachon Smelt **2-------------10** (River temp during spawning migration)
< --- 13 (Successful egg deposition)
18 (Rapidly lethal to adults)

Longfin Smelt **18.3** (Limit to occurrence)
4.4---7.2 (Spawn, primarily February)
9.4-10.6 (Eggs hatch)

Smelt (general) **7.2-8.3** (Preferred spawning)
8.3 (Optimal hatch)

Chiselmouth **17 --- >** (Spawn in summer)

Redside shiner **6.7---23.9** (Range)
10 --- > (Spawn, April-July)
12.8------------------20 (Summer preference)
19--------22 (Fluct. better than 12-15)
25 (24 hr LT50 at 9-11C acclimation)
27.6 (24 hr LT50 at 14C acclimation)

Longnose Dace **11.7 --- >** (Spawn, June-early July)
12.8-----------------------------21.2 (Prefers)
19.4-------------------------30 (Found over two years)

N. Squawfish **16.1---------------------------24.4** (Prefers)
18.3 (Spawn, late May-July, hatch)
29.3 (24 hr LT50 at 19-22C acclimation)

Tui Chub **12.8--------15.6** (Spawn, May-June)

Peamouth **12.2 --- >** (spawn, late May-early June)
26.6 (24 hr LT50 at 14C acclimation)
27 (24 hr LT50 at 11.5C acclimation)

Lake Chub **13.9** (In streams) **18.9** (Spawn, Apr-Jun, lakes)

Speckled Dace **17.8—18.9** (Eggs hatch)
Largescale sucker **29.4** (24 hr LT50 at 19C acclimation)
Sucker (generic ref.) **11.7-------------------------21.7** (Prefers)

Longnose Sucker **5 --- >** (Spawn, early spring)

Mtn. Sucker **12.8-------------------------------21.1** (Summer preference)

11.1----------------------------18.9 (Spawn, June-July)

Burbot **1.7** (Spawn, Jan-Feb) **21.2** (Final preferendum)

T-S. Stickleback **17.8** (Spawn, May-Aug, hatch)
26 (LT50 in 6 days)

Shorthead Sculpin **< --- 15.6** (Prefers) **23.8** (Found)

Piute Sculpin **15 --- >** (Frequents)
25 (Found)
12.2 (Spawn, May-June)

Prickly Sculpin **10------------------------------17.8** (Typical)
24.1 (24 hr LT50, 18-19C acclimation)
27.8 (Found)

Margined Sculpin **12.8----------------------18.9** (Typical)

Mottled Sculpin **12.8---------------------18.3** (Preferred)
15.6-------------------23.3 (Found over two years)
16.5 (Preferred)

21.1 (Found)
10-------------------15.6 (Spawn, Feb-June, hatch)

Riffle Sculpin **< --- 15.6** (Prefers)
22.2 (Found)
< --- 27.8 (Survive in lab)

Reticulate Sculpin **10--------------------------17.8** (Typical)
25.6 (Found)

Starry Founder **11.1** (Ave. temp., spawn late Nov-Feb)

Though the temperature preferences of most of these species appears to overlap that of rainbow trout, some of these species will thrive in waters warmer than what is optimal for rainbow trout. Species such as dace and redside shiner may actually rely on their ability to tolerate warmer water to maintain strong populations where they exist in sympatry with rainbow trout or other salmonids.

VIII. Synthesis of Requirements for Cold Water Fish Habitat

The following sections summarize the individual recommendations made previously to protect the state's cold water aquatic habitats.

1. Fish Disease

In summary, for most of the warm water enhanced diseases examined:

A) Average daily maximum temperatures below 14-15°C significantly and often completely eliminate both infection and mortality;
B) Average daily maximum temperatures above 17-18°C are associated with often serious rates of infection and mortality; and
C) Average daily maximum temperatures above 20-22°C are commonly associated with very severe infections and often catastrophic outbreaks of many fish

It is recommended that the 7-day average of the daily maximum temperatures not exceed 14-15°C in waters used for spawning, juvenile rearing, or long-term adult holding. It is also recommended that to protect salmonids and char from the risks of high-temperature induced fish diseases. It is further recommended that the 7-day average of the daily maximum temperatures not exceed 17-18°C in waters used exclusively for the pass-through migration of salmonids.

2. Temperature Sensitive Species Other than Char and Salmonids.

Of the species evaluated in this paper, only the freshwater spawning life-stage of the state's smelt species appear to have temperature requirements more sensitive than some of the salmonids. Although the data on smelt was not sufficient to establish specific water quality criteria, the fact that smelt will occur in waters also used by migrating and rearing salmon allows the data which is available to be used for supporting the salmon temperature requirements. The primary concern is the acute sensitivity of adult spawners to warm water and temperature increases, and the available information helps define winter to early spring temperature limits for waters supporting salmon and anadromous migration. In waters supporting smelt, it is recommended that the 7-day average of the daily maximum temperatures not exceed 12-14°C prior to May 1; with no single daily maximum temperature greater than 16°C. This will allow most stocks to spawn and have the newly hatched juveniles return to the sea (or lake where a landlocked population) under temperature regimes that should prevent acute lethality or interfere with spawning activity.

3. <u>Temperature Sensitive Amphibians</u>

Three stream dwelling amphibians are of concern when it comes to temperature alterations. These are the *Rhyacotriton* species (3 species of torrent salamanders), the *Dicamptodon* species (Pacific and Copes giant salamanders), and *Ascaphus truei* (tailed frog). The temperature sensitive larvae of these stream breeding amphibians rely primarily on cold perennial flows.

Although all of these species can withstand short-term exposures in the laboratory up to 22-27°C, their optimal limits are much lower, similar to the salmonids. The giant salamanders are typically found only in streams with temperatures below 16-17°C, torrent salamanders typically occur only below 11°C, and the young embryos of the tailed frog prefer temperatures below 8°C. Data was not sufficient to set definitive temperature standards for our indigenous amphibians. However, any temperature criteria set to protect salmonids should be set in a manner that will ensure widespread occurrence of temperatures in the ranges identified above for the states' stream dwelling amphibians. Temperature requirements for char are probably best associated with the needs of the tailed frog, and headwater reaches of streams meeting the salmon standards should be suitable for protecting the temperature sensitive the torrent salamander.

4. <u>Temperature Requirements for Char, Salmon, and Trout</u>

Spawning Temperatures:

Spawning signals the beginning of the most sensitive stage in the life-cycle of most of our indigenous fish species. For that reason, special consideration is given to ensuring that criteria to protect incubation are applied at the proper time of the year. Estimates of the spawning periods for the state's salmonid populations are presented in more detail in appendices D through G.

In Table 1 below, the upper end of the estimated upper optimal temperature range is shown along with the earliest date at which spawning is initiated by most stocks, and the lower end of the estimated upper optimal temperature range is shown along with the date after which the spawning season midpoints for most stocks occur. This approach produces a somewhat idealized temperature regime for Washington's waters (seen in Column 3 of Table 1). The spawning dates used in this analysis come from stock inventory reports produced by the Washington State Department of Fish and Wildlife (summarized in Appendix D). These dates were submitted by regional habitat managers familiar with the behavior of the stocks they manage. It is not clear, however, that these dates were set with a high level of precision or supporting documentation. Some additional considerations and concerns with applying these dates too strictly include:

- Documentation on spawner timing does not include information on the seasonal trends in water temperature, and it may well be that the earliest spawning dates reflect unusually cool years.

- Documentation on spawning time does not commonly identify the elevation where spawning occurs or the temperature at the time of spawning. In the upper reaches of watersheds, glacially fed streams reach optimum spawning temperatures during periods of the year that would be too warm in the spawning reaches located lower in the watersheds.

- A single stock may have early, middle, and late spawning populations with slightly different optimum temperatures. Early runs may have a slightly higher temperature tolerance, and later runs a slightly greater tolerance to cold waters. Based on the literature reviewed, however, these differences appear minor, but it is a factor that should be acknowledged.

- While ripe adults cannot hold for more than a few days to a week without causing a potential decrease in fertility and spawner success, warm waters also tend to inhibit maturation thus moderating the need to spawn immediately upon reaching the spawning grounds.

Since the temperature criteria being here are optimal values for fertilized eggs and developing embryos, and since they apply to climatically warm periods as well as average and cool periods (and the spawning periods listed may represent early spawning during climatically cool periods), they are very stringent values and should not be casually applied to streams during the months of the year where natural peak summer temperatures commonly occur. Thus while serving as good general guidelines, the spawning dates used in this analysis should not be relied upon too heavily to set state-wide criteria for incubation.

In Washington, temperatures begin to fall in mid August and have generally declined significantly by mid-September. This matches the general spawning pattern of our state's fall spawning salmonids; where spawning occurs during the cooling trend that follows peak summer temperatures. Spring spawning salmonids, on the other hand, begin spawning as soon as water temperatures warm sufficiently from the winter low temperatures. The spawning inventory dates suggest that most species and stocks assessed do not begin spawning until after September 1; the one exception is chinook salmon. It is recommended that the period of September 1 through June 1 be used to represent the period of time during which the eggs and embryos of Washington's salmon and trout stocks will be incubating.

Table 1. Upper optimal temperature regimes to achieve full spawning protection of the 9 key cold-water fish species indigenous to Washington.

Critical Spawn Dates Estimated dates of spawning initiation and midpoints		**Upper Optimal Temperature Range Recommended** 7-day average daily maximum (°C)	**Most Recommended Value**	**Single Daily Maximum Temperature Recommended** Daily maximum (°C)
Chinook	1-Aug	12	**12**	14.5
Chinook	23-Aug	11	**11**	14.5
Pink	1-Sep	12	**11**	14.5
Chum	1-Sep	12	**11**	14.5
Char	1-Sep	6.5	**6.5**	8
Sockeye	7-Sep	12	**11**	14.5
Char	15-Sep	5.5	**5.5**	7
Coho	22-Sep	11	**11**	14.5
Pink	22-Sep	10	**10**	13.5
Sockeye	3-Oct	10.5	**10**	13.5
Chum	8-Oct	10.5	**10**	13.5
Coho	1-Nov	9	**9**	13.5
Spring Season Begins				
Cutthroat	1-Apr	10	**9**	13.5
Rainbow	7-May	9	**9**	13.5
Steelhead	7-May	13	**12**	13.5
Rainbow	15-Jun	12	**12**	14.5
Steelhead	15-Jun	14	**12**	14.5

<u>State-Wide Salmonid Spawning Recommendations</u>

Any state-wide temperature standards should be designed so that the following spawning criteria will be met:

1) **In waters used for spawning by salmon, steelhead, cutthroat trout, and non-anadromous rainbow trout**, the 7-day average of the daily maximum temperatures (7-DADM) should not exceed 12°C from September 1 to June 1, with no single daily maximum temperature greater than 14.5°C.

2) **In waters used for spawning by native char**, the 7-DADM should not exceed 6.5°C after September 1, with no single daily maximum temperature greater than 8°C.

Since the above recommendation represents general state-wide spawning patterns, salmonid stocks with incubation periods not reasonably described by these ranges should be protected by establishing waterbody specific application dates in the regulation.

Juvenile Rearing Temperatures:

Information on the juvenile rearing and adult holding temperature requirements of the char, salmon, and trout taken from Sections IV are summarized in Table 2 below. From this it can be seen that char and rainbow trout have relatively distinct summertime temperature requirements, in comparison to the Pacific salmon. As discussed previously, it is recommended that to prevent problems with warmwater diseases, average daily maximum temperatures should not exceed 14-15°C where fish may rear or hold during the summer. Thus in Table 2 below, the "most recommended value" is typically set at 15°C, even if the potentially optimal range extends to 17°C or more, to prevent unnecessary risks of disease.

Table 2. Temperature requirements for the support of juvenile rearing and out-migration, where applicable, of the 9 key indigenous cold water fish species.

Fish Species, or Specific Species Life-stage	**Upper Optimal Average Maximum Temperature** 7-day average daily maximum (°C)	**Most Recommended Value**	**Upper Optimal Single Daily Maximum Value** Highest daily maximum (°C)	**Most Recommended Value**
Char (Trib. Rearing)	10-11	10	13-14	13
Char (Sub-adult)	11-12	12	13-14	14
Cutthroat	13-15.5	15	19-20	20
Steelhead	16.5-17.5	15	21-23	21
Sockeye	12-16	15	21-22	21
Chinook	14.2-16.8	15	20-21	20
Coho	14-17	15	20-21	20
Rainbow	15.5-18	18	21-23	22
Pink	12.5-14.5	N/A	19-20.5	20
Chum	N/A	N/A	20-21	21

<u>State-Wide Salmonid Rearing Recommendations</u>

The following represents a general state-wide recommendation for temperature criteria to protect the rearing of the state's salmonid species.

1) In waters used for rearing by **salmon, or steelhead and cutthroat trout**, temperatures should not exceed 15°C as a 7-day average of the daily maximum temperatures (7-DADM), with no single daily maximum temperature greater than 20°C.

2) a) In waters used for the **tributary rearing by native char**, the 7-DADM should not exceed 10°C, with no single daily maximum temperature greater than 13°C.

3) b) In **mainstem rivers used for rearing by subadult native char**, the 7-DADM should not exceed 12°C, with no single daily maximum temperature greater than 14°C.

4) In waters used exclusively for rearing by **non-anadromous rainbow trout**, temperatures should not exceed 18°C as a 7-DADM, with no single daily maximum temperature greater than 22°C.

Adult Fish Migration

Table 3 below summarizes the temperatures regimes recommended to protect the active migration salmonid and char species from Section IV. These temperatures were selected to represent levels which would not block migration, cause serious depletion of energy reserves, create serious risks from disease outbreaks, or reduce the viability of egg stocks. The widespread observation of blockages being caused by temperatures of 21°C or greater suggest any statewide criteria for the protection of migrating salmonids should not allow daily maximum temperatures to exceed 21°C.

Table 3. Temperature requirements to support the summer migrations of the 9 key indigenous cold water fish species.

Fish Species	**Upper Optimal Temperature Range Recommended** 7-day average daily maximum (°C)	**Most Recommended Value**	**Highest Single Daily Maximum Temperature Recommended** 1-day max (°C)	**Most Recommended Value**
Char	14-17	17	22	21
Chum	15-17	17	22	21
Cutthroat	14.5-17.5	17.5	23	21
Steelhead	14.5-17.5	17	21.5	21
Pink	14-17.5	17	21	21
Coho	16-18	17.5	23	21
Sockeye	15.5-17	17	21	21
Chinook	15-17.5	17	22.5	21

Concerns over outgoing smolts and over disease to adult spawners should establish a basis for any average daily maximum temperature criteria. The research reviewed for indicate that average daily maximum temperatures above 17-18°C are associated with often serious rates of infection and mortality, and the average daily maximum water temperatures experienced by outgoing smolts should not exceed 13.3-14.3°C.

State-Wide Salmonid Migration Recommendations

1. **In lower mainstem river segments used almost exclusively by salmon, char, and trout species for direct and expedient passage through to the sea as juveniles or from the sea as adults**, water temperatures should not exceed 17°C as a 7-day average of the daily maximum temperatures between June 1 and September 1, and not exceed 14°C as a 7-day average of the daily maximum temperatures from June 1 to September 1, with no single daily maximum temperature greater than 17°C.

Lethality:

Daily maximum criteria are recommended to protect specific species in Tables 2 and 3 above. However, it seems important, particularly considering some of the low lethal levels reported in the literature, to evaluate whether or not individual pieces of research unduly influenced the recommendations. In the following two figures, the lethality data for all salmon and char species are combined and are examined in two different ways to develop a greater basis for recommending state-wide daily maximum criteria.

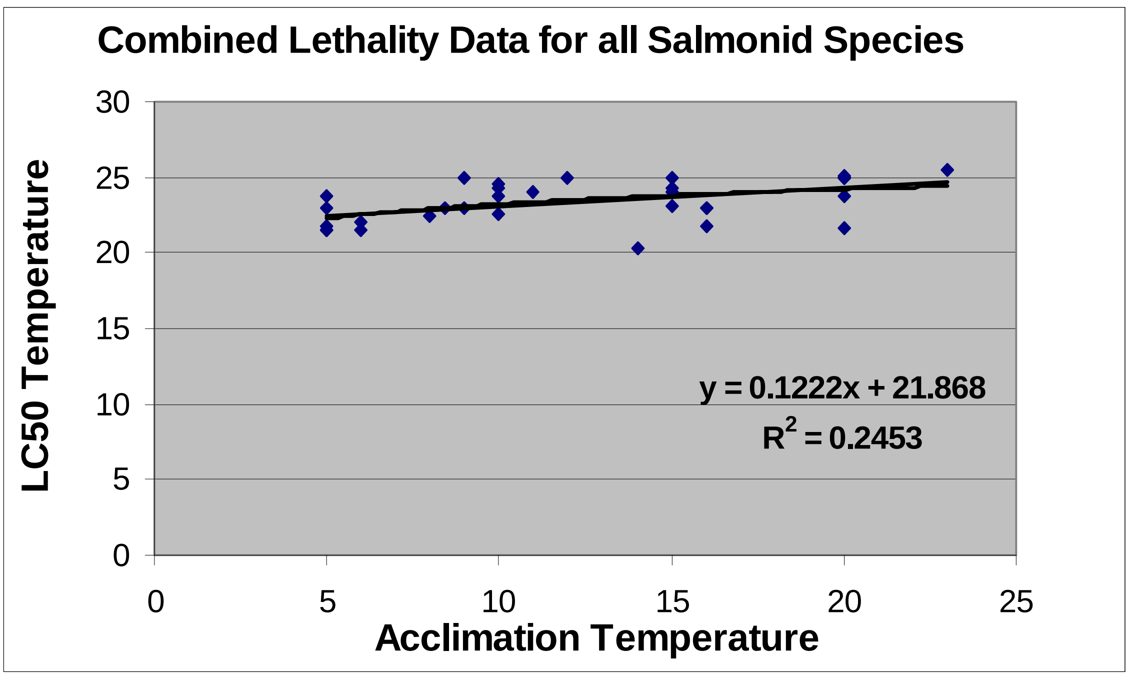
In Figure 1 below, all of the 7-day LT50 data (50% of test organisms die over a 7-day constant exposure test) for char and salmonids are presented by acclimation temperature. This distribution is then used to make criteria recommendations for individual acclimation temperatures. It can be seen that at low acclimation temperatures constant exposure to temperatures just above 22.5 would be expected to result in 50% mortality over a week's exposure. Adjusting this value (as discussed previously) to reduce it to a level where no lethality would be expected to any adults or juveniles would result in a recommendation that daily maximum temperatures not exceed 20.5°C.

In Figure 2 below, resistance time to short periods of exposure to high temperatures, as might occur in a natural fluctuating stream environment, is considered. The concept of resistance time is very important to estimating potential lethality. It is well demonstrated that it is the time spent above a lethal threshold that determines whether or not short term lethal effects will occur. Different peak temperatures (e.g., 22, 24, 27, 30°C), may all be lethal to an organism, but the organism can likely withstand these temperatures for variable lengths of time. A population of fish may be able to withstand 21°C for 7 days of constant exposure without any mortality, but have 50% of the population die after 2 days at 24°C. At 27°C 50% mortality may occur after less than 2 hours of exposure, and at 30°C complete mortality may occur in just a few minutes.

In considering the effect of repeated hot days, it is important to incorporate the potential for cumulative effects over a series of days. DeHart (1974) found that lethal effects occur in relation to the area of the temperature time curve that is above a fish's incipient lethal level (ILL); an accumulation of thermal effects occurs over periods of several days when the daily temperature cycle fluctuates above the incipient lethal level; and the time above the incipient lethal level influences the thermal resistance time independent of the lower temperatures experienced in fluctuating tests. In other words, the ability of a fish to resist a single day's exposure to a lethal temperature may not be sufficient, and fifteen minutes spent at 4°C over the ILL is of more consequence than the same time spent at 2°C over the ILL.

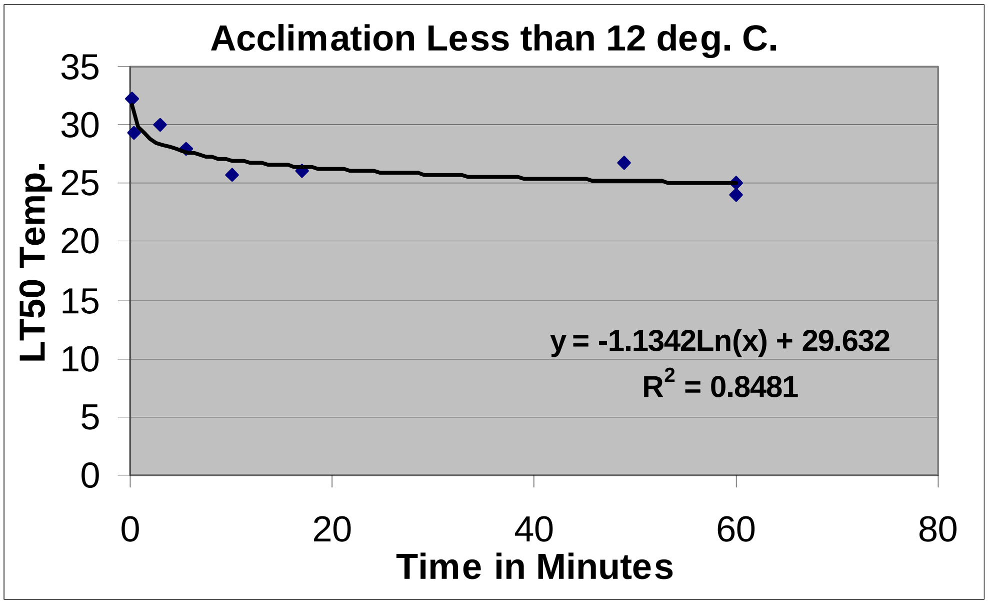
In Figure 2, LT50 results are plotted for durations of one hour or less. At acclimation levels less than 12°C, 50% mortality can be expected to occur at 25°C with a one-hour exposure, or at 24.2°C with a two-hour exposure. Adjusting these values to reduce them to levels where no lethality would be expected would result in recommendations that temperatures not exceed 23 or 22°C respectively. Since information suggests that adults are more sensitive than juveniles (all of the 1-hour or less data were for juvenile fish), and the effects of lethal exposures are cumulative at least over a period of succeeding days, it would be prudent to assume that lethality may occur with repeated exposure to daily maximum temperatures greater than 21-22°C. This estimate is very similar to the results (20.5-21.1°C) that were found at low acclimation temperatures in the approach shown above in Figure 1.

Figure 1. Combined lethality data for all salmonid species (based on 7-day LT50 estimates).



Acclimation Temperature	Combined LT50 for all Salmonids	Estimated LT1 with NAS Adjustment
5	**22.48**	**20.5**
10	**23.09**	**21.1**
15	**23.7**	**21.7**
20	**24.31**	**22.3**

Figure 2. Instantaneous lethality to salmon and char (based on LT50 data for exposure periods of less than 1-hour).



Time to LT50	Accl. <12C
1 sec	34.32
30 sec	30.42
1 min	29.62
60 min	24.99
120 min	24.2

5. Warm Water Aquatic Life

Water quality standards must be applied in some fashion to all types of waterbodies; however, some waters will naturally have higher temperatures than what would support healthy populations of salmonids, even the relatively temperature tolerant rainbow trout.

A natural warm water fish community in Washington would be characterized by the presence of redside shiner; tui chub; margined, mottled, or piute sculpin; longnose or speckled dace, sucker, and northern squawfish. These fish are known to exist in our warmest waters, where they often out-compete introduced populations of rainbow trout. Insufficient information exists to develop individual water quality recommendations for these species, however, so it is recommended that they be considered broadly as a community. Establishing criteria to protect our temperature tolerant non-salmonid fish species will also provide protection for desirable introduced warm water sport fish species such as bass and crappie (see Appendix I).

In general, Washington's indigenous warm water fish communities thrive in waters that have summer maximum temperatures as high as 25-27°C, though most prefer waters below 18-20°C. It is recommended that in waters supporting communities of indigenous warm water fish, the 7-day average of the daily maximum temperatures should not exceed 20°C from June 1 to August 31; with no single daily maximum over 25°C. Further, the 7-day average of the daily maximum temperatures should not exceed 15°C from September 1 to May 31; with no single daily maximum over 20°C to support the spring spawning period.

It should also be explicitly specified in the regulation that: *"The Warm Water Aquatic Life category may only be applied to waters that do not have naturalized populations of, or serve as migration corridors for, indigenous salmonids or char. It is appropriate only where the dominant species under natural conditions would be temperature tolerant indigenous non-salmonid species such as dace, redside shiner, chiselmouth, sucker, and northern squawfish; and which may also be serving as habitat for introduced warm water tolerant sport-fish species such as bass and crappie."*

IX. Boundaries Between Aquatic Life Uses

When a waterbody extends from glacially fed streams in an upper watershed through major rivers and finally to the Pacific ocean it goes through transformations in its physical characteristics. For temperature, this transformation is typically that the water gradually becomes warmer until it reaches the cool marine water. Water quality standards attempt to establish fixed boundaries at various points along this continuum to protect differing communities of aquatic life. This process works very well so long as we always move from cool higher elevations down to warmer lower reaches, but it does not work well where the warmer water is flowing into rivers or marine waters that have colder water quality criteria assigned. This tends to occur where low elevation streams enter Puget Sound or the Ocean, or where small warm streams on the arid eastside of our state flow into larger rivers that are remaining relatively cool because of their size and their source waters. At these junctions, or boundary areas, a stream or river meeting its assigned water quality criteria may cause a localized failure of the receiving water stream or marine embayment to meet its assigned water quality criteria.

Language in the existing water quality standards regulation states: "At the boundary between waters of different classifications, the water quality criteria for the higher classification shall prevail." This requirement creates areas of technical violation anywhere a water with warmer water quality criteria drains into a waterbody with cooler water quality criteria.

It is recommended that some language be added to the regulation that modifies this strict requirement to state: "*Temperatures must be maintained such that the water quality criteria of downstream waters are fully protected. An area of mixing, and localized non-attainment, however, can be allowed in the vicinity of where an upstream waterbody* *segment having less stringent criteria enters a downstream waterbody segment having more stringent criteria. This mixing proviso is allowed only where the localized change in quality would not have a likely potential to block or otherwise impair the aquatic life of the downstream waters.*"

X. Full Recommendations to Fully Protect Indigenous Species

The following recommendations consider the summary information presented above and seek to establish groups of species where possible that have similar temperature requirements. It is worth noting that the optimal ranges established previously are slightly exceeded for some species to create possible species groupings; to simplify the standards. It is important to recognize that compliance with these standards must occur in years that are warmer than the climatic average as well as in the years that are at or below the climatic average. This means that to be in compliance, streams will be well below the maximum criteria limit during most years.

There are three alternative recommendations provided below for establishing statewide temperature criteria. The first two alternatives take more generalized and less complicated approaches to setting water quality criteria, and assume that by maintaining optimal peak summer temperatures the natural fall cooling pattern will protect spawning and incubation. Both also work to maintain overall temperature regimes lower than the maximum allowed. The first alternative does this by including a cooler criteria as a 7-day average value and the second alternative does this by reducing the allowable single daily maximum. The third alternative establishes more detailed seasonal-based criteria that are tied directly to protecting the individual life-cycle requirements of key fish and amphibian species. It should be noted, however, that the state has been unable to identify any waterbodies where the sole use is as a migration corridor, thus the provision of Alternative 3(e) seems to have little practical value.

Alternative 1:

a) <u>**Char Spawning, Rearing, and Adult Holding**</u>. **Waters used for the spawning, rearing, and summer or fall holding by adult or juvenile bull trout or Dolly Varden.** Temperatures shall be maintained below 10°C as a moving 7-day average of the daily maximum temperatures, with no single daily maximum temperature greater than 13°C.

b) <u>**Salmon Spawning, Rearing, and Adult Holding**</u>. **Waters used for the spawning, rearing, and summer or fall holding by adult or juvenile Pacific salmon, steelhead trout, or cutthroat trout.** Temperatures shall be maintained below 15°C as a moving 7-day average of the daily maximum temperatures, with no single daily maximum temperature greater than 20°C.

c) <u>**Non-anadromous Rainbow Trout**</u>. **Waters where the only salmonid present is a non-anadromous form of naturalized rainbow or redband trout.** Temperatures shall be maintained below 18°C as a moving 7-day average of the daily maximum temperatures, with no single daily maximum greater than 22°C.

d) <u>**Warm Water Species Spawning, Rearing, and Holding**</u>. **Waters without naturalized populations of indigenous salmonid or char species, or that serve as migration corridors for such species; where the dominant species under natural conditions would be temperature tolerant indigenous non-salmonid species such as dace, redside shiner, chiselmouth, sucker, and northern squawfish.** Temperatures shall be maintained below 20°C as a moving 7-day average of the daily maximum temperatures, with no single daily maximum temperature greater than 25°C from June 1 to September 1; and below 15°C as a moving 7-day average of the daily maximum temperatures, with no single daily maximum temperature greater than 20°C between September 1 and June 1; in waters where the dominant species under natural conditions would be temperature tolerant indigenous non-salmonid species such as dace, redside shiner, chiselmouth, sucker, and northern squawfish. This criteria is not acceptable where naturalized populations of indigenous salmonid or char species exist, or in waters that serve as migration corridors for such species.

Alternative 2:

a) <u>**Char Spawning, Rearing, and Adult Holding**</u>. **Waters used for the spawning, rearing, and summer or fall holding by adult or juvenile bull trout or Dolly Varden.** Temperatures shall not exceed 12.5°C as a single daily maximum.

b) <u>**Salmon Spawning, Rearing, and Adult Holding**</u>. **Waters used for the spawning, rearing, and summer or fall holding by adult or juvenile Pacific salmon, steelhead trout, or cutthroat trout.** Temperatures shall not exceed 17.5°C as a single daily maximum.

c) <u>**Non-anadromous Rainbow Trout**</u>. **Waters where the only salmonid present is a non-anadromous form of naturalized rainbow or redband trout.** Temperatures shall not exceed 20.5°C.

d) <u>**Warm Water Species Spawning, Rearing, and Holding**</u>. **Waters without naturalized populations of indigenous salmonid or char species, or that serve as migration corridors for such species; where the dominant species under natural conditions would be temperature tolerant indigenous non-salmonid species such as dace, redside shiner, chiselmouth, sucker, and northern squawfish.** Temperatures shall not exceed 22.5°C as a single daily maximum in waters where the dominant species under natural conditions would be temperature tolerant indigenous non-salmonid species such as dace, redside shiner, chiselmouth, sucker, and northern squawfish. This criteria is not acceptable where naturalized populations of indigenous salmonid or char species exist, or in waters that serve as migration corridors for such species.

Alternative 3:

a) <u>Native Char and Tailed Frog</u>. **Waters used for spawning, or tributary rearing for the first years of life, by any species of native char or tailed frog.** Not to exceed 10°C as a 7-day average of the daily maximum temperatures year-round, with no single daily maximum temperature exceeding 13°C.

b) <u>Resident Cutthroat Trout, Torrent Salamanders, Subadult Char, and Tailed Frog.</u> **Waters used for spawning or rearing by non-migratory forms of cutthroat trout or torrent salamanders, used for rearing by subadult char or tailed frog.** Not to exceed 12°C as a 7-day average of the daily maximum temperatures, with no single daily maximum temperature greater than 14°C.

c) <u>Salmonids</u>. **Waters used for spawning or rearing by naturalized populations of indigenous salmon or trout.** Not to exceed 15°C as a 7-day average of the daily maximum temperatures from June 1 to September 1, with no single daily maximum temperature exceeding 20°C. Not to exceed 12°C a 7-day average of the daily maximum temperatures after September 1 and prior to June 1; with no single daily maximum temperature exceeding 14.5°C.

d) <u>Non-Anadromous Rainbow and Redband Trout</u>. **Waters where the only salmonid present is a non-anadromous form of naturalized rainbow or redband trout**. Not to exceed 18°C as a 7-day average of the daily maximum temperatures from June 1 to October 1, with no single daily maximum temperature exceeding 22°C. Not to exceed 12°C a 7-day average of the daily maximum temperatures after October 1 and prior to June 1; with no single daily maximum temperature exceeding 14.5°C.

e) <u>Anadromous Salmonids and Char</u>. **Where lower mainstem reaches are used exclusively as a migration corridor for the in-going and out-going saltwater migration of salmonids or char.** Not to exceed 17°C as a 7-day average of the daily maximum temperatures from June 1-September 1, with no single daily maximum greater than 21°C. Not to exceed 13°C as a 7-day average of the daily maximum temperatures between September 1 and June 1, with no single daily maximum greater than 16°C.

f) <u>Warm Water Fish Communities</u>. **Waters without naturalized populations of indigenous salmonid or char species, or that serve as migration corridors for such species; where the dominant species under natural conditions would be temperature tolerant indigenous non-salmonid species such as dace, redside shiner, chiselmouth, sucker, and northern squawfish.** Not to exceed 20°C as a 7-

day average of the daily maximum temperatures from June 1 to October 1, with no single daily maximum temperature greater than 25°C. Between October 1 and June 1 the 7-day average of the daily maximum temperatures is not to exceed 15°C, with no single daily maximum temperature greater than 20°C.

1. Regulatory Notes to Support Temperature Criteria:

The following statements should be included in the water quality standards regulation to serve as mandatory guidelines for the implementation of the temperature criteria:

6. **Insufficient Averaging Data.** Where data is not sufficient to directly calculate, or reasonably estimate compliance with, the criteria established as a running 7-day average of the daily maximum temperatures, the seven-day average criteria value must be used as a single daily maximum criteria limit.

7. **Natural Exceedences.** When temperatures naturally exceed the assigned criteria for a waterbody, no actions alone or in combination can be allowed that would raise the receiving water temperature by greater than 0.3°C above the estimated natural condition.

8. **Measuring Temperature.** Temperature measurements used to assess compliance with the recommended temperature criteria should be taken so as to generally represent the habitat as a whole within a segment of a waterbody. Measurements taken from shallow stagnant backwater areas, within isolated thermal refuges, at the surface, or at the waters edge should generally not to be compared with the criteria proposed in this paper. In reservoirs and lakes, temperature measurements can be taken from the cooler portion of a thermocline in the summer period, if the spatial extent and oxygen content of that cooler water would otherwise be sufficient to support fish populations.

9. **Boundary Areas.** Temperatures must be maintained such that the water quality criteria of downstream waters are fully protected. An area of mixing, and localized non-attainment, however, can be allowed in the vicinity of where an upstream waterbody segment having less stringent criteria enters a downstream waterbody segment having more stringent criteria. This mixing proviso is allowed only where the localized change in quality would not have a likely potential to block or otherwise impair the aquatic life of the downstream waters.

10. **Waterbody-Specific Application Dates**. Salmonid stocks known to have incubation or marine smoltification periods that are not reasonably described by the timeframes established in the state-wide temperature criteria recommendations should be

protected by setting waterbody specific application dates under the water quality standards regulation.

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