White Paper
Summary of EPA's Temperature Criteria Methodology Guidance
Nevada Division of Environmental Protection
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Introduction

EPA guidance (1977, 1986) recommends a very quantitative approach for determining appropriate temperature criteria. Based upon the results of basically two equations, EPA provides chronic and acute temperature criteria recommendations for a number of fish species. Tables 1 and 2 provide the resulting guidance criteria for some selected coldwater and warmwater species. The methods used to develop these criteria recommendations are described in the following sections.

Table 1. EPA Temperature Criteria for Growth and Survival of Juvenile and Adult Fish during the Summer

Species	Maximum Weekly Average Temperature for Growth (°C)	Maximum Temperature for Survival of Short Exposure (°C)
Coldwater Species		
Brook trout	19	24
Brown trout	17	24
Rainbow trout	19	24
Warmwater Species		
Channel catfish	32	35
Largemouth bass	32	34
Walleye	25	---

Table 2. EPA Temperature Criteria for Spawning and Embryo Survival During the Spawning Season

Species	Maximum Weekly Average Temperature for Spawning (°C)	Maximum Temperature for Embryo Survival of Short Exposure (°C)
Coldwater Species		
Brook trout	9	13
Brown trout	8	15
Rainbow trout	9	13
Warmwater Species		
Channel catfish	27	29
Largemouth bass	21	27
Walleye	8	17

Methodology

Experimental temperature responses of fish relative to acclimation temperature can be graphically represented (Figure 1). As shown in Figure 1, CTM, UILT and LILT are dependent upon acclimation temperatures. The results needed to create these response relationships are typically derived from laboratory experiments. EPA guidance builds off of these theoretical relationships plus additional literature-based thermal response information that may be based upon field studies.

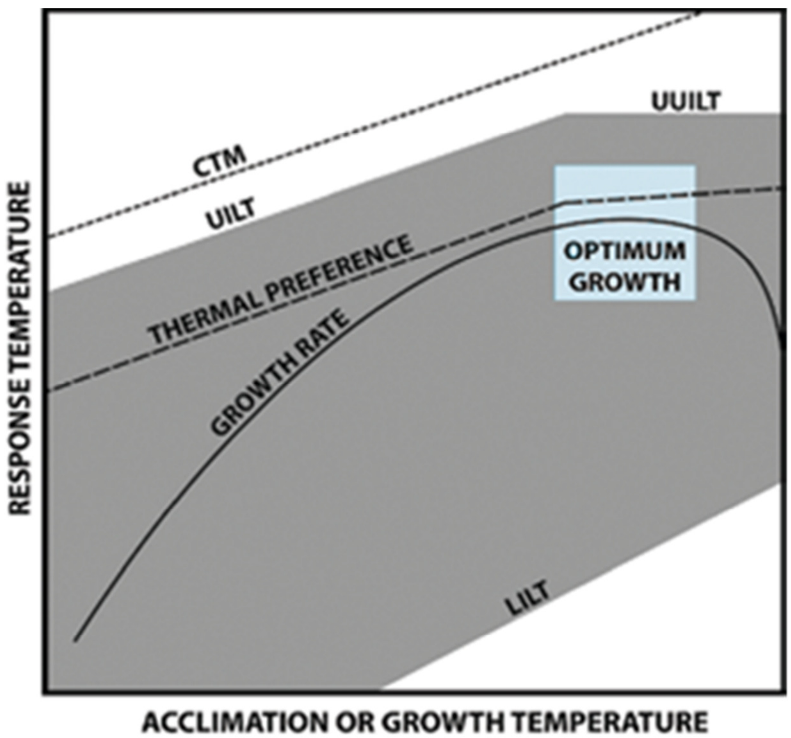

Figure 1. Theoretical Thermal Response for Fish

Acclimation Temperature – Temperature that test fish are experimentally conditioned to before a tolerance test

Response Temperature – Temperature at which a certain response is observed (50% mortality, maximum growth, etc.)

CTM (Critical Thermal Maximum) – Survival times above CTM are near zero.

UILT (Upper Incipient Lethal Temperature) and LILT (Lower Incipient Lethal Temperature) – Within this zone, 50% of test organisms could survive indefinitely

UUILT (Ultimate Upper Incipient Lethal Temperature) – The highest UILT produced with increasing acclimation times. The highest temperature at which tolerance does not increase with increasing acclimation temperatures

Optimum Growth – Preferred temperature zone for optimum growth

Thermal Preference – Approximate preferred temperature for a given acclimation temperature

Growth Rate – Growth rate for a given temperature

Summer Season Criteria Development

EPA guidance (1977, 1986) presents 2 equations for determining chronic (maximum weekly average temperature – MWAT) and short-term (24-hour, etc. exposure) temperature criteria based upon laboratory determinations of temperature tolerance responses as described in Figure 1. These temperature thresholds are intended to support the growth and survival of juvenile and adult fish during peak temperature periods.

Summer Season – Chronic Criteria for Juveniles and Adults

The guidance states that MWAT should not exceed the optimum temperature plus 1/3 of the range between the Optimum Temperature (OT) and the Ultimate Upper Incipient Lethal Temperature (UUILT), based upon OT and UUILT values for juveniles and adults as reported in the literature:

$$MWAT = OT + \frac{1}{3}(UUILT - OT) \quad \text{[Eq. 1]}$$

Where:
MWAT = Maximum Weekly Average Temperature (°C)
OT = Optimum Growth Temperature (°C)
UUILT = Ultimate Upper Incipient Lethal Temperature (°C)

Using this approach, MWAT values were calculated by EPA for various fish species for the growth and survival of juvenile and adult fish during the summer (Table 1). In calculating these values based upon the above equation, EPA generally used the middle of the range of OT values in the literature and the upper end of the range of UUILT values in the literature. However, EPA does state "*[s]ome subjectivity is inevitable and necessary because of variability in published data resulting from differences in age, day length, feeding regime, or methodology*." Therefore, some of the EPA criteria recommendations were calculating using OT and UUILT values that differed from these general rules.

Summer Season – Acute Criteria for Juveniles and Adults

In addition to MWAT, maximum temperature criteria are needed to protect juveniles and adults from short exposures. EPA calculated maximum temperature recommendations for the growth and survival of juvenile and adult fish based upon thermal resistance equations derived from laboratory studies. For temperatures above the UILT (see Figure 1), fish mortality due to temperature extremes occurs as a function of time. Thermal resistance equations relating survival time to exposure temperatures above UILT take the following general form:

$$log(time) = a + b\ (temperature) \quad \text{[Eq. 2]}$$

Where:
log time = logarithm of the time (in minutes) that 50 percent of the fish survive an exposure temperature used in the experimental study
a & b = regression equation constants derived from experimental study results similar to those shown on Figure 2
temperature = exposure temperature (°C)

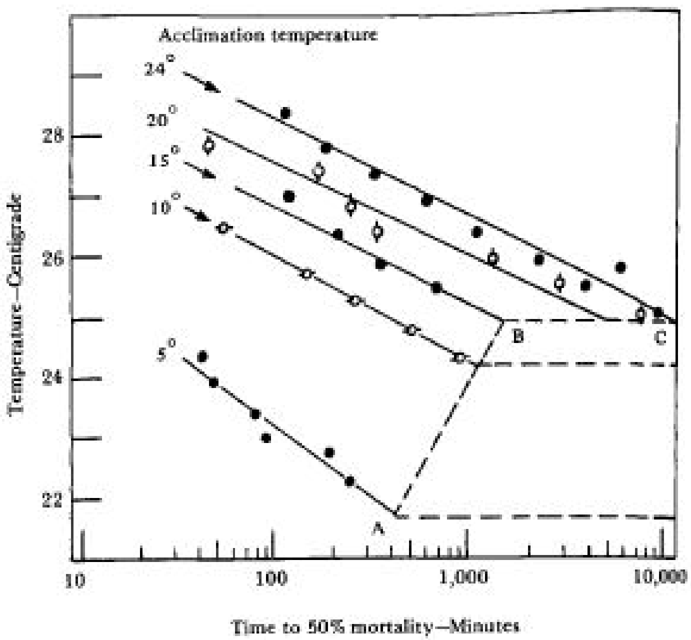

Figure 2. Median Resistance Times to High Temperature among Young Chinook (from "Temperature Criteria for Freshwater Fish: Protocol and Procedures", EPA, 1977). Line A-B denotes rising lethal threshold (upper incipient lethal temperature - UILT) with increasing acclimation temperature. This rise eventually ceases at the ultimate upper lethal threshold (UUILT) – line B-C.

Using a reordered thermal resistance equation (Eq. 1) and applying a safety factor, EPA calculated Short Term Maximum (STM) criteria (for growth and survival of juvenile and adult fish during the summer) based upon the following equation:

$$STM = \frac{log(time) - a}{b} - Safety\ Factor \qquad \text{[Eq. 3]}$$

Where:
log time = logarithm of exposure time of 1440 minutes (1 day)
Safety Factor = 2 °C factor of safety. The equation is based upon 50 percent survival. A factor of safety is applied to ensure 100 percent survival.

For each species, a variety of values for "a" and "b" are often reported in the literature. In calculating the recommended criteria, EPA used "a" and "b" values for those acclimation levels near the recommended MWAT for spawning to calculate a series of STM values. EPA then averaged these STM values to develop the recommended criteria.

It is important to note that the STM criteria recommendations in Table 1 were calculated assuming an exposure time of 1440 minutes (1 day). EPA states that *"[s]ince the MWAT is a weekly mean temperature an appropriate length of time for this limitation for short exposure would be 24 hour without risking violation of the MWAT."* **It is unclear if the Table 1 values would be suitable as a daily maximum criteria, given that high temperatures in Nevada streams are shorter in duration (typically a few hours).** However, many states have used these as daily maximums in their standards. It may have been their strategy for dealing with issues associated with cumulative exposure effects over multiple, consecutive days.

Spawning and Embryo Survival Criteria Development

EPA guidance (1977, 1986) provides recommended temperature criteria for the protection of spawning and embryo survival. Recommended criteria were derived from literature values suggested for spawning, incubation and hatching. EPA's chronic criteria are recommended to support spawning while the acute criteria are recommended to support incubation. EPA's approach for spawning and embryo survival criteria was much less rigorous compared to the approach for juveniles and adults. For the spawning and embryo survival criteria were not calculated, rather they relied on literature values derived by a variety of methods, such as: 1) field observations, 2) laboratory experiments, and 3) hatchery operations.

Spawning Protection – Chronic Criteria

For the spawning season, EPA recommends that MWAT be set at the optimum spawning temperature identified in the literature. While not well documented, it appears that EPA used the middle of the range of optimum spawning temperatures. If optimum temperatures are not available, EPA recommends setting MWAT equal to the middle of the range of acceptable spawning temperatures from the literature.

Incubation Protection – Acute Criteria

Spawning season maximum temperatures cannot be determined in the same manner as the growing season criteria. Therefore, the acute criteria for the spawning season should be set at either the maximum incubation temperature for successful embryo survival or the maximum temperature for spawning identified in the literature. If both are available, the highest of the two is preferred.

Winter Criteria Development

EPA guidance discusses only the use of chronic criteria (MWAT) for the winter season, and appear to be intended to set limits on a thermal discharge to a waterbody. According to the guidance, the MWAT for winter fish survival will apply in any area in which fish could congregate such as a thermal discharge zone. The MWAT criterion are intended to protect fish from a rapid drop in temperature due to the sudden shutdown of a thermal discharge, or movement of fish from a heated plume to an area with ambient temperatures. As a result, EPA's MWAT recommendations vary depending upon the temperature of the ambient water (Table 3).

Table 3. Summary of EPA Temperature Criteria Recommendations for Winter

Ambient Temperature (°C)	MWAT - Coldwater Fish (°C)	MWAT - Warmwater Fish (°C)
0	5	10
2.5	10	10
5	15	15
10	25	25

Conclusions

One option for NDEP may be to use these recommendations as they exist, with some exceptions. Additional information would have to be compiled for other species not covered by the EPA guidance.

One shortcoming of the EPA guidance values is that they are based upon thermal response laboratory experiments performed at least 30 years ago. More current literature likely needs to be researched to refine these criteria.