

## White Paper

# Summary of Colorado's Coldwater and Warmwater Temperature Criteria

Nevada Division of Environmental Protection

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## Introduction

Much like Nevada, Colorado first adopted temperature criteria in 1978. Colorado found that little historic record existed which documented the basis of these criteria and there was some confusion over the application of these standards. Beginning in 2001, Colorado convened a workgroup for the development of improved temperature criteria. Table 1 summarizes the criteria that were ultimately adopted in 2007. Colorado adopted two criteria (acute and chronic) based on a literature review of temperature requirements and tolerance limits for fish species present in Colorado waters. The acute criteria protect against lethality, and the chronic criteria protect against adverse effects that could include reduction of growth or reproduction. The methods used to develop these criteria are described in the following sections.

**Table 1. Colorado's Coldwater Stream Temperature Criteria**

Time Period	DM (Daily Maximum Temperature <sup>1</sup> ) - ° C	MWAT (Maximum Weekly Average Temperature) - ° C
<b>Rivers and Streams: Tier I<sup>2</sup></b>		
Jun-Sep	21.7	17.0
Oct-May (reproductive season)	13.0	9.0
<b>Rivers and Streams: Tier II<sup>3</sup></b>		
Apr-Oct	23.9	18.3
Nov – Mar (reproductive season)	13.0	9.0
<b>Lakes and Reservoirs (&lt;100 acres surface area)<sup>4</sup></b>		
Apr – Dec	21.2	17.0
Jan – Mar (reproductive season)	13.0	9.0
<b>Large Lakes and Reservoirs (&gt;= 100 acres surface area)<sup>5</sup></b>		
Apr – Dec	23.8	18.3
Jan – Mar (reproductive season)	13.0	9.0

<sup>1</sup> Highest two-hour average

<sup>2</sup> Tier I applies where cutthroat trout and brook trout occur

<sup>3</sup> Tier II applies where coldwater species, excluding cutthroat trout and brook trout, are expected to occur

<sup>4</sup> Based upon thermal needs of cutthroat trout, rainbow trout, brook trout, sockeye salmon, brown trout and Arctic grayling

<sup>5</sup> Based upon thermal needs of rainbow trout, brown trout and lake trout

**Table 2. Colorado’s Warmwater Stream Temperature Criteria**

<b>Time Period</b>	<b>DM (Daily Maximum Temperature<sup>1</sup>) - ° C</b>	<b>MWAT (Maximum Weekly Average Temperature) - ° C</b>
<b>Rivers and Streams: Tier I<sup>2</sup></b>		
Mar – Nov	29.0	24.2
Dec – Feb	14.5	12.1
<b>Rivers and Streams: Tier II<sup>3</sup></b>		
Mar – Nov	28.6	27.5
Dec – Feb	14.3	13.7
<b>Rivers and Streams: Tier III<sup>4</sup></b>		
Mar – Nov	31.3	28.7
Dec - Feb	15.7	14.3
<b>Lakes and Reservoirs<sup>5</sup></b>		
April – Dec	29.3	26.5
Jan – Mar	14.6	13.3

<sup>1</sup> Highest two-hour average

<sup>2</sup> Tier I applies where common shiner, Johnny darter, or orangethroat darter are expected to occur

<sup>3</sup> Tier II applies where brook stickleback, central stoneroller, creek chub, longnose dace, Northern redbelly dace, razorback sucker, finescale dace and white sucker occur

<sup>4</sup> Tier III applies where warmwater species are expected to occur and none of the Tier I and Tier II species are expected to occur. Based upon the thermal needs of 25 various warmwater fish

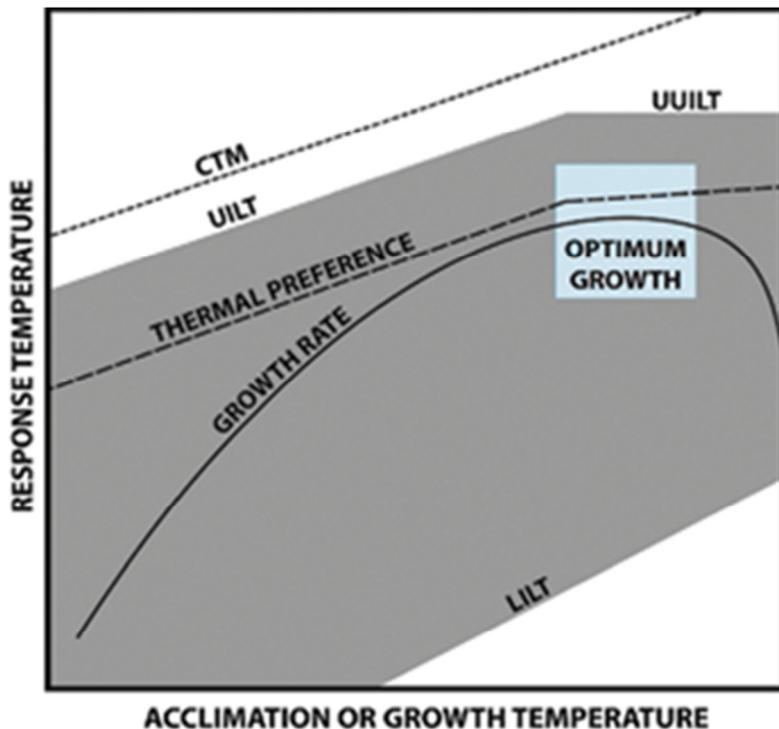
<sup>5</sup> Based upon thermal needs of 11 various warmwater fish

**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 generated using laboratory experiments. Colorado built off of these theoretical relationships and generally followed EPA guidance (1977/1986) in developing their criteria, but with some significant modifications. Colorado believed that these modifications were necessary to more accurately protect the fish. Even though there were some significant deviations from EPA guidance, Colorado reported no problems with garnering EPA approval of their proposed criteria. However, it is important to recognize that Colorado is in EPA Region 8 and Nevada is in EPA Region 9. Region 9 may have a different view on the methods Nevada uses to develop criteria.

During the process, Colorado decided to rely solely on laboratory-derived thermal tolerance data in the calculation of their criteria. Colorado concluded that “*..the inherent site-specificity and complexity of factors shaping relationships between stream conditions and thermal preferences render field data less reliable for the derivation of broadly applicable temperature criteria*”. However, Colorado did compare criteria calculated from laboratory results to field study results to facilitate some ground truthing of the proposed criteria.

Colorado researched available literature characterizing thermal requirements and tolerance limits and established a corresponding database which included metrics such as acclimation temperature, optimum temperature, UILT, UUILT, CTM, etc. As a result of this effort, Colorado incorporated more recent data than used in the EPA guidance (1977, 1986).



**Figure 1. Theoretical Thermal Response for Fish**

**Acclimation Temperature** – Temperature that test fish are experimentally exposed to for several days 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 virtually 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

Five hundred and four (504) papers were reviewed, however 346 papers were not included in the database because they failed to meet the screening criteria (Table 2). Most were eliminated because they were reviews or compilations of results from other studies, and did not present original study results. Other data were excluded for the following reasons: 1) too low acclimation temperature (<7° C for coldwater, <15° C for warmwater); 2) too high acclimation temperature (>23° C for coldwater, >30° C for

warmwater, or higher than minimum CTM); 3) data for embryo/larvae stage; and 4) data from field studies. Using the data deemed appropriate, chronic and acute thresholds were calculated for selected coldwater and warmwater species in Colorado. From these thresholds, temperature criteria were calculated for various water tiers and waterbody types, and ultimately incorporated into the regulations.

**Table 2. Factors Considering in Judging Quality of Experimental Data for Inclusion in Database**

<b>Criteria</b>	<b>Description</b>
Replications	Number of replications documented
Endpoint of the study	Intent to study thermal tolerance stated
	Clear biological endpoint stated
Acclimation history	Sufficient time allowed for acclimation of test organism
Acclimation rate	Acclimation rate reported
Life stage	Life stage of the test organism reported
Methods	Control group utilized and reported
	Adult- or juvenile-sized fish used
	Nutritional status well documented
	Standard testing environment used
Peer-reviewed study	Evidence of peer review presented
	Study present in a published scientific journal or referenceable report
	Data derived from original study
Quality of fish	Documented attempts to reduce stress on experimental fish
Fish source	Information on origin and history presented

**Development of Species Specific Chronic and Acute Thresholds**

Using the data that met the screening requirements, Colorado calculated summer season chronic and acute thresholds as described in the following sections.

**Summer Season - Chronic Thresholds**

Summer Season chronic thresholds (MWAT – maximum weekly average temperature) were calculated for each species using a slightly different approach than recommended by EPA guidance. Colorado believed this was a more appropriate method for protecting against chronic conditions. If Upper Optimum Temperature data were available for the species of interest, then MWAT was calculated using the following equation:

$$MWAT = UpperOT_{median} \quad [Eq. 1]$$

Where:

$UpperOT_{median}$  = median of the data reported to represent the upper end of the Optimum temperature range for growth and reproduction from literature

If Upper Optimum Temperature data were not available for the species, then an equation similar to that presented in EPA guidance was used to calculate MWAT:

$$MWAT = OT_{median} + \frac{1}{3} \left( \frac{UILT}{UUILT_{median}} - OT_{median} \right) \quad [\text{Eq. 2}]$$

Where:

$OT_{median}$  = median of Optimum temperatures reported for growth and reproduction from literature

$UILT/UUILT_{median}$  = median of the Upper Incipient Lethal Temperature (UILT) and Ultimate Upper Incipient Lethal Temperature (UUILT) data.

If UILT and/or UUILT data were not available, then  $UILT/UUILT_{median}$  was estimated based upon CTM (Critical Thermal Maximum) values in the literature along with a conversion factor used to convert CTM to an estimate of the median UILT/UUILT:

$$UILT/UUILT_{median} = CTM_{median} - \text{Conversion Factor} \quad [\text{Eq. 3}]$$

Where:

$CTM_{median}$  = median of Critical Thermal Maximum values from literature

$\text{Conversion Factor}$  = factor to convert  $CTM$  to  $UILT$  based upon scientifically defensible relationship between  $CTM$  and  $UILT$ ; following factors were used: cutthroat trout = 4.4; brook trout = 1.3, brown trout = 1.3, rainbow trout = 0.8, all warmwater fish = 0.8

Table 3 presents the summer chronic thresholds calculated for selected coldwater and warmwater species.

**Table 3. Summer Season Acute and Chronic Thresholds for Selected Coldwater and Warmwater Species in Colorado**

Common Name	Chronic (MWAT)		Acute (DM)	
	° C	Equations Used	° C	Equations Used
<i>Coldwater Species</i>				
Brook trout	18.3	2	21.7	4,5
Brown trout	19.6	1	24.6	3,4,5
Cutthroat trout*	17.0	1	22.1	4,5
Rainbow trout	18.2	1	23.8	4,5
<i>Warmwater Species</i>				
Channel catfish	32.2	2,3	35.4	3,4,5
Largemouth bass	31.4	2	34.1	4,5
Smallmouth bass	29.0	2,3	34.0	3,4,5

\* Derived from data for Bonneville, Lahontan, Snake River, Westslope, and Yellowstone sub-species

### Summer Season - Acute Thresholds

Rather than using the thermal resistance equation approach taken by EPA, Colorado calculated summer season acute species thresholds (DM – daily maximum temperature) were calculated for each species based upon UILT/UUILT and Optimum Temperatures reported in the literature:

$$MDMT = UILT / UUILT_{median} - MOS \quad [Eq. 4]$$

Where:  $UILT/UUILT_{median}$  = median of the Upper Incipient Lethal Temperature (UILT) and Ultimate Upper Incipient Lethal Temperature (UUILT) data from literature

$$MOS \text{ (margin of safety)} = (UILT/UUILT_{median} - OT_{median}) \times 0.2 \quad [Eq. 5]$$

If UILT and/or UUILT data were not available, then  $UILT/UUILT_{median}$  was estimated based upon CTM (Critical Thermal Maximum) values in the literature along with a conversion factor (See Equation 3). If there were insufficient data to calculate the MOS, a default value of 2°C was assumed (as was recommended in the EPA guidance).

Colorado had two main reasons for not using the thermal resistance equation approach presented in the EPA guidance for calculating the acute criteria. First of all, Colorado believed that use of the UILT/UUILT values was a more appropriate approach for acute temperature protection. Also, there are a number of thermal response findings in the literature that are deemed useful for criteria development, but did not provide the necessary inputs to EPA's thermal resistance equation. Therefore, a modified methodology was needed to take advantage of these data, much of which has been generated since 1977 when the EPA guidance was issued.

Table 3 presents the summer acute thresholds calculated for selected coldwater and warmwater species. It is important to note, that in generating acute thresholds for each species, Colorado calculated median UILT/UUILT, OT and CTM values using all available laboratory results with acclimation temperatures between 7 and 23 °C for coldwater species, and between 15 and 30°C for warmwater species. EPA acute thresholds were calculated using a smaller set of data, relying only on those laboratory results with acclimation temperatures near the MWAT value for each species.

### **Winter Season/Spawning Periods – Chronic and Acute Thresholds**

Colorado investigated the possibility of compiling a database of spawning temperatures and dates, but found that such data were not available. Instead spawning criteria from EPA guidance (1977/1986) were generally followed for coldwater streams. However for warmwater streams, Colorado chose not to follow EPA's warmwater spawning criteria recommendations, and winter criteria were developed as discussed below.

### **Development of Chronic and Acute Criteria for Various Waterbody Tiers and Types**

For purposes of the regulations, Colorado divided coldwater and warmwater systems into multiple tiers, with criteria for each tier based upon the thermal needs of the fish species expected to occur in each tier.

#### **Coldwater Fish**

In the regulations, Colorado divided coldwater streams into 2 groups:

- Tier I: Sensitive Coldwater Fish – waters with cutthroat trout and brook trout
- Tier II: Non-sensitive Coldwater Fish – waters with coldwater fish other than cutthroat trout and brook trout

Coldwater lakes were divided into 2 groups – lakes less than 100 acres in surface area, and lakes greater than or equal to 100 acres in size. Colorado found that lakes less 100 acres in size are more likely to have the more sensitive cutthroat trout and brown trout.

**Summer Season – Chronic and Acute Criteria:** To protect the Sensitive Coldwater Fish waters (Tier I), Colorado set the criteria at the level needed to fully protect cutthroat trout (the most restrictive use). Tier II non-sensitive Coldwater Fish criteria were calculated as the 5<sup>th</sup> percentile of the rainbow trout and brown trout thermal thresholds. Colorado selected the 5<sup>th</sup> percentile metric to be consistent with EPA’s risk-based approach used for calculating toxics criteria.

Small lake/reservoir (surface area < 100 acres) criteria were calculated as the 5<sup>th</sup> percentile of thermal needs of cutthroat trout, rainbow trout, brook trout, sockeye salmon, brown trout and Arctic grayling. Colorado found that large lakes generally don’t contain cutthroat or brook trout. Therefore, large lake/reservoir (surface area > 100 acres) criteria were calculated as the 5<sup>th</sup> percentile of the rainbow trout, brown trout and lake thermal thresholds.

**Winter/Spawning – Chronic and Acute Criteria:** Colorado found that temperature data for spawning/incubation was generally not available in the literature. Instead, Colorado investigated the possible use of EPA guidance (1986) numbers for spawning and embryo survival:

Winter season chronic = 9° C  
Winter season acute = 13° C

These criteria were available for only brook trout and rainbow trout, and were based upon pre-1980s literature. However, Colorado found additional, more recent studies that reported similar acute and chronic limits for salmonids, and deemed these criteria appropriate for spawning/incubation protection for all coldwater streams, lakes and reservoirs.

Colorado found it challenging to establish a generic coldwater winter/spawning/incubation season for use in the regulations. They found that the dates at which spawning occurs are driven by water temperatures, which can vary significantly from waterbody to waterbody, and from year to year. As a result, waterbodies could potentially experience quite variable spawning periods. Colorado had compiled a table of default early life stage dates, but these data were not specifically followed. According to their early life stage dates table, spawning/incubation periods for cutthroat trout occur from April to August. Spawning/incubation periods for brook trout were reported as September through February. However for Tier I waters (cutthroat and brook trout), the winter/spawning criteria were set to apply from October through May, covering only portions of their reported cutthroat and brook trout spawning/incubation periods. According to their methodology document, October-May was based on the typical timing of fall and spring spawning and broad attainability of the standards.

An analysis of temperature data for headwater streams (first through third order) indicated that October-May temperatures met the proposed winter/spawning criteria. Therefore, Colorado concluded that October-May was a justifiable reproductive season for the regulations.

For Tier II waters (primarily rainbow and brown trout), winter/spawning/incubation criteria were set to apply from November through March. However, the early life stage dates table indicates that rainbow trout spawning/incubation period extends from March-July and brown trout spawning/incubation period extends from September-April. As a result, Colorado’s Tier II winter/spawning criteria do not appear to provide much protection for the reported rainbow trout and brown trout spawning period. In an email

communication with Andrew Todd (biologist involved in the criteria development), the criteria season was ultimately determined by evaluating what months the 9° C (MDAT) and 13° C (MDMT) were actually attainable based upon measured temperatures.

### **Warmwater Fish**

In the regulations, Colorado divided warmwater streams into 3 groups:

- Tier I: applies where common shiner, Johnny darter, or orangethroat darter are expected to occur
- Tier II: applies where brook stickleback, central stoneroller, creek chub, longnose dace, Northern redbelly dace, razorback sucker, finescale dace and white sucker occur
- Tier III: applies where warmwater species are expected to occur and none of the Tier I and Tier II species are expected to occur.

However, warmwater lakes/reservoirs were not divided into tiers for the regulations.

**Summer Season – Chronic and Acute Criteria:** Summer warmwater criteria for each tier was calculated as the 5<sup>th</sup> percentile of the thermal thresholds of the species expected to occur in each tier. The species considered in the calculations are summarized in Table 4. The Colorado Water Quality Control Commission acknowledges that all of these species do not occur in all warmwater locations and has provided procedures by which site-specific criteria can be developed based upon the actual species in a given waterbody.

It must be noted Colorado found it difficult to populate the database for many of the warmwater species in Colorado. There was not as much data available for warmwater species compared to coldwater species.

**Table 4. Warmwater Fish Species Used in Development of Warmwater Criteria**

<b>Tier I</b>	<b>Tier II</b>	<b>Tier III</b>	<b>Lakes/Reservoirs</b>
common shiner	brook stickleback	Arkansas Darter	bluegill
Johnny darter	central stoneroller	bigmouth shiner	largemouth bass
orangethroated darter	creek chub	black bullhead	Northern pike
	finescale dace	bluegill	pumkinseed sunfish
	longnose dace	boneytail	smallmouth bass
	Northern redbelly dace	brown bullhead	spottail shiner
	Razorback sucker	channel catfish	striped bass
	white sucker	fathead minnow	tiger muskellunge
		golden shiner	walleye
		green sunfish	white bass
		horneyhead chub	yellow perch
		orangespotted sunfish	bluegill
		plains killifish	largemouth bass
		plains minnow	Northern pike
		plains topminnow	pumpkinseed sunfish
		pumpkinseed sunfish	smallmouth bass
		red shiner	spottail shiner
		roundtail chub	striped bass
		sand shiner	tiger muskellunge
		smallmouth bass	
		Southern redbelly dace	
		speckled dace	
		spottail shiner	
		western mosquitofish	
		yellow bullhead	
		Arkansas Darter	
		bigmouth shiner	

**Winter Season/Spawning Periods – Chronic and Acute Criteria:** Colorado found that thermal tolerance data for warmwater species spawning were generally not available in the literature. However, Colorado neglected to consider the warmwater spawning criteria from EPA’s 1977/1986 guidance.

Colorado noted that the coldwater winter criteria were about 50% of the coldwater summer criteria. Therefore for warmwater systems, the winter chronic and acute values were set at 50% of the summer chronic and acute values. This was believed to ensure that fish would not be induced to spawn in the winter due to anthropogenic warming. Winter criteria were set to be applicable during the periods December-February for all warmwater streams and January-March for warmwater lakes/reservoirs. No documentation justifying these dates have been found. It must be noted that the spawning period for the warmwater species of interest generally extends from April through August. The resulting criteria do not seem to be set protect for spawning and incubation, rather the criteria are set to prevent anthropogenic warming which could induce spawning.

Currently, Colorado is strategizing on options to develop scientifically-defensible criteria to protect warmwater aquatic life from acute effects in the winter. Colorado Parks and Wildlife has recently presented information claiming that acute criteria could be calculated using existing data and similar approaches used for the summer criteria.

## *Other Factors*

**Narrative Considerations:** Colorado regulations have narrative standards requiring that temperatures be maintained with a normal pattern of diel and seasonal fluctuations and spatial diversity with no abrupt changes and shall have no increase in temperature of a magnitude, rate, and duration deleterious to the resident aquatic life.

**Waters with No Fish:** Colorado has adopted temperature standards for waterbody segments that have aquatic life, but no fish. Generally, they have applied the least restrictive cold or warm temperature tier criteria in these cases.

**Coldwater-Warmwater Transition Areas:** In transition areas, where cold and warm aquatic species coexist or are expected to be present on a seasonal basis, Colorado's Temperature Methodology Criteria document states that it may be appropriate to adopt site-specific standards that reflect the seasonal presence of coldwater species. The regulations do not provide any specifics as to how a criterion value could be assigned to these waters.

**Temperature Shoulder Seasons:** Under the current standards, there is an abrupt change from the non-summer criteria to the summer criteria. For example, the Tier I coldwater acute criterion for May is 13° C and for June jumps to 21.7° C. Colorado has commented that this rigid, abrupt change does not reflect the normal pattern of the annual temperature cycle, and is currently strategizing on better options. One option is to limit the numeric criteria to only the core winter and summer months, and use a narrative standard for the transitional months. A second option would be to limit the current criteria to only the core winter and summer months, and develop a stepwise 30-day average criteria for the transitional months.

## *Impairment Assessments*

As part of their impairment assessments, Colorado considers a water impaired due to temperature if either the chronic or acute criteria are exceeded more than once in a three year period. However, Colorado regulations include a number of exceptions for conditions during which the temperature criteria are exceeded and the water is not considered impaired. The following are not considered an exceedance of the temperature criteria:

**Air Temperature Exception:** Water temperatures may exceed the criteria when the daily maximum air temperature exceeds the 90<sup>th</sup> percentile of the monthly maximum air temperatures.

**Low Flow Exception:** Water temperatures may exceed the criteria when the daily flow falls below statistically-derived flow thresholds.

**Lakes and Reservoirs Exception:** When a lake or reservoir is stratified, the mixed layer may exceed the temperature criteria provided that adequate refuge exists in the water below the mixed layer.

**Winter Shoulder-season Exception:** For purposes of assessment, water temperatures may exceed the winter criteria for 30 days before the winter/summer transition (Tier I – June 1, Tier II – April 1) and for 30 days after the summer/winter transition (Tier I – October 1, Tier II – November 1), provided that the natural seasonal progression of temperature is maintained, and that temperatures exceedances during these periods are not the result of human activities.

## ***Conclusions***

One option for NDEP may be to build off of Colorado's approach. However, we may want to do some additional research to further add to Colorado's database used in the calculations. Additionally, it would be desirable to obtain EPA Region 9 input on taking this approach early in the process.