DRAFT Methodology for Developing Thermal Tolerance Thresholds for Various Fish in Nevada – Juvenile and Adult, Summer

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INTRODUCTION

Nevada Division of Environmental Protection (NDEP), Bureau of Water Quality Planning, is embarking on an effort to update the Nevada temperature water quality standards for the protection of aquatic life because Nevada's current temperature criteria are not well documented and are in need of review. As a result, scientifically supported guidance is needed as NDEP reviews temperature standards throughout the state. To assist with the process of developing updated temperature criteria, NDEP has formed a Temperature Work Group (TWG) consisting of local and regional fisheries biologists.

The overall work effort can be generally divided into 4 parts:

1. Establish a methodology for defining thermal tolerances for various fish species and life stages;
2. Establish matrices of thermal tolerances for various fish species and life stages;
3. Establish a methodology for using thermal tolerance values to construct temperature criteria recommendations for a given waterbody; and
4. Establish a methodology for determining compliance with the proposed temperature criteria

This report focuses on Part 1 (thermal tolerance methodology) of this effort, with a focus on juvenile and adult life stages and summer periods at this time. Earlier life stages and other periods of the year will be addressed in future papers.

SPECIAL WATER QUALITY STANDARDS CONSIDERATIONS

States are required to adopt water quality criteria that will protect the designated uses of a waterbody. In this case, the interest is in setting temperature criteria for the protection of aquatic life uses in Nevada waters. States generally set temperature criteria based upon the needs of the fish, which also protects the broader aquatic life community in a waterbody.

In an EPA report, Brungs and Jones (1977) recommend the establishment of both chronic and acute temperature criteria for the protection of fish. Chronic criteria are intended to "… *maintain growth of aquatic organisms at rates necessary for sustaining actively growing and reproducing populations*…" Acute criteria are intended to protect fish from "…*short exposure to temperatures higher than those acceptable for reproduction and growth without significant adverse effects*." These criteria are not intended to protect fish from any effects, rather are to limit impacts to acceptable levels.

There are a variety of temperature metrics that have been utilized across the country when establishing temperature standards. The most common forms are as follows:

- MDMT – Maximum daily maximum temperature
- MWMT – Maximum weekly maximum temperature (Maximum average of maximum daily temperatures over any seven-day period) – Sometimes referred to 7-DADM (7-day average of daily maximum temperatures)

- MDAT – Maximum daily average temperature
- MWAT – Maximum weekly average temperature (Maximum average of average daily temperatures over any seven-day period)

The chronic criteria recommended by Brungs and Jones (1977) were calculated as MWAT values. However, Brungs and Jones provided no specific metric for the acute criteria. Nevertheless, some states have used these criteria as MDMT values. Currently, Nevada's temperature criteria use only MDMT values. While these criteria protect from short term exposures (acute), no protection is provided for longer term exposures (chronic). In accordance with EPA guidance, NDEP desires to develop both chronic and acute temperature criteria, using MWAT and MDMT, respectively.

POTENTIAL FISH SPECIES TO CONSIDER

Tables 1 and 2 list the native and non-native fish species for which thermal thresholds are to be researched. However, it is expected that little to no thermal threshold information may be available for several of these species. In general, sources of information for this list included:

- Nevada Department of Wildlife Fishable Waters Maps (2013)
- Fishes of Nevada (Prepared by Pat Coffin, Nevada Dept. of Wildlife, 1984)
- Annotated List of the Fishes of Nevada (J.E. Deacon and J.E. Williams, Proc. Biol. Soc. Wash., 1984)
- Nevada Natural Heritage Program Website (accessed April 28, 2015)
- Nevada Wildlife Action Plan (NDOW, 2013)

At this time, the potential development of thermal tolerance thresholds is limited to fish species that inhabit flowing streams, lakes, or reservoirs, whether native or non-native. NDEP is required to consider the needs of all species in a waterbody when setting standards, whether or not the species are native, and whether or not the species are naturally propagating. Species with limited distribution (other than Bull Trout) were not included in the list. Also, species limited to spring habitats and small discharge streams were not considered as these waters are not typically assigned water quality standards.

METHODOLOGY FOR DEVELOPING THERMAL TOLERANCE THRESHOLDS

Background

Methodology options available for the development of thermal response thresholds can generally be divided into 3 groups:

EPA guidance

EPA guidance (1977/1986) provides a very prescriptive approach for determining temperature tolerance thresholds for fish. The guidance generally relies on two equations for calculating chronic and acute temperature thresholds utilizing laboratory and field-derived thermal response values. See NDEP's White Paper (2015a), Brungs and Jones (1977), and EPA (1986) for more information.

Table 1. Coldwater Fish Species to Consider in Developing Thermal Thresholds

Common Name	Scientific Name	Native/Non-native
Salmon and Trout Family - Salmonidae		
Arctic Grayling	*Thymallus arcticus*	Non-native
Bonneville Cutthroat Trout	*Oncorhynchus clarkii utah*	Native
Bowcutt	*Oncorhynchus clarkii X Oncorhynchus mykiss*	Non-native
Brook Trout	*Salvelinus fontinalis*	Non-native
Brown Trout	*Salmo trutta*	Non-native
Bull Trout	*Salvelinus confluentus*	Native (Threatened)
Kokanee (Sockeye) Salmon	*Oncorhynchus nerka*	Non-native
Lahontan Cutthroat Trout	*Oncorhynchus clarkii henshawi*	Native (Threatened)
Mackinaw (Lake) Trout	*Salvelinus namaycush*	Non-native
Mountain Whitefish	*Prosopium williamsoni*	Native
Rainbow Trout	*Oncorhynchus mykiss*	Non-native
Redband Trout	*Oncorhynchus mykiss gairdneri*	Native
Tiger Trout	*Salmo trutta X Salvelinus fontinalis*	Non-native
Yellowstone Cutthroat Trout	*Oncorhynchus clarkii bouvieri*	Native
Sculpin Family - Cottidae		
Mottled Sculpin	*Cottus bairdii*	Native
Paiute Sculpin	*Cottus beldingii*	Native

EPA guidance with modification

Another option involves using EPA guidance (1977/1986) with some modifications, as was done by the State of Colorado. In 2007, Colorado developed updated temperature thresholds using prescriptive methods similar to the EPA guidance (1977/1986) approaches with some modifications. As part of the effort, Colorado developed a more extensive database of thermal response values than was used by EPA. Using these values, Colorado calculated temperature thresholds using EPA equation plus some additional approaches. See NDEP's White Paper (2015b) and Todd et al. (2008) for more information.

Multiple lines of evidence

A third option takes a broader approach by examining more lines of evidence than used in the EPA guidance (1977/1986), including a variety of laboratory tests and field studies. This approach was taken by EPA Region 10 in 2003 in their development of temperature guidance for the Pacific Northwest states. A few years later, both Oregon and Washington adopted new temperature criteria based upon the EPA Region 10 guidance and the multiple lines of evidence (MLOE) approach. For more information, see NDEP's White Papers (2015c, 2015d, and 2015e), EPA Region 10 (2003), Washington DEC (2002), and Oregon IMST (2004).

Table 2. Cool and Warmwater Fish Species to Consider in Developing Thermal Thresholds

Common Name	Scientific Name	Native/Non-native
Carp and Minnow Family – Cyprinidae		
Bonytail Chub	*Gila elegans*	Native (Endangered)
Colorado Pikeminnow	*Ptychocheilus lucius*	Native (Endangered)
Common Carp	*Cyprinus carpio*	Non-native
Fathead Minnow	*Pimephales promelas*	Non-native
Golden Shiner	*Notemigonus crysoleucas*	Non-native
Humpback Chub	*Gila cypha*	Native (Endangered)
Lahontan Redside	*Richardsonius egregius*	Native
Northern Leatherside Chub	*Lepidomeda copei*	Native
Tui Chub	*Siphateles bicolor*	Native
Northern Pikeminnow	*Ptychocheilus oregonensis*	Native
Redside Shiner	*Richardsonius balteatus*	Native
Roundtail Chub	*Gila robusta*	Native
Speckled Dace	*Rhinichthys osculus*	Native
Woundfin	*Plagopterus argentissimus*	Native (Endangered)
Herring Family - Clupeidae		
Threadfin Shad	*Dorosoma petenense*	Non-native
Live Bearers Family - Poeciliidae		
Western Mosquitofish	*Gambusia affinis*	Non-native
North American Catfish Family - Ictaluridae		
Black Bullhead	*Ameiurus melas*	Non-native
Brown Bullhead	*Ameiurus nebulosus*	Non-native
Channel Catfish	*Ictalurus punctatus*	Non-native
White Catfish	*Ameiurus catus*	Non-native
Yellow Bullhead	*Ameiurus natalis*	Non-native
Perch Family - Percidae		
Walleye	*Sander vitreus*	Non-native
Yellow Perch	*Perca flavescens*	Non-native
Sucker Family - Catostomidae		
Flannelmouth Sucker	*Catostomus latipinnis*	Native
Mountain Sucker	*Catostomus platyrhynchus*	Native
Razorback Sucker	*Xyrauchen texanus*	Native
Tahoe Sucker	*Catostomus tahoensis*	Native
Sunfish Family - Centrarchidae		
Black Crappie	*Pomoxis nigromaculatus*	Non-native
Bluegill Sunfish	*Lepomis macrochirus*	Non-native
Green Sunfish	*Lepomis cyanellus*	Non-native
Largemouth Bass	*Micropterus salmoides*	Non-native
Pumpkinseed Sunfish	*Lepomis gibbosus*	Non-native
Redear Sunfish	*Lepomis microlophus*	Non-native
Sacramento Perch	*Archoplites interruptus*	Non-native
Smallmouth Bass	*Micropterus dolomieu*	Non-native
Spotted Bass	*Micropterus punctulatus*	Non-native
White Crappie	*Pomoxis annularis*	Non-native

Table 2. Cool and Warmwater Fish Species to Consider in Developing Thermal Thresholds (cont'd)

Temperate Bass Family - Moronidae		
Striped Bass	*Morone saxatilis*	Non-native
White Bass	*Morone chrysops*	Non-native
Wiper	*Morone saxatilis x M. chrysops*	Non-native

Temperature Work Group Recommendations

During the April 22, 2015 meeting of the Temperature Work Group (TWG), these three options were discussed and the general consensus from the participating fisheries biologists was that the MLOE approach is a more desirable approach than the EPA/Colorado prescriptive methods, whereby a wider range of information can be incorporated into the threshold development process. Following the advice of the TWG, NDEP has taken the MLOE approach for developing thermal tolerance thresholds.

Multiple Lines of Evidence (MLOE) Approach

A wide variety of scientific information is available to support the MLOE approach, and can generally be grouped as: 1) laboratory-based, 2) field-based, and 3) other information.

- Laboratory-based
  - Growth studies
  - Temperature preference studies
  - Upper temperature avoidance studies
  - Lethal temperature studies
- Field-based
  - Growth
  - Distribution
- Other information
  - EPA guidance
  - Other state temperature criteria
  - Other sources

To the extent possible, thermal threshold values will be compiled from the original source papers. There will be some instances where a particular paper is not easily available, but its findings are cited in another publication. These cited values may be used, but with caution as some of the referencing papers may not completely state the findings of the earlier work. In some cases, the findings have been found to be misrespresented by the citing document.

Background on Thermal Response Relationships

Before the above lines of evidence can be discussed, it is necessary to first provide basic background information on relationships between temperature and fish responses. The thermal responses of fish (in the laboratory and the field), such as growth, loss of equilibrium, death, etc., varies with acclimation temperature and can be graphically represented in a theoretical conceptual plot of these relationships (Figure 1). In Figure 1, the **Zone of Thermal Tolerance** is bounded by the **Upper Incipient Lethal Temperature (UILT), Ultimate Upper Incipient Lethal Temperature (UUILT),** and the **Lower**

Incipient Lethal Temperature (LILT). Within this zone, theoretically 50% or more of a population could survive indefinitely. Outside this zone, there is a strong relationship between temperature and exposure time within the **Zone of Thermal Resistance**; with survival times above the **Critical Thermal Maximum (CTM)** virtually zero. Research has shown that the LILT, UILT, and CTM values for fish increase with increased acclimation levels. However at some point, increased acclimation temperatures yield no increase in the UILT. This boundary is defined as the UUILT in Figure 1 (Jobling, 1981).

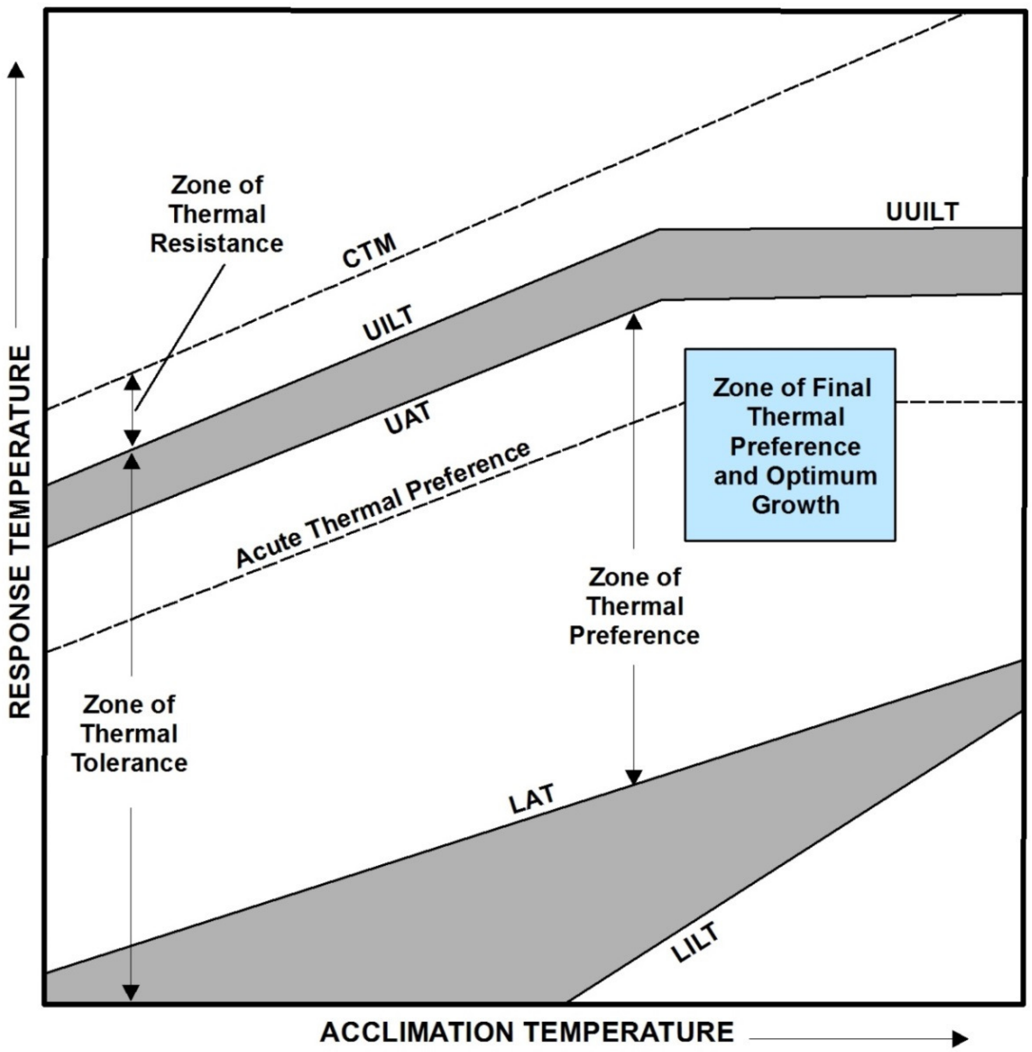

Figure 1. Conceptual Thermal Response for Fish (from Wismer and Christie, 1987))

CTM = Critical Thermal Maximum
UILT = Upper Incipient Lethal Temperature
LILT = Lower Incipient Lethal Temperature
UUILT = Ultimate Upper Incipient Lethal Temperature
UAT = Upper Avoidance Temperature
LAT = Lower Avoidance Temperature

Within a laboratory thermal gradient, over a short period of time (two hours or less), fish will gravitate toward preferred temperatures (Figure 1). This is called **Acute Thermal Preference** and has been found to vary with acclimation temperatures. The **Final Thermal Preference** is the temperature around which fish will ultimately congregate in water with an infinite temperature gradient. Additionally, researchers have identified lower and upper temperatures that fish will tend to avoid, termed **Lower Avoidance Temperature (LAT)** and **Upper Avoidance Temperature (UAT)**. The LAT and UAT define the boundary of the **Zone of Thermal Preference** (Wismer and Christie, 1987).

Relationships have also been identified between fish growth and temperature (Figure 1). The **Optimum Temperature** for growth is considered to be the temperature at which the growth rate is highest, typically under conditions of excess feeding in the laboratory setting (Jobling, 1981).

Much of the literature available for the MLOE approach addresses components of the conceptual thermal response relationships presented in Figure 1. Following is a further description of these lines of evidences and the methods used by the researchers to generate thermal response thresholds.

Laboratory Growth Studies

As described above, fish generally have temperature ranges for which growth is optimum. A majority of the laboratory studies on optimal growth are performed with water held at a constant temperature. In general, these studies involve acclimating fish to a given temperature for a period of time at the beginning of the study. Once acclimated, subgroups of the fish are held in different basins, each maintained at a different constant temperature for a significant period of time (up to 90 days). Over the course of the study, fish are weighed, and growth rates are calculated over the range of temperatures. From these data, optimum growth rates and associated temperatures are determined. It is recognized that constant temperatures are not representative of conditions in most waters, therefore some laboratory studies have been performed using daily fluctuating temperatures rather than constant temperatures.

Laboratory Temperature Preference Studies

Fish are ectotherms which are animals that do not produce heat to maintain their body temperatures. However fish can sense the temperature of their surrounding water and seek water temperatures that are warmer or colder, depending upon their preference. This is called the fish temperature preference. A number of laboratory studies have been performed to estimate the temperature preferences of numerous fish species. These laboratory studies typically involve acclimating the fish to a given temperature, followed by release into a water tank with a gradient of water temperatures. The water temperature of the areas in which the fish congregated represented their temperature preference under the laboratory conditions. Results are often presented as mean or median of observed values. It becomes important to examine the actual range of temperatures that the fish preferred.

Laboratory Upper Temperature Avoidance Studies

Just as fish have temperature preferences, fish also avoid higher temperatures that are outside of their preference zone. Avoidance temperatures are often estimated in the laboratory by placing acclimated fish into a water tank with a gradient of water temperatures. The water temperature of the areas avoided by the fish represents the avoidance temperature under the laboratory conditions. Results are often presented as mean or median of observed values. It becomes important to examine the actual range of temperatures that the fish were found to avoid.

Laboratory Lethal Temperature Studies

Two common laboratory approaches have been used to quantify lethal temperature tolerances in fish: the Fry or incipient lethal temperature (ILT) technique and the critical thermal method (CTM) (Beitinger et al., 2000). Unfortunately, few studies have quantified both ILT and CTM for the same species acclimated to similar temperatures. However a literature review by Beitinger et al. (2000) suggest that CTM values can be as much as 1 to 4°C higher than ILT (UILT/UUILT) values for the same species tested at the same acclimation temperature.

Incipient Lethal Temperature: With the ILT technique, fish are transferred from an acclimation temperature tank directly into a constant temperature tank. A range of acclimation temperatures are often used and for each acclimation temperature, several different constant test temperatures are used. For each test group, the time to 50% mortality is recorded. ILT tests have frequently been performed for a 7-day period, or shorter periods in some cases.

A sample of ILT data results are depicted on Figure 2 with regression lines developed for each acclimation temperature. An abrupt change in the slope of the line theoretically occurs at the upper incipient lethal temperature (UILT) – the boundary between the Zone of Thermal Resistance and the Zone of Thermal Tolerance. In Figure 2, the UILT for each acclimation temperature occurs at the intersection of the fitted lines with Line A-B and Line B-C. Generally, UILT values increase with increases in acclimation temperatures until the ultimate upper incipient lethal temperature (UUILT) is reached (Line B-C in Figure 2). At this point, the UILT values remain unchanged with changes in acclimation temperature.

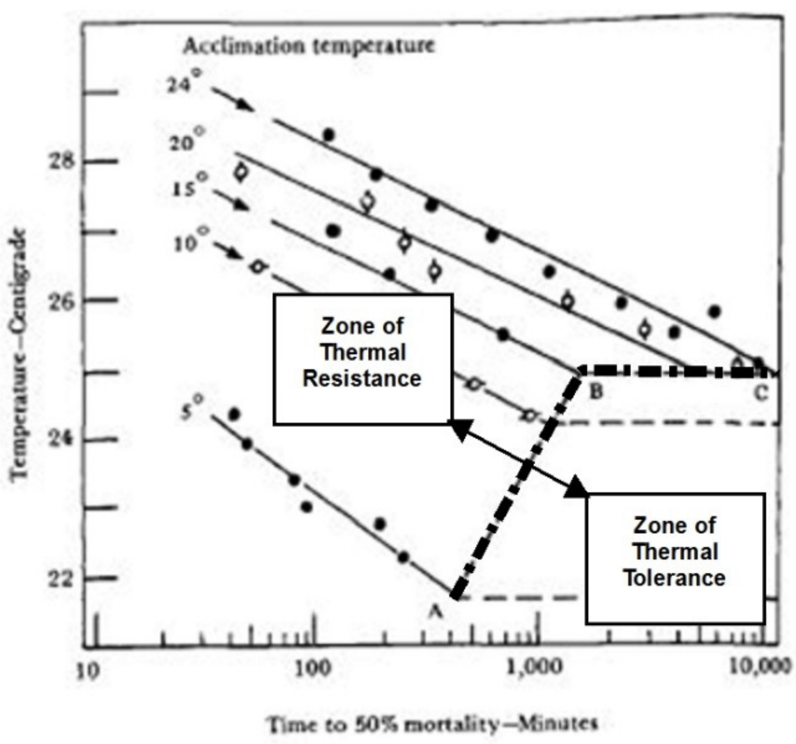

Figure 2. Median Resistance Times to High Temperature among Young Chinook (Brungs and Jones, 1977). Line A-B denotes rising lethal threshold (UILT) with increasing acclimation temperature. This rise eventually ceases at the ultimate upper lethal threshold (UUILT) – line B-C.

Not all ILT papers have identified UILT/UUILT values. In some cases, only the test temperatures and times to 50% mortality results (and fitted regression lines as shown in Figure 1) are presented for each acclimation level. No data are shown to identify the abrupt change in slope needed to estimate UILT/UUILT values.

Under the standard ILT test, fish experience abrupt temperature changes when moved from acclimation tanks to the test water tanks. This precludes fish from acclimating to the gradually changing temperatures occurring in most natural conditions. Zale (1984) developed a modified lethal temperature technique referred to as the acclimated chronic exposure (ACE) method. The ACE method involves gradually increasing the water temperature (with the fish) until the desired test temperature is reached. Once the desired temperature is reached, fish are maintained at that constant temperature for 60 days or until death. Because the fish are gradually acclimated to the test temperatures, the acclimation and test temperature are the same for the ACE method. From the laboratory data, relationships are then derived between the test temperatures and the time to 50% mortality. However with the ACE method, the overall exposure time is considerably longer than with the traditional ILT tests. According to Selong et al. (2001), the longer test period allows for chronic thermal effects to be evaluated. Therefore, ACE test results may be better suited to establishing chronic criteria.

Critical Temperature Maximum: With the traditional CTM method, acclimated fish are exposed to gradually increasing water temperatures (common rate of increase is 0.3°C/min; 18°C/hour) until a predefined endpoint (loss of equilibrium[1], muscle spasms, or death) is reached (Currie et al., 1998). Water temperatures are increased at a constant rate which is typically slow enough to permit deep body temperatures to follow test temperatures and too rapid to allow temperature reacclimation by fish (Currie et al., 2004). In addition to the traditional CTM approach, some researchers have also examined the impacts of daily varying temperatures on CTM values (Currie et al., 2004; Lee and Rinne, 1980).

Since fish in natural conditions rarely encounter rapid temperature changes typical of CTM studies, some researchers have opted to conduct CTM tests using much slower heating rates, in the range of 1-2°C/day. It was presumed that the results could be more readily extended to fish tolerance under natural conditions. Beitinger et al. (2000) refer to this modified CTM as a chronic lethal maximum (CLM).

Due to differences in the methodologies, CTM values can be several degrees higher than UILT and UUILT values (Beitinger et al., 2000; Todd et al., 2008). For example, Lohr et al. (1996) identified CTM values that were 3.6 to 5.4°C higher than UILT values for arctic grayling. In the development of new temperature standards, the State of Colorado relied on UILT/UUILT values derived from the ILT methods. For those cases when only CTM values were available, Colorado adjusted CTM values to UILT/UUILT, and used the results in calculating their criteria (Todd et al., 2008). Unfortunately, few studies have quantified both UILT and CTM for the same species acclimated to similar temperatures. Therefore, Colorado had to rely on CTM to UILT conversion factors derived by comparing the median CTMs to median UILTs from a range of different studies. As a result, Colorado developed CTM to UILT conversion factor that ranged from 0.8°C (rainbow and brook trout, all warmwater fish) to 4.4°C (cutthroat trout). However, a review of the documentation for these values suggests there are some significant flaws in Colorado's calculations.

[1] Loss of equilibrium represents the inability to maintain an upright position within the water column (Galbreath et al. 2004).

Field Studies

Laboratory studies of temperature preference and lethality may not adequately reflect the thermal requirements of fishes in nature (Huff et al. 2005; Wehrly et al. 2007). Fish confined in small tanks under artificial conditions are likely to experience more severe stress than in a natural stream (Flodmark et al. 2004). Also as laboratory results may not represent the full range of conditions that fish will endure, field information provides an additional line of evidence when characterizing temperature tolerances of fish. These studies typically rely on fish presence/abundance measurements from field surveys along with corresponding temperature conditions. A variety of different statistical methods may be applied by the researchers to quantify thermal tolerance thresholds. The thermal tolerance thresholds may be based upon any of the temperature metric discussed above: daily maximum (MDMT), weekly average of daily maximum (MWMT), daily average (MDAT), weekly average of daily averages (MWAT).

Chronic and Acute Thresholds Identified by EPA and Colorado

Detailed descriptions of the EPA guidance and the Colorado approach are provided in NDEP's White Papers (2015a, 2015b) and for the sake of brevity will not be repeated in this document. In summary, both relied on the following thermal thresholds from the literature in the development of their criteria. Both EPA and Colorado primarily used laboratory data in the derivation of thermal thresholds. However in some cases, EPA may have used some field studies to supplement the laboratory results. Colorado did not directly use field studies to develop their criteria, but did use field study results as a check.

Table 1. Temperature Measures used by EPA and Colorado

Temperature Measure	Used by EPA	Used by Colorado
Optimum Temperature	X	X
UILT and UUILT	X	X
CTM		X
Temperature Preferences		X
Avoidance Temperatures		X

Other Information

Occasionally, other lines of evidence may be encountered in the literature and may be incorporated into the analyses where appropriate. For example, some publications present thermal threshold ranges based upon the work of others. However, this line of evidence is to be used with caution as it is not always clear in the publications why the specific ranges were selected and what temperature metric (daily average (MDAT, daily maximum (MDMT), etc.) the values are associated with. Some publications may present information on thermal impacts on swimming performance, predation by other fish, etc. that may incorporated into the analysis.

SELECTION OF APPROPRIATE THERMAL RESPONSE THRESHOLDS FROM MLOE

For some fish species, the available literature may suggest that a wide range of temperature conditions are acceptable for both chronic and acute conditions. Selection of appropriate thermal response thresholds based upon this information will require a certain amount of best professional judgment. An important consideration is that water quality criteria to protect aquatic life are often set near the upper end of the acceptable range of values. In general, the intent of these standards is to protect the aquatic life during critical conditions, but not to ensure optimum levels. For example, Brungs and Jones (1977) recommend chronic temperature criteria that fall between temperatures that provide for optimum growth and temperatures that are lethal during acute conditions. In the case of dissolved oxygen criteria, EPA (1986) recommends criteria at levels that might allow for slight to moderate production impairment of fish. EPA argued that these criteria provide adequate protection during worst case conditions (such as could occur during low flows, high temperatures, and high nutrient loading), considering that most of the time conditions will be better than the criteria.

In general, NDEP's approach is to accept the EPA recommendations from Brungs and Jones (1977) unless the literature review provides a compelling reason to utilize other values. For those species not addressed in Brungs and Jones (1977), best professional judgment will be used to select thermal tolerance recommendations from within the range of acceptable values.

Following is a basic description of the general approaches for deriving the chronic and acute thermal tolerance values from the MLOE.

Chronic Thermal Tolerance Values

As discussed earlier, NDEP intends to define chronic thermal tolerance values in terms of Maximum Weekly Average Temperatures (MWAT). Chronic thermal tolerance values are to be derived from these primary sources:

- Growth studies
- Preference studies
- Avoidance studies
- Field studies
- Other information

<u>Growth Studies</u>

It is important to recognize that the intent of the chronic thresholds is to protect the aquatic life during critical conditions, but not to necessarily ensure optimum growth levels. Hokansen et al. (1977) states "*[c]riteria are not designed to produce maximum growth of fish, but to protect a balanced indigenous fauna of direct importance to man*." In 1973, the National Academy of Sciences suggested that an appropriate weekly mean temperature criteria could be set as the average of the optimum temperature and the temperature of zero net growth[2]. At this temperature level, optimum growth rates were thought to be reduced to about 80% of the optimum. Also, Brett (1960) suggested that a provisional long term exposure limit could represent that temperature that allowed 75% of optimum growth. The selected chronic thermal threshold may fall near the 80% of optimum growth temperature if deemed appropriate.

<u>Preference Studies</u>

Results are often presented as mean or median of observed values. It becomes important to examine the actual range of temperatures that the fish were found to prefer. The selected chronic thermal threshold may fall within this upper range if deemed appropriate.

[2] Zero net growth temperature – temperature at which growth and mortality rates for populations are equal.

Avoidance Studies

Results are often presented as mean or median of observed values. It becomes important to examine the actual range of temperatures that the fish were found to avoid. The selected chronic thermal threshold may fall within this upper range if deemed appropriate.

Field Studies

Field studies may report thermal tolerance/preferences in terms of a variety of metrics, e.g. daily maximum, daily average, weekly average. In general, thresholds defined for daily average and weekly average of daily averages were deemed applicable for derivation of the chronic criteria.

Other Information

Other lines of evidence may report thermal tolerance/preferences in terms of a variety of metrics, e.g. daily maximum, daily average, weekly average. In general, thresholds defined for daily average and weekly average of daily averages were deemed applicable for derivation of the chronic criteria.

Acute Thermal Tolerance Values

As discussed earlier, NDEP intends to define acute thermal tolerance values in terms of Maximum Daily Maximum Temperatures (MDMT). Acute thermal tolerance values are to be derived from these primary sources:

- ILT studies
- CTM studies
- Field studies
- Other information

ILT Studies

Brungs and Jones (1977) recommended Short Term Maximum thresholds be developed using the ILT thermal resistance relationships for a given fish (as shown in Figure 2) based upon an assumed exposure time of 1,440 minutes (1 day). However, only those relationships for acclimation temperatures near the chronic threshold recommendations are to be used. Brungs and Jones recognized that it is not appropriate to directly use these values for establishing criteria as these levels allow for 50% mortality. The National Academy of Sciences (1972) recommended that the derived thermal resistance values from Figure 2 relationships be reduced by 2°C to provide 100% survival. This approach forms the basis of EPA's recommended short term maximum (acute) criteria.

In theory, EPA's use of the thermal resistance equations with an exposure of 1,440 minutes (1 day) led to the derivation of values which fall within the Zone of Thermal Resistance, where a strong relationship between temperature and exposure time exists. While these calculations sometimes result in values close to reported UILT/UUILT values, this is not always the case. A slightly more conservative approach may be to rely on the UILT/UUILT estimates. This is basically the approach used by the State of Colorado. The State of Colorado (Todd et al., 2008) opted to not follow EPA's approach for calculating acute criteria, and instead relied on UILT/UUILT values, reduced by 2°C as recommended by the National Academy of Sciences (1972).

In evaluating ILT literature for possible acute thresholds, Nevada has decided to not use the EPA approach for calculating acute criteria and instead focus on those ILT studies with reported UILT/UUILT values for acclimation temperatures near an acceptable chronic (MWAT) criteria. In general, appropriate acute thresholds may be calculated by reducing the UILT/UUILT values by 2°C as recommended by the National Academy of Sciences (1972).

CTM Studies

While UILT values are preferred for deriving acute thresholds, CTM values may provide additional support for recommendations. CTM values are commonly higher than UILT values for the same species. CTM tests are thought to produce lethal temperature thresholds that are too high to be protective in nature because the procedure subjects test organisms to relatively rapid increases in test temperature (e.g., >1°C/hour) (Yoder 2012). A literature review by Beitinger et al. (2000) suggests that CTM values can be as much as 1 to 4°C higher than UILT/UUILT values for the same species tested at the same acclimation temperature. NDEP found similar "CTM minus UILT" values for several fish species found in Nevada (Tables 2 and 3). In general, quasi-UILT values may be calculated by reducing the CTM values by the Overall Median values in Table 2 and 3. For those species with an Overall Median value, CTM values are reduced by the species-specific Overall Median. For those species without an Overall Median value, CTM values are reduced by the Family-specific Overall Median. If no Family-specific Overall Median exists, then the Coldwater or Warmwater Overall Median values are used to reduce the CTM value to yield a quasi-UILT value. As with the UILT values described earlier, only CTM values for acclimation temperatures near an acceptable chronic (MWAT) criteria are to be used in the analysis. Also, the quasi-UILT values are to be reduced by 2°C as recommended by the National Academy of Sciences (1973).

Table 2. CTM minus UILT (quasi-UILT) Values – Coldwater Species

Common Name	Scientific Name	Median CTM minus UILT Values		
		Min Median	Max Median	Overall Median
Salmon and Trout Family – Salmonidae				
Brook Trout	*Salvelinus fontinalis*	4.3	5	4.7
Brown Trout	*Salmo trutta*	2.9	3.8	3.8
Rainbow Trout	*Oncorhynchus mykiss*	3.1	4.6	3.9
Coldwater and Family Median				***3.9***

Note: CTM minus UILT (quasi-UILT) values were calculated as followed for each species: 1) For each acclimation temperature with both CTM and UILT values, median values were calculated for all the CTM and UILT values for that acclimation temperature. Subtracting these median UILT values from the CTM values yielded a series of median CTM minus UILT values for each species. Table 2 summarizes the minimum and maximum median CTM minus UILT values for all acclimation values, with the Overall Median representing the median of the median CTM minus UILT values.

Table 3. CTM minus UILT (quasi-UILT) Values – Warmwater Species

Common Name	Scientific Name	CTM – UILT Values		
		Min	Max	Overall Median
Carp and Minnow Family – Cyprinidae				
Fathead Minnow	*Pimephales promelas*	0.3	3.1	2.0
Golden Shiner	*Notemigonus crysoleucas*	1.4	1.4	1.4
Northern Leatherside Chub	*Lepidomeda copei*	3.1	4.2	3.7
Family Median				***2.0***
Live Bearers Family – Poeciliidae				
Western Mosquitofish	*Gambusia affinis*	0.5	4.9	3.5
Family Median				***3.5***
North American Catfish Family – Ictaluridae				
Bullhead (Black, Brown, Yellow)	*Ameiurus melas, Ameiurus nebulosus, Ameiurus natalis*	2.8	4.3	3.5
Channel Catfish	*Ictalurus punctatus*	2.4	5.5	2.9
Family Median				***3.2***
Sunfish Family – Centrarchidae				
Black Crappie	*Pomoxis nigromaculatus*	4.2	4.2	4.2
Bluegill Sunfish	*Lepomis macrochirus*	1.8	5.8	3.9
Largemouth Bass	*Micropterus salmoides*	1.3	4.5	3.7
Pumpkinseed Sunfish	*Lepomis gibbosus*	1.5	1.5	1.5
Family Median				***3.8***
Temperate Bass Family – Moronidae				
Striped Bass	*Morone saxatilis*	2.5	4.9	3.4
Family Median				***3.4***
All Warmwater Species				
All Warmwater Median				***3.4***

Note: CTM minus UILT values were calculated as followed for each species: 1) For each acclimation temperature with both CTM and UILT values, median values were calculated for all the CTM and UILT values for that acclimation temperature. Subtracting these median UILT values from the CTM values yielded a series of median CTM minus UILT values for each species. Table 3 summarizes the minimum and maximum median CTM minus UILT values for all acclimation values, with the Overall Median representing the median of the median CTM minus UILT values.

<u>Field Studies</u>

Field studies may report thermal tolerance/preferences in terms of a variety of metrics, e.g. daily maximum, daily average, weekly average. In general, thresholds defined for daily maximums and weekly averages of daily maximums were deemed applicable for acute criteria.

<u>Other Information</u>

Other lines of evidence may report thermal tolerance/preferences in terms of a variety of metrics, e.g. daily maximum, daily average, weekly average. In general, thresholds defined for daily maximums and weekly averages of daily maximums were deemed applicable for acute criteria.

Standardizing Thermal Tolerance Thresholds Reported in the Literature

In accordance with EPA guidance, NDEP desires to develop both chronic and acute temperature criteria using both MWAT (Maximum Weekly Average Temperature) and MDMT (Maximum Daily Maximum Temperature) metrics, respectively. However, not all thermal tolerance threshold values are readily assignable to either of these metrics. For example, the State of Oregon adopted an acute criteria of 20°C (measured as 7-day average of daily maximum temperatures (MWMT)) for the protection of Lahontan cutthroat trout. In order to consider the applicability of this criterion for Nevada, a conversion factor is needed to translate the MWMT value to the desired MDMT criterion. Using data compiled for 377 stream monitoring sites throughout northern Nevada and adjoining areas (Figure 3), NDEP derived linear relationships for converting between different metrics (Table 4, Figures 4 through 6).

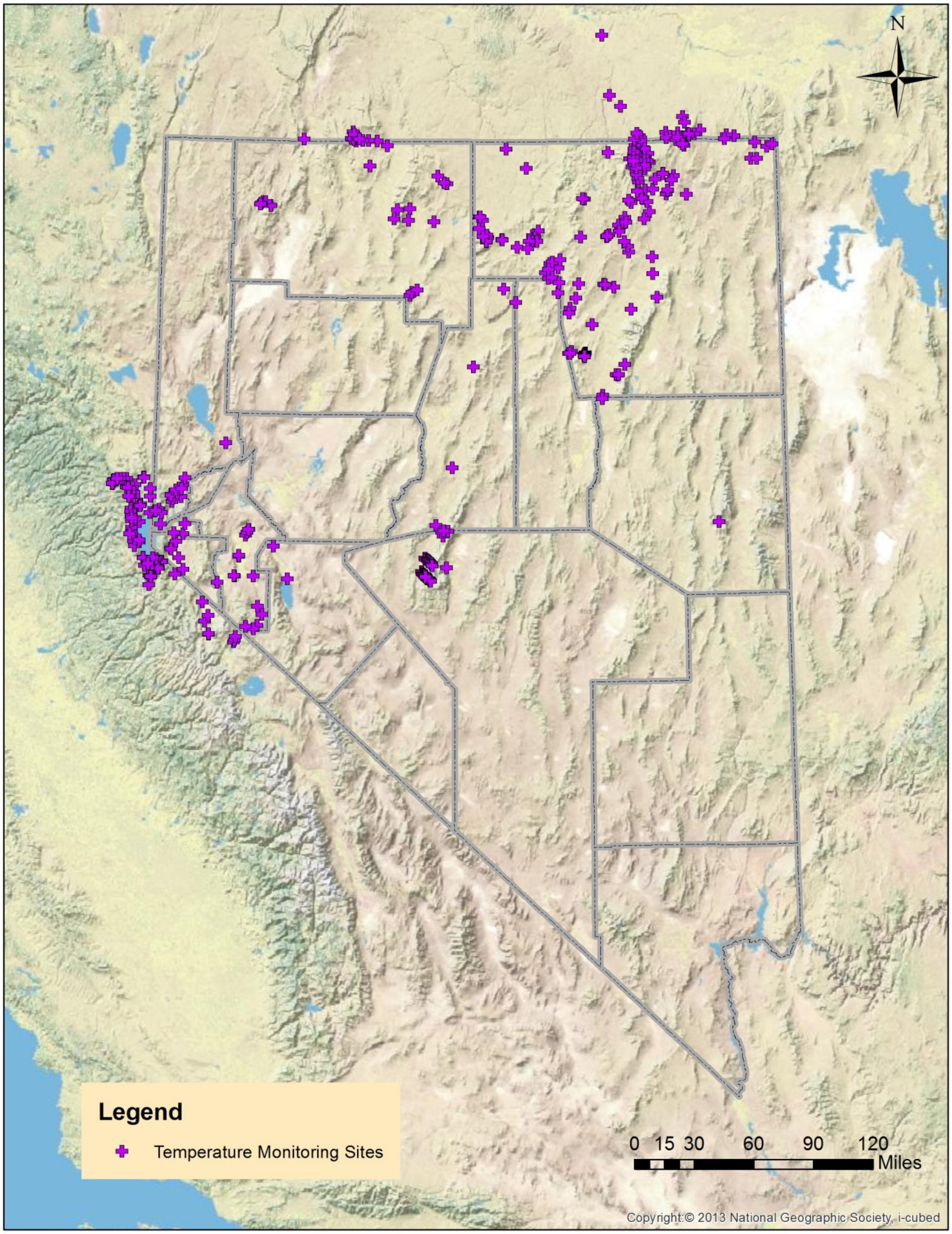

Figure 2. Detailed Temperature Monitoring Sites in and near Nevada

Table 4. Conversion Equations for Standardizing Thermal Tolerance Thresholds

Convert From:	Convert To:	Conversion Equation (°C)
MWMT	MDMT	MDMT = 1.04 x MWMT
MDAT	MWAT	MWAT = 0.96 x MDAT
June-August Average	MWAT	MWAT = 1.05 x Jun-Aug Average + 1.6
June-August Average	MWMT	MWMT = 1.26 x Jun-Aug Average + 2.6

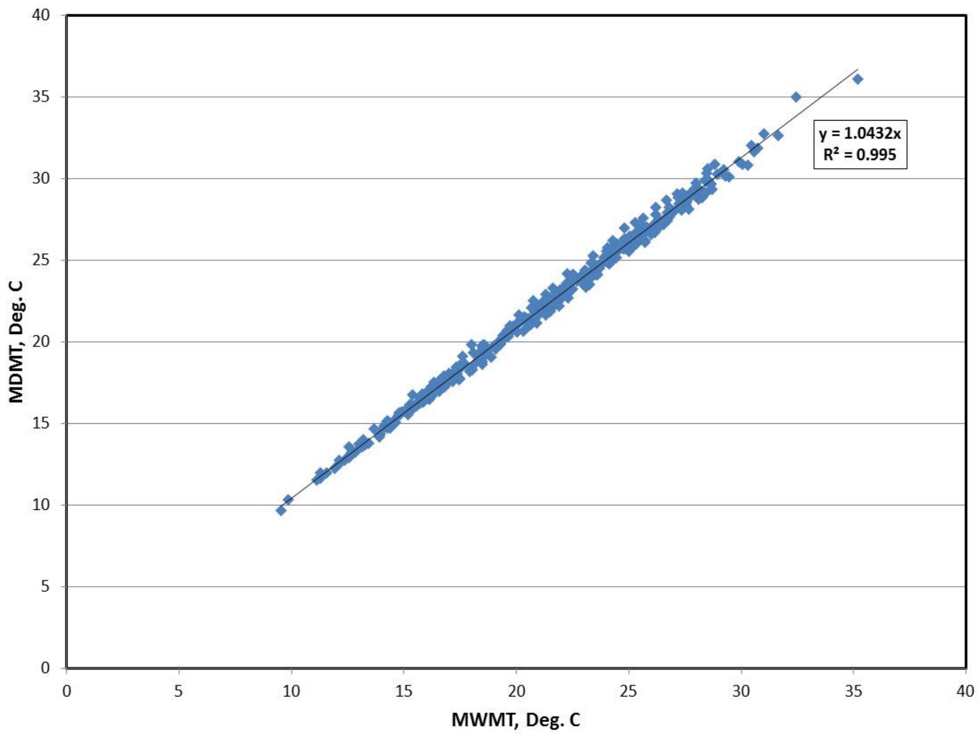

Figure 3. MWMT v. MDMT Relationship

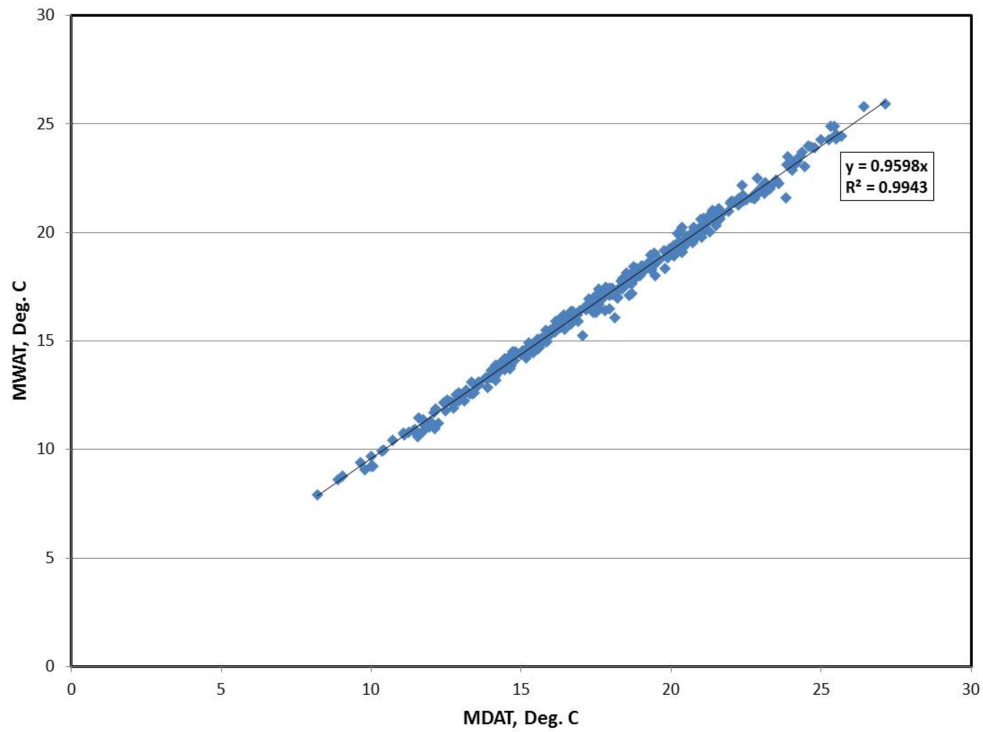

Figure 4. MDAT v. MWAT Relationship

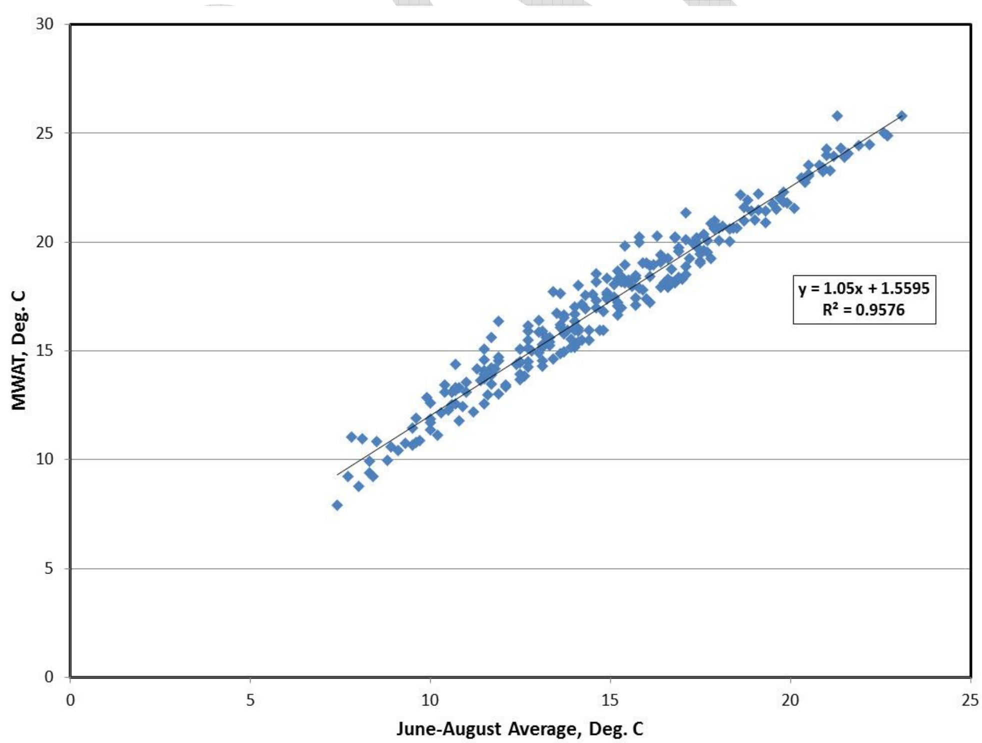

Figure 5. June-August Average v. MWAT Relationship

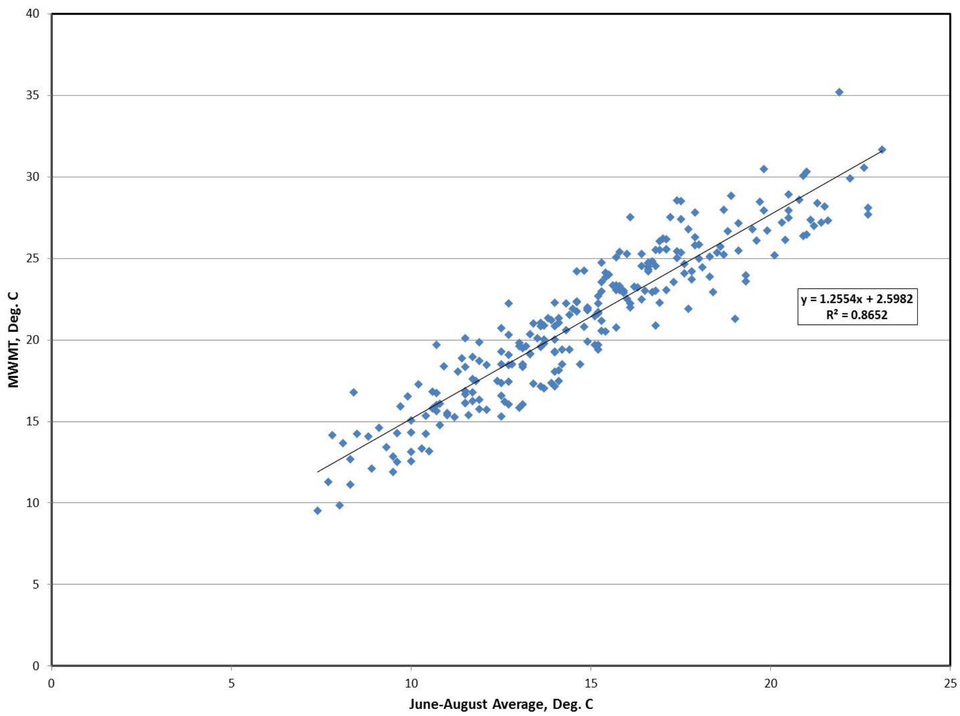

Figure 6. June-August Average v. MWMT Relationship

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