Paper Title: Updating a Temperature Criteria Methodology for the Ohio River Mainstem

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Introduction

Temperature criteria provide an important basis for evaluating and regulating effects from cooling water and other thermal discharges in order to protect fish and other aquatic life. The technical justification for the temperature criteria in the ORSANCO Pollution Control Standards was originally developed by Ohio EPA [1] using a standardized methodology for calculating seasonal and monthly average and daily maximum temperature criteria. This approach used data from the thermal effects literature to create a thermal effects database for fishes. This data was then used within a procedure that calculates various behavioral and physiological thresholds for a list of representative fish species that are intended to represent the fish assemblage of a particular river. Ohio EPA took this same approach in setting temperature criteria for inland waters and Lake Erie in the 1978 revisions to the Ohio water quality standards (WQS). The temperature criteria derivation process was later incorporated within the Fish Temperature Modeling system that is part of the Ohio ECOS data management system developed and operated by Ohio EPA. Much of the literature upon which the thermal effects database is based dates from before the late 1970s with some sources dating from the 1940s and 1950s. Because the literature database exceeds 30-40 years of age and newer sources have become available, concerns have been raised about the contemporary applicability of the existing Ohio River temperature criteria. The incorporation of more recent information is seen as being needed to determine the relevancy and appropriateness of the current temperature criteria. Other considerations, including the use of various thermal thresholds (e.g., incipient lethal temperature, critical thermal maxima) and of protecting 100% of the representative species vs. 95%, etc. have also been raised.

The current temperature criteria were derived using a methodology developed by Ohio EPA [1] to calculate seasonal temperature criteria for the Ohio River mainstem and the other major mainstem rivers of Ohio. The original Fish Temperature Modeling system was developed as a mainframe routine, but presently exists in FoxPro as part of the Ohio ECOS data management system. MBI is presently developing an update to this system for ORSANCO. This will include updating the thermal effects database and reviewing the applicability of other criteria derivation methods that have been developed since the inception of the Ohio EPA methodology in 1978. The key variables that determine the outputs of the model are the list of representative fish species and the temperature tolerance endpoints used for each. The temperature tolerance endpoints used in the model were derived from the extensive literature database that was assembled in support of the existing methodology prior to 1978 [1].

Methods

The primary input variables to the Fish Temperature Model are four thermal parameters for each representative fish species; a physiological optimum temperature, a maximum weekly average temperature for growth, an upper avoidance temperature, and an upper incipient lethal temperature. These were derived from an extensive literature review and were assigned to each Ohio River basin fish species for which sufficient thermal data could be found. When multiple thresholds were available for a particular species, the most ecologically and geographically relevant data was used.

Thermal Parameters

Four thermal input variables are used in the Fish Temperature Model to determine the summer (June 16 – September 15) average and daily maximum temperature criteria. However, in developing these baseline input variables, six thermal parameters were first considered by Ohio EPA[1]. General concepts of thermal responsiveness (e.g., acclimation) were considered and are discussed in more detail elsewhere [2]. Of the six thermal parameters that were inventoried for each fish species, the upper incipient lethal temperature (UILT) and the critical thermal maximum (CTM) are considered lethal thresholds and the remaining four (optimum, final preferendum, growth, and upper avoidance) are considered sublethal parameters. At the time the Ohio EPA [1] methodology was developed, the rapid transfer method (from which the UILT is derived) was viewed as providing a firmer basis for physiological response than does the slow heating method on which the CTM is based [2]. Each of the six thermal parameters are defined as follows:

Upper Incipient Lethal Temperature – at a given acclimation temperature this is the maximum temperature beyond which an organism cannot survive for an indefinite period of time;

Critical Thermal Maximum – the temperature at which a test organism experiences equilibrium loss resulting from a steady increase in temperature (approximately 0.5 ^{o}C/hr.);

Optimum – the temperature at which an organism can most efficiently perform a specific physiological or ecological function;

Final Preferendum – the temperature at which a fish population will ultimately congregate regardless of previous thermal experience [3];

Upper Avoidance Temperature – a sharply defined upper temperature at which an organism that a given acclimation temperature will avoid [4];

Growth – the mean weekly average temperature for acceptable growth [5].

A fish species was included in the database when a minimum of three of the six parameters was available. MBI is in the process of updating the literature database to include sources available since 1978. We expect that this will not only add new species to the thermal database, but also provide a wider availability of thermal parameters for each species.

Thermal Input Variables

The analysis used four thermal input parameters that included: 1) the optimum or final preferendum; 2) the mean weekly average temperature (MWAT) for growth as described by Brungs and Jones [5]; 3) the upper avoidance temperature as described by Coutant [4]; and, 4) the upper incipient lethal temperature (UILT) at acclimation temperatures of 27-30°C. Thermal parameters compiled from various literature sources for 84 freshwater fish species were used as the primary database for the model. Missing parameters were estimated by calculating relationships between some of the six thermal parameters that were gleaned from the literature for each species – at least three of the six had to be available for a species before this procedure could be used. In order to estimate the missing thermal parameters, calculation of the differences between the; 1) optimum and UAT, 2) optimum and UILT, 3) optimum and critical thermal maximum (CTM), 4) UAT and UILT, 5) UAT and CTM, and 6) UILT and CTM were made [1]. Extrapolations were then made in a stepwise procedure as follows:

1) based on the species family relationships (e.g., longnose gar, Lepisosteidae); or

2) based on the next closest family if information for a parameter did not exist within the species family; or,

3) based on the average of all families as a last choice.

The four primary thermal parameters are stored by species and accessed by the model when that species is designated as being representative.

Representative Fish Species

The derivation of temperature criteria is also dependent on the development of a list of representative fish species, which is the primary input variable for the model. Representative species constitute a *subset* of the assemblage that have sufficient thermal tolerance data upon which temperature criteria can be derived. There is a tendency for species regarded as being tolerant to a wide variety of environmental impacts to be included in these databases, which is similar to other water quality criteria databases. As such, there will likely be species present in the potential assemblage that are more sensitive to the parameter that is being considered. This approach is simply a best attempt to represent the entirety of the assemblage and it is limited by the extant tolerance databases. As such, the model output will propagate a degree of uncertainty, which can be considered in the eventual derivation and application of the temperature criteria. In developing a list of representative fish species for a particular water body or area, the following criteria for membership were used:

- species that represent the full range of response and sensitivity to environmental stressors;

- species that are commercially and/or recreationally important;

- species that are representative of the different trophic levels;

- rare, threatened, endangered, and special status species;
- species that are numerically abundant or prominent in the system;
- potential nuisance species; and,
- species that are indicative of the ecological and physiological requirements of representative species that lack thermal data.

In addition to these conceptual guidelines, the historical occurrence of fish species in a particular water body is also considered.

Temperature Criteria Derivation Process

Average and daily maximum summer temperature criteria were determined via an analytical process similar to that developed by Bush et al. [6]. Temperature tolerance values for 69 Ohio River basin fish species are presently contained in the Ohio EPA database (Table 1). These values include the four primary thermal parameters described previously; optimum, mean weekly average for growth, upper avoidance, and upper incipient lethal temperatures. The model permits alternative values to be substituted and these can be maintained as alternate databases to be used for computing the effect of any species-specific differences on the derivation of summer season thresholds. The tolerance values in the existing database [1] were used in the derivation of the summer average and maxima for the Ohio River mainstem. The procedure is simply one of listing each representative species under each thermal parameter adjacent to the whole Fahrenheit temperature when it is exceeded. The cumulative effect of increasing temperature is readily apparent as each species thermal criteria are exceeded. This process indicates where the various species occur (with respect to increasing temperature) relative to each other and does not indicate exact thresholds or limits. The temperatures at which 100%, 90%, 75% and 50% of the representative fish species for the four thermal thresholds are then derived to show what proportion of the representative assemblage is protected at a given temperature. The long-term survival temperature is calculated from the short-term survival (i.e., the UILT) as UILT minus 2^{o}C. The following guidelines are used to derive summer average and maximum temperature criteria.

Averages should be consistent with:

- 100% long-term survival of all representative fish species;
- growth of commercially or recreationally important fish species;
- growth of at least 50% of the non-game fish species;
- 100% long-term survival of all endangered fish species; and
- the observed historical ambient temperature record.

Daily maxima should be consistent with:

- 100% short-term survival of all representative fish species; and
- the observed historical ambient temperature record.

Table 1. Summary of behavioral, physiological, and reproductive temperature (^{o}C) thresholds for 69 species of freshwater fishes known to occur in Ohio rivers and streams [1]. Species considered representative of the Ohio River mainstem fish assemblage appear in boldface type. Thresholds denoted by an asterisk were estimated when data was not available. Each is applicable to all waters of the state excepting Lake Erie and adjacent embayments. All behavioral and physiological criteria apply to the summer season (June 16 - September 15) and assume acclimation to ambient field temperatures of 27-30^{o}C.

Species	Optimum or Final Preferendum	MWAT for Growth[1]	Upper Avoid. Temp.	Upper Incipient Lethal Temp.[2]	Spawning Temperatures									
					Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Shortnose Gar	33.0*	34.8	35.0	38.3*			19.0		30.0	30.0				
Longnose Gar	34.0*	35.4	35.0	38.3*			18.0		30.0					
Goldeye	28.0*	29.5	29.0	32.6*			12.8							
Mooneye	27.5*	29.2	29.0	32.6*										
Skipjack Herring	27.0*	29.4	30.5	34.1*										
Gizzard Shad	29.0	31.3	34.0	36.0			19.5	23.1/26.7	29.0					
Brown Trout	13.8	17.0	20.0	23.4								12.8	8.9/6.7	
Rainbow Trout	18.5	20.7	24.5	26.5			10.0	15.5						
Coho Salmon	16.6	19.4	23.5	25.0										
Chinook Salmon	17.3	19.9	24.1	25.0										
Brook Trout	18.0	20.4	23.0	25.3										
Smelt (spring)	8.3	13.7	16.0	24.4			14.5							
Redfin Pickerel	26.0	28.8	30.1*	34.3*										
Northern Pike	26.1	28.4	29.8*	33.3	4.4/10.0	11.1/14.0	17.2/20.0							
Muskellunge	24.0	27.1	28.8*	33.3		12.8/15.0	17.2							
Bigmouth Buffalo	32 9*	34.1	35.0	38.3*		15.5	18.3	27.0						
Black Buffalo	32 9*	34.1	35.0	38.3*										

Species	Optimum or Final Preferendum	MWAT for Growth[1]	Upper Avoid. Temp.	Upper Incipient Lethal Temp.[2]	Spawning Temperatures									
					Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Smallmouth Buffalo	33.0	35.1	36.0	39.3 *			16.0/20.0	27.0/28.0						
Quillback	29.5	32.4	35.0	38.3 *		19.0		28.0	28.0/28.0	28.0/28.0	28.0			
River Carpsucker	32.0	34.1	35 9	38.9 *		18.0	21.0/24.0							
Highfin carpsucker	30.2*	32.6	34.0	37.3*			19.0	28.0	28.0/28.0	28.0/28.0	28.0			
Golden Redhorse	26.0	27.9	28.5	31.8 *			15.0							
Shorthead Redhorse	27 9*	28.6	28.5	31.8 *		11.0	16.0							
Hog Sucker	27.2	29.5	31.7	34.2 *	15.6									
Common White Sucker	23.9	26.4	30.6	31.4			20.0	23.3						
Spotted Sucker	24.0	26.1	27.0	30.3 *		12.0/14.5	17.8/19.0							
Common Carp	33.0	35.7	36.0	41.0			17.0/19.0	26.0	28.0/28.0	28.0/28.0				
Goldfish	28.1	30.9	33.0	36.6*			16.0		30.0/30.0	30.0/30.0				
Golden shiner	27.2	29.6	33.5	34.5										
Blacknose Dace	23.9	25.8	27.2	29.5			15.0	22.0						
Longnose Dace	27.3*	29.2	31.0	33.1			11.1	23.3						
Creek Chub	23.9	26.5	29.4	31.6		12.8			26.7					
Emerald Shiner	27.0*	29.0	31.1	33.0*			20.0	27.0	27.0/27.0	27.0				
Silver Shiner	23.1*	25.1	27.2	29.1*										
Rosyface Shiner	26.8	28.8	31.0	32.9			/17.8	21.1/26.7	28.9/28.9					
Striped Shiner	27.9*	29.8	31.2*	33.5										
Common Shiner	25.4*	27.3	28.7*	31.0			15.6		28.3/28.3					
Spottail Shiner	27.2	29.3	31.7	33.4*			20.0							
Spotfin Shiner	29.7	31.9	35.0	36.3*				25.0	29.0/29.0	29.0				
Silverjaw Minnow	27.0*	29.1	31.1	33.4*										
Fathead Minnow	28.9	30.3	32.0	33.2			15.0	23.5/26.8						

Species	Optimum or Final Preferendum	MWAT for Growth[1]	Upper Avoid. Temp.	Upper Incipient Lethal Temp.[2]	Spawning Temperatures									
					Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Bluntnose Minnow	28.9	30.4	31.1	33.3			20.0/21.1	26.1						
Stoneroller	28.6	30.8	33.8	35.2*		14.4/18.3		24.0/27.0	27.0/27.0					
Channel Catfish	30.5	32.8	35.0	37.3				23.9/26.7	27.8/29.5					
Yellow Bullhead	28.0	30.6	31.0*	35.8*										
Brown Bullhead	31.1	33.2	36.1	37.5			21.0	25.0/27.0						
Flathead Catfish	32 9*	33.9	34.5	37.8*		22.0		30.0						
Mosquitofish	35.3	36.5	39.0	39.0										
White Bass	29.0	31.4	32.0	36.1*	12.0	14.4/17.8		24.0						
White Crappie	29.0	30.9	32.0	33.0		14.0/16.0	20.0	23.0						
Black Crappie	28.3	29.9	30.2	33.0		19.0								
Rockbass	28.2	30.4	29.6	33.7*			15.6	21.1						
Smallmouth Bass	28.0	30.3	31.0	35.0		15.0/18.3	23.9							
Spotted Bass	28.5	31.1	31.0	35.1*		15.0/18.3	23.9							
Largemouth Bass	28.0	30.8	31.5	36.5		18.9	21.0/23.9							
Green Sunfish	30.6	33.7	33.0	40.0			20.0		28.0/28.0	28.0/28.0				
Bluegill	31.8	33.5	33.6	36.8			16.0/23.9	26.0/27.8		32.0/32.0				
Longear Sunfish	30.4*	33.0	34.1*	38.2			20.0	25.0						
Pumpkinseed	28.5	30.7	32.0	35.0			20.0		29.0	29.0/29.0				
Sauger	27 9*	28.1	29.0	30.4		3.9	9.0/12.0	15.0						
Walleye	25.0	27.2	29.5	31.6		5.6	8.9/11.1	15.0						
Yellow Perch	27.1	28.8	31.0	32.3		8.5	14	16.1						
Dusky Darter	25.0	27.8	30.8*	33.3*										
Greenside Darter	26.7*	30.6	35.0*	38.3*				18.3						
Orangethroat Darter	26.0	28.8	31.8*	34.3*		13.0	25.0							
Fantail Darter	23.9	26.4	27.2	31.4*		18.9		24.4						

Species	Optimum or Final Preferendum	MWAT for Growth[1]	Upper Avoid. Temp.	Upper Incipient Lethal Temp.[2]	Spawning Temperatures									
					Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Freshwater Drum	29 9*	30.9	31.5	34.8*		/18		24.5/						
Mottled Sculpin	16.5	19.3	23.3*	25.0*			5.0	16.1						

1 - MWAT for growth calculated as: optimum + 0.333 (UUILT – optimum; Brungs and Jones 1976).
2 - Upper Lethal Temperature; 50% survival at 27-30^{o}C acclimation.
* - Estimate based on conversion factors in Ohio EPA [1].

Non-summer season temperature criteria are derived from the historical temperature record and considering other species-dependent criteria such as spawning periods.

Derivation of Ohio River Temperature Criteria

The derivation of seasonal temperature criteria for the Ohio River mainstem included summer average and daily maximum values based on the output of the Fish Temperature Model, consideration of species-specific spawning thresholds compiled in Ohio EPA [1], and consistency with the historical ambient temperature record. Twenty-five (25) species were considered representative of the Ohio River mainstem fish assemblage (Table 1). The list is most relevant to the upper and middle portions of the Ohio River mainstem as Trautman (1957) was the principle source of distribution data used when the list was developed by Ohio EPA [1].

Summer Average and Maximum Criteria

Summer average and maximum criteria were calculated in accordance with the outputs of the Fish Temperature Model (Table 2). These apply during the defined summer period of June 16-September 15 as daily maxima and a *period* average. The rationale for the period average as opposed to a daily or weekly average is in recognition of the realities of electric power generation and the thermal requirements of fish. Neither is a "smooth" function with power generation being driven by periodic short-term peak demand and fish being able to avoid short-term exceedences of the long-term survival thresholds. Meeting the long-term period average also requires equivalent "cool down" periods when temperatures are below the survival thresholds and closer to the equally important physiological thresholds for growth and maintenance. The results of the Fish Temperature Model outputs for the Ohio River mainstem appear in Table 2 (summer season thresholds). The results indicate that an average temperature of 28.4^{o}C (83.1 ^{o}F) and a daily maximum of 30.4^{o}C (86.7) will protect 100% of the representative species during the summer period. The period average of 28.4^{o}C exceeds the upper avoidance temperature for 10-25% and the growth temperature for 10-25% of the representative species. Sixteen (16) species are considered to be either commercially or recreationally important. Of these, the 28.4^{o}C average exceeds the growth temperatures for one species. No rare, threatened, or endangered species are among the representative fish species chosen by Ohio EPA for this analysis.

Seasonal Average and Daily Maximum Criteria

Establishing seasonal temperature criteria includes using not only the results in Table 2 for the summer period (June 16-September 15), but additional information for the remaining months (Table 3). These are set primarily in accordance with the historical ambient record, but also include an assessment of any exceedences of spawning temperature thresholds for each representative fish species (Table 2). Temperature duration analyses performed by USGS were used to determine the historical seasonal average and daily maximum temperatures. Averages were computed by averaging the daily maximums. Daily maximum temperatures were determined by examining the period of record and selecting the highest value that occurred at

Table 2. Temperatures at which 100%, 90%, 75%, and 50% of the representative fish species for the Ohio River mainstem are within each of five thermal tolerance categories during the summer season index period (June 16 – September 15). The long-term and short-term survival temperatures in ^{o}C (^{o}F) represent summer season average and maxima. Source: Ohio EPA [1].

Thermal Category	Proportion of Representative Fish Species			
	100%	90%	75%	50%
Optimum	26.0 (78.8)	27.0 (80.6)	27.5 (81.5)	29.0 (84.2)
Growth (MWAT)	27.9 (82.2)	28.1 (82.6)	29.5 (85.1)	30.9 (87.6)
Avoidance (UAT)	28.5 (83.3)	28.5 (83.3)	30.2 (86.4)	31.5 (88.7)
Survival (Long-term)	28.4 (83.1)	29.8 (85.6)	31.0 (87.8)	33.1 (91.6)
Survival (Short-term)	30.4 (86.7)	31.8 (89.2)	33.0 (91.4)	35.1 (95.2)

least three times during any one year and/or at least 10 times in a 10-year dataset. Any decimals derived from arithmetic transformation from degrees Centigrade to degrees Fahrenheit were rounded to the next highest whole number. Casual observations of summaries of the highest average and daily maximum ambient temperature record for any one year showed that the bi-weekly or monthly average was usually 6-10^{o}F lower than the daily maximum.

Review of ORSANCO Temperature Criteria

Ohio EPA used the same approach described here to derive temperature criteria for the inland rivers and streams of Ohio and the near shore and open waters of Lake Erie. These were adopted in the Ohio WQS (Ohio Administrative Code chapter 3745-1) in 1978 and remain unchanged today. ORSANCO adopted the temperature criteria shown in Table 3 in 1984 for the Ohio River mainstem using the criteria originally developed by Ohio EPA [1]. In 1995 questions were raised about the relevancy of those criteria, specifically regarding the age of the underlying database and the availability of a significant body of more recent thermal effects literature. To this end, ORSANCO commissioned a review of the existing methodology and the underlying thermal effects database. This study is currently in progress and the results will be forthcoming in 2004. In addition to updating the available thermal effects literature database, an effort will be made to characterize other criteria derivation methodologies that have emerged during the past 25 years. We expect that the products of this review will be useful elsewhere as thermal effects assessments under the Clean Water Act re-emerge, after a nearly 25 year period of comparative dormancy, as a priority for U.S. EPA and the states. We also expect that it will be relevant to other issues, particularly those that pertain to TMDLs and the potential for changing ambient conditions related to climate change assessment and research.

Table 3. Seasonal monthly/bi-monthly average and daily maximum temperature criteria (^{o}F) for the mainstem Ohio River as originally derived by Ohio EPA [1].

Month - inclusive dates	Monthly/Bi monthly Average	Daily Maximum	Criteria Rationale
January 1-31	45	50	Average and daily maximum criteria based on the historical temperature record at the Wheeling, Willow Island, and New Haven monitoring locations.
February 1-29	45	50	
March 1-15	51	56	
March 16-31	54	59	White bass initiate spawning.
April 1-15	58	64	White bass spawning; exceeds sauger spawning.
April 16-30	64	69	White bass, river carpsucker, smallmouth bass spawning.
May 1-15	68	73	Gizzard shad, river carpsucker, emerald shiner spawning; exceeds highfin carpsucker, sauger spawning criteria.
May 16-31	75	80	Smallmouth bass, river carpsucker spawning; exceeds sauger spawning criteria.
June 1-15	80	85	Exceeds spawning criteria for all species.
June 16-30	83	87	Long-term survival threshold exceeded by average July 1 – September 15; short-term survival exceeded July1 – August 31; growth of sport/commercial species exceeded July 1 – September 15.
July 1-31	84	89	
August 1-31	84	89	
September 1-15	84	89	
September 16-30	82	86	Average and daily maximum criteria based on the historical temperature record at the Wheeling, Willow Island, and New Haven monitoring locations.
October 1-15	77	82	
October 16-31	72	77	
November 1-30	67	72	
December 1-31	52	57	

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