Exhibit 1

Exhibit 1

ILLINOIS ENVIRONMENTAL PROTECTION AGENCY

1021 NORTH GRAND AVENUE EAST, P.O. BOX 19276, SPRINGFIELD, ILLINOIS 62794-9276 • (217) 782-2829
PAT QUINN, GOVERNOR LISA BONNETT, DIRECTOR

217/782-0610

September 19, 2013

RECEIVED 8/21/2013
ENVIRONMENTAL DEPARTMENT
MARATHON PETROLEUM COMPANY LP
ILLINOIS REFINING DIVISION
ROBINSON, ILLINOIS

Marathon Petroleum Company, LLC
P.O. Box 1200
Robinson, Illinois 62454

Re: Marathon Petroleum Company, LLC
Marathon Petroleum Company, LLC - Robinson Refinery
NPDES Permit No. IL0004073
Modification of NPDES Permit (After Public Notice)

Gentlemen:

The Illinois Environmental Protection Agency has reviewed the request for modification of the above-referenced NPDES Permit and issued a public notice based on that request. The final decision of the Agency is to modify the Permit as follows:

The 30-day average and daily maximum concentration limits for fluoride at outfall 001 have been changed to 4 and 17 mg/L. The respective load limits have been changed to 115 and 486 pounds per day. These changes are pursuant to updated regulations in 35 Ill. Adm. Code 302.208.

Special Conditions 22, 23, and 24 have been removed from the permit.

Enclosed is a copy of the modified Permit. You have the right to appeal this modification to the Illinois Pollution Control Board within a 35 day period following the modification date shown on the first page of the permit.

Should you have any question or comments regarding the above, please contact Mark E. Liska of my staff.

Sincerely,

Alan Keller

Alan Keller, P.E.
Manager, Permit Section
Division of Water Pollution Control

SAK:MEL:13052109.daa

Attachment: Final Permit

cc: Records
Compliance Assurance Section
Champaign Region
USEPA
Indiana Dept. of Environmental Management

NPDES Permit No. IL0004073

Illinois Environmental Protection Agency

Division of Water Pollution Control

1021 North Grand Avenue East

Post Office Box 19276

Springfield, Illinois 62794-9276

NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM

Modified (NPDES) Permit

Expiration Date: September 30, 2014

Issue Date: September 30, 2009
Effective Date: October 1, 2009
First Modification Date: December 9, 2010
Second Modification Date: May 11, 2012
Third Modification Date: September 19, 2013

Name and Address of Permittee:

Marathon Petroleum Company LP
P.O. Box 1200
Robinson, Illinois 62454

Facility Name and Address:

Marathon Petroleum Company LP - Robinson Refinery
100 Marathon Avenue
Robinson, Illinois 62454
(Crawford County)

Discharge Number and Name:	Receiving Waters:
001 - Wastewater Treatment Plant Discharge	Robinson Creek
002 - Treatment Plant Bypass	Marathon Creek
003 - East Impoundment Basin Discharge	Marathon Creek
005 - Coke Rail Car Repair Area Stormwater Runoff	Marathon Creek
006 - York Pond/North Culvert Outflow Stormwater	Robinson Creek
007 - Southeast Culvert/North Ditch Run-In Stormwater	Unnamed Creek tributary to Robinson Creek
008 - Southern Fence Line Stormwater Runoff	Drainage Tile tributary to Marathon Creek
009 - Southwest Gate Drainage Culvert/South Culvert Stormwater	Unnamed Ditch tributary to Robinson Creek
010 - Northwest Fence Pipe Outflow Stormwater	Unnamed Ditch tributary to Robinson Creek

In compliance with the provisions of the Illinois Environmental Protection Act, Title 35 of Ill. Adm. Code, Subtitle C and/or Subtitle D, Chapter 1, and the Clean Water Act (CWA), the above-named permittee is hereby authorized to discharge at the above location to the above-named receiving stream in accordance with the standard conditions and attachments herein.

Permittee is not authorized to discharge after the above expiration date. In order to receive authorization to discharge beyond the expiration date, the permittee shall submit the proper application as required by the Illinois Environmental Protection Agency (IEPA) not later than 180 days prior to the expiration date.

Alan Keller

Alan Keller, P.E.
Manager, Permit Section
Division of Water Pollution Control

SAK:MEL:13052109.daa

Effluent Limitations and Monitoring

1. From the modification date of this permit until the expiration date, the effluent of the following discharge(s) shall be monitored and limited at all times as follows:

Outfall(s): 001: Wastewater Treatment Plant Discharge and FCCU Scrubber Wastewater - (DAF = 2.666 MGD)

Outfall 001 consists of Treated Process Wastewater, which includes Coke Railcar Water, Fire Hydrant Flushings, Fire Training Water, Fire Water from Emergency Response Operations, Reverse Osmosis Rejection Water, Boiler and Cooling Tower Blowdown, Treated Sanitary Wastewater, Process Wastewater and Hydrostatic Test Water from Terminals and Pipelines, Stormwater Runoff, Hydrostatic Test Water, Treated Groundwater, and Filter Backwash Water, all treated in the Waste Water Treatment Plant. Discharge is to Robinson Creek. Average proposed discharge is 2.666 MGD; Peak Average Flow is 3.434 MGD.

	LOAD LIMITS lbs/day*** DAF (DMF)		CONCENTRATION LIMITS mg/l			
PARAMETER	30 DAY AVERAGE	DAILY MAXIMUM	30 DAY AVERAGE	DAILY MAXIMUM	SAMPLE FREQUENCY	SAMPLE TYPE
Flow (MGD)	See Special Condition 1				Continuous	Meter
pH	See Special Condition 2				2/Week	Grab
Temperature	See Special Condition 8				2/Week	Grab
BOD_5	222	573	10	20	2/Week	Composite
Total Suspended Solids	267	687	12	24	2/Week	Composite
Chemical Oxygen Demand	9,767	18,821			2/Week	Composite
Oil & Grease	333	763	15	30	1/Week	Mathematical Composite**
Phenol (4AAP)		2.9		0.1	2/Week	Composite
Ammonia as N*						
Spring/Fall	33	163	1.5	5.7	2/Week	Composite
Summer	33	198	1.5	6.9	2/Week	Composite
Winter	89	135	4.0	4.7	2/Week	Composite
Sulfide	7.4	16.5			2/Week	Composite
Total Chromium*****	9.8	28	1.0	2.0	2/Year	Composite
Hexavalent Chromium*****	0.24	0.46	0.011	0.016	2/Year	Composite
Chloride		28,643		1000	2/Week	Composite

	Monthly Average Minimum	Weekly Average Minimum	Daily Minimum		
Dissolved Oxygen					
March - July	NA	6	5	2/Week	Grab
August - February	5.5	4	3.5	2/Week	Grab

Effluent Limitations and Monitoring

1. From the modification date of this permit until the expiration date, the effluent of the following discharge(s) shall be monitored and limited at all times as follows:

Outfall 001: Wastewater Treatment Plant Discharge (continued)

	LOAD LIMITS lbs/day*** DAF (DMF)		CONCENTRATION LIMITS mg/l			
PARAMETER	30 DAY AVERAGE	DAILY MAXIMUM	30 DAY AVERAGE	DAILY MAXIMUM	SAMPLE FREQUENCY	SAMPLE TYPE
Sulfate		46,797****		1,634****	2/Week****	Composite
Mercury			Monitor*****		1/Year	Composite
Fluoride	115	486	4	17	2/month	Composite
Zinc (total)	1.2	8.7	0.055	0.305	2/Year*****	Composite

*For Ammonia as Nitrogen, Spring/Fall is March-May and September-October; Summer is June-August; Winter is November-February. Discharge from Outfall 001 will also be subject to weekly average Ammonia as Nitrogen limits. The Spring/Fall and Summer weekly average limit is 3.8 mg/L (85 lb/day). No weekly average limit applies in Winter months.

**See Special Condition 7.

***See Special Condition 19.

**** See also Special Condition 14.

*****Mercury will be sampled once per year. In the event that only one sample is collected during the calendar year, the Permittee shall report this value as a daily maximum on the January DMR form. Should the Permittee sample more frequently, the Permittee shall report the average value of all results as a monthly average value and the maximum of all results as a daily maximum on the January DMR form.

Total Chromium, Hexavalent Chromium, and Zinc shall be sampled twice per year. In the event that only one sample is collected in the six-month period, the permittee shall report the semiannual value as the daily maximum on the January or July DMR form and this value will be subject only to the daily maximum limit. Should the permittee sample more frequently, the permittee shall report the average value of all results obtained during the six-month period as the monthly average value subject to the monthly average limit and the maximum of all results as a daily maximum subject to the daily maximum limit on the January or July DMR form. If the Hexavalent Chromium concentration(s) is below the detection limit (< 0.01 mg/L), then the load limit shall be calculated using one-half the detection limit as the concentration.

Effluent Limitations and Monitoring

1. From the modification date of this permit until the expiration date, the effluent of the following discharge(s) shall be monitored and limited at all times as follows:

Outfall(s): 002: Treatment Plant Bypass - (Intermittent Discharge)

Outfall 002 consists of Process Area Stormwater, Cooling Tower and Boiler Blowdown, Stormwater Impoundments, and Overflow from Wastewater Treatment Plant (Including Process Wastewater). Discharge is to Marathon Creek. See Special Condition 9 regarding Bypass.

	LOAD LIMITS lbs/day**** DAF (DMF)		CONCENTRATION LIMITS mg/l			
PARAMETER	30 DAY AVERAGE	DAILY MAXIMUM	30 DAY AVERAGE	DAILY MAXIMUM	SAMPLE FREQUENCY*	SAMPLE TYPE
Flow (MGD)	See Special Condition 1				1/Day	Estimate
pH	See Special Condition 2				1/Day	Grab
BOD_5			10	20	1/Day	Grab
Total Suspended Solids			12	24	1/Day	Grab
Oil & Grease			15	30	1/Day	Grab
Ammonia as N**						
Spring/Fall			1.4	5.7	1/Day	Grab
Summer			1.4	6.9	1/Day	Grab
Winter			4.0	4.7	1/Day	Grab
Phenols				0.1	1/Day	Grab
Total Chromium			1.0	2.0	1/Day	Grab
Hexavalent Chromium			0.011	0.016	1/Day	Grab
Chemical Oxygen Demand			Monitor		1/Day	Grab
Chloride				500	1/Day	Grab
Total BETX***			Monitor		1/Day	Grab
Total PNAs***			Monitor		1/Day	Grab

Note: Ammonia, Biochemical Oxygen Demand, Oil and Grease, Total Chromium, Hexavalent Chromium, and Total Suspended Solids shall be sampled once per day during discharge. In the event that only one sample is collected during the month, the Permittee shall report the values as daily maximums on the DMR form and these values will be subject only to the daily maximum limits. Should the Permittee sample more frequently or discharge occurs for more than 24-hours during a month, the Permittee shall report the average value of all results obtained during the month as a monthly average value subject to the monthly average limit and the maximum of all results as a daily maximum subject to the daily maximum limit.

*One sample per day when discharging.

**For Ammonia as Nitrogen, Spring/Fall is March-May and September-October; Summer is June-August; and Winter is November-February. Should discharge occur on two or more days in a seven-day period, weekly average limits for Ammonia as Nitrogen shall apply. The Spring/Fall and Summer weekly average limit is 3.5 mg/L. No weekly average limit applies for Winter.

***For BETX and PNAs, the Permittee shall sample daily when discharging. The Permittee shall report a daily maximum for each month in which discharge occurs. For any month which two or more discharges occur, the Permittee shall report a monthly average on the DMR form. See Special Condition 12.

****See Special Condition 19.

NPDES Permit No. IL0004073

Effluent Limitations and Monitoring

1. From the modification date of this permit until the expiration date, the effluent of the following discharge(s) shall be monitored and limited at all times as follows:

Outfall(s): 003: East Impoundment Basin Discharge***** - (DAF = 2.631 MGD)

Outfall 003 consists of Hydrostatic Test Water, Coke Railcar Wash Water, Non-Process Area Stormwater, East and West Tank Farm Controlled Stormwater Drainage, Stormwater from Wabash Pond, Non-Emergency Use Firewater, Fire Hydrant Flushings, Fire Water from Emergency Use, Utility Water, and Frog Pond stormwater due to extreme rainfall. Discharge is to Marathon Creek.

	LOAD LIMITS lbs/day DAF (DMF)		CONCENTRATION LIMITS mg/l			
PARAMETER	30 DAY AVERAGE	DAILY MAXIMUM	30 DAY AVERAGE	DAILY MAXIMUM	SAMPLE FREQUENCY	SAMPLE TYPE
Flow (MGD)	See Special Condition 1				1/Day	Estimate
pH	See Special Condition 2				1/Day	Grab
Oil & Grease			15	30	1/Day	Mathematical Composite*
Phenol				0.1	1/Day	Composite
Total Chromium			1.0	2.0	1/Day	Composite
Total Organic Carbon****			Monitor		2/Year**	Composite
Ammonia as N***						
Spring/Fall			1.4	5.7	1/Day	Composite
Summer			1.4	6.9	1/Day	Composite
Winter			4.0	4.7	1/Day	Composite
Total Suspended Solids			15	30	2/Year**	Composite
BOD_5			Monitor		2/Year**	Composite
Chemical Oxygen Demand			Monitor		2/Year**	Composite
Sulfide			Monitor		2/Year**	Composite
Chloride				500	2/Year**	Composite
Fluoride				30	2/Year**	Composite
Sulfate				1,634	2/Year**	Composite

*See Special Condition 7.

**Total Organic Carbon, Total Suspended Solids, Biological Oxygen Demand, Chemical Oxygen Demand, Sulfide, Chloride, Fluoride, and Sulfate shall be sampled twice per year. In the event that only one sample is collected in the six-month period, the Permittee shall report the semiannual value as a daily maximum on the January or July DMR form and this value will be subject only to the daily maximum limit. Should the Permittee sample more frequently, the Permittee shall report the average value of all results obtained during the six-month period as a monthly average value subject to the monthly average limit and the maximum of all results as a daily maximum subject to the daily maximum limit on the January or July DMR form.

***For Ammonia as Nitrogen, Spring/Fall is March-May and September-October; Summer is June-August; and Winter is November-February. Ammonia as Nitrogen is subject to weekly average limits. Spring/Fall and Summer weekly average limit is 3.5 mg/L. For Winter no weekly average limit applies. In the event that only one sample is collected during a month, the Permittee shall report the value as a daily maximum and this value will be subject only to the daily maximum limit. Should the Permittee sample more frequently, the Permittee shall report the average value of all results obtained during the month as a monthly average value subject to the monthly average limit and the maximum of all results as a daily maximum subject to the daily maximum limit.

****See Special Condition 20.

*****See Special Condition 15.

NPDES Permit No. IL0004073
Special Conditions

SPECIAL CONDITION 1. Flow shall be reported in MGD as a daily maximum and a monthly average, and shall be reported on the monthly DMR form.

SPECIAL CONDITION 2. For outfalls 001, and 002, the pH shall be in the range 6.0 to 9.0. The monthly minimum and monthly maximum values shall be reported on the DMR form. For outfall 003, the minimum pH shall be 6.0, but the pH 9.0 maximum limitation may be exceeded if the elevated pH level is caused entirely by algae in treatment lagoons, in which case there is no upper pH limit. This shall be indicated by the permittee in the comment section of the DMR form.

SPECIAL CONDITION 3. Samples taken in compliance with the effluent monitoring requirements shall be taken at a point representative of the discharge, but prior to entry into the receiving stream.

SPECIAL CONDITION 4. If an applicable effluent standard or limitation is promulgated under Sections 301(b)(2)(C) and (D), 304(b)(2), and 307(a)(2) of the Clean Water Act and that effluent standard or limitation is more stringent than any effluent limitation in the permit or controls a pollutant not limited in the NPDES Permit, the Agency shall revise or modify the permit in accordance with the more stringent standard or prohibition and shall so notify the permittee.

SPECIAL CONDITION 5. The use or operation of this facility shall be by or under the supervision of a Certified Class K operator.

SPECIAL CONDITION 6. The Permittee shall record monitoring results on Discharge Monitoring Report (DMR) Forms using one such form for each outfall each month.

In the event that an outfall does not discharge during a monthly reporting period, the DMR Form shall be submitted with no discharge indicated.

The Permittee may choose to submit electronic DMRs (eDMRs) instead of mailing paper DMRs to the IEPA. More information, including registration information for the eDMR program, can be obtained on the IEPA website, http://www.epa.state.il.us/water/edmr/index.html.

The completed Discharge Monitoring Report forms shall be submitted to IEPA no later than the 20th day of the following month, unless otherwise specified by the permitting authority.

Permittees not using eDMRs shall mail Discharge Monitoring Reports with an original signature to the IEPA at the following address:

Illinois Environmental Protection Agency
Division of Water Pollution Control
1021 North Grand Avenue East
Post Office Box 19276
Springfield, Illinois 62794-9276
Attention: Compliance Assurance Section, Mail Code # 19

SPECIAL CONDITION 7. Mathematical composites for oil, fats and greases shall consist of a series of grab samples collected over any 24-hour consecutive period. Each sample shall be analyzed separately and the arithmetic mean of all grab samples collected during a 24-hour period shall constitute a mathematical composite. No single grab sample shall exceed a concentration of 75 mg/l.

SPECIAL CONDITION 8. For outfall 001, discharge of wastewater from this facility must not alone or in combination with other sources cause the receiving stream to violate the following thermal limitations at the edge of the mixing zone which is defined by Section 302.211, Illinois Administration Code, Title 35, Chapter 1, Subtitle C, as amended:

A. Maximum temperature rise above natural temperature must not exceed 5°F (2.8°C).

B. Water temperature at representative locations in the main river shall not exceed the maximum limits in the following table during more than one (1) percent of the hours in the 12-month period ending with any month. Moreover, at no time shall the water temperature at such locations exceed the maximum limits in the following table by more than 3°F (1.7°C). (Main river temperatures are temperatures of those portions of the river essentially similar to and following the same thermal regime as the temperatures of the main flow of the river.)

Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.

°F	60	60	60	90	90	90	90	90	90	90	90	60
°C	16	16	16	32	32	32	32	32	32	32	32	16

C. The monthly maximum value shall be reported on the DMR form.

D. Temperature monitoring may be performed manually using a certified portable temperature monitoring device. The Outfall 001 temperature will be monitored on-site at the sampling weir located south of the Sand Filter Building or other representative monitoring location in the event the sampling weir is out of service. In the event the Outfall 001 temperature exceeds the limits in the table, upstream and downstream temperature readings will be monitored at designated locations. The upstream temperatures will be monitored at the bridge north of Carter Lumber, or downstream of the City of Robinson Waste Water Treatment Plant, or other location that is representative of Robinson Creek prior to mixing with Outfall 001. The downstream temperatures will be monitored at the bridge at the Hog Farm east of Route 1, or the Route 1 Highway bridge, or other location that is representative of Robinson Creek and Outfall 001.

SPECIAL CONDITION 9. Discharge Number 002 is an emergency high level bypass. Discharges from this overflow are subject to the following conditions:

(1) Definitions

(i) "Bypass" means the intentional diversion of waste streams from any portion of a treatment facility.

(ii) "Severe property damage" means substantial physical damage to property, damage to the treatment facilities which causes them to become inoperable, or substantial and permanent loss of natural resources which can reasonably be expected to occur in the absence of a bypass. Severe property damage does not mean economic loss caused by delays in production.

(2) Bypass not exceeding limitations. The Permittee may allow any bypass to occur which does not cause effluent limitations to be exceeded, but only if it is for essential maintenance to assure efficient operation. Bypass of WWTP sand filters due to excess hydraulic loading to the sand filters is an acceptable bypass, provided the effluent does not cause effluent limitations to be exceeded. Bypass of WWTP Tank 79D-63 in order to impound off-spec wastewater so as to prevent a negative impact to the activated sludge treatment is an acceptable bypass, provided the effluent does not cause effluent limitations to be exceeded. These bypasses are not subject to the provisions of paragraphs (3) and (4) of this section.

(3) Notice

(i) Anticipated bypass. If the Permittee knows in advance of the need for a bypass, it shall submit prior notice, if possible at least ten days before the date of the bypass.

(ii) Unanticipated bypass. The Permittee shall submit notice of an unanticipated bypass as required in Standard Condition 12(e) of this Permit (24-hour notice). In the event that notice shall be given outside of business hours, the permittee shall contact the Illinois Emergency Management Agency at 800-782-7860.

(4) Prohibition of bypass. Bypass is prohibited, and the IEPA may take enforcement action against a Permittee for bypass, unless:

(i) Bypass was unavoidable to prevent loss of life, personal injury, or severe property damage;

(ii) There was no feasible alternatives to the bypass, such as the use of auxiliary treatment facilities, retention of untreated wastes, or maintenance during normal periods of equipment downtime. This condition is not satisfied if adequate back-up equipment should have been installed in the exercise of reasonable engineering judgment to prevent a bypass which occurred during normal periods of equipment downtime or preventive maintenance; and

(iii) The Permittee submitted notices as required under Standard Condition 12(e) of this Permit.

(5) Emergency Bypass when discharging, shall be monitored daily for parameters listed on Page 3 for outfall 002. The Permittee shall submit the monitoring results on Discharge Monitoring Report forms using one such form for each month in which bypassing occurs. The Permittee shall specify the number of discharges per month and the duration in days of each discharge that occur in the comments section of the DMR form. The Permittee shall report the average and maximum concentration values for the parameters listed on Page 3 for outfall 002 on the DMR form.

SPECIAL CONDITION 10.

STORM WATER POLLUTION PREVENTION PLAN (SWPPP)

A. A storm water pollution prevention plan shall be developed by the permittee for the storm water associated with industrial activity at this facility. The plan shall identify potential sources of pollution which may be expected to affect the quality of storm water discharges associated with the industrial activity at the facility. In addition, the plan shall describe and ensure the implementation of practices which are to be used to reduce the pollutants in storm water discharges associated with industrial activity at the facility and to assure compliance with the terms and conditions of this permit.

B. The plan shall be completed within 180 days of the effective date of this permit. Plans shall provide for compliance with the terms of the plan within 180 days of the effective date of this permit. The owner or operator of the facility shall make a copy of the plan available to the Agency at any reasonable time upon request. [Note: If the plan has already been developed and implemented it shall be maintained in accordance with all requirements of this special condition.]

C. The permittee may be notified by the Agency at any time that the plan does not meet the requirements of this condition. After such notification, the permittee shall make changes to the plan and shall submit a written certification that the requested changes have been made. Unless otherwise provided, the permittee shall have 30 days after such notification to make the changes.

D. The discharger shall amend the plan whenever there is a change in construction, operation, or maintenance which may affect the discharge of significant quantities of pollutants to the waters of the State or if a facility inspection required by paragraph G of this condition indicates that an amendment is needed. The plan should also be amended if the discharger is in violation of any conditions of this permit, or has not achieved the general objective of controlling pollutants in storm water discharges. Amendments to the plan shall be made within the shortest reasonable period of time, and shall be provided to the Agency for review upon request.

E. The plan shall provide a description of potential sources which may be expected to add significant quantities of pollutants to storm water discharges, or which may result in non-storm water discharges from storm water outfalls at the facility. The plan shall include, at a minimum, the following items:

1. A topographic map extending one-quarter mile beyond the property boundaries of the facility, showing: the facility, surface water bodies, wells (including injection wells), seepage pits, infiltration ponds, and the discharge points where the facility's storm water discharges to a municipal storm drain system or other water body. The requirements of this paragraph may be included on the site map if appropriate.

2. A site map showing:

   I. The storm water conveyance and discharge structures;

   ii. An outline of the storm water drainage areas for each storm water discharge point;

   iii. Paved areas and buildings;

   iv. Areas used for outdoor manufacturing, storage, or disposal of significant materials, including activities that generate significant quantities of dust or particulates.

   v. Location of existing storm water structural control measures (dikes, coverings, detention facilities, etc.);

   vi. Surface water locations and/or municipal storm drain locations

   vii. Areas of existing and potential soil erosion;

   viii. Vehicle service areas;

   ix. Material loading, unloading, and access areas.

3. A narrative description of the following:

   I. The nature of the industrial activities conducted at the site, including a description of significant materials that are treated, stored or disposed of in a manner to allow exposure to storm water;

   ii. Materials, equipment, and vehicle management practices employed to minimize contact of significant materials with storm water discharges;

   iii. Existing structural and non-structural control measures to reduce pollutants in storm water discharges;

   iv. Industrial storm water discharge treatment facilities;

   v. Methods of onsite storage and disposal of significant materials;

4. A list of the types of pollutants that have a reasonable potential to be present in storm water discharges in significant quantities.

5. An estimate of the size of the facility in acres or square feet, and the percent of the facility that has impervious areas such as pavement or buildings.

6. A summary of existing sampling data describing pollutants in storm water discharges.

F. The plan shall describe the storm water management controls which will be implemented by the facility. The appropriate controls shall reflect identified existing and potential sources of pollutants at the facility. The description of the storm water management controls shall include:

1. Storm Water Pollution Prevention Personnel - Identification by job titles of the individuals who are responsible for developing, implementing, and revising the plan.

2. Preventive Maintenance - Procedures for inspection and maintenance of storm water conveyance system devices such as oil/water separators, catch basins, etc., and inspection and testing of plant equipment and systems that could fail and result in discharges of pollutants to storm water.

3. Good Housekeeping - Good housekeeping requires the maintenance of clean, orderly facility areas that discharge storm water. Material handling areas shall be inspected and cleaned to reduce the potential for pollutants to enter the storm water conveyance system.

4. Spill Prevention and Response - Identification of areas where significant materials can spill into or otherwise enter the storm water conveyance systems and their accompanying drainage points. Specific material handling procedures, storage requirements, spill clean up equipment and procedures should be identified, as appropriate. Internal notification procedures for spills of significant materials should be established.

5. Storm Water Management Practices - Storm water management practices are practices other than those which control the source of pollutants. They include measures such as installing oil and grit separators, diverting storm water into retention basins, etc. Based on assessment of the potential of various sources to contribute pollutants, measures to remove pollutants from storm water discharge shall be implemented. In developing the plan, the following management practices shall be considered:

   i. Containment - Storage within berms or other secondary containment devices to prevent leaks and spills from entering storm water runoff;

   ii. Oil & Grease Separation - Oil/water separators, booms, skimmers or other methods to minimize oil contaminated storm water discharges;

   iii. Debris & Sediment Control - Screens, booms, sediment ponds or other methods to reduce debris and sediment in storm water discharges;

   iv. Waste Chemical Disposal - Waste chemicals such as antifreeze, degreasers and used oils shall be recycled or disposed of in an approved manner and in a way which prevents them from entering storm water discharges.

   v. Storm Water Diversion - Storm water diversion away from materials manufacturing, storage and other areas of potential storm water contamination;

   vi. Covered Storage or Manufacturing Areas - Covered fueling operations, materials manufacturing and storage areas to prevent contact with storm water.

6. Sediment and Erosion Prevention - The plan shall identify areas which due to topography, activities, or other factors, have a high potential for significant soil erosion and describe measures to limit erosion.

7. Employee Training - Employee training programs shall inform personnel at all levels of responsibility of the components and goals of the storm water pollution control plan. Training should address topics such as spill response, good housekeeping and material management practices. The plan shall identify periodic dates for such training.

8. Inspection Procedures - Qualified plant personnel shall be identified to inspect designated equipment and plant areas. A tracking or follow-up procedure shall be used to ensure appropriate response has been taken in response to an inspection. Inspections and maintenance activities shall be documented and recorded.

G. The permittee shall conduct an annual facility inspection to verify that all elements of the plan, including the site map, potential pollutant sources, and structural and non-structural controls to reduce pollutants in industrial storm water discharges are accurate. Observations that require a response and the appropriate response to the observation shall be retained as part of the plan. Records documenting significant observations made during the site inspection shall be submitted to the Agency in accordance with the reporting requirements of this permit.

H. This plan should briefly describe the appropriate elements of other program requirements, including Spill Prevention Control and Countermeasures (SPCC) plans required under Section 311 of the CWA and the regulations promulgated thereunder, and Best Management Programs under 40 CFR 125.100.

I. The plan is considered a report that shall be available to the public under Section 308(b) of the CWA. The permittee may claim portions of the plan as confidential business information, including any portion describing facility security measures.

J. The plan shall include the signature and title of the person responsible for preparation of the plan and include the date of initial preparation and each amendment thereto.

Construction Authorization

K. Authorization is hereby granted to construct treatment works and related equipment that may be required by the Storm Water Pollution Prevention Plan developed pursuant to this permit.

This Authorization is issued subject to the following condition(s).

1. If any statement or representation is found to be incorrect, this authorization may be revoked and the permittee there upon waives all rights thereunder.

2. The issuance of this authorization (a) does not release the permittee from any liability for damage to persons or property caused by or resulting from the installation, maintenance or operation of the proposed facilities; (b) does not take into consideration the structural stability of any units or part of this project; and (c) does not release the permittee from compliance with other applicable statutes of the State of Illinois, or other applicable local law, regulations or ordinances.

3. Plans and specifications of all treatment equipment being included as part of the stormwater management practice shall be included in the SWPPP.

4. Construction activities which result from treatment equipment installation, including clearing, grading and excavation activities which result in the disturbance of one acre or more of land area, are not covered by this authorization. The permittee shall contact the IEPA regarding the required permit(s).

REPORTING

L. The facility shall submit an annual inspection report to the Illinois Environmental Protection Agency. The report shall include results of the annual facility inspection which is required by Part G of the Storm Water Pollution Prevention Plan of this permit. The report shall also include documentation of any event (spill, treatment unit malfunction, etc.) which would require an inspection, results of the inspection, and any subsequent corrective maintenance activity. The report shall be completed and signed by the authorized facility employee(s) who conducted the inspection(s).

M. The first report shall contain information gathered during the one year time period beginning with the effective date of coverage under this permit and shall be submitted no later than 60 days after this one year period has expired. Each subsequent report shall contain the previous year's information and shall be submitted no later than one year after the previous year's report was due.

N. Annual inspection reports shall be mailed to the following address:

Illinois Environmental Protection Agency
Bureau of Water
Compliance Assurance Section
Annual Inspection Report
1021 North Grand Avenue East
Post Office Box 19276
Springfield, Illinois 62794-9276

O. If the facility performs inspections more frequently than required by this permit, the results shall be included as additional information in the annual report.

SPECIAL CONDITION 11. For outfalls 001, 002, and 003, the Agency has determined that the effluent limitations in this permit constitute

BAT/BCT for storm water for purposes of this permit reissuance, and no pollution prevention plan will be required for such storm water. In addition to the chemical specific monitoring required elsewhere in this permit, the permittee shall conduct an annual inspection of the facility site to identify areas contributing to a storm water discharge associated with industrial activity, and determine whether any facility modifications have occurred which result in previously-treated storm water discharges no longer receiving treatment. If any such discharges are identified the permittee shall request a modification of this permit within 30 days after the inspection. Records of the annual inspection shall be retained by the permittee for the term of this permit and be made available to the Agency on request.

SPECIAL CONDITION 12. For the purposes of this permit, Total PNAs is defined as the arithmetic sum of the following polynuclear aromatic compounds: Acenaphthene, Acenaphthylene, Anthracene, Benzo(a)anthracene, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(g,h,i)perylene, Dibenzo(a,h)anthracene, Indeno(1,2,3-c,d)pyrene, Chrysene, Fluoranthene, Fluorene, Naphthalene, Phenanthrene, and Pyrene. Total BETX shall be defined as the arithmetic sum of Benzene, Toluene, Ethylbenzene, and Total Xylenes. For the purpose of showing compliance, concentrations found to be below detection shall be considered zero in calculations and will be reported as zero on the DMR form if all concentrations are below the detection limits.

SPECIAL CONDITION 13. The permittee shall prepare a biomonitoring plan for the testing of outfall 001 as outlined in Special Condition 13 and Special Condition 14. The plan must be submitted to the Compliance Assurance Section within forty-five (45) days of the effective date of this permit.

1. Chronic Toxicity - Standard definitive chronic toxicity tests shall be run on Fathead Minnow. Testing must be consistent with Short-term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms, (Fourth Edition - October 2002) EPA/821-R-02-013. Results shall be reported according to Section 10 of this publication. The selection of an appropriate control for the toxicity tests shall be submitted to IEPA for review and approval prior to use. Unless substitute tests are pre-approved; the following tests are required:

    a. Fish - Fathead Minnow (Pimephales promelas) Larval Survival and Growth Test.

    b. Ceriodaphnia Survival and Reproduction Test.

    c. This test shall be conducted on Waste Water Treatment Plant effluent, tributary to outfall 001, prior to entering the receiving stream and prior to mixing with any other wastewater sources.

2. Testing Frequency - The above tests shall be conducted on a monthly basis for six (6) months after Agency approval of the biomonitoring plan. The permittee shall conduct the test semi-annually thereafter. Tests shall be performed using 24-hour composite effluent samples unless otherwise authorized by the IEPA. Results shall be submitted to IEPA within fifteen (15) days of becoming available to the Permittee. The permittee shall submit results to the following address.

Illinois Environmental Protection Agency
Bureau of Water
Compliance Assurance Section, Mail Code 19
1021 North Grand Avenue East
P.O. Box 19276
Springfield, IL 62794-9276

Illinois Environmental Protection Agency
Bureau of Water
Attn: Bob Mosher, Water Quality Standards
1021 North Grand Avenue East
P.O. Box 19276
Springfield, IL 62794-9276

3. Toxicity Assessment - Should the review of the results of the biomonitoring program indicate a significant baseline shift in toxicity, the IEPA may require that the Permittee prepare a plan for toxicity reduction evaluation and identification. This plan shall be developed in accordance with Toxicity Reduction Evaluation Guidance for Municipal Wastewater Treatment Plants, EPA/833B-99/002, and shall include an evaluation to determine which chemicals have a potential for being discharged in the plant wastewater, a monitoring program to determine their presence or absence and to identify other compounds which are not being removed by treatment, and other measures as appropriate. The Permittee shall submit to the IEPA its plan for toxicity reduction evaluation within ninety (90) days following notification by the IEPA. The Permittee shall implement the plan within ninety (90) days or other such date as contained in a notification letter received from the IEPA.

    The IEPA may modify this Permit during its term to incorporate additional requirements or limitations based on the results of the biomonitoring. In addition, after review of the monitoring results, the IEPA may modify this Permit to include numerical limitations for specific toxic pollutants. Modifications under this condition shall follow public notice and opportunity for hearing.

SPECIAL CONDITION 14. Untreated FCCU Scrubber Wastewater shall not be discharged to any waters of the state unless a modification to this permit is obtained. Modification under this special condition shall follow public notice and opportunity for hearing.

SPECIAL CONDITION 15. For the purpose of this permit, the discharge at outfall 003 shall be limited at all times to Hydrostatic Test Water, Coke Railcar Wash Water, Non-Process Area Stormwater, East and West Tank Farm Controlled Stormwater Drainage, Stormwater from Wabash Pond, Non-Emergency Use Firewater, Fire Hydrant Flushings, Fire Water From Emergency Use, Utility Water, and Frog Pond stormwater due to extreme rainfall. In the event that the permittee must discharge process wastewater or contaminated stormwater runoff into the East Impoundment Basin for temporary storage, there shall be no discharge from outfall 003, and the permittee shall notify the IEPA, Division of Water Pollution Control, Champaign Field Operations Section within 24 hours (or the next business day). The permittee shall notify the Agency on each such occasion.

SPECIAL CONDITION 16. This permit does not authorize the permittee to operate an on-site sludge disposal facility or the land application of sludge on-site. Sludge handling activities are authorized by RCRA permit issued to the permittee.

SPECIAL CONDITION 17. The permittee shall add 300 pounds of powdered activated carbon (PAC) per day at an appropriate point in the WWTP process to address chronic toxicity and comply with outfall 001 limits. The permittee shall maintain a daily log of the amount of PAC injected into the Waste Water Treatment Plant. The amount of PAC may be reduced based upon review of appropriate data and Agency approval.

SPECIAL CONDITION 18. In addition to the other requirements of this permit no effluent shall contain settleable solids, floating debris, visible oil, grease, scum, or sludge solids. Color, odor, and turbidity shall be reduced to below obvious levels.

SPECIAL CONDITION 19.
Storm Water Credit:

An additional mass allowance may be calculated for Outfalls 001 and 002 Load Limitations, for the following parameters, based on 100% of the storm water flow as defined below.

	Pounds per 1000 gallons of storm water flow	
Parameter	Average	Maximum
COD	1.5	3.0
Oil and Grease	0.067*	0.13*
Chromium (total)	0.0018	0.005
BOD_5	0.22	0.4
Phenolic Compounds	0.0014	0.0029

Dry Weather Flow - The average flow from the API separator for the last three consecutive zero precipitation days. Previously collected storm water shall not be included.

Storm Water Flows - The storm water runoff which is treated in the waste water treatment facility shall be defined as that portion of the flow greater than the dry weather flow.

The quantity of pollutants discharged shall not exceed the quantity determined by multiplying the flow of storm water as determined by the permittee times the concentrations listed in the above table.

The stormwater credit does not authorize the permittee to exceed the concentration limits contained in the Effluent Limitations and Monitoring for outfalls 001and 002.

In computing monthly average permit limits to include storm water credit, the pound credit calculated above shall be averaged along with the process pound limits over the 30 day period. Explanatory calculations and flow data shall be submitted together with the DMR form.
*At no time shall oil and grease exceed 450 lb/day monthly average, 844 lbs/day daily maximum, for Outfall 001.

SPECIAL CONDITION 20. The permittee shall monitor outfall 003 for Total Organic Carbon (TOC) and shall report the daily maximum value and a monthly average if more than one sample is collected in a one-month period. Based upon reported values, the Agency may impose limits on outfall 003 for Total Organic Carbon if necessary.

SPECIAL CONDITION 21. The effluent, alone or in combination with other sources, shall not cause a violation of any applicable water quality standard outlined in 35 Ill. Adm. Code 302.

Attachment H

Standard Conditions

Definitions

Act means the Illinois Environmental Protection Act, 415 ILCS 5 as Amended.

Agency means the Illinois Environmental Protection Agency.

Board means the Illinois Pollution Control Board.

Clean Water Act (formerly referred to as the Federal Water Pollution Control Act) means Pub. L 92-500, as amended. 33 U.S.C. 1251 et seq.

NPDES (National Pollutant Discharge Elimination System) means the national program for issuing, modifying, revoking and reissuing, terminating, monitoring and enforcing permits, and imposing and enforcing pretreatment requirements, under Sections 307, 402, 318 and 405 of the Clean Water Act.

USEPA means the United States Environmental Protection Agency.

Daily Discharge means the discharge of a pollutant measured during a calendar day or any 24-hour period that reasonably represents the calendar day for purposes of sampling. For pollutants with limitations expressed in units of mass, the "daily discharge" is calculated as the total mass of the pollutant discharged over the day. For pollutants with limitations expressed in other units of measurements, the "daily discharge" is calculated as the average measurement of the pollutant over the day.

Maximum Daily Discharge Limitation (daily maximum) means the highest allowable daily discharge.

Average Monthly Discharge Limitation (30 day average) means the highest allowable average of daily discharges over a calendar month, calculated as the sum of all daily discharges measured during a calendar month divided by the number of daily discharges measured during that month.

Average Weekly Discharge Limitation (7 day average) means the highest allowable average of daily discharges over a calendar week, calculated as the sum of all daily discharges measured during a calendar week divided by the number of daily discharges measured during that week.

Best Management Practices (BMPs) means schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of waters of the State. BMPs also include treatment requirements, operating procedures, and practices to control plant site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage.

Aliquot means a sample of specified volume used to make up a total composite sample.

Grab Sample means an individual sample of at least 100 milliliters collected at a randomly-selected time over a period not exceeding 15 minutes.

24-Hour Composite Sample means a combination of at least 8 sample aliquots of at least 100 milliliters, collected at periodic intervals during the operating hours of a facility over a 24-hour period.

8-Hour Composite Sample means a combination of at least 3 sample aliquots of at least 100 milliliters, collected at periodic intervals during the operating hours of a facility over an 8-hour period.

Flow Proportional Composite Sample means a combination of sample aliquots of at least 100 milliliters collected at periodic intervals such that either the time interval between each aliquot or the volume of each aliquot is proportional to either the stream flow at the time of sampling or the total stream flow since the collection of the previous aliquot.

(1) **Duty to comply.** The permittee must comply with all conditions of this permit. Any permit noncompliance constitutes a violation of the Act and is grounds for enforcement action, permit termination, revocation and reissuance, modification, or for denial of a permit renewal application. The permittee shall comply with effluent standards or prohibitions established under Section 307(a) of the Clean Water Act for toxic pollutants within the time provided in the regulations that establish these standards or prohibitions, even if the permit has not yet been modified to incorporate the requirements.

(2) **Duty to reapply.** If the permittee wishes to continue an activity regulated by this permit after the expiration date of this permit, the permittee must apply for and obtain a new permit. If the permittee submits a proper application as required by the Agency no later than 180 days prior to the expiration date, this permit shall continue in full force and effect until the final Agency decision on the application has been made.

(3) **Need to halt or reduce activity not a defense.** It shall not be a defense for a permittee in an enforcement action that it would have been necessary to halt or reduce the permitted activity in order to maintain compliance with the conditions of this permit.

(4) **Duty to mitigate.** The permittee shall take all reasonable steps to minimize or prevent any discharge in violation of this permit which has a reasonable likelihood of adversely affecting human health or the environment.

(5) **Proper operation and maintenance.** The permittee shall at all times properly operate and maintain all facilities and systems of treatment and control (and related appurtenances) which are installed or used by the permittee to achieve compliance with conditions of this permit. Proper operation and maintenance includes effective performance, adequate funding, adequate operator staffing and training, and adequate laboratory and process controls, including appropriate quality assurance procedures. This provision requires the operation of back-up, or auxiliary facilities, or similar systems only when necessary to achieve compliance with the conditions of the permit.

(6) **Permit actions.** This permit may be modified, revoked and reissued, or terminated for cause by the Agency pursuant to 40 CFR 122.62 and 40 CFR 122.63. The filing of a request by the permittee for a permit modification, revocation and reissuance, or termination, or a notification of planned changes or anticipated noncompliance, does not stay any permit condition.

(7) **Property rights.** This permit does not convey any property rights of any sort, or any exclusive privilege.

(8) **Duty to provide information.** The permittee shall furnish to the Agency within a reasonable time, any information which th Agency may request to determine whether cause exists fo. modifying, revoking and reissuing, or terminating this permit, or to determine compliance with the permit. The permittee shall also furnish to the Agency upon request, copies of records required to be kept by this permit.

(9) **Inspection and entry.** The permittee shall allow an authorized representative of the Agency or USEPA (including an authorized contractor acting as a representative of the Agency or USEPA), upon the presentation of credentials and other documents as may be required by law, to:

(a) Enter upon the permittee's premises where a regulated facility or activity is located or conducted, or where records must be kept under the conditions of this permit;

(b) Have access to and copy, at reasonable times, any records that must be kept under the conditions of this permit;

(c) Inspect at reasonable times any facilities, equipment (including monitoring and control equipment), practices, or operations regulated or required under this permit; and

(d) Sample or monitor at reasonable times, for the purpose of assuring permit compliance, or as otherwise authorized by the Act, any substances or parameters at any location.

(10) **Monitoring and records.**

(a) Samples and measurements taken for the purpose of monitoring shall be representative of the monitored activity.

(b) The permittee shall retain records of all monitoring information, including all calibration and maintenance records, and all original strip chart recordings for continuous monitoring instrumentation, copies of all reports required by this permit, and records of all data used to complete the application for this permit, for a period of at least 3 years from the date of this permit, measurement, report or application. Records related to the permittee's sewage sludge use and disposal activities shall be retained for a period of at least five years (or longer as required by 40 CFR Part 503). This period may be extended by request of the Agency or USEPA at any time.

(c) Records of monitoring information shall include:

(1) The date, exact place, and time of sampling or measurements;

(2) The individual(s) who performed the sampling or measurements;

(3) The date(s) analyses were performed;

(4) The individual(s) who performed the analyses;

(5) The analytical techniques or methods used; and

(6) The results of such analyses.

(d) Monitoring must be conducted according to test procedures approved under 40 CFR Part 136, unless other test procedures have been specified in this permit. Where no test procedure under 40 CFR Part 136 has been approved, the permittee must submit to the Agency a test method for approval. The permittee shall calibrate and perform maintenance procedures on all monitoring and analytical instrumentation at intervals to ensure accuracy of measurements.

(11) **Signatory requirement.** All applications, reports or information submitted to the Agency shall be signed and certified.

(a) **Application.** All permit applications shall be signed as follows:

(1) For a corporation: by a principal executive officer of at least the level of vice president or a person or position having overall responsibility for environmental matters for the corporation:

(2) For a partnership or sole proprietorship: by a general partner or the proprietor, respectively; or

(3) For a municipality, State, Federal, or other public agency: by either a principal executive officer or ranking elected official.

(b) **Reports.** All reports required by permits, or other information requested by the Agency shall be signed by a person described in paragraph (a) or by a duly authorized representative of that person. A person is a duly authorized representative only if:

(1) The authorization is made in writing by a person described in paragraph (a); and

(2) The authorization specifies either an individual or a position responsible for the overall operation of the facility, from which the discharge originates, such as a plant manager, superintendent or person of equivalent responsibility; and

(3) The written authorization is submitted to the Agency.

(c) **Changes of Authorization.** If an authorization under (b) is no longer accurate because a different individual or position has responsibility for the overall operation of the facility, a new authorization satisfying the requirements of (b) must be submitted to the Agency prior to or together with any reports, information, or applications to be signed by an authorized representative.

(d) **Certification.** Any person signing a document under paragraph (a) or (b) of this section shall make the following certification:

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

(12) **Reporting requirements.**

(a) **Planned changes.** The permittee shall give notice to the Agency as soon as possible of any planned physical alterations or additions to the permitted facility.
Notice is required when:

(1) The alteration or addition to a permitted facility may meet one of the criteria for determining whether a facility is a new source pursuant to 40 CFR 122.29 (b); or

(2) The alteration or addition could significantly change the nature or increase the quantity of pollutants discharged. This notification applies to pollutants which are subject neither to effluent limitations in the permit, nor to notification requirements pursuant to 40 CFR 122.42 (a)(1).

(3) The alteration or addition results in a significant change in the permittee's sludge use or disposal practices, and such alteration, addition, or change may justify the application of permit conditions that are different from or absent in the existing permit, including notification of additional use or disposal sites not reported during the permit application process or not reported pursuant to an approved land application plan.

(b) **Anticipated noncompliance.** The permittee shall give advance notice to the Agency of any planned changes in the permitted facility or activity which may result in noncompliance with permit requirements.

(c) **Transfers.** This permit is not transferable to any person except after notice to the Agency.

(d) **Compliance schedules.** Reports of compliance or noncompliance with, or any progress reports on, interim and final requirements contained in any compliance schedule of this permit shall be submitted no later than 14 days following each schedule date.

(e) **Monitoring reports.** Monitoring results shall be reported at the intervals specified elsewhere in this permit.

(1) Monitoring results must be reported on a Discharge Monitoring Report (DMR).

(2) If the permittee monitors any pollutant more frequently than required by the permit, using test procedures approved under 40 CFR 136 or as specified in the permit, the results of this monitoring shall be included in the calculation and reporting of the data submitted in the DMR.

(3) Calculations for all limitations which require averaging of measurements shall utilize an arithmetic mean unless otherwise specified by the Agency in the permit.

(f) **Twenty-four hour reporting**. The permittee shall report any noncompliance which may endanger health or the environment. Any information shall be provided orally within 24-hours from the time the permittee becomes aware of the circumstances. A written submission shall also be provided within 5 days of the time the permittee becomes aware of the circumstances. The written submission shall contain a description of the noncompliance and its cause; the period of noncompliance, including exact dates and time; and if the noncompliance has not been corrected, the anticipated time it is expected to continue; and steps taken or planned to reduce, eliminate, and prevent reoccurrence of the noncompliance. The following shall be included as information which must be reported within 24-hours:

(1) Any unanticipated bypass which exceeds any effluent limitation in the permit.

(2) Any upset which exceeds any effluent limitation in the permit.

(3) Violation of a maximum daily discharge limitation for any of the pollutants listed by the Agency in the permit or any pollutant which may endanger health or the environment.

The Agency may waive the written report on a case-by-case basis if the oral report has been received within 24-hours.

(g) **Other noncompliance.** The permittee shall report all instances of noncompliance not reported under paragraphs (12) (d), (e), or (f), at the time monitoring reports are submitted. The reports shall contain the information listed in paragraph (12) (f).

(h) **Other information**. Where the permittee becomes aware that it failed to submit any relevant facts in a permit application, or submitted incorrect information in a permit application, or in any report to the Agency, it shall promptly submit such facts or information.

(13) **Bypass.**

(a) Definitions.

(1) Bypass means the intentional diversion of waste streams from any portion of a treatment facility.

(2) Severe property damage means substantial physical damage to property, damage to the treatment facilities which causes them to become inoperable, or substantial and permanent loss of natural resources which can reasonably be expected to occur in the absence of a bypass. Severe property damage does not mean economic loss caused by delays in production.

(b) Bypass not exceeding limitations. The permittee may allow any bypass to occur which does not cause effluent limitations to be exceeded, but only if it also is for essential maintenance to assure efficient operation. These bypasses are not subject to the provisions of paragraphs (13)(c) and (13)(d).

(c) Notice.

(1) Anticipated bypass. If the permittee knows in advance of the need for a bypass, it shall submit prior notice, if possible at least ten days before the date of the bypass.

(2) Unanticipated bypass. The permittee shall submit notice of an unanticipated bypass as required in paragraph (12)(f) (24-hour notice).

(d) Prohibition of bypass.

(1) Bypass is prohibited, and the Agency may take enforcement action against a permittee for bypass, unless:

(i) Bypass was unavoidable to prevent loss of lif personal injury, or severe property damage;

(ii) There were no feasible alternatives to the bypass, such as the use of auxiliary treatment facilities, retention of untreated wastes, or maintenance during normal periods of equipment downtime. This condition is not satisfied if adequate back-up equipment should have been installed in the exercise of reasonable engineering judgment to prevent a bypass which occurred during normal periods of equipment downtime or preventive maintenance; and

(iii) The permittee submitted notices as required under paragraph (13)(c).

(2) The Agency may approve an anticipated bypass, after considering its adverse effects, if the Agency determines that it will meet the three conditions listed above in paragraph (13)(d)(1).

(14) **Upset.**

(a) Definition. Upset means an exceptional incident in which there is unintentional and temporary noncompliance with technology based permit effluent limitations because of factors beyond the reasonable control of the permittee. An upset does not include noncompliance to the extent caused by operational error, improperly designed treatment facilities, inadequate treatment facilities, lack of preventive maintenance, or careless or improper operation.

(b) Effect of an upset. An upset constitutes an affirmativ defense to an action brought for noncompliance with suc technology based permit effluent limitations if the requirements of paragraph (14)(c) are met. No determination made during administrative review of claims that noncompliance was caused by upset, and before an action for noncompliance, is final administrative action subject to judicial review.

(c) Conditions necessary for a demonstration of upset. A permittee who wishes to establish the affirmative defense of upset shall demonstrate, through properly signed, contemporaneous operating logs, or other relevant evidence that:

(1) An upset occurred and that the permittee can identify the cause(s) of the upset;

(2) The permitted facility was at the time being properly operated; and

(3) The permittee submitted notice of the upset as required in paragraph (12)(f)(2) (24-hour notice).

(4) The permittee complied with any remedial measures required under paragraph (4).

(d) Burden of proof. In any enforcement proceeding the permittee seeking to establish the occurrence of an upset has the burden of proof.

(15) **Transfer of permits.** Permits may be transferred by modification or automatic transfer as described below:

(a) Transfers by modification. Except as provided in paragraph (b), a permit may be transferred by the permittee to a new owner or operator only if the permit has been modified or revoked and reissued pursuant to 40 CFR 122.62 (b) (2), or a minor modification mad pursuant to 40 CFR 122.63 (d), to identify the new permittee and incorporate such other requirements as may be necessary under the Clean Water Act.

(b) Automatic transfers. As an alternative to transfers under paragraph (a), any NPDES permit may be automatically transferred to a new permittee if:

(1) The current permittee notifies the Agency at least 30 days in advance of the proposed transfer date;

(2) The notice includes a written agreement between the existing and new permittees containing a specified date for transfer of permit responsibility, coverage and liability between the existing and new permittees; and

(3) The Agency does not notify the existing permittee and the proposed new permittee of its intent to modify or revoke and reissue the permit. If this notice is not received, the transfer is effective on the date specified in the agreement.

(16) All manufacturing, commercial, mining, and silvicultural dischargers must notify the Agency as soon as they know or have reason to believe:

(a) That any activity has occurred or will occur which would result in the discharge of any toxic pollutant identified under Section 307 of the Clean Water Act which is not limited in the permit, if that discharge will exceed the highest of the following notification levels:

(1) One hundred micrograms per liter (100 ug/l);

(2) Two hundred micrograms per liter (200 ug/l) for acrolein and acrylonitrile; five hundred micrograms per liter (500 ug/l) for 2,4-dinitrophenol and for 2-methyl-4,6 dinitrophenol; and one milligram per liter (1 mg/l) for antimony.

(3) Five (5) times the maximum concentration value reported for that pollutant in the NPDES permit application; or

(4) The level established by the Agency in this permit.

(b) That they have begun or expect to begin to use or manufacture as an intermediate or final product or byproduct any toxic pollutant which was not reported in the NPDES permit application.

(17) All Publicly Owned Treatment Works (POTWs) must provide adequate notice to the Agency of the following:

(a) Any new introduction of pollutants into that POTW from an indirect discharge which would be subject to Sections 301 or 306 of the Clean Water Act if it were directly discharging those pollutants; and

(b) Any substantial change in the volume or character of pollutants being introduced into that POTW by a source introducing pollutants into the POTW at the time of issuance of the permit.

(c) For purposes of this paragraph, adequate notice shall include information on (i) the quality and quantity of effluent introduced into the POTW, and (ii) any anticipated impact of the change on the quantity or quality of effluent to be discharged from the POTW.

(18) If the permit is issued to a publicly owned or publicly regulated treatment works, the permittee shall require any industrial user of such treatment works to comply with federal requirements concerning:

(a) User charges pursuant to Section 204 (b) of the Clean Water Act, and applicable regulations appearing in 40 CFR 35;

(b) Toxic pollutant effluent standards and pretreatment standards pursuant to Section 307 of the Clean Water Act; and

(c) Inspection, monitoring and entry pursuant to Section 308 of the Clean Water Act.

(19) If an applicable standard or limitation is promulgated under Section 301(b)(2)(C) and (D), 304(b)(2), or 307(a)(2) and that effluent standard or limitation is more stringent than any effluent limitation in the permit, or controls a pollutant not limited in the permit, the permit shall be promptly modified or revoked, and reissued to conform to that effluent standard or limitation.

(20) Any authorization to construct issued to the permittee pursuant to 35 Ill. Adm. Code 309.154 is hereby incorporated by reference as a condition of this permit.

(21) The permittee shall not make any false statement, representation or certification in any application, record, report, plan or other document submitted to the Agency or the USEPA, or required to be maintained under this permit.

(22) The Clean Water Act provides that any person who violates a permit condition implementing Sections 301, 302, 306, 307, 308, 318, or 405 of the Clean Water Act is subject to a civil penalty not to exceed $25,000 per day of such violation. Any person who willfully or negligently violates permit conditions implementing Sections 301, 302, 306, 307, 308, 318 or 405 of the Clean Water Act is subject to a fine of not less than $2,500 nor more than $25,000 per day of violation, or by imprisonment for not more than one year, or both.
Additional penalties for violating these sections of the Clean Water Act are identified in 40 CFR 122.41 (a)(2) and (3).

(23) The Clean Water Act provides that any person who falsifies, tampers with, or knowingly renders inaccurate any monitoring device or method required to be maintained under this permit shall, upon conviction, be punished by a fine of not more than $10,000, or by imprisonment for not more than 2 years, or both. If a conviction of a person is for a violation committed after a first conviction of such person under this paragraph, punishment is a fine of not more than $20,000 per day of violation, or by imprisonment of not more than 4 years, or both.

(24) The Clean Water Act provides that any person who knowingly makes any false statement, representation, or certification in any record or other document submitted or required to be maintained under this permit, including monitoring reports or reports of compliance or non-compliance shall, upon conviction, be punished by a fine of not more than $10,000 per violation, or by imprisonment for not more than 6 months per violation, or by both.

(25) Collected screening, slurries, sludges, and other solids shall be disposed of in such a manner as to prevent entry of those wastes (or runoff from the wastes) into waters of the State. The proper authorization for such disposal shall be obtained from the Agency and is incorporated as part hereof by reference.

(26) In case of conflict between these standard conditions and any other condition(s) included in this permit, the other condition(s) shall govern.

(27) The permittee shall comply with, in addition to the requirements of the permit, all applicable provisions of 35 Ill. Adm. Code, Subtitle C, Subtitle D, Subtitle E, and all applicable orders of the Board or any court with jurisdiction.

(28) The provisions of this permit are severable, and if any provision of this permit, or the application of any provision of this permit is held invalid, the remaining provisions of this permit shall continue in full force and effect.

Exhibit 2

Exhibit 2

ROBINSON REFINERY

Robinson, Illinois

Site: Located in Crawford County in southeastern Illinois
History: Built in 1906 by Lincoln Oil Company and purchased in 1924 by MPC (then The Ohio Oil Company)
Refining Capacity: 231,000 barrels per calendar day
Crude Oil Supply: Sweet and sour crude oils
Operations: Crude distillation, catalytic cracking, hydrocracking, hydrotreating, coking, reforming, alkylation, aromatics extraction, isomerization and sulfur recovery
Products: Gasoline, distillates, propane, anode-grade coke, aromatics, fuel-grade coke and slurry
Product Distribution: Pipeline, transport truck and rail
Employment: Approximately 710 employees

Safety & Environmental Stewardship: ■ MPC was the first U.S. refining company to adopt the American Chemistry Council's Responsible Care® principles across all of its organizations to address continual improvement in health, environmental, safety and security performance. ■ MPC is an Environmental Protection Agency (EPA) ENERGY STAR Partner company, demonstrating commitment to energy efficiency. **At Robinson:** ■ 2016 Illinois Governor's Sustainability Award from the Illinois Sustainable Technology Center ■ 2015 Monarch Sustainer of the Year Award from the United States Business Council for Sustainable Development and the Pollinator Partnership ■ 2015 Southern Illinois Occupational Safety and Health Governor's Award for Contributions in Health and Safety ■ 2014-2016: Energy Star certification ■ Five Wildlife Habitat Council certified sites ■ 2014 Occupational Safety and Health Administration (OSHA) Voluntary Protection Program Participants' Association (VPPPA) National Innovation Award ■ 2013 Outstanding Behavior-Based Safety Outreach Award ■ 2013 and 2015: OSHA VPPPA National Safety and Health Outreach Award ■ 2011 Wings Over Wetlands Award ■ 2009 OSHA VPPPA National and 2013 VPPPA Regional Voluntary Protection Program (VPP) Outreach Award ■ 2008 OSHA VPP Best Practice Award for refinery's contractor behavior-based safety program ■ 2007-present: Responsible Care Management System Certification ■ 2005-present: Cambridge Center for Behavioral Studies (CCBS) - Behavioral Safety Accreditation and 2015 inaugural CCBS Platinum Accreditation ■ 1999-present: OSHA VPP Star Site ■ American Fuel and Petrochemical Manufacturers Safety Awards

Community Involvement: ■ United Way of Crawford County ■ Local Chambers of Commerce (Robinson, Oblong, Palestine, Hutsonville) ■ Leadership Crawford County ■ Community Household Hazardous Waste Day ■ Community Electronics Takeback Day ■ Education programs at Certified Wildlife Habitat sites in Crawford County ■ Community Advisory Panel ■ Mutual aid for fire and other emergencies ■ Emergency response drills with local emergency responders ■ Teen Reach ■ Fundraisers for Alzheimer's research ■ Humane Society Dog Show ■ Nutrition on Weekends ■ University of Illinois Conservation Day ■ Soles for Souls ■ Harmony Park

Marathon Petroleum Company LP

MPC operates a seven-refinery system that processes approximately 1.8 million barrels of crude oil into clean transportation fuels and other products every day. We are the largest Midwest refiner and third-largest refiner in the U.S. with approximately 9.8 percent of the U.S. capacity. For more information, visit **www.MarathonPetroleum.com**.

MPC is in the business of creating value for our shareholders through the quality products and services we provide for our customers. We strongly believe how we conduct our business is just as integral to our performance. Several core principles guide our approach to doing business, including: Health and Safety, Environmental Stewardship, Integrity, Corporate Citizenship and Diversity and Inclusion.

September 2017

Exhibit 3

Exhibit 3

	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	average
Winter Max	87	86	85	88	89	92	81	85	82	80	85	82	79	80	75	84
Winter Avg	78	72	76	79	76	74	68	71	70	70	70	68	70	70	70	72
Summer Max	97	100	100	96	98	99	98	92	96	95	96	96	96	94	97	97
Summer Avg	85	88	89	90	88	88	88	82	85	83	87	84	84	83	85	86

Monthly Max
January
Feburary
March
April
May
June
July
August
September
October
November
December

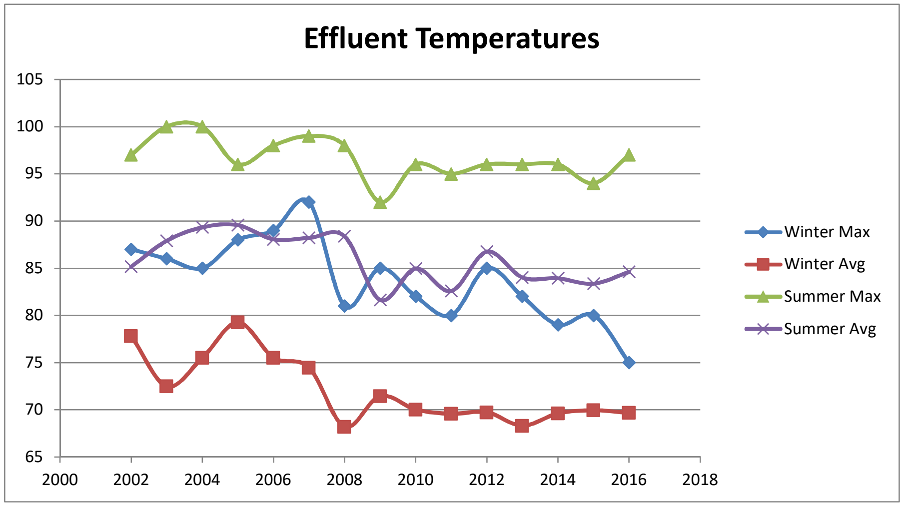


Exhibit 4

Technical Support Documentation for Alternative Thermal Effluent Limitations under Section 316(a) of the Clean Water Act and 35 Ill. Adm. Code 304.141(c) for the Marathon Petroleum Company LP Refinery located in Robinson, Illinois

-FINAL REPORT-

by

Midwest Biodiversity Institute
P.O Box 21561
Columbus, OH 43221-0561

to

Marathon Petroleum Company LP
Illinois Refining Division
400 S Marathon Ave.
Robinson, IL 62454

December 15, 2017

TABLE OF CONTENTS

LIST OF TABLES

TABLE OF FIGURES

Technical Support Documentation for Alternative Thermal Effluent Limitations under Section 316(a) of the Clean Water Act and 35 Ill. Adm. Code 304.141(c) for the Marathon Petroleum Company LP Refinery located in Robinson, Illinois

Midwest Biodiversity Institute
P.O. Box 21561
Columbus, OH 43221-0561

BACKGROUND

Marathon Petroleum Company LP (MPC) seeks alternative thermal effluent limitations pursuant to Section 316(a) of the Clean Water Act (CWA) (33 U.S.C. § 1326(a)), Section 304.141(c) of the Illinois Pollution Control Board's (Board) Water Pollution regulations (35 Ill. Admin. Code § 304.141(c)), and the Board's Subpart K procedural rules (35 Ill. Admin. Code 106, Subpart K). Section 106.1115 of the Board's procedural rules describes the Early Screening information that is required to be submitted to Illinois EPA prior to filing a petition for an alternative thermal effluent limitation as follows:

a) Prior to filing a petition for an alternative thermal effluent limitation, the petitioner must submit the following early screening information to the Agency:

1) A description of the alternative thermal effluent limitation requested;
2) A general description of the method by which the discharger proposes to demonstrate that the otherwise applicable thermal discharge effluent limitations are more stringent than necessary;
3) A general description of the type of data, studies, experiments and other information that the discharger intends to submit for the demonstration; and
4) A proposed representative important species list and supporting data and information.

b) *Within 30 days after the early screening information is submitted under subsection (a), the petitioner shall consult with the Agency to discuss the petitioner's early screening information.*

The Early Screening Submittal (Appendix A) was submitted to Illinois EPA (IEPA) on March 11, 2016 and approved by IEPA on March 24, 2016. This was followed by a Detailed Plan of Study (MPC 2016), in accordance with Section 106.1120, submitted to Illinois EPA on April 18, 2016. The study plan was approved by IEPA on May 17, 2016 and with Illinois DNR (IDNR) concurrence on June 2, 2016.

This report details the technical documentation in support of the Section 316(a) alternative thermal effluent limitations petition to the IPCB. It contains the rationale and justification for the granting of alternative thermal effluent limitations for the MPC 001 discharge to Robinson

Creek, based on data collected in 2016 and analysis of that data in this report and the *Biological and Water Quality Assessment of Robinson and Sugar Creeks* (MBI 2017).

SUMMARY AND CONCLUSIONS

The principal conclusion of the 316(a) demonstration is that the existing discharge of heat by the MPC 001 discharge poses no threat to the eventual recovery of the aquatic biota in Robinson Creek to attain the Illinois General Use for aquatic life. This finding *"will assure the protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife in and on that body of water."* Because the biota in Robinson Creek are currently impaired by multiple non-thermal stressors both upstream and downstream of the MPC 001 outfall, a predictive demonstration was undertaken. This is in keeping with the *Interagency 316(a) Technical Guidance Manual and Guide for Thermal Effects Sections of Nuclear Facilities Environmental Impact Statements* (U.S. EPA 1977). The predictive demonstration consisted of using the Fish Temperature Modeling System (FTMS; Yoder 2008) to determine protective "true summer" (June 16-Septmber 15) maximum and average temperatures for a list of Representative Important Species (RIS) and comparing the results to the measured and modeled summer temperature regime. While it is true the impaired status of Robinson Creek precludes a Type I demonstration (no prior appreciable harm), recent results show the creek to be on a trajectory of improvement in response to abatement of non-thermal chemical impacts.

The 316(a) demonstration includes a description of the need for alternative thermal effluent limitations, characterization of the measured and modeled temperature regime in Robinson Creek, quantification of measured and modeled excursions of certain of the water quality based effluent temperature limitations in MPC's current and proposed draft renewal permit applicable to the discharge of heat via the MPC 001 outfall, the rationale for the development of a list of RIS, a description of outputs from the FTMS, and an analysis of the frequency of thermal stress and recovery periods with an evaluation of the significance of intermittent high temperatures as these are offset by stress recovery periods. The latter is a contemporary concept that challenges a sole reliance on maximum only criteria.[1] MPC's 5°F Δ effluent limitation was evaluated and it was concluded that it is more stringent than necessary for MPC's discharge to Robinson Creek. This finding is consistent with recent scientific literature and State examples of water quality standard (WQS) modernization that emphasize averages and exceedance of maximum thresholds and frequencies in lieu of maximum only criteria and °F Δ provisions. Lastly, the FTMS results for the summer (June 16-September 15) and analysis of the ambient and modeled temperature regime were used to develop the alternative thermal effluent limitations for the non-summer months.

The FTMS derived summer period maximum of 90.7°F and average of 87.1°F are sufficiently protective to serve as alternatives to the current 90°F maximum and 5°F Δ effluent limitations. MPC's proposal, however, takes a conservative approach by using the maximum of 90°F,

[1] The terms "criteria" and "criterion" may be used interchangeably (in this report and in other reports prepared by Midwest Biodiversity Institute) with the term "standard" in the context of discussions related to the Illinois water quality standard for temperature as set forth in 35 Ill. Adm. Code 302.211, including in tables and figures.

instead of 90.7°F, and the average of 87°F, instead of 87.1°F. The 3°F allowance above the maximum and one percent exceedance provisions of MPC's current effluent limitations are sufficient to preclude excessive exceedances of the maximum FTMS threshold. For the non-summer periods, maximum temperature criteria consistent with the thermal regime downstream from the MPC 001 discharge should apply given the absence of any evidence or expectation of adverse effects during these periods. Monthly maximums that account for seasonal increases and decreases in temperature during the Spring and Fall periods are also included as an alternative to the abrupt change from 60°F to 90°F in April and 90°F to 60°F in December. These alternative thermal effluent limitations are based upon Datasonde data, HOBO data, and modeling projections, and are consistent with the seasonal acclimation requirements of warmwater fish assemblages in Robinson Creek.

Based on the determination of true summer season short and long-term protective thresholds and the analysis of the dynamics of the temperature regime downstream from the MPC 001 outfall in Robinson Creek, the current MPC 001 thermal discharge should not preclude recovery of the resident biota to meet the Illinois General Use for aquatic life. This meets the goal of 316(a) in that the current temperature regime *"will assure the protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife in and on that body of water*", *i.e.,* Robinson Creek. Exceedances of the FTMS short-term threshold of 90.7°F are brief and sufficiently offset by lower temperatures that provide for adequate recovery periods. Summer period averages were well below the FTMS long-term survival threshold and virtually 100% of the upper avoidance temperatures of the RIS. The Mean Weekly Average Temperature for growth is exceeded for only two recreational species and this using a liberal interpretation of recreational (*e.g.,* including white sucker). The analyses and observations in this 316(a) demonstration support the conclusion that the current thermal regime is sufficiently protective of the RIS and the full assemblages by extension. As such, this satisfies the demonstration that the requested alternative thermal effluent limitation under Section 316(a) is justified.

Alternative Thermal Effluent Limitation

As required by Section 106.1130(g):

Marathon requests that, in lieu of the existing temperature limitations in Marathon's NPDES Permit based on 35 Ill. Admin. Code §§ 302.211(d) and (e), the Board approve the following alternative thermal effluent limitations for discharges from the Refinery's Outfall 001:

- Water temperature in Robinson Creek downstream from the MPC 001 outfall at a point instream in the vicinity of the IL Route 1 bridge shall not exceed the maximum limits in the following table during more than one (1) percent of the hours in the 12-month period ending with any month. Moreover, at no time shall the water temperature at such location exceed the maximum limits in the following table by more than 3°F (1.7°C). (Robinson Creek temperatures are temperatures of those portions of the creek essentially similar to and following the same thermal regimes as the temperature of the main flow of the creek.) The average water temperature in Robinson Creek downstream from the MPC 001 outfall at a point instream in the vicinity of the IL Route 1 bridge for the period June 16 – September 15 shall not exceed 87°F.

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
°F	65	65	74	82	88	90	90	90	90	87	85	74
°C	18.3	18.3	23.3	27.8	31.1	32.2	32.2	32.2	32.2	30.6	29.4	23.3

- In lieu of 35 Ill. Admin. Code § 302.102(b)(8), the following shall apply: the area and volume of mixing shall extend from the MPC 001 Outfall to a point instream in the vicinity of the IL Route 1 bridge.

Also, Marathon proposes that the instream sampling location for monitoring the alternative thermal effluent limitations, i.e. the point of compliance, be located at a point instream in the vicinity of the IL Route 1 bridge.

EARLY SCREENING SUBMITTAL

MPC submitted an Early Screening Submittal (Appendix A) pursuant to seeking an alternative thermal effluent limitation for its thermal effluent discharged via Outfall 001 (NPDES Permit IL0004703 September 19, 2013). The current effluent limitations for temperature are set forth in Special Condition 8 of the NPDES Permit as follows:

For outfall 001, discharge of wastewater from this facility must not alone or in combination with other sources cause the receiving stream to violate the following thermal limitations at the edge of the mixing zone which is defined by Section 302.211, Illinois Administration (sic) Code, Title 35, Chapter 1, Subtitle C, as amended:

A. Maximum temperature rise above natural temperature must not exceed 5°F (2.8°C).

B. Water temperature at representative locations in the main river shall not exceed the maximum limits in the following table during more than one (1) percent of the hours in the 12-month period ending with any month. Moreover, at no time shall the water temperature at such locations exceed the maximum limits in the following table by more than 3°F (1.7°C). (Main river temperatures are temperatures of those portions of the river essentially similar to and following the same thermal regimes as the temperature of the main flow of the river.)

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
°F	60	60	60	90	90	90	90	90	90	90	90	60
°C	16	16	16	32	32	32	32	32	32	32	32	16

* * *

Method of Alternative Thermal Effluent Limitations Demonstration

As required by Section 106.1115 (a)(2), MPC proposed to develop and submit a 316(a) demonstration that has elements of both Predictive and Type II demonstrations that are supported by field studies of the receiving stream, predictive modeling, and comparisons to thermal tolerance information for representative important species (RIS). This conclusion was reached in accordance with the *Interagency 316(a) Technical Guidance Manual and Guide for Thermal Effects Sections of Nuclear Facilities Environmental Impact Statements* (U.S. EPA 1977), in particular the decision criteria that appear in Section 3.0. The predictive demonstration applies to Robinson Creek as it is impaired due to a variety of causes identified by Illinois EPA (IEPA 2016) and MBI (2017) which, in accordance with the Interagency Technical Guidance (U.S. EPA 1977), precludes showing of a lack of prior appreciable harm due to the thermal effluent.

The Early Screening Submittal (Appendix A) was done in accordance with the Interagency Technical Guidance (U.S. EPA 1977) by assuring that only the most relevant aquatic assemblages would be assessed and without collecting data that is either redundant or of little value to MPC or the IEPA. The biotic category determinations were based on historical data available for Robinson Creek and other area streams and a general knowledge about the suitability of certain aquatic assemblages for assessing thermal effects and water quality in warmwater streams of the Midwestern U.S.

Selection of Biotic Categories

Each biotic category listed in the Interagency Technical Guidance (U.S. EPA 1977) was evaluated in the Early Screening Submittal (Appendix A) as to whether it merited inclusion in the 316(a) demonstration. The conclusions reached for each biotic category about the potential for their applicability in Robinson Creek and other area streams were based on:

1. A search of readily available biological databases and reports for Robinson Creek and nearby Wabash Faunal Region streams;
2. Recent knowledge about which biotic categories (i.e., biological assemblages) are routinely used to assess streams and rivers in the Midwestern U.S;
3. The likelihood of a biotic category showing adverse impacts due the discharge of heat by the MPC Refinery, and;
4. The general utility of a biotic category for exhibiting non-thermal responses, which is an important need for separating thermal and non-thermal stressors.

Because the terminology in the Interagency Technical Guidance (U.S. EPA 1977) is dated, more modern terminology was used to describe the attributes of a bioassessment. For example, the term *biological assemblages,* particularly as they relate to established methodologies in widespread use for the purpose of assessing the health and well-being of warmwater streams, is used in lieu of the Interagency Technical Guidance (U.S. EPA 1977) term *biotic categories.* The following biological assemblages were selected for the 2016 bioassessment as detailed in the Early Screening submittal.

Shellfish/Macroinvertebrates

The Interagency Technical Guidance (U.S. EPA 1977) does not completely distinguish the difference between shellfish and macroinvertebrates, but this was done in the Early Screening submittal. In terms of freshwater bioassessment there is a clear distinction between macroinvertebrates and "shellfish" in streams. As explained in more detail below, each requires a distinct sampling and evaluation methodology so they are considered as distinct biological assemblages.

a. Macroinvertebrates

Macroinvertebrates are a mainstay of stream and river biological assessments and include all invertebrate taxa that can be seen by the "unaided" eye, i.e., without magnification aids. Many different approaches to sampling and assessing the health of the macroinvertebrate assemblage exist across the U.S. The procedures of the Illinois EPA (IEPA 2011 a-e) were followed with taxonomic resolution to the lowest practicable level (i.e., genus/species for the common families and orders). While macroinvertebrates are generally regarded as being more thermally tolerant than fish, their inclusion was deemed necessary since they are used by IEPA to determine the status of the General Use for aquatic life for Section 303(d) impaired waters listings. They are also useful to assess non-thermal causes of impairment and were included in the 2016 field studies.

b. Shellfish

Shellfish generally refers to marine species of clams, mussels, and snails where they are commercially important and susceptible to adverse thermal effects. In freshwater rivers and streams this biotic category primarily includes freshwater mussels of the family Unionidae and freshwater snails. While some snails and small freshwater clams are collected in the macroinvertebrate assemblage sampling, the larger Unionidae are not included and require a separate sampling effort and assessment method. Recent information suggests that certain species of mussels are as thermally sensitive as fish and they are the principal driver of the recently proposed U.S. EPA ammonia criterion (U.S. EPA 2013). Based on this recent information, mussels were included as a biological assemblage due to the potential for adverse effects from thermal enrichment and non-thermal impacts. The Illinois Natural History Survey (INHS) database includes mussel data for other area streams (Shasteen et al. 2012) and at watershed sizes larger than the area of interest in Robinson and Sugar Creeks. None of that information supported an expectation of a robust mussel assemblage in the Robinson Creek which was unchanged by the 2016 sampling results (MBI 2017). However, given their sensitivity to a wide range of pollutants it was prudent to include them in the bioassessment.

Fish

Fish are widely recognized as having the highest sensitivity to thermal enrichment and are frequently the singular focus of predictive demonstrations and Representative Important Species (RIS) lists. Prior assessments of Robinson Creek conducted by IEPA provide the most complete species occurrence database which is essential to a predictive demonstration.

SUPPORTING INFORMATION AND ANALYSES

As required by Section 106.1115 (a)(3), the Early Screening Submittal described the supporting data and studies that would be included in a 316(a) demonstration. A detailed plan of study

(MBI 2016) immediately followed approval of the Early Screening Submittal, was submitted in accordance with Section 106.1120, and was approved ahead of the biological and water quality sampling during late June through mid-October 2016.

Biological and Water Quality Assessment 2016

A biological and water quality assessment (referred to hereafter as the "bioassessment") was conducted during June-October 2016 and included field studies of the high potential impact biological assemblages (fish, macroinvertebrates, mussels), habitat, and the chemical water quality of the Sugar Creek watershed which includes Robinson and Sugar Creeks and their major tributaries. The bioassessment was designed to produce the quantity and quality of data needed to meet the following objectives:

1) Document the current General Use aquatic life status in Robinson, Marathon, and Sugar Creeks and their tributaries;
2) Assess the chemical/physical quality of each stream with chemical water column, chemical sediment, physical habitat, and temperature monitoring techniques;
3) Determine the major causes and sources of any observed impairments; and,
4) Document the trajectory of any changes in biological and chemical/physical conditions as compared to available historical data from the IEPA FRSS and IEPA/IDNR Basin Surveys.

The 2016 bioassessment accomplished this by building on prior Facility Related Stream Surveys (FRSS) conducted by Illinois EPA in Robinson Creek dating to 1992 (1992, 2008 and 2013). Given the need to account for a complex array of overlapping impacts from upstream sources, non-thermal chemical stressors, and physical alterations to flow and habitat, an intensive pollution survey design was used. This design included more sites than the prior FRSS efforts (MPC 2016). Sampling sites were located in proximity to each potential source (point and nonpoint in origin) to distinguish a complex array of overlapping stressors (Figure 1; Table 1).

The bioassessment revealed that biological impairments persisted for the entire length of Robinson Creek both upstream and downstream from MPC 001 in 2016 (Figure 2). Fish and macroinvertebrate Index of Biotic Integrity (fIBI and mIBI) values were below thresholds[2] for full support of the Illinois General Use in the entirety of Robinson Creek and in Sugar Creek immediately downstream from Robinson Creek. Key biological response signatures to non-thermal toxicity were evident in Robinson Creek downstream from the MPC 001 outfall extending for ~3 miles in late-August/early-September and ~4 miles in late-September/early-October 2016. This accounts for the majority of the biological impairment observed downstream from MPC 001 in Robinson Creek. These results support the use of a predictive demonstration to address thermal issues in Robinson Creek under Section 316(a). The bioassessment document (MBI 2017) describes these findings in more detail.

[2] IEPA 303(d) listing methodology (IEPA 2016).

Ambient Temperature Regime

Characterizing the ambient temperature regime was accomplished in 2016 by deploying Datasonde and HOBO continuous monitors at selected locations upstream and downstream from the MPC 001 outfall. Datasondes were deployed for consecutive 3-4 day periods once each month during 2016 at five locations as follows:

1) Site RC04 – Located immediately upstream from the MPC 001 outfall in Robinson Creek. This location is downstream from the Robinson WWTP and is considered as the upstream “control” site for evaluating any additive impact from MPC 001.
2) Site RC05 – Located immediately downstream from the MPC 001 discharge to Robinson Creek. This location represents the point of maximum instream impact from MPC 001.
3) Site RC07 – Located at IL State Route 1 approximately 1.7 miles downstream from MPC 001. This is the compliance location in the draft NPDES permit.
4) Site RC09 – Located at Crawford County Route 1150E and also known as the “hog farm” location. This is the compliance location in the current NPDES permit.
5) Site SC01 – Located at Crawford County Route 1150N in Sugar Creek. This is considered a “background site” that is not subject to any other direct point sources of heat.

HOBO recorders were deployed continuously during June 2016-February 2017 at RC04, RC05 (Sept. 2016-Feb. 2017), and RC09. HOBO data also exists for Nov. 2015-Jan. 2016 at RC04 and RC09. Together these results were used to characterize the ambient temperature regime in Robinson Creek both outside and within the influence of the MPC 001 discharge.

The Datasonde results during 2016 are summarized in Table 2 and with respect to the Illinois temperature criteria including the monthly maximum, frequency not to exceed, and the 5°F Δ provisions of the standard at each location and inclusive time period. The HOBO results are summarized in a similar manner in Table 3. Exceedance frequencies were also determined for each location and inclusive time period. The frequency of exceedance of the Illinois maximum criteria and frequency of exceedance allowances were determined for the “summer” (April-November) and “winter” (December-March) periods specified by the Illinois standard. Although not part of the Illinois standard, exceedances of an average temperature of 86°F during the true summer period of June 16-September 15 was used as an initial screen for potential adverse effects on the aquatic biota. Gammon (1973) documented rapid declines in Wabash River fish community diversity and abundance (density and biomass) in two thermal plumes between 86°F (30°C) and 89.6°F (32°C) (Figure 3). While diversity (species richness) was maintained up to a temperature of 88.7°F (31.5°C), density (numbers) peaked at 40 fish/km between 80.6°F (27°C) and 86°F (30°C) declining to <10 fish/km at temperatures >89.6°F (32°C). Biomass (weight) declined sharply >89.6°F (32°C), but thermally sensitive species were replaced by thermally tolerant species in terms of biomass between 86°F (30°C) and 89.6°F (32°C). Thus 86°F can serve as a general screening value for potential adverse effects due to heat with 86°F (30°C) being used as a summer average to compliment the Illinois maximum of 90°F (32.2°C). Gammon (1973) further observed that most fish species preferred the warmer thermal plumes at ambient temperatures <77°F (25°C), but during warmer periods in the summer fish avoided the thermal plumes when water temperatures exceeded 89.6°F (32°C). However, fish quickly returned when these higher temperatures subsided. Although Gammon's research was conducted well before the contemporary development of the "stress/recovery concept" by Bevelhimer and Bennet (2000), the concept that an aquatic assemblage subjected to artificially elevated temperatures will be sustained provided there are sufficient intervening periods of lower temperatures that provide sufficient periods of relief from short-term thermal stress, is amply demonstrated in the Wabash River results documented by Gammon (1973).

The Datasonde and HOBO results show frequent exceedances of the 5°F Δ provision using the RC04 control site as the benchmark of comparison (Tables 2 and 3). Exceedances of the 60°F maximum during the "winter" months of December-March (%max Wi) were the most frequent in December, February, and early March and during the transition from winter to spring and fall to winter. Tables 2 and 3 also include statistics on the frequency of exceedance of the Illinois maximum criteria and the frequency of exceedance of the maximums by >3°F, the latter of which are also parts of the Illinois temperature standard.

Graphed results of selected Datasonde and field grab sampling results show that the extent of thermal alteration resulting from the MPC 001 effluent in terms of exceedances of the Illinois criteria were the greatest and most frequent immediately downstream from MPC 001 (RC05) and generally dissipating with distance downstream (Figure 4). These results also show that thermal alterations do not extend beyond the mouth of Robinson Creek which has an approximate 15 mi.^{2} catchment. The results from the monthly Datasonde deployment in June 2016 (Figure 5, upper) show that temperatures can be higher at RC07 presumably due to solar insolation during daylight hours and when ambient air temperature is higher than the MPC 001 effluent and downstream temperature. However, this downstream increase was only 1.8°F (1°C) and was the only instance of this phenomenon in any of the Datasonde results. The median and quartile temperatures were all indicative of temperature decreasing with downstream distance. This could not be ascertained with the HOBO results since RC07 was not included during the summer of 2016. The HOBO data from July-September 2016 are depicted in Figure 5 (lower) and reveal the degree and duration of intermittent periods of temperatures that exceed the 90°F Illinois maximum at RC05. The increases over temperatures at RC04 illustrate the effect of the thermal loading from the MPC 001 effluent.

Modeled Temperature Regimes

Modeling was also used to characterize the ambient temperature regime for the period 2011-16 using HOBO data collected in 2015 and 2016 by MPC and Datasonde data collected by MBI in 2016 as the calibration dataset and the MPC 001 effluent as the verification dataset. The Environmental Fluid Dynamics Code (EFDC) hydrodynamic and temperature model was used to quantify the sources (Robinson WWTP, MPC 001, tributary inputs, and meteorological inputs) of potential variations on ambient temperatures in Robinson Creek (TetraTech 2017). It was also used to predict instream temperatures over a broad range of ambient conditions deriving the same monthly and summer period exceedances and durations as was done with the 2016 ambient temperature data in Tables 2 and 3 and for three time periods, 2011-16, 2012 only, and 2016 only (Tables 4, 5, and 6). The 2011-16 period represents a reasonably extended period of time, 2012 represents a critical year with high ambient air temperatures and critically low stream flows, and 2016 represents the time period of the comprehensive water quality and biological assessment. Modeled temperature exceedances were less frequent than the Datasonde results and more in line with the 2016 HOBO results. As with the measured data, exceedances of the 5°F Δ and the winter maximum temperature criterion of 60°F were frequent. Exceedances of the true summer (June 16-September 15) 86°F average screening value and the frequency of exceedances of the Illinois maximum summer criterion of 90°F were less frequent. The modeled results for 2012 (Figure 6) and 2016 (Figure 7) at four Robinson Creek locations (RC01, RC06, RC07, and RC09) illustrate the annual seasonal cycles of temperature and when the periods of exceedance of the "winter" criterion of 60°F and the "summer" criterion of 90°F are simulated to occur. In 2012 there were a few instances of predicted exceedances of the 3°F allowance above the summer maximum, but none were predicted for 2016.

Synthesis of the Monitored and Modeled Ambient Temperature Regimes

The frequency of exceedances of the Illinois maximum temperature criterion on an annual basis, the May-November "summer" period, and the December-March "winter" period along with the true summer period (June 16-September 15) average and % greater than 86°F are summarized for each of the four Robinson Creek locations from the Datasonde and HOBO data and the modeling predictions for 2011-16, 2012, and 2016 in Table 7. Exceedances of the Illinois 5°F Δ criterion, the winter maximum of 60°F, and the allowable exceedance rates (no maximum >3°F and <1% hours annually) were documented in both the monitored and modeled results. Exceedances of the summer thresholds were less frequent in the modeled results compared to the Datasonde results, the latter being somewhat biased by being measured only under base flow conditions. However, the 2012 modeled results were in closer agreement with the 2016 HOBO results. The summarized values from Table 7 are graphically depicted in Figure 8 to visually illustrate the high rates of exceedance of the maximum criterion during the winter (Dec.-March) period compared to much lower rates of exceedance during the summer (April-November) period. The differences among the Table 7 results between RC04 upstream from MPC 001 and RC09 one mile upstream from the mouth illustrate that thermal alteration is largely confined to Robinson Creek. Net increases that occurred were small and mostly for the winter period and in some cases were zero or negative in the modeled results. The results were used in the predictive analyses in support of the 316(a) petition to determine if the magnitude and duration of temperature exceedances could be harmful to aquatic life focused on the seasonal period (i.e., during the true summer period of mid-June to mid-September) during which sustained high temperatures would present the greatest risk of harm.

DESCRIPTION & CONTENT OF A PREDICTIVE ANALYSIS PERFORMED IN SUPPORT OF a 316(a) DEMONSTRATION

Rationale for Selecting a Predictive 316(a) Demonstration

The Interagency Technical Guidance (U.S. EPA 1977) describes options for conducting a 316(a) demonstration, the selection which requires a thorough understanding of the current status of the receiving water body. A type I demonstration seeks to show that a thermal discharge has not resulted in any prior appreciable harm to the biota in the receiving water, which suggests that the thermal discharge is the only potential source of harm. A type II demonstration is a predictive demonstration or a best estimate of "what will happen" and is appropriate for:

1. New sources not yet discharging;
2. Facilities which have not been discharging heated effluent for a sufficient period of time to allow evaluation of the effects of the effluent;
3. Facilities discharging into waters which, during the period of the applicant's prior thermal discharge, were so despoiled as to preclude evaluation of the effects of the thermal discharge on species of shellfish, fish, and wildlife; and,
4. Major changes in the facility operational mode.

Because the current status of Robinson Creek downstream from the MPC 001 discharge best fits criteria number 3 above a predictive demonstration was developed. Here again, we are employing more modern terms by describing the status of Robinson Creek as *impaired,* which is more precise than the *"so despoiled"* terminology which was a fitting description of many U.S. waterbodies at the time these guidelines were written. While it is true that the impaired status of Robinson Creek precludes a Type I demonstration (no prior appreciable harm), recent results show it to be on a trajectory of improvement and in direct response to the abatement of non-thermal chemical impacts. At the same time, other non-thermal causes and sources may limit the extent of that improvement in the future.

Determining potential adverse effects of the temperature regime downstream from the MPC 001 outfall in Robinson Creek is the primary focus of the predictive analysis selected to determine if alternative thermal effluent limitations pursuant to a 316(a) demonstration are warranted. Both measured and modeled excursions of certain of the water quality based effluent temperature limitations in MPC's current and proposed draft renewal permit applicable to the discharge of heat via the MPC 001 outfall results in the need to seek alternative thermal effluent limitations under 316(a). A strict interpretation of these results concludes that reductions in heat discharged by MPC are needed to meet MPC's current thermal effluent limitations on a continuous basis.

Description of the Predictive Analysis

A predictive analysis for Robinson Creek was accomplished using the Fish Temperature Modeling System (FTMS; Yoder 2008) methodology and a thermal effects database for fish and macroinvertebrates originally complied by Yoder et al. 2006, updated by Yoder 2012, and updated again for this study (Appendix B). The previously described temperature results (both measured and modeled) for Robinson Creek upstream and downstream from MPC 001 were also key ingredients of the predictive demonstration. The principal parts of a predictive analysis in support of the 316(a) demonstration for justifying alternative thermal effluent limitations for the MPC 001 effluent included the following:

1) Development of a list of Representative Important Species (RIS);
2) Assigning representative thermal tolerance data to each RIS;
3) Determination of protective true summer average and maximum temperatures;
4) Comparisons with the seasonal temperature regime in Robinson Creek at selected locations both outside and within the direct influence of the MPC 001 effluent; and,
5) An assessment of the risk of the current thermal regime for precluding the full recovery of the aquatic biota to attain the General Use aquatic life biocriteria thresholds in Robinson Creek within the current reach of thermal alteration.

Performing each step outlined above required a detailed examination of historical and present-day data. Historical data collected by IEPA/IDNR, the 2016 MBI bioassessment data, the monitored and modeled temperature results, and their application within the FTMS methodology were all used to support the conclusions of this predictive 316(a) demonstration.

The Fish Temperature Modeling System (FTMS)

The Fish Temperature Modeling System (FTMS; Yoder 2008) was designed to provide summer average and maximum temperatures that are protective of both short and long-term survival requirements of the most sensitive of Representative Important Species (RIS) that are specific to a region, a river or stream, or a reach of a river or stream. It also incorporates endpoints for the protection of chronic behavioral and physiological thresholds such as avoidance and growth of selected RIS. Non-summer season criteria are not based on any particular RIS tolerance endpoint because fish are attracted to and can tolerate temperatures that are well in excess of non-summer season ambient temperatures. Criteria for these months are simply set to be consistent with the seasonal temperature regime. The FTMS is supported by a thermal effects database compiled from the literature from which the primary input variables are selected. This database consists of seven thermal thresholds that include preferred/optimum, growth, avoidance, and lethal temperature endpoints for both cold and warmwater fish species and selected macroinvertebrates. The four primary FTMS thermal tolerance variables (optimum, mean weekly average for growth, upper avoidance, and upper incipient lethal temperatures) are selected from this database as the primary FTMS input variables for determining protective temperature criteria for a specific list of RIS. The selection of thermal tolerance endpoints is made for each RIS based on geographical relevance and experimental variables such as the acclimation temperature of a particular tolerance endpoint. The database includes both laboratory and field studies. The FTMS approach was first used to develop river and basin specific monthly and bi-monthly average and maximum temperature criteria for Ohio rivers and streams (Ohio EPA 1978) and more recently for the Lower Desplaines River (Illinois; Yoder and Rankin 2006), the Ohio River (Yoder et al. 2006), and the Connecticut River (Yoder 2012).

Representative Important Species (RIS)

As required by Section 106.1115 (a)(4) the following is a description of the process used to select Representative Important Species (RIS) in support of the demonstration of the alterative thermal effluent limitations under Section 316(a) in Illinois. The selection of RIS followed the FTMS procedure (Yoder 2008) and includes:

1) species that represent the full range of response and sensitivity to environmental stressors;
2) species that are commercially and/or recreationally important;
3) species that are representative of the different trophic levels;
4) rare, threatened, endangered, and special status species;
5) species that are numerically abundant or prominent in the system including the consideration of historical data;
6) potential nuisance species; and,
7) species that are indicative of the ecological and physiological requirements of representative species that lack thermal data.

The RIS selection process emphasized fish as they are generally regarded as the most thermally sensitive assemblage, especially as compared to macroinvertebrates. Recent research suggests that mussels are worthy of consideration, but these were represented only by relict shells of a single species at 3 sites in Robinson Creek and 3 individuals of a second species in Lamotte Creek (MBI 2017). Available fish data from IEPA/IDNR surveys in the Wabash Faunal Region, the 2008 and 2013 IEPA FRSS of Robinson Creek, and the 2016 MBI fish surveys were used to screen and select the final RIS. Fish species that were in numbers sufficient to suggest either an established or potential residency were selected based on an established occurrence in Robinson Creek, being observed in sufficient numbers at the Sugar Creek background site (SC01), and present in ~0.5% of the total fish collected in the Wabash Faunal Region and were initially included in the RIS.

The selection of RIS was also restricted to sites $\leq$15 mi.^{2} as this is the watershed size range of Robinson Creek that is within the thermal impact reach based on temperature monitoring and modeling. The fish assemblages of headwater streams like Robinson Creek are distinctive and lack certain species that are common in larger wadeable streams. Fish species that occurred in sufficient numbers only at sites with larger catchments (Lamotte Creek, lower Sugar Creek) were not included as “core” RIS. This excluded the two downstream sites in Sugar Creek (SC02 and SC03) and the Lamotte Creek (LC01) site. Species that are common in these larger catchments that were not included in the “core” RIS include shortnose gar, smallmouth buffalo, shorthead redhorse, black redhorse, white crappie, and spotted bass. Three of these species (smallmouth buffalo, white crappie, spotted bass) were retained as RIS in an alternate FTMS scenario as part of a sensitivity analysis. The two *Moxostoma* (redhorse) species are not well represented in small streams of the IEPA/IDNR Wabash Faunal Region dataset thus they were excluded from the Robinson Creek FTMS scenarios. However, the 86°F summer average screening threshold used in the initial analysis of monitored and modeled temperatures described earlier would be protective of these *Moxostoma* species.

Table 8 summarizes the results of the RIS selection process by examining the available fish data applicable to the ≤15 mi.^{2} reach of Robinson Creek. Species with sufficient thermal data in the thermal effects database (Appendix B) are indicated in Table 8 as well. The methodology allows for the inclusion of species that do not occur in the study area, but which are "representative" of the ecological and physiological requirements of RIS that lack thermal effects data. However, that criterion was not exercised as the species with thermal effects data are sufficiently representative of those RIS that lack such data. The final RIS list in Table 8 includes fewer species than the initial RIS list in the Early Screening demonstration because the ≤15 mi.^{2} restriction was not used in that process (Appendix A). The specific documentation of the extent of thermal alterations was simply not available at that time.

The RIS for Robinson Creek (Table 8) includes 25 species that meet the occurrence criteria previously described, i.e., sufficient numbers at sites ≤15 mi.^{2} among the IEPA/IDNR and MBI datasets – this is out of a total of 66 species in all of the Wabash Faunal Region databases. Sufficient temperature tolerance data was available for 21 of the 25 final RIS plus 3 non-RIS that were included in the alternate FTMS output scenario. No non-RIS proxy species with thermal effects data were included for the four (4) RIS that do not have thermal effects data available because the species in Table 8 with thermal effects data were deemed sufficiently representative (per RIS criterion 7). The three Non-RIS species with thermal effects data were not included as "core" RIS because they did not strictly meet the RIS selection criteria being found primarily in Wabash Faunal Region streams >15 mi.^{2}. However, they were retained for an alternate FTMS analysis because they occurred in lower Sugar Creek and sporadically occurred in Robinson Creek thus they were included in the alternate FTMS output scenario as part of a sensitivity analysis.

Selection of Thermal Tolerance Thresholds

Thermal parameters compiled from literature sources for 127 freshwater fish species, 3 hybrids, and 28 macroinvertebrate taxa are presently included in the primary thermal effects database of the FTMS (Appendix B; updated from Yoder et al. 2006 and Yoder 2012). This represents a substantial increase in the fish species included in the thermal effects database compared with the original Ohio EPA (1978) methodology that is the precursor of the current FTMS.

The thermal effects data used as the primary thermal tolerance inputs for the core and alternate FTMS scenarios are provided in Table 9. This includes an optimum temperature (either physiological or behavioral, laboratory or field derived), an upper avoidance temperature (UAT; field or laboratory derived), and an upper incipient lethal temperature (UILT; laboratory derived) at an appropriate acclimation temperature. For Robinson Creek acclimation temperatures of 77°F-80.6°F (25°-27°C) were used. Missing values were derived from seasonal average family level differences between one or more of the seven thermal tolerance endpoints recorded in Appendix B-1 for warmwater fish species (Appendix B-2). Table 9 also includes the primary literature reference for the thermal endpoints selected from Appendix B-1 that best represent the FTMS application. Geographical representativeness and having a relevant acclimation temperature are two of the most important considerations in selecting a thermal effect threshold from Appendix B-1.

Application of the FTMS to Robinson Creek

The thermal tolerance values for the RIS are the primary FTMS inputs used to derive true summer (mid-June through mid-September) average and maxima for two Robinson Creek FTMS scenarios as follows:

1) Using the core RIS applicable to the $\leq$15 mi.^{2} catchment of Robinson Creek; and
2) Adding three non-RIS species in Table 7 as part of an alternate FTMS output as part of a sensitivity analysis.

FTMS Output Methodology

The four thermal endpoints for each RIS in Table 9 were entered into the base FTMS MasterFile in Excel. The base FTMS MasterFile includes all of the possible fish species in the master thermal tolerance database in Appendix B. A ReadMe file (Appendix B-3) includes the specific instructions and steps to obtain an FTMS output for a given list of fish species. Following these steps the RIS for Robinson Creek were selected by adding an "x" in the select (SEL) column on the MasterFile and then using the Excel data sort function to produce a MasterFile specific to Robinson Creek. A routine in Visual Basic then calculates the four thermal endpoints for temperatures that are within 100%, 90%, 75%, and 50% of the short-term survival thresholds (i.e., the UILT) for all RIS as the first output. This was done separately for the "core" RIS and the "core" plus non-RIS scenarios.

FTMS Output Scenarios for Robinson Creek

An FTMS output scenario is the result of ranking the RIS for each of the four primary thermal tolerance values against the temperature at which an RIS tolerance value is exceeded. The FTMS produces a summary table of temperatures at which 100%, 90%, 75% and 50% of the RIS are within the four thermal effect categories. This output is used to determine what proportion of the RIS would be protected at a given set of true summer (June 16-September 15) average and maximum temperatures. A calculated value termed the long-term survival temperature is included in this output and it represents the protection of the RIS as a summer period average. It is calculated from the short-term survival temperature (i.e., the Upper Incipient Lethal Temperature (UILT)) for the most sensitive RIS as the UILT minus 3.6°F (2°C). The short-term survival temperature represents the daily maximum within the true summer period. The second output is a listing of each RIS for each of the four FTMS thermal endpoints (optimum, MWAT for growth, UAT, and UILT) in ascending order from most thermally sensitive to most thermally tolerant by the Celsius and Fahrenheit temperature at which an endpoint is exceeded. This provides for an evaluation of FTMS criteria 2-5 (below) for determining if true summer average and maximum temperatures are also reasonably protective for non-lethal effects for a particular RIS scenario. The following guidelines were recommended by Yoder (2008) to derive protective summer average and daily maximum temperature criteria.

Summer averages should be consistent with:

1) 100% long-term survival of all representative fish species;

2) growth of commercially or recreationally important fish species;
3) growth of at least 50% of the non-game fish species;
4) 100% long-term survival of all endangered fish species; and
5) the observed historical ambient temperature record.

Daily maxima should be consistent with:

6) 100% short-term survival of all representative fish species; and
7) the observed historical ambient temperature record.

Determination of the Potential for Adverse Effects from Elevated Temperatures in Robinson Creek

A 316(a) demonstration provides the opportunity to show that the current discharge of heat will not result in any appreciable adverse effects on the resident aquatic biota in Robinson Creek. Key to this demonstration is determining if the current temperature regime that exceeds certain of the water quality based effluent temperature limitations in MPC's current and proposed draft renewal permit applicable to the discharge of heat via the MPC 001 outfall downstream from the MPC 001 discharge poses an adverse risk to the recovery of Robinson Creek to eventually meet the IEPA General Use for aquatic life. The two principal technical components of the predictive demonstration are:

1) A thorough understanding and depiction of the seasonal thermal regime in Robinson Creek via both measured and modeled temperature; and,
2) Determining if the temperature regime documented in 1 above poses an adverse risk to Representative Important Species (RIS) based on predictive analyses.

The temperature regime has been documented via both continuously measured and modeled temperatures as discussed in the preceding sections. The determination of the potential for adverse effects to RIS is accomplished by producing an FTMS output and then evaluating it against the instream temperature regime.

Using FTMS Outputs to Evaluate Potential Adverse Effects

Determining adverse effects of temperature on fish emphasizes the true summer season (June 16-September 15) when ambient temperatures are high and flows are low resulting in the potential for adverse exposure for the most sensitive RIS. Evaluating such exposures includes the frequency and magnitude of high temperatures that exceed the short-term and long-term RIS survival thresholds. The FTMS produces daily maximum and season average temperatures that are protective of RIS under these dynamics. This can be used to set protective criteria and/or determine the risk for unacceptable effects on a site-specific or reach-specific basis.

The FTMS produces long and short-term survival thresholds that are the first choice for deriving the true summer season average and daily maximum protective temperatures (Yoder 2008). While the other summer average criteria listed above (2-5) can play a role in determining the summer season average, the long-term survival threshold is the primary choice for a summer period average. The true summer period is the period of greatest concern about potential adverse impacts thus it is the principal focus of this 316(a) demonstration. Non-summer season temperature criteria *are not* derived from the FTMS - the observed or predicted temperature regime is generally used to decide the non-summer season temperature criteria provided that seasonal cycles are not abrogated. This was accomplished herein by using the monitored and modeled temperatures outside of the June 16-September 15 periods.

FTMS "Core" RIS Scenario

The long and short-term survival temperatures for the 21 "core" RIS are 90.5°F (32.5°C) and 94.1°F (34.5°F) (Table 10), respectively, for 100% short and long term survival of the RIS. The long-term threshold meets the criteria for growth for only two of six recreationally important species (fails criteria number 2) and the upper avoidance temperature (UAT) of >50% of non-game species (Table 11). There are no rare, threatened, or endangered fish species in Robinson Creek or any of the other area streams so that FTMS criterion was not a consideration. The long and short-term thresholds for the core RIS scenario are higher than what we have determined in prior FTMS applications for larger streams and rivers and it exceeds the 86°F summer average value used initially in screening for potential long-term adverse effects. The restriction of the RIS to the ≤15 mi.^{2} catchments (i.e., the zone of thermal alteration in Robinson Creek) in the Wabash Faunal Region excludes more thermally sensitive fish species. As a result an alternate FTMS RIS scenario was developed as part of a sensitivity analysis.

FTMS Alternate RIS Scenario

The alternate FTMS scenario added three non-RIS that occur in the lower reaches of Sugar Creek, Lamotte Creek, and Wabash Faunal Region streams of >15-30+ mi.^{2}. Their addition to the RIS resulted in long and short-term survival temperatures for the 21 "core" RIS plus 3 non-RIS of 87.1°F (30.6°C) and 90.7°F (32.6°F)(Table 12) for 100% of the FTMS alternate RIS scenario. The long-term threshold meets the criteria for growth for seven of nine recreationally important species and the upper avoidance temperature (UAT) of 100% of the non-game species (Table 13). This scenario was included to serve as a sensitivity analysis and the results are more in line with prior FTMS applications and the 86°F screening value for initially evaluating potential long-term effects. As such we believe that this scenario more fairly represents the thermal sensitivity of the fish assemblage that could potentially exist in Robinson Creek with the successful abatement of non-thermal stressors.

Reconciling the FTMS Outputs with the Observed Temperature Regime

The natural thermal regime of Robinson Creek has been substantially altered by urban development, the Robinson WWTP effluent, riparian habitat modifications, and the discharge of heat via the MPC 001 outfall. This was especially evident during the non-summer period between mid-September and mid-June. Because fish are not adversely affected by temperatures that are elevated above ambient during non-summer periods, exceedances of the 5°F Δ effluent limitation and the 60°F maximum in particular are not a concern for adverse biological effects in Robinson Creek (see Discussion section, below). Exceedances of the 90°F April-November maximum during the true summer period are of greater concern because it is close to the upper lethal limit of tolerance for the most sensitive Robinson Creek RIS (alternate FTMS scenario). While this concern would exist during any time of the year, it is realistically only encountered immediately before, during, and immediately after what is defined herein as the true summer season of June 16-September 15.

The emphasis of the FTMS in producing both a true summer season average and a daily maximum temperature threshold is based on:

1) limiting the exposure of the RIS to comparatively brief and intermittent periods of temperatures that approach or exceed the short term survival temperature (which is the basis for the maximum criterion); and,
2) assuring that recovery periods with lower temperatures over sufficient durations also exist during the summer period.

This is consistent with the concept that an aquatic assemblage subjected to artificially elevated temperatures will be sustained under such an altered thermal regime provided there are sufficient intervening periods of lower temperatures that provide periods of relief from periods of short-term thermal stress (Bevelhimer and Bennet 2000; Bevelhimer and Coutant 2007; Figure 9). Including a true summer season average based on a long-term survival threshold assures this dynamic as opposed to having a maximum only. Once the protective summer season average and maximum thresholds are derived, the frequency and magnitude of exceedances of these thresholds then supports an assessment of whether or not that temperature regime *"will assure the protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife in and on that body of water."*

The temperature at which stress begins to occur for an aquatic organism is dependent on its acclimation experience. The "typical" seasonal acclimation process where winter and spring temperatures steadily increase to summer levels allows fish to adjust to and become tolerant of higher temperatures during the summer. However, there is a maximum temperature beyond which adverse effects will occur regardless of the acclimation experience and this aspect is considered when the thermal endpoints are selected for each RIS as the primary FTMS input variables. One aspect of stress accumulation about which comparatively little is known is the time required for stress recovery following an exposure to stressful temperatures. The temperature at which recovery occurs, the rate of recovery, and the length of time for full recovery are largely unknown (Bevelhimer and Bennet 2000). However, some reasonable conclusions about an observed or predicted series of thermal stress and stress recovery periods are possible.

Stress/Recovery Analysis of Robinson Creek Thermal Regime

In applying the stress/recovery concept to the evaluation of potential adverse impacts in Robinson Creek, the daily HOBO monitoring results immediately downstream from the MPC 001 outfall (RC05) between July 10 and September 15, 2016 and the modeled temperatures for June 16-September 15, 2012 and 2016 at RC05, RC07, and RC09 were evaluated. The duration and severity of thermal stress periods greater than the 90.7°F RIS short-term survival (or maximum criterion) and stress recovery periods less than the 87.1°F RIS long term survival (or summer average criterion) in hours were determined. The stress/recovery analysis results include the duration of each period of thermal stress and stress recovery separately for the 2016 HOBO data and the 2012 and 2016 EFDC modeled results plus the total number of events over the summer period (Table 14). Each thermal stress period is numbered with the event duration in hours, the maximum temperature observed or predicted, and with the subsequent stress recovery period receiving the same event number along with the duration in hours. In a few instances there were no subsequent stress recovery periods before the onset of another thermal stress period or there were multiple recovery periods the latter which were indicated as sub-event A and B.

The analysis of the 2016 HOBO results included the site immediately downstream from MPC 001 (RC05) only because there was either no or insufficient summer data at the downstream locations (RC07 and RC09). There were a total of eight thermal stress periods of 1.5 to 14.5 hours in duration for a total of 74.4 hours over the summer or 3.4% of the time. Each was followed by one or two stress recovery periods for a total of 779.3 hours or 36.1% of the time for a summer period recovery to stress ratio of 10.5:1. The highest maximum temperature of 92.3°F occurred on August 28. The first thermal stress period occurred on July 24 (9.5 hrs.) and was followed by three recovery periods ranging from 5.3 to 193 hours in duration each. The longest thermal stress period of 14.5 hours occurred on August 10 and was followed by a 12.2 hour stress period on August 12 and a shorter period on August 13 (1.5 hrs.). A stress recovery period initiated on August 13 and lasted for 302 hours (until August 26). The last two stress periods occurred on August 28 (9.5 hours) and August 30 (9.7 hours) and were followed by two recovery periods totaling nearly 183 hours beginning on August 31 and ending on September 7.

The EFDC modeling results included the RC05 site, the Illinois Rt. 1 site (RC07), and the Co. Rt. 1150E (RC09) site which were combined for this analysis. Altogether the EFDC model predicted eleven and six thermal stress periods in 2012 and 2016, respectively, the longest of 7.0 hours in duration on August 30, 2016. The total hours of thermal stress were 28 (1.3%) in 2012 (11 events) and 30 (1.4%) in 2016 (6 events). The 653 hours (30.2%) of stress recovery in 2012 were less than one-half of the 1340 hours (62.0%) in 2016 resulting in recovery to stress ratios of 23.3:1 and 44.7:1, respectively. The 2012 EFDC results tracked more closely with the 2016 HOBO results than did the 2016 EFDC results.

Key differences between measured and modeled results include about 2.5 times *fewer* predicted thermal stress hours, but *higher* maximum temperatures at RC07 of 94.7°F and 94.2°F on July 6 and July 18, 2012 and 94.7°F on June 25, 2016. The 94.2°F and 94.7°F values exceed the 3°F allowance over the RIS maximum of 90.7°F, but are the only two such instances in any dataset. These values also represent a downstream increase in predicted temperature compared to the MPC 001 effluent and the RC05 values on the same or immediately preceding dates. The predicted downstream increase in the EFDC modeled temperatures occurred with high solar insolation and high summer air temperatures that exceeded the MPC 001 effluent and RC05 instream temperatures. This was observed in only one brief instance with the 2016 measured ambient temperatures.

Discussion

Demonstration of No Adverse Impacts from Heat

The 2016 HOBO results at RC05 and the 2012 EFDC modeled results at RC07 were graphed (Figure 10) to visually illustrate the pattern of intra-seasonal temperature fluctuations similar to the Bevelhimer and Bennet (2000) thermal stress and recovery concept illustrated by Figure 9. The results of the stress/recovery analysis summarized in Table 14 show that any exceedances of the 90.7°F short-term survival threshold were brief and interspersed with much longer durations of stress recovery temperatures. To enhance their visualization, periods of thermal stress (i.e., temperatures approaching and exceeding 90.7°F) are indicated on both graphs by red ellipses and stress recovery (i.e., temperatures <87.1°F) periods by blue ellipses. Periods of thermal stress were generally followed by longer periods of stress recovery in both the monitored and modeled results.

The ratio of recovery to stress hours was 10.5:1 for the 2016 HOBO results and is sufficient to rule out any long term adverse effects to the fish assemblage and the balance of the aquatic biota in Robinson Creek under that thermal regime. As was stated previously, non-summer season temperatures downstream from MPC 001 are not of concern for adverse effects. This includes temperatures that exceed the December-March maximum of 60°F, 5°F Δ, the 3°F above maximum allowance, and the 1% frequency of exceedance in MPC's current effluent limitations. The change in temperatures throughout the seasonal cycle are sufficiently gradual to allow fish to acclimate to both rising and falling temperatures. Given a choice, fish will always prefer temperatures that are warmer when ambient temperatures typical of the non-summer season prevail.

Based on the determination of true summer season short and long-term protective thresholds and the analysis of the dynamics of the temperature regime downstream from the MPC 001 outfall in Robinson Creek, the current MPC 001 thermal discharge *alone* should not preclude recovery to meet the Illinois General Use targets for aquatic life. In other words, it meets the goal of Section 316(a) that the prevailing temperature regime *"will assure the protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife in and on that body of water*", *i.e.,* Robinson Creek.

Any exceedances of the FTMS short-term threshold of 90.7°F are brief and sufficiently offset by lower temperatures of sufficient magnitude and duration to provide for adequate recovery periods as defined by Bevelhimer and Bennet (2000). Further, brief exposures to critical temperatures are not necessarily harmful and recovery periods of as little as one hour are needed (Bevelhimer and Coutant 2007). Summer period averages were well below the FTMS long-term survival threshold and virtually 100% of the upper avoidance temperatures of the alternate scenario RIS. The MWAT for growth is exceeded for only two recreational species and this using a liberal interpretation of recreational (*e.g.,* including white sucker). Together, these analyses and observations support the conclusion that the current thermal regime is sufficiently protective of the RIS and the full assemblages by extension. As such, this satisfies the demonstration of the requested alternative thermal effluent limitation under Section 316(a).

Technical Evaluation of the 5°F Δ Provision

MPC's current 5°F Δ effluent limitation is deleted in the alternative thermal effluent limitations. The proposed summer maximum and averages are sufficient to preclude large swings in temperature that may be harmful. The Δ effluent limitation is based upon a 5°F Δ provision that is a "rule-of-thumb" that emanates from the FWPCA (1968) "Green Book" and National Academy of Sciences "Blue Book" (NAS 1973) with no supporting technical documentation about its ecological need or efficacy. States that have modernized their temperature criteria (e.g., Ohio, Pennsylvania, ORSANCO) have done so by adopting maximum and average criteria and dropping the Δ provisions altogether. ORSANCO in particular detailed the rationale for dropping the 5°F Δ provision in 1984:

> *"The majority of states have not revised or updated their temperature criteria since the publication of the "blue book" (NAS/NAE 1973), thus most retain what are now regarded by some as outdated concepts. An example is the concept of an allowable rise in temperature above ambient, such as the "5°F rise" that remains in most state WQS. Brown (1974) first raised the issue that this criterion had little if any biological justification – it was quite simply a "rule-of-thumb". In a memo from Charles C. Coutant to Stanley I. Auerbach, Oak Ridge National Laboratory, in response to a question posed by ORSANCO, Coutant concluded that the 5°F rise had no biological justification and should be dropped. This explains its absence from the current ORSANCO temperature criteria and from Ohio's WQS. These are two of the few states or entities that modernized their temperature criteria in the post "blue book" period. Coutant favored what ORSANCO adopted in 1984, fixed temperature values based on multiple tolerance endpoints for representative fish species that are seasonally varied to reflect normal ambient temperature changes. (Yoder et al. 2006)"*

Pennsylvania DEP (2009) offered the following rationale for dropping the 5°F Δ provision:

> *"Unlike the previous temperature criteria, which were single maximums applicable year-round, the revised criteria are monthly and semi-monthly values. They also eliminate the previous maximum allowable 5°F change in stream temperature, thereby eliminating the need to evaluate thermal effluent limits on this basis. Instead, the new criteria establish stream assimilative capacities for temperature based solely on the difference between the ambient temperature and the criterion temperature at the design stream flow." . . . and,*
>
> *"The previous requirement limiting temperature changes to a maximum of 5°F has been obviated by the seasonal nature of these criteria and has thus been dropped from regulation."*

Coutant (2015), commenting about the failure of states to adopt temperature criteria that reflect modern science, was especially critical of the 5°F Δ saying *" . . . some states are enforcing*

ΔT rules that make no scientific sense for the particular water body." In another literature review, Coutant et al. (2008) concluded:

> *"Review of the scientific literature provides little technical justification for a generally applicable limitation on rate of temperature change. Numerous studies have examined fish survival under daily fluctuations of different magnitudes and rates of change, with the general conclusion that the important factor in fish survival is the temperature extremes attained and whether they exceeded temperatures known to be lethal. Studies in which temperatures changed repeatedly for many days and at different rates within the thermal tolerance zone showed no detrimental effects and often indicated improved fish survival or growth. There is some evidence that the rate of temperature decline may be important for cold shock. Given the lack of a sound scientific foundation for a widely applicable limit on rate of temperature change, stakeholders may choose to take into account site-specific characteristics when setting standards. These may include physical size and thermal properties of the water body, the magnitude (volume) and variability of the thermal discharge, and the local aquatic species and human uses to be protected. By examining all of these aspects, it should be possible to determine the combinations of water body and thermal discharge characteristics that will adequately protect aquatic species and uses on a site-specific basis."*

The above indicate no scientific support for the 5°F Δ provision. At the same time, there is broad support in the current literature and by the examples of modernized WQS for the adoption of temperature requirements that incorporate stress/recovery concepts. Such criteria protect against extreme exposures to high temperatures while recognizing that occasional and short-term exceedances of stress thresholds can be offset by periods of thermal relief. This is achieved by adhering to maximum criteria accompanied by a period average during the summer months and with reasonable exceedance allowances of the maximum. Coutant et al. (2008) in particular emphasized doing this at the site-specific scale, which this demonstration using the FTMS methodology exemplifies.

Alternative Temperature Criteria

While the weaknesses of fixed maximum temperature criteria have been amply exposed, evaluating the ecological relevance of fixed temperature criteria exceedances has been a challenge for states and the regulated community alike. Setting the criteria too high to avoid the regulatory consequences of such exceedances can result in potentially adverse ecological consequences. Setting the criteria too low can result in exceedances that are ecologically meaningless (Essig 1998) and which can trigger unnecessary controls on heated discharges (as is the case with MPC 001). These issues must be considered together when deriving and applying ambient temperature criteria that have sufficient flexibility so as to avoid unwanted environmental or regulatory consequences. Contemporary research on thermal effects has focused on fluctuating temperature exposures in terms of chronic intermittent thermal stresses on aquatic life (Bevelhimer and Bennet 2000; Bevelhimer and Coutant 2007), the latter challenging a strict adherence on maximum criteria alone. The preferred alternative is to develop temperature criteria that allow for brief periods of high temperatures that are offset by subsequent periods of stress recovery when temperatures are well below the observed maximums. Including a summer period average along with protective exceedance of maximum allowances results in alternative temperature criteria that better reflect contemporary thermal stress/recovery concepts. The compilation of the temperature monitoring and modeling results combined with the outputs of the Fish Temperature Modeling System (FTMS) for Robinson Creek provide the essential information for predicting that the MPC 001 discharge presents no adverse risk to biological recovery to attain the Illinois General Use aquatic life use.

The proposed alternative thermal effluent limitations for the MPC 001 discharge to Robinson Creek consist of the following:

1) monthly maximum temperatures that reflect annual seasonal cycles (see values below);

2) a summer average criterion of 87°F that applies during June 16-September 15, along with a maximum; and,

3) exceedance allowances of 3°F over the maximum and one (1) percent as a cumulative annual limitation for such exceedances.

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
°F	65	65	74	82	88	90	90	90	90	87	85	74
°C	18.3	18.3	23.3	27.8	31.1	32.2	32.2	32.2	32.2	30.6	29.4	23.3

Although the FTMS methodology supports a summer maximum of 90.7°F and summer average of 87.1°F, MPC's proposed alternative thermal effluent limitations take a conservative approach by using the summer maximum of 90°F and the summer average of 87°F. The proposed alternative thermal effluent limitations for October through May are based upon Datasonde data, HOBO data, and modeling projections, and are consistent with the seasonal acclimation requirements of warmwater fish assemblages in Robinson Creek.

REFERENCES

Bevelheimer, M. and C.C. Coutant. 2007. Effects of Fluctuating Temperatures on Fish Health and Survival. Topical Rept. 1012545. Electric Power Research Institute, Palo Alto, CA. 78 pp. www.epri.com.

Bevelheimer, M. and W. Bennett. 2000. Assessing cumulative stress in fish during chronic intermittent exposure to high temperatures. Env. Science & Policy, 211-216.

Brown, H.W. 1974. Handbook of the effects of temperature on some North American fishes. American Electric Power Service Corporation. 431 pp.

Coutant, C.C. 2015. Are we there yet? Section 2, *in* C. Lew and R. Goldstein (eds.). Proceedings: The Fourth Thermal Ecology and Regulation Workshop. 3002008550 Final Report, April 2016. 498 pp. www.epri.com.

Coutant, C.C., S. McDougall, and J. Young. 2008. Establishing Alternative Numerical Limits for Rate of Temperature Change. Electric Power Research Institute (EPRI) 1016470, Palo Alto, CA. 24 pp. + appendices. www.epri.com.

Essig, D.A. 1998. The dilemma of applying uniform temperature criteria in a diverse environment: an issue analysis. Idaho Division of Environmental Quality, Water Quality Assessment and Standards Bureau, Boise, ID. 29 pp.

Federal Water Pollution Control Administration (FWPCA). 1968. Industrial waste guide on thermal pollution. U.S. Dept. Interior, Pacific Northwest Water Lab. Corvallis, Oregon. 112 pp.

Gammon, J. R. 1973. The effect of thermal inputs on the populations of fish and macroinvertebrates in the Wabash River, Tech. Rep. No. 32. Purdue University Water Resources Res. Center.

Illinois EPA. 2016. Illinois Integrated Water Quality Report and Section 303(d) List, 2014. Clean Water Act Sections 303(d), 305(b) and 314. Water Resource Assessment Information and List of Impaired Waters. Volume I: Surface Water. Bureau of Water, Springfield, IL. 109 pp.

Illinois EPA. 2011a. Standard Operating Procedure for Method to Collect Aquatic Macroinvertebrates from Wadeable Streams for Biotic Integrity Assessments. Surface Water Section. Document Control No. 168. IEPA BOW SOP002-00-1111. Revision No. 0. 8 pp.

Illinois EPA. 2011b. Methods Utilized to Determine the Types and Amounts of Pertinent Macroinvertebrate Habitats in Perennial Wadeable Streams for 20-Jab Allocation.

Surface Water Section. Document Control No. 177. IEPA BOW ID003-00-1111. Revision No. 0. 6 pp.

Illinois EPA. 2011c. Standard Operating Procedure for Sample Processing for the Macroinvertebrate Index of Biotic Integrity (mIBI). Surface Water Section. Document Control No. 167. IEPA BOW SOP001-00-1111. Revision No. 0. 14 pp.

Illinois EPA. 2011d. Macroinvertebrate Tolerance List and Functional Feeding Group Classification. Surface Water Section. Document Control No. 176. IEPA BOW ID002-00-1111. Revision No. 0. 75 pp.

Illinois EPA. 2011e. Genus-List: Macroinvertebrate-Index of Biotic Integrity (m-IBI) Tolerance List and Functional Feeding Group Classification. Surface Water Section. Document Control No. 178. IEPA BOW ID004-00-1111. Revision No. 0. 31 pp.

Midwest Biodiversity Institute (MBI). 2017. Biological and Water Quality Assessment of Robinson and Sugar Creek and Tributaries 2016. Crawford County, Illinois. Technical Report MBI/2017-3-2. Marathon Petroleum Corp., Illinois Refining Division. Columbus, OH 43221-0561. 73 pp. + appendices.

Midwest Biodiversity Institute (MBI). 2016. Biological, Habitat, and Water Quality Assessment Project Study Plan for Robinson Creek and Tributaries Crawford Co., Illinois. Marathon Petroleum Company LP, Illinois Refining Division. 10 pp. + appendices.

National Academy of Sciences (NAS). 1973. Water quality criteria 1972. A report to the committee on water quality criteria. U.S. EPA Pub. No. EPA-R3-73-033. Washington, D.C., 553 pp.

Ohio Environmental Protection Agency. 1978. Methods and rationale used for establishing seasonal average and daily maximum temperature limitations as proposed in OAC 3745-1. Office of Wastewater Pollution Control, Division of Industrial Wastewater, Columbus, OH. 48 pp. + appendices.

Pennsylvania Department of Environmental Protection. 2009. Implementation Guidance for Temperature Criteria. Doc. 391-2000-017. Volume 29, Tab 13. Bureau of Water Standards and Facility Regulation, Harrisburg. PA. 20 pp.

Shasteen, D.K., S. A. Bales, A. L. Price. 2012. Freshwater mussels of the Embarras River basin and minor Wabash tributaries in Illinois. Illinois Natural History Survey, 1816 South Oak Street, Champaign, IL 61820, NHS Technical Report 2012 (30).

TetraTech, Inc. 2017. Final Hydrodynamic Temperature and Modeling Report for Robinson Creek, Illinois. Tetra Tech, Inc., Atlanta, GA. 68 pp.

U.S. EPA. 2013. Aquatic Life Ambient Water Quality Criteria for Ammonia – Freshwater 2013. EPA 822-R-13-001. Office of Water, Washington, D.C. 242 pp.

U.S. EPA. 1977. Interagency 316(a) technical guidance manual and guide for thermal effects sections of nuclear facilities environmental impact statements. Office of Water Enforcement, Permits Division, Industrial Permits Branch. 147 pp.

Yoder, C.O. 2012. Development of a Database for Upper Thermal Tolerances for New England Freshwater Fish Species. MBI Technical Report MBI/2012-4-6. Connecticut Watershed Council, Greenfield, MA. 15 pp. + appendices.

Yoder, C.O. 2008. Challenges with modernizing a temperature criteria derivation methodology: the fish temperature modeling system, pp. 1-1 to 1-19. *in* Robert Goldstein and Christine Lew (eds.). Proceedings of the Second Thermal Ecology and Regulation Workshop, Electric Power Research Institute, Palo Alto, CA.

Yoder, C.O., E.T. Rankin, and B.J. Armitage. 2006. "Re-evaluation of the technical justification for existing Ohio River mainstem temperature criteria." Report to Ohio River Valley Water Sanitation Commission. Tech. Rept. MBI/05-05-2. Columbus, OH. 56 pp. + 4 appendices.

Yoder, C.O. and E.T. Rankin. 2006. Temperature Criteria Options for the Lower Des Plaines River. Final Report to U.S. EPA, Region V and Illinois EPA. Center for Applied Bioassessment and Biocriteria, Midwest Biodiversity Institute, Columbus, OH. EPA Grant X-97580701. 87 pp.

Tables and Figures Presented in Order of Mention in Preceding Text

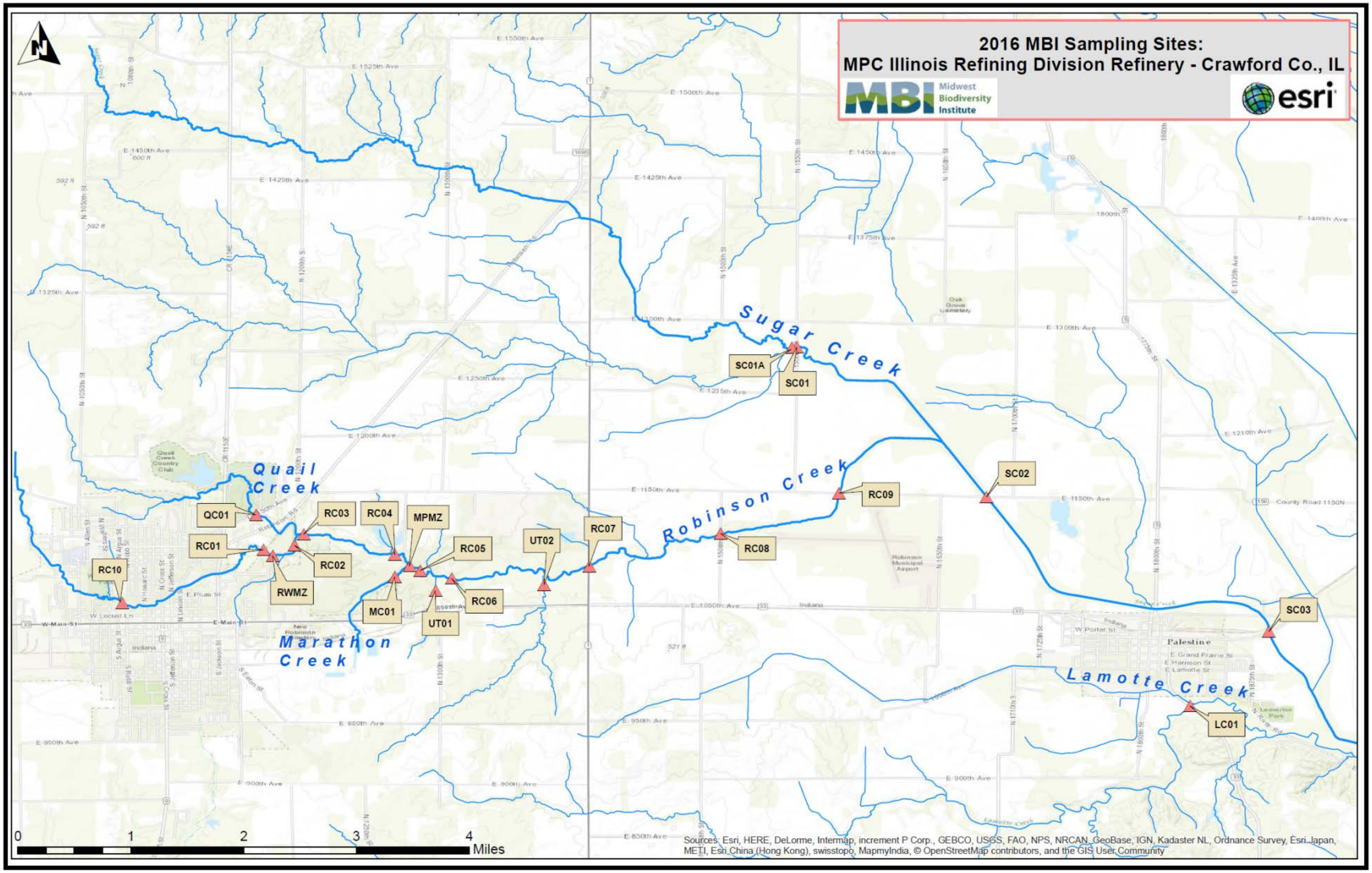


Figure 1. *Map of sampling locations for the Robinson Creek study area, 2016. Site codes correspond to Table 1 (from the MPC Study Plan (MPC 2016)).*

***Table 1**. Master list of sampling sites, biological and habitat indicators, and chemical parameters for the Robinson and Sugar Creek biological and water quality survey in 2016. Sites assessed by IEPA in prior Facility Related Stream Surveys (FRSS) are provided for reference.*

MPC Site ID	FRSS ID	River_Stream Name	RM	Latitude	Longitude	Location-Description	Drain. Area	Fish Type	EF Gear	Macroinvertebrates	Mussels	Habitat	Datasonde	Field WQ	Demand	Nutrients	Metals	Organics	Sed. Metals & Organics
RC10		Robinson Creek	7.9	39.008300	-87.744620	Praire Street near Meserve Cabin	1.40	F	F			QHEI		1X					
QC01	BFCB	Quail Creek	0.50	39.019625	-87.727450	Ust. confl. with Robinson Creek	2.29	F	F	IEPA MH	INHS TP	QHEI		8X	6X	6X	6X	6X	1X
RC01	BFC-20	Robinson Creek	6.50	39.015168	-87.726464	RR bridge 0.1 mi. ust. Robinson WWTP	2.59	F	E	IEPA MH	INHS TP	QHEI	S	8X	6X	6X	6X	6X	1X
RWMZ	BFC-RB-EI	Robinson Creek	6.45	39.014383	-87.725301	Robinson WWTP mixing zone	3.24	E (MZ)	E	MZ		QHEI (MZ)		8X	6X	6X	6X	6X	
RC02		Robinson Creek	6.25	39.015714	-87.722492	0.2 mi. dst. Robinson WWTP	3.27	E	E	IEPA MH	INHS TP	QHEI	S	8X	6X	6X	6X	6X	1X
RC03	BFC-19	Robinson Creek	6.00	39.017105	-87.721340	Dst. Quail Cr. confl.; 0.4 mi dst. Robinson WWTP	5.73	E	E	IEPA MH	INHS TP	QHEI	S	8X	6X	6X	6X	6X	1X
RC04	BFC-25	Robinson Creek	5.20	39.014534	-87.709609	Farm access road ust. MPC 001 outfall	6.51	E	E	IEPA MH	INHS TP	QHEI	W,S	8X	6X	6X	6X	6X	1X
MPMZ	BFC-MR-EI	Robinson Creek	5.00	39.013060	-87.707780	MPC 001 outfall mixing zone	6.53	E (MZ)	E	MZ		QHEI (MZ)		8X	6X	6X	6X	6X	
MC01	BFCA-22	Marathon Creek	0.16	39.011665	-87.709664	Farm access - MPC 002, 003, 005, 008; Ill. Rain CII	1.24	F	E	IEPA MH	INHS TP	QHEI	S	8X	6X	6X	6X	6X	1X
RC05	BFC-26	Robinson Creek	4.90	39.012500	-87.706390	0.1 mi. dst. MPC 001 (outside mixing zone)	7.94	E	E	IEPA MH	INHS TP	QHEI	W,S	8X	6X	6X	6X	6X	1X
UT01		U.T. Robinson Creek[1]	0.10	39.009917	-87.704437	MPC 006 tributary	0.33	F	F	IEPA MH	INHS TP	QHEI	S	4X	2X	2X	2X	2X	1X
RC06		Robinson Creek	4.60	39.011488	-87.702346	Dst. 006 trib.; 0.4 mi. dst. MPC 001	8.39	E	E	IEPA MH	INHS TP	QHEI	S	8X	6X	6X	6X	6X	1X
UT02		U.T. Robinson Creek[1]	0.10	39.010649	-87.690496	MPC RR yard trib. - 007, 009, 010 outfalls	1.47	F	F	IEPA MH	INHS TP	QHEI	S	4X	2X	2X	2X	2X	1X
RC07	BFC-11	Robinson Creek	3.30	39.013038	-87.684726	IL Rt 1 - 1.7 mi. dst. MPC 001	10.4	D,E	E	IEPA MH	INHS TP	QHEI	W,S	8X	6X	6X	6X	6X	1X
RC08		Robinson Creek	2.00	39.017250	-87.667852	1500 N - 3.0 mi. dst. MPC 001	12.3	D,E	E	IEPA MH	INHS TP	QHEI	S	8X	6X	6X	6X	6X	1X
RC09	BFC-10	Robinson Creek	1.00	39.022390	-87.652680	1150 E - 4.0 mi. dst. MPC 001	13.0	D,E	E	IEPA MH	INHS TP	QHEI	W,S	8X	6X	6X	6X	6X	1X
SC01A		Sugar Creek	6.00	39.041060	-87.658730	Ust. U.T. confluence	14.1	F	F	IEPA MH	INHS TP	QHEI		2X					
SC01B	BF-22	Sugar Creek	5.90	39.041110	-87.658060	1550 N - background site	14.2	E	E	IEPA MH	QL	QHEI	W,S	8X	6X	6X	6X	6X	1X
SC02	BF-11	Sugar Creek	4.10	39.021902	-87.633767	1150 E - 0.5 mi. dst. Robinson Creek	30.7	D,E	D	IEPA MH	INHS TP	QHEI	S	8X	6X	6X	6X	6X	1X
SC03	BF-01	Sugar Creek	1.60	39.004657	-87.597527	Palestine - E. Franklin Street - dst. RR yard	35.1	D,E	D	IEPA MH	INHS TP	QHEI	S	8X	6X	6X	6X	6X	1X
LC01	BFB-13	Lamotte Creek	1.90	38.995150	-87.607661	IL Rt 33 - S of Palestine - background site	26.7	E	D	IEPA MH	INHS TP	QHEI	S	8X	6X	6X	6X	6X	1X
							Totals	**17**	17	17	15	17	16	144	110	110	110	110	17

1 - contingent on having sufficient water to sample biota.

Key to Graph Labels
1 - Robinson WWTP
2 - MPC 001
A - Quail Creek
B - Marathon Creek (MPC 002, 003, 005, 008; Illinois Rain CII)
C - Unnamed tributary #1 (MPC 006)
D - Unnamed tributary #2 (MPC 007, 009, 010)
E - Lamotte Creek

Fish Sampling Codes:
D - Roller barge - 200 meters
E - Longline - 150 meters
F - Backpack - 100-125 meters; Wisconsin
MZ - mixing zone site - 50 meters
EF Gear - 2.5 GPP (2500 W)
EF Gear - 5.0 GPP (5000 W)

Macroinvertebrates:
MH - IEPA multihabitat method
MZ - Mixing zone sample

Mussels:
INHS TP - INHS Timed Protocol
QL - qualitative search

Datasonde:
S - summer deployment (5 Sondes/week over 6 total weeks)
W - winter deployment (4X January 25 - March 31)

Field WQ:
Temperature, D.O., Conductivity, pH
2X collected by fish crew
6X collected by chemical crew
All water and sediment samples collected by chemical crew mid-June to mid-October

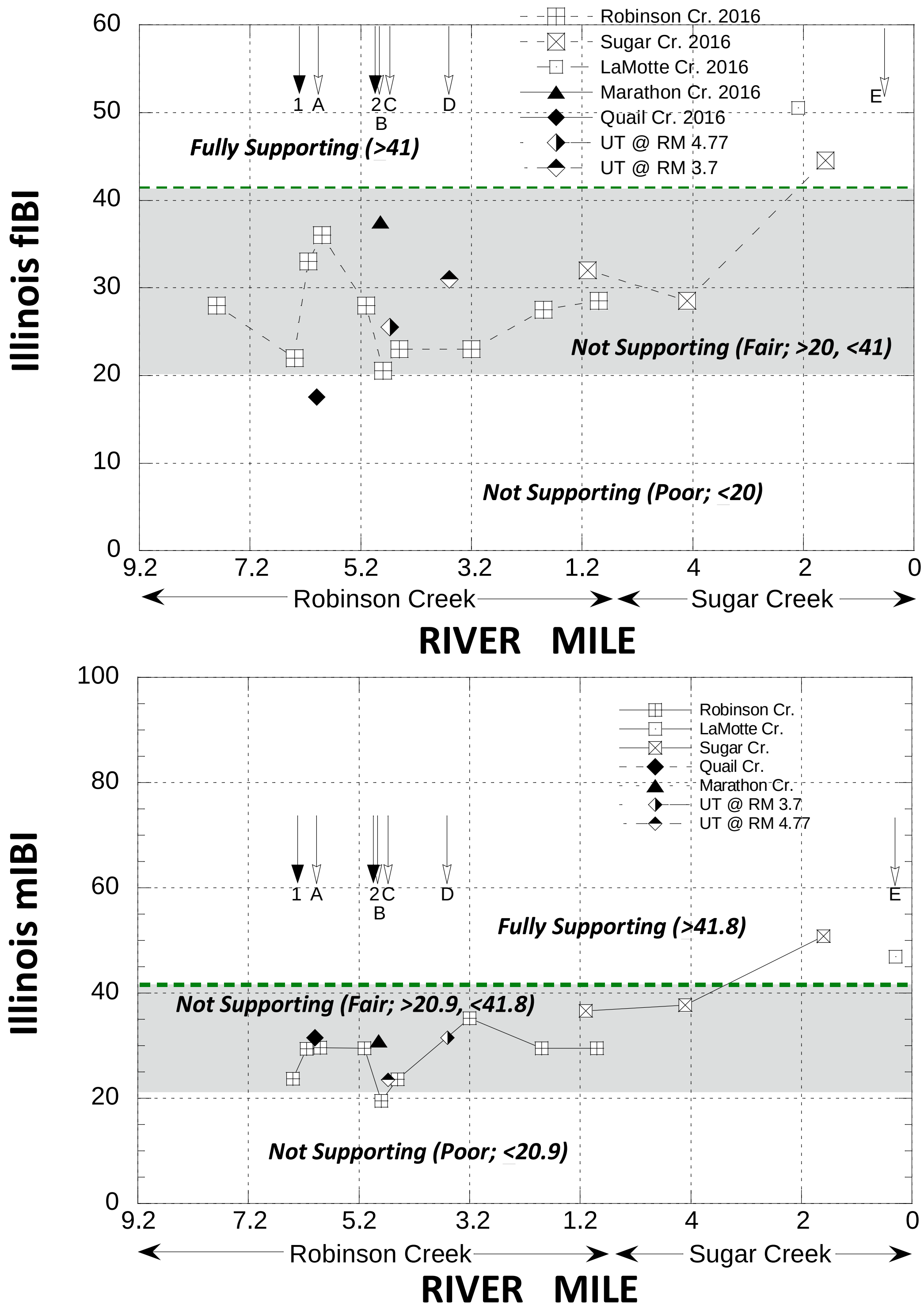


***Figure 2**. Illinois fish Index of Biotic Integrity (IBI) scores (mean of two samples) at 19 sites sampled in 2016 (upper) and macroinvertebrate mIBI scores at 17 sites sampled in 2016 (lower). Sites are arranged so that Robinson Creek and Sugar Creek are on a longitudinal continuum. The solid arrows are the Robinson WWTP (1) and MPC 001 (2) outfalls. Tributary sites are positioned at their confluences with Robinson and Sugar Creeks (open arrows and letters – see Table 1 for legend). IEPA (2016) boundaries for General Use full support and non-support are indicated.*

***Table 2**. Summary of temperature results from Datasonde continuous monitor deployments over 3-4 day periods once each month in 2016 at four sites in Robinson Creek (RC05, RC05, RC07, RC09) and one site in Sugar Creek (SC01). The number of observations and frequency of exceedance of IEPA maximum temperature criteria, 95th percentile and maximum temperatures, exceedances of the 3°F over the maximum allowance, the 5°F rise, and >86°F are provided (April-November exceedances are red shaded; December-March exceedances are blue shaded).*

Month	N	Maximum Temperature Criteria						5°F Rise Criterion				% Summer >86°F (6-16 to 9-15)	Mean Summer °F (6-16 to 9-15)
		Number >Max. Criterion	% >Max. Criterion	Mean of Values >Max. Criterion	95th %ile Temp.	Max. Temp.	Number >Never Exceed Max. by 3°F	Number >5°F Above Control	% >5°F Above Control	Min. °F > Control	Max. °F > Control		
RC04 – Robinson Creek Upstream MPC 001 Outfall (Control Site)													
JAN	471	0	0	0	43.0	43.7	0	0	0	0	0		
FEB	605	0	0	0	50.7	51.0	0	0	0	0	0		
MAR (early)	284	12	4.2	60.1	59.9	60.2	0	0	0	0	0		
MAR (late)	375	57	15.2	60.8	60.8	62.0	0	0	0	0	0		
MAY	426	0	0	0	62.8	63.2	0	0	0	0	0		
JUN	431	0	0	0	80.6	82.4	0	0	0	0	0	0%	75.5°F
JUL	424	0	0	0	79.8	81.1	0	0	0	0	0		
AUG	385	0	0	0	79.6	79.8	0	0	0	0	0		
SEP	470	0	0	0	74.8	75.5	0	0	0	0	0		
OCT	879	0	0	0	65.4	66.7	0	0	0	0	0	Exceedance of Max. = 1.1% (Dec.-Mar. 3.2%) (Apr.-Nov. 0%)	
NOV	456	0	0	0	56.9	58.3	0	0	0	0	0		
DEC	451	0	0	0	44. 6	45.1	0	0	0	0	0		
DEC-MAR	2186	69	3.2	60.7	59.2	62.0	0	0	0	0	0		
APR-NOV	3846	0	0	0	79.0	82.4	0	0	0	0	0		

***Table 2**. Summary of temperature results from Datasonde continuous monitor deployments over 3-4 day periods once each month in 2016 at four sites in Robinson Creek (RC05, RC05, RC07, RC09) and one site in Sugar Creek (SC01). The number of observations and frequency of exceedance of IEPA maximum temperature criteria, 95th percentile and maximum temperatures, exceedances of the 3°F over the maximum allowance, the 5°F rise, and >86°F are provided (April-November exceedances are red shaded; December-March exceedances are blue shaded).*

Month	N	Maximum Temperature Criteria						5°F Rise Criterion				% Summer >86°F (6-16 to 9-15)	Mean Summer °F (6-16 to 9-15)
		Number >Max. Criterion	% >Max. Criterion	Mean of Values >Max. Criterion	95th %ile Temp.	Max. Temp.	Number >Never Exceed Max. by 3°F	Number >5°F Above Control	% >5°F Above Control	Min. °F > Control	Max. °F > Control		
RC05 – Robinson Creek Immediately Dst. MPC 001													
JAN	470	4	0.8	60.1	59.8	60.1	0	470	100.0	8.2	22.3		
FEB	607	234	38.6	62.8	64.3	64.9	122	457	75.3	5.2	20.4		
MAR (early)	284	284	98.9	64.3	68.4	68.7	176	254	89.4	5.3	13.7		
MAR (late)	375	155	4.1	61.5	63.4	63.9	33	138	36.8	5.0	9.1		
MAY	426	0	0	0	69.5	69.8	0	403	94.6	5.0	12.0		
JUN	430	30	7.0	90.2	90.1	90.6	0	405	94.2	5.1	17.9	46.5%	85.8°F
JUL	424	22	5.2	90.4	90.1	90.7	0	329	77.6	5.0	13.7		
AUG	380	134	35.3	90.8	91.5	92.0	0	380	100	7.0	16.8		
SEP	474	0	0	0	86.0	87.2	0	472	100	6.0	16.3		
OCT	872	0	0	0	78.5	79.2	0	860	98.6	5.0	19.2	Exceedance of Max. = 14.2% (Dec.-Mar. 30.8%) (Apr.-Nov. 4.8%)	
NOV	458	0	0	0	71.5	72.9	0	434	95.2	5.2	21.5		
DEC	452	0	0	0	59.4	59.8	0	452	100.0	10.4	23.4		
DEC-MAR	2189	675	30.8	63.1	64.5	68.7	331	1771	80.9	5.0	23.4		
APR-NOV	3840	186	4.8	90.7	89.6	92.0	0	3421	89.1	5.0	21.5		

***Table 2**. Summary of temperature results from Datasonde continuous monitor deployments over 3-4 day periods once each month in 2016 at four sites in Robinson Creek (RC05, RC05, RC07, RC09) and one site in Sugar Creek (SC01). The number of observations and frequency of exceedance of IEPA maximum temperature criteria, 95th percentile and maximum temperatures, exceedances of the 3°F over the maximum allowance, the 5°F rise, and >86°F are provided (April-November exceedances are red shaded; December-March exceedances are blue shaded).*

Month	N	Maximum Temperature Criteria						5°F Rise Criterion				% Summer >86°F (6-16 to 9-15)	Mean Summer °F (6-16 to 9-15)
		Number >Max. Criterion	% >Max. Criterion	Mean of Values >Max. Criterion	95th %ile Temp.	Max. Temp.	Number >Never Exceed Max. by 3°F	Number >5°F Above Control	% >5°F Above Control	Min. °F > Control	Max. °F > Control		
RC07 – Robinson Creek @IL Route 1 - 1.7 mi. Dst. MPC 001													
JAN	469	0	0	0	53.4	54.1	0	469	100	9.1	12.9		
FEB	606	36	5.9	60.7	60.2	61.5	0	274	45.2	5.0	12.1		
MAR (early)	279	174	62.4	62.8	65.7	66.1	67	277	99.3	5.1	12.1		
MAR (late)	0	*Datasonde deployed – no data recorded due to unit failure*											
MAY	419	0	0	0	67.8	68.2	0	276	65.9	5.0	8.0		
JUN	426	30	6.9	91.0	90.7	91.6	0	413	96.9	5.0	10.0	20.8%	82.9°F
JUL	414	0	0	0	87.9	88.8	0	242	58.5	5.0	9.7		
AUG	316	18	5.7	90.7	90.2	91.0	0	313	99.1	5.0	13.3		
SEP	279	0	0	0	76.2	76.3	0	254	91.0	5.0	7.7		
OCT	863	0	0	0	71.4	71.7	0	660	76.5	5.0	8.4	Exceedance of Max. = 5.2% (Dec.-Mar. 11.6%) (Apr.-Nov. 1.5%)	
NOV	456	0	0	0	63.9	64.1	0	217	47.6	5.0	7.8		
DEC	454	0	0	0	48.2	48.6	0	128	28.2	5.0	9.5		
DEC-MAR	1814	210	11.6	62.5	62.9	66.1	67	1148	63.3	5.0	12.9		
APR-NOV	3195	48	1.5	90.9	86.8	91.6	0	2375	74.3	5.0	13.3		

***Table 2**. Summary of temperature results from Datasonde continuous monitor deployments over 3-4 day periods once each month in 2016 at four sites in Robinson Creek (RC05, RC05, RC07, RC09) and one site in Sugar Creek (SC01). The number of observations and frequency of exceedance of IEPA maximum temperature criteria, 95th percentile and maximum temperatures, exceedances of the 3°F over the maximum allowance, the 5°F rise, and >86°F are provided (April-November exceedances are red shaded; December-March exceedances are blue shaded).*

Month	N	Maximum Temperature Criteria						5°F Rise Criterion				% Summer >86°F (6-16 to 9-15)	Mean Summer °F (6-16 to 9-15)
		Number >Max. Criterion	% >Max. Criterion	Mean of Values >Max. Criterion	95^{th} %ile Temp.	Max. Temp.	Number >Never Exceed Max. by 3°F	Number >5°F Above Control	% >5°F Above Control	Min. °F > Control	Max. °F > Control		
RC09 – Robinson Creek @Co. Rt. 1150 E - 4.0 mi. Dst. MPC 001													
JAN	464	0	0	0	47.9	49.3	0	381	82.1	5.0	8.1		
FEB	602	0	0	0	55.2	55.7	0	195	32.4	5.0	8.7		
MAR (early)	280	89	31.8	61.9	63.0	63.1	13	55	19.6	5.0	8.7		
MAR (late)	375	61	16.3	60.9	61.2	61.8	0	5	1.3	5.0	9.0		
MAY	421	0	0	0	65.6	66.4	0	8	1.9	5.1	5.8		
JUN	422	0	0	0	85.8	86.3	0	63	14.9	5.0	7.3	2.9%	79.2°F
JUL	423	0	0	0	84.6	86.3	0	20	4.7	5.1	5.8		
AUG	374	0	0	0	86.0	86.9	0	135	36.1	5.0	8.8		
SEP	474	0	0	0	78.4	79.5	0	0	0	0	0		
OCT	851	0	0	0	68.1	68.7	0	0	0	0	0	Exceedance of Max. = 2.5% (Dec.-Mar. 6.8%) (Apr.-Nov. 0%)	
NOV	454	0	0	0	57.0	59.1	0	0	0	0	0		
DEC	455	0	0	0	45.3	45.5	0	0	0	0	0		
DEC-MAR	2180	150	6.8	61.5	60.8	63.1	13	636	15.3	5.0	9.0		
APR-NOV	3814	0	0	0	82.7	86.8	0	231	6.1	5.0	8.8		

***Table 2**. Summary of temperature results from Datasonde continuous monitor deployments over 3-4 day periods once each month in 2016 at four sites in Robinson Creek (RC05, RC05, RC07, RC09) and one site in Sugar Creek (SC01). The number of observations and frequency of exceedance of IEPA maximum temperature criteria, 95th percentile and maximum temperatures, exceedances of the 3°F over the maximum allowance, the 5°F rise, and >86°F are provided (April-November exceedances are red shaded; December-March exceedances are blue shaded).*

Month	N	Maximum Temperature Criteria						5°F Rise Criterion				% Summer >86°F (6-16 to 9-15)	Mean Summer °F (6-16 to 9-15)
		Number >Max. Criterion	% >Max. Criterion	Mean of Values >Max. Criterion	95th %ile Temp.	Max. Temp.	Number >Never Exceed Max. by 3°F	Number >5°F Above Control	% >5°F Above Control	Min. °F > Control	Max. °F > Control		
SC01 – Sugar Creek @Co. Rt. 1150N - Background Site													
JAN	468	0	0	0	36.4	37.9	0	0	0	0	0		
FEB	604	0	0	0	46.0	46.4	0	0	0	0	0		
MAR (early)	282	0	0	0	56.7	56.9	0	0	0	0	0		
MAR (late)	375	0	0	0	57.7	58.5	0	0	0	0	0		
MAY	423	0	0	0	59.8	60.4	0	0	0	0	0		
JUN	429	0	0	0	78.6	79.2	0	0	0	0	0	0%	74.7°F
JUL	165	0	0	0	78.9	80.6	0	0	0	0	0		
AUG	312	0	0	0	78.2	78.4	0	0	0	0	0		
SEP	289	0	0	0	64.9	65.0	0	0	0	0	0		
OCT	854	0	0	0	62.8	64.0	0	0	0	0	0	Exceedance of Maximums = 0% (all time periods)	
NOV	461	0	0	0	46.4	47.4	0	0	0	0	0		
DEC	458	0	0	0	39.4	39.8	0	0	0	0	0		
DEC-MAR	2187	0	0	0	55.9	58.5	0	0	0	0	0		
APR-NOV	3308	0	0	0	77.8	80.7	0	0	0	0	0		

***Table 3**. Summary of temperature results from HOBO continuous monitor deployments in 2016 at three sites in Robinson Creek (RCO4, RC05, RC09). The number of observations and frequency of exceedance of IEPA maximum temperature criteria, 95th percentile and maximum temperatures, exceedances of the 3°F over the maximum allowance, the 5°F rise, and >86°F are provided (April-November exceedances are red shaded; December-March exceedances are blue shaded).*

Month	N	Maximum Temperature Criteria						5°F Rise Criterion				% Summer >86°F (6-16 to 9-15)	Mean Summer °F (6-16 to 9-15)
		Number >Max. Criterion	% >Max. Criterion	Mean of Values >Max. Criterion	95th %ile Temp.	Max. Temp.	Number >Never Exceed Max. by 3°F	Number >5°F Above Control	% >5°F Above Control	Min. °F > Control	Max. °F > Control		
RC04 – Robinson Creek Upstream MPC 001 Outfall (Control Site)													
NOV-15	7572	0	0	0	63.0	66.4	0	0	0	0	0		
DEC-15	7969	128	1.6	60.8	58.8	61.2	0	0	0	0	0		
JAN-16	1308	0	0	0	43.8	44.0	0	0	0	0	0		
JUL-16	2639	0	0	0	81.0	83.8	0	0	0	0	0	0	75.8
AUG-16	4446	0	0	0	80.3	80.3	0	0	0	0	0		
SEP-16	4304	0	0	0	77.3	73.0	0	0	0	0	0		
OCT-16	4459	0	0	0	70.6	68.7	0	0	0	0	0	Exceedance of Max. (2016-17) = 0% (Dec.-Feb. 0%) (Jul.-Nov. 0%)	
NOV-16	4315	0	0	0	65.9	68.7	0	0	0	0	0		
JUL-NOV	20163	0	0	0	79.3	83.8	0	0	0	0	0		
DEC-16	4446	0	0	0	48.7	50.0	0	0	0	0	0		
JAN-17	4464	0	0	0	50.1	53.5	0	0	0	0	0		
FEB-17	2068	0	0	0	53.0	54.4	0	0	0	0	0		
DEC-FEB	10978	0	0	0	50.9	54.4	0	0	0	0	0		

***Table 3**. Summary of temperature results from HOBO continuous monitor deployments in 2016 at three sites in Robinson Creek (RCO4, RC05, RC09). The number of observations and frequency of exceedance of IEPA maximum temperature criteria, 95th percentile and maximum temperatures, exceedances of the 3°F over the maximum allowance, the 5°F rise, and >86°F are provided (April-November exceedances are red shaded; December-March exceedances are blue shaded).*

Month	N	Maximum Temperature Criteria						5°F Rise Criterion				% Summer >86°F (6-16 to 9-15)	Mean Summer °F (6-16 to 9-15)
		Number >Max. Criterion	% >Max. Criterion	Mean of Values >Max. Criterion	95th %ile Temp.	Max. Temp.	Number >Never Exceed Max. by 3°F	Number >5°F Above Control	% >5°F Above Control	Min. °F > Control	Max. °F > Control		
RC05 – Robinson Creek Immediately Dst. MPC 001 Outfall													
JUL-16	2639	135	5.1	90.8	90.0	92.3	0	2446	92.7	5.0	15.6		
AUG-16	4446	426	9.6	90.8	90.8	92.3	0	3474	78.1	5.0	15.7	36.4%	84.7°F
SEP-16	4304	0	0	0	86.7	88.0	0	3863	89.8	5.0	18.1		
OCT-16	4459	0	0	0	78.6	80.4	0	3461	77.6	5.0	18.3		
NOV-16	4315	0	0	0	76.2	80.2	0	3460	80.2	5.0	22.5		
JUL-NOV	20163	561	2.8	90.8	89.0	92.3	0	16704	82.9	5.0	22.5	Exceedance of Max. (2016-17) = 2.1% (Dec.-Feb. 1.1%) (Jul.-Nov. 2.8%)	
DEC-16	4446	44	1.0	61.1	56.9	62.1	0	2489	56.0	5.0	16.3		
JAN-17	4464	0	0	0	52.9	56.4	0	912	20.4	5.0	20.3		
FEB-17	2068	80	3.9	61.3	59.4	62.7	0	806	39.0	5.0	20.1		
DEC-FEB	10978	124	1.1	61.3	56.1	62.7	0	4207	38.3	5.0	20.3		

***Table 3**. Summary of temperature results from HOBO continuous monitor deployments in 2016 at three sites in Robinson Creek (RCO4, RC05, RC09). The number of observations and frequency of exceedance of IEPA maximum temperature criteria, 95th percentile and maximum temperatures, exceedances of the 3°F over the maximum allowance, the 5°F rise, and >86°F are provided (April-November exceedances are red shaded; December-March exceedances are blue shaded).*

Month	N	Maximum Temperature Criteria						5°F Rise Criterion				% Summer >86°F (6-16 to 9-15)	Mean Summer °F (6-16 to 9-15)
		Number >Max. Criterion	% >Max. Criterion	Mean of Values >Max. Criterion	95th %ile Temp.	Max. Temp.	Number >Never Exceed Max. by 3°F	Number >5°F Above Control	% >5°F Above Control	Min. °F > Control	Max. °F > Control		
RC09 – Robinson Creek @Co. Rt. 1150 E - 4.0 mi. Dst. MPC 001													
NOV-15	7572	0	0	0	65.9	68.8	0	270	3.6	5.0	5.8		
DEC-15	7969	885	11.1	61.9	62.2	64.5	230	158	2.0	5.0	5.5		
JAN-16	1308	0	0	0	46.7	47.2	0	77	81.5	5.0	5.6		
JUL-16	*No Data Collected*											NA (no June-Sept.)	NA (no June-Sept.)
AUG-16	*No Data Collected*												
SEP-16	2385	0	0	0	80.1	82.6	0	104	4.5	5.0	6.3		
OCT-16	4459	0	0	0	72.8	77.0	0	11	0.2	5.0	7.4		
NOV-16	4315	0	0	0	67.8	70.4	0	3	0.1	5.0	7.0		
JUL-NOV	11159	0	0	0	77.3	82.6	0	118	1.1	5.0	7.4		
DEC-17	4446	0	0	0	50.3	52.3	0	54	1.2	5.0	6.0	Exceedance of Max. (2016-17) = 0% (Jul.-Nov. = 0%) (Nov.-Feb. = 0%)	
JAN-17	4464	0	0	0	52.2	54.7	0	30	0.8	5.0	7.6		
FEB-17	2068	0	0	0	54.5	56.1	0	0	0	0	0		
DEC-MAR	10978	0	0	0	52.2	56.1	0	90	0.8	5.0	7.6		

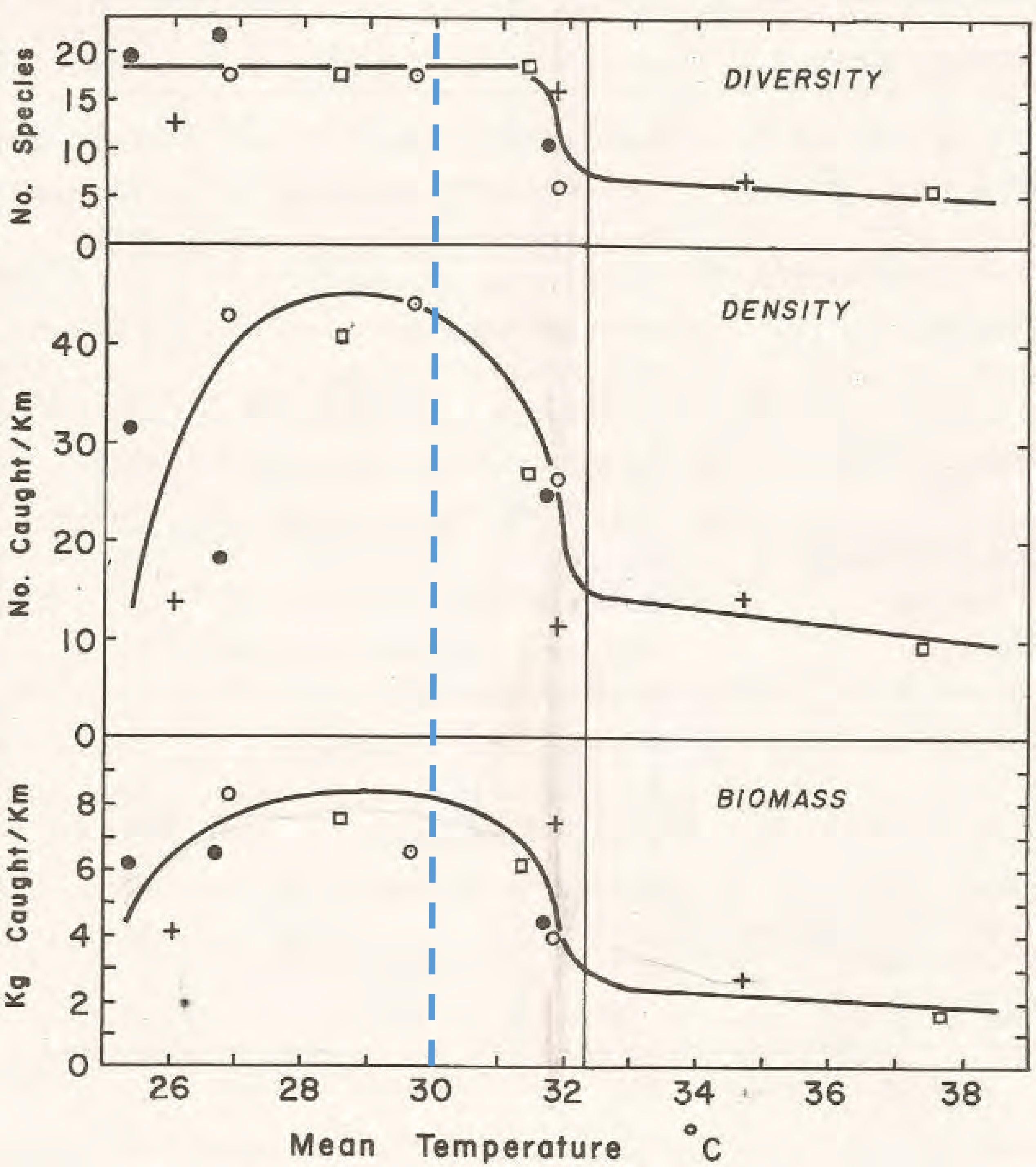


Figure 18: Diversity, density, and biomass of fish in three thermal zones of the Wabash segment as determined by D. C. electrofishing. The vertical line is the current thermal maximum allowed during summer months - 32.2°C. (90°F.) o 1968; • 1969; + 1970; □ 1971.

***Figure 3**. Fish community diversity, density, and biomass changes across a gradient of temperature in two thermal plumes in the Wabash River (after Gammon 1973).*

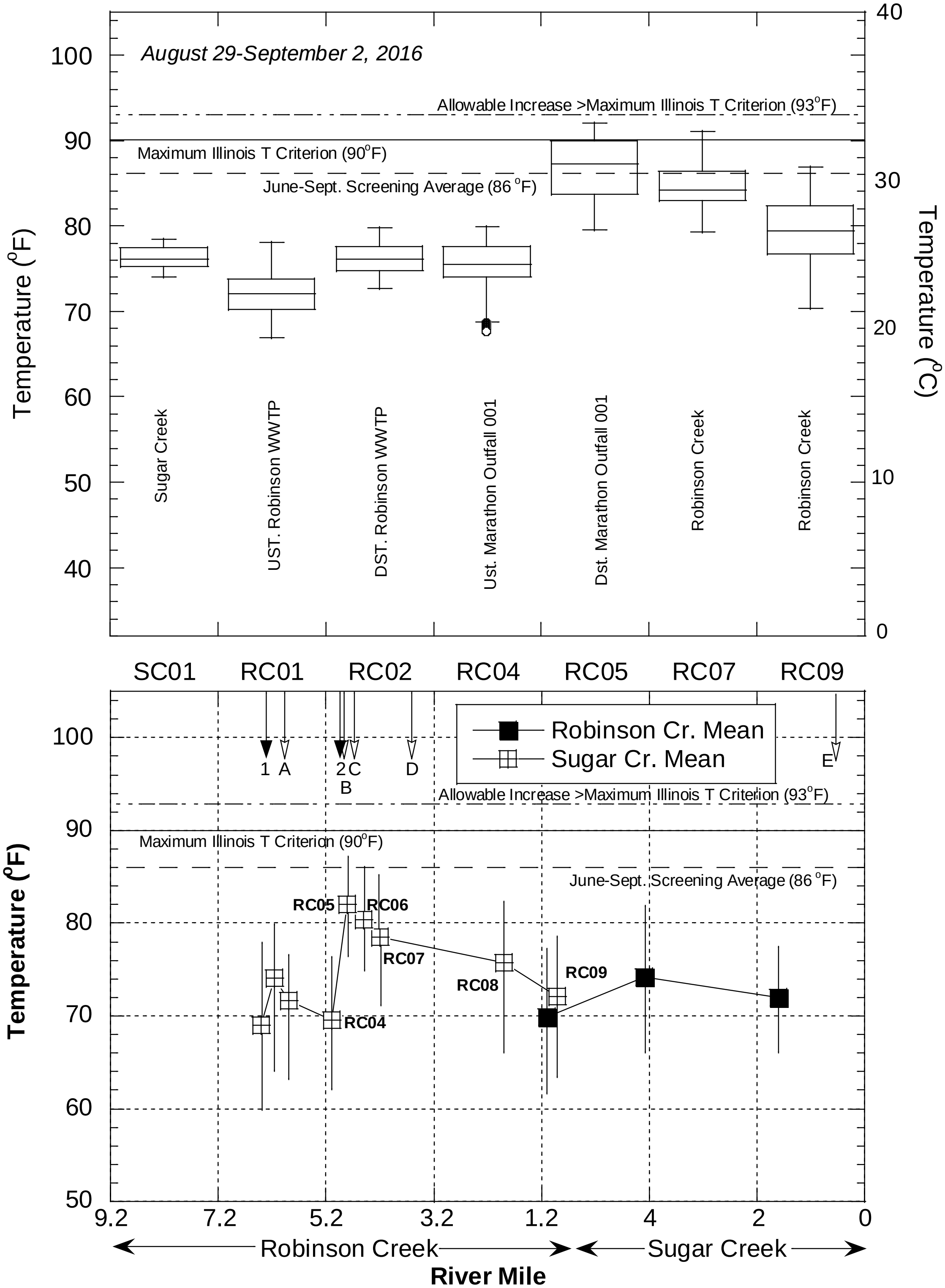


***Figure 4**. Ambient temperature measured continuously with Datasonde units over four-day periods at seven locations in Robinson and Sugar Creek during August 29-September 2, 2016 (upper) and grab sampling at all chemical and biological locations during June-Sept., 2016 (lower). The Illinois maximum temperature criterion, the maximum allowable increase over the maximum, and average screening value are indicated on each graph. The solid arrows across the top of each panel are the Robinson WWTP (1) and MPC 001 (2) outfalls. Tributary sites are positioned at their confluences with Robinson and Sugar Creeks (open arrows and letters – see Table 1 for legend).*

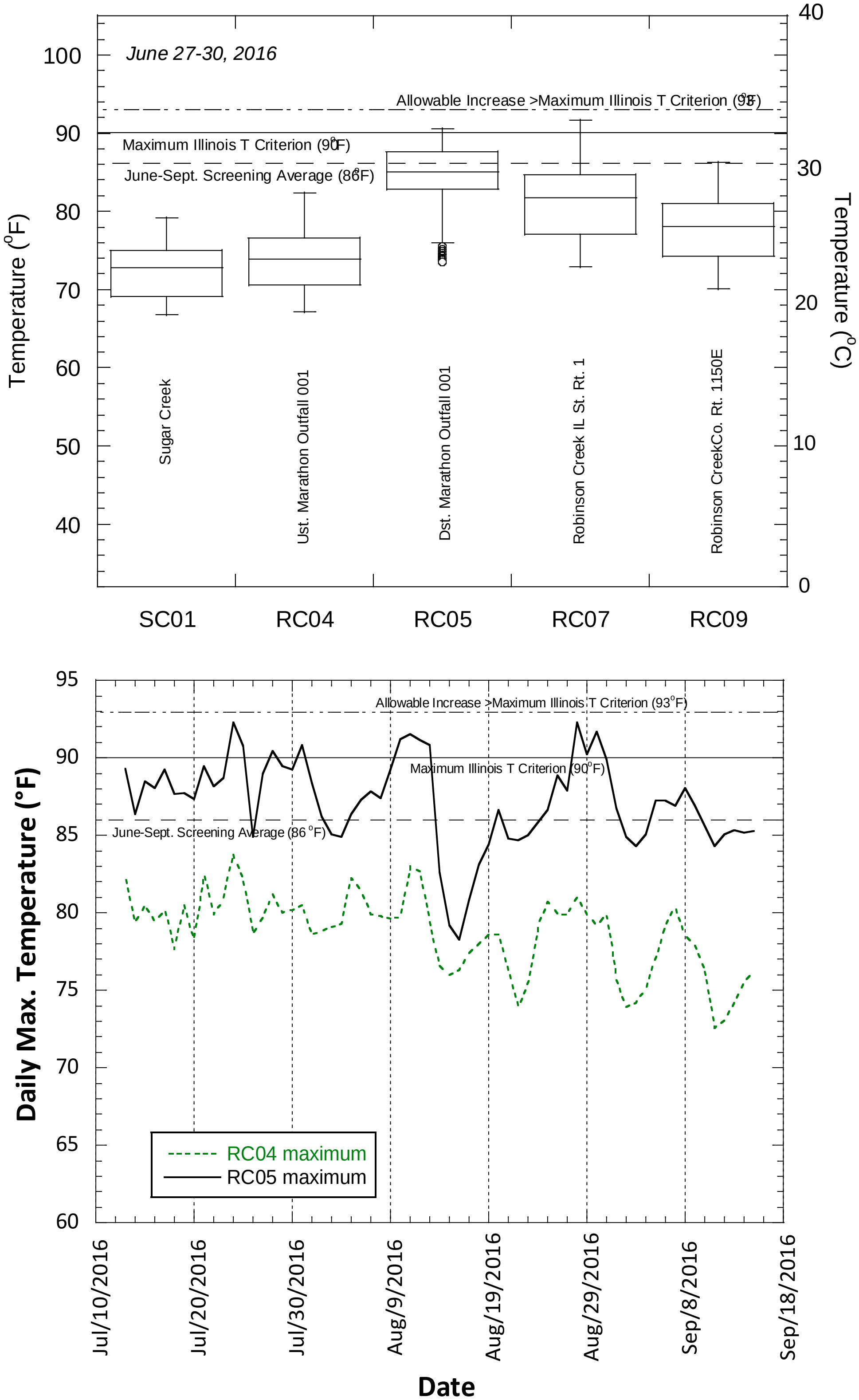


***Figure 5**. Ambient temperature measured continuously with Datasonde units over a four-day period at five locations in Robinson and Sugar Creek during June 27-30, 2016 (upper) and with HOBO continuous recorders at RC04 and RC05 during July-Sept., 2016 (lower). The Illinois maximum temperature criterion, the maximum allowable increase over the maximum, and an average screening value are indicated on each graph.*

***Table 4**. Summary of temperature monitoring results from EFDC Temperature model for Robinson Creek in 2011-2016 at four sites in Robinson Creek (RCO4, RC05, RC07, RC09). The number of observations and frequency of exceedance of IL maximum temperature criteria, 95th percentile and maximum temperatures, exceedances of the 3°F allowance, the 5°F rise, and >86°F are provided (April-November exceedances are red shaded; December-March exceedances are blue shaded).*

Month	N	Maximum Temperature Criteria						5°F Rise Criterion				% Summer >86°F (6-16 to 9-15)	Mean Summer °F (6-16 to 9-15)
		Number >Max. Criterion	% >Max. Criterion	Mean of Values >Max. Criterion	95th %ile Temp.	Max. Temp.	Number >Never Exceed Max. by 3°F	Number >5°F Above Control	% >5°F Above Control	Min. °F > Control	Max. °F > Control		
RC04 – Robinson Creek Upstream MPC 001 Outfall (Control Site)													
JAN	4464	0	0	0	51.5	55.4	0	0	0	0	0		
FEB	4080	5	0.1	60.2	53.0	60.3	0	0	0	0	0		
MAR	4464	510	11.4	64.8	65.0	73.9	322	0	0	0	0		
APR	4320	0	0	0	68.1	74.4	0	0	0	0	0		
MAY	4464	0	0	0	77.4	85.4	0	0	0	0	0		
JUN	4320	0	0	0	79.5	89.4	0	0	0	0	0	0.8%	73.3°F
JUL	4464	1	0.02	90.1	83.9	90.1	0	0	0	0	0		
AUG	4464	0	0	0	82.1	87.1	0	0	0	0	0		
SEP	4320	0	0	0	78.6	84.9	0	0	0	0	0		
OCT	4464	0	0	0	71.3	78.5	0	0	0	0	0	Exceedance of Max. (2011-2016) = 1.1% (Dec.-Mar. 3.2%) (Apr.-Nov. 0%)	
NOV	4320	0	0	0	60.7	66.9	0	0	0	0	0		
DEC	4464	48	1.1	61.8	55.2	65.6	7	0	0	0	0		

***Table 4**. Summary of temperature monitoring results from EFDC Temperature model for Robinson Creek in 2011-2016 at four sites in Robinson Creek (RCO4, RC05, RC07, RC09). The number of observations and frequency of exceedance of IL maximum temperature criteria, 95th percentile and maximum temperatures, exceedances of the 3°F allowance, the 5°F rise, and >86°F are provided (April-November exceedances are red shaded; December-March exceedances are blue shaded).*

Month	N	Maximum Temperature Criteria						5°F Rise Criterion				% Summer >86°F (6-16 to 9-15)	Mean Summer °F (6-16 to 9-15)
		Number >Max. Criterion	% >Max. Criterion	Mean of Values >Max. Criterion	95th %ile Temp.	Max. Temp.	Number >Never Exceed Max. by 3°F	Number >5°F Above Control	% >5°F Above Control	Min. °F > Control	Max. °F > Control		
RC05 – Robinson Creek Immediately Dst. MPC 001 Outfall													
JAN	4464	19	0.4	60.9	57.8	67.5	1	3413	76.5	5.0	30.8		
FEB	4080	190	4.7	61.5	59.9	63.6	20	3234	79.3	5.0	21.2		
MAR	4464	1272	28.5	64.59	68.8	76.1	670	2655	59.5	5.0	13.3		
APR	4320	0	0	0	71.3	79.0	0	1191	27.6	5.0	13.4		
MAY	4464	0	0	0	81.4	86.4	0	1343	30.1	5.0	12.0		
JUN	4320	10	0.2	90.7	85.5	92.2	0	2408	55.7	5.0	22.5	14.7%	81.4°F
JUL	4464	37	0.8	90.8	88.3	92.2	0	3149	70.5	5.0	19.9		
AUG	4464	47	1.1	90.7	88.2	92.6	0	4047	90.7	5.0	22.4		
SEP	4320	0	0	0	85.8	89.9	0	3917	90.7	5.0	25.4		
OCT	4464	0	0	0	78.4	83.2	0	3642	81.6	5.0	25.6	Exceedance of Max. (2011-2016) = 4.3% (Dec.-Mar. 12.5%) (Apr.-Nov. 0.3%)	
NOV	4320	0	0	0	69.4	76.3	0	3901	90.3	5.0	23.3		
DEC	4464	709	15.9	63.9	65.0	72.9	352	3458	77.5	5.0	24.2		

***Table 4**. Summary of temperature monitoring results from EFDC Temperature model for Robinson Creek in 2011-2016 at four sites in Robinson Creek (RCO4, RC05, RC07, RC09). The number of observations and frequency of exceedance of IL maximum temperature criteria, 95th percentile and maximum temperatures, exceedances of the 3°F allowance, the 5°F rise, and >86°F are provided (April-November exceedances are red shaded; December-March exceedances are blue shaded).*

Month	N	Maximum Temperature Criteria						5°F Rise Criterion				% Summer >86°F (6-16 to 9-15)	Mean Summer °F (6-16 to 9-15)
		Number >Max. Criterion	% >Max. Criterion	Mean of Values >Max. Criterion	95th %ile Temp.	Max. Temp.	Number >Never Exceed Max. by 3°F	Number >5°F Above Control	% >5°F Above Control	Min. °F > Control	Max. °F > Control		
RC07 – Robinson Creek @IL Route 1 - 1.7 mi. Dst. MPC 001													
JAN	4464	0	0	0	52.3	59.0	0	624	14.0	5.0	16.4		
FEB	4080	20	0.5	60.6	55.3	61.3	0	265	6.5	5.0	9.7		
MAR	4464	732	16.4	64.6	66.3	74.5	422	201	4.5	5.0	10.2		
APR	4320	0	0	0	69.4	76.6	0	79	1.8	5.0	13.4		
MAY	4464	0	0	0	79.3	86.5	0	265	5.9	5.0	9.6		
JUN	4320	38	0.9	91.6	84.4	94.7	6	842	19.5	5.0	16.3	5.4%	76.7°F
JUL	4464	63	1.4	91.3	87.0	94.7	7	453	10.1	5.0	13.0		
AUG	4464	32	0.7	90.6	86.2	91.6	0	995	22.3	5.0	12.1		
SEP	4320	16	0.4	91.3	83.4	92.9	0	1172	27.1	5.0	14.1		
OCT	4464	0	0	0	74.1	81.2	0	778	17.4	5.0	13.7	Exceedance of Max. (2011-2016) = 1.9% (Dec.-Mar. 5.0%) (Apr.-Nov. 0.4%)	
NOV	4320	0	0	0	64.7	71.1	0	1151	26.6	5.0	12.1		
DEC	4464	122	2.7	62.4	58.3	68.0	41	439	9.8	5.0	13.8		

***Table 4**. Summary of temperature monitoring results from EFDC Temperature model for Robinson Creek in 2011-2016 at four sites in Robinson Creek (RCO4, RC05, RC07, RC09). The number of observations and frequency of exceedance of IL maximum temperature criteria, 95th percentile and maximum temperatures, exceedances of the 3°F allowance, the 5°F rise, and >86°F are provided (April-November exceedances are red shaded; December-March exceedances are blue shaded).*

Month	N	Maximum Temperature Criteria						5°F Rise Criterion				% Summer >86°F (6-16 to 9-15)	Mean Summer °F (6-16 to 9-15)
		Number >Max. Criterion	% >Max. Criterion	Mean of Values >Max. Criterion	95th %ile Temp.	Max. Temp.	Number >Never Exceed Max. by 3°F	Number >5°F Above Control	% >5°F Above Control	Min. °F > Control	Max. °F > Control		
RC09 – Robinson Creek @Co. Rt. 1150 E - 4.0 mi. Dst. MPC 001													
JAN	4464	0	0	0	49.3	57.2	0	63	1.4	5.1	12.3		
FEB	4080	0	0	0	52.8	59.5	0	54	1.3	5.0	10.2		
MAR	4464	574	12.9	64.4	65.1	72.3	349	140	3.1	5.0	13.6		
APR	4320	0	0	0	68.5	75.2	0	126	2.9	5.0	15.0		
MAY	4464	0	0	0	78.7	85.1	0	198	4.4	5.0	11.9		
JUN	4320	4	0.1	90.5	83.3	91.6	0	735	17.0	5.0	13.7	2.1%	74.6°F
JUL	4464	34	0.8	91.2	85.5	93.7	3	338	7.6	5.0	12.4		
AUG	4464	0	0	0	82.8	88.0	0	131	2.9	5.0	10.0		
SEP	4320	0	0	0	80.3	86.2	0	187	4.3	5.0	13.7		
OCT	4464	0	0	0	69.9	79.2	0	33	0.7	5.1	11.1	Exceedance of Max. (2011-2016) = 1.2% (Dec.-Mar. 3.5%) (Apr.-Nov. 0.1%)	
NOV	4320	0	0	0	60.4	65.3	0	42	1.0	5.0	10.4		
DEC	4464	31	0.7	61.9	54.7	65.2	10	66	1.5	5.0	9.5		

***Table 5**. Summary of temperature monitoring results from EFDC Temperature model for Robinson Creek in 2012 at four sites in Robinson Creek (RCO4, RC05, RC07, RC09). The number of observations and frequency of exceedance of IL maximum temperature criteria, 95th percentile and maximum temperatures, exceedances of the 3°F allowance, the 5°F rise, and >86°F are provided (April-November exceedances are red shaded; December-March exceedances are blue shaded).*

Month	N	Maximum Temperature Criteria						5°F Rise Criterion				% Summer >86°F (6-16 to 9-15)	Mean Summer °F (6-16 to 9-15)
		Number >Max. Criterion	% >Max. Criterion	Mean of Values >Max. Criterion	95th %ile Temp.	Max. Temp.	Number >Never Exceed Max. by 3°F	Number >5°F Above Control	% >5°F Above Control	Min. °F > Control	Max. °F > Control		
RC04 – Robinson Creek Upstream MPC 001 Outfall (Control Site)													
JAN	744	0	0	0	52.4	55.3	0	0	0	0	0		
FEB	696	2	0.3	60.2	52.8	60.3	0	0	0	0	0		
MAR	744	412	55.4	65.6	70.4	73.9	312	0	0	0	0		
APR	720	0	0	0	69.3	74.3	0	0	0	0	0		
MAY	744	0	0	0	79.7	82.6	0	0	0	0	0		
JUN	720	0	0	0	80.6	89.4	0	0	0	0	0	1.5%	73.9°F
JUL	744	1	0.1	90.1	85.2	90.1	0	0	0	0	0		
AUG	744	0	0	0	81.8	84.6	0	0	0	0	0		
SEP	720	0	0	0	75.9	81.1	0	0	0	0	0		
OCT	744	0	0	0	68.5	72.6	0	0	0	0	0	Exceedance of Max. (2012) = 5.1% (Dec.-Mar. 15.3%) (Apr.-Nov. <0.1%)	
NOV	720	0	0	0	58.5	63.0	0	0	0	0	0		
DEC	744	34	4.6	62.1	59.1	65.6	7	0	0	0	0		

***Table 5**. Summary of temperature monitoring results from EFDC Temperature model for Robinson Creek in 2012 at four sites in Robinson Creek (RCO4, RC05, RC07, RC09). The number of observations and frequency of exceedance of IL maximum temperature criteria, 95th percentile and maximum temperatures, exceedances of the 3°F allowance, the 5°F rise, and >86°F are provided (April-November exceedances are red shaded; December-March exceedances are blue shaded).*

Month	N	Maximum Temperature Criteria						5°F Rise Criterion				% Summer >86°F (6-16 to 9-15)	Mean Summer °F (6-16 to 9-15)
		Number >Max. Criterion	% >Max. Criterion	Mean of Values >Max. Criterion	95th %ile Temp.	Max. Temp.	Number >Never Exceed Max. by 3°F	Number >5°F Above Control	% >5°F Above Control	Min. °F > Control	Max. °F > Control		
RC05 – Robinson Creek Immediately Dst. MPC 001 Outfall													
JAN	744	0	0	0	57.2	58.9	0	303	40.7	5.0	8.9		
FEB	696	14	2.0	61.7	57.1	63.4	3	109	15.7	5.0	8.8		
MAR	744	504	67.7	68.0	73.1	76.1	457	260	34.9	5.0	9.4		
APR	720	0	0	0	74.2	79.0	0	434	60.3	5.0	13.4		
MAY	744	0	0	0	83.8	86.0	0	427	57.4	5.0	11.3		
JUN	720	0	0	0	86.1	88.9	0	669	92.9	5.0	19.0	25.3%	83.5°F
JUL	744	14	1.9	91.3	89.3	92.2	0	623	83.7	5.0	17.7		
AUG	744	0	0	0	88.3	89.9	0	724	97.3	5.0	22.4		
SEP	720	0	0	0	83.3	87.5	0	642	89.2	5.0	16.6		
OCT	744	0	0	0	74.0	77.1	0	616	82.8	5.0	19.4	Exceedance of Max. (2012) = 8.2% (Dec.-Mar. 23.9%) (Apr.-Nov. 0.2%)	
NOV	720	0	0	0	68.8	71.3	0	720	100.0	5.1	23.3		
DEC	744	184	24.7	67.1	70.4	72.9	163	487	65.5	5.0	18.4		

***Table 5**. Summary of temperature monitoring results from EFDC Temperature model for Robinson Creek in 2012 at four sites in Robinson Creek (RCO4, RC05, RC07, RC09). The number of observations and frequency of exceedance of IL maximum temperature criteria, 95th percentile and maximum temperatures, exceedances of the 3°F allowance, the 5°F rise, and >86°F are provided (April-November exceedances are red shaded; December-March exceedances are blue shaded).*

Month	N	Maximum Temperature Criteria						5°F Rise Criterion				% Summer >86°F (6-16 to 9-15)	Mean Summer °F (6-16 to 9-15)
		Number >Max. Criterion	% >Max. Criterion	Mean of Values >Max. Criterion	95th %ile Temp.	Max. Temp.	Number >Never Exceed Max. by 3°F	Number >5°F Above Control	% >5°F Above Control	Min. °F > Control	Max. °F > Control		
RC07 – Robinson Creek @IL Route 1 - 1.7 mi. Dst. MPC 001													
JAN	744	0	0	0	52.1	54.1	0	11	1.5	5.2	8.0		
FEB	696	1	0.1	60.2	53.5	60.2	0	9	1.3	5.0	6.3		
MAR	744	441	59.3	66.4	71.2	74.5	357	23	3.1	5.0	10.0		
APR	720	0	0	0	71.6	76.6	0	34	4.7	5.0	8.0		
MAY	744	0	0	0	81.6	85.1	0	20	2.7	5.1	9.6		
JUN	720	9	1.3	90.9	84.1	92.4	0	125	17.4	5.0	7.8	9.1%	78.0°F
JUL	744	44	5.9	91.5	90.2	94.7	7	148	19.9	5.0	13.0		
AUG	744	5	0.7	90.9	86.9	91.5	0	286	38.4	5.0	12.1		
SEP	720	0	0	0	81.0	86.6	0	114	15.8	5.0	8.3		
OCT	744	0	0	0	69.1	73.6	0	32	4.3	5.0	11.4	Exceedance of Max. (2012) = 6.3% (Dec.-Mar. 17.0%) (Apr.-Nov. 1.0%)	
NOV	720	0	0	0	61.3	66.5	0	301	41.8	5.0	11.0		
DEC	744	56	7.5	64.2	63.5	68.0	41	83	11.2	5.0	9.8		

***Table 5**. Summary of temperature monitoring results from EFDC Temperature model for Robinson Creek in 2012 at four sites in Robinson Creek (RCO4, RC05, RC07, RC09). The number of observations and frequency of exceedance of IL maximum temperature criteria, 95th percentile and maximum temperatures, exceedances of the 3°F allowance, the 5°F rise, and >86°F are provided (April-November exceedances are red shaded; December-March exceedances are blue shaded).*

Month	N	Maximum Temperature Criteria						5°F Rise Criterion				% Summer >86°F (6-16 to 9-15)	Mean Summer °F (6-16 to 9-15)
		Number >Max. Criterion	% >Max. Criterion	Mean of Values >Max. Criterion	95th %ile Temp.	Max. Temp.	Number >Never Exceed Max. by 3°F	Number >5°F Above Control	% >5°F Above Control	Min. °F > Control	Max. °F > Control		
RC09 – Robinson Creek @Co. Rt. 1150 E - 4.0 mi. Dst. MPC 001													
JAN	744	0	0	0	49.3	52.3	0	13	1.7	5.1	11.0		
FEB	696	0	0	0	51.8	58.7	0	8	1.1	5.2	7.2		
MAR	744	388	52.2	65.5	69.5	72.3	300	22	3.0	5.0	12.3		
APR	720	0	0	0	70.0	75.2	0	27	3.8	5.1	8.6		
MAY	744	0	0	0	80.2	83.1	0	39	5.2	5.1	11.9		
JUN	720	2	0.3	90.9	81.6	91.6	0	10	1.4	5.2	6.7	4.4%	75.8°F
JUL	744	26	3.5	91.4	88.7	93.7	3	43	5.8	5.0	12.4		
AUG	744	0	0	0	83.2	87.2	0	38	5.1	5.0	10.0		
SEP	720	0	0	0	81.3	86.0	0	110	15.3	5.0	8.3		
OCT	744	0	0	0	66.8	69.3	0	20	2.7	5.1	11.1	Exceedance of Max. (2012) = 5.0% (Dec.-Mar. 14.0%) (Apr.-Nov. 0.5%)	
NOV	720	0	0	0	55.9	58.5	0	16	2.2	5.0	8.2		
DEC	744	23	3.1	62.4	57.2	65.2	10	16	2.2	5.1	9.5		

***Table 6**. Summary of temperature monitoring results from EFDC Temperature model for Robinson Creek in 2016 at four sites in Robinson Creek (RCO4, RC05, RC07, RC09). The number of observations and frequency of exceedance of IL maximum temperature criteria, 95th percentile and maximum temperatures, exceedances of the 3°F allowance, the 5°F rise, and >86°F are provided (April-November exceedances are red shaded; December-March exceedances are blue shaded).*

Month	N	Maximum Temperature Criteria						5°F Rise Criterion				% Summer >86°F (6-16 to 9-15)	Mean Summer °F (6-16 to 9-15)
		Number >Max. Criterion	% >Max. Criterion	Mean of Values >Max. Criterion	95^{th} %ile Temp.	Max. Temp.	Number >Never Exceed Max. by 3°F	Number >5°F Above Control	% >5°F Above Control	Min. °F > Control	Max. °F > Control		
RC04 – Robinson Creek Upstream MPC 001 Outfall (Control Site)													
JAN	744	0	0.	0	51.5	54.4	0	0	0	0	0		
FEB	696	0	0	0	53.2	57.4	0	0	0	0	0		
MAR	744	13	1.7	61.1	58.6	62.7	0	0	0	0	0		
APR	720	0	0	0	63.2	67.3	0	0	0	0	0		
MAY	744	0	0	0	75.7	80.0	0	0	0	0	0		
JUN	720	0	0	0	79.9	83.4	0	0	0	0	0	0.1%	74.3°F
JUL	744	0	0	0	82.5	86.5	0	0	0	0	0		
AUG	744	0	0	0	82.0	85.7	0	0	0	0	0		
SEP	720	0	0	0	78.1	80.9	0	0	0	0	0		
OCT	744	0	0	0	71.2	75.0	0	0	0	0	0	Exceedance of Max. (2016) = 0.1% (Dec.-Mar. 0.4%) (Apr.-Nov. 0%)	
NOV	720	0	0	0	62.0	64.9	0	0	0	0	0		
DEC	744	0	0	0	48.6	59.2	0	0	0	0	0		

***Table 6**. Summary of temperature monitoring results from EFDC Temperature model for Robinson Creek in 2016 at four sites in Robinson Creek (RCO4, RC05, RC07, RC09). The number of observations and frequency of exceedance of IL maximum temperature criteria, 95th percentile and maximum temperatures, exceedances of the 3°F allowance, the 5°F rise, and >86°F are provided (April-November exceedances are red shaded; December-March exceedances are blue shaded).*

<table>
<tr><th rowspan="2">Month</th><th rowspan="2">N</th><th colspan="6">Maximum Temperature Criteria</th><th colspan="4">5°F Rise Criterion</th><th rowspan="2">% Summer >86°F (6-16 to 9-15)</th><th rowspan="2">Mean Summer °F (6-16 to 9-15)</th></tr>
<tr><th>Number >Max. Criterion</th><th>% >Max. Criterion</th><th>Mean of Values >Max. Criterion</th><th>95th %ile Temp.</th><th>Max. Temp.</th><th>Number >Never Exceed Max. by 3°F</th><th>Number >5°F Above Control</th><th>% >5°F Above Control</th><th>Min. °F > Control</th><th>Max. °F > Control</th></tr>
<tr><td colspan="14">RC05 – Robinson Creek Immediately Dst. MPC 001 Outfall</td></tr>
<tr><td>JAN</td><td>744</td><td>12</td><td>1.6</td><td>61.3</td><td>59.3</td><td>67.5</td><td>1</td><td>742</td><td>99.7</td><td>5.1</td><td>30.8</td><td colspan="2" rowspan="5"></td></tr>
<tr><td>FEB</td><td>696</td><td>93</td><td>13.4</td><td>61.6</td><td>61.9</td><td>63.6</td><td>11</td><td>687</td><td>98.7</td><td>5.0</td><td>18.3</td></tr>
<tr><td>MAR</td><td>744</td><td>264</td><td>35.5</td><td>62.1</td><td>63.7</td><td>65.3</td><td>75</td><td>386</td><td>51.9</td><td>5.0</td><td>11.8</td></tr>
<tr><td>APR</td><td>720</td><td>0</td><td>0.0</td><td>0</td><td>67.2</td><td>69.5</td><td>0</td><td>300</td><td>41.7</td><td>5.0</td><td>9.6</td></tr>
<tr><td>MAY</td><td>744</td><td>0</td><td>0.0</td><td>0</td><td>83.4</td><td>86.4</td><td>0</td><td>464</td><td>62.4</td><td>5.0</td><td>12.0</td></tr>
<tr><td>JUN</td><td>720</td><td>10</td><td>1.4</td><td>90.7</td><td>88.2</td><td>92.2</td><td>0</td><td>665</td><td>92.4</td><td>5.1</td><td>22.5</td><td rowspan="4">23.9%</td><td rowspan="4">83.7°F</td></tr>
<tr><td>JUL</td><td>744</td><td>2</td><td>0.3</td><td>90.3</td><td>88.5</td><td>90.5</td><td>0</td><td>618</td><td>83.1</td><td>5.1</td><td>15.0</td></tr>
<tr><td>AUG</td><td>744</td><td>44</td><td>5.9</td><td>90.7</td><td>90.2</td><td>92.6</td><td>0</td><td>642</td><td>86.3</td><td>5.0</td><td>20.8</td></tr>
<tr><td>SEP</td><td>720</td><td>0</td><td>0.0</td><td>0</td><td>86.4</td><td>89.9</td><td>0</td><td>709</td><td>98.5</td><td>5.2</td><td>25.4</td></tr>
<tr><td>OCT</td><td>744</td><td>0</td><td>0.0</td><td>0</td><td>80.0</td><td>83.2</td><td>0</td><td>709</td><td>95.3</td><td>5.0</td><td>25.6</td><td colspan="2" rowspan="3">Exceedance of Max. (2016) = 5.9% (Dec.-Mar. 15.8%) (Apr.-Nov. 1.0%)</td></tr>
<tr><td>NOV</td><td>720</td><td>0</td><td>0.0</td><td>0</td><td>74.7</td><td>76.3</td><td>0</td><td>714</td><td>99.2</td><td>5.2</td><td>22.6</td></tr>
<tr><td>DEC</td><td>744</td><td>93</td><td>12.5</td><td>61.4</td><td>61.2</td><td>65.8</td><td>9</td><td>742</td><td>99.7</td><td>5.4</td><td>24.2</td></tr>
</table>

***Table 6**. Summary of temperature monitoring results from EFDC Temperature model for Robinson Creek in 2016 at four sites in Robinson Creek (RCO4, RC05, RC07, RC09). The number of observations and frequency of exceedance of IL maximum temperature criteria, 95th percentile and maximum temperatures, exceedances of the 3°F allowance, the 5°F rise, and >86°F are provided (April-November exceedances are red shaded; December-March exceedances are blue shaded).*

Month	N	Maximum Temperature Criteria						5°F Rise Criterion				% Summer >86°F (6-16 to 9-15)	Mean Summer °F (6-16 to 9-15)
		Number >Max. Criterion	% >Max. Criterion	Mean of Values >Max. Criterion	95th %ile Temp.	Max. Temp.	Number >Never Exceed Max. by 3°F	Number >5°F Above Control	% >5°F Above Control	Min. °F > Control	Max. °F > Control		
RC07 – Robinson Creek @IL Route 1 - 1.7 mi. Dst. MCP001													
JAN	744	0	0	0	55.0	59.0	0	325	43.7	5.0	16.4		
FEB	696	14	2	60.7	58.5	61.3	0	219	31.5	5.0	9.7		
MAR	744	141	19	61.6	62.5	64.3	27	91	12.2	5.0	7.7		
APR	720	0	0	0	63.3	66.0	0	2	0.3	5.4	5.5		
MAY	744	0	0	0	81.2	86.5	0	213	28.6	5.0	7.9		
JUN	720	29	4	91.8	89.3	94.7	6	642	89.2	5.0	16.3	8.4%	79.6°F
JUL	744	1	0.1	90.0	86.0	90.0	0	159	21.4	5.0	9.7		
AUG	744	17	2.3	90.7	88.2	91.6	0	285	38.3	5.0	10.8		
SEP	720	0	0	0	84.6	88.3	0	511	71.0	5.0	12.0		
OCT	744	0	0	0	75.3	79.9	0	200	26.9	5.0	13.7	Exceedance of Max. (2016) = 2.3% (Dec.-Mar. 5.4%) (Apr.-Nov. 0.8%)	
NOV	720	0	0	0	68.0	71.1	0	449	62.4	5.0	12.1		
DEC	744	3	0.4	60.5	54.7	60.8	0	223	30.0	5.0	10.4		

***Table 6**. Summary of temperature monitoring results from EFDC Temperature model for Robinson Creek in 2016 at four sites in Robinson Creek (RCO4, RC05, RC07, RC09). The number of observations and frequency of exceedance of IL maximum temperature criteria, 95th percentile and maximum temperatures, exceedances of the 3°F allowance, the 5°F rise, and >86°F are provided (April-November exceedances are red shaded; December-March exceedances are blue shaded).*

Month	N	Maximum Temperature Criteria						5°F Rise Criterion				% Summer >86°F (6-16 to 9-15)	Mean Summer °F (6-16 to 9-15)
		Number >Max. Criterion	% >Max. Criterion	Mean of Values >Max. Criterion	95th %ile Temp.	Max. Temp.	Number >Never Exceed Max. by 3°F	Number >5°F Above Control	% >5°F Above Control	Min. °F > Control	Max. °F > Control		
RC09 – Robinson Creek @Co. Rt. 1150 E - 4.0 mi. Dst. MPC 001													
JAN	744	0	0	0	51.5	57.2	0	10	1.3	5.3	7.1		
FEB	696	0	0	0	55.6	58.6	0	18	2.6	5.0	10.2		
MAR	744	100	13.4	62.0	62.3	66.1	23	33	4.4	5.0	7.3		
APR	720	0	0	0	61.0	65.3	0	12	1.7	5.0	7.6		
MAY	744	0	0	0	79.3	85.1	0	72	9.7	5.0	9.5		
JUN	720	2	0.3	90.1	87.5	90.2	0	480	66.7	5.0	13.7	2.9%	76.6°F
JUL	744	0	0	0	83.1	86.9	0	12	1.6	5.0	6.7		
AUG	744	0	0	0	84.0	87.8	0	7	0.9	5.2	5.5		
SEP	720	0	0	0	79.7	81.6	0	7	1.0	5.1	6.0		
OCT	744	0	0	0	70.6	75.4	0	0	0	0	0	Exceedance of Max. (2016) = 1.2% (Dec.-Mar. 3.4%) (Apr.-Nov. <0.1%)	
NOV	720	0	0	0	61.9	64.0	0	7	1.0	5.1	6.5		
DEC	744	0	0	0	47.4	58.2	0	0	0	0	0		

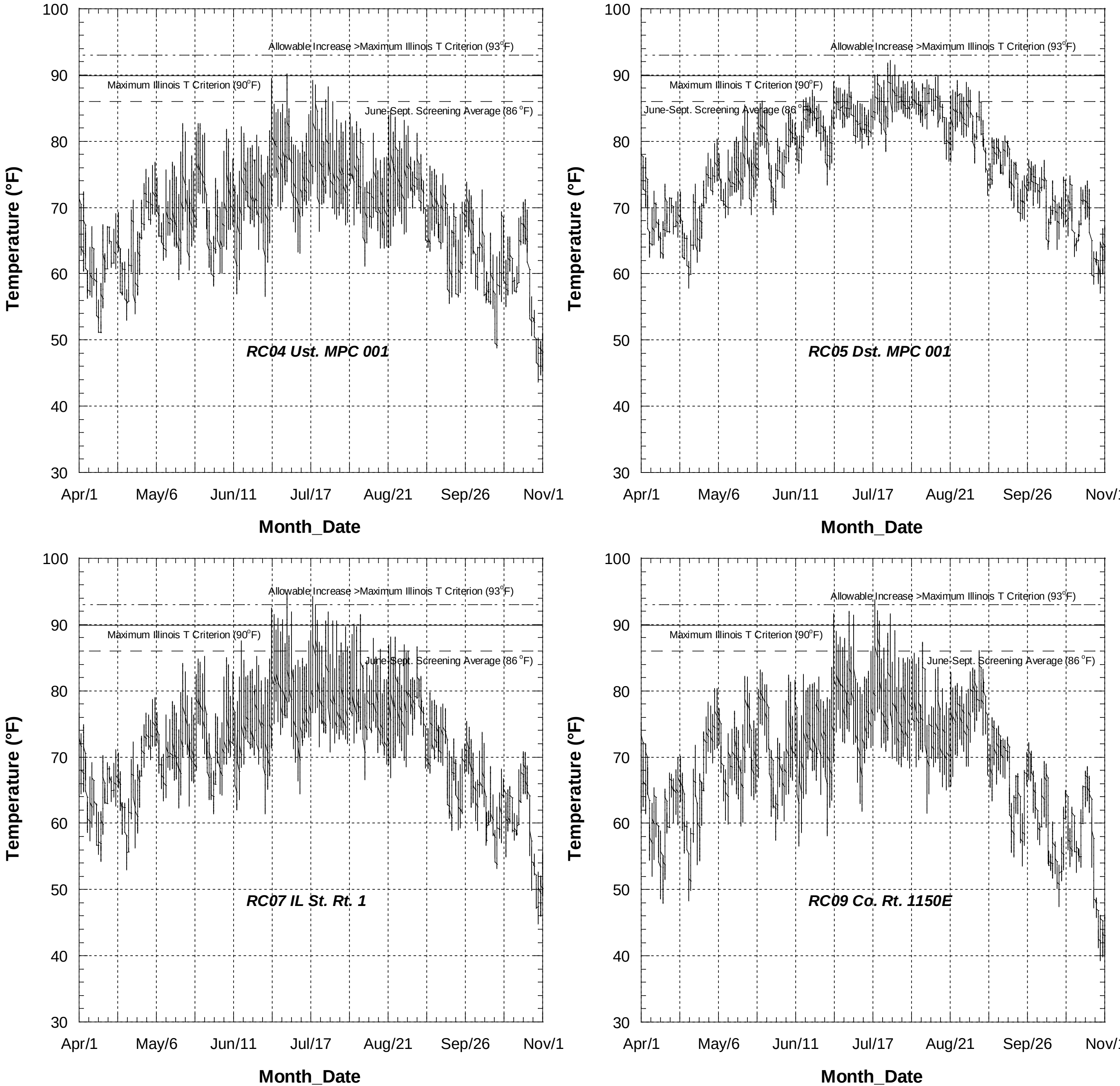


***Figure 6**. Daily temperature profile of Robinson Creek immediately downstream from the MPC 001 outfall (RC05) based on modeled temperatures May 1-October 31, 2012. The Illinois maximum temperature criteria of 90°F is shown along with the 86°F true summer average threshold and the Illinois 3°F not-to-exceed the 90°F maximum criterion.*

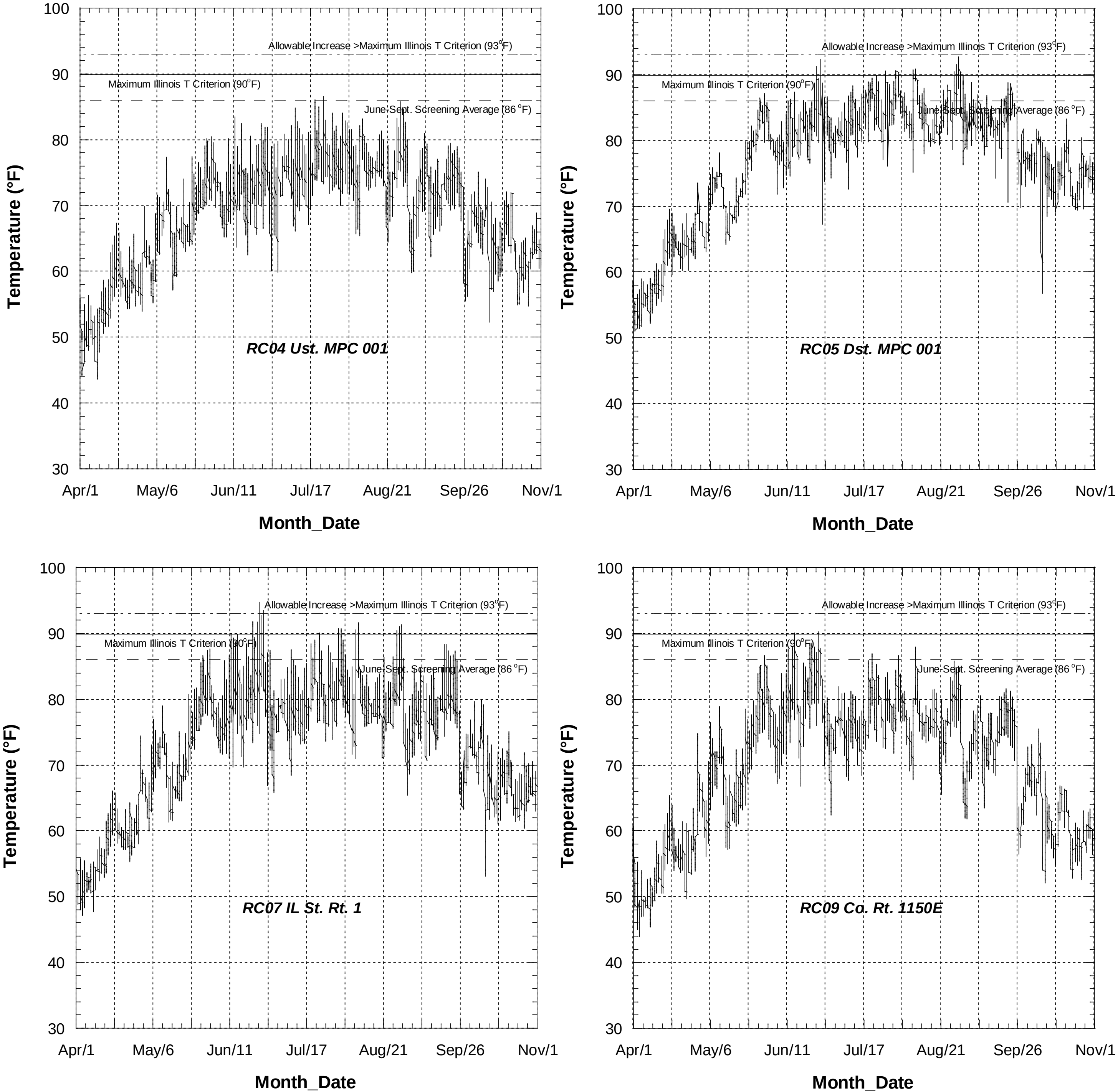


***Figure 7**. Daily temperature profile of Robinson Creek immediately downstream from the MPC 001 outfall (RC05) based on modeled temperatures May 1-October 31, 2016. The Illinois maximum temperature criteria of 90°F is shown along with the 86°F true summer average threshold and the Illinois 3°F not-to-exceed the 90°F maximum criterion.*

***Table 7**. Exceedance of key temperature thresholds in Robinson Creek upstream and downstream from the MPC 001 outfall based on Datasonde and HOBO continuous monitors (upper table) and Modeled temperatures for 2011-16, 2012, and 2016. The frequency of temperatures >86°F, the true summer average (June 16-September 15), the frequency of temperatures >maximum temperature criterion for all months, April-November (%max Su), and December-March (%max Wi) are shown. Exceedances of the IL temperature criteria are yellow highlighted.*

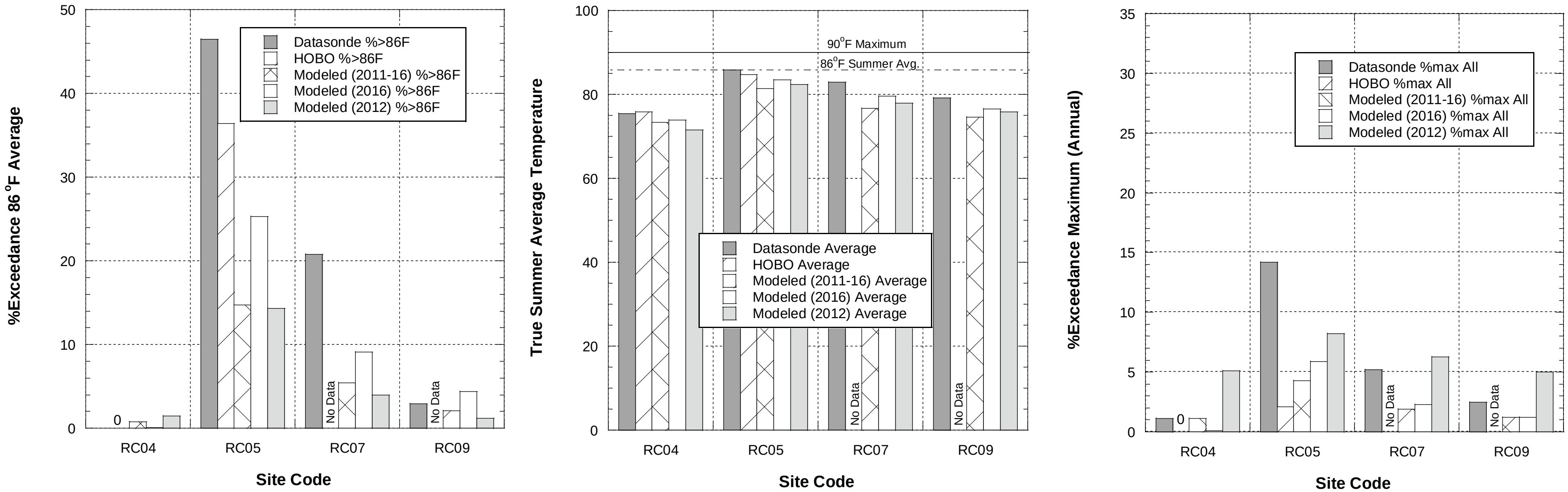
Comparison of selected exceedance thresholds for 2016 Datasonde and HOBO temperature data.

		Datasonde (Jan. - Dec. 2016)					HOBO (July 2016-Feb. 2017)				
Site	**Location**	**%>86F**	**Average**	**%max All**	**%max Su**	**%max Wi**	**%>86F**	**Average**	**%max All**	**%max Su**	**%max Wi**
RC04	Ust. MPC 001	0.0%	75.5°F	1.1%	0.0%	3.2%	0.0%	75.8°F	0.0%	0.0%	0.0%
RC05	Dst. MPC 001	46.5%	85.8°F	14.2%	4.8%	30.8%	36.4%	84.7°F	2.1%	2.8%	1.1%
RC07	IL Rt. 1	20.8%	82.9°F	5.2%	1.5%	11.6%	insufficient data		0.0%	ND	0.0%
RC09	Co. Rt. 1150E	2.9%	79.2°F	2.5%	0.0%	6.8%	NA	NA	0.0%	0.0%	0.0%

Comparison of selected exceedance thresholds for modeled temperature 2011-16, 2012, and 2016.

		Jan. - Dec. 2011-16					Jan. - Dec. 2012				
Site	**Location**	**%>86F**	**Average**	**%max All**	**%max Su**	**%max Wi**	**%>86F**	**Average**	**%max All**	**%max Su**	**%max Wi**
RC04	Ust. MPC 001	0.8%	73.3°F	1.1%	0.0%	3.2%	1.5%	73.9°F	5.1%	<0.1%	15.3%
RC05	Dst. MPC 001	14.7%	81.4°F	4.3%	0.3%	12.6%	25.3%	83.5°F	8.2%	0.2%	23.9%
RC07	IL Rt. 1	5.4%	76.7°F	1.9%	0.4%	5.0%	9.1%	78.0°F	6.3%	0.1%	17.0%
RC09	Co. Rt. 1150E	2.1%	74.6°F	1.2%	<0.1%	3.5%	4.4%	75.8°F	5.0%	0.5%	14.0%

		Jan. - Dec. 2016				
Site	**Location**	**%>86F**	**Average**	**%max All**	**%max Su**	**%max Wi**
RC04	Ust. MPC 001	0.1%	74.3°F	0.1%	0.0%	0.1%
RC05	Dst. MPC 001	23.9%	83.7°F	5.9%	1.0%	15.8%
RC07	IL Rt. 1	8.4%	79.6°F	2.3%	0.8%	5.4%
RC09	Co. Rt. 1150E	2.9%	76.6°F	1.2%	<0.1%	3.4%



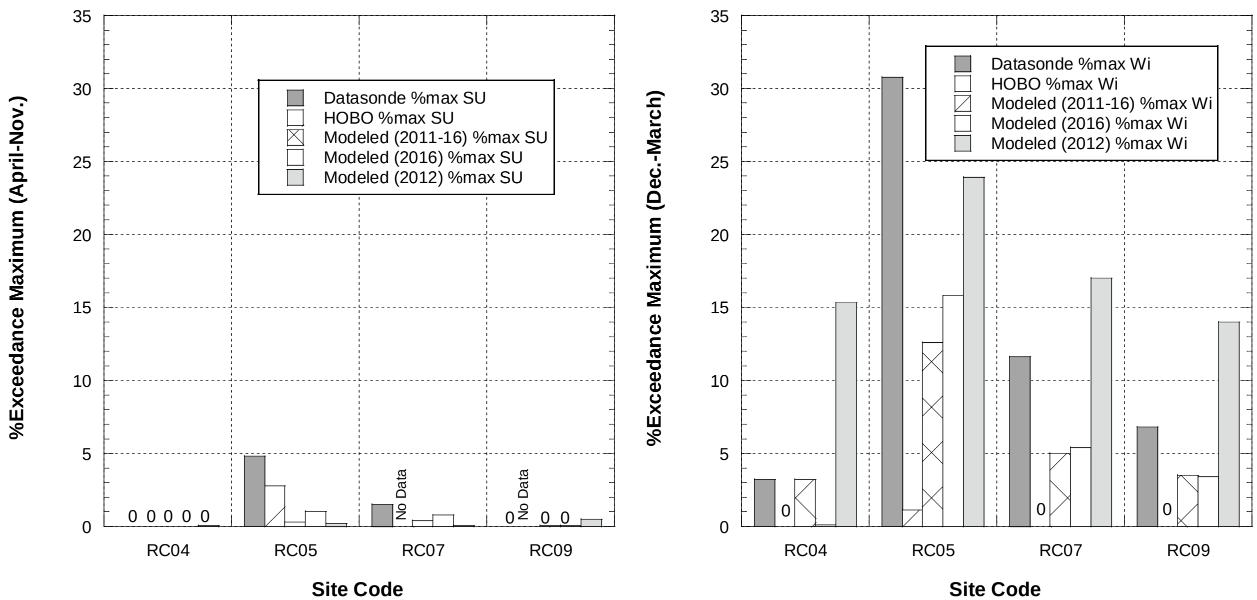


***Figure 8**. The frequency of exceedance of Illinois maximum temperature criteria annually and by summer and winter periods at four locations in Robinson Creek upstream and downstream from the MPC 001 outfall based on Datasonde and HOBO continuous monitors and modeled temperatures for 2011-16, 2012, and 2016. The frequency of temperatures >86°F (screening threshold) and the true summer (June 16-September 15) average temperatures at the same locations are also provided. The same results appear in tabular format in Table 7.*

Table 8*. Representative fish species (RIS) for the predictive analysis done in support of the 316(a) demonstration for the MPC Robinson Refinery thermal effluent. RIS were selected from data collected by IEPA/IDNR at sites ≤15 mi.[2] in streams of the Wabash Faunal Region, collected by IEPA in Robinson and sugar Creeks in the 2008 and 2013 Facility Related Stream Surveys (FRSS), and by MBI in Robinson and Sugar Creeks in 2016 (MBI 2017). An X indicates the species was collected in sufficient numbers in that survey and a √indicates species with sufficient thermal effects data.*

Species	Wabash Faunal Region	IEPA FRSS 2008-13	MBI 2016	Thermal Data Available?	Final RIS
Gizzard Shad	X		X	√	X
Smallmouth buffalo		X		√	*
Quillback	X		X	√	X
White sucker	X		X	√	X
Creek chubsucker	X		X		
Common carp	X	X	X	√	X
Creek chub	X	X	X	√	X
Suckermouth minnow			X		
Emerald shiner	X	X	X	√	X
Redfin Shiner	X			√	X
Striped shiner			X	√	X
Red shiner		X		√	X
Spotfin shiner	X	X	X	√	X
Silverjaw minnow	X	X	X	√	X
Mississippi silvery minnow	X	X	X		
Bluntnose minnow	X	X	X	√	X
Central stoneroller	X		X	√	X
Yellow bullhead	X		X	√	X
Blackstripe topminnow	X	X		√	X
Western mosquitofish	X		X	√	X
Pirate perch	X		X		
White crappie		X		√	*
Spotted bass		X		√	*
Largemouth bass	X		X	√	X
Green sunfish	X	X	X	√	X
Bluegill	X	X	X	√	X
Longear sunfish	X		X	√	X
Johnny darter	X		X	√	X
TOTALS (28 species)	**22**	**14**	**22**	**24**	**21**

* - non-RIS species that were retained for an alternate FTMS scenario.

Table 9. *Thermal endpoints (optimum, MWAT, UAT, upper lethal) used as input variables for the two Robinson Creek FTMS scenarios for core RIS and adding the three non-RIS (cited references are in Appendix B-4).*

Species	Optimum			MWAT for Growth[a]		UAT[b]			Upper Lethal[c,d]		Temperature Threshold References: Optimum	UAT	Upper Lethal
Robinson Cr. RIS <15 mi.[2]	**°F**	**°C**		**°F**	**°C**	**°F**	**°C**		**°F**	**°C**			
Gizzard Shad	86.0	30.0		89.5	31.9	89.6	32.0		96.4	35.8	Gammon 1973	Gammon 1973	Hart 1952
Quillback	86.0	30.0		90.3	32.4	93.7	34.3		99.0	37.2	Gammon 1973	Gammon 1973	Reutter & Herdendorff 1974
White Sucker	73.6	23.1		80.7	27.0	88.9	31.6	X	94.8	34.9	Smale & Rabeni 1995		Smale & Rabeni 1995
Common Carp	91.4	33.0		95.0	35.0	97.0	36.1		102.2	39.0	Yoder & Gammon 1976	Proffit & Benda 1971	Reutter & Herdendorff 1974
Emerald Shiner	80.6	27.0	X	85.1	29.5	88.0	31.1		94.1	34.5		Proffit & Benda 1971	Matthews 1981
Striped Shiner	87.1	30.6	X	90.4	32.5	93.0	33.9	X	97.2	36.2			Mundahl 1990
Spotfin Shiner	87.1	30.6		90.3	32.4	91.4	33.0		96.8	36.0	Cherry et al. 1977	Cherry et al. 1977	Cherry et al. 1977
Redfin Shiner	87.1	30.6	X	90.4	32.5	93.0	33.9	X	97.2	36.2			Smale & Rabeni 1995
Red Shiner	87.1	30.6	X	90.4	32.5	91.2	32.9	X	97.2	36.2			Takle et al. 1983
Creek Chub	86.2	30.1	X	89.5	32.0	93.0	33.9		96.3	35.7		Stauffer et al. 1976	Smale & Rabeni 1995
Central Stoneroller	82.8	28.2		87.3	30.7	91.4	33.0		96.3	35.7	Cherry et al. 1977	Cherry et al. 1977	Mundahl 1990
Bluntnose Minnow	81.5	27.5		86.5	30.3	91.4	33.0		96.6	35.9	Cherry et al. 1977	Cherry et al. 1977	Mundahl 1990
Silverjaw Minnow	84.9	29.4	X	88.3	31.3	90.9	32.7	X	95.0	35.0			Mundahl 1990
Western Mosquitofish	89.6	32.0		93.8	34.3	96.8	36.0		102.2	39.0	Cherry et al. 1977	Cherry et al. 1977	Cherry et al. 1977
Blackstripe Topminnow	86.9	30.5	X	91.6	33.1	95.0	35.0	X	100.9	38.3			Smale & Rabeni 1995
Yellow Bullhead	83.1	28.4		87.9	31.1	91.6	33.1	X	97.5	36.4	Reynolds & Casterlin 1978		Reutter & Herdendorff 1974
Largemouth Bass	81.5	27.5		87.9	31.0	91.4	33.0	X	100.6	38.1	Coutant 1975	Yoder & Gammon 1976a	Smith 1975
Bluegill	86.2	30.1		89.7	32.1	91.4	33.0		96.8	36.0	Cherry et al. 1977	Stauffer et al. 1976	Cherry et al. 1982
Green Sunfish	87.3	30.7		91.6	33.1	91.4	33.0		100.2	37.9	Cherry et al. 1975	Cherry et al. 1975	Smale & Rabeni 1995
Longear Sunfish	86.0	30.0	X	90.7	32.6	92.7	33.7	X	100.0	37.8			Smale & Rabeni 1995
Johnny Darter	76.1	24.5		83.3	28.5	91.6	33.1	X	97.5	36.4	Smale & Rabeni 1995		Smale & Rabeni 1995
Non-RIS "Boundary" Species													
Smallmouth Buffalo	90.5	32.5		93.9	34.4	94.6	34.8	X	100.6	38.1	Gammon 1973	Gammon 1973	
Spotted Bass	85.8	29.9		89.5	31.9	91.4	33.0		96.8	36.0	Cherry et al. 1977	Cherry et al. 1977	Cherry et al. 1977
White Crappie	78.8	26.0		82.8	28.2	88.0	31.1		90.7	32.6	Gebhart & Summerfelt 1975	Proffit & Benda 1971	Kleiner 1981

a - Calculated as: Optimum + 0.333(UUILT[d]-Optimum); "MWAT: for growth (Brungs and Jones 1977).
b - Upper Avoidance Temperature (UAT)
c - Ultimate Upper Incipient Temperature (UUILT) or equivalent endpoint (i.e., Chronic Thermal Maximum; ChTM).
d - Default translation from Critical Thermal Maximum (CTM) used when UILT was not available: UUILT + CTM - 2°C.
X - Estmated value (see conversion factors in Appendix B-2).

***Table 10**. Input variables and fish species included in the FTMS "core" RIS scenario (upper) and the FTMS outputs in terms of the proportion of the 21 RIS that consistent with temperatures (C°) for each of five thermal effect thresholds.*

SEL	Family Code	Species Code	Common Name	Optimum °C	MWAT Growth °C	Upper Avoidance °C	UILT °C	Latin Name
x	57	001	Western Mosquitofish	32.0	34.3	36.0	39.0	Gambusia affinis
x	43	032	Spotfin Shiner	30.6	32.4	33.0	36.0	Cyprinella spiloptera
x	43	025	Striped Shiner	30.6	32.5	33.0	36.0	Luxilus chrysocephalus
x	43	048	Red Shiner	30.6	32.5	32.9	36.2	Cyprinella lutrensis
x	43	023	Redfin Shiner	30.6	32.5	33.9	36.2	Lythrurus umbratilis
x	54	002	Blackstripe Topminnow	30.5	33.1	35.0	38.3	Fundulus notatus
x	77	009	Bluegill Sunfish	30.1	32.1	33.0	36.0	Lepomis macrochirus
x	43	013	Creek Chub	30.1	32.0	33.9	35.7	Semotilus atromaculatus
x	20	003	Gizzard Shad	30.0	31.9	32.0	35.8	Dorosoma cepedianum
x	77	011	Longear Sunfish	30.0	32.6	33.7	37.8	Lepomis megalotis
x	40	005	Quillback Carpsucker	30.0	32.4	34.3	37.2	Carpiodes cyprinus
x	43	039	Silverjaw Minnow	29.4	31.3	32.7	35.0	Notropis buccatus
x	47	004	Yellow Bullhead	28.4	31.1	33.1	36.4	Ameiurus natalis
x	43	044	Central Stoneroller	28.2	30.7	33.0	35.7	Campostoma anomalum
x	43	043	Bluntnose Minnow	27.5	30.3	33.0	35.9	Pimephales notatus
x	77	006	Largemouth Bass	27.5	31.0	33.0	38.1	Micropterus salmoides
x	43	020	Emerald Shiner	27.0	29.5	31.1	34.5	Notropis atherinoides
x	80	014	Johnny Darter	24.5	28.5	33.1	36.4	Etheostoma nigrum
x	40	016	White Sucker	23.1	27.0	31.6	34.9	Catostomus commersoni
x	43	001	Common Carp	33.0	35.7	36.0	39.0	Cyprinus carpio

	RIS Included			
Category	100%	90%	75%	50%
	°F(°C)	°F(°C)	°F(°C)	°F(°C)
Optimum	75.8 (23.1)	80.2 (26.8)	82.4 (28.0)	86.0 (30.0)
Growth	80.6 (27.0)	84.9 (29.2)	87.6 (30.9)	89.8 (32.1)
Avoidance (UAT)	88.0 (31.1)	89.6 (32.0)	91.4 (33.0)	91.4 (33.0)
Survival (LT)	90.5 (32.5)	91.4 (33.0)	92.8 (33.8)	93.4 (34.1)
Survival (ST)	94.1 (34.5)	95.0 (35.0)	96.4 (35.8)	97.0 (36.7)
Species Used	N =	21		

Table 11*. FTMS ranks of "core" RIS by their respective temperature thresholds for the optimum, growth, upper avoidance, and lethal temperature endpoints.*

Temperature °C	°F	Optimum Exceeded	Growth Exceeded	UAT Exceeded	ULIT Exceeded
23.1	73.6	White Sucker [1]			
24.5	76.1	Johnny Darter [2]			
27.0	80.6	Emerald Shiner [3]			
27.0	80.6		White Sucker [1]		
27.5	81.5	Bluntnose Minnow [4]			
27.5	81.5	Largemouth Bass [5]			
28.2	82.8	Central Stoneroller [6]			
28.4	83.1	Yellow Bullhead [7]			
28.5	83.3		Johnny Darter [2]		
29.4	84.9	Silverjaw Minnow [8]			
29.5	85.1		Emerald Shiner [3]		
30.0	86.0	Gizzard Shad [9]			
30.0	86.0	Longear Sunfish [10]			
30.0	86.0	Quillback Carpsucker [11]			
30.1	86.2	Bluegill Sunfish [12]			
30.1	86.2	Creek Chub [13]			
30.3	86.5		Bluntnose Minnow [4]		
30.5	86.9	Blackstripe Topminnow [14]			
30.6	87.1	Spotfin Shiner [15]			
30.6	87.1	Striped Shiner [16]			
30.6	87.1	Red Shiner [17]			
30.6	87.1	Redfin Shiner [18]			
30.7	87.3		Central Stoneroller [5]		
31.0	87.8		Largemouth Bass [6]		
31.1	88.0		Yellow Bullhead [7]		
31.1	88.0			Emerald Shiner [1]	
31.3	88.3		Silverjaw Minnow [8]		
31.6	88.9			White Sucker [2]	
31.9	89.4		Gizzard Shad [9]		
32.0	89.6	Western Mosquitofish [19]			
32.0	89.6		Creek Chub [10]		
32.0	89.6			Gizzard Shad [3]	
32.1	89.8		Bluegill Sunfish [11]		
32.4	90.3		Spotfin Shiner [12]		
32.4	90.3		Quillback Carpsucker [13]		
32.5	90.5		Striped Shiner [14]		
32.5	90.5		Red Shiner [15]		
32.5	90.5		Redfin Shiner [16]		
32.6	90.7		Longear Sunfish [17]		
32.7	90.9			Silverjaw Minnow [4]	
32.9	91.2			Red Shiner [5]	
33.0	91.4			Spotfin Shiner [6]	
33.0	91.4			Striped Shiner [7]	
33.0	91.4			Bluegill Sunfish [8]	
33.0	91.4			Central Stoneroller [9]	
33.0	91.4			Bluntnose Minnow [10]	
33.0	91.4			Largemouth Bass [11]	
33.0	91.4	Common Carp [20]			
33.1	91.6		Blackstripe Topminnow [18]		
33.1	91.6			Yellow Bullhead [12]	
33.1	91.6			Johnny Darter [13]	
33.7	92.7			Longear Sunfish [14]	
33.9	93.0			Redfin Shiner [15]	
33.9	93.0			Creek Chub [16]	
34.3	93.7		Western Mosquitofish [19]		
34.3	93.7			Quillback Carpsucker [17]	
34.5	94.1				Emerald Shiner [1]
34.9	94.8				White Sucker [2]
35.0	95.0			Blackstripe Topminnow [18]	
35.0	95.0				Silverjaw Minnow [3]
35.7	96.3				Creek Chub [4]
35.7	96.3				Central Stoneroller [5]
35.7	96.3		Common Carp [20]		
35.8	96.4				Gizzard Shad [6]
35.9	96.6				Bluntnose Minnow [7]
36.0	96.8			Western Mosquitofish [19]	
36.0	96.8				Spotfin Shiner [8]
36.0	96.8				Striped Shiner [9]
36.0	96.8				Bluegill Sunfish [10]
36.0	96.8			Common Carp [20]	
36.2	97.2				Red Shiner [11]
36.2	97.2				Redfin Shiner [12]
36.4	97.5				Yellow Bullhead [13]
36.4	97.5				Johnny Darter [14]
37.2	99.0				Quillback Carpsucker [15]
37.8	100.0				Longear Sunfish [16]
38.1	100.6				Largemouth Bass [17]
38.3	100.9				Blackstripe Topminnow [18]
39.0	102.2				Western Mosquitofish [19]
39.0	102.2				Common Carp [20]

***Table 12**. Input variables and fish species included in the FTMS “alternate” RIS + non-RIS scenario (upper) and the FTMS outputs (lower) in terms of the proportion of the 24 RIS that are consistent with temperatures (C°) for each of five thermal effect thresholds.*

SEL	Family Code	Species Code	Common Name	Optimum °C	MWAT Growth °C	Upper Avoidance °C	UILT °C	Latin Name
x	57	001	Western Mosquitofish	32.0	34.3	36.0	39.0	Gambusia affinis
x	43	032	Spotfin Shiner	30.6	32.4	33.0	36.0	Cyprinella spiloptera
x	43	025	Striped Shiner	30.6	32.5	33.0	36.0	Luxilus chrysocephalus
x	43	048	Red Shiner	30.6	32.5	32.9	36.2	Cyprinella lutrensis
x	43	023	Redfin Shiner	30.6	32.5	33.9	36.2	Lythrurus umbratilis
x	54	002	Blackstripe Topminnow	30.5	33.1	35.0	38.3	Fundulus notatus
x	77	009	Bluegill Sunfish	30.1	32.1	33.0	36.0	Lepomis macrochirus
x	43	013	Creek Chub	30.1	32.0	33.9	35.7	Semotilus atromaculatus
x	20	003	Gizzard Shad	30.0	31.9	32.0	35.8	Dorosoma cepedianum
x	77	011	Longear Sunfish	30.0	32.6	33.7	37.8	Lepomis megalotis
x	40	005	Quillback Carpsucker	30.0	32.4	34.3	37.2	Carpiodes cyprinus
x	43	039	Silverjaw Minnow	29.4	31.3	32.7	35.0	Notropis buccatus
x	47	004	Yellow Bullhead	28.4	31.1	33.1	36.4	Ameiurus natalis
x	43	044	Central Stoneroller	28.2	30.7	33.0	35.7	Campostoma anomalum
x	43	043	Bluntnose Minnow	27.5	30.3	33.0	35.9	Pimephales notatus
x	77	006	Largemouth Bass	27.5	31.0	33.0	38.1	Micropterus salmoides
x	43	020	Emerald Shiner	27.0	29.5	31.1	34.5	Notropis atherinoides
x	80	014	Johnny Darter	24.5	28.5	33.1	36.4	Etheostoma nigrum
x	40	016	White Sucker	23.1	27.0	31.6	34.9	Catostomus commersoni
x	40	004	Smallmouth Buffalo	32.5	34.4	34.8	38.1	Ictiobus bubalus
x	77	005	Spotted Bass	29.9	31.9	33.0	36.0	Micropterus punctulatus
x	77	001	White Crappie	26.0	28.2	31.1	32.6	Pomoxis annularis
x	43	001	Common Carp	33.0	35.7	36.0	39.0	Cyprinus carpio

	RIS Included			
Category	**100%**	**90%**	**75%**	**50%**
	°F(°C)	**°F(°C)**	**°F(°C)**	**°F(°C)**
Optimum	73.6 (23.1)	79.2 (26.2)	82.2 (27.9)	86.0 (30.0)
Growth	80.6 (27.0)	83.7 (28.7)	87.6 (30.9)	89.7 (32.0)
Avoidance (UAT)	88.0 (31.1)	89.1 (31.7)	91.4 (33.0)	91.4 (33.0)
Survival (LT)	87.1 (30.6)	91.2 (32.9)	92.8 (33.8)	93.2 (34.0)
Survival (ST)	90.7 (32.6)	94.8 (34.9)	96.4 (35.8)	96.8 (36.0)
Species Used	**N =**	**24**		

***Table 13**. FTMS ranks of "alternate" RIS by their respective temperature thresholds for the optimum, growth, upper avoidance, and lethal temperature.*

Temperature °C	°F	Optimum Exceeded	Growth Exceeded	UAT Exceeded	ULIT Exceeded
23.1	73.6	White Sucker [1]			
24.5	76.1	Johnny Darter [2]			
26.0	78.8	White Crappie [3]			
27.0	80.6	Emerald Shiner [4]			
27.0	80.6		White Sucker [1]		
27.5	81.5	Bluntnose Minnow [5]			
27.5	81.5	Largemouth Bass [6]			
28.2	82.8	Central Stoneroller [7]			
28.2	82.8		White Crappie [2]		
28.4	83.1	Yellow Bullhead [8]			
28.5	83.3		Johnny Darter [3]		
29.4	84.9	Silverjaw Minnow [9]			
29.5	85.1		Emerald Shiner [4]		
29.9	85.8	Spotted Bass [10]			
30.0	86.0	Gizzard Shad [11]			
30.0	86.0	Longear Sunfish [12]			
30.0	86.0	Quillback Carpsucker [13]			
30.1	86.2	Bluegill Sunfish [14]			
30.1	86.2	Creek Chub [15]			
30.3	86.5		Bluntnose Minnow [5]		
30.5	86.9	Blackstripe Topminnow [16]			
30.6	87.1	Spotfin Shiner [17]			
30.6	87.1	Striped Shiner [18]			
30.6	87.1	Red Shiner [19]			
30.6	87.1	Redfin Shiner [20]			
30.7	87.3		Central Stoneroller [6]		
31.0	87.8		Largemouth Bass [7]		
31.1	88.0		Yellow Bullhead [8]		
31.1	88.0			Emerald Shiner [1]	
31.1	88.0			White Crappie [2]	
31.3	88.3		Silverjaw Minnow [9]		
31.6	88.9			White Sucker [3]	
31.9	89.4		Gizzard Shad [10]		
31.9	89.4		Spotted Bass [11]		
32.0	89.6	Western Mosquitofish [21]			
32.0	89.6		Creek Chub [12]		
32.0	89.6			Gizzard Shad [4]	
32.1	89.8		Bluegill Sunfish [13]		
32.4	90.3		Spotfin Shiner [14]		
32.4	90.3		Quillback Carpsucker [15]		
32.5	90.5		Striped Shiner [16]		
32.5	90.5		Red Shiner [17]		
32.5	90.5		Redfin Shiner [18]		
32.5	90.5	Smallmouth Buffalo [22]			
32.6	90.7		Longear Sunfish [19]		
32.6	90.7				White Crappie [1]
32.7	90.9			Silverjaw Minnow [5]	
32.9	91.2			Red Shiner [6]	
33.0	91.4			Spotfin Shiner [7]	
33.0	91.4			Striped Shiner [8]	
33.0	91.4			Bluegill Sunfish [9]	
33.0	91.4			Central Stoneroller [10]	
33.0	91.4			Bluntnose Minnow [11]	
33.0	91.4			Largemouth Bass [12]	
33.0	91.4			Spotted Bass [13]	
33.0	91.4	Common Carp [23]			
33.1	91.6		Blackstripe Topminnow [20]		
33.1	91.6			Yellow Bullhead [14]	
33.1	91.6			Johnny Darter [15]	
33.7	92.7			Longear Sunfish [16]	
33.9	93.0			Redfin Shiner [17]	
33.9	93.0			Creek Chub [18]	
34.3	93.7		Western Mosquitofish [21]		
34.3	93.7			Quillback Carpsucker [19]	
34.4	93.9		Smallmouth Buffalo [22]		
34.5	94.1				Emerald Shiner [2]
34.8	94.6			Smallmouth Buffalo [20]	
34.9	94.8				White Sucker [3]
35.0	95.0			Blackstripe Topminnow [21]	
35.0	95.0				Silverjaw Minnow [4]
35.7	96.3				Creek Chub [5]
35.7	96.3				Central Stoneroller [6]
35.7	96.3		Common Carp [23]		
35.8	96.4				Gizzard Shad [7]
35.9	96.6				Bluntnose Minnow [8]
36.0	96.8			Western Mosquitofish [22]	
36.0	96.8				Spotfin Shiner [9]
36.0	96.8				Striped Shiner [10]
36.0	96.8				Bluegill Sunfish [11]
36.0	96.8				Spotted Bass [12]
36.0	96.8			Common Carp [23]	
36.2	97.2				Red Shiner [13]
36.2	97.2				Redfin Shiner [14]
36.4	97.5				Yellow Bullhead [15]
36.4	97.5				Johnny Darter [16]
37.2	99.0				Quillback Carpsucker [17]
37.8	100.0				Longear Sunfish [18]
38.1	100.6				Largemouth Bass [19]
38.1	100.6				Smallmouth Buffalo [20]
38.3	100.9				Blackstripe Topminnow [21]
39.0	102.2				Western Mosquitofish [22]
39.0	102.2				Common Carp [23]

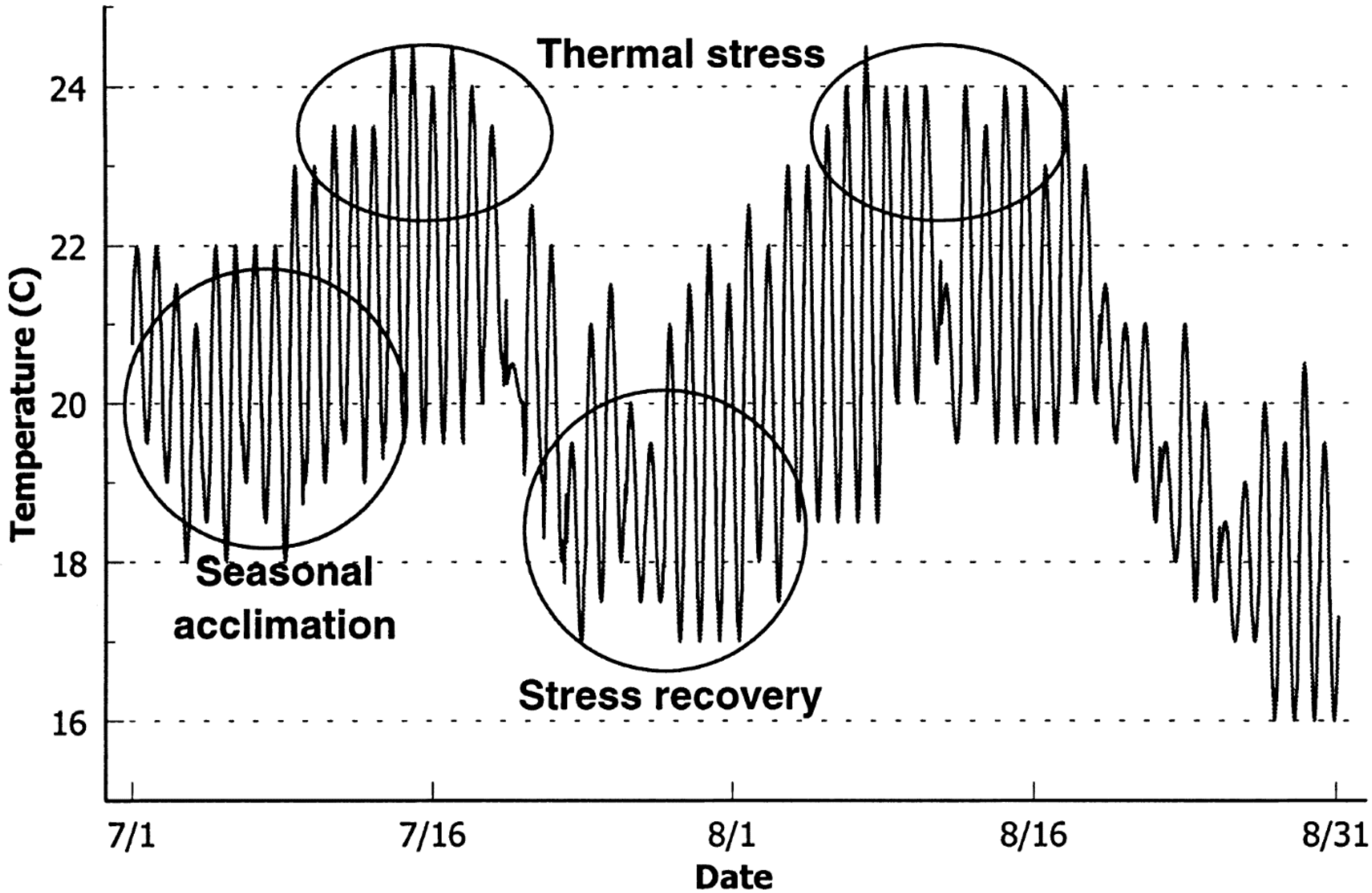


Figure 9. *Factors that affect thermal stress accumulation in fish in environments with fluctuating temperatures (after Bevelhimer and Bennet 2000).*

***Table 14**. Summarized results of a stress/recovery analysis of measured and predicted temperatures in Robinson Creek based on 2016 HOBO data immediately downstream from the MPC 001 discharge (RC05) and EFDC modeled temperatures at RC05, RC07, and RC09 for 2012 and 2016 for the true summer period (June 16-Septmebr 15). Yellow highlighted cells are the maximum temperatures for each scenario.*

2016 HOBO Data					
Period	**Stress (hrs.)**	**Date(s)**	**Max. T (°F)**	**Recovery (hrs.)**	**Date(s)**
1	9.5	7-24	92.3	3.5	7-24 to 7-25
1A				1.8	7-25
2	4.8	7-25	90.8	42.0	7-25 to 7-27
2A				1.7	7-27
3	3.2	7-28	90.4	26.3	7-28 to 7-29
3A				8.3	7-29
4	4.0	7-31	90.8	150.2	8-1 to 8-7
4A				42.8	8-7 to 8-9
5	14.5	8-10	91.2		
5A	12.2	8-11	91.5	1.5	8-12
6	5.5	8-12	91.2		
6A	1.5	8-13	90.8	302.0	8-13 to 8-26
7	9.5	8-28	92.3	16.3	8-28 to 8-29
8	9.7	8-30	91.7	4.2	8-31
8A				178.7	8-31 to 9-7
Totals	74.4	3.4%		779.3	36.1%
2012 EFDC Model Results					
1	1.0	6-29	92.4	18.0	6-29 to 6-30
2	1.0	6-29	91.5	41.0	6-30 to 7-1
3	1.0	7-2	90.8	86.0	7-2 to 7-6
4	5.0	7-6	94.7	42.0	7-6 to 7-8
5	1.0	7-8	91.8	232.0	7-8 to 7-18
6	5.0	7-18	94.2	14.0	7-18
7	5.0	7-19	92.9	132.0	7-20 to 7-25
8	3.0	7-24	91.7		
9	4.0	7-25	91.8	44.0	7-25 to 7-27
10	2.0	7-27	91.5	44.0	7-27 to 8-9
11	2.0	8-9	91.5	890.0	8-9 to 9-15
Totals	28.0	1.3%		653.0	30.2%
2016 EFDC Model Results					
1	3.0	6-22	91.7	15.0	6-22 to 6-23
2	5.0	6-25	94.7	14.0	6-25 to 6-26
3	3.0	6-26	92.6	9.0	6-26 to 6-27
4	5.0	6-27	93.4	855.0	6-22 to 8-1
5	3.0	8-10	90.8	447.0	8-10 to 8-29
6	4.0	8-29	91.5		
6A	7.0	8-30	92.6		
6B	3.0	8-30	91.1	365.0	8-31 to 9-15
	30.0	1.4%		1340.0	62.0%

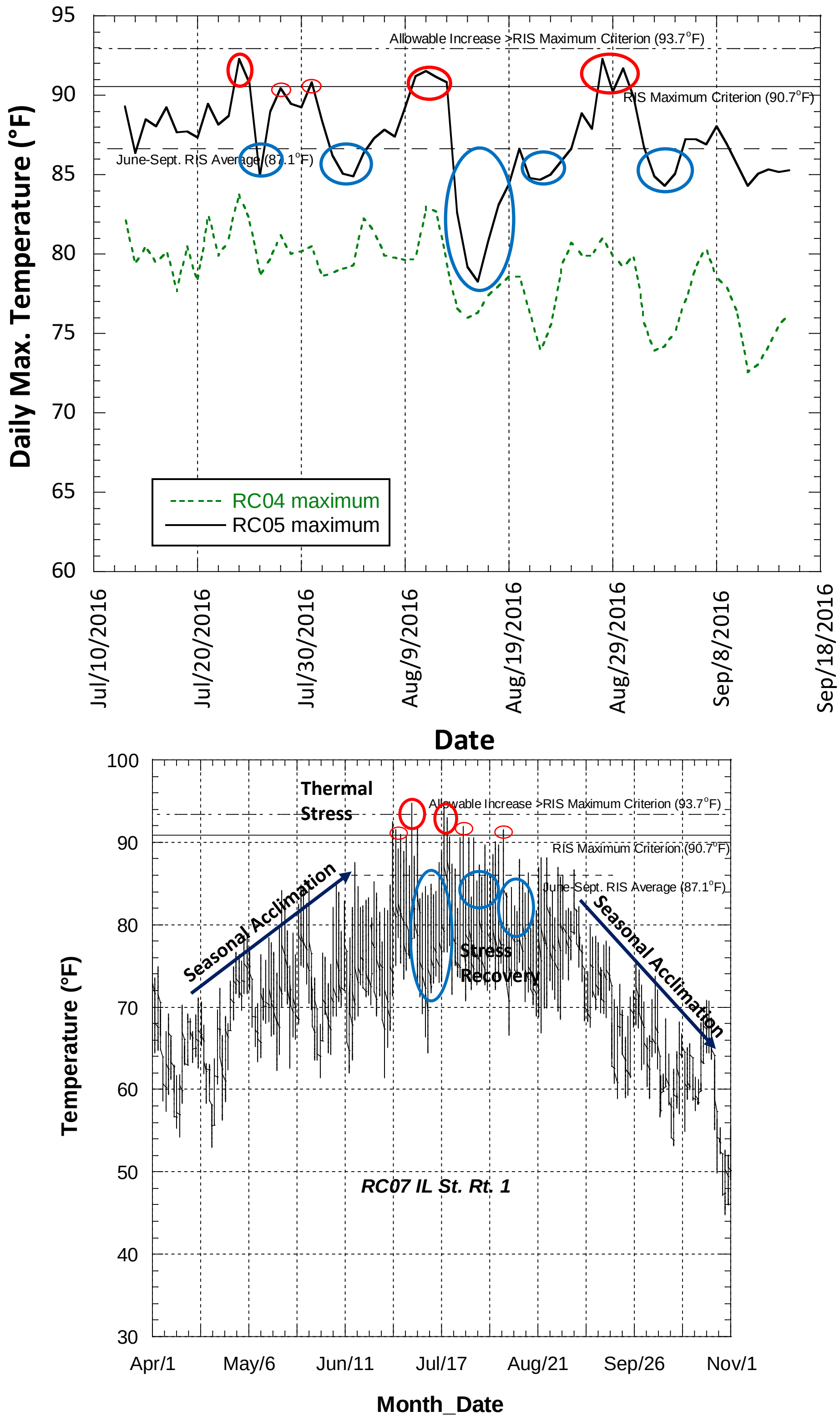


***Figure 10**. Daily temperature profile of Robinson Creek immediately downstream from the MPC 001 outfall (RC05) based on HOBO deployment July 10-September 15, 2016 (upper) and 2012 EFDC modeled temperature at IL Rt. 1 (RC07). The FTMS maximum temperature threshold of 90.7°F is shown along with the 87.1°F FTMS summer season average threshold and the Illinois 3°F not-to-exceed the 90°F maximum criterion. Red circles indicate general periods of thermal stress and blue circles indicate subsequent periods of stress recovery (after Bevelhimer and Bennet 2000).*

APPENDIX A

Section 106.1115 Early Screening Submittal

35 Ill. Admin. Code § 106.1115 Early Screening Submittal

by

Marathon Petroleum Company LP
Illinois Refining Division
400 S Marathon Ave.
Robinson, IL 62454

and

Midwest Biodiversity Institute
P.O Box 21561
Columbus, OH 43221-0561

to

Illinois EPA
Bureau of Water
Division of Water
1021 North Grand Ave. East
P.O. Box 19276
Springfield, IL 62794-9276

March 11, 2016

35 Ill. Admin. Code § 106.1115 Early Screening Submittal

Marathon Petroleum Company LP
Illinois Refining Division, Robinson Refinery
400 S Marathon Ave,
Robinson, IL 62454

BACKGROUND

Marathon Petroleum Company LP (MPC) seeks an alternative thermal effluent limitation pursuant to Section 316[a] of the Clean Water Act (CWA) (33 U.S.C. § 1326[a]), Section 304.141[c] of the Illinois Pollution Control Board's (Board) Water Pollution regulations (35 Ill. Admin. Code § 304.141[c]), and the Board's Subpart K procedural rules (35 Ill. Admin. Code 106, Subpart K). Section 106.1115 of the Board's procedural rules describes the Early Screening information that is required to be submitted to Illinois EPA prior to filing a petition for an alternate thermal effluent limitation. Specifically it states:

a) Prior to filing a petition for an alternative thermal effluent limitations, the petitioner must submit the following early screening information to the Agency:

    1) A description of the alternative thermal effluent limitation requested;
    2) A general description of the method by which the discharger proposes to demonstrate that the otherwise applicable thermal discharge effluent limitations are more stringent than necessary;
    3) A general description of the type of data, studies, experiments and other information that the discharger intends to submit for the demonstration; and
    4) A proposed representative important species list and supporting data and information.

b) Within 30 days after the early screening information is submitted under subsection [a] the petitioner shall consult with the Agency to discuss the petitioner's early screening information.

The Early Screening process precedes the development of a Detailed Plan of Study that is described in Section 106.1120 and is to be submitted to the Agency within 60 days of the Early Screening submittal and discussion.

EARLY SCREENING SUBMITTAL

Marathon Petroleum Company LP, Illinois Refining Division is making an Early Screening submittal pursuant to seeking an alternative thermal effluent limitation under Section 316[a] of the CWA for the Robinson Refinery thermal effluent that is currently discharged via outfall 001 (NPDES Permit IL0004703 September 19, 2013). The present limitations for temperature are described in Special Condition 8 of the NPDES permit as follows:

A. Maximum temperature rise above natural temperature must not exceed 5°F (2.8°C).

B. Water temperature at representative locations in the main river shall not exceed the maximum limits in the following table during more than one (1) percent of the hours in the 12-month period ending with any month. Moreover, at no time shall the water temperature at such locations exceed the maximum limits in the following table by more than 3°F (1.7°C). (Main river temperatures are temperatures of those portions of the river essentially similar to and following the same thermal regimes as the temperature of the main flow of the river.)

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
°F	60	60	60	90	90	90	90	90	90	90	90	60
°C	16	16	16	32	32	32	32	32	32	32	32	16

Alternative Thermal Effluent Limitation

As required by Section 106.1115 [a][1] MPC will request one of the following alternative thermal effluent limitations:

Alternative #1:

~~Maximum temperature rise above natural temperature must not exceed 5°F (2.8°C).~~
Water temperature at representative locations in the main river shall not exceed the maximum limits in the following table during more than ~~one (1.0)~~ [a new alternative percent limitation will be determined by the aquatic life study and assessment] percent of the hours in the 12-month period ending with any month. Moreover, at no time shall the water temperature at such locations exceed the maximum limits in the following table by more than 3°F (1.7°C). (Main river temperatures are temperatures of those portions of the river essentially similar to and following the same thermal regimes as the temperature of the main flow of the river.)

	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
°F	X_1	X_1	X_1	X_1	X_1	X_1	X_1	X_1	X_1	X_1	X_1	X_1
°C	X_1	X_1	X_1	X_1	X_1	X_1	X_1	X_1	X_1	X_1	X_1	X_1

X_1 Temperature limit to be determined by the aquatic life study and assessment.

Under alternative #1 it is possible that the thermal limitations requested may be listed as an end of pipe limitation.

Alternative #2:

~~Maximum temperature rise above natural temperature must not exceed 5°F (2.8°C).~~

A limitation based upon maximum thermal load to be determined during the study period.

Method of Alternate Thermal Effluent Limit Demonstration

As required by Section 106.1115 [a][2] MPC proposes to develop and submit a 316[a] demonstration that has elements of both Predictive and Type II demonstrations that will be supported by field studies of the receiving stream, predictive modeling, and comparisons to thermal tolerance information for representative important species (RIS). This conclusion was reached in accordance with the *Interagency 316[a] Technical Guidance Manual and Guide for Thermal Effects Sections of Nuclear Facilities Environmental Impact Statements* (U.S. EPA 1977) and decision criteria that appear in Section 3.0. The predictive demonstration applies to Robinson Creek as it is impaired due to a variety of causes identified by Illinois EPA (IEPA 2014) which precludes the showing of a lack of prior appreciable harm due to the thermal effluent.

This early submittal is also intended to document the applicant's screening process and conclusions. The intent is to assure that relevant aquatic assemblages are adequately addressed without collecting data that is either redundant or of little value to the applicant and regulatory agencies in accordance with the Interagency Technical Guidance (U.S. EPA 1977). The following is a summary of the biotic category determinations based on an examination of historical data available for Robinson Creek and other area streams and our general knowledge about the suitability of certain aquatic assemblages for assessing thermal effects and water quality in general in warmwater streams of the Midwestern U.S.

Biotic Category Determinations

The Interagency Technical Guidance (U.S. EPA 1977) identifies the following biotic categories as needing to be considered for their potential applicability:

- Phytoplankton
- Zooplankton and Meroplankton
- Habitat Formers
- Shellfish/Macroinvertebrates
- Fish
- Other Vertebrate Wildlife

Each biotic category is to be evaluated as to whether it has a low potential for adverse impacts or if it merits inclusion in the 316[a] demonstration. The conclusions reached for each biotic category about the potential for applicability in Robinson Creek and other area streams are based on recent knowledge about which groups are routinely used to assess streams and rivers, the likelihood of showing adverse impacts due the discharge of heat by the MPC Robinson Refinery, and the general utility of a biotic category for exhibiting non-thermal effects.

The terminology used by the Interagency Technical Guidance is dated compared to more modern terminology used to describe biological assemblages particularly as they relate to established methodologies in widespread use for the purpose of assessing the health and well-being of warmwater streams. The following discussion of each biotic category reflects the more recent terminology.

Algal Assemblage
An algal assemblage in a freshwater system includes both phytoplankton and periphyton and there are methods available to assess each in rivers and streams. This assemblage group is regarded as having a low potential by the Interagency Technical Guidance (U.S. EPA 1977) in terms of their applicability to rivers and streams. In addition, algal assemblages are generally less sensitive to thermal effects than are fish and freshwater mussels. The response of algae to nutrient enrichment is a relevant concern in rivers and streams, but the proposed field studies will include other parameters and indicators that can adequately reveal the adverse effects of nutrient enrichment including diel dissolved oxygen (D.O.) and pH swings, and sestonic and benthic chlorophyll α levels.

<u>Recommendation</u>: Low Potential Impact

Zooplankton and Meroplankton Assemblages
Neither assemblage group is of major prominence or concern in a small stream or a river system with the possible exception of larval fish in the latter (U.S. EPA 1977). Both are considered to be of low potential impact in the study area.

<u>Recommendation</u>: Low Potential Impact

Habitat Formers
This category includes biota that provide the formation of habitat for other aquatic organisms. In freshwater streams and rivers this most commonly includes submergent and emergent aquatic macrophytes. These can be of major consequence in soft bottom low gradient streams and rivers with soft substrates, but much less so in moderate and high gradient streams. While they are gaining prominence as an aquatic assemblage that is monitored in lakes, wetlands, and some large rivers, they are usually not employed to assess warmwater streams. If present at all, they are included as a cover type in the habitat assessment that will be used in the proposed field studies. The vast majority of the habitat in Midwestern U.S. streams is comprised of physical and other features such as pools, riffles, runs, undercut banks, overhanging terrestrial vegetation, and woody debris, all of which are included in the habitat assessment protocol.

<u>Recommendation</u>: Low Potential Impact

Shellfish/Macroinvertebrates
a. *Macroinvertebrates*
Macroinvertebrates are a mainstay of stream and river biological assessments and include all invertebrate taxa that can be seen by the “unaided” eye, i.e., without magnification aids. Many different approaches to sampling and assessing the health of the macroinvertebrate assemblage exist. For the proposed field studies the procedures of the Illinois EPA will be

followed with taxonomic resolution to the lowest practicable level (i.e., genus/species for the common families and orders). While macroinvertebrates are generally regarded as being more thermally tolerant than fish, their inclusion is deemed necessary since they are used by Illinois EPA to determine the status of the General aquatic life use in terms of Section 303[d] impaired waters listings. They are also useful to assess other non-thermal causes of impairment and will be included in the proposed field studies.

Recommendation: High Potential Impact

b. Shellfish

Shellfish generally refers to marine species of clams, mussels, and snails where they are commercially important and susceptible to adverse thermal effects. In freshwater rivers and streams this biotic category primarily includes freshwater mussels of the family Unionidae and snails. While some snails and small freshwater clams are included in the macroinvertebrate assemblage sampling that was previously described, the larger Unionidae are not included and require a separate sampling effort and assessment method. Recent information suggests that certain species of mussels are as thermally sensitive as fish and they are the driver of the recently proposed U.S. EPA ammonia criterion. Based on this recent information, mussels should be regarded as a strong candidate for having a high potential for adverse effects from thermal enrichment and non-thermal impacts. The Illinois Natural History Survey (INHS) database includes mussel data for Robinson Creek and other area streams as follows (Shasteen et al. 2012):

Site BM-01 Sugar Creek – North, Edgar Co., Elbridge-Vermilion Rd Bridge, 51 mi.^{2}
Lampsilis cardium – Relict
Lampsilis siliquoidea - Relict
Mussel Community Index (MCI) = 0; Resource Classification = Restricted

Site BM-02 Sugar Creek – North, Edgar Co., 2 miles SE of Elbridge near state line, 67 mi.^{2}
Uniomerus tetralasmus – Relict
Leptodea fragilis - Dead
Mussel Community Index (MCI) = 0; Resource Classification = Restricted

Site BED-03 Big Creek, Crawford Co., 4 miles E and 2 miles N Oblong, 28.6 mi.^{2}
Uniomerus tetralasmus – Relict
Uniomerus tetralasmus – (1)
Mussel Community Index (MCI) = 9; Resource Classification = Moderate

Site BZO-01 Hutson Creek, Crawford Co., 2 miles S of Hutsonville, 24.3 mi.^{2}
Uniomerus tetralasmus – (1)
Toxoplasma parvum – (9)
Truncilla donaciformis – Dead
Mussel Community Index (MCI) = 4; Resource Classification = Restricted

None of these results convey a robust mussel assemblage in the small streams of the area, but it could be a reflection of a low level of effort in smaller streams of the size of Robinson Creek (≈15 $mi.^2$ drainage area). Given their sensitivity to thermal enrichment and other pollutants it is prudent to consider this assemblage as having a high potential impact.

Recommendation: High Potential Impact

Fish

Fish are widely recognized as having the highest sensitivity to thermal enrichment and are frequently the singular focus of predictive demonstrations and Representative Important Species lists. As such they have a high potential for adverse impacts from thermal and other impacts.

Recommendation: High Potential Impact

Other Vertebrate Wildlife

This biotic category can be wide ranging to include birds, mammals, amphibians, and reptiles that are not included in the preceding categories. While species of all four groups occur in Robinson Creek and other area stream drainages none are compelling enough to warrant inclusion as having a high potential for adverse impacts from thermal enrichment.

Recommendation: Low Potential Impact

Summary of Recommendations

The two principal assemblages for the proposed field studies are fish and macroinvertebrates with mussels as a third assemblage to be considered for inclusion.

General Description of Supporting Data and Studies

As required by Section 106.1115 [a][3] this section describes the supporting data and studies that will be included in a 316[a] demonstration. MPC proposes to conduct field studies of the high potential impact biological assemblages, habitat, and water quality of the Sugar Creek watershed which includes Robinson Creek and tributaries. Predictive thermal modeling and the Fish Temperature Modeling System (FTMS; Yoder 2008) will also be utilized to develop a 316[a] demonstration in support of the alterative thermal effluent limitations sought by MPC.

Proposed Field Studies

The proposed field studies will need to produce the quantity and quality of data needed to meet the following objectives:

1) Document the current General Use aquatic life status in Robinson, Marathon, and Sugar Creeks;
2) Determine the major causes and sources of any observed impairments; and,
3) Document the trajectory of any changes in biological and chemical/physical conditions as compared to available historical data from Illinois EPA FRSS and Basin Surveys.

MPC proposes to accomplish this by building on the Facility Related Stream Surveys (FRSS) conducted by Illinois EPA in six prior assessments dating to 1978 (1978, 1986, 1992, 2008 and 2013). Given the need to account for a complex array of overlapping impacts from upstream sources and non-thermal chemical and physical agents, an initial survey design was developed (Appendix Tables 1 and 2). The need to have sites in proximity to each potential source including point and nonpoint sources is essential to sorting out overlying impacts. Appendix Table 1 lists the proposed sampling sites and the biological, chemical, and physical indicators to be collected at each. Appendix Table 2 lists the chemical parameters to be analyzed in water and sediment samples. The proposed study will be described in more detail under the information requirements of Section 106.1120 Detailed Plan of Study.

Predictive Analyses

Predictive analyses will be accomplished using the FTMS methodology and the thermal effects database for fish and selected macroinvertebrates complied by MBI for the Midwest U.S. and Great Lakes regions with updates as new studies are examined. This will be used to develop predictive analyses using the predictive temperature modeling supported by MPC and an examination of the efficacy of the current Illinois temperature criteria. The process will be very similar to that used for the Lower Des Plaines River temperature criteria analyses (Yoder and Rankin 2006).

Representative Important Species (RIS)

As required by Section 106.1115 [a][4] the following is the initial selection of Representative Important Species (RIS) in support of the demonstration of the alterative thermal effluent limitations sought by MPC. The preliminary selection of RIS followed the FTMS procedure (Yoder 2008) and includes any species with sufficient thermal effects data (Table 1). This initial

Table 1. Preliminary list of representative important fish species for the predictive analyses to be conducted as part of the 316[a] demonstration for the MPC Robinson Refinery thermal effluent.

Species	Wabash Bioregion	IEPA FRSS 2008	IEPA FRSS 2013	Thermal Data Available?
Shortnose gar			X	√
Grass pickerel	X			
Smallmouth buffalo	X		X	√
White sucker	X			√
Creek chubsucker	X			
Common carp	X		X	√
Golden shiner	X			√
Creek chub	X	X	X	√
Suckermouth minnow	X			
Emerald shiner	X	X	X	√
Redfin Shiner	X			
River shiner	X			
Steelcolor shiner	X		X	
Sand shiner			X	
Red shiner			X	
Spotfin shiner	X	X	X	√
Silverjaw minnow	X	X	X	
Mississippi silvery minnow	X		X	
Bluntnose minnow	X	X	X	√
Central stoneroller	X		X	√
Yellow bullhead	X			√
Blackstripe topminnow	X	X	X	√
Western mosquitofish	X	X	X	
Pirate perch	X			
White crappie			X	√
Spotted bass			X	√
Largemouth bass	X			√
Green sunfish	X		X	√
Bluegill	X	X	X	√
Johnny darter	X			
Orangethroat darter	X			√
Slough darter	X			
TOTALS (32 species)	**27**	**8**	**19**	**18**

list was compiled by querying the Illinois EPA databases for the 2008 and 2013 FRSS surveys combined (Appendix Table A-3) and all sites in the Wabash bioregion at sites draining <30 square miles (Appendix Table B-4). Species that were found in “sufficient numbers” were included. Sufficient numbers can vary by the species since some species are inherently more numerous than others. For example, species such as bluntnose minnow would be expected to occur in the hundreds whereas the slough darter will occur in low numbers wherever it is found, thus these tendencies were taken into account when deciding about including a particular species as an RIS.

The preliminary selection of RIS resulted in 32 total species between the Wabash bioregion and 2008 and 2013 FRSS datasets of which 16 have thermal effects data (Table 1). The inclusion of the wider area of the Wabash bioregion assures that the RIS list will not be unintentionally truncated by selecting species only from an area with widespread impairments, which would have happened if only the 2008 FRSS results were considered. The 2013 FRSS added 5 new species not included from the Wabash bioregion. In addition, the proposed 2016 sampling could reveal additional RIS and these will be added to the final FTMS analyses. A literature search will be conducted to determine if new thermal effects data exists for any of the species listed in Table 1.

The preliminary RIS currently includes only fish species. Depending on the outcome of the further consideration of freshwater mussels during the Early Screening process and/or a new field assessment, mussel species could be added as RIS.

REFERENCES

Shasteen, D.K., S. A. Bales, A. L. Price. 2012. Freshwater mussels of the Embarras River basin and minor Wabash tributaries in Illinois. Illinois Natural History Survey, 1816 South Oak Street, Champaign, IL 61820, NHS Technical Report 2012 (30).

U.S. EPA. 1977. Interagency 316(a) technical guidance manual and guide for thermal effects sections of nuclear facilities environmental impact statements. Office of Water Enforcement, Permits Division, Industrial Permits Branch. 147 pp.

Yoder, C.O. 2008. Challenges with modernizing a temperature criteria derivation methodology: the fish temperature modeling system, pp. 1-1 to 1-19. *in* Robert Goldstein and Christine Lew (eds.). Proceedings of the Second Thermal Ecology and Regulation Workshop, Electric Power Research Institute, Palo Alto, CA.

Yoder, C.O. and E.T. Rankin. 2006. Temperature Criteria Options for the Lower Des Plaines River. Final Report to U.S. EPA, Region V and Illinois EPA. Center for Applied Bioassessment and Biocriteria, Midwest Biodiversity Institute, Columbus, OH. EPA Grant X-97580701. 87 pp.

Appendix Table A-1. Marathon Petroleum Corporation (MPC) Robinson Refinery proposed study area sites and parameters.

MPC Site ID	FRSS ID	River_Stream Name	RM	Latitude	Longitude	Location-Description	Drain. Area	Fish	Macroinvertebrates	Habitat	Datasonde	Field WQ	Demand	Nutrients	Metals	Organics	Sed. Metals & Organics
QC01	BFCB	Quail Creek	0.50	39.019625	-87.72745	Ust. confl. with Robinson Creek	2.29	F	IEPA MH	QHEI		8X	6X	6X	6X	6X	1X
RC01	BFC-20	Robinson Creek	6.50	39.015168	-87.726464	RR bridge 0.1 mi. ust. Robinson WWTP	2.59	F	IEPA MH	QHEI	S	8X	6X	6X	6X	6X	1X
RWMZ	BFC-RB-EI	Robinson Creek	6.45	39.014383	-87.725301	Robinson WWTP mixing zone	3.24	E (MZ)	MZ	QHEI (MZ)		8X	6X	6X	6X	6X	
RC02		Robinson Creek	6.25	39.015714	-87.722492	0.2 mi. dst. Robinson WWTP	3.27	E	IEPA MH	QHEI	S	8X	6X	6X	6X	6X	1X
RC03	BFC-19	Robinson Creek	6.00	39.017105	-87.72134	Dst. Quail Cr. confl.; 0.4 mi dst. Robinson WWTP	5.73	E	IEPA MH	QHEI	S	8X	6X	6X	6X	6X	1X
RC04	BFC-25	Robinson Creek	5.20	39.014534	-87.709609	Farm access road ust. MPC 001 outfall	6.51	E	IEPA MH	QHEI	W,S	8X	6X	6X	6X	6X	1X
MPMZ	BFC-MR-EI	Robinson Creek	5.00	39.01306	-87.70778	MPC 001 outfall mixing zone	6.53	E (MZ)	MZ	QHEI (MZ)		8X	6X	6X	6X	6X	
MC01	BFCA-22	Marathon Creek	0.16	39.011665	-87.709664	Dst. farm access road - 002, 003, 005, 008 outfalls;	1.24	F	IEPA MH	QHEI	S	8X	6X	6X	6X	6X	1X
RC05	BFC-26	Robinson Creek	4.90	39.0125	-87.7064	0.1 mi. dst. MPC 001 (outside mixing zone)	7.94	E	IEPA MH	QHEI	W,S	8X	6X	6X	6X	6X	1X
UT01		U.T. Robinson Creek[1]	0.10	39.0099	-87.7044	MPC 006 tributary	0.33	F	IEPA MH	QHEI	S	4X	2X	2X	2X	2X	1X
RC06		Robinson Creek	4.60	39.0115	-87.7023	Dst. 006 trib.; 0.4 mi. dst. MPC 001	8.39	E	IEPA MH	QHEI	S	8X	6X	6X	6X	6X	1X
UT02		U.T. Robinson Creek[1]	0.10	39.0106	-87.6905	MPC RR yard trib. - 007, 009, 010 outfalls	1.47	F	IEPA MH	QHEI	S	4X	2X	2X	2X	2X	1X
RC07	BFC-11	Robinson Creek	3.30	39.0130	-87.6847	IL Rt 1 - 1.7 mi. dst. MPC 001	10.4	D,E	IEPA MH	QHEI	W,S	8X	6X	6X	6X	6X	1X
RC08		Robinson Creek	2.00	39.01725	-87.667852	1500 N - 3.0 mi. dst. MPC 001	12.3	D,E	IEPA MH	QHEI	S	8X	6X	6X	6X	6X	1X
RC09	BFC-10	Robinson Creek	1.00	39.02239	-87.65268	1150 E - 4.0 mi. dst. MPC 001	13	D,E	IEPA MH	QHEI	W,S	8X	6X	6X	6X	6X	1X
SC01	BF-22	Sugar Creek	5.90	39.04111	-87.65806	1550 N - background site	14.2	E	IEPA MH	QHEI	W,S	8X	6X	6X	6X	6X	1X
SC02	BF-11	Sugar Creek	4.10	39.021902	-87.633767	1150 E - 0.5 mi. dst. Robinson Creek	30.7	D,E	IEPA MH	QHEI	S	8X	6X	6X	6X	6X	1X
SC03	BF-01	Sugar Creek	1.60	39.0047	-87.5975	Palestine - E. Franklin Street - dst. RR yard	35.1	D,E	IEPA MH	QHEI	S	8X	6X	6X	6X	6X	1X
LC01	BFB-13	Lamotte Creek	1.90	38.99515	-87.607661	IL Rt 33 - S of Palestine - background site	26.7	E	IEPA MH	QHEI	S	8X	6X	6X	6X	6X	1X
							Totals	17	17	17	16	144	110	110	110	110	17

1 - contingent on having sufficient water to sample biota.

Fish Sampling Codes:
D - Roller barge - 200 meters
E - Longline - 150 meters
F - Backpack - 100 to 125 meters
MZ - mixing zone site - 50 meters

Macroinvertebrates:
MH - IEPA multihabitat method
MZ - Mixing zone sample

Datasonde:
S - summer deployment (5 Sondes/week over 6 total weeks)
W - winter deployment (4X January 25 - March 31)

Field WQ:
Temperature, D.O., Conductivity, pH
2X collected by fish crew
6X collected by chemical crew
All water and sediment samples collected by chemical crew mid-June to mid-October

Appendix Table A-2. Chemical parameters for laboratory analysis by parameter groups.

MPC Chemical Lab Analyses - Parameter Groups for Water and Sediment Sampling					
Field (Fi):	**Demand (De):**	**Nutrients (Nu):**	**Metals (Me)**	**Organics (O):**	**Sediment:**
Conductivity	Alkalinity	Benthic Chl a	Ag	BNAs	BNAs
D.O.	BOD5	Chlorophyll a	Al	Cyanide[1]	Metals
pH	Chloride	NH3-N	As	Pesticides	PAHs
Temp.	COD	NO2-N	Be	Phenol (4AAP)	PCB
	Conductivity	NO3-N	Bo	Total BETX	Pesticides
	Fluoride	TKN	Ca	Total PNAs	VOCs
	pH	Total P	Cd	VOCs	
	SSC		Co		
	Sulfate		Cr		
	Sulfide		Cr^{+6}		
	TDS		Cu		
	TOC		Fe		
	TSS		K		
			Mg		
			Mn		
			Na		
			Ni		
			Pb		
			Se		
			Sr		
			Vd		
			Zn		
(yellow)	- specifically listed in MPC Robinson Refinery NPDES permit.				
(tan)	- Listed by IEPA for FRSS or Basin Surveys.				

[1] - To be analyzed for in samples collected at sites RC04, MPMZ, and RC05 only.

Appendix Table A-3. Fish species collected in the IEPA FRSS survey of Robinson Creek in 2008 and 2013.

	Stream:		Robinson Creek			Marathon Creek	Robinson Creek		Sugar Creek	Sugar Creek	Lamotte Creek	
	Site:		**BFC-20**	**BFC-19**	**BFC-25**	**BFCA-22**	**BFC-26**	**BFC-11**	**BF-01**	**BF-11**	**BFB-13**	
	Date:		Combined	Combined	Combined	Combined	Combined	Combined	Combined	Combined	Combined	
Scientific name	**Common name**	**T. ind**	**SH**	**SH**	**SH**	**SH**	**SH**	**SH**	**SH**	**SH**	**SH**	**RIS**
Lepisosteus platostomus	Shortnose gar	10	0	9	0	0	0	0	0	0	1	**X**
Dorosoma cepedianum	Gizzard shad	4	0	0	0	0	0	3	0	0	1	
Campostoma anomalum	Central stoneroller	12	1	5	2	0	0	0	0	4	0	**X**
Ctenopharyngodon idella	Grass carp	23	0	0	0	3	4	1	0	8	7	
Cyprinus carpio	Carp	34	3	1	3	5	6	9	0	7	0	**X**
Notropis buccatus	Silverjaw minnow	69	3	0	15	0	0	1	9	12	29	**X**
Hybognathus nuchalis	Silvery minnow	2211	5	16	100	11	263	1004	0	812	0	**X**
Notropis atherinoides	Emerald shiner	567	0	0	12	4	33	10	364	11	133	**X**
Notropis blennius	River shiner	0	0	0	0	0	0	0	0	0	0	
Notropis stramineus	Sand shiner	25	1	0	4	0	0	0	0	19	1	
Cyprinella spiloptera	Spotfin shiner	301	1	91	40	0	7	0	6	25	131	**X**
Cyprinella whipplei	Steelcolor shiner	16	0	2	1	0	1	0	0	4	8	
Cyprinella luntrensis	Red shiner	29	1	20	0	0	0	0	0	8	0	**X**
Lythrurus umbratilus	Redfin shiner	18	0	0	4	0	0	0	0	0	14	**X**
Luxilus chrysocephalus	Striped shiner	2	1	1	0	0	0	0	0	0	0	
Notemigonus crysoleucas	Golden shiner	1	1	0	0	0	0	0	0	0	0	
Pimephales notatus	Bluntnose minnow	116	5	3	78	0	1	1	3	1	24	**X**
Semotilus atromaculatus	Creek chub	69	12	13	38	5	0	0	0	0	1	**X**
Carpiodes carpio	River carpsucker	1	0	0	0	0	0	1	0	0	0	
Carpiodes cyprinus	Quillback	0	0	0	0	0	0	0	0	0	0	
Catostomus commersoni	White sucker	3	0	0	0	1	0	0	0	1	1	
Erimyzon oblongus	Creek chubsucker	0	0	0	0	0	0	0	0	0	0	
Ictiobus bubalus	Smallmouth buffalo	38	0	0	0	4	1	16	0	7	10	**X**
Moxostoma erythrurum	Golden redhorse	1	0	0	0	0	0	1	0	0	0	
Ictalurus punctatus	Channel catfish	0	0	0	0	0	0	0	0	0	0	
Ameiurus natalis	Yellow bullhead	1	0	0	0	0	0	0	0	0	1	
Aphredoderus sayanus	Pirate perch	0	0	0	0	0	0	0	0	0	0	
Fundulus notatus	Blackstripe topminnow	30	5	8	10	0	0	5	0	0	2	**X**
Gambusia affinis	Mosquitofish	35	0	0	0	0	0	9	0	0	26	**X**
Labidesthes sicculus	Brook silverside	0	0	0	0	0	0	0	0	0	0	
Lepomis cyanellus	Green sunfish	22	3	0	1	13	0	0	0	4	1	**X**
Lepomis macrochirus	Bluegill	52	4	6	2	6	12	8	0	12	2	**X**
Lepomis megalotis	Longear sunfish	11	0	0	1	0	0	2	2	0	6	**X**
Pomoxis annularis	White crappie	54	0	0	0	54	0	0	0	0	0	**X**
Micropterus punctulatus	Spotted bass	36	4	1	6	17	0	2	0	0	6	**X**
Miropterus dolomieu	Smallmouth bass	2	0	0	0	0	0	2	0	0	0	
Micropterus salmoides	Largemouth bass	8	2	2	0	0	2	2	0	0	0	
Etheostoma blennioides	Greenside darter	0	0	0	0	0	0	0	0	0	0	
Etheostoma caeruleum	Rainbow darter	0	0	0	0	0	0	0	0	0	0	
Etheostoma flabellare	Fantail darter	0	0	0	0	0	0	0	0	0	0	
Etheostoma nigrum	Johnny darter	8	0	0	0	0	0	0	6	0	2	**X**
Etheostoma spectabile	Orangethroat darter	0	0	0	0	0	0	0	0	0	0	
Percina caprodes	Log perch	2	1	0	0	0	0	1	0	0	0	
Percina maculata	Blackside darter	0	0	0	0	0	0	0	0	0	0	
Aplodinotus grunniens	Freshwater drum	0	0	0	0	0	0	0	0	0	0	
*Lepomis macrochirus*L cyaneli*	Bluegill x Greenn sunfish hybrid	4	0	4	0	0	0	0	0	0	0	
Hypophthalmichthys molitrix	Silver Carp	6	0	0	0	2	0	4	0	0	0	
	Number of Individuals:	3815	53	182	317	125	330	1082	390	935	407	
	Number of Taxa:		47	47	47	47	47	47	47	47	47	
		Site:	**BFC-20**	**BFC-19**	**BFC-25**	**BFCA-22**	**BFC-26**	**BFC-11**	**BF-01**	**BF-01**	**BFB-13**	**19**
		Seine hauls	4	4	4	4	4	4	4	4	4	

Appendix Table A-4. Fish species collected by IEPA/IDNR in the Wabash faunal region at sites <30 mi^2.

FAMILY	SPECIES	SPECIES NAME	SCIENTIFIC NAME	NUMBER	RIS
10	002	SHORTNOSE GAR	*Lepisosteus platostomus*	2	
15	001	BOWFIN	*Amia calva*	1	
20	003	GIZZARD SHAD	*Dorosoma cepedianum*	16	
37	001	GRASS PICKEREL	*Esox americanus vermiculatus*	37	X
40	002	BIGMOUTH BUFFALO	*Ictiobus cyprinellus*	1	
40	004	SMALLMOUTH BUFFALO	*Ictiobus bubalus*	46	X
40	005	QUILLBACK CARPSUCKER	*Carpiodes cyprinus*	14	
40	006	RIVER CARPSUCKER	*Carpiodes carpio carpio*	11	
40	010	GOLDEN REDHORSE	*Moxostoma erythrurum*	2	
40	016	WHITE SUCKER	*Catostomus commersoni*	193	X
40	018	SPOTTED SUCKER	*Minytrema melanops*	3	
40	020	CREEK CHUBSUCKER	*Erimyzon oblongus*	313	X
43	001	COMMON CARP	*Cyprinus carpio*	21	X
43	003	GOLDEN SHINER	*Notemigonus crysoleucas*	79	X
43	013	CREEK CHUB	*Semotilus atromaculatus*	769	X
43	015	SUCKERMOUTH MINNOW	*Phenacobius mirabilis*	89	X
43	020	EMERALD SHINER	*Notropis atherinoides*	58	X
43	023	REDFIN SHINER	*Lythrurus umbratilis*	352	X
43	025	STRIPED SHINER	*Luxilus chrysocephalus*	3	
43	027	RIVER SHINER	*Notropis blennius*	100	X
43	031	STEELCOLOR SHINER	*Cyprinella whipplei*	72	X
43	032	SPOTFIN SHINER	*Cyprinella spiloptera*	175	X
43	034	SAND SHINER	*Notropis stramineus*	29	X
43	039	SILVERJAW MINNOW	*Notropis buccatus*	506	X
43	040	MISS. SILVERY MINNOW	*Hybognathus nuchalis*	196	X
43	041	BULLHEAD MINNOW	*Pimephales vigilax*	3	
43	043	BLUNTNOSE MINNOW	*Pimephales notatus*	1508	X
43	044	CENTRAL STONEROLLER	*Campostoma anomalum*	334	X
43	048	RED SHINER	*Cyprinella lutrensis*	5	
43	137	Ribbon shiner	*Lythrurus fumeus*	1	
47	002	CHANNEL CATFISH	*Ictalurus punctatus*	1	
47	004	YELLOW BULLHEAD	*Ameiurus natalis*	57	X
47	013	TADPOLE MADTOM	*Noturus gyrinus*	12	
54	002	BLACKSTRIPE TOPMINNOW	*Fundulus notatus*	706	X
54	005	BLACKSPOTTED TOPMINNOW	*Fundulus olivaceus*	36	X
57	001	WESTERN MOSQUITOFISH	*Gambusia affinis*	356	X
68	001	PIRATE PERCH	*Aphredoderus sayanus*	379	X
70	001	BROOK SILVERSIDE	*Labidesthes sicculus*	1	
77	001	WHITE CRAPPIE	*Pomoxis annularis*	2	
77	002	BLACK CRAPPIE	*Pomoxis nigromaculatus*	1	
77	006	LARGEMOUTH BASS	*Micropterus salmoides*	29	X
77	007	WARMOUTH SUNFISH	*Lepomis gulosus*	8	
77	008	GREEN SUNFISH	*Lepomis cyanellus*	673	X
77	009	BLUEGILL SUNFISH	*Lepomis macrochirus*	214	X
77	010	ORANGESPOTTED SUNFISH	*Lepomis humilis*	9	
77	011	LONGEAR SUNFISH	*Lepomis megalotis*	738	X
77	012	REDEAR SUNFISH	*Lepomis microlophus*	2	
80	005	BLACKSIDE DARTER	*Percina maculata*	17	
80	014	JOHNNY DARTER	*Etheostoma nigrum*	170	X
80	023	ORANGETHROAT DARTER	*Etheostoma spectabile*	49	X
80	028	MUD DARTER	*Etheostoma asprigene*	3	
80	030	SPOTTAIL DARTER	*Etheostoma squamiceps*	5	
80	031	SLOUGH DARTER	*Etheostoma gracile*	13	X
80	032	BLUNTNOSE DARTER	*Etheostoma chlorosomum*	4	
85	001	FRESHWATER DRUM	*Aplodinotus grunniens*	3	
					27

APPENDIX B

DATABASES AND PROCEDURES FOR USING THE FISH TEMPERATURE MODELING SYSTEM (FTMS)

APPENDIX B

DATABASES AND PROCEDURES FOR USING THE FISH TEMPERATURE MODELING SYSTEM (FTMS)

Appendix B-1: Database of temperature endpoints for 125 fish species and 28 macroinvertebrate taxa.

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
Petromyzondidae	Silver lamprey (*Ichthyomyzon unicuspis*)	W.L. Erie - Ohio	1973-74	Lab A	Ad.					(4.5)31.6[ee]	Reutter and Herdendorf 1976
	Northern brook lamprey (*Ichthyomyzon fossor*)	Big Garlic R. - Mich.	1975	Lab A	larvae (ammocoetes)					(15) 30.5[q]	Potter and Beamish 1975
	American brook lamprey (*Lampetra appendix*)	Big Creek - Ontario	1975	Lab A	larvae (ammocoetes)					(15) 29.5[q]	Potter and Beamish 1975
	Sea lamprey (*Petromyzon marinus*)	Great Lakes - Canada	1963	Lab A	larvae					(20) 29[m,n] (20) 29.7[m,o] (20) 30.3[m,p] (20) 31.1[m,q] (20) 31.4[m,r]	McCauley 1963
				Lab B	eggs	12-26[e]	18[e]				Spotilla et al. 1979
		Fish Creek - New York	1975	Lab A	larvae (ammocoetes)					(5) 29.5[q] (15) 30[q] (25) 31[q] 31.4[t]	Potter and Beamish 1975
					larvae (ammocoetes)			13.6[dd]			Jobling 1981
					Ad.			(10) 14.3[dd]			Talmadge and Coutant 1979
		L. Superior tribs.			Ad. larvae (ammocoetes)			(Su) 6-15[kk] (Sp) 10-26.1[kk] (Su) 15-20[kk]			Moman et al. 1980
					larvae (ammocoetes)		15-20				Farmer et al. 1977
Polyodontidae	Paddlefish *(Polyodon spathula)*	Texas	1990+	Lab A-2	yoy					(21) 33.4[ee] [5 da.] (21) 33.5[ee] [25 da.] (21) 35.2[ee] [80 da.]	Kurten and Hutchinson 1992
Lepisosteidae	Longnose gar (*Lepisosteus osseus*)	L. Monona - Wisc.	1970	Field A	Ad. Ad.			30.2 - 31,8[i,l,m]	32[i,l,m] 32[l,m]		Neill and Magnuson 1974
		Wabash R. - Ind.	1968-73	Field A	Ad.			(Su) 33-35[kk]	34.8[m]		Gammon 1973
		W.L. Erie - Ohio	1973-74	Lab C	yoy (1) Ad. (1)			(Su) 25.3[tt,dd] (Su) 33.1[tt,dd]			Reutter and Herdendorf 1974, 1976

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Longnose gar (cont'd)	Ohio R. - Ohio, Ky.	1974	Field A	Ad. - juv.	(Su) 30-34[kk] (Fa) 24-28[kk] (Wi) 12-16[kk]					Yoder and Gammon 1976b
		Ohio R. - Ohio, Ky.	1970-75	Field A	Ad. - juv.	(Su) 31-34[kk]			35[m]		Yoder and Gammon 1976a
		White R. - Indiana	1965-72	Field A	Ad. - juv.				33.9[j]		Proffitt and Benda 1971
				Lab C			26.4				Scott and Crossman 1973
	Shortnose gar (*Lepisosteus platosomus*)	Wabash R. - Indiana	1968-73	Field A	Ad.			(Su) 33-35[kk]	34.8[m]		Gammon 1973
		White R.-Indiana		Field A	Ad.				36.1[j]		Proffitt and Benda 1971
Amiidae	Bowfin (*Amia calva*)	Western Pennsylvania	1978	Lab D	Ad.			30.5[dd] 31.3[tt,k] 29.6[tt,l]			Reynolds et al. 1978
		W. L. Erie - Ohio	1973-74	Lab A	Ad.					(23.8) 37[ee]	Reutter and Herdendorff 1976
		Pond - Oklahoma	1965	Lab B	Ad.					(24) 35.2[ee]	Horn and Riggs 1973
								30.5[dd]			Houston 1982
Hiodontidae	Mooneye (*Hiodon tergisus*)	Wabash R. - Indiana	1968-73	Field A	Ad.			(Su) 27.5-29[kk]	28.5[m]		Gammon 1973
	Goldeye (*Hiodon alosoides*)	Wabash R. - Indiana	1968-73	Filed A	Ad.			(Su) 27-29[kk]	29[m]		Gammon 1973
	American eel *(Anguilla rostrata)*	Connecticut - Connecticut R.		Field A	Ad.			20.5[dd]	33[j]		Marcy 1976
Clupeidae	Alewife (*Alosa pseudoharengus*)	Delaware R. - Delaware	1971	Lab C	juv.			(21.1) 21.7 (17.8) 20	(17.2) 26.1 (17.8) 24.2 (25) 30		Meldrim and Gift 1971
		L. Michigan - Illinois	1976	Lab A	Ad.					(10)23.5[r], 29.5[ee] (15)23,5[r],30.1[ee] (20)24.5[r],31.2[ee]	Otto et al. 1976

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Alewife (cont'd)	L. Michigan - Illinois	1976	Lab A	yoy					(10-12)26.5[r],28.3[ee] (18-20)30.3[r],32.7[ee] (24-26)32.1[r],34.4[ee]	McCauley 1981
		L. Michigan - Illinois		Lab E	Ad.			May (9-11) 21[s] June(10-11) 19[s] Aug (15-18) 16[s] Sep (10-12) 16[s] Nov (5-9) 16[s] Dec (1-4) 11[s] Jan (1-3) 12[s]			McCauley 1981
					yoy			May (7-10) 21[s] Aug (15-18) 25[s] (24-25) 25[s] Sep (10-12) 24[s] Nov (5-9) 21[s] Dec (1-4) 19[s]			
		W. L. Erie - Ohio	1973-74	Lab C	Ad.			(Su) 21.3[tt,dd]			Reutter and Herdendorff 1974
		W. L. Erie - Ohio	1973-74	Lab A	Ad.					(18.2) 30.2[ee]	Reutter and Herdendorff 1976
		L. Michigan - Wisconsin	1979	Lab A	yoy					(27) 28.2[t] (30) 31-34[ww]	McCauley and Binkowski 1982
	Gizzard shad (*Dorosoma cepedianum*)	Wabash R.- Indiana	1968-73	Field A	Ad.			(Su) 28.5-31[kk]	32[m]		Gammon 1973
		Tennessee R. - Alabama	1972-73	Field A	Ad. - juv.					36[yy]	Wrenn 1975
		W.L. Erie - Ohio	1973-74	Lab C	Ad.			(Su) 19[tt,dd] (Fa) 20.5[tt,dd]			Reutter and Herdendorff 1974
		W.L. Erie - Ohio	1973-74	Lab A					(15.9) 31.7[j]		Reutter and Herdendorff 1976
		Put-in-Bay - Ohio	1945-47	Lab A	Ad. - juv.					(25) 34[o] (30) 36[o] (35) 36.5[o]	Hart 1952
		Knoxville, Tenn.	1945-47	Lab A	Ad. - juv.					(25) 34.6[o] (30) 35.8[o]	
		Ohio R. - Ohio, Kentucky	1974	Field A	Ad. - juv.	(Su) 26-34[kk] (Fa) 10-22[kk] (Wi) 4-10[kk]					Yoder and Gammon 1976b
		Ohio R. - Ohio, Kentucky	1970-75	Field A	Ad. - juv.	(Su) 26-29[m,kk]		(Su) 30[m]			Yoder and gammon 1976a

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Gizzard shad (cont'd)	White R. - Indiana	1965-72	Field A	Ad. - juv.						Proffitt and Benda 1971
		Mississippi R. - Minnesota	1973-4	Lab A-2	yoy					(26) 28.5[p]	Cvancara et al. 1977
		Tennessee - Reservoirs		Field B	Ad.			22.5-23.0[dd]			Dendy 1948
		Tennessee - Reservoirs		Field A	Ad.				33.9-34.4[j]		Churchill and Wojtalik 1969
	Skipjack herring (*Alosa chrysochloris*)	Wabash R. - Indiana	1968-73	Field A	Ad.			(Su) 26-28.5[kk]	31.6[m]		Gammon 1973
		Tennessee R. - Alabama	1972-73	Field A	Ad. - juv.				30[cc]		Wrenn 1975
		Ohio R. - Ohio, Kentucky	1974	Field A	Ad. - juv.	(Fa) 16-30[kk] (Wi) 10-16[kk]					Yoder and Gammon 1976b
		Ohio R. - Ohio, Kentucky	1970-75	Field A	Ad. - juv.	(Su) 25-29[m,kk]			30.5[m]		Yoder and Gammon 1976a
Salmonidae	Lake trout (*Salvelinus namaycush*)	L. Minnewanka - Canada (Alberta)	1951	Lab B	Ad.					(10) 22.9m,n (15) 24m,n (15) 23.6m,o (20) 25.1m,n (20) 24.6m,o (20) 24m,p (20) 23.5m,q	Fry and Gibson 1953
		Hatchery - Canada	1953, 1964	Lab E	yr.			(5) 11.7[s] (10) 11.6[s] (15) 11.9[s] (20) 11.8[s] 11.7[dd]			McCauley and Tait 1970
		L. Michigan - Wisconsin	1972-73	Field A	Ad.	9.9 - 14.1[i]	11.8[i,tt]				Spigarelli 1975
	Brook Trout *(Salvelinus fontinalis)*	Hatchery - Virginia	1974+	Lab C[bb]	Juv.	(12) 12.8-15.0[kk] (15) 14.5-16.1[kk] (18) 16.0-17.3[kk] (21) 17.2-18.8[kk] (24) 18.2-20.5[kk] (27)[aaa] (30)[aaa] (33)[aaa] (36)[aaa]		(12) 13.7[tt] (15) 15.2[tt] (18) 17.2[tt] (21) 18.3[tt] (24) 19.0[tt] (27) [aaa] (30)[aaa] (33)[aaa] (36)[aaa] 16.8[dd]	(12) 15[j] (15) 18[j] (18) 21[j] (21) 24[j] (24) 26[j] (27)[aaa] (30)[aaa] (33)[aaa] (36)[aaa]	(24) 24[xx]	Cherry et al. 1977

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Brook Trout (cont'd)	Hatchery - Virginia	1973+	Lab C[aa]	yoy	(6) 9.4-12.2[kk] (9) 11.1-13.4[kk] (12) 12.9-14.6[kk] (15) 14.4-16.0[kk] (18) 15.8-17.6[kk] (21) 17.1-19.3[kk] (24) 18.3-21.1[kk] (27)[aaa] (30)[aaa]		(6) 11.2[tt] (9) 11.3[tt] (12) 13.7[tt] (15) 15.2[tt] (18) 18.0[tt] (21) 18.3[tt] (24) 19.0[tt] (27)[aaa] (30)[aaa]	(6) 14[j] (9) 15[j] (12) 16[j] (15) 18[j] (18) 20[j] (21) 23[j] (24) 25[j] (27)[aaa] (30)[aaa]		Cherry et al. 1975
		Ord Creek - Arizona	pre 1980	Lab A-2	Juv.					(10) 28.7[ee] (20) 29.8[ee] (10) 22-28[ww]	Lee and Rinne 1980
		Hatchery - Minnesota	1970+	Lab C	yoy		15.6[a]			20.1[t]	McCormick et al. 1972
		Hatchery - Minnesota	1970+	Lab C	Ad./Juv.		16.1[a]			25.3[t]	Hokanson et al. 1973b
	Rainbow trout (*Oncorhynchis mykiss*)	Firehole R. - Montana	1974, 1975	Field A	Ad.				25[cc]		Kaya et al 1977
		Hatchery - Ontario	1967	Lab C	juv.			(10) 15.8[s] (15) 17.5[s] (20) 22[s]			Javaid and Anderson 1967a
		Hatchery - Ontario	1967	Lab C	juv.			(20) 18.2[u] (20) 21.4[v]			Javaid and Anderson 1967b
		L. Superior - Minnesota	1972	Lab A	juv.					(16) 25.6[q] (16) 25.7[o]	Hokanson et al 1977
				Lab B	juv.	17.2-18.6[w] 15.5-17.3[x]	17.2[w] 15.5[x] 23[y,w] 21[y,x]				
		Hatchery - Ontario	1955	Lab E	yoy			(5) 16[s] (10) 15[s] (15) 13[s] (20) 11[s] 13[t]			Garside and Tait 1958
		England	1962	Lab F	yoy					(18) 26.7[n] (18) 26.4[o] (18) 26.2[p] (18) 26.1[n,z]	Alabaster and Welcomme 1962
		Great Lakes - Ontario	1969	Lab A	yoy					(15) 25-26[q]	Bidgood and Berst 1969
		Hatchery - Ontario	1971	Lab C Lab E	yoy yoy	17-20[kk] 17-18[kk]		19s,18.4[tt] 18s,18.4[tt]			McCauley and Pond 1971
		Hatchery - Ontario	1966	Lab C	yoy			(20) 22[s,bb] (10) 15.2[s,aa]			Jaraid 1972

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Rainbow trout (continued)	Horsetooth Res. - Colorado	1960	Field B	juv. - Ad.	18.9 - 21.1[s]					Horak and Tanner 1964
		L. Michigan - Wisconsin	1972-73	Field A	Ad.	8.5 - 23.5[i]	16.5i,tt				Spigarelli 1975
		W.L. Erie - Ohio	1973-74	Lab A	Ad.					(6.3) 17.5[ee]	Reutter and Herdendorf 1976
		Hatchery - England	1966	Lab A	juv.					(15) 25.3[o] (20) 26.6[o]	Alabaster and Downing 1966
		Hatchery - Maryland	1980+	Lab C	yoy			14.7[tt]	(6) 18[j] (12) none[xx] (18) 24[j] (24) 27[j]	(6) 24.6[t] (12) 25.9[t] (18) 26.7[t] (24) 26.0[t]	Stauffer et al. 1984
		Hatchery - Michigan	198	Lab C	Juv.			(12) 14.1[dd] (18) 18.6[dd]	(12) 18[j] (18) 21[j]	(12) 25[ww]	Cherry et al. 1982
		Hatchery - Virginia	1974+	Lab C[bb]	Ad.	(12) 13.4-15.7[kk] (15) 15.7-17.3[kk] (18) 17.8-19.1[kk] (21) 19.6-21.1[kk] (24) 21.2-23.4[kk] (27)[aaa] (30)[aaa] (33)[aaa] (36)[aaa]		(12) 14.1[tt] (15) 17.1[tt] (18) 18.6[tt] (21) 20.2[tt] (24) 22.2[tt] (27)[aaa] (30)[aaa] (33)[aaa] (36)[aaa] 19.8[dd]	(12) 15[j] (15) 18[j] (18) 21[j] (21) 24[j] (24) 25[j] (27)[aaa] (30)[aaa] (33)[aaa] (36)[aaa]	(24) 23[xx]	Cherry et al. 1977
		Hatchery - Virginia	1973+	Lab C[aa]	yoy	(6) 10.6-11.7[kk] (9) 12.5-13.4[kk] (12) 14.4-15.1[kk] (15) 16.2-16.9[kk] (18) 17.9-18.7[kk] (21) 19.7-20.6[kk] (24) 21.4-22.5[kk] (27)[aaa] (30)[aaa]		(6) 11.6[tt] (9) 12.6[tt] (12) 14.4[tt] (15) 16.9[tt] (18) 18.1[tt] (21) 20.1[tt] (24) 22.0[tt] (27)[aaa] (30)[aaa]	(6) 13[j] (9) 15[j] (12) 17[j] (15) 19[j] (18) 19[j] (21) 23[j] (24) 25[j] (27)[aaa] (30)[aaa]		Cherry et al. 1975
		Hatchery - Missouri	1995+	Lab A-2	yoy					(10) 28.0[ee] (15) 29.1[ee] (20) 29.8[ee]	Currie et al. 1998
		Hatchery - Arizona	pre 1980	Lab A-2	Juv.					(10) 28.5[ee] (20) 29.4[ee] (10) 21-27[ww]	Lee and Rinne 1980

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Brown trout (*Salmo trutta*)	Firehole R. - Montana	1974, 1975	Field A	Ad.				25[cc]		Kaya et al 1977
		England	1960	Lab A	larvae					(5) 24.6[o],24,2[p],23.1[q] (10) 26[n],25[o],24.5[p],23[r] (20) 26[o],24.8[p],23.8[q],23[r],22[ee]	Bishai 1960 (58)
		L. Michigan - Wisconsin	1972-73	Field A	Ad.	7.1 - 21.3[i]	13.8[i,tt]				Spigarelli 1975 (27)
		Hatchery - England	1966	Lab A	juv.					(6) 23.2[o] (15) 26[o] (20) 26.4[o]	Alabaster and Downing 1966 (100)
				Lab C	Juv.			15 - 18[kk,m]	20[m]		
		Hatchery - Virginia	1974+	Lab C[bb]	Ad.	(12) 9.5-16.2[kk] (15) 12.4-17.0[kk] (18) 14.7-18.4[kk] (21) 16.0-20.8[kk] (24) 16.6-22.8[kk] (27)[aaa] (30)[aaa] (33)[aaa] (36)[aaa]		(12) 11.7[tt] (15) 15.5[tt] (18) 17.9[tt] (21) 18.8[tt] (24) 18.5[tt] (27)[aaa] (30) [aaa] (33)[aaa] (36)[aaa] 17.8[dd]	(12) 18[j] (15) 21[j] (18) 21[j] (21) 27[j] (24) 26[j] (27)[aaa] (30)[aaa] (33)[aaa] (36)[aaa]	(24) 25[xx]	Cherry et al. 1977
		Ord Creek - Arizona	pre 1980	Lab A-2	Juv.					(10) 29.0[ee] (20) 29.9[ee] (10) 21-27[ww]	Lee and Rinne 1980
		Hatchery -									
	Chinook salmon *(Oncorhynchus tshawytscha)*	Hatchery - Washington	1949, 1950	Lab A	yoy					(5) 21.5[q] (10)24.3[q] (15)25[q] (20)25.1[q] (24)25.1[r],25.5[q],25.1[t]	Brett 1952
		L. Michigan - Wisconsin	1972-73	Field A	Ad.	10.6 - 23.3[i]	17.3[i,tt]				Spigarelli 1975
	Coho salmon (*Oncorhynchus kisutch*)	Hatchery - British Columbia	1949, 1950	Lab A	yoy					(5) 22.9[q] (10) 23.7[q] (15) 24.3[q] (20) 25[q] (23) 25[q],24.9[r],25[t]	Brett 1952

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Coho salmon (continued)	L. Michigan - Wisconsin	1972-73	Field A	Ad.	12.8 - 22.8[i]	16.6[i,tt]				Spigarelli 1975
		W.L. Erie - Ohio	1973-74	Lab C	Ad.			(Sp) 11.4[tt,dd]			Reutter and Herdendorff 1974, 1976
		Hatchery - Michigan	198	Lab C	Juv.			(12) 14.3[dd] (18) 16.6[dd]	(12) 21[j] (18) 21[j]	(12) 21[ww]	Cherry et al. 1982
Coregonidae	Cisco *(Coregonus artedii)*	Clearwater L. - Minnestoa	1970	Lab A,B	larvae		13 - 18[a]			(3) 19.8o (3) 21(75% mortality) (3) 18(9% mortality)	McCormick et al. 1971
		Clearwater L. - Michigan	1969	Lab B	eggs		5.6[g]			12[mm]	Colby and Broake 1970
		Pickerel L. - Michigan	1967	Lab A						(2) 19.8[r] (5) 21.8[r] (10) 24.3[r] (20) 26.3[r] (25) 25.8[r] 25.8[t]	Edsall and Colby 1970
		Halfmoon L. - Michigan	1968	Field A						(<10) >20[pp]	Colby and Broake 1969
		Lakes - Indiana	1955	Field A,B					20[oo]		Frey 1955
	Lake whitefish (*Coregonus clupeaformis*)	L. Huron - Ontario	1970	Lab A	yoy					(5) 20.6[r] (10) 22.7[r] (15) 25.8[r] (20) 26.6[r] (22.5) 26.6[r] 26.6[t]	Edsall and Rottiers 1976
		L. Erie - Ohio	1934-38	Lab B	egg	0.5 - 6[e]	0.5[e]				Price 1940
Osmeridae	Smelt *(Osmerus mordax)*	W.L. Erie - Ohio	1973-74	Lab A	Ad.					(6) 24.9[ee]	Reutter and Herdendorff 1976
				Lab A-2						(15) 28.5[ee]	Ellis 1984
		Canada - L. Ontario		Lab A-2	Ad.					(1) 22.6[ee] (1.6) 22.8[ee] (3.1) 23.3[ee] (5.4) 24.1[ee] (6.5) 20.1[ee] (8.2) 25.2[ee] (12.2) 26.4[ee]	McCauley 1981

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Smelt (continued)	Wisconsin - L. Michigan			Ad.			(Fa) 6-8[dd] (Fa) 7.8[dd] (Fa) 11-16[dd]	14[j]		Brandt et al. 1980
		L. Superior & L. Erie		Field A	Ad.			(Su) 7-8[kk] [L. Erie] (Su) 11-16[kk] {L. Superior]	(Su) 15.5[j]		Heist and Swenson 1983
Umbridae	Central mudminnow *(Umbra limi)*	Michigan - Pond		Field B						38[cc]	Beltz et al. 1974
		Ontario - streams		Field A	Ad.				28.9[cc]		Scott and Crossman 1973
Esocidae	Chain pickerel (*Esox niger*)	? - Pennsylvania	1977	Lab D	Ad.			24[s]			Reynolds and Casterlin 1977
	Redfin pickerel *(Esox americanus)*	Canada	1958	Lab C			26 (Su)				Ferguson 1958
	Northern pike (*Esox lucius*)	Cow Horn L. - Minn.	1968, 1969	Lab A,B	egg larvae (1 day)	6 - 17.7[e]	11.7[e]			19.2 - 19.9[r] (6.1) 22[o],20.6[q],20.6[r] (11.8) 28[o],26.5[q],24.1[r] (17.7) 28.4[o],27.1[q],25[r]	Hokanson et al. 1973a
					larvae (swimming)	18 - 25.6[b]	25.6[a] 20.8[b]			(7.2) 23.6[o],23.4[q],23.4[r] (12.6) 26.4[o],26.3[q],26.3[r] (17.7) 28.4[o],28.4[q],28.4[r]	
		Westensee- Germany	1966	Lab B	egg	9 - 18[e]	15[e]			19.7[r]	Lillelund 1966
		Brahmsee - Germany	1966	Lab B	egg					19.3[r]	Hokanson et al. 1973a
		England	1965	Lab B	egg	6-16[e]	16[e]			18.9[r]	Switt 1965
		Hatchery - Ontario	1963	Lab A	juv.					(25) 32.2[o] (27.5) 32.7[o] (30) 33.2[o]	Scott 1964 (56)
		Hatchery - Wisconsin	1968	Lab B	eggs		12.2 - 13.3[e]				Steucke 1968
		Mississippi R. - Minnesota	1973-4	Lab A-2	yoy					(26) 30.8[p]	Cvancara et al. 1977
		Ottawa R. - Canada	1978	Review			28.3[bbb]				Christie 1979
		Canada		Lab C	juv.			23.7[dd]			McCauley 1980

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Muskellunge (*Esox masquinongy*)	Hatchery - Ontario	1963	Lab A	juv.					(25) 32.2[o] (27.5) 32.7[o] (30) 33.2[o]	Scott 1964
		Hatchery - New York	1975	Lab A	larvae					(20-25) 32.8[ee]	Bonin and Spotila 1978
		Ottawa R. - Canada	1978	Review			27.0[bbb]				Christie 1979
	Muskellunge X Northern pike	Hatchery - Ontario	1963	Lab A	juv.					(25) 32.5[o] (27.5) 32.7[o] (30) 33.2[o]	Scott 1964
		Hatchery - New York	1975	Lab A	larvae					(20-25) 34[ee]	Bonin and Spotila 1978
Catostomidae	Smallmouth buffalo (*Ictiobus bubalus*)	Wabash R. - Indiana	1968-73	Field A	Ad.			(Su) 31-34[kk]	34.8[m]		Gammon 1973
		Ohio R. - Ohio, Kentucky	1974	Field A	Ad.	(Su) 22-32[kk] (Fa) 18-26[kk] (Wi) 6-14[kk]					Yoder and Gammon 1976b
		Ohio R. - Ohio, Kentucky	1970-75	Field A	Ad.	(Su) 29-31[m,kk]			34[m]		Yoder and Gammon 1976a
		White R. - Indiana	1965-1972	Field A	Ad.				33.6[j]		Proffitt and Benda 1971
				Lab A-2	Juv.					(10) 31.3[ee]	Lutterschmidt and Hutchinson 1997
	Bigmouth buffalo (*Ictiobus cyprinellus*)	Wabash R. - Indiana	1968-73	Field A	Ad.			(Su) 31-34[kk]	34.8[m]		Gammon 1973
		White R. - Indiana	1965-1972	Field A	Ad.				31.7[j]		Proffitt and benda 1971
	River Carpsucker (*Carpiodes carpio*)	Wabash R. - Indiana	1968-73	Field A	Ad.			(Su) 31.5-34.5[kk]	34.8[m]		Gammon 1973 (9)
		Ohio R. - Ohio, Kentucky	1974	Field A	Ad.	(Su) 26-32[kk] (Fa) 16-22[kk] (Wi) 12-16[kk]					Yoder and Gammon 1976b
		Ohio R. - Ohio, Kentucky	1970-75	Field A	Ad.	(Su) 28-31[m,kk]			33.5[m]		Yoder and Gammon 1976a
		White R. - Indiana	1965-1972	Field A	Ad.				37.5[j]		Proffitt and benda 1971
		Mississippi R. - Minnesota	1973-4	Lab A-2	yoy					(26) 35.2[p]	Cvancara et al. 1977
	Quillback carpsucker (*Carpiodes cyprinus*)	Wabash R. - Indiana	1968-73	Field A	Ad.			(Su) 29-31[kk]	34.3[m]		Gammon 1973

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Quillback carpsucker (cont'd)	W.L. Erie - Ohio	1973-74	Lab C	Ad (1)			(Fa) 22.1[tt,dd]			Reutter and Herdendorff 1974
		W.L. Erie - Ohio	1973-74	Lab A	Ad (1)					(23.3) 37.2[ee]	Reutter and Herdendorff 1976
		Ohio R. - Ohio, Kentucky	1974	Field A	Ad.	(Su) 26-32[kk] (Wi) 10-16[kk]					Yoder and Gammon 1976b
		Ohio R. - Ohio, Kentucky	1970-75	Field A	Ad.	(Su) 29-33[m,kk]			34[m]		Yoder and Gammon 1976a
		Indian Cr.- Ohio	199	Lab A-2	Ad.?					(24) 38.8[ee]	Mundahl 1990
	Highfin carpsucker (*Carpiodes velifer*)	White R. - Indiana	1965-1972	Field A	Ad.				33.9j[t]		Proffitt and Benda 1971
	Golden redhorse (*Moxostoma erythrurum*)	Wabash R. - Indiana	1968-73	Field A	Ad.			(Su) 26-27.5[kk]	28.5[m]		Gammon 1973
		Ohio R. - Ohio, Kentucky	1970-75	Field A	Ad.	(Su)26-27.5[m,kk]			28[m]		Yoder and Gammon 1976a
		Walhonding R. - Ohio	200	Lab A-2	juv.-Ad.					(21.1) 35.4[ee]	Reash et al. 2000
	Smallmouth redhorse (*Moxostoma breviceps*)	Wabash R. - Indiana	1968-73	Field A	Ad.			(Su) 26-27.5[kk]	28.5[m]		Gammon 1973
		Walhonding R. - Ohio	200	LabA-1 Lab A-2	Ad. Juv.					(20.6-23.8) 31.5[ww] (20.6-23.8) 34.4[ww] (19.9) 35.1[ee]	Reash et al. 2000
	Robust redhorse *(Moxostoma robustum)*	Oconee R. - Georgia (parent stock)	1993-5	Lab A-2	Juv.					(20) 34.9[ee] (30) 37.2[ee]	Walsh et al. 1998
	White sucker (*Catostomus commersonii*)	L. Amikeus, L. Opeongo - Ontario	1941	Lab A	juv.					(25-26) 31.2[n],29[ll]	Brett 1944
		Greenwood L. - Michigan	1968-69	Lab A,B	eggs larvae larvae (newly hatched) larvae (swim-up)	9-17.2[e]	15.2[e] 26.9[a,b]			(15) 30[nn] (8.9) 29[o],29[p],28.6[r] (15.2)31.1[o],31[p],30[r] (21.1)31.5[o],21[p],28.2?[r] (10) 28.5[o],28.5[p],28.1r (15.8)30.7[o],30.7[o],30.7[r] (21.1)32[o],32[p],30.5[r]	McCormick et al. 1977

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	White sucker (cont'd)	Minnesota	1977	Lab A,B	larvae juv. Ad.	 21-28[a] 21-26[a]	 26[a] 26[a]			(26) 30.5[r] (26) 32.5[r]	Brungs and Jones 1977
		Pennsylvania	1978	Lab D	Ad.	22.8 - 26.1[kk]		(23)24.2[k,tt],25[k,s] (23)24[l,tt],24[l,s] (23)24.1[dd]			Reynolds and Casterlin 1978a
		Horsetooth Res. - Colorado	1960	Field B	juv. - Ad.	18.9 - 21.1[s]					Horak and Tanner 1964
		W.L. Erie - Ohio	1973-74	Lab C	Ad (3)			(Fa) 2.4[tt,dd]			Reutter and Herdendorf 1974
		W.L. Erie - Ohio	1973-74	Lab A	Ad (3)					(19) 31.6[ee]	Reutter and Herdendorf 1976
		Don R. - Ontario	1945-46	Lab A	juv.					(5) 26.3[n] (10) 27.7[n] (15) 29.3[n] (20) 29.3[n] (25) 29.3[n]	Hart 1947
		Ohio R. - Ohio, Kentucky	1970-74	Field A	Ad.	(Su) 25-27[kk] (Fa) 16-19[kk]					Yoder and Gammon 1976a
		New R. - Virginia	1973	Field A	Ad. - juv.	20 - 23.9[cc,kk]			30.6[j]		Stauffer et al. 1974
		New R. - Virginia	1973-74	Field A	Ad. - juv.			26.7			Stauffer et al. 1976
		Ottawa R. - Canada	1978	Review			(larval) 28.0[bbb] (Ad.) 25.1[bbb]				Christie 1979
		British Columbia	1950+	Lab A	Juv.					(23) 26.6-27.0[t]	Black 1953
		Missouri streams	1995	Lab A-2	juv.		22.1-24.1[kk]			(26) 34.9[eee]	Smale and Rabeni (1995)
				Lab A-2	larval					(23) 37.0[ee]	Tatarko 1966
				Lab A-2	Juv.					(26.3-28) 40.6[ee]	Horoszewica 1973
				Lab A-2	Ad.					35-36[ee]	Meuwis and Heuts 1957
	Longnose sucker *(Catostomus catostomus)*	British Columbia	1950+	Lab A	Juv.					(11.5) 27[j] (14) 26.5[t]	Black 1953
	Hog sucker *(Hypentelium nigricans)*	New R. - Virginia	1973	Field A	Ad. - juv.	26.7 - 27.2[cc,kk]			31.7[m] 35[j]		Stauffer et al. 1974

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Hog sucker (cont'd)	New R. - Virginia	1973-74	Lab C	Ad.			(20.6) 25.9[tt] (23.9) 26.8[tt] (27.2) 27.7[tt] (30) 28.5[tt] (33.3) 29.4[tt] 27.8[dd]	27[m]		Stauffer et al. 1975
		New R. - Virginia	1973-74	Field A Lab C	Ad. - juv. Ad. - juv.			26.6 - 27.7[cc] 27.9[dd]	27[m] (18) 27 (21) 30 (24) 33 (27) 30 (30) 33		Stauffer et al. 1976
		New R. - Virginia	1974+	Lab C[bb]	Ad.	(12) 12.5-19.8[kk] (15) 15.4-21.2[kk] (18) 18.1-22.8[kk] (21) 20.6-24.6[kk] (24) 23.7-26.8[kk] (27) 24.5-29.2[kk] (30) 26.1-30.2[kk] (33) 27.6-34.8[kk] (36) [aaa]		(12) 15.3[tt] (15) 20.2[tt] (18) 16.9[tt] (21) 23.0[tt] (24) 27.0[tt] (27) 28.7[tt] (30) 29.4[tt] (33) 28.8[tt] (36)[aaa] 29.8[dd]	(12) - (15) - (18) 27[j] (21) 30[j] (24) 33[j] (27) 33[j] (30) 33[j] (33) 34[j] (36)[aaa]	(33) 33[xx]	Cherry et al. 1977
		?	1975+	Lab A-2	Juv.					(15) 30.8[ee]	Kowalski et al. 1978
	Spotted sucker (*Minytrema melanops*)	Ohio R. - Ohio, Kentucky	1974	Field A	Ad.	(Su) 25-27[kk] (Fa) 16-19[kk]					Yoder and Gammon 1976a
		Ohio R. - Ohio, Kentucky	1970-75	Field A	Ad.	(Su) 21-26[kk]			27[m]		Yoder and Gammon 1976b
		W.L. Erie - Ohio	1973-74	Lab A	Ad.					(20) >31.0[ee]	Reutter and Herdendorff 1976
Cyprinidae	Grass carp *(Ctenopharyngodon idella)*	Hatchery - Arkansas	198	Lab A-2 Lab C	Juv.			(23) 25.3[tt]		(23) 39.3[ee]	Bettoli et al. 1985
	Bighead carp *(Hypophthalmichthys nobilis)*	Hatchery - Arkansas	198	Lab A-2 Lab C	Juv.			(23) 25.4[tt]		(23) 38.8[ee]	Bettoli et al. 1985
	Grass X Bighead Carp	Hatchery - Arkansas	198	Lab A-2 Lab C	Juv.			(23) 28.2[tt]		(23) 40.3[ee]	Bettoli et al. 1985

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Common Carp *(Cyprinus carpio)*	L. Monona - Wisconsin	1970	Lab D	juv.				34.4[m]		Neill et al. 1972
		L. Monona - Wisconsin	1970	Field A Lab D	Ad. Ad. Ad. Ad. juv. Juv.			28.3 - 30.7[i,km,] 29.3 - 31.8[i,l,m] 30.0 - 32.2[l,m] 29.8 - 31.9[k,m]	32.6[i,k,m] 31[i,l,m] 33.2[l,m] 32.7[k,m] 33.3[l,m] 32.2[k,m]		Neill and Magnuson 1974
		Belgium	1957	Lab A,B	juv. Ad.					38 - 39[r] 35.5 - 37[r]	Meuwis and Heuts 1957
		Wabash R. - Indiana	1968-73	Field A	Ad.			(Su) 33 - 35[kk]	34.5[m]		Gammon 1973
		Ontario	1956	Lab E	yoy			(10) 17[s] (15) 25[s] (20) 27[s] (25) 31[s] (30) 31[s] (35) 32[s] 32[dd]			Pitt et al. 1956
		Lichenskiel - Poland	1966	Lab A	Ad.					(26.7) 34[xx],40.2[ee] (24.5) 32.4[xx],40.3[ee]	Horoszewica 1973
		W.L. Erie - Ohio	1973-74	Lab C	Ad.			(Su) 29.7[tt,dd] (Sp) 27.4[tt,dd]			Reutter and Herdendorf 1974
		W.L. Erie - Ohio	1973-74	Lab A	Ad.					(23.3) 39[t]	Reutter and Herdendorf 1976
		Ohio R. - Ohio, Kentucky	1974	Field A	Ad.	(Su) 26-34[kk] (Fa) 16-20[kk] (Wi) 5-16[kk]					Yoder and Gammon 1976a
		Ohio R. - Ohio, Kentucky	1970-75	Field A	Ad.	(Su) 32-34[m,kk]			35.5[m]		Yoder and Gammon 1976b
		? - Pennsylvania	1977	Lab D	Ad.			29[s]			Reynolds and Casterlin 1977
		White R. - Indiana	1965-72	Field A	Ad.				36.1[j]		Proffitt and Benda 1971
	Goldfish *(Carrasius auratus)*	Commercial supplier - Ontario	1942	Lab A	juv.					(1-2) 28[m,o] (10) 31[m,o] (17) 34[m,o] (24) 36.5[m,o] (32) 39.5[m,o] (36.5) 41[m,o],41[t]	Fry et al. 1942
		pet store - Ontario	1968-69	Lab C	juv.	(15) 25-29 (20) 28-32		(15) 27-29[kk] (20) 29-31[kk]			Roy and Johansen 1970

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Goldfish (cont'd)	Commercial supplier - Ontario	1946				(5) 18[c] (15) 23[c] (25) 28[c] (35) 38[c] 28[c]				Fry and Hart 1948
		Hatchery - British Columbia	1955	Lab A	yoy					(20) 36.5[r] (20) 36.1[r]	Hoar 1956
		Hatchery - Pennsylvania	1977	Lab D	juv.	26 - 30[kk]		27.7[dd,tt]			Reynolds et al. 1978
		W.L. Erie - Ohio	1973-74	Lab C	Ad (1)			(Su) 27[tt,dd] (Fa) 24[tt,dd] (Wi) 24.2[tt,dd] (Sp) 25.3[tt,dd]			Reutter and Herdendorf 1974
		W.L. Erie - Ohio	1973-74	Lab A	Ad.					(23.9) 35[ee]	Reutter and Herdendorf 1976
		Commercial supplier - Ontario	1950+	Lab A-2	Juv.					(5) 29.0[t] (10) 30.8[t] (15) 32.8[t] (20) 34.8[t] (25) 36.6[t] (30) 38.6[t]	Brett 1956
		Commercial supplier - Ontario	1940+	Lab A-2	Juv.					(5) 29.9[t] (10) 31.5[t] (15) 33.0[t] (20) 35.0[t] (25) 37.5[t] (30) 39.0[t] (35) 41.0[t] (40) 41.0[t]	Brett 1944
				Lab A-2	Juv.					(25) 36.6[ee]	Hart 1947
	Carp X Goldfish	W.L. Erie - Ohio	1973-74	Lab A	Ad.					(9.3) 25.3[ee] (14.4) 30.5[ee]	Reutter and Herdendorf 1976

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Golden shiner (*Notemigonus crysoleucas*)	L. Opeongo - Ontario	1941	Lab A	juv.					(14.2) 30.4[n,aa] (14.8) 30.3[n,bb] (16.8) 31.8[n,bb] (17.4) 31.6[n,aa] (19.3) 33.4[n,aa] (21.2) 32.8[n,aa] (21.7) 33.5[n,bb] (22.2) 33.2[n,bb]	Brett 1944
		New Jersey	1972	Lab A	juv.					(22) 39.5-40[ee]	Alpugh 1972
		W.L. Erie - Ohio	1973-74	Lab C	Ad.			(Su) 22.3[tt,dd] (Fa) 21[tt,dd] (Wi) 16.8[tt,dd] (Sp) 23.7[tt,dd]			Reutter and Herdendorf 1974
		Algonquin Park, Ontario Put-in-Bay - Ohio Welaka, Florida	1945-47 1945-47 1945-47	Lab A Lab A Lab A	Ad. - juv. Ad. - juv. Ad. - juv.					(10) 29.3[o] (20) 31.8[o] (20) 32.1[o] (25) 33.7[o] (15) 33.7[o] (20) 31.9[o] (25) 33.2[o] (30) 34.7[o]	Hart 1952
		Ottawa R. - Canada	1978	Review			29.3[bbb]				Christie 1979
				Field B	Ad.			28.9-32.2[kk]			Trembley 1961
		Missouri streams	1995	Lab A-2	Ad.					(26) 36.8[eee]	Smale and Rabeni 1995
	Bigeye chub *(Hybopsis amblops)*			Lab A-2						(10) 31.7[ee]	Lutterschmidt and Hutchinson 1997
	Sand shiner *(Notropis stramineus)*	Arkansas/Oklahoma streams	198	Lab A Lab C	Ad.			18.9		(15) 36.1[ee]	Matthews 1981
			1975+	Lab A-2	Ad.					(Dec.) 32.3[ee] (Jan.) 32.3[ee] (March) 31.9[ee]	Kowalski et al. 1976
				Lab A-2						(15) 32.3-33.0[ee]	Kowalski et al. 1978
		Missouri streams	1995	Lab A-2	Ad.					(26) 37.0[eee]	Smale and Rabeni 1995

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Emerald Shiner *(Notropis atherinoides*)	L. Superior - Minnesota	1970	Lab A,B	yoy		28.9[a] (24 - 28.9)[a]			(20) 35.2[r] (20-25) 32.6[r]	McCormick and Kleiner 1976
		L. Erie - Ohio	1972	Lab C	Ad. Yoy				27 30		Barans 1972
		L. Simcoe - Ontario	1967	Lab E	yoy			(2.5) 13[s] (5) 18[s] (10) 21[s] (15) 24[s] (20) 25[s] (25) 26[s] (30) 25[s] 25[dd]			Campbell and MacCrimmon 1970
		L. Erie - Ohio	1971	Lab C	yoy Ad.	(Su) 21-23[s] (Fa) 13-15[s] (Wi) 11-13[s] (Sp) 13-15[s] (Su) 22-23[s] (Fa) 15-18[s] (Wi) 6-7[s] (Sp) 16-18[s]		(Su) 22[m,s] (Fa) 14[m,s] (Wi) 10.5[m,s] (Sp) 15[m,s] (Su) 23[m,s] (Fa) 18[m,s] (Wi) 5.5[m,s] (Sp) 17.5[m,s]	(Su) 27.5[m] (Fa) 18.3[m] (Wi) 15.8[m] (Sp) 19[m] (Su) 25.2[m] (Fa) 21.5[m] (Wi) 13[m] (Sp) 21.5[m]		Barans and Tubb 1973
		W.L. Erie - Ohio	1973-74	Lab C	Ad.			(Wi) 9.3[tt,dd]			Reutter and Herdendorf 1974
		W.L. Erie - Ohio	1973-74	Lab C	Ad.			(Wi) 8.3[tt,dd]		(7.8) 28.6[ee]	Reutter and Herdendorf 1976
		Toronto, Ontario Put-in-Bay - Ohio	1947 1946	Lab A Lab A	Ad Ad.					(25-Wi)32.1[o],30.7[q] (25-Su)30.7[o]	Hart 1952
		L. Simcoe - Ontario	1945-46	Lab A	Ad.					(5) 23.2[n] (10) 26.7[n] (15) 28.9[n] (20) 30.7[p] (25) 30.7[r]	Hart 1947
		White R.-Indiana	1965-72	Field A	Ad.				31.1[j]		Proffit and Benda 1971
		Arkansas/Oklahom a streams	198	Lab A Lab C	Ad.			19.4[tt]		(15) 34.5[ee]	Matthews 1981
		Ottawa R. - Canada	1978	Review			29.6[bbb]				Christie 1979
	Bigeye shiner *(Notropis boops)*	Arkansas/Oklahom a streams	198	Lab A Lab C	Ad.			18.9[tt], 27.7[tt]		(15) 35[ee]	Matthews 1981
	Common shiner *(Luxilis cornutus*)	L. Opeongo, L. Amikeus-Ontario	1941	Lab A	juv.					(25-26) 32[n],30[ll]	Brett 1944

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Common shiner (continued)	Toronto, Ontario	1947	Lab A	Ad.					(5) 26.7[o] (10) 28.6[o] (15) 30.3[o]	Brett 1952
		Don R. - Ontario	1945-46	Lab A	Ad.					(5) 26.7[n] (10) 28.6[n] (15) 30.3[o] (20) 31[p] (25) 31[r]	Hart 1947
		Buffalo Creek - New York	198	Lab A-2	Ad.					(15) 31.9-32[ee]	Schubauer et al. 1980
			1975+	Lab A-2	Ad.					(Dec.) 30.6[ee] (March) 31.9[ee]	Kowalski et al. 1976
		Missouri streams	1995	Lab A-2	Ad.					(26) 35.7[eee]	Smale and Rabeni 1995
	Striped shiner *(Luxilis chrysocephalus*)	Knoxville, Tennessee	1947	Lab A	Ad.					(25) 32.3[o] (30) 33.5[o]	Hart 1952
		Arkansas/Oklahom a streams	198	Lab A Lab C	Ad.			15.3[tt]		(15) 34.5[ee]	Matthews 1981
		Indian Cr.- Ohio	199	Lab A-2	Ad.?					(24) 36.2[ee]	Mundahl 1990
		Dicks Cr.- Ohio	1987-8	Lab A-2	Ad.					(11) 30.8[ee]	Hockett and Mundahl 1989
		Missouri streams	1995	Lab A-2	Ad.					(26) 36.2[eee]	Smale and Rabeni 1995
	Spotfin shiner *(Cyprinella spiloptera)*	Susquehanna R. - Pennsylvania	1973	Lab B	juv.		30[c]				Hocutt 1973
		New R. - Virginia	1973	Field A	Ad. - juv.	20 - 27.2[cc,kk]			35[m,t]		Stauffer et al. 1974
		New R. - Virginia	1973-74	Lab C	Ad.			(12.2) 21.5[tt] (15) 22.8[tt] (17.8) 24.1[tt] (21.1) 25.7[tt] (24.4) 27.3[tt] (27.2) 28.6[tt] (30) 29.9[tt] (32.8) 31.2[tt] (35.6) 32.5[tt]	35[m]		Stauffer et al. 1975

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Spotfin shiner (cont'd)	New R. - Virginia	1973-74	Lab C	Ad. - juv.			29.8[dd]	(12) 24 (15) 24 (21) 27 (24) 30 (27) 33 (30) 36 (33) 36		Stauffer et al. 1976
		Conowingo Pond - Pennsylvania	1974	Lab C	Ad.			(26.7) 30[s]	(25.5) 32.2		Robbins and Mathur 1974
		White R. - Indiana	1965-72	Field A	Ad.				31.1[j]		
		Dicks Cr.- Ohio	1987-8	Lab A-2	Ad.					(11) 31.8[ee]	Hockett and Mundahl 1989
		New R. - Virginia	1974+	Lab C[bb]	Ad.	(12) 19.3-24.4[kk] (15) 21.0-25.2[kk] (18) 22.7-26.2[kk] (21) 24.3-27.2[kk] (24) 25.7-28.4[kk] (27) 26.9-29.8[kk] (30) 28.0-31.4[kk] (33) 28.9-33.1[kk] (36) 29.8-34.8[tt]		(12) 21.4[tt] (15) 21.8[tt] (18) 24.1[tt] (21) 26.4[tt] (24) 27.3[tt] (27) 30.6[tt] (30) 31.8[tt] (33) 31.0[tt] (36) 29.2[tt] 31.9[dd]	(12) 27[j] (15) 24[j] (18) 27[j] (21) 27[j] (24) 30[j] (27) 33[j] (30) 36[j] (33) 36[j] (36) 38[j]	(36) 36[xx]	Cherry et al. 1977
		New R./East R. - Virginia	1973+	Lab C[aa]	yoy	(6) 14.7-16.9[kk] (9) 16.6-18.5[kk] (12) 18.6-20.1[kk] (15) 20.4-21.7[kk] (18) 22.2-23.5[kk] (21) 23.9-25.2[kk] (24) 25.6-27.1[kk] (27) 27.2-29.0[kk] (30) 28.7-30.9[kk]		(6) 16.3[tt] (9) 16.0[tt] (12) 20.4[tt] (15) 21.4[tt] (18) 22.4[tt] (21) 24.7[tt] (24) 26.5[tt] (27) 28.2[tt] (30)29.7[tt]	(6) 21[j] (9) 22[j] (12) 25[j] (15) 26[j] (18) 28[j] (21) 29[j] (24) 29[j] (27) 33[j] (30) 35[j]		Cherry et al. 1975
							28.6-29.2				Jobling 1981
	Rosyface shiner *(Notropis rubellus)*	New R. - Virginia	1973	Field A	Ad. - juv.	20 - 27.2[cc,kk]			27.2[m] 35[t]		Stauffer et al. 1974
		New R. - Virginia	1973-74	Field A Lab C	Ad. - juv.			28.8 - 30[cc] 28.8[dd]	35[t] (12) 21 (15) 24 (18) 21 (21) 27 (24) 27 (27) 33		Stauffer et al. 1976

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Rosyface shiner (cont'd)	Arkansas/Oklahoma streams	1981-2	Lab A Lab C	Ad.			21.3[tt]		(15) 34.6[ee]	Matthews 1981
		New R. - Virginia	1974+	Lab C[bb]	Ad.	(12) 18.7-22.2[kk] (15) 20.2-23.0[kk] (18) 21.7-24.0[kk] (21) 23.0-25.0[kk] (24) 24.2-26.2[kk] (27) 25.2-27.5[kk] (30) 26.2-29.0[kk] (33) 27.0-30.5[kk] (36) [aaa]		(12) 20.8[tt] (15) 21.7[tt] (18) 22.2[tt] (21) 22.5[tt] (24) 25.8[tt] (27) 28.1[tt] (30) 28.0[tt] (33) 27.7[tt] (36)[aaa] 28.4[dd]	(12) 21[j] (15) 24[j] (18) 21[j] (21) 27[j] (24) 27[j] (27) 33[j] (30) 33[j] (33) 34[j] (36)[aaa]	(33) 33[xx]	Cherry et al. 1977
		New R./East R. - Virginia	1973+	Lab C[aa]	yoy	(6) 13.3-16.9[kk] (9) 15.3-18.3[kk] (12) 17.3-19.7[kk] (15) 19.2-21.3[kk] (18) 20.9-22.9[kk] (21) 22.5-24.9[kk] (24) 23.9-26.9[kk] (27) 25.3-28.9[kk] (30)[aaa]		(6) 15.8[tt] (9) 14.8[tt] (12) 19.4[tt] (15) 21.3[tt] (18) 21.7[tt] (21) 22.7[tt] (24) 26.2[tt] (27) 26.8[tt] (30)[aaa]	(6) 21[j] (9) 22[j] (12) 24[j] (15) 25[j] (18) 26[j] (21) 26[j] (24) 28[j] (27) 31[j] (30)[aaa]		Cherry et al. 1975
				Lab A-2						(15) 31.8[ee]	Kowalski et al. 1978
		Missouri streams	1995	Lab A-2	Ad.					(26) 35.3[eee]	Smale and Rabeni 1995
							25.3-25.7				Jobling 1981
	Silver shiner *(Notropis photogenis)*	New R. - Virginia	1973	Field A	Ad. - juv.	26.7 - 27.2[cc,kk]			27.2[m] 35[w]		Stauffer et al. 1974
		New R. - Virginia	1973-74	Field A	Ad. - juv.				35[w]		Stauffer et al. 1976
	Scarlet shiner *(Lythrurus ardens)*	New R. - Virginia	1973-74	Field A	Ad. - juv.				32.2[w]		Stauffer et al. 1976
	Redfin shiner *(Lythrurus umbratilis)*	Arkansas/Oklahoma streams	198	Lab A Lab C	Ad.			13.2[tt]		(15) 35.5[ee]	Matthews 1981
		Missouri streams	1995	Lab A-2	Ad.					(26) 38.1[eee]	Smale and Rabeni 1995
	Red shiner *(Cyprinella lutrensis)*	Denton Co.- Texas	1980+	Lab A-2	Ad.					(22) 36.2[ee]	Takle et al. 1983

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Red shiner (cont'd)	Kansas, Oklahoma, Texas	198	Lab A-2	Ad.					(21) 35.9-36.3[ee]	Matthews 1986
	Mimic shiner *(Notropis volucellus*)	New R. - Virginia	1973-74	Field A	Ad. - juv.				35[j] 32.5[m]		Stauffer et al. 1976
	Bigmouth shiner *(Notropis dorsalis)*	Missouri streams	1995	Lab A-2	Ad.					(26) 36.6[eee]	Smale and Rabeni 1995
	Blackchin shiner *(Notropis heterodon)*	Michigan - Pond		Field B	Ad.					38[cc]	Beltz et al. 1974
	Spottail shiner *(Notropis hudsonius*)	Delaware R. - Delaware	1971	Lab C	Ad.			(15) 13.9[tt]			Meldrim and Gift 1971
		W.L. Erie - Ohio	1973-74	Lab C	Ad.			(Wi) 10.2[tt,dd] (Sp) 14.3[tt,dd]			Reutter and Herdendorf 1974
		W.L. Erie - Ohio	1973-74	Lab A,C	Ad.			(Wi) 9[tt,dd]		(21.7) 32.8[ee]	Reutter and Herdendorf 1976
		New R. - Virginia	1973	Field A	Ad. - juv.	23.3 - 27.2[cc,kk]			31.7m 35[j]		Stauffer et al. 1974
		New R. - Virginia	1973-74	Field A	Ad. - juv.				35[j]		Stauffer et al. 1976
		Susquehenna R. - Pennsylvania	1980+	Lab C	1-3 yrs.			29[tt]	(6) none[xx] (12) 27[j] (18) 21[j] (24) 33[j] (30) 36[j]	(6) 26.9[t] (12) 27.0[t] (18) 26.7[t] (24) 33.1[t] (30) 33.1[t]	Stauffer et al. 1984
		Hudson R. - New York	1977	Lab B, C	Juv.		27.3[a] 25.4-32.3[ddd]	29[dd]		(26) 34.7[t]	Kellog and Gift 1983
		Hudson R. - New York		Lab A	yoy, Juv.					(23) 36-37.3[t] (26) 36.8-37.9[t]	Jinks et al. 1981
	Telescope shiner *(Notropis telescopus)*	New R. - Virginia	1974+	Lab C[bb]	Ad.	(12) 11.5-16.3[kk] (15) 14.4-18.0[kk] (18) 17.0-19.9[kk] (21) 19.3-22.1[kk] (24) 21.2-24.8[kk] (27) 22.8-27.6[kk] (30)[aaa] (33)[aaa] (36)[aaa]		(12) 14.2[tt] (15) 15.4[tt] (18) 17.7[tt] (21) 22.6[tt] (24) 23.2[tt] (27) 24.4[tt] (30)[aaa] (33)[aaa] (36)[aaa] 23.6[dd]	(12) 18[j] (15) 21[j] (18) 24[j] (21) 27[j] (24) 27[j] (27) 29[j] (30)[aaa] (33)[aaa] (36)[aaa]	(27) 30[xx]	Cherry et al. 1977

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Bluehead chub *(Nocomis leptocephalus)*	New R./East R. - Virginia	1973+	Lab C[aa]	yoy	(6) - (9) - (12) 13.4-14.1[kk] (15) 15.4-15.9[kk] (18) 17.4-17.8[kk] (21) 19.3-19.8[kk] (24) 21.2-21.8[kk] (27)[aaa] (30)[aaa]		(6) - (9) - (12) 13.7[tt] (15) 15.0[tt] (18) 17.5[tt] (21) 19.6[tt] (24) 21.5[tt] (27)[aaa] (30)[aaa]	(6) - (9) - (12) 16[j] (15) 17[j] (18) 21[j] (21) 22[j] (24) 25[j] (27)[aaa] (30)[aaa]		Cherry et al. 1975
	Creek chub (*Semotilus atromaculatus*)	L. Opeongo - Ontario	1941	Lab A	juv.					(12.8) 28.2[n,bb] (14.7) 30[n,aa] (14.8) 29.9[n,b] (14.8) 30.3[n,bb] (16.1) 30.6[n,bb] (17.4) 31.0[n,aa] (19.3) 32[n,aa] (21) 31.8[n,bb] (22) 32.6[n,bb]	Brett 1944
		Toronto, Ontario	1947	Lab A	Ad.					(10) 27.3[o] (15) 29.3[o] (20) 30.3[o] (25-Su) 31.5[o] (25-Wi) 30.3[n]	Hart 1952
		Knoxville, Tenn.	1947	Lab A	Ad.					(25) 31.6[o]	
		Don R. - Ontario	1945-46	Lab A	Ad.					(5) 24.7[n] (10) 27.3[n] (15) 29.3[n] (20) 30.3[o] (25) 30.3[p]	Hart 1947
		New R. - Virginia	1973-74	Field A	Ad. -juv.				33.9[j]		Stauffer et al. 1976
		Missouri streams	1995	Lab A-2	Ad.					(26) 35.7[eee]	Smale and Rabeni 1995
	River chub *(Nocomis micropogon)*		1975+	Lab A-2	Ad.					(15) 30.9[ee]	Kowalski et al. 1978
	Hornyhead chub *(Nocomis biggutattus)*	Missouri streams	1995	Lab A-2	Ad.					(26) 35.6[eee]	Smale and Rabeni 1995

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Suckermouth minnow *(Phenacobius mirabilis)*			Lab A-2						(10) 33.4[ee]	Lutterschmidt and Hutchinson 1997

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Fathead minnow *(Pimephales promelas)*	Ponds - Oklahoma	1965	Lab C	Ad.			(4) 8.8 (10) 15.2 (15) 23.3 (22) 20.7 (30) 22.6 23.4[dd]			Jones and Irwin 1965
		L. Amikeus - Ontario	1941	Lab A	Ad.					(9) 29[n,bb] (12.8) 30.1[n,bb] (15.3) 31.6[n,bb] (17.4) 30.8[n,aa] (19.8) 33.8[n,aa] (21) 31.3[n,bb] (21) 34[n,aa] (21.2) 33.6[n,bb]	Brett 1944
		Hatchery - Tennessee	1972	Lab A	Ad.					(6) 26.7[n]	Jensen 1972
		Don R. - Ontario	1945-46	Lab A	Ad.					(10) 28.2[o] (20) 31.7[o] (30) 33.2[r]	Hart 1947
		New R. - Virginia	1973-74	Field A Lab C	Ad. -juv. Ad. - juv.				25.6[j] 26.2[j]		Stauffer et al. 1976
		N. Texas State lab reared	1990+	Lab A-2	Ad.					(24) 36.9[ee] (non-spawn) 36.2[ee] (post-spawn)	Pyron and Beitinger 1993
		New R. - Virginia	1974+	Lab C[bb]	Ad.	(12) 17.0-20.7[kk] (15) 18.9-21.9[kk] (18) 20.8-23.2[kk] (21) 22.6-24.6[kk] (24) 24.0-26.4[kk] (27) 25.3-28.3[kk] (30) 26.5-30.3[kk] (33)[aaa] (36)[aaa]		(12) 19.5[tt] (15) 21.2[tt] (18) 20.9[tt] (21) 22.0[tt] (24) 25.4[tt] (27) 27.6[tt] (30) 28.7[tt] (33)[aaa] (36)[aaa] 26.0[dd]	(12) 18[j] (15) 24[j] (18) 24[j] (21) 27[j] (24) 30[j] (27) 33[j] (30) 32[j] (33)[aaa] (36)[aaa]		Cherry et al. 1977
		New R./East R. - Virginia	1973+	Lab C[aa]	yoy	(6) - (9) - (12) 17.9-20.6[kk] (15) 20.0-22.1[kk] (18) 22.0-23.7[kk] (21) 23.8-25.5[kk] (24) 25.4-27.5[kk] (27) 26.9-29.6[kk] (30)[aaa]		(6) - (9) - (12) 19.8[tt] (15) 21.3[tt] (18) 22.1[tt] (21) 23.8[tt] (24) 26.6[tt] (27) 28.9[tt] (30)[aaa]	(6) - (9) - (12) 22[j] (15) 25[j] (18) 26[j] (21) 28[j] (24) 30[j] (27) 32[j] (30)[aaa]		Cherry et al. 1975

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Fathead minnow (cont'd)	Ottawa R. - Canada	1978	Review			30.1[bbb]				Christie 1979
		Missouri streams	1995	Lab A-2	Ad.					(26) 36.3[eee]	Smale and Rabeni 1995
	Bluntnose minnow *(Pimephales notatus)*	W. L. Erie - Ohio	1973-74	Lab A	Ad.					(6) 27.8[ee]	Reutter and Herdendorf 1976
		Toronto, Ontario	1947	Lab A	Ad.					(20-Wi) 31.7[o] (25-Wi) 33.3[n]	Hart 1952
		Put-in-Bay - Ohio	1946	Lab A	Ad.					(20-Su) 32.7[o] (25-Su) 34[n]	
		Etobicoke Creek - Ontario	1945-46	Lab A	Ad.					(5) 26[n] (10) 28.3[n] (15) 30.6[o] (20) 31.7[p] (25) 33.3[r]	Hart 1947
		New R. - Virginia	1973	Field A	Ad. - juv.	20 -27.2[cc,kk]			31.7[m] 35[j]		Stauffer et al. 1974
		New R. - Virginia	1973-74	Field A					35[j] 27[m]		Stauffer et al. 1976
				Lab C				26.7[dd]	(12) 21 (15) 21 (18) 27 (21) 27 (24) 27 (27) 30		
		White R. - Indiana	1965-72	Field A	Ad.				31.1[t]		Proffit and Benda 1971
		Potomac R. - Maryland	1980+	Lab C	1-3 yrs.			26.3[tt]	(6) 15[j] (12) none[xx] (18) 33[j] (24) 30[j] (30) 36[j] (36) 39[j]	(6) 31.9[t] (12) 27[t] (18) 33.1[t] (24) 33.1[t] (30) 32[xx]	Stauffer et al. 1984
		Indian Cr.- Ohio	199	Lab A-2	Ad.?					(24) 37.9[ee]	Mundahl 1990
		Dicks Cr.- Ohio	1987-8	Lab A-2	Ad.					(11) 31.3[ee]	Hockett and Mundahl 1989

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Bluntnose minnow (cont'd)	New R. - Virginia	1974+	Lab C[bb]	Ad.	(12) 18.0-20.0[kk] (15) 19.9-21.5[kk] (18) 21.7-23.0[kk] (21) 23.5-24.6[kk] (24) 25.2-26.4[kk] (27) 26.7-28.8[kk] (30) 28.2-30.2[kk] (33)[aaa] (36)[aaa]		(12) 19.3[tt] (15) 20.9[tt] (18) 21.9[tt] (21) 23.2[tt] (24) 26.4[tt] (27) 27.9[tt] (30) 29.0[tt] (33)[aaa] (36)[aaa] 29.3[dd]	(12) 21[j] (15) 24[j] (18) 27[j] (21) 27[j] (24) 27[j] (27) 30[j] (30) 33[j] (33)[aaa] (36)[aaa]	(30) 32[xx]	Cherry et al. 1977
		New R./East R. - Virginia	1973+	Lab C[aa]	yoy	(6) 13.9-17.3[kk] (9) 15.9-18.7[kk] (12) 17.9-20.1[kk] (15) 19.8-21.7[kk] (18) 21.5-23.4[kk] (21) 23.0-25.2[kk] (24) 24.5-27.2[kk] (27) 25.9-29.2[kk] (30)[aaa]		(6) 15.7[tt] (9) 17.2[tt] (12) 20.5[tt] (15) 20.4[tt] (18) 21.5[tt] (21) 22.8[tt] (24) 25.7[tt] (27) 28.9[tt] (30)[aaa]	(6) 20[j] (9) 21[j] (12) 23[j] (15) 25[j] (18) 26[j] (21) 25[j] (24) 30[j] (27) 31[j] (30)[aaa]		Cherry et al. 1975
		Missouri streams	1995	Lab A-2	Ad.					(26) 36.6[eee]	Smale and Rabeni 1995
	Bullhead minnow *(Pimephales vigilax)*	Denton Cr. - Texas	199	Lab A-2	Ad.					(30) 39.3[ee]	Rutledge and Beitinger 1989
	Silverjaw minnow *(Notropis buccatus)*	White R. - Indiana	1965-72	Field A	Ad.				31.1[w]		Proffit and Benda 1971
		Indian Cr.- Ohio	199	Lab A-2	Ad.?					(24) 37.0[ee]	Mundahl 1990
	Western Blacknose dace (*Rhinicthys obtusus*)	Cazenovia Creek - New York	1976	Lab A	Ad.					(20) 28.8[r,qq],29.9[r,rr]	Terpin et al. 1976
		Toronto, Ontario	1945-46	Lab A	Ad.					(5) 26.5[o] (10) 28.8[o] (15) 29.6[o] (20-Wi) 30.4[o],29.3[q] (25-Wi) 30.8[o],29.5[q]	Hart 1952
		Knoxville, Tennessee	1947	Lab A	Ad.					(25-Su) 31.2[o] (20-Su) 30.2[o],29.3[q] (25-Su) 31.6[o],30.5[q]	

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Western blacknose dace (cont'd)	Don R. - Ontario	1945-46	Lab A	Ad.					(5) 26.5[n] (10) 28.8[n] (15) 29.6[p] (20) 29.3[r] (25) 29.3[r]	Hart 1947
		New R. - Virginia	1973	Field A	Ad. - juv.	23.3 - 27.2[cc,kk]			27.2[m] 33.9[j]		Stauffer et al. 1974
		New R. - Virginia	1973-74	Field A	Ad. - juv.				33.9[j] 27[m]		Stauffer et al. 1976
				Lab A-2						(15) 31.9[ee]	Kowalski et al. 1978
	Longnose dace *(Rhinicthys cataractae)*	New R. - Virginia	1973-74	Field A					30[j]		Stauffer et al. 1976
			1975+	Lab A-2	Ad.					(15) 31.4[ee]	Kowalski et al. 1978
	Redside dace *(Clinostomus elongatus)*	Cattaraugus Co., New York	1995+	Lab A-2	Ad.					(6) 25.5[ee] (12) 27.5[ee] (20) 32.6[ee]	Novinger and Coon 2000
	Southern Redbelly Dace *(Phoxinus erythrogaster)*	L. Coyote Cr.- New Mexico	1981-2	Lab A-2	Ad.					(0) 17.6, 19.7[ee] (1) 18.2[ee] (10) 29.3[ee] (19) 25.4[ee] (21.5) 32.2[ee]	Scott 1987
		Missouri streams	1995	Lab A-2	Ad.					(26) 35.9[eee]	Smale and Rabeni 1995
	Northern Redbelly Dace *(Phoxinus eos)*	Ontario		Lab A						(6) 21.5[t] (10) 30[t] (15) 31[t] (20) 31.5[t] (25) 32.7[t] (20) 29[ee]	Tyler 1966
	Finescale Dace *(Phoxinus neogaeus)*	Ontario		Lab A						(9) 27[t] (15) 31[t] (22) 32.2[t] (25) 32.2t (20) 28.5[ee]	Tyler 1966

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Central stoneroller *(Campostoma anomalum*)	New R. - Virginia	1973	Field A	Ad. - juv.	23.3 - 27.2[cc,kk]			27.2[m] 35[w]		Stauffer et al. 1974
		New R. - Virginia	1973-74	Lab C	Ad.			(11.7) 16.1[aaa] (15) 18.4[aaa] (18.3) 20.8[aaa] (21.7) 23.2[aaa] (23.9) 24.8[aaa] (26.7) 26.7[aaa] (29.4) 28.7[aaa] 36.9[dd]			Stauffer et al. 1975
		New R. - Virginia	1973-74	Field A Lab C				22.7 - 28.3[cc]	34.3[j] 27[m] (12) 21 (15) 24 (18) 24 (21) 27 (24) 30 (27) 33		Stauffer et al. 1976
		Brier Creek - Oklahoma	1981	Lab A Lab C	Ad.			24[tt]		(15) 35.5[ee]	Matthews 1981
		Indian Cr.- Ohio	1990	Lab A-2	Ad.?					(24) 37.7[ee]	Mundahl 1990
		New R. - Virginia	1974+	Lab C[bb]	Ad.	(12) 14.2-18.2[kk] (15) 16.7-19.8[kk] (18) 19.2-21.6[kk] (21) 21.4-23.6[kk] (24) 23.4-25.9[kk] (27) 25.2-28.3[kk] (30) 26.9-30.8[kk] (33)[aaa] (36)[aaa]		(12) 16.5[tt] (15) 17.0[tt] (18) 21.0[tt] (21) 22.4[tt] (24) 25.1[tt] (27) 28.2[tt] (30) 27.4[tt] (33)[aaa] (36)[aaa] 28.8[dd]	(12) 21[j] (15) 24[j] (18) 24[j] (21) 27[j] (24) 30[j] (27) 33[j] (30) 33[j] (33)[aaa] (36)[aaa]	(30) 31[xx]	Cherry et al. 1977
		New R./East R. - Virginia	1973+	Lab C[aa]	yoy	(6) 12.2-16.5[kk] (9) 14.6-18.1[kk] (12) 16.9-19.7[kk] (15) 19.1-21.5[kk] (18) 21.1-23.5[kk] (21) 22.9-25.7[kk] (24) 24.6-28.0[kk] (27) 26.2-30.4[kk] (30)[aaa]		(6) 15.7[tt] (9) 17.2[tt] (12) 20.5[tt] (15) 20.4[tt] (18) 21.5[tt] (21) 22.8[tt] (24) 25.7[tt] (27) 28.9[tt] (30)[aaa]	(6) 18[j] (9) 19[j] (12) 23[j] (15) 22[j] (18) 25[j] (21) 30[j] (24) 29[j] (27) 33[j] (30)[aaa]		Cherry et al. 1975

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Central stoneroller (cont'd)	?	?	Lab A-2						(7.5) 28.8[ee] (23) 35.8[ee]	Chagnon and Hlohowskyj 1989
		Missouri streams	1995	Lab A-2	Ad.					(26) 37.2[eee]	Smale and Rabeni 1995
				Lab A-2						(10) 31.8[ee]	Lutterschmidt andHutchinson 1997
		New York - Niagra R. tribs.		Lab C	Ad.			(6) 13.4[dd] (9) 15.2[dd] (12) 20.7[dd] (15) 21.7[dd] (18) 22.3[dd] (21) 23.6[dd] (24) 25.3[dd] (27) 28.6[dd]			Spotilla et al. 1979
Poecillidae	Mosquitofish *(Gambusia affinis)*	Savannah R. Project - S. Carolina	1976	Lab F,G	Ad.			(6) 24.4[s] (12) 27.9[s] (18) 30.9[s] (24) 32[s] (30) 35.3[s] (36) 33.6[s]	(12) 30 (18) 33 (24) 36 (30) 39 (36) 39	(30) 39[r] (36) 39[r]	Cherry et al. 1976
		Knoxville, Tenn. Weleka, Florida	1947 1945-47	Lab A Lab A	Ad. Ad.					(30) 37.3[o] (15) 35.4[o] (20) 37.3[o] (35) 37.3[o]	Hart1952
		S. Carolina stream	198	Lab C	Juv.			(12) 26.8[dd] (24) 31.3[dd]	(12) 30[j] (24) 36[j]	(12) 38[xx]	Cherry et al. 1982
Fundulidae	Blackstripe topminnow *(Fundulus notatus)*	Denton Cr. - Texas	199	Lab A-2	Ad.					(30) 41.6[ee]	Rutledge and Beitinger 1989
		Missouri streams	1995	Lab A-2	Ad.					(26) 38.3[eee]	Smale and Rabeni 1995
	Banded killifish (*Fundulus diaphanus*)	Porters Lake - Nova Scotia	1973	Lab E,G	Ad.			(5) 23-25[dd],14[jj] (15) 25[dd],12[jj] (25) 19[dd],14[jj] (30) 28[dd],23[jj]			Garside and Harrison, 1977
		Brier Cr. - Oklahoma	198	Lab A Lab C	Ad.			27.3[tt]		(15) 36.8[ee]	Matthews 1981
		Denton Cr. - Texas	199	Lab A-2	Ad.					(30) 41.6[ee]	Rutledge and Beitinger 1989

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
Atherinidae	Brook silversides *(Labidesthes sicculus)*	Missouri streams	1995	Lab A-2	Ad.					(26) 36.0[eee]	Smale and Rabeni 1995
		Mississippi R.			larvae			22-27[kk]			Holland and Sylvester 1983
Moronidae	Striped bass *(Morone saxatilis)*	Hudson R. - New York	1977	Lab B, C	yoy		28.5[a] 26.9-30.3[ddd]	27[dd]			Kellog and Gift 1983
		Hatchery - Tennessee	1979	Lab C	Juv.			23.2-26.4[kk]			Coutant et al. 1984
	White perch *(Morone americana)*	Hudson R. - New York	1977	Lab B, C	Juv.		28.5[a] 26.4-32.6[ddd]	30[dd]			Kellog and Gift 1983
	White bass *(Morone chrysops)*	Wabash R. - Indiana	1968-73	Field A	Ad.			(Su) 28-29.5[kk]	32[m]		Gammon 1973
		L. Erie - Ohio	1972	Lab C	yoy Ad.	(Su) 30-34[s] (Fa) 28-29[s] (Wi) 18-21[s] (Sp) 18-20[s] (Su) 30-32[s] (Fa) 14-25[s] (Wi) 19-25[s] (Sp) 16-21[s]		(Su) 30.2[m,s] (Fa) 14[m,s] (Wi) 10.5[m,s] (Sp) 15[m,s] (Su) 30.2[m,s] (Fa) 25.5[m,s] (Wi) 18[m,s] (Sp) 19.5[m,s]	(Su) 34[m] (Fa) 29[m] (Wi) 22[m] (Sp) 22[m] (Su) 32.5[m] (Fa) 26[m] (Wi) 26[m] (Sp) 24.2[m]		Reutter and Herdendorf 1974
		Tennessee R. - Alabama	1972-73	Field A	Ad. - juv.				34[j]		Wrenn 1975
		W. L. Erie - Ohio	1973-74	Lab C	yoy			(Su) 27,8[tt,dd]			Reutter and Herdendorf 1976
		W. L. Erie - Ohio	1973-74	Lab A	Ad.					(21.7) 35.3[ee]	Reutter and Herdendorf 1976
		Ohio R. - Ohio, Kentucky	1974	Field A	Ad.	(Su) 26-29[kk] (Fa) 16-28[kk] (Wi) 12-16[kk]					Yoder and Gammon 1976a
		Ohio R. - Ohio, Kentucky	1970-75	Field A	Ad.	(Su) 26-29[m,kk]			31[m]		Yoder and Gammon 1976b
		Mississippi R. - Minnesota	197	Lab A	larvae					(14) 31.7[q] (18) 30.8[q] (20) 32.0[q] (26) 30.6[q]	McCormick 1978
		Mississippi R. - Minnesota	1973-4	Lab A-2	yoy					(26) 35.6[p]	Cvancara et al. 1977
				Field A	Juv.				33.9-34.4[j]		Churchill and Wojtalik 1969

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Striped Bass X White Bass	Unknown	1990+	Lab A-2	Unknown					(6.5) 28.0[ee] (12.2) 30.5-31.0[ee] (18.0) 30.7-33.4[ee] (23.0) 35.8-36.2[ee] (27.0) 38.1-38.3[ee] (29.2) 39.0-39.1[ee] (31.0) 38.8-39.2[ee] (33.1) 40.3-40.5[ee]	Woiwode and Adelman 1992
Ictaluridae	Channel catfish (*Ictalurs punctatus*)	Susquehanna R. - Pennsylvania	1973	Lab B	juv.		30[c]				Hocutt 1973
		Wabash R. - Indiana	1968-73	Field A	Ad.			(Su) 30-32kk	32[m]		Gammon 1973
		Orangeburg Hatchery - S. Carolina	1973	Lab A,C	yoy			(12) 17[dd] (16) 22[dd] (20) 22[dd] (24) 27.8[dd] (28) 26.3[dd] (32) 29.7[dd]		(12) 34.6[cc],36.2[gg] (16) 34.3[cc],36.6[gg] (20) 35.8[cc],37.1[gg] (24) 37.6[cc],38.4[gg] (28) 39.2[cc],40.4[gg] (32) 41.2[cc],42.3[gg]	Cheetham et al. 1976
		Georgia	1972	Lab B	yoy - Ad.	28 - 30[a]	28[a,b]				Andrews et al. 1972
		Muddy Run Pond - Pennsylvania	1975	Lab A,C	Ad.			(27.2) 31.1		(27.2) 35[p]	Peterson and Stutsky 1975
		W.L. Erie - Ohio	1973-74	Lab C	Ad.			(Su) 25.2[tt,dd] (Fa) 25.3[tt,dd]			Reutter and Herdendorf 1974
		W.L. Erie - Ohio	1973-74	Lab A	Ad.					(22.7) 38[tt,dd]	Reutter and Herdendorf 1976
		Put-in-Bay - Ohio	1946	Lab A	Ad. - juv.					(20) 32.7[o] (25) 33.5[o]	Hart 1952
		Welaka, Florida	1945-47	Lab A	Ad. - juv.					(15) 30.3[o] (20) 32.8[o] (25) 33.5[o]	
		Ohio R. - Ohio, Kentucky	1974	Field A	Ad. - juv.	(Su)32-36[kk] (Fa)30-32[kk] (Wi) 9-14[kk]					Yoder and Gammon 1976a
.		Ohio R. - Ohio, Kentucky	1970-75	Field A	Ad. - juv.	(Su)31-34.5[m,kk]			35[m]		Yoder and Gammon 1976b
		New R. - Virginia	1973	Field A	Ad. - juv.	34.4 - 35[cc,kk]			35[m] 35t		Stauffer et al. 1974
		New R. - Virginia	1973-74	Lab C	Ad. - juv.			33.8[dd]			Stauffer et al. 1975
		New R. - Virginia	1973-74	Field A Lab C	Ad. - juv. Ad. - juv.			33.9 - 35[cc] 33.8[dd]	35t		Stauffer et al. 1976

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Channel catfish (cont'd)	White R. - Indiana	1965-72	Field A	Ad.				37.8t		Proffitt and Benda 1971
		Sonora, Mexico	1990+	Lab A-2	Juv.			(20) 27[dd],30[j] (23) 26.7[dd],29.7[j] (26) 27.3[dd],31.3[j] (29) 29[dd],34.5[j] (32) 30[dd],31[j]		(20) 34.5[ee], 35.0[gg] (23) 37.0[ee], 37.0[gg] (26) 39.0[ee], 39.0[gg] (29) 40.5[ee], 41.0[gg] (32) 41.5[ee], 42.5[gg]	Diaz and Buckle 1999
		New R./East R. - Virginia	1973+	Lab C[aa]	yoy	(6) 16.2-19.6[kk] (9) 18.1-20.9[kk] (12) 19.9-22.3[kk] (15) 21.8-23.8[kk] (18) 23.4-25.3[kk] (21) 24.9-26.9[kk] (24) 26.4-28.8[kk] (27) 27.8-30.6[kk] (30) 29.1-32.6[kk]		(6) 18.9[tt] (9) 20.4[tt] (12) 19.9[tt] (15) 21.7[tt] (18) 22.9[tt] (21) 26.1[tt] (24) 29.4[tt] (27) 29.5[tt] (30) 30.5[tt]	(6) 25[j] (9) 26[j] (12) 29[j] (15) 30[j] (18) 30[j] (21) 32[j] (24) 33[j] (27) 34[j] (30) 35[j]		Cherry et al. 1975
		Fish Farm - Oklahoma	1995+	Lab A-2	Juv.					(20) 36.4[ee] (25) 38.7[ee] (30) 40.3[ee]	Currie et al. 1998
		Ottawa R. - Canada	1978	Review			34.3[bbb]				Christie 1979
				Lab A	Juv.					(34) 37.8[t]	Allen and Strawn 1968
				Field A	Ad.				33.9-34.4[j]		Churchill and Wojtalik 1969
	Blue catfish (*Ictalurus furcatus*)	White R. - Indiana	1965-72	Field A	Ad.				33.9[j]		Proffitt and Benda 1971
	White catfish (*Ameiurus catus)*	Hudson R. - New York	1977	Lab B, C	Juv.		29.6[a] 26.8-32.6[ddd]	30[dd]			Kellog and Gift 1983
	Brown bullhead (*Ameiurus nebulosus*)	Delaware R. - Delaware	1971	Lab C	juv.			(26.1) 31.1	(25) 36.1		Meldrim and Gift 1971
		L. Opeongo - Ontario	1941	Lab A	juv.					(6) 28.9[n],28[ll] (13) 31[n],30[ll] (20) 33.4[n],32[ll] (26) 35.3[n],34[ll] (31.2)36.9[n],36[ll] (36) 37.5[n],37[ll]	Brett 1944

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Brown bullhead (cont'd)	Cedar Dell Pond - Massachusetts	1973-74	Lab C	juv.	(3.5) 11-16 (11) 15-26 (15.5) 17-22 (21) 21-26 (28) 26-28	(3.5) 12.5[m,s] (11) 18[m,s] (15.5)18.5[m,s] (21) 25[m,s] (28) 27.8[dd]				Richards and Ibara 1978
		Connecticut	1975	Lab C	Ad.			(7) 16[s] (16) 21[s] (24) 26[s] (32) 31[s] 29-31[dd]			Crawshaw 1975
		Hatchery - California	1974	Lab C	juv.		26[i]				Crawshaw & Hammel 1974
		W.L. Erie - Ohio	1973-74	Lab C	Ad.			(Su) 24.9[tt,dd] (Fa) 23.6[tt,dd] (Wi) 11.9[tt,dd] (Sp) 23.5[tt,dd]			Reutter and Herdendorf 1974
		W.L. Erie - Ohio	1973-74	Lab A	Ad.					(23) 37.8[ee]	Reutter and Herdendorf 1976
		Algonquin Park, Ontario	1945-46	Lab A	Ad.					(10) 29[o] (20-Wi) 32.3[o] (30-Wi) 35.4[o]	Hart 1952
		Toronto, Ontario	1945-46	Lab A	Ad.					(10) 27.7[o] (15) 29[o] (20) 31.7[o] (25-Wi) 34.5[o]	
		Put-in-Bay - Ohio	1946	Lab A	Ad.						
		Welaka, Florida	1945-47	LabA	Ad.					(20-Su) 32.7[o] (25-Su) 33.7[p],34.1[o] (30-Su) 34.7[p],35.6[o]	
		Ottawa R. - Canada	1978	Review			(Juv.) 32.3[bbb] (Ad.) 33.0[bbb]				Christie 1979
		Delaware R. - Pennsylvania		Lab A-2						(22.8) 37.3[ee]	Trembley 1960
		Delaware R. - Pennsylvania		Lab C				23.9 -32.2[kk]			Trembley 1960
	Yellow bullhead (*Ameirus natalis*)	Pennsylvania	1977	Lab D	Ad. Juv. Ad. - juv.			(23) 27.9[k,tt],27.6[l,tt] (23) 20.6[k,tt],29.1[l,tt] (23) 28.4[tt]			Reynolds and Casterlin 1978b
		W.L. Erie -Ohio	1973-74	Lab C	Ad.			(Su) 28.3[tt,dd]			Reutter and Herdendorf 1974
		W.L. Erie -Ohio	1973-74	Lab A	Ad.					(22.2) 36.4[t]	Reutter and Herdendorf 1976
		Missouri streams	1995	Lab A-2	Ad.					(26) 37.9[eee]	Smale and Rabeni 1995

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Black bullhead *(Ameiurus melas)*	Mississippi R. - Minnesota	1973-4	Lab A-2	yoy					(26) 35.7[p]	Cvancara et al. 1977
		British Columbia	1950+	Lab A	Juv.					(23) 35[t]	Black 1953
		Missouri streams	1995	Lab A-2	Ad.					(26) 38.1[eee]	Smale and Rabeni 1995
	Flathead catfish (*Pylodictis olivaris*)	Wabash R. - Indiana	1968-73	Field A	Ad.			(Su) 31.5-33.5[cc]	34.3[m]		Gammon 1973
		Ohio R. - Ohio, Kentucky	1974	Field A	Ad.	(Su) 24-36[kk] (Fa) 18-29[kk]					Yoder and Gammon 1976a
		New R. - Virginia	1973	Field A	Ad. - juv.	26.7 - 35[cc,kk]			35[m] 35[j]		Stauffer et al. 1974
		New R. - Virginia	1973-74	Field A	Ad. - juv.				35[j] 35[m]		Stauffer et al. 1976
		White R. - Indiana	1965-72	Field A	Ad.				33.6t		Proffitt and Benda 1971
	Stonecat madtom (*Noturus flavus*)	W.L. Erie -Ohio	1973-74	Lab C	Ad.			(Fa) 25.1[tt,dd] (Wi) 5.5[tt,dd]			Reutter and Herdendorf 1974, 1976
		W.L. Erie -Ohio	1973-74	Lab A	Ad.					(16) 29[ee]	Reutter and Herdendorf 1976
	Tadpole mdatom *(Noturus gyrinus)*	Michigan - Pond		Field B	Ad.					38[cc]	Beltz et al. 1974
Percopsidae	Troutperch (*Percopsis omiscomaycus*)	W.L. Erie -Ohio	1973-74	Lab A	Ad.					(17) 22.9[ee]	Reutter and Herdendorf 1976
	Burbot *(Lota lota)*	Ontario - lakes and streams		Field B	Ad.			15.6-18.3[cc]	23.3[cc]		Scott and Crossman 1973
		Maine - Moosehead L.		Lab C	Juv.			21.2[dd]			Coutant 1977
Centrarchidae	White crappie (*Pomoxis annularis*)	Wabash R. - Indiana	1968-73	Field A	Ad.			(Su) 27 - 28.5[kk]	30.2[m]		Gammon 1973
		W.L. Erie -Ohio	1973-74	Lab C	Ad.			(Su) 19.4[tt,dd] (Fa) 10.4[tt,dd] (Wi) 19.8[tt,dd] (Sp) 18.3[tt,dd]			Reutter and Herdendorf 1974
		W.L. Erie -Ohio	1973-74	Lab A	Ad.					(24.4) 32.8[ee]	Reutter and Herdendorf 1976

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	White crappie (cont'd)	Ohio R. - Ohio, Kentucky	1974	Field A	Ad.	(Su) 26-31[kk] (Fa) 18-26[kk] (Wi) 5-8[kk]					Yoder and Gammon 1976b
		Ohio R. - Ohio, Kentucky	1974	Field A	Ad.	(Su) 29-30[m,kk]			31[m]		Yoder and Gammon 1976a
		White R. - Indiana	1965-72	Field A	Ad.				31.1[j]		Proffit and Benda 1971
		Missouri lakes	199	Lab A-2	3 yrs.					(30) 32.0[t]	Walton and Noltie 1998
				Lab A	Juv.		25.1[a]			(29) 32.6[t]	Kleiner 1981
				Lab A	Juv./Ad.					(25.6) 32.8[j]	Peterson et al. 1974
		Oklahoma - reservoir		Field A	Ad.			23-29[kk]			Gebhart and Summerfelt 1975
	Black crappie (*Pomoxis nigromaculatus*)	L. Monona - Wisconsin	1970	Lab D	juv.				31.0m		Neill et al. 1972
		L. Monona - Wisconsin	1970	Field A Lab D	Ad. Ad. Ad. Ad. juv. juv.			27 - 28.2[i,k,m] 27.8 -29.8[i,l,m] 28 - 28.3[l,m] 25.9 - 29[k,m]	28.6[i,k,m] 29.9[i,l,m] 29[k,m] 30.2[l,m] 30[l,m] 29.4[k,m]		Neill and Magnuson 1974
		W.L. Erie - Ohio	1973-74	Lab C	Ad.			(Su) 21.7[tt,dd] (Fa) 22.2[tt,dd] (Wi) 20.5[tt,dd] (Sp) 21[tt,dd]			Reutter and Herdendorf 1974
		W.L. Erie - Ohio	1973-74	Lab A	Ad.					(23.8) 34.9[ee]	Reutter and Herdendorf 1976
		? - Pennsylvania	1977	Lab D	Ad.			24[s]			Reynolds and Casterlin 1977
		Illinois - Hatchery	1990+	Lab A Lab A-2	yoy/Juv.					(24) 33.8, 35.1, 31.5[o,t] (24) 38,39,35[ee] (30) 38.5,39,38[ee] (32) 39,40,39[ee]	Baker and Heidinger 1996
		Ottawa R. - Canada	1978	Review			27.6[bbb]				Christie 1979
		Minnesota	1980	Lab A,C			22-25[a]			(29) 32.5[j]	Hokanson and Kleiner 1981

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
				Lab A-1						(7.2) 28.9[ee]	Trembley 1961
	Rockbass (*Ambloplites rupestris*)	L. Monona - Wisconsin	1970	Lab D	juv.				29.4m		Neill et al. 1972
		L. Monona - Wisconsin	1970	Field A Lab D	Ad. Ad. Ad. Ad. juv. juv.			26.8 - 28.3[i,k,m] 27.1 -27.8[i,l,m] 27.2 - 28.6[l,m] 27.1 - 29[k,m]	28.3[i,k,m] 28[i,l,m] 30.2[k,m] 31.5[l,m] 29[l,m] 29.3[k,m]		Neill and Magnuson 1974
		W.L. Erie - Ohio	1973-74	Lab C	Ad.			(Su) 18.7[tt,dd] (Fa) 22.8[tt,dd] (Wi) 21.6[tt,dd] (Sp) 20.5[tt,dd]			Reutter and Herdendorf 1974
		W.L. Erie - Ohio	1973-74	Lab A	Ad.					(23.5) 36[ee]	Reutter and Herdendorf 1976
		New R. - Virginia	1973-74	Lab A	Ad. - juv.			30.2[dd]	35[j] (18) 27 (21) 27 (24) 30 (27) 33 (30) 33		Stauffer et al. 1976
		New R. - Virginia	1974+	Lab C[bb]	Ad.	(12) - (15) - (18) 21.3-26.3[kk] (21) 23.2-27.2[kk] (24) 25.1-28.2[kk] (27) 26.6-29.4[kk] (30) 27.9-31.0[kk] (33) 28.9-32.8[kk] (36) 29.8-34.8[kk]		(12) - (15) - (18) 23.2[tt] (21) 24.0[tt] (24) 28.4[tt] (27) 28.4[tt] (30) 29.7[tt] (33) 32.2[tt] (36) 30.4[tt] 29.8[dd]	(12) - (15) - (18) 27[j] (21) 27[j] (24) 30[j] (27) 33[j] (30) 33[j] (33) 36[j] (36) 37[j]	(36) 36[xx]	Cherry et al. 1977
		Ottawa R. - Canada	1978	Review			26.4[bbb]				Christie 1979
	Largemouth bass (*Micropterus salmoides*)	L. Monona - Wisconsin	1970	Lab D	juv.				30.8[m]		Neill et al. 1972

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
		L. Monona - Wisconsin	1970	Field A Lab D	juv. Juv. Ad. Ad. Ad. Ad. juv. juv.			29.3 - 30.9[i,l,m] 26.4 -29.1[i,k,m] 29.3 - 32[i,l,m] 28.6 - 29.5[l,m] 27.2 - 30.6[k,m]	31.4[i,k,m] 32[l,m] 28.8[i,k,m] 32.2[i,l,m] 30.8[k,m] 33.3[l,m] 30.6[l,m] 31[k,m]		Neill and Magnuson 1974
	Largemouth bass (cont'd)	Delaware R. - Delaware	1971	Lab C	juv.				(25)30.6-32.8		Meldrim and Gift 1971
		Susquehanna R. - Pennsylvania	1973	Lab B	juv.		30[c]				Hocutt 1973
		Cornell Hatchery - New York	1966	Lab B	eggs	(17.2)12.8-23.9[e] (18.9)12.8-23.9[e] (21.1)15.6-26.7[e] (21.1)12.8-23.9[e]	(17.2)15.6[e,m] (18.9)18.3[e,m] (21.1)18.3[e,m] (21.1)23.9[e,m]				Kelley 1968
		Pond C(SREL) - S. Carolina	1973	Field A	Ad.				30[cc]		Siler and Clugston 1975
		Oak Ridge Nat'l Lab - Tennessee	1975	Lab B	eggs yoy	15 - 25[g]	27[a] 25 - 30[ss]				Coutant 1975a
		Reservoir - E. Tennessee			Ad.			27[cc,dd]			
		Pennsylvania	1976	Lab D	juv. - Ad.			30.2[i,tt]			Reynolds et al. 1976
		Pennsylvania	1976	Lab D,G	juv.			30.1[tt] 32.2[tt,uu]			Reynolds et al. 1976
		Hatchery - Texas	1961	Lab B	yoy	27.5 - 30[a]	27.5[a]				Strawn 1961
		Pennsylvania	1977	Lab D	juv. (?)			26[l,m],30[k,m]			Reynolds 1977a
		W.L. Erie	1973-74	Lab A	Ad.					(0.7) 12[ee]	Reutter and Herdendorf 1976
		Put-in-Bay - Ohio	1945-47	Lab A	Ad. - juv.					(20) 32.5[o] (25) 34.5[o] (30) 36.4[o]	Hart 1952
		Knoxville, Tenn.	1945-47	Lab A	Ad. - juv.					(30) 36.4[o]	
		Welaka, Florida	1945-47	Lab A	Ad. - juv.					(20) 31.8[o] (25) 32.7[o] (30) 33.7[o]	
		Par Pond - S. Carolina	1973	Lab A	juv.					(20) 36.7[ee] (28) 40.1[ee]	Smith 1975

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
		Lake Mendota - Wisconsin	1927	Lab A	juv.					(23) 32.2[zz]	Hathaway 1927
		Ohio R. - Ohio, Kentucky	1974	Field A	Ad.	(Su) 24-31[kk] (Fa) 18-21[kk]					Yoder and Gammon 1976b
		Ohio R. - Ohio, Kentucky	1970-75	Field A	Ad.	(Su) 29-30.5[m,kk]			33[m]		Yoder and Gammon 1976a
		Hatchery - Virginia	1982	Lab C	Juv.			(12) 19.6[dd] (24) 27.3[dd]	(12) 24[j] (24) 33[j]	(12) 36[xx]	Cherry et al. 1982
	Largemouth bass (cont'd)	Mississippi R. - Minnesota	1973-4	Lab A-2	yoy					(26) 35.6[p]	Cvancara et al. 1977
		Pond C(SREL) - S. Carolina	1979-82	Field A	Ad.	(Su) 26.1-32.5 (Su) 20.0-30.4 (Fa) 20.4-32.5 (Sp) 24.4-31.3					Block et al. 1984
		Fish Farm - Oklahoma	1995+	Lab A-2	Juv.					(20) 35.4[ee] (25) 36.7[ee] (30) 38.5[ee]	Currie et al. 1998
		Ottawa R. - Canada	1978	Review			(Juv.) 31.3[bbb] (Ad.) 31.1[bbb]				Christie 1979
		Missouri streams	1995	Lab A-2	juv.					(26) 36.3[eee]	Smale and Rabeni 1995
	Northern Largemouth Bass *(Micropterus salmoides salmoides)*	Minnesota/Wiscon-sin	1976	Lab A, B	gamete embryo fry yoy Juv.		32[b] 34.8[v] 33.4[bbb]			fry (20) 31.2[o] fry (24) 32.4[o] fry (27) 33.0[o] fry (30) 31.7[o] fry (20) 33.7[r] (early emryo) 29.5[o] (late embryo) 32.3[o]	McCormick and Wegner 1981
		Bone L. - Wisconsin	1978	Lab A-2	Juv.					(8) 29.2[ee] (16) 33.6[ee] (24) 36.5[ee] (32) 40.9[ee] (32) 37.3[ww]	Fields et al. 1987
	Florida Largemouth Bass *(Micropterus salmoides floridanus)*	Florida	1976	Lab A, B	gamete embryo fry yoy Juv.		32[b] 35.3[v] 33.6[bbb]			fry (24) 32.8[o] fry (27) 31.9[o] fry (20) 32.0[r] fry (24) 32.7[o] fry (27) 33.6[r] (early emryo) 29.1[o] (late embryo) 30.9[o]	McCormick and Wegner 1981

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
		L. Dora - Florida	1980-1	Lab A-2	Juv.					(8) 30.4[ee] (16) 34.1[ee] (24) 37.5[ee] (32) 41.8[ee] (32) 39.2[ww]	Fields et al. 1987
	Spotted bass (*Micropterus punctulatus*)	Wabash R. - Indiana	1968-73	Field A	Ad.			(Su) 27-28.5[kk]	31.5[m]		Gammon 1973
		Ohio R. - Ohio, Kentucky	1970-74	Field A	Ad.	(Fa) 16-21[kk] (Wi) 6-15[kk]					Yoder and Gammon 1976b
	Spotted bass (cont'd)	New R. - Virginia	1973-74	Lab C	Ad.- juv.			(17.7) 27.6[aaa] (21.1) 28.6[aaa] (23.9) 29.5[aaa] (27.2) 30.5[aaa] (30) 31.4[aaa] (32.8) 32.2[aaa] 30[dd]			Stauffer et al. 1975
		New R. - Virginia	1973-74	Field A Lab C	Ad. - juv. Ad. - juv.			32[dd]	32.2[w] (18) 33 (21) 30 (24) 33 (27) 33 (30) 39 (33) 39		Stauffer et al. 1976
		White R. - Indiana	1965-72	Field A	Ad.						Proffitt and Benda 1971
		New R. - Virginia	1974+	Lab C[bb]	Ad.	(12) - (15) 20.5-24.4[kk] (18) 25.6-28.2[kk] (21) 26.8-28.8[kk] (24) 27.8-29.6[kk] (27) 28.7-30.5[kk] (30) 29.5-31.6[kk] (33) 30.2-32.7[kk] (36) 30.8-33.9[kk]		(12) - (15) 24.8[tt] (18) 26.8[tt] (21) 28.0[tt] (24) 30.6[tt] (27) 29.9[tt] (30) 30.5[tt] (33) 31.5[tt] (36) 31.4[tt] 31.4[dd]	(12) - (15) - (18) 33[j] (21) 30[j] (24) 33[j] (27) 33[j] (30) 36[j] (33) 39[j] (36) 38[j]	(36) 36[xx]	Cherry et al. 1977
		New R./East R. - Virginia	1973+	Lab C[aa]	yoy	(6) 14.7-19.4[kk] (9) 17.2-21.2[kk] (12) 19.8-23.1[kk] (15) 22.2-24.9[kk] (18) 24.4-27.0[kk] (21) 26.5-29.3[kk] (24) 28.4-31.7[kk] (27) 30.2-34.2[kk] (30) 31.9-36.8[kk]		(6) 16.9[tt] (9) 17.9[tt] (12) 20.1[tt] (15) 24.8[tt] (18) 26.7[tt] (21) 29.5[tt] (24) 32.2[tt] (27) 31.4[tt] (30) 32.1[tt]	(6) 18[j] (9) 21[j] (12) 25[j] (15) 29[j] (18) 31[j] (21) 32[j] (24) 33[j] (27) 34[j] (30) 34[j]		Cherry et al. 1975

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Smallmouth bass (*Micropterus dolomieui*)	St. Croix R. - Minnesota	1970-71	Lab A,B	juv.	26 - 29[a]	26[a]		29[vv]		Horning and Pearson 1973
	Smallmouth bass (cont'd)	L. Erie - Ohio	1971	Lab C	yoy	(Su) 29-31[s] (Fa) 26-30[s] (Wi) 24-28[s] (Sp) 22-28[s]		(Su) 30[m,s] (Fa) 28.8[m,s] (Wi) 25[m,s] (Sp) 24.5[m,s]	(Su) 33[m] (Fa) 31[m] (Wi) 27.8[m] (Sp) 27.5[m]		Barans and Tubb 1973
					Ad.	(Su) 30-31[s] (Fa) 21-27[s] (Wi) 13-26[s] (Sp) 18-26[s]		(Su) 30.8[m,s] (Fa) 25[m,s] (Wi) 25.7[m,s] (Sp) 17.7[m,s]	(Su) 33[m] (Fa) 29[m] (Wi) 27.8[m] (Sp) 25.8[m]		
		Pennsylvania	1977	Lab D	juv. (?)			29[l,m],31[k,m]			Reynolds 1977a
		Tennessee R. - Alabama	1972-73	Field A	Ad. - juv.				35.1[j]		Wrenn 1975
		W.L. Erie - Ohio	1973-74	Lab C	yoy			(Fa) 26.6[tt,dd]			Reutter and Herdendorf 1974
		W.L. Erie - Ohio	1973-74	Lab A	Ad.					(23.3) 36.3[ee]	Reutter and Herdendorf 1976
		Ohio R. - Ohio, Kentucky	1970-75	Field A	Ad.				31[m]		Yoder and Gammon 1976a
		New R. - Virginia	1973	Field A	Ad. - juv.				35[j] 27.2[m]		Stauffer et al. 1974
		New R. - Virginia	1973-74	Lab C	Ad. - juv.			(17.7) 25.8[aaa] (21.1) 27.1[aaa] (23.9) 28.2[aaa] (27.2) 29.5[aaa] (30) 30.5[aaa] (32.8) 31.6[aaa] 28.3[dd]			Stauffer et al. 1975
		New R. - Virginia	1973-74	Field A	Ad. - juv.				35[t]		Stauffer et al. 1976
				Lab C	Ad. - juv.				(18) 27 (21) 30 (24) 33 (27) 33 (30) 33 (33) 36		

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Smallmouth bass (cont'd)	New R. - Virginia	1974+	Lab C[bb]	Ad.	(12) - (15) 19.5-21.7[kk] (18) 21.7-26.6[kk] (21) 23.7-27.5[kk] (24) 25.4-28.8[kk] (27) 26.7-30.6[kk] (30) 27.7-32.6[kk] (33) 28.5-34.8[kk] (36)[aaa]		(12) - (15) 20.2[tt] (18) 25.5[tt] (21) 25.8[tt] (24) 28.2[tt] (27) 29.7[tt] (30) 30.9[tt] (33) 29.4[tt] (36)[aaa] 31.5[dd]	(12) - (15) - (18) 27[j] (21) 30[j] (24) 33[j] (27) 33[j] (30) 33[j] (33) 35[j] (36)[aaa]	(33) 35[xx]	Cherry et al. 1977
		New R./East R. - Virginia	1973+	Lab C[aa]	yoy	(6) -[kk] (9) -[kk] (12) -[kk] (15) 18.5-23.7[kk] (18) 21.4-25.3[kk] (21) 24.2-27.2[kk] (24) 26.5-29.5[kk] (27) 28.3-32.2[kk] (30) 29.9-31.9[kk]		(6) -[tt] (9) -[tt] (12) -[tt] (15) 20.2[tt] (18) 22.9[tt] (21) 26.5[tt] (24) 29.8[tt] (27) 30.1[tt] (30) 31.3[tt]	(6) -[j] (9) -[j] (12) -[j] (15) 26[j] (18) 27[j] (21) 30[j] (24) 31[j] (27) 31[j] (30) 33[j]		Cherry et al. 1975
		Hatchery - Alabama	1977-8	Lab C	yoy/Juv.		32-33[bbb]			35[ccc]	Wrenn 1980
		Ottawa R. - Canada	1978	Review			24.7[bbb]				Christie 1979
		Missouri streams	1995	Lab A-2	juv.					(26) 36.9[eee]	Smale and Rabeni 1995
	Bluegill *(Lepomis macrochirus)*	Private Pond-S.C. (ambient T)	1970, 1972	Lab A-2	juv.					(25) 37.3[gg],37.8[ee] (30) 39.4[gg],40[ee] (35) 41.9[gg],43.4[ee]	Holland et al. 1974
		Par Pond (Hot) - S.C. (30-40C, Su)	1970, 1972	Lab A-2	juv.					(25) 37.6[gg],38.5[ee] (30) 39.1[gg],40.2[ee] (35) 42.4[gg],43.9[ee]	
		Par Pond (Cold)) - S.C. (near ambient)	1970, 1972	Lab A-2	juv.					(25) 37[gg],37.7[ee] (30) 39[gg],40.6[ee] (35) 42.4[gg],43.9[ee]	
		Pond C - S.C. (30-50C, year-round)	1970, 1972	Lab A-2	juv.					(25) 39.1[gg],41.2[ee] (30) 40.9[gg],42.2[ee] (35) 42.8[gg],44.2[ee]	
		Brier Cr. - Oklahoma	198	Lab A-2 Lab C	Ad.					(15) 36.8[ee]	Matthews 1981

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Bluegill (cont'd)	Hatchery - Tennessee	1969	Lab A	juv.					(5[KLm]25)6.5[hh],2.5[ii] (5[KLm]30)1.9[hh],0.8[ii] (5[KLm]30)3.9[hh],1.8[ii] (30)36[r]	Speakman and Krenbel 1972
		Canals, Hatchery, L. Apopka, Fla. (Cu and Cd in test water exceeded "safe" limits).	1971	Lab A Lab B	egg egg juv.	18 - 36[e]	22.2 - 23.9[e]			(26) 33.8[q] (12.1) 27.5[q] (19) 33[q] (26) 36.1[q] (32.9) 37.3[q]	Banner and Van Arman 1973
		Lake Mills Hatchery-Wisc.	1977	Lab B	juv.	28.34[a]	30.1[a]				Lemke 1977
		Pennsylvania	1976	Lab D,G	Ad.			30.5[tt] 33.2[tt,uu]			Reynolds et al. 1976
		L. Monona - Wisconsin	1975	Lab D	juv. - Ad.			31.2[tt]			Beitinger & Magnuson 1975
		L. Monona - Wisconsin	1974	Lab D	juv. - Ad.			(21) 31.3[tt] (31) 31.2[tt] (36.1) 33.1[tt]	(21) 33.1 (31) 33.1 (36.1) 33.1		Beitinger 1974
		Muddy Run Pond-Pennsylvania	1975	Lab A,C	Ad.			(27.2) 27.2[dd]	(27.2) 35	(27.2) 35.6[p]	Peterson & Saburtsky 1975
		W.L. Erie - Ohio	1973-74	Lab C	Ad.			(Wi) 27.4[tt,dd]			Reutter and Herdendorf 1974
		L. Monona - Wisconsin	1970	Lab D	juv.				31.8m		Neill et al. 1972
		L. Monona - Wisconsin	1970	Field A Lab D	juv. juv. juv. juv. Ad. Ad. Ad. Ad. juv. juv.			27.1 - 29.1[i,k,m] 28.8 - 31.2[i,l,m] 27.8 - 28.9[i,k,m] 29.6 - 32.7[i,l,m] 29.6 - 31.2[l,m] 29.3 - 31.4[k,m]	29.3[i,k,m] 31.3[i,l,m] 30[k,m] 32.2[l,m] 30.2[i,k,m] 32.8[i,l,m] 30.5[k,m] 33[l,m] 32[l,m] 32.5[k,m]		Neill and Magnuson 1974
		L. Texoma - Oklahoma	1971	Lab C	y.			(16) 22.5[tt] (21) 23.4[tt] (26) 28.2[tt]			Hill et al. 1975
		Conowingo Pond - Pennsylvania	1972	Lab A,C	Ad. - juv.			(13) 24.6[s] (27) 30.7[s]	(1) 22[ww],27.6 (13)28[ww],30.3 (27)35[ww],33.5	(1) 23.3[q],23.5[t] (13) 29.3[q],30[t] (27) 35.8[q],36[t]	Peterson and Shutsky 1976
		W.L. Erie - Ohio	1973-74	Lab A	Ad.					(22.8) 38.3[ee]	Reutter and Herdendorf 1976

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Bluegill (cont'd)	Welaka, Florida	1945-47	Lab A	Ad.					(15) 30.7[o] (20) 31.5[o] (30) 33.8[o]	Hart 1952
		L. Mendota - Wisconsin	1927	Lab A	juv.					(23) 34zz	Hathaway 1927
		Ohio R. - Ohio, Kentucky	1974	Field A	Ad. - juv.	(Su) 22-34[kk] (Fa) 14-24[kk] (Wi) 5-8[kk]					Yoder and Gammon 1976b
		Ohio R. - Ohio, Kentucky	1970-75	Field A	Ad. - juv.	(Su) 27-32[m,kk]			34[m]		Yoder and Gammon 1976a
		White R. - Indiana	1965-72	Field A	Ad.				33.6[j]		Proffitt and Benda 1971
		New R. - Virginia	1973-74	Field A Lab C	Ad. - juv. Ad. - juv.				35[t] (12) 24 (15) 27 (18) 30 (21) 30 (24) 33 (27) 33 (30) 33 (33) 36		Stauffer et al. 1976
		Hatchery - Virginia	198	Lab C	Juv.			(12) 23.9[dd] (24) 28.2[dd]	(12) 24[j] (24) 33[j]	(12) 36[ww]	Cherry et al. 1982
		Texas, Oklahoma, Mississippi	200	Lab A-2	Ad.?					(10) 33.4-34.8[ee] (20) 37.1-37.3[ee] (30) 41.2[ee]	Dent and Lutterschmidt 2003
		Mississippi R. - Minnesota	1973-4	Lab A-2	yoy					(26) 28.5[p]	Cvancara et al. 1977
		New R. - Virginia	1974+	Lab C[bb]	Ad.	(12) 23.2-25.7[kk] (15) 24.5-26.5[kk] (18) 25.7-27.4[kk] (21) 26.8-28.3[kk] (24) 27.8-29.2[kk] (27) 28.9-30.3[kk] (30) 29.8-31.5[kk] (33) 30.6-32.7[kk] (36) 31.4-33.9[kk]		(12) 24.1[tt] (15) 25.2[tt] (18) 26.8[tt] (21) 27.8[tt] (24) 28.2[tt] (27) 30.0[tt] (30) 32.4[tt] (33) 30.9[tt] (36) 31.8[tt] 32.1[dd]	(12) 24[j] (15) 27[j] (18) 30[j] (21) 30[j] (24) 33[j] (27) 36[j] (30) 36[j] (33) 39[j] (36) 38[j]	(36) 36[xx]	Cherry et al. 1977

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Bluegill (cont'd)	New R./East R. - Virginia	1973+	Lab C[aa]	yoy	(12) 17.3-22.3[kk] (15) 19.5-23.6[kk] (18) 21.6-25.0[kk] (21) 23.7-26.5[kk] (24) 25.5-28.2[kk] (27) 27.2-30.1[kk] (30) 28.7-32.1[kk] (33) 30.1-34.2[kk] (36) 31.5-36.4[kk]		(12) 18.7[tt] (15) 19.6[tt] (18) 23.9[tt] (21) 25.9[tt] (24) 29.2[tt] (27) 30.1[tt] (30) 31.2[tt] (33) 31.4[tt] (36) 31.7[tt]	(12) 22[j] (15) 23[j] (18) 25[j] (21) 26[j] (24) 31[j] (27) 33[j] (30) 33[j] (33) 34[j] (36) 35[j]		Cherry et al. 1975
		Oklahoma streams	1995+	Lab A-2	Ad./juv.					(10) 32.6[ee] (Su) (10) 30[ee] (Wi)	Schaefer et al. 1999
		Missouri streams	1995	Lab A-2	Ad./juv.					(26) 37.9[eee]	Smale and Rabeni 1995
	Green Sunfish *(Lepomis cyanellus)*	Ponds - Oklahoma	1965	Lab C	juv.			(4) 10.6 (10) 15.2 (22) 26.8 (30) 26.8 27.3[dd]			Jones and Irwin 1965
		Ponds - Wisconsin	1975	Lab D	juv.	26-30[m]		28.2[s]	30.3[j] 30.4[j,k] 29.7[j,l]		Beitinger et al. 1975
		Lake Texoma - Oklahoma	1971	Lab C	y.			(16) 18.9tt (21) 25.5[tt] (26) 26[tt]			Hill et al. 1975
		White R. - Indiana	1965-72	Field A	Ad.				36.1[j]		Proffit and Benda 1971
		Brier Cr. - Oklahoma	198	Lab A Lab C	Ad.			30.8[tt]		(15) 36.5[ee]	Matthews 1981
		New R./East R. - Virginia	1973+	Lab C[aa]	yoy	(6) 14.7-18.8[kk] (9) 17.0-20.5[kk] (12) 19.3-22.1[kk] (15) 21.5-23.9[kk] (18) 23.5-25.8[kk] (21) 25.4-27.8[kk] (24) 27.2-30.0[kk] (27) 28.8-32.3[kk] (30) 30.5-34.6[kk]		(6) 16.9[tt] (9) 18.2[tt] (12) 21.1[tt] (15) 20.7[tt] (18) 25.2[tt] (21) 28.1[tt] (24) 30.4[tt] (27) 30.7[tt] (30) 30.6[tt]	(6) 20[j] (9) 21[j] (12) 24[j] (15) 25[j] (18) 29[j] (21) 31[j] (24) 33[j] (27) 33[j] (30) 33[j]		Cherry et al. 1975
				Lab A-2						(20) 35.8[ee]	Carrier and Beitinger 1988

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Green Sunfish (continued)	Missouri streams	1995	Lab A-2	Ad./juv.					(26) 37.9[eee]	Smale and Rabeni 1995
				Lab A-2						(10) 34.2[ee]	Lutterschmidt and Hutchinson 1977
				Lab A	Juv./Ad.					(30) 35.4[p]	Boswell 1967
				Lab B	Juv./Ad.		30				Jude 1973
	Pumpkinseed sunfish (*Lepomis gibbosus*)	L. Monona - Wisconsin	1970	Field A	Ad. Ad. Ad. Ad.			27 - 29.1[i,k,m] 28.5 - 32[i,l,m]	30.4[i,k,m] 32.2[i,l,m] 30.5[k,m] 33[l,m]		Neill and Magnuson 1974
		L. Amikeus, L. Opeongo,Ontario	1941	Lab A	juv.					(25-26) 34.5[n],33[ll]	Brett 1944
		Laboratory - Massachusetts	1976	Lab A	juv.					32 - 39[ee]	Power and Todd 1976
		Lake-on-the-Mountain-Ontario	1966-67	Lab B	juv.		30[a],25[b]				Pessah and Powles 1974
		W.L. Erie - Ohio	1973-74	Lab C	Ad.			(Su) 27.7[tt,dd] (Sp) 24.2[tt,dd]			Reutter and Herdendorf 1974
		W.L. Erie - Ohio	1973-74	Lab A Lab C	Ad.			(Sp) 23.8[tt,dd]		(23.1) 37.5[ee]	Reutter and Herdendorf 1976
		L. Mendota - Wisconsin	1927	Lab A	juv.					(23) 34[zz]	Hathaway 1927
		? - Pennsylvania	1977	Lab D	Ad.			26[s]			Reynolds & Casterlin 1977
				Lab A-2						(10) 30.1[ee] (20) 35.1[ee]	Becker and Galloway 1979
		White R. - Arkansas	1964	Lab A	yoy - juv.					(25)35.5[n],35.5[o,m],35.4[q,m],35.4[r,m] (30)36.6[n],36.5[o,m],36.5[q,m],36.5[r,m] (35)38.2[n],37.8[o,m],37.5[q,m],37.2[r,m]	Neill et al. 1966
		Lake Texoma - Oklahoma	1971	Lab C	y.			(16) 20.1[tt] (21) 23.2[tt] (26) 24.1[tt]			Hill et al. 1975
		White R. - Indiana	1965-72	Field A	Ad.				37.8[j]		Proffitt and Benda 1971
		Brier Cr. - Oklahoma	198	Lab A Lab C	Ad.			20.8[tt]		(15) 36.5[ee]	Matthews 1981

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Pumpkinseed sunfish (cont'd)	Texas, Oklahoma, Mississippi	200	Lab A-2	Ad.?					(10) 34.7-34.9[ee] (20) 36.6-37.2[ee] (30) 40.0[ee]	Dent and Lutterschmidt 2003
		Oklahoma streams	1995+	Lab A-2	Ad./juv.					(10) 31.6[ee] (Su) (10) 29.8[ee] (Wi)	Schaefer et al. 1999
	Longear sunfish *(Lepomis megalotis)*	Missouri streams	1995	Lab A-2	juv.					(26) 37.8[eee]	Smale and Rabeni 1995
				Lab A-2						(10) 34.1[ee]	Lutterschmidt and Hutchison 1997
	Redear sunfish *(Lepomis microlophus)*	Lake Texoma - Oklahoma	1971	Lab C	y.			(16) 22.5[tt] (21) 23.1[tt] (26) 28.7[tt]			Hill et al. 1975
		W.L. Erie - Ohio	1973-74	Lab A	Ad.					(22.7) 37.4[ee]	Reutter and Herdendorf 1976
	Orangespotted sunfish *(Lepomis humilis)*	Lake Texoma - Oklahoma	1971	Lab C	y.			(16) 18.6[tt] (21) 20.8[tt] (26) 21.9[tt]			Hill et al. 1975
		W.L. Erie - Ohio	1973-74	Lab A	Ad.					(5.6) 26[ee]	Reutter and Herdendorf 1976
		Brier Cr. - Oklahoma	1981	Lab A Lab C	Ad.			21.0[tt]		(15) 37.2[ee]	Matthews 1981
		Missouri streams	1995	Lab A-2	Ad.					(26) 36.4[eee]	Smale and Rabeni 1995
	Warmouth *(Lepomis gulosus)*			Lab A-2						(10) 32.9[ee]	Lutterschmidt and Hutchinson 1997
Percidae	Yellow perch *(Perca flavescens)*	Park L. - Minnesota	1973	Lab B	yoy		28[a]			(28) 32-34[q] 32[nn]	McCormick 1976
		?	?	Lab B	gonadal egg	3.9 - 18.6[d]	4 - 6[h](winter) 8 - 11[d]				Jones et al. (ms)
		Little Cut Foot Sioux L. - Minnesota	1971	Lab B	egg(constantT) egg(neural keel) egg (rising T) larvae		10.1 - 18.2[e] 13.1 - 22.1[e] 24.3[e](upper)	13.1 - 18.2			Hokanson and Kleiner 1974
		L. Monona - Wisconsin	1970	Lab D	juv.				27.4[m]		Neill et al. 1972

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Yellow perch (cont'd)	L. Monona - Wisconsin	1970	Field A	juv. juv.			26.7 - 28.3[i,l,m]	28.9[i,l,m] 32.2[l,m]		Neill and Magnuson 1974
				Lab D	juv. juv.			23.7 - 24.2[l,m] 21.2 - 23.7[k,m]	26.3[l,m] 25[k,m]		
		Delaware R. - Delaware	1971	Lab C	juv.			(18) 23.3 (25) 22.3	(25) 33.4-34		Meldrim and Gift 1971
		L. Amikeus, L. Opeongo,Ontario	1941	Lab A	juv.					(25-26) 30.9[n],29[ll]	Brett 1944
		Hatchery - Wisconsin	1976	Lab B	yoy		22[a,ff]				Huh et al. 1976
		Clear L., Ontario	1976	Lab E	larvae			(20) 21.5[s],22.8[tt] (23) 24.5[s],24[tt] (25) 22.5[s],22.6[tt]			Ross et al. 1977
		W.L. Erie - Ohio	1971	Lab C	yoy Ad.	(Su) 28-29[s] (Fa) 24-31[s] (Wi) 11-15[s] (Sp) 17-25[s] (Su) 23-26[s] (Fa) 13-21[s] (Wi) 12-16[s] (Sp) 10-14[s]		(Su) 29[m,s] (Fa) 25[m,s] (Wi) 13[m,s] (Sp) 24[m,s] (Su) 25[m,s] (Fa) 17[m,s] (Wi) 15[m,s] (Sp) 10[m,s]	(Su) 31[m] (Fa) 30.7[m] (Wi) 20.2[m] (Sp) 27.5[m] (Su) 30[m] (Fa) 29[m] (Wi) 18.5[m] (Sp) 19.8[m]		Barans and Tubb 1973
		Grand R., L. St. Clair - Ontario	1971	Lab E	yoy juv. Ad.			(24) 23[s],23.3[tt] (24) 24[s],23.3[tt] (24) 20[s],20.1[tt]			McCauley and Read 1973
		L. St. Clair - Ontario	1974	Lab C	Ad.			(Wi) 25[dd] (Sp) 21[dd] (Su) 17[dd]			McCauley 1977
		L. St. Clair - Ontario	1975	Lab C	Ad.			(Wi) 30[dd] (Sp) 21.1[dd] (Su) 18[dd]			
		W.L. Erie - Ohio	1973-74	Lab C	Ad.			(Su) 20.9[tt,dd] (Fa) 19.9[tt,dd] (Wi) 14.1[tt,dd]			Reutter and Herdendorf 1974
		W.L. Erie - Ohio	1973-74	Lab A						(22) 35[ee]	Reutter and Herdendorf 1976
		Toronto, Ontario	1945-46	Lab A	Ad. - juv.					(25-Wi) 29.7[o]	Hart 1952
		Put-in-Bay - Ohio	1946	Lab A	Ad. - juv.					(25-Su) 32.3[o]	
		L. Mendota - Wisconsin	1927	Lab A	juv.					(23) 29.6[zz]	Hathaway 1927

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Yellow perch (cont'd)	Chippewa Cr. - Ontario	1945-46	Lab A	juv.					(5) 21.3[n] (10) 25[n] (15) 27.7[n] (25) 29.7[q]	Hart 1947
		Hatchery - Virginia	1974+	Lab C[bb]	Juv.	(12) - (15) 18.5-19.9[kk] (18) 19.8-20.7[kk] (21) 20.8-21.8[kk] (24) 21.6-28.0[kk] (27)[aaa] (30)[aaa] (33)[aaa] (36)[aaa]		(12) - (15) 19.2[tt] (18) 20.4[tt] (21) 21.1[tt] (24) 22.4[tt] (27)[aaa] (30)[aaa] (33)[aaa] (36)[aaa] 22.2[dd]	(12) - (15) 21[j] (18) 27[j] (21) 27[j] (24) 29[j] (27) - (30) - (33) - (36) -	(24) 26[xx]	Cherry et al. 1977
		Ottawa R. - Canada	1978	Review			24.0[bbb]				Christie 1979
	Walleye *(Sander vitreus)*	L. Cutfoot Sioux L., Upper Red L. - Minnesota	1971, 1972	Lab A Lab B	egg egg larvae		6 - 12[f] 9 - 15[g] 15 - 21[e]				Smith and Koenst 1975; Koenst and Smith 1976
					juv. (small) juv. (large) juv.		25[a] 22[a]			(8) 27[q],26[ll] (10.1) 28.6[q],28[ll] (12.1) 29[q],28[ll] (13.9) 29.5[q],28.6[ll] (16) 30.6[q],30[ll] (18.2) 30.5[q],30[ll] (20.2) 30.5[q],30[ll] (22.1) 30.5[q],30[ll] (24) 31.5[q],30.8[ll] (25.8) 31.6[q],31[ll]	
		Canada ?	?	?	juv.		20[a]				Kelso 1972
		? Oklahoma	?	Field B	Ad.	26-27					Eley et al. 1967
		? Wisconsin	?	Lab B	egg		17.8 - 19.4[e]				Anonymous 1967
		Hatchery - Wisconsin	1976	Lab B	yoy		22[a,ff]				Huh et al. 1976
		Tennessee R. - Alabama	1972-73	Field A	Ad. - juv.				30[cc]		Wrenn 1975

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Walleye (continued)	W.L. Erie - Ohio	1972-73	Lab A-2	Ad.					(23.3) 34.4[ee]	Reutter and Herdendorf 1976
		Hatchery - Wisconsin	1968	Lab B	egg		16.7 - 19.4[e]				Steucla 1968
		Hatchery - Minnesota	1978	Lab A-1	juv.		22-26[a]			(22.1) 33.0[ww] (26.0) 34.1[ww] (28.0) 34.1[ww] (25.8) 31.6[t]	Hokanson and Koenst 1986
		Iowa and Mississippi - hatchery	1990+	Lab A-2	Juv.					(23) 34.8-35.0[ee]	Peterson 1993
		Ottawa R. - Canada	1978	Review			25.0[bbb]				Christie 1979
	Sauger *(Sander canadense)*	L. Winnebago-Wisconsin; Mississippi R. - Minnesota; L. Pepin - Minnesota	1971, 1972, 1973	Lab A Lab B	egg egg larvae juv.		12 - 15[g] 9 - 15[f] 9 - 21[e] 22[e]			(10.1) 26.6[q],26[ll] (12.0) 26.7[q],26[ll] (13.9) 28.4[q],27.8[ll] (16.0) 28.6[q],28[ll] (18.3) 28.7[q],28[ll] (19.9) 29.5[q],29[ll] (22.0) 29.9[q],29[ll] (23.9) 30.4[q],29.8[ll] (25.8) 30.4[q],29.8[ll]	Smith and Koenst 1975; Koenst and Smith 1976
		Wabash R. - Indiana	1968-73	Field A	Ad.			(Su) 26 - 28[kk]	28.7[m]		Gammon 1973
		Tennessee R. - Alabama	1972-73	Field A	Ad. - juv.				30[cc]		Wrenn 1975
		Ohio R. - Ohio, Kentucky	1974	Field A	Ad. - juv.	(Fa) 14 - 21[kk] (Wi) 8 - 11[kk]					Yoder and Gammon 1976b
		Ohio R. - Ohio, Kentucky	1970-75	Field A	Ad. - juv.	(Su) 27 - 28[m,kk]			29[m]		Yoder and Gammon 1976a
		White R. - Indiana	1965-72	Field A	Ad.				33.6[j]		Proffitt and Benda 1971
		Ottawa R. - Canada	1978	Review			24.6[bbb]				Christie 1979
		Tennessee R. - Alabama		Lab C	Ad. Juv.					(cont.) 33.2[j] (cont.) 33.9[j]	Heuer and Wrenn 1981
		Tennessee - reservoir		Field B	Ad.			18.6-19.2[dd]			Dendy 1948
	Orangethroat darter (*Etheostoma apectabile*)	Colorado R. - Texas	1960	Lab B	egg larvae		23[m,f] 23[m]			27[m]	Hubbs 1961

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Orangethroat darter (continued)	5 streams-Arkansas-Missouri	1962	Lab B	egg larvae	23 - 28[f] 25 - 27	26m,f 26[m]			29[m]	Hubbs and Armstrong 1962
		4 streams-Texas	1962	Lab B	egg larvae	18 - 26[f] 18 - 24	26[m,f] 22m			28[m]	
		Clear Creek - Arkansas	1965	Lab B			26[a]				West 1966
		Brier Cr. - Oklahoma	198	Lab A Lab C	Ad.					(15) 35.8[ee]	Matthews 1981
		Boone Co., Missouri	200	Lab A-2	Ad.				(16) 29.0[j]	(16) 31.0[ee]	Strange et al. 2002
		4 creeks in Oklahoma	1981	Lab A-2	Ad.				(20) 29.0[j]	(20) 32.28[ee] [low ambient flux] (20) 32.9[ee] [intermediate flux] (20) 34.0[ee] [intermediate flux] (20) 34.3[ee] [high ambient flux]	Feminella and Matthews 1984
		Missouri streams	1995	Lab A-2	Ad.					(26) 36.4[eee]	Smale and Rabeni 1995
	Rainbow darter *(Etheostoma caeruleum)*	Indian Cr.- Ohio	1983-4	Lab C	Ad.	16.0-24.4 (Su) 13.2-23.8 (Fa) 14.5-25.6 (Wi) 17.2-25.7 (Sp)		19.8[tt] (Su) 18.0[tt] (Fa) 19.5[tt] (Wi) 20.4[tt] (Sp)			Hlohowskyi and Wissing 1987
		?	1975+	Lab A-2						(15) 32.1[ee]	Kowalski et al. 1978
		Missouri streams	1995	Lab A-2	Ad.					(26) 35.6[eee]	Smale and Rabeni 1995
	Dusky darter *(Percina sciera)*	Colorado R. - Texas	1960	Lab B	egg larvae		22[m,f] 23[m]			27[m]	Hubbs 1961
	Eastern Sand Darter *(Ammocrypta pellucida)*	Quebec - Chateauguay R.						25[dd]			Scott and Crossman 1973
	Logperch *(Percina caprodes)*	Colorado R. - Texas	1960	Lab B	egg larvae		22[m,f] 22[m]			26[m]	Hubbs 1961
	Greenside darter *(Etheostoma blennioides)*	New R. - Virginia	1973	Field A	Ad. - juv.	20 - 27.2[cc,kk]			35[m,t]		Stauffer et al. 1974
		New R. - Virginia	1973-74	Field A	Ad. - juv.				35[j]		Stauffer et al. 1976

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
		Indian Cr.- Ohio	1983-4	Lab C	Ad.	18.4-25.7 (Su) 18.8-27.6 (Fa) 19.2-26.2 (Wi) 16.9-28.3 (Sp)		21.4[tt] (Su) 21.5[tt] (Fa) 22.8[tt] (Wi) 23.8[tt] (Sp)			Hlohowskyi and Wissing 1987
	Greenside darter (cont'd)	?	1975+	Lab A-2	Ad.					(15) 32.2[ee]	Kowalski et al. 1978
	Johnny darter (*Etheostoma nigrum*)		1984	Lab A-2						(15) 30.5[ee]	Ingersoll and Claussen 1984
			1995	Lab A-2			24.5[dd]			(26) 36.4[e]	Smale and Rabeni 1995
	Fantail darter *(Etheostoma flabellare*)	New R. - Virginia	1973	Field A	Ad. - juv.	20 - 23.9[cc,kk]			23.9[m] 30.6[j]		Stauffer et al. 1974
		New R. - Virginia	1973-74	Field A	Ad. - juv.				23.9[m]		Stauffer et al. 1975
		New R. - Virginia	1973-74	Field A	Ad. - juv.			19.4 - 20[cc]	30.6[j] 23.9[m]		Stauffer et al. 1976
		Indian Cr.- Ohio	199	Lab A-2	Ad.?					(24) 37.7[ee]	Mundahl 1990
		Harker's Run - Ohio	198	Lab A-2 Lab C	Ad.	16.2-24.5 (Su) 12.2-23.2 (Wi)		20.3[tt (Su)] 19.3[tt] (Wi)		(15) 31.3[ee] (Su) (15) 31.1[ee] (Wi)	Ingersoll and Claussen 1984
		Indian Cr.- Ohio	1983-4	Lab C	Ad.	14.5-24.0 (Su) 14.8-27.6 (Fa) 15.0-25.4 (Wi) 13.5-26.3 (Sp)		19.0[tt] (Su) 20.6[tt] (Fa) 20.4[tt] (Wi) 19.8[tt] (Sp)			Hlohowskyi and Wissing 1987
		?	1975+	Lab A-2	Ad.					(15) 32.1[ee]	Kowalski et al. 1978
		Missouri streams	1995	Lab A-2	Ad.					(26) 36.0[eee]	Smale and Rabeni 1995
	Johnny darter *(Etheostoma nigrum)*	Harker's Run - Ohio	198	Lab A-2 Lab C	Ad.	18.9-28.2 (Su) 17.6-26.8 (Wi)		22.9[tt] (Su) 22.0[tt] (Wi)			Ingersoll and Claussen 1984
		?	1975+	Lab A-2	Ad.					(5) 30.7[ee] (15) 31.4[ee]	Kowalski et al. 1978
		Missouri streams		Lab A-2	Ad.					(26) 36.4[eee]	Smale and Rabeni 1995
		Colorado streams	1995+	Lab A-2	Ad.					(20) 34.0[ee] (30) 37.4[ee]	Smith and Fausch 1997
				Lab A-2						(20) 33.0[ee]	Lydy and Wissing 1988

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
Sciaenidae	Freshwater drum (*Aplodinotus grunniens*)	L. Monona - Wisconsin	1970	Field A	Ad. Ad. Ad. Ad.			27.3 - 29[i,k,m] 29.4 - 30.2[i,l,m]	29.2[i,k,m] 30[i,l,m] 32.2[k,m] 33.2[l,m]		Neill and Magnuson 1974
	Freshwater drum (continued)	Wabash R. - Indiana	1968-73	Field A	Ad.			(Su) 29-31[kk]	31.4[m]		Gammon 1973
		W.L. Erie - Ohio	1973-74	Lab A,C	yoy Ad.			(Su) 31.3[tt,dd] (Su) 26.5[tt,dd] (Fa) 19.6[tt,dd]		(21.2) 34[ee]	Reutter and Herdendorf 1976
		Ohio R. - Ohio, Kentucky	1970-74	Field A	Ad.	(Fa) 22-30[kk] (Wi) 6-11[kk]					Yoder and Gammon 1976
		Mississippi R. - Minnesota	1973-4	Lab A-2	yoy					(26) 32.8[p]	Cvancara et al. 1977
		Tennessee - Resrvoir	1945+	Field B	Ad.			21.6-22.2[dd]			Dendy 1948
Gasterosteidae	Brook Stickleback (*Culeae inconstans*)	L. Amikeus, L. Opeongo- Ontario	1941	Lab A	Ad.					(25-26) 30.6[n],29[ll]	Brett 1844
	Three-spine Stickleback (*Gasterosteus aculeatus*)									(19) 25.8[t]	Houston 1982
Cottidae	Mottled sculpin (*Cottus bairdi*)	Sweetwater Cr. - Georgia	1995+	Lab A-2	Ad.					(10) 29.6[ee] (15) 30.4[ee] (20) 32.0[ee] (25) 33.8[ee]	Walsh et al. 1997
		?	1975+	Lab A-2	Ad.					(15) 30.9[ee]	Kowalski 1978
	Winter stonefly (*Teniopteryx maura)*	Duluth, MN area streams		Lab A-2	Larvae					(10) 21[q]	Nebeker and Lemke 1968
	Mayfly (*Ephemerella subvaria)*									(10) 21.5[q]	
	Stonefly (*Isogenus frontalis)*									(10) 22.5[q]	
	Winter stonefly (*Allocapnia granulata)*									(10) 23[q]	
	Mayfly (*Stenonema tripunctatum)*									(10) 25.5[q]	
	Caddisfly (*Brachycentrus americanus)*									(10) 29[q]	

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Stonefly *(Pteronarcys dorsata)*									(10) 29.5[q]	
	Stonefly *(Acroneuria lycorius)*									(10) 30[q]	
	Stonefly *(Paragnetina media)*									(10) 30.5[q]	
	True Fly *(Atherix variegata)*									(10) 32[q]	
	Dragonfly *(Boyeria vinosa)*									(10) 32.5[q]	
	Dragonfly *(Ophigomphus rupinsulensis)*									(10) 33[q]	
	Dragonfly *(Neurocordulia alabamensis)*	Steel Cr./Skinface Pond - S. Carolina	1974	Lab A-2						38.2[ee]	Garten and Gentry 1976
	Dragonfly *(Macromia illinoiensis)*									38.8[ee]	
	Dragonfly *(Celithemis sp.)*									40.8[ee]	
	Dragonfly *(Epitheca cynosura)*									41.0[ee]	
	Dragonfly *(Ladona deplanata)*									41.3[ee]	
	Dragonfly *(Pachydiplax longipennis)*									41.7, 42.8[ee]	
	Dragonfly *(Libellula auripennis)*									42.4, 43.6[ee]	
	Mayfly *(Ephemerella invaria)*	L. River - Tennessee	1978	Lab A						(10) 22.9[r]	deKozlowski and Bunting 1981
	Caddisfly *(Symphitopsyche morosa)*									(10) 30.4[r]	
	Mayfly *(Stenonema ithaca)*									(10) 31.8[r]	
	Caddisfly *(Brachycentrus lateralis)*									(10) 32.8[r]	
	Dragonfly *(Libellula auripennis)*	Four Mile Cr.- S. Carolina	1974	Lab A-2						(16) 42.8[ee] (24) 43.6[ee] (32) 44.8[ee]	Martin et al. 1976

Appendix Table B-1. Thermal endpoints for 125 fish species and 28 macroinvertebrate taxa.

Family	Species	Location	Date	Type	Age Class	Observed Range	Physiological Optimum	Behavioral Optimum	Upper Avoidance (UAT)	Upper Lethal	Reference(s)
	Caddisfly *(Hydropysche simulans)*	Brazos R.- Texas	1991	Lab A-2						(12) 34.3[ee] (19) 35.6[ee] (26) 37.5[ee]	Moulton et al. 1993
	Caddisfly *(Chimarra obscura)*									(12) 31.4[ee] (19) 36.5[ee] (26) 38.5[ee]	
	Caddisfly *(Ceratopsyche morosa)*									(19) 34.2[ee]	
	Caddisfly *(Chimarra aterrima)*									(19) 33.6[ee]	

APPENDIX B

DATABASES AND PROCEDURES FOR USING THE FISH TEMPERATURE MODELING SYSTEM (FTMS)

Appendix B-2: Conversion factors used to estimate missing temperature criteria for RIS.

Appendix Table B-2. Conversion factors (± 1 SE) used to estimate temperature criteria (optimum, upper avoidance, and upper incipient lethal temperatures) in Appendix Table A-1 (all values in degrees C).

Family	UAT[a] - Optimum	UILT[b] - Optimum	CTM[c] - Optimum	UILT-UAT	CTM-UAT	CTM-UILT
Lepisosteidae	1.5 (± 0.3)	-	-	-	-	-
Hiodontidae, Clupeidae	2.2 (± 0.5)	-	-	3.6 (± 0.1)	-	1.3 (± 0.6)
Coregonidae, Salmonidae, Osmeridae	6.8 (± 1.0)	8.5 (± 1.9)	15.9 (± 0.3)	-	5.8 (± 0.9)	-
Esocidae	-	8.3 (± 0.7)	-	-	-	-
"Deep-bodied" Catostomidae	3.4 (± 0.1)	-	-	-	-	-
"Round-bodied" Catostomidae	2.9 (± 0.6)	-	-	-	-	2.5 (± 0.6)
"Large" Cyprinidae	2.7 (± 0.5)	8.5 (± 1.5)	8.4 (± 0.4)	-	-	-
"Small" Cyprinidae	4.1 (± 0.4)	5.6 (± 0.5)	11.2 (± 0.5)	2.3 (± 0.0)	-	2.5 (± 1.5)
Ictaluridae	3.0 (± 0.8)	-	-	-	-	4.0 (± 0.8)
Moronidae, Centrarchidae	2.6 (± 0.2)	7.8 (± 0.6)	8.7 (± 1.1)	4.1 (± 1.2)	4.5 (± 0.7)	-
Percidae	5.8 (± 1.2)	8.3 (± 1.0)	10.3 (± 1.2)	-	1.5 (± 0.2)	-
Average*	3.5 (± 0.5)	7.8 (± 0.6)	10.9 (± 1.4)	3.3 (± 0.5)	3.9 (± 1.3)	2.6 (± 0.5)

a - Upper Avoidance Temperature (UAT)
b - Upper Incipient Lethal Temperature (UILT)
c - Critical Thermal Maximum (CTM)
* - Does not include Amiidae, Scianidae, Cottidae, or Poecillidae

APPENDIX B

DATABASES AND PROCEDURES FOR USING THE FISH TEMPERATURE MODELING SYSTEM (FTMS)

Appendix B-3: FTMS ReadMe file.

Appendix B-3: Instructions for Operation of the Fish Temperature Modeling Program

1. Open the Master File (named "MasterFile.xls") in Excel. A security warning dialog box will appear if your security level is set to high or medium. Click the "Always trust macros from this source" box which will add MBI to your list of trusted sources. The macro has been digitally signed.

2. Please use the "File" menu at the top of the screen and the "Save As" menu option to save the Master File under a work file name that you choose. Under no circumstances should you employ the Master File in any of your trials – **always use a copy**. By using "Save As", you are replacing the Master File as the active workbook file.

3. Make changes to the temperature tolerance values on your working file. Only make changes on the "MasterFile" worksheet. Do not make changes or alter in any way the data or formatting on the "Selected Taxa" worksheet.

4. When you have made changes to the tolerance values (including adding values for species with no temperature values, i.e., all numbers for that species were originally zero), place the cursor in the blank gray cell in the upper left-hand corner of the spreadsheet (to the left of the "A" column and above the "1" row) and press select to highlight the entire spreadsheet. Choose the "Data" tab and select the "Sort" option. Sort by Column "E" in the selection window and select the "Descending" option. Make sure that the "My list has header row" button is selected. Then press "OK". This will sort the species with tolerance values together at the top of the spreadsheet

5. Place a **lower case** "x" in Column A (labeled "SEL") next to each fish species you wish to include in a given scenario (see Figure 1).

Figure 1. Selection of fish ("x") from the worksheet.

x	40	002	Bigmouth Buffalo	32.0	34.1	35.0	36.3	Ictiobus cyprinellus
	40	003	Black Buffalo	32.0	34.1	35.0	36.3	Ictiobus niger
x	77	002	Black Crappie	28.3	29.9	30.2	31.0	Pomoxis nigromaculatus
x	43	011	Blacknose Dace	23.9	25.8	27.2	27.5	Rhinichthys atratulus
	77	009	Bluegill Sunfish	31.8	33.5	33.6	34.8	Lepomis macrochirus
	43	043	Bluntnose Minnow	28.9	30.4	31.1	31.3	Pimephales notatus
	25	003	Brook Trout	18.0	20.4	23.0	23.3	Salvelinus fontinalis
	47	005	Brown Bullhead	31.1	33.2	36.1	35.5	Ameiurus nebulosus
	25	001	Brown Trout	13.8	17.0	20.0	21.4	Salmo trutta
	43	044	Central Stoneroller	28.6	30.8	33.8	33.2	Campostoma anomalum
x	47	002	Channel Catfish	30.5	32.8	35.0	35.3	Ictalurus punctatus
	25	006	Chinook Salmon	17.3	19.9	24.1	23.0	Oncorhynchus tshawytscha
	25	005	Coho Salmon	16.6	19.4	23.5	23.0	Oncorhynchus kisutch
x	43	001	Common Carp	33.0	35.7	36.0	39.0	Cyprinus carpio
x	43	026	Common Shiner	25.4	27.3	28.7	29.0	Luxilus cornutus
x	43	013	Creek Chub	23.9	26.5	29.4	29.6	Semotilus atromaculatus
	80	004	Dusky Darter	25.0	27.8	30.8	31.3	Percina sclera
	43	020	Emerald Shiner	27.0	29.0	31.1	31.0	Notropis atherinoides
	80	024	Fantail Darter	23.9	26.4	27.2	29.4	Etheostoma flabellare
x	43	042	Fathead Minnow	28.9	30.3	32.0	31.2	Pimephales promelas
	47	007	Flathead Catfish	32.0	33.9	34.5	35.8	Pylodictis olivaris
	85	001	Freshwater Drum	29.0	30.9	31.5	32.8	Aplodinotus grunniens
x	20	003	Gizzard Shad	29.0	31.3	34.0	34.0	Dorosoma cepedianum
x	40	010	Golden Redhorse	26.0	27.9	28.5	29.0	Moxostoma erythrurum
	43	003	Golden Shiner	27.2	29.6	33.5	32.5	Notemigonus crysoleucas
	18	001	Goldeye	28.0	29.5	29.0	30.6	Hiodon alosoides

6. When the selection process is complete, select all of the worksheet cells. Select "Data" and "Sort" on Column A or "SEL", whichever shows in the selection window. Make sure that the header row button is on. Then press "OK".

7. Once the data matrix has sorted and all the selected fish are grouped at the top of the worksheet (see Figure 2), place your cursor in cell "B2" and drag it to the right and down until all of the selected data is highlighted (see Figure 3). DO NOT include column A ("SEL") in the selection.

8. To run the program press the "CTRL" key and briefly press the "a" key. Various screens will rapidly appear and disappear followed by a return to the Master File worksheet and your highlighted cells. The programming generates three outputs (example included with these instructions).

9. You can rerun the program with a subset of your selected records or a new set. Generating a new selection of species will require repeating steps 5-9.

Figure 2. Sorting of selected fish ("x").

x	40	002	Bigmouth Buffalo	32.0	34.1	35.0	36.3	Ictiobus cyprinellus
x	77	002	Black Crappie	28.3	29.9	30.2	31.0	Pomoxis nigromaculatus
x	43	011	Blacknose Dace	23.9	25.8	27.2	27.5	Rhinichthys atratulus
x	47	002	Channel Catfish	30.5	32.8	35.0	35.3	Ictalurus punctatus
x	43	001	Common Carp	33.0	35.7	36.0	39.0	Cyprinus carpio
x	43	026	Common Shiner	25.4	27.3	28.7	29.0	Luxilus cornutus
x	43	013	Creek Chub	23.9	26.5	29.4	29.6	Semotilus atromaculatus
x	43	042	Fathead Minnow	28.9	30.3	32.0	31.2	Pimephales promelas
x	20	003	Gizzard Shad	29.0	31.3	34.0	34.0	Dorosoma cepedianum
x	40	010	Golden Redhorse	26.0	27.9	28.5	29.0	Moxostoma erythrurum
	40	003	Black Buffalo	32.0	34.1	35.0	36.3	Ictiobus niger
	77	009	Bluegill Sunfish	31.8	33.5	33.6	34.8	Lepomis macrochirus
	43	043	Bluntnose Minnow	28.9	30.4	31.1	31.3	Pimephales notatus
	25	003	Brook Trout	18.0	20.4	23.0	23.3	Salvelinus fontinalis
	47	005	Brown Bullhead	31.1	33.2	36.1	35.5	Ameiurus nebulosus
	25	001	Brown Trout	13.8	17.0	20.0	21.4	Salmo trutta
	43	044	Central Stoneroller	28.6	30.8	33.8	33.2	Campostoma anomalum
	25	006	Chinook Salmon	17.3	19.9	24.1	23.0	Oncorhynchus tshawytscha
	25	005	Coho Salmon	16.6	19.4	23.5	23.0	Oncorhynchus kisutch
	80	004	Dusky Darter	25.0	27.8	30.8	31.3	Percina sciera
	43	020	Emerald Shiner	27.0	29.0	31.1	31.0	Notropis atherinoides
	80	024	Fantail Darter	23.9	26.4	27.2	29.4	Etheostoma flabellare
	47	007	Flathead Catfish	32.0	33.9	34.5	35.8	Pylodictis olivaris
	85	001	Freshwater Drum	29.0	30.9	31.5	32.8	Aplodinotus grunniens
	43	003	Golden Shiner	27.2	29.6	33.5	32.5	Notemigonus crysoleucas

Figure 3. Highlight selected fish beginning in cell B2.

x	40	002	Bigmouth Buffalo	32.0	34.1	35.0	36.3	Ictiobus cyprinellus
x	77	002	Black Crappie	28.3	29.9	30.2	31.0	Pomoxis nigromaculatus
x	43	011	Blacknose Dace	23.9	25.8	27.2	27.5	Rhinichthys atratulus
x	47	002	Channel Catfish	30.5	32.8	35.0	35.3	Ictalurus punctatus
x	43	001	Common Carp	33.0	35.7	36.0	39.0	Cyprinus carpio
x	43	026	Common Shiner	25.4	27.3	28.7	29.0	Luxilus cornutus
x	43	013	Creek Chub	23.9	26.5	29.4	29.6	Semotilus atromaculatus
x	43	042	Fathead Minnow	28.9	30.3	32.0	31.2	Pimephales promelas
x	20	003	Gizzard Shad	29.0	31.3	34.0	34.0	Dorosoma cepedianum
x	40	010	Golden Redhorse	26.0	27.9	28.5	29.0	Moxostoma erythrurum
	40	003	Black Buffalo	32.0	34.1	35.0	36.3	Ictiobus niger
	77	009	Bluegill Sunfish	31.8	33.5	33.6	34.8	Lepomis macrochirus

APPENDIX B

DATABASES AND PROCEDURES FOR USING THE FISH TEMPERATURE MODELING SYSTEM (FTMS)

Appendix B-4: Thermal Effects Database References.

Appendix B-4: Thermal Effects Database References

1. Angilletta, Michael J. Jr. Niewiarowski Peter H. and Carlos A. Narvas. 2002. Evolution of thermal physiology in ectotherms. *J. Thermal Biology* 27: 249-68.

2. Armour, Carl L. 1993. Evaluation Temperature Regimes for Protection of Smallmouth Bass. *U.S. Dept. of the Interior, Resource Publication 191*.

3. ———. 1993. Evaluation Temperature Regimes for Protection of Walleye. *U.S. Dept. of the Interior, Resource Publication 195*.

4. ———. 1991. *Guidance for Evaluation and Recommending Temperature Regimes to Protect Fish*, Biological Report 90 (22), Instream Flow Information Paper 27. Fish and Wildlife Service.

5. Baker, S. C. and R. C Heidinger. 1996. Upper lethal temperature tolerance of fingerling black crappie. *Journal of Fish Biology* 48: 1123-29.

6. Barwick, D. H. 1981. Fecundity of the Black Crappie in a Reservoir Receiving Heated Effluent. *Prog. Fish-Cult.* 43, no. 3, July: 153-54.

7. Beamish, F. William H. 1990. Swimming metabolism and temperature in juvenile walleye, *Stizostedion vitreum vitreum*. *Env. Biology of Fishes* 27: 309-14.

8. Becker, C. Dale and Robert G. Genoway. 1979. Evaluation of the critical thermal maximum for determining thermal tolerance of freshwater fish. *Env. Biol. Fish.* 4, no. 3: 245-56.

9. Bevelheimer, M. and W. Bennett. 2000. Assessing cumulative stress in fish during chronic intermittent exposure to high temperatures. *Env. Science & Policy*: S211-S216.

10. Beyers, Robert J. 1974. Ecological Impacts of Energy Production on Rivers and Lakes. *Am. Medical Assoc. Congress on Env. Health*: 87-116.

11. Black, Marsha C. Deborah S. Millsap and John R. McCarthy. 1991. Effects of acute temperature change on respiration and toxicant uptake by rainbow trout, *Salmo gairdneri* (Richardson). *Physiological Zoology* 64, no. 1: 145-68.

12. Block, Claire J. James R. Spotila Edward A. Standora and J. Whitfield Gibbons. 1984. Behavioral thermoregulation of largemouth bass, *Micropterus salmoides,* and bluegill, *Lepomis macrochirus*, in a nuclear reactor cooling reservoir. *Env. Biology of Fishes* 11, no. 1: 41-52.

13. Bonin, J. D. 1981. Measuring thermal limits of fish. *Trans. Amer. Fish. Soc.* 110: 662-64.

14. Brown, Hunting W. 1978. Reappraisal of the justification for a 5 F temperature rise

limitation.
Manuscript submitted to ORSANCO, June 14, 22 pgs.

15. Cairns, John Jr. Kenneth L. Dickson and Guy Lanza. 1979. Studies evaluation the biological effects of thermal additions to aquatic ecosystems. *Revista De Biologia* 11, no. 1-4: 1-53.

16. Cherry, Donald S. Kenneth Dickson John Cairns and Jay R. Stauffer. 1976. Preferred, avoided, and lethal temperature of fish during rising temperature conditions. *J. Fish. Res. Bd. of Canada* 34: 239-46.

17. Cherry, Donald S. Kenneth L. Dickson and John Cairns Jr. 1975. Temperatures selected and avoided by fish at various acclimation temperatures. *J. Fish. Res. Bd. of Canada* 32, no. 4: 485-91.

18. Cherry, Donald S. Rufus K. Guthrie Fred F. Sherberger and Stephan R. Larrick. 1979. Influence of coal ash and thermal discharges upon the distribution and bioaccumulation of aquatic invertebrates. *Hydrobiologia* 62, no. 3: 257-67.

19. Christie, A. E. 1979. *The calculation of temperature guidelines to protect fish resident in the Ottawa River*, Report No. 79382. Environmental Studies and Assessments Department.

20. Clugston, J. P. and E. E. Provost. 1976. *Effects of heated effluents on the reproduction of selected species of the Centrarchid family*, SRO-757-5. Georgia Cooperative Fishery Research Unit, Athens, GA.

21. Coutant, C. C. 1997. Thermal pollution. pp. 963-984, *In* Encyclopedia of Chemical Technology, 4th edition. New York, N.Y: John Wiley & Sons.

22. Coutant, C. C. K. L. Zachman D. K. Cox and B. L. Pearman. 1984. Temperature selection by juvenile striped bass in laboratory and filed. *Trans. Amer. Fish. Soc.* 113: 666-71.

23. Coutant, Charles C. 1962. Effect of a heated water effluent upon the macroinvertebrate riffle fauna of the Delaware River. *Pennsylvania Academy of Science* 36: 58-71.

24. ———. 1987. Thermal preference: when does an asset become a liability? *Environmental Biology of Fishes* 18, no. 3: 161-72.

25. Currie, R.J., W.A. Bennett, and T.L. Beitinger. 1998. Critical thermal minima and maxima of three freshwater game-fish spices acclimated to constant temperature. *Env. Biology of Fishes* 51: 187-200.

26. Cvancara, Victor A., Scott F. Stieber, and Bruce Cvancara. 1977. Summer temperature tolerance of selected species of Mississippi River acclimated young of the year fishes. *Comp. Biochem. Physiol.* 56A: 81-85.

27. Davis, Darrian and David J. Behmer. 1980. Hatching success of lake whitefish eggs in heated water. *Prog. Fish-Cult.* 42, no. 4, October: 215-17.

28. deKozlowski, Steven J. and Dewey L. Bunting II. 1981. Laboratory study on the thermal tolerance of four southeastern stream insect species (Trichoptera, Ephemeroptera). *Hydrobiologia* 79: 141-45.

29. Diana, J. S. 1984. Growth of largemouth bass, *Micropterus salmoides* (Lacepede), under constant and fluctuating temperatures. *J. Fish Biol.* 24: 165-72.

30. Diaz, Fernando and L. Fernando Buckle. 1999. Effect of the critical thermal maximum on the preferred temperatures of *Ictalurus punctatus* exposed to constant and fluctuating temperatures. *J. Thermal Biology* 24: 155-60.

31. Eaton, J. G. J. H. McCormick B. E. Goodno D. G. O'Brien H. G. Stefany M. Hondzo and R. M. Scheller. 1995. Field information-based system for estimating fish temperature tolerances. *Fisheries* 20, no. 4: 10-18, April.

32. Elliott, J. M. J. A. Elliott and J. D. Allonby. 1994. Critical thermal limits for the stone loach, *Noemacheilus barbarulus*, from three populations in north-west England. *Freshwater Biology* 32: 593-601.

33. Esch, G. W. and R. W. McFarlane editors. 1976. *Thermal Ecology II. Proceedings of a symposium held at Augusta, Georgia, April 2-5, 1975*Technical Information Center, Energy Research and Development Administration.

34. Feminella, J. W. and W. J. Matthews. 1984. Intraspecific differences in thermal tolerance of *Etheostoma spectabile* (Agassiz) in constant versus fluctuating environments. *J. Fish Biol.* 25: 455-61.

35. Fields, R. S. S. Lowe C. Kaminski G. S. Whitte and D. P. Phillip. 1987. Critical and chronic thermal maxima of northern and Florida largemouth bass and their reciprocal F_1 and F_2 hybrids. *Trans. Amer. Fish. Soc.* 116: 856-63.

36. Fong, Peter P. Kehchiro Kyozuka Jill Duncan Stacy Rynkowski Daniel Mekasha and Jeffrey L. Ram. 1995. Effect of salinity and temperature on spawning and fertilization in the Zebra Mussel *Dreissena polymorpha* (Pallas) from North America. *Biology Bull.* 189: 320-329.

37. Garten, C. T. Jr. and J. B. Gentry. 1976. Thermal tolerance of dragonfly nymphs. II. Comparison of nymphs from control and thermally altered environments. *Physiological Zoology* 49, no. 2: 206-13.

38. Giattina, J. D. D. S. Chery John Cairns Jr. and S. R. Larrick. 1981. Comparison of laboratory and field avoidance behavior of fish in heated chlorinated water. *Trans. Amer. Fish. Soc.* 110: 526-35.

39. Goss, L. B. 1980. Temperature tolerance determinations for daphnia. *Aquatic Toxicology*: 354-65.

40. Gray, R. H. 1988. *Ecotoxicology: behavior, exposure, and effects*, supported by the U.S. Dept. of Energy, under Contract DE-AC06-76RLO 1830. Presented at the First European Conf. on Ecotoxicology, Copenhagen, October 16-21.

41. Guest, W. Clell. Temperature tolerance of Florida and northern largemouth bass: effects of subspecies, fish size, and season. *Texas J. of Science* XXXVI, no. 1, August: 75-84.

42. Hall, Lenwood W. Jr. Charles H. Hocutt and Jay R. Stauffer Jr. 1978. Implication of geographic location on temperature preference of white perch, *Morone americana*. *J. Fish. Res. Bd. Can.* 35: 1464-68.

43. Hanazato, Takayuki and Masayuki Yasuno. 1989. Effect of temperature in laboratory studies on growth of *Chaoborus flavicans* (Diptera: Chaoboridae). *Arch. Hydrobiol.* 114, no. 4: 497-504.

44. Hathaway, Edward S. 1999. Quantitative study of the changes predicted by acclimation in the tolerance of high temperatures by fishes and amphibians. *Bull. Bur. Fisheries* 43, no. part 2: 169-92.

45. Henderson, Bryan A. and Edward H. Brown Jr. 1985. Effects of abundance and water temperature on recruitment and growth of alewife (*Alosa pseudoharengus*) near South Bay, Lake Huron, 1954-82. *Can. J. Fish. Aquat. Sci.* 42: 1608-13.

46. Hlohowskyi, I. and T. E. Wissing. 1987. Seasonal changes in the thermal preferences of fantail (*Etheostoma flabellare*), rainbow (*E. caeruleum*), and greenside (*E. blennioides*) darters. Pages 105-110 *In,* W.J. Matthews and D.C. Heins [eds.], Community and Evolutionary Ecology of North American Stream Fishes. Norman, OK: University of Oklahoma Press.

47. Hokanson, K. E. F. 1990. A National Compendium of Freshwater Fish and Water Temperature Data. Volume II: Temperature Requirement Data for Thirty Fishes. Duluth, MN: U.S. EPA Environmental Research Laboratory.

48. Hokanson, Kenneth E. F. Temperature requirements of some percids and adaptations to the seasonal temperature cycle. *J. Fish. Res. Bd. Canada* 34: 1524-50.

49. Hokanson, Kenneth E. F. and Walter M. Koenst. 1986. Revised estimates of growth requirements and lethal temperature limits of juvenile walleyes. *Prog. Fish-Cult.* 48: 90-94.

50. Hokanson, Kenneth E. F. Charles F. Kleiner and Todd W. Thorslund. 1977. Effects of constant temperatures and diel temperature fluctuations on specific growth and mortality rates and yield of juvenile rainbow trout, *Salmo gairdneri*. *J. Fish. Res. Bd.*

Canada 34: 639-48.

51. Houston, Arthur H. 1980. Components of the hematological response of fishes to environmental temperature change: a review. *Environmental Physiology of Fishes*: 241-98.

52. Hudson, Jay and Joe Bob Cravens. 1991. Thermal effects. *Res. J. WPCF* 63, no. 4, June: 593-607.

53. Ingersoll, Christopher G. and Dennis L. Claussen. 1984. Temperature selection and critical thermal maxima of the fantail darter, *Etheostoma flabellare*, and johnny darter, *E. nigrum*, related to habitat and season. *Environ. Biology of Fishes* 11, no. 2: 131-38.

54. Janssen, John and John P. Giesy. Thermal effluent as a sporadic cornucopia: effects on fish and zooplankton. *Environ. Biol. of Fishes* 11, no. 3: 191-203.

55. Johnson, Jennifer A. and Steven W. Kelsch. 1998. Effects of evolutionary thermal environment on temperature-preference relationships in fishes. *Environmental Biology of Fishes* 53: 447-58.

56. Johnston, Thomas A. and John A. Mathias. 1994. Effects of temperature on feeding in zooplanktivorous walleye, *Stizostedion vitreum*, larvae. *Environ. Biol. of Fishes* 40: 189-98.

57. Kellogg, R. L. and J. J. Gift. 1983. Relationship between optimum temperatures for growth and preferred temperatures for the young of four fish species. *Trans. Amer. Fish. Soc.* 112: 424-30.

58. Kellogg, Robert L. 1982. Temperature requirements for the survival and early development of the anadromous alewife. *Prog. Fish-Cult.* 44, no. 2, April: 63-73.

59. Kelsch, S. W. and W. H. Neill. 1990. Temperature preference versus acclimation in fishes: selection for changing metabolic optima. *Trans. Amer. Fish. Soc.* 119: 601-10.

60. Kilgour, D. Marc and Robert W. McCauley. 1986. Reconciling the two methods of measuring upper lethal temperatures in fishes. *Environ. Biol. of Fishes* 7, no. 4: 281-90.

61. Konecki, John T. Carol A. Woody and Thomas P. Quinn. 1995. Temperature preference in two populations of juvenile coho salmon, *Oncorhynchus kisutch*. *Environ. Biol. of Fishes* 44: 417-21.

62. Koonce, J. F. T. B. Bagenal R. F. Carline K. E. F. Hokanson and M. Nagiec. 1977. Factors influencing year-class strength of percids: a summary and a model of temperature effects. *J. Fish. Res. Bd. Can.* 34, no. 10: 1900-1909.

63. Magnuson, John J. Larry B. Crowder and Patricia A. Medvick. 1979. Temperature as an ecological resource. *Amer. Zool.* 19: 331-43.

64. Martin, W. J. C. T. Garten Jr. and J. B. Gentry. 1976. Thermal tolerances of dragonfly nymphs. I. Sources of variation in estimating critical thermal maximum. *Physiological Zoology* 49, no. 2, April: 200-205.

65. Mathur, Dilip and Carl A. Silver. 1980. Statistical problems in studies of temperature preference of fishes. *Can. J. Fish. Aquat. Sci.* 37: 733-37.

66. Mathur, Dilip and Pauline L. McCreight. 1980. Effects of heated effluent on the reproductive biology of white crappie, *Pomoxis annularis*, in Conowingo Pond, Pennsylvania. *Arch. Hydrobiol.* 88, no. 4: 491-99.

67. Mathur, Dilip Robert M. Schutsky Edmund J. Purdy Jr. and Carl A. Silver. 1981. Similarities in acute temperature preferences of freshwater fishes. *Trans. Amer. Fish. Soc.* 110: 1-13.

68. ———. 1983. Similarities in avoidance temperatures of freshwater fishes. *Can. J. Fish. Aquat. Sci.* 40: 2144-52.

69. Matthews, W. J. 1981. Physicochemical tolerance and selectivity of stream fishes as related to their geographic ranges and local distributions. Pages 111-120 *In*, W.J. Matthews and D.C. Heins [eds.], Community and Evolutionary Ecology of Stream Fishes. Norman, OK: University of Oklahoma Press.

70. Mattice, J. S. and L. L. Dye. Thermal Tolerance of the Adult Asiatic Clam. 130-135.

71. McCauley, R. W. and J. M. Casselman. Final Preferendum as an Index of the Temperature for Optimum Growth in Fish. *Proc. World Symposium on Aquaculture in Heated Effluents & Recirculation Systems, Volume II.* 1981, Stavanger, May 28-30, Berlin.

72. McCauley, Robert W. and Fred P. Binkowski. 1982. Thermal tolerance of the alewife. *Trans. Amer. Fish. Soc.* 111: 389-91.

73. McCormick, J. H. and J. A. Wegner. 1981. Responses of largemouth bass from different latitudes to elevated water temperatures. *Trans. Amer. Fish. Soc.* 110: 417-29.

74. McCormick, J. Howard. 1978. Effects of temperature on hatching success and survival of larvae in the white bass. *Progress Fish-Cult.* 40, no. 4, October: 133-37.

75. McCormick, J. Howard and Charles F. Kleiner. 1976. Growth and Survival of young-of-the-year emerald shiners (*Notropis atherinoides*) at different temperatures. *J. Fish. Res. Bd. of Canada* 33, no. 4, Part 1: 839-42.

76. McCormick, J. Howard Bernard R. Jones and Kenneth E. F. Hokanson. 1977. White sucker

(*Catostomus commersoni*) embryo development, and early growth and survival at different temperatures. *J. Fish. Res. Bd. Can.* 34: 1019-25.

77. Meffe, Gary K. 1992. Plasticity of life-history characters in eastern mosquitofish (*Gambusia holbrooki:* Poecilidae) in response to thermal stress. *Copeia* 1: 94-102.

78. Meffe, Gary K Stephen C. Weeks Margaret Mulvey and Karen L. Kandl. 1995. Genetic differences in thermal tolerance of eastern mosquitofish (*Gambusia holbrooki:* Poeciliidae) from ambient and thermal ponds. *Can. J. Fish. Aquat. Sci.* 52: 2704-11.

79. Mihursky, J. A. and V. S. Kennedy. Water temperature criteria to protect aquatic life. 20-32.

80. Modlin, Richard F. and Richard D. Jayne. 1981. Effect of temperature on the oxygen consumption of three species of isoperia (Plecoptera: Periodidae). *J. Freshwater Ecology* 1, no. 3, December: 299-306.

81. Moulton, Stephen R. II Thomas L. Beitinger Kenneth W. Steward and Rebecca J. Currie. 1993. Upper temperature tolerance of fours species of caddisflies (Insecta: Trichoptera). *J. Freshwater Ecology* 8, no. 3, September: 193-98.

82. Mundahl, Neal D. 1990. Heat depth of fish in shrinking stream ponds. *Am. Midl. Nat.* 123: 40-46.

83. Myrick, Christopher A. and Joseph J. Cech Jr. 1999. Temperature effects on chinook salmon and steelhead: a review focusing on California's Central Valley populations. 57 pgs. published electronically by the Bay-Delta Modeling Forum.

84. Nebeker, Alan V. and Armond E. Lemke. 1968. Preliminary studies on the tolerance of aquatic insects to heated waters. *J. Kansas Entomological Soc.* 41, no. 3, July: 413-18.

85. Neill, William H. and John J. Magnuson. 1974. Distributional ecology and behavioral thermoregulation of fishes in relation to heated effluent from a power plant at Lake Monona, Wisconsin. *Trans. Amer. Fish. Soc.* 103, no. 4, October: 663-710.

86. Nichols, S. Jerrine. 1981. Effect of thermal effluents on oligochaetes in Keowee Reservoir, South Carolina. *Hydrobiologia* 79: 129-36.

87. Nordlie, Kathleen J. and John W. Arthur. 1981. Effect of elevated water temperature on insect emergence in outdoor experimental channels. *Environ. Pollution.* Series A, Vol. 25: 53-65.

88. Olson, P. A. and R. F. Foster. Temperature tolerance of eggs and young of Columbia River chinook salmon. *American Fish. Soc.* 203-7.

89. Osborne, Lewis L. and Ronald W. Davies. 1987. Effects of a chlorinated discharge and a thermal outfall on the structure and composition of the aquatic macroinvertebrate communities in the Sheep River, Alberta, Canada. *Water Res.* 21, no. 8: 913-21.

90. Ostrand, Kenneth G. and Gene R. Wilde. 2001. Temperature, dissolved oxygen, and salinity tolerances of five prairie stream fishes and their role in explaining fish assemblage patterns. *Trans. Amer. Fish. Soc.* 130: 742-49.

91. Otto, Robert G. Max A. Kitchel and John O'Hara Rice. 1976. Lethal and preferred temperatures of the alewife (*Alosa pseudoharengus*) in Lake Michigan. *Trans. Am. Fish. Soc.* 1: 96-106.

92. Parsons, P. A. 1989. Environmental stresses and conservation of natural populations. *Annu. Rev. Ecol. Syst.* 20: 29-49.

93. Peterson, M. S. 1993. Thermal tolerance of Iowa and Mississippi populations of juvenile walleye, *Stizostedion vitreum*. *Copeia* 3: 890-894.

94. Poff, N. LeRoy and Robin A. Matthews. 1985. Replacement of Stenonema spp. by *Caenis diminuta* Walker as the numerical dominant in the mayfly assemblage of a thermally-stressed stream. *J. Freshwater Ecology* 3, no. 1, June: 19-26.

95. Rader, Russell B. and James V. Ward. 1990. Mayfly growth and population density in constant and variable temperature regimes. *Great Basin Naturalist, Provo, UT* 50, no. 2: 97-106.

96. Reash, Rob J. *Results of Ohio River biological monitoring during the 1988 drought*, EPA 905/9-90-005. Proc. of the 1990 Midwest Pollution Control Biologists Meeting, April 10-13, October, Chicago, IL.

97. Reash, Robin J Gregory L. Seegert and William L. Goodfellow. 2000. Experimentally-derived upper thermal tolerances for redhorse suckers: revised 316(a) variance conditions at two generating facilities in Ohio. *Environmental Science & Policy* 3: S191-S196.

98. Reutter, Jeffrey M. and Charles E. Herdendorf. Laboratory Estimates of the Seasonal Final Temperature Preferenda of Some Lake Erie Fish. *Proc. 17th Conf. Great Lakes Res.* pp. 59-67.

99. Rice, James A. James E. Breck Steven M. Bartell and James F. Kitchell. 1983. Evaluating the constraints of temperature, activity and consumption on growth of largemouth bass. *Env. Biol. Fish* 8, no. 3.

100. Richards, F. P. W. W. Reynolds and R. W. McCauley. 1977. Temperature preference studies in environmental impact assessments: an overview with procedural recommendations. *J. Fish. Res. Bd. Can.* 34, no. 5: 728-61.

101. Robinson, William T. and Joe Bob Cravens. 1993. Thermal effects. *Water Environ. Res.* 65, no. 4, June: 585-96.

102. Rondorf, Dennis W. and James F. Kitchell. 1989. *Reproduction and Distribution of Fishes in a Cooling Lake: Wisconsin Power Plant Impact*, EPA/600/S3-85/049, August, 6pgs.

103. Scheide, John I. and Phyllis N. Bonaminio. 1994. Effect of low water temperature on ion balance in the zebra mussel, *Dreissena polymorpha*, and the unionid mussel, *Lampsilis radiata*. *Nautilus* 107, no. 4: 113-17.

104. Schneider, Mark J. and Thomas J. Connors. 1982. Effects of elevated water temperature on the critical swim speeds of yearling rainbow trout, *Salmo gairdneri*. *J. Therm. Biol.* 7: 227-29.

105. Selong, J. H. T. E. McMahon A. V. Zale and F. T. Barrows. 2001. Effect of temperature on growth and survival of bull trout, with application of an improved method for determining thermal tolerance in fishes. *Tran. Amer. Fish. Soc.* 130: 1026-37.

106. Shuter, B. J. D. A. Wismer H. A. Regier and J. E. Matuszek. 1985. An application of ecological modeling: impact of thermal effluent on a smallmouth bass population. *Trans. Amer. Fish. Soc.* 114: 631-51.

107. Smith, Wesley E. 1973. Thermal tolerance of two species of Gammarus. *Trans. Amer. Fish. Soc.* 102, no. 2: 431-33.

108. Spigarelli, S. A. and M. M. Thommes. 1979. Temperature selection and estimated thermal acclimation by rainbow trout (*Salmo gairdneri*) in a thermal plume. *J. Fish. Res. Bd. Can.* 36: 366-76.

109. Spotila, J. R. and E. A. Standora. 1986. *Thermoregulation of fish and other aquatic vertebrates in thermally stressed habitats: roles of behavior, competition, predation and nutrients*, DOE/EV/02502-23.

110. Spotila, James R. Kenneth M. Terpin Robert R. Koons and Ralph L. Bonati. 1979. Temperature requirements of fishes from eastern Lake Erie and the upper Niagara River: a review of the literature. *Env. Biol. Fish.* 4, no. 3: 281-307.

111. Stanczykowska, Anna Krzysztof Lewandowski and Jolanta Ejsmont-Karabin. 1988. Abundance and distribution of the mussel *Dreissena polymorpha* (Pall.) in heated lakes near Konin (Poland). *Ekologia Polska* 36, no. 1-2: 261-73.

112. Stanley, Emily H. and Robert A. Short. 1988. Temperature effects on warmwater stream insects: a test of the Thermal Equilibrium Hypothesis. *OIKOS* 52: 313-20.

113. Stauffer, J. R. Jr. J. H. Wilson and K. L. Dickson. 1976. Comparison of stomach contents and condition of two catfish species living at ambient temperatures and in a heated

discharge. *Prog. Fish-Cult.* 38, no. 1, January: 33-35.

114. Stauffer, Jay R. Jr. Daniel R. Lispi and Charles H. Hocutt. 1984. Preferred temperatures of three Semotilus species. *Arch. Hydrobiol.* 101, no. 4: 595-600.

115. Stauffer, Jay R. Jr. Edward L. Melisky and Charles H. Hocutt. 1984. Interrelationships among preferred, avoided, and lethal temperatures of three fish species. *Arch. Hydrobiol.* 100, no. 2: 159-69.

116. ———. 1980. Temperature preference of the northern redbelly dace, *Phoxinus eos* (Cope). *Arch. Hydrobiol.* 90, no. 1, September: 121-26.

117. Stauffer, Jay R. Jr. Kenneth L. Dickson John Cairns Jr. and Donald S. Cherry. 1976. Potential and realized influences of temperature on the distribution of fishes in the New River, Glen Lyn, Virginia. *(Supplement to J. Wildlife Management, Vol. 40, No. 4, October)* 50, no. November: 40 pgs.

118. Stauffer, Jay R. Jr. Roger L. Kaesler John Cairns Jr. and Kenneth L. Dickson. 1980. Selecting groups of fish to optimize acquisition of information on thermal discharges. *Water Resources Bull.* 16, no. 6: 1097-101.

119. Taylor, B. E. J. M. Aho D. L. Mahoney and R. A. Estes. 1991. Population dynamics and food habits of bluegill (*Lepomis macrochirus*) in a thermally stressed reservoir. *Can. J. Fish. Aquat. Sci.* 48: 768-75.

120. Thorp, James H. James E. Alexander Jr. Bonny L. Bukaveckas Gary A. Cobbs and Kurt L. Bresko. 1998. Responses of Ohio River and Lake Erie dreissenid mollusks to changes in temperature and turbidity. *Can. J. Fish. Aquat. Sci.* 55: 220-229.

121. U.S. Department of Commerce. 1999. *Assessing cumulative thermal stress in fish during chronic exposure to high temperature*, NTIS, Oak Ridge National Lab, TN: pp. 1-10, Nov. 14.

122. U.S. Department of the Interior. 1994. *Evaluating Temperature Regimes for Protection of Brown Trout*, Resource Publication 201: 21 pgs. National Biological Survey, Midcontinent Ecological Science Center, Fort Collins, Colorado.

123. U.S. EPA. 1977. *Temperature Criteria for Freshwater Fish: Protocol and Procedures*, EPA-600/3-77-061. U.S. EPA Environmental Research Laboratory, Duluth, MN.

124. ———. 1980. *Temperature Water Quality Standards Criteria Digest: A Compilation of State/Federal Criteria*, U.S. EPA Office of Water, Washington, D.C.

125. van der Have, T. M. 2002. Proximate model for thermal tolerance in ectotherms. *OIKOS* 98: 141-55.

126. Walsh, S. J. D. C. Haney and C. M. Timmerman. 1997. Variation in thermal tolerance and routine metabolism among spring and stream-dwelling freshwater sculpins (Teleostei: Cottidae) of the southeastern United States. *Ecol. Fresh. Fish* 6: 84-94.

127. Walsh, Stephen J. Dennis C. Haney Cindy M. Timmerman and Robert M Dorazio. 1998. Physiological tolerances of juvenile robust redhorse, *Moxostoma robustrum*: conservation implications for an imperiled species. *Environ. Biol. Fishes* 51: 429-44.

128. WAPORA, Inc. 1972. *The effect of temperature on aquatic life in the Ohio River*, Final report, July 1970 - September 1971.

129. Webster, Dwight A. Relation of temperature to survival and incubation of the eggs of smallmouth bass (*Micropterus dolomieu*). *Amer. Fish. Soc.* 43-47.

130. Wehrly, K. E. M. J. Wiley and P. W. Seelbach. 2003. Classifying regional variation in thermal regime based on stream fish community patterns. *Trans. Amer. Fish. Soc.* 132: 18-38.

131. Wilkonska, Halina. 1988. Effect of heated-water discharge in the Konin Lakes (Poland) on their ichthyofauna. *Ekologia Polska* 36, no. 1-2: 145-63.

132. Wrenn, W. B. 1980. Effects of elevated temperature on growth and survival of smallmouth bass. *Trans. Amer. Fish. Soc.* 109: 617-25.

133. ———. 1984. Smallmouth bass reproduction in elevated temperature regimes at the species' native southern limit. *Trans. Amer. Fish. Soc.* 113: 295-303.

134. Zdanovich, V. V. 2001. Some specific features of temperature preference of juvenile fish acclimated to constant and alternating temperatures. *J. Ichthyology* 41, no. 8: 654-57.

135. Zeitoun, Ibrahim H. 1978. Assessment of intermittently chlorinated heated effluents on survival of adult rainbow trout (*Salmo gairdneri*) at power generating facilities. *Environ. Sci. & Tech.* 12, no. 10, October: 1173-79.

136. Smale, M. A., and C. F. Rabeni. 1995. Hypoxia and hyperthermia tolerances of headwater stream fishes. Transactions of the American Fisheries Society 124:698–710.

APPENDIX C

DATABASES USED TO DEVELOP THE LIST OF REPRESENTATIVE IMPORTANT SPECIES (RIS) FOR ROBINSON CREEK

APPENDIX C

DATABASES USED TO DEVELOP THE LIST OF REPRESENTATIVE IMPORTANT SPECIES (RIS) FOR ROBINSON CREEK

Appendix C-1: Illinois EPA/DNR Fish Species in Wabash Fish Faunal Region <u><</u>15 mi.^{2} RIS Selection.

Appendix Table C-1. Illinois EPA/DNR Fish Species in Wabash Fish Faunal Region <15 mi.[2] RIS Selection.

Family	Species	Common Name	Scientific Name	Counted	%	RIS
10	002	SHORTNOSE GAR	Lepisosteus platostomus	9	0.1%	
15	001	BOWFIN	Amia calva	2	0.0%	
20	003	GIZZARD SHAD	Dorosoma cepedianum	130	0.9%	X
37	001	GRASS PICKEREL	Esox americanus vermiculatus	18	0.1%	
40	002	BIGMOUTH BUFFALO	Ictiobus cyprinellus	1	0.0%	
40	004	SMALLMOUTH BUFFALO	Ictiobus bubalus	29	0.2%	
40	005	QUILLBACK CARPSUCKER	Carpiodes cyprinus	74	0.5%	X
40	006	RIVER CARPSUCKER	Carpiodes carpio carpio	2	0.0%	
40	009	BLACK REDHORSE	Moxostoma duquesnei	1	0.0%	
40	010	GOLDEN REDHORSE	Moxostoma erythrurum	1	0.0%	
40	011	SHORTHEAD REDHORSE	Moxostoma macrolepidotum	2	0.0%	
40	015	NORTHERN HOG SUCKER	Hypentelium nigricans	3	0.0%	
40	016	WHITE SUCKER	Catostomus commersoni	482	3.3%	X
40	018	SPOTTED SUCKER	Minytrema melanops	2	0.0%	
40	020	CREEK CHUBSUCKER	Erimyzon oblongus	235	1.6%	X
43	001	COMMON CARP	Cyprinus carpio	191	1.3%	X
43	002	GOLDFISH	Carassius auratus	12	0.1%	
43	003	GOLDEN SHINER	Notemigonus crysoleucas	32	0.2%	
43	007	BIGEYE CHUB	Notropis amblops	4	0.0%	
43	013	CREEK CHUB	Semotilus atromaculatus	2590	17.7%	X
43	015	SUCKERMOUTH MINNOW	Phenacobius mirabilis	58	0.4%	
43	020	EMERALD SHINER	Notropis atherinoides	116	0.8%	X
43	023	REDFIN SHINER	Lythrurus umbratilis	68	0.5%	X
43	025	STRIPED SHINER	Luxilus chrysocephalus	34	0.2%	
43	027	RIVER SHINER	Notropis blennius	2	0.0%	
43	031	STEELCOLOR SHINER	Cyprinella whipplei	25	0.2%	
43	032	SPOTFIN SHINER	Cyprinella spiloptera	254	1.7%	X
43	034	SAND SHINER	Notropis stramineus	34	0.2%	
43	039	SILVERJAW MINNOW	Notropis buccatus	2173	14.9%	X
43	040	MISS. SILVERY MINNOW	Hybognathus nuchalis	2367	16.2%	X
43	041	BULLHEAD MINNOW	Pimephales vigilax	2	0.0%	
43	042	FATHEAD MINNOW	Pimephales promelas	2	0.0%	
43	043	BLUNTNOSE MINNOW	Pimephales notatus	937	6.4%	X

RIS >~0.5%
GIZZARD SHAD
QUILLBACK CARPSUCKER
WHITE SUCKER
CREEK CHUBSUCKER
COMMON CARP
CREEK CHUB
EMERALD SHINER
REDFIN SHINER
SPOTFIN SHINER
SILVERJAW MINNOW
MISS. SILVERY MINNOW
BLUNTNOSE MINNOW
CENTRAL STONEROLLER
BLUEGILL SUNFISH
GREEN SUNFISH
YELLOW BULLHEAD
BLACKSTRIPE TOPMINNOW
WESTERN MOSQUITOFISH
PIRATE PERCH
LARGEMOUTH BASS
GREEN SUNFISH
BLUEGILL SUNFISH
LONGEAR SUNFISH
JOHNNY DARTER
24 RIS

Appendix Table C-1. Illinois EPA/DNR Fish Species in Wabash Fish Faunal Region <15 mi.[2] RIS Selection.

Family	Species	Common Name	Scientific Name	Counted	%	RIS
43	044	CENTRAL STONEROLLER	Campostoma anomalum	638	4.4%	X
43	047	GRASS CARP	Ctenopharyngodon idella	33	0.2%	
43	048	RED SHINER	Cyprinella lutrensis	33	0.2%	
43	079	SILVER CARP	Hypophthalmichthys molitrix	16	0.1%	
47	004	YELLOW BULLHEAD	Ameiurus natalis	133	0.9%	X
47	006	BLACK BULLHEAD	Ameiurus melas	15	0.1%	
47	008	STONECAT MADTOM	Noturus flavus	2	0.0%	
47	013	TADPOLE MADTOM	Noturus gyrinus	4	0.0%	
54	002	BLACKSTRIPE TOPMINNOW	Fundulus notatus	261	1.8%	X
54	005	BLACKSPOTTED TOPMINNOW	Fundulus olivaceus	30	0.2%	
57	001	WESTERN MOSQUITOFISH	Gambusia affinis	222	1.5%	X
68	001	PIRATE PERCH	Aphredoderus sayanus	152	1.0%	X
77	001	WHITE CRAPPIE	Pomoxis annularis	54	0.4%	
77	002	BLACK CRAPPIE	Pomoxis nigromaculatus	1	0.0%	
77	004	SMALLMOUTH BASS	Micropterus dolomieui	3	0.0%	
77	005	SPOTTED BASS	Micropterus punctulatus	41	0.3%	
77	006	LARGEMOUTH BASS	Micropterus salmoides	162	1.1%	X
77	007	WARMOUTH SUNFISH	Lepomis gulosus	5	0.0%	
77	008	GREEN SUNFISH	Lepomis cyanellus	1107	7.6%	X
77	009	BLUEGILL SUNFISH	Lepomis macrochirus	1216	8.3%	X
77	010	ORANGESPOTTED SUNFISH	Lepomis humilis	13	0.1%	
77	011	LONGEAR SUNFISH	Lepomis megalotis	321	2.2%	X
77	012	REDEAR SUNFISH	Lepomis microlophus	52	0.4%	
77	015	GREEN SF X BLUEGILL SF	HYBRID	3	0.0%	
80	005	BLACKSIDE DARTER	Percina maculata	9	0.1%	
80	011	LOGPERCH	Percina caprodes	22	0.2%	
80	014	JOHNNY DARTER	Etheostoma nigrum	120	0.8%	X
80	023	ORANGETHROAT DARTER	Etheostoma spectabile	43	0.3%	
80	028	MUD DARTER	Etheostoma asprigene	1	0.0%	
80	031	SLOUGH DARTER	Etheostoma gracile	15	0.1%	
		TOTALS		14619		**24**

APPENDIX C

DATABASES USED TO DEVELOP THE LIST OF REPRESENTATIVE IMPORTANT SPECIES (RIS) FOR ROBINSON CREEK

Appendix C-2: Illinois EPA Robinson Run Facility Related Stream Survey (FRSS) Fish Results 2008 and 2013 Screened $\leq$15 mi.^{2} RIS Selection.

Appendix Table C-2. Fish species collected in the IEPA FRSS survey of Robinson Creek in 2008 and 2013 RIS selection.

	Stream:		Robinson Creek			Marathon Creek	Robinson Creek		Sugar Creek		Sugar Creek	Lamotte Creek	
	Site:		BFC-20	BFC-19	BFC-25	BFCA-22	BFC-26	BFC-11	BF-01	All Sites	BF-11	BFB-13	
	Date:		Combined	Combined	Combined	Combined	Combined	Combined	Combined	≤15 sq. mi.	Combined	Combined	
Scientific name	**Common name**	**T. ind**	**SH**	**SH**	**SH**	**SH**	**SH**	**SH**	**SH**	**SH**	**SH**	**SH**	**RIS**
Lepisosteus platostomus	Shortnose gar	10	0	9	0	0	0	0	0	9	0	1	
Dorosoma cepedianum	Gizzard shad	4	0	0	0	0	0	3	0	3	0	1	
Campostoma anomalum	Central stoneroller	12	1	5	2	0	0	0	0	8	4	0	
Ctenopharyngodon idella	Grass carp	23	0	0	0	3	4	1	0	8	8	7	
Cyprinus carpio	Carp	34	3	1	3	5	6	9	0	27	7	0	X
Notropis buccatus	Silverjaw minnow	69	3	0	15	0	0	1	9	28	12	29	X
Hybognathus nuchalis	Mississippi Silvery minnow	2211	5	16	100	11	263	1004	0	1399	812	0	X
Notropis atherinoides	Emerald shiner	567	0	0	12	4	33	10	364	423	11	133	X
Notropis blennius	River shiner	0	0	0	0	0	0	0	0	0	0	0	
Notropis stramineus	Sand shiner	25	1	0	4	0	0	0	0	5	19	1	
Cyprinella spiloptera	Spotfin shiner	301	1	91	40	0	7	0	6	145	25	131	X
Cyprinella whipplei	Steelcolor shiner	16	0	2	1	0	1	0	0	4	4	8	
Cyprinella luntrensis	Red shiner	29	1	20	0	0	0	0	0	21	8	0	X
Lythrurus umbratilus	Redfin shiner	18	0	0	4	0	0	0	0	4	0	14	
Luxilus chrysocephalus	Striped shiner	2	1	1	0	0	0	0	0	2	0	0	
Notemigonus crysoleucas	Golden shiner	1	1	0	0	0	0	0	0	1	0	0	
Pimephales notatus	Bluntnose minnow	116	5	3	78	0	1	1	3	91	1	24	X
Semotilus atromaculatus	Creek chub	69	12	13	38	5	0	0	0	68	0	1	X
Carpiodes carpio	River carpsucker	1	0	0	0	0	0	1	0	1	0	0	
Carpiodes cyprinus	Quillback	0	0	0	0	0	0	0	0	0	0	0	
Catostomus commersoni	White sucker	3	0	0	0	1	0	0	0	1	1	1	
Erimyzon oblongus	Creek chubsucker	0	0	0	0	0	0	0	0	0	0	0	
Ictiobus bubalus	Smallmouth buffalo	38	0	0	0	4	1	16	0	21	7	10	X
Moxostoma erythrurum	Golden redhorse	1	0	0	0	0	0	1	0	1	0	0	
Ictalurus punctatus	Channel catfish	0	0	0	0	0	0	0	0	0	0	0	
Ameiurus natalis	Yellow bullhead	1	0	0	0	0	0	0	0	0	0	1	
Aphredoderus sayanus	Pirate perch	0	0	0	0	0	0	0	0	0	0	0	
Fundulus notatus	Blackstripe topminnow	30	5	8	10	0	0	5	0	28	0	2	X
Gambusia affinis	Mosquitofish	35	0	0	0	0	0	9	0	9	0	26	
Labidesthes sicculus	Brook silverside	0	0	0	0	0	0	0	0	0	0	0	
Lepomis cyanellus	Green sunfish	22	3	0	1	13	0	0	0	17	4	1	X
Lepomis macrochirus	Bluegill	52	4	6	2	6	12	8	0	38	12	2	X
Lepomis megalotis	Longear sunfish	11	0	0	1	0	0	2	2	5	0	6	
Pomoxis annularis	White crappie	54	0	0	0	54	0	0	0	54	0	0	X
Micropterus punctulatus	Spotted bass	36	4	1	6	17	0	2	0	30	0	6	X
Micropterus dolomieu	Smallmouth bass	2	0	0	0	0	0	2	0	2	0	0	

Appendix Table C-2. Fish species collected in the IEPA FRSS survey of Robinson Creek in 2008 and 2013 RIS selection.

	Stream:		Robinson Creek			Marathon Creek	Robinson Creek		Sugar Creek		Sugar Creek	Lamotte Creek	
	Site:		**BFC-20**	**BFC-19**	**BFC-25**	**BFCA-22**	**BFC-26**	**BFC-11**	**BF-01**	**All Sites**	**BF-11**	**BFB-13**	
	Date:		Combined	Combined	Combined	Combined	Combined	Combined	Combined	**<15 sq. mi.**	Combined	Combined	
Scientific name	**Common name**	**T. ind**	**SH**	**SH**	**SH**	**SH**	**SH**	**SH**	**SH**	**SH**	**SH**	**SH**	**RIS**
Micropterus salmoides	Largemouth bass	8	2	2	0	0	2	2	0	8	0	0	
Etheostoma blennioides	Greenside darter	0	0	0	0	0	0	0	0	0	0	0	
Etheostoma caeruleum	Rainbow darter	0	0	0	0	0	0	0	0	0	0	0	
Etheostoma flabellare	Fantail darter	0	0	0	0	0	0	0	0	0	0	0	
Etheostoma nigrum	Johnny darter	8	0	0	0	0	0	0	6	6	0	2	
Etheostoma spectabile	Orangethroat darter	0	0	0	0	0	0	0	0	0	0	0	
Percina caprodes	Log perch	2	1	0	0	0	0	1	0	2	0	0	
Percina maculata	Blackside darter	0	0	0	0	0	0	0	0	0	0	0	
Aplodinotus grunniens	Freshwater drum	0	0	0	0	0	0	0	0	0	0	0	
L. macrochirus X L. cyanellus	Bluegill x Green Sunfish hybrid	4	0	4	0	0	0	0	0	4	0	0	
Hypophthalmichthys molitrix	Silver Carp	6	0	0	0	2	0	4	0	6	0	0	
	Number of Individuals:	3815	53	182	317	125	330	1082	390	2479	935	407	
	Number of Species:		47	47	47	47	47	47	47		47	47	
		Site:	**BFC-20**	**BFC-19**	**BFC-25**	**BFCA-22**	**BFC-26**	**BFC-11**	**BF-01**		**BF-01**	**BFB-13**	**15**
		Seine hauls	4	4	4	4	4	4	4		4	4	

APPENDIX C

DATABASES USED TO DEVELOP THE LIST OF REPRESENTATIVE IMPORTANT SPECIES (RIS) FOR ROBINSON CREEK

Appendix C-3: MBI Robinson Run 2016 Fish Sampling Results Compendium and RIS Selection.

Appendix Table C-3. MBI Robinson Creek 2016 fish sampling results compendium and RIS selection August 29-Sept. 2.

			Robinson Creek				Quail Creek	Robinson Creek			Marathon Cr.	Robinson Cr.	U. Trib.	Robinson Cr.	U. Trib.	Robinson Creek			Sugar Creek				LaMotte Cr.
			RC10	RC01	RWMZ	RC02	QC01	RC03	RC04	MPMZ	MC01	RC05	UT01	RC06	UT02	RC07	RC08	RC09	SC01A	SC01	SC02	SC03	LC01
Scientific name	Common name	Individuals	29-Sep	1-Sep	1-Sep	1-Sep	1-Sep	1-Sep	2-Sep	2-Sep	2-Sep	2-Sep	31-Aug	2-Sep	31-Aug	31-Aug	31-Aug	31-Aug	30-Aug	30-Aug	30-Aug	30-Aug	30-Aug
Amia calva	Bowfin	2														2							
Esox americanus	Grass pickerel	1						1															
Lepisosteus platostomus	Shortnose gar	1																					1
Dorosoma cepedianum	Gizzard shad	66					5	1	2	1		1		2		6	4					26	18
Campostoma anomalum	Central stoneroller	263	11	54	72	49	9	32	7	1	5			1			3		3	1			15
Ctenopharyngodon idella	Grass carp	9								1							5					1	2
Cyprinus carpio	Common carp	106	15	7	4			1		15		6		9		27	2	1		10		2	7
Carassius auratus	Goldfish	10								3						3							4
Phenacobius mirabilis	Suckermouth minnow	35				1		1										5		3	3	2	20
Notropis buccatus	Silverjaw minnow	1399	13	42	1	57		25		8	23	133				79	109	201	10	281	137	102	178
Hybognathus nuchalis	Mississippi Silvery minnow	68									3	30		1			20			10		4	
Notropis atherinoides	Emerald shiner	95												2		10	3	3			4	69	4
Notropis blennius	River shiner	12																			1	11	
Notropis stramineus	Sand shiner	0																					
Cyprinella spiloptera	Spotfin shiner	55		1	1	2				6		9		22		9		1					4
Cyprinella whipplei	Steelcolor shiner	6														1	5						
Cyprinella luntrensis	Red shiner	0																					
Lythrurus umbratilus	Redfin shiner	27																					27
Luxilus chrysocephalus	Striped shiner	12						1						1						10			
Notemigonus crysoleucas	Golden shiner	1	1																				
Pimephales promelas	Fathead minnow	2	1	1																			
Pimephales notatus	Bluntnose minnow	306	11	11		4	1			3	1	6		2		4		3	1	180	2	1	76
Hyboposis amblops	Bigeye chub	3										2											1
Semotilus atromaculatus	Creek chub	1208	198	243	24	120	68		18	1	198	32	2	21	119	5	3	40	32	33	15	29	7
Carpiodes carpio	River carpsucker	0																					
Carpiodes cyprinus	Quillback	33																		33			
Catostomus commersoni	White sucker	263	16	19	14	1		29	105	5	7			1		3	3	4		27	1	4	24
Hypentelium nigricans	Northern hogsucker	1						1															
Minytrema melanops	Spotted sucker	5												1			1					1	2
Erimyzon oblongus	Creek chubsucker	67						67															
Ictiobus cyprinellus	Bigmouth buffalo	1															1						
Ictiobus bubalus	Smallmouth buffalo	1														1							
Moxostoma erythrurum	Golden redhorse	5																				4	1
Moxostoma duquesnei	Black redhorse	3																1				2	
Moxostoma anisurum	Silver redhorse	0																					
Moxostoma macrolepidotum	Shorthead redhorse	5																1				3	1
Ictalurus punctatus	Channel catfish	2																				2	
Noturus gyrinus	Tadpole madtom	1																					1
Noturus flavus	Stonecat madtom	1												1									
Ameiurus melas	Black bullhead	9								7						2							
Ameiurus natalis	Yellow bullhead	64	1	7	4	9	2	14	10	3	1	4					1	1		1	4	2	
Aphredoderus sayanus	Pirate perch	30		1		1		1	1											18	1	4	3
Fundulus notatus	Blackstripe topminnow	5																		2		1	2
Gambusia affinis	Western mosquitofish	23								6		3				1	6	5		1			1
Labidesthes sicculus	Brook silverside	0																					
Lepomis cyanellus	Green sunfish	443	7	41	19	10	9	35	38	13	6	28		28	86	13	8	9		20	18	10	45
Lepomis macrochirus	Bluegill	626	32	59	18	11	47	29	43	49	99	87	2	53		29	27	3		9	11	8	10
Lepomis humilis	Orangespotted sunfish	12								2		2				6	2						
Lepomis microlophus	Redear sunfish	2										1		1									
Lepomis megalotis	Longear sunfish	127			4			6	17							3	1			2		10	84
Lepomis gulosus	Warmouth	3					1	1								1							
Pomoxis annularis	White crappie	0																					
Micropterus punctulatus	Spotted bass	10																		3	4		3
Miropterus dolomieu	Smallmouth bass	1																			1		
Micropterus salmoides	Largemouth bass	120	5	3	2	4	6	3	5	3	56	3	5	2		1	2	1		4	1	4	10
Etheostoma blennioides	Greenside darter	0																					
Etheostoma gracile	Slough darter	6													3								3
Etheostoma asprigene	Mud darter	0																					
Etheostoma caeruleum	Rainbow darter	5																					5
Etheostoma flabellare	Fantail darter	0																					
Etheostoma nigrum	Johnny darter	85		4		8		24	3		1						1		6	15	2	1	20
Etheostoma spectabile	Orangethroat darter	0																					
Percina caprodes	Logperch	13			1			2	7	1		2											
Percina maculata	Blackside darter	0																					
Aplodinotus grunniens	Freshwater drum	0																					
*Lepomis macrochirus*L cyanellus*	Bluegill x Green SF hybrid	3																					3
Hypophthalmichthys molitrix	Silver Carp	0																					
	Number of Individuals	5662	311	493	164	277	148	274	256	128	400	349	9	148	208	206	207	279	52	663	205	303	582
	Numer of Taxa		12	14	12	13	9	19	12	18	11	16	3	16	3	20	20	15	5	20	15	24	31
	Index of Biotic Integrity (IBI)		28	23	28	31	16	40	28	22	38	25	27	26	30	25	32	27	20	31	27	46	53
	Site Code		**RC10**	**RC01**	**RWMZ**	**RC02**	**QC01**	**RC03**	**RC04**	**MPMZ**	**MC01**	**RC05**	**UT01**	**RC06**	**UT02**	**RC07**	**RC08**	**RC09**	**SC01A**	**SC01B**	**SC02**	**SC03**	**LC01**
	Drainage Area		**1.4**	**2.59**	**3.24**	**3.27**	**2.29**	**5.73**	**6.51**	**6.53**	**1.24**	**7.94**	**0.33**	**8.39**	**1.47**	**10.4**	**12.3**	**13**	**14.1**	**14.2**	**30.7**	**35.1**	**26.7**

Appendix Table C-3. MBI Robinson Creek 2016 fish sampling results compendium and RIS selection August 29-Sept. 2.

			Robinson Creek				Quail Creek	Robinson Creek			Marathon Cr.	Robinson Cr.	U. Trib.	Robinson Cr.	U. Trib.	Robinson Creek			Sugar Creek				LaMotte Cr.
			RC10	RC01	RWMZ	RC02	QC01	RC03	RC04	MPMZ	MC01	RC05	UT01	RC06	UT02	RC07	RC08	RC09	SC01A	SC01	SC02	SC03	LC01
Scientific name	Common name	Individuals	29-Sep	1-Sep	1-Sep	1-Sep	1-Sep	1-Sep	2-Sep	2-Sep	2-Sep	2-Sep	31-Aug	2-Sep	31-Aug	31-Aug	31-Aug	31-Aug	30-Aug	30-Aug	30-Aug	30-Aug	30-Aug
Lepisosteus platostomus	Shortnose gar	0																					
Dorosoma cepedianum	Gizzard shad	106			2		3		1	1		2					26	1		69		1	
Campostoma anomalum	Central stoneroller	142		26	36	41	5	5	9					3				4		10	3		
Ctenopharyngodon idella	Grass carp	13												1		1	9						2
Cyprinus carpio	Common carp	63		4	5					5		5		2		35	2			3			2
Carassius auratus	Goldfish	9														6							3
Phenacobius mirabilis	Suckermouth minnow	32																6		10	4	8	4
Notropis buccatus	Silverjaw minnow	895		28		67		3		61	14	35		2		48	32	119		74	240	88	84
Hybognathus nuchalis	Mississippi Silvery minnow	55								4	1						35	4		11			
Notropis atherinoides	Emerald shiner	258								1						12	1	9			1	234	
Notropis blennius	River shiner	52																			1	51	
Notropis stramineus	Sand shiner	0																					
Cyprinella spiloptera	Spotfin shiner	63			3	3	1			11		1		13		2	1	3					25
Cyprinella whipplei	Steelcolor shiner	0																					
Cyprinella luntrensis	Red shiner	0																					
Lythrurus umbratilus	Redfin shiner	22																					22
Luxilus chrysocephalus	Striped shiner	17			1			2		1								2		10	1		
Notemigonus crysoleucas	Golden shiner	2								1										1			
Pimephales promelas	Fathead minnow	0																					
Pimephales notatus	Bluntnose minnow	231		2		2	3			10							2	3		81	9		119
Hybopsis amblops	Bigeye chub	5				1												1					3
Semotilus atromaculatus	Creek chub	825		155	43	67	42	34	15	3	84	15	17	17	116	11	5	39		91	43	24	4
Carpiodes carpio	River carpsucker	0																					
Carpiodes cyprinus	Quillback	43																		41			2
Catostomus commersoni	White sucker	215		14	7	7	6	28	46	1	4	3		6			15	5		32		4	37
Hypentelium nigricans	Northern hogsucker	5						1													1	3	
Minytrema melanops	Spotted sucker	0																					
Erimyzon oblongus	Creek chubsucker	0																					
Ictiobus cyprinellus	Bigmouth buffalo	0																					
Ictiobus bubalus	Smallmouth buffalo	0																					
Moxostoma erythrurum	Golden redhorse	5																				3	2
Moxostoma duquesnei	Black redhorse	0																					
Moxostoma anisurum	Silver redhorse	2																				1	1
Moxostoma macrolepidotum	Shorthead redhorse	7														1						5	1
Ictalurus punctatus	Channel catfish	0																					
Noturus gyrinus	Tadpole madtom	0																					
Noturus flavus	Stonecat madtom	1												1									
Ameiurus melas	Black bullhead	6								5						1							
Ameiurus natalis	Yellow bullhead	49		7	4	12	2	6	6	1		2						3			3		3
Aphredoderus sayanus	Pirate perch	20							2											13	2	2	1
Fundulus notatus	Blackstripe topminnow	21																		2			19
Gambusia affinis	Western mosquitofish	21									1	3					13			2			2
Labidesthes sicculus	Brook silverside	0																					
Lepomis cyanellus	Green sunfish	291		22	16	7	3	34	33	18	8	31		33	32	2	4	4		6	11	5	22
Lepomis macrochirus	Bluegill	391		53	17	4	48	28	21	15	41	40	4	46	1	5	35	2		16	8	5	2
Lepomis humilis	Orangespotted sunfish	1															1						
Lepomis microlophus	Redear sunfish	50				23	6		3	2	4	4		4			4						
Lepomis megalotis	Longear sunfish	113			2			8	9							4				12	6	7	65
Lepomis gulosus	Warmouth	1												1									
Pomoxis annularis	White crappie	0																					
Micropterus punctulatus	Spotted bass	8																		2	2		4
Miropterus dolomieu	Smallmouth bass	0																					
Micropterus salmoides	Largemouth bass	61			1	3	5	4	6		3	4	3	2		3	4			2		2	19
Etheostoma blennioides	Greenside darter	0																					
Etheostoma gracile	Slough darter	5													3								2
Etheostoma asprigene	Mud darter	1																				1	
Etheostoma caeruleum	Rainbow darter	3																					3
Etheostoma flabellare	Fantail darter	0																					
Etheostoma nigrum	Johnny darter	76		4		11		5			1							2		5	7	4	37
Etheostoma spectabile	Orangethroat darter	0																					
Percina caprodes	Logperch	7		1					4	2													
Percina maculata	Blackside darter	0																					
Aplodinotus grunniens	Freshwater drum	1																					1
*Lepomis macrochirus*L cyanellus*	Bluegill x Greenn sunfish hybrid	1						1															
Hypophthalmichthys molitrix	Silver Carp	0																					
	Number of Individuals	4195	0	316	137	248	124	160	155	142	161	145	24	131	152	131	189	207	0	493	342	448	491
	Numer of Species		0	11	12	13	11	14	12	17	10	12	3	13	4	13	16	16	0	21	16	18	28
	Index of Biotic Integrity (IBI)		N/A	21	25	35	19	32	28	24	37	16	24	20	32	22	23	30	N/A	33	31	43	50
	Site Code		**RC10**	**RC01**	**RWMZ**	**RC02**	**QC01**	**RC03**	**RC04**	**MPMZ**	**MC01**	**RC05**	**UT01**	**RC06**	**UT02**	**RC07**	**RC08**	**RC09**	**SC01A**	**SC01B**	**SC02**	**SC03**	**LC01**
	Drainage Area		**1.4**	**2.59**	**3.24**	**3.27**	**2.29**	**5.73**	**6.51**	**6.53**	**1.24**	**7.94**	**0.33**	**8.39**	**1.47**	**10.4**	**12.3**	**13**	**14.1**	**14.2**	**30.7**	**35.1**	**26.7**