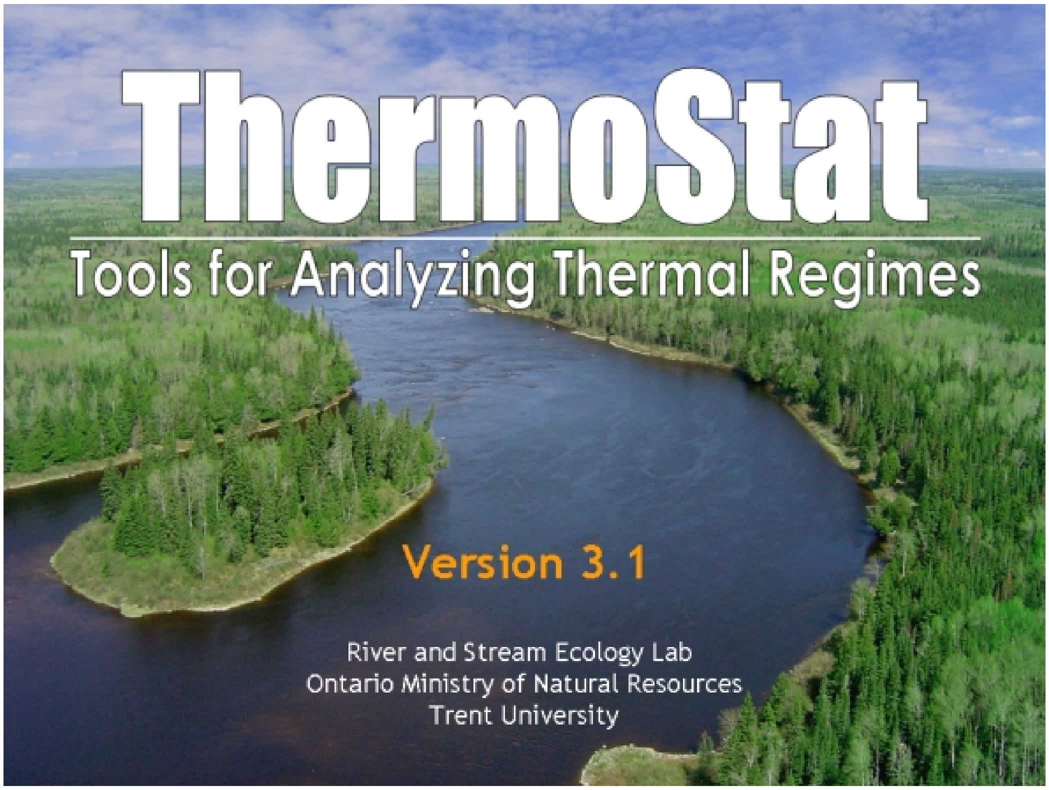
# Stream Temperature Regime Report

## ThermoStat 3.1




Publication date 12-Mar-2013

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# Chapter 1. General Information

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## Introduction

Thermal regime is of central importance in sustaining the ecological integrity of aquatic ecosystems and limits the distribution and abundance of riverine species. Water temperature has been described as the ‘abiotic master factor’ for fishes (Brett 1971; Poff et al.1997) and as an ecological resource (Magnuson et al. 1979). Temperature influences overall water quality, nutrient and ice dynamics, and the metabolic activity, growth, timing of migration and spawning events. Species-specific thermal preferences and tolerances define thermal habitat. Recently, the “natural thermal regime” and its components: magnitude, frequency, duration, timing and rate of change, have been acknowledged as fundamental ecological variables (Chu et al. 2009; Olden and Naiman 2010) that need to be included in environmental flow management. This report summarizes some key measures of the thermal regime.

## Data Considerations

ThermoStat can be used to describe a thermal regime in a variety of ways that incorporate measures of timing, magnitude, variability, duration, rate of change, and species specific temperatures. ThermoStat does not perform statistical tests or generate p-values. Output from ThermoStat can be used in statistical tests to examine trends through time, before-after, or control-impact experimental designs. ThermoStat will calculate measures even if you feed it an insufficient quantity or quality of data (e.g., missing data, poor data). It is the responsibility of the user to know the limitations of their input data and make appropriate judgment calls on the quality of the resulting output.

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## Metadata

**Table 1.1. Report Information**

| | |
|---|---|
| Report Version | 1 |
| Current Version Date | 12-Mar-2013 |
| Previous Version Date | Not Provided |
| Primary Report Objective(s) | Demo |

**Table 1.2. Report Author Information**

| | |
|---|---|
| Name | James T. Kirk |
| Organization | United Federation of Planets |
| Position/Title | Captain |

| | |
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**Table 1.3. Report Request Origin Information**

| | |
|---|---|
| Name | Jack O'Neill |
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| Position/Title | Colonel |
| Telephone | 555-1234 |
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**Table 1.4. Input Data Source Description**

| | |
|---|---|
| Country | Canada |
| Province/State | Ontario |
| OMNR Region | Northeast |
| OMNR District | Chapleau |
| Site ID | 00AA00-000 |
| Site Name | Station A |
| Drainage Area | 1234 |
| Time Step | 30 Minutes |
| Period of Record | 2005 to 2008 |
| Winter | December 1 to February 28 |
| Spring | March 1 to May 31 |
| Summer | June 1 to August 31 |
| Autumn | September 1 to November 30 |
| Site Coordinates | X: -77.123456, Y: 43.000000 |
| Coordinate System | Geographic, NAD83 |
| Data Source Description | Popular Logger Brand Extreme S/N 987654 |

**Table 1.5. Time Series Summary Statistics**

| | |
|---|---|
| n (equivalent years) | 55864 (3.2) |
| Median | 14.1 |
| Mean | 13.1 |
| Standard Dev. | 9.4 |
| Minimum | 0.0 |
| Maximum | 32.3 |
| Range | 32.3 |

# Chapter 2. Thermal Classification

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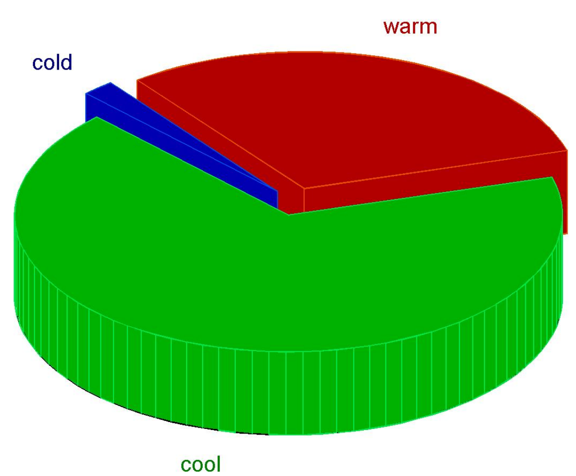
## Background

Fish are good integrators of environmental conditions, so the thermal classification of a river is frequently defined by the thermal preferences and tolerances of the fish (i.e. warm-water, cool-water, and cold-water). Classifying rivers and their reaches by the thermal requirements of fish is a useful preliminary assessment tool. This provides a simplistic representation of thermal regime. It will not provide information about other ecologically important aspects of temperature such as spatial/temporal variation and rates of change. The results show the proportion of all summer (June 1 to August 31) stream temperature records above 25°C (warm-water), between 19-25°C (cool-water), and below 19°C (cold-water)(Coker et al. 2001).

## Summer Thermal Class Percentages



| Thermal Range | Percentage within Range |
|---|---|
| Cold | 1.9 |
| Cool | 67.2 |
| Warm | 30.9 |

# Chapter 3. Timing

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# Background

The cyclical pattern of water temperature fluctuations, both daily and seasonally, generally resemble a sinusoidal curve with a specific phase (i.e. temporal "location" of minima and maxima). Most biota inhabiting lotic environments are adapted to the timing of these diurnal and seasonal fluctuations. Diurnal fluctuations which occur naturally on a 24 hour basis (Hubbs 1972) usually reach a minimum in the early morning and a maximum late in the afternoon. These daily fluctuations can be significant, particularly on wide and shallow rivers with little groundwater input (Caissie 2006). Events such as spawning, feeding, hatching and emergence, frequently correspond to the daily timing of these changes. Measures of seasonal maximum and minimum timing are useful in assessing the shape of the seasonal pattern of temperature change. Such measures are key for defining species' thermal habitat. The seasonal timing also determines the formation, persistence, and break-up of river ice, which help define the physical character of rivers and fish habitat. A shift in the pattern of a stream's daily and seasonal timing of temperature fluctuations may indicate a shift in the stream's entire thermal profile.

# Day-of-Year of Annual Minima and Maxima

The following results are a list of the dates (day-of-year) of the annual maxima and minima for each year within the period of record. Note: Two time windows are used to indicate data quality (Winter = November 1 to February 28 and Summer = June 1 to August 31). The %Data field represents the percentage of time each time window contains data values (i.e. non-null values). If this field contains any value less than 100% the results should be interpreted with caution since the times the actual maxima/minima occurred maybe missing.

| Minimum Date | Day-of-Year | Degrees | % Winter Data |
|---|---|---|---|
| 24/06/2006 | 175 | 20.670 | 0 |
| 19/02/2007 | 50 | 0.000 | 99 |
| 04/03/2008 | 63 | 0.020 | 100 |
| 27/12/2008 | 361 | 0.000 | 99 |
| 12/08/2009 | 224 | 17.770 | 0 |

| Maximum Date | Day-of-Year | Degrees | % Summer Data |
|---|---|---|---|
| 18/07/2006 | 199 | 30.3 | 77 |
| 02/08/2007 | 214 | 32.3 | 99 |
| 02/08/2008 | 214 | 30.6 | 100 |
| 01/08/2009 | 213 | 29.8 | 100 |

# Monthly Modal Hour of Daily Temperature Maxima and Minima

The following table shows the most common (mode) hour of the day when a stream's minimum and maximum temperature was reached for each month. It should be noted that two filters are applied when determining daily min/max values. These filters identify days that have no significant troughs or peaks. Since these days will produce unreliable minima/maxima timing results they are excluded when creating the histogram. For example, winter days where temperature remains very close to 0°C (with a daily range < 0.25ºC) or cooling/warming trend days, where temperature declines/rises steadily from midnight to midnight, are excluded. Sample size units are days.

| Month | Daily Min. Mode Hr | Daily Max. Mode Hr | Min. Sample Size | Max. Sample Size |
|---|---|---|---|---|
| Jan | 10:00 | 15:00* | 62 | 66 |
| Feb | 08:00 | 16:00 | 54 | 54 |
| Mar | 09:00* | 19:00 | 73 | 74 |
| Apr | 10:00 | 19:00 | 88 | 86 |
| May | 10:00 | 18:00* | 93 | 87 |
| Jun | 10:00 | 19:00 | 99 | 96 |
| Jul | 10:00 | 18:00* | 124 | 124 |
| Aug | 09:00 | 17:00 | 123 | 123 |
| Sep | 10:00 | 18:00 | 91 | 91 |
| Oct | 10:00 | 17:00 | 93 | 91 |
| Nov | 10:00 | 01:00 | 83 | 84 |
| Dec | 09:00 | 22:00 | 79 | 81 |

* Multiple hourly bins contain equal number of occurrences. In this case the earliest hour is shown.

# Chapter 4. Magnitude

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# Background

The following results show the period-of-record averages of daily and seasonal extreme temperatures. A shift in the magnitude of stream's daily and seasonal temperature extremes may indicate a shift in the stream's entire thermal profile.

# Period-of-Record Means of Annual Maxima and Minima

The following mean minimum and maximum values are based on the list of annual extreme values found in the Day-of-Year of Annual Minima and Maxima table of the Timing Section of this report. The same data quality considerations outlined in that section apply here by association.

| Mean Annual Minimum | Mean Annual Maximum |
|---|---|
| 7.7 | 30.8 |

# Monthly Means of Daily Temperature Minima and Maxima

Two filters are applied when determining daily min/max values. These filters identify days that have no significant troughs or peaks. Since these days will produce unreliable minima/maxima timing results they are excluded from the analysis. For example, winter days where temperature remains very close to 0°C (with a daily range < 0.25ºC) or cooling/warming trend days, where temperature declines/rises steadily from midnight to midnight, are excluded. The sample sizes of the maxima and minima bins may be different for the same month because it is possible for a day to have a peak, but no through, and vice versa. Sample size units are days.

| Month | Mean Daily Min. | Mean Daily Max. | Min. Sample Size | Max. Sample Size |
|---|---|---|---|---|
| Jan | 1.7 | 2.4 | 62 | 66 |
| Feb | 0.7 | 1.3 | 54 | 54 |
| Mar | 3.1 | 5.2 | 73 | 74 |
| Apr | 10.2 | 13.9 | 88 | 86 |
| May | 15.4 | 19.0 | 93 | 87 |
| Jun | 21.2 | 24.4 | 99 | 96 |
| Jul | 23.1 | 26.2 | 124 | 124 |

| | | | | |
|---|---|---|---|---|
| Aug | 22.5 | 25.5 | 123 | 123 |
| Sep | 18.5 | 20.7 | 91 | 91 |
| Oct | 12.5 | 13.9 | 93 | 91 |
| Nov | 5.8 | 6.9 | 83 | 84 |
| Dec | 1.4 | 2.0 | 79 | 81 |

# Chapter 5. Variability

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# Background

The cyclical pattern of water temperature fluctuations, both daily and seasonally, generally resemble a sinusoidal curve with a specific amplitudes. The amplitude (i.e. range) between daily and seasonal extreme values are useful in assessing the shape of the daily and seasonal pattern of temperature change. Artificially stabilizing water temperatures could negatively affect some species whose body processes require a wide daily temperature range for optimal energetic efficiency (Lehmkuhl 1972; Sweeney 1978; Ward and Stanford 1979). For example, spawning fishes and the subsequent emergence and survival of their young may be affected, as well as the emergence of benthic invertebrates that may serve as a source of food for them. A change in the range of a stream's daily and seasonal temperature fluctuations may indicate a shift in the stream's entire thermal profile.

# Period-of-Record Mean of Annual Temperature Ranges

The following range value is based on the list of annual extreme values found in the Day-of-Year of Annual Minima and Maxima table of the Timing Section of this report. The same data quality considerations outlined in that section apply here by association.

| Mean Annual Range | |
|---|---|
| 23.1 | |

# Monthly Means of Daily Temperature Range

The following values are calculated by subtracting the monthly mean minima from the monthly mean maxima found in the Monthly Means of Daily Temperature Minima and Maxima table of this report's Magnitude Section.

| Month | Mean Daily Range |
|---|---|
| Jan | 0.7 |
| Feb | 0.6 |
| Mar | 2.0 |
| Apr | 3.7 |
| May | 3.6 |
| Jun | 3.2 |

| | |
|---|---|
| Jul | 3.1 |
| Aug | 3.0 |
| Sep | 2.2 |
| Oct | 1.5 |
| Nov | 1.1 |
| Dec | 0.6 |

# Chapter 6. Rate of Change

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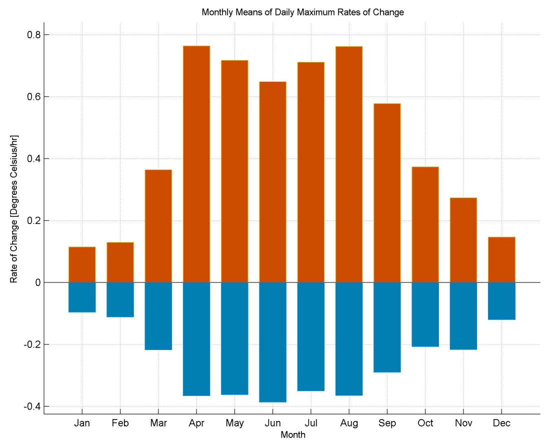
# Background

Large and/or sudden changes in water temperature can cause thermal shock in aquatic biota (Donaldson et al. 2008). Evidence suggests the response to thermal shock is highly dependent on the acclimation temperature (both constant and cyclic), the magnitude of the temperature shift, and the final endpoint value (Threader and Houston 1983; Thomas et al. 1986; Tang et al. 1987). Sub-lethal effects have also been noted for smaller rates of change including physiological stress leading to metabolic dysfunction (Wedemeyer 1973), growth inhibition and disease initiation (Wedemeyer and McLeay 1981) and increased predation (Coutant 1973). Slower rates of heating or cooling exposure can provide a period of acclimation to facilitate physiological adjustment (McCullough 1999).

# Monthly Means of Daily Maximum Rates of Change (Degrees Celsius / Hour)

The monthly values in the table below are calculated by first determining the maximum warming and cooling hourly rates of change for each day. These daily extreme hourly rates of change are then gathered into monthly bins and the average of each bin is taken. Sampe size units are days.




| Month | Warming Rate | Cooling Rate | Sample Size [days] |
|---|---|---|---|
| January | 0.1146 | -0.0955 | 92 |
| February | 0.1290 | -0.1110 | 85 |
| March | 0.3637 | -0.2172 | 92 |
| April | 0.7637 | -0.3657 | 90 |

| | | | |
|---|---|---|---|
| May | 0.7171 | -0.3617 | 93 |
| June | 0.6485 | -0.3859 | 99 |
| July | 0.7110 | -0.3502 | 124 |
| August | 0.7617 | -0.3649 | 124 |
| September | 0.5775 | -0.2895 | 91 |
| October | 0.3737 | -0.2067 | 93 |
| November | 0.2736 | -0.2161 | 90 |
| December | 0.1468 | -0.1201 | 92 |

# Chapter 7. Duration

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# Background

The thermal characteristics of the streams play an important role in defining the species specific habitat supply. Species-specific thermal preferences and tolerances are critical biological elements that define these thermal habitats. Shifting the thermal regime outside a species' preferred thermal range or beyond its temperature tolerances can lead to changes in community composition and/or the loss of some species. This procedure calculates species-specific temperature durations for the range of +/-2 Degrees Celsius around the Final Temperature Preferrendum (FTP) and the Optimal Growth Temperature (OGT); and the duration of Upper Incipient Lethal Temperature (UILT) and the Critical Maximum Temperature (CTmax) exceedence of the summer season (June 1st to August 31st). Species-specific temperature values for FTP, OGT, UILT and CTmax are found in Hasnain et al. (2010).

# Optimal Range and Critical Threshold Species-Specific Summer Temperature Durations

Percentage of summer temperature measurements within +/- 2 Degrees Celsius of the optimal temperatures (FTP and OGT) and above the critical temperatures (UILT and CTmax). --- indictaes that the metric was not reported by Hasnain et al (2010)

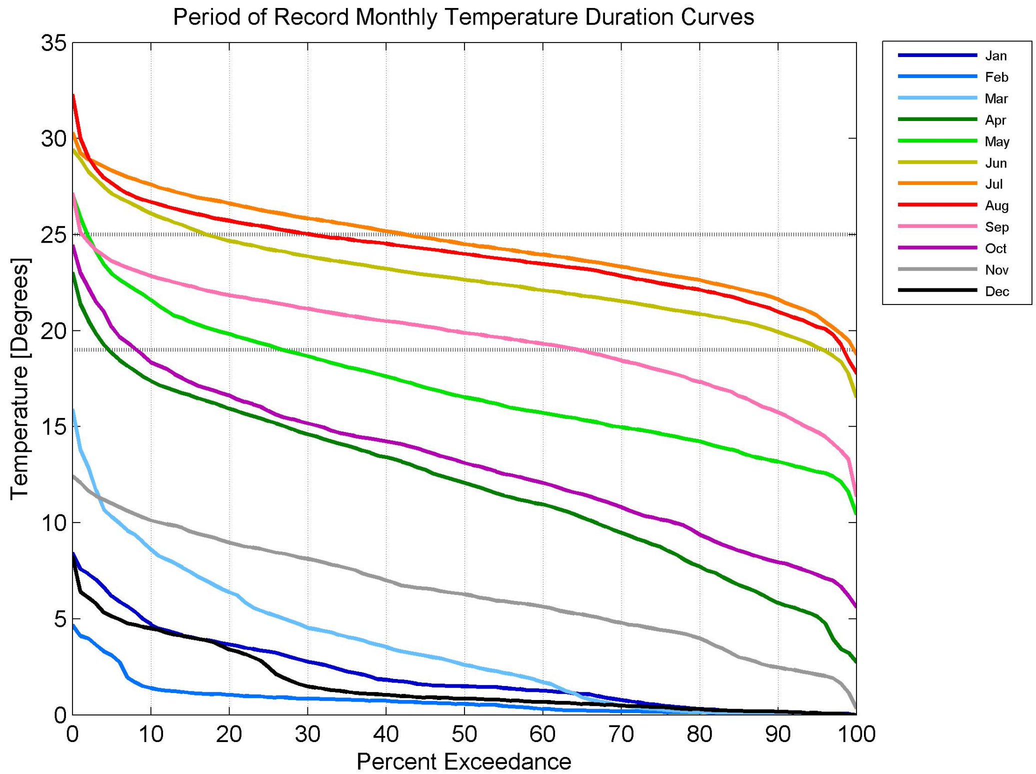
| Species | FTP | OGT | UILT | CTmax |
|---|---|---|---|---|
| Alewife | 1.7 | 23.8 | 61.5 | 0.1 |
| American Eel | 21.1 | 53.0 | --- | --- |
| Atlantic Salmon | 0.2 | 0.0 | 6.5 | 0.0 |
| Banded Killifish | 56.8 | --- | 0.0 | --- |
| Bigmouth Buffalo | 20.0 | --- | --- | --- |
| Black Bullhead | --- | --- | 0.0 | 0.0 |
| Black Crappie | 58.0 | 5.3 | 0.0 | 0.0 |
| Blackchin Shiner | --- | --- | 0.0 | 0.0 |
| Blacknose Dace | 17.9 | --- | 2.7 | 0.3 |
| Bloater | 0.0 | 9.0 | 14.2 | --- |
| Bluegill | 3.9 | 8.4 | 0.0 | 0.0 |
| Bluntnose Minnow | 58.5 | 39.6 | 0.1 | 0.4 |
| Bowfin | 3.6 | --- | --- | 0.0 |
| Brook Stickleback | 39.1 | --- | 0.2 | --- |
| Brook Trout | 0.1 | 0.0 | 32.2 | 1.0 |

| | | | | |
|---|---|---|---|---|
| Brown Bullhead | 39.6 | 4.6 | 0.0 | 0.0 |
| Brown Trout | 0.3 | 0.0 | 30.9 | 3.6 |
| Burbot | 0.0 | 1.2 | 58.7 | --- |
| Carp | 21.8 | 26.5 | 0.0 | 0.0 |
| Central Mudminn-ow | --- | --- | 0.0 | --- |
| Central Stoneroller | 58.7 | 54.7 | 0.1 | 0.0 |
| Channel Catfish | 26.5 | 6.9 | 0.0 | 0.0 |
| Chinook Salmon | 0.0 | 0.0 | 55.0 | 29.7 |
| Chum Salmon | 0.0 | 0.0 | --- | --- |
| Coho Salmon | 0.0 | 0.0 | 41.7 | 6.5 |
| Common Shiner | 47.0 | 48.3 | 0.2 | 0.1 |
| Creek Chub | 53.7 | --- | 1.4 | 0.0 |
| Cutthroat Trout | 0.1 | 1.1 | 78.6 | 4.7 |
| Deepwater Sculpin | 0.0 | --- | --- | --- |
| Eastern Sand Dar-ter | 55.9 | --- | --- | --- |
| Emerald Shiner | 15.0 | 45.7 | 7.5 | 2.7 |
| Fallfish | 48.3 | --- | --- | --- |
| Fathead Minnow | 34.4 | 44.6 | 0.1 | 0.0 |
| Finescale Dace | 58.5 | --- | 0.3 | 0.0 |
| Fourhorn Sculpin | 0.0 | --- | --- | --- |
| Freshwater Drum | 55.9 | 48.3 | 0.0 | 0.0 |
| Gizzard Shad | 31.5 | 1.9 | 0.0 | 0.0 |
| Golden Shiner | 45.8 | 53.0 | 0.0 | 0.0 |
| Goldfish | 25.4 | 34.4 | 0.0 | 0.0 |
| Grass Pickerel | 45.7 | --- | --- | --- |
| Green Sunfish | 49.7 | 18.4 | 0.0 | 0.0 |
| Lake Herring (Cis-co) | 0.0 | 5.9 | 48.5 | --- |
| Lake Sturgeon | 0.0 | --- | --- | --- |
| Lake Trout | 0.0 | 0.0 | 41.7 | --- |
| Lake Whitefish | 0.0 | 0.1 | 48.5 | --- |
| Largemouth Bass | 13.0 | 34.4 | 0.0 | 0.0 |
| Longnose Dace | 0.2 | --- | --- | 0.1 |
| Longnose Gar | 25.4 | 36.7 | --- | --- |
| Longnose Sucker | 0.0 | --- | 11.5 | --- |
| Mooneye | 18.4 | --- | --- | --- |
| Mottled Sculpin | 0.5 | --- | 41.7 | 0.1 |
| Mummichog | 53.0 | 57.5 | 6.5 | 0.0 |

| | | | | |
|---|---|---|---|---|
| Muskellunge | 49.7 | 52.4 | 0.0 | 0.0 |
| Ninespine Stickleback | 1.1 | --- | --- | --- |
| Northern Hog Sucker | 29.3 | 46.9 | 0.5 | 0.1 |
| Northern Pike | 31.5 | 56.8 | 0.1 | --- |
| Northern Redbelly Dace | 50.8 | --- | 1.2 | 1.6 |
| Pink Salmon | 0.0 | 0.2 | --- | --- |
| Pugnose Shiner | 1.1 | --- | --- | --- |
| Pumpkinseed | 21.8 | 53.0 | 0.0 | 0.0 |
| Quillback | 28.6 | --- | --- | 0.0 |
| Rainbow Darter | 21.1 | --- | --- | 0.0 |
| Rainbow Trout | 0.2 | 0.3 | 30.9 | 76.1 |
| Rock Bass | 53.7 | 14.9 | 0.0 | 0.0 |
| Rosyface Shiner | 50.8 | 48.2 | 0.0 | 0.0 |
| Round Whitefish | 0.0 | --- | --- | --- |
| Sauger | 17.9 | 48.3 | --- | --- |
| Sea Lamprey | 0.0 | 3.3 | 0.1 | --- |
| Slimy Sculpin | 0.0 | --- | 66.1 | 17.9 |
| Smallmouth Bass | 53.0 | 42.3 | 0.0 | 0.0 |
| Sockeye Salmon | 0.0 | 0.2 | 5.6 | --- |
| Spoonhead Sculpin | 0.0 | --- | --- | --- |
| Spotfin Shiner | 24.3 | 10.4 | 0.0 | --- |
| Spottail Shiner | 1.2 | 26.5 | 0.0 | 0.0 |
| Spotted Gar | 0.4 | --- | --- | --- |
| Spotted Sucker | 45.8 | --- | --- | 0.1 |
| Stonecat | 0.2 | --- | --- | 1.6 |
| Striped Bass | --- | --- | 2.1 | 19.9 |
| Threespine Stickleback | 0.0 | 2.2 | 8.4 | 2.4 |
| Trout-Perch | 0.0 | --- | --- | 64.2 |
| Walleye | 53.5 | 49.2 | 0.5 | 57.0 |
| White Bass | 26.5 | --- | 0.0 | 0.0 |
| White Crappie | 13.2 | 53.5 | --- | 0.0 |
| White Perch | 5.6 | 14.0 | 0.0 | --- |
| White Sucker | 58.0 | 48.2 | 5.6 | 0.1 |
| Yellow Bullhead | 16.6 | --- | --- | 0.0 |
| Yellow Perch | 3.7 | 49.7 | 23.5 | 0.0 |

# Monthly Temperature Duration Curves

A duration curve graphically illustrates the percentage of time that a given temperature value was exceeded for the period of interest (in this case months). For example, the 10th percent exceedance value represents the temperture that 10% of all the measurements within a month are above (and 90% fall below). Measurements are gathered into monthly bins from the entire period of record. In the table below n represents the number of measurements used to create each curve.




| Month | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1% | 8.4 | 4.7 | 15.9 | 23.0 | 27.1 | 29.4 | 30.3 | 32.3 | 27.2 | 24.5 | 12.4 | 8.3 |
| 5% | 6.6 | 3.3 | 10.7 | 19.3 | 23.4 | 27.5 | 28.5 | 28.0 | 23.9 | 21.0 | 11.2 | 5.3 |
| 10% | 5.0 | 1.5 | 9.0 | 17.6 | 21.9 | 26.3 | 27.7 | 26.8 | 23.0 | 18.7 | 10.3 | 4.6 |
| 25% | 3.4 | 1.0 | 5.4 | 15.4 | 19.3 | 24.3 | 26.3 | 25.4 | 21.6 | 16.0 | 8.6 | 2.8 |
| 50% | 1.5 | 0.6 | 2.7 | 12.2 | 16.6 | 22.7 | 24.6 | 24.1 | 20.0 | 13.3 | 6.3 | 0.8 |
| 75% | 0.6 | 0.2 | 0.3 | 8.9 | 14.7 | 21.3 | 23.0 | 22.5 | 18.0 | 10.3 | 4.5 | 0.4 |
| 90% | 0.2 | 0.1 | 0.1 | 6.0 | 13.3 | 20.1 | 21.8 | 21.1 | 15.9 | 8.0 | 2.5 | 0.2 |
| 95% | 0.1 | 0.0 | 0.1 | 5.3 | 12.8 | 19.3 | 21.0 | 20.4 | 14.9 | 7.4 | 2.2 | 0.1 |
| 99% | 0.1 | 0.0 | 0.0 | 3.5 | 12.1 | 18.4 | 19.8 | 19.3 | 13.8 | 6.7 | 1.6 | 0.1 |
| n | 4464 | 4032 | 4460 | 4320 | 4464 | 4752 | 5952 | 5904 | 4368 | 4464 | 4220 | 4464 |

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