DWM Technical Memorandum (CN 135.0)
TM-51-14

Continuous Temperature Data at Four Locations in the Blackstone River Watershed (August-September, 2003)

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Introduction:

Cost-efficient, continuous water temperature data can be useful to environmental managers when attempting to understand surface water temperature dynamics in single waterbodies or at many locations within watersheds. Specifically, validated data can help to determine maximum, minimum and daily mean temperatures, examine the timing of diurnal temperature fluctuations, assess the potential for exceedances of State surface water quality standards, determine appropriate thermal NPDES permit limits, and assist in waterbody classifications based on temperature (e.g. cold vs. warm water fishery).
Continuous, in-stream temperature data were gathered during summertime 2003 baseflow conditions in four tributaries located within the Blackstone River watershed.

Background Information:

Watershed Description

The Blackstone River Watershed is located in southcentral Massachusetts (Figure 1). It is bordered by the Concord, Nashua, and Chicopee River Watersheds to the north, the French River Watershed to the west and by the Ten Mile River and Charles River Watersheds to the southeast.
The southern portion of the watershed is located in the state of Rhode Island. The Blackstone River is formed in the City of Worcester by the confluence of the Middle River and Mill Brook. The mainstem flows generally southeast through Worcester, Millbury, Sutton, and Grafton to Fisherville Pond, where it converges with the Quinsigamond River. Below Fisherville Pond, the Blackstone River flows in a southerly direction through Northbridge, Uxbridge, Millville, and Blackstone and crosses for the first time into Rhode Island. Just south of the RI border, it is joined by the Branch River, turns north and re-enters Massachusetts for a short distance, then turns south again and enters Woonsocket RI. Major tributaries that discharge to the Blackstone River in Massachusetts include the Quinsigamond, West, and Mumford Rivers. The Mill and Peters Rivers originate in Massachusetts but join the Blackstone River in Rhode Island. There are 188 lakes in the Massachusetts portion of the basin that cover approximately 7,087 acres.

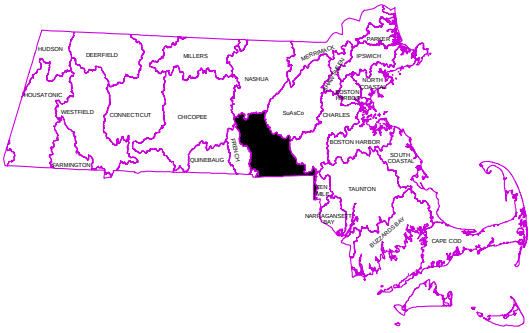


Figure 1. Location of Blackstone River Basin.

The drainage area of the Blackstone River Basin encompasses a total of 540 square miles of which approximately 335 square miles lie in Massachusetts including portions of Bristol, Middlesex, Norfolk, and Worcester counties. The communities of Attleboro, Auburn, Bellingham, Blackstone, Boylston, Douglas, Franklin, Grafton, Holden, Hopedale, Hopkinton, Leicester, Milford, Millbury, Millville, Northbridge, Mendon, North Attleborough, Oxford, Paxton, Plainville, Shrewsbury, Sutton, Upton, Uxbridge, Webster, Westborough, West Boylston, Worcester, and Wrentham lie wholly or in part within the watersheds Massachusetts boundaries.

Water Quality

An historical perspective on water quality issues in the Blackstone River watershed can be found in the current MassDEP watershed assessment report: http://www.mass.gov/dep/water/resources/wqassess.htm#wqar

Waterbody and Fisheries Classifications

Consistent with the National Goal Uses of "fishable and swimmable waters," the classification of waters in the Blackstone River Watershed according to the SWQS (314 CMR 4.0), include Class A, Class B and other waters as described below (MA DEP 2006a):.

Class A Public Water Supplies in the Blackstone River Basin (including Cold Water Fishery)

Class A waters are designated for protection as Outstanding Resource Waters (ORWs). These include public drinking water supplies, vernal pools, and all surface waters within an Area of Critical Environmental Concern (ACEC).:In addition, "Cold Waters" are waters in which the mean of the maximum daily temperature over a seven day period generally does not exceed 68°F (20°C) and, when other ecological factors are favorable (such as habitat), are capable of supporting a year-round population of cold water stenothermal aquatic life such as trout (*salmonidae*). In the Blackstone watershed, registered and/or permitted Class A Public Water Supplies include the following

- Kettle Brook, source to dam at Reservoir #1,
- Kettle Brook Reservoir Nos. 1-4, source to outlets in Leicester and Paxton and those tributaries thereto,
- Lynde Brook Reservoir, source to outlet in Leicester and those tributaries thereto,
- Holden Reservoirs Nos. 1 and 2, source to outlet in Holden and those tributaries thereto, and
- All interstate surface waters that are public water supplies in Rhode Island from 1,000 feet upstream of the state line.
- Cold Spring Brook, entire length (cold water)
- Warren Brook, entire length (cold water)

Class B Cold Water Fisheries in the Blackstone River Basin

Class B waters are designated as a habitat for fish, other aquatic life, and wildlife, including for their reproduction, migration, growth and other critical functions, and or primary and secondary contact recreation. Where designated in 314 CMR 4.06, they shall be suitable as a source of public water supply with appropriate treatment ("Treated Water Supply"). Class B waters shall be suitable for irrigation and other agricultural uses and for compatible industrial cooling and process uses. These waters shall have consistently good aesthetic value. These waters shall not exceed 68°F (20°C) based on the mean of the daily maximum temperature over a seven day period in cold water fisheries, unless naturally occurring. Where a reproducing cold water aquatic community exists at a naturally occurring higher temperature, the temperature necessary to protect the community shall not be exceeded and the natural daily and seasonal temperature fluctuations necessary to protect the community shall be maintained. Temperature shall not exceed 83°F (28.3°C) in warm water fisheries.

- West River, source to the Upton STP (WWTP)

The Massachusetts Department of Fisheries and Wildlife (MDFW) requested that the recent (2006) revisions to the water quality standards include the designation of 26 additional brooks, streams, and rivers currently on their *Coldwater Fishery Resource (CFR) List* as Class B Cold Water Fisheries. There are a number of mechanisms which MDFW uses in the development of this list, including the presence of a reproducing salmonid population and temperatures that do not generally exceed 68 degrees Fahrenheit throughout the year. MDFW also considers any tributary to a CFR to be a CFR.

Class B Warm Water Fisheries in the Blackstone River Basin

- Kettle Brook, from Dam at Reservoir # 1 to outlet of Curtis Pond
- Middle River, entire length
- Blackstone River, source to outlet of Fisherville Pond (CSO), and to the Rhode Island State Line
- Mill Brook, entire length (CSO)
- Quinsigamond River, entire length
- Mumford River, source to the confluence with the Blackstone River
- West River, from the Upton STP to the Blackstone River
- Mill River, entire length
- Beaver Brook, entire length
- Weasel Brook, entire length

Other waters

Unless otherwise designated in 314 CMR 4.06 or unless otherwise listed in the tables to 314 CMR 4.00, other waters are Class B, and presumed High Quality Waters for inland waters and Class SA, and presumed High Quality Waters for coastal and marine waters. Inland fisheries designations and coastal and marine shellfishing designations for unlisted waters shall be made on a case-by-case basis as necessary. The four Blackstone River Watershed waterbodies which were monitored for temperature (and sampled for fish) in 2003 fall into this category.

Historical Temperature Monitoring in the Blackstone Watershed

In 1998, DWM obtained instantaneous temperature measurements from 24 stations (on up to four occasions) using a Hydrolab® multi-probe unit. These data are contained in the "Blackstone River Basin 1998 Water Quality Assessment Report" (MA-DEP 2000).

Consistent with DWM's five-year rotating basin cycle, instantaneous temperature measurements at 34 stations (on up to five occasions) using a Hydrolab® multi-probe unit were obtained in 2003. These data can be found in the 2003 Water Quality Technical Memorandum (MassDEP 2003). In addition to these data, continuous temperature loggers were deployed at four locations for this project.

Project Objectives, Sampling Design and Quality Assurance:

The project objectives in gathering continuous temperature data at selected locations in the Blackstone watershed were as follows:

1. To document and evaluate the field methods for deployment and data retrieval, and to assess in-situ equipment accuracy, in order to further evaluate DWM standard operating procedures for continuous temperature monitoring
2. To record "worst case" temperature conditions over a several-week period at four separate locations under summertime baseflow conditions,
3. To assess the possible effects of small man-made impoundments on sub-watershed stream temperatures, and
4. To assist in assessing each waterbody's health with regard to designated uses, including the evaluation of current and future water quality classifications using the Massachusetts Surface Water Quality Standards

The data quality objectives (DQOs) for the project are presented in Table 1.

Table 1: Project DQOs

Analyte	Units	Expected Range	Accuracy (+/-)	Resolution	Overall Precision (RPD)
Temperature	°C	15-35	0.2	0.15	NA
Time (logger internal clock)	minutes	NA	< 5 minutes over an approximate 1 month deployment	NA	NA

Optic Stowaway® Temp sensors and BoxCar Pro 4 software (Onset Computer Corporation, Bourne, MA) were used, along with an "optic shuttle" (for portable field data downloading) and an optic "base station" (for data transmittal to PC). The seasonal timing of data collection aligned with theoretical "worst case" temperature conditions (late July through August), and was limited by other planned deployments. The recording interval was set at 15 minutes to maximize data quantity while ensuring adequate available storage though the anticipated monitoring period (approx. 1 month). About 82 days of data storage is available using a logger reading interval of 15 minutes.

Logger temperature accuracy and logging capability was tested prior to deployment in the lab. In-situ accuracy was tested by side-by-side comparison against a NIST-traceable precision thermometer (Eutechnics 4400 series) at each location on three occasions: when initially deployed on August 11th, 2003, on August 19th, 2003, and when retrieved on September 22nd, 2003. Logger time accuracy was limited by the Onset loggers, which can vary up to one hour per year at 20 deg. C. The internal clock of each logger was set at launch (via the BoxCar software) by a DWM office network PC in Worcester, MA. Due to the relatively short monitoring period and the purpose of the data collection effort, time errors are considered much less important than potential errors in temperature.

Due to limited staff and scheduling issues, a formal project-specific Quality Assurance Project Plan (QAPP) was not produced for this monitoring. A formal SOP for continuous temperature monitoring was developed in 2002, based in part on insights gained during other projects (MADEP, 2002a).

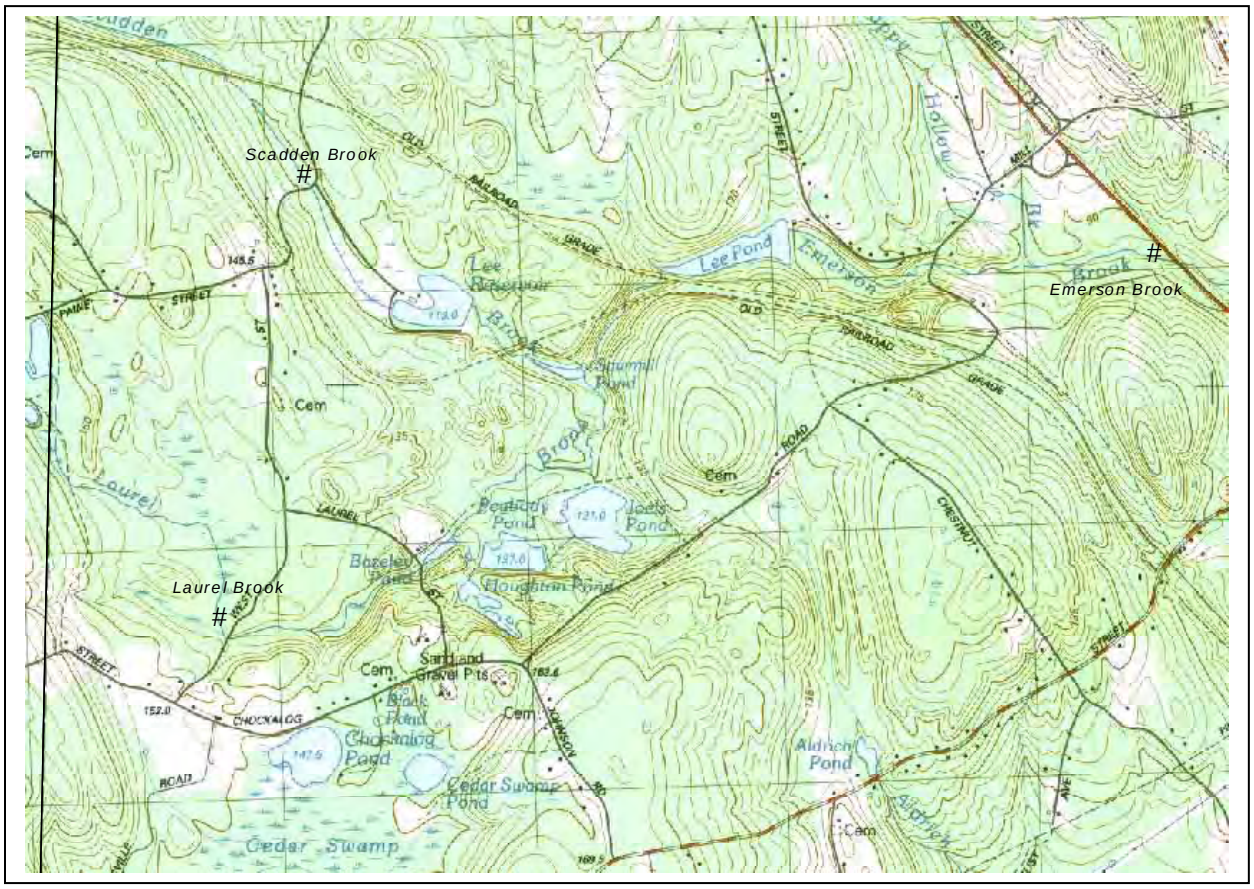
The number of continuous temperature sensors deployed was limited to four, based on the number of available sensors. Due to resource constraints, timing of sensor deployment was not ideal; sampling did not commence until August 11. Sampling site locations were chosen to coincide with a subset of 2003 DWM sampling stations where fish population monitoring was conducted (See Table 2). In addition, one station was chosen which was believed to exhibit unusually high summertime temperatures. Three of the stations which were chosen were in the Emerson Brook sub-watershed with two on feeder tributaries (Scadden and Laurel brooks) and one located on the mainstem Emerson Brook (downstream of these tributaries and three small impoundments) (See Figures 3 and 4). Although reproducing trout populations were documented by MassWildlife in both Laurel Brook and Emerson Brook, neither location is currently classified as a cold water fishery in the Massachusetts Water Quality Standards (MassDEP 2006a).

Table 2: Project Monitoring Stations

Sensor #	Station Name	Station ID#	Site Description	Parameters	Frequency
1	Laurel Brook	15A	Upstream of West Street, Uxbridge, MA (approximately 100 meters) 42° 01' 58.6"/ -71° 40' 19"	Temperature	15 minute intervals from 8/11-9/22
2	Scadden Brook	20A	Upstream of West Street Uxbridge, MA (approximately 25 meters upstream of road, mid stream) 42°.02' 46.8" / -71° 40' 05"		
3	Emerson Brook	NA	Upstream of Route 146 Chocolog Road Exit offramp, Uxbridge MA 42°.02'.46.8"/-71°.37'.37.3"	Fish Pop.	Once per site
4	Coal Mine Brook	HB	Upstream of Lake Avenue North, Worcester, MA 42°.17' 26.2" /-71°.45' 32.3"		

Figure 2: Coal Mine Brook Locator, Worcester MA.

Figure 3: Emerson Brook Sub-Watershed Locator, Uxbridge MA.



Materials and Methods:

See Appendix A for temperature logging equipment descriptions and manufacturer specifications. The following materials were used in this project:

Sensing and Data Retrieval Equipment:
Optic Stowaway® Temp loggers, optic shuttle, optic base station and BoxCar Pro software (Onset Computer Corp.). The 6" long, sealed polycarbonate optic loggers were initially launched (logging initiated) using the BoxCar program loaded on a DWM PC, and tested for logging capability and accuracy over several days. All sensors were deemed fit to use and were re-launched prior to placement in rigid plastic tubes for field use. At the same time, the optic shuttle (used for field downloading without a laptop) and the optic base station (for data transmittal from a logger or the shuttle to the PC) were also tested. The BoxCar program was also tested and used to look for any potential software problems and none were found. After placement in the plastic tubes, the loggers were anchored at representative stream/river locations at each of the four stations.

Sensor Housing and Anchoring Assembly:
Each sensor was placed in a 9-12" long, 2" O.D. ABS plastic pipe with glued, white caps on both ends for protection. Several ¾" holes were drilled into each pipe section so each assembly would sink and so that water would flow through the tube and over the probe. Prior to gluing the caps, a small, round rock was placed inside each pipe to reduce buoyancy and guarantee submergence. Also, the white caps were numbered (#1-4) to keep track of which loggers were at which locations. Approximate 10-15' long, 1/8" diameter, flexible steel cables were swage-fitted to each pipe (on one end) and attached to the top loop of 18" long steel screw anchors.

Field Deployment:
At each station, the anchors were screwed into a stable streambank at the water's edge. The cable was hidden as much as possible and the pipe containing the sensor allowed to drift downstream and sink (or the pipe was secured under large rock). All locations and placements were selected to be representative of typical stream/river conditions. The pipe number, station name and number, exact time and other relevant field data were documented.

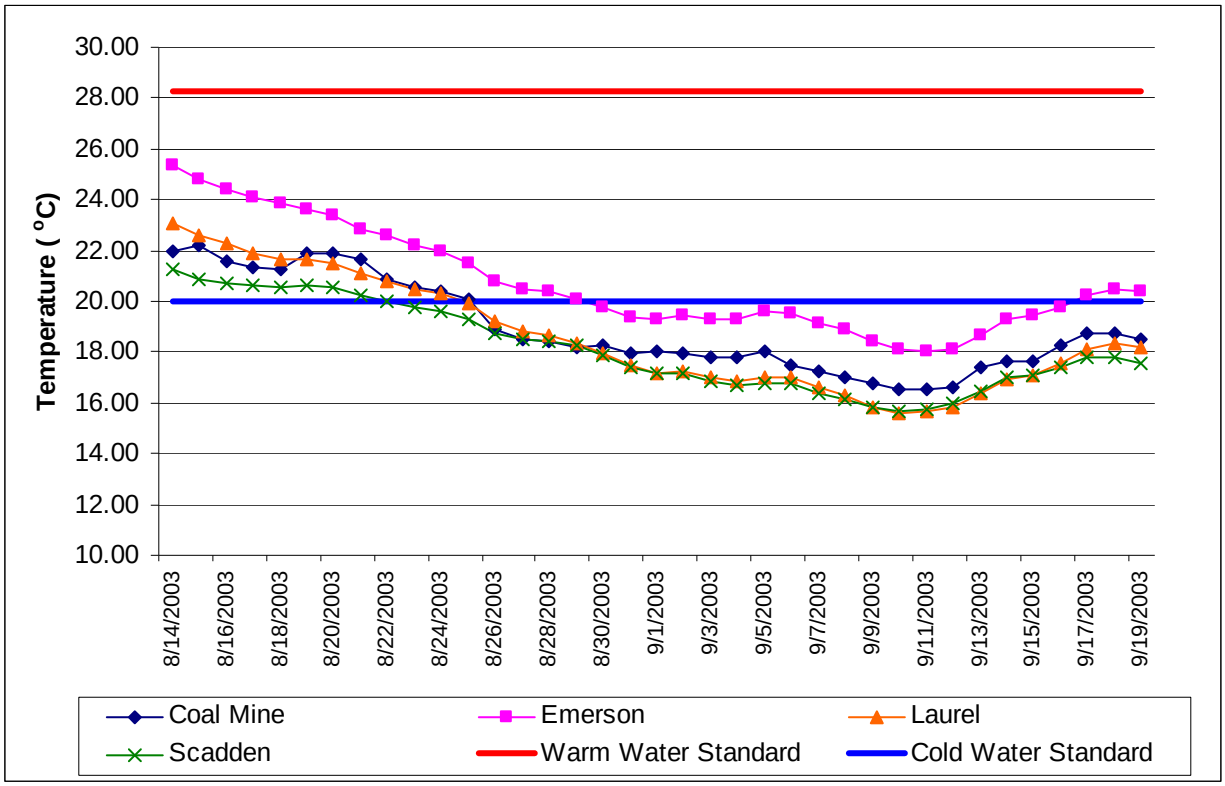
Data Analysis:
Recorded data were viewed, graphed and exported using the BoxCar Pro 4 software (Onset Computer Corp.). Exported data were analyzed using MS Excel.

NIST-traceable accuracy checks:
A hand-held digital thermometer (Eutechnics 4400 Series) traceable to a NIST-certified thermometer was used in the field to check logger accuracy at deployment and at retrieval. (This unit was purchased in 6/2001 and came with a National Institute of Standards and Technology traceable calibration certificate; the unit was then checked against a DEP NIST-certified thermometer (from Wall Experiment Station) in September, 2002). Based on manufacturer specifications, the Eutechnics unit is accurate within 0-50 deg. C to +/- 0.015 (plus probe tolerance) deg. C. The resolution is listed as 0.01 deg. C, with a one year probe drift of +/- 0.010 deg. C.

Results and Discussion:

The temperature loggers were deployed on August 11, 2003 and were retrieved on September 22, 2003. Data are tabulated and summarized graphically in Figure 4 and Table 3. The final Excel spreadsheet containing the data analysis is available here: ..\CN 135.1 - TM 2003 Blackstone temperature (data analysis).xls

Figure 4. Seven day rolling average* of the daily maximum temperature at four streams within the Blackstone River Watershed - 2003.



*the 7-day rolling average of the daily maxima was calculated for the sampled day and the three days prior to and after the sample day.

Table 3. Summary statistic for temperature data collected at four streams within the Blackstone River Watershed – 2003.

Waterbody	Coal Mine Brook	Emerson Brook	Laurel Brook	Scadden Brook
Max temp (^{o}C)	26.1	25.8	23.5	21.9
Min Temp (^{o}C)	11.9	13.2	11.6	10.7
Average Temp (^{o}C)	17.6	19.9	17.9	17.3
Max Variation per Day	7.1	3.5	3.2	3.8
Mean Variation per Day	2.5	2.2	1.7	2
Days Deployed	43	43	43	43
Days with temperatures exceeding 20^{o} C	15	25.0	12	12
Average number of hours exceeded for days with >20^{o} C temps	11	16.3	20.85	13.69
Total Hours above Cold Water Fishery Standard	165	406.5	250.25	164.25
Percent of Hours Above Cold Water Fishery Standard	16.3%	40.3%	24.8%	16.2%

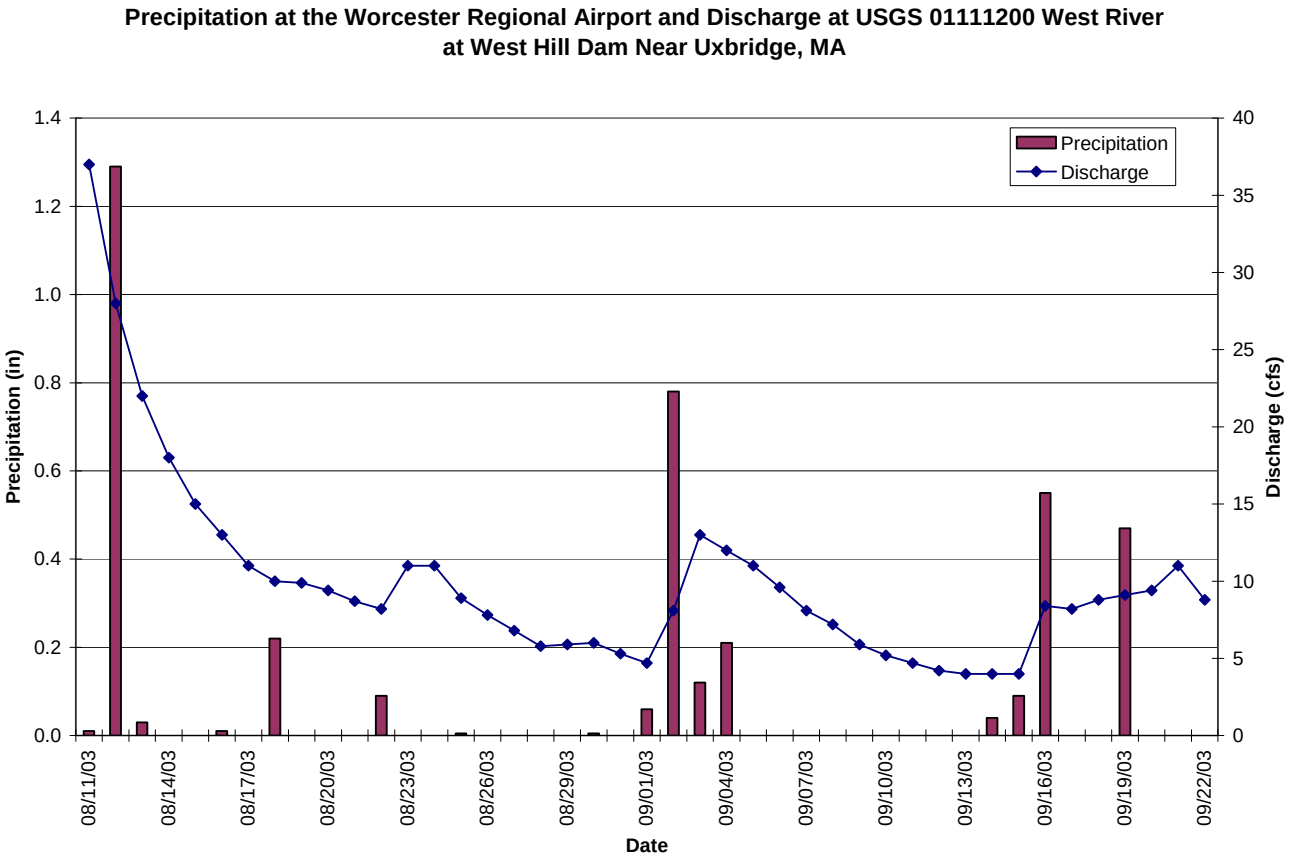
Although we appeared to miss the worst-case conditions, the Cold Water Fishery temperature standard was exceeded at all four monitoring locations during the summer of 2003. Emerson Brook consistently exhibited the highest temperature but this is expected due to the fact that it has the largest drainage area and is located downstream of a number of ponds and impoundments.
Coal Mine Brook exhibited the highest overall temperature reading (26.1^{o}C) and the greatest daily temperature variation (as high as 7.1^{o}C). This is most likely attributable to the high amount of impervious surface in the watershed (24.5%).

All four Blackstone River tributaries currently meet Class B warmwater temperature criteria, however, it should again be noted that we missed the warmest period during the summer 2003. The warmest period appears to have occurred sometime mid to late July or early August, based both on this survey as well as on instantaneous readings taken during monthly water quality surveys.

Precipitation at Worcester Airport and discharge at West River, Uxbridge

The closest known precipitation station is located in Worcester, MA, and is more than 27 kilometers from the gage station on the West River in Uxbridge. In general, rainfall amounts in the summer of 2003 were normal but localized. The rainfall data shows good relationship to the stream flow at the gage except for the very first storm at the Airport on August 12th which does not appear to have affected flows in the West River sub-watershed. Flows at West River were slightly below mean August and September flows during August and September of 2003 (Figure 5). It is unclear how precipitation and flow relate to water temperature in each of the brooks sampled.

Figure 5: Representative river flow and precipitation data within the Blackstone River Watershed.



Fish Sampling Results and Fishery Status

Fish populations were sampled by backpack electroshocking at each of the four thermistor locations. Results of these surveys are summarized below. The complete report can be found in a Technical Memorandum titled Blackstone River Watershed 2003 Fish Population Monitoring and Assessment (MassDEP 2006b).Information from MassWildlife (Richards, 2006) was also used in assessing fishery status.

Coal Mine Brook
DWM sampling in 2003 resulted in the collection of only two golden shiner *Notemigonus crysoleucas*, a macrohabitat generalist which is commonly sold and used as bait by fishermen targeting larger freshwater fish. It is possible that the shiners captured were bait bucket releases.

Scadden Brook
DWM sampling in 2003 resulted in the collection of eastern blacknose dace *Rhinichthys atratulus*, white sucker *Catostomus commersonii*, and largemouth bass *Micropterus salmoides*. Many young of the year (yoy) eastern blacknose dace were also noted on the field sheet. MassWildlife sampled Scadden Brook (a short distance upstream from the DWM sampling location) in the summer of 2004 and a very similar fish assemblage was documented. MassWildlife also found eastern blacknose dace, white sucker, and one yellow bullhead *Ameiurus natalis*. Although no trout species were collected or observed, local sportsmen from the Uxbridge Rod and Gun Club report the historic occurrence of native brook trout *Salvelinus fontinalis* in Scadden Brook.

Laurel Brook
The DWM fish sample in 2003 included white sucker, two age classes of brook trout, and largemouth bass. During the summer of 2007 MassWildlife found 38 brook trout and 100 white sucker while sampling upstream and downstream of West Street. It should be noted that the Laurel Brook Club annually stocks this section of Laurel Brook with brook trout parr and there is a possibility that the fish collected here are the result of these stockings. The source of immature largemouth bass is most likely one of the small ponds located upstream.

Emerson Brook
Emerson Brook was sampled in 2003 by DWM downstream of four small impoundments (Bazeley Pond located on Laurel Brook, Lee Reservoir located on Scadden Brook, Sawmill and Lee ponds located on un-named tributaries). Fish species captured, in order of abundance, included eastern blacknose dace, fallfish *Semotilus corporalis*, common shiner *Luxilus cornutus*, longnose dace *Rhinichthys cataractae*, white sucker, an individual brook trout, and largemouth bass. MassWildlife sampled Emerson Brook (a short distance downstream from the DWM sampling location) in the summer of 2001 and a very similar fish assemblage was documented. MassWildlife found a greater number of brook trout (n=5) along with seven brown trout (*Salmo trutta*). All brook trout appeared to be a native fish, however, historic trout stocking (of parr) and in the upper watershed by the Laurel Brook Club make this determination very difficult. Brown trout collected by MassWildlife are suspected to have been stocked by the agency in 2000 (Richards, 2006).

Summary and Recommendations:

1. Based on the continuous ("worst case") temperature data collected during this study, it is clear that Laurel Brook, Scadden Brook, Emerson Brook, and Coal Mine Brook did not meet cold water fishery standards with regard to temperature and therefore would not support CWF designations during the summer of 2003 (subject to additional considerations as noted in #3 below). It is interesting to note that Mass Wildlife was successful in capturing reproducing brook trout from both Laurel and Emerson brooks, however, it is unclear what effect if any parr stocking by the Laurel Brook Club is having on these fish populations. These data will be shared with the DFW to assist in making informed decisions regarding CWF/WWF classifications.
2. All four Blackstone River tributaries currently meet Class B warmwater temperature criteria. It should be noted, however, that we appeared to miss the warmest period for the summer of 2003.
3. Additional work should be conducted in Laurel, Scadden and Emerson brooks to try and better assess the presence of reproducing brook trout and thermal refugia within these waterbodies.

Bibliography and References:

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MA DEP. 2002a. *Standard Operating Procedure for Continuous Temperature Monitoring.* CN 103.0. Massachusetts Department of Environmental Protection, Division of Watershed Management. Worcester, MA.

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MassDEP. 2006a. *Massachusetts Surface Water Quality Standards (Revision of 314 CMR 4.00, effective December 29, 2006)*. Massachusetts Department of Environmental Protection, Boston, MA.

MADEP 2006b, *Blackstone River Watershed 2003 Fish Population Monitoring and Assessment* Technical Memorandum, Massachusetts Department of Environmental Protection, Division of Watershed Management. Worcester, MA.

Richards, T. 2006. *MA DFG Fish Population Database (Distribution Copy) 1998-2005*. Massachusetts Department of Fish and Game, Division of Fisheries and Wildlife, Westborough, MA.

USGS. 2000. *Guidelines and Standard Procedures for Continuous Water-Quality Monitors: Site Selection, Field Operation, Calibration, Record Computation and Reporting*, WRIR 00-4252

Appendix A: Temperature Logging Equipment:

Stowaway sensor, plastic tube and cable/anchoring assembly shown.

Optic Stowaway Temp Specifications: (as provided by Onset Computer Corp.)

◊ *Accuracy* (maximum measurement error, including thermistor error, resistor value errors and quantization errors) for –5 to 37 deg. C unit: 0.2 deg. C at ambient temps of 10-30 deg. C

◊ *Resolution* for –5 to 37 deg. C unit: 0.15 deg. C at ambient temps of 10-30 deg. C

◊ *Depth Resistance*: >100 feet

◊ *Battery Life*: 10 years, but depends on how used…

◊ *Time Error*: Up to one hour per year

◊ *Storage*: About 82 days of data storage is available using a sensor reading interval of 15 minutes (8K sensor).

Appendix B: Quality Control Data:

Based on in-situ, side-by-side QC checks at deployment, mid study and upon retrieval, the data generally met project data quality objectives for temperature and time logging, with minor exceptions as presented in Table 4. The QC /thermistor temperature difference at Laurel Brook on the date of retrieval exceeded project DQOs by 0.01 degree C and the QC /thermistor temperature difference at Scadden Brook on the date of deployment exceeded project DQOs by 0.04 degrees C. Note that this is a violation of the data quality objectives, however overall performance and accuracy of equipment was considered excellent. Therefore, none of the data was qualified or censored.

Table 4. Quality Assurance Data for Blackstone River Watershed Stream Temperature Data.

Stream	Type of Check	Date	QC Temp	Thermistor Temp	QC Time	Thermistor Time	Difference between QC temp and thermistor temp (QC-Therm)
Coal Mine Brook	Deploy	8/11/2003	20.10	20.17	11:10	11:19:15	-0.07
	Mid	8/19/2003	18.66	18.7	10:00	10:04:15	-0.04
	Pickup	9/22/2003	16.40	16.46	14:13	14:04:15	-0.06
Emerson Brook	Deploy	8/11/2003	23.12	23.16	10:10	10:23:21	-0.04
	Mid	8/19/2003	21.25	21.16	11:56	11:53:21	0.09
	Pickup	9/22/2003	18.46	18.39	11:40	11:38:21	0.07
Laurel Brook	Deploy	8/11/2003	21.83	21.81	9:45	9:52:22	0.02
	Mid	8/19/2003	19.4	19.34	12:10	12:07:22	0.06
	Pickup	9/22/2003	16.17	15.96	12:08	12:07:22	**0.21**
Scadden Brook	Deploy	8/11/2003	19.84	20.08	9:20	9:33:08	**-0.24**
	Mid	8/19/2003	18.97	19.09	13:30	13:33:08	-0.12
	Pickup	9/22/2003	15.96	16.03	13:12	13:03:08	-0.07