MUSSEY BROOK TEMPERATURE TMDL

Approved by EPA
Region #1
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VERMONT DEPARTMENT OF ENVIRONMENTAL CONSERVATION
WATERSHED MANAGEMENT DIVISION

1 Table of Contents

2 INTRODUCTION

Section 303(c) of the Clean Water Act (CWA) requires states to establish water quality standards (WQS) that identify each waterbody's designated uses and the criteria needed to support those uses. Such WQS must be sufficient to ensure, wherever attainable, a level of water quality that provides for the protection and propagation of fish, shellfish, and wildlife and recreation in and on the water.

Section 303(d) of the CWA requires states to develop lists of impaired waters that fail to meet WQS set by jurisdictions even after implementing technology-based and other pollution controls. The Environmental Protection Agency's (EPA) regulations for implementing CWA section 303(d) are codified in the Water Quality Planning and Management Regulations at 40 CFR Part 130. The law requires that states establish priority rankings and develop Total Maximum Daily Loads (TMDLs) for waters on the lists of impaired waters (40 CFR 130.7).

A TMDL specifies the maximum amount of a pollutant that a waterbody can receive and still meet applicable WQS. A mathematical definition of a TMDL is written as the sum of the individual wasteload allocations (WLAs) for point sources, the load allocation (LAs) for nonpoint sources and natural background, and a margin of safety (MOS)[CWA 303(d)(1)(C)]:

$TMDL = \Sigma WLA + \Sigma LA + MOS$

Where:

WLA = wasteload allocation, or the portion of the TMDL allocated to existing and/or future point sources.

LA = load allocation, or the portion of the TMDL attributed to existing and/or future nonpoint sources and natural background.

MOS = margin of safety, or the portion of the TMDL that accounts for any lack of knowledge concerning the relationship between effluent limitations and water quality, such as uncertainty about the relationship between pollutant loads and receiving water quality, which can be provided implicitly by applying conservative analytical assumptions or explicitly by reserving a portion of loading capacity.

The process of calculating and documenting a TMDL involves a number of tasks and can require substantial effort and resources. Major tasks involved in the TMDL development process include the following:

- characterizing the impaired waterbody and its watershed;
- identifying and inventorying the relevant pollutant source sectors;
- applying the appropriate WQS;
- calculating the loading capacity using appropriate modeling analyses to link pollutant loads to water quality; and
- identifying the required source allocations.

This TMDL addresses the water quality impairment of Mussey Brook in the City of Rutland (the City) caused by elevated summertime temperatures. These intermittent elevated temperatures impact aquatic life use to such a degree that this use isn't fully supporting the requirements of the Vermont water quality standards (VTWQS).

2.1 Legal History

Since 2005, the City of Rutland (the City) and the Vermont Agency of Natural Resources (Agency) have not agreed on the cause of the impairment of Moon Brook (including its tributary Mussey Brook). This disagreement led to continued differences as to how and when stormwater runoff and temperature impacts to the stream should be mitigated.

In December 2012, the Agency issued the final NPDES General Permit 3-9014 for Stormwater Discharges from Small Municipal Separate Storm Sewer Systems (MS4 General Permit). The MS4 General Permit requires municipalities that must comply with the permit to develop, implement, and enforce stormwater management programs (SWMP) designed to reduce the discharge of pollutants from their storm sewer systems to the maximum extent practicable, to protect water quality, and to satisfy the appropriate water quality requirements of the federal Clean Water Act. Concurrently, the Agency designated the City as subject to the requirements of the MS4 General Permit. In January 2013, The City filed appeal of the designation.

The City and the Agency negotiated a temporary resolution of the issues raised in the Appeal and in 2013 they jointly filed a settlement agreement which the court subsequently approved. Among other things, the settlement required the joint retention of an independent third party expert to examine relevant data and evidence to answer specific questions raised by the parties concerning the impairment of Mussey Brooks and what pollutant(s) are the cause of that impairment. The third party selected for the investigation was Kleinschmidt Associates and Midwest Biodiversity Institute that filed their final report (Third-Party Report) summarizing its conclusions in 2015 (Kleinschmidt 2015).

The Third-Party Report found that stormwater and thermal alteration are significant contributing sources to Mussey Brook's impairment as well as habitat degradation. Thus, the Third-Party Report does not identify a single "principal cause of the impairment," whether stormwater or thermal alteration, but rather identifies the foregoing suite of factors as the causes of the impairment.

After expansion of the initial settlement agreement, in part, it was settled that the Agency agreed to develop a thermal TMDL to address the thermal impact to the brook. The Agency agreed to submit the TMDL to EPA for review and approval by no later than August 31, 2017.

3 General Watershed Setting

Moon Brook drains a watershed of approximately 5,545 acres located in the City of Rutland and the Towns of Rutland and Mendon in Rutland County Vermont (Figure 1). As a tributary to Moon Brook, Mussey Brook is located at the southern edge of the Moon Brook watershed and is comprised of 1,856 acres. As similar to the entire Moon Brook watershed, Mussey Brook headwaters drain the undeveloped forested area of East Mountain and the stream flows through an increasingly residential area until it reaches Cold River Road. From there the stream travels through more densely developed residential and commercial areas, passes beneath Route 7 and enters the fairgrounds, a short reach of residential area and then flows into Moon Brook. Figure 2 shows a more detailed view of the confluence of Moon and Mussey Brooks

Figure 1. Moon Brook watershed showing the nested Mussey Brook watershed.

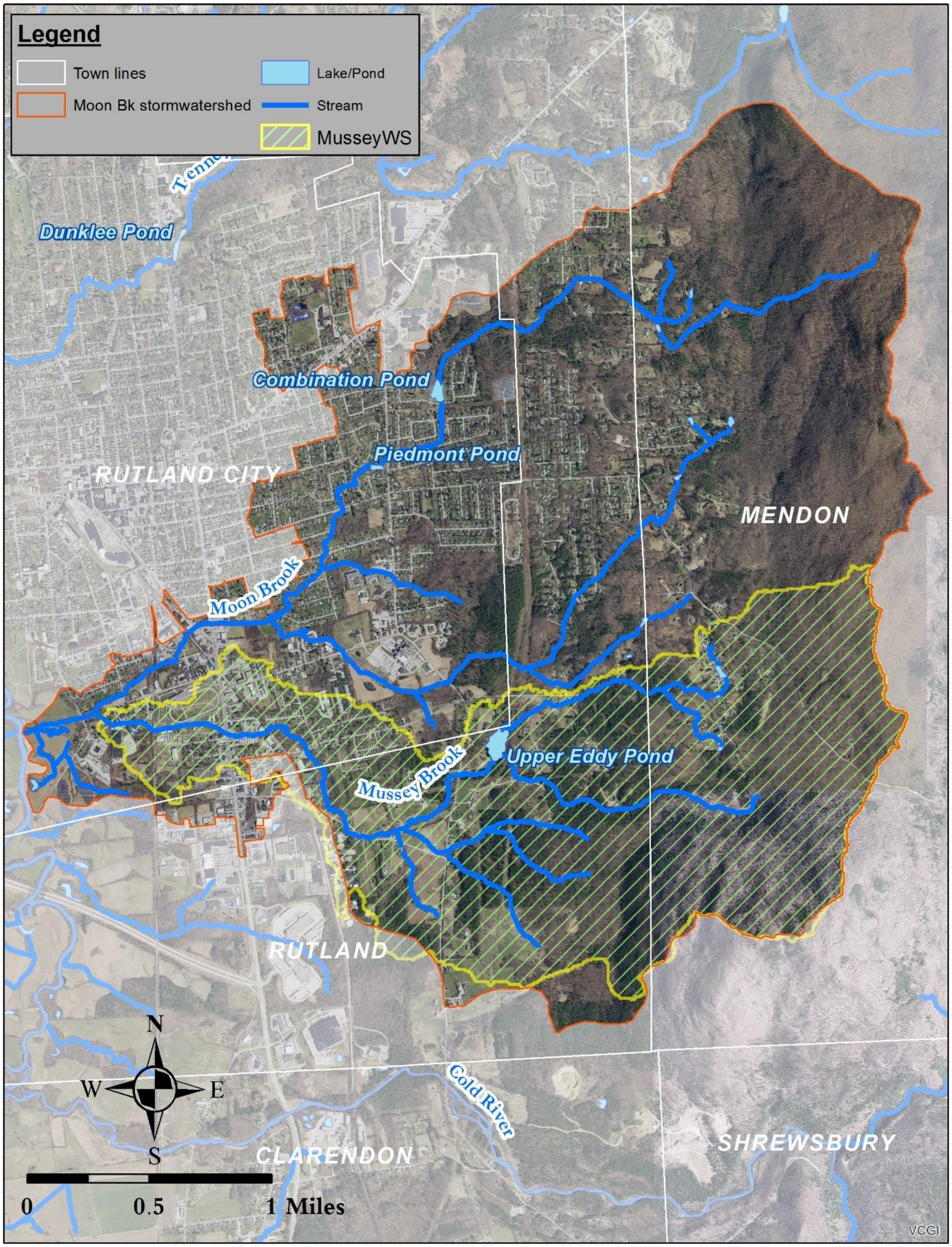
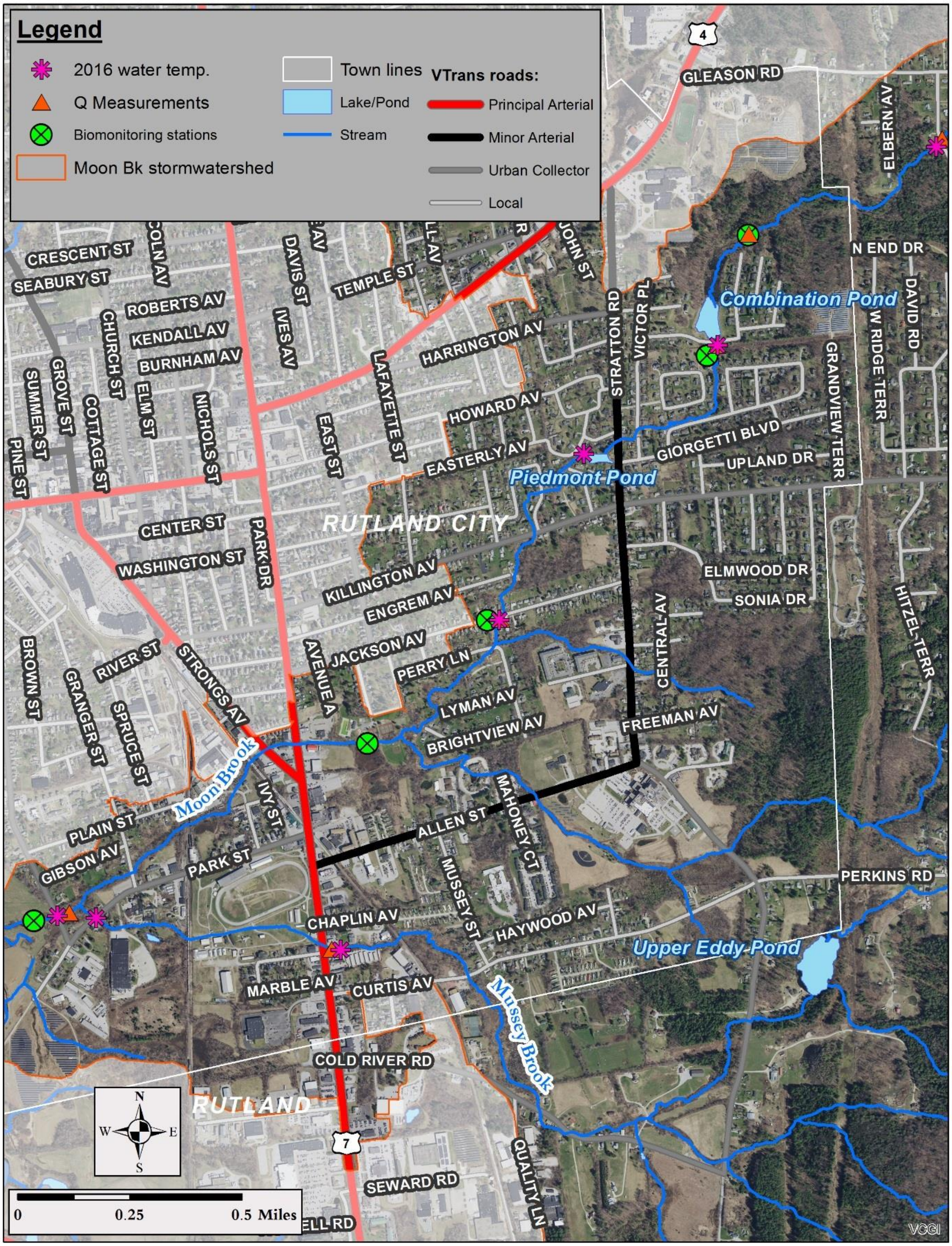


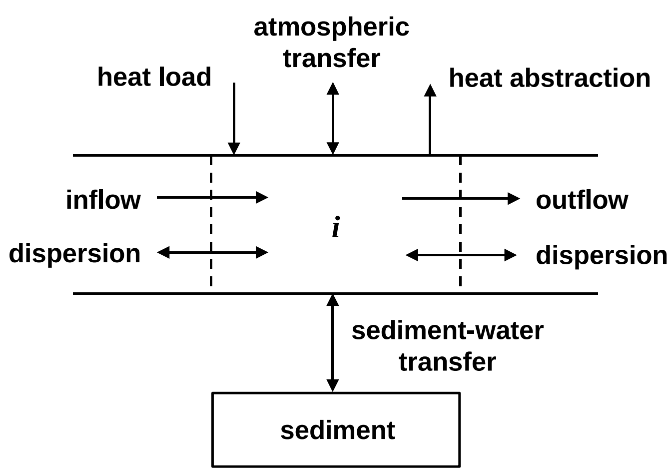
Figure 2. Area of interest in the Mussey Brook watershed.



3.1 Pollutants and Surrogate Measures

This Mussey Brook TMDL identifies heat as the pollutant of concern with the primary source being shortwave solar radiation reaching the stream surface causing excessive heating. Figure 3 shows the various heat energy pathways, or fluxes, that control heat energy transfer either to or from a water body. Many of these pathways are essentially unchangeable but the initial heat loading from the atmosphere can be greatly affected by management actions, i.e. stream shading. Elevated summertime stream temperatures have been documented as the impairment caused primarily from the lack of riparian vegetation along the length of the impaired reach

Figure 3.Heat balance for a body of water (Chapra, 2012).



This TMDL assessment for Mussey Brook uses riparian shade as a surrogate measure of heat flux. The resultant effect of "effective shade" is the fraction of potential solar radiation that is blocked by vegetation and topography before it reaches the water's surface and thus reducing the most significant factor in stream heating. There will be an accounting of heat flux terms in the TMDL but the effective shade metric is more conducive to understanding management actions that need to occur and will also be presented in the allocation.

4 Impairment of Water Quality Standards

4.1 Assessment and Listing Status of Mussey Brook

The Vermont Water Quality Standards (VTWQS) identify the following designated uses applicable to Mussey Brook as well as all other waters in Vermont:

- Aquatic biota and wildlife that may utilize or are present in the waters;
- Aquatic habitat to support aquatic biota, wildlife, or plant life;
- The use of waters for swimming and other primary contact recreation;
- The use of waters for boating and related recreational uses;
- The use of waters for fishing and related recreational uses;

- The use of waters for the enjoyment of aesthetic conditions;
- The use of the water for public water source; and
- The use of water for irrigation of crops and other agricultural uses.

The primary assessment mechanism for determining the overall health of Mussey Brook in relation to the VTWQS is through the assessment of the aquatic biota. Biosurvey techniques (i.e. biomonitoring), are best used for detecting aquatic life impairments and assessing their relative severity. These are primarily detected through monitoring of fish and/or macroinvertebrate communities whereby data from reference sites to define biological community goals for a given stream type. Once an impairment is detected, however, additional ecological data, such as chemical and physical testing is helpful to identify the causative agent, its source, and to implement appropriate mitigation. This biomonitoring approach is provided for in the VTWQS and specific numeric biological criteria have been established for several stream types to indicate compliance with the standards.

The monitoring framework is extremely useful in that it directly measures the health of the aquatic life community and is reflective of environmental conditions that occur in the stream over an extended period (i.e. months) including the effects of intermittent discharges such as stormwater or elevated water temperatures. The ultimate determination of an impaired water's compliance with the VTWQS in the case of aquatic use is consistent attainment of the relevant biocriteria.

4.1.1 Stormwater impaired segment

While Mussey Brook has been considered a contributing factor to the impairment of Moon Brook for aquatic life use since 1992, the lower reaches of Mussey Brook itself have been identified as impaired since 2014 due to multiple stressors related to stormwater runoff. In streams draining developed watersheds with substantial impervious surfaces, biological communities are subjected to many stressors associated with stormwater runoff. These stressors are related either directly or indirectly to stormwater runoff volumes and include increased watershed pollutant load (e.g. sediment), increased pollutant load from in-stream sources (e.g., bank erosion), habitat degradation (e.g. siltation, scour, over-widening of stream channel), washout of biota, and loss of habitat due to reductions in stream base flow. The stressors associated with stormwater runoff may act individually or cumulatively to degrade the overall biological community in a stream to a point, as in Mussey Brook, where aquatic life uses are not fully supported and the stream does not attain the VTWQS.

A stormwater TMDL was developed for Moon Brook, which also encompasses Mussey Brook as a tributary, from its mouth to RM 2.9 and was approved by USEPA Region 1 in 2009 (VTDEC 2008). This TMDL utilizes the surrogate of stormwater runoff volume in place of the traditional "pollutant of concern" approach. The combination of stressors is represented by the surrogate of stormwater runoff volume. First, the use of this surrogate has the primary benefit of addressing the physical impacts to the stream channel caused by stormwater runoff such as sediment release from channel erosion and scour from increased flows. These physical alterations to the stream are substantial contributors to the aquatic life impairment. Also, reductions in stormwater runoff volume will help restore diminished base flow (increased groundwater recharge), another aquatic life stressor. This surrogate is also appropriate because the amount of sediment and other pollutants discharged from out of channel sources is a function of the amount of stormwater runoff generated from a watershed.

4.1.2 Temperature impaired segment

Several years of in-stream temperature monitoring was conducted by the City of Rutland to better understand where the temperature impacts to Moon and Mussey Brooks were the greatest. That data is presented in Table 1 for two sites that bracket the impaired segment. The temperature impaired segment was limited to this lowest reach since no temperature data was available upstream.

Table 1. Percentage of time of occurrence of June -August stream temperatures based on 2007-2014 data. (Third-Party Report, Table 4-2)

	<54.9 F	55-55.9F	60-64.9F	65-69.9F	70-74.9F	75-79.9F	>80F	Temperature meets or exceeds 70 F
Mussey Bk. at Main St.	0	8	38	46	8	0	0	8%
Mussey Bk. at Park St.	1	7	40	32	16	3	1	20%

A literature review identified 70°F as a critical threshold for the most sensitive species native to Mussey Brook, brook trout. Optimal temperatures for Brook Trout are in the 64-68 °F range; stress thresholds are above 68°F; avoidance is exhibited at approximately 70°F and 75°F is an upper lethal limit threshold.

Fish monitoring data collected in 2014 indicated that the distribution of brook trout in Mussey Brook is negatively correlated with summer temperatures that exceed 70°F (Table 2). No brook trout occurred where temperatures exceeded 70°F for more than 10 % of the time and even very low numbers where exceedances were measured at 8% at the Main street site. Unfortunately, there are no upstream data available to determine the extent of the low brook trout numbers.

Table 2. Density and abundance of brook trout in VTDEC samples collected at Moon Brook, including Mussey Brook, temperature monitoring locations during 2014. (Third-Party Report, Table 4-9)

MOON BROOK	PERCENTAGE OF TIME EXCEEDING 70°F.[7]	DENSITY AND % OF BROOK TROUT[8]
above Combination Pond	*0*	*15.8 / 96.3*
Combination Pond outfall	**14**	0 / 0
Whites Playground	**10**	0.8 / 0.7
Forest Street	**17**	0 / 0
Tributaries		
Mussey Brook at Main St	*8*	*0.9 / 1.7*
Mussey Brook at Park St	**20**	0 / 0
Paint Mine Brook	*1*	*14/19.5*

A review of VTDEC biomonitoring data also indicate a change in the health of the biotic community moving downstream from above Main St. to the confluence with Moon Brook. Figure 4 gives overall fish community scores for two sampling sites located in the lower reaches of Mussey Brook prior to its confluence with Moon Brook. Although the latest two assessments were rated as "good" for the lower site, the assessment details show that no brook trout were present indicating that elevated temperatures are still likely having a negative impact. The number and diversity of other more tolerant species allowed the site to reach the minimum assessment requirements for "good". The macroinvetebrate monitoring data show significant impairment at this site (Figure 5).

Figure 4. Vermont DEC fish community assessment results for: a) site above main Street, and b) the mouth of Mussey Brook. Assessments of "poor" or "fair" indicate non-compliance of aquatic life use in the VTWQS.

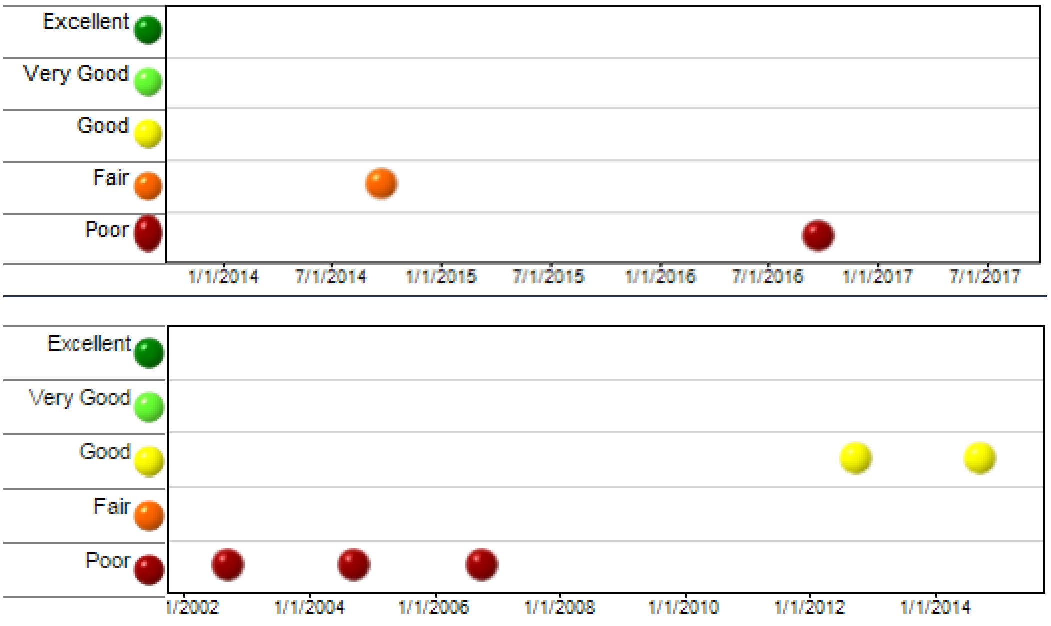
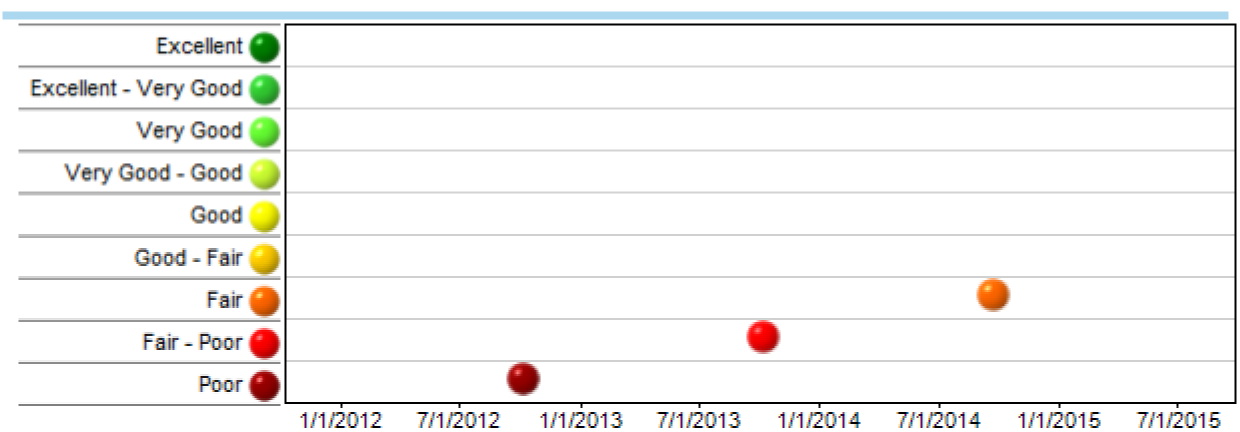


Figure 5. Vermont DEC macroinvertebrate community assessment results for the mouth of Mussey Brook. Assessments of "poor" or "fair" indicate non-compliance of aquatic life use in the VTWQS.



Based on the available data in Mussey Brook, the segment from the confluence with Moon Brook to Route 7 was identified as impaired due to elevated water temperatures on Vermont's 2016 303(d) List of Impaired Waters as a high priority for TMDL development. Figure 6 shows the temperature impaired reach of Mussey Brook.

Figure 6. Temperature impaired reach of Mussey Brook.

4.2 TEMPERATURE TARGET

There are no explicit numeric temperature targets as for aquatic life use in the VTWQS, although there are general temperature criteria at §29A-302:

> (1) Temperature.
>
> > (A) General. The change or rate of change in temperature, either upward or downward, shall be controlled to ensure full support of aquatic biota, wildlife, and aquatic habitat uses. For the purpose of applying this criterion, ambient temperature shall mean the water temperature measured at a control point determined by the Secretary to be outside the influence of a discharge or activity.

Without an applicable numeric target for water temperature, a site-specific target has been derived from existing data as put forth in the Third-Party Report. Literature values and fish collection data suggests that brook trout is the most sensitive indicator species with regards to elevated temperatures. Site specific data from Mussey Brook shows that brook trout populations avoid waters where temperatures exceed 70°F for all but very minimal times. Therefore, the temperature target proposed for this TMDL is for stream temperatures to not exceed 70°F for more than 10% of the time from June through September when critical conditions of low flow, solar radiation and elevated air temperature are generally most pronounced. While ultimate compliance with the VTWQS is a healthy aquatic biota community as measured by the Department's biomonitoring protocols, compliance with this TMDL is consistent attainment of the above stated temperature target.

5 TECHNICAL ANALYSIS

5.1 GENERAL APPROACH

The overall analysis approach for the development of this TMDL includes the development of a stream temperature model that can then be used to predict temperatures as certain input parameters are manipulated. Observed conditions such as water temperature, flow, stream geometry, climate and shade need to be measured for a temperature model to be developed and calibrated. Once calibrated, management measures can be simulated to determine if instream temperature targets (i.e. WQS) are expected to be met. Modeling of stream temperature is a well-developed area of inquiry and many models are available to help understand the factors impacting water temperatures. The discussion below describes the data collected for model inputs, model selection and the results of model calibration.

5.2 CURRENT CONDITIONS

5.2.1 Water temperature data

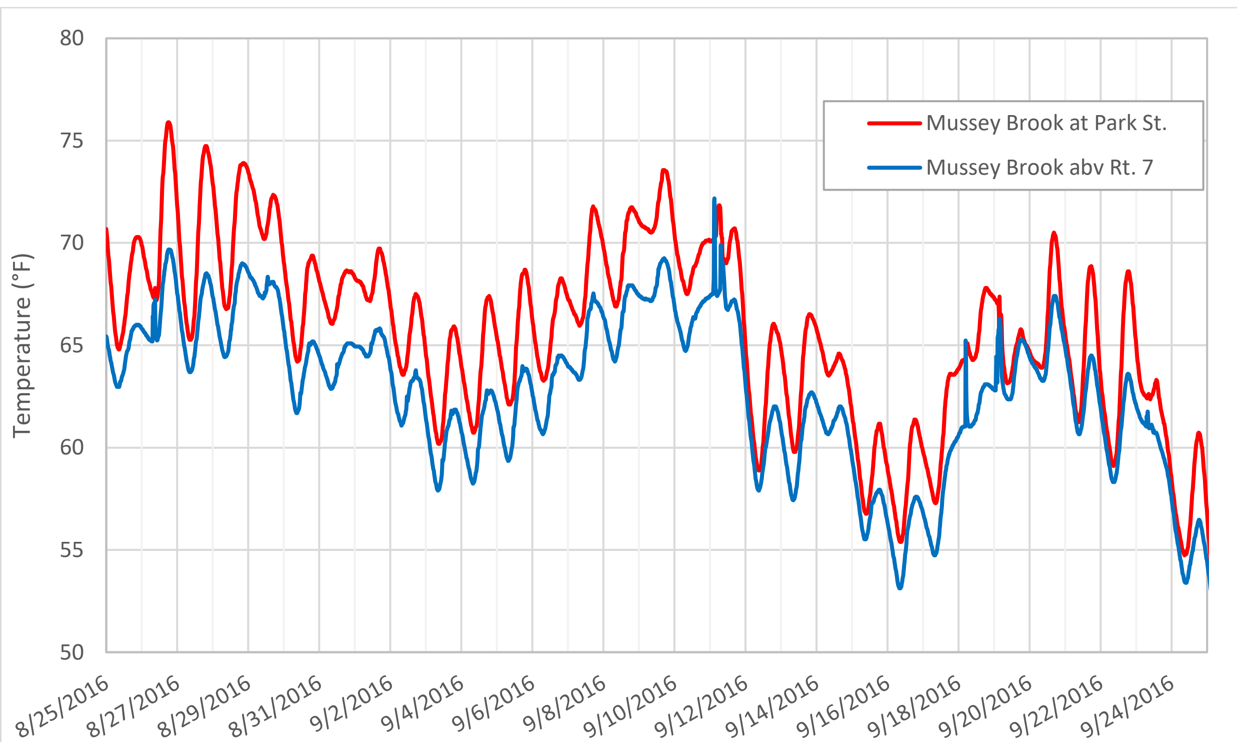
Historic water temperature data for Mussey Brook exists for periods of the years 2006 -2015. However, additional spatially explicit water temperature data with coincident local flow measurements were required to develop a temperature model for the thermally impaired reach of Mussey Brook. Continuous water temperature loggers were deployed from 8/25/2016 through 9/25/2016. This period was selected to target annual low flows and higher air temperatures. Two in-stream stations were established (Table 3, Figure 6) and water temperature was logged at 15-minute intervals within protective perforated PVC housings, affixed to either a cinder block or rebar driven 1-foot or more into the stream bed. All loggers used have a stated accuracy of ±0.38°F and a resolution of 0.04°F.

Table 3. Temperature logger locations in Mussey Brook.

Location	Drainage area (sq. mi.)	Latitude (DD)	Longitude (DD)
Mussey Brook above Rt. 7	2.74	43.5932	-72.9686
Mussey Brook at Park St.	2.91	43.5942	-72.9796

The late summer monitoring period of 2016 did include critical low-flow conditions, with observed streamflows as low as 0.06 cfs at the upstream station, and temperatures as high as 75.9°F at Park Street (Figure 7). The warmest temperatures occurred from 8/25/2016 through 9/11/2016, after which overall temperatures began to decline, however maximum daily temperature still exceeded 70°F on 9/20/2016 at Park Street.

Figure 7. Stream temperature data for two locations in Mussey Brook.



5.2.2 Stream flow data

No known streamflow data are publicly available for Mussey Brook. New discharge measurements were collected near the upstream temperature monitoring station (6) for two separate days during baseflow conditions, coincident with the August – September 2016 temperature monitoring. Measurements were collected at low-baseflows during midday hours, and these individual discharge measurements were assumed to be representative of daily mean streamflow for the day they were collected. It is worth noting that for these discharge measurements, scaling streamflow down from the mouth of Moon Brook based on drainage area alone was not shown to be reliable predictor of streamflow throughout the study area. Results are summarized in Table 4 below.

Table 4. Stream discharge data collected for Mussey Brook.

Date	Location	Discharge (cfs)	Discharge (csm)	Method
8/31/2016	Mussey Brook above Rt. 7	0.11	0.04	velocity/area
9/9/2016	Mussey Brook above Rt. 7	0.06	0.02	velocity/area

An acoustic Doppler velocimeter was used with the velocity-area method (Turnipseed and Sauer, 2010) to measure streamflow. The discharge cross-section was selected to optimize the following characteristics:

- Proximity to temperature measurement stations
- A relatively straight stream channel with defined edges and a fairly uniform shape
- Limited vegetative growth, large cobbles, and boulders
- Limited eddies, slack water, or turbulence

5.2.3 Hydraulic geometry

The hydraulic geometry of the stream channel is required to get velocity and depth inputs for the temperature model. A cross-sectional survey was completed just above Park Street on 9/26/2016, which were used to get side slopes, bottom width, and to solve Manning's Equation for Manning's n roughness coefficient using discharge data (Eq. 1). Channel slope was calculated in a GIS using LiDAR data collected within the past 4 years.

$$Q = VA = \left(\frac{1.49}{n}\right) AR^{\left(\frac{2}{3}\right)}\sqrt{S} \qquad \text{[Eq.1]}$$

Where,
Q = discharge (ft.^{3}/sec)
V = velocity (ft./sec)
A = ft.^{2}
n = Manning's roughness coefficient (dimensionless)
R = hydraulic radius (ft.) = $\frac{A}{WP}$
    Where WP = wetted perimeter (ft.)
S = channel slope (ft./ft.)

5.2.4 Weather data

August and September 2016 Integrated surface global hourly data from the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environment Information (NCEI) were downloaded for the Rutland State Airport (KRUT) National Weather Service (NWS) station. These data provided air temperature, dew point temperature, and wind speed values, as well as categorical estimates of cloud cover for model inputs. Sub-hourly readings were averaged on an hourly basis, and all measurements were converted to metric system units.

In order to assess critical conditions, some additional climatic data were obtained and processed. Current and historical NCEI data were downloaded from U.S. Air Force Weather-Bureau-Army-Navy (USAF WBAN) stations 725165 94737 and 725165 99999, which correspond to historic and current observations at KRUT. The available period of record (POR) for these data is 1-1-1973 to present. Precipitation data were downloaded from NOAA's Applied Climate Information System (ACIS); the quality assured POR for these data is 1-1-1982 to present.

5.2.5 Riparian vegetation and effective shade

A multi-step process was used to estimate riparian shading and solar flux inputs (Figure 8).

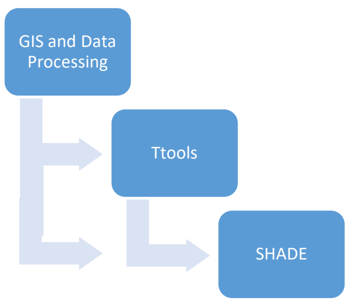


Figure 8. Schematic of riparian and solar flux modeling.

GIS data processing involved the creation of multiple geospatial data layers. Riparian vegetation along the modeled reach was characterized using Light Detection and Ranging (LiDAR) point cloud data obtained from the Vermont Center for Geographic Information (VCGI). Two riparian vegetation characteristics were modeled: canopy height and density. These data were derived using a raster, or grid cell data format in GIS. In order to estimate canopy height, maximum LiDAR return z-values were used to create a digital surface model (DSM) corresponding to the highest observed elevations within a 300m buffer around the modeled reach. Next, LiDAR points classified as ground returns were used to create a bare earth digital elevation model, or DEM. The difference between these two elevation grids (maximum DSM height – bare earth DEM elevation) was calculated and used as an estimate of canopy and built infrastructure height. Canopy density was derived by calculating the ratio of above ground to ground LiDAR point returns within each grid cell.

A number of hydrographic and geomorphic data layers were also created. Stream hydrography data, including centerline and streambank extent, were digitized using 2016 VCGI color imagery and field cross-sectional data. Stream channel incision estimates were calculated in GIS using LiDAR-based transect profile graphs as well as field observations and VT stream geomorphic assessment data (Bear Creek, 2006).

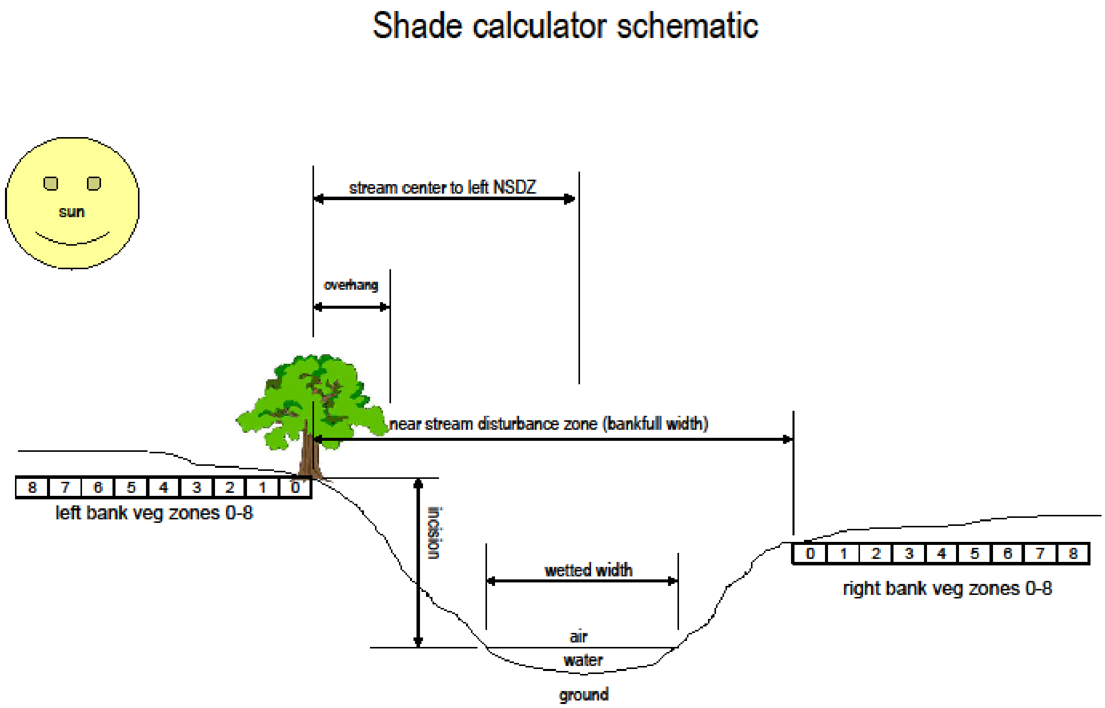
These geospatial data layers were used as inputs to Ttools, a Python language add-in for ArcMap that samples GIS data at user defined points along a modeled stream reach. Multiple GIS data layers are sampled at each point (Table 5). In addition, riparian elevation and vegetation are sampled at nine riparian zones that extend orthogonally to the stream channel. Because Ttools requires discrete land use classes for sampling, the canopy height and density layers described above were classified into 30 classes using a hierarchical clustering routine implemented in the statistical computing software package R. Mean canopy height and density were then calculated for each land cover class.

Table 5. GIS variables sampled by Ttools.

VARIABLE	DEFINITION	DATA SOURCE
COORDINATES	Latitude and longitude of reach point	Reach point shapefile
LENGTH	Length of reach	Stream hydrography
ASPECT	Aspect of reach length	Stream hydrography
CHANNEL WIDTH	Width of channel	Polygon of stream channel
RIGHT DISTANCE	Distance from stream centerline to right channel bank	Stream hydrography and channel polygon
LEFT DISTANCE	Distance from stream centerline to left channel bank	Stream hydrography and channel polygon
ELEVATION	Elevation of reach point	LiDAR-derived DEM
GRADIENT	Slope of reach	LiDAR-derived DEM
TOPOGRAPHIC SHADE	Angle of topographic shading; calculated for E, W, and S	LiDAR-derived DEM
RIPARIAN ZONE ELEVATION	Elevation at mid-point of each of nine riparian zones	LiDAR-derived DEM; riparian zone set at 5m
RIPARIAN ZONE VEGETATION CLASS	Vegetation class ID at mid-point of each of nine riparian zones	Classified LiDAR derived canopy height and density; riparian zone set at 5m

The output from Ttools, along with estimates of channel incision, form the inputs to the SHADE program (Chen et al., 1998). SHADE is a spreadsheet tool that estimates riparian shading and solar flux for each stream reach. The program accounts for multiple variables that influence surface heating, including: topographic shading, elevation, riparian zone shading, cloud cover, reach aspect, channel width, wetted width, vegetation overhang, and channel incision (Figure 9). In addition, the date, latitude, longitude, and time zone of each reach are used to calculate the angle and path of the sun for each 24 hour period. The output from SHADE includes an hourly percent estimate of shading per stream reach per day and an estimate of hourly solar flux (W/m^2) per day. These two results – percent shade and solar flux – are key inputs for the stream water quality model QUAL2KW.

Figure 9. SHADE program schematic.



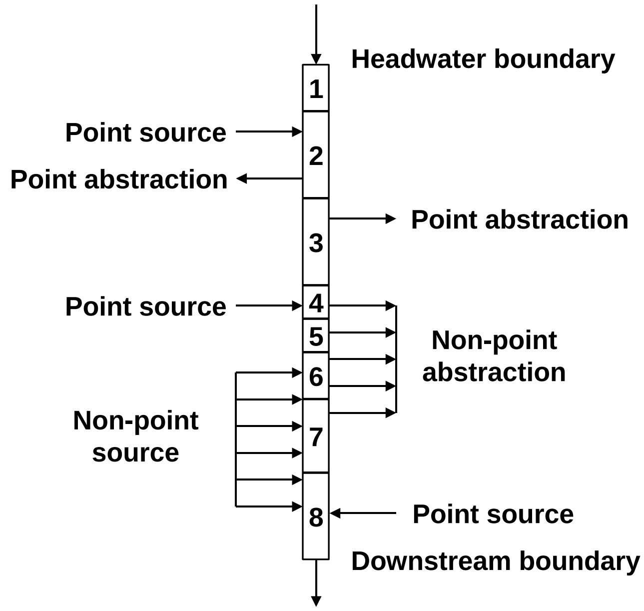
5.3 Analytical Framework

After consultation with EPA and a review of applicable literature, VTDEC chose QUAL2KW, a stream water quality model, to characterize water temperature in the impaired segment of Mussey Brook. QUAL2KW is listed as an approved surface water model with EPA's Center for Exposure Assessment Modeling (CEAM). The most recent version – version 6 – was developed by Chapra, Pelletier, and Tao (Chapra et al. 2012), and is available for download from Washington State's Department of Ecology (http://www.ecy.wa.gov/programs/eap/models.html).

QUAL2KW simulates dynamic diel heat budget and water quality kinetics in streams and rivers. The modeled stream is divided into a series of discrete reaches, with defined headwater and downstream boundaries (Figure 10). Hydraulics within a reach can include point and non-point inflows (sources) and outflows (abstractions). The stream model is one dimensional, assuming a vertically and horizontally mixed channel, and can simulate non-steady, non-uniform flow.

The QUAL2KW temperature model takes into account heat transfers from adjacent reaches, loads, abstractions, the atmosphere, and the sediments. Heat budget and water temperature are simulated as a function of channel morphology, hydrology, land cover, and meteorology on a continuous or repeating diel basis. Flow and meteorological data are entered on an hourly basis for the model period, and temperature simulations occur at a user-specified timestep. This timestep, and the overall model period, are chosen so that the various QUAL2KW component models – flow, temperature, etc. – arrive at stable estimates.

Figure 10. Schematic of QUAL2KW modeled stream.



5.4 Calibration of QUAL2K model

The initial Mussey Brook QUAL2KW model was populated with data obtained from Ttools, SHADE (Section 5.2.5), field hydraulic measurements (Section 5.2.3), flow data (Section 5.2.2), and temperature (Section 5.2.1) observations. Initial conditions were based on flow observations, water temperature, and climate data measured on 8/31/2016. The model was run for a 10-day period from this starting date, with hourly water temperature, climate data, and SHADE riparian shade and flux estimates as inputs.

Temperature data from the two Mussey Brook monitoring stations – Route 7 and Park St. – were summarized over the model period and compared to initial model estimates. Calibration efforts to improve the fit of the Mussey Brook QUAL2KW focused on three hydraulic variables: depth, velocity, and flow. Data from cross-sectional surveys, flow measurements, and channel incision estimates were used as reference points. The primary mechanism of adjustment was Manning's equation, used in this application of the model to characterize channel variables, although shade, solar flux estimates, and Ttools sampling point locations were also reevaluated for select reaches. The fitted values of the calibrated Mussey Brook QUAL2KW model are compared to observed values in Figure 13. The mean absolute error between observed and fitted values was also calculated (Table 6). The model period maximum temperature estimate has a 1.09 degree C (1.96 degree F) error.

Table 6. Mean absolute model error by temperature statistic.

Metric	Mean Absolute Error (Degrees Celsius)
All temperatures data	1.37
Model period minimum	1.8
Model period mean	1.21
Model period max	1.09

5.5 Critical Conditions

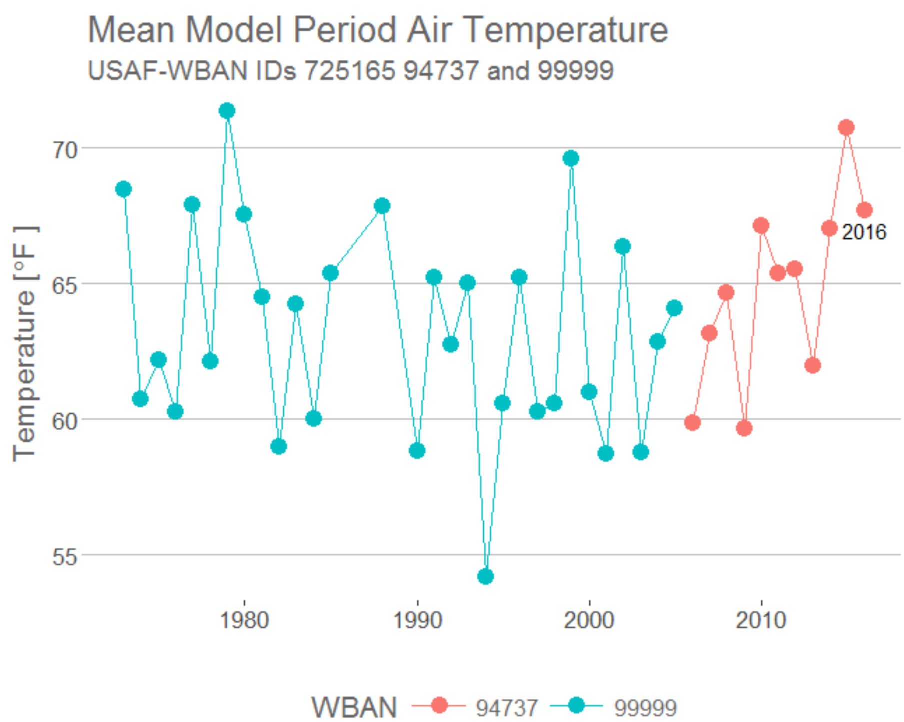
Two factors were evaluated when assessing critical conditions: stream flow and air temperature.

Hydrologic inputs for QUAL2KW were measured in August 2016 and September 2016, a period when stream flows in Vermont are generally expected to represent low/baseflow conditions. These field observations coincided with a period of below average precipitation in the state. The 7-month window from April to September 2016 is ranked by NOAA's NCEI in the bottom 1/3 of all observations for statewide precipitation, specifically the 17th driest such period in the climatological record (https://www.ncdc.noaa.gov/temp-and-precip/climatological-rankings); the previous 12-month period also falls into the bottom third of observations, at the 34th driest 12-month period.

Flow conditions on Mussey Brook were measured above the Route 7 culvert on 8/31/2016 and 9/9/2016. At the time of flow monitoring, no precipitation had been recorded locally for >72 hours. The observed flow values on these dates were 0.11 and 0.06 cfs, respectively. Although no long term hydrologic records are available for Mussey Brook, an analysis of flow conditions on Mussey Brook during the same time period indicated that observed flows were < 1% occurrence probability based on synthetic and empirical flow duration curves. Given that Mussey Brook does not receive any known point discharges per VT Wastewater Management Program's NPDES permits page (VTDEC Wastewater Program), a reasonable assumption is that the flow values observed on Mussey Brook during this period also represent low baseflow conditions. The observed flow values were therefore deemed to adequately represent critical conditions for flow.

Air temperature was also considered in the critical condition framework. Climate data from the Rutland State Airport weather station was obtained for the station's full period of record (1973-present). The 10-day model period used in QUAL2KW (8/31 - 9/09) was extracted for each year. The mean air temperature for each year was then calculated and ranked (Figure 11). Based on these data, observed air temperatures in 2016 fall in the 85th percentile of the climate record. The highest mean air temperature occurred in 1979; however, this year does not contain consistent hourly measurements, as required by QUAL2KW. The second highest ranked year in the record is 2015; this year does contain consistent hourly measurements. For critical conditions, air temperature and dew point temperature from 2015 were used in QUAL2KW in conjunction with the observed flow values. Based on available data, these inputs represent critical warm weather and low flow conditions in the system.

Figure 11. Mean air temperature for model period by year. Data obtained from Rutland State Airport weather station.



6 LOADING CAPACITY

This temperature TMDL is somewhat unusual in that by using effective shade as the surrogate measure for heat loading, there is no fixed "loading capacity" as might be calculated with a more traditional concentration/load TMDL. Since with effective shade, there could be nearly an infinite number of scenarios that equal the temperature target (and resultant heat flux) because much of the effective shade is location dependent. Various effective shade scenarios would result in various total heat flux loading depending on the heating/cooling regions in the stream that could occur with changing shade levels.

For this TMDL, the calibrated QUAL2K model was used to determine the loading capacity for effective shade in Mussey Brook. Loading capacity was determined based on prediction of water temperature under extreme flow and temperature conditions as described above in Section 5.5. This "critical condition" was combined with a reasonable future effective shade scenario. The TMDL treatment scenario specifies a 5m buffer of alder, willow, or similar vegetation along an unshaded portion of the impaired Mussey Brook segment; this segment extends from the Route 7 culvert to the railroad right of way. This portion of the impaired segment was targeted as the stream channel is partly to mostly shaded below the railroad culvert. The modeled riparian vegetation was assumed to have an average height at maturity of 2 meters and a canopy, or ground cover, density of 85%. In addition, a channel overhang from vegetation was assumed at 0.3 meters.

This loading capacity scenario is represented in Figure 12 and Table 7. Figure 12 shows the buffer and shading changes that were applied according the loading capacity scenario. The details of the applied shading and buffer areas are given in Table 7. The "height" column represents the estimated height of mature buffer vegetation; "canopy density" is the fraction of ground covered by vegetation as viewed from above; "overhang" is the distance vegetation extends over the stream channel; and "average buffer distance" is the distance from the channel where the buffer can grow.

Figure 12. Representation of loading capacity scenario. The light green area represents the modeled riparian channel shading buffer.

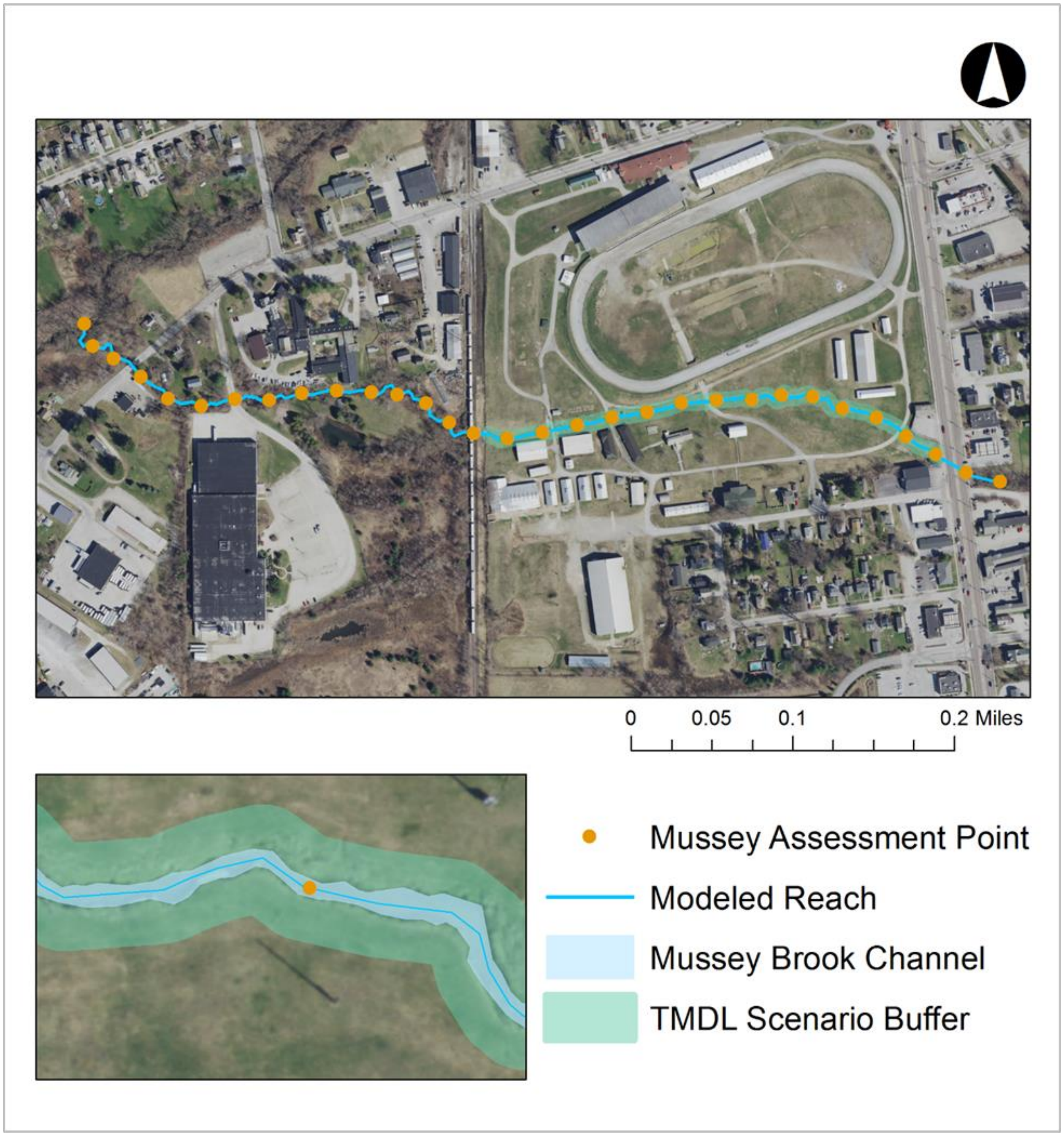


Table 7. Details of simulated shade and buffer conditions set forth in the loading capacity scenario as seen in Figure 12.

Location	Height (m)	Canopy Density (%)	Overhang (m)	Average Buffer Distance (m)
Route 7 culvert to railroad right of way	2	85	0.3	5

As described in the model setup section above, Figure 13 depicts the average observed 2016 temperature conditions and the modeled fit of current stream temperatures moving from upstream to downstream over the modeled reach. The model estimate predicts increasing temperatures below the Route 7 culvert, with gradually decreasing temperatures in the forested reach below the railroad right of way. Observed water temperatures above the Route 7 culvert did not exceed the temperature standard during the model period, while temperatures at Park St. exceeded the standard approximately 18% of the time. Tables 8 and 9 provide summary information on the percent of time the WQS was exceeded based on observed temperature logger data.

Figure 13. Observed and predicted stream temperatures in Mussey Brook. The 0.0 km distance represents the uppermost stream temperature monitoring station (Section 5.2.1). Distances are measured from that point downstream.

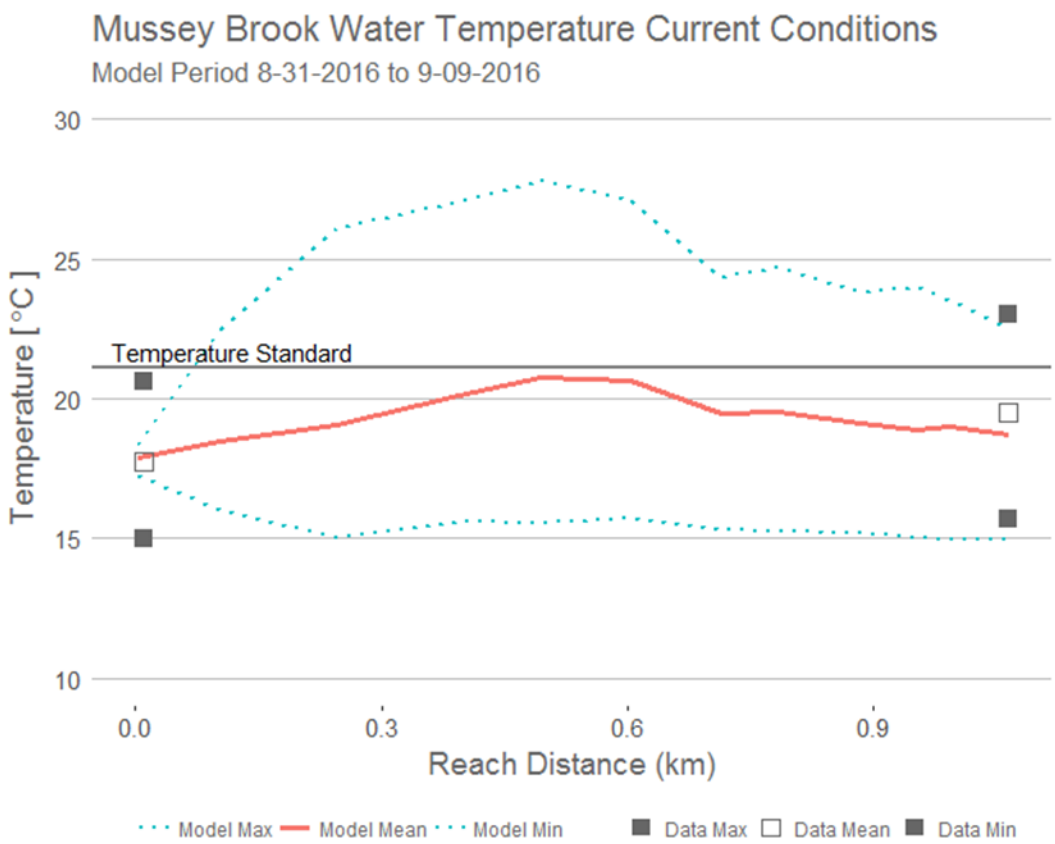


Table 8. Percent of time above target temperature during model period by station. Data are from temperature logger monitoring stations.

Monitoring Station	Percent of time above 70 F
Route 7	0%
Park Street	18.2%

Table 9. Percent of all 15 minute Park Street logger intervals above temperature target during model period.

Date	Percent of time above 70 F
8/31/2016	0%
9/1/2016	0%
9/2/2016	0%
9/3/2016	0%
9/4/2016	0%

Date	Percent of time above 70 F
9/5/2016	0%
9/6/2016	0%
9/7/2016	38.5%
9/8/2016	40.6%
9/9/2016	100%
9/10/2016	20.8%

After application of the treatment scenario, Figure 14 gives the resulting average predicted temperatures in Mussey Brook under the critical conditions described in Section 5.5. Figure 15 shows that increases in effective shade have the potential to produce water temperatures that would meet the water quality target. The highest predicted point temperature for all simulated model time-steps under the treatment scenario is 19.53 C. Adding the mean absolute model error of 1.37 C (Table 6) to this value equals 20.9 (69.62 F), or 0.21 C below the temperature standard of 21.11 C (70 F). It should be noted that even though modeled temperatures in the impaired reach approach 70 F, there would remain areas in and adjacent to Moon Brook where temperatures would remain somewhat cooler, such as shaded pools, groundwater seeps and cooler tributaries (e.g. Paint Mine Brook). These areas would provide additional temperature refugia during brief periods of elevated temperatures.

Figure 14. Predicted temperatures after applying the loading capacity scenario under critical conditions. The 0.0 km distance represents the uppermost stream temperature monitoring station (Section 5.2.1). Distances are measured from that point downstream.

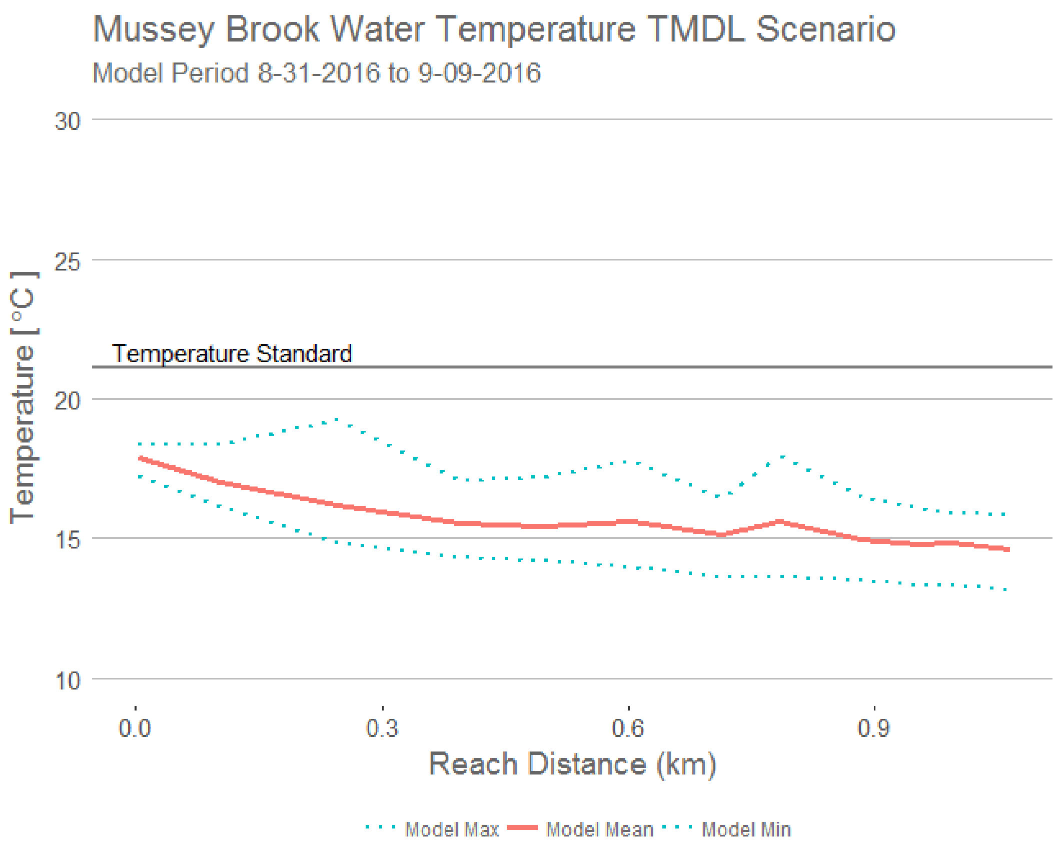
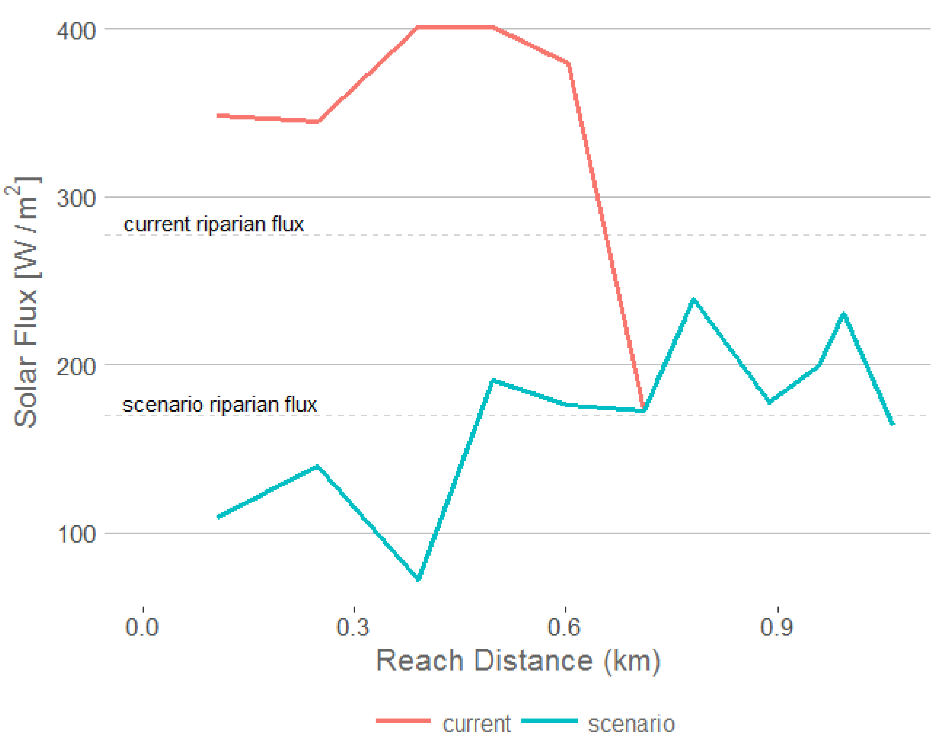


Figure 15 Comparison of average percent shade by reach for current conditions and TMDL scenario. Dotted lines represent average percent shade over the modeled reach.

6.1 ESTIMATED SOLAR FLUX

The loading capacity in terms of the flux of shortwave solar radiation to the surface of the water was estimated as the flux that would occur at the effective shading evaluated in the loading capacity scenario (Figure 16). The loading capacity was translated into the solar flux that would occur with the treatment scenario described above in Figure 12 and Table 7. The overall estimated average solar flux is predicted to decrease from 277 W/m^2 under current conditions to 170 W/m^2 in the TMDL loading scenario.

Figure 16. Comparison of average solar flux by reach for current conditions and TMDL scenario. Dotted lines represent average solar flux in modeled reach.



7 ESTABLISHING ALLOCATIONS

7.1 GENERAL APPROACH FOR ESTABLISHING ALLOCATIONS

The primary pollutant vectors for heat flux to and from the water are through energy transfer between the channel bed and the atmosphere and therefore why the TMDL establishes effective shade as its surrogate. In this TMDL instance, there are no data that supports point source discharges are contributing to the impairment. When considering that the critical conditions for the temperature impairment are during low flow conditions, periods of stormwater discharge would likely occur during precipitation events when critical low flow conditions do not exist. Any temperature transfer to the stream through stormwater discharges would likely be overwhelmed and mitigated by cooler, non-stormwater discharge flow increases. Without point sources contributing to the impairment, there is no wastelaod allocation and the entire TMDL will be allocated amongst the load allocation and the margin of safety.

As presented, the load allocation conforms to the daily time-step normally identified in TMDLs, both in terms of the effective shade surrogate and the heat flux. The effective shade as modeled in the loading capacity scenario represents that level of shade that is continuously present (i.e. every day) throughout the summer months (June through September). Regarding the heat flux associated with the loading capacity scenario, it's given as $W/m^2/day$, and thus a daily allocation.

7.2 LOAD ALLOCATION

The load allocation for effective shade for Mussey Brook is presented in Table 10. The solar flux estimated under critical conditions for both current conditions and the loading capacity scenario are given in Figure 16. Table 10 shows on a segment by segment basis how the current conditions for effective shade and solar flux are compared to those of the loading capacity scenario. The load allocation is given as each segment's effective shade (assuming mature vegetation) and as its resultant solar flux.

Table 10. Effective shade and solar flux for Mussey Brook.

					Load Allocation	
Distance from end of impaired reach to upstream segment boundary (km)	Distance from end of impaired reach to downstream segment boundary (km)	Reach length (km)	Mean effective daylight shading under current condition land cover on 8/31/2016	Mean estimated daylight solar flux under current conditions on 8/31/2016 (W/m^2)	Mean effective daylight shading under TMDL scenario land cover on 8/31/2016	Mean estimated daylight solar flux under TMDL scenario on 8/31/2016 (W/m^2)
1.06433	0.95789	0.10644	39%	348	83%	109
0.95789	0.81597	0.14192	43%	345	80%	140
0.81597	0.67405	0.14192	21%	401	84%	72
0.67405	0.56761	0.10644	16%	401	58%	191
0.56761	0.46117	0.10644	36%	379	73%	176
0.46117	0.35473	0.10644	73%	172	73%	172
0.35473	0.28377	0.07096	54%	239	54%	239
0.28377	0.17733	0.10644	65%	178	65%	178
0.17733	0.10637	0.07096	74%	199	74%	199
0.10637	0.07089	0.03548	66%	230	66%	230
0.07089	0	0.07089	77%	164	77%	164

As described in Section 6, there is no absolute effective shade scenario (or resultant heat flux scenario) for this type of TMDL. The segment by segment allocation of effective shade could, in theory, be "moved around" such that the water targets could still be met. This different scenario would undoubtedly result in an overall differing heat flux value too. The loading capacity scenario developed for this TMDL was done so with an understanding that it may be one of the most practical options and therefore most likely to occur. However, this exact scenario does not have to be adhered to precisely for water quality targets to be met. Although it does provide guidance for the "level of effort" required for stream temperatures to be adequately reduced.

7.3 Future Growth

Since the temperature impairment of Mussey Brook was a product of a lack of sufficient riparian shade and so too was its calculated scenario for recovery, no WLA was necessary. It may appear concerning that without a WLA there may not be capacity in the watershed for certain NPDES or state permitted stormwater treatment practices that could theoretically increase water temperatures such as detention. However, VTDEC believes that there are sufficient protections in the stormwater permitting program that are either established in the newly adopted stormwater treatment standards or can be required on an individual basis to offset any threat of increased water temperatures from Stormwater practices.

The Vermont Stormwater Management Manual (VSMM) was initially published in 2002 but underwent a significant re-packaging in 2017 to include advances in design, practices and new methodologies for managing stormwater runoff. These methodologies include an emphasis on practices that minimize stormwater runoff, disperse runoff across vegetated areas, and utilize filtering and infiltration.

The VSMM now more fully integrates approaches for designing and sizing STPs for water quality treatment, groundwater recharge, downstream channel protection, and flood protection under the umbrella of runoff reduction through the Hydrologic Condition Method to ensure runoff volumes delivered to local receiving waters after site development more closely mimics pre-development conditions. In addition, this Manual provides guidance on a range of site planning and green stormwater infrastructure design practices for minimizing the generation of runoff from the developed portions of Vermont’s landscape, including requirements for restoring healthy soils as part of development activity.

This guiding principal, known in the VSMM as the Runoff Reduction Framework, focusses on runoff reduction from a site such that most of the treatment standards in the Manual may be met wholly or partially through this approach. By minimizing the generation of runoff from a site in the first place, there is inherently a general protection against sites needing larger scale detention practices that could impact stream temperature. Table 11 identifies those practices that reduce runoff.

Table 11. Stormwater treatment practices in the VSMM that reduce runoff. (VSMM, Table 2-2)

Runoff Reduction STPs	
Practice	**Manual Section**
Reforestation	4.2.1
Simple Disconnection	4.2.2
Disconnection to Filter Strip or Vegetated Buffer	4.2.3
Bioretention (designed for infiltration)	4.3.1
Dry Swales (designed for infiltration)	4.3.2
Infiltration Trenches and Basins	4.3.3
Filtering Systems (designed for infiltration)	4.3.4
Green Roofs[1]	4.3.7
Permeable Pavement[1]	4.3.8
Rainwater Harvesting[1]	4.3.9

As Stormwater system designers develop the appropriate set of treatment options for a site, the VSMM requires that they consider three levels of practices, Tiers 1-3, whereby the practices are organized by order of design preference and are based upon pollutant removal efficiencies and potential for runoff reduction. Tier 1 Practices providing the greatest degree of water quality treatment and runoff reduction and Tier 3 Practices providing the minimum required level of water quality treatment and runoff reduction. As treatment practices are designed for a site, the designer must attempt to utilizes practices from Tier 1 first. If Tier 1 practices are infeasible, Tier 2 practices must be thoroughly evaluated before moving to Tier 3 options. The most potentially problematic practices that could affect temperature are shallow ponds or wetlands that detain water for what could be long periods of time. These practices are identified as Tier 3 practices. Although, even these Tier 3 practices have protective measures in place to encourage cooling of water as it is released. Shallow wetlands and wet ponds draining to cold water fisheries shall be designed to discharge through an under-drained stone trench outlet that acts to dissipate warm water energy to the gravel and earth.

However, even if some type of Tier 3 practices are selected to comply with the treatment standards, based on feasibility as outlined in the Manual, the VTDEC has authority to include additional permit conditions or other requirements deemed necessary to implement the applicable TMDL.

With these Stormwater permitting backstops in place VTDEC is confident that whatever approved future stormwater practices are installed, they will be protective of stream temperature.

7.4 Margin of Safety

Several factors lend themselves to offer an implicit margin of safety to account for model uncertainty associated with developing allocations for this TMDL. Namely, observed flow conditions and factors affecting observed and estimated riparian shading.

Mussey Brook flow data collected in August 2016 and used in QUAL2KW represent reasonable worst case conditions. Observed Moon Brook flow data were compared both with data from USGS Station 04280910 and with a synthetic flow duration curve (FDC) developed for Moon Brook using an urban watershed rainfall-runoff model and referenced in the 2008 Moon Brook stormwater TMDL. Both analyses indicate that the observed August 2016 flow at Moon Brook above Forest Street has significantly less than a 1% chance of annual occurrence in this system. The establishment of a LA to meet applicable thermal WQS under these extreme low flow conditions therefore functions as an implicit margin of safety.

In addition, several conservative estimates were made regarding current conditions. Estimates of riparian vegetation used in the model were based on LiDAR-derived measurements of canopy height and density; since the LiDAR data used in the analysis were flown during leaf-off conditions, estimates of canopy density are extremely conservative in areas with standing tree cover. This fact effectively underestimates riparian shading under current conditions. A further assumption was made with regards to channel overhang from existing riparian vegetation; in the absence of observed field data, overhang was assumed to be zero. However, based on satellite imagery, existing overhang in areas with riparian vegetation appears to be greater than 0. This assumption also functions to underestimate riparian shading.

8 Implementation / Reasonable assurance

Since the lack of shading along the stream channel is a known contributor to thermal inputs, the settlement agreement stipulates that within one year, the City shall provide a tree planting plan for publicly owned lands to the Agency for review and approval. In addition, the City shall submit a plan for promoting the preservation and planting of shade trees on private lands. Both plans shall include the types of trees to be planted, the expected number of trees to be planted, and the approximate preferred locations the City will seek to plant them along Moon/Mussey Brooks. After receiving approval from the Agency, the City shall implement its tree planting plans.

The settlement agreement also stipulates that The Agency and the City agree to use an individual permit approach to address the thermal and stormwater TMDLs for Moon Brook as well as the City's general obligations as a regulated small MS4. Within the first 5-year permit term, the City is required to develop an implementation plan.

Since overall compliance with this TMDL requires satisfactory support of the aquatic biologic community, it's important that the aquatic biota can recolonize the impaired reach. One important species that would show a considerably improved fish community would be the reestablishment of the cold water dependent brook trout. If an appropriate temperature regime is reestablished, two potential sources of recolonization of brook trout exist. The first is the headwater of Mussey Brook where it's hoped that brook trout are plentiful, however, data is currently not available as to the brook trout population condition in these reaches. The second and most promising source of brook trout reintroduction is from Paint Mine Brook, the tributary to Moon Brook. This tributary remains relatively cool during the summer months and fish sampling revealed it supports heathy population of brook trout (Table 2). Since the brook joins Moon Brook in close proximity to the mouth of Mussey Brook, recolonization should occur quickly if suitable temperature habitat conditions prevail.

9 MONITORING

No specific monitoring plan has been developed to track the recovery of aquatic life in Mussey Brook; however, there are several components that could be developed to show progress as implementation measures occur.

The first set of components of a monitoring plan should incorporate indicators of progress such as stream temperature and an accounting of riparian shade. Continuous stream temperature monitoring can be done at several locations, as done in the past, relatively inexpensively. Temperature probes can be deployed for the summer and track temperatures through the season. These data can be correlated to nearby weather station data such as air temperature and/or cloud cover to detect relative trends over time. In addition to temperature, the extent of riparian vegetation can be analyzed through time. For this TMDL analysis, leaf-off LIDAR was interpreted as to the extent of streamside vegetation, although, other techniques could be developed such as actual field reconnaissance or examination of satellite imagery. Whatever method is ultimately selected; repeatable protocols should be developed so data collection remains consistent to be comparable over time. Since temperature monitoring is relatively inexpensive, it could be conducted annually. Riparian vegetation analysis could be conducted less frequently or could be tied to the extent of plantings that have occurred and their expected growth rates.

While ultimate compliance with the VTWQS is a healthy aquatic biota community as measured by the Department's biomonitoring protocols, compliance with this TMDL is consistent attainment of the above stated temperature target. Unfortunately, in the case of Mussey Brook, where there are multiple stressors at work, biological recovery from temperature impacts could be masked by other stressors such as stormwater. However, tracking brook trout recovery could be a useful measure to track improvement in the temperature regime.

10 PUBLIC PARTICIPATION

A draft of this TMDL was released for public comment on August 25, 2017 and notice was posted to the Division website as well as through direct email contact of interested parties in the watershed. The deadline for written comment was September 29, 2017 and comments were received from one party. A responsiveness summary was prepared under separate cover and submitted to EPA Region 1 along with the draft TMDL for approval.

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