MOON BROOK TEMPERATURE TMDL

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

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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 Moon 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 from the outlet of Combination Pond downstream to Moon Brook's confluence with Otter Creek. 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 Moon Brook 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 Moon Brook's impairment as well as habitat degradation and other pollutant impacts (chlorides and PAH compounds). 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). The headwaters drain the undeveloped forested area of East Mountain and the streams flow through an increasingly residential area below Town Line Road. The Rutland City landfill is in this area at approximately river mile (RM) 3.3. From there the stream travels through a wooded area until flattening out just upstream of the Combination Pond at RM 2.9. From there the watershed becomes more highly developed characterized primarily by dense residential housing. A second onstream pond, Piedmont Pond, is situated at RM2.4. The stream crosses under Route 7 at RM 1.2 and finally under Forest St. (RM 0.4). Below Forest Street RM 0.3, the brook flattens out in a field before entering Otter Creek. A more detailed view of the area of interest is shown in Figure 2.

Other significant tributaries of Moon Brook include Mussey Brook which joins in the lower reaches and Paint Mine Brook that joins in the middle reaches.

Figure 1. Moon Brook watershed

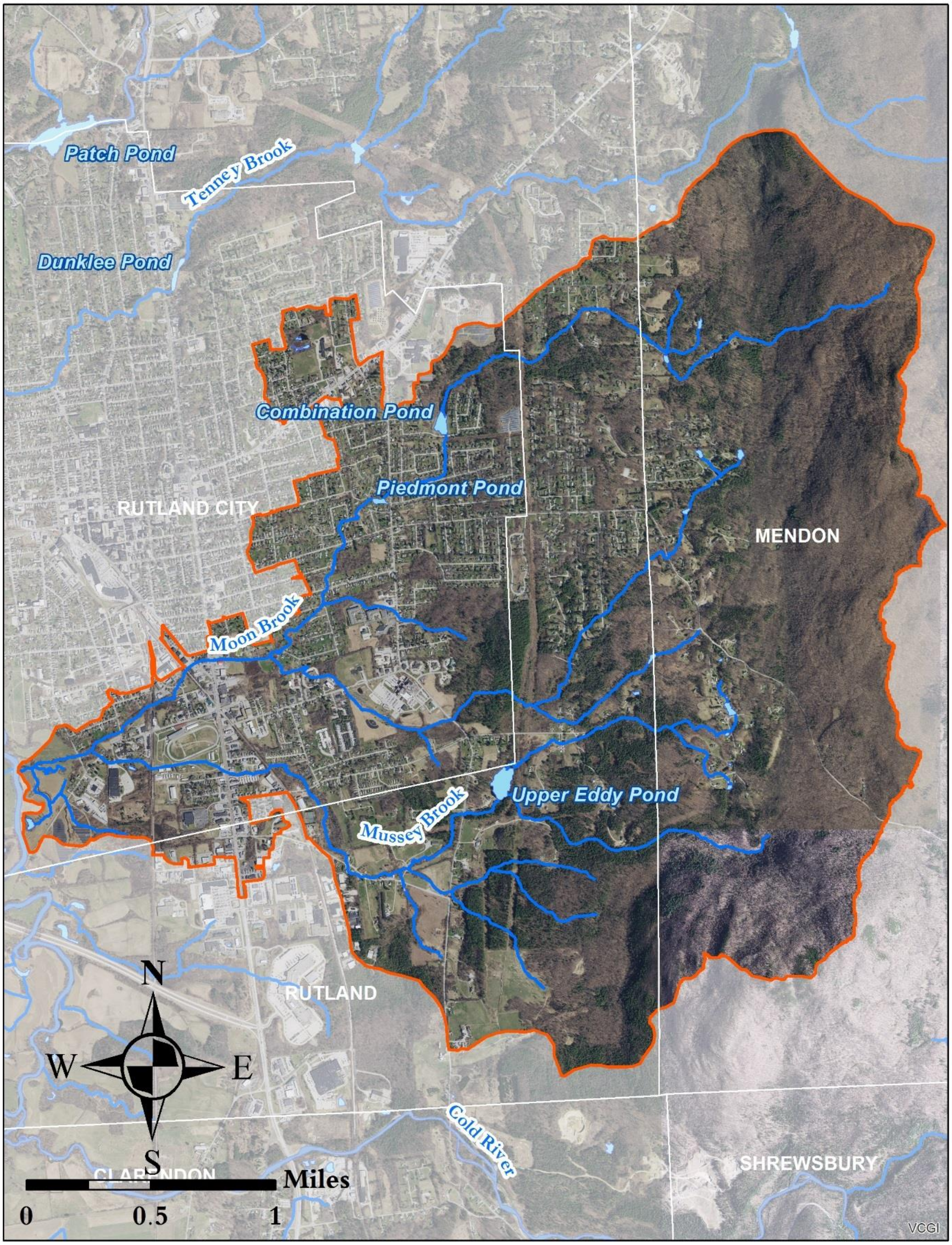
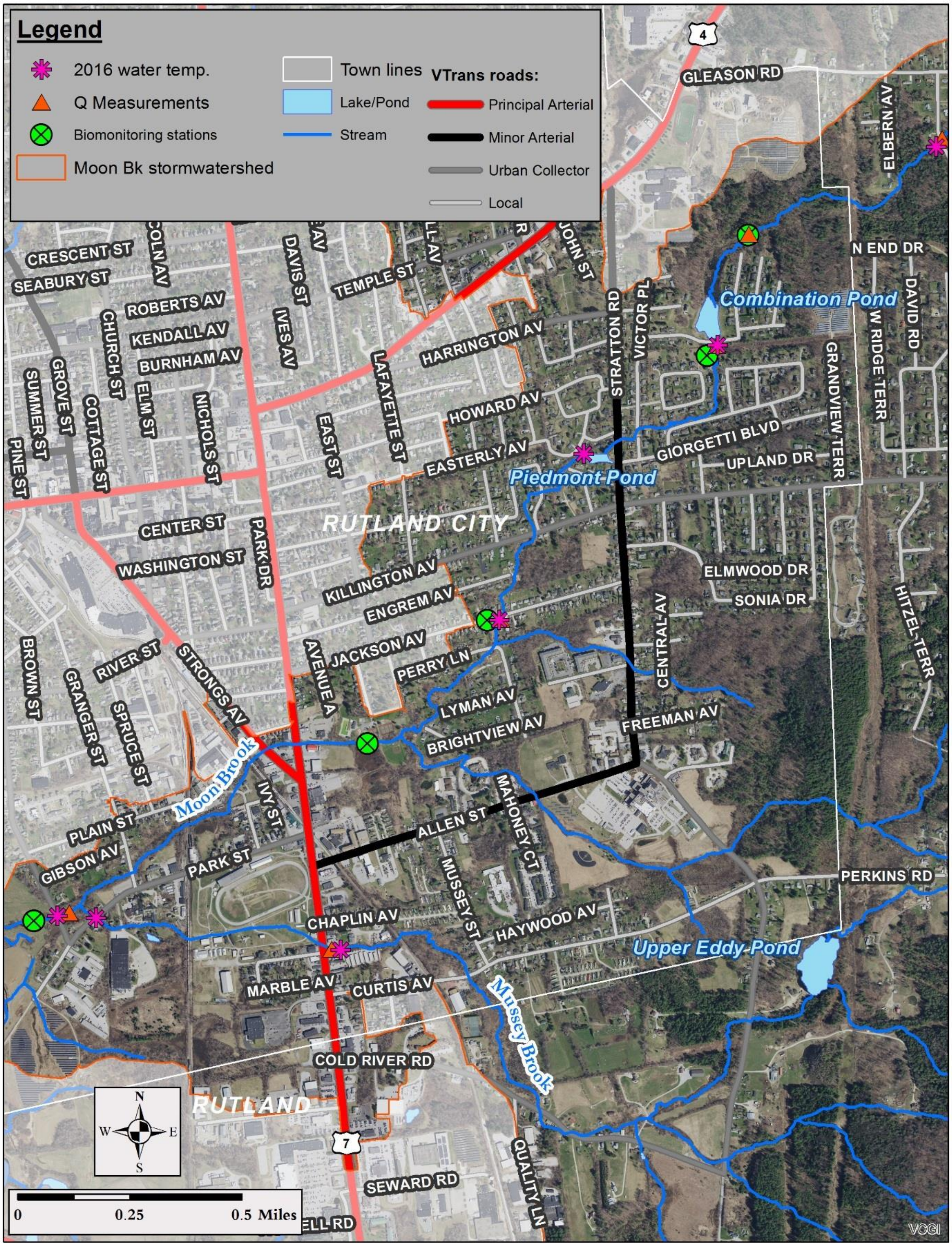


Figure 2. Area of interest in the Moon Brook watershed.

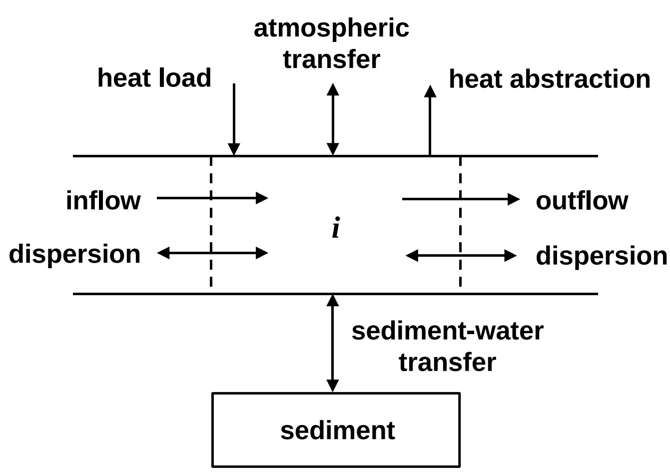


3.1 POLLUTANTS AND SURROGATE MEASURES

This Moon 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 by the following processes occurring in the watershed:

- Two on-stream impoundments, (Combination Pond and Piedmont pond). These ponds considerably slow the flow and widen the stream channel. The slowing of the flow allows more time for the water to heat and the channel widening substantially increases the stream's interception of solar radiation. Historical temperature data from the inlet/outlets of these ponds confirms that these are the largest heat source to these streams.
- Reduced riparian vegetation. Throughout the course of the stream, including the areas around the ponds, there are several areas with no or very sparse riparian vegetation; a condition that also increases solar radiation reaching the stream.

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



This TMDL assessment for Moon Brook uses riparian shade as a surrogate measure of heat flux. Stream surface area reduction is also used as a mechanism to reduce solar radiation uptake. It is identified as a viable measure that results in the same outcome – reduced heat flux to the water. 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 MOON BROOK

The Vermont Water Quality Standards (VTWQS) identify the following designated uses applicable to Moon 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 Moon 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

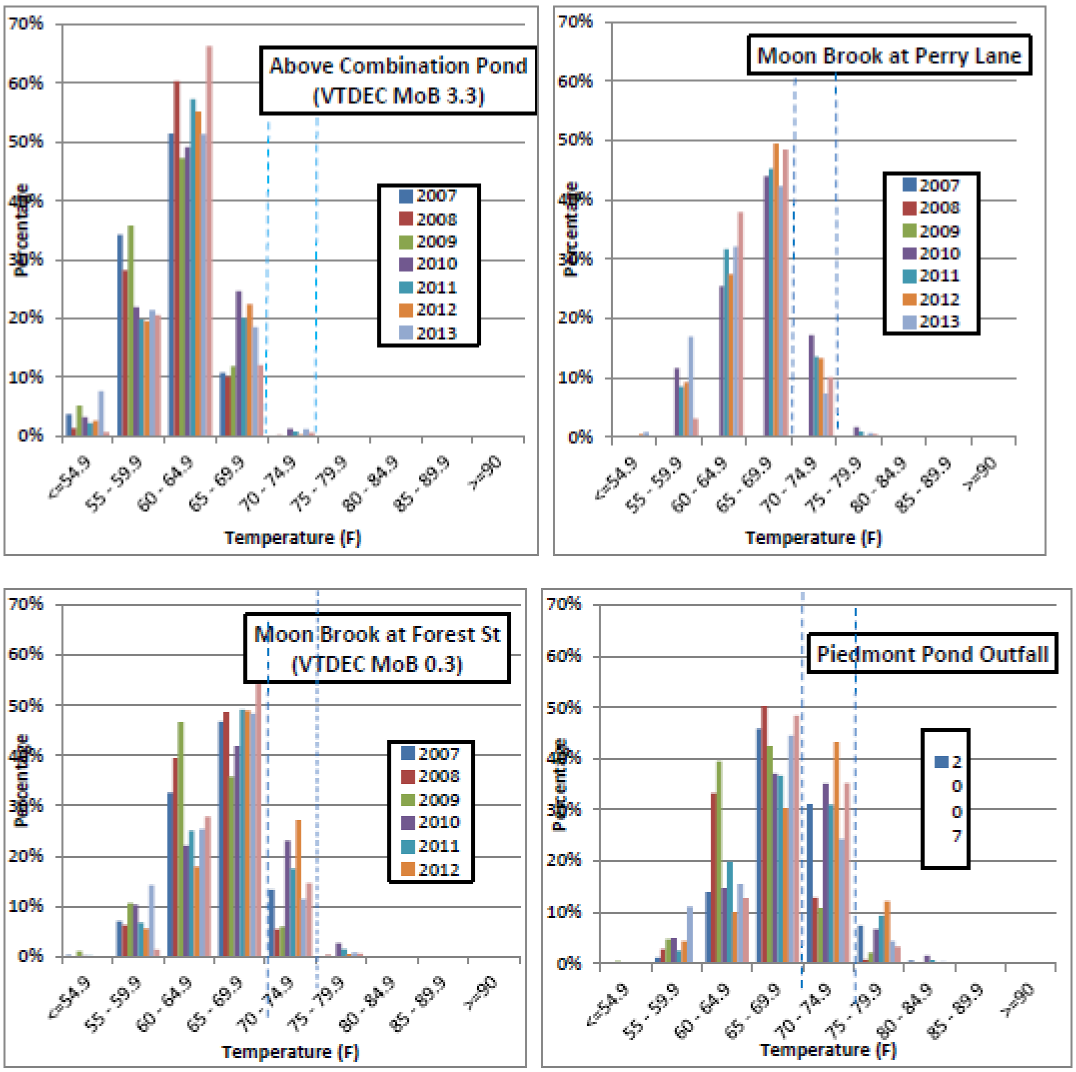
Moon Brook was initially identified as impaired for aquatic life use in 1992, however, the primary stressor was further refined in 2004 as multiple stressors related to stormwater runoff. In streams draining developed watersheds with substantial impervious surfaces, biological communities are subjected 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 Moon 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 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

The original biological assessments and the stormwater TMDL acknowledged that temperature was an additional source of stress to a biotic community, primarily fish, in Moon Brook. Namely, the on-stream impoundments of Combination and Piedmont Ponds were of concern. Several years of in-stream temperature monitoring was conducted by the City of Rutland to better understand where the temperature impacts were the greatest. Figure 4 gives temperature range frequencies at several monitoring sites on Moon Brook. In order of upstream to downstream, the sites represented here are above Combination Pond, Piedmont Pond outfall, Perry Lane, and Forest street. As a general trend, one sees a significant jump in temperatures between above Combination Pond and the Piedmont Pond outfall. Downstream of the Piedmont Pond outfall, stream temperatures cool somewhat where no more impoundments occur. It appears the impoundments of Combination and Piedmont Ponds are the primary cause of the chronic elevated summertime water temperatures.

Figure 4. Frequency of occurrence of stream temperatures at four monitoring sites on Moon Brook, June through August, 2007-2014. Blue dashed lines indicate avoidance (70°F) and upper lethal limit (75°F) thermal thresholds for brook trout. (from Third-Party Report, Figure 4-3).



The Third-Party Report also compiled the same data in a tabular format, albeit with more monitoring sites. The site locations in the Table 1 are listed from upstream to downstream.

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

	Percentage of time at Temperature (°F) increments							
Moon Brook	**< 54.9**	**55-55.9**	**60-64.9**	**65-69.9**	**70-74.9**	**75-79.9**	**80 >**	**Temperature meets or exceeds 70° F**
above Combination Pond	5	25	55	15	2	0	0	**2 %**
Combination Pond outfall	5	19	32	30	12	1	1	**14 %**
above Piedmont Pond	1	5	23	45	24	2	0	**26 %**
Piedmont Pond outfall	1	4	20	42	27	5	1	**33 %**
Perry Street	1	10	30	44	13	2	0	**15 %**
Whites Playground	0	8	39	43	9	1	0	**10 %**
Forest Street	0	8	29	46	15	2	0	**17 %**

A literature review identified 70°F as a critical threshold for the most sensitive species native to Moon 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.

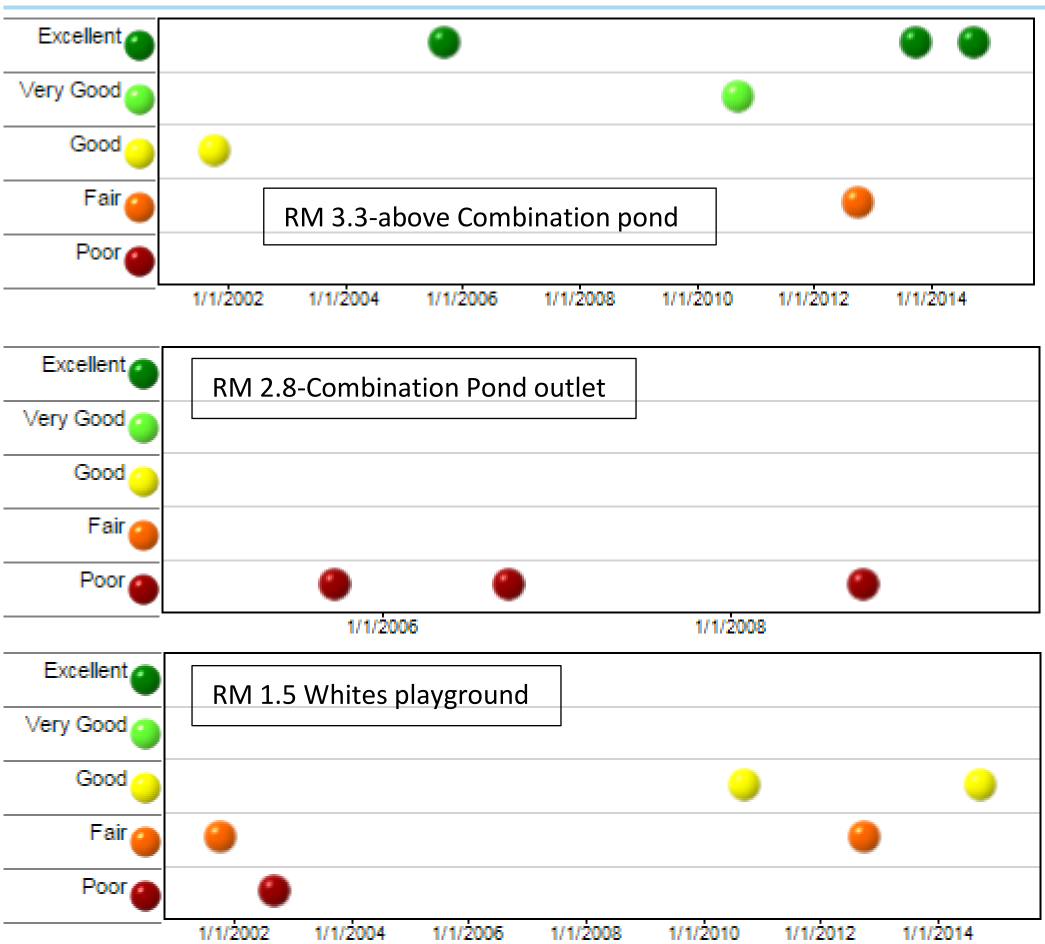
Fish monitoring data collected in 2014 indicated that the distribution of brook trout in Moon Brook is negatively correlated with summer temperatures that exceed 70°F (Table 2). Brook trout abundance in Moon Brook was high at stations where 70°F was not or rarely exceeded; conversely no brook trout occurred where temperatures exceeded 70°F for more than 10 % of the time.

Table 2. Density and abundance of brook trout in VTDEC samples collected at Moon 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 fish community moving downstream from above Combination Pond. Generally, fish community ratings in cold water habitat are negatively impacted when brook trout are few or absent. This is the case when comparing upstream to downstream sites. Figure 5 gives overall fish community scores for three sites corresponding to sites in Table 2. A considerable and consistent degradation of the community appears below Combination Pond. However, there does appear to be some recovery in the lower reaches. This trend closely matches the general trend in historical temperatures in Moon Brook whereby the coolest waters are above Combination pond, temperatures rise dramatically below the ponds and moderate somewhat in the lower reaches.

Figure 5. Vermont DEC fish community assessment results for three sites on Moon Brook. Assessments of "poor" or "fair" indicate non-compliance of aquatic life use in the VTWQS.



Since multiple stressors to the biotic community become more entwined as one moves downstream, an effort was made in the listing process to identify the segment, and thus the biotic community, most impacted by the temperature increase. Since the impacts of stormwater runoff tend to increase further toward the mouth of Moon Brook, while the temperature impacts tend to dissipate slightly (Figure 5, Table 2), the temperature impaired reach was limited to RM 1.8 to RM 2.9 – from Jackson Avenue to the Combination Pond outlet. If temperature regimes can be improved in these upstream reaches, the biotic communities in the lower stormwater impaired reaches will be significantly relieved of thermal stress.

Based on this analysis, the Moon Brook segment from RM 1.8 to RM 2.9 (Perry Street to Combination Pond outfall) 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. Figures 6 and 7 show both the stormwater and temperature impaired reaches of Moon Brook respectively.

Figure 6. Stormwater impaired reaches of Moon Brook.

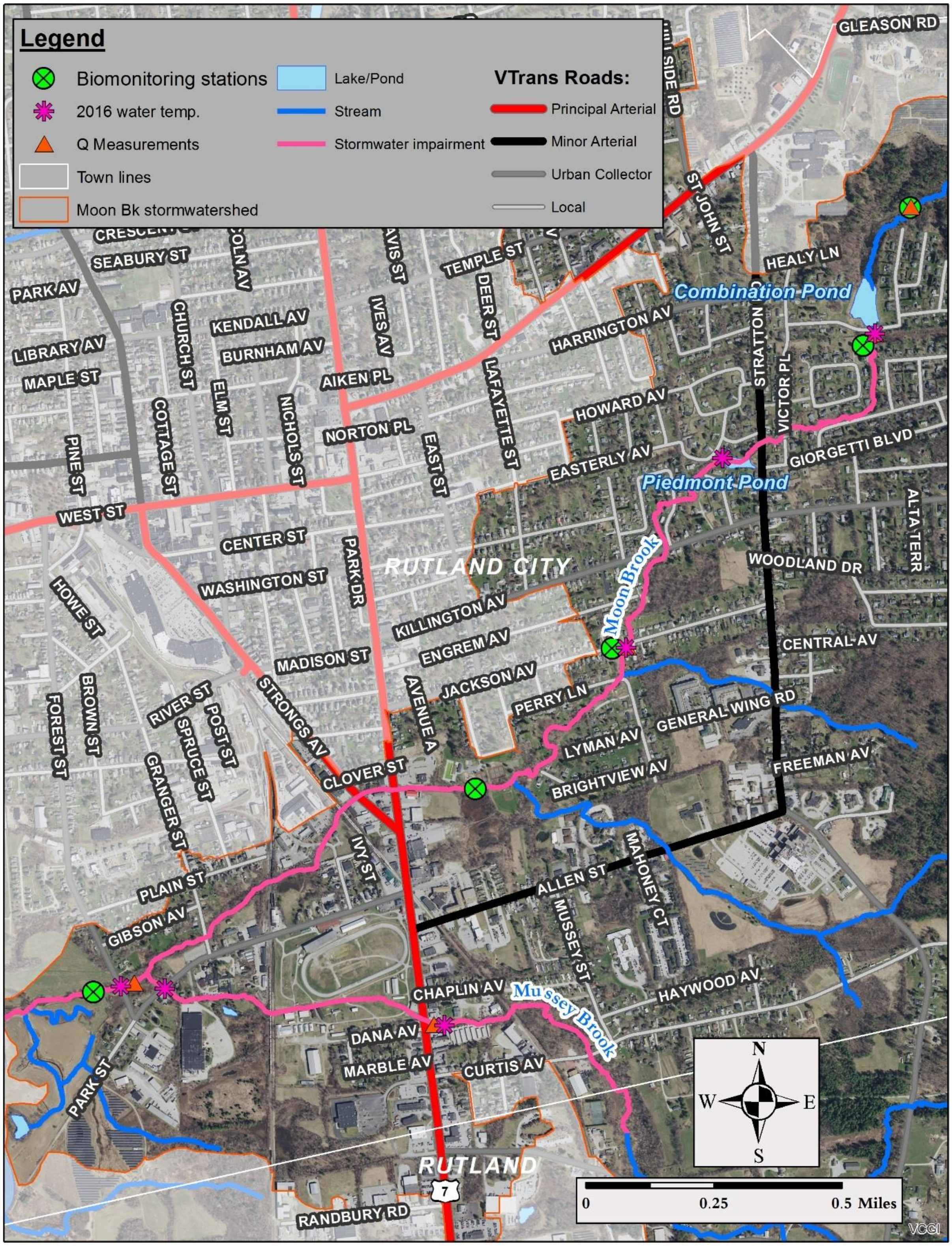
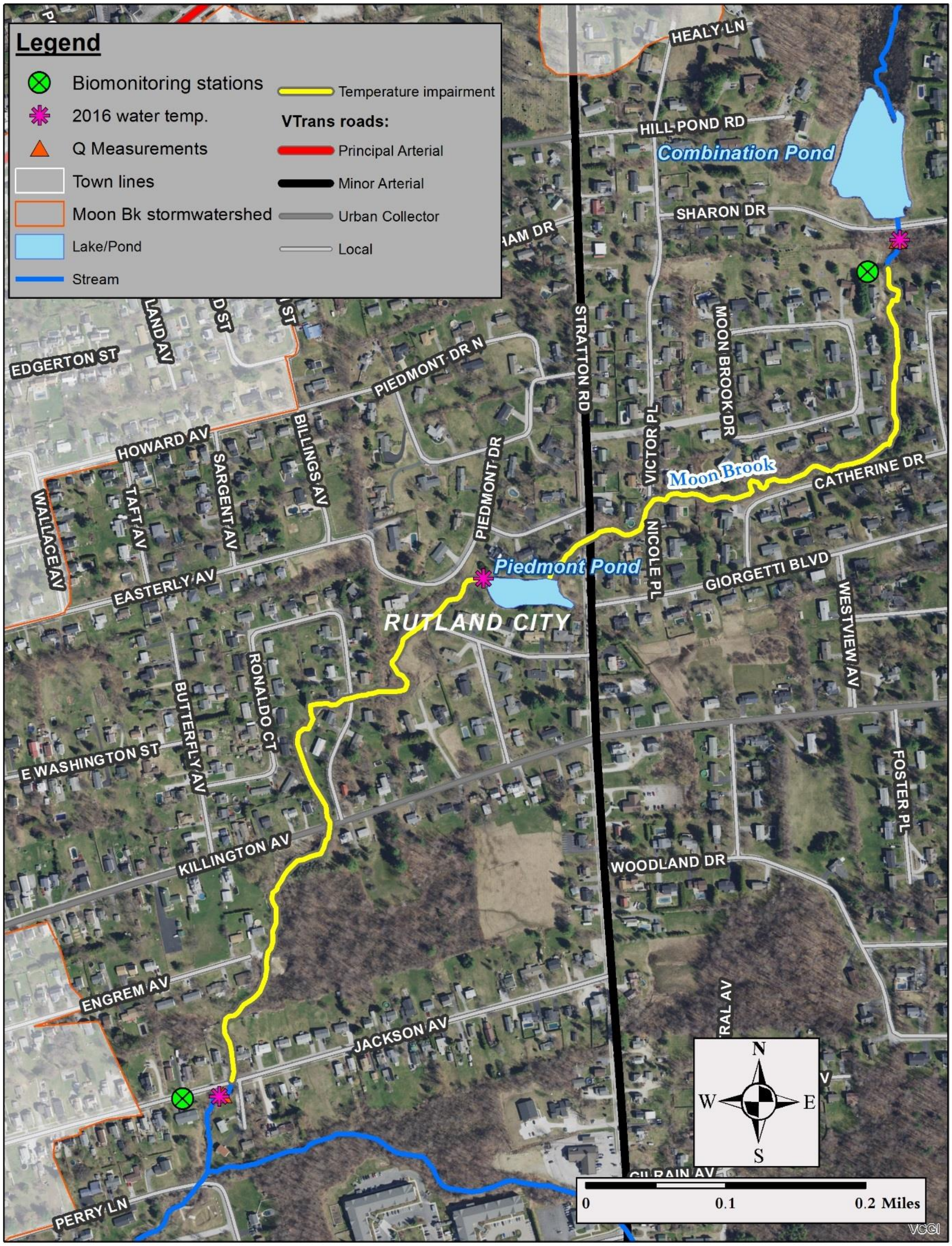


Figure 7. Temperature impaired reaches of Moon Brook.



4.2 Temperature target

There are no explicit numeric temperature targets 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 Moon Brook shows that brook trout populations avoid waters where temperatures exceed 70°F 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 Moon Brook exists for periods of the years 2006 -2014. 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 Moon 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. Five in-stream stations were established (Table

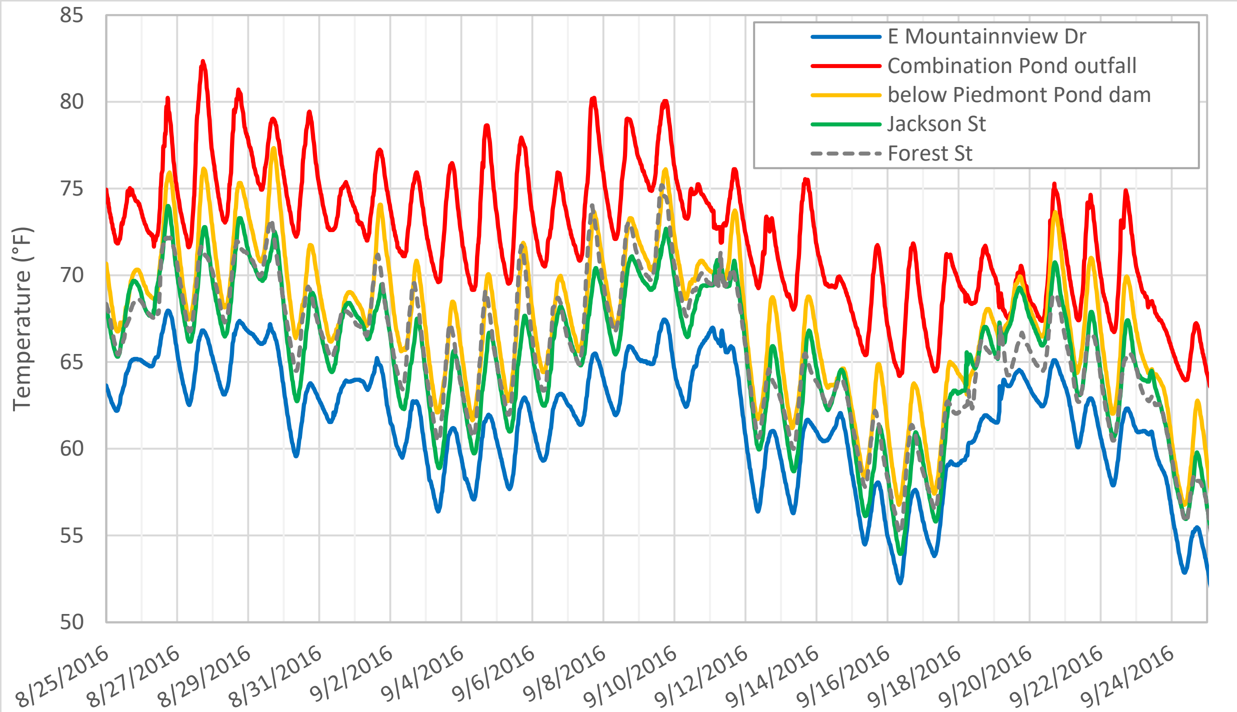
3, Figure 2) and water temperature was logged at 15-minute intervals within protective perforated PVC housings, affixed to rebar and driven 1-foot or more into the stream bed. All loggers used have a stated accuracy of ±0.38°F and a resolution of 0.04°F.

Table 3. Temperature logger locations in Moon Brook.

Location	Drainage area (sq. mi.)	Latitude (DD)	Longitude (DD)
Moon Brook above Combination Pond at E. Mountainview Drive	1.07	43.6193	-72.9424
Moon Brook at Combination Pond outfall	1.64	43.6128	-72.9521
Moon Brook at Peidmont Pond outfall	1.96	43.6093	-72.958
Moon Brook at Jackson Street	2.69	43.6039	-72.9617
Moon Brook at Forest Street	8.29	43.5943	-72.9813

The late summer monitoring period of 2016 did include critical low-flow conditions, reaching streamflows as low as 0 cfs at the uppermost station, and temperatures as high as 82.4°F at the Combination Pond outfall (Figure 8). The warmest temperatures occurred from 8/25/2016 and 9/10/2016, after which overall temperatures began to decline, however maximum daily temperatures still exceeded 70°F frequently.

Figure 8. Stream temperature data for five locations in Moon Brook.



5.2.2 Stream flow data

Moon Brook has been monitored for streamflow for various periods within the past 20 years by the consulting firm Heindel and Noyes, the University of Vermont, and the U.S. Geological Survey. Periods of record include June 2005- January 2006; May – November of 2006, 2007, and 2008; and for one-year from October 2010 – September 2011. In each instance flows were collected near the mouth of Moon Brook at Forest Street. Historic data lacked the spatial coverage needed to develop a model for the upstream thermally impaired reaches of Moon Brook. Given the variable degree of urbanization and resultant flow alteration in different parts of the watershed, scaling flows upstream by drainage area proved to be too uncertain for reliable model development. As such, synoptic discharge measurements were collected in the upstream portions of the watershed (Figure 2) for three separate days during baseflow conditions, coincident with the August – September 2016 temperature monitoring. Measurements were collected at low-baseflows generally 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 down from the mouth based topographic 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 Moon Brook.

Date	Location	Drainage area (sq. mi.)	Discharge (cfs)	Discharge (csm)	Method
8/31/2016	Moon Brook at E Mountainview Dr	1.07	0.01	0.01	velocity/area
	Moon Brook at Combination Pond outfall	1.64	0.12	0.07	volumetric w/ timed bucket
	Moon Brook above Forest St.	8.29	0.23	0.03	velocity/area
	Mussey Brook above Rt. 7	2.74	0.11	0.04	velocity/area
9/9/2016	Moon Brook @ E Mountainview Ave	1.07	0.00	0.00	visual observation
	Moon Brook above Combination Pond near Charter Hill Dr	1.54	0.13	0.08	velocity/area
	Moon Brook at Combination Pond outfall	1.64	0.12	0.07	volumetric w/ timed bucket
	Moon Brook at Jackson Ave	2.69	0.12	0.04	velocity/area
	Moon Brook above Forest St.	8.29	0.04	0.00	velocity/area
	Mussey Brook abv Rt. 7	2.74	0.06	0.02	velocity/area
9/26/2016	Moon Brook at Combination Pond outfall	1.64	0.16	0.10	volumetric w/ timed bucket

Extreme low-flow conditions and relatively small size of Moon Brook warranted several different streamflow measurement methods depending on the hydraulic conditions at each site. Where the velocity-area method (Turnipseed and Sauer, 2010) was possible, an acoustic Doppler velocimeter was used at sites 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

Not all criteria could be met for all sites and best professional judgement was required for methods based on site-specific conditions. The reliable and accurate volumetric method (Turnipseed and Sauer, 2010) was possible at the Combination Pond outfall, where the time elapsed to fill a container to a known volume is recorded and discharge calculated as the average of 5-10 measurements. This is generally the most accurate flow measurement method. In one instance, no-flow conditions were confirmed visually.

5.2.3 Hydraulic geometry

The hydraulic geometry of the stream channel is required to get velocity and depth inputs to the temperature model. Cross-sectional surveys were completed at four locations representative of the general channel reach during low-flow conditions on 9/26/2016, which were used in conjunction with cross-sectional data collected during velocity-area discharge measurements to get side slopes, bottom width, and to solve Manning's Equation for derive 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 9).

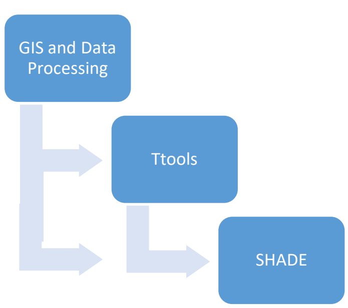


Figure 9. Schematic of riparian and solar flux modeling.

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. Current areal extents for Combination and Piedmont ponds were also digitized using 2016 VCGI imagery. 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).

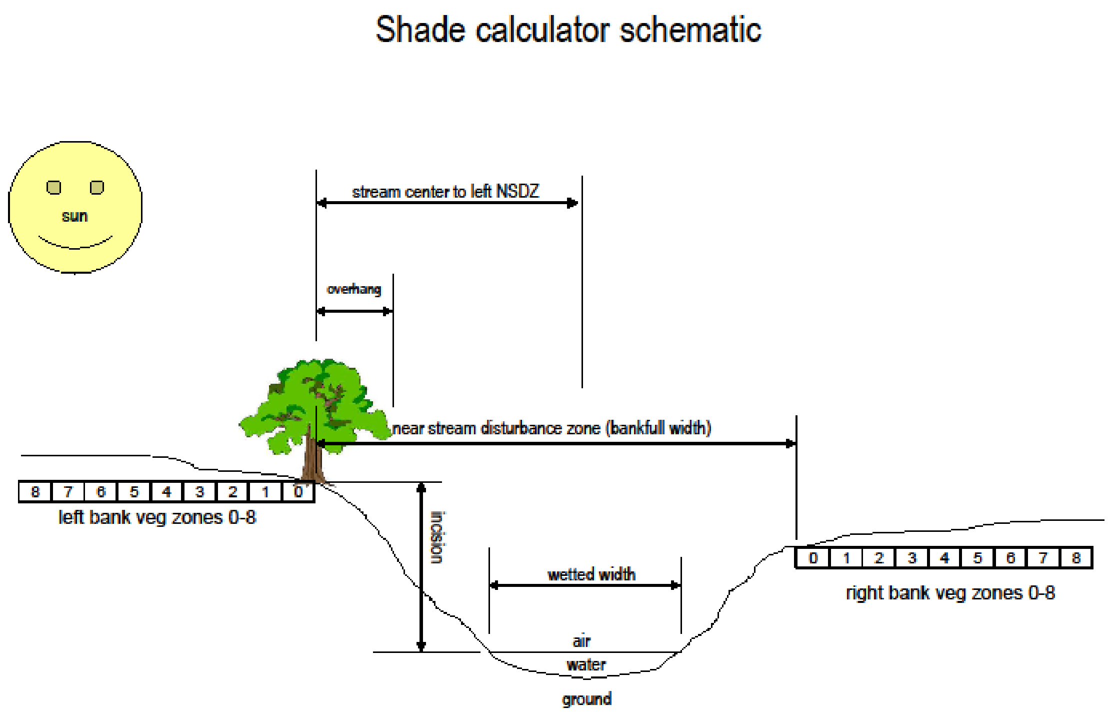
These geospatial data layers were used as inputs to Ttools, a Python language add-in for ArcMap that samples GIS data at user defined points along a modeled stream reach. Multiple GIS data layers are sampled at each point (Table 5). In addition, riparian elevation and vegetation are sampled at nine riparian 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 10). 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 10. SHADE program schematic.



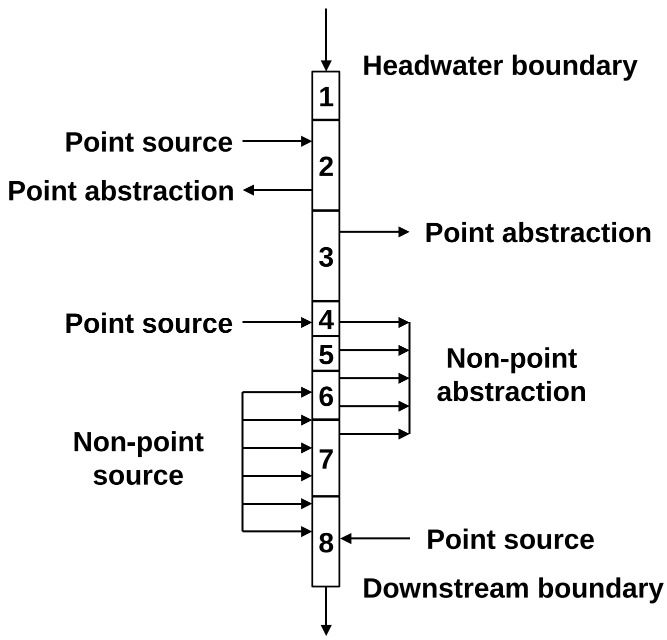
5.3 Analytical Framework

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 Moon 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 11). 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 11. Schematic of QUAL2KW modeled stream.



5.4 Calibration of QUAL2K model

The initial Moon 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, 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 four Moon Brook monitoring stations – headwater boundary, Combination Pond, Piedmont Pond, and Jackson Street – were summarized over the model period and compared to initial model estimates. Calibration efforts to improve the fit of the Moon Brook QUAL2KW focused on three flow and hydraulic variables: depth, velocity, and flow. Data from cross-sectional surveys, flow measurements, and existing depth and contour studies of Combination and Piedmont ponds were used as reference points. The primary mechanism of adjustment was Manning's equation, used in this application of the model to characterize hydraulic variables, although shade, solar flux estimates, and Ttools sampling point locations were also reevaluated for select reaches. The fitted values of the calibrated Moon Brook QUAL2KW model are compared to observed values in Figure 14. The mean absolute error between observed and fitted values was also calculated (Table 6). The model period average and maximum temperature values have a ~1 degree C (1.8 degree F) error.

Table 6. Mean absolute model error by temperature statistic.

Metric	**Mean Absolute Error (Degrees Celsius)**
All temperatures data	1.21
Model period minimum	1.51
Model period mean	1.02
Model period max	1.07

5.5 Critical Conditions

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

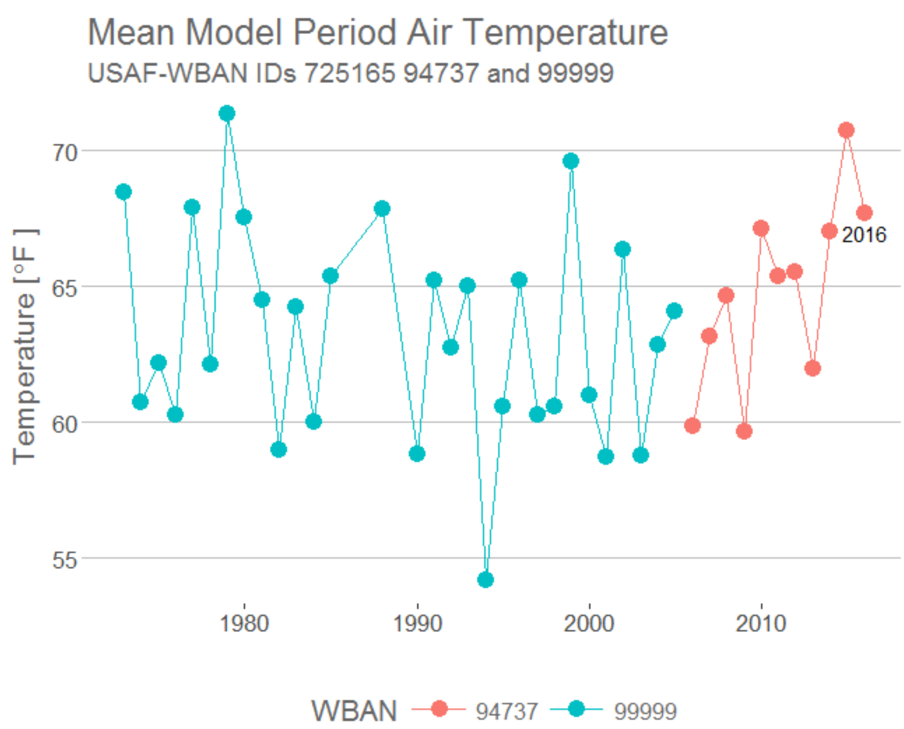
Hydrologic inputs for QUAL2KW were measured in August 2016 and September 2016, a period when stream flows in Vermont are generally expected to represent low or baseflow conditions. These field observations coincided with a period of below average precipitation in the state. The 7-month window from April 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 Moon Brook were measured on 8/31/2016. At the time of flow monitoring, no precipitation had been recorded locally for >72 hours. The observed flow value at the headwater boundary of the modeled stream segment was 0.012 cfs. Measured flow at Moon Brook below the confluence with Mussey Brook was 0.23 cfs; this location is near the confluence of Moon Brook and Otter Creek. In order to assess the criticality of these observed values, two reference sources were consulted: a flow record from a short term USGS gage station located on Moon Brook below Mussey, and a synthetic flow duration curve (FDC) derived from a calibrated P8- Urban Catchment Model (P8-UCM) run completed for the 2008 Moon Brook stormwater TMDL (VTDEC, 2008). Both sources estimated the occurrence probability of the observed Moon Brook below Mussey Brook flow as <1%. The 2008 stormwater TMDL also derived a 7Q10 estimate from the 95th percentile estimated flow; the Moon Brook field measurement of 0.23 cfs was 13% of this threshold. The observed flow values were therefore deemed to adequately represent critical conditions for flow.

Air temperature was also considered in the critical conditions 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 12). Based on these data, observed air temperatures in 2016 fall in the 85th percentile of the climate record. The highest mean model period air temperature occurred in 1979; however, this year does not contain consistent hourly records, as required by QUAL2KW. The second highest ranked year in the record is 2015; this year contains consistent hourly records. 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 12. 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 comply with 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 QUAL2KW model was used to determine the loading capacity for effective shade in Moon 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.

In cooperation with a public process initiated by the City, several key elements that were being considered as potential stream cooling implementation options were incorporated into the effective shade loading capacity. Important considerations included:

- Combination Pond. Based on historical stream temperature data this pond was known to be a large contributor to excessive stream heating both because of its large surface area and relatively long water residence time. Elimination of the Pond, while overall beneficial to water quality, was a point of contention among City residents. A moderate treatment scenario was therefore considered. This scenario consisted of reducing the areal footprint of the pond to the current 2-foot depth interval and buffering the entire pond with mature trees providing a canopy density of 80%.
- Piedmont Pond. Although smaller than Combination Pond, this pond has similar impacts to stream heating. The treatment scenario for this pond includes buffering the entire pond with mature trees providing a canopy density of 80%.
- Streamside shading. The treatment scenario also specifies a minimum riparian shading along the impaired stream reach. A 3-meter buffer of alder or similar vegetation was modeled along the stream, or non-impounded, portion of Moon Brook. This vegetation was assumed to have a height of 2 meters at maturity, with an average canopy density of 85%. For stream reaches where current vegetation provides a higher estimated effective shade, no changes were made. Open or thinly shaded near-shore riparian areas, by contrast, were changed to the 3-meter buffer described above.

This loading capacity scenario is represented in Figure 13 and Table 7. Figure 13 shows the buffer and shading changes modeled in 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 13. Representation of loading capacity scenario. Blue and red areas represent buffer and shade areas around Combination and Piedmont Ponds respectively. The light green area represents riparian channel shading.

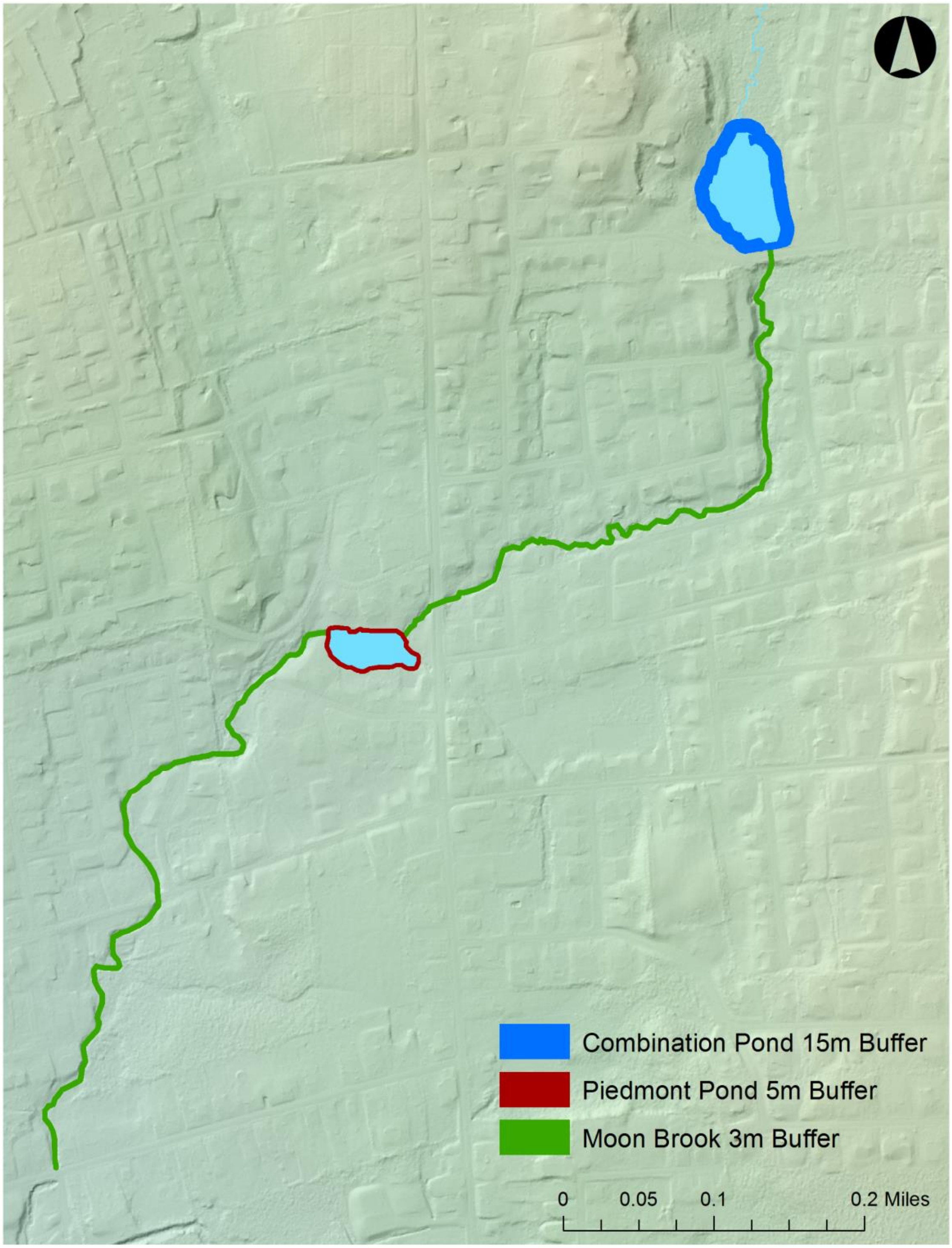


Table 7. Details of simulated shade and buffer conditions set forth in the loading capacity scenario as seen in Figure 13.

Location	Height (m)	Canopy Density (%)	Overhang (m)	Average Buffer Distance (m)
Combination	20	0.8	0.5	15
Piedmont	18	0.8	0.5	5
Riparian	2	0.85	0.5	3

As described in the model setup section above, Figure 14 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 two abrupt increases in temperature at approximately 1.4 km and 2.4 km represent the outlets of Combination and Piedmont Ponds respectively. It's at these pond outlets where violations of the water quality target occur most frequently. Tables 8 and 9 provide summary information on the percent of time the target was exceeded based on observed temperature logger data.

Figure 14. Observed and predicted stream temperatures in Moon Brook. The 0.0 km distance represents the uppermost stream temperature monitoring station (Section 5.2.1). Distances are measured from that point downstream.

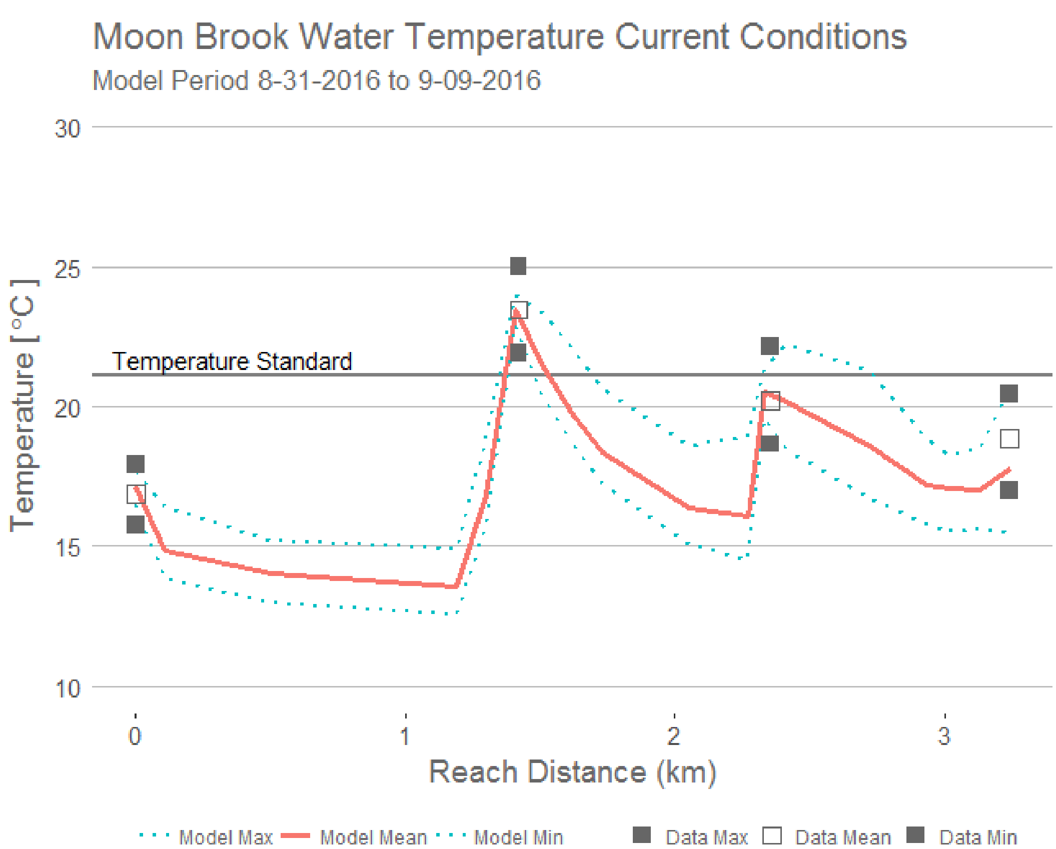


Table 8. Percent of time above target temperature during model period by station. Data are from temperature logger monitoring stations.

Monitoring Station	Percent of time above 70 F
Headwaters	0.00%
Combination Pond	95.17%
Piedmont Pond	30.11%
Jackson Street	8.90%

Table 9. Percent of all 15 minute temperature logger intervals above target during model period by day. Only data from the impaired stream reach stations (Combination Pond, Piedmont Pond, and Jackson Street) are represented.

Date	Percent of time above 70 F
8/31/2016	33.33%
9/1/2016	47.92%
9/2/2016	38.19%
9/3/2016	28.47%
9/4/2016	27.43%
9/5/2016	36.11%
9/6/2016	33.33%
9/7/2016	50.69%
9/8/2016	59.72%
9/9/2016	84.03%
9/10/2016	52.78%

After application of the treatment scenario, Figure 15 gives the resulting average predicted temperatures in Moon Brook under the critical conditions described in Section 5.5. Figure 16 shows that increases in effective shade and reduced surface area of Combination Pond have the potential to produce water temperatures that would meet the water quality target. Temperatures at the outlets of both the ponds follow a similar pattern of increases but the magnitude of the increases is substantially muted. The highest predicted point temperature for all simulated model time-steps under the treatment scenario is 19.25 C (66.7 F). Adding the mean absolute model error of 1.21 C (Table 6) to this value equals 20.46 (68.8 F), or 0.65 C below the temperature target 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 15. 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.

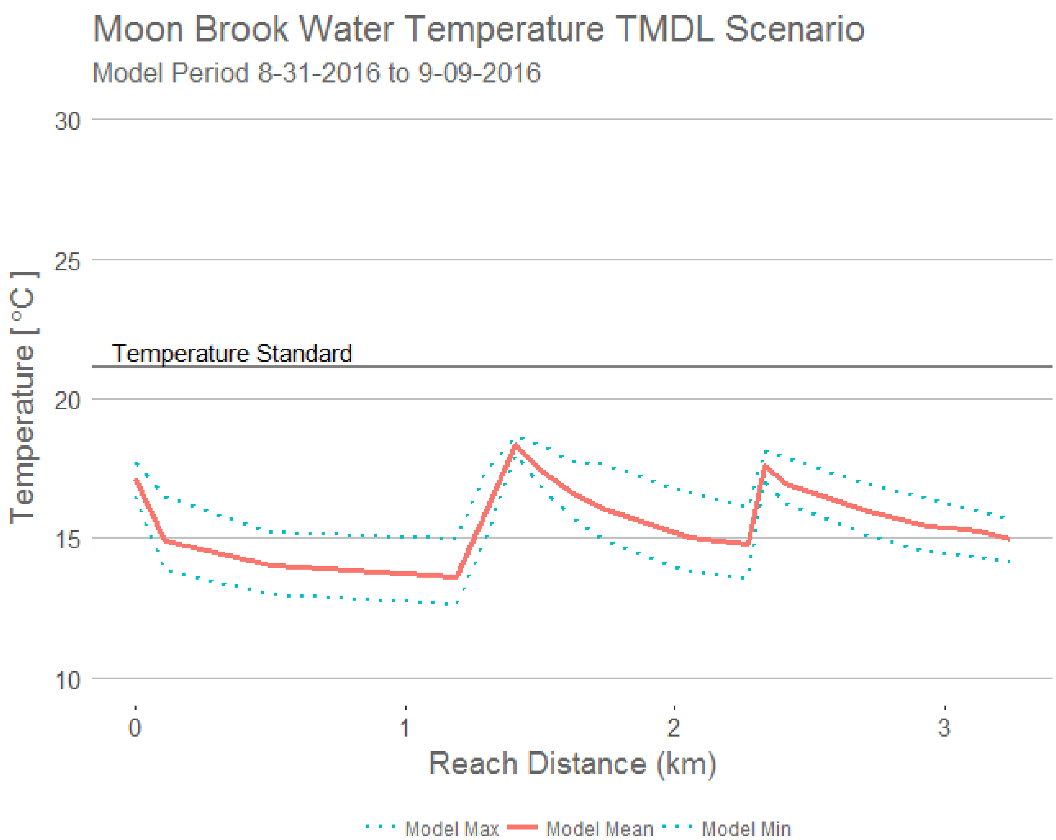
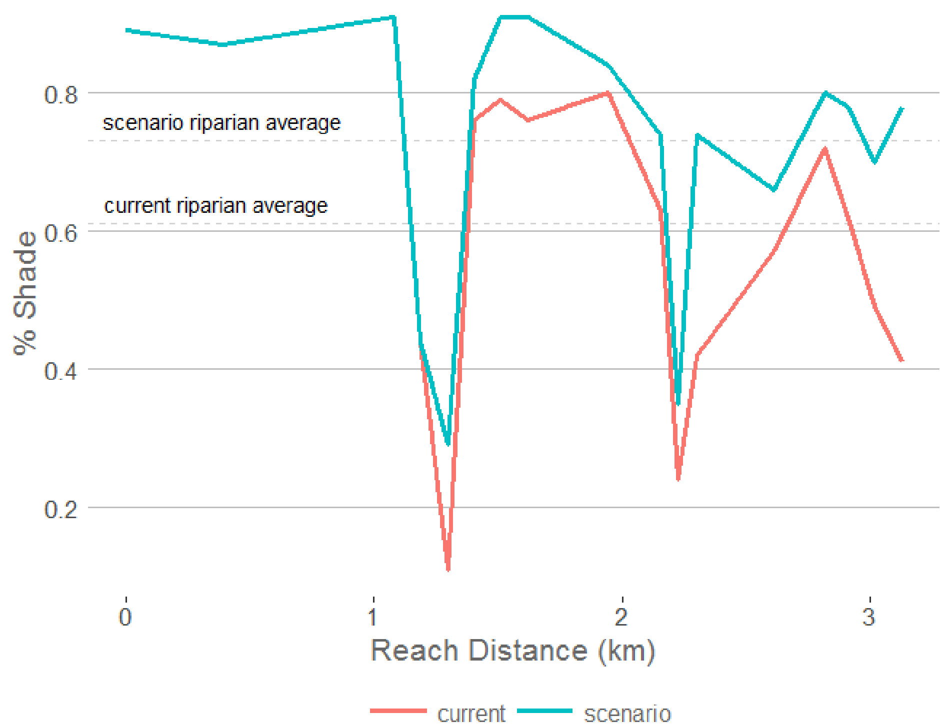


Figure 16 identifies the changes in effective shade under the TMDL loading scenario. The overall estimated average percent shade is predicted to increase from 61% under current conditions to 73% in the TMDL loading scenario.

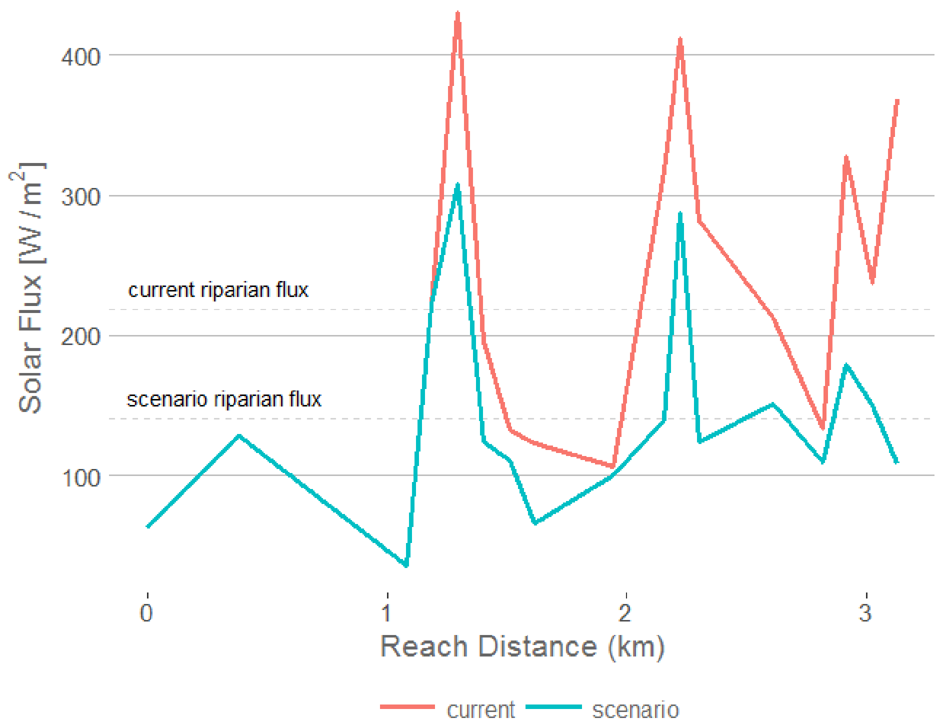
Figure 16. Comparison of average percent shade by reach for current conditions and TMDL scenario. Dotted lines represent average shade in modeled reaches.



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 17). The loading capacity was translated into the solar flux that would occur with the treatment scenario described above in Figure 13 and Table 7. The overall estimated average solar flux is predicted to decrease from 219 W/m^2 under current conditions to 141 W/m^2 in the TMDL loading scenario.

Figure 17. Comparison of average solar flux by reach for current conditions and TMDL scenario. Dotted lines represent average solar flux in modeled reaches.



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 Moon 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 17. 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 Moon 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 currrent 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)
3.237	3.129	0.108	89%	63	89%	63
3.129	2.745	0.384	87%	128	87%	128
2.745	2.050	0.695	91%	36	91%	36
2.050	1.952	0.098	44%	221	44%	221
1.952	1.824	0.128	11%	431	29%	307
1.824	1.726	0.098	76%	196	82%	123
1.726	1.619	0.108	79%	133	91%	110
1.619	1.511	0.108	76%	123	91%	66
1.511	1.187	0.324	80%	106	84%	100
1.187	0.981	0.206	63%	317	74%	140
0.981	0.905	0.076	24%	412	35%	287
0.905	0.828	0.077	42%	282	74%	124
0.828	0.517	0.311	57%	212	66%	151
0.517	0.310	0.207	72%	133	80%	109
0.310	0.216	0.094	62%	327	78%	179
0.216	0.108	0.108	49%	238	70%	150
0.108	0.000	0.108	41%	368	78%	108

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 popular 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 Moon 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 (VTANR 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.

Moon Brook flow data collected in August 2016 and used in QUAL2KW represent reasonable worst case conditions; in fact, subsequent field observations in September 2016 revealed zero flow conditions at the headwater boundary. 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

As described in Section 2, the settlement agreement between the Agency and the City goes on to imposes certain specific implementation planning actions directed toward alleviation of the thermal impairment. The City has agreed to act in good faith to seek modification of the impoundments of Combination and Piedmont Ponds to address thermal as well as convene meetings with neighborhood property owners to review design alternatives for modifications to the impoundments. The City is currently in the process of working with its citizens on the issue of impoundment modification; a result of which is the loading capacity scenario identified in this TMDL. If despite best efforts the City is unable to commence implementation and construction of selected designs, the Agency shall convene a conference pursuant to 10 V.S.A. § 1003 to cooperate with identified dam owners to ensure that flows from the Impoundments protect the public's interest. If the dam owners fail to cooperate, the Agency may seek injunctive relief against the owners of the impoundment requiring modification.

Since the lack of shading along the stream channel is a known contributor to thermal inputs, the settlement agreement also 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 Brook. 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 which, in part, is to include any additional measures beyond modifications to the impoundments, necessary to address the thermal impacts to Moon Brook and bring the Brook into full compliance with the Thermal TMDL.

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 primary sources of recolonization of brook trout exist. The first is the stream reach upstream of Combination Pond where brook trout are plentiful. However, if the pond remains and its outlet structure remains as a drop inlet spillway, reintroduction will likely occur but at a very slow rate. The second and most promising source of brook trout reintroduction is from Paint Mine 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 at the base of the temperature impaired reach, 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 Moon Brook; however, there are several components that could be developed to show progress toward attainment of the temperature target 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 Moon 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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