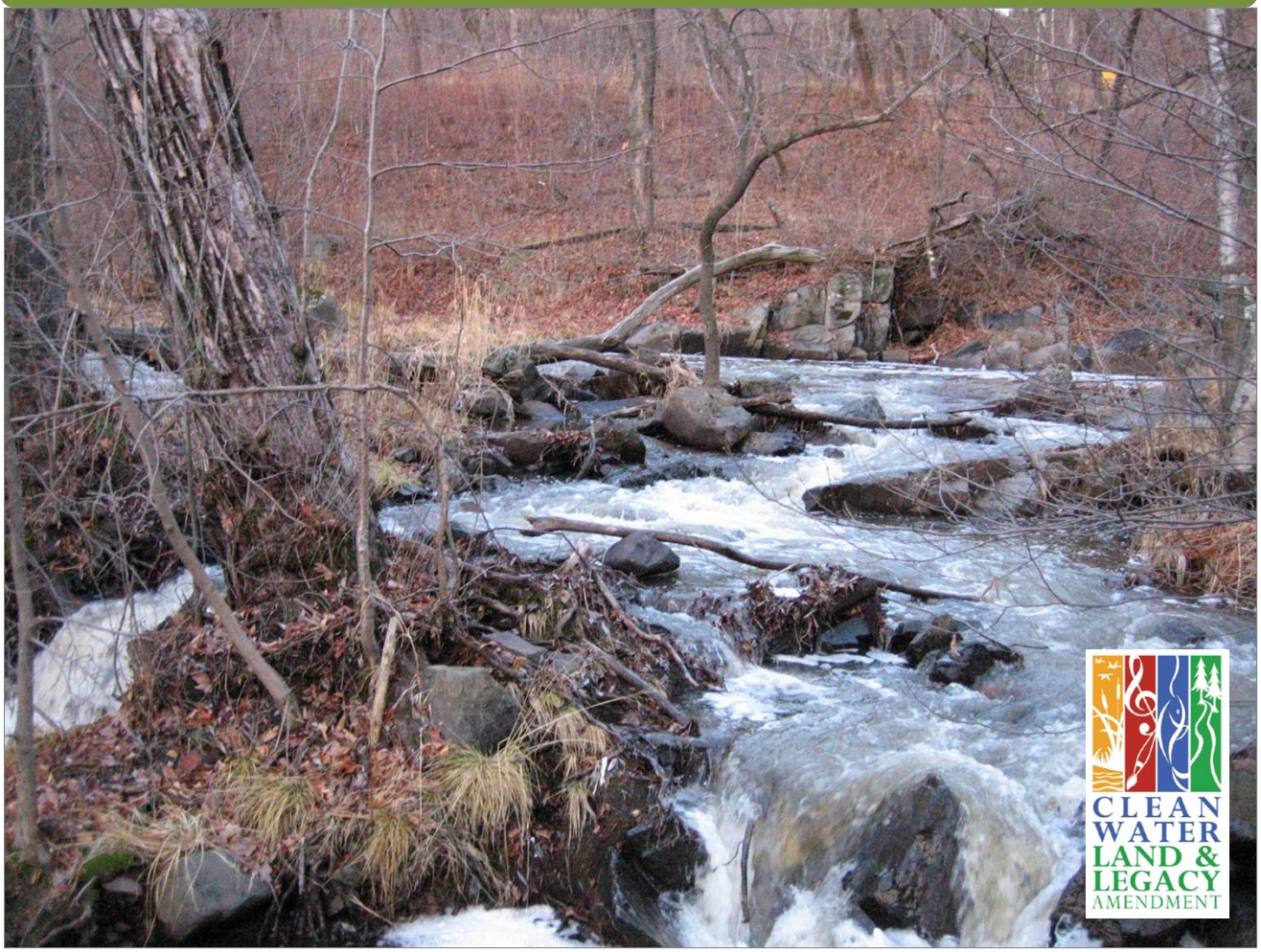
Miller Creek Water Temperature Total Maximum Daily Load

A report to address impairment of aquatic life due to elevated stream temperature.



Minnesota Pollution Control Agency

June 2017

wq-iw10-07b

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- City of Hermantown
- St. Louis County
- Minnesota Department of Natural Resources
- Minnesota Department of Transportation
- Minnesota Pollution Control Agency
- EPA, Mid-Continent Ecology Division
- Natural Resources Conservation Service
- Lake Superior College
- Minnesota Sea Grant
- University of Minnesota – Duluth
- University of Minnesota – Duluth, Natural Resources Research Institute (NRRI)
- University of Minnesota, St. Anthony Falls Laboratory
- Laurentian Resource Conservation & Development
- Isaak Walton League
- St. Louis River Alliance

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Acronyms

AUID	Assessment Unit ID
BMP	Best Management Practice
BTU	British Thermal Unit
C	Celsius
CFR	Code of Federal Regulations
cfs	cubic feet per second
CWA	Clean Water Act
DM	Daily Maximum
DNR	Minnesota Department of Natural Resources
EPA	U.S. Environmental Protection Agency
EPT	Ephemeroptera, Plecoptera & Trichiptera
F	Fahrenheit
EQuIS	Environmental Quality Information System
GIS	Geographic Information System
GJ	Gigajoule (10^9 Joules)
LA	Load Allocation
LC	Load Capacity
LSC	Lake Superior College
MINUHET	Minnesota Urban Heat Export Tool
MnDOT	Minnesota Department of Transportation
MOS	Margin of Safety
MPCA	Minnesota Pollution Control Agency
MS4	Municipal Separate Storm Sewer Systems
MWAT	Maximum Weekly Average Temperature
NPDES	National Pollutant Discharge Elimination System
NRRI	Natural Resources Research Institute
RSPT	Regional Stormwater Protection Team
SAFL	St. Anthony Falls Laboratory
SDS	State Disposal System
SWCD	Soil and Water Conservation District
SWMM	Storm Water Management Model
SWPPP	Stormwater Pollution Prevention Plan
TAG	Technical Advisory Group
TMDL	Total Maximum Daily Load
UMD	University of Minnesota, Duluth
USGS	United States Geologic Survey
WCA	Wetlands Conservation Act
WLA	Wasteload Allocation
WRAPS	Watershed Restoration and Protection Strategies

Executive Summary

This report addresses the impairment of aquatic life in Miller Creek due to elevated water temperature. Miller Creek is a small, urban trout stream flowing through the cities of Duluth and Hermantown in northeastern Minnesota. The watershed includes parks, trails and residential neighborhoods, but also crisscrosses the regions retail, commercial and transportation corridors. The importance of the stream, along with other streams and natural resources of this area, is continually reinforced by the many efforts and activities undertaken by citizens, businesses, schools, and community and government organizations to protect and restore stream water quality and ecology.

Water temperature data demonstrate that problems occur in summer months, mostly from high air temperatures during periods of lower stream flows, or less frequently from runoff from summer rains that occur after high air temperatures. Elevated stream temperatures are believed to also be negatively affecting the fish and aquatic insect communities.

The Clean Water Act (CWA) requires a process to analyze and correct water problems. This is called a Total Maximum Daily Load (TMDL) study. The TMDL establishes the maximum amount of a pollutant a water body can receive on a daily basis and still meet water quality standards. The TMDL is divided into wasteload allocations (WLA) for point or permitted sources, and load allocations (LA) for nonpoint sources, which includes natural background, and a margin of safety (MOS). The heat load (pollutant) and load reductions in this TMDL are in gigajoules (GJ), a measure of energy, per day (GJ/day). An energy-based allocation was used in order to express temperature as a load-based TMDL.

This study used a variety of methods including a temperature model, a heat export model and a stormwater model. The models evaluated overall heat inputs to the stream, contributions of heat from all sources, and determined the heat limits to achieve a healthy stream. The heat analysis:

- determined actual and allowable heat inputs as a function of flow conditions;
- estimated the contributions from atmospheric heating and stormwater to the overall heat budget; and
- determined the contributions of each Municipal Stormwater Permit.

The TMDL and associated WLAs and LAs were further divided into five flow regimes: high, moist, mid, dry and low. Most heat violations occurred under “dry” flow conditions. Improvement efforts should be focused on the lower flow conditions, and especially within the stream segment from Haines Road and U.S. Highway 53 to below Miller Hill Mall, to have the greatest temperature mitigation impact. Moderate reductions of heat input from stormwater (40%) are required, under dry flow conditions. A summary of the heat loading, WLAs and LAs can be found in Table 6 in Section 4.1.7.

1. Project Overview

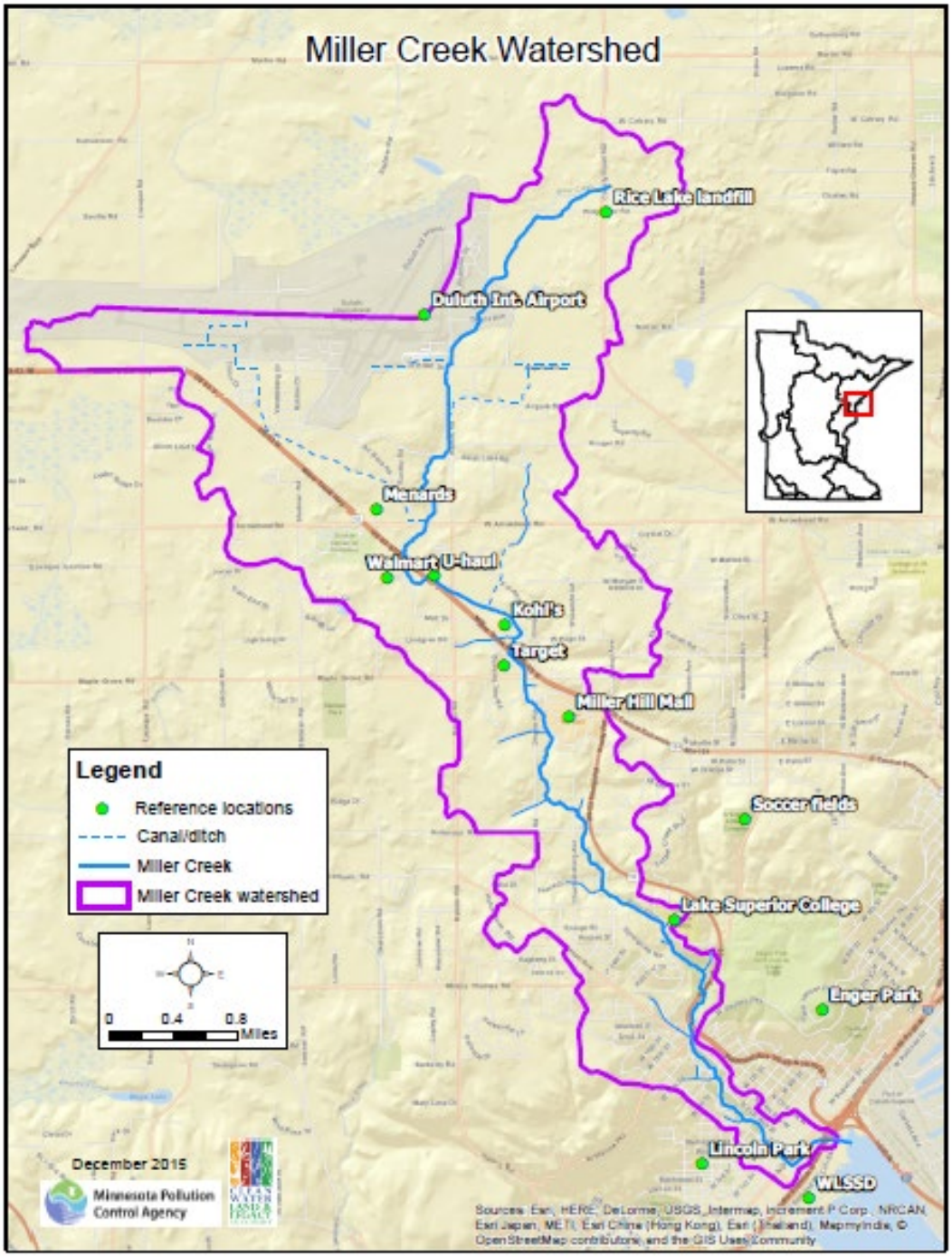
1.1 Purpose

The CWA Section 303(d) requires states to publish, every two years, a list of surface waters that do not meet water quality standards and do not support their designated uses. These waters are classified as impaired. Once a water body is placed on the impaired waters list, a TMDL must be developed for it. The TMDL provides a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards, and allocates pollutant loads to the various sources of the pollutant.

This study serves to address the federal CWA requirement to establish a TMDL for the temperature impairment in Miller Creek. In addition, the report will serve as a resource to be used by water quality agencies, individual citizens, watershed planners, and local and state government officials to identify the key causes and implement solutions for these impairments.

Miller Creek was placed on Minnesota's 2002 Impaired Waters List for not meeting the assigned beneficial uses for aquatic life, based upon elevated water temperatures for Class 2A waters. Minnesota's chronic standard for temperature in Class 2A waters is "no material increase". For this TMDL, a numeric target for water temperature was set at 19 degrees Celsius (°C), which is equivalent to 66 degrees Fahrenheit (°F). This study focuses on temperature (heat) as a primary factor that is affecting the coldwater biotic communities. The TMDL study was completed through analysis of existing and newly collected data and field measurements, watershed modeling, calculation of loading capacity, and through developing implementation strategies to meet TMDL goals.

Figure 1: Miller Creek Watershed with locations identified in the TMDL document.



1.2 Identification of Waterbody

Miller Creek was placed on Minnesota's 2002 Impaired Waters List due to aquatic life use impairments, based upon water temperatures for Class 2A waters, as summarized in Table 1. There are additional aquatic life and aquatic recreation impairments on Miller Creek, as detailed in Table 2. Because impairments caused by elevated temperature are so different from impairments caused by more typical pollutants, these water quality impairments are not addressed in this TMDL study and will be addressed separately in the future. The TMDL for the Aquatic Recreation impairment (due to *Escherichia coli*) is

anticipated to be completed in 2017 as part of the Duluth Urban Watershed Restoration and Protection Strategies (WRAPS) project. The TMDLs for the Aquatic Life impairments (due to Lack of Coldwater Assemblage, Macroinvertebrate Bioassessments, and Chloride) are anticipated to be completed in the future as part of the second cycle of the Duluth Urban Watershed WRAPS, by approximately 2025.

Table 1: Impaired designated uses for Miller Creek addressed in this TMDL study.

Name	River AUID	Year Listed	Affected Use	Pollutant or Stressor
Miller Creek	04010201-512, Headwaters to St. Louis River	2002	Aquatic Life	Water Temperature (Heat)

Table 2: Impaired designated uses for Miller Creek not addressed in this TMDL study.

Name	River AUID	Year Listed	Affected Use	Pollutant/Stressor
Miller Creek	04010201-512, Headwaters to St. Louis River	2002	Aquatic Life	Lack of Coldwater Assemblage
Miller Creek	04010201-512, Headwaters to St. Louis River	2010	Aquatic Life	Chloride
Miller Creek	04010201-512, Headwaters to St. Louis River	2012	Aquatic Recreation	*Escherichia coli*
Miller Creek	04010201-512, Headwaters to St. Louis River	2012	Aquatic Life	Aquatic Macroinvertebrate Bioassessements

1.3 Priority Ranking

The Minnesota Pollution Control Agency's (MPCA's) schedule for TMDL completions, as indicated on the 303(d) impaired waters list, reflects Minnesota's priority ranking of this TMDL. MPCA developed a state plan, Minnesota's TMDL Priority Framework Report, to meet the needs of EPA's national measure (WQ-27) under EPA's Long-Term Vision for Assessment, Restoration and Protection under the Clean Water Act Section 303(d) Program. As part of these efforts, MPCA identified water quality impaired segments that will be addressed by TMDLs by 2022. Miller Creek, addressed by this TMDL, is part of that MPCA prioritization plan to meet EPA's national measure.

2. Applicable Water Quality Standards and Numeric Water Quality Targets

The criteria used for determining stream reach and lake impairments are outlined in the MPCA's document Guidance Manual for Assessing the Quality of Minnesota Surface Waters for the Determination of Impairment: 305(b) Report and 303(d) List (MPCA 2014). Minnesota's Surface Water Quality Standards provide information on beneficial uses assigned to waterbodies, numeric and narrative standards for pollutants, and non-degradation provisions assigned to high-quality and unique waters.

Applicable water body classifications and water quality standards are specified in Minn. R. 7050. Miller Creek (headwaters to St. Louis River) is classified as a 2A stream (Minn. R. 7050.0470). The Class 2 water designation pertains to aquatic life and recreation, where Class 2A waters "shall be such as to permit the propagation and maintenance of a healthy community of cold water sport or commercial fish and associated aquatic life" (Minn. R. 7050.222).

2.1 Water Temperature

The temperature standard for Class 2A waters is a narrative statement of "no material increase" (Minn. R. 7050.0222). In order to quantify and determine a TMDL for Miller Creek, numeric temperature target values for the TMDL were chosen, based on the values set forth in U.S. Environmental Protection Agency (EPA's) *Quality Criteria for Water* (EPA 1986), which provides the following numeric temperature criteria for brook trout:

- 19 °C (66 °F) = maximum weekly average temperature (MWAT) for growth (chronic), and
- 24 °C (75 °F) = daily maximum (DM) temperature for survival of short term exposure (acute).

The MWAT temperature (19 °C) was selected as the numeric temperature target for the TMDL because there were more exceedances of the MWAT than the DM temperature in the 2007 to 2009 data set (Herb 2011). The number of exceedances for each criteria at the Miller Creek sites are shown in Table 4. Given that the exceedances generally paralleled each other over time, use of the MWAT as the target for the TMDL will also address the acute target (Figures 2, 3, and 4).

Figure 2: Miller Creek temperature exceedances 2007, MWAT and DM, Mall Drive Target.

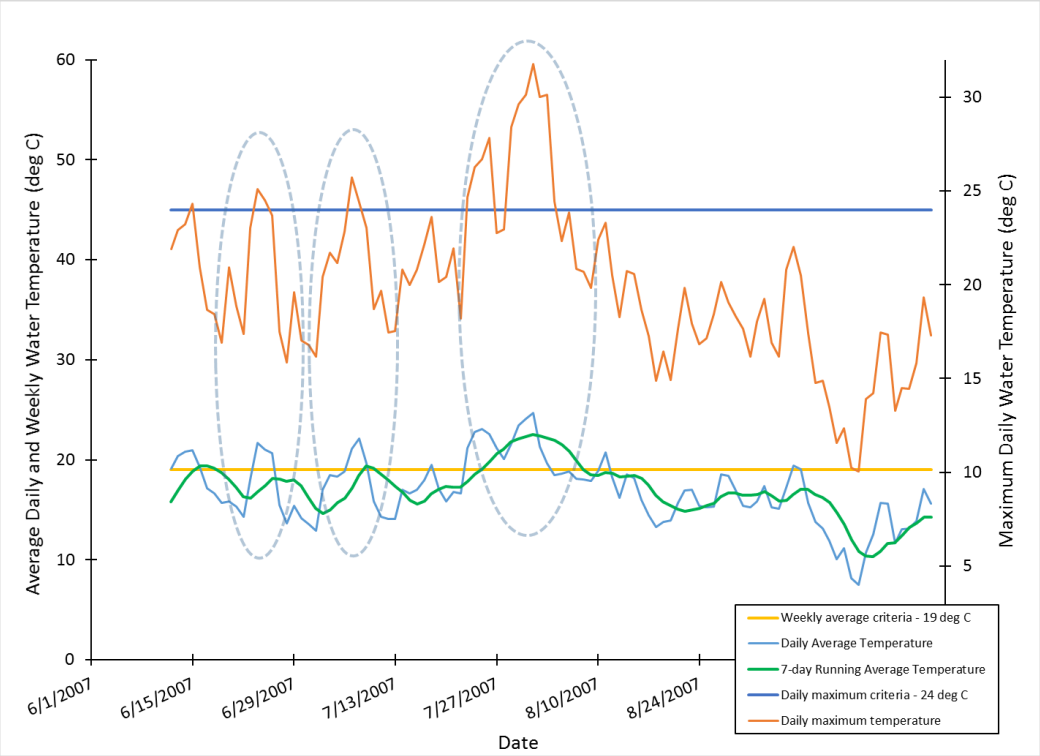


Figure 3: Miller Creek temperature exceedances 2008, MWAT and DM, Mall Drive Target.

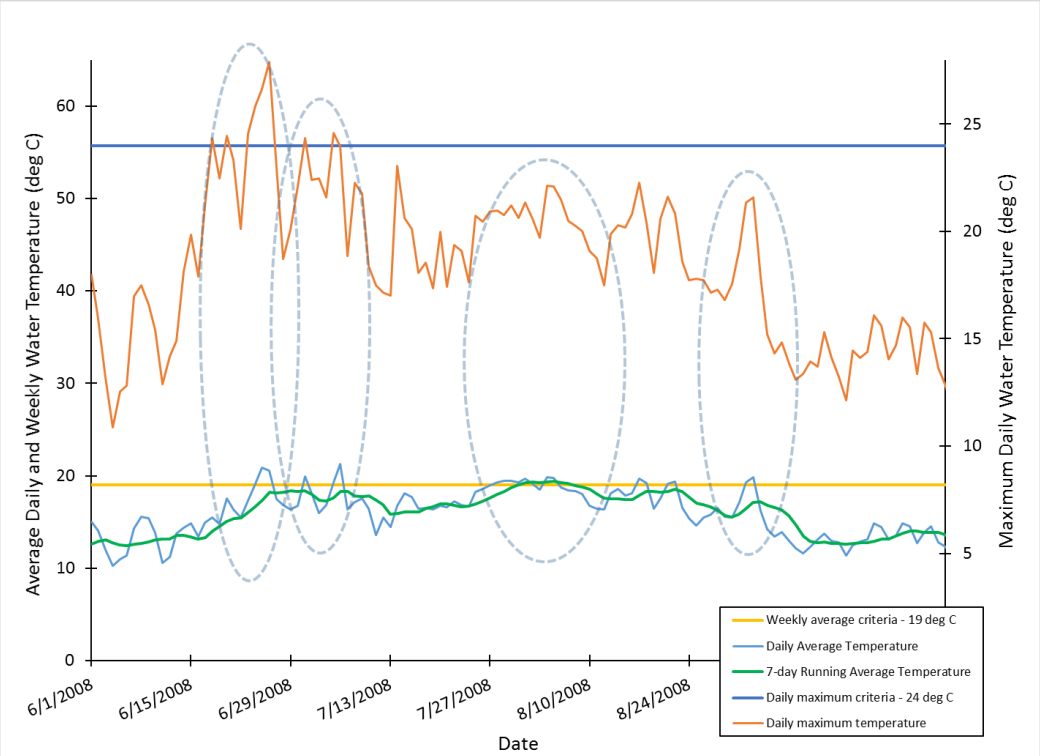
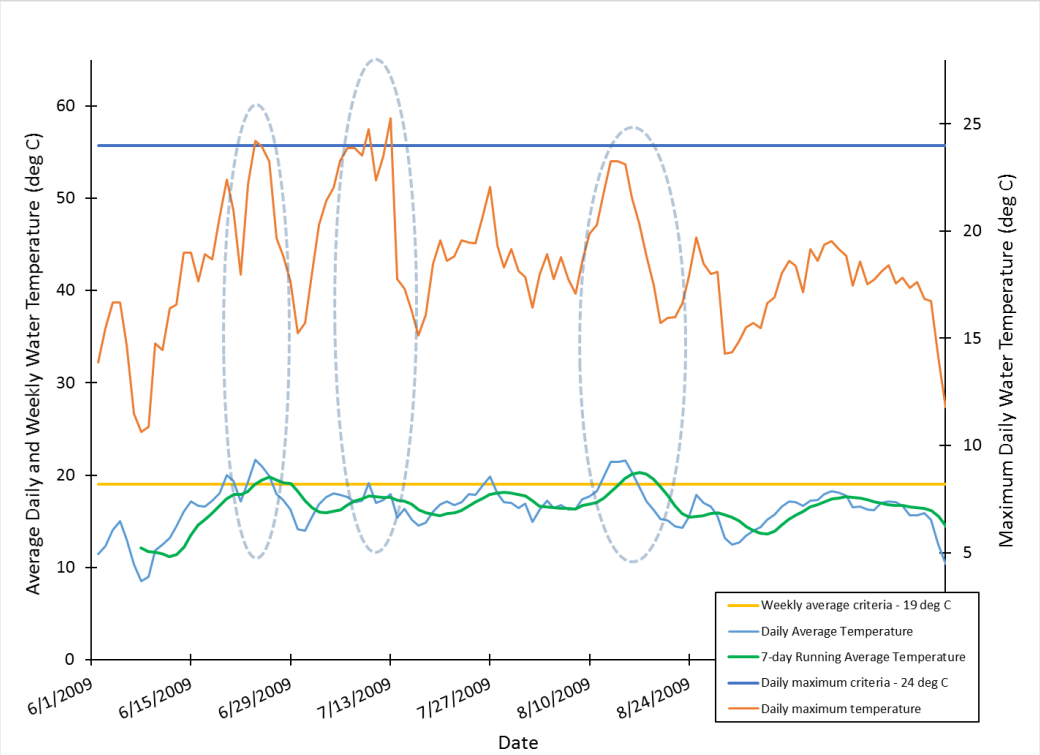


Figure 4: Miller Creek temperature exceedances 2009, MWAT and DM, Mall Drive Target.



Restoring the temperature regime will be beneficial to aquatic biota by reducing the occurrences and frequencies of thermal stress, allowing for an expanded potential range for fish movement during periods of lower flows and higher thermal stress, and lessening the reliance of biota on isolated refugia. A more favorable temperature (and flow) regime may also potentially provide conditions for greater quantity and diversity of coldwater macroinvertebrates.

3. Watershed and Waterbody Characterization

The Miller Creek Watershed is located within the municipalities of Duluth and Hermantown in northeastern Minnesota and covers 9.4 square miles (6,028 acres). The stream originates from wetlands near the Rice Lake Landfill and Duluth International Airport (Figure 1). This portion of the watershed has the lowest gradient and is the largest proportion (area) of the watershed, containing most of the wetlands and undeveloped lands. Current land uses include low to mid-density urban residential, and commercial and industrial development. The middle section of the watershed is at the heart of the urbanized area, with Miller Hill Mall and surrounding retail and commercial businesses, and a regional transportation corridor. This portion also includes low to mid-density urban residential and institutional development, and contains considerable green space along the stream corridor. The lower Piedmont and Lincoln Park neighborhoods largely make up the lower section of the watershed. This section also contains the Enger Park Golf Course, Lake Superior College (LSC) and Lincoln Park, along with commercial and industrial properties along the St. Louis River. Much of the bottom 0.5 miles of Miller Creek has been channelized and buried. Miller Creek discharges to the St. Louis River, and is within the Lake Superior Basin.

3.1 Lakes

This TMDL covers a single resource, Miller Creek, and there are no lakes in the watershed.

3.2 Streams

This TMDL covers a single stream, Miller Creek, and encompasses the entire watershed, headwaters to mouth.

3.3 Subwatersheds

Miller Creek is located in the St. Louis River Watershed. For the purposes of this TMDL, the Miller Creek Watershed has been treated as a single subwatershed entity, and was not divided into further subwatersheds.

3.4 Land Use

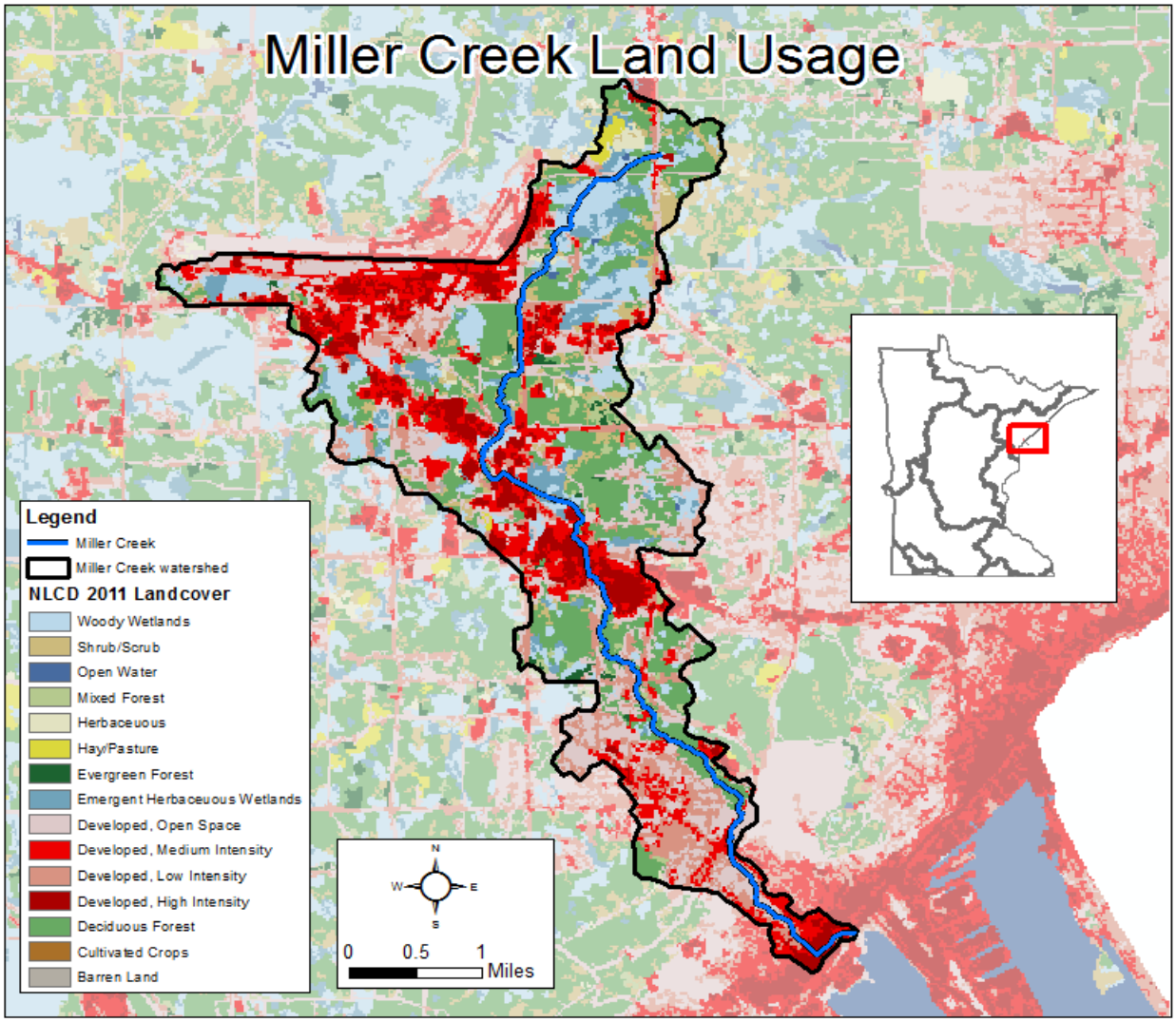
Land uses in the Miller Creek Watershed encompass a broad range of uses, as shown in Table 3 and in Figure 5.

Table 3: Land Uses in the Miller Creek TMDL study area.

Land Uses in Miller Creek Watershed	Area (acres)	Percent
Deciduous Forest	1269	21%
Developed, Open Space	1131	19%
Developed, Medium Density	998	16%
Developed, Low Density	773	13%
Woody Wetlands	611	10%
Developed, High Intensity	574	9%
Emergent Herbaceous Wetlands	274	5%
Scrub/Shrub	248	4%
Mixed Forest	55	1%
Grassland/Herbaceous	52	1%
Pasture/Hay	33	1%
Evergreen Forest	29	<1%
Open Water	9	<1%
Cultivated Crops	4	<1%
Barren Land (Rock/Sand/Clay)	3	<1%
Total =	6063	100%

Source: 2011 NLCD Data Set (USGS)

Figure 5: Land Uses within Miller Creek Watershed.



3.5 Current/Historic Water Quality

Water quality monitoring data for Miller Creek were obtained from MPCA's Environmental Quality Information System (EQuIS) database. Stream flow and stage data were obtained from the Minnesota Department of Natural Resources (DNR)/MPCA Cooperative Stream Gaging web page (Hydstra database). Stream and water chemistry data were augmented with other data collected in support of the TMDL (e.g., stream temperature, stormwater temperature, air temperature, precipitation, relative humidity, and solar radiation). No long term, continuous data set exists for Miller Creek, so data from 1997 to 2009 were analyzed to better understand the more recent data, and to establish average conditions. Data from 2007 to 2009 were used in development of the TMDL.

The following reports provide a detailed summary of data used for the TMDL and should be referred to regarding detailed data analysis and modeling underlying the TMDL:

- **Analysis of Flow Data from Miller Creek, Duluth, Minnesota,** University of Minnesota, St. Anthony Falls Laboratory (SAFL), Project Report No. 522, September 2009.

- **Analysis of Stream Temperature Data from Miller Creek, Duluth, Minnesota**, University of Minnesota, SAFL, Project Report 529, October 2009.
- **Stream Temperature Modeling of Miller Creek, Duluth, Minnesota**, University of Minnesota, SAFL, Project Report No. 535, October 2009.
- **Streamflow Modeling of Miller Creek, Duluth, Minnesota**, University of Minnesota, SAFL, Project Report No. 536, January 2010.
- **Miller Creek Macroinvertebrate, Habitat, and Temperature Report**, Natural Resources Research Institute (NRRI), University of Minnesota Duluth, NRRI Technical Report Number NRRI/TR2010/11, June 2010.
- **Characterization of Stream Temperature and Heat Loading for Miller Creek, Duluth, Minnesota**, University of Minnesota, SAFL, Project Report No. 552, August 2011.

Key findings, conclusions and recommendations from these studies include:

- Only 5% to 10% of all temperature exceedances appear to be associated with surface runoff due to rainfall, and even fewer were caused exclusively by runoff (Herb and Stephan 2009b).
- The temperature of Miller Creek is driven by atmospheric heat transfer during dry weather periods, by surface runoff during wet weather with substantial runoff, and by both mechanisms during small rainfall events (Herb et al. 2011).
- Temperature changes are most apparent in the stream from reaches with low shading, but persist for several kilometers downstream into reaches of higher shading (Herb et al. 2011).
- The temperature of Miller Creek was found to be relatively sensitive to air temperature, e.g., a 1 degree C increase in air temperature led to a 0.6 C increase in stream temperature. This sensitivity is likely due to low groundwater inputs, which tend to buffer diurnal and seasonal changes in air temperature (Herb et al. 2011).
- Wetlands provide an important role in Miller Creek through supplying the baseflow to the stream. The rapid recession in the storm hydrographs points to channel storage and surface storage in wetlands rather than in aquifers as the source of water during low flow periods. The wetlands in the upper reaches of Miller Creek therefore need to be protected because they play a key role in the hydrology during low flow periods (Erickson et al. 2010).

Please note that the supporting reports include calculations and discussions for splitting Miller Creek into two sections and developing two separate temperature TMDLs. For the purposes of submitting this Water Temperature TMDL to EPA for approval, a single TMDL was completed for the entire stream reach (headwaters to mouth). The detailed work in these reports has been and will continue to be very useful in planning and targeting implementation activities. The reports can be access through links in Appendix C or through the Miller Creek TMDL web page:
https://www.pca.state.mn.us/water/tmdl/miller-creek-water-temperature-tmdl-project

Temperature is a measure of the concentration of thermal energy (heat) in a substance such as water. Heat can enter a stream from atmospheric heat transfer and heat conduction, through the sediment, and by inputs of surface water or groundwater (Herb 2011). Figure 7 depicts the major heat flux processes in streams. The temperature impairment indicates that the stream is receiving excess heat

energy for particular climate, flow conditions, and for the prescribed designated uses (for Miller Creek, as a coldwater fishery). Recent data from 2016 demonstrated a strong correlation between stream temperatures and water levels, with the strongest correlations during low flow periods and higher stream temperatures (Labuz 2017) (Figure 6).

Figure 6: Water temperatures versus water levels at Kohl's 2016 (Labuz 2017).

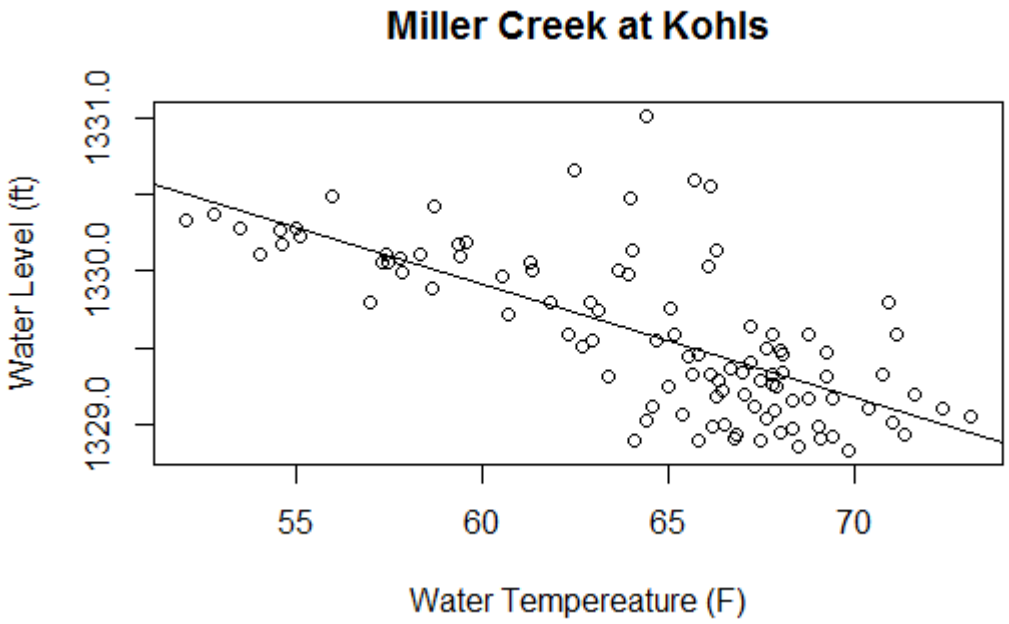
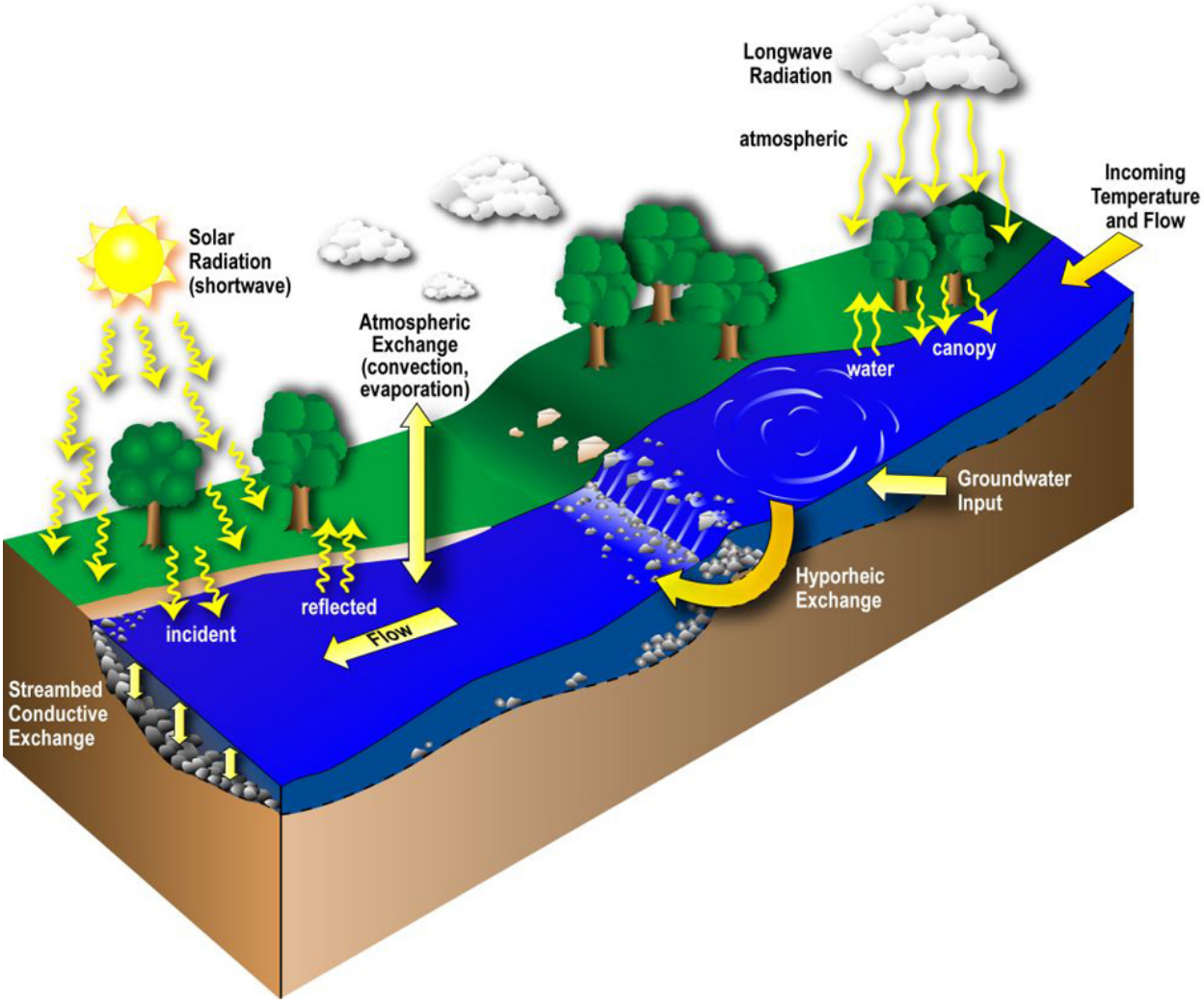
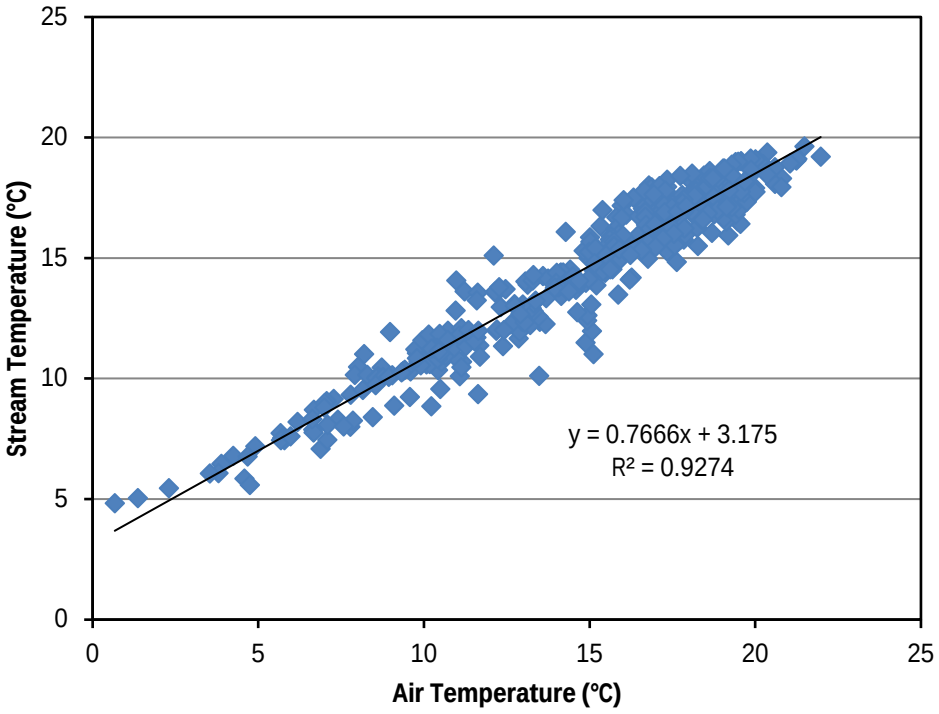


Figure 7: Major heat fluxes in streams (EPA 2010 Release, CADDIS)



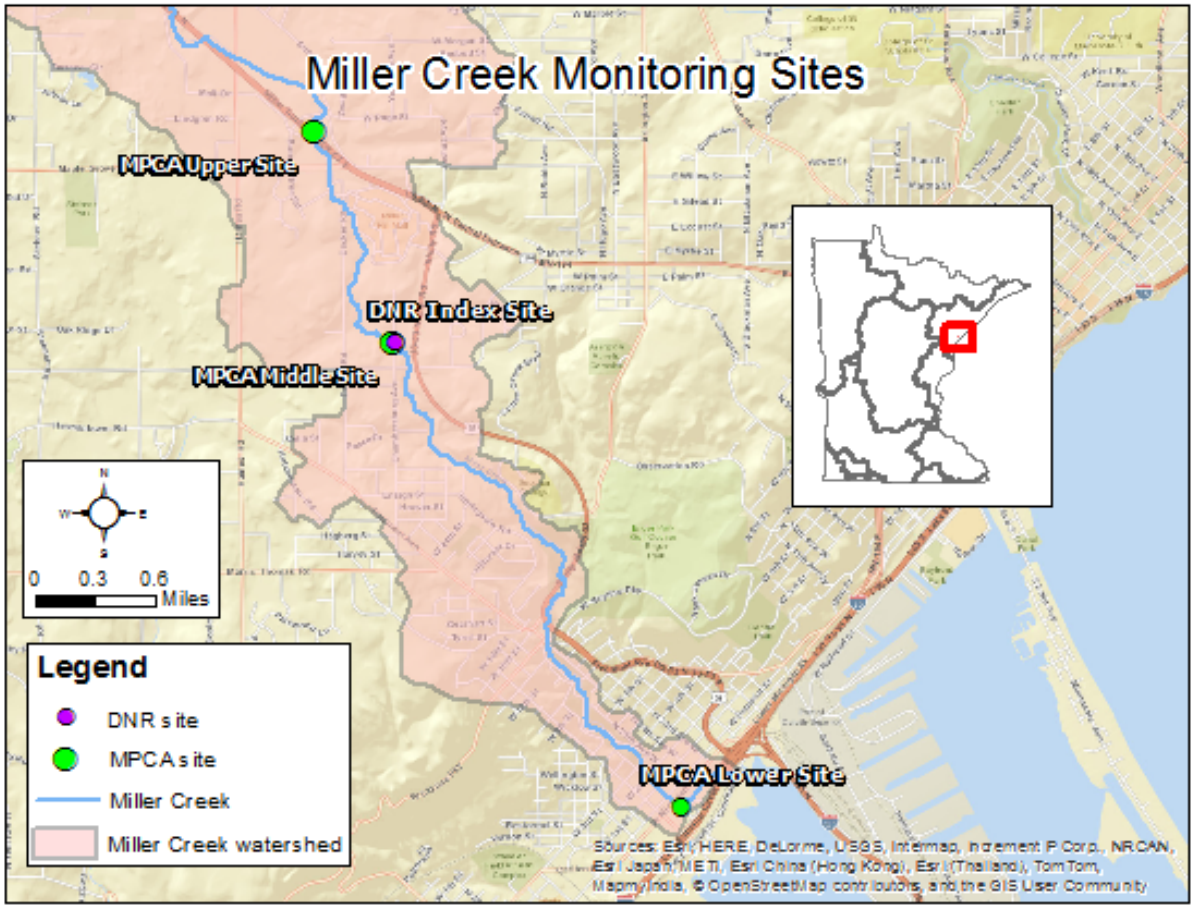
Herb and Stefan (2009b) found stream temperature in Miller Creek to be highly correlated to air temperatures at daily to annual time scales (Figure 8). This relationship was found to become stronger as stream flows become lower, less than 5 cubic feet per second (cfs), and suggests low groundwater inputs into the stream (Herb et al. 2009). Water temperature exceedances above 20 °C (68 °F) are caused mainly from strong heat transfer from the atmosphere to the stream. This is especially true for the middle reaches with low channel shading, such as the channelized section above Kohl's Department Store in Duluth (Herb 2011).

Figure 8: Weekly running average stream temperature at 26th Avenue West versus weekly running average air temperature at Duluth International Airport for 2007, 2008, and 2009 (Herb 2011).



Stream temperature exceedances were observed throughout Miller Creek, however, most exceedances occurred in the middle section of the stream, from Haines 53 to Mall Drive Target. Over half (56%) of the temperature exceedances (greater than 19 °C) occurred within this portion of the watershed. Table 4 summarizes the number of stream temperature exceedances by temperature station for 2007 to 2009 for MWAT (greater than 19 °C) and DM (greater than 24 °C) temperature targets. July and August had the most exceedances (84%), while September had no temperature exceedances during the three-year period (Herb 2011).

Figure 9: MPCA stream stations and DNR brook trout index site (mile 3.6).



The TMDL utilizes data collected at three stream stage locations on the main stem of Miller Creek: the 'Upper' station is located between U.S. 53/TH 194 and Kohl's Department Store, the 'Middle' station is located at the crossing with Chambersburg Road, and the 'Lower' station is located at 26th Avenue West (Figure 9). Stream flow data was collected at these sites at regular and intermittent intervals in years 1997 through 2009 (Herb and Stefan 2009a).

The upper watershed contains the largest portion of land and the watershed and stream channel are less steep than the middle and lower portions, providing water a longer residence time. Analysis of flow data suggests that, on average, the flow at the middle site is about 80% of the flow volume (cfs) at the lower station, and flow at the upper station is about 70-75% of the lower station (i.e., total flow) (Herb and Stefan 2009a; Labuz 2017). The higher gradient stream slope and associated higher flow velocities in the lower section provide less time for the stream to respond to local climate conditions. Flow data from 2007 to 2009 indicate that 60% of the flows in Miller Creek are less than 5 cfs, 10% of flows are 0.5 cfs or less, while only 10% of flows are equal to or exceed approximately 22 cfs. The observed low flows suggest that baseflow in Miller Creek originates from the drawdown of wetland areas and from channel storage. Labuz (2017) found that stream flows during low flows were comprised of 70% surface water and 30% groundwater. Because bedrock in the Miller Creek Watershed is found at shallow depths, it is likely that the hydrogeology includes groundwater recharge from the wetlands; wetlands most likely also supply the source water for springs that exist in the watershed. It is likely that wetlands play a significant role in the hydrology of Miller Creek by reducing stormwater peak flows, absorbing and

slowly releasing stormwater and supplying baseflows to the stream, and by providing areas and sources for groundwater recharge (Erickson et al. 2010).

3.5.1 Fish

The primary species of concern, brook trout (Salvelinus fontinalis), are members of the salmon family that inhabit small spring-fed streams and spring ponds. They prefer cool and clear water with sandy and gravely bottoms and moderate vegetation. In northeastern Minnesota, they inhabit the headwaters and small streams along the north shore of Lake Superior. Brook trout generally live for three to four years and typically reach six to ten inches in length. The low productivity and smallness of north shore streams prevent many trout from exceeding one foot in length. Brook trout are highly susceptible to stream degradation and climate change, including low oxygen levels due to sediments from runoff and warm waters (DNR 2009).

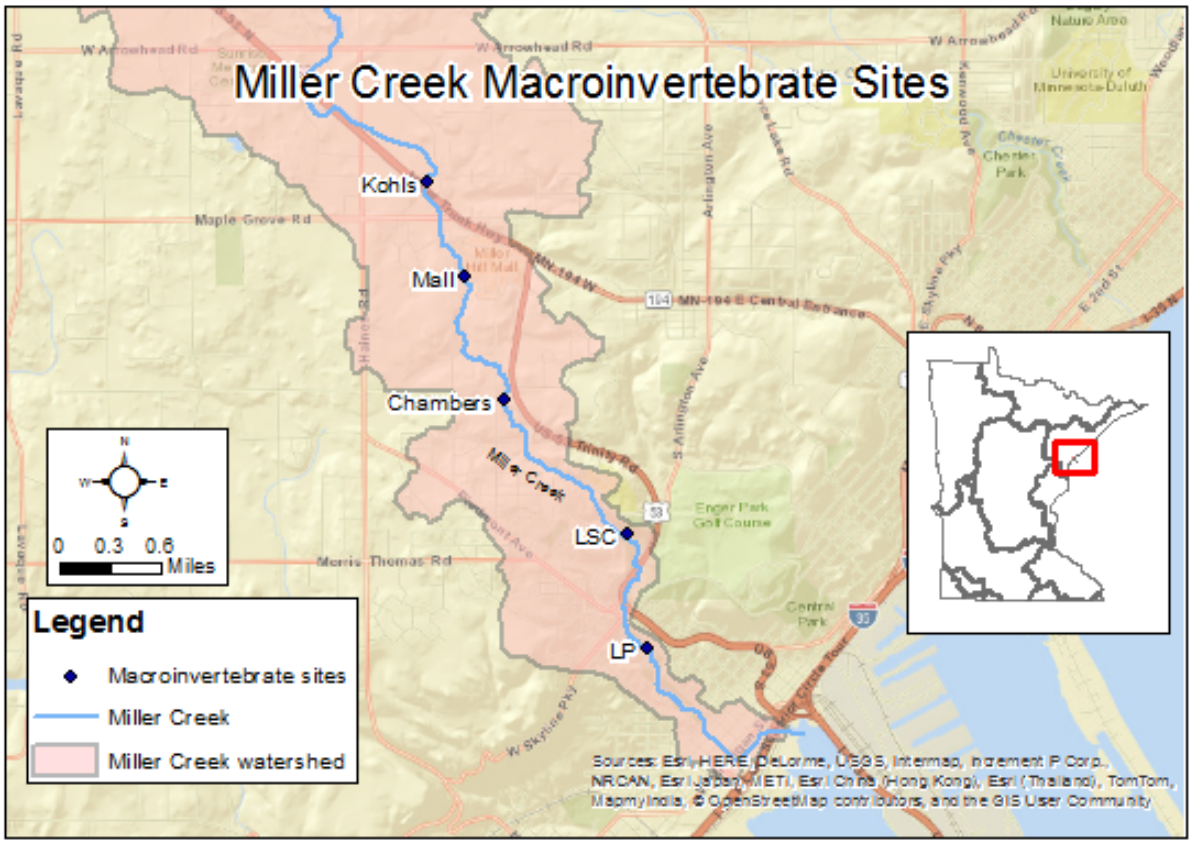
Historically, brook trout and brown trout were frequently stocked in Miller Creek between 1955 and 1973. However, no stocking has taken place since 1973. Stream station 3.6 (below Chambersburg Avenue) (Figure 9) is assessed annually for trout populations and temperature as a brook trout index station for the DNR Duluth Area Fisheries. The annual surveys indicate that the trout population has steadily declined since the early 1990s. A sharp decline during 2002 and 2003 was due to a severe winter in which the creek water froze solid in some areas and killed fish in portions of the stream (DNR 2014).

Recent fish population survey results indicate that the thermal regime remains favorable for brook trout. However, localized, short term periods of stress occur and are driven by low summer flows and radiant warming, combined with warm water inputs from impervious surfaces in the watershed. One of the biggest threats to the long-term survival of brook trout populations continues to be water quality and temperature. A major rain event and subsequent flooding in June 2012 resulted in changes to stream channel morphology and habitat within Miller Creek, including at station 3.6 (DNR 2014).

3.5.2 Macroinvertebrates

A benthic macroinvertebrate study was completed at five locations on Miller Creek in 2008 by NRRI (Figure 10). A total of 116 macroinvertebrate taxa were collected from the five sites, with up to 62 taxa found at any one site. Most of the sites have reasonably good habitat conditions for macroinvertebrates, with low embeddedness and appropriate substrate size to provide interstitial space for macroinvertebrates. However, only one of the sites (Chambersburg) had abundances of taxa sensitive to stress, especially mayflies, stoneflies and caddisflies (Ephemeroptera, Plecoptera, and Trichoptera, or EPT taxa). The other sites contained high proportions of taxa more tolerant to stress, such as Chironomidae (Diptera) and oligochaete and nematode worms (Brady and Breneman 2010).

Figure 10: Macro-invertebrate sampling sites on Miller Creek 2008.



3.5.3 Watershed Climate/Weather Variability/Atmospheric Conditions

The weather in the Duluth area can be strongly influenced by the proximity to Lake Superior and the topographic relief of Miller Creek, with over 800 feet of elevation change from the headwaters to mouth. Herb and Stefan (2009b) found that climate conditions in the upper part of the watershed (above LSC) are the most important factor in determining stream flow and stream temperature. In the summer, it is not uncommon to experience at least a 20° difference in air temperature between the headwaters area "on top of the hill" and at the confluence with the St. Louis River Estuary. The headwaters area frequently experiences warmer air temperatures in the summer and cooler in the winter. The reverse is often true for the lower section near the St. Louis River Estuary and nearby Lake Superior, with cooler air temperatures in the summer than the headwaters and warmer temperatures in the winter. For this TMDL, 2008 was found to be a typical climate year, with near normal precipitation and air temperatures (Herb 2011).

3.6 Pollutant Source Summary

3.6.1 Water Temperature

Potential sources of temperature (heat) loading in Miller Creek were investigated through field data collection, analysis and modeling, as described in Section 3.5 and in technical reports in Appendix C. Water temperature data from 2007 to 2009 identified the middle sections of Miller Creek, from the U.S. Highway 53/Haines Road to Mall Drive Target stream temperature stations, to be contributing over 50% of the total temperature exceedances (greater than 19°C), and mainly caused by the transfer of heat

from the atmosphere. Data suggests that this area extends to just below Miller Hill Mall (Herb and Stefan 2009b). Exceedances in this section were largely contributed to by lack of riparian/channel shading and overhead tree canopy. Overall, stormwater runoff to the stream does cause some of the temperature exceedances; however data suggests that only a small percentage of the observed exceedances are caused by stormwater (Herb and Stefan 2009b; Herb 2011). These conclusions support earlier work by South St. Louis Soil and Water Conservation District (SWCD) under a Clean Water Partnership Grant (South St. Louis SWCD 2001). Table 4 summarizes the number of water temperature exceedances for weekly average temperatures (greater than 19 °C) and DM temperatures (greater than 24 °C). Temperature exceedances for DM were further analyzed to segregate the data into wet days and dry days, to determine the number of exceedances associated with stormwater inputs (wet days) and solar radiation inputs (dry days) (Herb 2011).

Figure 11: Stream temperature monitoring station locations 2007 to 2009, Miller Creek.

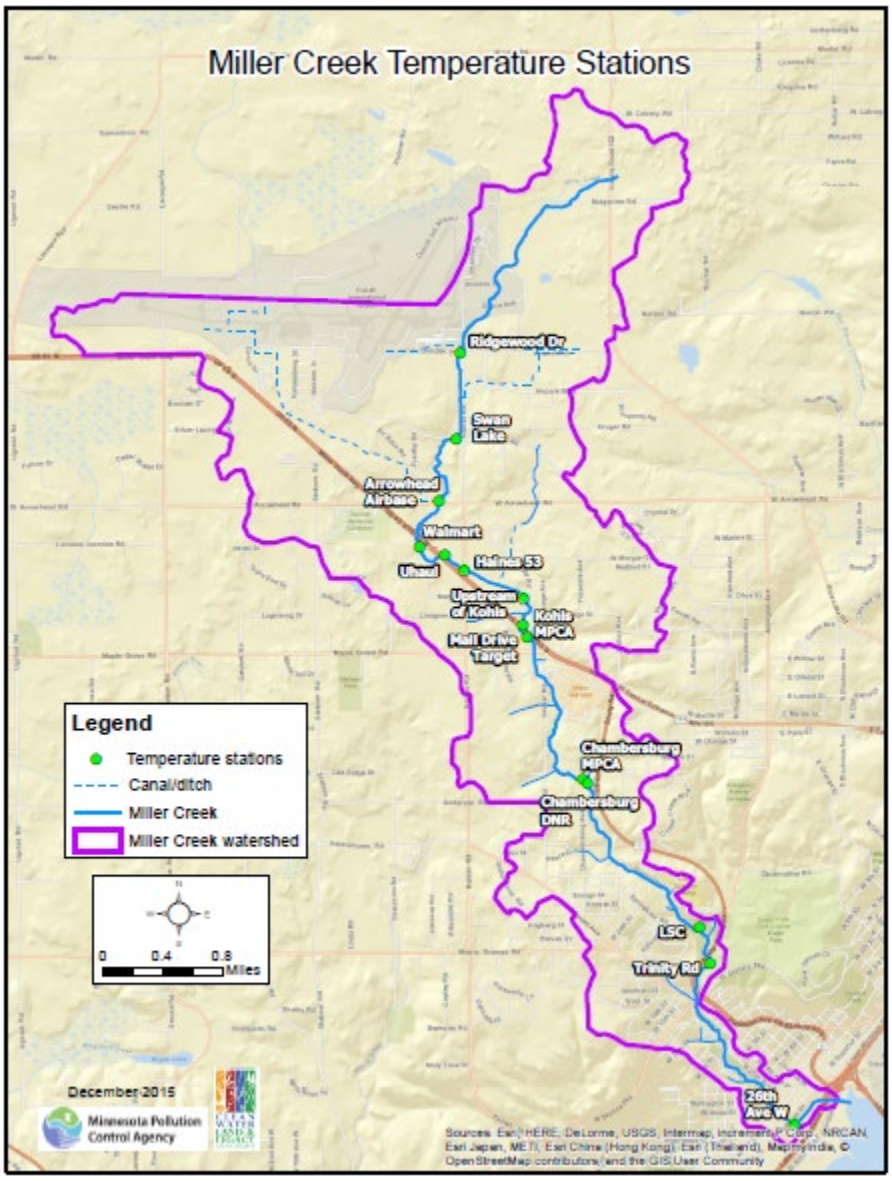


Table 4: Compilation of Weekly (T > 19 °C) and Daily (T > 24 °C) stream temperature exceedances by station and precipitation conditions (wet/dry day) (modified from Herb 2011).

Temperature Exceedances 2007 to 2009	Weekly Exceedances (T > 19 °C)	Daily Exceedances (T > 24 °C)		
Temperature Station	**Total**	**Total**	**Dry**	**Wet**
26th Avenue (downstream)	10	0	0	0
Trinity Rd	15	6	5	1
LSC	18	6	5	1
Chambersburg DNR	5	1	1	0
Chambersburg MPCA	21	7	6	1
Mall Drive Target	38	22	21	1
Kohls MPCA	46	20	17	3
Upstream of Kohls	54	16	15	1
Haines 53	36	6	6	0
Uhaul	10	0	0	0
Walmart	28	2	1	1
Arrowhead Airbase	19	9	8	1
Swan Lake	7	0	0	0
Ridgewood (upstream)	6	0	0	0
Total Exceedances =	313	95	85	10

3.6.1.1 Permitted

Stormwater discharges in Minnesota are permitted through National Pollutant Discharge Elimination System (NPDES) and State Disposal System (SDS) Permits (Permits). Stormwater runoff, which may contain heat that is transferred to receiving waters, may originate from or be conveyed through municipal separate storm sewer systems (MS4), and from runoff associated with construction and industrial activities. This includes runoff during precipitation events, and through discharges from public and private stormwater infrastructure (e.g., curb & gutter, ditches, and stormwater treatment systems). For Miller Creek, stormwater is delivered to the stream via curb & gutter, road ditches, overland runoff, and as discharges from stormwater treatment systems.

For this TMDL, the relative contribution of each permittee to Miller Creek was estimated, because separate stormwater monitoring data was not available for each permittee. It was assumed that each permittee contributed heat to Miller Creek in proportion to the total impervious surface area of each entity (Herb 2011).

3.6.1.2 Non-permitted

Atmospheric Heating: Atmospheric heat transfer to the stream is the dominant mechanism for stream temperature exceedances in Miller Creek. The section from U.S. Highway 53/Haines Road downstream to Miller Hill Mall (a largely channelized section) has lower levels of shading and exhibited the most of all temperature exceedances (in both total number and duration) (Herb and Stefan 2009b).

Unregulated stormwater runoff: Direct runoff and any stormwater that reaches the waterbody without MS4 infrastructure is considered to be non-regulated stormwater, unless regulated by other NPDES permits. Unregulated stormwater runoff makes up only a very small fraction of total stormwater entering Miller Creek and was not quantified for this TMDL.

4 TMDL Development

A TMDL is an established value (or set of values) determining the amount of a pollutant that a waterbody can withstand without exceeding its water quality standard. A TMDL report includes the diagnostic work of: monitoring, inventory, modeling, calculating allocations, reduction strategies, and documenting a public process.

Allocations of the allowable pollutant load are also determined for the various pollutant sources. A TMDL is defined as "the sum of the individual WLA for point sources and LA for nonpoint sources and natural background sources," such that the waterbody's ability to receive pollutant loadings (Loading Capacity) is not exceeded (40 CFR 130.2). The requirements of a TMDL are described in 40 CFR 130.2 and 130.7 and Section 303(d) of the CWA.

The TMDL is developed according to the following equation:

TMDL = LC = ΣWLA + ΣLA + MOS, where:

- Σ = the sum of;
- LC = loading capacity, the greatest pollutant load a waterbody can assimilate without exceeding water quality standards;
- WLA = wasteload allocation, existing and future point source pollutant sources that would require a NPDES Permit;
- LA = load allocation, includes existing and future nonpoint sources of pollution, "natural background" contributions, and any other pollutant sources;
- MOS = margin of safety, the uncertainty in the relationship between pollutant loads and the quality of the receiving water.

The TMDL loading capacity and allocations were calculated in terms of the GJ per day (GJ/day) of heat that Miller Creek can assimilate and still maintain water temperatures below the 19°C MWAT, the numeric temperature target in the TMDL. An energy-based allocation was used in order to express temperature as a load-based TMDL. GJ is a metric term for available energy. For context, the energy of one GJ of electricity will light a 60-watt bulb continuously for six months. Or, it would require approximately 43 GJ of heat energy to raise the temperature of an Olympic-sized swimming pool (660,000 ft^3) by one degree F.

To complete a TMDL for the temperature impairment, temperature is represented as the amount of heat that would be required to raise a given volume of water a given number of degrees above 32 °F (0 °C). Heat is a form of energy that can be described in various units including BTUs (British Thermal Units) and Joules. SAFL (Herb 2011) describes the theory, computations, and modeling completed to determine the loading capacities for this TMDL. Work by Poole and Berman (2001) provides a detailed explanation of heat dynamics and mechanisms affecting stream temperature.

The amount of heat loading, in Joules of energy, to a stream is a function of the density and specific heat of water (ρ and C_p), volume (Q) and temperature (T) of water, and time (t). For any location in a stream, the heat (H) required for the stream temperature to be X degrees above freezing can be calculated as the product of ρ, C_p, Q, T, and t as shown in the equation,

$$H = \rho \times C_p \times Q, \times T \times t,$$

where ρ = 4.186 joule/gram °C and C_p = 62.4 lb/ft^3. Q is stream flow. T is either the observed or target temperature. And, t is 1 day for the TMDL. The observed load is computed with the observed temperature in °C and the loading capacity is computed with the target temperature (19 °C).

The load duration curves were computed using the flow record for Miller Creek at the 26th Avenue West monitoring site, and the target temperature of 19 °C MWAT was used. The observed heat loads were computed using the observed water temperatures and corresponding flow values.

4.1 Water Temperature

In order to characterize the water temperatures in Miller Creek, stream temperature and stormwater temperature were monitored at 25 sites from 2007 to 2009. Data from 14 sites were used for the TMDL. Overhead canopy, bank slope angle and stream orientation data were also collected at the temperature sites. Table 4 provides a summary of the temperature station data and the station locations are depicted in Figure 11.

4.1.1 Loading Capacity

The TMDL builds upon detailed data analysis and modeling that is documented in several reports that are listed in Section 3.5, with links available in Appendix C. Several models were used to calculate pollutant loading and determine necessary load reductions. The year 2008 was chosen as a baseline year because it comprised the most complete set of data for stream flows and temperatures, and it was the most representative to near normal conditions for air temperature and precipitation of the 2007, 2008 and 2009 data sets.

The Stream Network Temperature (SNTEMP) model, United States Geologic Survey (USGS) 2008, a heat transport model, was used to predict daily average and DM stream temperatures from nonpoint source heat inputs to Miller Creek, based upon current riparian shading conditions (June 2008 through September 2008). In addition, several mitigation scenarios with increased shading were also completed utilizing SNTEMP (discussed further in Section 8). Water temperatures were modeled with a focus on low flow (base flow) conditions when trout habitat becomes critical (Herb et al. 2009).

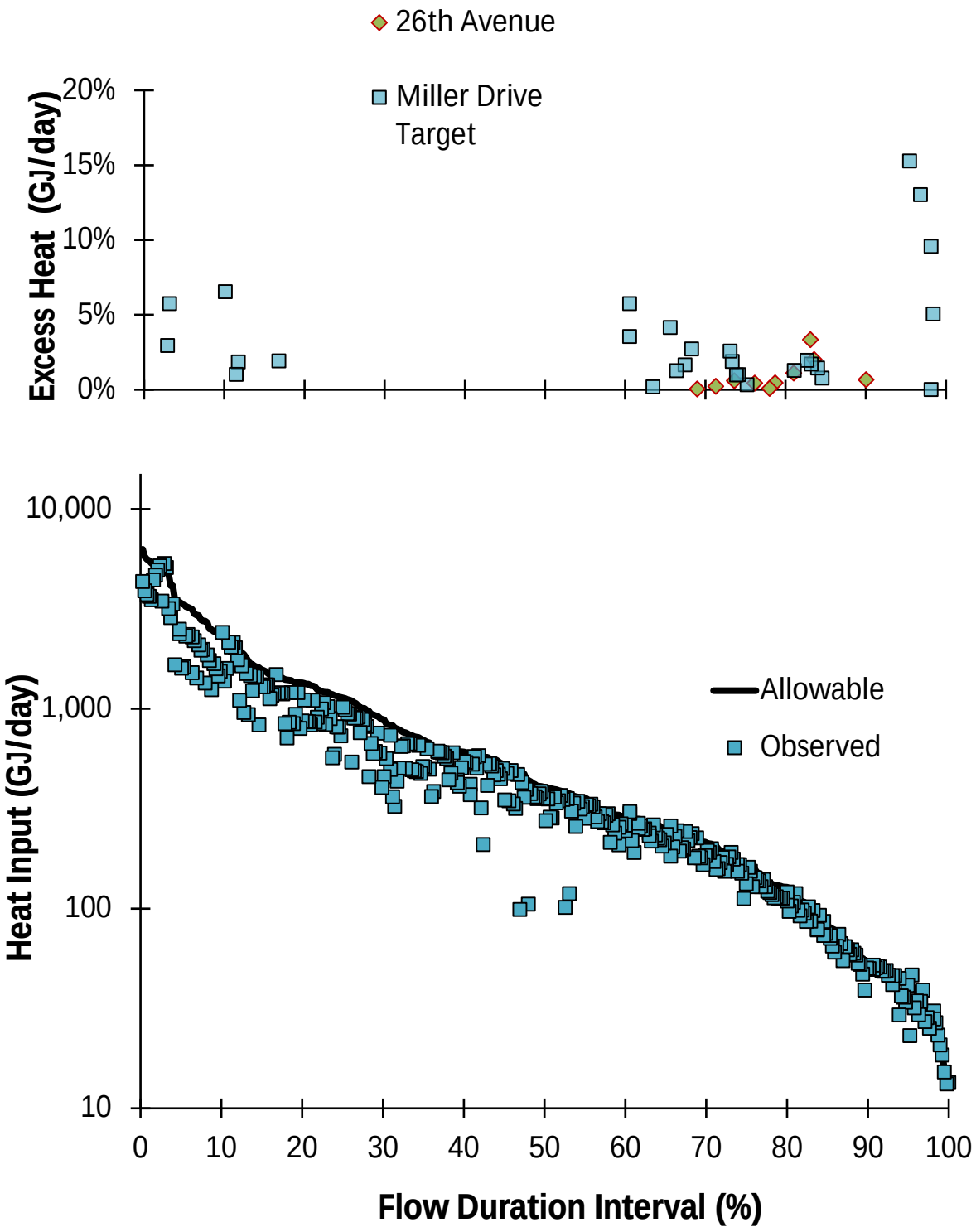
The Minnesota Urban Heat Export Tool (MINUHET), University of Minnesota, a surface runoff modeling tool, was used to predict stormwater runoff temperatures for Miller Creek. Runoff was simulated using 2008 data for typical residential and commercial subwatersheds and calibrated to observed stormwater discharge temperatures. This data was applied to the entire watershed, using runoff volumes from the SWMM model. The simulated runoff temperatures and volumes were used to estimate point source heat loadings to Miller Creek (Herb et al. 2009).

A Storm Water Management Model (SWMM), EPA, was constructed for Miller Creek to simulate continuous time series of stream flow at 15-minute intervals using observed precipitation, stream bathymetry, watershed hydrogeology, and tributary and storm sewer characteristics as input. The model was calibrated and validated against 2008 data, and is able to predict mean flows, peak flows, base flows, and storm runoff volumes. Stream alteration scenarios were also simulated using the SWMM (Erickson et al. 2010).

A load duration curve approach was used to determine the flow regimes during which thermal loads to Miller Creek exceed water quality targets. The load duration curve method is based on an analysis that encompasses the cumulative frequency of historic flow data over a specified period. Because this method uses a long-term record of daily flow volumes, virtually the full spectrum of allowable loading capacities is represented by the resulting curve. Only five points on the entire loading capacity curve are depicted (the midpoints of the designated flow zones). However, it should be understood that the entire curve represents the TMDL and is what is ultimately approved by the EPA.

Figure 12 depicts actual (observed) and allowable heat inputs to Miller Creek, plotted as a function of stream flow as load duration curves. Flow data is from the 26th Avenue West station (2007 to 2009), and excess heat data is derived from observed stream temperature values (2007 to 2009). The lower graph shows the values of observed and allowable heat inputs on a log scale. The upper graph shows the difference between the observed and allowable (excess) heat. The upper graph is scaled such that only positive values are shown (observed > allowable). Note that the highest actual heat inputs to Miller Creek are quite close to the allowable heat inputs over a wide range of flow conditions. This implies that the highest weekly average stream temperatures are close to 19 °C over a wide range of flow conditions and monitoring stations. As expected, actual heat inputs exceed the allowable most commonly at monitoring sites with the most temperature exceedances (Table 4) (e.g., Kohl's and Upstream of Kohl's MPCA temperature stations). The relatively low number of heat input exceedances in the lower section implies that excess heat inputs to Miller Creek in the upper reaches are partially mitigated in the lower section by improved shading, underground reaches, and coldwater inputs from the Chambersburg tributary and other sources. Overall, most temperature exceedances occur at lower flows (e.g., flows corresponding to a duration interval greater than 50%. The upper portion of Miller Creek has more heat exceedances than the lower portion, with most of the exceedances occurring during dry conditions (60% to 90% flow percentile) (Herb 2011).

Figure 12: Actual (observed) and allowable weekly heat loadings versus flow duration interval for Miller Creek, based on 2007, 2008, and 2009 data (modified from Herb 2011).



4.1.2 Load Allocation Methodology

The LAs represent the portion of the loading capacity that is designated for non-regulated sources of temperature (heat) to Miller Creek, as described in Section 3.6.1.2. The LA includes natural background, and all non-permitted sources, such as solar radiation & atmospheric heating and unregulated stormwater runoff. Natural background means characteristics of the waterbody resulting from the multiplicity of factors in nature, including climate and ecosystem dynamics, that affect the physical, chemical, or biological conditions in a waterbody, but does not include measurable and distinguishable pollution that is attributable to human activity or influence (https://www.revisor.mn.gov/statutes/?id=114D.15). Generally, the LA is the TMDL minus the MOS and WLAs for each flow range. For this TMDL, the LA due to atmospheric heating was calculated as the total allowable heat minus the heat fraction attributed to stormwater (Herb 2011).

Miller Creek is an urbanized watershed, with very few remaining areas without human alteration or influence. Remnant natural or least disturbed areas do exist but are scattered throughout the watershed. The land uses in the watershed (Table 3) indicate that 57% of the watershed has been altered in some manner. The remaining 43% is considered natural or regenerated landscapes. The potential exists for exceedances of water quality standards under natural background conditions (due to extended periods of high air temperatures during low stream flow conditions). However, for this TMDL, natural background sources were not quantified, and there is no evidence at this time to suggest natural background sources are a major driver of any of the impairments and/or affect the creek's ability to meet water quality standards. Natural background sources are implicitly included in the LA portion of the TMDL allocation.

4.1.3 Wasteload Allocation Methodology

Separate stormwater monitoring data was not available for each MS4 in the Miller Creek Watershed. In order to determine the relative contribution to the total thermal loading to Miller Creek for each MS4, the total impervious surface was calculated using Geographic Information System (GIS) methods. It was assumed that each MS4 contributed heat to Miller Creek in proportion to the total impervious area contained in each MS4. WLAs were calculated, where the WLA for heat (H_{wla}) was equal to the total heat allocation for a particular flow regime ($H_{a,\,tot}$), multiplied by the fraction of stormwater (f_{sw}) and multiplied by the fraction of impervious surface (f_{imp}) (Herb 2011).

Wastewater: There are no wastewater point sources that discharge to Miller Creek.

Municipal stormwater: The entire Miller Creek watershed is covered under NPDES MS4 stormwater discharge permits (Figure 13). Seven entities are permittees under the General NPDES/SDS Permit MNR040000 for MS4s:

- city of Duluth (MS400086), the largest contributor by area;
- city of Hermantown (MS400093), the second largest contributor by area;
- Minnesota Department of Transportation ((MnDOT), MS400180), for U.S. Highway 53;
- St. Louis County (MS400158), for county roads;
- LSC (MS400225), covering its campus along Trinity Rd.;

- University of Minnesota Duluth (UMD) (MS400214), for the NRRI property; and
- city of Rice Lake (MS400151), for a small corner of the municipality.

Non-municipal stormwater: There are two individual, non-municipal stormwater permits within the watershed: Walmart Store #1757 (MN0060372) in Hermantown and Miller Hill Mall (MN0056979) in Duluth.

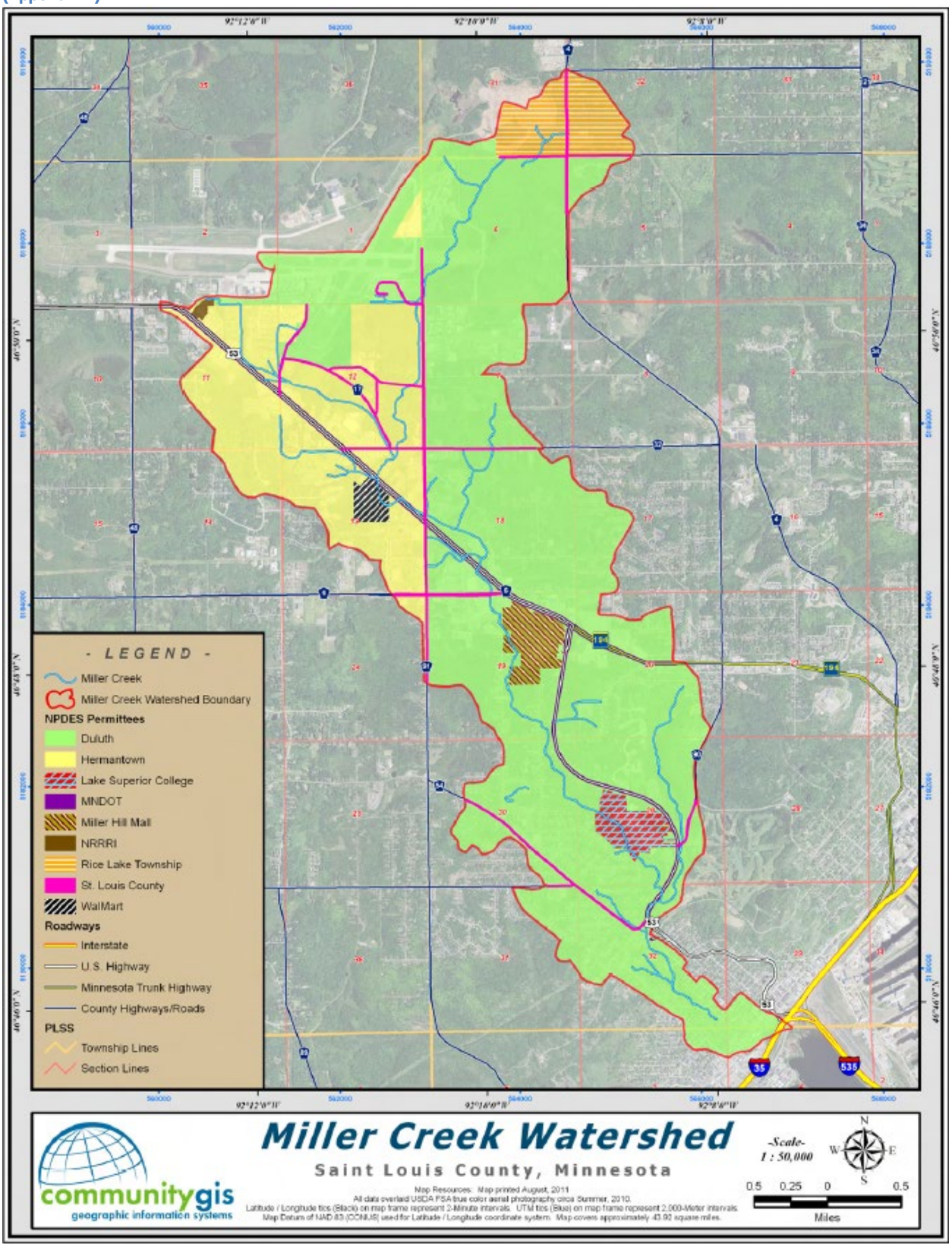
Construction stormwater: The WLA for construction stormwater is based on an estimate of the average annual percentage of the watershed being under an MPCA Construction Stormwater Permit, using the MPCA Construction Stormwater Permit data provided from 2007 through 2013 for Miller Creek Watershed. For the period from 2007 through 2013, the estimated average annual area of the watershed under the MPCA Construction Stormwater Permit was 0.14%.

The WLA for stormwater discharges from sites where there are construction activities reflects the number of construction sites of one or more acres expected to be active in the watershed at any one time, and the best management practices (BMPs) and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at construction sites are defined in the State's NPDES/SDS General Stormwater Permit for Construction Activity (MNR100001). If a construction site owner/operator obtains coverage under the NPDES/SDS General Stormwater Permit [Permit] and properly selects, installs and maintains all BMPs required under the permit, including those related to impaired waters discharges and any applicable additional requirements found in Appendix A of the Construction General Permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. All local construction stormwater requirements must also be met.

Industrial stormwater: For industrial stormwater, a categorical WLA was set at 0.1% of the watershed. Acreage data is not readily available for industrial stormwater; however, the general Industrial Stormwater Permits (approximately 10) comprise only a small fraction of Miller Creek Watershed.

The WLA for stormwater discharges from sites where there is industrial activity reflects the number of sites in the watershed for which NPDES Industrial Stormwater Permit coverage is required, and the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at the industrial sites are defined in the State's NPDES/SDS Industrial Stormwater Multi-Sector General Permit (MNR050000), facility specific Individual Wastewater Permit (MN00XXXXX), or NPDES/SDS General Permit for Construction Sand & Gravel, Rock Quarrying and Hot Mix Asphalt Production facilities (MNG490000). If a facility owner/operator obtains stormwater coverage under the appropriate NPDES/SDS Permit and properly selects, installs and maintains all BMPs required under the permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. All local stormwater management requirements must also be met.

Figure 13: MS4s within Miller Creek Watershed (Miller Creek Water Temperature TMDL Implementation Plan (Draft) (Appendix A).



4.1.4 Margin of Safety

A MOS is a requirement of all TMDLs to account for inherent uncertainties in the data, modeling and assumptions that were used. The TMDL process allows for either an explicit MOS, expressed in the TMDL as a portion of the allocations along with the WLA and LA, and/or an implicit MOS, which is incorporated through conservative assumptions in the analysis and modeling of the data.

The TMDL includes an implicit MOS, through the use of the EPA recommended (EPA 1986) chronic temperature value (19° C) instead of the acute temperature value (24° C) for brook trout in the analysis and modeling of acceptable heat loading to Miller Creek. Also, the TMDL was calculated without taking into account the installation of BMPs in the watershed. BMPs that were installed during 2007 to 2009 are partially accounted for in the load calculations, in that the BMP improvements are reflected in the monitoring data. BMPs installed after 2008 (the baseline year for model calibration) have not been accounted for in the reductions needed by each source. The TMDL is more conservative by not accounting for the recent improvements and by using a time period when loading rates were higher than existing (after 2008).

In addition to the implicit MOS, MPCA best professional judgement defined an explicit 10% MOS to provide an accounting for uncertainties in data analysis, interpretation and modeling approximations.

4.1.5 Seasonal Variation

The critical conditions occur in summer months (June through September) when air temperatures are highest and aquatic activity (growth and reproduction) is at its greatest. Critical conditions may be further exacerbated by extended hot periods, periods with little precipitation, and rainstorms that produce heated stormwater runoff. The TMDL utilizes data collected during the period from June through September over a three-year period, from 2007 to 2009. Elevated water temperatures due to atmospheric heat transfer to the stream were found to be the dominant mechanism for temperature exceedances above 19° C MWAT. The TMDL addresses these conditions through implementation strategies that will reduce stream temperatures.

The TMDL includes the assumption that practices to reduce MWAT are expected to also lower daily peak temperatures (DM), given the strong correlation between daily peaks and weekly average temperatures, weekly average temperatures and air temperatures, and highest loading due to solar radiation.

4.1.6 Reserve Capacity

Miller Creek Watershed is completely contained within MS4 Permit coverage (Figure 12). There are no point sources to Miller Creek and none are proposed or anticipated within the watershed. Much of the new development consists of redevelopment of areas that were developed prior to stormwater management requirements. As part of any redevelopment, stormwater management practices will improve from existing conditions. The loading calculations in this TMDL allow for adequate capacity and no separate reserve capacity is required.

4.1.7 Water Temperature TMDL Summary

The observed thermal load during the monitoring period was generally less than the allowable load. When the observed load exceeded the allowable load, the observed loads were only slightly greater than the loads, as shown in Figures 14, 15, 16, and in Table 5.

Figure 14: Miller Creek actual and allowable heat 2007, Mall Drive Target.

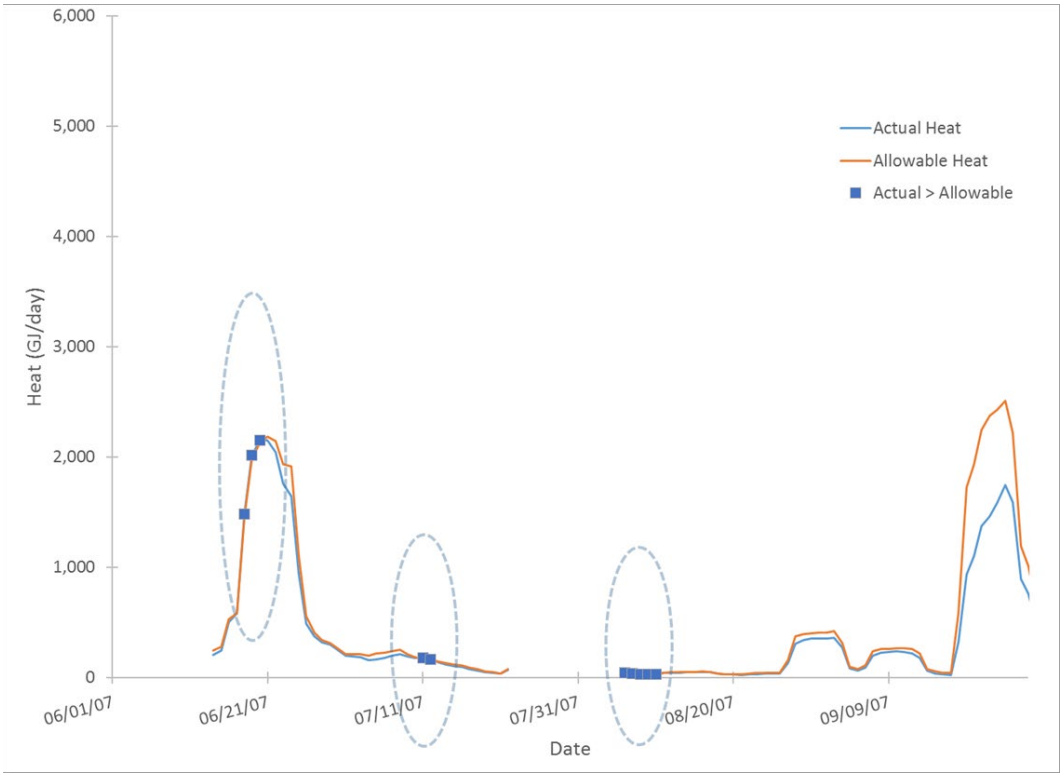


Figure 15: Miller Creek actual and allowable heat 2008, Mall Drive Target.

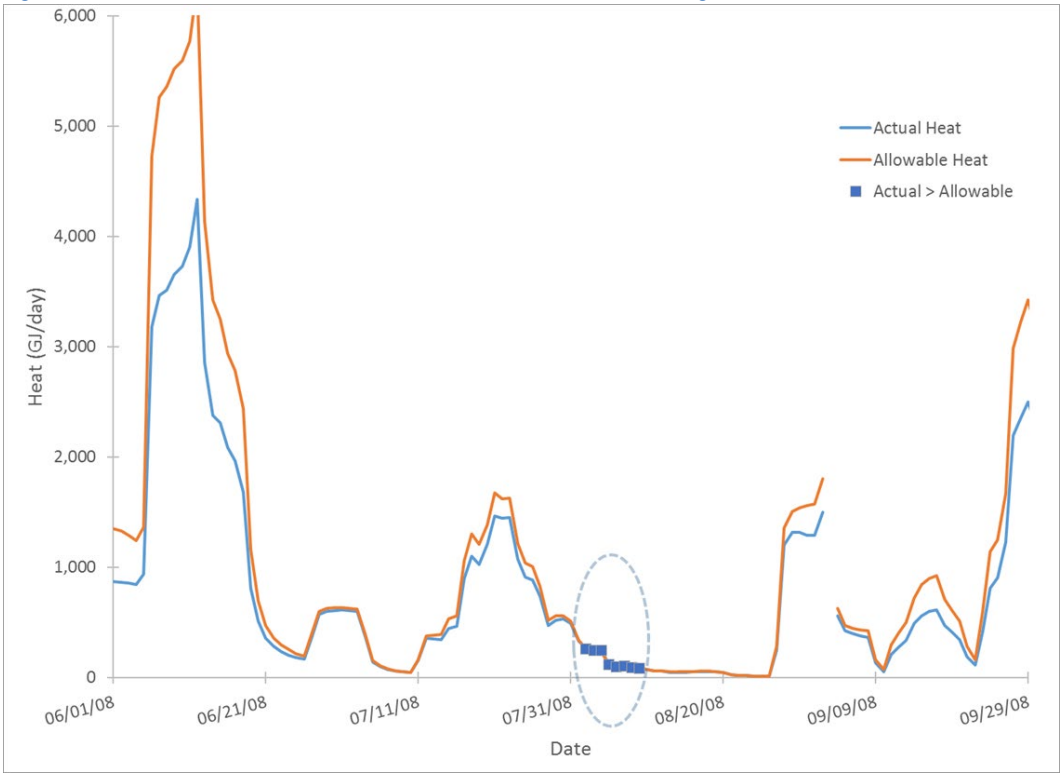


Figure 16: Miller Creek actual and allowable heat 2009, Mall Drive Target.

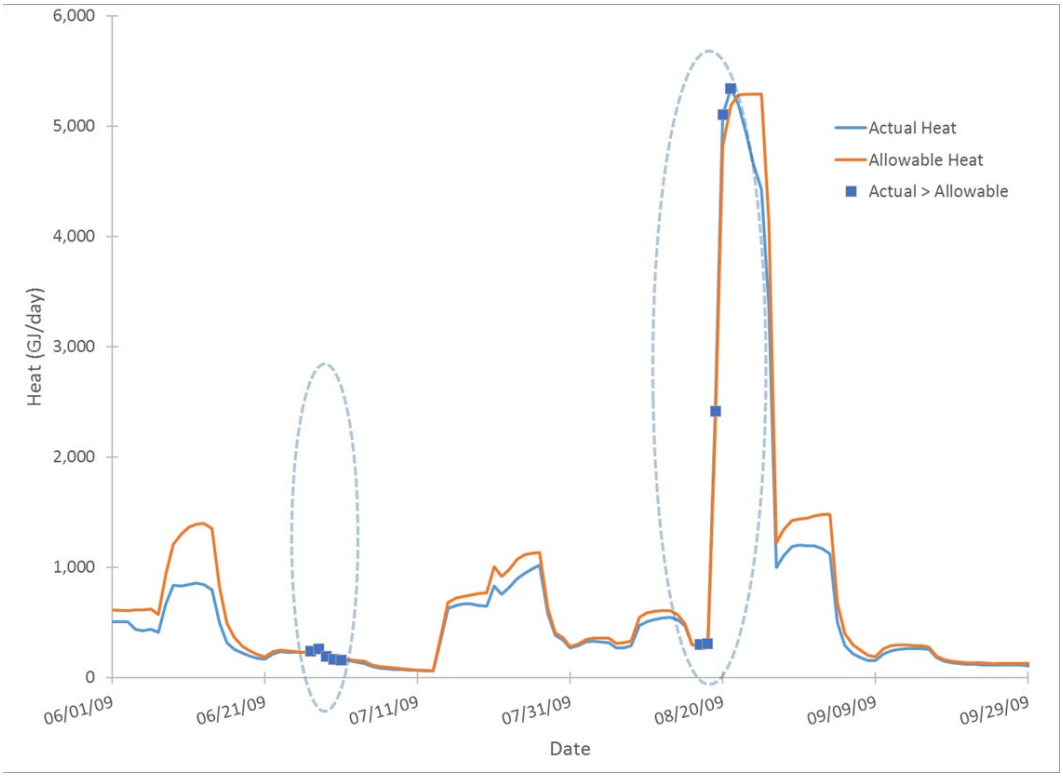


Table 5: Observed and allowable loads (GJ/day) for time periods where 7-day running average water temperatures exceeded 19 °C.

Time Period	Observed Load	Allowable Load	Amount Exceeded	Percent Exceeded
June 18 – 20, 2007	5,653	5,567	86	1.5
July 11 – 12, 2007	343	338	5	1.5
August 6 – 10, 2007*	171	156	15	9
August 2 – 9, 2008	1,249	1,234	15	1.2
June 27 – July 1, 2009	1,014	990	24	2.4
August 18 – 21, 2009	13,464	12,859	605	4.7

* Missing temperature data prior to August 6, 2007.

The water temperature LA and WLAs for Miller Creek are described in Table 6. The load and WLAs are described in terms of heat units, in GJ/day.

Table 6: Heat loading, wasteload allocations and load allocations for Miller Creek Watershed.

Miller Creek Temperature TMDL *					
Flow Duration Interval (%)	High 0-10	Moist 10-40	Mid-range 40-60	Dry 60-90	Low 90-100
Flow Range (cfs)	>11.8	3.1-11.8	1.5-3.1	0.28-1.5	< 0.28
Total Heat Capacity	**5521**	**1302**	**574**	**234**	**33**
Margin of Safety**	**552**	**130**	**57**	**23**	**3.3**
Total Waste Load Allocation	**4,014**	**865**	**299**	**92**	**10**
City of Duluth (MS40086)	2,347	506	175	54	6.1
City of Hermantown (MS400093)	821	177	61	19	2.1
City of Rice Lake (MS400151)	68	15	5.0	1.6	0.18
MN DOT (MS400180)	215	46	16	4.9	0.56
St. Louis County (MS400158)	277	60	21	6.4	0.72
UMD-NRRI (MS400214)	12	2.7	0.92	0.28	0.03
Walmart (MN0060372)	36	7.8	2.7	0.83	0.09
Miller Hill Mall (MN0056979)	200	43	14.9	4.6	0.52
Lake Superior College (MS400225)	38	8.2	2.8	0.87	0.10
Other Waste Load Allocation	**13.2**	**3.1**	**1.37**	**0.56**	**0.08**
Construction Stormwater	7.7	1.8	0.80	0.33	0.05
Industrial Stormwater	5.5	1.3	0.57	0.23	0.03
Load Allocation	**942**	**304**	**216**	**117**	**19**

* Heat units: gigajoules (GJ) per day (GJ/day)

** MOS = 10% of total heat capacity

5 Future Growth Considerations

5.1 New or Expanding Permitted MS4 WLA Transfer Process

Future transfer of watershed runoff loads in this TMDL may be necessary if any of the following scenarios occur within the project watershed boundaries:

1. New development occurs within a regulated MS4. Newly developed areas that are not already included in the WLA must be transferred from the LA to the WLA to account for the growth.
2. One regulated MS4 acquires land from another regulated MS4. Examples include annexation or highway expansions. In these cases, the transfer is WLA to WLA.
3. One or more non-regulated MS4s become regulated. If this has not been accounted for in the WLA, then a transfer must occur from the LA.
4. Expansion of a U.S. Census Bureau Urban Area encompasses new regulated areas for existing permittees. An example is existing state highways that were outside an Urban Area at the time the TMDL was completed, but are now inside a newly expanded Urban Area. This will require either a WLA to WLA transfer or a LA to WLA transfer.
5. A new MS4 or other stormwater-related point source is identified and is covered under a NPDES Permit. In this situation, a transfer must occur from the LA.

For this TMDL, allocations were established using the percentage of impervious surface for each MS4 within Miller Creek Watershed. Load transfers will be based on methods consistent with the area-weighted methodology used in setting the allocations in this TMDL. In cases where WLA is transferred from or to a regulated MS4, the permittees will be notified of the transfer and have an opportunity to comment on proposed changes.

6 Reasonable Assurance

Reasonable assurances must be provided in the TMDL that demonstrate the ability to achieve the targeted water quality goals. Several factors control reasonable assurance, including a thorough knowledge of the ability to implement BMPs, as well as the overall effectiveness of the BMPs. The implicit and explicit MOS applied to this TMDL, at the critical seasonal conditions and all portions of the flow regime, also provides reasonable assurance that the standards will be met with the allocated loadings. Local, state and federal agencies have the authority for oversight and regulation through permitting, zoning controls, and in compliance with permit(s) that they are subject to (Table 7). Permitted MS4s through the MPCA's Stormwater Program is the framework in place to ensure progress to achieving the water quality targets identified in this TMDL.

Natural background sources were not quantified for the TMDL, however there is no evidence to suggest natural background sources are a major driver of the impairments and/or affect the creek's ability to meet water quality standards.

Appendices A & B provide details on appropriate types of BMPs, targeted locations in the watershed, targeted permittees, and special considerations for implementation activities. These activities have been incorporated into the TMDL as a means to reinforce the responsibility and commitment of permittees to work to reduce thermal loading to Miller Creek. BMPs designed to address the WLA may also benefit the LA, and BMPs designed to address the LA may also benefit the WLA. BMPs to address the LA, such as riparian shading, may be a cost effective approach to reduce the thermal loading (a majority of the TMDL) to Miller Creek from atmospheric heating. BMPs to address the WLA would still be necessary, especially in the targeted areas for implementation.

Table 7: Regulatory controls in place that provide reasonable assurance allocations will be achieved (Miller Creek Water Temperature TMDL Implementation Plan (Draft) (Appendix A).

Entity	Regulatory Authority or Control
MS4 Permittees in Miller Creek Watershed	Comprehensive Plans that guide the types and locations of development in a community Zoning Ordinances that regulate where and how development may occur, and measures to minimize environmental impacts Stormwater Utility, where applicable Adoption and/or compliance with state and federal requirements (Wetland Conservation Act (WCA), Shoreland, MS4-SWPPP, NPDES, 404 and 401 of CWA)
State Government Agencies	NPDES regulation of stormwater discharges Shoreland and Floodplain Management Wetlands management (WCA and 401)
Federal Government Agencies	404 Authority over aquatic resources
Non-Government Agencies (businesses, institutions)	Facility management plans Compliance with local, state and federal requirements

6.1 MPCA Stormwater Programs

The MPCA's MS4 General Permit requires MS4 permittees to provide reasonable assurances that progress is being made toward achieving all WLAs in TMDLs approved by the EPA prior to the effective date of the permit. In doing so, they must determine if they are currently meeting their WLA(s). If the WLA is not being achieved at the time of application, a compliance schedule is required that includes interim milestones, expressed as BMPs, that will be implemented over the current five-year permit term to reduce loading of the pollutant of concern in the TMDL. Additionally, a long-term implementation strategy and target date for fully meeting the WLA must be included.

The MPCA is responsible for applying federal and state regulations to protect and enhance water quality within the Miller Creek Watershed. The MPCA oversees all regulated MS4 entities in stormwater management accounting activities. All regulated MS4s in the Miller Creek watershed fall under the category of Phase II. The MS4 NPDES/SDS Permits require regulated municipalities to implement BMPs to reduce pollutants in stormwater runoff to the Maximum Extent Practicable.

All owners or operators of regulated MS4s (also referred to as "permittees") are required to satisfy the requirements of the MS4 General Permit. The MS4 General Permit requires the permittee to develop a Stormwater Pollution Prevention Program (SWPPP) that addresses all permit requirements, including the following six minimum control measures:

- public education and outreach
- public participation
- Illicit Discharge Detection and Elimination Program
- construction-site runoff controls;
- post-construction runoff controls; and
- pollution prevention and municipal good housekeeping measures

A SWPPP is a management plan that describes the MS4 permittee's activities for managing stormwater within their jurisdiction or regulated area. In the event a TMDL study has been completed, approved by the EPA prior to the effective date of the general permit, and assigns a WLA to an MS4 permittee, that permittee must document the WLA in their application and provide an outline of the BMPs to be implemented in the current permit term to address any needed reduction in loading from the MS4.

The MPCA requires applicants to submit their application materials and the SWPPP document to MPCA for review. Prior to extension of coverage under the general permit, all application materials are placed on 30-day public notice by the MPCA, to ensure adequate opportunity for the public to comment on each permittee's stormwater management program. Upon extension of coverage by the MPCA, the permittees are to implement the activities described within their SWPPP, and submit annual reports to the MPCA by June 30 of each year. These reports document the implementation activities, which have been completed within the previous year, analyze implementation activities already installed, and outline any changes within the SWPPP from the previous year.

The MPCA has assigned heat loads for the TMDL to the regulated MS4s. The pollutant WLAs for each MS4 entity are outlined in Section 4.1.7 of the TMDL. The MS4 General Permit, which became effective August 1, 2013, requires permittees to develop compliance schedules for any TMDL that received the

EPA-approval prior to the effective date of the general permit. This schedule must identify the BMPs that will be implemented over the five-year permit term, timelines for their implementation, an assessment of progress, and a long term strategy for continued progress toward ultimately achieving those WLAs. MS4s will not be required to report on WLAs contained in this TMDL until the effective date of the next general permit, expected in 2018, because the TMDL for Miller Creek will be approved after the effective date of the current general permit. Updating the SWPPP to incorporate the TMDL will help to ensure that WLA reductions are implemented.

The Reasonable Assurance that the WLAs calculated for Miller Creek TMDL will be implemented is provided by regulatory actions. According to 40 CFR 122.44(d)(1)(vii)(B), the NPDES Permit effluent limits must be consistent with assumptions and requirements of all WLAs in an approved TMDL. The MPCA's stormwater program and its NPDES Permit program are the state programs responsible for ensuring that implementation activities are initiated and maintained, and effluent limits are consistent with the WLAs calculated from the TMDLs. The NPDES program requires construction and industrial sites to create the SWPPPs, which summarize how stormwater will be minimized from construction and industrial sites.

7 Monitoring Plan

Monitoring for TMDL implementation activities is important in order to measure the effectiveness of those activities implemented, and to inform future direction and choice of activities implemented (i.e., adaptive management). Monitoring should continue throughout implementation until water quality standards are attained. However, monitoring for temperature and heat energy reductions is a challenging and complex endeavor for permittees. An alternative means to measure progress toward TMDL reduction goals will be developed by the MPCA (in coordination with permittees) and applied throughout implementation.

For Miller Creek, there are a number of monitoring activities currently underway, or will be occurring in the future:

- Those parties with activities subject to NPDES/SDS Permits (MS4, CSW, ISW, and Non-municipal Stormwater Permit holders) will continue to conduct monitoring and other methods of evaluation of BMPs as a requirement of the applicable permit(s).
- DNR currently conducts, and will continue to conduct, stream population and temperature assessments on an annual basis at the brook trout index station, and at other select locations in Miller Creek.
- MPCA installed a new stream station near the mouth of Miller Creek for stream stage and flow monitoring during 2014 to 2017. In 2017, the station equipment will be changed to a mulita-parameter water chemistry probe, collecting continuous stream temperature, specific conductivity, estimated stream flows, and precipitation. The station will be maintained into the foreseeable future by UMD-NRRI.
- Under the Watershed Approach and the WRAPS process, MPCA and local partners will begin two years of intensive watershed monitoring in the St. Louis River Watershed, which includes Miller Creek, in 2019 as part of the second 10-year cycle of intensive watershed monitoring. Monitoring will include water chemistry parameters, biotic community health, and assessing habitat conditions. This effort will continue under the Duluth Urban WRAPS, with additional monitoring and evaluation.
- UMD-NRRI redeployed multi-parameter water chemistry probe at LSC in 2015, collecting continuous stream temperature, specific conductivity, estimated stream flows, and precipitation, with the intent to continue data collection for the foreseeable future.
- Miller Creek Watershed has been, and continues to be, a focus for research by local, state, and federal agencies, and by academic institutions. Voluntary activities implemented to reduce heat loading to Miller Creek will be tracked and reported by MPCA, in coordination with local partners.
- As part of ongoing civic engagement activities, input from citizens and targeted groups will be collected to gauge interest, concerns, and participation in watershed-related activities by local partners, in coordination with MPCA.

8 Implementation Strategy Summary

Appendix A, The Miller Creek Water Temperature TMDL Implementation Plan (Draft), is a detailed implementation plan defining the actions, timelines, and cost estimates for activities necessary to achieve the stream temperature (heat) reductions specified in this TMDL. The implementation plan is summarized in the remainder of this section.

Table 8 provides a summary of BMPs that could potentially be implemented to provide thermal loading reductions to Miller Creek, and are creditable to both the WLA and LA. Appendix B (BMPs for MS4 Permittees) of this TMDL provides more specific details on appropriate types of BMPs, targeted locations, targeted permittees, and special considerations for implementation. The information in Appendices A & B are incorporated into the TMDL as a means to reinforce the responsibility and commitment of permittees to work to reduce thermal loading to Miller Creek.

Temperature mitigation and baseflow augmentation were modeled for the Miller Creek Watershed. Increased riparian shading in the upper watershed, the lower watershed, and the entire watershed were evaluated. The largest increases in shading for potential future scenarios were in the impacted wetland above Kohl's Department Store. Increasing the shading upstream of Kohl's provides substantial reductions in DM temperatures (up to 2° C), with reductions in maximum daily temperature persisting for approximately two kilometers downstream of Kohl's (Herb et al. 2009). Stormwater runoff rate and volume controls were also evaluated, including reducing peak flow rates through wet detention basins, bottom outlet discharges, underground stormwater storage, and infiltration. Each method can provide some thermal reductions, but may be muted depending on the pre-runoff conditions, intensity and duration of runoff, and other site limitations (Herb et al. 2009).

Increasing stream baseflows may reduce stream temperatures, and provide better habitat for brook trout. While four scenarios were evaluated, increasing the channel length in the wetland above Kohl's was the most realistic and beneficial scenario. The restored channel would represent more natural stream function. Increasing the length would decrease channel slope, and increase the residence time of water, which could provide additional channel storage and result in increased baseflow (Erickson et al. 2010).

Table 8: Potential heat-reducing BMP implementation strategies (Miller Creek Water Temperature TMDL Implementation Plan (Draft) (Appendix A).

Potential Implementation BMPs and Heat Reduction Strategies
Stormwater improvements: Develop a comprehensive stormwater management plan for Miller Hill Mall; install BMPs to newly developed, redeveloped and to existing impervious surfaces (e.g., tree trenches, wet rock cribs, underground storage, wet pond bottom outlets, rain gardens and bio-filtration); maintain existing stormwater infrastructure; reduce the amount of existing impervious surfaces (removal or replacement with pervious); disconnect direct runoff from rooftops.
Vegetation improvements: Conduct tree plantings in riparian areas; reestablish native plant communities in areas of turf grass.
Stream Restoration: Restore channel morphology and habitat on select channelized sections of Miller Creek.
Education: Outreach and education with homeowners along the stream; develop materials for Miller Hill Mall tenants and patrons. Hold public workshops, festivals, stream clean-ups.

Code: Enhanced enforcement of zoning codes; encourage low impact development practices.
Land Preservation Activities: Establish conservation easements on sensitive lands, including wetlands and riparian lands.

8.1 Permitted Sources

8.1.1 Construction Stormwater

See section 4.1.3.

8.1.2 Industrial Stormwater

See section 4.1.3.

8.1.3 MS4

The NPDES Permit requirements must be consistent with the assumptions and requirements of an approved TMDL and associated WLAs. For the purposes of this TMDL, the MS4s are required to implement additional measures that will reduce the heating to Miller Creek within their jurisdiction (See the Miller Creek TMDL Implementation Plan (Draft) in Appendix A). In addition, the Regional Stormwater Protection Team (RSPT), a local conglomerate of municipalities and agencies working to prevent stormwater pollution to local streams, has a mission "to protect and enhance the region's shared water resources through stormwater pollution prevention by providing coordinated educational programs, and technical assistance" (http://www.lakesuperiorstreams.org/stormwater/rspt.html). Table 8, above, provides a summary of BMPs identified during development of the Draft Implementation Plan. More detailed information can be found in Appendices A and B.

Permit holders should use the list of BMPs in Appendix B to address the excess thermal loading to Miller Creek. Stormwater BMPs should be focused primarily on the developed portions of the upper watershed, targeting that portion of the watershed above LSC. Data collected for the TMDL identified the stream segment from U.S. Highway 53/Mall Drive, near Walmart to Chambersburg Avenue with the greatest exceedances of stream temperatures (See Table 3, Section 3.6). Implementation projects should utilize existing research to inform the locations and types of projects undertaken. This includes project reports from SAFL regarding temperature mitigation for Miller Creek (Herb et al. 2009) and simulations for baseflow augmentation scenarios (Erickson et al. 2010), as well as peer-reviewed research on thermal reductions from stormwater BMPs. It is important to note that BMPs designed to address the WLA may also provide benefit to the LA, and BMPs designed to address the LA may also benefit the WLA.

8.2 Non-Permitted Sources

8.2.1 Atmospheric Heating

A majority of the allocations for this TMDL have been assigned to LA, due to atmospheric heat transfer to Miller Creek. While there are no regulatory mechanisms in place to track progress and implementation towards meeting the LA for Miller Creek, many of the implementation activities, such as tree plantings, riparian vegetation management restoration of channelized stream sections will be

completed by, and/or in cooperation with the MS4 entities. Projects implemented to address WLAs may also benefit LAs and those implemented to address LAs may also benefit WLAs. Table 8 and Appendix B provide a summary of activities that will lead to heat energy reductions to Miller Creek.

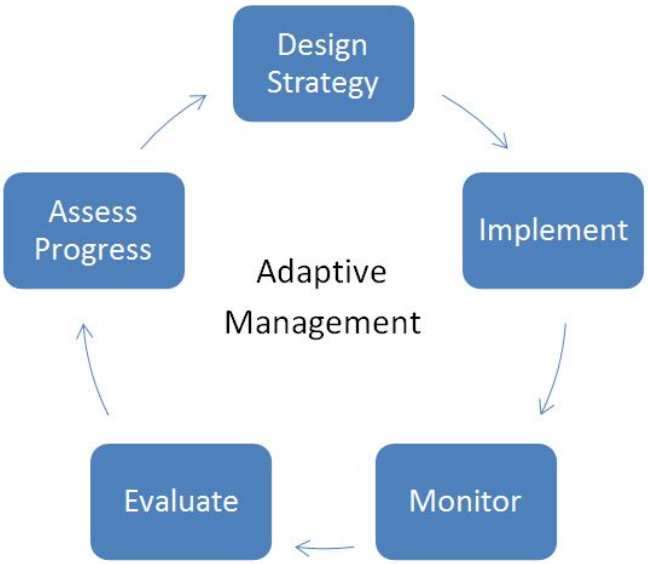
8.3 Cost

The Clean Water Legacy Act (CWLA) requires that a TMDL include an overall approximation of costs for TMDL implementation (Minn. Stat. 2007 § 114D.25). The initial estimate for implementing this TMDL ranges from $750,000 to $3,500,000, based upon cost estimates for various BMPs and other activities defined in the Implementation Plan. However, this is a broad estimate and a number of factors may affect the total costs for implementation, such as the number, scope and detail of individual projects implemented to achieve the TMDL reductions.

8.4 Adaptive Management

A list of implementation elements was prepared in conjunction with TMDL development, with an emphasis on adaptive management (Figure 17). Continued monitoring and "course corrections" responding to monitoring results are the most appropriate strategy for attaining the water quality goals established in this TMDL. Management activities will be changed or refined accordingly to efficiently meet the TMDL and lay the groundwork for de-listing the impaired water body.

Figure 17: Adaptive Management.



9 Public Participation

Public involvement was an important part of the Miller Creek TMDL process. The Miller Creek Watershed has a wide variety of interested parties seeking opportunities for involvement in watershed activities, including the TMDL process.

Annual meetings were held to keep stakeholders and other interested parties informed, and annual newsletters were also developed. A Technical Advisory Group (TAG) was established at the beginning of the TMDL study and represented a broad spectrum of organizations, including MS4 permittees, government organizations, and natural resource organizations. The TAG reviewed data, provided feedback to the project manager and SWCD staff on the approaches taken for the study, and provided advice in helping to find solutions to any problems that emerged over the course of the study.

Monthly meetings of the RSPT also served as a forum for updating local entities (especially MS4s) about the progress of the TMDL Study. An opportunity for public comment on the draft TMDL report was provided via a public notice in the State Register from [DATE] through [DATE]. An overview of all public participation efforts is summarized in Table 9.

Table 9: Public outreach activities for the Miller Creek TMDL (Miller Creek Water Temperature TMDL Implementation Plan (Draft) (Appendix A).

What	Audience	When	Response	Notes
Flyer/Invite to Lunch Meeting	All businesses in the watershed.	February, 2008	Poor - cancelled lunch but met privately with three interested businesses.	Two Best Management Practices came out of this effort.
Four Newsletters	All homeowners and businesses in the watershed.	Annually 2007 – 2010	unknown	Approx. 2,000 households and 250 businesses received the newsletters.
Meetings	Homeowners	June & October, 2007	Poor	Due to poor response, used newsletters to keep people informed instead.
Presentation	Service corps employees at Community Action Duluth	7/23/09	Good - 15 service corps staff	Followed by a watershed clean-up.
Rain garden and rain barrel workshop	Homeowners	9/18/09	Very good - 20 in attendance	Attendees received free rain garden plants and instructions for building their own rain garden.
Brochure	All	2008-2011	Unknown	Distributed at SWCD booth at various public events including the St. Louis County fair, Harvest Fest, and Earth Trax.

South St. Louis SWCD Website	All	2008-current	Unknown	Updated information on the Miller Creek TMDL was continually provided on the SWCD website.
TAG Meetings	TAG Members	10/10/07, 3/25/08, 12/15/09, 1/21/11, 6/30/11	Good, approx. 25 in attendance at each meeting.	Meetings held annually during data collection to review data and approach. 2011 meetings held to discuss approach for calculating loading capacity, WLAs and LAs.
RSPT Meetings	RSPT members	Monthly September 2007 – current	Good, approx. 20 in attendance at each meeting.	RSPT has an agenda for each meeting and Miller TMDL updates were included on many of these agendas.
Special Topics Meeting	City of Duluth Stormwater Staff	Periodic, 2010 to 2016	Good	City of Duluth and other MS4s wanted a meeting to discuss what possible implementation strategies they could use to meet their Wasteload Allocations.
Formal MPCA 30-Day Comment Period	All interested parties	TBD	Wait for comments received.	Formally respond to comments.

There is a noteworthy reduction in more formal, organized communications over the last five years. However, during this time, there continued to be significant, ongoing, informal communications with agency staff, local partners, and affected parties. It took an extended period of time to draft the TMDL based on several complicating factors, including: 1) the extreme complexity and uniqueness of a TMDL based on heat (energy), and 2) changes in the project approach several years ago, from a TMDL that addresses several pollutants to one pollutant, and changes from two temperature TMDLs to one.

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Appendix A: Implementation Plan

Miller Creek
Water Temperature TMDL
Implementation Plan (Draft)

A plan to address impairment of aquatic life due to elevated stream temperature

Prepared by the South St. Louis Soil & Water Conservation District
For the Minnesota Pollution Control Agency

May 10, 2017

wq-iw10-07c

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Cover photo: Jeff Jasperson, MPCA

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Document number: wq-iw10-07c

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Introduction

This document presents the Implementation Plan for the Miller Creek Total Maximum Daily Load (TMDL) study for water temperature. The ultimate goal of all TMDL Implementation Plans is to help citizens, organizations and municipalities living and conducting business within the watershed of the impaired water body to implement practices and policies that lead to restoring the designated uses. This Implementation Plan provides actions, timelines and cost estimates for activities that should eventually lead to the achievement of this water quality goal for Miller Creek.

Implementation Plans are not required under the Clean Water Act (CWA), nor do they need to be approved by the United States Environmental Protection Agency (U.S. EPA). However, Minnesota requires that Implementation Plans be completed within one year of a TMDL being approved. Unlike TMDLs, which need to go through a formal public review process and be re-approved by the U.S. EPA if any changes are made, Implementation Plans are working documents that are meant to evolve and be updated regularly.

This Implementation Plan is not intended to provide enough detail to serve as technical guidance for individual restoration projects – it only prescribes actions that target thermal pollution sources in the watershed. Landowners and local governments needing technical assistance with specific stream restoration and protection projects should consult with professional staff familiar with the Miller Creek watershed.

TMDL Summary

A TMDL is the total amount of a pollutant that a waterbody can absorb without violating the water quality standard set for its designated use. A TMDL is the sum of wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint and natural background sources, and a margin of safety (MOS) to account for uncertainty, expressed as this equation: $TMDL = \sum(WLA) + \sum(LA) + MOS$.

In general, TMDL studies: 1) determine the current load of the pollutant(s), in this case, heat; 2) determine the sources of the pollutant; and 3) allocate acceptable loads of the pollutant to point and nonpoint sources, in the form of wasteload and load allocations, respectively. Miller Creek is a Class 2A, coldwater trout stream, and must be protected in such a way that permits the propagation and maintenance of a healthy community of cold water sport or commercial fish and associated aquatic life, and their habitats (Minnesota Rules chapter 7050.0222). For Miller Creek, the species of interest is its native brook trout population (*Salvelinus fontinalis*), which need water colder than around 66 °F to support their life cycle requirements. From Poole 2001b: "Stream temperature directly influences the metabolic rates, physiology, and life-history traits of aquatic species and helps to determine rates of important community processes such as nutrient cycling and productivity. Fluctuations in water temperature induce behavioral and physiological responses in aquatic organisms and permanent shifts in stream temperature regimes can render formerly suitable habitat unusable for native species. Because of the ecological importance of stream temperature, preventing or mitigating anthropogenic thermal degradation is a common concern for resource managers." Therefore, the primary goal of the Miller Creek TMDL study is to identify the stream flow and environmental conditions that contribute the temperature threshold for brook trout and to calculate "budgets," or, allocations, for sources of excess heat in the watershed.

The Minnesota chronic water quality standard for coldwater streams (class 2A waters), is a narrative statement of "no material increase". Therefore, in order to calculate pollutant loads for the TMDL, a numeric target had to be assigned. For this TMDL, the numeric target selected was a weekly maximum average temperature of 19 °C / 66 °F. The process by which the TMDL was determined is discussed in greater detail in the Miller Creek Water Temperature TMDL study.

Temperature is one of the more complicated pollutants to articulate through a TMDL study. It cannot be directly described as a load, so the TMDL and allocations were calculated using the amount of heat energy in the water (expressed as gigajoules (GJ) per day (GJ/day)) that the stream can assimilate and still meet the temperature criteria for a Class 2A water. GJ is a metric term for available energy. For context. The energy of one GJ of electricity will light one 6—watt bulb continuously for six months. Or, it would require approximately 43 GJ of heat energy to raise the temperature of an Olympic-sized swimming pool (660,000 ft^3 by one degree F. Under the "Dry" flow condition (60-90% flow duration range), the TMDL for Miller Creek is:

TMDL = 234 GJ/day

The TMDL study determined that heat inputs exceed allowable values in Miller Creek by up to 10%, and that these exceedances are driven by atmospheric heat transfer during dry weather periods, by surface runoff during wet weather with substantial runoff, and by both mechanisms during small rainfall events. Herb (2007) found that rainfall events producing the highest runoff temperature and heat export (thermal impact) are "cold front" storms that have a rapid onset of rainfall preceded by warm, sunny weather that produces high surface temperatures. Although stormwater was found to contribute the majority of flow and heat at higher stream flows, the data indicate that stormwater contributes on the order of 40% of the total heat under the "Dry" flow condition, the condition under which most of the temperature exceedances occurred. Based on the 10% exceedance of total heat input and the 40% fraction attributable to stormwater, relatively moderate reductions in total heat loading from stormwater are required. See Table 1.

Table 1: **Heat input reduction goals by source.**

Overall Heat Input Reduction Needed	Reduction needed from point sources (stormwater)	Reduction needed from nonpoint sources
10%	4%	6%

303d Listed Impairments to Miller Creek

Miller Creek was placed on Minnesota's 2002 303(d) Impaired Waters List for not meeting the assigned beneficial uses for aquatic life, based upon elevated water temperature for Class 2A waters (Table 2a).

Subsequent monitoring and assessment of data on Miller Creek since 2002 identified additional aquatic life and aquatic recreation impairments, as detailed in Table 2b. These impairments are not addressed in this TMDL study but will be addressed in the future through a separate TMDL effort.

Table 2: Water quality impairments addressed in the Miller Creek Water Temperature TMDL study and Implementation Plan.

Waterbody Name	Location	Waterbody ID	Year Listed	Affected Use	Pollutant or Stressor
Miller Creek	Headwaters to St. Louis River	04010201-512	2002	Aquatic life	Temperature, water

Table 3: Water quality impairments in Miller Creek not included in the TMDL study or Implementation Plan.

Waterbody Name	Location	Waterbody ID	Year Listed	Affected Use	Pollutant/Stressor
Miller Creek	Headwaters to St. Louis River	04010201-512	2010	Aquatic Life	Lack of Coldwater Assemblage
Miller Creek	Headwaters to St. Louis River	04010201-512	2010	Aquatic Life	Chloride
Miller Creek	Headwaters to St. Louis River	04010201-512	2012	Aquatic Recreation	Escherichia coli
Miller Creek	Headwaters to St. Louis River	04010201-512	2012	Aquatic Life	Aquatic Macroinvertebrate Bioassessements

The sources of thermal pollution in Miller Creek were determined based on strength of evidence approach and the professional judgment of the TMDL Study's Technical Advisory Group, which identified the following to be likely causes of excessive heat loading in the creek:

1. Lack of baseflow (due to limited groundwater influences)
2. Lack of riparian area (due to development)
3. Influx of stormwater (due to development)

Allocations

The TMDL Study determined that 60% of the required load reduction needs to be achieved by mitigating the nonpoint sources of head loading , specifically the effects of atmospheric heating on the creek and maintaining and possibly enhancing baseflow. These sources are addressed through the load allocation. The remaining 40% of the reduction must be achieved by mitigating stormwater runoff, the point source of heat loading. This source is addressed through the wasteload allocation.

The TMDL and associated wasteload allocations and load allocations were divided into five flow regimes: high, moist, mid, dry and low. However, since most of the temperature exceedances occurred under "Dry" flow conditions (60-90 % flow duration range), the TMDL study recommended that heat mitigation efforts be targeted on the critical "Dry" flow condition. Therefore, only the TMDLs for the "Dry" flow condition are referenced in this Implementation Plan. Improvement efforts should be focused on the lower flow conditions to have the greatest effect at mitigating temperature impacts.

Wasteload Allocation

Influx of stormwater due to development is one of the three sources of thermal pollution identified in the Miller Creek Water Temperature TMDL, and is addressed via the wasteload allocation. Forty percent of the required reduction for heat loading is assigned to the wasteload allocation.

Under "Dry" flow conditions the wasteload allocation is:

WLA = 92 GJ/day

The wasteload allocation was further divided among seven municipal and two non-municipal stormwater discharge permittees. WLAs for each permitted entity are provided in Table 3. In accordance with U.S. EPA guidance, when individual wasteload allocations are provided, the WLA is the target load.

Table 4: Target loads by permittee.

Permittee	Preferred ID	WLA (GJ/day)
City of Rice Lake	MS400151	1.6
City of Hermantown	MS400093	19
University of Minnesota Duluth (NRRI facility)	MS400214	0.28
Walmart Store #1757	MN0060372	0.83
City of Duluth	MS400086	54
Minnesota Department of Transportation Outstate (District 1)	MS400180	4.9
St. Louis County	MS400158	6.4
Miller Hill Mall	MN0056979	4.6
Lake Superior College	MS400225	0.87

Load Allocation

Under "Dry" flow conditions the load allocation is:

LA = 117 GJ/day

Two thermal pollution sources identified by the Technical Advisory Group are addressed via the Load Allocation: lack of baseflow and lack of riparian area due to development. Sixty percent of the required reductions for heat loading are assigned to the Load Allocation(s). The Load Allocations are associated with nonpoint sources of thermal pollution to Miller Creek and are not formally regulated through permits.

1. *Lack of baseflow*

Baseflow refers to streamflow conditions that are directly influenced by water storage in the stream system (e.g., groundwater, wetland, springs, etc.) rather than precipitation events (stormflows). The following passage from Boyd and Sturevant (1997) sums up the importance of baseflow as it relates to temperature:

> Stream temperatures are highly dependent on flow volume. Streams with low flow volumes become extremely temperature sensitive. As the flow rate decreases, the volume of water that is involved in the heat energy balance is reduced. However, the energy processes inherent to the stream environment remain relatively unchanged. The result is that during heating periods the stream water tends to accumulate more energy per unit volume. The daily fluctuation of temperature in a small stream will be far greater than that of a large volume stream or river. Preservation of in-stream flow is helpful in establishing a healthy temperature regime.

Herb et al. (2009) found that extremely low flows (< 0.1 cubic feet per second) can occur in Miller Creek in mid- to late-summer when rainfall can be sparse, snowmelt is absent, and wetlands are low. The

temperature of Miller Creek was also found to be relatively sensitive to air temperature – a 1 °C increase in air temperature led to a 0.6 °C increase in stream temperature. The presence of exposed and shallow bedrock in the lower half of the Miller Creek watershed reduces the capacity for groundwater storage. The highly developed character of this watershed (22% impervious surfaces) may exacerbate existing conditions and low groundwater inputs by preventing infiltration. These facts and findings suggest that Miller Creek has very low groundwater inputs, which results in very low baseflows. While groundwater may mitigate stream temperatures, it is believed that groundwater makes up only a small percentage of flow in Miller Creek.

2. *Lack of riparian area due to development*

Trees and other vegetation located along a stream provide many benefits including shading from the sun, stabilizing banks to prevent erosion, taking up water to prevent saturation and slumping of the banks, and providing habitat and food for aquatic organisms. Destroying or otherwise altering riparian areas for development, landscaping or recreation eliminates the benefits provided by a robust, natural riparian area.

Streams lacking riparian areas can also be subject to greater impacts from climate change, especially those that have limited baseflows, like Miller Creek. Without shading, infiltration processes and bank stabilization benefits provided by established riparian areas, atmospheric heating could have a greater effect on surface water temperatures. In addition, the more frequent, higher intensity rain events caused by climate change could erode destabilized banks and destroy trout habitat. See Figure 1.

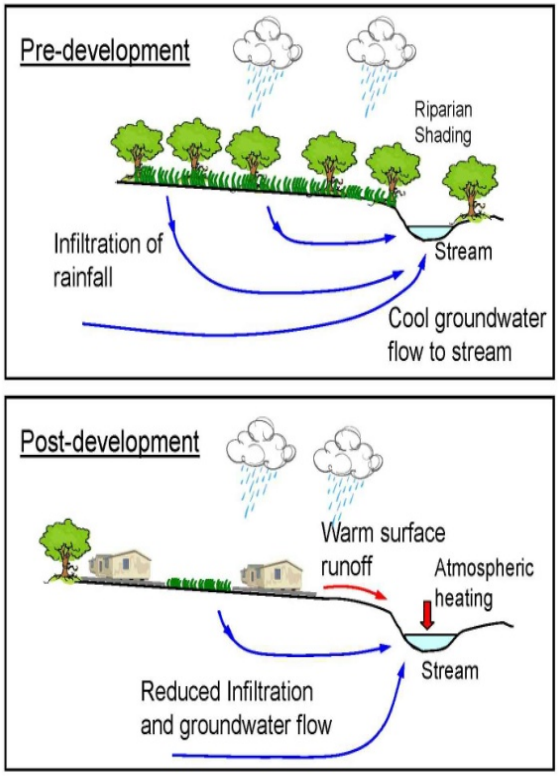


Figure 1: Impacts of development on the availability of groundwater to a stream. Source: http://troutstreamresearch.safl.umn.edu/

How the Allocations Were Derived

The Minnesota Pollution Control Agency (MPCA) contracted with the South St. Louis Soil & Water Conservation District (SWCD) to complete a water temperature TMDL study for Miller Creek. Under guidance from MPCA and a Technical Advisory Group, the SWCD collected data (flow, temperature and other water quality parameters) for the TMDL study, from 2007 through 2009. The TMDL load allocation and wasteload allocation were then determined with assistance from staff at the University of Minnesota St. Anthony Falls Laboratory (SAFL), using models specifically constructed and calibrated for Miller Creek. A numerical TMDL was then calculated, as required by the U.S. EPA.

SWCD and SAFL staff worked closely with MPCA stormwater and TMDL staff regarding a suitable approach for assigning target loads to the entities receiving WLAs. Individual stormwater monitoring data (volumes, rate, and temperatures) were not available for each MS4, so the thermal loading attributable to each MS4 was calculated using the percent of impervious area contained within the watershed. It was assumed that each permittee contributed heat to Miller Creek in proportion to the total impervious area (and corresponding stormwater runoff) contained within their boundaries. Additional information on the process used to calculate target loads can be found in the Miller Creek Water Temperature TMDL and SAFL Project Report #552 (Herb 2011).

Models Used, Inputs and Limitations

Three models were used to calculate loads and allocations for the Miller Creek TMDL:

1. **Stream Network Temperature (SNTEMP) Model. USGS, 2008.** SNTEMP is a heat transport model used to predict daily average and daily maximum stream temperatures. Several models were constructed for Miller Creek, using stream temperature data from June through September 2008 for calibration. The stream temperature models were used to characterize atmospheric (nonpoint source) heat inputs to Miller Creek for current riparian shading conditions and for several mitigation scenarios with increased shading (Herb 2009).
2. **Minnesota Urban Heat Export Tool (MINUHET). Herb et al. (University of Minnesota), 2009.** MINUHET is used to simulate stormwater runoff flows and corresponding temperatures. The main output of MINUHET is a time series of flow rates and temperatures at the outlet of a watershed, which enables users to predict thermal impacts on receiving streams. For the Miller Creek TMDL, MINUHET was used to characterize runoff temperatures for typical residential and commercial areas in the watershed. Continuous simulations were performed for the period from June to September 2008. This model was calibrated to observed stormwater discharge temperatures, capturing a variety of storms during this time period. The modeling results were generalized and applied to the entire watershed based on impervious area combined with the volumes generated by the SWMM model. This resulted in an estimate of heat loading that could be attributed to stormwater for the entire watershed.
3. **Storm Water Management Model (SWMM). EPA and Herb et al., 2010.** SWMM is a general purpose urban hydrology and conveyance system model developed by the U.S. EPA that is widely used for planning and the analysis of urban stormwater runoff and drainage systems. It can also be used to study the effects of urban development on stream temperatures. Erickson, et al (2010) developed a SWMM model specifically for the Miller Creek TMDL Study in order to predict daily runoff volumes for the 41 sub-catchments in the watershed. Model inputs included watershed land uses, drainage networks, and 2007-2008 climate and stream flow measurements.

Known limitations to the above-described models included:

- The models did not account for the potential thermal mitigation capabilities of any existing stormwater best management practices (BMPs) in the watershed.
- Regression equations were used to determine flow rates along with continuous flow data. Regression equations helped define the variability in topography, geology and gradient across the watershed.
- The SWMM model has a limited capacity for modeling wetland hydrology, which plays a major role in the Miller Creek's water budget.
- Data on hydrogeology is limited; some surrogate data had to be used to populate the model.

Geographic Boundaries of the Study Area

The Minnesota Department of Natural Resources (MN DNR) "Minor Watershed" GIS layer was used to delineate the Miller Creek watershed for the TMDL study. See Figure 2 for a map showing the boundaries of the watershed and the areas covered under MS4 permits.

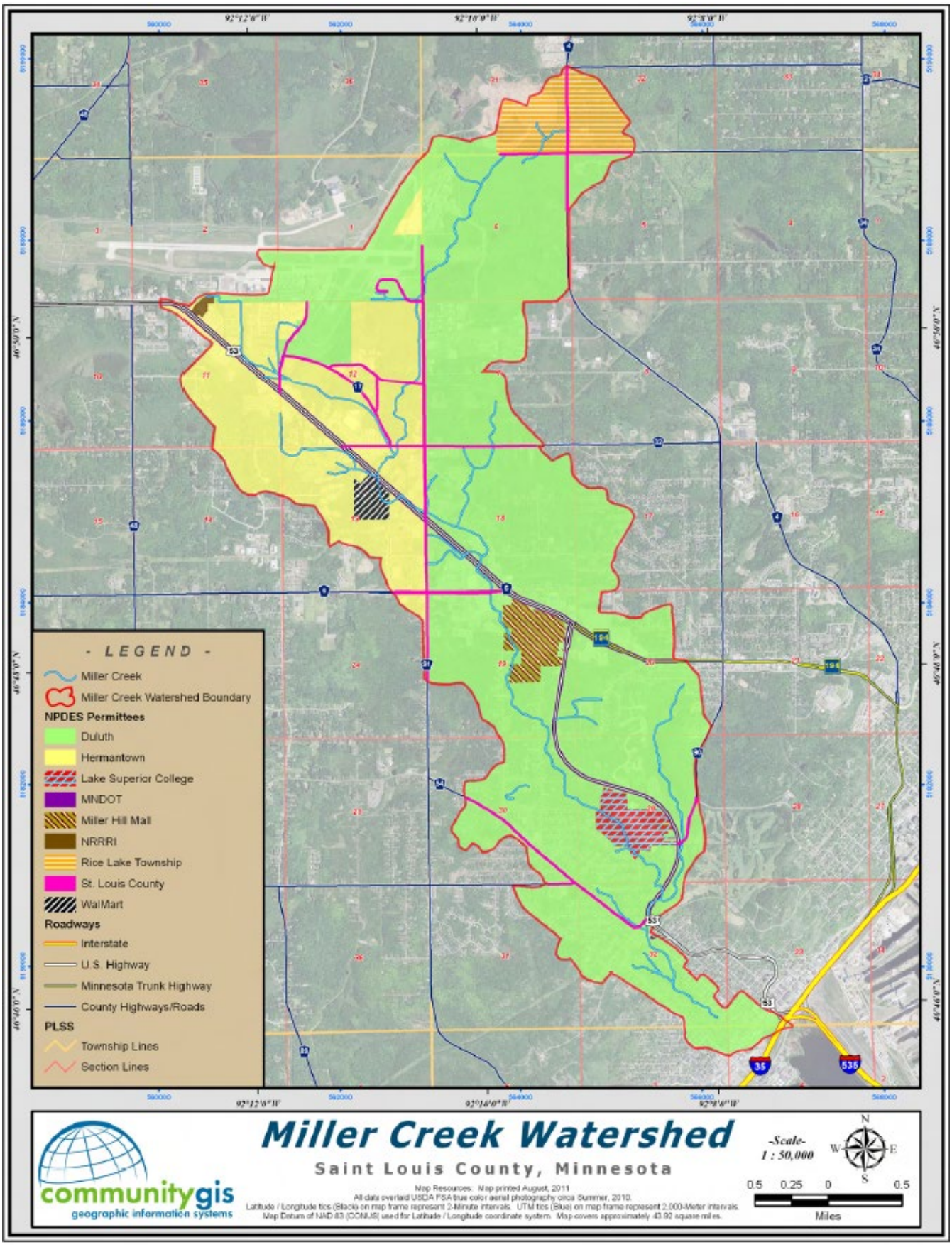


Figure 2: Map of the Miller Creek Watershed and MS4 permit areas.

Implementation Approach

Adaptive Management Approach

Meeting the WLAs and LA for the Miller Creek Water Temperature TMDL will be achieved using an adaptive management approach. The adaptive management approach is an ongoing assessment process whereby mitigation activities are implemented, monitoring is conducted to gauge the effectiveness of those activities, and then decisions regarding the next phase of mitigation activities are made based on the results. For example, if monitoring shows that elevated water temperatures in Miller Creek have been reduced, then the entities implementing the activities can assume that their strategies are working. However, if monitoring shows that stream temperatures are staying the same or increasing, then entities trying to achieve WLAs or the LA will have to alter their approach in order to achieve the reduction goals.

Flexibility and creativity will be necessary from MPCA, the permittees, and the watershed community to achieve temperature reductions in Miller Creek. Ultimately, the goal of any TMDL is to restore the waterbody back to a condition where the designated uses are achieved. The MPCA is allowing the permittees to use a performance-based approach for demonstrating compliance with their WLAs. A performance-based approach involves implementing and annually accounting for temperature-mitigating BMPs that are put in place. The adaptive management strategy will shape this performance-based approach, in that, BMPs will be installed, their performance assessed, and improvements made as needed going forward. The U.S. EPA has approved the adaptive management approach for achieving WLAs and LAs as long as the National Pollutant Discharge Elimination System (NPDES) permitting authority, (in this case, the MPCA) approves of such an approach, which it does (Trojan, 2009).

Priority Restoration and Protection Areas

It is the recommendation of this plan that restoration efforts focus on those reaches exhibiting the most temperature exceedances and the lowest density of cool/cold water preference macroinvertebrates and that protection efforts focus on those areas with the fewest temperature exceedances and the greatest density of cool/cold water preference macroinvertebrates.

Data analysis for the TMDL found that actual heat inputs exceeded the allowable heat inputs most frequently in the middle sections of Miller Creek watershed (Figure 3). Such results were expected, since this section is highly commercialized with large areas of impervious surfaces. Herb (2011) proposed that the fewer exceedances in the lower section of the watershed is a likely indication that excess heat inputs in the upper section are partially mitigated in the lower section by improved shading, underground reaches and coldwater inputs. Based on these findings, the upper portions of the watershed should generally be the area of focus for most restoration efforts; protection efforts should generally be focused on the lower portions of the watershed.

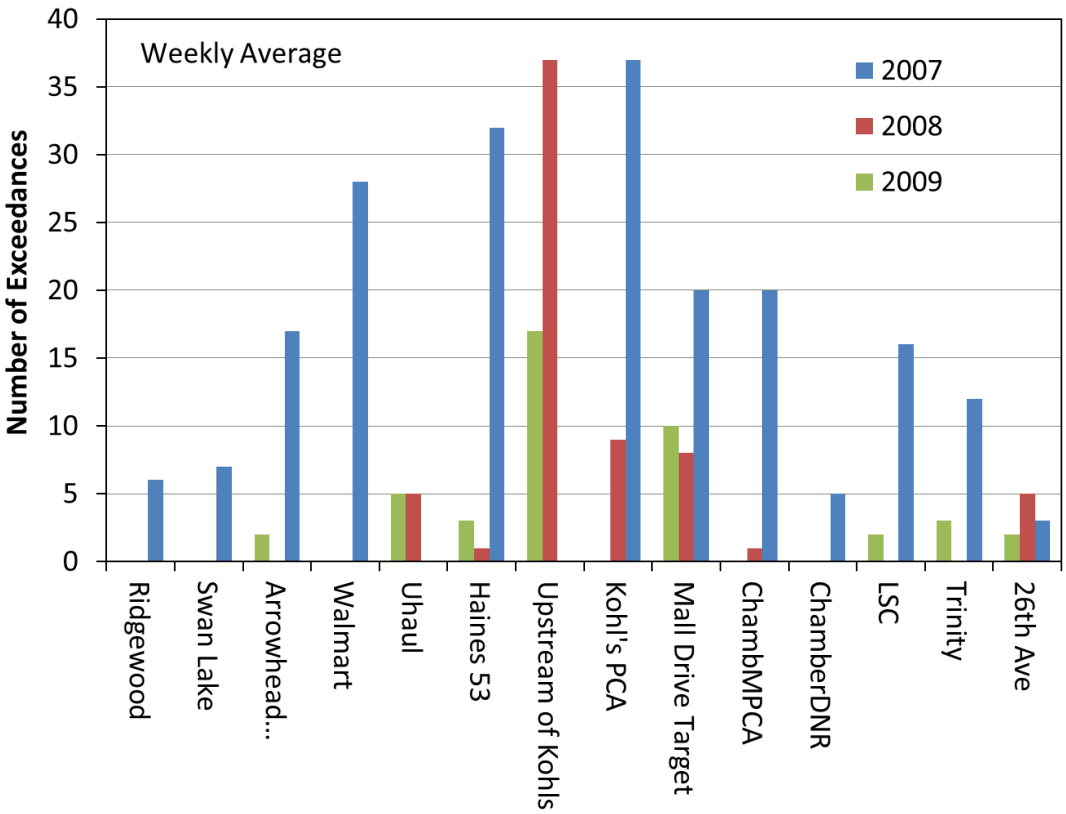


Figure 3: Number of weekly maximum average temperature exceedances (T>19 °C) at main stem monitoring locations in Miller Creek in 2007, 2008, and 2009 (Figure from Herb, 2011).

The Miller Creek Macroinvertebrate, Habitat, and Temperature Report, which was completed for the Miller Creek TMDL (Brady et al., 2010), identified the Mall Drive-Target monitoring site as having the most unsuitable habitat for macroinvertebrates, along with the least amount of shading. The report also identified the Kohl's monitoring site as having more macroinvertebrates that prefer warmer waters than any of the other sampling sites. The findings of this report should be considered in planning and completing future restoration and protection activities. Macroinvertebrates are often used as an indicator of stream health, since they are well-studied, spend their entire life cycle in one small section of stream, and are sensitive to water quality stressors, including thermal stressors.

Herb et al. (2009), modeled the effect of increased shading on atmospheric heat inputs to the creek and found that increased shading in the large wetland just upstream of Kohl's (Outlot A of the Miller Creek Subdivision) provided a substantial benefit – up to a 2 °C reduction in daily maximum temperatures – and that the reduction in maximum daily temperatures persisted for approximately 1.2 miles downstream, as a result. Based on this study, tree planting efforts in this stretch should provide a high amount of return for the effort and costs incurred, and should be considered as a high priority area for restoration activities.

The Lake Superior College and Lincoln Park sampling sites had the highest proportion and numbers of macroinvertebrates that prefer colder water. This stretch also has the highest aesthetic and ecological values with high quality riparian areas, plenty of large woody debris for habitat and low development pressure. Therefore, this stretch should be considered a high priority area for protection activities.

Coordination with National Pollutant Discharge Elimination System/State Disposal System Permit (NPDES/SDS) Programs

Miller Creek is located within a metropolitan area and the entire watershed is encompassed by seven permittees under the General National Pollutant Discharge Elimination System (NPDES)/State Disposal System (SDS) Permit MNR040000 for Municipal Separate Storm Sewer Systems (MS4). These seven include: City of Duluth, City of Hermantown, City of Rice Lake, University of Minnesota Duluth Natural Resources Research Institute, Lake Superior College, St. Louis County, and Minnesota Department of Transportation District 1 (MN DOT). In addition, Miller Hill Mall and Walmart Store #1757 are permittees under individual non-municipal NPDES/SDS permits for stormwater discharges. Figure 2 depicts the areas of coverage for these nine permittees within the Miller Creek Watershed.

For each permittee, the TMDL wasteload allocation will become a requirement of the respective permit requirements. The South St. Louis SWCD met with all seven of the municipal NPDES stormwater permittees and Miller Hill Mall in both individual and group meetings in an effort to develop the TMDL Implementation Plan that will provide relevant and feasible guidance to permitted entities in meeting their WLAs. All permittees except Walmart participated in the development of this Implementation Plan, which was submitted to the MPCA in September of 2014.

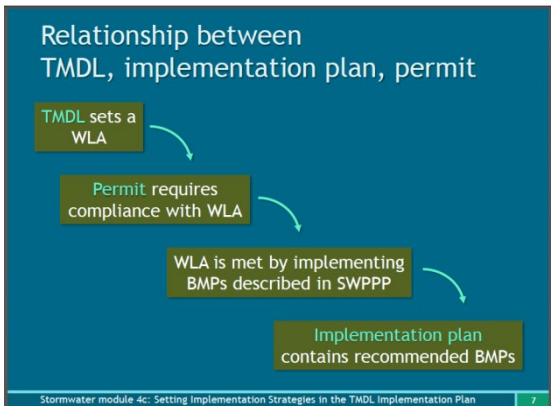


Figure 4: Relationship between TMDLs, the NPDES Stormwater Permit and Implementation Plans. (Stormwater Module 4c, MPCA, date unknown.)

The MPCA re-issued the MS4 General Permit effective August 1, 2013. By federal law, NPDES permits must be consistent with all assigned WLAs in any U.S. EPA-approved TMDL. Figure 4 illustrates the relationship between the TMDL program and MS4 permits.

Because TMDLs are approved as they are completed and the MS4 General Permit has a five-year term, the MPCA requires MS4s to report on and be accountable for WLAs that are assigned *before* the effective date of the most recent General Permit (August 1, 2013). Because the Miller Creek TMDL and its associated allocations will not be completed and assigned until after August 1, 2013, progress towards meeting WLAs will not be formally required until the next MS4 permit revision in 2018.

The current MS4 General Permit requires MS4s to submit the following information regarding their assigned WLAs as part of their annual reporting once the TMDL is approved:

1. TMDL name and pollutant(s) of concern.
2. Description of applicable WLA.
3. For each applicable WLA that will not be achieved during the permit term, a compliance schedule that outlines how the applicant plans to comply with the applicable WLA.
4. Description of the actions that will take place over the permit term to achieve each applicable WLA or to make progress toward interim milestones as described in a compliance schedule.

During the development of this TMDL Implementation Plan, many of the regulated parties expressed concern about implementing potentially expensive mitigation activities in limited amounts of time with little evidence of such activities working. There was also concern about conveying complex information regarding TMDLs to the public in order to gain support for implementing these activities. The MPCA is aware of these concerns and grants flexibility to regulated entities that are assigned to reduce the discharge of pollutants, as long as they are doing so to the “maximum extent practicable” (Trojan, 2012).

Strategies for Meeting Allocations

Existing Regulatory Controls

Because Miller Creek is located entirely within an urban area, there are many regulatory controls already in place to help meet the assigned allocations, as summarized in Table 4.

Table 5: Regulatory controls currently in place to meet allocations (as of 2014).

Entity(ies)	Type	Reference Name	Reference #	Language
City of Hermantown, City of Duluth, St. Louis County, MN DNR, USACE, EPA	Laws, Regulations and Rules	Wetlands	Various	"No Net Loss" of wetlands. Extensive language across all levels of government protecting wetlands to, among other things, help replenish groundwater and mitigate flooding.
State of MN	Permit	NPDES Construction Stormwater Permit	Appendix A Parts B and C -Requirements for Discharges to Special and Impaired Waters	Special BMPs required for stormwater discharge points on the site that are within 1 mile of an impaired water. 100-foot buffer zone must be maintained. Temperature controls required for BMPs discharging to trout streams.
State of MN	Permit	NPDES Municipal Stormwater Permit	Part II.D.6 -Reporting requirements for WLAs. Part II.E – Discharges to Impaired Waters with an EPA-Approved TMDL	Permittee will demonstrate progress made toward each WLA.
State of MN	Administrative Rules	MN Department of Natural Resources – Shoreland and Floodplain Management - Zoning Provisions	6120.3300, subpart 4	Existing shading of water surfaces must be preserved along rivers.
City of Hermantown	Zoning	Shoreland	555.07.01	Clear cutting of natural vegetation within a 50-foot buffer along a stream is prohibited.
City of Hermantown	Stormwater Management Ordinance	Control of post-construction stormwater run-off	1080.07.04	New development > ½ acre must include a permanent stormwater BMP. First inch of run-off must be treated to remove pollutants.
City of Hermantown	Stormwater Management Ordinance	Control of post-construction stormwater run-off	1080.07.05.01	Redevelopment > ½ acre must reduce impervious areas by 20%.
City of Hermantown	Stormwater Management Ordinance	Control of post-construction stormwater run-off	1080.07.09.02	Temperature controls required for stormwater discharges to trout streams.
City of Duluth	Unified Development Code-Natural Resources Overlay	Stormwater Management & Erosion Control	50-18.E.3.e.(iii)	Requirements to describe and provide additional BMPs for temperature control of runoff from development.

Entity(ies)	Type	Reference Name	Reference #	Language
City of Duluth	Unified Development Code-Natural Resources Overlay	Stormwater Management & Erosion Control	50-18.E.3.d(i, ii)	Restrictions on impervious areas in shoreland zones.
City of Duluth	Unified Development Code-Natural Resources Overlay	Shorelands	50-18.1.D	Special permitting required and standards for impervious surfaces, natural vegetation removal, and vegetative buffer width for projects within 300 feet of a creek.
City of Duluth	Unified Development Code-Natural Resources Overlay	Stormwater Management and Erosion Control	50-18.1.E	Limitations on development within shoreland zones. Water quality treatment required for new development. Impervious areas in redevelopment must be reduced along with stormwater runoff volume.
City of Duluth	Unified Development Code-Natural Resources Overlay	Landscaping and Tree Preservation	50-25.6 and 50-25.9	Credit for tree preservation during development. Trees should be preserved for water quality purposes.
City of Duluth	Central Entrance Miller Hill Small Area Plan	Recommendation	4-A	Avoid wetlands, minimize impervious surfaces, shade streams, and treat stormwater runoff to mitigate temperature impacts.
City of Rice Lake	Comprehensive Plan, 2007	Recommendation	Page 7	Natural drainage courses should be allowed to remain in their natural state as they provide conduits for stormwater runoff and provide open space.

Mitigation Activities Enacted Since 2008 (TMDL Baseline Year)

The modeling used to calculate the TMDL and the allocations for Miller Creek was based upon 2008 monitoring data. Therefore, the "baseline year" for tracking progress towards achieving both the wasteload and load allocations is 2008. This means that once the NPDES permittees are required to start reporting on the efforts they are making towards meeting their WLAs (expected in 2018 with renewal of MS4 General Permit), all temperature reduction activities taken since 2008 can be counted towards that progress. Tables 5 & 6 identify some of the recently installed. It is assumed that additional measures have been installed since this information was compiled. This portion of the Implementation Plan will be updated when new information is available.

Table 6: BMPs targeting wasteload allocations that were implemented after 2008 (baseline year).

Permittee	BMPs	Year
Lake Superior College	Installed an underground stormwater storage and treatment structure in the main parking lot on the south side of Building "S." This structure can mitigate spikes in temperature by reducing the volume of run-off and cooling runoff underground before it enters the creek.	2012
	Converted about 3,000 square feet of turf on the campus' front lawn to native grasses and forbs to help capture and infiltrate runoff from campus parking lots and buildings.	2012
	Installed additional educational signs along the Miller Creek Interpretive Trail regarding Miller Creek's temperature impairment and native Brook Trout	2012

	population. Many students and members of the public use this trail for educational and recreational purposes.	
	Installed a series of vegetated and terraced rock swales on the south-facing hill above the "S" building. The terraces allow stormwater to slow down and soak in to the ground instead of running off directly into Miller Creek.	2012
Walmart Store #1757	Hired a consulting company to develop a stormwater management system that would treat 100% of the property's impervious area as part of its 2011 expansion project. Three bioretention basins and an underground storage structure with a filter bed were designed and built to specifically mitigate potential temperature impacts to the creek by allowing runoff to soak in and co-mingle with cold groundwater before entering the creek.	2011
	Placed a conservation easement on Outlot A of the Walmart Addition Plat, an eight-acre forested buffer along the creek, and donated the property to the City of Hermantown.	2011
City of Duluth	Coordinates and leads the Regional Stormwater Protection Team, which provides public education regarding water quality, how to protect streams and how to mitigate and prevent the potential impacts of stormwater runoff.	Continuous
	Provides incentives in the form of reduced stormwater fees to businesses that implement a stormwater BMPs on their property.	Continuous
MNDOT	Cooperated with the South St. Louis SWCD to restore a 600 foot section of stream within the MNDOT right-of-way just upstream of Haines Road.	2015

Table 7: BMPs targeting load allocations that were implemented after 2008 (baseline year).

Entity	BMP	Year
Kolar Automotive Group	As part of a recent expansion, installed stormwater infiltration ponds that capture and treat about 90% of runoff from roofs and pavement areas at its 4770 W. Arrowhead Rd. facility before it discharges to wetlands adjacent to Miller Creek.	2012
Duluth International Airport	As part of its recent expansion and renovation, installed an underground stormwater treatment structure (Triton Stormwater Solutions) that stores and cools runoff under the airport parking lots before discharging it to a small pond, which provides further treatment. Cooled and treated runoff is then discharged to ditches that eventually flow to Miller Creek. See Figure 5.	2012
Duluth Stream Corps	Under a Great Lakes Restoration Initiative Grant, the Duluth Stream Corps, in cooperation with private riparian landowners, planted thousands of trees and shrubs along the many streams and waterways flowing through the Duluth area including 400 trees along 1,980 feet of Miller Creek during the 2011-2012 planting seasons. All eleven of the planting sites were in the lower section (downstream of the Mall Drive monitoring station) of the creek. See Figure 6.	2011-2012
Irresistible Ink	A private company, located across the street from Miller Creek at the intersection of Haines Road and Airport Road installed a vegetated swale/rain garden to capture and treat the runoff from their extensive roof.	2009
Energy Plus	A private business located near the corner of Arrowhead Rd. and Hwy. 53 installed porous concrete and a rain garden on their property to help infiltrate runoff from the parking lot.	2009

It is important to note that there may be many more BMPs installed by businesses and individuals than can be counted towards the load allocation, but Table 5 provides known BMPs installed at the time of this writing.

Figure 5: Underground stormwater treatment structure installed at the Duluth International Airport. Photo: Ryan Erdmann, RS&H.

Figure 6: Planting trees along Miller Creek in Lincoln Park. Photo: Community Action Duluth.

Thermal Mitigation BMPs: Research, Applicability and Special Considerations

A review of the literature reveals that data is limited regarding heat-load reduction capabilities of temperature-mitigating BMPs that could reasonably be implemented in Miller Creek. Many studies have been conducted regarding the performance of stormwater BMPs generally, but these studies are mostly focused on the capacity of BMPs to mitigate more conventional pollutants such as nitrogen, phosphorus and sediment, not temperature (Winston et al., 2011). Due to this relative lack of data, it is challenging to identify the exact combination of BMPs that will be needed to address elevated temperatures in Miller Creek.

Fortunately, a few BMPs have been studied for their thermal mitigation performance, including a recent study on the Vermillion River, in southeastern Minnesota, by the Vermillion River Joint Powers Board (Carlson et al., 2012). The Vermillion River watershed is a trout stream that runs through the southern fringe of the Minneapolis-St. Paul metropolitan area, a region that is experiencing rapid development and changing land uses. Although Miller Creek is a much smaller stream running through a smaller urban area, results from the Vermillion River study do provide some relative guidance on thermal mitigation through BMPs. The Vermillion River study authors chose low-cost, low-maintenance BMPs that could be installed as part of new development, or easily retrofitted to existing sites with limited available space. This is applicable to the Miller Creek watershed due to the amount of existing development and related high percentages in impervious surfaces, especially in the middle sections of the watershed. The Vermillion River study focused on eight mechanical (non-infiltrating) cooling BMPs: rock crib, biofiltration, vegetated buffer swale with storage, bottom draw pond outlet, pond shading with trees, vegetated wet swale, pond bench trench filter, and iron enhanced sand filter. The authors evaluated the performance of the BMPs by comparing water temperatures entering and exiting each BMP during summer rain events. This approach is simpler than the more complex methods of calculating and comparing heat loading.

Weighted temperature averages based on rainfall amounts and distribution indicated six of the eight BMP types reduced stormwater runoff temperatures between approximately 0.1 and 5 °C during critical precipitation events (Table 7).

Table 8: BMP List with Temperature Mitigation Results (Carlson, et al., 2012).

BMP	Weighted Average Temperature Reduction (Degrees Celsius (°C)	Cost
Pond shading with trees	- 4.55	Existing BMP
Bottom Draw Pond Outlet	- 3.69	$15,950
Biofiltration Cell #1 / #2	- 2.77 / 2.40	$8,348
Rock Crib with Wet Pump	- 2.63	$7,268
Vegetated Wet Swale	- 1.27	Existing BMP
Vegetated Buffer Swale with Storage	- 1.18	$6,422
Rock Crib with a Dry Sump	- 1.16	$7,268
Pond Bench Trench Filter	+ 0.14	Existing BMP
Iron Enhanced Sand Filter	Not able to Measure	Existing BMP

A different study, conducted by North Carolina State University, examined the impacts that conventional stormwater BMPs have on the temperature of stormwater runoff and the design parameters that could enhance the performance of those BMPs (Jones et al., 2010). Table 8 lists some of these suggested parameters based on the study results. Although the study was conducted in North Carolina, it may offer some guidance on special considerations that should be made specifically for stormwater BMPs in order to insure that the greatest thermal mitigation benefit possible is realized.

Table 9: Summary of BMP design recommendations to increase thermal mitigation capability (adapted from Jones et al., 2010).

Thermal BMPs	Design Considerations
Stormwater Wetland	
Outlet Structure	· Draw water from the bottom of the deep pool at the wet pond's outlet. · Aerate water before discharging into a stream. · Limit outflow rates early in a storm.
Bioretention Area	
Soil Depth	· Create a soil depth of 4 ft. or greater.
Vegetation	· Keep soil well shaded using broad leaf vegetation with a separation between the leaves and soil surface.
Wet Pond	
Outlet Structure	· Draw water from the bottom of the deep pool at the wet pond's outlet. · Aerate water before discharging into a stream. · Limit outflow rates early in a storm.
Bioretention Area	
Soil Depth	· Create a soil depth of 4 ft. or greater.
Vegetation	· Keep soil well shaded using broad leaf vegetation with a separation between the leaves and soil surface.
Mulch	· Use light-colored mulch.
Drainage Configuration	· Incorporate an internal water storage (IWS) layer at the bottom of the bioretention media. The top of the IWS layer should be at least 3 ft. from the soil media surface.
Watershed	
Conveyance Mechanism	· Convey treated stormwater through buried pipes when appropriate.
Parking Lot Design	· Incorporate shading. · Promote infiltration.

One third study that might offer guidance was conducted by Herb et al., (2007). The purpose of this study was to "analyze runoff temperatures and runoff heat export rates for a variety of terrestrial land covers and aquatic surfaces." The study found that pavement, commercial rooftops, bare soil, wet detention ponds and lakes/reservoirs produced runoff temperatures that were high enough to significantly impact stream temperatures. The study also found that, due to their low thermal mass, residential roofs exhibited the lowest runoff temperatures. With limited data available on the thermal mitigation capacity of specific stormwater BMPs, stormwater practitioners, builders and local governments can, at the very least, try to avoid the land uses that are known to exacerbate an existing problem.

Based on the literature review (and on practices that have been successfully implemented in the watershed), six thermal mitigation options seem most feasible for achieving TMDL reductions for stream temperatures in the Miller Creek watershed: shading, infiltration, underground storage, bottom-draw pond outlets, wetland protection and the restoration of altered stream channels.

Stream Channel Shading with Vegetation

Shading a stream is relatively inexpensive and proven temperature mitigation BMP that also benefits aquatic habitat. Shading reduces the temperature of a stream prior to a storm, helping to dilute any introduced heat from stormwater runoff. In this way, it is a type of "pre-treatment" BMP, as it is different than routing runoff through a BMP in an effort to remove heat. It should be noted that although shading can help mitigate chronic temperature problems, it appears to do little to mitigate acute temperature conditions (Chapman, 2008). Several organizations, including the Minnesota Conservation Corps, Hermantown High School, Lake Superior College and private landowners, have planted trees along Miller Creek over the past two decades, many of which have grown tall enough to provide adequate shade to some portions of the stream.

A special consideration that should be made for this BMP is climate change. Researchers at the University of Minnesota have been studying the effects of climate change on northern Minnesota forests and are predicting that in 100 years, fir, spruce and birch will be on the decline and maple, oak and basswood will be increasing (Axelson, 2010). Therefore, it is the recommendation of this plan that maples, red oak, yellow birch, and eastern hemlock and white pine (with protection from deer) be planted along Miller Creek instead of spruce, fir and red pine in order to insure that these efforts are not wasted on trees that cannot adapt to a warming climate.

Infiltration

Herb and Stefan (2009), along with many other researchers, have found that infiltration practices give the greatest benefit in reducing temperature impacts from runoff. The effectiveness is due to the fact that since runoff volume and temperature concentration are direct factors in thermal loading, BMPs that either prevent new runoff from being created and/or reduce the volume of existing runoff (such as infiltration) are the most effective way to reduce thermal loading (Carlson et al., 2012). The following criteria are often cited and used to help insure that infiltration systems will be successful: 1.) the bed of the infiltration system should be at least three feet from any limiting layer (seasonal high water table, bedrock or relatively impermeable soil layer; 2.) soils should not have > 30% clay or > 40% clay/silt content; and 3.) the system should not be constructed on fill material or on slopes > 15%. Unfortunately, infiltration is not the most feasible or cost effective option for all areas of Miller Creek due to the high clay content of some soils, the large areas of existing impervious surfaces and the close proximity of a limiting layer (bedrock). However, several rain gardens have been used successfully in the watershed already, including large rain gardens at Lake Superior College and at Irresistible Ink, a business located near the headwaters of Miller Creek.

Underground Storage

Although underground storage and treatment structures are usually more expensive, they are a better choice for mitigating temperatures than conventional stormwater ponds. This BMP mitigates spikes in stream temperatures by reducing peak flow rates, and reduces stormwater heating from the sun. In addition, these systems do not take up valuable real estate as they are usually placed beneath parking lots. Safety and aesthetic concerns associated with stormwater ponds are also eliminated. There are several underground stormwater management structures within the Miller Creek watershed, including in the City of Hermantown and most recently at the Duluth International Airport, and at Lake Superior College.

Bottom-draw pond outlets

Bottom-draw pond outlets were recognized as having good temperature reduction properties by both Jones et al. (2010) and Carlson et al. (2012). This BMP appears to be an affordable improvement that could be made to existing stormwater ponds in the Miller Creek watershed. Conventional stormwater retention/detention systems, such as ponds, are a common method used to treat stormwater runoff. MNDOT alone has nine pond structures within the Miller Creek watershed (eight dry ponds and one wet pond). Miller Hill Mall also has two ponds to mitigate runoff from its parking lots. Stormwater ponds are good for settling out sediment and holding back peak flows via runoff retention, but they can potentially exacerbate temperature problems if water in the ponds heats up prior to infiltration or drawdown, unless adequately shaded. In addition, ponds occupy valuable commercial land, making them especially undesirable in dense commercial areas such as the middle sections of the watershed. Discharging water from the bottom of a wet pond instead of the top is a good way to address the threat of thermal pollution, since the water at the bottom of the pond can be much cooler than at the surface (Figure 7).

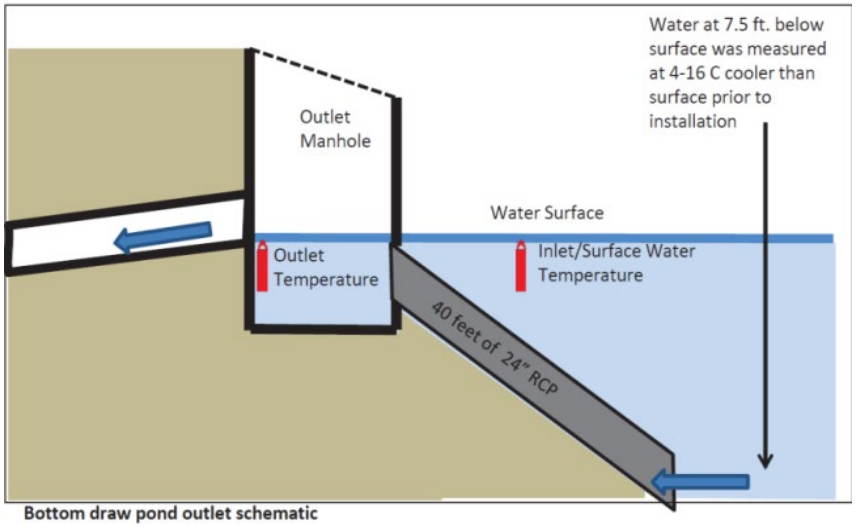


Figure 7: Wet pond with bottom outlet (Carlson et al., 2012).

Preserved, restored or constructed wetlands

Erickson et al. (2010) and Herb and Stefan (2010) hypothesize that the groundwater system in the Miller Creek watershed is controlled by a system of inter-connected wetlands that formed in bedrock depressions in the upper part of the watershed. If this hypothesis is correct, Miller Creek's baseflow is generated by the slow release of water stored in wetlands and not by groundwater inputs, making the preservation or restoration of wetlands an important mitigation effort that can help restore Miller Creek.

Keiser et al. (2003) found that wetlands are far more successful at attenuating flow and heat load than conventional stormwater treatment approaches, such as, in the case of his study, a stormwater pipe leading to a sediment forebay followed by a wet detention pond. The wetland provided a 43.9% reduction in heat while the forebay/pond combination provided only a 1.3% reduction in heat. The wetland's high infiltration rate, together with the shade provided by dense summer vegetation, contributed to the superior treatment capacity of this wetland. Based on these studies it appears critical that, in order to preserve adequate baseflow, protection of existing wetlands and/or creation of new wetlands should be a high priority in the restoration of this impaired watershed.

Restoration of altered stream channels

In the 1930s, it was common engineering practice to channelize streams in order to increase their efficiency at moving water off the land (primarily for farming and flood prevention purposes). This has happened to Miller Creek in several stretches. Today, we know that simplifying a stream's morphology has harmful effects on habitat, the life cycle of aquatic organisms, stream stability and on water quality. The homogeneity of a simplified stream system means that there is less variation in stream depth, flow velocity and habitat and therefore a narrower range of thermal environments that aquatic organisms can choose from, including pockets of cool water in which they can find refuge when excess heat is being introduced to the stream. Straightening also focuses the stream's energy towards the middle of the channel, leading to down-cutting and cutting the stream off from its floodplain. Restoring channelized sections of the creek, such as those identified in Table 9, should help to alleviate the elevated temperatures in Miller Creek, along with providing additional habitat and flood mitigation benefits.

The actions discussed in this section are the suggested BMPs for meeting allocations. An extensive suite of stormwater BMPs can also be accessed on the MPCA's Minnesota Stormwater Manual Wiki website at: http://stormwater.pca.state.mn.us/index.php/Main_Page.

This website is continually updated with the latest research on stormwater BMPs. Additionally, with increasing attention on nonpoint source pollution and the continuing evolution of stormwater regulation, it can be expected that additional research on thermal mitigation BMPs will be conducted in the future. Therefore, entities and persons responsible for meeting an allocation under the Miller Creek Water Temperature TMDL should consult the body of stormwater research regularly for the latest information.

Proposed Implementation Actions by Entity and Allocation Type

Best Management Practices to Manage TMDL Wasteload Allocations

TMDL Implementation Plans are written for the entities responsible for meeting the allocations in the TMDL study. The South St. Louis SWCD held both individual and group meetings with the permittees receiving a wasteload allocation to determine which BMPs may be feasible to undertake. It is important to note that project funding and project feasibility may change over time, and the reduction needs will continue to evolve as projects are constructed. Therefore, even though the initial input from those entities subject to WLAs identified potential proposed implementation actions (see Tables 9 through 16); this list of activities will change over time and should be updated periodically as part of the adaptive management approach for TMDL implementation. The permitted entities have agreed to take actions, such as those listed in the following tables in an effort to meet their wasteload allocations according to the timeline provided in Figure 10.

Table 10: City of Duluth proposed implementation activities.

Action	Location	Potential Funding Source(s)	Estimated Cost (2013)
Evaluation of riparian corridor – GIS / LIDAR analysis.	Portions of creek running through City of Duluth.	Stormwater utility.	$2,000 of existing staff time.
Restore the approx. 3,500 foot channelized stretch behind Kohl's Department store.	Legally platted as Outlot B of the Miller Creek Subdivision.	Clean Water Fund. *Note: A design for this project has been completed by the South St. Louis SWCD.*	$400,000
Tree planting in riparian areas.	Current unshaded areas identified through the riparian corridor analysis.	Clean Water Fund. Conservation Partners Legacy Grant Program. Philanthropic contributions. Duluth Superior Community Foundation.	$15/tree with fencing. Labor presumed in-kind.
Targeted outreach and education for homeowners regarding Miller Creek's temperature impairment.	Residential and commercial properties within the watershed.	GreenCorps service member project (coordinated. by MPCA). Duluth Superior Community Foundation. Coastal Program.	Would vary widely depending on the type of campaign. Estimated at ~$20,000 for a one-year watershed-wide effort.
Stream restoration and riparian corridor improvements in Lincoln Park.	Lincoln Park. (Badly damaged from 2012 flood.)	Clean Water Fund (water-quality focused). Outdoor Heritage Fund. Parks and Trails Fund (DNR). PFA TMDL Grant Program.	$10,000 for riparian corridor improvement. Approx. $100 per lineal foot to restore the stream channel with a natural channel design approach. Costs would vary widely depending on extent of project, historic structure considerations and consulting/design costs.
Enhanced enforcement of UDC requirements for development /redevelopment stormwater control, shoreland protection, and landscaping within Miller Creek's watershed.	Throughout the watershed.	City-funded.	$4,000 of existing staff time.
Build a public trail along Miller Creek behind Kohl's once the restoration is done. Include signs explaining Miller Creek, its impairment and the purpose of the restoration project.	Outlot B, Miller Creek Division.	Parks and Trails Fund (DNR). Philanthropic contributions. Coastal Program. See City of Duluth Trail and Bikeway Plan for additional funding possibilities.	$200,000

Table 11: City of Hermantown Proposed Implementation Activities.

Action	Location	Potential Funding Source	Estimated Cost (2013)
Encourage landowners to plant trees in the riparian area.	Privately owned parcels along the stream.	Privately funded by landowners.	$15/tree incl. fencing.
Restore straightened portions of the stream in Outlot A, Walmart Addition to a more natural, meandering channel.	Outlot A, Walmart Addition	Clean Water Fund.	$150,000
Place two parcels currently owned by Krenzen Auto Dealerships under a conservation easement or acquire fee title to prevent development from occurring in wetlands.	Between the China Star and Outback restaurants along Haines Road. Parcel numbers are 395-0125-00045 and 395-0125-00030.	DNR Conservation Partners Legacy Grant program.	$274,400 (taxable land values of both parcels).

Table 12: City of Rice Lake proposed implementation activities.

Action	Location	Potential Funding Source	Estimated Cost (2013)
Plant Trees/Shading.	In riparian area where feasible.	City of Rice Lake Donations.	$15/tree incl. fencing.

Table 13: Lake Superior College proposed implementation activities.

Action	Location	Potential Funding Source	Estimated Cost (2013)
Plant trees.	Ditch along the north end of upper parking lot and around stormwater ponds.	Philanthropic contributions, LSC Legacy Revolving Fund.	$15/tree incl. fencing.
Maintain and monitor permanent water quality monitoring equipment. LSC has been collecting summer data related to Miller Creek's water quality since 2008. Data from their water monitoring station can be found at lakesuperiorstreams.org.	In the creek.	Lake Superior College	$1,000 of existing staff time.
Continue annual hardwood tree planting (~300) to replace dying birch population and in case of Ash decline from Emerald Ash Borer.	Both sides of the creek	LSC Biology Dept.	$1,500/ year
Expand native plantings/eliminate turf.	In ditches along main entrance off of Piedmont Ave. Other areas of campus as identified.	LSC Legacy Revolving Fund. LSC's Student Senate has committed to re-purposing part of the front lawn to a usable native and edible landscape.	$2,500
Maintain existing rain gardens to insure maximum effectiveness (remove weeds and remove sediment).	The bio-retention pond in the west parking lot and the rain garden between the "E" and "S" buildings.	Volunteer labor (students and staff).	$0

Table 14: University of MN Duluth at NRRI campus proposed implementation activities.

Action	Location	Potential Funding Source	Estimated Cost (2013)
Reduce the size of or remove the seldom-used parking lot on the north side of the building.	Behind the building (only used for the air show or unloading).	NRRI, donated time and equipment.	$2,500
Install wet rock crib(s) to cool runoff from parking lot(s).	Adjacent to parking lots where space allows.	Clean Water Fund, Coastal Program, research grants.	$7,268 for a 20W x 10L x 4D foot crib. (*2010 cost, courtesy of Dakota County SWCD.)*

It should be noted that there are two transportation-based MS4s within the Miller Creek watershed: MNDOT District 1 and St. Louis County. Because the safety of drivers is paramount for all transportation agencies, these permittees have limitations on the types of BMPs available to them. For example, no obstructions, such as trees planted for shading would be allowed in any road right-of-way since they may pose a hazard. Transportation departments in other parts of the country have had to spend millions of dollars just to acquire property outside of the right-of-way on which to build stormwater structures (Water Environment Foundation, 2013). The U.S. EPA recognizes that, "Because of their unique configuration, linear transportation networks are often an awkward fit for the existing municipal stormwater regulatory framework" (Water Environment Foundation, 2013).

Pollutant trading is an option, and the MS4s did consider this as a group for the Miller Creek Water Temperature TMDL, but there is currently limited experience throughout Minnesota with trading scenarios and the group had concerns about one entity having to do an inordinate amount of work identifying, siting and funding BMPs and then having to share the credit. Thus, the leanness of proposed implementation activities for MNDOT and St. Louis County may be influenced by the uncertainty of this yet-to-be-resolved issue.

Table 15: St. Louis County proposed implementation activities.

Action	Location	Potential Funding Source	Estimated Cost (2013)
Restore about 2,000 ft. of straightened stretch in parcel numbers 395-0010-03215 and 395-0010-03165.	West side of Haines Rd., just south of the airport. Would require cooperation of adjacent private landowners.	Clean Water Fund (water quality focus) or Conservation Partners Legacy Grant Program (DNR-habitat focus).	$200,000 or $100 per lineal foot using a natural channel design approach.
Retrofit existing stormwater ponds with bottom draw outlets.	County ponds next to Sam's Club.	PFA TMDL Grant Program.	$15,950. (*2010 cost, courtesy of Dakota County SWCD.)*
Use Limited Impact Development standards.	Where practicable.	County funding.	$0. Calculate into budget of new projects and retrofits.

Table 16: MNDOT District 1 proposed implementation activities.

Action	Location	Potential Funding Source	Estimated Cost
Retrofit "Country Kitchen Pond" with a bottom draw outlet to mitigate for temperature in addition to sediment.	At SW intersection of Hwy 53 and Maple Grove Rd. near Target.	PFA TMDL Grant Program.	$15,950 *(2010 cost, Dakota County SWCD.)*
Remeander the approximately 600 foot stretch in the Right-of-way between Hwy. 53 and U-Haul.	Immediately upstream of the Haines Rd. culvert.	Clean Water Fund.	$77,000 ***funded.*** Slated for spring of 2015 by the South St. Louis SWCD.

It should also be noted that Miller Hill Mall and Walmart Store #1757 have industrial stormwater discharge permits that are specifically tailored to their properties. The Miller Hill Mall is the largest contiguous impervious site in the watershed. As of 2005, 100% of the site's stormwater is treated using two sediment ponds, four (sand) infiltration basins, and a combination of sumps, filters and pipes (Figure 8). The system is not designed to mitigate temperature impacts specifically – its primary function is to capture sediment and other nonpoint pollutants such as trash and oil. However, the infiltrative capacity of several of the structures could result in runoff being cooled before discharging into Miller Creek. The Mall is situated on a hill above the creek, which runs along the west side of the property. This stretch of the creek currently has an adequate riparian area, so BMPs should be focused on treating and infiltrating runoff from the expansive parking lots around the mall. As of 2014, the development of a comprehensive stormwater management plan and temperature monitoring are both underway to help identify stormwater management options for this site.

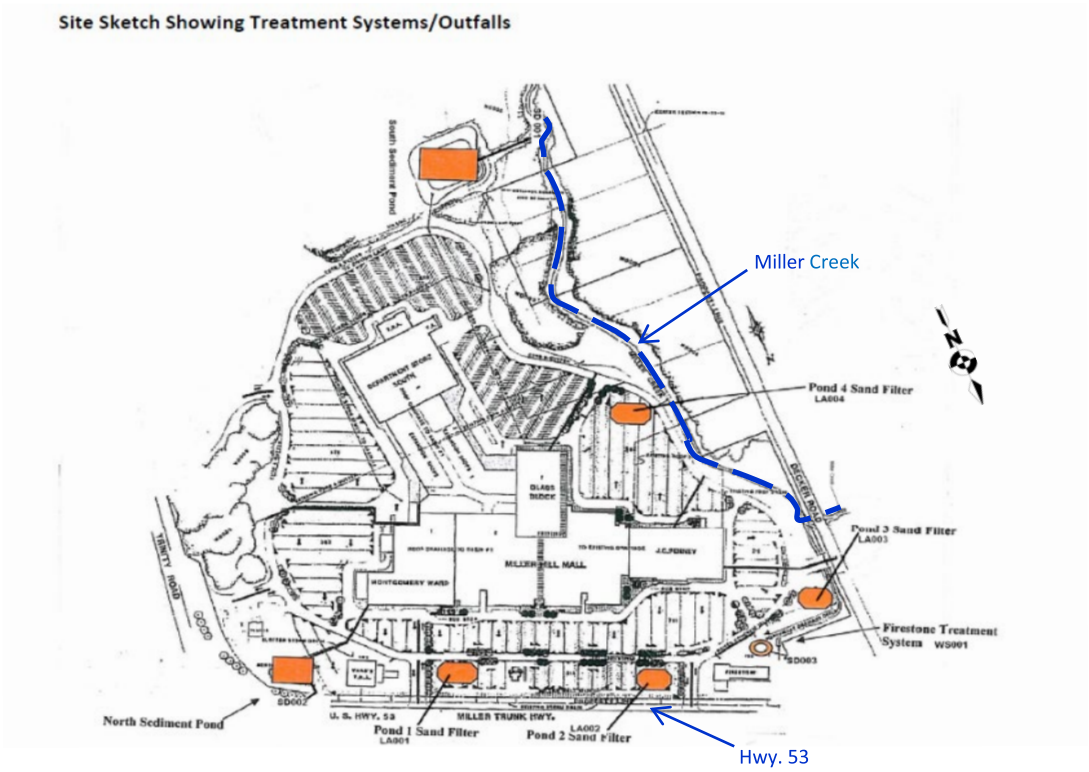


Figure 8: Miller Hill Mall Stormwater Treatment System as of 2013. Figure from NPDES / SDS Permit #MN0056979.

Table 17: Miller Hill Mall proposed mitigation activities.

Action	Location	Potential Funding Source	Estimated Cost (2013)
Develop a Comprehensive Stormwater Management Plan focused on temperature mitigation for the Mall's 66 acres of impervious area.	Parking areas under ownership by Simon Properties.	Clean Water Fund.	$187,000 ***funded*** for 2014-2015 with the South St. Louis SWD and Barr Engineering.
Tree trenches. Would capture runoff from approx. 90% of the ~23 acres draining to the south sediment pond.	Area that drains to the south sediment pond.	PFA TMDL Grant Program. Clean Water Fund.	$200,000 per acre of tributary drainage area. (*2012 cost, estimated by Barr Engineering based on Maplewood Mall stormwater project.)*
Combination of tree trenches and rain gardens. Would capture runoff from approx. 90% of the ~23 acres draining to the south sediment pond.	Area that drains to the south sediment pond.	PFA TMDL Grant Program. Clean Water Fund.	$70,000 per acre of tributary drainage area. (*2012 cost, estimated by Barr Engineering based on Maplewood Mall stormwater project.)*
Educational Elements - Incorporate educational elements featuring Miller Creek into the Mall's interior to help educate the public about the proximity of the Creek about their role in nonpoint source pollution.	Possible opportunities include: Use a Retail Mobile Unit (RMU) as an educational kiosk; creating a mural on the large blank wall by the food court entrance; hanging posters above the existing fountain; retrofitting the existing fountain with stream/fish - themed art.	Coastal Program. Donated time from local artists or art students. Donated time from local environmental educators or environmental education students from UMD.	Would vary, depending on action. $0 (in-kind contributions) to $30,000 (total renovation of existing fountain).

Action	Location	Potential Funding Source	Estimated Cost (2013)
Provide educational information to Mall tenants (stores) regarding Miller Creek.	In the "Hill Shopper" the monthly newsletter distributed to Mall tenants providing updates and information on mall events and policies.	General Mall Budget: This activity is already being performed.	~$200 for staff time and printing per issue.

Walmart did not participate in providing input on this Implementation Plan. The stormwater treatment system updates as part of their 2011 store expansion are anticipated to provide adequate mitigation to meet their wasteload allocation (Figure 9). A review by the MPCA is needed to determine if Walmart needs to take more formal action towards meeting their WLA once reporting is required.

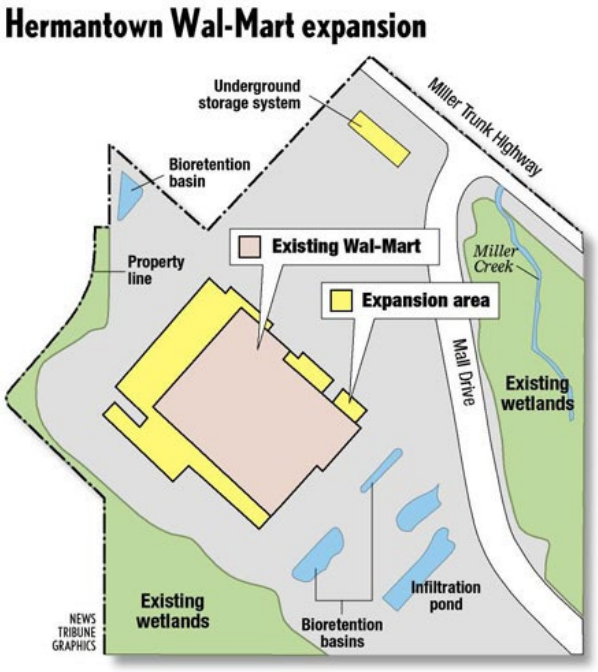


Figure 9: Walmart expansion map, Hermantown, MN. Figure from the Duluth News Tribune, April 14, 2009.

Best Management Practices to Manage TMDL Load Allocation

Sixty percent of the TMDL reductions for Miller Creek's temperature impairment are assigned to nonpoint sources of heat loading such as direct solar radiation, which studies have found to be the largest contributor to changes in daily temperature (Thompson, 2005). Other nonpoint sources of heat loading include lack of cold groundwater inputs, shallow or over-widened stream channels, and excess sediment.

There are currently no regulatory mechanisms (such as NPDES/SDS permits) to track and enforce progress made towards meeting the load allocation for the Miller Creek Water Temperature TMDL. Therefore, the load allocation must be met by a collective, voluntary effort on the part of all residents and businesses within the watershed. This would be done in conjunction with government agencies and organizations providing leadership, coordination, and/or in documenting activities completed.

Oftentimes, public education activities are the least expensive and easiest TMDL activity to implement. However, educational efforts must clearly identify the issues, demonstrate benefits to the local environment and illustrate the specific role that individual landowners/participants play in the solution (Bongard, 2009) in order for them to be effective. For the load allocation, education will likely be the

primary implementation action. Programs can be developed and existing programs can be enhanced to provide information to residents and businesses within the watershed regarding the need to mitigate thermal impacts to Miller Creek. Community events, classes, print materials, social media and hands-on workshops can all be part of this strategy. Table 18 lists potential mitigation activities for achieving the load allocation. Citizen engagement is especially timely with the advent of the MPCA's new Watershed Approach, which stresses the need for citizen involvement on water quality issues. One existing resource available to help engage citizens and implement educational activities is the Regional Stormwater Protection Team. The mission of this informal group of local stormwater practitioners is to educate the public about pollutants that are carried by stormwater runoff to local creeks and streams.

Table 18: Mitigation activities to meet the load allocation.

BMP	Est. Cost *(source)*	Location(s)	Maintenance needs/Comments
Preserve existing trees/riparian buffers	$0	Along the entire stream.	None.
Plant trees/Create riparian buffers	Potted trees at $15 a tree including fencing *(2012 estimated cost).*	Along the entire stream.	Water first season after planting. Remove fencing when trees outgrow them.
Preserve existing wetlands	$0		None.
Bio-infiltration – rain gardens, grassed infiltration swales and similar infiltration practices	Approximately $12 per cubic foot *(2009 cost, based on Irresistible Ink grassed swale/rain garden project*)	Anywhere where soils and space allow.	Watering plants to get them established. Weeding first three years.
Public Involvement and educational activities: workshops, festivals, stream clean-ups.	Varies by method.	Businesses and residents located right along the stream.	Citizens will need frequent, consistent attention to stay interested and engaged.
Use conservation easements or trout easements donated by private landowners to reduce development pressure. Easements can also provide a mechanism for accessing the stream and monitoring its health over time.	Varies depending on land value. If the easements are donated, then only staff time and legal and recording fees would be needed.	Privately held parcels along the creek.	Regular monitoring of protected parcels to insure that the easement terms are being upheld.
Restore habitat and channel morphology of straightened / channelized stream segments running through private parcels.	$100 / lineal foot for restorations using "natural channel design" methods (*2013 cost, professional engineer estimate*).	West of Haines Rd just south of airport. (Across from Irresistible Ink.) Parcel #s: 395-0010-03160 395-0010-03200 South and West of Federal Prison Camp off of Stebner Rd. Parcel #s: 395-0010-02925 395-0010-02955	Monitor structural integrity of project for several years after the project and after significant rain events.
Install or retrofit small commercial parking lots within the watershed with pervious asphalt or other pervious materials.	$10 per square foot for pervious asphalt *(2009 cost, based on St. Scholastica parking lot project.)*	Miller Hill / Hwy 53 commercial district.	Must vacuum out regularly and cannot use sand in winter.

BMP	Est. Cost *(source)*	Location(s)	Maintenance needs/Comments
Disconnect commercial rooftops and/or direct runoff from commercial roofs to rain gardens.	$11.13 per square foot (*2008 cost, from Types and Costs of Heat Mitigating Practices)*	Miller Hill / Hwy 53 commercial district.	Commercial rooftops are one of the greatest exporters of heat loading in runoff. A 100 sq. ft. rain garden drains 1,000 sq. ft. of roof.
Disconnect Commercial Rooftop and/or direct runoff from commercial roofs to rock cribs.	$6.00 per square foot *(2008 cost, from Types and Costs of Heat Mitigating Practices)*	Miller Hill / Hwy 53 commercial district.	Commercial rooftops are one of the greatest exporters of heat loading in runoff.
Install underground stormwater detention chambers under parking lots.	$1.2 Million for a 4-acre parking lot *(2012 cost, based on Lake Superior College project).*	New development.	Annual monitoring to insure proper functioning.
Constructed wetlands.	$50,000 for 0.5 acre *(2008 cost, from Types and Costs of Heat Mitigating Practices).*		0.5 acre, 3 ft. deep wetland can treat runoff from 5 acres, ½ of which is impervious.
TMDL Kick-off event.	***Funded*** at $1,500 through CWF grant with the South St. Louis SWCD.	Along the restored stretch near U-Haul (MNDOT Right-of-Way).	Slated for spring of 2015.

Tracking and Monitoring

As previously noted, tracking progress towards achieving the wasteload allocations will occur through the MS4 General Permits and the NPDES non-municipal stormwater permits administered by the MPCA (via Storm Water Management Plans, Discharge Monitoring Reports and through annual reporting).

Unfortunately, water quality monitoring for temperature is a sophisticated endeavor that permittees may or may not have the skills to undertake. The temperature impairment is expressed as heat input in gigajoules per day, is a function of flow, and must be measured at several points using a relatively sophisticated formula (see Miller Creek Water Temperature TMDL and/or Herb 2011). Moreover, the equipment required for temperature monitoring, along with calibration supplies and software, are expensive and require continuous attention and training.

Annual variability in climatic conditions and time required for BMPs to achieve full load reduction potential will also need to be considered in assessing the success of mitigation efforts. In light of all of these considerations, the MPCA is prepared to grant flexibility to the permittees in achieving their WLAs.

The MPCA's approach towards determining permittee compliance with WLAs has been to assume compliance if MS4s are implementing the Best Management Practices set forth in the TMDL Implementation Plan (Trojan, 2011). If MS4s choose to use BMPs that are not identified in the Implementation Plan, then those actions must be separately evaluated by the MPCA in order to provide evidence of compliance (Trojan, 2009).

Tracking progress towards meeting the load allocation will be done through the collective efforts of the watershed community and through voluntary reporting of actions taken to help reduce heat loading to Miller Creek. Environmental agencies and organizations in the watershed area could also solicit this information through educational events and newsletters, depending on available staff and funding. The formation of a Miller Creek Citizens Watershed Group would be the best way to track progress made towards meeting the load allocation, but this is dependent on citizen interest, which has been weak in the past, based on the limited success experienced by South St. Louis SWCD in garnering public participation for the TMDL.

A number of monitoring activities are currently underway and are listed below.

1. **City of Hermantown:** Requires monitoring of runoff for five years after a business installs its stormwater management structure.
2. **Miller Hill Mall (Simon Property Group):** Unlike the MS4s, which are regulated under a general permit (same requirements for everyone), Walmart and the Miller Hill Mall are regulated under individual (industrial) permits written specifically for their sites. Both of them are required to submit Discharge Monitoring Reports (DMRs) to the MPCA regularly as a requirement of their permits. The Mall has two sampling locations – the South Sediment Pond's discharge point to Miller Creek and the North Sediment Pond's discharge point to a drainage ditch. Sampling protocol is provided in the permit. Temperature monitoring is not specifically required, but there is a provision in the permit that requirements must be met for the Miller Creek Water Temperature TMDL when it is approved.
3. **Walmart Store #1757:** Must submit DMRs for four sampling locations: 1) in the ditch along Hwy 53 upstream of outfall (control site); 2) on the NE side of Hwy 53 in the Creek, as it crosses under Hwy 53; 3) in the ditch along Hwy 53 downstream of the discharge site from the underground treatment system; 4) in the creek downstream of the wetland buffer (Outlot A). The first three stations are measuring background water quality and the last (downstream) station is meant to measure improvements provided by the treatment system and wetland buffer. Temperature monitoring is required at all four of these sites. A sampling protocol is provided in the permit.
4. **The Duluth International Airport:** Uses a consulting company to collect and test water quality samples from the airport's stormwater structures regularly, and reports the results to the City of Duluth.
5. **The Natural Resources Research Institute:** Has been collecting temperature data on Miller Creek on the Lake Superior College (LSC) Campus since 2008 in cooperation with LSC. In addition to temperature, they also collect data on turbidity, specific conductivity, stage height, flow and precipitation with equipment that is maintained by staff at LSC. This data is posted in real time on the LakeSuperiorStreams.org website. The NRRI – LSC monitoring effort is funding-dependent (Axler, pers. comm., 2011). The water quality sensor (sonde) was replaced in 2015 after being destroyed during the June 2012 rainstorm and flooding event.
6. **The Minnesota Pollution Control Agency**: Follow-up monitoring on Miller Creek to measure progress towards achieving the TMDL for temperature. Under the Watershed Approach and Watershed Restoration and Protection Strategies (WRAPS) process, MPCA and local partners completed intensive watershed monitoring in the St. Louis River watershed, including Miller Creek in 2009 as part of a ten-year cycle. Monitoring included water chemistry parameters, biotic community health, and assessing habitat conditions. This work will be replicated in 2019.
7. **The Minnesota DNR:** Conducts stream fish population and temperature assessments on a regular basis at select locations in Miller Creek. The status of the fish population, specifically, the density, diversity and overall vitality of cold-water species is a good way to gauge if temperature mitigation efforts are working.
8. **Natural Resources Research Institute:** Conducted a macroinvertebrate study for the TMDL in 2008. Monitoring and research efforts continue to include Miller Creek watershed as an area of focus.

General Compliance Schedule

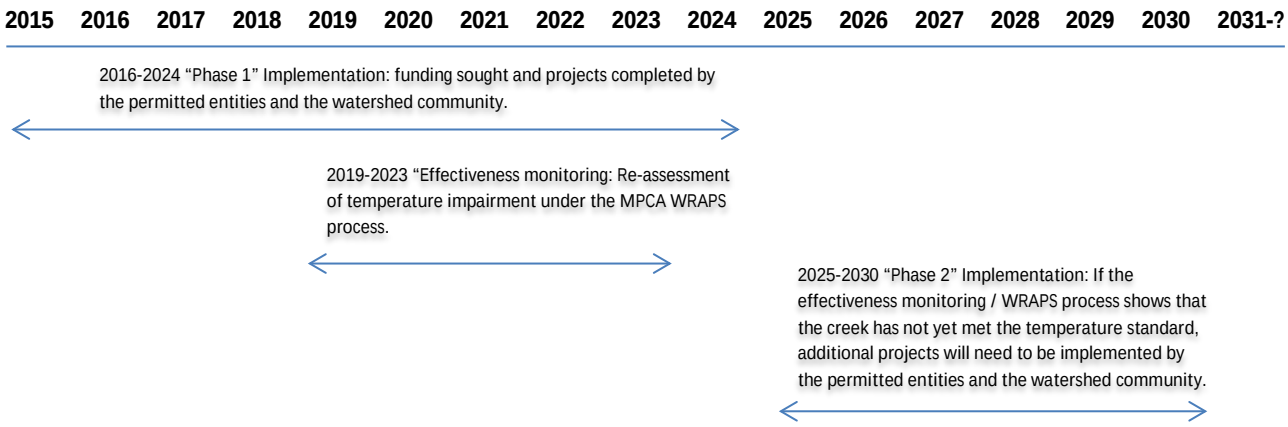
It is the recommendation of this Plan that the permitted entities and the watershed community implement the actions that they have agreed to implement over the period beginning when the TMDL is approved and ending in 2023, when the NPDES MS4 General Stormwater Permit is expected to be reissued (Figure 10). This period will be considered "Phase 1" of the Miller Creek TMDL Implementation Strategy and purposefully coincides with the NPDES MS4 stormwater permitting process, the program through which the MS4s will be held accountable for meeting their WLAs. The current permit expires in 2018. It is during the 2018 to 2023 NPDES/SDS permit cycle that MS4s will be required to start formally reporting on the progress towards meeting their WLAs for Miller Creek.

If the actions taken during "Phase 1" do not lead to the achievement of the TMDL, then the recommendation of this Plan is for the permitted entities, together with the watershed community, to embark on a "Phase 2" Implementation Strategy using the adaptive management approach. At the beginning of "Phase 2," this Implementation Plan should be revisited by all stakeholders involved in the Miller Creek Water Temperature TMDL process and revised as needed.

This Phase 1/Phase 2 recommendation is based on the following:

1. The relatively minor (10%) reduction in heat loading that is needed to solve the temperature problem for Miller Creek based on the TMDL study;
2. The lack of data available regarding the heat load reduction capability of temperature mitigation BMPs;
3. The need for cities and other entities to prepare budgets a year or more ahead of time; and
4. The changes that will inevitably occur between the completion of this plan and the commencement of formal reporting by the MS4s to the MPCA regarding their WLAs.

Figure 10: illustrates the proposed timeline for achieving the TMDL as discussed above:



This compliance schedule is provided as a required component of this plan, with the understanding that it will be updated as needed.

Funding Needs and Mechanisms

Many of the MS4s need an estimate of costs to validate the use of public money on TMDL implementation activities and to develop sound annual budgets. In addition, many circumstances could affect the timing and types of projects and activities undertaken by the time the permittees are required to account for their progress towards meeting their WLAs, including:

- changes in material and labor costs
- new research and data on the impacts of temperature and BMPs for addressing temperature
- warmer temperatures (climate change)
- changes in storm frequency and intensity
- political priorities
- other circumstances

The availability of funds will determine the timing, complexity and quantity of actions completed within the proposed compliance schedule. Available grant programs, available cost-share opportunities, legislative priorities, and local level budgets will all play a role in the speed at which the wasteload and load allocations can be met.

Potential funding sources as of this writing include the following:

Grant Programs:

1. **Clean Water Fund.** These are state funds from the Clean Water, Land and Legacy Amendment administered through an annual competitive grant process by the Board of Water and Soil Resources. Entities must have a state approved and locally adopted local water management plan to be eligible. Typically, cities and townships in this area do not have the required water management plan, but the South St. Louis Soil & Water Conservation can apply for projects on their behalf. The 2015 Miller Creek MNDOT/U-Haul re-meander project and the Miller Hill Mall Comprehensive Stormwater Management Plan were both funded under this program. A 25% match is required.
2. **Outdoor Heritage Fund.** These are state funds from the Clean Water, Land and Legacy Amendment that are distributed through an annual competitive process as recommended to the legislature by the Lessard-Sams Outdoor Heritage Council (LSOHC). These funds are for larger projects that must be on public land. For the Miller Creek TMDL, they could be used for restoring trout habitat or enhancing wetlands or for buying property along the creek and putting it under easement.
3. **Conservation Partners Legacy Grant Program.** These are state funds administered by the DNR to restore, enhance and/or protect habitats for Minnesota's fish, game and wildlife. It is the smaller grants program of the Outdoor Heritage Fund. Projects must be on public land open to public hunting and fishing. Funds are distributed through an annual competitive grant program. A 10% match is required.
4. **Parks and Trails Legacy Grant Program.** This is an annual grant program funded by the Clean Water Land and Legacy Amendment and administered by the MN DNR. Funding can cover up to 100% of a project and are focused on projects outside of the metro area. Interpretive trails focused on the importance of restoring Miller Creek and temperature impairments in trout streams would be good candidates for this funding source.
5. **Public Facilities Authority Total Maximum Daily Load (TMDL) Grant Program.** This program is run by the Public Facilities Authority, a multi-agency authority that provides municipal financing expertise and infrastructure financing programs to enhance the environmental and economic vitality of the State. It provides grants to local government units to assist with the cost of projects necessary

to meet wasteload reduction requirements under TMDL Implementation Plans. Funds for this grant program are appropriated by the legislature from the Clean Water Fund via the Clean Water, Land and Legacy Amendment. The program provides grants for 50% of eligible costs up to a maximum of $3,000,000.

6. **The Environment and Natural Resources Trust Fund**. These are state funds generated by the Minnesota State Lottery. They are distributed through an annual competitive process as recommended to the legislature by the Legislative-Citizen Commission on Minnesota Resources (LCCMR). Projects must align with LCCMR's Six-Year Strategic Plan for the Environment and Natural Resources Trust Fund, which include water resources, land acquisition and environmental education.
7. **Minnesota's Lake Superior Coastal Program's annual grants and STAR (Short Term Action Request) grants.** These are federal funds distributed through a competitive process for projects that help achieve regional and state goals for managing land and water resources in the Lake Superior coastal area, of which Miller Creek is a part. There is usually a 50% match required. This is an especially good source for funding educational activities.
8. **Clean Water Partnership grants and loans, administered by the MPCA.** These are state funds available for addressing nonpoint source water pollution projects including TMDL implementation projects. A 10% match is usually required. Funding levels are contingent upon appropriations.
9. **Clean Water Act Section 319 Grants, administered by the MPCA.** These are federal funds available for addressing nonpoint source water pollution projects including TMDL implementation projects. A match is required. Funding levels are contingent upon appropriations. The MPCA uses the CWP and Section 319 programs to support the leadership efforts of local units of government and citizens to address nonpoint sources of pollution, such as pollution carried by stormwater runoff.

Cost-Share Programs:

State and federal cost-share programs are available through the South St. Louis SWCD and the Natural Resource Conservation Service. These programs provide technical and financial assistance, usually to private landowners, who are committed to implementing and maintaining BMPs for water quality on their property. Several BMPs have already been installed within the Miller Creek watershed through cost-sharing agreements including at Lake Superior College, Irresistible Ink and Energy Plus.

Stormwater Utility Fees/General Funds:

The City of Duluth currently has a stormwater utility program through which temperature mitigation activities could feasibly be funded depending on infrastructure needs and priorities. The City of Hermantown is exploring the creation of stormwater utility to help fund stormwater management projects including projects to help meet TMDLs that identify stormwater as a source of impairment.

Philanthropic Contributions:

The Duluth Superior Area Community Foundation coordinates philanthropic initiatives through myriad grant programs and could be a potential funding source for projects relating to Miller Creek. The NRRI has also administered a funding program called the Weber Stream Restoration Initiative. This funding is mainly focused on the Amity Creek-Lester River system, but is an example of local funding focused exclusively on local water quality.

Partnerships:

Many entities are, and continue to be, interested in restoring Miller Creek back to a sustainable trout stream. Partnerships between these entities should be easy to cultivate since many of them collaborate on other projects relating to water quality on a regular basis. For example, in 2014, the City of Duluth

and the South St. Louis SWCD worked together to restore a large eroding bank on Amity Creek, another impaired trout stream within the City of Duluth. The Regional Stormwater Protection Team and the Coldwater Coalition (an association of local fishing groups, citizens and government organizations) are two good forums through which partnerships can be developed and fostered as they meet regularly and include many of the entities who are interested in or could provide support for Miller Creek restoration projects.

Conclusion

This Miller Creek Water Temperature Implementation Plan presents information and guidance that permitted entities, interested groups and agencies and the general public can consider as they work together to restore Miller Creek. This watershed has long been considered unique because of its potential to be a viable trout fishery in an urban setting. The collective efforts taken to achieve the temperature TMDL for Miller Creek provides many great opportunities for developing creative solutions, sustainable partnerships and useful data that can be replicated on future TMDL studies and plans in this region.

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Appendix B: BMPs for MS4 Permittees

Appendix B
BMPs for MS4 Permittees

BMP Categories	Target Locations	Target Permitees	Considerations
Improved Stormwater Treatment			*Note: See SAFL report 536 on baseflow augmentation scenarios and report 535 on stormwater management scenarios.*
Increase stormwater treatment	Upper watershed: commercial, industiral, and transportation areas	Duluth, Hermantown, St. Louis County, MnDOT, NRRI	Add stormwater treatment to areas lacking treatment. Reduce the need for treatment by reducing impervious surfaces or diverting potential stormwater from impervious surfaces.
	Entire watershed: residential areas	Duluth, Hermantown	Technical assistance to watershed residences (e.g., rain gardens, rain barrels, disconnecting impervious surfaces, redirecting runoff, etc.).
Retrofit existing stormwater BMPs	Upper watershed: Examples include St. Louis County ponds near Sam's Club, MnDOT at US Hwy 53/Maple Grove Rd	Duluth, Hermantown, St. Louis County, MnDOT	Evaluate existing BMPs for thermal reduction potential and implement projects based on outcomes. Miller Hill Mall completed a comprehensive Stormwater Management Plan for temperature mitigation in 2016.
Reduced Impacts from Solar Radiation			*Note: See SAFL report 535 on shading scenarios, see other common methods used.*
Improve riparian vegetation density and composition	Upper watershed: US Hwy 53/Mall Drive, near Walmart to Chambersburg Ave	Duluth, Hermantown, St. Louis County, MnDOT	Identify and prioritize projects based on existing condtions (e.g., stream orientation, bank angle, and soils).
	Upper watershed: Chambersburg Ave to Lake Superior College	Duluth, St. Louis County, Lake Superior College	Technical assistance to riparian landowners (e.g., planting trees and native plants, and reducing turfgrass areas).
	Upper Watershed: above Rice Lake Landfill to US Hwy 53/Mall Drive, near Walmart	Rice Lake, Duluth, Hermantown, St. Louis County, St. Louis County, MnDOT	Analyze stream orientation, bank angle, soils, and vegetation potential and use this information to target projects.
	Lower watershed: Lincoln Park	Duluth	Coordinate with implementation of Lincoln Park Mini Master Plan (draft 2016).
Retrofit existing stormwater BMPs, where feasible	Upper watershed: commercial, industiral, and transportation areas	Duluth, Hermantown, St. Louis County, MnDOT, Lake Superior College	Evaluate existing BMPs for thermal reduction potential and implement projects based on outcomes
Improved water retention			*Note: See SAFL report 536 on baseflow augmentation scenarios.*
Mitigate the negative effects resulting from stream channelization	Upper watershed: Examples include: Haines Rd, below Duluth International Airport; US Hwy 53/Mall Drive, near Walmart; US Hwy 53/Haines Rd to Kohl's store; Mall Drive/Burning Tree Rd to Decker Rd. Lower watershed: Enger Park Golf Course, Lincoln Park, above 3rd St	Dependent on project	Feasibility and project scope is dependent on existing conditions and limitations (e.g., adjacent infrastructure) within the stream corridor and floodplain. Stream segment from US Hwy 53/Haines Rd to Kohl's store has completed design and is awaiting funding.
Restore and maintain wetland functions	Upper watershed: Ridgewood Rd to Lake Superior College. Lower watershed: Trinity Road to Lincoln Park	Upper watershed: Rice Lake, Duluth, Hermantown, St. Louis County, MnDOT; Lower watershed: Duluth, MnDOT	Update Miller Creek Wetland Functional Assessment and use this information to implement projects that will restore and maintain wetland condition and function.
Protect coldwater source waters	Upper watershed: US Hwy 53/Mall Drive near Walmart (and/or stream areas within brook trout potential) to Lake Superior College Lower watershed: Trinity Road to Lincoln Park. Entire watershed: wetlands and tributaries.	Rice Lake, Duluth, Hermantown, St. Louis County, MnDOT	Identify cold water inputs and sources. Implement projects that will maintain cold water inputs to Miller Creek.
Promote infiltration, where appropriate	Upper watershed: commercial, industrial, transporation, and residential areas	Duluth, Hermantown, St. Louis County, MnDOT	Identifiy areas with greatest infiltration potential and implement projects based on findings.
Other			*Note: See NRRI Macroinvertebrate, Habitat, and Temperature Report, St. Louis River Watershed Stressor Identification Report (draft), and applicalble DNR Fisheries management plans.*
Thermal refuge for brook trout	Upper watershed: US Hwy 53/Mall Drive near Walmart (and/or stream areas with potential for brook trout habitat) to Lake Superior College Lower watershed: Trinity Road to Lincoln Park	Upper watershed: Hermantown, Duluth, Lake Superior College; Lower watershed: Duluth, MnDOT	Determine cold water input locations and sources. Evaluate stream channel for thermal refuge for brook trout. In conjunction with DNR Fisheries staff, use this informatation to target creation, enhancement, and protection of thermal refuges in Miller Creek.
Temporary and permanent controls of land (conservation easements, management of public lands, purchase of private lands)	Upper watershed: riparian and wetland land owners in watershed	Duluth, Hermantown, St. Louis County, MnDOT, Lake Superior College	Undeveloped parcels containing wetlands, or stream channel and tributaries, especially those under pressure for development. Developed parcels containing wetlands, stream channel or tributaries (e.g., formal or informal conservation easements).

Notes:
Upper watershed equals headwaters to Lake Superior College.
Lower watershed equals Lake Superior College to St. Louis River.

Appendix C: TMDL Supporting Documents

Analysis of Flow Data from Miller Creek, Duluth, Minnesota. University of Minnesota St. Anthony Falls Laboratory Project Report No. 522

https://www.pca.state.mn.us/sites/default/files/wq-iw10-07n.pdf

Analysis of Stream Temperature Data from Miller Creek, Duluth, Minnesota. University of Minnesota St. Anthony Falls Laboratory Project Report No. 529

https://www.pca.state.mn.us/sites/default/files/wq-iw10-07o.pdf

Stream Temperature Modeling of Miller Creek, Duluth, Minnesota. University of Minnesota St. Anthony Falls Laboratory Project Report No. 535

https://www.pca.state.mn.us/sites/default/files/wq-iw10-07p.pdf

Streamflow Modeling of Miller Creek, Duluth, Minnesota. University of Minnesota St. Anthony Falls Laboratory Project Report No. 536

https://www.pca.state.mn.us/sites/default/files/wq-iw10-07q.pdf

Characterization of Stream Temperature and Heat Loading for Miller Creek, Duluth, Minnesota. University of Minnesota St. Anthony Falls Laboratory Project Report No. 552

https://www.pca.state.mn.us/sites/default/files/wq-iw10-07s.pdf

Miller Creek Macroinvertebrate, Habitat, and Temperature Report. NRRI Technical Report Number NRRI/TR-2010/11

https://www.pca.state.mn.us/sites/default/files/wq-iw10-07r.pdf

Miller Creek Diagnostic Study and Implementation Plan: Clean Water Partnership Phase I Report, South St. Louis Soil and Water Conservation District

http://www.lakesuperiorstreams.org/archives/MILLER_final.pdf