Watershed

October 2018

Mississippi River-LaCrescent Stressor Identification Report

A study of local stressors limiting the biotic communities in the Mississippi River –LaCrescent Watershed

MINNESOTA POLLUTION CONTROL AGENCY

CLEAN WATER LAND & LEGACY AMENDMENT

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Document number: wq-ws5-07040006a

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Key terms & abbreviations

AUID	Assessment Unit ID
BOD	Biological Oxygen Demand
CADDIS	Causal Analysis/Diagnosis Decision Information System
CBI	Coldwater biotic index
Cfs	Cubic feet per second
CL	Confidence limits
cm	Centimeter
DELT	Deformities, Eroded fins, Lesions, and Tumors
DO	Dissolved Oxygen
DOP	Dissolved Orthophosphate Phosphorus
EPA	Environmental Protection Agency
EPT	Ephemeroptera, Plecoptera, and Trichoptera
FIBI	Fish Index of Biological Integrity
GP	Glide/Pool
HUC	Hydrologic Unit Code
HSPF	Hydrological Simulation Program – FORTRAN
IBI	Index of Biotic Integrity
IWM	Intensive Watershed Monitoring
µg/L	Microgram per liter
µS/cm	Microsiemens per centimeter
DNR	Minnesota Department of Natural Resources
MIBI	Macroinvertebrate Index of Biological integrity
mg/L	Milligrams per liter
MPCA	Minnesota Pollution Control Agency
MSHA	MPCA Stream Habitat Assessment
SID	Stressor Identification
SOE	Strength of Evidence
TMDL	Total Maximum Daily Load
TP	Total Phosphorus
TSS	Total Suspended Solids
TSVS	Total Suspended Volatile Solids
WRAPS	Watershed Restoration and Protection Strategy

Executive summary

Over the past few years, the Minnesota Pollution Control Agency (MPCA) has substantially increased the use of biological monitoring and assessment as a means to determine and report the condition of the state's rivers and streams. This basic approach is to examine fish and aquatic macroinvertebrate communities and related habitat conditions at multiple sites throughout a major watershed. From these data, an Index of Biological Integrity (IBI) score can be developed, which provides a measure of overall community health. If biological impairments are found, stressors to the aquatic community must be identified.

Stressor identification (SID) is a formal and rigorous process that identifies stressors causing biological impairment of aquatic ecosystems and provides a structure for organizing the scientific evidence supporting the conclusions (Cormier et al. 2000). In simpler terms, it is the process of identifying the major factors causing harm to aquatic life. Stressor identification is a key component of the major watershed restoration and protection projects being carried out under Minnesota's Clean Water Legacy Act.

This report summarizes stressor identification work in the Mississippi River LaCrescent Watershed (MRLC). A total of 4 AUIDs were assessed for biology in the MRLC Watershed (Table 2). There was one biological impairment identified in this watershed, on Pine Creek, which is detailed in Section 4 of this report.

After examining many candidate causes for the biological impairments, the following stressors were identified as probable causes of stress to aquatic life in Pine Creek:

- Temperature
- TSS (Total Suspended Solids)
- Habitat

A summary of recommendations for the entire Mississippi River LaCrescent watershed, in addition to protection considerations are found at the end of this document, in Section 5.

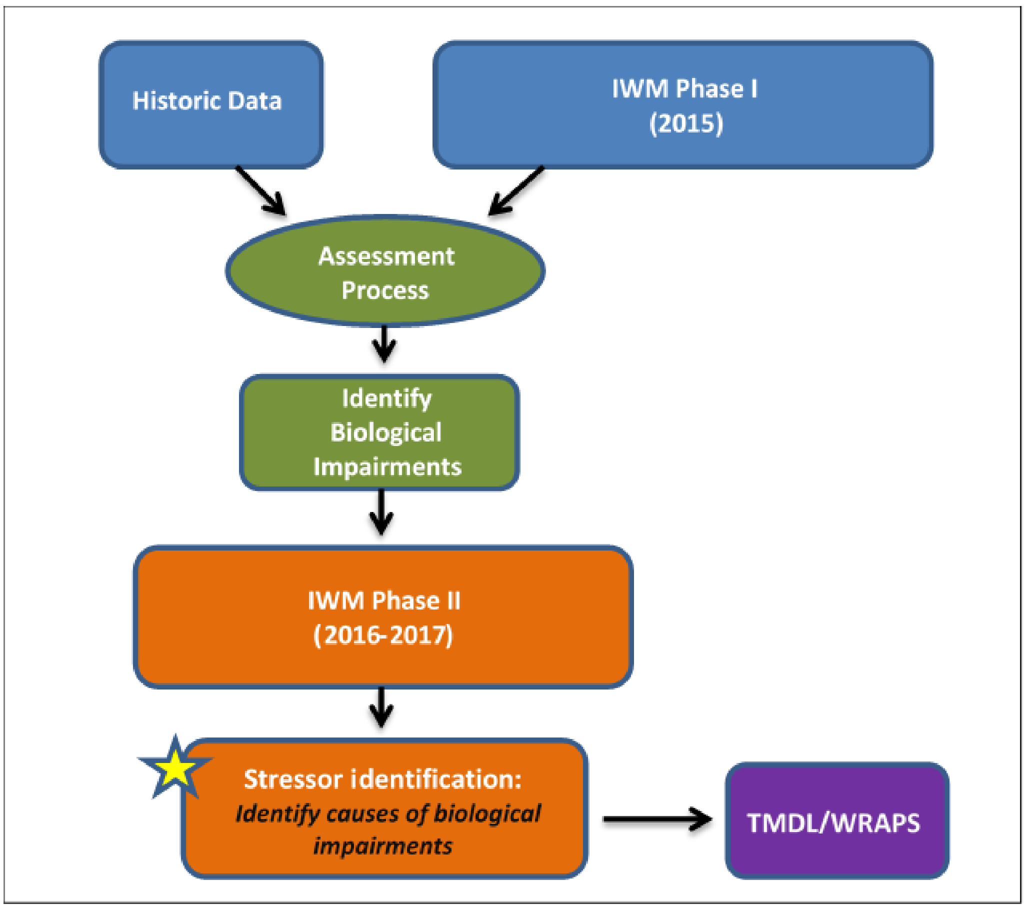
1. Introduction

1.1 Monitoring and assessment

As part of the MPCA's Intensive Watershed Monitoring (IWM) approach, monitoring activities increased in rigor and intensity during the years of 2015-2016, and focused more on biological monitoring (fish and macroinvertebrates) as a means of assessing stream health. The data collected during this period, as well as historic data, were used to identify stream reaches that were not supporting healthy fish and macroinvertebrate assemblages (Figure 1).

Once a biological impairment is discovered, the next step is to identify the source(s) of stress on the biological community. A SID analysis is a step-by-step approach for identifying probable causes of impairment in a particular system. Completion of the SID process does not result in a finished total maximum daily load (TMDL) study. The product of the SID process is the identification of the stressor(s) for which the TMDL may be developed. In other words, the SID process may help investigators nail down excess fine sediment as the cause of biological impairment, but a separate effort is then required to determine the TMDL and implementation goals needed to restore the impaired condition.

Figure 1. Process map of IWM, Assessment, SID and TMDL processes.

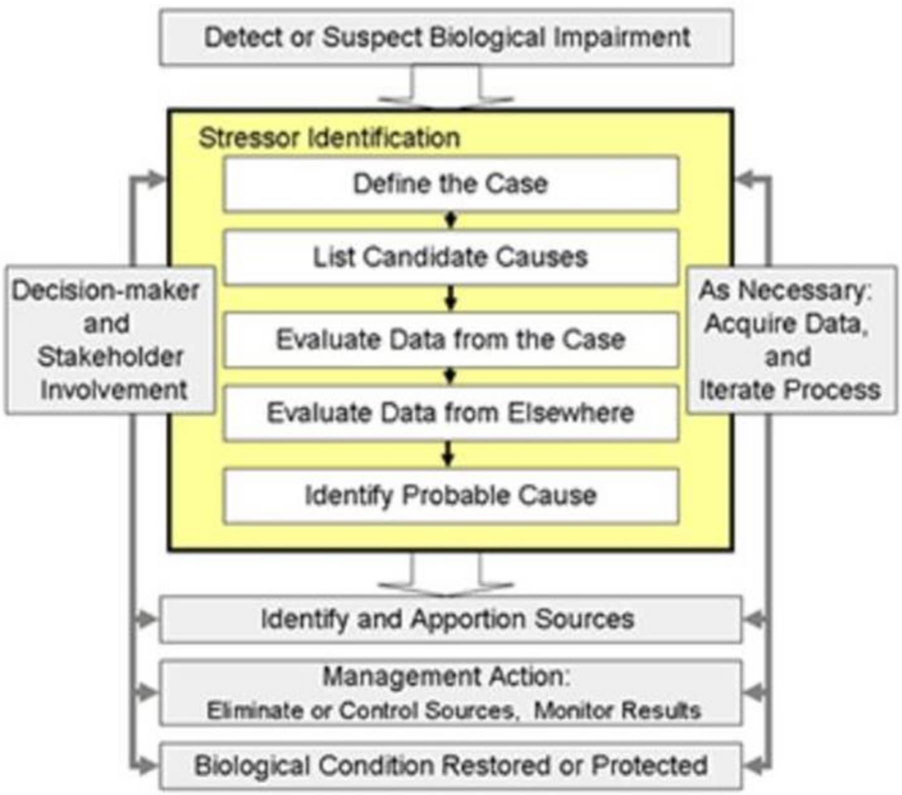


1.2 Stressor identification process

The MPCA follows the U.S. Environmental Protection Agency's (EPA's) process of identifying stressors that cause biological impairment, which has been used to develop the MPCA's guidance to SID (Cormier et al. 2000; MPCA 2008). The EPA has also developed an updated, interactive web-based tool, the Causal Analysis/Diagnosis Decision Information System (CADDIS; EPA 2010). This system provides an enormous amount of information designed to guide and assist investigators through the process of SID. Additional information on the SID process using CADDIS can be found here: http://www.epa.gov/caddis/.

SID is a key component of the major watershed restoration and protection projects being carried out under Minnesota's Clean Water Legacy Act. Stressor identification draws upon a broad variety of disciplines and applications, such as aquatic ecology, geology, geomorphology, chemistry, land-use analysis, and toxicology. A conceptual model showing the steps in the SID process is shown in Figure 2. Through a review of available data, stressor scenarios are developed that aim to characterize the biological impairment, the cause, and the sources/pathways of the various stressors.

Figure 2. Conceptual model of SID process (Cormier et al. 2000).



Strength of evidence (SOE) analysis is used to evaluate the data for candidate causes of stress to biological communities. The relationship between stressor and biological response are evaluated by considering the degree to which the available evidence supports or weakens the case for a candidate cause. Typically, much of the information used in the SOE analysis is from the study watershed (i.e., data from the case). However, evidence from other case studies and the scientific literature is also used in the SID process (i.e., data from elsewhere).

Developed by the EPA, a standard scoring system is used to tabulate the results of the SOE analysis for the available evidence. A narrative description of how the scores were obtained from the evidence should be discussed as well. The SOE table allows for organization of all of the evidence, provides a checklist to ensure each type have been carefully evaluated and offers transparency to the determination process.

The existence of multiple lines of evidence that support or weaken the case for a candidate cause generally increases confidence in the decision for a candidate cause. A scoring scale is used for evaluating each type of evidence in support of or against a stressor. Additionally, confidence in the results depends on the quantity and quality of data available to the SID process. In some cases, additional data collection may be necessary to accurately identify the stressor(s) causing impairment. Additional detail on the various types of evidence and interpretation of findings can be found here: https://www.epa.gov/caddis-vol1/caddis-volume-1-stressor-identification-summary-tables-types-evidence.

1.3 Common stream stressors

The five major elements of a healthy stream system are stream connections, hydrology, stream channel assessment, water chemistry and stream biology. If one or more of the components are unbalanced, the stream ecosystem may fail to function properly and is listed as an impaired water body. Table 1 lists the common stream stressors to biology relative to each of the major stream health categories.

Table 1. Common streams stressors to biology (i.e., fish and macroinvertebrates).

Stream health	Stressor(s)	Link to biology
Stream connections	**Loss of connectivity** • Dams and culverts • Lack of wooded riparian cover • Lack of naturally connected habitats/ causing fragmented habitats	Fish and macroinvertebrates cannot freely move throughout system. Stream temperatures also become elevated due to lack of shade.
Hydrology	**Altered hydrology** **Loss of habitat due to channelization** **elevated levels of TSS** • Channelization • Peak discharge (flashy) • Transport of chemicals	Unstable flow regime within the stream can cause a lack of habitat, unstable stream banks, filling of pools and riffle habitat, and affect the fate and transport of chemicals.
Stream channel assessment	**Loss of habitat due to excess sediment** **elevated levels of TSS** • Loss of dimension/pattern/profile • Bank erosion from instability • Loss of riffles due to accumulation of fine sediment • Increased turbidity and or TSS	Habitat is degraded due to excess sediment moving through system. There is a loss of clean rock substrate from embeddedness of fine material and a loss of intolerant species.
Water chemistry	**Low dissolved oxygen concentrations** **elevated levels of nutrients** • Increased nutrients from human influence • Widely variable DO levels during the daily cycle • Increased algal and or periphyton growth in stream • Increased nonpoint pollution from urban and agricultural practices • Increased point source pollution from urban treatment facilities	There is a loss of intolerant species and a loss of diversity of species, which tends to favor species that can breathe air or survive under low DO conditions. Biology tends to be dominated by a few tolerant species.
Stream biology	Fish and macroinvertebrate communities are affected by all of the above listed stressors	If one or more of the above stressors are affecting the fish and macroinvertebrate community, the IBI scores will not meet expectations and the stream will be listed as impaired.

2. Overview of the Mississippi River LaCrescent Watershed

2.1 Background

The Mississippi River-LaCrescent watershed is located in northeast Houston County and southeast Winona County. The watershed drains 95 square miles and includes a collection of tributaries that flow directly to the Mississippi River. Pine Creek is the largest stream in the watershed. Beginning just south of Highway 90, the stream flows south then east before meeting the Mississippi River in LaCrescent.

The Mississippi River-LaCrescent is located entirely in the Driftless Area, an area of the state that was missed by the last glaciation. The area is known for its karst features, deep limestone lined valleys, and coldwater streams. Trout fishing is a common recreation. The Minnesota Department of Natural Resources (DNR) manages streams for fishing and fishing easements provide anglers with access to streams. The scenic natural setting and coldwater streams are a source of tourism in the area, providing income to a number of local businesses. LaCrescent is the largest town in the watershed with a population of 4,830. Other towns in the watershed include New Hartford, Dresbach, and Dakota.

The Mississippi River-LaCrescent watershed is also defined as Driftless loess hills and bedrock by the NRCS. This means the soils consist of silt well to moderately well drained soils over bedrock in a landscape dominated by dissected hills and valleys.

In 2007, a large flood devastated areas of southeast Minnesota. The Mississippi River-LaCrescent watershed received 8-14 inches of rain in 24 hours. The floods washed out roads, buildings, and even railroad tracks. In some locations, stream channels were entirely changed or moved. Effects from the floods have diminished, but can still be seen in parts of the watershed. Subsequent floods in 2009 and 2010 continued the damage done in 2007. Large sections of streams were washed away and people living near the downstream reaches were highly impacted.

2.2 Monitoring overview

Four stream AUIDs in the Mississippi River LaCrescent were assessed for aquatic life use, aquatic recreational use or both. Of the assessed streams, three streams were considered to be fully supporting of aquatic life. One AUID is considered non-supporting for aquatic life and recreation (Pine Creek) which will be discussed further in this report.

The biological monitoring stations that led to aquatic life listing and are included in this report are mapped in Figure 3. Additional information can be found in subsequent sections of this report, in addition to the comprehensive assessment report for the Mississippi River LaCrescent Watershed. Other details on the watershed can be found here.

2.3 Summary of biological impairments

The approach used to identify biological impairments includes assessment of fish and aquatic macroinvertebrates communities, and related habitat conditions at sites throughout a watershed. The information is used to develop an index of biological integrity (IBI). The IBI scores can then be compared to range of thresholds.

The fish and macroinvertebrates within each Assessment Unit Identification (AUID) were compared to a regionally developed impairment threshold and confidence interval and utilized a weight of evidence approach. The water quality standards call for the maintenance of a healthy community of aquatic life. IBI scores provide a measurement tool to assess the health of the aquatic communities. IBI scores higher than the impairment threshold indicate that the stream reach supports aquatic life. Conversely, scores below the impairment threshold indicate that the stream reach does not support aquatic life as it is expected. Confidence limits around the impairment threshold help to ascertain where additional information may be considered to help inform the impairment decision. When IBI scores fall within the confidence interval, interpretation and assessment of the waterbody condition involves consideration of potential stressors, and draws upon additional information regarding water chemistry, physical habitat, and land use, etc.

In the **Mississippi River- LaCrescent** watershed, **one** AUID has a biological impairment (Table 2).

Table 2. All biologically assessed AUIDs in the Mississippi River La-Crescent watershed.
Those highlighted in "red" indicate biological impairments and are discussed further in section 4.

			Impairments	
Stream Name	AUID #	Reach Description	Biological	Water Quality
Pine Creek	07040006-507	T105 R6W S13, north line to T105 R5W S32, south line	None	None
Rose Valley Creek	07040006-511	T105 R5W S22, north line to Pine Cr	None	None
Dakota Creek	07040006-512	T105 R5W S3, south line to Mississippi R	None	None
Pine Creek	07040006-576	T104 R5W S4, north line to Hwy 16	FIBI	E.coli, TSS

Table 3 provides the FIBI and MIBI scores for each of the biological monitoring stations in the Mississippi River LaCrescent. A total of six biological stations were sampled in the watershed, with three in Pine Creek below their FIBI impairment threshold (highlighted red). Pine Creek generally had fewer coldwater species like trout (with the exception of 15LM041 in the headwaters), while sites at other streams in the watershed were dominated by coldwater species.

Table 3. Summary of FIBI and MIBI scores for biological monitoring stations in the Mississippi River LaCrescent Watershed. Scores below impairment threshold are in red. Most of the stations and scores were from sampling in 2015, some 2016. If there were multiple visits from the same year, the mean is presented.

Location		Fish				Macroinvertebrate		
Stream Name	AUID suffix	Station (Year)	FIBI Class (Use)	FIBI impairment threshold	FIBI score (mean)	MIBI Class (Use)	MIBI impairment threshold	MIBI score (mean)
Rose Valley Creek	511	04LM093 (2015)	Southern Coldwater	50	64	Southern Coldwater	43	49
Pine Creek	576	15LM039 (2015)			38			57
		15LM043 (2015)			42			57
		15LM043 (2016)			12			49
		15LM040 (2015)			36			52
		15LM040 (2016)			30			42
Pine Creek	507	15LM041 (2015)			77			86
Dakota Creek	512	15LM042 (2016)			78			73

3. Possible stressors to biological communities

A candidate cause is defined as a "hypothesized cause of an environmental impairment that is sufficiently credible to be analyzed" (EPA, 2012). Identification of a set of candidate causes is an important early step in the SID process and provides the framework for gathering key data for causal analysis. A more detailed description of possible candidate causes or stressors specific to Minnesota is provided in the document *Stressors to Biological Communities in Minnesota's Rivers and Streams* (MPCA, 2017). This information provides an overview of the pathway and effects of each candidate stressor considered in the biological stressor identification process with relevant data and water quality standards specific to Minnesota. The U.S. Environmental Protection Agency (EPA) has additional information, conceptual diagrams of sources and causal pathways, and publication references for numerous stressors on its CADDIS website.

Table 4 shows eleven candidate causes that were selected as possible drivers of biological impairment in the MRLC watershed. The list was developed based upon the results of the Mississippi River LaCrescent Monitoring and Assessment process and other completed SID reports in the state. The credibility of each candidate cause as a possible stressor to the fish and/or macroinvertebrate community of the biologically impaired reaches in the watershed was then evaluated through a comprehensive review of available information, including water quality and quantity data, as well as existing plans and reports. Based upon the results of this evaluation, six candidate causes were identified to undergo causal analysis (Section 4).

Table 4. Summary of stressors evaluated as potential candidate causes for the biologically impaired reaches (i.e. Pine Creek) of the MRLC Watershed.

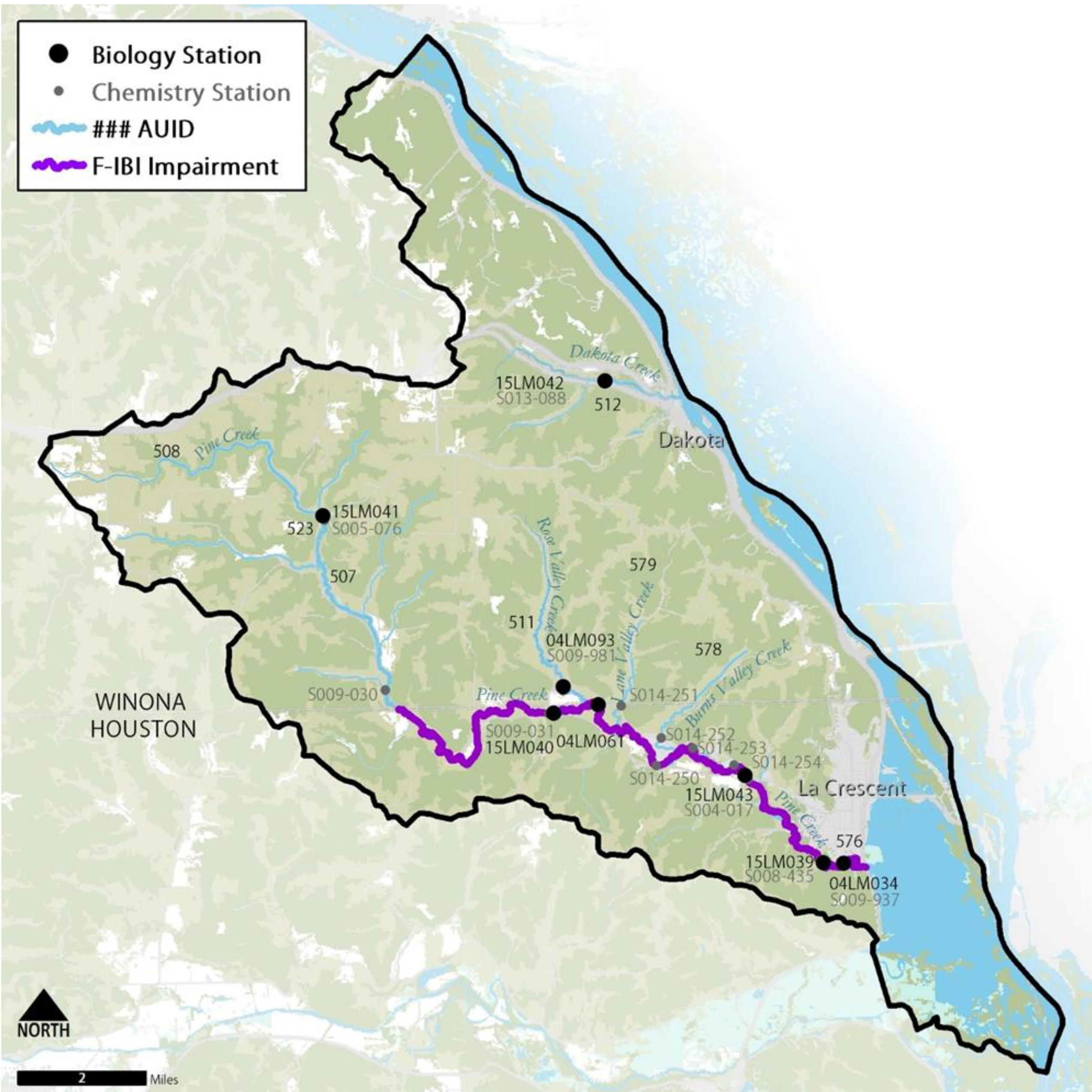
Stressor	Candidate cause identification	
	Summary of available information	Candidate cause (Yes/No/Inconclusive)
Connectivity/Fish Passage	Pine Creek has documented connectivity barriers (e.g., dams and private road crossings and beaver dams) that are potential obstructions to fish passage.	Yes
Temperature	Current data and DNR reports suggest Pine Creek is a Coldwater stream that experiences higher than normal temperature values.	Yes
Physical habitat	Pine Creek shows visual indications of insufficient instream habitat, bank erosion, and sedimentation.	Yes
TSS (Total Suspended Solids)	Several samples from Pine Creek have discrete total suspended solids (TSS) values that exceed the applicable state standard.	Yes
Low dissolved oxygen and/or Eutrophication	Samples show discrete and/or continuous dissolved oxygen (DO) values that were near the applicable state standard (7 mg/L). Multiple wetlands on lower end of watershed may be affecting stream oxygen levels and in-stream production. Several instances of total phosphorus values exceed the proposed river eutrophication standard values for the central region (0.100 mg/L) which may or may not be linked to DO	Yes
Nitrate	Nitrate-nitrite concentrations in the watershed and associated Pine Creek were lower than most of the region. However, given the spatial prevalence of high nitrate stress in surrounding watersheds, further analysis was warranted	Yes

Stressor	Candidate cause identification	
	Summary of available information	Candidate cause (Yes/No/Inconclusive)
pH	All of the pH values associated with Pine Creek and within the watershed were within the state standard range (Coldwater Streams: 6.5-8.5).	No
Chloride	Chloride is meeting aquatic life use standards as there are no exceedances over the assessment period in the biologically impaired reach of Pine Creek (11 samples in 2015)	No
Ammonia	Unionized ammonia is meeting aquatic life use for Pine Creek over the assessment period (11 samples in 2015; 1 in 2017).	No
Flow Alteration	Pine Creek, among others in SE MN have a naturally flashy hydrology. Overall, there is little suggestion that flows (peak and low flow) have been altered significantly beyond what is considered normal in the region. However, it is not clear how much climate change and/or other land practices may be impacting flows generally in the region. More specific information is needed to understand this potential stressor.	Inconclusive
Pesticides	There is not pesticide data available in Pine Creek. Additional sampling and information regarding aquatic toxicity, duration, and responses to pesticide exposure is needed before stressor determinations can be made specific to pesticides.	Inconclusive

4. Evaluation of candidate causes to biological impairments in the MRLC

4.1 Pine Creek (07040006-576)

Figure 3. Map of Mississippi River LaCrescent watershed, impairments, and monitoring stations.



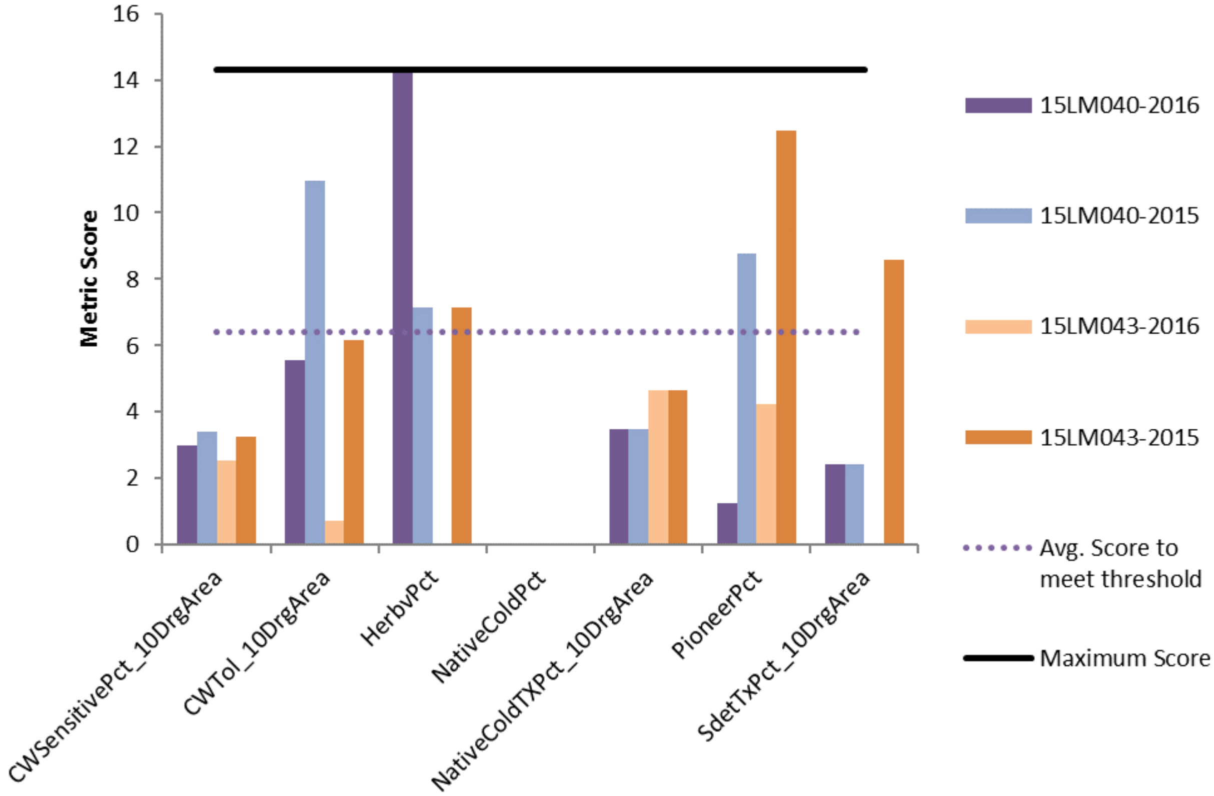
Biological and background information

There were five biological stations with available fish data on the impaired AUID of Pine Creek (04LM034, 04LM061, 15LM039, 15LM040, 15LM043), as shown in Figure 3. This AUID (576) was previously designated as warm water, and was reclassified to coldwater in 2017. Pine Creek in its entirety is not a designated trout water by DNR; only the upstream AUID (507) is designated at this time. Station 15LM041 was sampled on that reach and was found to be fully supporting for both fish and macroinvertebrates. The newly classified coldwater stream AUID extends from the Winona/Houston county line all the way down to Highway 61, near the mouth of the watershed. Therefore, currently Pine Creek upstream of Highway 61 is considered coldwater to the headwaters, while the small section downstream of the highway remains warmwater as it flows closer through the Mississippi River backwater area. Water chemistry sampling locations from the impaired reach are also shown (S009-031, S014-250, S004-017, S008-435, and S009-937) as well as other water sampling locations in the subwatershed. See Figure 3 for details on site locations and stream reaches.

Of the five total biological stations, two sites on the impaired AUID of Pine Creek, 15LM040 and 15LM043, were assessed for fish and represent the Pine Creek fish impairment in this report. Both were sampled once in 2015 and once in 2016; all samples scored below the coldwater impairment threshold for fish. *(Note: Three of the biological stations on this AUID were not included in the most recent assessments. Stations 15LM039 and 04LM034 were too close to the Mississippi River to be considered assessable since the fish community has a number of large river species. The other site 04LM061 had expired data, which was used only as supporting information during assessments. Data is considered expired if it is greater than 10 years old).*

Details on biological IBI scores for each site are found in Table 3. Station 15LM040 was in an open pasture and had pastureland with many eroded banks upstream from the sample location. The downstream location on the impaired reach, 15LM043, was dominated by fine sediment and had lower water clarity comparatively. Both lower stations had reduced native coldwater species, and coldwater sensitive species (NativeColdPct, and CWSensitivePct_10DrgArea). The relative abundance of taxa that are detritivores (SdetTXPct_10DrgArea) scored below average at the upstream sites, but increased moving downstream. The taxa richness of tolerant species in coldwater streams (CWTol_10DrgArea), the relative abundance of individuals that are herbivorous (HerbvPct), and the relative abundance of individuals that are pioneer species (PioneerPct) were the only FIBI metrics with above average scores (Figure 4). However, these results were variable among sites and years. Herbivores are not generally a good indicator in coldwater streams, and 15LM040 had some weed shiners (herbivore) in each sample. Fewer were present in 2016, which explains the higher score that year. In 2016 at 15LM043, weed shiners made up almost 25% of the community; leading to a metric score of zero. The number of detritivores also varied depending on the sample site and year. These fish feed on dead or decaying organic matter and populations will increase with stress in coldwater streams. The types of fish that are detritivores found in Pine Creek include white sucker, common shiner, weed shiner, and bluntnose minnow.

Figure 4. Fish metrics for Pine Creek 0704006-576, two stations from two different sampling years.



The macroinvertebrate community is often used as supporting evidence for investigating stressor determinations, even if macroinvertebrates are not impaired. For Pine Creek, sites 15LM040 and 15LM043 were both sampled for macroinvertebrates in 2015 and 2016 (Table 3). Site 15LM040 scored well above impairment threshold in 2015 and just below the threshold in 2016. Site 15LM043, scored above the threshold both years it was sampled (in 2015 it was 13 points above the threshold, and 2016 only 3 points). Site 15LM039 also scored well above impairment threshold. While coldwater taxa were not diverse at these sites, they were relatively abundant at all sites in Pine Creek. Even though one MIBI score was just below the threshold at 15LM043, the evidence suggests a supporting condition for macroinvertebrates overall in Pine Creek. It is possible that some of the stressors affecting the fish community are also impacting the macroinvertebrates at select locations, but are not making enough impact to cause impairment at this time. Therefore, the macroinvertebrates remain susceptible to impairment.

Temperature

According to DNR climate journal summary, 2016 was the fifth warmest year on record in Minnesota, which likely influenced the warmer summer average stream temperatures in Pine Creek (Table 4). The maximum temperature measurement over the four years of temperature data collected in Pine Creek was from July 22, 2016. On that day, station 15LM040 had a maximum temperature of 25.3°C, while the max at 15LM043 was just slightly lower, at 24.5°C. This maximum temperature is higher than many in the region and demonstrates a high potential for thermal stress in the summer months in Pine Creek. The summer maximum temperature for similar size drainages in the Lower Mississippi River basin are generally around 19°C. This comparison was obtained from looking at summaries of continuous temperature readings from over 100 different coldwater streams of Southeast Minnesota. The maximum temperatures recorded in Pine Creek are concerning, and likely represent stressful time periods for taxa that typically thrive in coldwater.

Table 5. Continuous temperature summer averages (June 1-August 31) for three stations in Pine Creek over the course of four different years. The farthest downstream station only had continuous temperature monitoring in 2015.

Year	15LM040 (CR16)	15LM043 (CR6)	15LM039 (LaCrescent)
2013	17.4	17.2	NA
2014	17.4	17.7	NA
2015	18	18	18.6
2016	19.7	19.3	NA

Additionally, to see summer *average* temperatures in the 18-19°C range is concerning for a coldwater stream of this size (Table 5). Smaller streams like Pine Creek are more commonly around 15-16°C for a summer average temperature. The majority of coldwater streams that see higher summer averages are much larger drainages, like the outlets of the major branches of the Whitewater, Vermillion, and more "warmwater-coolwater" transitional streams of the Root River (Middle Branch, Bear Creek). This is shown in data from Pine Creek near New Hartford (15LM041), where, in one year of temperature data collection in 2008, the summer average temperature was 14.5°C, with a maximum of 20.8°C (data courtesy of Winona State University). Station 15LM041 is near the headwaters, near more springs and expected to be colder, but it demonstrates a very fast pattern of warming temperatures moving downstream in Pine Creek (approx. seven stream miles from 15LM041 to 15LM040).

In 2017, multi-parameter sondes were placed in August at three different locations in Pine Creek (Figure 5). Comparing temperature longitudinally, it shows the warming trend moving downstream. However, the deployment period did not experience high air temperatures, and was a bit of an anomaly compared to other years. On August 17, there was a storm event that also influenced the stream. This is displayed by a large drop in conductivity during the storm event and a notable temperature signature (lack of temperature fluctuation) compared to what is seen on a typical day. Overall, the 2017 temperatures from all three sites are within expectations for coldwater streams, but due to the cool summer, this does not capture the peak temperatures from other years of Pine Creek, as shown in Figure 6. Four years of temperature monitoring from 2013—2016 show a much different story; with all years demonstrating higher peak temperatures than the stress threshold (24°C) and the stream spending much of its time above 19°C, the stress threat threshold for trout and other coldwater species.

Figure 5. Temperature comparisons for Pine Creek, upstream to downstream, 2017. The upstream site (15LM041) is not on the impaired reach, while the two brown lines are in the impaired reach (15LM040 and 15LM043).

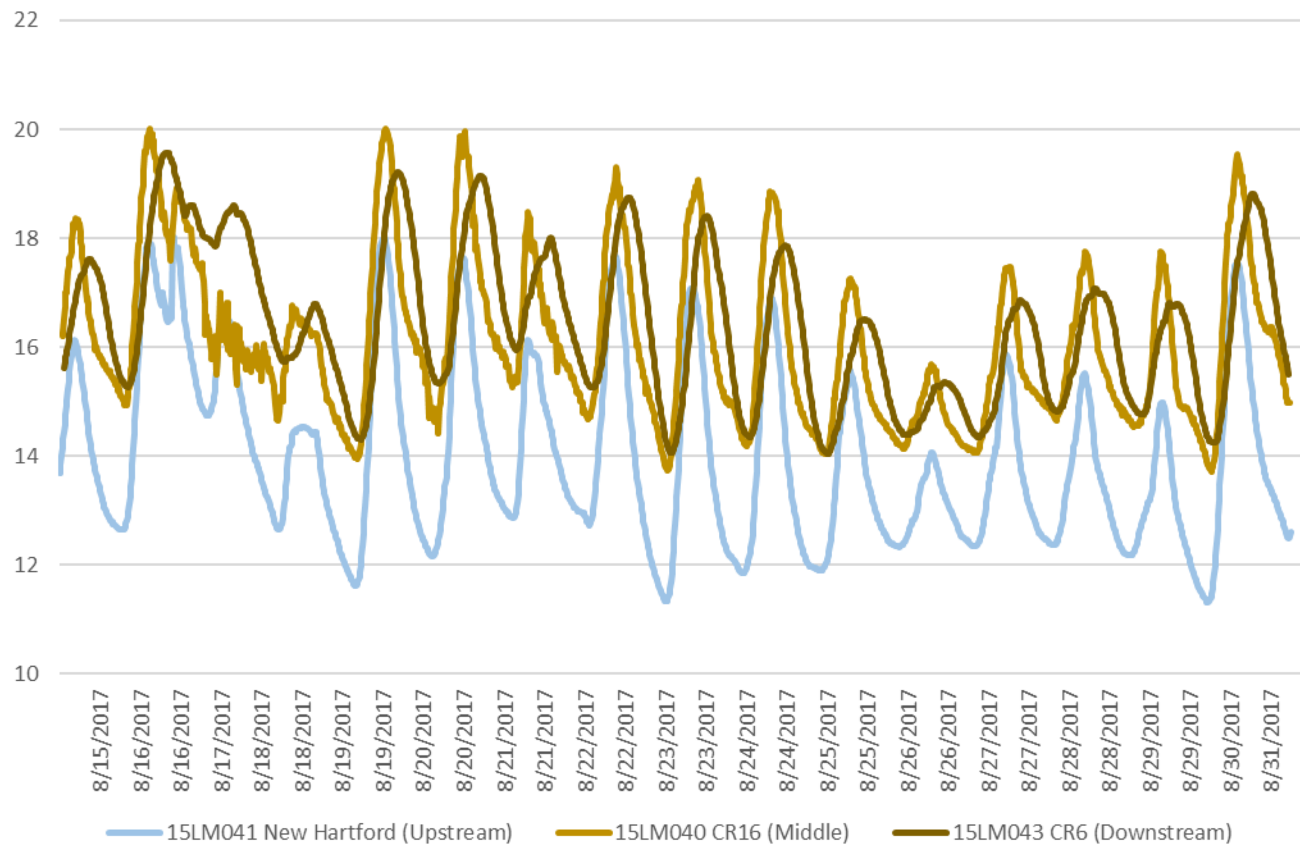
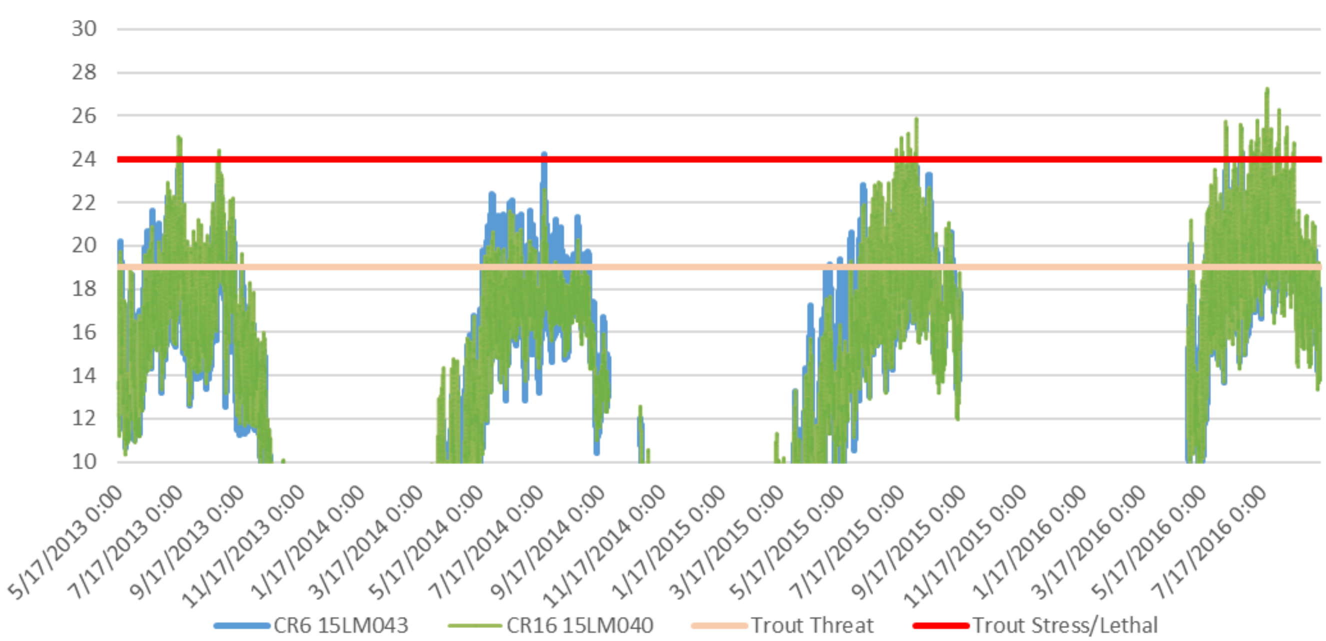


Figure 6. Four years of continuous temperature monitoring at 15LM040 (CR16) and 15LM043 (CR6). The light orange line indicates the trout threat temperature of 19°C, while the red line indicates the trout stress temperature of 24°C.



The percentage of coldwater fish species (ColdPct metric) are used to determine the abundance of coldwater fish species in a fish population sample. Most coldwater streams in SE MN have at least 50% coldwater fish species present, with many closer to 100%. This is observed at 15LM041, near the headwaters at New Hartford, where there are 99%-100% coldwater fish species. Again, this location is not in the impaired reach, nor do temperatures appear unsuitable here. Moving downstream into the impaired reach, however, the percentage of coldwater fish individuals decreases significantly. It ranges from 8%-13% at the farthest downstream station of Pine Creek (15LM043), and 10%-11% at 15LM040. Similarly, coldwater sensitive fish species (CWSensitivePct) and native coldwater species (NativeColdPct) are low or absent resulting in low IBI metric scores (Figure 4). Fish species that considered "coolwater" are even limited at these stations with all sites having 20% or less for both cold and coolwater fish individuals. All of these metrics correlate to poor thermal regime and/or can decline because of other stressors.

Macroinvertebrate species that are present can also provide indications regarding the thermal regime in any given stream. The CBI MIBI metric scores, which are based on coldwater tolerance values derived from Minnesota macroinvertebrate taxa and temperature data, ranged from 5.5-10.3 in Pine Creek. The average CBI metric score needed to meet impairment threshold is 6.6, and the two visits at 15LM040 were the only two that scored below this. Interestingly, the CBI score actually improved moving downstream (i.e. 15LM043 and 15LM039), meaning there were more coldwater macroinvertebrates in those locations compared to upstream site 15LM040. Typically, coldwater streams will get warmer moving downstream, simply because they are larger and can be farther away from spring (coldwater/headwater) sources. Coldwater macroinvertebrate taxa do require adequate coldwater temperatures, among other things. Therefore, the fact that they are somewhat limited at 15LM040 (in the middle of the watershed) may be due to an inadequate coldwater regime, difference in temperatures, or a combination of stressors influencing abundance and diversity of coldwater taxa and individuals at that particular location.

Longitudinal grab sampling and continuously logged temperature data have also shown that peak temperatures in Pine Creek have sometimes been highest at 15LM040, in the middle of the watershed. On average during the summer months, from the New Hartford headwater area (15LM041) to the middle section(15LM040), the stream warms about 4 degrees in the roughly 6 mile stream section. The area of 15LM040 (from Bobcat Rd downstream of New Hartford to CR16), has very little to no stream shading and few coldwater inputs which perhaps naturally limit the stream's ability to maintain coldwater temperatures. At least four identified springs or tributaries in this area are ponded, likely negatively impacting the in-stream temperatures (Figure 7).

Figure 7. Aerial photos of spring/tributary ponds between 15LM041 (New Hartford) and 15LM040 (CR16). Google Earth (2008, 2015).

Downstream of 15LM040 there are some significant coldwater tributaries (Rose Valley, Burns Valley, and Lanes Valley) which likely provide some thermal buffering in the lower reaches before 15LM043. Temperature measured in those tributaries, compared to Pine Creek, are all considerably lower. Increased shading of the stream in the area downstream of 15LM040 is also a likely contributor to a less dramatic temperature increase in this section.

The thermal regime in Pine Creek has been identified as a limiting factor in the past by DNR, and present data confirms this as well. The DNR Stream Survey Report from 1991 states, “There are few trees along the stream to provide shade, causing the water to warm to unsuitable temperatures for trout.” Many beaver dams have also been noted throughout the years on Pine Creek, which can have impacts on temperature as well. Beaver dams have historically been an issue, but presently do not seem abundant, and not likely a significant contributor to current thermal issues. Overall, there are many potential sources including lack of shade, extreme bank erosion, ponded springs, and sedimentation that are all contributing to the thermal stress observed in Pine Creek. Coldwater sources in Pine Creek watershed (i.e. springs and coldwater tributaries) should be protected, as they are vitally important in maintaining adequate temperatures in this stream. **Increased shading near the stream, better riparian buffers, and decreased sedimentation are especially important in the area downstream of New Hartford to CR16 (15LM040)**. All of the historical information, in addition to the current supporting chemical, physical, and biological evidence point to temperature as a stressor to the fish community in Pine Creek.

Nitrate

Nitrate concentrations in this section of Pine Creek are some of the lowest in the region. There were 63 nitrate samples overall, taken from 2011, 2015, 2016 and 2017. The samples represented a range of conditions, and most were evenly distributed over the 2015-2017 monitoring periods. Of those samples, the average nitrate concentration was 1.4 mg/L, with a maximum of 2.3 mg/L. Samples taken upstream of this reach near 15LM041 were actually slightly higher (2 mg/L average of 26 samples in 2016/2017) suggesting possible dilution from groundwater sources lower in nitrate when moving downstream into the impaired reach. A SEMN regional regression of baseflow nitrate concentrations compared to cultivated cropland shows that generally those watersheds with low percentages of cultivated crops are generally not high in baseflow nitrate. The entire MRLC watershed is about 8%-cultivated crops, and the regression predicts concentrations at about 2 mg/L or less, which agrees with the grab sample results.

Biological response to nitrate varies and is different for warmwater streams compared to coldwater streams. Overall, fish lack strong biological response evidence in relation to elevated nitrate in coldwater streams and therefore are not good indicators of nitrate degradation. Better relationships have been made correlating macroinvertebrate impairment with nitrate concentrations. Macroinvertebrates are not impaired in Pine Creek, and the macroinvertebrate metrics for Pine Creek do not show indications of nitrate related stress (Table 5). Within the impaired reach, there was a mixed response of Trichoptera (caddisfly) taxa, who are often considered sensitive to elevated nitrate, but also commonly respond to other stressors like habitat degradation (TrichopteraChTxPct). However, the nitrate index score, which characterizes the community's overall tolerance to high nitrate, is better than average at most sites. While the nitrate tolerant taxa did vary across sites, the abundance metric (Nitrate Tolerant Pct) did not indicate they were overly abundant at most sites. There were three nitrate intolerant taxa present at the farthest upstream (not-impaired) site, and zero at the other sites. The upstream site also showed slightly higher nitrate concentrations comparatively, which directly conflicts with the results shown below. Macroinvertebrates are not impaired and support a conclusion that reducing nitrate concentrations is not an important priority for Pine Creek. Actually, the results are good evidence that nitrate is not likely making an impact to the biological communities in Pine Creek, and the small responses seen are due to other stressors. At this time, nitrate is not considered a stressor to Pine Creek.

Table 6. Macroinvertebrate metrics that respond to nitrate stress in Pine Creek compared to the statewide average of visits meeting the coldwater biocriteria. Bold indicates metric value indicative of stress. The impaired reach is shown in red, while the surrounding stations (upstream and downstream) are included for comparison.

Station (Year sampled)	TrichopteraChTxPct	Nitrate Index Score	Nitrate Intolerant Taxa	Nitrate Tolerant Taxa	Nitrate Tolerant Pct
15LM041 (2015)	23.33	2.58	3	**15**	34.16
15LM040 (2015)	21.05	2.82	**0**	10	45.45
15LM040 (2016)	17.64	2.56	**0**	**16**	51.24
15LM043 (2015)	**14.81**	2.98	**0**	14	**62.61**
15LM043 (2016)	**13.51**	2.99	**0**	**18**	51.09
Southern Coldwater Average	*17.3*	*3.04*	*1.35*	*14.29*	*60.79*
Expected response to stress	↓	↑	↓	↑	↑

Total Suspended Solids

The grab sample results during fish sampling all exceeded the total suspended solids (TSS) standard (10 mg/L) in the impaired reach of Pine Creek (Table 6). In contrast, TSS results from fish sampling at the upstream, non-impaired site (15LM041), met TSS standards at the time of fish sampling. There were 62 additional samples for TSS taken from the impaired reach during monitoring in 2011, 2015, 2016 and 2017. The average TSS concentration of those samples was 169 mg/L, well over the standard of 10 mg/L for coldwater streams. The maximum TSS concentration was 2300 mg/L, taken at 15LM043 during a storm event on May 18th , 2017. When that particular event is taken out of the average calculation, it drops to 76 mg/L (from 169 mg/L), which is still well above the standard. In fact, **89%** of the samples taken from the impaired reach exceeded the TSS coldwater standard. Similarly, Pine Creek was determined to be impaired for TSS during assessment (18 samples; 94% exceeded the standard at 15LM043). The Secchi tube readings agree with the TSS chemistry data and suggest impairment as well, with 54.5% of the readings exceeding the 55 cm surrogate impairment listing standard. The TSS impairment is also evident in visual photo documentation; the middle to lower end of Pine Creek is regularly cloudy or muddy in appearance. In comparison, while the headwater site (15LM041) does have turbid water conditions occasionally, it clears up much more quickly and does not seem to have persistent turbid conditions like that of the impaired reach.

Figure 8. Monitoring station 15LM040 at CR16; May 18 2017 (left) and October 4,2017 (right) showing turbid water.

Figure 9. Longitudinal TSS sampling from multiple locations in Pine Creek in 2016. The sampling was scheduled monthly, and demonstrates multiple exceedences of the TSS standard, especially at the middle and downstream locations.

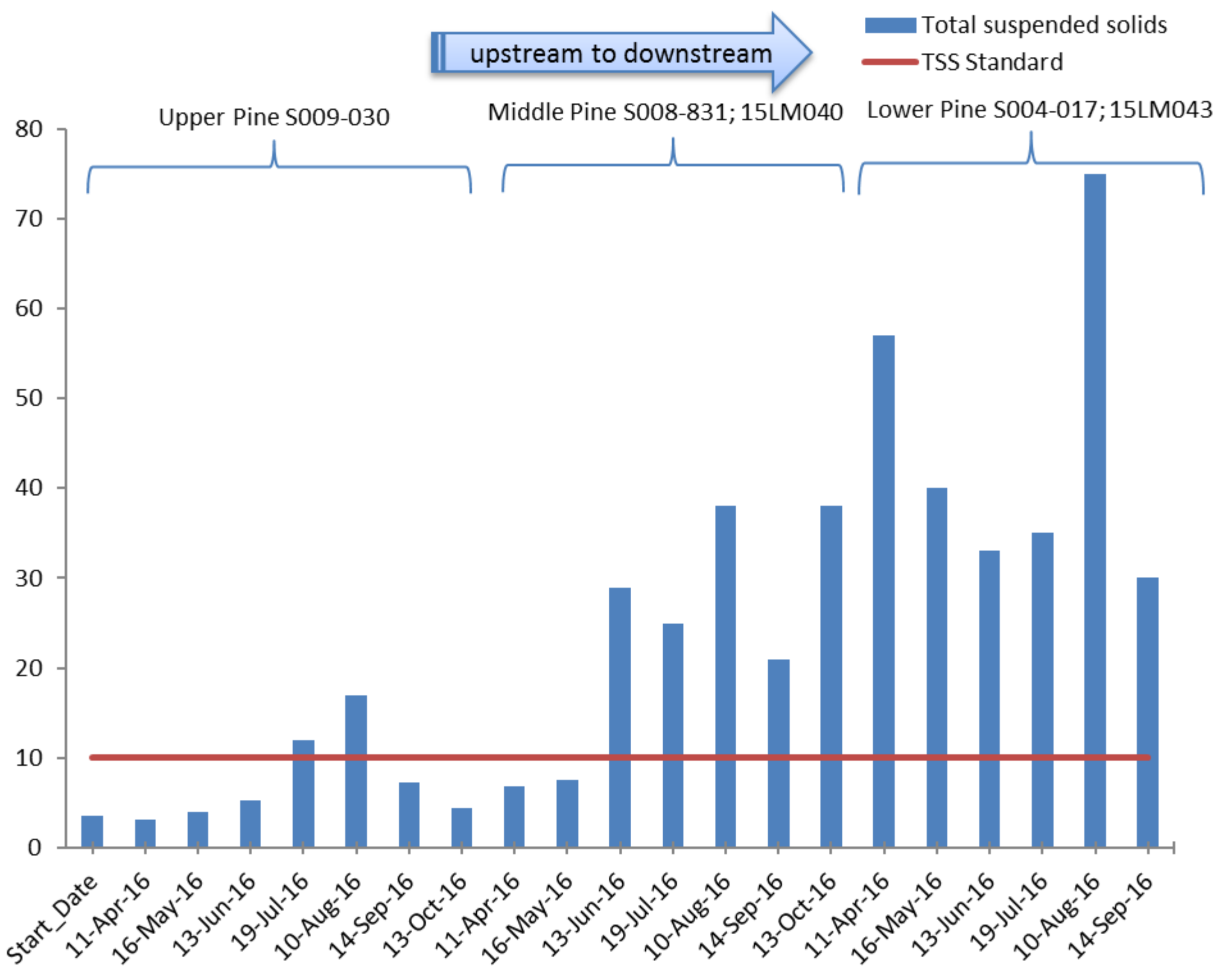
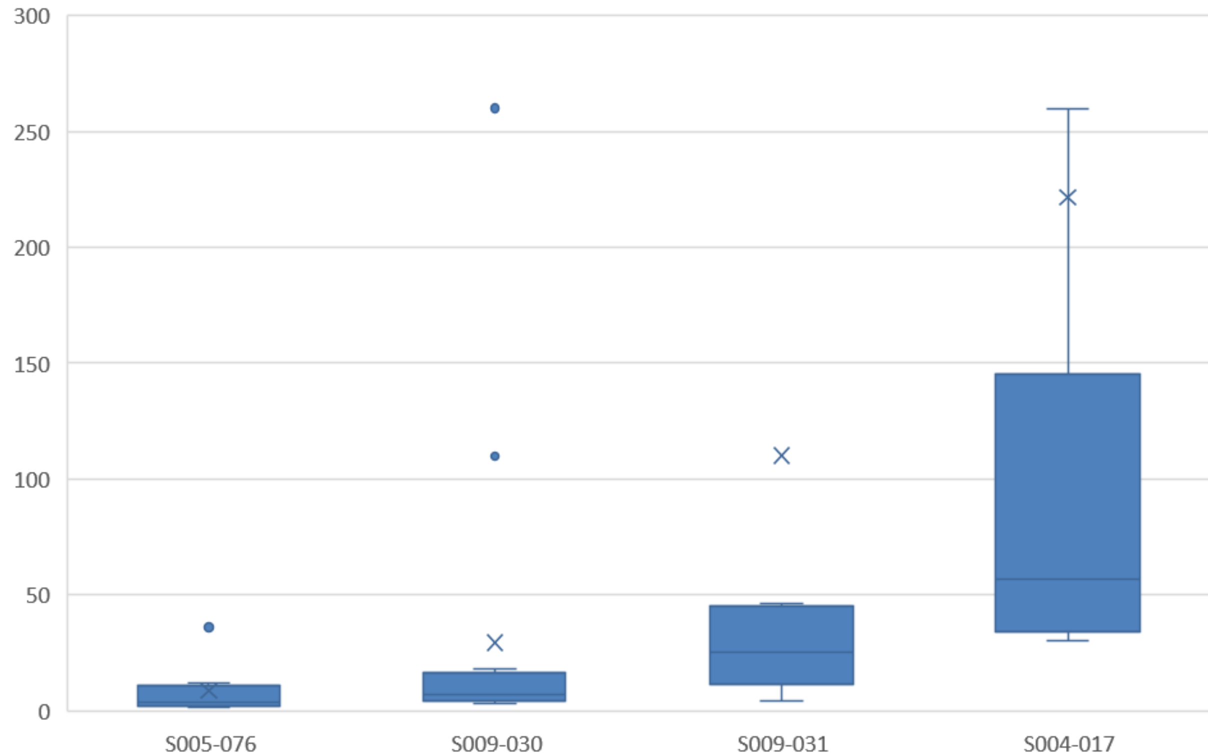


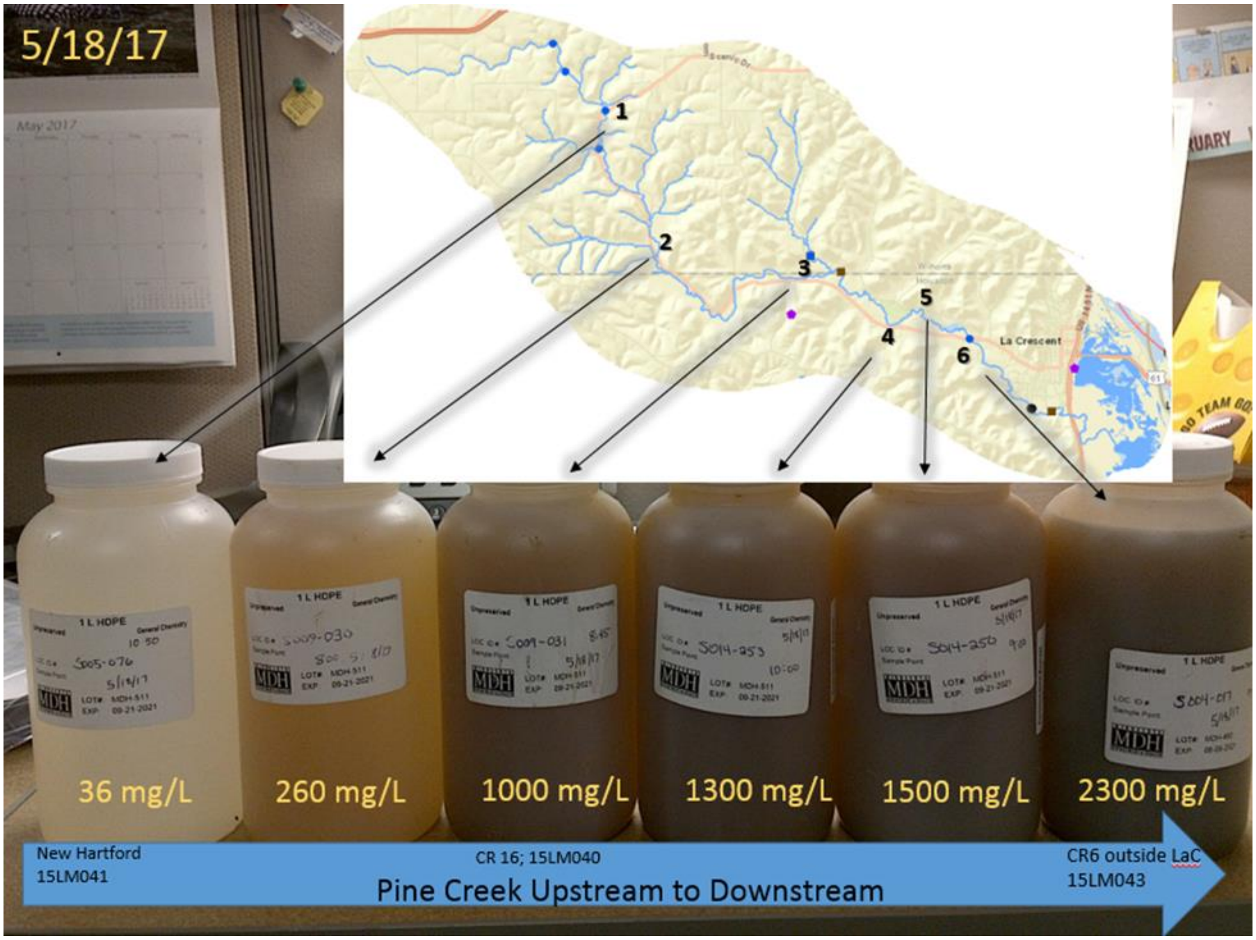
Figure 10. TSS concentrations (mg/L) from 59 samples taken longitudinally (upstream-left to downstream right) at multiple Pine Creek sites in 2016 and 2017. Stations are organized upstream to downstream, which shows increases in TSS moving downstream in the impaired AUID (S009-031 and S004-017). The red dashed line (10 mg/L) indicates the TSS standard for coldwater streams. S005-076=15LM041, S009-031=15LM040, and S004-017=15LM043



In 2016 and 2017, detailed longitudinal monitoring took place to help understand the variations in TSS spatially throughout the watershed (Figure 10). The data prior to that had mainly been collected at station S004-017(15LM043), the downstream site responsible for the suggested TSS listing. This additional data helped show that S009-031 (15LM040) also sees concentrations exceeding the standard regularly. The farthest upstream site (not impaired; S005-076/15LM041) shows very few exceedances of the standard compared to samples taken on the same days farther downstream. The longitudinal data shows evidence of sedimentation starting downstream of the County Line (which is near S009-030). Moving downstream from the County Line, sediment appears to increase exponentially and supports the chronic turbid conditions observed (Figure 11). Overall, TSS concentrations do vary but seem to show an increasing trend moving downstream. Samples were collected during both years, during multiple flow conditions, but the majority were baseflow. When comparing VSS (volatile suspended solids) to TSS samples taken across the watershed, those that exceed the TSS standard (10 mg/L) on average contain only 13% VSS. This indicates that the majority composition of solids in the form of sediment instead of organics. Some shallow marsh areas in the lower end of the watershed could be sources of this sediment as they may have acted as sediment sinks from past land use practices. It is not clear what amount (if any) of sediment is being discharged from these areas, but it is a possible source of sediment between 15LM040 and 15LM043. What is clear, based on the data, is that the TSS is mineral/sediment and not organic solids (in theory could originate from wetland/marsh areas).

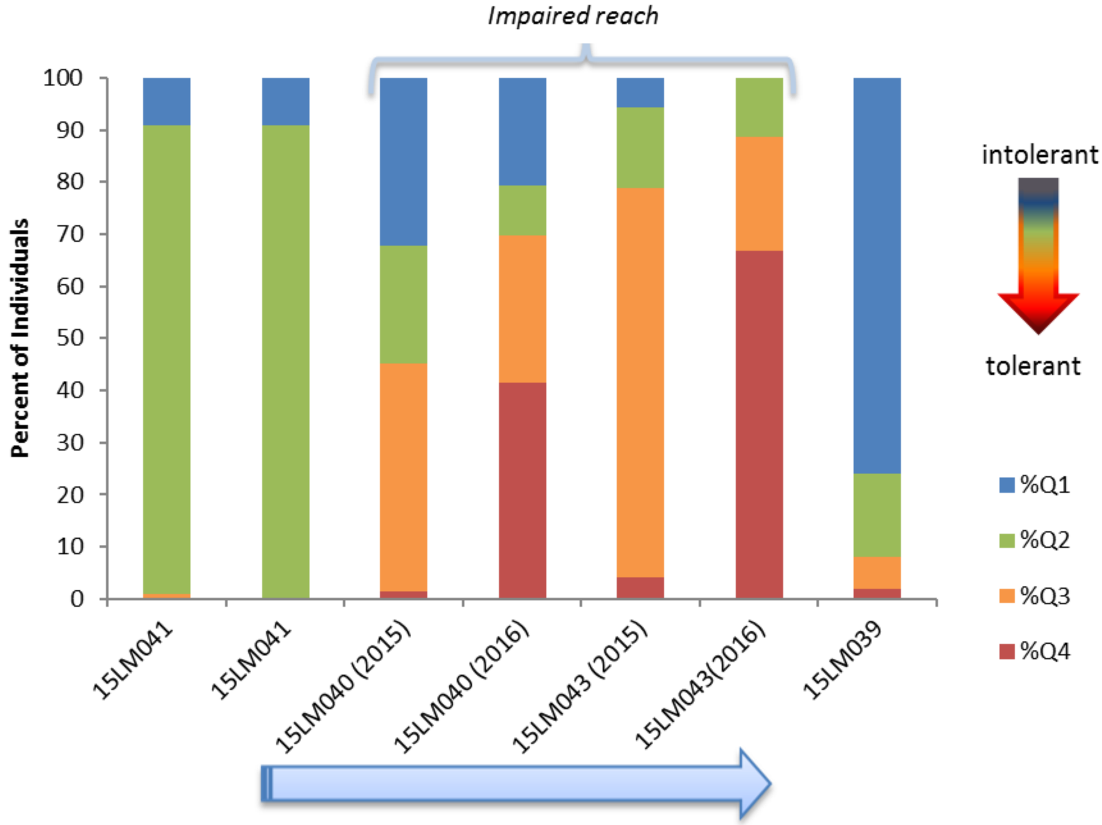
Figure 11. Photos from 15LM043 taken from May – Oct of 2016. All samples were scheduled (monthly) and all exceeded the TSS standard of 10 mg/L; demonstrating chronic turbid conditions.

Figure 12. Longitudinal sampling from 2017 showing significant sediment transport from an event occurred on May 18, 2018.



Longitudinal sampling from 2017 showed significant sediment transport from an event that occurred on May 18, 2017 (Figure 12). Sampling was repeated again three days after this event, and results showed continued elevated concentrations at the middle to downstream site locations, similar to the trend noted in**Error! Reference source not found.**Figure 10. Another sample seven days after this event s howed the upper two sites (S005-076 and S009-030) had cleared up, while the lower sites (S009-031 and S004-017) were still elevated (between 46 and 100 mg/L). Stream flow had also returned to baseflow. Therefore, the stream channel itself (bed/banks) became a likely source of sediment during this time frame since moderate to severe bank erosion also co-occurs in this area. It is also possible that other sources of sediment may have contributed to the TSS during this time period (i.e. active pasturing, etc.) Regardless, this represents a likely stressful duration of high TSS for aquatic life. The small tributaries (Burns Valley, Lanes Valley, Rose Valley) were also sampled during this time frame and cleared up, while the main stem of Pine Creek remained turbid, which further supports the idea that the stream bed/banks were likely the main contributors of sediment in the stream. It is also possible that significant groundwater flow paths exist which may be contributing to the sediment load near the channel. At this time, there is no evidence to support this conclusion but further information could be collected.

Figure 13. TSS tolerance indicator values for the fish community at four stations in Pine Creek: organized from upstream (left) to downstream (right) (Sandberg, MPCA). Shades of blue and green represent fish species composition that are relatively intolerant to high TSS, while those that are orange and red represent the fish species present with more tolerance to high TSS.



Taking a closer look at the biology, the fish community at 15LM039 was dominated by blackchin shiners (75% of the community), a small minnow species that requires clear vegetated waters. Their presence is likely due to the proximity to the vast Mississippi River backwater area, about one mile downstream of this site, which is not subjected to the TSS in Pine Creek. Fish were not assessed at this location due to its proximity to the backwater, but it was included in the graph (Figure 13) for comparison purposes. This graph describes the disparity in fish community seen at this location and in the TSS tolerance percentages. However, in the impaired reach, there are an abundance of TSS tolerant fish and a lack of TSS intolerant fish at 15LM040 and 15LM043. In contrast, the upstream location that is not impaired (15LM041) had a good amount of fairly intolerant to TSS fish, and very few TSS tolerant species in its two samples.

Overall, the majority of fish metrics showed a response to elevated TSS (Table 7). TSS index scores were higher than average and probability of meeting the TSS standard was less than average based on the fish community present. This reveals a community that is tolerant of high TSS. Additionally, the percentage of fish that were carnivores were below average for most visits. Carnivores often respond negatively to increases in TSS. The TSS concentration during fish sampling visits exceeded the standard in the impaired reach, but not at 15LM041 (non-impaired reach).

In 2016, both 15LM040 and 15LM043 had green sunfish as the most abundant species; not a characteristic of a coldwater stream. In 2015, the species composition was a little more mixed, but still showing stress. It is possible that because the samples from 2016 were in June, that late spring flooding and high water from the Mississippi River allowed the green sunfish to migrate up the stream to these locations. Overall, both years of sampling resulted in high numbers of warmwater tolerant species and fewer coldwater species expected in a coldwater stream like Pine Creek.

Table 7. Fish metrics and data that correspond to TSS stress in Pine Creek. The impaired reach stations are shown in red, while the upstream station is included for comparison. *TSS concentration is shown as 10 mg/L, which is the standard for coldwater streams (not the southern coldwater average).

Station (Year sampled)	TSS Index Score	Conditional probability for TSS (%)	% Carnivores	TSS concentration at time of fish sample (mg/L)
15LM041 (2015)	9.7	61	99	*2.4*
15LM041 (2015)	9.7	61	99	*1.6*
15LM040 (2015)	**12.7**	**56**	**38**	***32***
15LM040 (2016)	**17.8**	**48**	58	***31***
15LM043 (2015)	**13.9**	**54**	**31**	***38***
15LM043 (2016)	**17.4**	**48**	**46**	***66***
Southern Coldwater Average	*12.45*	*60%*	*56%*	*10 mg/L**
Expected response to stress	↑	↓	↓	↑

While macroinvertebrates are not impaired, they are often analyzed to determine if responses to TSS seem to be affecting them as well. Based on the results in Table 7, macroinvertebrates seem to be responding to elevated TSS. Moving downstream into the impaired reach, the TSS index scores increase, which demonstrate a higher tolerance to TSS based on the macroinvertebrate community composition. Similarly, there are fewer intolerant taxa, and more tolerant taxa moving downstream compared to the upstream non-impaired site (15LM041). These results provide further evidence that high TSS is impacting both fish and macroinvertebrate communities even though macroinvertebrates are not impaired. Because of this impact, macroinvertebrates are susceptible to future impairment due to the high TSS observed.

Table 8. Macroinvertebrate metrics that respond to high TSS for stations in Pine Creek compared to statewide median for southern coldwater stations meeting impairment threshold. Bold and highlighted equals the metric score is higher or lower than average, depending on expected response with increased stress. The impaired reach is shown in red, while the surrounding stations (upstream and downstream) are included for comparison.

Station (Year sampled)	TSS Index Score	TSS Intolerant Taxa	TSS Tolerant Taxa	TSS Tolerant Pct
15LM041 (2015)	**12.10**	**4**	**2**	**9.09**
15LM040 (2015)	**13.48**	**1**	**4**	**14.73**
15LM040 (2016)	**11.99**	**1**	**9**	**12.73**
15LM043 (2015)	**14.34**	**1**	**7**	**20.24**
15LM043 (2016)	**15.71**	**1**	**7**	**31.77**
15LM039 (2015)	**17.07**	**0**	**9**	**27.79**
Statewide median for Southern Coldwater stations that are meeting the MIBI Threshold (43)	*13.42*	*2*	*5*	*8.34*
Expected response to stress	↑	↓	↑	↑

During stressor identification, a large quarry was observed upstream of 15LM040; S009-031. (Figure 14). This quarry does have the potential to affect sedimentation in the stream, but at this time, there is not any evidence that sediment from the quarry is discharging to Pine Creek. Two holding ponds have been capturing overland runoff from the quarry. During multiple rain events in early 2017, the drainage areas were checked to ensure runoff from the quarry was not discharging to Pine Creek. It appeared that only during a very large storm event, would the second holding pond fill up and potentially release water. Until then the pond would allow solids to settle and release the clean water. As long as the ponds are maintained, they should continue to be effective.

Figure 14. Google earth imagery of quarry location in Pine Creek.

Station 15LM043 had a sonde deployed in 2017 for two weeks at the end of August (Figure 15). There was very little rainfall documented during this time, yet during sonde retreival, the sediment accumulation was dramatic. Most sites where sondes are deployed have no where near this much sediment accumulation during a two week deployment. This demonstrates the amount of fine sediment moving through this system, some of which is being settled out at this monitoring location.

Figure 15. Sediment accumulation on sonde deployed at 15LM043 for two weeks at the end of August 2017.

The DNR conducted a detailed stream geomorphology study at two locations in Pine Creek. During assessment, they found that much of Pine Creek is in a state of accelerated change: 68% was classified as typically unstable stream types (63% F and 5% G); while only 32% as potentially stable stream types (22% C, 1% E and 9% B). Historic damming from mills and other historic poor farming practices deposited extensive fine sediments in the Pine Creek Valley and the stream is currently cutting back through those fine sediment deposits.

The sources of TSS to Pine Creek are likely bank erosion, poor pasturing practices, and other near channel sediment impacts (Figure 16, Figure 17, and Figure 18). Overall, the valleys in this watershed are very steep and have a loamy soil characteristic susceptible to erosion. Coupling these watershed features with steep stream slopes and excessive grazing (unvegetated pastures and unrestricted cattle access) favors turbid stream conditions. The biological, chemical, and physical evidence all overwhelmingly support that TSS is a stressor to Pine Creek.

Figure 16. Aerial photo example of pasturing, stream channel changes and erosion/sedimentation impacts. Credit: Pictometry Houston County, 2017.

Figure 17. Collection of photos from the impaired reach of Pine Creek, documenting many areas of severe bank erosion. MPCA Photos, 2017.

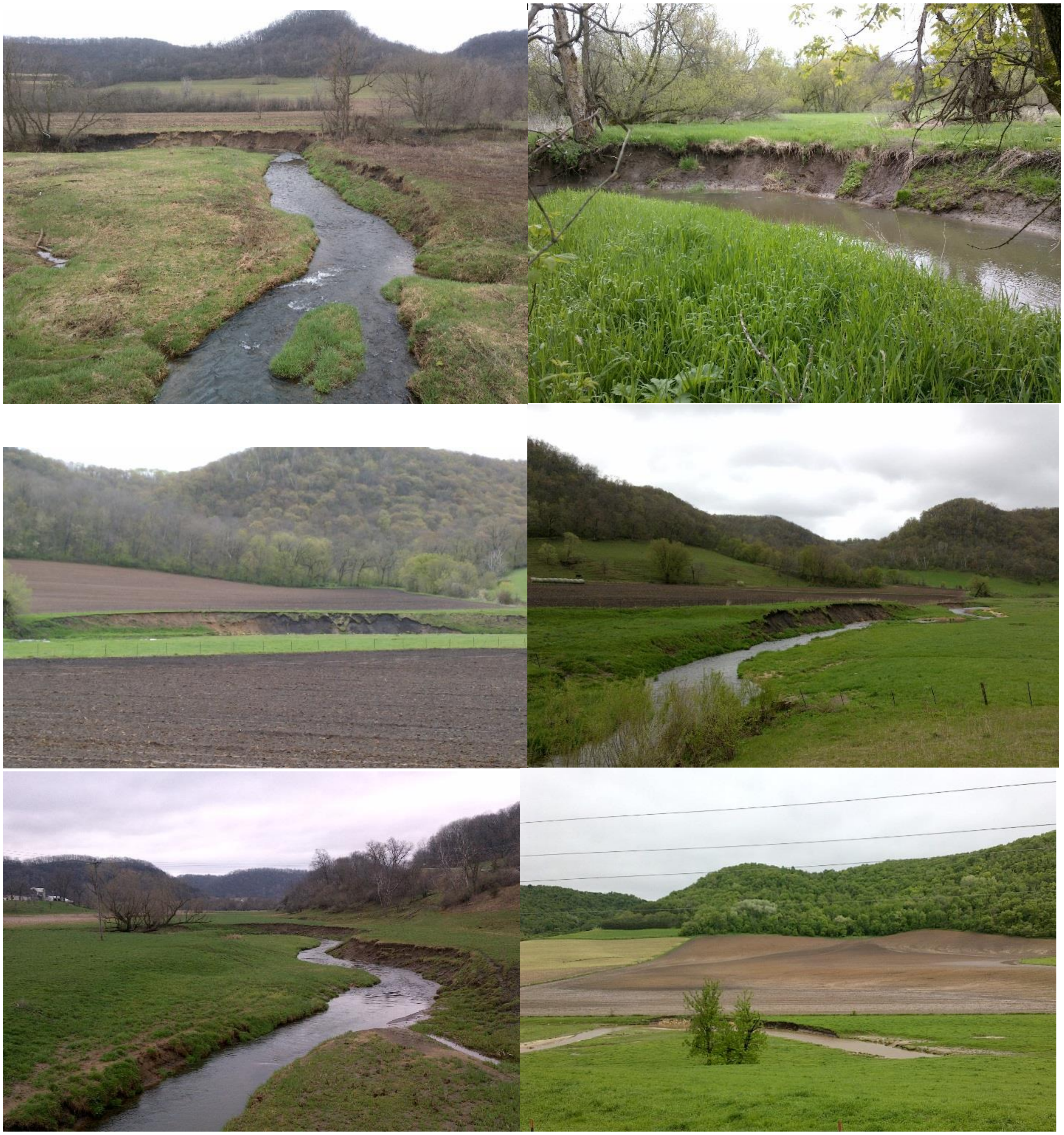


Figure 18. Images of bank erosion in the impaired reach (next road crossing upstream of 15LM040). The upstream photo is from 2008 and captures large changes to the stream channel from the 2007 flood. The bottom photo shows the current photo (2017), with areas of bank erosion still present. Note large ravine in upper right corner of photos that appears to be contributing a large amount of sediment to the stream. Image Credit: Pictometry Houston County, 2008 and 2017.

Dissolved oxygen/Eutrophication

In 2015, 2016 and 2017, Pine Creek had 89 grab samples taken for dissolved oxygen (DO) across the watershed total. None of the samples fell below the coldwater standard of 7 mg/L. A good number (59) of these values were actually early morning samples (before 9 am) when DO levels are typically lowest. The lowest concentration observed during grab sampling was 7.73 mg/L at 15LM040.

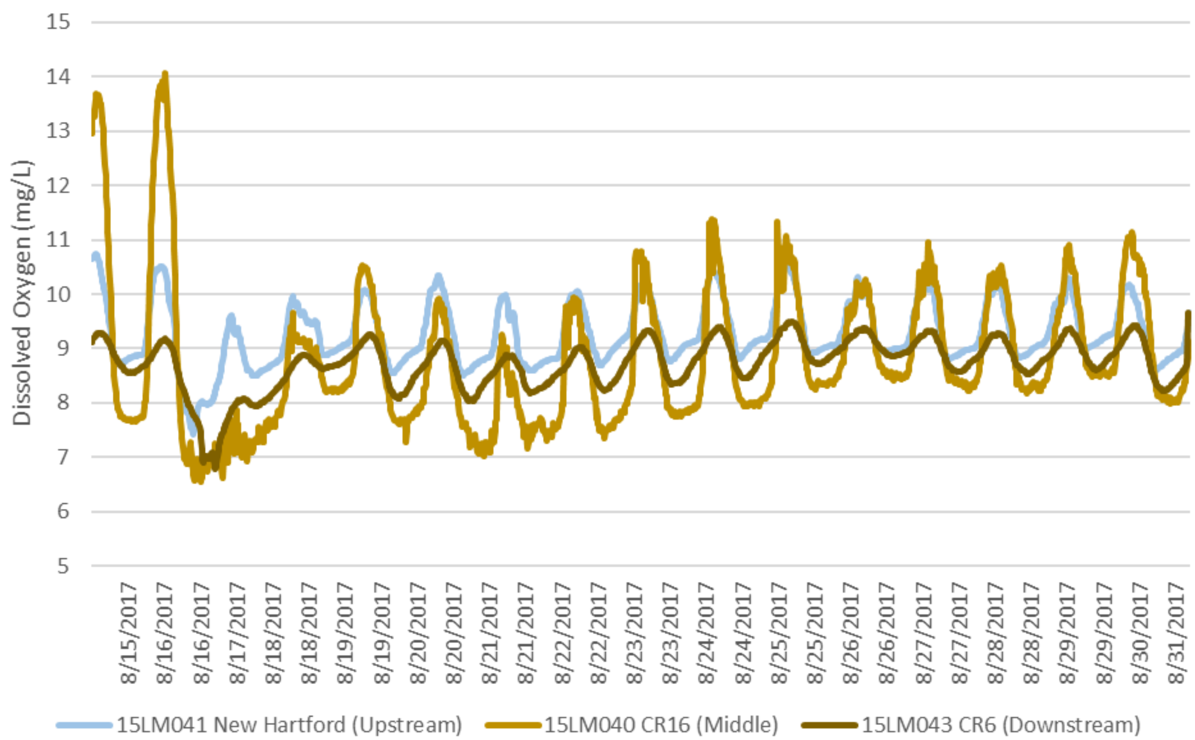
In 2015, a sonde was deployed at 15LM039 (7/21/15-8/1/15), which is near the mouth of the watershed. DO levels from that deployment were characteristic of normal; no values fell below the low DO standard of 7 mg/L. DO flux was also within normal ranges, at an average daily DO flux of 1.3 mg/L. In 2017, three additional sondes were deployed showing longitudinal DO variations in Pine Creek (Figure 19). Overall, there were a few readings of DO falling below the 7 mg/L standard, one that appeared to correspond to a rain event on August 16 and August 17. Groundwater inputs and/or runoff may explain this scenario. Often during the summer months, the cooler ground water inflow may at first lower the DO concentration, but it also tends to reduce the river temperature, which increases the capacity of the water to hold oxygen in the long term. Additionally, the DO flux was within an acceptable range at all three stations (Table 9). These results show a suitable DO regime across the watershed and multiple sites.

Total phosphorus, DO flux, chlorophyll-a and BOD data can be used when looking closer at the potential for eutrophication and related DO issues. Total Phosphorus concentrations exceed the Central River Nutrient standard (0.100 mg/L) with an average concentration of 0.215 mg/L for 62 samples collected in 2015, 2016 and 2017. Thirty-five of those samples (56%) exceeded the standard for total phosphorus. Of those samples, the majority of them that exceed the standards for phosphorus also exceed the standard for TSS, which points to phosphorus from sediment as the major source. The DO flux data available from multiple deployment periods all meet the standard and is within the expected range (3.5 mg/L). Chlorophyll-a data was limited to three (August) samples on the impaired reach. Two samples from the two biological stations were taken on the same day in 2017, and one in 2016. The concentrations ranged from 2-6 μg/L, which is low and does not suggest suspended algae and eutrophication causing measurable impact. Similarly, a BOD sample was available from one sample in 2017; the BOD result was considered low and normal (i.e. meeting standards). While phosphorus concentrations are consistently high and can result in eutrophication, the corresponding response variables do not suggest eutrophication is occurring due to excess phosphorus nor do the DO levels appear to be stressful. The highest phosphorus concentrations have been documented during stormflow conditions, and reductions in sediment and phosphorus are important to ensure sediment and phosphorus loading does not result in more water quality issues in Pine Creek or downstream.

Table 9. Eutrophication related water chemistry statistics for Pine Creek. Bold values indicate some exceedances of water quality standards. *The samples for 15LM039 were mainly taken from samples in 2015; while the other sites had samples from 2016 and 2017 (mainly 2017 for 15LM041). The impaired reach is shown in red, while the surrounding stations (upstream and downstream) are included for comparison.

		TP AVERAGE	TP MAX	CHLOROPHYLL A	BOD5 *(ONE SAMPLE EVENT ON 8/15/17)*	DO FLUX AVERAGE	LOWEST DO OBSERVED DURING SONDE DEPLOYMENT
UPSTREAM ↓ DOWNSTREA	15LM041	0.068	**0.540**	NA	0.7	1	7.42
	15LM040	**0.157**	**1.12**	6	1.1	3	**6.55**
	15LM043	**0.219**	**1.83**	2	1.0	1.5	**6.79**
	15LM039	**0.116**	**0.186**	NA	NA	1.3	7.29
	WQ Standards	*0.100 mg/L*	*0.100 mg/L*	*18 µg/L*	*2 mg/L*	*3.5 mg/L*	*7 mg/L*

Figure 19. Longitudinal DO comparisons for Pine Creek, from three sites in 2017. Station 15LM041 is from the non-impaired reach, while 15LM040 and 15LM043 are from the impaired reach. Red dashed line represents the DO standard of 7 mg/L for coldwater streams.



Biologically, the percentage of sensitive fish species (SensitivePct) and tolerant species (TolPct) are often correlated to low DO, among other stressors. Sensitive species will often decline in low DO and tolerant species will increase. In the impaired reach of Pine Creek, there is response noted in the metrics for all the visits. The abundance of fish individuals where the females mature at greater than three years in age decrease with low DO conditions and show a response in all but one visit. These responses can indicate possible DO issues, but can also be signaling responses to other stressors as these metrics are somewhat general. Fish that are serial spawning (SSpnPct) show a mix of response between the sites. Serial spawning fish (fish that have multiple bursts of spawning in one season) will often increase if low DO is a stressor. Overall, they are low at 15LM040, but seem to increase slightly at 15LM043. Low DO index scores and probability of meeting the DO standard (Cond Prob for DO early AM) was below average at all stations in the impaired reach. These results can indicate low DO is a stressor, as they point to fish community that is generally tolerant of low DO.

Overall, the chemical data does not provide any indication that eutrophication is a concern in Pine Creek. While the total phosphorus concentrations are high (due to high-suspended sediment), low DO flux has been measured at multiple locations, and the current limited information on response variables do not indicate the stream is experiencing eutrophic conditions. Additionally, when storm events are removed from the average phosphorus calculations, they would meet the standard. There are instances where DO does appear to drop near the standard and could be cause for concern. However, much of the current available data does not show violations of the standard, or that the DO is responding to high photosynthetic or respiration production. Biologically, there appears to be consistent response among the fish metrics (Table 10). The TSS and temperature issues that have already been discussed are a likely cause of the biological response seen. Further, high TSS (in the form of sediment) would limit the ability of vegetation and plant growth that would cause any potential eutrophication issues. At this time, there is a strong likelihood the biological responses are a result of the other stressors, and not low DO or eutrophication.

Table 10. Fish metrics that respond to low DO compared to the statewide average of visits meeting the biocriteria.

Bold indicates metric value indicative of stress. The impaired reach is shown in red, while the surrounding stations (upstream and downstream) are included for comparison.

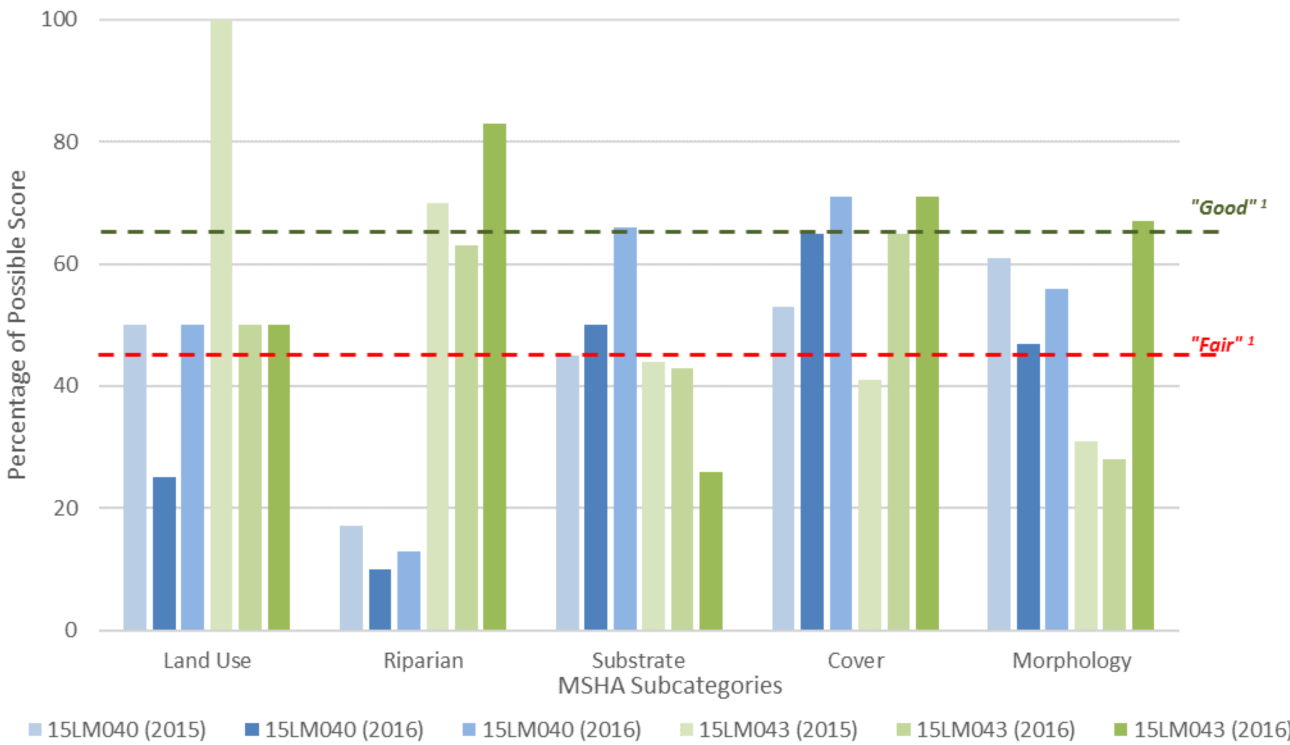
	Station (Year Sampled)	SensitivePct	MA>3Pct	SSpnPct	TolPct	DO Index Score	Cond Prob for DO early AM (%)
Upstream ↓ Downstream	15LM041 (2015 Avg)	99.15	99.61	0.00	0.85	9.80	99
	15LM040 (2015)	**22.58**	**34.84**	**4.52**	**69.68**	**7.39**	**83**
	15LM040 (2016)	**17.16**	**28.19**	1.72	**82.84**	**7.69**	**66**
	15LM043 (2015)	**21.13**	71.83	**8.45**	**66.20**	**7.00**	**35**
	15LM043 (2016)	**36.22**	**28.57**	**26.53**	**63.78**	**7.32**	**61**
	Southern Coldwater Average	72.5	75.1	1.79	23.9	8.8	93
	Expected response to stress	↓	↓	↑	↑	↓	↓

Habitat

The MSHA scores ranged from poor to good in the Pine Creek watershed. The best MSHA score was at 15LM041, the headwater station near New Hartford, with a score of 65. Biology and habitat are good in this location but when moving downstream to the impaired reach, MSHA scores are worse and vary from fair to poor, depending on the site and year (Figure 20). The largest discrepancy between the two impaired stations is the "riparian" metric. The upstream station in blue (15LM040) occurs in a pasture, while station 15LM043 (green) is surrounded by woodland. The other sub metric scores are fairly comparable between the two stations.

Figure 20. MSHA subcategory scores for two impaired stations in Pine Creek from 2015 and 2016.

Station 15LM040 is shown in blue, while visits from 15LM043 are shown in green. [1] The minimum percentage of each subcategory score needed for the station to achieve a "fair" and "good" MSHA rating.



When looking closer at more specific habitat characteristics, there are large discrepancies between the upstream and downstream sites (Table 11). Embeddedness, siltation, and bank erosion increase dramatically moving downstream. Additionally, shade and course substrate decreases. This agrees with other characteristics outlined in the TSS and temperature sections of the report, and further demonstrates how these characteristics are connected to potential habitat limitations. Photos taken at each location (Figure 21) demonstrate some of the differences moving downstream.

Table 11. Habitat MSHA Scores and select characteristics of each site moving upstream to downstream. Sites in red are in the impaired reach. Text that is in bold, demonstrates connection to potential habitat stress.

	Station (Year Sampled)	MSHA Score	Embeddedness	Siltation	Dominant Substrate	Bank Erosion	Shdae
Upstream ↓ Downstream	15LM041 (2015)	73-Good	None	Normal	Cobble/Gravel	Little	50%-75%
	15LM040 (2015)	48-Fair	**Moderate**	**Moderate**	Cobble/Sand	**Moderate/Severe**	**Light (5%-25%)**
	15LM040 (2016)	**44-Poor**	**Moderate**	**Heavy**	Gravel/Sand	**Heavy**	**None**
	15LM043 (2015)	45-Fair	**No Coarse Substrate**	Normal	**Sand**	Little	Moderate
	15LM043 (2016)	**44-Poor**	**Severe**	**Moderate**	**Sand/Clay**	**Moderate**	Moderate
	15LM039	50-Fair	**No Course Substrate**	Normal	**Sand/Clay**	Little	Moderate

Figure 21. Photos from biological sampling, upstream (not impaired) to downstream Pine Creek (impaired).

From Left to Right: 15LM041 (Good MSHA score: 65); 15LM040 (Fair/Poor MSHA Score: 44-48) and 15LM043 (Fair/Poor MSHA Score: 44-45).

Insectivores (e.g., darters and sculpins), simple lithophilic spawners, and riffle dwelling species require quality benthic habitat (e.g., clean, coarse substrate and riffles) for feeding and/or reproduction purposes. Pine Creek sites in the impaired reach actually have fair percentages of simple lithophilic spawners, due to the presence of White Suckers-a more tolerant warmwater fish. The upstream site near New Hartford (15LM041) did not have white suckers, or any other simple lithophilic spawners, which is why the illusion of a response is demonstrated there (Table 12).

Detritivores utilize decomposing organic matter (i.e. detritus) as a food resource and are less dependent upon instream habitat quality (Aadland et al., 2006). Detritivores species richness is represented in Table 12 as "DetNWQPct." All stations in the impaired reach had a higher percentage of detritivores, compared to the non-impaired station, 15LM041.

The pioneer percent in Pine Creek was higher than average in the impaired reach (21% at 15LM040 and 7% at 15LM043) compared to the Southern Coldwater average (4.7%). Pioneer fish species thrive in unstable environments and are the first to invade a stream after disturbance. Piscivores were also found in reduced abundance at these two sites in particular (only 18% and 24%), compared to the statewide average of 50%. Piscivores generally require good substrate, and good pool habitats for predator-prey relationships. Coarse substrates and good pool habitats are lacking in the impaired reach.

Overall, there is a consistent response to habitat related stress in the impaired reach (Table 12). Abundance of pioneers and detritivores was above average in the impaired reach while piscivore abundance was low. This is indicative of poor habitat conditions. Scores for percent lithophilic spawners were higher than expected, likely due to abundance of white suckers in the impaired reach. Low scores for percent riffle dwellers was expected in the impaired reach. Comparing results to the upstream non-impaired site (15LM041), two of the five metrics metrics appear to be signaling habitat stress. At station 15LM041, the fish community was almost entirely brook trout and brown trout, which are not riffle dwelling species, nor are they simple lithophilic spawners. This creates an illusion of response to habitat in the metric table but the exact opposite response is seen with the other metrics. If the site had sculpin as well (which are the only coldwater fish that are simple lithophilic spawners and riffle dwelling species) the percentages would be improved. The fact that sculpin are not present at this station does not necessarily translate to poor habitat, as we know habitat is more suitable there (Table 12 and Figure 22). Overall, the fish metrics show a response in the impaired reach, and the evidence points to lack of suitable habitat as a stressor especially as compared to the unimpaired reach (15LM041).

Table 12. Fish metrics that respond to habitat stress in Pine Creek compared to the statewide average of visits meeting the biocriteria. Bold indicates metric value indicative of stress. The impaired reach is shown in red, while the surrounding non-impaired station (upstream) is included for comparison.

Station (Year Sampled)	SLithopPct	PioneerPct	DetNWQPct	PiscivorePct	RifflePct
15LM041 (August 2015)	**0.00**	0.00	0.00	99.23	**0.00**
15LM041 (July 2015)	**0.92**	0.00	0.92	99.08	**0.92**
15LM040 (August 2015)	56.77	**21.29**	**28.39**	**18.06**	**32.26**
15LM040 (June 2016)	39.22	**50.25**	**20.34**	**9.56**	**25.74**
15LM043 (July 2015)	56.34	**7.04**	**63.38**	**23.94**	54.93
15LM043 (June 2016)	**20.41**	**38.78**	**46.94**	**8.16**	**20.41**
Southern Coldwater Average	*21.1*	*4.79*	*15.4*	*53.5*	*34.8*
Expected response to stress	↓	↑	↑	↓	↓

Figure 22. Station 15LM041 on September 14, 2016 showing good riffle habitat including coarse substrate and cover

Connectivity/Fish Passage

Beaver dams have been noted in historical DNR reports in Pine Creek. Currently, beaver dams were not identified during field surveys as affecting the impaired reach. Furthermore, beaver dams are often ephemeral in nature, especially in streams like Pine Creek that have high gradient and steep topography. At this point, it is very unlikely they are contributing to the fish impairment or any fish passage issues in Pine Creek.

According to a DNR Culvert Inventory and Prioritization Report, the Mississippi River LaCrescent Watershed has seven culverts recommended for replacement. Forty-six stream crossings were visited in the watershed; 20 culverts and 26 bridges. The culverts recommended for replacement are considered significant barriers, but were located on tributaries to Pine Creek, not Pine Creek itself. These barriers could have impacts on some migration to a lesser degree and/or could cutoff fish from potential spawning habitat. **No culvert barriers were identified on the impaired reach of Pine Creek**.

Upstream Pine Creek near New Hartford, as well as in several tributaries, good trout populations are present; confirmed by DNR surveys and management plans. However, the culverts present on the tributaries can negatively impact geomorphology and channel stability resulting in habitat degradation. Some culverts are perched and/or have steep slopes that cause barriers to fish movement and induce scouring. Thus, culverts may be affecting the fish community in Pine Creek in the form of habitat degradation and sedimentation, but not as barriers to fish movement in Pine Creek itself. Additionally, a fair number of migratory species still exist throughout Pine Creek, with almost half of the fish community at 15LM043 considered migratory (Table 13). The highest percentage of migratory fish are found in the "not impaired" headwaters site, which was comprised almost entirely of trout. Moving downstream, while those percentages do decrease, it is more likely due to other stressors affecting the abundance of those individuals (evidence presented earlier in this report). Therefore, connectivity/fish passage are not a stressor to Pine Creek at this time.

Table 13. Percentage of fish that are migratory for various sites in the Pine Creek Watershed.

	Site	Migratory percent (Avg of visits)
UPSTREAM ↓ DOWNSTREAM	15LM041	99%
	15LM040	31%
	15LM043	50%
	15LM039	17%

Pine Creek Summary

The stressors that are contributing to the fish impairment in Pine Creek are temperature, TSS, and habitat (Table 14). The upstream area near New Hartford does not show the same level of biological stress and impacts as the downstream impaired reach. Moving downstream from New Hartford, Pine Creek changes dramatically. Shading decreases and direct stress to the stream channel becomes very apparent with multiple areas of extreme bank erosion. These issues are linked to all of the biological stressors observed in Pine Creek.

Temperatures in Pine Creek are limited by lack of shade, extreme bank erosion, ponded springs, and sedimentation. All coldwater sources in the Pine Creek watershed (i.e. springs and coldwater tributaries) should be protected, as they are vitally important in maintaining adequate temperatures in this stream. Increased shading near the stream, better riparian buffers, and decreased sedimentation are especially important in the area downstream of New Hartford to CR16 (15LM040).

Overall, there is a consistent response to habitat related stress in the impaired reach. Fish species that are pioneers and detritivores are all much higher than expected in the impaired reach, both of which can thrive in less than ideal habitat situations. Piscivores are also reduced, and will commonly decline if habitat is not suitable. It becomes clear that embeddedness, siltation, and bank erosion all are contributing factors to the habitat stress observed. Additionally, shade and course substrate both decrease when moving downstream into the impaired reach. These habitat limitations are all connected to the temperature and TSS issues observed as well.

Pine Creek is susceptible to elevated amounts of stream bank erosion, especially during high or extreme flood events. Active cattle pastures are likely destabilizing many stream reaches and contribute to excess sedimentation (and TSS) in the stream. Pine Creek would benefit from increased shading/better stream buffers, restricted cattle access to the stream, and possible stream channel restoration projects. As noted by DNR, management strategies are needed to help strengthen and stabilize banks to a stable condition. More frequent and larger rain events would increase the risk of instability to the stream in the future. Management through active restoration such as bank stabilizations and full channel restorations would speed up the timeline of stability, but require significant investment of money and local participation. A sequenced and targeted approach is needed to make the best use of limited financial resources. An ideal area to target initially would be the larger head cuts in the stream (to stop further degradation) while using upland BMPs to address the systemic stressors responsible for the excess sediment. All of these types of restoration practices would likely provide some benefit to the stressors observed in Pine Creek.

Table 14. Summary of probable stressors to impaired biological communities in the Mississippi River LaCrescent Watershed.

Stream Name	AUID	Biological Impairment	Stressors					
			Temperature	Nitrate	TSS	Dissolved Oxygen/Eutrophication	Lack of Habitat	Connectivity/Fish Passage
Pine Creek	576	Fish	●		●		●	

● = probable stressor; o = inconclusive stressor; blank = not a stressor

5. Recommendations for the MRLC Watershed

Recommendations

The stressors and recommended actions for the biological impairment in Pine Creek in the Mississippi River LaCrescent Watershed are shown in Table 15. The recommended actions listed below, as well as included in *The Aquatic Biota Stressor and Best Management Practice Selection Guide*, will help to reduce the influence of the stressors that are limiting the biology in the entire watershed.

Table 15. Recommended actions relative to the stressors contributing to the biological impairment for Pine Creek in the Mississippi River LaCrescent Watershed.

Stressor	Priority	Comment
TSS	High	Focus on reducing sediment input from riparian corridor (cattle pastures/increased fencing) and immediate stream channel (stream bank restoration; See appendix for DNR info and restoration recommendations).
TSS/flow	High	Control sediment and runoff from upland areas. Soil conservation practices; reducing flows, CRP, grassed waterways,etc, WASCOBs
Temperature and Habitat	High	Aim to re-establish quality riparian corridor buffers to increase woody debris, CPOM inputs, and stream shading.
Temperature	High	Protect spring sources; etc. Improve near channel riparian cover and reduce sedimentation (see all above)

Protection

In the Mississippi River LaCrescent Watershed, there were two other sites sampled that were not discussed in this report since they were not considered biologically impaired (Table 3Table 3). **Dakota Creek**, in the far northern edge of this watershed, is a small direct tributary to the Mississippi River and scores close to exceptional for both fish and macroinvertebrates. This stream represents a high quality resource that should be protected. Additionally, **Pine Creek headwaters (near New Hartford)** which has been discussed in this report as a comparison to the impaired reach, *scored the highest overall in the* *watershed for macroinvertebrates (86) and also represents a stream in need of protection*. **Rose Valley Creek**, a small tributary to Pine Creek, is a stream that scores above impairment thresholds, but may be at risk of impairment and needing protection. See the next sections for more details on Dakota Creek and Rose Valley Creek.

Dakota Creek

The Dakota Creek site scored quite well (in the 70 range) for both fish and macroinvertebrates. Habitat is considered fair to good. Some bank erosion was noted with gravel and sand as the predominant substrates. Overall, nutrients were low during one biological sample (Nitrates 0.85 mg/L and Phosphorus 0.044 mg/L). TSS concentrations were right at the standard (11 mg/L). The headwaters and some of the drainage of this small creek contains Great River Bluffs State Park. However, I-90 surrounds this stream for much of its length as well, which is a potential impact, but does not appear to be adversely affecting aquatic life at this time. Similarly, large beaver dams were noted downstream of the reach, yet fish scores were high. Beaver dams are often ephemeral in nature due to flooding and natural variations and may provide intermittent impacts. At this point, there is no indication they are adversely affecting the fish community. Bank erosion and instability, including sedimentation, in addition to potential impacts from I-90 are the main threats to aquatic life in this stream.

Figure 23. Dakota Creek 15LM042 at time of biological sampling in 2016.

Figure 24. Dakota Creek drainage and sampling location (brown square).

Rose Valley Creek

Rose Valley Creek, a tributary to Pine Creek scored above the impairment thresholds for both fish and macroinvertebrates in 2015. The site scored well for fish in 2015 (14 points above impairment threshold) but the macroinvertebrates scored only by 6 points above the threshold. This station is in a pasture that appears to be managed fairly well and not overgrazed. However, within the sampling station, there was an overall lack of course substrates, which likely limits the macroinvertebrates present. Sand is the dominant substrate; no riffles were present in this reach, and it was comprised mainly of pools and run features. As such, the dominant macroinvertebrate habitat was aquatic macrophytes and overhanging vegetation. These habitat limitations likely prevent many coldwater bugs from thriving.

Nitrate concentrations are consistently at about 2 mg/L; measured during biological sampling in 2015, and for multiple samples taken in 2017, (eight total). Phosphorus was generally low and meeting standards for these samples as well, except during times of excess sediment (high TSS). Interestingly, of nine samples taken in 2015 and 2017, 8 exceeded the TSS standard of 10 mg/L for coldwater streams. The average TSS concentration was 48 mg/L with maximum of 120 mg/L. However, many of these samples were taken in May of 2017 during storm events (to compare the tributaries to the main stem of Pine Creek). While this stream often is flowing clearer then Pine Creek, it does underscore the tributaries as sources of sediment in the watershed. The other tributaries (Lanes Valley and Burns Valley) showed similar TSS concentrations on the same sampling days as Rose Valley Creek. A sonde was deployed in 2015, which showed adequate DO concentrations, and minimal DO flux (1 mg/L average). Similarly, temperatures were very cold and considered normal for a small trout stream. Sedimentation and habitat are likely the largest limiting factors to biology in Rose Valley Creek. Good pasture management, restricting cattle access to the stream to only specific places, and soil conservation practices would all help ensure excess sediment in the watershed does not end up causing fish or macroinvertebrate impairments in the future.

Figure 25. Rose Valley Creek 04LM093 in 2015.

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8. Appendix

Pine Creek: DNR Geomorphology Summary

Pine Creek is a direct tributary to the Mississippi River, draining a watershed of 58.5 square miles in southeastern Minnesota. Two geomorphic surveys were completed on Pine Creek (Figure 1) to support the Watershed Restoration and Protection Strategies (WRAPS) process. Understanding and determining stream channel stability is a primary goal of these geomorphic surveys. Stability is defined as the ability of a stream, over time, in the present climate, to transport the sediment and flows produced by its watershed in such a manner that the stream maintains its dimension, pattern and profile without either aggrading or degrading (Rosgen 1996). To begin the assessment, stream channel and valley types were classified using desktop practices (Figure 1). These classifications are useful in providing initial clues into channel stability issues, identifying potential reference segments and stratifying sampling. Certain stream and valley type combinations are frequently found in disequilibrium, while others are more likely to be in better condition. Much of Pine Creek is in a state of accelerated change, 68% was classified as typically unstable stream types (63% F and 5% G); compared to only 32% as potentially stable stream types (22% C, 1% E and 9% B) (Figure 1).

Steep slopes along with agricultural conversion followed by reforestation and changing land use practices characterize the current state of watershed health of Pine Creek. The underlying geology, within the Drift-less area, consists of loamy gravel, sand and silt soils. Loamy soils combined with steep slopes increases the risk of erosion (Figure 2). Further exacerbating this are changes in the hydraulic regime, which accelerates many of the processes responsible for destabilizing stream channels.

Originally comprised of forested land, the watershed underwent a conversion to agricultural land use in the 1850's. A subsequent reforestation of the uplands and shift from crop production to grazing animals, the landscape is currently 50.4% forested, 33.1% hay and pasture with only 3.7% cultivated land and 5.1% developed (Figure 3). The likely conditions and processes impacting stream stability arise from past aggradation of sediments on the floodplain due to historical land use such as water retention structures such as mills, and current grazing pressure compromising stream bank integrity.

Figure 1. Map of the Pine Creek Watershed including survey sites.

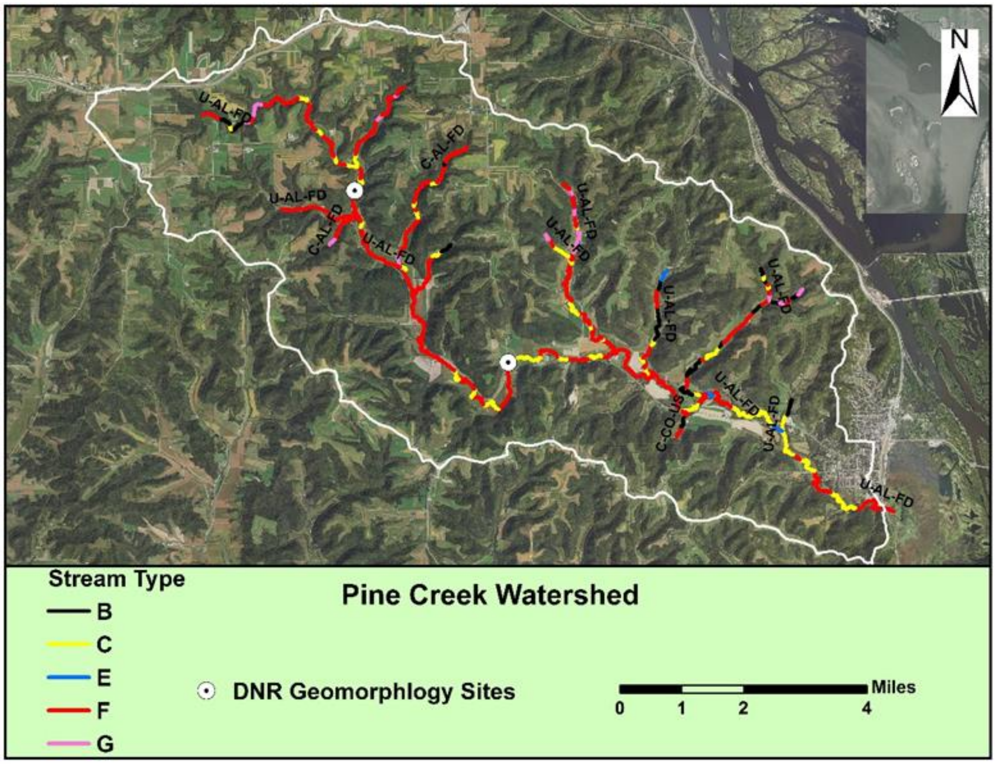


Figure 2. Steep slopes combined with highly erodible areas within the Pine Creek Watershed

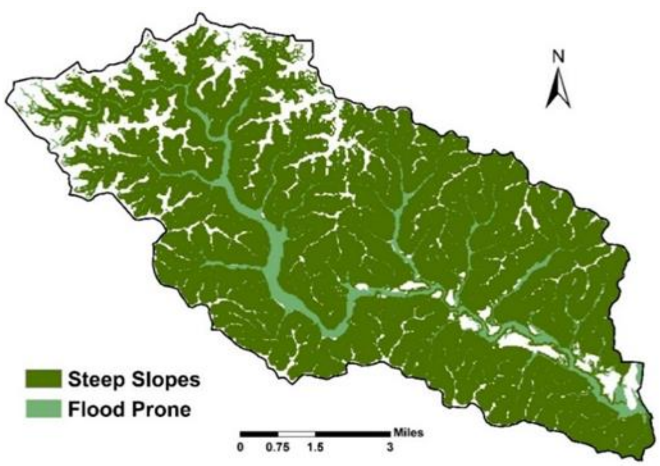
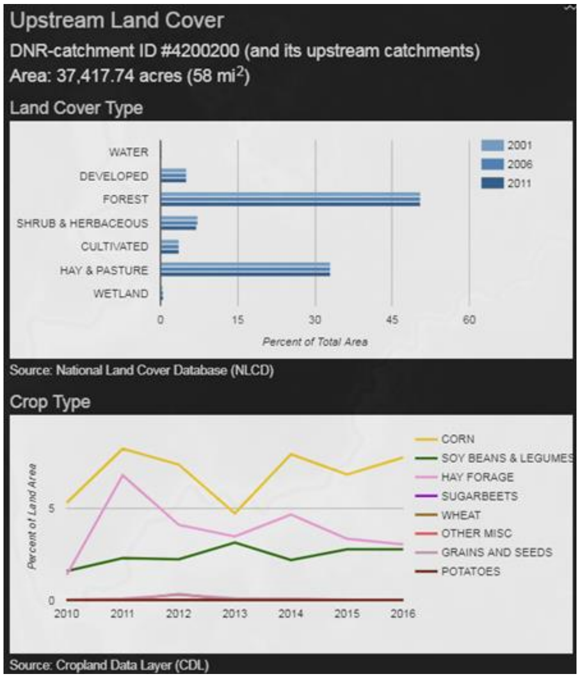


Figure 3. Land use comparison from 2001 to 2011 for Pine Creek Watershed (WHAF).



Pfankuch Stability Rating

Pfankuch stability rating procedure categorizes indices of channel stability for quick, observational field assessment of stream stability. The upstream site was rated as poor (unstable) and the downstream site was rated as fair (moderately unstable) following the Pfankuch stream channel stability rating procedure. The upstream site scored poorer (114) than the downstream site (103) due to greater bank slope gradient and incision. Bed material in both stream channels consists of silt and sand particles filling in pools and easily movable at most flows. This material would be a stress on stream fish and macroinvertebrates through reduced quality habitat in riffles and pools.

W/D Ratio State

Pine Creek width-to-depth ratio increases from the upstream to downstream surveyed reach. An over-wide channel is likely unstable and has excess amounts of deposition. A C stream type reference reach located on Crooked Creek was used for departure analysis (Table 1). The width-to-depth ratio of the upstream surveyed reach (17.70) is slightly wider than the reference ratio (15.38) but still considered within the range of stability. The downstream survey width-to-depth ratio (20.09) is more than 30% larger than the reference and moderately unstable.

Table 1. Dimensional survey and reference reach data collected from Pine Creek.

Stream: **Pine Creek**

Riffle Cross-Section	Dimension							
	Stream Type	Drainage Area (mi^2)	Bankfull Mean Depth (ft)	Bankfull Width (ft)	Cross-sectional Area (ft^2)	Width/ Depth Ratio	Bankfull Maximum Depth (ft)	Entrenchment Ratio
Upstream Cross- section	C	10.9	1.36	24.07	32.68	17.70	2.14	2.61
Downstream Cross-section	C	29.3	1.59	31.95	50.70	20.09	2.81	6.26
Reference Cross-section	C	8.7	0.99 ± 0.03	15.15 ± 0.73	14.91 ± 0.56	15.38 ± 1.12	1.31 ± 0.03	2.78 ± 0.03

Degree of confinement

Confinement of the floodplain limits the streams ability to meander and can lead to changes in the dimension, pattern and profile of the stream. Pine Creek has access to adequate floodplain throughout most of the watershed but is cut off from the floodplain in some sections, likely a result of historical straightening and channel down cutting. Fewer meanders and increased confinement is often associated with channel enlargement, sediment transport reductions and higher streambank erosion. Portions of the stream from the downstream survey site and further have widen to form new active floodplains and may be in the early stages of recovery (Figure 4).

Incision

Incision is a lowering of the water level and abandonment of an active floodplain of a stream. Incision is estimated from Bank Height Ratios (BHR) of the lowest bank height to the maximum bank full depth of the channel. The upstream reach has a BHR of 1.81 and is classified as deeply incised (Figure 4). Within the downstream reach the BHR ranges from stable to moderately incised, 1.0 to 1.38, likely part of an active head cut moving upstream (Figure 5). A head cut is also illustrated by a stream slope increase just upstream of the survey site (Figure 6). Streams vertically contained within their banks lose access to the floodplain, there by concentrating flood flows within the stream channel. Such as the large flood event in 2007, flood flows within the channel caused increased shear stress on banks and resulted in excessive bank erosion (Figure 7). This section of stream is 13,041 feet long in 1930 and only 10,880 feet in 2011, a loss of 16.5% (2,160.5 feet) of stream length.

Figure 4. Representative riffle cross-section from the upstream survey location.

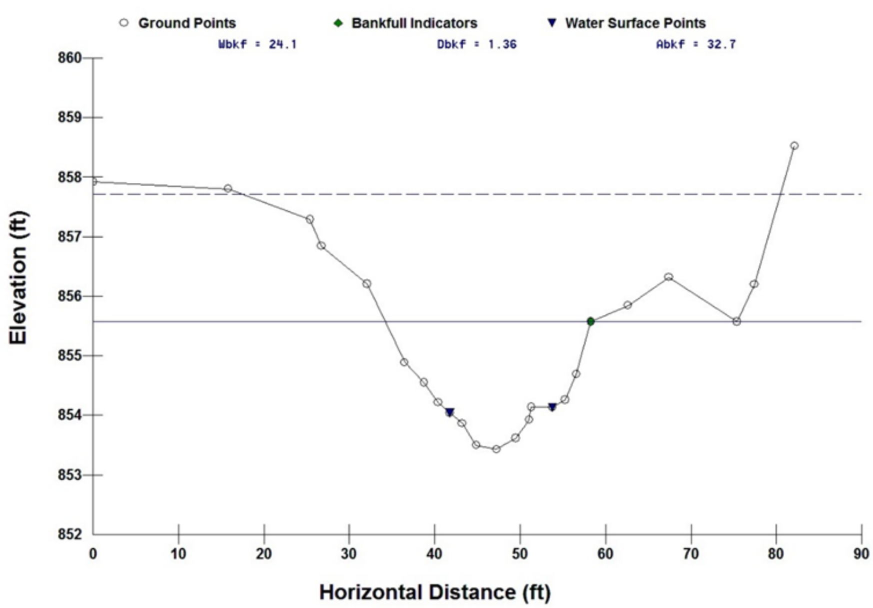


Figure 5. Representative riffle cross-section from the downstream survey location.

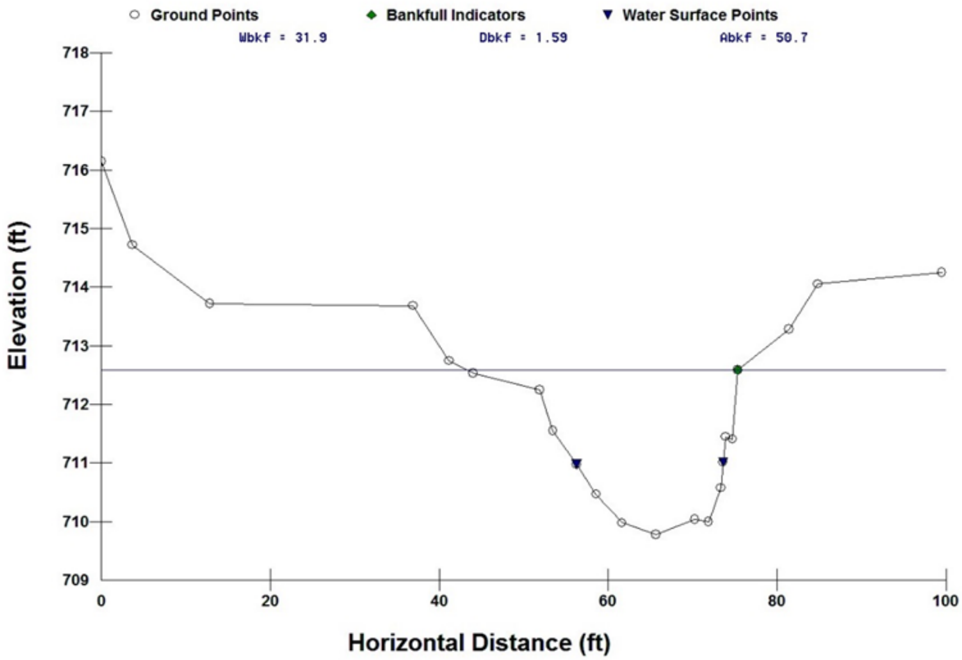


Figure 6. Longitudinal profile illustrating slope change (red arrow) near survey site.

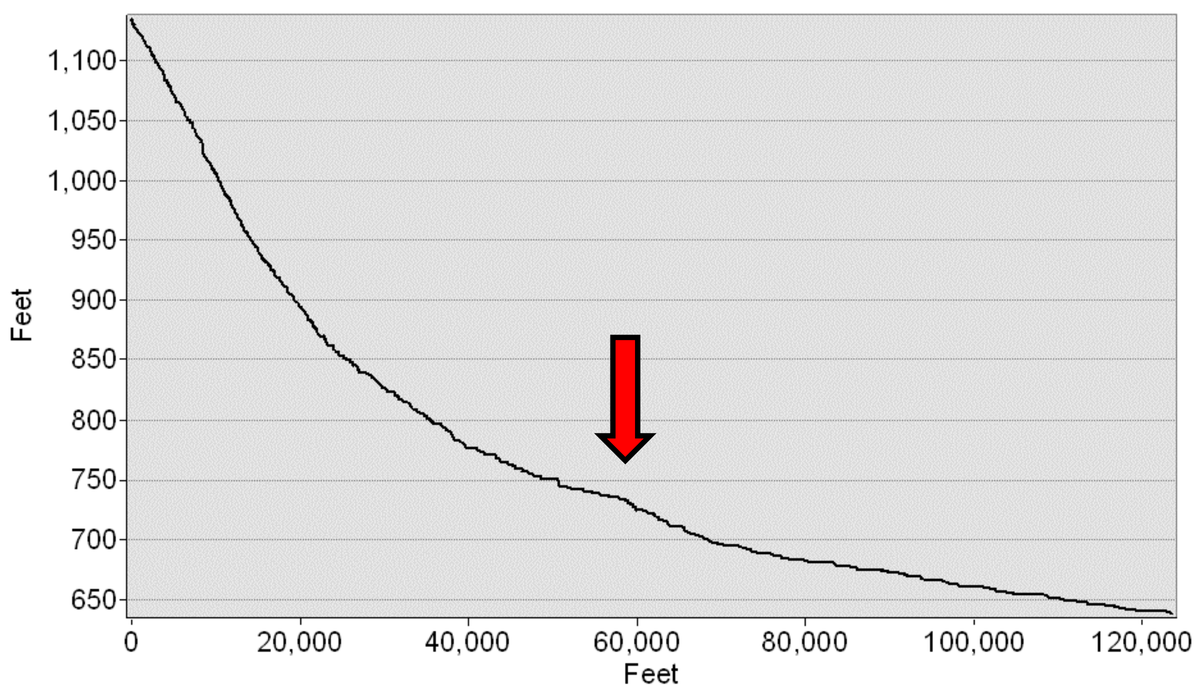
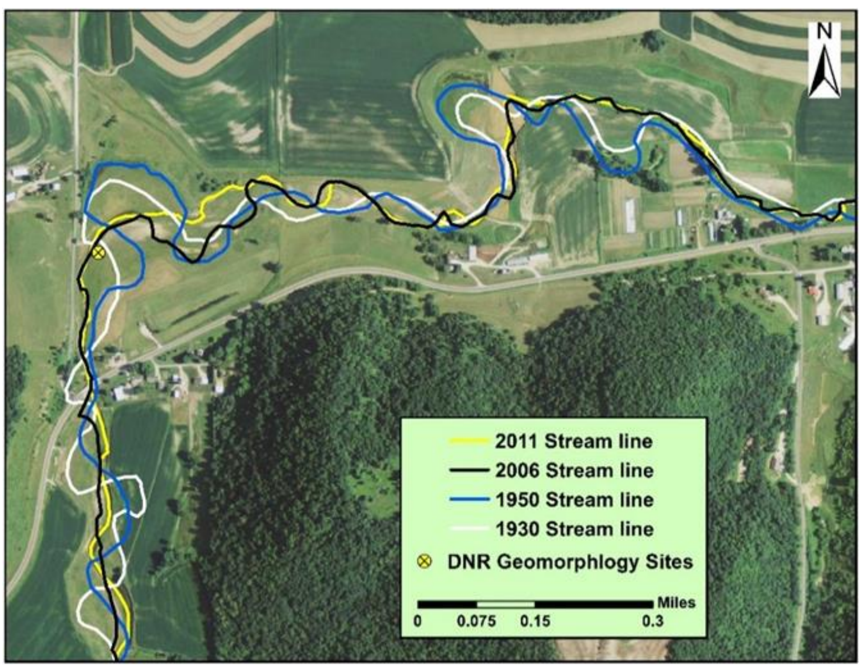


Figure 7. Widening and straightening as a result of a large flood event in 2007.

Bank Erosion

LiDAR imagery, aerial photography, and field observation revealed significant bank erosion within the majority of the watershed. The upstream reach is eroding approximately 0.054 tons/yr./ft. (unstable rate) of sediment solely from the steam banks. The downstream reach is eroding approximately 0.084 tons/yr./ft. (highly unstable) from steam bank sediment, though this reach and downstream is likely evolving to a more stable form and erosion could decrease in the future (Figure 8).

Figure 8. Stream centerlines from 1937, 1952, 2006, and 2011 illustrating the lateral movement of the stream overtime and the loss of stream sinuousity.



Geomorphic Summary

Water surface slope is 0.003 in the upstream reach and 0.002 in the downstream reach. In both surveys, the stream has good sinuosity (approximately 1.3) (Tables 2and 3). The upstream riffle cross section (Figure 4) was classified as a C stream type, though the channel is entrenched and over wide (Table 1). The downstream surveyed site is less entrenched. Also classified as a C stream type (Figure 5), the downstream channel is narrower and deeper, allowing for improved sediment transport. Two apparent stressors within the watershed are hoof shear and intense riparian grazing of livestock. In addition, numerous head cuts occur throughout the stream likely due to historical events and/or changes in hydrology. The most significant head cut is occurring near the downstream survey site.

Table 2. Upstream site geomorphology summary.

Survey Results			
Stream Type	C4	**Velocity (fps)**	2.37
Valley Type	U-AL-FD	**Bankfull Discharge (cfs)**	77.48
Sinuosity	1.28	**Riffle D50 (mm)**	60.83
Water Slope	0.003	**Mean Riffle Depth (ft)**	1.36
Bankfull Width	24.07	**Max Pool Depth (ft)**	5.45
Entrenchment Ratio	2.61	**Bank Erosion Estimates (tons/yr/ft)**	0.0535
Width/Depth Ratio	17.7	**Pfankuch Stability Rating**	Poor
Bankfull Area (ft^2)	32.68	**Competence Condition**	NA

Table 3. Downstream site geomorphology summary.

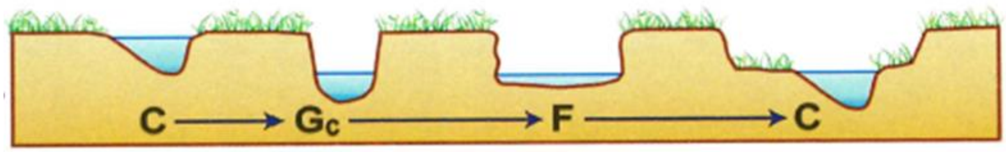
Survey Results			
Stream Type	C4	**Velocity (fps)**	3.24
Valley Type	U-AL-FD	**Bankfull Discharge (cfs)**	164.32
Sinuosity	1.30	**Riffle D50 (mm)**	33.53
Water Slope	0.00193	**Mean Riffle Depth (ft)**	1.59
Bankfull Width	31.95	**Max Pool Depth (ft)**	5.63
Entrenchment Ratio	6.26	**Bank Erosion Estimates (tons/yr/ft)**	0.084
Width/Depth Ratio	20.09	**Pfankuch Stability Rating**	Fair
Bankfull Area (ft^2)	50.70	**Competence Condition**	NA

SID Implications

Pine creek is susceptible to elevated amounts of stream bank erosion, especially during high or extreme flood events. Pine Creek has been straightened over time as a result of land use practices (Figure 7). Erosion signatures are evident from LiDAR and field observation throughout much of Pine creek (Figure 8). Hoof shear stress is known to cause bank erosion and active cattle pastures are likely destabilizing many stream reaches. Overtime the stream will likely evolve back to a stable state, in this case a narrower C stream type channel at a lower base level with less sinuosity then the original channel (Figure 9). Although, unchanged land use practices would likely continue to compromise the banks of the channel attempting to stabilize and extend the cycle of degradation, erosion and repair. Well-vegetated banks are helping to maintain ditch dimension in the upstream reach; though flat slopes and low water velocities lead to a buildup of organic material in channel. All of which would negatively impact the fish and macroinvertebrate communities due to a lack of suitable habitat.

Management strategies, such as rotational grazing, promoting the growth of perennial vegetation would help strengthen and stabilize banks during and after evolution to a stable condition. Climate change will complicate the evolution to channel stability. More frequent and larger rain events would increase the risk of instability to the stream. There is evidence using historical aerial photos of the current channel evolution process likely ongoing for 80-100 years. This process may continue at this same rate without active intervention. A passive restoration approach would allow the channel to naturally evolve and may take another 50 – 100 years establish a stable C channel at a lower elevation. Management through active restoration such as bank stablizations and full channel restorations would speed up the timeline but require significant investment of money and local participation. A sequenced and targeted approach is needed to make the best use of limited finacial resources. A likely area to target intially would be to address the larger headcuts to stop further degradation while using a watershed approach (i.e. BMPs) to address the systemic stressors responsible for the excess sediment.

Figure 9. Likely stream succession scenario for Pine Creek (Rosgen 2014).



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