Stressor identification

April 2020

Upper St. Croix River Watershed Stressor Identification Report

Assessment of stress factors affecting aquatic biological communities of streams in the Upper St. Croix River Watershed.

MINNESOTA POLLUTION CONTROL AGENCY

CLEAN WATER LAND & LEGACY AMENDMENT

Authors

Tom Langer (Wenck Associates, Inc.)
Jeff Strom (Wenck Associates, Inc.)

Contributors/acknowledgements

DNR Stream Crossing Team - Road crossing fish passage assessments

Manuscript reviewers:

Mike Koschak (MPCA)
Dani McNeil (DNR)
Katie Petzel (Pine County SWCD)
Tim Schwarz (MPCA)
Kevin Stroom (MPCA)

Cover photo: Hay Creek at Piedmont Trail in Pine County

Project dollars provided by the Clean Water Fund (from the Clean Water, Land and Legacy Amendment).

Minnesota Pollution Control Agency

520 Lafayette Road North | Saint Paul, MN 55155-4194 |

651-296-6300 | 800-657-3864 | Or use your preferred relay service. | Info.pca@state.mn.us

This report is available in alternative formats upon request, and online at www.pca.state.mn.us.

Document number: wq-ws5-07030001

Contents

Figures

Tables

Acronyms and term definitions

AUID .... Assessment Unit (Identification Number) MPCA's pre-determined stream segments used as units for stream/river assessment – each has a unique number.
AWC .... MPCA's Altered Watercourse Project
CR .... County Road
DO .... Dissolved Oxygen
DOC .... Dissolved Organic Carbon
DNR .... Minnesota Department of Natural Resources
EPT .... Three important taxonomic orders of stream macroinvertebrates whose members are typically sensitive to stream degradation - **E**phemeroptera (mayflies), **P**lecoptera (stoneflies), and **T**richoptera (caddisflies)
FIBI .... Fish-based lake Index of Biological Integrity; an index developed by the DNR that compares the types and numbers of fish observed in a lake to what is expected for a healthy lake (range from 0–100). More information can be found at the DNR Lake Index of Biological Integrity website
GIS .... Geographic Information System
HDS .... Human Disturbance Score – a measurement of human disturbance at and upstream of a biological monitoring site. The best score is 81 points.
HUC .... Hydrologic Unit Code (a multi-level coding system of the US Geological Survey, with levels corresponding to scales of geographic region size)
IBI .... Index of Biological Integrity – a multi-metric index used to score the condition of a biological community.
Insectivorous species.. A species that predominantly eats insects
Intolerant species ...... A species whose presence or abundance decreases as human disturbance increases
KRW .... Kettle River Watershed
IWM .... MPCA's **I**ntensive **W**atershed **M**onitoring, which includes chemistry, habitat, and biological sampling.
m .... The abbreviation for meter
mg/L .... Milligrams per liter
µg/L .... Micrograms per liter (1 milligram = 1000 micrograms), equivalent to parts per billion (ppb)
MPCA .... Minnesota Pollution Control Agency
MSHA .... Minnesota Stream Habitat Assessment
M&A Report .... MPCA Monitoring and Assessment Report for the Upper St. Croix River Watershed
MS4 .... municipal separate storm sewer system
NLCD .... National Land Cover Database, a GIS layer
NPDES .... National Pollutant Discharge Elimination System
Natural background ... An amount of a water chemistry parameter coming from natural sources, or a situation caused by natural factors.
P .... Phosphorus
Periphyton .... Algae and diatoms that grow attached to hard substrates in streams.
SID .... Stressor Identification – The process of determining the factors (stressors) responsible for causing a reduction in the health of aquatic biological communities.
Small benthic dwelling species .... A species that is small and predominantly lives in close proximity to the bottom

Sonde .... A deployable, continuous-recording water quality instrument that collects temperature, pH, DO, and conductivity data and stores the values which can be transferred to a computer for analysis

SSTS............................... Subsurface sewage treatment systems

TALU .... Tiered Aquatic Life Uses, a new process of setting standards for different categories of streams. MPCA plans to implement this approach around 2015.

Taxa .... Plural form - refers to types of organisms; singular is taxon. May refer to any level of the classification hierarchy (species, genus, family, order, etc.). In order to understand the usage, one needs to know the level of biological classification being spoken of. For MPCA fish analyses, taxa/taxon usually refers to the species level, whereas for macroinvertebrates, it usually refers to genus level.

TIV .... Tolerance Indicator Value

Tolerant species .... A species whose presence or absence does not decrease, or may even increase, as human disturbance increases

TMDL .... Total Maximum Daily Load

TSS .... Total Suspended Solids (i.e. all particulate material in the water column)

TSVS .... Total Suspended Volatile Solids (i.e. organic particles)

TP .... Total Phosphorus (measurement of all forms of phosphorus combined)

US .... Upstream

USCRW .... Upper St. Croix River Watershed

USEPA .... United States Environmental Protection Agency

Vegetative dwelling species .... A species that has a life cycle dependent upon vegetated habitats

Weight of evidence approach .... A method of using multiple sources or pieces of information to classify a waterbody as impaired

WRAPS .... Major Watershed Restoration and Protection Strategy, with watershed at the 8-digit Hydrological Unit Code scale.

Executive summary

This report documents the efforts that were taken to identify the causes, and to some degree the source(s) of impairments to aquatic biological communities in the Upper St. Croix River Watershed (USCRW). Information on the Stressor Identification (SID) process can be found on the United States Environmental Protection Agency's (EPA) website http://www.epa.gov/caddis/.

The USCRW is a hydrologic unit code 8 (HUC-8) watershed in the St. Croix River Basin in northeast Minnesota. Sand Creek, Tamarack River, and Crooked Creek are the main tributary systems in the USCRW. There are also many smaller tributaries across the watershed, including Hay Creek and Wolf Creek.

The USCRW is situated within a mixed land cover region consisting of forests, wetlands, agricultural fields and pastures. Deciduous forests cover large portions of the watershed often transitioning into bog or wood shrub wetland habitats. The southeast portion of the watershed is located within Saint Croix State Park which offers hiking and camping but is largely unaltered. Very minimal residential areas exist within the watershed with one town (Askov) located in the western part of the watershed. Other residential areas are comprised of smaller community developments sparsely scattered across the watershed or farmsteads. Agricultural land usage is primarily concentrated in the western part of the watershed. Much of the agriculture is related to animal rearing, with many of the fields being used for hay, rather than for row crops. However, row crop agriculture is present.

Stressors related to developed lands (impervious surfaces, stormwater runoff, wastewater facility discharges, etc.) do exist within the watershed, however, are not expected to be a significant contributor to biotic stressors. There are minimal industrial effluent dischargers in the USCRW. Given these landscape/land use attributes, the primary anthropogenic stressors in the USCRW are likely to be non-point stressors from agricultural activities, logging and changes in hydrology. Some Subsurface Sewage Treatment System (SSTS) failure may be present as well but expected to have a minimal impact due to sparse human population within the USCRW. One stressor, which can occur anywhere roads are present, is barriers to fish migration caused by the structures used to place a road over a stream. Culverts, in particular, are commonly found to be at least partial barriers to fish passage.

Three Assessment Unit (AUID) reaches on three different streams are included in this stream SID process (Figure 1). These reaches were determined to have substandard biological communities during the 2018 watershed assessment of the USCRW.

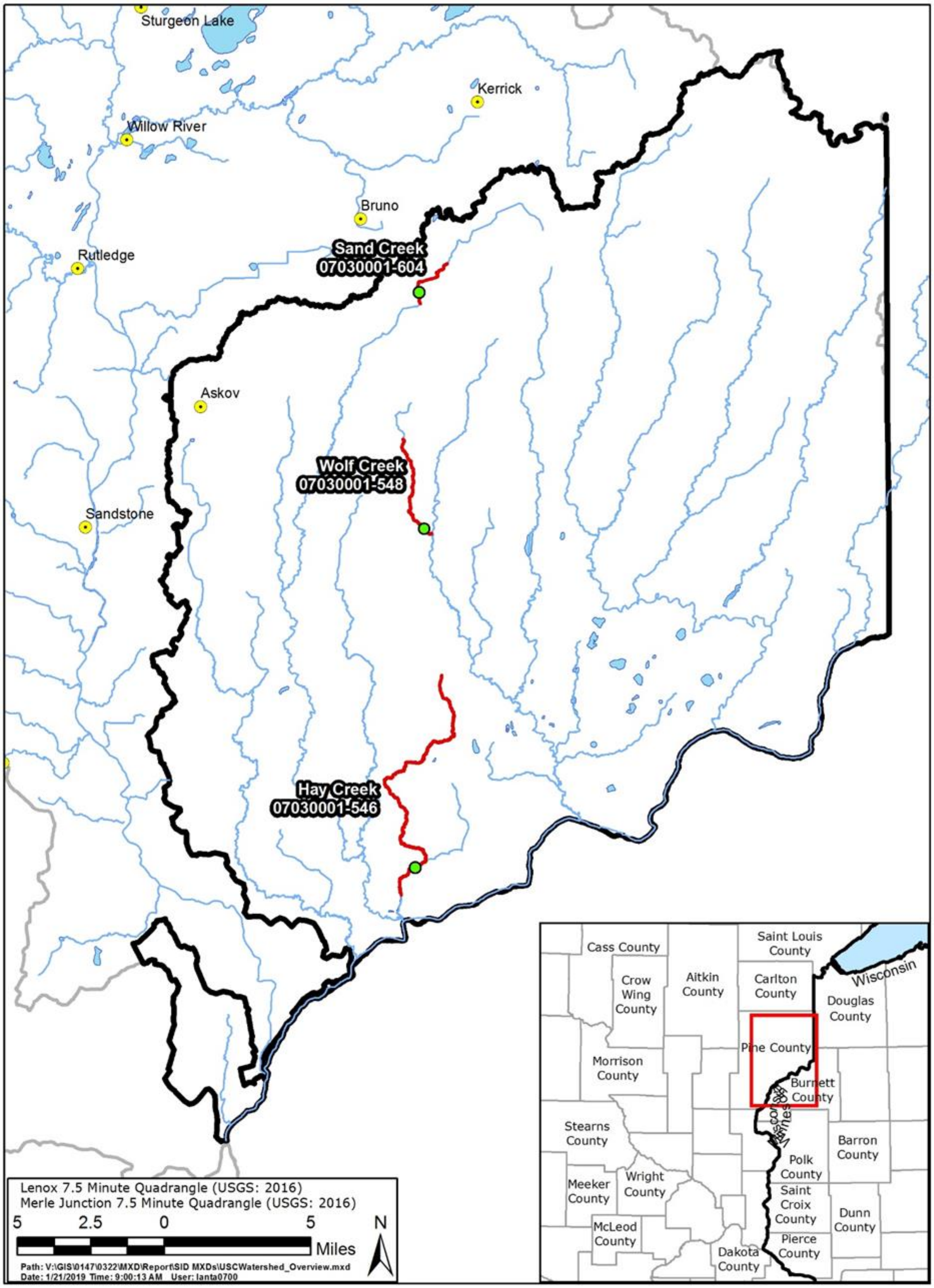
- Hay Creek (AUID 07030001-546) – Biotic (fish and macroinvertebrates)
- Wolf Creek (AUID 07030001-548) - Biotic (macroinvertebrates)
- Sand Creek (AUID 07030001-604) - Biotic (fish)

A number of potential stressors to the stream biological communities were found. These involved only non-point source pollution, infrastructure, or naturally occurring circumstances. No point source pollution was associated with the biological impairments. The non-point source pollution concerns include increased nutrient loading, sedimentation, habitat alterations, and physical/chemical changes in the water.

Agriculture practices, row-crop and/or pasture, are apparent along stretches of the impaired reaches and can result in changes to hydrology, sedimentation and nutrient loading. Specific to Sand Creek, evidence of historical bog drain and stream straightening has occurred. These activities were intended to move water out of the bogs and in doing so, can significantly alter the downstream channel and health of the stream ecosystem.

The primary infrastructure stressors are culverts that have the potential to prevent fish passage or may be undersized in locations causing temporary increased water levels on the upstream end and scouring and bank destabilization in localized areas downstream of the crossing. Evidence of beaver dams and beaver activity is apparent on certain reaches that can block fish migration and change hydrology. An additional natural stressor is the extensive wetland habitat within the watersheds and adjacent to the impaired reaches. Flow-through wetlands have the ability to change chemical (e.g. dissolved oxygen, phosphorus) and physical (e.g. temperature) properties of water, causing natural stressors that are not observed on non-wetland flow-through streams.

Figure 1. Map of the USCRW showing stream reaches with biological impairments and the location of biological sampling stations (green circle). Stream labels are names and AUID.



Introduction

The Minnesota Pollution Control Agency (MPCA), in response to the Clean Water Legacy Act, has developed a strategy for improving water quality of the state's streams, rivers, wetlands, and lakes in Minnesota's 80 Major Watersheds, known as Major Watershed Restoration and Protection Strategy (WRAPS). A WRAPS is comprised of several types of assessments. For the USCRW, MPCA and partners from state and local agencies conducted the first assessment, known as the Intensive Watershed Monitoring Assessment (IWM), during the summers of 2016 and 2017. The IWM assessed the aquatic biology and water chemistry of the USCRW streams, rivers, and lakes. Following assessment, an effort known as the SID, builds on the results of the IWM and seeks to discover the cause(s) of impairments to the biological communities of streams and lakes. Wenck Associates, Inc. (Wenck), along with its partner, the MPCA (Minnesota Pollution Control Agency), conducted the SID assessment during 2018 and 2019. This document reports results of the SID portion of the USCRW WRAPS process.

It is important to recognize that this report is part of a series for the Kettle and Upper St. Croix River Watersheds, and thus not a stand-alone document. Information pertinent to understanding of this report can be found in the Upper St. Croix River Watershed Monitoring and Assessment (M&A) Report. That document should be read together with this Stressor ID Report and can be found from a link on the MPCA's Upper St. Croix River Watershed webpage.

Landscape of the USCRW

A detailed description of various geographical and geological features of the landscape of the USCRW is documented in the Upper St. Croix River Watershed M&A Report (MPCA, 2019). That information is useful and necessary for understanding the settings of the various USCRW subwatersheds, and how various landscape factors influence the hydrology within the USCRW. The following information is intended to provide a basic description of the USCRW landscape.

The majority of the USCRW is relatively flat terrain with the exception of the bluffs near the St. Croix River valley. As such, the streams and rivers that run throughout the watershed are primarily low gradient with the confluences to the St. Croix River becoming steeper gradient systems. Throughout the USCRW, streams flow through extensive wetland habitats. This situation affects many other characteristics of the streams and aquatic biological communities. The streams and rivers flow slowly, and thus accumulate fine grained or organic particulate material as their primary substrate. Slow flows can influence the DO levels in the streams both due to lower mixing of water that aids contact with the atmosphere, and because low gradient streams can take on wetland characteristics, having higher temperatures and accumulations of organic particulate sediment. The amount of DO in the water column is reduced as bacteria consume oxygen as they decompose this organic material.

The original, pre-settlement landscape was almost exclusively forests and forested bogs (Figure 2). Though the original forest harvest at the turn of the century changed much of the forest from older growth to the younger forests that exist now, a large percentage of the originally forested landscape is still in a forested state. The primary area that contains lands utilized for agriculture is in the western part of the watershed, with the agriculture occurring there primarily hay and cattle production, rather than row crops. The percentages of various categories of land cover are presented in Table 1.

Table 1. Current and historic land cover in the USCRW

Land cover type	Current Land Cover		Historic Land Cover	
	Acres	Percent	Acres	Percent
Developed	7,158	2%	-	-
Cultivated Crops	7,022	2%	-	-
Hay/Pasture	23,937	7%	-	-
Water	4,199	1%	655	<1%
Wetland	132,580	38%	147,474	42%
Forest	172,703	50%	199,470	57%
TOTAL	347,599	100%	347,599	100%

Figure 2. Original land cover of the USCRW (Marschner, 1930).

Sources: Marschner 1930 (historic) and 2011 NLCD GIS (current) coverages (MPCA, 2017b)

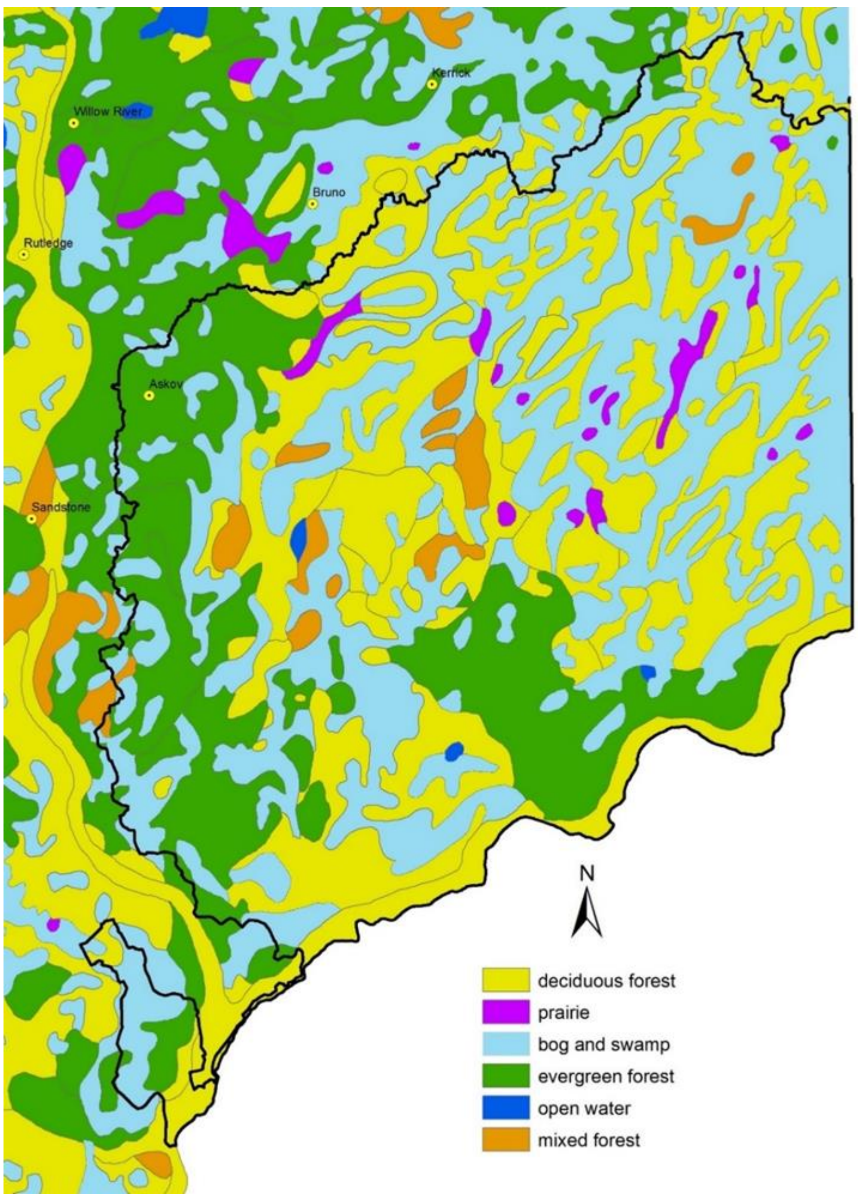
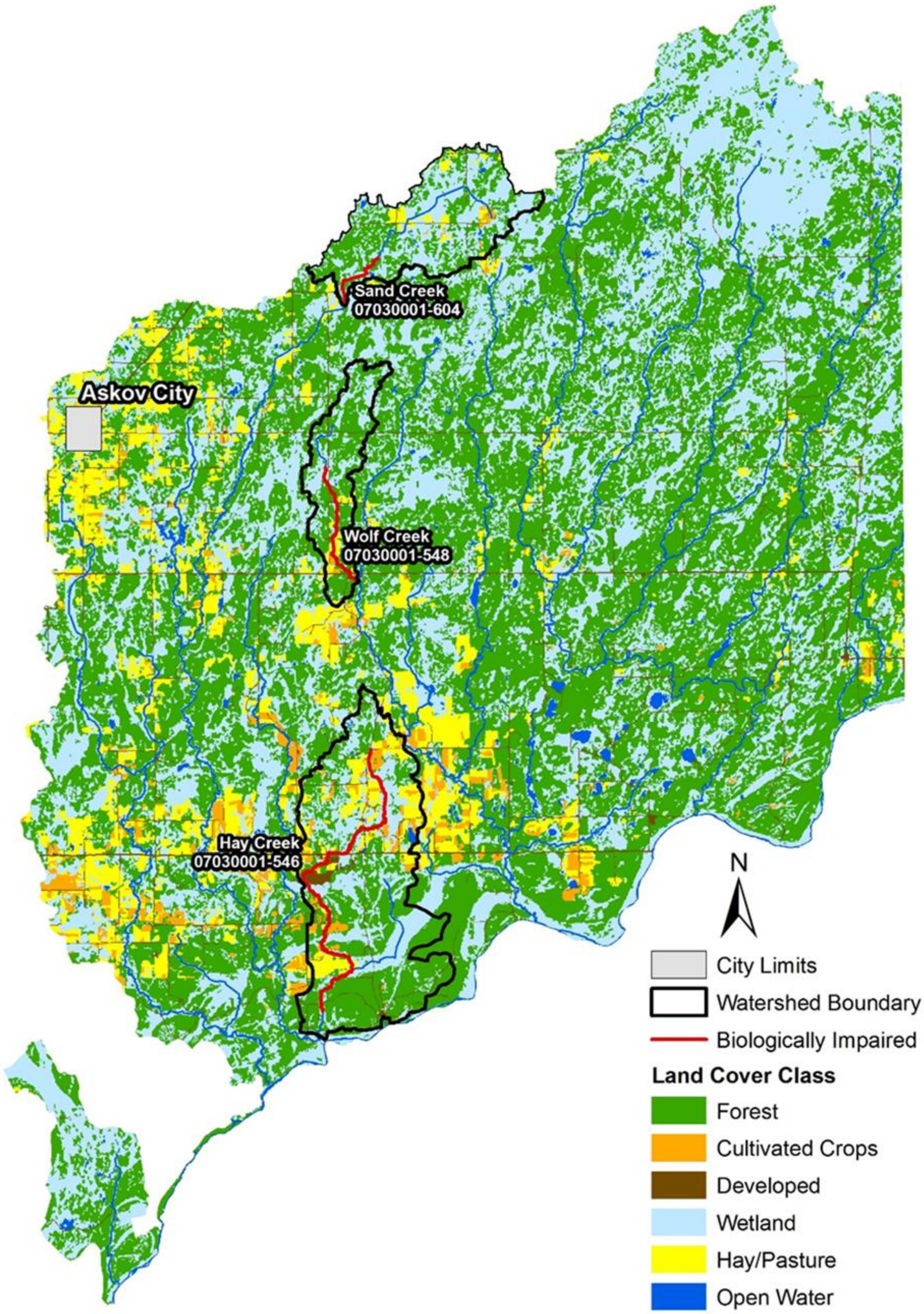


Figure 3. Land cover class as determined by the NLCD 2011 within the USCRW.



Determination of Candidate Stream Stressors

The process

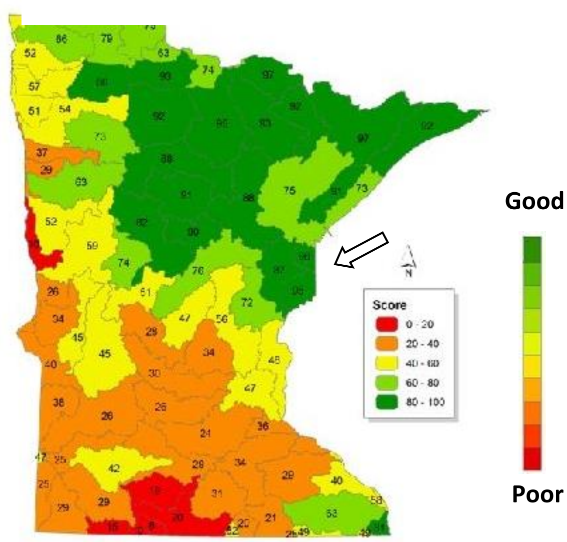
A wide variety of human activities on the landscape can create stress on water resources and their biological communities, including urban and residential development, industrial activities, agriculture, and forest harvest. An investigation is required to link the observed effects on an impaired biological community to the cause(s), referred to as stressors. The EPA provides a long list of stressors that have potential to lead to disturbance of the ecological health of rivers and streams (see EPA's CADDIS website http://www.epa.gov/caddis/). Many of those stressors are associated with unique human activities (e.g., specific types of manufacturing and mining) and can be readily eliminated from consideration due to the absence of those activities in the watershed. The first step in the evaluation of possible stressor candidates was to review existing data sources that describe land use and other human activities. These sources included various GIS coverages, aerial photographs, and the Minnesota Department of Natural Resources' (DNR) Watershed Health Assessment Framework. Additionally, census records and various MPCA records, such as National Pollutant Discharge Elimination System (NPDES)-permitted locations, added to preliminary hypotheses generation and the ruling out of some stressors or stressor sources.

In conjunction with the anthropological and geographical data, actual water quality, habitat, and biological data were analyzed to make further conclusions about the likelihood of certain stressors impacting the biological communities. Water chemistry and flow volume data is very limited within the USCRW. The determination of candidate stressors used all available information to create as large of a dataset as possible for this assessment. Preliminary hypotheses were generated from all of these types of data, and the SID process (including further field investigations) sought to confirm or refute the preliminary hypotheses.

DNR Watershed Health Assessment Framework

The DNR developed the Watershed Health Assessment Framework (WHAF), which is a computer tool that can provide insight into stressors within Minnesota watersheds (http://www.dnr.state.mn.us/whaf/index.html). The water quality component of the WHAF includes an assessment of the nonpoint source pollution threat to water quality within the watershed. Specifically, the WHAF considers the level of chemical application rates to agriculture lands and the amount of impervious surface in the floodplain riparian buffer. This assessment shows non-point pollution, relative to other parts of the state, is not a widespread stressor in the USCRW (Figure 4). According to the Non-point Source Pollution Index, the USCRW had a very good score of 95 (100 = no chemical application and no impervious in riparian area). A major urban source of non-point pollution is runoff from impervious surfaces, however, no cities or towns exist within the subwatersheds of the three impaired stream reaches (Figure 5).

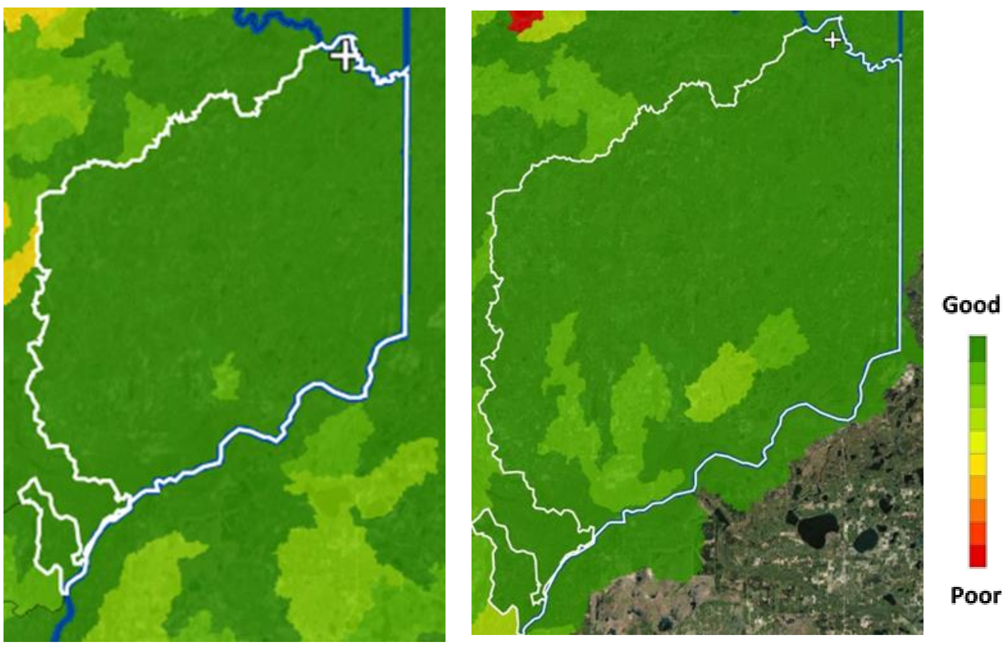
Figure 4. Scores and relative ranking of the Upper St. Croix River Watershed for the DNR Non-point Source Pollution Index.



The Point Source Index in the WHAF captures possible impact from point source and similar types of pollution sources, including pollutant contributions from animal husbandry, hazardous waste and superfund sites, wastewater treatment effluent, mining, and SSTS (septic systems). Point source pollution is also not a significant source of stream stressors in the USCRW. There are no permitted industrial dischargers and Askov WWTP is the only NPDES permitted point source discharger in the USCRW, however, this facility does not discharge to any of the biological impaired reaches covered in this report

The WHAF map for the Localized Pollutant Source Index (LPSI) showed relatively little concern overall across the USCRW, however, select areas do pose localized pollution concerns. Farm animals, septic systems, wastewater treatment plants and superfund sites were identified as localized concerns in certain subwatersheds within the USCRW. The level of concern ranged from slight to high, however, only septic systems posed a slight level of concern within one of the impaired stream reaches (Hay Creek). Further, there are almost no locations that have "high" septic system densities per the WHAF tool output (Figure 5). Overall, the "Point Source" WHAF score for USCRW is 97 out of 100. The only subwatersheds that are not in the high category are those along the southern boundary of the USCRW, and almost all of those are still considered moderately high. The "Water Quality" WHAF score for the USCRW was 81 out of 100.

Figure 5. Catchment-scale impervious surface (right) and WHAF Septic metric within the Nonpoint Source Index (left) scores for the USCRW.



Other MPCA Water Monitoring Programs

Aside from the IWM monitoring, MPCA has other programs that conduct various water monitoring efforts that can shed light on possible stressors. For example, MPCA's wastewater program compiles nutrient data routinely collected as part of a wastewater permit requirement. Recent trend data for phosphorus originating from wastewater discharges is available for the major watersheds of MN. The MPCA has a load monitoring network, where numerous water quality parameters are frequently monitored, with sample sites near the pour point of each of Minnesota's 80 HUC-8 scale watersheds. Phosphorus loads from each of Minnesota's HUC-8 watersheds are found on MPCA's webpage: http://mpca.maps.arcgis.com/apps/Compare/storytelling_compare/index.html?appid=c53c280bb959419e891aaebfc1da9bb4. MPCA also provides water quality monitoring grants to local organizations, and this data, as well as all of the MPCA-collected data, is stored in the publicly available EQuIS database, at the following web page: http://www.pca.state.mn.us/index.php/data/environmental-data-access.html. Data from these other programs is included in the water chemistry discussions of individual AUIDs that follow later in the report, if applicable to the site.

Desktop review

Urbanization/Development/Population density

Census data provides a way to look at human-induced stress or pressure on the water resources of a region. Stressor sources that are related to population density include: wastewater effluent, impervious surface areas, and stormwater runoff, which all increase with population density. According to the 2010 census data, the USCRW is sparsely populated relative to the state as a whole. Askov, with a population of 364 according to the 2010 U.S. Federal Census (MSDC, 2015), is the only municipality within the USCRW. Askov is not large enough to require an MS4 stormwater permit and city runoff does not directly impact the impaired reaches covered in this report.

One potential human stressor in rural areas is SSTS. Unsewered areas can have old SSTS that are either failing, or do not conform to current design standards. Most rural homes/cabins in the USCRW are not connected to a municipal sewer system, and thus have individual SSTS. Rural areas may also have residences that unlawfully discharge wastes directly to streams, but those numbers are declining. These systems can contribute significant levels of nutrients and other chemicals to water bodies. Recent SSTS statistics for Pine County suggest that 5% of the SSTS are considered imminent threats to public health and safety (ITPHS) (i.e., direct discharge to stream), and 10% fail to protect groundwater (FTPGW) (MPCA personal communication, 2018).

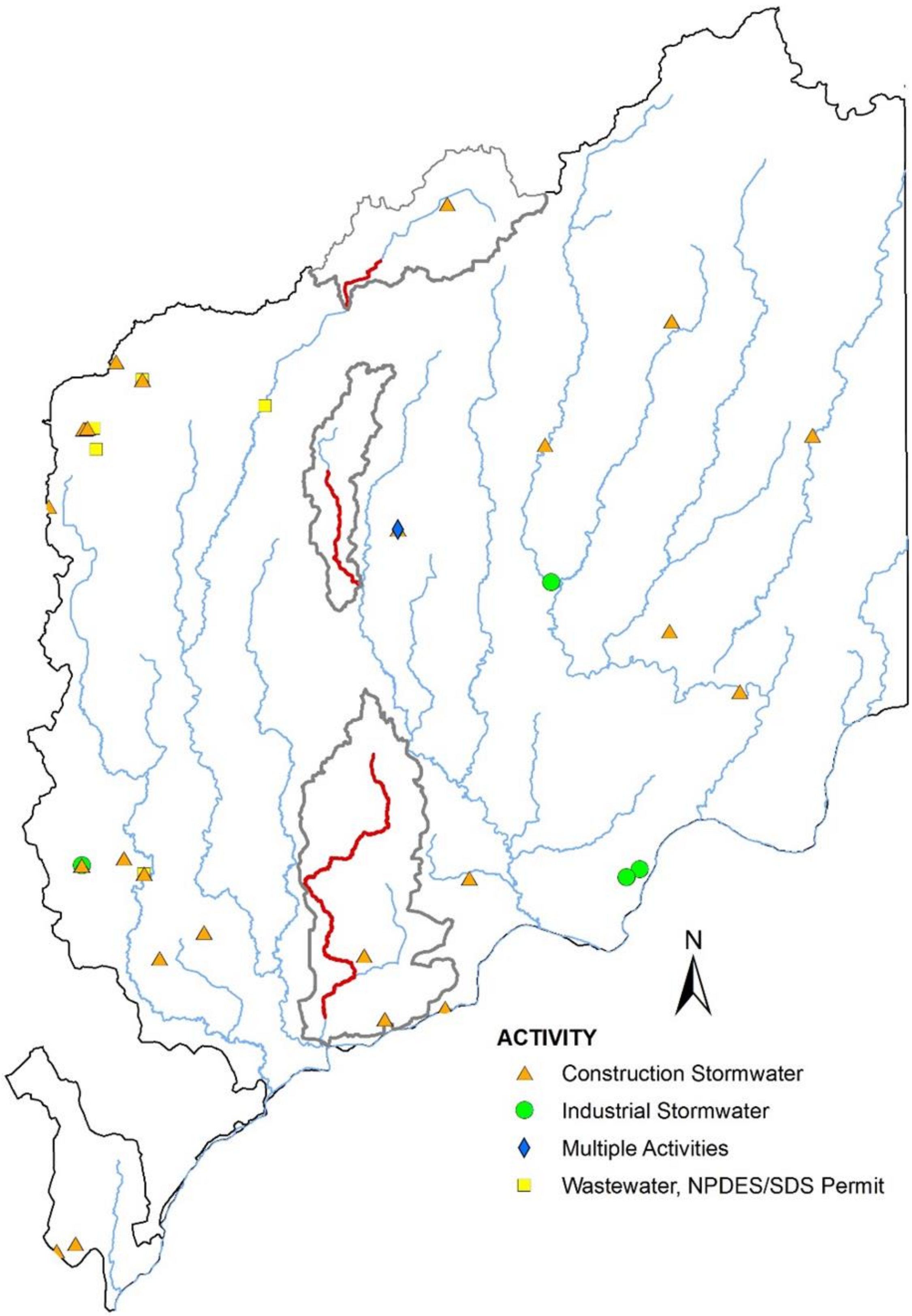
Industrial activities

Industrial activities are another potential cause of impairments and stressors within the watershed. The USCRW has very little industry and construction-related activities. There are five industrial NPDES permits and eight industrial stormwater permits within the USCRW, none of which are in subwatersheds of the biologically impaired reaches. There are a total of 64 construction stormwater permits, one of which is in the Sand Creek subwatershed and two which are in the Hay Creek subwatershed (Figure 6). Thus, industrial and construction discharges are not considered a major source of pollutants or stressors to the biotic community in the impaired reach watersheds.

Forestry

Forest harvest can create stress on water resources. The majority of land within the USCRW is forested or wetland; some lands are used for timber production and the area has a history of forest removal. Nearly all of the non-wetland land area in the USCRW was originally forested or wetland (Marschner, 1930). Tools to examine forest harvest impacts are limited; however, stressors related to harvesting are possible in the USCRW. For example, periodic alteration of hydrology can occur by changing the vegetation through timber harvesting. Similarly, more sediment is expected to move across a newly disturbed landscape than from intact forest systems.

Figure 6. Registered construction and industrial activities in the USCRW (black outlined) and impaired reach subwatersheds (gray outlined).

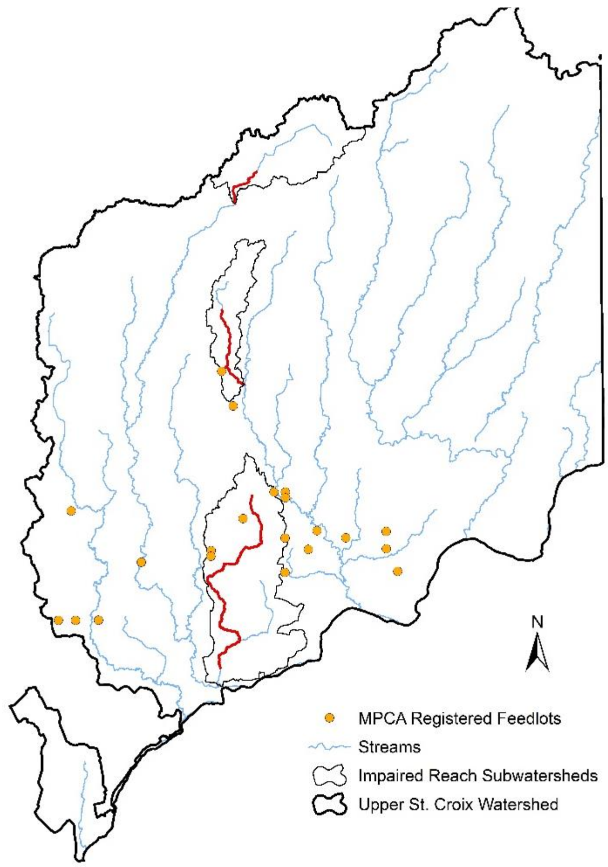


Agricultural activities

Agriculture-related stressors can include nutrients, sediment, and altered hydrology. The lands of the USCRW, as with those in much of northcentral Minnesota, are not extensively used for row crop agricultural production. The western portion of the USCRW watershed is where a majority of the cultivated cropland (~2% of watershed), hay and pasture land (~7% of watershed) and livestock operations are concentrated (Figure 3 and Figure 7). Thus, agricultural activities should be considered as a possible contributor to impairments in the impaired reach subwatersheds.

Significant professional research has been conducted to investigate the link between agricultural landscape changes/alterations and water quality degradation and impacts to biological communities (e.g., Fitzpatrick et al., 2001; Houghton and Holzenthal 2010; Diana et al., 2006; Sharpley et al., 2003, Blann et al., 2009, Riseng et al., 2011). Agricultural activity can result in elevated sediment and nutrients in downstream receiving waters (Sharpley et al., 2003, Riseng et al., 2011, MPCA, 2013). While the USCRW has a substantially lesser degree of agriculture compared to other regions of Minnesota, elevated pollutant loading from these sources are likely occurring in localized areas.

Figure 7. Registered feedlots in the USCRW



Hydrologic alteration has occurred in the USCRW through changes in the vegetation from original forest to open farmland. In addition, soil compaction from farm equipment or animal grazing can increase runoff. More sediment will move to streams from cultivated fields than from fields with perennial grasses. Since farmland acreage overall is relatively light in the USCRW, and with much of that acreage being hay or pasture, erosion and alteration of hydrology due to agriculture is not a systemic issue in the USCRW, although localized hotspots may occur.

Pesticides

Given that the USCRW is not an intensely agricultural watershed, it is reasonable to disregard pesticides as a major stressor to aquatic life. Pesticide testing is very expensive, and monitoring for pesticides is difficult as applications are spotty and occur irregularly. More information on pesticide occurrence in Minnesota's environment continues to be gathered via Minnesota's statewide pesticide sampling program and results are available from the Minnesota Department of Agriculture (MDA) at http://www.mda.state.mn.us/monitoring.

Summary of Candidate Stressor Review

Based on review of human activity in the USCRW in general, and then specifically the subwatershed and riparian areas in close proximity to the USCRW impaired reaches, the initial list of candidate/potential causes was narrowed down by eliminating eight potential stressors (see summary below). This resulted in nine candidate causes for which more detailed investigation was conducted.

Eliminated Causes

- Ammonia – minimal row crop agriculture exists within subwatersheds
- Elevated nitrogen – minimal row crop agriculture exists within subwatersheds
- Industrial stressors (i.e., toxic chemical, high conductivity discharges) – minimal industrial sources within impaired subwatersheds
- Mining stressors – no mining activities in area
- Nitrate as nutrient – minimal row crop agriculture exists within subwatersheds
- Nitrate as a toxicant – minimal row crop agriculture exists within subwatersheds
- Pesticides - Impacts from pesticides are deemed unlikely due to small human population and minimal agricultural land use.
- Urban development/municipal stressors - there are no urbanized areas within the subwatersheds

Inconclusive Causes

- Forest management stressors - historical/legacy effects are difficult to determine. Impaired subwatersheds have had recent forest harvest, though understanding and quantifying the effects of forest harvest, and threshold levels for stress to occur to streams is not well known. There are current efforts planned or underway by MPCA to better understand the effects of forest harvest impacts on streams. Therefore, we will not investigate this candidate cause in greater detail.

Candidate Causes

- Altered geomorphology
- Altered hydrology (non-urban sources)
- Connectivity loss
- Elevated phosphorus
- Excess sediment (both suspended and deposited)
- Habitat loss
- Low dissolved oxygen
- Water temperature

Mechanisms of candidate stressors and applicable standards

A separate document has been developed by MPCA describing the various candidate stressors of aquatic biological communities, including where they are likely to occur, and their mechanism of harmful effect, and Minnesota's Standards for those stressors (MPCA, 2017). Many literature references are cited that are additional sources of information. The document is titled "Stressors to Biological Communities in Minnesota's Rivers and Streams" and can be found on the web at: https://www.pca.state.mn.us/sites/default/files/wq-ws1-27.pdf. Additional information on Stressor Identification in Minnesota can be found on MPCA's website: https://www.pca.state.mn.us/water/your-stream-stressed. EPA (2017) has yet more information, conceptual diagrams of sources and causal pathways, and publication references for numerous stressors on their CADDIS website at https://www.epa.gov/caddis.

Notes on analysis of biological data

Biological data (the list of taxa sampled and the number of each) form the basis of the assessment of a stream's aquatic life use status. Various metrics can be calculated from the fish or macroinvertebrate sample data. An Index of Biological Integrity (IBI), a collection of metrics that have been shown to respond to human disturbance, is used in the assessment process (https://www.pca.state.mn.us/water/index-biological-integrity). Similarly, metrics calculated from biological data can be useful in determining more specifically the cause(s) of a biological impairment. Numerous studies have been done to search for particular metrics that link a biological community's characteristics to specific stressors (Hilsenhoff, 1987, Griffith et al., 2009, Álvarez-Cabria et al., 2010). This information can be used to inform situations encountered in impaired streams in Minnesota's WRAPS process. This is a relatively new science, and much is still being learned regarding the best metric/stressor linkages. Use of metrics gets more complicated if multiple stressors are acting in a stream (Statzner and Beche, 2010; Ormerod et. al., 2010, Piggott et. al., 2012).

Staff in MPCA's Standards, Biological Monitoring, and Stressor ID programs have worked to find metrics that link biological communities to stressors, and work continues toward this goal. Much work in this area was recently done to show the impact of nutrients (particularly phosphorus) on biological stream communities when Minnesota's River Nutrient Standards were developed (Heiskary et al., 2013). The

Biological Monitoring Units of MPCA have worked to develop species or genera (for macroinvertebrates) Tolerance Indicator Values (TIVs) for many water quality parameters and habitat features. This is a take-off on the well-known work of Hilsenhoff (1987; EPA, 2006), which has been further developed by USGS scientists (Meador and Carlisle, 2007). For each parameter, a relative score (a TIV) is calculated for each taxon regarding its sensitivity to that particular parameter by calculating the weighted average of a particular parameter's values collected during the biological sampling for all sampling visits in the MPCA biological monitoring database. The weighting factor is the abundance of that species or genera (for macroinvertebrates) at each site. Using those individual TIVs for the taxa present in a sample, a weighted average community score (a community index) can be calculated. Using logistical regression, the biologists have also determined the probability of the sampled community being found at a site meeting the TSS and/or DO standards, based on a site's community score compared to all MPCA biological sites sampled to date. Such probabilities are only available for parameters that have established standards, though community-based indices can be created for any parameter for which data exists from sites overlapping the biological sampling sites.

Some of these stressor-linked metrics and/or community indices will be used in this report as contributing evidence of a particular stressor's responsibility in degrading the biological community in an impaired reach. It is best, when feasible, to also include field observations, chemistry samples, and physical data from the impaired reach in determining the stressor(s).

Notes on culvert assessment

DNR has recently developed a program to assess culvert crossings for the effect they have on stream channel stability and the fish community. Effects include blocking the passage of fish and harming the local stream channel by causing erosion. The complete USCRW was assessed in 2016, and a report has been generated, "High Priority Sites for Fish Passage Projects in the Upper St. Croix Watershed" (DNR, 2017).

Biologically impaired streams

The AUIDs assessed as impaired in the USCRW are discussed individually from this point on. The general format will be: 1) a section that reviews and discusses the data that was collected prior to the SID process 2) a section discussing the data that was collected during the SID process; and 3) a section discussing the conclusions for the impaired reach based on all the data reviewed.

Note: From this point on, the AUIDs referred to in the text (except main headings) will only include the unique part of the 11-number identifier, which is the last three digits.

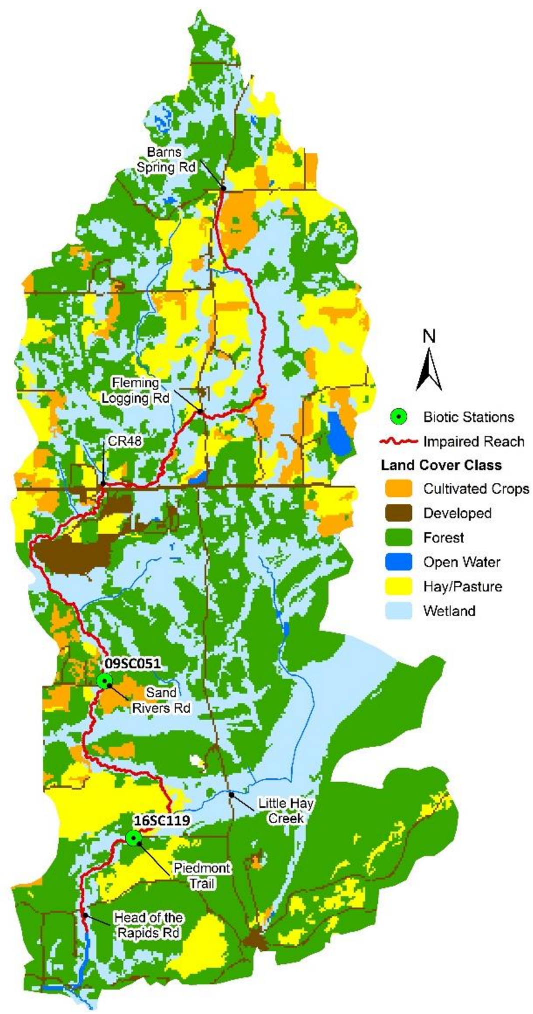
Hay Creek (AUID 07030001-546)

Impairment: Hay Creek is classified as a coldwater stream (2A designation) and was therefore assessed using coldwater IBIs to determine the health of the biotic communities. Hay Creek was observed as having non-support of general aquatic life based on both macroinvertebrate (M-IBI) and fish (F-IBI) communities with IBI scores falling below their respective general use thresholds.

Hay Creek's macroinvertebrate community was assessed using 2010, 2016, and 2017 samples from two stations (09SC051, 16SC119; Figure 8). All three M-IBI scores are below the general life use threshold and confirm impairment status under the coldwater IBI. Two visits were within the lower confidence limit and one was below the lower confidence limit.

Hay Creek's fish community was sampled in 2010, 2016, and 2017 at two stations (09SC051, 16SC119). Two F-IBI scores were above the general life use threshold (score = 35) and within the upper confidence interval and two F-IBI scores were below the general life use threshold and within the lower confidence interval. With mixed results and half the sampling events not meeting the coldwater IBI, the reach was also deemed as having an impaired fish community.

Figure 8. Biotic sampling stations, impaired stream reach and land cover class as determined by the NLCD 2011 within Hay Creek subwatershed.



Sub-watershed characteristics

Most of the land within the Hay Creek subwatershed is forested or wetland, with the majority of the forest being comprised of deciduous trees (Figure 8 and Table 2). Common land cover types intermixed with the forests are wooded wetland forests, shrub swamps and hay/pasture. Row crop and developed (namely roads and farmsteads) land covers do occur but are sparse. Agriculture comprises <20% of the watershed land cover with majority occurring in the form of hay/pasture lands.

Table 2. Land cover within the Hay Creek subwatershed

Land cover type	Acres	Percent
Developed	811	4%
Cultivated Crops	982	5%
Hay/Pasture	2,577	14%
Open Water	109	<1%
Wetland	5,640	30%
Forest	8,438	46%
TOTAL	18,577	100%

Source: 2011 NLCD GIS coverage

Image: Downstream view of Hay Creek at Sand Rivers Road/ County Road 136 (09SC051)

Data and Analyses

Chemistry

Limited chemical data has been collected at the two sampling locations (09SC051 and 16SC119) within the Hay Creek impaired reach (Table 3).

Table 3. Water chemistry measurements collected at 09SC051 and 16SC119.

Note: all values in mg/L unless otherwise noted

Site	Date	Water Temp. (°C)	Cond. (µS/cm)	DO	pH	Secchi Tube (cm)	TSS	NO2/ NO3	NH4	TP	VSS
09SC051	7/21/2010	21.0	138.9	7.7	7.5	--	6	0.08	0.05	0.096	2.8
	6/29/2010	20.2	146.5	7.7	7.5	--	10	0.07	0.08	0.116	3.6
16SC119	6/21/2016	15.4	146.7	8.4	7.3	75	9.6	0.43	0.05	0.049	4
	8/23/2016	19.6	133.0	6.9	7.4	54	--	--	--	--	--
	9/7/2017	11.0	139.0	9.4	6.7	83	4.8	0.26	0.05	0.059	3.2
	9/13/2017	13.9	118.5	8.8	7.2	90	--	--	--	--	--

Nutrients – phosphorus

Three of the four total phosphorus (TP) samples collected exceeded the region's river nutrient threshold of 0.050 mg/L. Site location comparisons are not conclusive since samples were not collected in both locations on the same days or years. However, concentrations within Hay Creek were either greater in 2010 or are greater at site 09SC051 (upstream), however, limited data does not allow further explanation.

Image: Deployed continuous monitoring probe.

Nutrients – nitrate and ammonia

Nitrate and ammonia were at very low concentrations and considered to be at non-problematic levels. Observed concentrations at both sites were far below the 10 mg/L drinking water standard and are common for north-central Minnesota streams.

Dissolved oxygen

Dissolved oxygen (DO) data collected during biological monitoring showed all individual DO measurements were meeting the coldwater DO standard (7 mg/L); (Table 3). In 2018, Wenck deployed a continuous DO monitoring sonde at 09SC051 starting in early August until late September (Table 4 and Figure 9). These results showed that DO levels fell below the coldwater DO standard and experienced periods of diel DO fluxes ≥ 3.0 mg/L. During the 51 sample days, five were observed to have DO fluctuations ≥3.0 mg/L. These large diel DO fluctuations were combined with minimum DO concentrations below 7.0 mg/L, which can be stressful to coldwater biota. Precipitation events also appear to have a significant impact on DO levels and fluctuations at this site. Diel DO was dampened following larger storm events and minimum daily DO generally increased.

Wenck also conducted a morning longitudinal DO survey at three locations along the Hay Creek on August 21, 2018 (Table 4). The upstream sample location (Barns Spring Road) observed very low DO measurements that are considered stressful conditions (or potentially lethal) to aquatic biota. It appears that watershed features, such as wetlands and altered hydrology, may be causing localized DO differences along Hay Creek.

Figure 9. Hay Creek station 09SC051 continuous DO data from August 2018.

Notes: The red triangle indicates field grab readings. Precipitation is daily total precipitation from the Bruno, MN weather station (ID 211074).

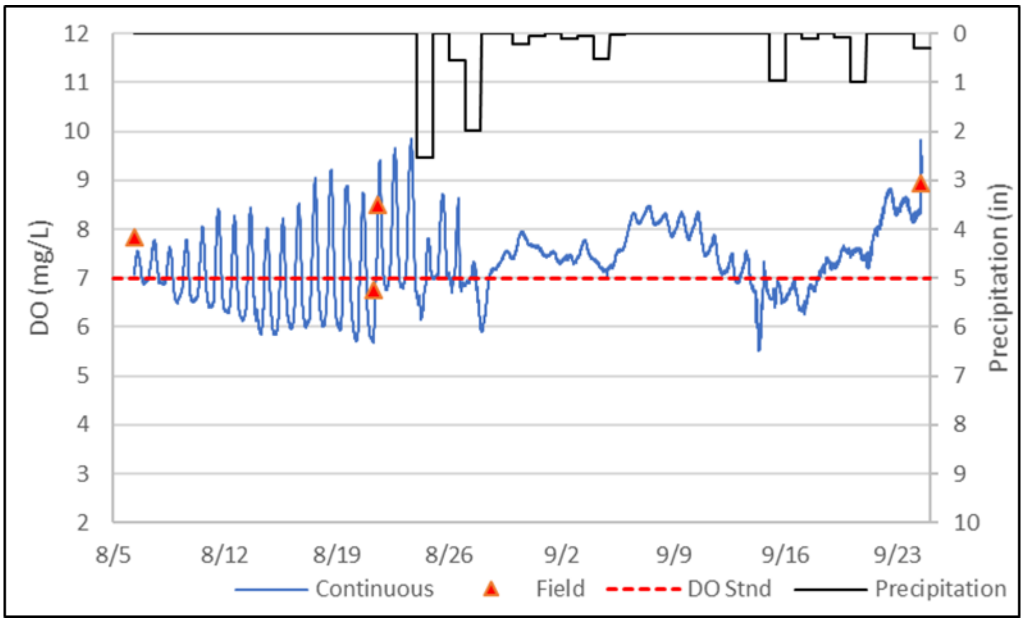


Table 4. Morning longitudinal DO survey along Hay Creek on 8/21/2018.

Site/Location	Relative Reach Location	Time (am)	Temp (°C)	DO (mg/L)	DO saturation (percent)
Barn Spring Rd	Upstream	8:15	17.46	**1.23**	12%
County Road 48	Middle	8:05	20.84	**3.37**	38%
Sand River Rd (09SC051)	Downstream	7:30	16.34	**6.75**	69%
Piedmont Trail	Downstream	7:45	16.56	8.21	84%

Total Suspended Solids (TSS)

Only four TSS measurements have been collected within the Hay Creek impaired reach (Table 3). None of the TSS measurements exceeds the 10 mg/L threshold for coldwater streams; however, two of the measurements were at or very close to the threshold. More TSS measurements will need to be collected within this reach to determine impairment and whether TSS is stressor to the invertebrate and/or fish communities.

Temperature

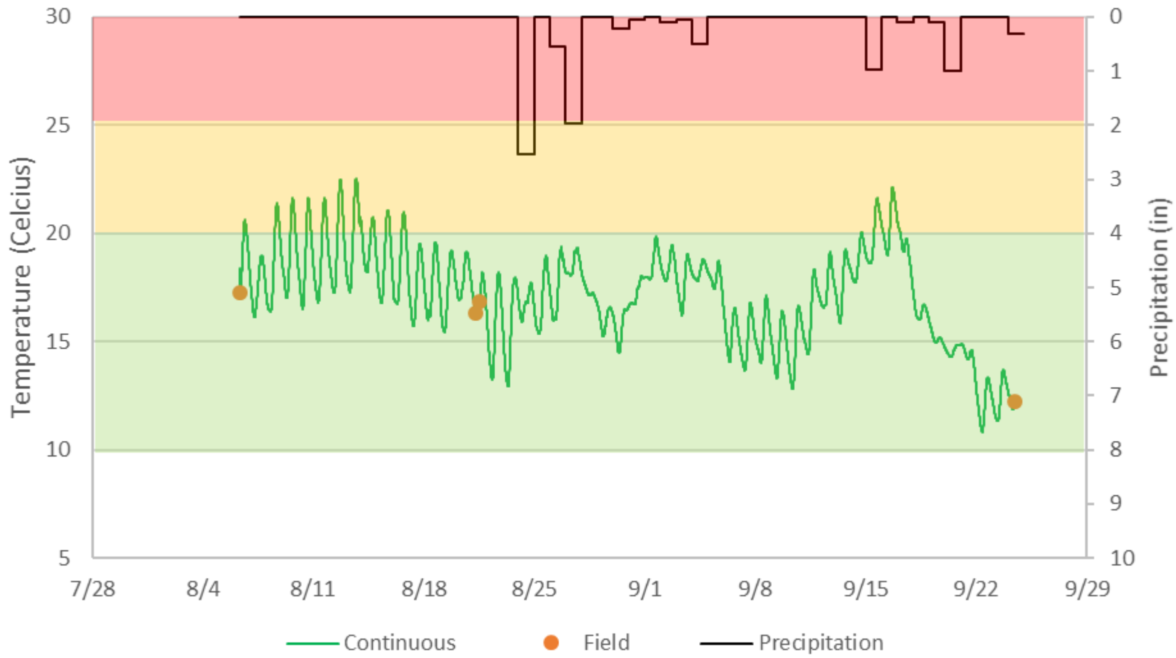
Discrete water temperature samples collected during biological sampling ranged from 11 to 21°C (Tables 3 and 4). In 2018, Wenck deployed a continuous monitoring sonde with a temperature sensor at 09SC051 starting in early August until late September (Figure 10). These results showed that temperature levels ranged from 10.8 to 22.5°C during the sampling period with five days of diel temperature changes >5.0°C. Large and abrupt temperature fluctuations combined with temperatures 20-25°C can be stressful to brown trout (a cold-water species). Therefore, using brown trout as a proxy to other cold-water species, water temperatures within Hay Creek have the ability to create stressful environments.

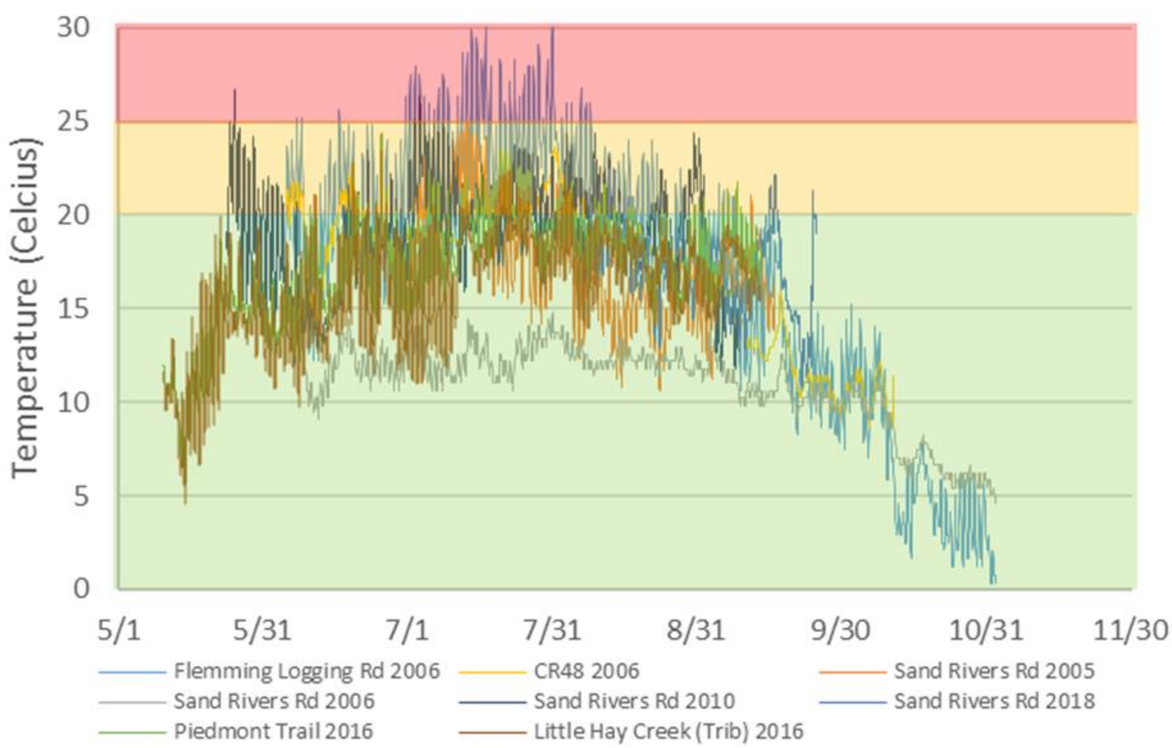
Additional water temperature data was available for 2005 (Sand Rivers Rd), 2006 (Flemming Logging Rd, County Rd 48, Sand Rivers Rd), 2010 (Sand Rivers Rd), 2016 (Piedmont Trail and Little Hay Creek), and 2018 (Sand Rivers Rd). These data suggest differences in Hay Creek temperatures depending on year and location along the reach. For example, monitoring from 2005 and 2006 at the Sand Rivers Road site observed strong differences. In 2005, water temperatures during the month of July and a few days in August reached stressful conditions for coldwater species. The 2006 water temperatures never reached above 15°C. The difference in temperature between these two years was quite dramatic and demonstrates two different environments for biota to live in. Review of the historic precipitation data from a nearby weather station (Bruno, Minnesota) suggests rainfall totals in 2005 were slightly above average (~2 inches above average) while 2006 was extremely dry and well below average (~9 inches below average). Thus, it can be concluded that streamflow in 2006 was largely groundwater driven, while 2005 streamflow had greater inputs of surface water runoff.

Though only one season of temperature data has been collected (2006), the Flemming Logging Road site, which is one of the most upstream road crossings, displayed significantly higher temperatures than the downstream sites (CR48 and Sand Rivers Road) that were monitored in 2006 (Figure 10). 2006 stream temperatures at the Flemming Logging Road site commonly exceeded 25°C from early July through mid-August, which is stressful to coldwater fish species (e.g. trout). More stream temperature data would need to be collected in the upper portion of the reach to identify where and how often stressful temperature conditions occur in this part of the impaired reach.

Figure 10. Hay Creek continuous temperature data from 2018 (top) and historically (bottom – all years and sites). The orange circle indicates the field grab readings for 2018. Precipitation is daily total precipitation from the Bruno weather station (ID 211074).

* Red= >25°C and is lethal, Orange = 20- 25°C and is stressful, Green = 10- 20°C is ideal to brown trout





Habitat

The Minnesota Stream Habitat Assessment (MSHA) scores habitat health by assessing local land use and in-stream characteristics. MSHA scores are comprised of land use, riparian, substrate, cover and channel morphology metrics. Within these metrics, questions are answered with each answer associated to a point score. Scores are totaled up to an overall site score. The MPCA has developed health classifications with total scores $\geq$ 66 as "Good", 45 < score < 66 as "Fair", and score $\leq$ 45 as "Poor". We report individual metric scores as percentage of the total metric points possible; therefore, 100% reporting is a perfect score for a given metric.

A summary of metric scores and health classifications for Hay Creek are provided in Table 5. Overall, riparian buffer scored well while all other metrics scored poorly. Site 09SC051 scored better overall and for most metrics compared to the upstream site 16SC119. In-stream characteristics appear to be the most degraded component of the MSHA within Hay Creek. Spatial difference in scoring suggest that there may be areas of concern that could have an overall impact on the biotic health of the impaired reach.

Table 5. Minnesota Stream Habitat Assessment scores and classification for Hay Creek. Metric scores are presented as a percentage of the maximum allowable points for a given metric.

Site 09SC051 = green rows, 16SC119 = tan rows.

Date	Land Use	Riparian	Substrate	Cover	Channel Morph	Total Score	
Max Points	5	14	28	18	35	100	**Classification**
7/21/2010	100%	86%	50%	44%	63%	61	Fair
6/29/2010	100%	93%	62%	72%	74%	74.4	Good
6/21/2016	50%	100%	46%	83%	49%	61.5	Fair
8/23/2016	50%	86%	46%	61%	34%	50.5	Fair
9/7/2017	100%	86%	46%	33%	37%	49	Fair
9/13/2017	50%	75%	39%	67%	66%	59	Fair

Hydrology

Alterations

Aerial photography review using Google Earth found minimal landscape-related hydrological alterations. Alterations that were apparent in the watershed were related to forest harvest, conversion of forestland into agriculture practices, and roads built across wetland habitats. These disturbances have a long history within the watershed, and are therefore difficult activities to evaluate and can also be difficult to remediate.

Riparian Wetlands

Much of the Hay Creek watershed is comprised of wetland habitat, especially the landscape immediately adjacent to the Hay Creek channel (Figures 8 and 11). Wetland habitats can alter chemical, physical and hydrologic properties of water (i.e., increasing water temperature, lowering of dissolved oxygen), therefore, streams that flow through wetland habitats can be expected to have properties that differ from streams that do not. However, it is often difficult to determine whether the chemical/ physical changes are naturally occurring or if human induced stress on the wetlands is resulting in increased chemical/ physical changes observed in the stream.

The Rapid Floristic Quality Assessment (RFQA) is a vegetation based ecological condition assessment for wetlands. The assessment scores are responsive and reliable indicators to disturbance and provide a means to assess human impact to the wetland community (Table 6). The RFQA scores the health of a wetland based on the wetland species present, their relative abundance within a community and their tolerance of disturbance (score of conservatism; *C*). Characteristics of a site's vegetation community are used to develop a weighted score of conservatism (*wC*), that is then associated to a Biological Condition Gradient (BCG) and an overall site condition (Table 6). Sites with low BCG classification are associated to healthy wetlands and minimal human impacts, while sites with high BCG classification are associated to disturbed wetlands and high human impact (Table 7). The BCG is a classification representation of the most pristine (BCG Tier 1) to degraded (BCG Tier 4) wetland conditions. Communities that tend to have greater native diversity, relatively site-specific species and no invasive species score well and are placed into a higher Tier ranking (i.e. Tier 1).

We further the RFQA conclusions, proposing that the health of wetlands immediately surrounding stream habitats could be an indicator to whether deviation from anticipated stream characteristics are the result of natural or human induced disturbance. Since healthy wetland condition (i.e. good/exceptional RFQA scores) suggests minimal human impact to a wetland, wetlands with good health that buffer Hay Creek indicate deviations from expected stream characteristics (i.e. temp, DO, nutrients, etc.) may be due to natural wetland phenomena. Poor wetland condition (i.e. poor/fair RFQA scores) suggests there has likely been human impact(s) to the wetland and deviations from expected stream characteristics may be due to human induced stresses.

Table 6. Biological Condition Gradient tier assessment for shrub-carr communities.

BCG Tier	wC	Condition
1	> 4.5*	Exceptional
2	> 4.3	Good
3	3.2 - 4.3	Fair
4	< 3.2	Poor

* Total introduced species cover <1%.

Table 7. Generalized wetland vegetation Biological Condition Gradient scoring, classification and description.

BCG Tier	Condition Category	Description
1	Exceptional	Community composition and structure as they exist/ likely existed in the absence of measurable effects of anthropogenic stressors representing pre-European settlement conditions. Non-native taxa may be present at very low abundance and not causing displacement of native taxa.
2	Good	Community structure similar to natural community. Some additional taxa present and/or there are minor changes in the abundance distribution from the expected natural range. Extent of expected native composition for the community type remains largely intact.
3	Fair	Moderate changes in community structure. Sensitive taxa are replaced as the abundance distribution shifts towards more tolerant taxa. Extent of expected native composition for the community type diminished.
4	Poor	Large to extreme changes in community structure resulting from large abundance distribution shifts towards more tolerant taxa. Extent of expected native composition for the community type reduced to isolated pockets and/or wholesale changes in composition.

To evaluate wetland conditions, we conducted RFQAs at four locations along Hay Creek (Figure 11). Assessments were made upstream of road/culvert crossings and did not consider any vegetation within 50 feet of the roadway due to observed disturbance (i.e. brush cutting, etc.).

Wetland sites were dominated by shrub-carr communities comprised of native (≥ 15) and introduced (≤ 2) species (Table 8). Observed *wCs* ranged from 3.1 - 3.6 with site conditions being rated as fair or poor on the

MPCA wetland health assessment scale (Table 6). Conditions generally improved moving down stream through the impaired reach as the surrounding landscape appeared to have less agricultural activities buffering the wetlands.

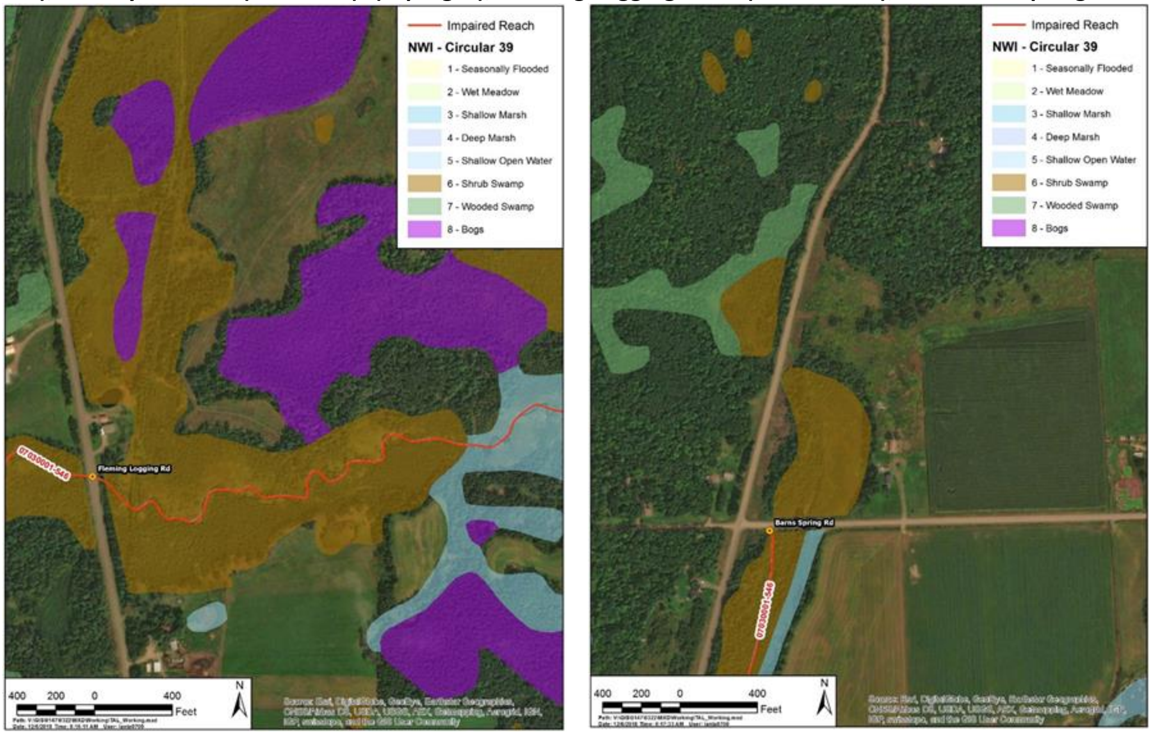
Table 8. Rapid floristic quality assessment summaries and resulting condition categories (sites ordered from upstream to downstream).

Site Name	Native Species	Introduced Species	*wC*	Introduced Species Cover	BCG Tier	Condition
Barn Springs	16	1	3.1	17%	4	Poor
Fleming Logging	18	0	3.0	0%	4	Poor
09SC051 - Hay Creek	15	0	3.4	0%	3	Fair
CR48	19	2	3.6	1%	3	Fair

Overall, the health of the wetlands indicate moderate to significant disturbance occurring within the wetlands adjacent to Hay Creek. Land use may be a factor; however, the landscape is relatively pristine compared to many areas within the State. It is possible that localized land use manipulations, historic logging, and alterations to hydrology have impacted these wetlands. With the addition of roads through these wetland habitats, surface flow of water through the wetlands may have been altered and restricted to flow through culverts rather than larger unrestricted meandering sheet flow along the entire wetland. While we do not have direct evidence at this time to support this hypothesis, it is a possible explanation to the lower than anticipated (based on land use features) scores.

Images: Common wetland (shrub carr) community habitats along Hay, Sand, and Wolf Creeks assessed using RFQA sampling methodology.

Figure 11. National wetland inventory classification of wetland complex upstream of County Road 136 (09SC051); (top left), County Road 48 (CR48 site); (top right), Fleming Logging Road (bottom left), and Barns Spring Road (bottom right).



Connectivity

The 2017 DNR report “High Priority Sites for Fish Passage Project in the Upper St. Croix Watershed” assessed 10 road and private crossings for fish passage. Of these 10 crossings, two were identified as high priority connectivity barriers (Sand Rivers Road and a private crossing downstream of County Road 48). The Sand Rivers Road crossing (09SC051) contains an undersized culvert and the channel on the downstream end of the culvert is washed out and over-widened, which is common for undersized culverts. Over-widened channels have the potential to slow the flow of water, increase temperature, and lower dissolved oxygen. No notes or information was available regarding the private crossing downstream of County Road 48.

Beaver dams were not observed along the impaired reach using high-resolution aerial photography. However, the DNR receives federal funding to trap and remove beavers along Hay Creek. Beaver/ muskrat activity (chewed sticks) was seen by Wenck staff during RFQA at 09SC051. Debris was stuck into the culvert causing slightly altered flow and water level. This is likely a frequent occurrence along Hay Creek but does not currently appear to be impeding fish passage due to the beaver management efforts by the DNR.

Biology

Fish

The fish community was sampled a total of four times across two different locations; 09SC051 and 16SC119 (Table 9). Species diversity during any given community assessment ranged from seven to 12 species and was made up of 37 to 122 individual specimens. At least seven species were observed during all four sampling events with creek chub being the most common species observed. Creek chub are considered a tolerant pioneer species that does well in warm disturbed water systems. Brook trout were also observed and are a cold water, stress intolerant species that requires high dissolved oxygen. Therefore, the fishes that comprise the community are drastically different in terms of ecological niches. Two additional species found in cool or coldwater habitats (mottled sculpin and pearl dace) were found at both sites in low numbers.

The health of the fish community was assessed using the northern coldwater streams IBI. In total, the IBI is comprised of nine metrics that relate information about habitat condition, community tolerance, reproduction, life history and general composition. Eight of the nine metrics have a range from 0 to 12.5 with a greater score representing a more positive condition (see metric relationship in Table 10). The percentage individuals with deformities metric either scores a 0 (no deformities observed) or a -5.0 (deformity (ies) observed). Therefore, the total IBI score for a given site could score 100 points. Three of the four fish IBI scores from Hay Creek sites were relatively consistent, however, many individual metric scores were highly variable across all four sampling efforts (Table 10). This is reflected by the community summary (Table 9) in which we observed significant swings in the numbers and species present during a given survey. The community changes have occurred both within the same year and among years, suggesting volatile community dynamics within the reach. Unstable biotic community composition is an undesired characteristic. When communities go through significant shifts in the species and their abundances it suggests that the resilience and robustness of the community is weak. It is supportive to the idea of biological impairment and that stressors are impacting the stream.

Table 9. Summary of fish survey results from Hay Creek

	09SC051		16SC119	
Species	**6/29/2010**	**7/21/2010**	**6/21/2016**	**9/7/2017**
blacknose dace	13	13	4	9
blackside darter		1		
brook stickleback	8	7	2	1
brook trout	1	2	10	9
central mudminnow	2		8	2
common shiner	1	5		
creek chub	37	14	4	24
fathead minnow	1			1
Iowa darter	4	2		
Johnny darter	35	9	6	4
mottled sculpin	5	1		4
northern redbelly dace		3		
pearl dace	3		3	
white sucker	12	8		1

Table 10. IBI metric summary from fish survey results on Hay Creek.

Metric	Metric relationship*	7/21/2010	6/29/2010	6/21/2016	9/7/2017
coldwater taxa	+	12.5	12.5	6.25	12.5
% coldwater intolerant individuals	+	0.46	0.12	4.04	2.45
% coldwater sensitive taxa	+	4.74	6.33	9.00	7.52
% tolerant individuals	-	12.5	7.97	1.11	5.69
% ind. with deformities	-	0	0	-5.0	0
% non-lithophilic nest building ind.	-	2.01	0.81	2.41	4.48
% omnivorous taxa	-	6.82	2.08	12.5	0.00
% ind. from Order Perciformes	-	1.93	0.05	2.37	4.98
% pioneer taxa	-	5.68	3.12	1.79	0.00
IBI Score		**46.6**	**33.0**	**34.5**	**37.6**
General Use Threshold		**35.0**			

* +/- equates to a net positive or net negative impact by having more individuals within that metric

In addition to the IBIs, the MPCA has developed tolerance index values (TIV) in which the community composition is assessed directly for DO and TSS induced stressors. Results of analyses using TIVs are presented here to help identify possible stressors to the biotic communities within Hay Creek.

The fish community within Hay Creek displayed relatively consistent DO TIV and improving TSS TIV scores and percentile ranking across sampling events (Table 11). TSS index scores improved to the 57th percentile for class 11 streams in 2016; however, assessments prior to 2016 suggested a TSS stress on the system. Review of TSS species tolerance classification does not show evidence that TSS is a stressor. There was a greater dominance of intolerant taxa and individuals compared to tolerant taxa and individuals. Combined taxa richness of intolerant or very intolerant ranged from two to four while tolerant to very tolerant species were not observed. The percent of individuals classified as intolerant or very intolerant ranged from 5% to 27% of the individuals (Table 12). TSS is a known stressor in Minnesota streams, however, the characteristics of the biological community collected for Hay Creek indicate it is a not a primary stressor on the coldwater biotic community.

The DO TIV Index scores have been consistently poor across sampling events with Hay Creek ranking at the 27th to 33rd percentile. Review of DO species tolerance classification observed moderate dominance by very tolerant and tolerant taxa and individuals. Combined taxa richness of intolerant or very intolerant ranged from 2 to 3 while tolerant to very tolerant richness ranged from 5 to 8 taxa. The percent of individuals classified as tolerant or very tolerant was greater than intolerant and very intolerant ranging from 14.7% to 35.1% of individuals (Table 12). Overall, the Hay Creek fish community is comprised of more DO tolerant species which suggests DO is a likely stressor to the community.

Table 11. Fish Community DO and TSS Tolerance Index scores in Hay Creek sites. For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within the appropriate stream class.

Site	Year	Parameter	Fish Class	DO TIV Index	Class avg./median	Percentile
09SC051	2010	TSS	11	13.5	10.84 / 11.25	12
		DO	11	7.17	7.61 / 7.55	27
	2010	TSS	11	13	10.84 / 11.25	21
		DO	11	7.17	7.61 / 7.55	28
16SC119	2016	TSS	11	10.7	10.84 / 11.25	57
		DO	11	7.27	7.61 / 7.55	33
	2017	TSS	11	*	10.84 / 11.25	*
		DO	11	*	7.61 / 7.55	*

* Data have not been reported in the MPCA database

Table 12. Fish Tolerance metrics for DO and TSS in Hay Creek sites. Reported values are number of taxa and percent individuals.

Site	Year	Parameter	Very Intolerant	Intolerant	Tolerant	Very Tolerant
09SC051	2010	TSS	1 (0.82%)	2 (4.1%)	0 (0%)	0 (0%)
		DO	1 (0.82%)	2 (4.1%)	5 (5.74%)	3 (9.02%)
	2010	TSS	1 (3.08%)	3 (6.15%)	0 (0%)	0 (0%)
		DO	1 (3.08%)	2 (1.54%)	3 (3.08%)	2 (15.38%)
16SC119	2016	TSS	1 (27.03%)	1 (0%)	0 (0%)	0 (0%)
		DO	1 (27.03%)	1 (0%)	3 (8.11%)	2 (27.03%)
	2017	TSS	*	*	*	*
		DO	*	*	*	*

* Data have not been reported in the MPCA database

Macroinvertebrates

The macroinvertebrate community was sampled three times (2009, 2016, and 2017) across two locations; 09SC051 & 16SC119. Species diversity ranged from 44 to 53 taxonomic units per sampling event and 313 to 327 individual specimens across all sampling events (not shown here). The Baetis genus (belonging to the mayflies) and Simulium genus (commonly called blackflies or gnats) were the most dominant species observed within the samples.

Overall IBI scores differed between sampling events with 2009 and 2017 scores being relatively similar compared to 2016 scores. Only the Very Intolerant Taxa Richness remained relatively similar and low across all three years. All other metrics deviated by > 1.0 metric points across all three surveys suggesting that species composition does exhibit some variability across sampling years. Non-insect Taxa percentage was the best overall scoring metric in the IBI, however, this metric only displayed moderately high scores. The majority of macroinvertebrate IBI metrics scored near or less than 3.0 points (Table 13) which resulted in IBI scores below the General Use Threshold. Overall, the site's macroinvertebrate community was skewed toward tolerant, short-lived species and had limited diversity of sensitive taxa.

The macroinvertebrate community within Hay Creek displayed relatively consistent TIV scores and percentile ranking across sampling events (Table 13). Observed TSS index scores were always above the stream class average and median values (a negative in the case of TSS), and only ranked in the 16th to 22nd percentile. Review of TSS species tolerance classification found dominance by very tolerant and tolerant taxa and individuals. Combined taxa richness of tolerant or very tolerant ranged from 5 to 11 while intolerant to very intolerant ranged from 2 to 6. The percent of individuals classified as tolerant or very tolerant ranged from 11.6 to 23.5% of the individuals, while individuals classified as intolerant to very intolerant ranged from 0.9 to 9.2% (Table 15).

Table 13. IBI metric summary from macroinvertebrate survey results on Hay Creek.

Metric	Metric relationship*	8/25/2009	8/23/2016	9/13/2017
Collector-Gatherer Taxa %	-	2.63	0.00	0.61
Hilsenhoof Biotic Index	-	2.10	1.66	4.48
Very Intolerant Taxa Richness	+	0.00	0.93	0.93
Long-lived Taxa %	+	3.12	0.54	1.20
Non-insect Taxa %	-	6.96	4.14	5.18
Odonata Taxa %	+	5.41	2.71	2.37
POET Taxa	+	3.17	2.64	4.23
Predator Taxa Richness	+	2.02	0.00	4.04
Very Tolerant Taxa %	-	1.06	5.51	4.78
IBI Score		**26.50**	**18.13**	**27.81**
General Use Threshold			**32.0**	

* +/- equates to a net positive or net negative impact by having more individuals within that metric

Observed DO index scores consistently scored slightly better than stream class average but fell below stream class median values a majority of the time. DO percentile ranking varied from the 41st to 53rd percentile. Review of DO species tolerance classification observed dominance by very intolerant and intolerant taxa and individuals. Combined taxa richness of intolerant or more intolerant ranged from 8 to 16 while tolerant to very tolerant richness ranged from 2 to 6 taxa. The percent of individuals classified as intolerant or very intolerant was greater than tolerant and very tolerant ranging from 21.1% to 38.3% of the individuals (Table 15). These results do not point to DO as a clear stressor on the macroinvertebrate community within Hay Creek as the TIV scores are about average and there is a mixture of tolerant and sensitive taxa present. That said, as discussed above, monitored DO levels occasionally fall below the coldwater standard and are therefore likely having an impact on the biotic communities.

Table 14. Macroinvertebrate Community DO and TSS Tolerance Index scores in Hay Creek sites. For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within the appropriate stream class.

Site	Year	Parameter	Invert Class	TIV Index	Class avg./median	Percentile
09SC051	2010	TSS	8	13.9	12.23 / 12.24	16
		DO	8	7.5	7.33 / 7.46	53
16SC119	2016	TSS	8	13.88	12.23 / 12.24	17
		DO	8	7.34	7.33 / 7.46	41
	2017	TSS	8	13.6	12.23 / 12.24	22
		DO	8	7.36	7.33 / 7.46	42

Table 15. Macroinvertebrate Tolerance metrics for DO and TSS in Hay Creek sites. Reported values are number of taxa and percent individuals.

Site	Year	Parameter	Very Intolerant	Intolerant	Tolerant	Very Tolerant
09SC051	2009	TSS	0 (0%)	2 (0.9%)	10 (11%)	1 (0.6%)
		DO	3 (30.6%)	5 (0.9%)	5 (2.1%)	1 (0.3%)
16SC119	2016	TSS	1 (0.6%)	5 (3.7%)	5 (17.4%)	0 (0%)
		DO	4 (17.1%)	8 (4%)	2 (4%)	0 (0%)
	2017	TSS	1 (5.1%)	4 (4.1%)	9 (22.9%)	2 (0.6%)
		DO	6 (32.2%)	10 (6.1%)	4 (1%)	1 (0.6%)

Conclusions

The biotic impairments within Hay Creek appear to be caused by a few primary stressors including:

- Low DO
- Hydrology alterations

There is a large amount of wetland habitat adjacent to Hay Creek. These wetlands have the ability to slow flow, increase water temperatures, and deplete oxygen levels of water moving across the landscape through them. Additionally, restriction of flow through the development of roadways across the wetlands as well as altered land cover adjacent and/or upstream of these wetlands have the potential to increase the rate and amount of water interacting with the wetland before entering the stream. This increased interaction likely results in increased temperature and decreased DO levels. The RFQA of these wetland habitats along the stream indicate signs of human-induced stress, therefore, we cannot simply conclude that these conditions are 100% natural background. It is possible that historic and/or current land use and/or hydrologic alteration have impacted these wetland habitats.

One possible strategy to improve both wetland health and DO within the system would be to restore more natural hydrologic flow conditions of surface waters. Culverts should be assessed to see if they contribute to backing up water into riparian wetlands, or are creating downstream pools that deplete oxygen. A longitudinal DO survey conducted along Hay Creek showed early morning DO levels are very low near the headwaters of the reach (Barns Spring Road) and gradually increase moving downstream through the reach. Thus, upstream culverts and riparian wetlands should be investigated near the headwaters first for potential projects to improve hydrology and DO.

The DNR has identified two crossings, Sand Rivers Road and a private crossing downstream of County Road 48, as high priority connectivity barriers. These barriers are likely acting as stressors to the community and should be prioritized for future investigation and improvements.

In-stream substrate could be a contributing factor to diminished biotic health. MSHA assessment revealed poor substrate conditions that was comprised largely of fine sediments and sands. These fine materials are easily transported and moved during flow and precipitation events. Fine materials that continuously shift can result in a homogenous substrate type throughout the reach. The relatively low landscape alteration from natural forest cover suggests the predominantly fine, sandy sediment is likely a natural feature (i.e., not arriving to the stream from surface runoff eroding exposed soil) that would be difficult, if not impossible to change/control. It is recommended that more TSS data be collected during future assessments to evaluate sediment as a potential stressor to the biotic communities.

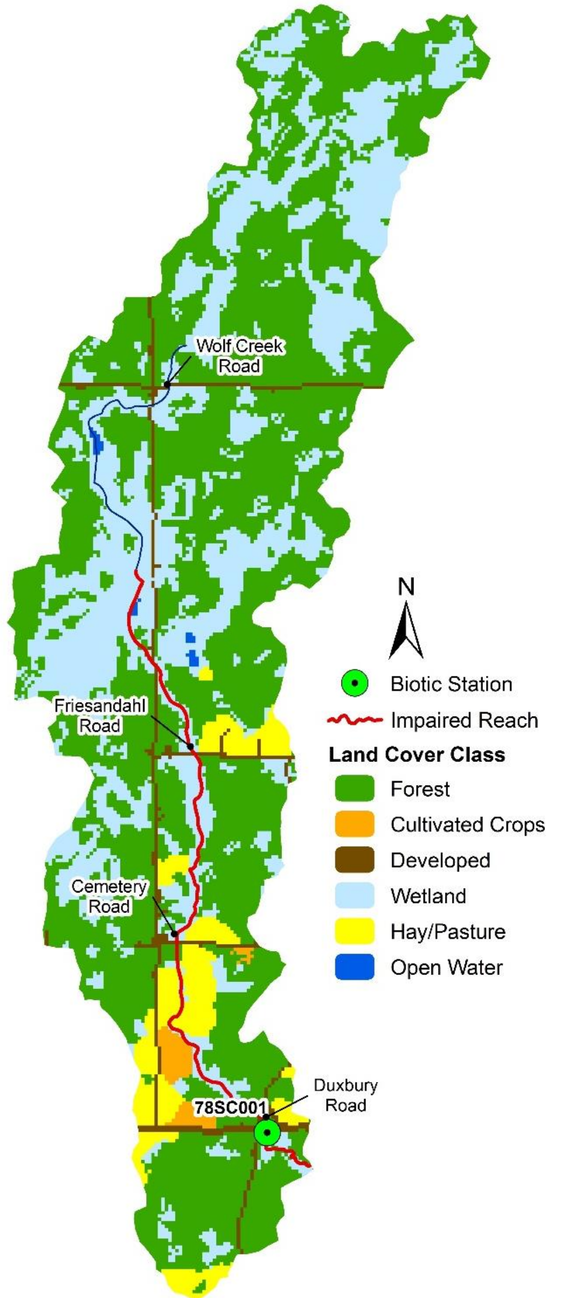
Wolf Creek (AUID 07030001-548)

Impairment: Wolf Creek is classified as a coldwater stream (2A designation) and was therefore assessed using coldwater IBIs to determine the health of the biotic communities. The stream was assessed as having non-support of general aquatic life based on the macroinvertebrate community.

Wolf Creek's macroinvertebrate community was assessed at one station (78SC001) in 2009 and 2010. Both visits scored below the general use threshold (32), one within, and one below the lower confidence limit.

Wolf Creek's fish community was assessed at one station sampled in 2010. Assessment resulted in a F-IBI score above the general life use threshold (35) and the upper confidence interval, suggesting non-impairment status. The visit has a biological condition gradient score of three, generally indicating minimal changes to fish community and ecosystem function.

Figure 12. Biotic sampling stations, impaired stream reach and land cover class as determined by the NLCD 2011 within Wolf Creek subwatershed.



Subwatershed characteristics

Most of the land within the Wolf Creek subwatershed is forested or wetland, with most of the forest being comprised of deciduous trees (Figure 12 and Table 16). Common land cover types intermixed with the forests include wooded wetland forests, shrub swamps and hay/pasture. Row crop acreage and developed land (roads and farmsteads) do occur but are sparse. A minor amount (<10%) of row crop agriculture and pasturelands exists in the watershed.

Table 16. Percentages of the various land cover types from 2011 NLCD GIS coverage within Wolf Creek subwatershed.

Land cover type	Acres	Percent
Developed	150	3%
Cultivated Crops	50	1%
Hay/Pasture	271	5%
Open Water	11	<1%
Wetland	1,632	32%
Forest	3,074	59%
TOTAL	5,188	100%

Data and analyses

Chemistry

Two samples have been collected at one site (78SC001) within the Wolf Creek impaired reach, in July and August 2010 (Table 17).

Table 17. Water chemistry measurements collected at 78SC001. Values in mg/L.

Date	Water Temp. (°C)	Cond. (µS/cm)	DO	pH	Secchi Tube (cm)	TSS	NO2/NO3	NH4	TP	VSS
7/7/2010	23.3	203.3	6.94	7.2	--	3.6	0.17	< 0.05	0.081	1
8/17/2010	15.9	1594	8.46	7.6	--	--	--	--	--	--

Nutrients – phosphorus

Only one TP sample has been collected in Wolf Creek. This measurement (0.081 mg/L) was above the region's river nutrient threshold of 0.050 mg/L (Table 17).

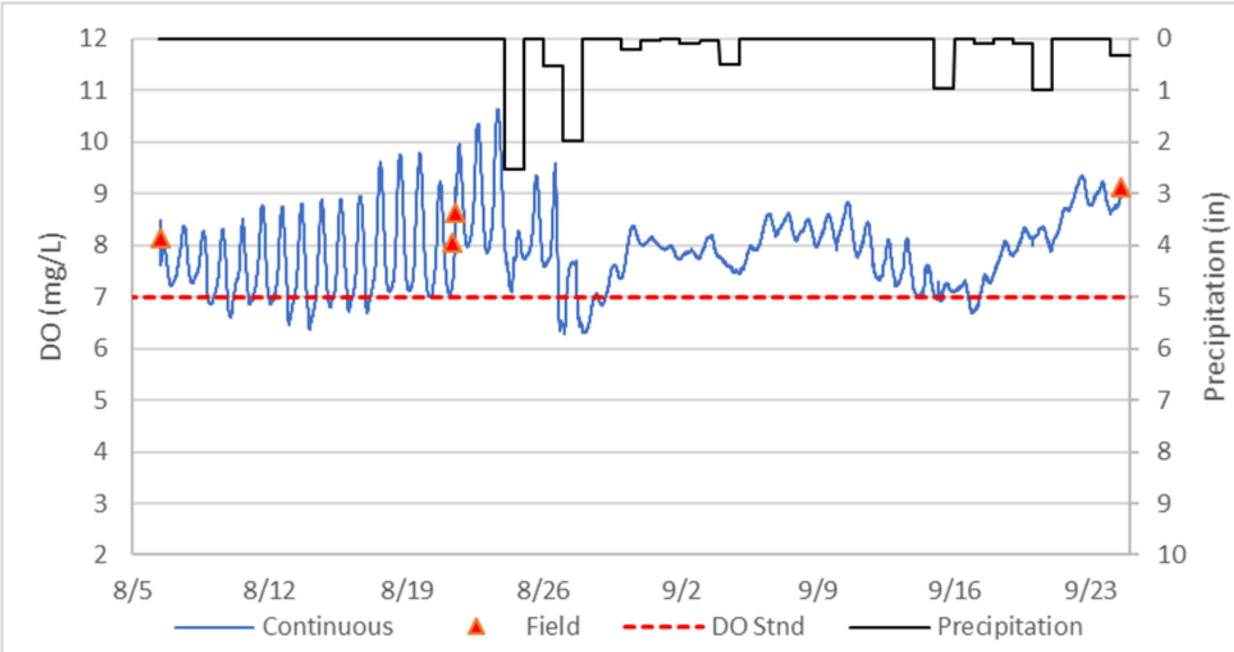
Nutrients – nitrate and ammonia

One nitrate and ammonia sample has been collected in Wolf Creek. Results of this sample indicate concentrations are well below levels thought to be toxic to aquatic organisms.

Dissolved oxygen

Dissolved oxygen (DO) data collected during biological monitoring showed one of the individual samples did not meet the coldwater DO standard (7 mg/L; Table 17). In 2018, Wenck deployed a continuous DO monitoring sonde at 78SC001 starting in early August until late September (Figure 13). These results showed that DO levels occasionally fell below the coldwater DO standard, though by a relatively small margin, and for fairly short periods of the day. Additionally, this site experienced three days in which diel DO fluxes ≥ 3.0 mg/L. Large diel DO fluctuations and minimum DO concentrations below 7.0 mg/L can be stressful to coldwater biota. However, DO may be less of stressor in Wolf Creek compared to Hay Creek since minimum daily DO levels dropped below 7.0 mg/L on only a few occasions and there were minimal large diel flux during the 2018 deployment. Precipitation events also appear to have an impact on DO levels and fluctuations at this site. DO levels dropped below the 7.0 mg/L DO standard and diel flux was dampened immediately following a series of storm events in late August.

Figure 13. Wolf Creek continuous DO data from 2018. The red triangle indicates field grab readings. Precipitation is daily total precipitation from the Bruno weather station (ID 211074).



Wenck also conducted a morning longitudinal DO survey at three locations along Wolf Creek on August 21, 2018 (Table 18). Similar to Hay Creek, the upstream sample location (Wolf Creek Road) showed a drastically lower DO compared to the other sites and would result in stressful (or potentially lethal) conditions to aquatic biota. It appears that watershed features, such as wetlands and altered hydrology, may be causing localized DO differences along Hay Creek. Review of aerial imagery observed significant beaver activity which could also impact DO levels. More hydrology investigation and discussion is presented below.

Table 18. Morning longitudinal DO survey along Wolf Creek on 8/21/2018.

Site/Location	Relative Location	Time (am)	Temp (C)	DO (mg/L)	DO Saturation (percent)
Wolf Creek Rd	Upstream	8:55	17.6	**1.61**	17
Friesandahl Rd	Midstream	8:45	16.1	8.04	82
Duxbury Rd (78SC001)	Downstream	8:35	15.1	8.06	80

Turbidity – TSS

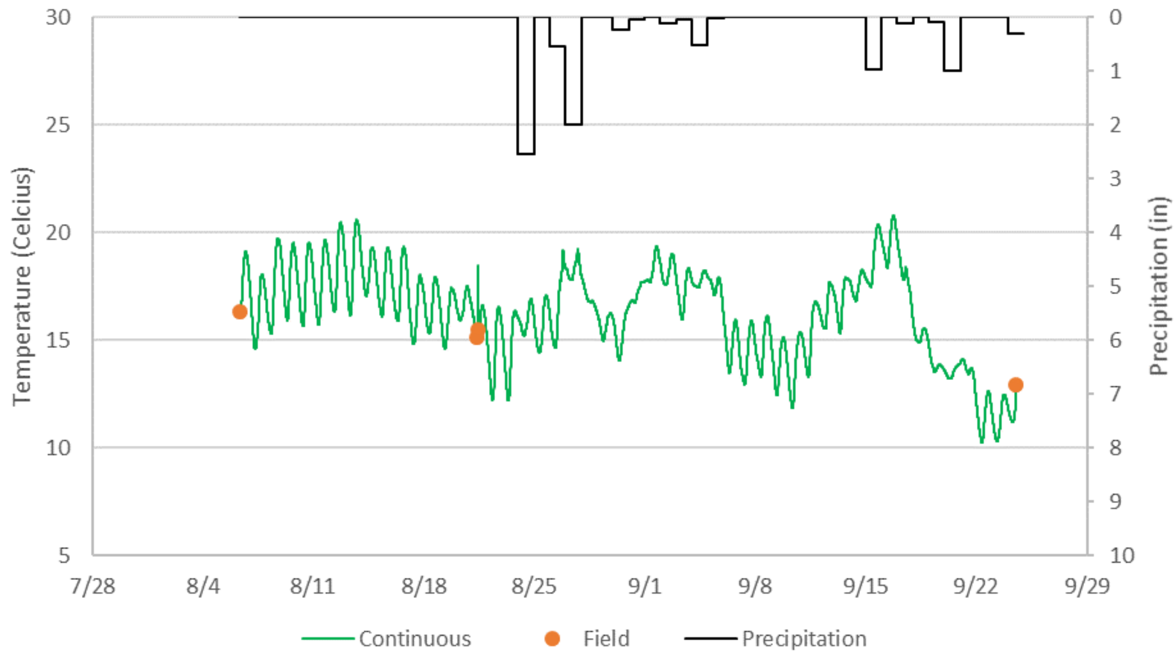
The single TSS observation did not exceed the coldwater TSS threshold of 10 mg/L (Table 17). More TSS measurements will need to be collected within this reach to determine the range of TSS concentrations that occur in the reach and whether TSS is stressor to the invertebrate community.

Temperature

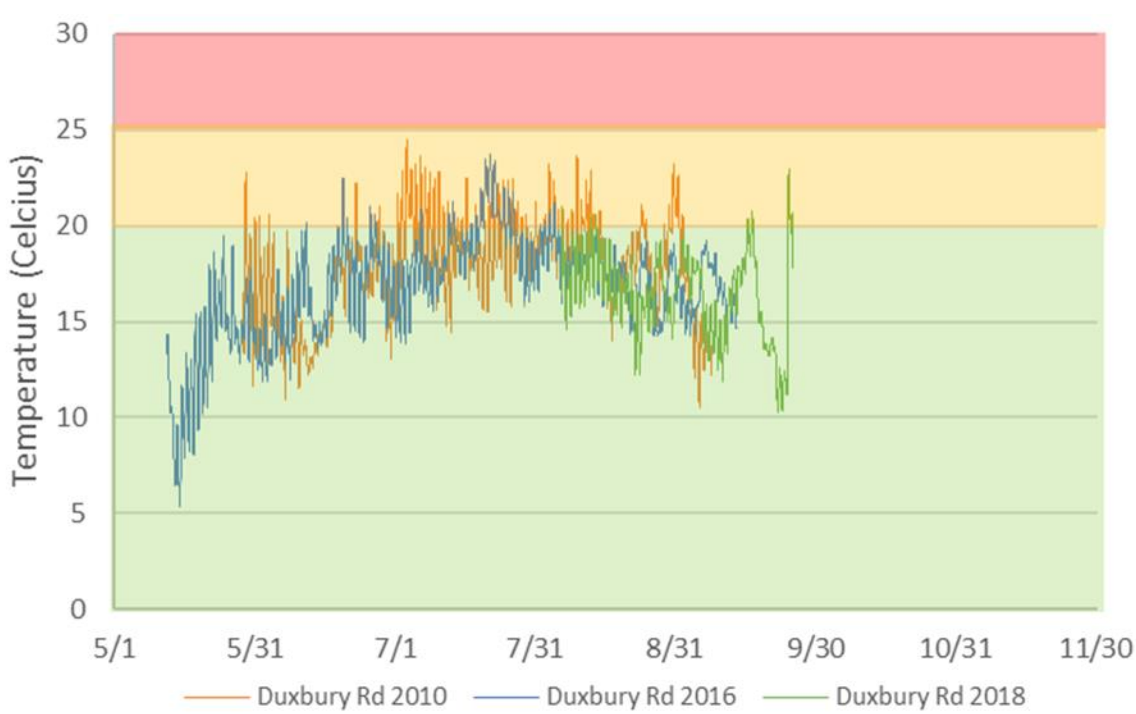
Discrete water temperature samples collected by the MPCA ranged from 15.9 to 23.3°C (Table 17). In 2018, Wenck deployed a continuous temperature monitoring sonde at 78SC001 starting in early August until late September (Figure 14). These results showed that temperature ranged from 10.2 to 21.0°C over the sampling period. During this time, the greatest diel temperature flux was approximately 4.0°C. Large and sudden fluctuations along with temperatures 20-25°C can be stressful to brown trout (a cold-water species). Using brown trout as a proxy to other cold-water species, water temperatures within Wolf Creek do not appear to create significant amounts of stressful conditions. However, there were occasions in 2010 and 2016 where temperatures approached 25°C. More data could be collected at upstream sites to evaluate whether temperature is a stressor at other locations along the impaired reach.

Figure 14. Wolf Creek continuous temperature data from 2018 (top) and historically (bottom – all years). The orange circle indicates the field grab readings for 2018. Precipitation is daily total precipitation from the Bruno weather station (ID 211074).

* Red= >25°C and is lethal, Orange = 20-25°C and is stressful, Green = 10-20°C is ideal for brown trout



Habitat



A summary of metric scores and health

classifications for Wolf Creek are provided in Table 19. Overall, the metrics (land use, riparian, within stream) for Wolf Creek scored at a moderate level and suggest impaired conditions buffering and within the stream. These impaired conditions could limit the stream's ability to buffer against upland pollutant sources and create stress to the biotic community.

Table 19. Minnesota Stream Habitat Assessment scores and classification on Wolf Creek. Metric scores are presented as a percentage of the maximum allowable points for a given metric.

Date	Land Use	Riparian	Substrate	Cover	Channel Morph	Total Score	Classification
Max Points	5	14	28	18	35	100	
7/7/2010	50%	68%	44%	44%	51%	50.3	Fair

Hydrology

Alterations

The Wolf Creek watershed does appear to have altered hydrology. Certain areas within the watershed appear to have been harvested for timber or have been converted to agriculture practices that could impact runoff rates and sedimentation (temporarily for logged lands that are allowed to re-grow forest), but visual evidence of stream straightening is not apparent. Several culvert crossings are likely undersized as washouts and widening are common downstream of road crossings. Wenck staff visited several road crossings and noticed over-widening of the stream channel and/or small pools at the downstream end of several road crossings (e.g. Flemming Logging Road, Friesandahl Road, and Wolf Creek Road). Recent (2018) culvert replacement occurred at 78SC001 (Flemming Logging Rd crossing) and may significantly alleviate hydrology concerns at this location. Beaver activity was also apparent and is discussed below.

Wetland Buffer

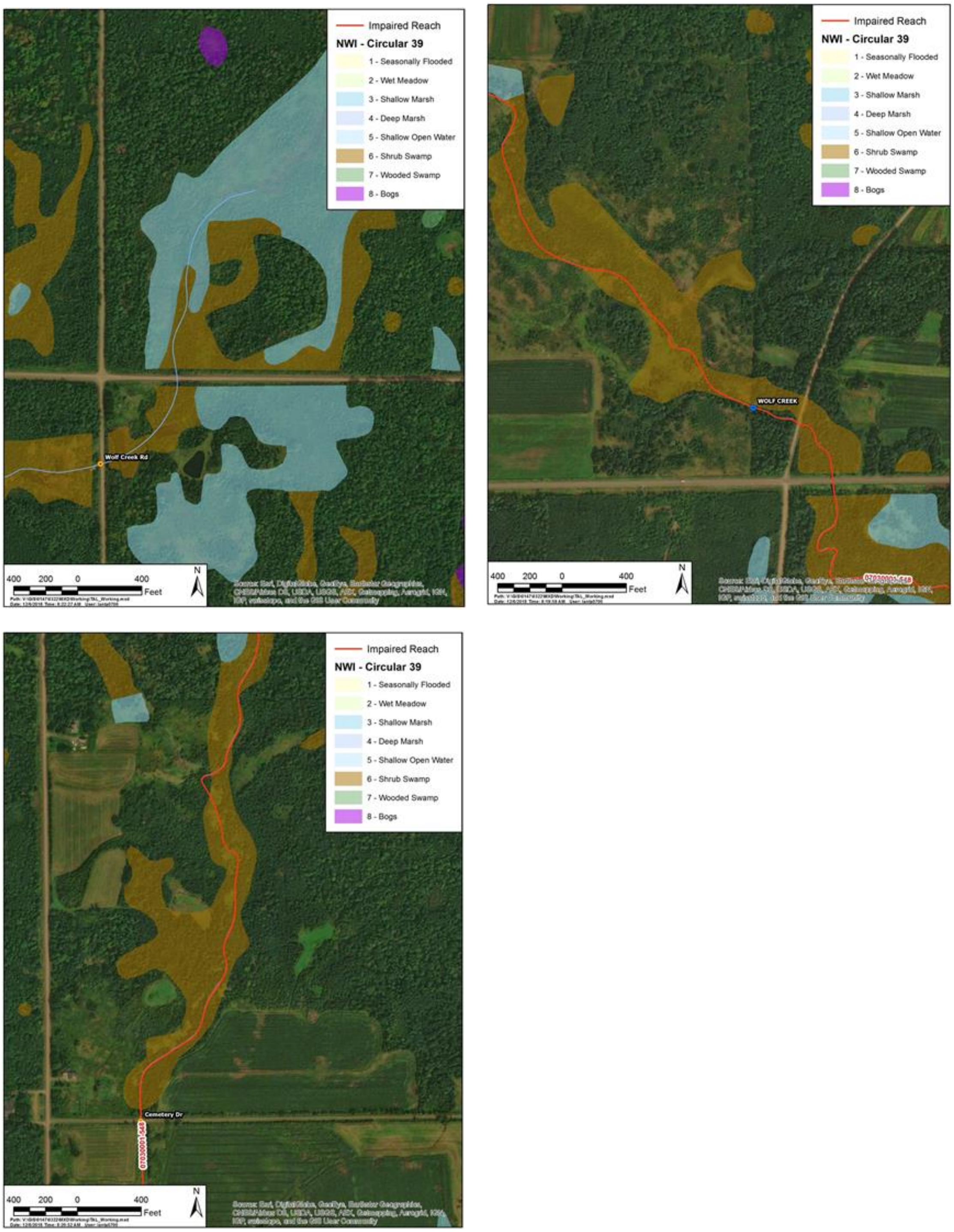
Much of the Wolf Creek watershed is comprised of wetland habitat, especially the landscape immediately adjacent to the Wolf Creek channel. To evaluate wetland conditions, we conducted RFQAs (see Hay Creek for detailed description of RFQA process and methods) at three locations along Wolf Creek (Figure 15). Assessments were made upstream of road/culvert crossings and did not consider any vegetation within 50 feet of the roadway due to observed disturbance (i.e. brush cutting, etc.).

The riparian lands at sample sites were dominated by shrub-carr communities comprised of native (≥ 9) and introduced (≤ 2) species (Table 20). Observed *wCs* ranged from 2.3 - 3.9 with site conditions being rated as fair or poor (Table 20). Site health did not follow any spatial pattern from upstream to downstream; however, the Cemetery Drive site was immediately adjacent to agricultural activities and demonstrated the poorest score among the three sites assessed. Overall, the RFQA scores indicate a moderate to significant disturbance occurring within the wetlands adjacent to Wolf Creek.

Table 20. Rapid floristic quality assessment summaries and resulting condition categories.

Site Name	Native Species	Introduced Species	*wC*	Introduced Species Cover	BCG Tier	Condition Category
Wolf Creek Rd	13	0	3.9	0%	3.0	Fair
Cemetery Rd	9	2	2.3	30%	4.0	Poor
Duxbury Rd (78SC001)	14	1	3.8	0%	3.0	Fair

Figure 15. National wetland inventory classification of wetland complex upstream of Wolf Creek Road (top left) Duxbury Road (top right), and Cemetery Drive (bottom left).



Connectivity

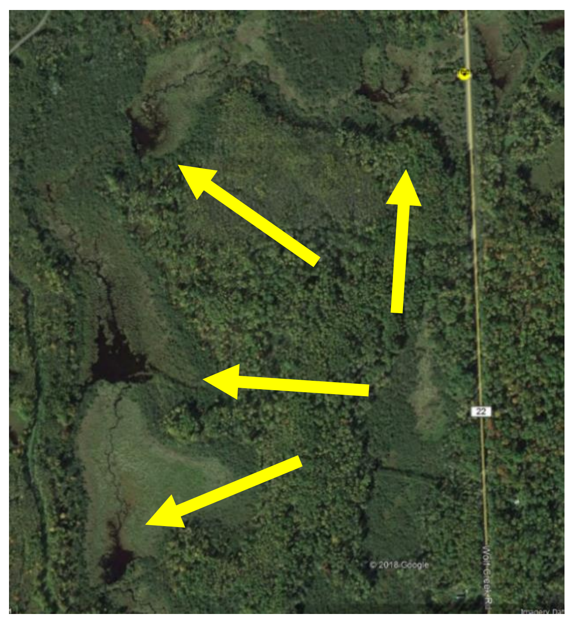
There are nine road/private crossings along Wolf Creek: Duxbury Road (Pine County 30), Flemming Logging Road, a private crossing upstream of Flemming Logging Road, Cemetery Drive, Friesandahl Road, Wolf Creek Road (two crossings), and Rutabaga Road. Five of these crossings (Duxbury Road, Flemming Logging Road, the private crossing, Cemetery Drive, Friesandahl Road, and the downstream Wolf Creek Road crossing) were assessed for fish passage by the DNR as part of the 2017 culvert inventory report (DNR 2017). None of the assessed crossing were identified by the DNR as high priority connectivity barriers.

The Flemming Logging Road crossing was visited by Wenck staff in August 2018. Culverts at this crossing were reconstructed in the summer of 2018 and the new culverts do not appear to impede fish migration. Cemetery, Friesandahl and the southern Wolf Creek Road crossings were also visited by Wenck staff and did not appear to block migrations; however, they may be restrictive. The northern Wolf Creek Road crossing could potentially impede larger fish movement as it contains a grate on the upstream side of the culvert (Figure 16).

Figure 16. Culvert construction on Wolf Creek at Flemming Logging Road crossing (left) and metal grate on culvert at the most northern Wolf Creek Road crossing (right).

Beaver dams were observed upstream of the southern Wolf Creek Road Crossing using high-resolution aerial photography (Figure 17). The DNR indicated they do not currently perform any beaver removal activities along Wolf Creek.

Figure 17. Locations of beaver dams (yellow arrows)



Fish movement upstream (north) of the first beaver dam is likely impeded under most conditions. Beaver activity (chewed sticks) was also seen by Wenck staff during RFQA and water sampling events at the northern Wolf Creek Road crossing where sticks were being placed along the grated culvert. This is likely a frequent occurrence along Wolf Creek in this area. As seen in Figure 17, these beaver dams slow the flow of water and create backwater pools that have the potential to warm water and lower DO levels.

Biology

Fish

Wolf Creek was sampled one time at site 78SC001 which resulted in an IBI score above the threshold. The sampling event captured nine species and 188 individuals (Table 21). Creek chub was the most dominant species (47% of total catch) followed by blacknose dace (17% of total catch). The sample did contain brook trout.

Table 21. Summary of fish survey results from Wolf Creek.

Species	78SC001 7/7/2010
blacknose dace	32
brook stickleback	11
brook trout	6
common shiner	12
creek chub	89
hornyhead chub	1
johnny darter	6
pearl dace	18
white sucker	13

The IBI assessment scored well on coldwater taxa, sensitive taxa, tolerant individual and perciformes-related metrics. The site did not score well on the percent of intolerant individuals within the community (Table 22).

Table 22. IBI metric summary from fish survey results on Wolf Creek.

Metric	Metric relationship*	7/7/2010
coldwater taxa	+	6.25
% coldwater intolerant individuals	+	0.48
% coldwater sensitive taxa	+	6.12
% tolerant individuals	-	12.50
% ind. with deformities	-	0.00
% non-lithophilic nest building ind.	-	5.04
% omnivorous taxa	-	5.56
% ind. from Order Perciformes	-	7.40
% pioneer taxa	-	4.17
IBI Score		**47.5**
General Use Threshold		**35.0**

* +/- equates to a net positive or net negative impact by having more individuals within that metric

In addition to the IBIs, the MPCA has developed tolerance index values (TIV) in which the community composition is assessed directly for DO and TSS induced stressors. We have implemented the TIV assessments here to help identify possible stressors to the biotic communities within Wolf Creek.

The fish community within Wolf Creek was observed to have DO and TSS TIV scores worse than average and median scores for same-class streams (Table 23). The lower than average TIV scores indicates that while the IBI score was above the General Use Threshold for Class 11 streams, DO and TSS may be influencing the fish community. Observed TSS index scores ranked at the ninth percentile for class 11 streams. Review of TSS species tolerance classification observed one very intolerant species (brook trout) and one intolerant (hornyhead chub) that comprised 3.2% of the individuals (Table 24). There were no TSS tolerant species collected. Observed DO index scores ranked at the 32nd percentile for class 11 streams. Review of DO species tolerance classification observed one very intolerant species and one intolerant comprising 3.2% of the individuals while three tolerant to very tolerant species were observed comprising 15.4% of the total individuals (Table 24). There is some indication that DO levels are having a moderate negative influence on the fish community.

Table 23. Fish Community DO and TSS Tolerance Index scores in Wolf Creek sites. For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within the appropriate stream class.

Site		Year	Parameter	Fish Class	TIV Index	Class avg./median	Percentile
78SC001		2010	TSS	11	13.8	10.84 / 11.25	9
			DO	11	7.24	7.61 / 7.55	32

Table 24. Fish Tolerance metrics for DO and TSS in Wolf Creek sites. Reported values are number of taxa and percent individuals.

Site	Year	Parameter	Very Intolerant	Intolerant	Tolerant	Very Tolerant
78SC001	2010	TSS	1 (3.19%)	1 (<0.5%)	0 (0%)	0 (0%)
		DO	1 (3.19%)	1 (<0.5%)	2 (9.57%)	1 (5.85%)

Macroinvertebrates

The macroinvertebrate community was sampled during two different events at a single site; 78SC001. Larvae of the small fly *Simulium* (commonly called blackflies or gnats) were the most dominant species observed within the samples followed by two midge genera, *Tanytarsus* and *Polypedilum*. Midges (insect family Chironmidae) are common in all streams and rivers. Certain genera can be dominant in eutrophic systems and many genera prefer soft, fine sediment habitats. There were very few coldwater obligate taxa present in the samples, primarily a few *Tipula* (cranefly) a single individual *Brillia* (a midge), and a single individual *Lepidostoma* (caddisfly). Coldwater streams typically have many EPT taxa, and there were relatively few at 78SC001.

Overall IBI scores differed between sampling events with the primary difference being the Very Tolerant Taxa percentage metric. The majority of remaining IBI metrics deviated < 1.0 metric point suggesting that very few additional community changes occurred between sampling events. Non-insect Taxa percentage metric was the only remaining metric that scored relatively well in both assessments. All additional metrics scored poorly with no observed metric scores above 3.0 points (Table 25) which resulted in IBI scores below the General Use Threshold. Overall, the site's macroinvertebrate community suffered from tolerant short-lived species and limited desired taxa diversity.

Table 25. IBI metric summary from macroinvertebrate survey results on Wolf Creek.

Metric	Metric relationship*	8/25/2009	8/17/2010
Collector-Gatherer Taxa %	-	0.00	2.02
Hilsenhoff Biotic Index	-	1.73	2.18
Very Intolerant Taxa Richness	+	1.85	1.85
Long-lived Taxa %	+	2.31	0.21
Non-insect Taxa %	-	6.44	6.15
Odonata Taxa %	+	0.00	2.48
POET Taxa	+	2.64	2.11
Predator Taxa Richness	+	0.00	0.00
Very Tolerant Taxa %	-	0.12	6.36
IBI Score		**15.10**	**23.40**
General Use Threshold		**32.0**	

* +/- equates to a net positive or net negative impact by having more individuals within that metric

The macroinvertebrate community within Wolf Creek displayed relatively consistent TIV scores and percentile ranking across sampling events (Table 26). Observed TSS index scores always scored above (worse than) the stream class average and median values ranking in the 19th to 24th percentile. Review of TSS species tolerance classification observed greater dominance by very tolerant and tolerant taxa and individuals. Combined taxa richness of tolerant or very tolerant ranged from 8 to 15 while intolerant to very intolerant ranged from 5 to 6 taxonomic classifications. The percent of individuals classified as tolerant or very tolerant ranged from 13.4 to 19.3% of the individuals (Table 26). Overall, TSS does appear to be a stressor on the macroinvertebrate community within Wolf Creek.

The DO index scores both scored below the stream class average and median values. DO percentile ranked at the 30th percentile for both sampling events. Review of DO species tolerance classification observed dominance by very intolerant and intolerant taxa and individuals. Combined taxa richness of intolerant or more intolerant ranged from 12 to 14 while tolerant richness ranged from 5 to 6 taxa. The percent of individuals classified as intolerant or very intolerant was also greater than tolerant and very tolerant ranging from 20.3 to 26.1% of the individuals (Table 27). This evidence suggests that low DO is not a stressor on the macroinvertebrate community within Wolf Creek.

Table 26. Macroinvertebrate Community DO and TSS Tolerance Index scores in Wolf Creek sites. For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within the appropriate stream class.

Site	Year	Parameter	Invert Class	TIV Index	Class avg./median	Percentile
78SC001	2009	TSS	8	13.76	12.23 / 12.24	19
		DO	8	7.12	7.33 / 7.46	30
	2010	TSS	8	13.5	12.23 / 12.24	24
		DO	8	7.12	7.33 / 7.46	30

Table 27. Macroinvertebrate Tolerance metrics for DO and TSS in Wolf Creek sites. Reported values are number of taxa and percent individuals.

Site	Year	Parameter	Very Intolerant	Intolerant	Tolerant	Very Tolerant
78SC001	2009	TSS	0 (0%)	5 (2.9%)	11 (16.7%)	4 (2.6%)
		DO	4 (17.4%)	10 (8.7%)	5 (4.8%)	0 (0.3%)
	2010	TSS	1 (0.3%)	5 (2.5%)	6 (12.5%)	2 (0.9%)
		DO	4 (6.9%)	8 (13.4%)	6 (11.3%)	0 (0%)

Conclusions

The biotic impairments within Wolf Creek appear to be caused by multiple stressors including:

- Hydrology alterations
- Low DO (possible stressor but inconclusive until more data is collected)

There is a large amount of wetland habitat adjacent to Wolf Creek. These wetlands have the ability to slow flow, increase water temperature, and lower oxygen levels of water as it flows through them across the landscape. The RFQA conducted on these wetland habitats along the stream show signs of human-induced stress, therefore, we cannot conclude at this time that these conditions are due entirely too natural effects. It is possible that historical and or current land use and/or hydrologic alteration have impacted the wetland habitats.

There is significant beaver activity along Wolf Creek. The damming of water by beavers in several locations along Wolf Creek can result in warmer water temperatures and depletion of DO.

In areas not impacted by beaver activity, the restriction of flow and the development of roadways across wetlands have the potential to increase the amount of water interacting with the wetland before entering the stream. Similar to beaver activity, this increased interaction would result in decreased DO and warming of the water that is interacting with the wetland. Several culvert crossings (e.g. Flemming Wolf Creek Road, Friesandahl Road, and Duxbury Road) appear to be undersized and have caused washouts and/or over-widening at the downstream end of the road crossings.

One possible strategy to improve both wetland health and DO levels within Wolf Creek is to restore more natural hydrologic flow conditions of surface waters. Culverts and beaver dams should be assessed to further evaluate the degree to which they are backing up water and/or creating pools that deplete oxygen. A longitudinal DO survey conducted along Wolf Creek showed early morning DO levels are very low near the headwaters of the reach (Wolf Creek Road) and increase moving downstream through the reach. Thus, upstream culverts and riparian wetlands should be investigated first for potential projects to improve hydrology and DO. It is recommended that more longitudinal and continuous DO monitoring data be collected to determine where, when (i.e. high and low-flow conditions), and to what degree DO may be affecting biota along Wolf Creek.

In-stream substrate could be a contributing factor to diminished biotic health. MSHA revealed moderate to poor habitat due to adjacent land use and riparian and substrate conditions. In-stream observations also indicated that the substrate is largely homogenous and consists of fine sediments and sands. These fine materials are easily transported and moved during flow and precipitation events, which can cause the substrate to constantly shift, covering and uncovering other forms (i.e. rock, gravel, cobble, vegetation) of habitat that may exist within the stream. The soil types are natural of for the area and since most of the landscape is not developed or in the form of row crop agriculture, we suspect land use contribution to be relatively low.

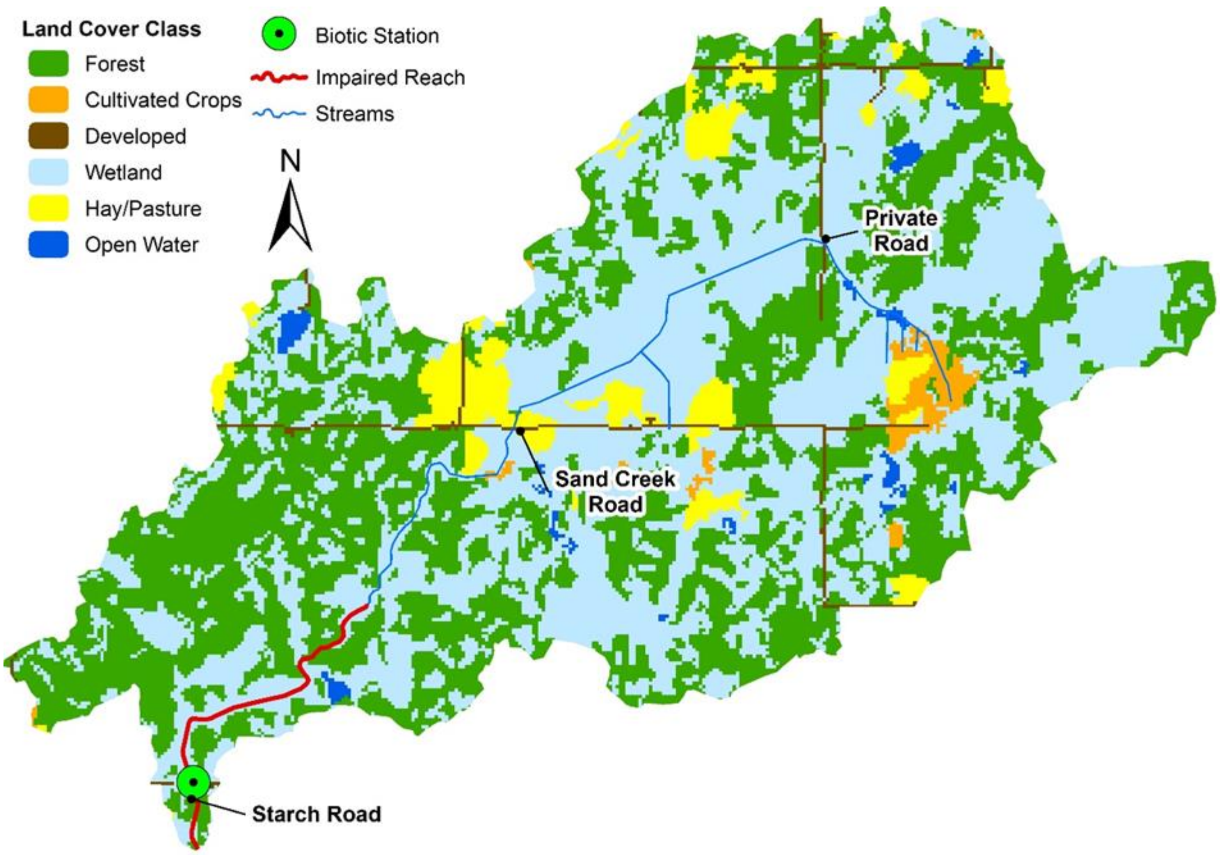
Sand Creek (AUID 07030001-604)

Impairment: Lower Sand Creek (Figure 18) is classified as a coldwater stream (2A designation) and was therefore assessed using coldwater IBIs to determine the health of the biotic (fish and macroinvertebrate) communities. The upstream section of Sand Creek (07030001-538) has not been sampled for biota and is classified as a warmwater reach (2B designation). Sand Creek Reach 604 was assessed as having non-support of general aquatic life based on the fish community.

Sand Creek's macroinvertebrate community was assessed at one station (67SC008) using 2016 and 2017 data. Both visits scored above the general use threshold, meaning the stream supports a healthy coldwater macroinvertebrate community.

Sand Creek's fish community was assessed at one station (67SC008) using 2016 and 2017 data. The F-IBI scores fell below the general life use threshold and the creek was assessed as having an impaired fish community.

Figure 18. Biotic sampling stations, impaired stream reach and land cover class as determined by the NLCD 2011 within Wolf Creek subwatershed.



Subwatershed characteristics

Most of the land within the Sand Creek subwatershed is wetland or forested (Figure 18 and Table 28). The forest that persists is predominantly deciduous while wetlands include wooded, marsh, and bog types. Land cover types throughout the uplands are primarily forest with some hay/pasture lands. There is minimal cultivated crop agriculture or developed areas (~1% of watershed) within the Sand Creek watershed. Visual inspection using recent air photos of the cropland areas shown in Figure 18 suggests many of these areas are currently not in production. The reach upstream (07030001-538) of the impaired reach was straightened, as was the full length of the impaired reach, with further review provided in later sections.

Table 28. Percentages of the various land cover types from 2011 NLCD GIS coverage within Sand Creek subwatershed.

Land cover type	Acres	Percent
Developed	132	2%
Cultivated Crops	124	1%
Hay/Pasture	458	5%
Open Water	88	1%
Wetland	4,540	49%
Forest	3,870	42%
TOTAL	9,212	100%

Data and analyses

Chemistry

Limited chemical data has been collected within the Sand Creek impaired reach. Data collected by the MPCA at 67SC008 is shown in Table 29.

Table 29. Water chemistry measurements collected at 67SC008. Values in mg/L.

Date	Water Temp. (°C)	Cond. (µS/cm)	DO	pH	Secchi Tube (cm)	TSS	NO2/NO3	NH4	TP	VSS
6/22/2016	18.4	76	6.5	6.5	81	5.2	<0.05	< 0.05	0.046	2.4
8/16/2016	13.9	72.8	5.94	6.3	75	--	--	--	--	--
9/7/2017	11.2	63	7.51	6.9	56	18	<0.5	< 0.10	0.063	6.8
9/12/2017	11.3	53	7.03	6.7	92	--	--	--	--	--

Nutrients – phosphorus

Two TP samples were collected at station 67SC008 in 206 and 2017. Both TP samples were near the region's river nutrient threshold (0.050 mg/L) with one sample exceeding the standard (Table 29).

Nutrients – nitrate and ammonia

Nitrate and ammonia were observed at extremely low concentrations which is common for north-central Minnesota streams.

Total Suspended Solids (TSS)

Only two TSS measurements have been collected within the Sand Creek impaired reach (Table 29). One of the TSS measurements was below the 10 mg/L threshold for coldwater streams while the other exceed the threshold. More TSS measurements will need to be collected within this reach to determine impairment and whether TSS is stressor to the invertebrate and/or fish communities.

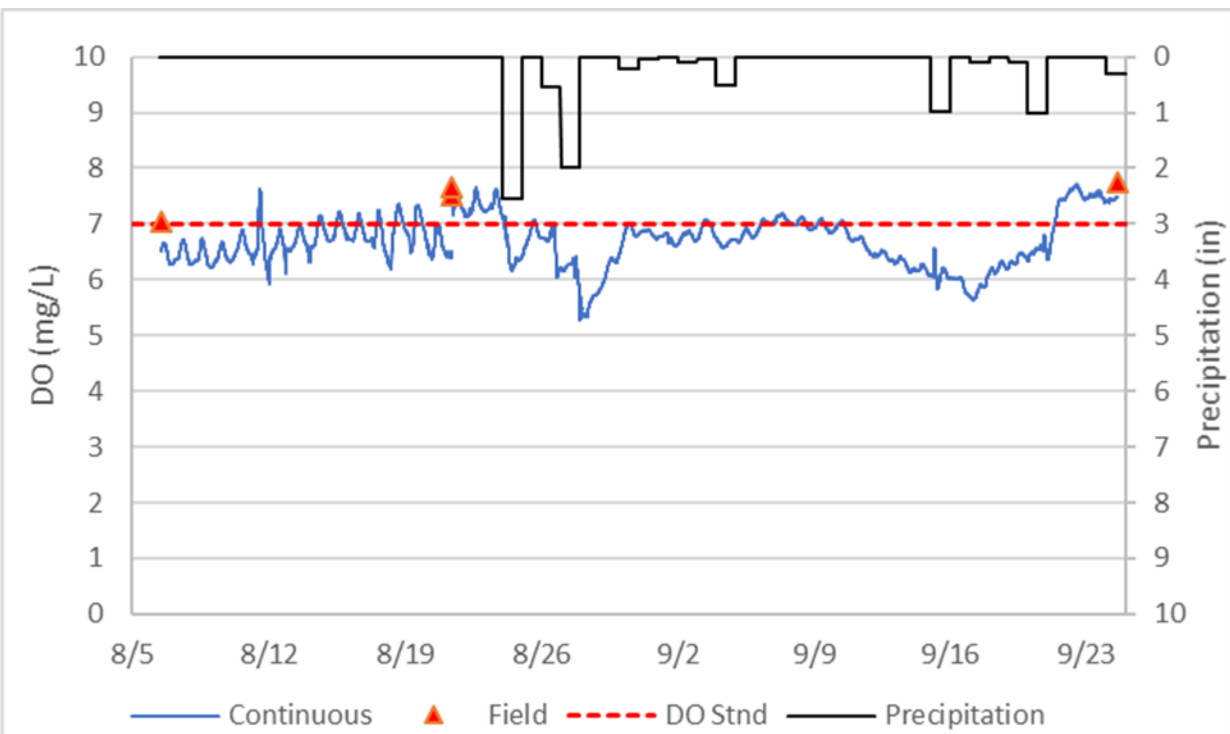
Iron

Heavy iron floc and red staining were observed during several visits during the Sand Creek stressor identification data collection process. The iron floc was most noticeable at the biotic monitoring station (67SC008) at Starch Road (see Figure 24 below) which is downstream of the riparian wetlands discussed in more detail below. The EPA has determined that iron concentrations exceeding 1,000 µg/L may become toxic to aquatic life (USEPA 2013). The complete range and cause of iron toxicity is not fully known, but effects can include gill interference, intra-cellular damage, and smothering effect of iron deposits on egg membranes, fish/macroinvertebrate gill tissues, and periphyton abundance and community diversity (Vuori 1995). The routine IWM monitoring does not include iron among the parameters that are collected, and therefore no iron samples have been collected along this reach of Sand Creek. It is recommended that iron samples be collected in the future to determine if iron may be a stressor to the biotic communities.

Dissolved oxygen

DO data collected during biological monitoring showed two of the four individual samples were below the coldwater stream DO standard (7 mg/L; Table 29). In 2018, Wenck deployed a continuous DO monitoring sonde at 67SC008 starting from early August until late September (Figure 19). These results showed that DO levels typically did not meet the DO standard. On 8/28, DO dropped to <6.0 mg/L. The timing of this drop coincided with multiple large precipitation events. It is possible that the multiple large rain events flushed a large volume of DO depleted water into the stream.

Figure 19. Sand Creek continuous DO data from 2018. The red triangle indicates the field grab reading. Precipitation is daily total precipitation from the Bruno weather stations (ID 211074).



Wenck also conducted a morning longitudinal DO survey at two locations along Sand Creek on August 21, 2018 (Table 30). The upstream sample location (Sand Creek Road) observed significantly lower DO that would result in stressful conditions (or potentially lethal) to aquatic biota. It appears that watershed features are causing localized DO differences along Sand Creek. Review of aerial imagery suggest alterations in hydrology (wetland ditching) and significant wetland habitats from Sand Creek Road upstream are likely a driver of the low DO levels in that part of the creek. More discussion of these is provided below.

Table 30. Longitudinal survey of dissolved oxygen along Sand Creek on 8/21/2018.

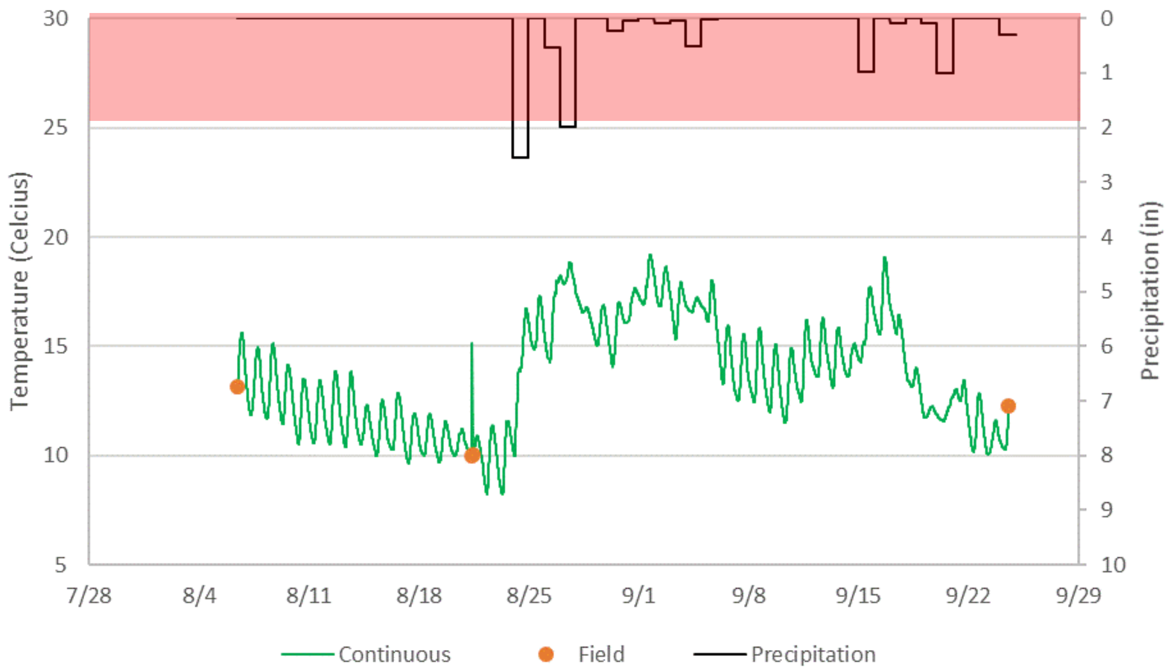
Site/Location	Relative Location	Time (am)	Temp (C)	DO (mg/L)	DO saturation (percent)
Sand Creek Rd	Upstream	9:35	18.59	**0.54**	6%
Starch Road (67SC008)	Downstream	9:15	10.00	7.50	66%

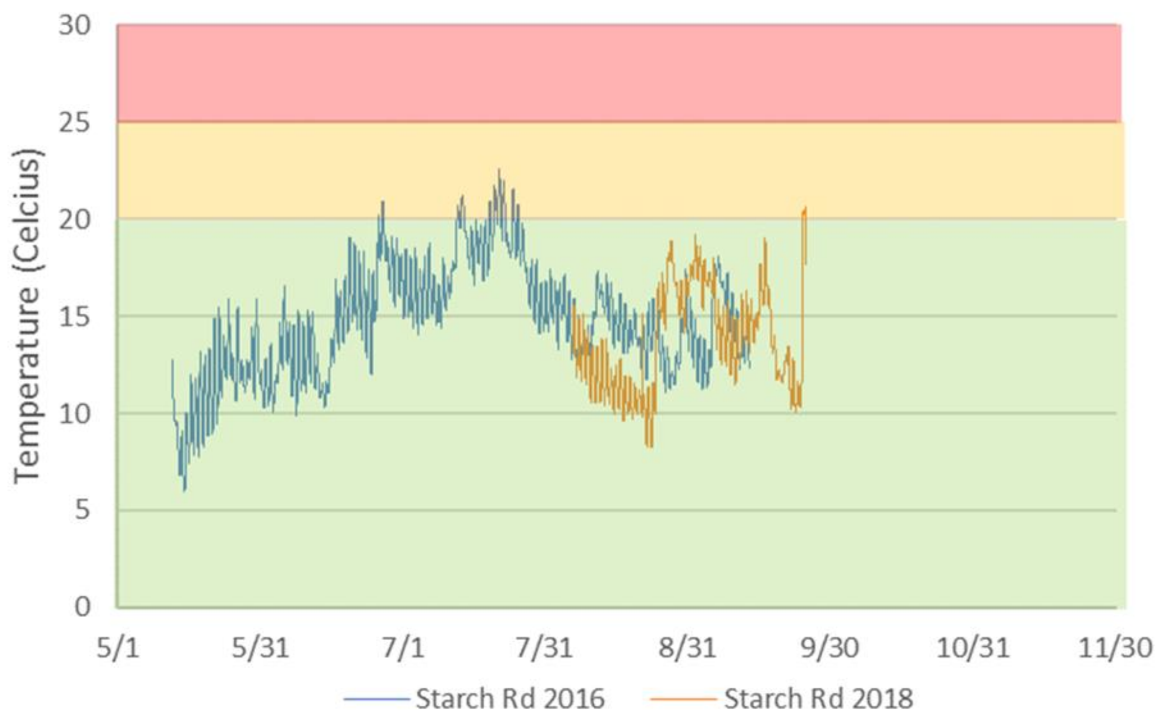
Temperature

Discrete water temperature samples collected by the MPCA ranged from 11.2 to 18.4°C (Table 29). In 2018, Wenck deployed a continuous temperature monitoring sonde at 67SC008 starting in early August until late September (Figure 20). These results showed that DO levels ranged from 8.2 to 19.2°C during deployment with some of the greatest diel temperature changes being < 4.0°C (outside of irregular events). Sudden increases in temperature were observed during precipitation events during the month of August. It is hypothesized that this is an indicator that a large pulse of warm surface water entering the system during/ following the rain event. The large diel swings in temperature associated with precipitation events is likely the only form of temperature stress on the system as overall temperatures were within ideal range for coldwater species in both 2016 and 2018. More data could be collected at upstream sites to evaluate whether temperature is a stressor at other locations along the impaired reach.

Figure 20. Sand Creek continuous temperature data from 2018 and historically (bottom – all years). The orange circle indicates the field grab readings for 2018. Precipitation is daily total precipitation from the Bruno weather station (ID 211074).

* Red= >25°C and is lethal, Orange = 20- 25°C and is stressful, Green = 10- 20°C is ideal for brown trout.





Habitat

A summary of metric scores and health classifications for Sand Creek are provided in Table 31. Overall, the land use and riparian metrics did not suggest any level of significant impairment, while substrate, cover, and particularly channel morphology scored poorly. Ariel imagery supports this poor channel morphology as the stream has been straightened. Straightened streams are well documented to have homogenous substrates and depth. These are likely leading to the fish impairment and increased flashiness of the reach during precipitation events. Areas upstream of 067SC008 were noted to have limited riparian buffers which could be having impacts at this site.

Table 31. Minnesota Stream Habitat Assessment scores and classification on Sand Creek site 067SC008. Metric scores are presented as a percentage of the maximum allowable points for a given metric.

Date	Land Use	Riparian	Substrate	Cover	Channel Morph	Total Score	
Max Points	5	14	28	18	35	100	Classification
6/22/2016	100%	100%	50%	83%	34%	60	Fair
9/7/2017	100%	100%	40%	33%	31%	47.2	Fair
9/12/2017	100%	100%	39%	67%	37%	55	Fair

Hydrology

Alterations

The Sand Creek watershed does appear to have significantly altered hydrology due to land use. Aerial photo interpretation indicates large stretches of Sand Creek have been straightened through bog and wetland habitats and beaver dams may also exist (Figure 21). During the RFQA process, Wenck observed dredging activities occurring along Sand Creek south of Sand Creek Road. The Sand Creek Road culvert crossing may be undersized (or was historically) with observed stream washout and widening downstream of the crossing (Figure 22).

Figure 21. Aerial imagery captured potential beaver dam (red line) and natural channel meandering (yellow arrow) adjacent to ditching (orange arrow) through wetland habitats along Sand Creek. (Note that this figure continues onto the next page.)

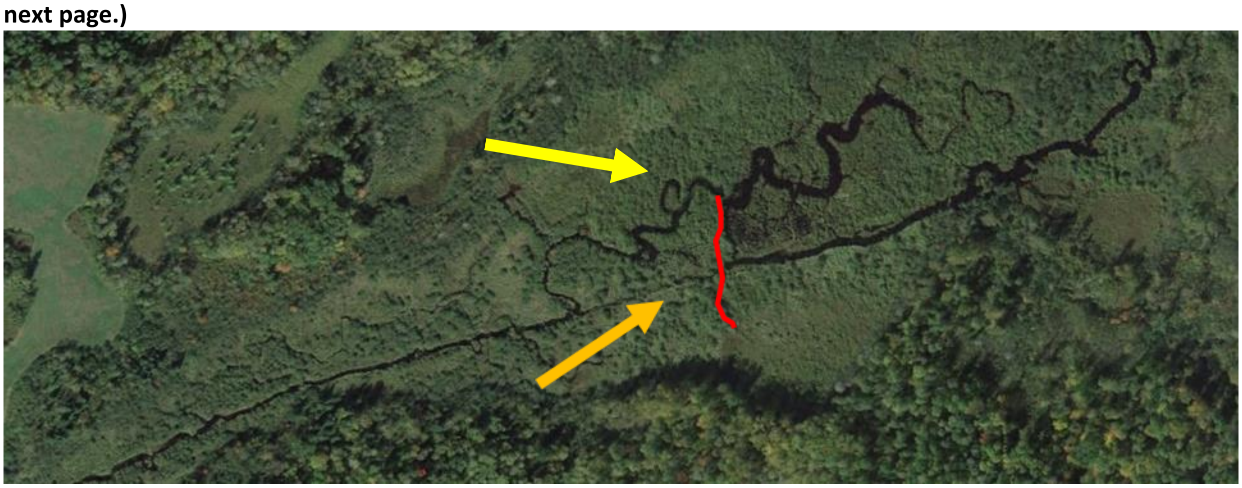
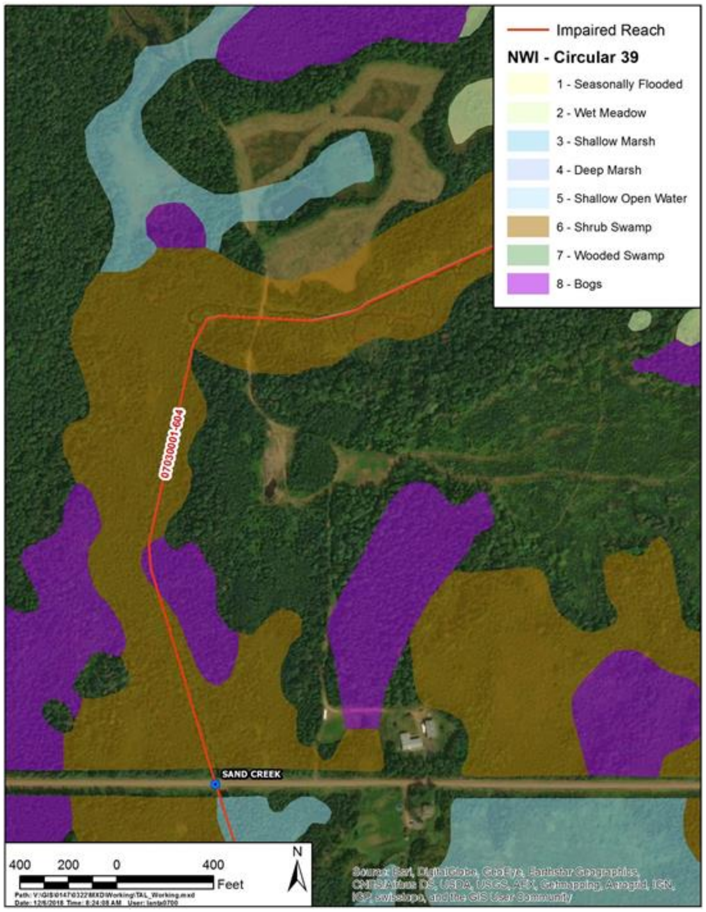


Figure 22. Upstream stream width entering culverts (left) and downstream widening of stream exiting culverts (right) along Sand Creek at Sand Creek Road.

Wetland Buffer

Much of the Sand Creek watershed is comprised of wetland habitat, especially the landscape immediately adjacent to the Sand Creek channel. To evaluate wetland conditions, we conducted RFQAs (see Hay Creek for detailed description of RFQA process and methods) at one location (67SC008) along Sand Creek (Figure 23). Assessments were made upstream of the road/culvert crossing and did not consider any vegetation within 50 feet of the roadway due to observed disturbance (i.e., brush cutting, etc.).

Figure 23. National wetland inventory classification of wetland complex upstream of 067SC008.



The sampled site was dominated by a shrub-carr community comprised of 15 native and one introduced species (Table 32). Observed *wCs* was 2.9 with site conditions being rated poor. The immediate surrounding landscape is highly forested with some slight deforestation occurring upstream of the wetland complex. Overall, the health of the wetland is poor and indicates a disturbance occurring within the wetland adjacent to Sand Creek.

Table 32. Rapid floristic quality assessment summaries and resulting condition categories.

Site Name	Native Species	Introduced Species	*wC*	Introduced Species Cover	BCG Tier	Condition Category
Sand Creek	15	1	2.9	14%	4	Poor

Connectivity

There are three road/private crossings along the Sand Creek impaired reach and upstream of the impaired reach: Starch Road, Sand Creek Road, and one private road crossing (Figure 18). Two of these crossings (Starch Road and Sand Creek Road) were assessed for fish passage by the DNR as part of the 2017 culvert inventory report (DNR 2017). None of the assessed crossing were identified by the DNR as high priority connectivity barriers. Culverts at the Sand Creek Road do not appear to be undersized, but may have been in the past (Figure 24). There is a large scour pool on the downstream side of this road crossing. These pools have the potential to slow the flow of water, increase temperature, and lower dissolved oxygen. No notes or information was available regarding the private crossing near the headwaters of Sand Creek.

Beaver dams were not observed along the AUID during field visits, however air photos suggest dams may occur throughout parts of Sand Creek (Figure 21). Beaver dams also have the potential to restrict connectivity and flow, increase water temperature, and decrease DO. More assessments will be needed to determine if and to what extent beaver activity is occurring along this reach and if management is warranted.

Figure 24. Shallow upstream water levels entering culvert (left) and downstream widening of stream exiting culverts (right) along Sand Creek at Starch Road (067SC008).

Biology

Fish

Sand Creek was sampled two times (2016 and 2017) at site 67SC008 which resulted in IBI scores below the threshold. The sampling events captured seven and six species and 57 and 30 individuals, respectively (Table 33). Pearl dace was the most abundant species (53% of total catch) during the first assessment but was not found during the second assessment. Johnny darter was the most abundance species during the second assessment (40% of total catch).

Table 33. Summary of fish survey results from Sand Creek.

	67SC008	
Species	6/22/2016	9/7/2017
blacknose dace		7
brook stickleback	14	1
burbot	1	
central mudminnow	5	1
common shiner		3
creek chub	5	6
Johnny darter	1	12
pearl dace	30	
white sucker	1	

IBI scores were relatively consistent across both surveys as many metrics were quite similar, however a few metrics did vary significantly between the two efforts. The IBI assessment scored poorly on coldwater taxa, percentage intolerant, non-lithophilic nest, and pioneer taxa related metrics. The site did not score well on any given metric but did score well during specific assessments (Table 34). Overall, the site displayed a low abundance of fish, limited diversity, and few coldwater-dependent fish species (one sample had none).

Table 34. IBI metric summary from fish survey results on Wolf Creek.

Metric	Metric relationship*	6/22/2016	9/7/2017
coldwater taxa	+	0.00	0.00
% coldwater intolerant individuals	+	0.00	0.00
% coldwater sensitive taxa	+	6.43	3.10
% tolerant individuals	-	4.18	7.14
% ind. with deformities	-	0.00	0.00
% non-lithophilic nest building ind.	-	1.80	0.23
% omnivorous taxa	-	3.57	12.50
% ind. from Order Perciformes	-	8.89	0.00
% pioneer taxa	-	1.79	0.00
IBI Score		**26.7**	**23.0**
General Use Threshold		**35.0**	

* +/- equates to a net positive or net negative impact by having more individuals within that metric

In addition to the IBIs, the MPCA has developed tolerance index values (TIV) in which the community composition is assessed directly for DO and TSS induced stressors. We have implemented the TIV assessments here to help identify possible stressors to the biotic communities within Sand Creek.

The fish community within Sand Creek was observed to have poor DO and average TSS TIV scores for similar fish class streams (Table 35). Observed TSS index scores ranked at the 45th percentile for class 11 streams. Review of TSS species tolerance classification observed one very intolerant species and one intolerant that comprised 1.75% of the individuals (Table 36). Observed DO index scores ranked at the sixth percentile for class 11 streams. Review of DO species tolerance classification observed no intolerant species. Three tolerant and two very tolerant species were observed comprising 85.9% of the total individuals (Table 36). 2017 data was not found within the MPCA TIV database—therefore, these data are not reported. Overall, DO does appear to be a stressor on the fish community within Sand Creek.

Table 35. Fish Community DO and TSS Tolerance Index scores in Sand Creek sites. For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within the appropriate stream class.

Site	Year	Parameter	Invert Class	TIV Index	Class avg./median	Percentile
67SC008	2016	TSS	11	11.6	10.84 / 11.25	45
		DO	11	6.22	7.61 / 7.55	6
	2017	TSS	11	*	10.84 / 11.25	*
		DO	11	*	7.61 / 7.55	*

* Data have not been reported in the MPCA database

Table 36. Fish Tolerance metrics for DO and TSS in Sand Creek sites. Reported values are number of taxa and percent individuals.

Site	Year	Parameter	Very Intolerant	Intolerant	Tolerant	Very Tolerant
67SC008	2016	TSS	1 (1.75%)	1 (0%)	0 (0%)	0 (0%)
		DO	0 (0%)	0 (0%)	3 (52.63%)	2 (33.33%)
	2017	TSS	*	*	*	*
		DO	*	*	*	*

* Data have not been reported in the MPCA database

Macroinvertebrates

The macroinvertebrate community was sampled at one site (67SC008) during two different events. Both events passed IBI thresholds, however, results are presented here to further evaluate potential stressors to the impaired fish community. The two-macroinvertebrate sampling events identified 57 and 55 taxonomic units and collected 309 and 312 individuals, respectively. *Simulium* genus (commonly called blackflies or gnats) were the most abundant taxon observed within the samples, however, no single genus comprised more than 17% of the total catch suggesting a relatively balanced community.

IBI scores were relatively consistent between the two, however, most metrics deviated > 1.0 metric point suggesting that the communities varied between sampling events. The IBI assessments scored relatively poor on Very Intolerant Taxa, Long-lived, and POET taxa. The assessments scored relatively well on Predator Taxa Richness during both surveys. All other metrics scored adequately in at least one assessment (Table 37) which resulted in IBI scores above the General Use Threshold. Overall, the site's macroinvertebrate community was relatively short-lived, comprised of few very intolerant species, and suffered from loss of Odonata (dragonfly/damselfly) while having more Tolerant and Collector-Gather taxa in the second sample.

Table 37. IBI metric summary from macroinvertebrate survey results on Sand Creek.

Metric	Metric relationship*	8/16/2016	9/12/2017
Collector-Gatherer Taxa %	-	5.18	2.60
Hilsenhoof Biotic Index	-	2.43	4.35
Very Intolerant Taxa Richness	+	0.93	2.78
Long-lived Taxa %	+	2.33	1.02
Non-insect Taxa %	-	2.71	6.66
Odonata Taxa %	+	9.50	4.56
POET Taxa	+	2.11	2.64
Predator Taxa Richness	+	8.07	9.08
Very Tolerant Taxa %	-	6.73	5.20
IBI Score		**40.00**	**38.90**
General Use Threshold		**32.0**	

* +/- equates to a net positive or net negative impact by having more individuals within that metric

The macroinvertebrate community within Sand Creek displayed relatively consistent TIV scores and percentile ranking for TSS but differs significantly in DO scores across sampling events (Table 38). Observed TSS index scores scored above (worse than) the stream class average and median values ranking in the 27th to 28th percentile. Review of TSS species tolerance classifications found a moderate skewing of the community of TSS tolerant taxa and individuals (Table 39). Combined taxa richness of tolerant or more tolerant ranged from seven to 13 while intolerant and very intolerant richness was six taxa. The percent of individuals classified as tolerant or very tolerant was also greater than intolerant and very intolerant ranging from 16.1 to 19.9% of the individuals (Table 39).

Observed DO index scores scored below the stream class average and median values. DO percentile shifted from the 23rd percentile in 2016 to the 51st in 2017. The first sample was very balanced regarding the taxa count and percent of individuals that are intolerant or tolerant to low DO. In the second sample, more of the taxa and individuals were those that are very intolerant or intolerant to low DO. Combined taxa richness of intolerant or more intolerant ranged from 10 to 19 while tolerant and very tolerant richness ranged from seven to nine taxa. The percent of individuals classified as intolerant or very intolerant was greater than tolerant and very tolerant in the 2017 sample comprising 27.3% of the individuals. In 2016, tolerant and very tolerant species comprised 9% of the individuals which dropped to 2.6% in 2017 (Table 39). Overall, there is little evidence in the macroinvertebrate data to suggest that insufficient DO levels are influencing the macroinvertebrate community within Sand Creek based on the TIV analysis.

Table 38. Macroinvertebrate Community DO and TSS Tolerance Index scores in Sand Creek sites. For DO, a higher index score is better, while for TSS, a lower index score is better. "Percentile" is the rank of the index score within the appropriate stream class.

Site	Year	Parameter	Invert Class	TIV Index	Class avg./median	Percentile
67SC008	2016	TSS	8	13.3	12.23 / 12.24	27
		DO	8	6.92	7.33 / 7.46	23
	2017	TSS	8	13.2	12.23 / 12.24	28
		DO	8	7.47	7.33 / 7.46	51

Table 39. Macroinvertebrate Tolerance metrics for DO and TSS in Sand Creek sites. Reported values are number of taxa and percent individuals.

Site	Year	Parameter	Very Intolerant	Intolerant	Tolerant	Very Tolerant
67SC008	2016	TSS	2 (3.5%)	4 (0.6%)	5 (14.2%)	2 (1.9%)
		DO	3 (4.8%)	7 (1.9%)	6 (7.4%)	3 (1.6%)
	2017	TSS	2 (9%)	4 (5.4%)	10 (18.6%)	3 (1.3%)
		DO	8 (24.4%)	11 (2.9%)	5 (1.6%)	2 (1%)

Conclusions

The biotic impairment within Sand Creek appear to be caused by multiple stressors including:

- Hydrology alterations
- Low DO

There is a large amount of wetland habitat upstream of the impaired section of Sand Creek. These wetlands have the ability to slow flow, increase water temperature, and lower oxygen levels of water as it flows through them across the landscape. Additionally, large sections of Sand Creek have been ditched and straightened. This can increase the flashiness of the stream during precipitation events and convey water much quicker across the landscape. Pools at the downstream end of historically undersized culverts (e.g. Sand Creek Road) is apparent along Sand Creek.

Results of one RFQA of a wetland habitat along the impaired reach of Sand Creek suggested signs of human-induced stress; therefore, we cannot conclude that DO conditions are entirely natural background. It is possible that historical and/or current land use as well as hydrologic alteration have impacted the wetland habitats. One possible source of remediation to improve both wetland health and DO within the system would be to restore more natural hydrologic flow conditions in specific locations. Further assessments to determine whether beaver activity is causing connectivity and/or low DO stressors is also suggested.

Heavy iron floc and staining was observed downstream of the riparian wetlands at the long-term biological monitoring station for this reach. It is recommended that iron samples be collected in the future to determine if iron may be a stressor to the biotic communities in Sand Creek.

MSHA results suggest in-stream substrate and channel morphology appear to be contributing factors to diminished biotic health. Fine materials are easily transported and moved during flow and precipitation events which results in a homogenous, unstable substrate throughout the reach. The soil types are natural of the area.

Land use disturbance in this subwatershed is relatively low, which makes it difficult to determine how much may have been transported from land use practices. This may be a natural feature that would be difficult, if not impossible to change/control.

Overall conclusion for USCRW streams

All of the stressors identified in this report for the three impaired reaches of the USCRW are non-point source in nature (Table 40). Some of the non-point stressors are anthropogenic and are likely having localized impacts within the impaired reaches. The stressors include:

- Undersized and possibly perched culverts that prevent fish movement, increase bank erosion and downstream scouring, and restrict natural water movement across the stream and buffering wetland habitats.
- Road crossings where roadways are built across wetlands and alter hydrology.
- Beaver activity is common throughout the watershed. Reaches that do not undergo trapping and removal efforts have impoundments within the stream that warm stream water and can prevent fish migration.
- Water temperature and DO appear to change significantly after large precipitation events. In some years surface runoff may play a bigger role in driving stream characteristics and conditions.

Restoring hydrology conditions to more natural conditions (e.g. re-creating natural meandering channels and/or reconnecting natural channels where ditching and straightening has occurred) could help address many stressors to the communities and provide multiple benefits to the impaired reaches covered in this report. Given the high amount of beaver activity in the area, natural conditions themselves may also contribute too many of the same signals and stressors currently being observed. Regardless, efforts to fix, widen, and repair undersized culverts may alleviate many of the localized stressors on these systems.

Table 40. Summary of stressors causing biological impairment in USCRW streams by location.

Stream	Biological Impairment	Stressor							
		Water Temp.	Dissolved Oxygen	Phosphorus	Sediment/TSS	Iron	Connectivity	Altered Hydrology	Habitat
Hay Creek	Fish and MI	?	♦	?	?	?	♦	♦	o
Wolf Creek	MI	o	?	?	?	?	o	♦	o
Sand Creek	Fish	o	♦	?	?	?	o	♦	o

♦ Primary Stressor
o Not a Stressor
? Inconclusive or not enough data at this time to evaluate

References

Álvarez-Cabria, M., J. Barquín, and J.A. Juanes. 2010. **Spatial and seasonal variability of macroinvertebrate metrics: Do macroinvertebrate communities track river health?** Ecological

Blann, Kristen L., James L. Anderson, Gary R. Sands & Bruce Vondracek. 2009. **Effects of Agricultural Drainage on Aquatic Ecosystems: A Review**. Critical Reviews in Environmental Science and Technology, 39:11, 909-1001, DOI: 10.1080/10643380801977966

Diana, M., J.D. Allan, and D. Infante. 2006. **The Influence of Physical Habitat and Land Use on Stream Fish Assemblages in Southeastern Michigan**. American Fisheries Society Symposium 48: 359-374.

DNR. 2017. **High Priority Sites for Fish Passage Projects in the Upper St. Croix River Watershed**.

EPA. 2017. **CADDIS Volume 2: Sources, Stressors & Responses.** Office of Water, Washington, DC. https://www.epa.gov/caddis

Fitzpatrick, F.A., B.C. Scudder, B.N. Lenz, and D.J. Sullivan. 2001. **Effects of multi-scale environmental characteristics on agricultural stream biota in eastern Wisconsin**. Journal of the American Water Resources Association 37(6): 1489-1507.

Griffith, M. B., F.B. Daniel, M.A. Morrison, M.E. Troyer, J.M. Lazorchak, and J.P. Schubauer-Berigan. 2009. **Linking Excess Nutrients, Light, and Fine Bedded Sediments to Impacts on Faunal Assemblages in Headwater Agricultural Streams**. Journal of the American Water Resources Association 45(6): 1475-1492.

Heiskary, S., Bouchard, W., and H. Markus. 2013. **Minnesota Nutrient Criteria Development for Rivers**. https://www.pca.state.mn.us/sites/default/files/wq-s6-08.pdf

Hilsenhoff, W.L. 1987. **An improved biotic index of organic stream pollution.** Great Lakes Entomologist 20(1):31-39.

Houghton, D.C., and R. Holzenthal. 2010. **Historical and contemporary biological diversity of Minnesota caddisflies: a case study of landscape-level species loss and trophic composition shift**. Journal of the North American Benthological Society 29(2): 480-495.

Marschner, Francis Joesph. 1930. **The Original Vegetation of Minnesota**. Map (St. Paul, Minnesota: Published by North Central Forest Experiment Station, Forest Service, U.S. Department of Agriculture, 1974). Map6F G4141.D2 1930 .M37 1974

Meador, M., & Carlisle, D. 2007. **Quantifying tolerance indicator values for common stream fish species of the United States**. Ecological Indicators, 7(2):329-338. https://doi.org/10.1016/j.ecolind.2006.02.004.

MPCA. 2013. **Nitrogen in Minnesota's Surface Waters**. Doc. #: wq-s6-26a, Minnesota Pollution Control Agency, St. Paul, MN. 510pp.

MPCA. 2017. **Stressors to Biological Communities in Minnesota's Rivers and Streams**. Doc. #: wq-ws1-27, Minnesota Pollution Control Agency, St. Paul, MN. 27pp. https://www.pca.state.mn.us/sites/default/files/wq-ws1-27.pdf

MPCA. 2019. **Upper St. Croix River Monitoring and Assessment Report**. Minnesota Pollution Control Agency, St. Paul, MN. 117pp.https://www.pca.state.mn.us/sites/default/files/wq-ws3-07030001.pdf

MSDC (Minnesota State Demographic Center). 2015. http://mn.gov/admin/demography/data-by-topic/population-data/2010-decennial-census/index.jsp

Ormerod, S.J., M. Dobson, A.G. Hildrew, and C.R. Townsend. 2010. **Multiple stressors in freshwater ecosystems**. Freshwater Biology, 55(Supplement 1):1-4.

Piggott, J.J., K. Lange, C.R. Townsend, and C.D. Matthaei. 2012. **Multiple Stressors in Agricultural Streams: A Mesocosm Study of Interactions among Raised Water Temperature, Sediment Addition and Nutrient Enrichment.** PLoS ONE 7(11).

Riseng, C.M., M.J. Wiley, R.W. Black, and M.D. Dunn. 2011. **Impacts of agricultural land use on biological integrity: a causal analysis**. Ecological Applications 21(8): 3128-3146.

Sharpley, A.N., T. Daniel, T. Sims, J. Lemunyon, R. Stevens, and R. Parry. 2003. **Agricultural Phosphorus and Eutrophication**. 2nd ed., ARS-149, Agricultural Research Service, U.S. Department of Agriculture. 44pp.

Statzner, B. and L.A. Beche. 2010. **Can biological invertebrate traits resolve effects of multiple stressors on running water ecosystems?** Freshwater Biology, 55(Supplement 1):80-119.

USEPA. August, 2013. **National Recommended Water Quality Criteria, Aquatic Life Criteria Table**. http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm

Vuori, K.-M. 1995. **Direct and Indirect effects of iron on river ecosystems**. Ann. Zool. Fennici 32:317-329.