Stressor Identification

June 2018

Roseau River Watershed
Stressor Identification Report

MINNESOTA POLLUTION CONTROL AGENCY

CLEAN WATER LAND & LEGACY AMENDMENT

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

Document number: wq-ws5-09020314a

Contents

Figures

Tables

Acronyms

AUID – Assessment Unit Identification

BMP – Best Management Practice

Chl-a – Chlorophyll-a

CR – County Road

CSAH – County State Aid Highway

cfs – cubic feet per second

DNR – Minnesota Department of Natural Resources

DO – Dissolved Oxygen

EPA – United States Environmental Protection Agency

EPT – Ephemeroptera, Plecoptera, and Trichoptera

F-IBI – Fish Index of Biological Integrity

HSPF – Hydrological Simulation Program - FORTRAN

IBI – Index of Biological Integrity

IWM – Intensive Watershed Monitoring

M-IBI – Macroinvertebrate Index of Biological Integrity

MPCA – Minnesota Pollution Control Agency

MSHA – MPCA's Stream Habitat Assessment

NAIP – National Agriculture Imagery Program

NLCD – National Land Cover Database

RRW – Roseau River Watershed

RRWD – Roseau River Watershed District

SD – Standard Deviation

SID – Stressor Identification

TIV – Tolerance Indicator Value

TP – Total Phosphorus

TSS – Total Suspended Solids

USGS – United States Geological Survey

WHAF – Watershed Health Assessment Framework

Executive summary

The Minnesota Pollution Control Agency (MPCA) follows a watershed approach to systematically monitor and assess surface water quality in each of the state's 80 major watersheds. A key component of this approach is Intensive Watershed Monitoring (IWM), which includes biological (i.e., fish and macroinvertebrate) monitoring to evaluate overall stream health. In 2015 and 2016, the MPCA conducted biological monitoring at several stations throughout the Roseau River Watershed (RRW). An Index of Biological Integrity (IBI) score was calculated for each fish (F-IBI) and macroinvertebrate (M-IBI) monitoring visit. The biological monitoring results for the RRW were then assessed to identify individual stream reaches that were not supporting a healthy fish and/or macroinvertebrate assemblage. A reach with a low IBI score(s) (i.e., below an established threshold) is considered "impaired" (i.e., unable to support its designated beneficial use) for aquatic life. A total of four reaches were determined to have a F-IBI and/or M-IBI impairment in the RRW, including segments of Hay Creek, Pine Creek, and Severson Creek.

This report identifies the probable causes, or "stressors", that are likely contributing to the biological impairments in the RRW. Five candidate causes were examined as potential stressors for the biologically impaired reaches: loss of longitudinal connectivity, flow regime instability, insufficient physical habitat, high suspended sediment, and low dissolved oxygen (DO). Causal analysis was then performed to determine and evaluate connections between each candidate cause and the biological impairments.

Table 1 lists the stressors identified for each of the biologically impaired reaches. Connectivity barriers (i.e., beaver dams and private road crossings) appear to be adversely affecting fish passage along Pine Creek. Beaver dams have also caused extensive water impoundment along Severson Creek. Each of the biologically impaired reaches are prone to high and quick peak flows and/or prolonged periods of low or no discharge. Historical changes in land cover (e.g., native vegetation to cropland) and drainage patterns (e.g., channelization and ditching) are the primary factors contributing to this flow regime instability. The flow regime of Pine Creek is substantially altered by an upstream diversion located in Canada. Alterations to the natural hydrology of the landscape have also caused the degradation of instream habitat (e.g., loss of facets and embeddedness of coarse substrate) for many of the reaches. The reaches are prone to periods of high suspended sediment. Instream and soil erosion are the primary sources of this sediment. Lastly, low DO is a stressor for Hay Creek and Pine Creek. While the severity of low DO conditions varies amongst the reaches, the lowest concentrations generally occur in the summer, when flow is low and the water temperature is high.

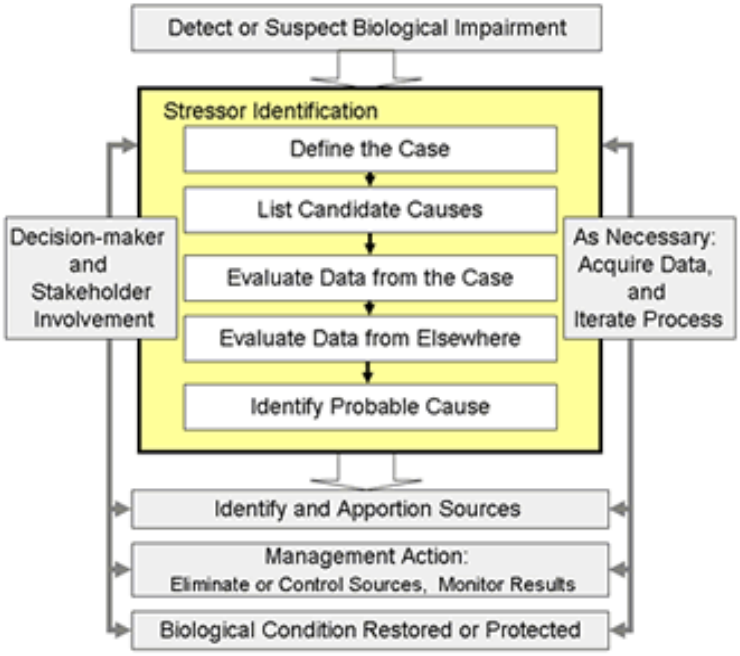
Table 1. Summary of the stressors associated with the biologically impaired reaches in the RRW.

Reach name (AUID suffix)	Biological impairment(s)	Stressors				
		Loss of longitudinal connectivity	Flow regime instability	Insufficient physical habitat	High suspended sediment	Low dissolved oxygen
Severson Creek (AUIDs 516, 541)	M-IBI		●	●	●	
Hay Creek (AUID 505)	F-IBI/M-IBI		●	●	●	●
Pine Creek (AUID 542	F-IBI	●	●	●	●	●

Introduction

Stressor identification (SID) is a formal and rigorous methodology for determining the causes, or "stressors", that are likely contributing to the biological impairment of aquatic ecosystems (United States Environmental Protection Agency (EPA), 2000). The initial step in the SID process (Figure 1) is to define the subject of the analysis (i.e., the case) by determining the geographic scope of the investigation and the effects that will be analyzed. Thereafter, a list of candidate causes (i.e., potential stressors) that may be responsible for the observed biological effects is developed. The candidate causes then undergo causal analysis, which involves the evaluation of available data. Typically, the majority of the data used in the analysis is from the study watershed, although evidence from other case studies or scientific literature can also be drawn upon. Analyses conducted during this step combine measures of the biological response, with direct measures of proximate stressors. Upon completion of causal analysis, strength-of-evidence analysis is used to determine the probable stressors for the biological impairment. Confidence in the final SID results often depends on the quality of data available to the process. In some cases, additional data collection may be necessary to accurately identify the stressors.

Figure 1. Conceptual model of the SID process (EPA, 2012).



Section 1: Watershed overview

1.1 Physical setting

The Roseau River Watershed, situated in northwestern Minnesota and south central Manitoba, is part of the larger Red River of the North Basin. The Minnesota portion of the Roseau River Watershed (herein referred to as the "RRW"), United States Geological Survey (USGS) Hydrologic Unit Code 09020314, has a drainage area of 1,062 square miles and encompasses portions of the following counties, listed in order of the percentage of watershed area: Roseau (89%), Lake of the Woods (4%), Beltrami (3%), Kittson (3%), and Marshall (1%). The city of Roseau is the only incorporated community in the RRW.

1.2 Surface water resources

The Roseau River is the prominent water feature in the RRW. The river extends from its origins in the Beltrami Island State Forest, situated approximately 26 miles southeast of the unincorporated community of Wannaska, to its confluence with the Red River of the North, located at Ginew, Manitoba. The RRW contains 598 miles of intermittent drainage ditch, 382 miles of intermittent stream, 251 miles of perennial drainage ditch, and 229 miles of perennial stream and river (DNR, 2003). There are also several small lakes and impoundments in the RRW (e.g., Hayes Lake and Roseau Lake).

According to the MPCA (2013), at least 61% of the watercourses in the RRW have been physically altered (i.e., channelized, ditched, or impounded). These alterations, coupled with historical changes in land cover (i.e., native vegetation to cropland), have altered the natural flow regime of many watercourses, causing them to be prone to high and quick peak flows, along with prolonged periods of low discharge (Van Offelen et al., 2003; RRWD, 2004).

1.3 Geology and soils

The surficial geology of the RRW is complex. The central portion of the RRW is characterized by a flat topography and fine textured soils (i.e., silt and clay) derived from lacustrine sediments deposited by glacial Lake Agassiz. A series of beach ridges and sandbars, representing the ancient shorelines of glacial Lake Agassiz, are found in the southeastern portion of the RRW. The topography of this region is undulating and the soils are generally coarse textured (i.e., sand and gravel). Organic deposits, formed from herbaceous and woody plant remains, are found in the northern and southern portions of the RRW. The degree of decomposition and thickness of the deposits account for the localized differences among the soils in these areas. Lastly, the remainder of the RRW is dominated by till that was later modified and reworked by glacial Lake Agassiz. These areas are typified by a relatively flat topography and loamy textured soils.

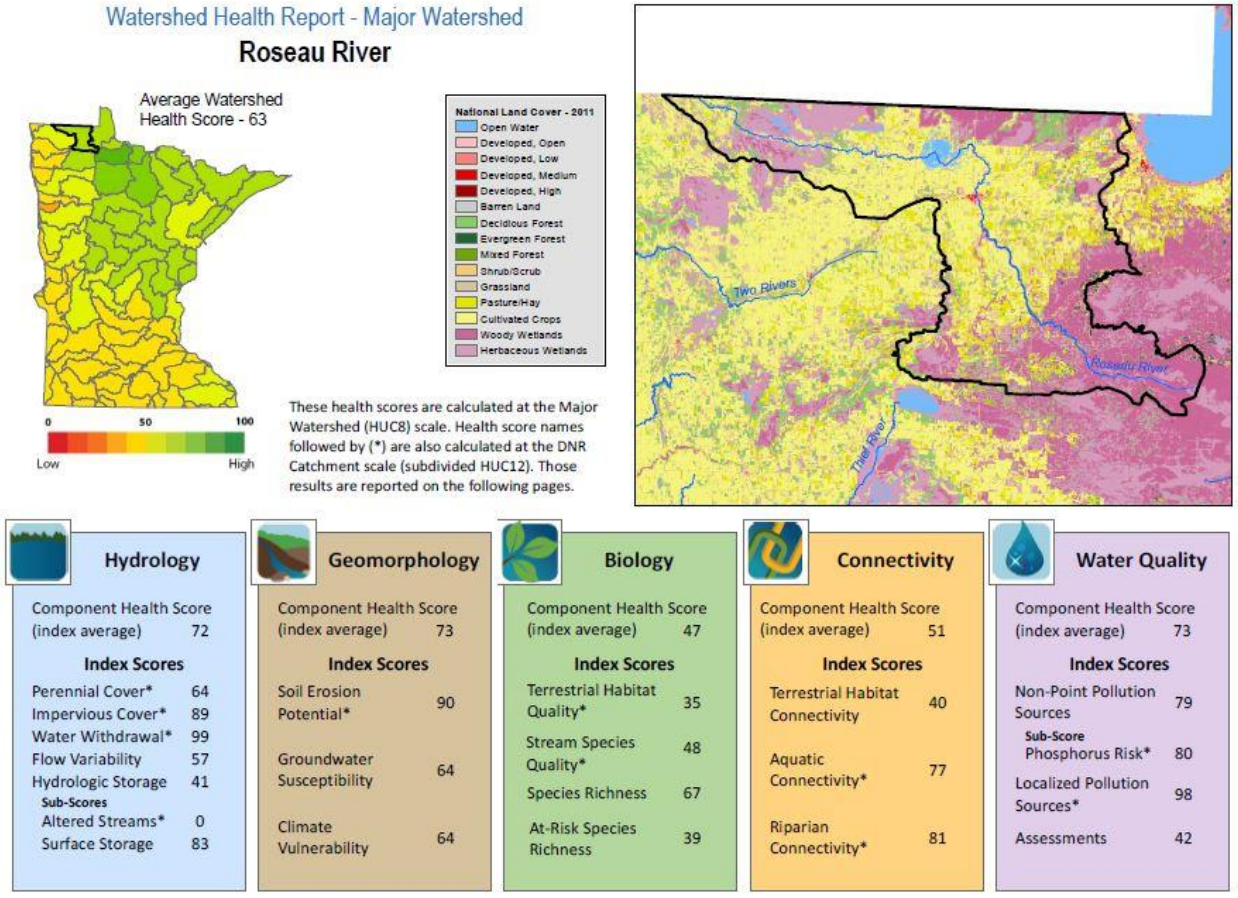
1.4 Land use and ecoregions

According to the National Land Cover Database (NLCD) 2011 (USGS, 2011), wetlands (44%) and cultivated crops (32%) are the prominent land uses in the RRW. Other notable land cover groups in the RRW included hay/pasture (8%), forest (8%), developed (3%), open water (2%), shrub/scrub (1%), and herbaceous (1%). The RRW intersects two distinct ecoregions (EPA, 2006). The Northern Minnesota Wetlands ecoregion (72%) covers the largest portion of the RRW, while the Red River Valley ecoregion (28%) is found in the western extent.

1.5 Ecological health

The Minnesota Department of Natural Resources (DNR) developed the Watershed Health Assessment Framework (WHAF) to assess the overall ecological health of a watershed. The WHAF evaluates and provides a score to each of the five core components of watershed health: hydrology, geomorphology, biology, connectivity, and water quality. Scores are ranked on a scale from 0 ("low") to 100 ("high"). Figure 2 presents the watershed health scorecard for the RRW. The mean health score for the RRW was 63. The individual mean component scores for biology (47) and connectivity (51) limited the overall score.

Figure 2. Watershed health assessment scores for the RRW.



1.6 Hydrological Simulation Program – FORTRAN Model

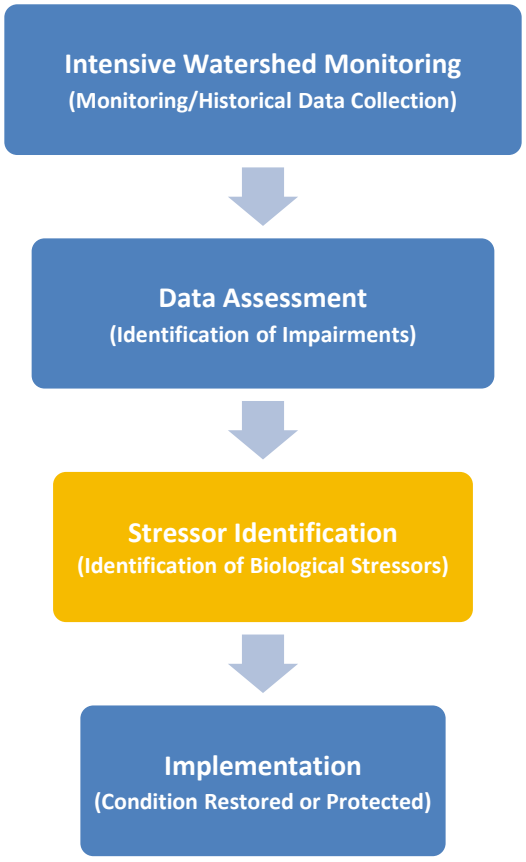
A Hydrological Simulation Program – FORTRAN (HSPF) model was developed for the RRW to simulate the hydrology and water quality conditions throughout the watershed on an hourly basis from 1995 to 2014. The HSPF model incorporates watershed-scale Agricultural Runoff Model and Non-Point Source models into a basin-scale analysis framework that includes fate and transport in one dimensional stream channels. The model enables the integrated simulation of land and soil contaminant runoff processes with in-stream hydraulic and sediment-chemical interactions. The result of this simulation is a time history of the water quality and quantity at the outlet of each subwatershed. The HSPF model outputs were used in the evaluation of several of the candidate causes outlined in this SID report.

Section 2: Biological monitoring and impairments

2.1 Watershed approach

The MPCA utilizes a watershed approach (Figure 3) to systematically monitor and assess surface water quality in each of the state's 80 major watersheds. A key component of this approach is IWM, which includes biological (i.e., fish and macroinvertebrate) monitoring to evaluate overall stream health. In 2015 and 2016, the MPCA conducted biological monitoring at several stations throughout the RRW. An Index of Biological Integrity score was calculated for each F-IBI and M-IBI monitoring visit. The biological monitoring results for the RRW were then assessed to identify individual stream reaches that were not supporting a healthy fish and/or macroinvertebrate assemblage. A reach with a low IBI score(s) (i.e., below an established threshold) is considered "impaired" (i.e., unable to support its designated beneficial use) for aquatic life. The biological impairments of the RRW are the focus of this SID report. The results of the SID process will guide the development of implementation strategies to correct the impaired conditions, which may include the preparation of a Total Maximum Daily Load study.

Figure 3. Conceptual model of the watershed approach processes.



2.2 Monitoring stations

Table 2 lists the 25 biological monitoring stations that were sampled for fish and/or macroinvertebrates in the RRW. The stations are situated along 13 separate reaches; individual reaches will be referred to by their respective three-digit Assessment Unit Identification (AUID) number suffix.

Table 2. List of biological monitoring stations in the RRW.

AUID suffix	AUID	Name	Monitoring station(s)
501	09020314-501	Roseau River	14RD300, 15RD002, 15RD007, 15RD022, 15RD025
502	09020314-502	Roseau River	15RD008, 15RD027
503	09020314-503	Roseau River, S. Fork	05RD128, 15RD003, 15RD032, 15RD034
504	09020314-504	Roseau River	15RD005, 15RD006, 15RD033
505	09020314-505	Hay Creek	05RD043, 05RD084
508	09020314-508	Sprague Creek	15RD004, 15RD024
512	09020314-512	County Ditch 9	15RD017
516	09020314-516	Severson Creek/CD 23	05RD085
517	09020314-517	Hansen Creek	05RD083
522	09020314-522	Mickinock Creek	15RD011
540	09020314-540	Paulson Creek	15RD013
541	09020314-541	Severson Creek/CD 23	15RD016
542	09020314-542	Pine Creek	15RD029

2.3 Monitoring results

Table 3 provides the F-IBI and M-IBI scores for each of the biological monitoring stations in the RRW. A total of three stations (12%) scored below their F-IBI impairment threshold, while seven stations (30%) scored below their M-IBI impairment threshold; these stations are highlighted red.

Table 3. Summary of F-IBI and M-IBI scores for biological monitoring stations in the RRW.

Fish					Macroinvertebrate				
AUID suffix	Station	F-IBI class[1] (Use[3])	F-IBI impairment threshold	F-IBI score (mean)	AUID suffix	Station	M-IBI class[2] (Use[3])	M-IBI impairment threshold	M-IBI score (mean)
501	14RD300	NR(G)	38	66	501	14RD300	PF(G)	31	35
501	15RD002	NR(G)	38	72	501	15RD002	Not Sampled		
501	15RD007	NR(G)	38	58	501	15RD007	PF(G)	31	47
501	15RD022	NR(G)	38	67	501	15RD022	PF(G)	31	44
501	15RD025	NR(G)	38	58	**501**	**15RD025**	**PF(G)**	**31**	**29**
502	15RD008	NR(G)	38	63	502	15RD008	Not Sampled		
502	15RD027	NR(G)	38	60	502	15RD027	PG(G)	41	45
503	05RD128	NS(G)	47	62	503	05RD128	NGPG)	51	60
503	15RD003	NS(G)	47	66	503	15RD003	NG(G)	51	64
503	15RD032	NS(G)	47	52	503	15RD032	NG(G)	51	81
503	**15RD034**	**NH(G)**	**42**	**41**	**503**	**15RD034**	**NR(G)**	**53**	**50**
504	15RD005	NS(G)	47	76	504	15RD005	NG(G)	51	86
504	15RD006	NS(G)	47	58	504	15RD006	NG(G)	51	86
504	15RD033	NS(G)	47	51	504	15RD033	NR(G)	53	57
505	**05RD043**	**NS(G)**	**47**	**43**	**505**	**05RD043**	**NR(G)**	**53**	**20**
505	05RD084	NH(G)	42	60	**505**	**05RD084**	**NR(G)**	**53**	**15**
508	15RD004	NS(G)	47	64	508	15RD004	NG(G)	51	83
508	15RD024	NS(G)	47	61	508	15RD024	NG(G)	51	71
512	15RD017	NC(G)	35	50	**512**	**15RD017**	**NC(G)**	**32**	**29**
516	05RD085	NH(G)	42	44	**516**	**05RD085**	**NG(G)**	**51**	**33**
517	05RD083	NH(G)	42	54	517	05RD083	NG(G)	51	64
522	15RD011	NH(G)	42	60	522	15RD011	NG(G)	51	75
540	15RD013	NH(G)	42	58	540	15RD013	NR(G)	53	53
541	15RD016	NH(G)	42	52	**541**	**15RD016**	**NG(G)**	**51**	**40**
542	**15RD029**	**NS(G)**	**47**	**14**	542	15RD029	PG(G)	41	43

[1] F-IBI Classes: Northern Coldwater (NC), Northern Headwaters (NH), Northern Rivers (NR), Northern Streams (NS)
[2] M-IBI Class: Northern Coldwater (NC), Northern Forest Streams-Glide/Pool Habitats (NG), Northern Forest Streams-Riffle/Run Habitats (NR), Prairie Forest Rivers (PF), Prairie Streams-Glide/Pool Habitats (PG)
[3] Tiered Aquatic Life Use Framework Designation: General Use (G), Modified Use (M)

2.4 Assessments and impairments

The biological monitoring results for the RRW were formally assessed as part of the development of the *Roseau River Watershed Monitoring and Assessment Report* (MPCA, 2018) to determine if individual stream reaches met applicable aquatic life standards. As shown in Table 4, four reaches were determined to be biologically impaired; these reaches are highlighted red. The relative location of these reaches is displayed in Figure 4.

Table 4. Assessment results for reaches with biological monitoring data in the RRW.

AUID suffix	Name	Description	Length (mi)	Biological impairment(s)
501	Roseau River	Hay Cr to Minnesota/Canada Border	50	None
502	Roseau River	Roseau River, South Fork to Hay Creek	9	None
503	Roseau River, South Fork	Headwaters to Roseau River	50	None
504	Roseau River	Headwaters to Roseau River, S. Fork	61	None
505	**Hay Creek**	**Headwaters to Roseau River**	**17**	**F-IBI, M-IBI**
508	Sprague Creek	Minnesota/Canada Border to Roseau River	9	None
512	County Ditch 9	T161, R37W, S29, South Line to Hay Creek	3	None
516	**Severson Creek/CD 23**	**Unnamed Creek to Roseau River**	**2**	**M-IBI**
517	Hansen Creek	Unnamed Lake to Roseau River	6	None
522	Mickinock Creek	Unnamed Ditch to Unnamed Creek	1	None
540	Paulson Creek	Unnamed Ditch to Roseau River, S. Fork	1	None
541	**Severson Creek/CD 23**	**Severson Creek to Unnamed Creek**	**1**	**M-IBI**
542	**Pine Creek**	**Unnamed Creek to Roseau River**	**6**	**F-IBI**

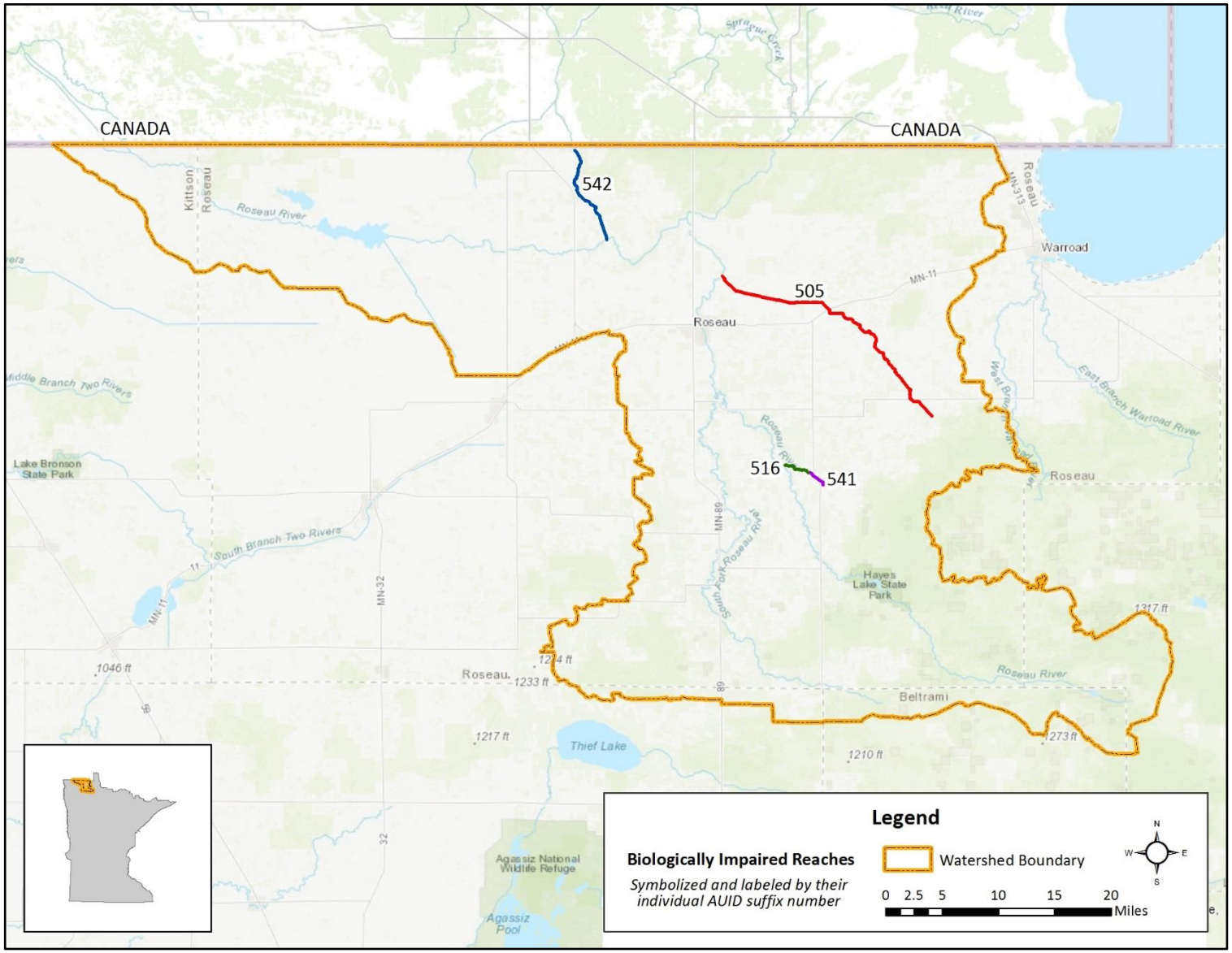
In addition to the abovementioned biological impairments, two reaches in the RRW have an existing or proposed water quality impairment that affects aquatic life (Table 5). Only AUID 505 is also biologically impaired.

Table 5. Conventional water quality impairments affecting aquatic life associated with reaches in the RRW.

AUID suffix	Name	Description	Water Quality impairment(s)
505	Hay Creek	Headwaters to Roseau River	Total Suspended Solids[1]
508	Sprague Creek	Minnesota/Canada Border to Roseau River	Turbidity[2,3]

[1] New impairment to be included on the proposed 2018 Impaired Waters List.
[2] Existing impairment included on the 2012 Impaired Waters List.
[3] Turbidity standard has since been replaced with a total suspended solids standard.

Figure 4. Map of the RRW and associated biologically impaired reaches.



Section 3: Possible stressors to biological communities

3.1 Identification of candidate causes

A candidate cause is defined as a "hypothesized cause of an environmental impairment that is sufficiently credible to be analyzed" (EPA, 2012). Identification of a set of candidate causes is an important early step in the SID process and provides the framework for gathering key data for causal analysis. Table 6 lists the seven common biotic stressors that were considered as potential candidate causes in the RRW; an overview of these stressors is provided in *Stressors to Biological Communities in Minnesota's Rivers and Streams* (MPCA, 2017). The list was developed based upon the results of the *Red River Valley Biotic Impairment Assessment* (EOR, 2009) and other completed SID reports in the state. The credibility of each candidate cause as a possible stressor to the fish and/or macroinvertebrate community of the biologically impaired reaches in the RRW was then evaluated through a comprehensive review of available information, including water quality and quantity data, as well as existing plans and reports, including the *Roseau River Watershed Monitoring and Assessment Report* (MPCA, 2018), the *Roseau River Watershed District's (RRWD) Overall Plan* (RRWD, 2004), and the *Red River Basin Stream Survey Report: Roseau River Watershed* (Van Offelen et al., 2003). Based upon the results of this evaluation, five candidate causes were identified to undergo causal analysis (Section 3.2).

Table 6. Summary of common biotic stressors evaluated as potential candidate causes for the biologically impaired reaches of the RRW.

Stressor	Candidate cause identification	
	Summary of available information	Candidate cause (Yes/No)
Loss of longitudinal connectivity	Several of the biologically impaired reaches have connectivity barriers (e.g., beaver dams) that are potential obstructions to fish passage.	**Yes**
Flow regime instability	The biologically impaired reaches are prone to high and quick peak flows and/or prolonged periods of very low discharge.	**Yes**
Insufficient physical habitat	Several of the biologically impaired reaches have insufficient instream habitat to support a diverse and healthy biotic community.	**Yes**
High suspended sediment	Several of the biologically impaired reaches have discrete total suspended solids (TSS) values that exceed the applicable state standard.	**Yes**
Low dissolved oxygen	Several of the biologically impaired reaches have discrete and/or continuous dissolved oxygen (DO) values that are below the applicable state standard. Eutrophication may be a contributing factor to these low DO values.	**Yes**
High nitrate-nitrite	Nitrate-nitrite concentrations associated with the biologically impaired reaches were generally well below the level expected to cause stress to aquatic biota (<10 mg/L).	No
pH	All of the pH values associated with the biologically impaired reaches were within the state standard range (6.5-9.0).	No

3.2 Causal analysis – Profile of individual biologically impaired reaches

3.2.1 Severson Creek/County Ditch 23 (AUIDs 516 and 541)

Physical setting

Severson Creek/County Ditch (CD) 23 was split into two reaches (Figure 5) for the purposes of biological monitoring. The first reach (AUID 541; herein referred to as "Upper Severson Creek") extends from the CSAH 13 crossing, to its confluence with an unnamed creek, located approximately 0.4 mile downstream of the County Road (CR) 9 crossing; a total length of one mile. The second reach (AUID 516; herein referred to as "Lower Severson Creek") extends from the end of Upper Severson Creek, to the confluence with the Roseau River, located approximately 0.8 mile downstream of the 450th Avenue crossing; a total length of two miles. Severson Creek has a total subwatershed area of 24 square miles (15,215 acres). The subwatershed contains 24 miles of intermittent stream, 20 miles of intermittent drainage ditch (e.g., Upper Severson Creek), two miles of perennial drainage ditch (i.e., Lower Severson Creek), and one mile of perennial stream (DNR, 2003). According to the MPCA (2013), 45% of the watercourses in the subwatershed have been physically altered (i.e., channelized, ditched, or impounded), including the entire lengths of Upper and Lower Severson Creek. The NLCD 2011 (USGS, 2011) lists wetlands (60%) as the predominant land cover in the subwatershed. Other notable land cover groups in the subwatershed included cultivated crops (14%), hay/pasture (12%), forest (5%), shrub/scrub (4%), developed (3%), and herbaceous (2%).

Figure 5. Map of Upper (AUID 541) and Lower (AUID 516) Severson Creek and associated biological monitoring stations and water quality monitoring sites (2013 National Agriculture Imagery Program [NAIP] aerial image).

Biological impairments

Macroinvertebrate (M-IBI)

On August 11, 2015, the MPCA monitored the macroinvertebrate community of Upper Severson Creek at Station 15RD016 (0.1 mile downstream of the CR 9 crossing). On August 11, 2015 and August 18, 2016, the MPCA performed macroinvertebrate monitoring on Lower Severson Creek at Station 05RD085 (0.1 mile upstream of 450th Avenue crossing). The locations of the stations are shown in Figure 5. Both stations were designated as General Use within the Northern Forest Streams-Glide/Pool Habitats M-IBI Class (Class 4). Accordingly, the impairment threshold for the stations is an M-IBI score of 51. Monitoring of Upper Severson Creek (Station 15RD016) yielded an M-IBI score of 40 (Table 7), which was below the General Use threshold but within the lower confidence interval. Only 33 taxa were sampled, with the majority of the taxa representative of streams with high total suspended solid concentrations and habitat degradation. In 2005, Lower Severson Creek offered supporting conditions with an M-IBI score meeting the threshold at Station 05RD085 (Table 7). Between the 2005 and 2015 visits, the M-IBI score declined 43 points indicating non-support for the macroinvertebrate community. The 2016 M-IBI score showed some improvements; however, it was still 24 points below the 2005 M-IBI scores and well below the General Use threshold. Furthermore, the 2005 sample contained 29 taxa that were not observed in either of the 2015 and 2016 samples. Many taxa that have been extirpated were indicative of good water quality and sensitive to pollution.

Table 7. Summary of macroinvertebrate monitoring data for Stations 15RD016 and 05RD085 along Severson Creek.

	Species (order)	05RD085			15RD016
		2005	2015	2016	2015
Insects	Beetles	25	8	0	8
	Biting flies (midges)	83	200	175	244
	Caddisflies	96	2	79	3
	Dragonflies	0	2	2	2
	Mayflies	34	0	14	3
	True bugs	4	0	0	0
Non-insects	Leech	0	1	0	0
	Mites	0	0	13	3
	Snails	9	92	12	52
	Worms	43	1	5	2
Total species collected:		47	32	34	33
M-IBI scores		**67**	**24**	**44**	**40**

Candidate causes

Loss of longitudinal connectivity

Available data

Severson Creek periodically experiences a loss of longitudinal connectivity due to beaver dams and other woody debris obstructions. The biological monitoring staff observed many logjams due to trees falling into the stream. According to the DNR (2014), there are no man-made dams along Severson Creek. The MPCA SID staff conducted a longitudinal assessment of Severson Creek on August 9, 17, 28, 2017 and September 28, 2017. Staff viewed all of the road crossing on the reach as part of the assessments. While no anthropogenic barriers (e.g. perched culvert) were found, two beaver dams were documented on Upper and Lower Severson Creek (Figure 6). In addition to the surveys, MPCA SID staff performed a detailed review of a May 8, 2013, aerial photo (courtesy of Google Earth) of the reach. No connectivity-related issues were identified in the photo. However, it is unknown whether velocity barriers caused by culverts or private road crossings impede passage along Severson Creek. Overall, Severson Creek periodically experiences a loss of connectivity.

Figure 6. Photos taken by SID staff of beaver dams located on Severson Creek. The upper two photos were captured 30 feet (upper left) and 80 feet (upper right) upstream from the confluence with the Roseau River (Lower Severson Creek) on August 9, 2017. The lower two pictures were captured at Station 15RD016 just upstream of CR 9 road crossing (Upper Severson Creek) on August 2, 2017.

Biological respo nse: Macroinvertebrate

Given the limitations of a macroinvertebrate community to migrate along a river continuum, there is no evidence for analysis of a loss of longitudinal connectivity as a stressor. It has been documented that macroinvertebrate populations can re-establish in a segmented stream channel to reflect stable community composition upstream and downstream of a connectivity barrier. However, barriers related to altered hydrology, specifically drought conditions, can cause direct or indirect changes in sensitive macroinvertebrate populations.

Flow regime instability

Available data

According to the MPCA (2013), 45% of the watercourses in the subwatershed have been physically altered (i.e., channelized, ditched, or impounded), including the entire lengths of Upper and Lower Severson Creek. The MPCA biological monitoring staff did not encounter any flow-related issues (e.g., intermittency) at Stations 15RD016 (Upper Severson Creek) and 05RD085 (Lower Severson Creek). There are no flow monitoring data for Severson Creek. The USGS (2017) estimated that the normal range of flow values for the creek at its outlet was 1.6 (Q25; value exceeded 25% of the time) to 0.1 (Q75; value exceeded 75% of the time) cubic feet per second (cfs). Additionally, the estimated median flow (Q50) was 0.3 cfs, while the projected Q5 (value exceeded 5% of the time) flow was 25.2 cfs and the Q95 (value exceeded 95% of the time) flow was less than 0.1 cfs. The Q25 to Q75 flow values ratio was 25:1, which is high and indicative of a flashy system that is influenced by runoff. By comparison, several of the more hydrologically stable rivers in the Red River Basin (e.g., Buffalo River, Clearwater River, and Otter Tail River) had a ratio of 7:1 or less. The MPCA SID staff conducted reconnaissance along the reach on five separate dates (i.e., August 2, 2017, August 9, 2017, August 17, 2017, August 28, 2017, and September 28, 2017) and documented flow conditions. Lentic-like conditions (due to beaver activity) were observed along Lower Severson Creek on each of these dates. Overall, the available data suggest that Severson Creek is prone to extended periods of minimal to no flow.

Biological response: Macroinvertebrate

Flow regime instability has been documented to limit the diversity and taxa richness of macroinvertebrates and favor tolerant individuals that can adapt to disturbances. Instability can lead to a decline in long-lived individuals. Taxa belonging to the orders of Ephemeroptera, Plecoptera, and Trichoptera generally require stable flow conditions. Many authors have documented an inverse relationship between flow regime instability and benthic aquatic insects, particularly Trichoptera (Bunn and Arthington, 2002; Bragg et al., 2005; Dewson et al., 2007). According to Table 8, Severson Creek is consistently below the statewide average for EPT taxa, long-lived taxa, and abundance of taxa in the order Tricoptera. The total taxa richness of macroinvertebrates is below the statewide average and below the lower confidence interval. The 2005 sampling event at Station 05RD085 had passing scores for EPT taxa, long-lived taxa, and total taxa richness. Thus, the recent decline in flow dependent taxa suggest degradation due to flow regime instability. The available data ***convincingly supports*** the case for flow regime instability as a stressor to the macroinvertebrate community of Severson Creek.

Table 8. Summary of biological indices for Severson Creek (Stations 15RD016 and 05RD085) compared with the statewide Class 4 streams that support a healthy macroinvertebrate community.

Metric	Description	Statewide score[1] [mean ± SD]	Severson Score [mean ± SD]	Station (score)	*Station (2005 score[2])*
EPTPct	Relative abundance (%) of Ephemeroptera, Plecoptera, and Trichoptera	23 ± 18	11 ± 17	15RD016 (2) 05RD085[15] (1) 05RD085[16] (31)	*05RD085 (44)*
LongLived Pct	Relative abundance (%) of long-lived individuals	5 ± 6	1 ± 0	15RD016 (1) 05RD085[15] (1) 05RD085[16] (1)	*05RD085 (5)*
TaxaCount AllChir	Total taxa richness of macroinvertebrates	40 ± 6	32 ± 1	15RD016 (33) 05RD085[15] (31) 05RD085[16] (31)	*05RD085 (44)*
Tolerant2 ChTxPct	Relative abundance (%) of taxa with tolerance values equal to or greater than six	70 ± 8	77 ± 2	15RD016 (79) 05RD085[15] (77) 05RD085[16] (74)	*05RD085 (70)*
TrichwoH ydroPct	Relative abundance (%) of non-hydrospsychid Trichoptera individuals	4 ± 5	0 ± 0	15RD016 (1) 05RD085[15] (0) 05RD085[16] (0)	*05RD085 (1)*

[1] Statewide score includes stations that provide General Use habitat within the same IBI class and meet or exceed the applicable IBI threshold.

[2] 2005 data were not used for the purposes of assessment; data were outside of 10-year assessment window.

[15] 2015 sampling event at Station 05RD085 occurring on August 11, 2015.

[16] 2016 sampling event at Station 05RD085 occurring on August 16, 2016.

Good: Score for the impaired reach met or was equal to the statewide average.

Fair: Score for the impaired reach failed to meet the statewide average but was within the standard deviation range.

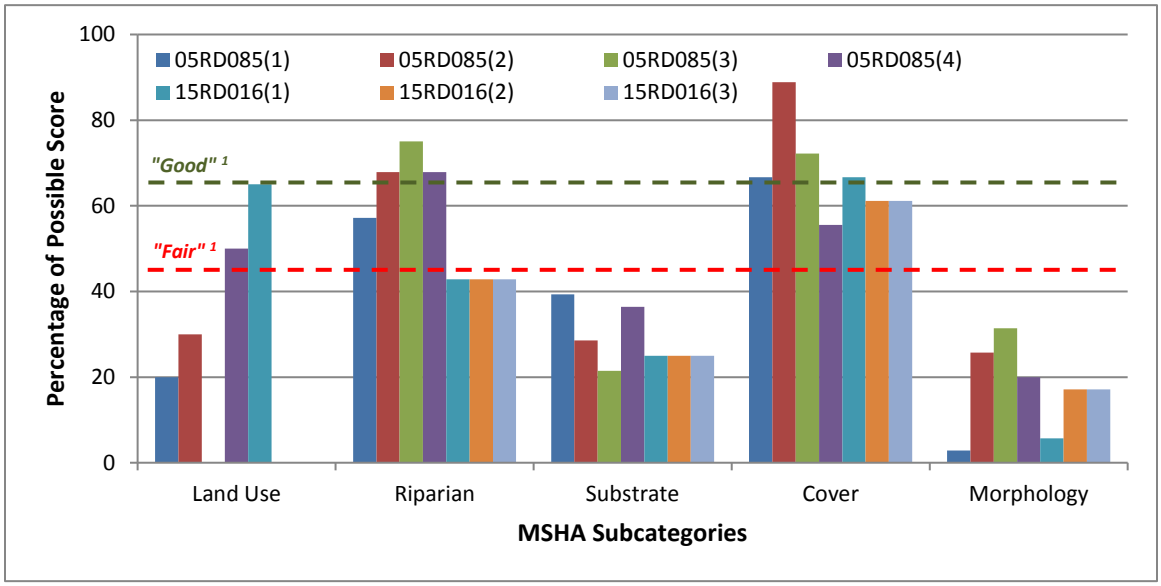
Poor: Score for the impaired reach failed to meet the statewide average and was outside the standard deviation range.

Insufficient physical habitat

Available data

The physical habitat of Severson Creek was evaluated at Stations 15RD016 (Upper Severson Creek) and 05RD085 (Lower Severson Creek) using the Minnesota Stream Habitat Assessment (MSHA). Both of the AUIDs are entirely channelized (MPCA, 2013). Station 15RD016 had "poor" MSHA scores (MSHA=30, 30, 30). By comparison, Station 05RD085 had slightly higher scores (MSHA=33, 44, 41, and 39). Figure 7 displays the MSHA subcategory results for each of the stations. The predominance of agricultural row crops in the immediate vicinity of Stations 15RD016 and 05RD085 limited their land use subcategory scores. The riparian subcategory scores for Station 15RD016 were negatively affected by a very limited riparian zone width. In addition, a "moderate" to "heavy" amount of bank erosion was noted at Station 05RD085. The stations scored uniformly poor in the substrate subcategory due to a lack of riffle habitat and coarse substrate (e.g., cobble and gravel). Both stations offered a "moderate" to "extensive" amount of cover. Noted cover types along Severson Creek included deep pools, logs, macrophytes (emergent, floating leaf, and submergent), overhanging vegetation, rootwads, and undercut banks. Lastly, both stations scored poorly in the morphology subcategory due in part to "low" to "moderate" channel stability and "poor" channel development.

Figure 7. MSHA subcategory results for Stations 15RD016 (Upper Severson Creek) and 05RD085 (Lower Severson Creek) along Severson Creek.



[1] The minimum percentage of each subcategory score needed for the station to achieve a "fair" and "good" MSHA rating.

Clark and Vinje (2017) completed fluvial geomorphic assessments at Stations 15RD085 and 05RD016 along Severson Creek. Station 15RD016 was evaluated on July 12, 2017. The stream type at this location was estimated to be an E5 (low width-to-depth ratio, slightly entrenched, sand bed stream). The station yielded a Pfankuch stability rating of 87 (moderately unstable). Below are excerpts from the assessment summary for Station 15RD016:

> *"Though this site has access to its floodplain, it has been channelized and the adjacent upland is pasture. Some of the that factors of the Pfankuch Stability pushed the rating towards moderately unstable include large amounts of downed wood on the upper banks, obstructions to flow on the lower banks, and consolidation of particles and deposition on the channel bottom. Aquatic vegetation was common and the bottom material was dull, indicating little bed material movement."*
>
> *"At bankfull, the channel does have access to a narrow floodplain (not incised), and during large flood events the channel is connected to its floodplain as well (not entrenched). The channel at this location has been channelized and sinuosity is approximately 1.0. The pools were deeper, larger, and wider than the riffles. The maximum bankfull pool depth was 4.4 feet. The 50th percentile particle size of the reach pebble count was very fine sand. Particle sizes from silt/clay up to coarse gravel were tallied."*

Station 05RD085 was evaluated on October 24, 2017. The stream type at this location was estimated to be an E5 (low width-to-depth ratio, slightly entrenched, sand bed stream). The station yielded a Pfankuch stability rating of 96 (moderately unstable). Below are excerpts from the assessment summary for Station 05RD085:

> *"Severson Creek at this location had access to a floodplain and was only slightly entrenched. The estimated bankfull elevation was below the top of the bank, indicating that is was slightly incised and does not have access to a floodplain during minor flood events. The upper banks were in good condition, except for the large amount of woody debris. The lower banks were in fair condition, with*

cutting, obstructions to flow, and deposition noted. The bottom of the channel did exhibit excessive deposition, primarily as a result of the large amounts of woody debris present in the lower banks and bed, and little to no aquatic vegetation was observed in the channel."

"This section of Severson Creek has been channelized, and a spoil pile exists along portions of the right bank. There were large amounts of wood, both on the upper and lower banks. It was surprising the channel was not scouring more around some of the obstructions. However, the stream was impounded downstream of this site, before its confluence with the Roseau River, and water was being backed up within this reach. The impounding effect has the potential to decrease flow velocities and scour. Similarly, the channel bottom was inundated with fine sediment in areas as a result of decreased flow velocities and obstructions to flow."

In summary, the MSHA data suggest that the physical habitat of the reach is primarily limited by the absence of riffles, lack of coarse substrate, and poor channel morphology characteristics. Clark and Vinje (2017) identified areas of the stream that exhibited poor habitat including moderately unstable banks and excessive fine sediment deposited on the stream bottom. Many of these deficiencies can be attributed to the effects of past channelization.

Biological response: Macroinvertebrate

Loss of physical habitat will limit the streambed composition and morphology overall affecting the species adapted for specific microhabitats. The effects of erosion and sedimentation will decrease the species that cling onto hard surfaces, while promoting burrower, legless, and sprawler taxa (Gore et al., 2001). According to Table 9, Severson Creek has a sufficient quantity of clinger and sprawler taxa compared to the statewide averages, indicating the availability of hard-aerated surfaces (e.g., riffles). However, 2005 sampling at Station 05RD085 shows almost one and a half times more clinger taxa then recent sampling (2015-2016), indicating a decline in habitat for these species. Additionally, Severson Creek supports a higher abundance of burrower and legless individuals compared to the statewide averages indicating fine sediments for midge taxa. The available data ***somewhat supports*** the case for insufficient physical habitat as a stressor to the macroinvertebrate community of Severson Creek.

Table 9. Summary of biological indices for Severson Creek (Stations 15RD016 and 05RD085) compared with the statewide Class 4 streams that support a healthy macroinvertebrate community.

Metric	Description	Statewide score[1] [mean ± SD]	Severson Score [mean ± SD]	Station (score)	*Station (2005 score[2])*
Burrower Pct	Relative abundance (%) of burrower individuals	15 ± 16	4 ± 4	15RD016 (3) 05RD085[15] (1) 05RD085[16] (8)	*05RD085 (24)*
ClingerPct	Relative abundance (%) of clinger individuals	33 ± 19	33 ± 22	15RD016 (31), 05RD085[15] (12) 05RD085[16] (57)	*05RD085 (51)*
LeglessPct	Relative abundance (%) of legless individuals	51 ± 23	75 ± 17	15RD016 (75) 05RD085[15] (91) 05RD085[16] (57)	*05RD085 (42)*
SprawlerPct	Relative abundance (%) of sprawler individuals	24 ± 14	6 ± 2	15RD016 (5) 05RD085[15] (6) 05RD085[16] (8)	*05RD085 (7)*

[1] Statewide score includes stations that provide General Use habitat within the same IBI class and meet or exceed the applicable IBI threshold.
[2] 2005 data were not used for the purposes of assessment; data were outside of 10-year assessment window.
[15] 2015 sampling event at Station 05RD085 occurring on August 11, 2015.
[16] 2016 sampling event at Station 05RD085 occurring on August 16, 2016.
Good: Score for the impaired reach met or was equal to the statewide average.
Fair: Score for the impaired reach failed to meet the statewide average but was within the standard deviation range.
Poor: Score for the impaired reach failed to meet the statewide average and was outside the standard deviation range.

High suspended sediment

Available data

The MPCA biological monitoring staff collected a discrete water quality sample at Stations 15RD016 and 05RD085 at the time of each fish monitoring visit. The samples were analyzed for several parameters, including TSS (*n*=5). The TSS concentrations were generally below the 30 mg/L standard, with the exception of the June 22, 2005, sample at Station 05RD085 (48 milligrams per liter [mg/L]), which was taken during a rain event. The RRW HSPF model estimates that the reaches had a TSS concentration in excess of the standard 3% of the time during the period of 1995 to 2014. Overall, the available data suggest that Severson Creek likely experiences at least occasional periods of high suspended sediment.

Biological response: Macroinvertebrate

Excessive TSS can adversely affect macroinvertebrates in various ways depending on the concentration and duration of exposure. High TSS often results in a limited macroinvertebrate community that is dominated by tolerant taxa (Henley et al., 2000; EPA, 2012; Jones et al., 2012). Sediment suspended in the water column can limit collector species and species that filter using a net-spinning casing. According to Table 10, Severson Creek is limited in species that are intolerant to high TSS and is comprised of a higher abundance of species that are tolerant to TSS compared to the statewide average. In 2005, the relative abundance of taxa tolerant to high TSS was 40%, while in recent years (2015-2016) there has been an increase in taxa that are capable of tolerating high TSS. The available data ***somewhat supports*** the case for high suspended sediment as a stressor to the macroinvertebrate community of Severson Creek.

Table 10. Summary of biological indices for Severson Creek (Stations 15RD016 and 05RD085) compared with the statewide Class 4 streams that support a healthy macroinvertebrate community.

Metric	Description	Statewide score[1] [mean ± SD]	Severson Score [mean ± SD]	Station (score)	*Station (2005 score[2])*
TSS TIV	Mean TSS (mg/L) tolerance indicator value	14 ± 2	18 ± 2	15RD016 (18) 05RD085[15] (20) 05RD085[16] (16)	*05RD085 (15)*
TolTSS	Relative abundance (%) of high TSS tolerant taxa	19 ± 14	60 ± 11	15RD016 (58) 05RD085[15] (72) 05RD085[16] (49)	*05RD085 (40)*
InTolTSS	Relative abundance (%) of high TSS intolerant taxa	4 ± 5	1 ± 1	15RD016 (1) 05RD085[15] (0) 05RD085[16] (1)	*05RD085 (0)*

[1] Statewide score includes stations that provide General Use habitat within the same IBI class and meet or exceed the applicable IBI threshold.

[2] 2005 data were not used for the purposes of assessment; data were outside of 10-year assessment window.

[15] 2015 sampling event at Station 05RD085 occurring on August 11, 2015.

[16] 2016 sampling event at Station 05RD085 occurring on August 16, 2016.

Good: Score for the impaired reach met or was equal to the statewide average.

Fair: Score for the impaired reach failed to meet the statewide average but was within the standard deviation range.

Poor: Score for the impaired reach failed to meet the statewide average and was outside the standard deviation range.

Low dissolved oxygen

Available data

The MPCA biological monitoring staff collected a combined five discrete DO measurements at Stations 15RD016 and 05RD085 at the time of fish and macroinvertebrate monitoring. Measurement values ranged from 7.2 to 12.5 mg/L; all of which were well above the 5.0 mg/L standard. The MPCA conducted continuous DO monitoring at Site W71065001 (Lower Severson Creek; 450th Avenue crossing) from August 17, 2017, to August 28, 2017, as well as at Site W71065002 (Upper Severson Creek; CSAH 9); the locations of the sites are shown in Figure 5. The monitoring results are provided in Table 11, as well as displayed in Figure 8 and Figure 9. Site W71065001 had a substantial proportion of total values (29%) that were below the standard and an even higher amount of daily minimum values (80%) that were below the standard. In contrast, none of the values for Site W71065002 fell below the standard. The difference between these sites was likely attributed to beaver dams near the outlet of Severson Creek, which impounded water along Lower Severson Creek. Additionally, the RRW HSPF model estimates that the reaches had a DO concentration below the standard less than 1% of the time during the period of 1995 to 2014. Overall, the available data suggest that Severson Creek likely experiences at least occasional periods of low DO.

Table 11. Continuous DO data for Sites W71065002 (Upper Severson Creek) and W71065001 (Lower Severson Creek).

Site	Start date - End date	*n*	Max. (mg/L)	Min. (mg/L)	% Total values below standard	% Daily min. values below standard	Mean daily flux (mg/L)
W71065001	8/17/2017 - 8/28/2017	1039	9.0	2.3	29	80	2.6
W71065002	8/2/2017 - 8/9/2017	671	7.7	5.7	0	0	1.0

Figure 8. Continuous DO data for Site W71065001 along Lower Severson Creek.

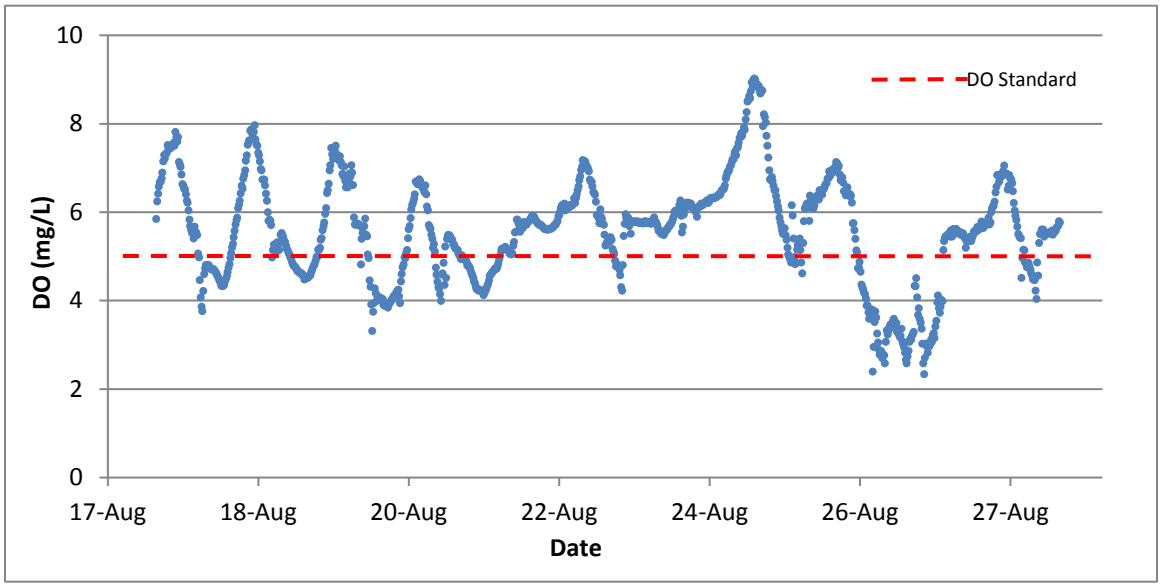
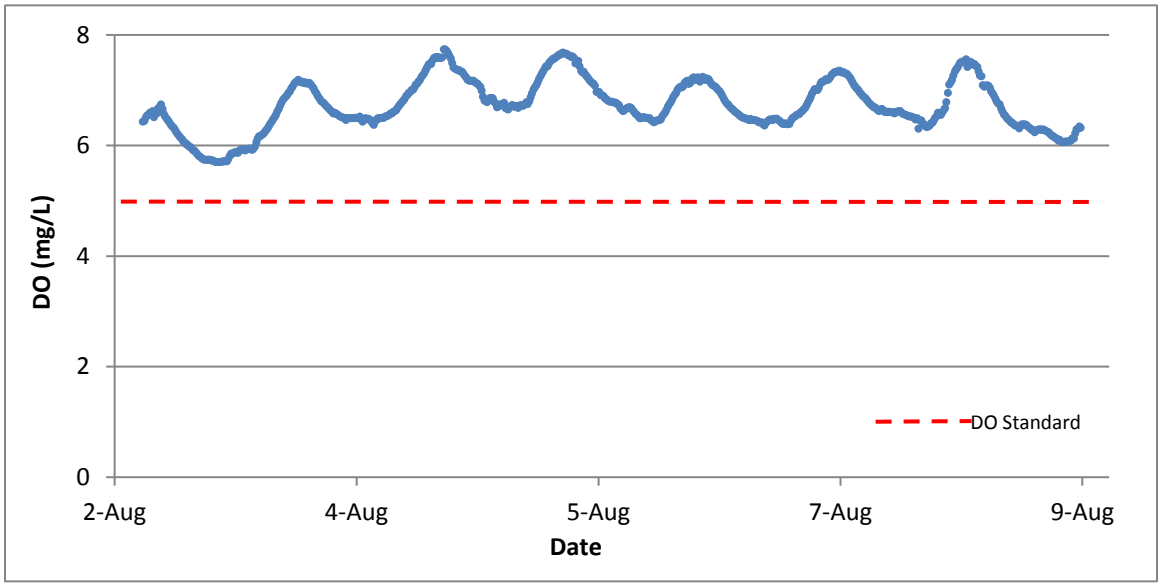


Figure 9. Continuous DO data for Site W71065002 along Upper Severson Creek.



Eutrophication-related data for Severson Creek includes the following parameters: total phosphorus (TP) and DO flux. The MPCA biological monitoring staff collected a discrete water quality sample at Stations 15RD016 (Upper Severson Creek) and 05RD085 (Lower Severson Creek) at the time of each fish monitoring visit. The samples were analyzed for several parameters, including TP (*n*=5). The stations had TP concentrations ranging from 19 to 232 micrograms per liter (µg/L), with one value exceeding the 50 µg/L North River Nutrient Region TP standard. The mean daily DO flux documented during continuous DO monitoring at Sites W71065001 (2.6 mg/L) and W71065002 (1.0 mg/L) was below the 3.0 mg/L North River Nutrient Region standard. In addition, MPCA SID staff did not observe any signs of eutrophication (e.g., excessive algal growth) during reconnaissance visits along the reach. Overall, there is insufficient data to determine if eutrophication is adversely affecting the DO regime of the reach.

Biological response: Macroinvertebrate

Dissolved oxygen concentrations can alter the biological community by limiting species that are intolerant of low levels for an extended period of time, along with species that are sensitive to dramatic shifts in concentration (Davis 1975, EPA, 2012). Low dissolved oxygen can especially limit the taxa for the orders of, Ephemeroptera, Plecoptera, and Tricoptera (EPT). The EPT individuals favor environments that provide adequate dissolved oxygen, including riffles and swift aerated portions of the stream channel. According to Table 12, Severson Creek has an above statewide average of species that are intolerant to low DO and contains a lower abundance of species that are tolerant to low DO compared to the statewide average. However, Severson Creek has a lower percentage of EPT individuals. The available data **neither supports nor weakens** the case for low dissolved oxygen as a stressor to the macroinvertebrate community of Severson Creek.

Table 12. Summary of biological indices for Severson Creek (Stations 15RD016 and 05RD085) compared with the statewide Class 4 streams that support a healthy macroinvertebrate community.

Metric	Description	Statewide score[1] [mean ± SD]	Severson Score [mean ± SD]	Station (score)	*Station (2005 score[2])*
DO TIV	Mean DO (mg/L) tolerance indicator value	6 ± 1	7 ± 0	15RD016 (7) 05RD085[15] (7) 05RD085[16] (7)	*05RD085 (6)*
TolDO	Relative abundance (%) of low DO tolerant taxa	26 ± 20	2 ± 2	15RD016 (2) 05RD085[15] (4) 05RD085[16] (0)	*05RD085 (4)*
InTolDO	Relative abundance (%) of low DO intolerant taxa	5 ± 8	5 ± 4	15RD016 (3) 05RD085[15] (2) 05RD085[16] (9)	*05RD085 (15)*

[1] Statewide score includes stations that provide General Use habitat within the same IBI class and meet or exceed the applicable IBI threshold.

[2] 2005 data were not used for the purposes of assessment; data were outside of 10-year assessment window.

[15] 2015 sampling event at Station 05RD085 occurring on August 11, 2015.

[16] 2016 sampling event at Station 05RD085 occurring on August 16, 2016.

Good: Score for the impaired reach met or was equal to the statewide average.

Fair: Score for the impaired reach failed to meet the statewide average but was within the standard deviation range.

Poor: Score for the impaired reach failed to meet the statewide average and was outside the standard deviation range.

Summary of stressors

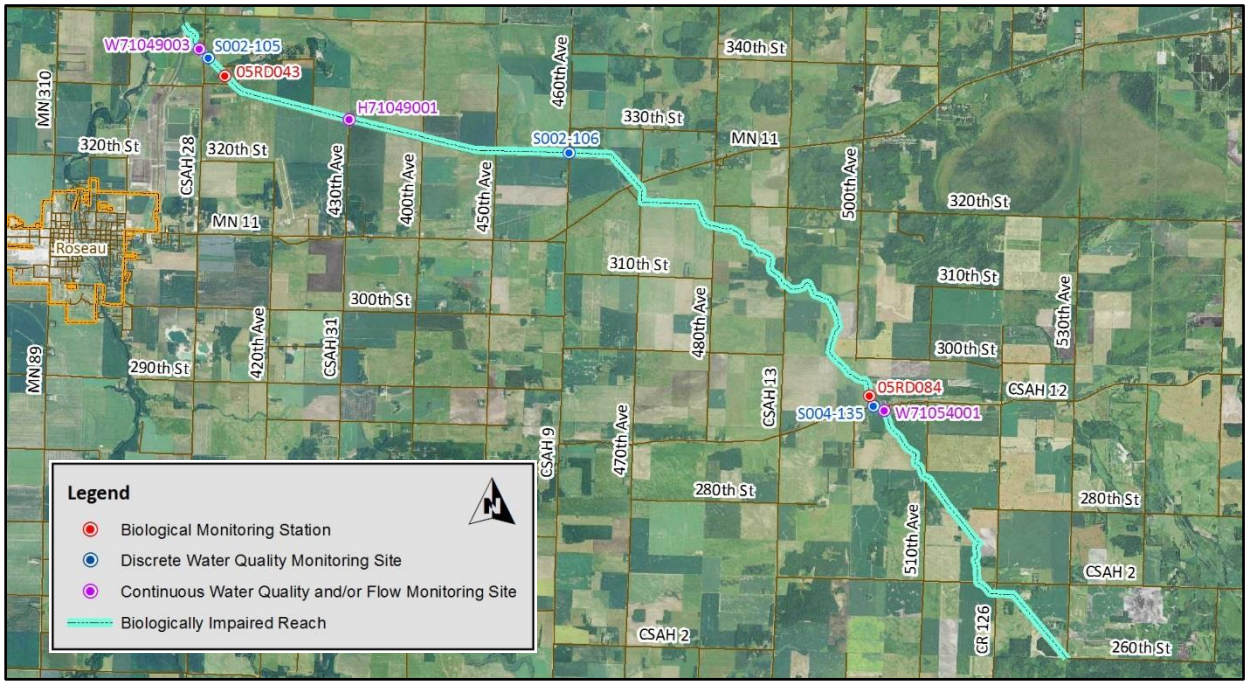
The evidence suggests that the M-IBI impairments associated with Severson Creek are primarily attributed to flow regime instability and insufficient physical habitat, and to a lesser extent, high suspended sediment. These reaches are prone to extended periods of minimal to no flow. Evidence of beaver dams is not directly linked to macroinvertebrate degradation through connectivity; however, the impounding effect has degraded the habitat through altered sediment transport, flow regime instability, and periods of low dissolved oxygen from pooling and stagnant flows. Additionally, Severson Creek is entirely channelized with the adjacent upland comprised of agriculture and pasture. Overall, the anthropogenic consequences causes sediment issues involving bed and bank instability with extreme embeddedness and deposition on the channel bottom. A few small efforts could be made to this reach with increasing benefits, including the removal of beaver dams, along with restricting cattle access to the stream channel. Due to the lack of TSS data, it is recommended that additional sampling be conducted along Severson Creek in the future. Additionally and with more involvedness, this system would benefit immensely by re-establishing the natural channel and morphology along with water detention/retention over the landscape.

3.2.4 Hay Creek (AUID 505)

Physical setting

Hay Creek (AUID 505) (Figure 10) extends from its headwaters (530th Avenue crossing), to its confluence with the Roseau River, located approximately 0.5 mile downstream of the CSAH 28 crossing; a total length of 17 miles (herein referred to as "Hay Creek"). Hay Creek has a subwatershed area of 116 square miles (74,331 acres). The subwatershed contains 117 miles of intermittent drainage ditch, 56 miles of intermittent stream, 21 miles of perennial drainage ditch (i.e., Hay Creek), and two miles of perennial stream (DNR, 2003). According to the MPCA (2013), 68% of the watercourses in the subwatershed have been physically altered (i.e., channelized, ditched, or impounded), including the entire length of Hay Creek. According to S. Klamm (personal communication, 2018), Roseau County completed a ditch clean out on the lower extend of Hay Creek between 2009 and 2010. The NLCD 2011 (USGS, 2011) lists cultivated crops (38%) and wetlands (34%) as the predominant land covers in the subwatershed. Other notable land cover groups in the subwatershed included hay/pasture (14%), forest (7%), developed (4%), shrub/scrub (1%), and herbaceous (1%).

Figure 10. Map of Hay Creek and associated biological monitoring stations and water quality/flow monitoring sites (2013 NAIP aerial image).



Biological impairments

Fish (F-IBI)

The fish community of Hay Creek was monitored at Station 05RD084 (0.1 mile downstream of the CSAH 12 crossing) on August 4, 2015, as well as Station 05RD043 (0.4 mile upstream of the CSAH 28 crossing) on August 19, 2015 and August 16, 2016. The locations of the stations are shown in Figure 10. Station 05RD084 was designated as General Use within the Northern Headwaters F-IBI Class (Class 6); the impairment threshold is an F-IBI score of 42. Station 05RD043 was designated as General Use within the Northern Streams F-IBI Class (Class 5); the associated impairment threshold is an F-IBI score of 47. According to Table 13, Hay Creek once supported sensitive species that have since been extirpated. Specifically, longnose dace, a sensitive species typically found in cool, high-gradient streams, has not been recorded since the 1970's. Several other sensitive species were recorded in 2005 but were not recorded in 2015 (i.e., pearl dace, northern redbelly dace, and burbot). The F-IBI scores indicate support at the upstream station (05RD084); however, some changes to the fish community are apparent. The downstream station (05RD043) indicates impairment with the 2015 sample scoring well below the General Use threshold.

Table 13. Summary of fish monitoring data for Stations 05RD084 and 05RD043 along Hay Creek.

Species	05RD084	
	2005	2015
blacknose dace	5	42
blackside darter	14	2
brook stickleback	65	7
burbot	2	X
central mudminnow	144	8
common shiner	1	97
creek chub	2	144
fathead minnow	3	X
finescale dace	X	2
johnny darter	39	31
northern pike	1	7
northern redbelly dace	9	X
pearl dace	3	X
silver redhourse	X	4
trout-perch	6	X
white sucker	1	56
F-IBI Scores	**60**	**60**

Species	05RD043		
	2005	2015	2016
black bullhead	X	X	1
blacknose dace	1	18	2
blackside darter	29	22	26
brook stickleback	X	1	X
burbot	2	2	3
central mudminnow	X	12	3
common carp	1	5	X
common shiner	X	6	36
creek chub	5	5	6
fathead minnow	2	12	10
johnny darter	5	89	41
largemouth bass	X	3	3
northern pike	2	35	30
rock bass	X	10	3
spotfin shiner	X	4	2
tadpole madtom	X	11	13
trout-perch	1	X	X
white sucker	1	5	25
yellow perch	X	X	26
F-IBI Scores	**51**	**39**	**48**

Macroinvertebrate (M-IBI)

The macroinvertebrate community of Hay Creek was monitored at Station 05RD043 on August 19, 2015 and August 17, 2016; and Station 05RD084 on August 4, 2015 and August 24, 2016. Both stations were designated as General Use within the Northern Forest Streams Riffle/Run Habitats M-IBI Class (Class 3) and have an impairment threshold of 53 for the M-IBI score. According to Table 14, biological sampling in 2005 indicated the stream was capable of supporting a diverse macroinvertebrate community. Since 2005, the M-IBI scores have significantly declined at both stations. In 2015 and 2016, all M-IBI scores were below the impairment threshold and lower confidence intervals indicating non-support for aquatic life. These results indicate an increase in the level of exposure to stressors resulting in a decline of biological condition.

Table 14. Summary of macroinvertebrate monitoring data for Stations 05RD084 and 05RD043 along Hay Creek.

	Species (order)	05RD084			05RD043		
		2005	2015	2016	2005	2015	2016
Insects	Beetles	84	7	X	41	X	X
	Biting flies (midges)	67	92	226	86	183	206
	Caddisflies	43	X	35	3	1	42
	Dragonflies	7	X	2	26	5	X
	Mayflies	79	2	23	126	1	47
	True bugs	3	1	1	16	1	X
Non-insects	Crayfish	2	X	X	13	X	X
	Crustacean (scuds)	24	X	X	28	X	X
	Leech	X	11	2	X	3	X
	Mites	X	3	4	X	5	X
	Snails	20	148	12	6	57	5
	Worms	3	60	22	2	60	1
Total species collected:		55	27	38	60	23	19
M-IBI Scores		**59**	**9**	**22**	**55**	**19**	**23**

Candidate causes

Loss of longitudinal connectivity

Available data

The biological monitoring staff did not observe any connectivity issues during any visits to Stations 05RD084 and 05RD043. According to the DNR (2014), there are no man-made dams along Hay Creek. The MPCA SID staff completed a longitudinal assessment of Hay Creek on August 9, 17, 28, and September 28 of 2017. Staff viewed all of the road crossing on the reach as part of the assessments. No obstructions to connectivity (e.g. perched culverts and beaver dams) were identified. In addition to the assessments, MPCA SID staff performed a detailed review of a May 8, 2013, aerial photo (courtesy of Google Earth) of Hay Creek. No connectivity-related issues were identified in the photo. However, it is unknown whether velocity barriers caused by culverts or private road crossings impede passage along Hay Creek. Overall, there are no apparent longitudinal connectivity stressors along Hay Creek.

Biological response: Fish

A waterway that is not longitudinally connected results in an inability for migratory fish to gain access to spawning grounds or different suitable habitats required for certain life history stages (Saunders, 2007). Dams often result in changes to the natural habitat, causing sensitive species to decline in abundance along with the overall diversity (Poole, 2002; Aadland, 2015; Gardner, et al. 2013; Cross et al., 2013). Long-lived and late maturing species require well-connected habitat for various life history stages, including spawning and fixed retreats. Table 15 explains that Hay Creek is exceeding the statewide averages in both migratory taxa and late maturing females at Station 05RD084. However, further downstream near the confluence with the Roseau River, the scores are below the statewide average but within confidence limits at Station 05RD043. Based on reconnaissance, the downstream reach only has one bridge crossing and one private road crossing and it appears that it is unlikely these crossings impede fish passage. The available data ***neither supports nor weakens*** the case for connectivity as a stressor to the fish community of Hay Creek (Table 15).

Table 15. Summary of biological indices for Hay Creek compared with the statewide Class 6 streams (A – upstream Station 05RD084) and Class 5 streams (B- downstream Station 05RD043) that support a healthy fish community.

Metric	Description	Statewide score[1] [mean ± SD]	Hay Creek score [mean ± SD]	Station (score)	*Station (2005 score[2])*
***A**: 05RD084*					
MgrTxPct	Relative abundance (%) of taxa that are migratory	12 ± 7	27	05RD084 (27)	*05RD084 (14)*
MA>3-TolTxPct	Relative abundance (%) of taxa with a female mature age of equal to or greater than three years, excluding tolerant taxa	2 ± 4	9	05RD084 (9)	*05RD084 (7)*
***B**: 05RD043*					
MgrTxPct	Relative abundance (%) of taxa that are migratory	20 ± 8	13 ± 0	05RD043[15] (13) 05RD043[16] (13)	*05RD043 (20)*
MA>3-TolTxPct	Relative abundance (%) of taxa with a female mature age of equal to or greater than three years, excluding tolerant taxa	17 ± 11	16 ± 4	05RD043[15] (13) 05RD043[16] (19)	*05RD043 (10)*

[1] Statewide score includes stations that provide General Use habitat within the same IBI class and meet or exceed the applicable IBI threshold.

[2] 2005 data were not used for the purposes of assessment; data were outside of 10-year assessment window.

[15] 2015 sampling event at Station 05RD043 occurring on August 19, 2015.

[16] 2016 sampling event at Station 05RD043 occurring on August 16, 2016.

Good: Score for the impaired reach met or was equal to the statewide average.

Fair: Score for the impaired reach failed to meet the statewide average but was within the standard deviation range.

Poor: Score for the impaired reach failed to meet the statewide average and was outside the standard deviation range.

Biological response: Macroinvertebrate

Given the limitations of a macroinvertebrate community to migrate along a river continuum, there is no evidence for analysis of a loss of longitudinal connectivity as a stressor. It has been documented that macroinvertebrate populations can re-establish in a segmented stream channel to reflect stable community composition upstream and downstream of a connectivity barrier. However, barriers related to altered hydrology, specifically drought conditions, can cause direct or indirect changes in sensitive macroinvertebrate populations.

Flow regime instability

Available data

According to the MPCA (2013), 68% of the watercourses in the subwatershed have been physically altered (i.e., channelized, ditched, or impounded), including the entire length of Hay Creek. The Norland Impoundment and associated diversion channel are located on the lower extent of Hay Creek. This project was completed for the purposes of flood control and provides 9,500 acre-feet of gated and un-gated runoff storage (RRWD, 2018). The MPCA biological monitoring staff did not encounter any flow-related issues (e.g., intermittency) at Stations 05RD084 and 05RD043. During geomorphic analysis, the DNR staff noted the presence of groundwater seeps along Hay Creek. Groundwater helps to sustain baseflow in Hay Creek (S. Kalmm, personal communication, 2018). There are no flow monitoring data for Hay Creek. The USGS (2017) estimated that the normal range of flow values for the Hay Creek at its outlet was 11.2 (Q25) to 0.5 (Q75) cfs. Additionally, the estimated median flow (Q50) was 2.0 cfs, while the projected Q5 flow was 131.0 cfs and the Q95 flow was less than 0.1 cfs. The Q25 to Q75 flow values ratio was 24:1, which is high and indicative of a flashy system that is influenced by runoff. By comparison, several of the more hydrologically stable rivers in the Red River Basin (e.g., Buffalo River, Clearwater River, and Otter Tail River) had a ratio of 7:1 or less. The MPCA SID staff conducted reconnaissance along the reach on six separate dates (i.e., May 18, 2017, August 2, 2017, August 9, 2017, August 17, 2017, August 28, 2017, and September 28, 2017) and documented flow conditions. No flow-related issues were noted. Overall, the available data suggest that the reach is prone to extreme peak flows, as well as periods of minimal flow.

Biological response: Fish

Flow regime instability has been shown to limit species diversity and favor taxa that are generalists, early maturing and short lived, pioneering, and intolerant to disturbances (Aadland et al., 2005; Poff and Zimmerman, 2010). According to Table 16, the Hay Creek fish community is limited in the diversity of fish species. Specifically, over half (60%) of the individuals sampled at Station 05RD084 were comprised of two taxa (i.e., creek chub and common shiner). These taxa are relatively tolerant species that are typically abundant in areas prone to flow instability. The available data ***somewhat supports*** the case for flow regime instability as a stressor to the fish community of Hay Creek (Table 16).

Table 16. Summary of biological indices for Hay Creek compared with the statewide Class 6 streams (A – upstream Station 05RD084) and Class 5 streams (B- downstream Station 05RD043) that support a healthy fish community.

***A**: 05RD084*

Metric	Description	Statewide score[1] [mean ± SD]	Hay Creek score [mean ± SD]	Station (score)	*Station (2005 score[2])*
DomTwoPct	Relative abundance (%) of the two most abundant taxa	59 ± 13	60	05RD084 (60)	*05RD084 (71)*
GeneralTxPct	Relative abundance (%) of individual that are generalists	35 ± 11	36	05RD084 (36)	*05RD084 (36)*
MA<2TxPct	Relative abundance (%) of taxa with a female mature age equal to or less than two years	87 ± 10	82	05RD084 (82)	*05RD084 (86)*
NumPerMeter-Tol	Number of individuals per meter of stream sampled, excluding tolerant species	1 ± 1	1	05RD084 (1)	*05RD084 (0.5)*
PioneerTxPct	Relative abundance (%) of taxa that are pioneers	19 ± 7	18	05RD084 (18)	*05RD084 (21)*
SLvdPct	Relative abundance (%) of individuals that are short-lived	42 ± 24	12	05RD084 (12)	*05RD084 (30)*
SensitiveTxPct	Relative abundance (%) of sensitive taxa	28 ± 12	9	05RD084 (9)	*05RD084 (21)*

***B**: 05RD043*

DomTwoPct	Relative abundance (%) of the two most abundant taxa	61 ± 14	43 ± 13	05RD043[15] (52) 05RD043[16] (33)	*05RD043 (69)*
GeneralTxPct	Relative abundance (%) of individual that are generalists	25 ± 12	38 ± 0	05RD043[15] (38) 05RD043[16] (38)	*05RD043 (50)*
MA<2TxPct	Relative abundance (%) of taxa with a female mature age equal to or less than two years	67 ± 12	69 ± 9	05RD043[15] (75) 05RD043[16] (63)	*05RD043 (80)*
NumPerMeter-Tol	Number of individuals per meter of stream sampled, excluding tolerant species	1 ± 2	0.7 ± 0	05RD043[15] (0.7) 05RD043[16] (0.7)	*05RD043 (0.3)*
PioneerTxPct	Relative abundance (%) of taxa that are pioneers	15 ± 6	19 ± 0	05RD043[15] (19) 05RD043[16] (19)	*05RD043 (30)*
SLvdPct	Relative abundance (%) of individuals that are short-lived	15 ± 19	9 ± 5	05RD043[15] (13) 05RD043[16] (5)	*05RD043 (8)*
SensitiveTxPct	Relative abundance (%) of sensitive taxa	27 ± 12	13 ± 13	05RD043[15] (13) 05RD043[16] (13)	*05RD043 (10)*

[1] Statewide score includes stations that provide General Use habitat within the same IBI class and meet or exceed the applicable IBI threshold.

[2] 2005 data were not used for the purposes of assessment; data were outside of 10-year assessment window.

[15] 2015 sampling event at Station 05RD043 occurring on August 19, 2015.

[16] 2016 sampling event at Station 05RD043 occurring on August 16, 2016.

Good: Score for the impaired reach met or was equal to the statewide average.

Fair: Score for the impaired reach failed to meet the statewide average but was within the standard deviation range.

Poor: Score for the impaired reach failed to meet the statewide average and was outside the standard deviation range.

Biological response: Macroinvertebrate

Flow regime instability has been documented to limit the diversity and taxa richness of macroinvertebrates and favor tolerant individuals that can adapt to disturbances. Instability can lead to a decline in long-lived individuals. Taxa belonging to the orders of Ephemeroptera, Plecoptera, and Trichoptera generally require stable flow conditions. Many authors have documented an inverse relationship between flow regime instability and benthic aquatic insects, particularly Trichoptera (Bunn and Arthington, 2002; Bragg et al., 2005; Dewson et al., 2007). In 2005, Hay Creek displayed scores that often surpass the statewide standard in all categories (Table 17). Recent sampling in Hay Creek shows metric scores that are well below the statewide average in all categories that indicate stressors caused by flow regime instability. However, this decline could also be attributed to the effects of the ditch clean out (e.g. habitat alteration) that was performed between 2009 and 2010. The available data ***somewhat supports*** the case for flow regime instability as a stressor to the macroinvertebrate community of Hay Creek.

Table 17. Summary of biological indices for Hay Creek (Stations 05RD084 and 05RD043) compared with the statewide Class 3 streams that support a healthy macroinvertebrate community.

Metric	Description	Statewide score[1] [mean ± SD]	Hay Creek score [mean ± SD]	Station (score)	*Station (2005 score[2])*
EPTPct	Relative abundance (%) of Ephemeroptera, Plecoptera, and Trichoptera	43 ± 17	12 ± 14	05RD084[15] (1), 05RD084[16] (18), 05RD043[15] (1), 05RD043[16] (30)	*05RD084 (37) 05RD043 (37)*
LongLived Pct	Relative abundance (%) of long-lived individuals	9 ± 7	0.2 ± 0.5	05RD084[15] (1), 05RD084[16] (0), 05RD043[15] (0), 05RD043[16] (0)	*05RD084 (23) 05RD043 (6)*
TaxaCount AllChir	Total taxa richness of macroinvertebrates	49 ± 10	27 ± 7	05RD084[15] (25), 05RD084[16] (37), 05RD043[15] (22), 05RD043[16] (22)	*05RD084 (53) 05RD043 (59)*
Tolerant2 ChTxPct	Relative abundance (%) of taxa with tolerance values equal to or greater than six	54 ± 8	86 ± 7	05RD084[15] (96), 05RD084[16] (81), 05RD043[15] (86), 05RD043[16] (82)	*05RD084 (68) 05RD043 (78)*
TrichwoH ydroPct	Relative abundance (%) of non-hydrospsychid Trichoptera individuals	12 ± 9	4 ± 4	05RD084[15] (0), 05RD084[16] (5), 05RD043[15] (0), 05RD043[16] (9)	*05RD084 (4) 05RD043 (1)*

[1] Statewide score includes stations that provide General Use habitat within the same IBI class and meet or exceed the applicable IBI threshold.

[2] 2005 data were not used for the purposes of assessment; data were outside of 10-year assessment window.

[15] 2015 sampling events at Station 05RD084 occurring on August 4, 2015 and 05RD043 on August 19, 2015.

[16] 2016 sampling events at Station 05RD084 occurring on August 24, 2016 and 05RD043 on August 17, 2016.

Good: Score for the impaired reach met or was equal to the statewide average.

Fair: Score for the impaired reach failed to meet the statewide average but was within the standard deviation range.

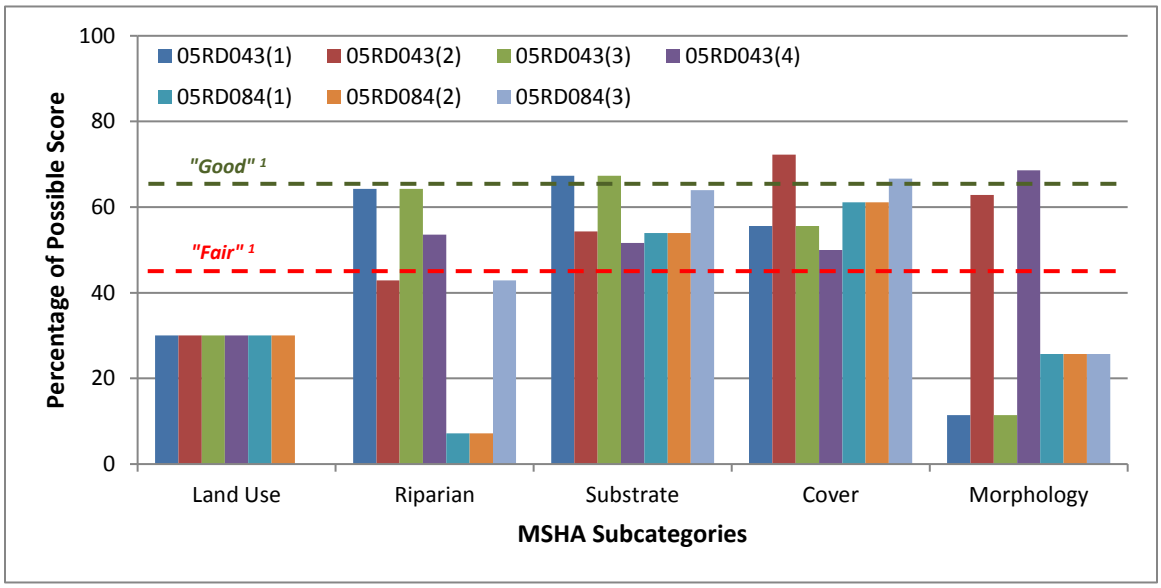
Poor: Score for the impaired reach failed to meet the statewide average and was outside the standard deviation range.

Insufficient physical habitat

Available data

The physical habitat of Hay Creek was evaluated at Stations 05RD084 and 05RD043 using the MSHA. Hay Creek is entirely channelized (MPCA, 2013). Station 05RD043, which is located near the outlet of Hay Creek, had "fair" MSHA scores (MSHA=43, 58, 43, and 56). The scores for Station 05RD084, which is situated in the upstream portion of Hay Creek, were substantially lower and within the "poor" rating range (MSHA=38, 38, and 45). Figure 11 displays the MSHA subcategory results for each of the stations. The predominance of agricultural row crops in the immediate vicinity of Stations 05RD084 and 05RD043 limited their land use subcategory scores. The riparian subcategory scores for Station 05RD084 were negatively affected by a very limited riparian zone width and a "heavy" amount of bank erosion. Both stations offered riffle habitat and coarse substrate (e.g., boulders, cobble, and gravel); however, a "moderate" to "severe" amount of embeddedness was documented at each station. The stations scored above the "fair" rating threshold in the cover subcategory, providing a "moderate" amount of cover. Noted cover types along Hay Creek included boulders, deep pools, logs, macrophytes (emergent, floating leaf, and submergent), and overhanging vegetation. Lastly, both stations received multiple poor scores in the morphology subcategory due in part to "moderate" to "low" channel stability and "poor" channel development.

Figure 11. MSHA subcategory results for Stations 05RD043 and 05RD084 along Hay Creek.



[1] The minimum percentage of each subcategory score needed for the station to achieve a "fair" and "good" MSHA rating.

Clark and Vinje (2017) completed fluvial geomorphic assessments at Stations 05RD084 and 05RD043 along Hay Creek. Station 05RD084 was evaluated on June 26, 2017. The stream type at this location was estimated to be an F4/B4 (moderate to high width-to-depth ratio, moderately to well entrenched, gravel bed stream). Based on observations in the field, the potential stream type is likely a C4 (moderate width-to-depth ratio, slightly entrenched, gravel bed stream). The station yielded a Pfankuch stability rating of 92 (moderately unstable). Below are excerpts from the assessment summary for Station 05RD084:

> *"There were some depositional benches along the reach, but those may have been a product of slumping and healing-over rather than the build-up of an approximately-sized bankfull channel. The channel appears to be confined during minor and major flood flows. The channel is pastured on both*

banks, but cattle are fenced out on the right bank and only have access to the channel on the left banks. Trampling of the banks appeared to be limited to specific locations and was not continuous. Groundwater seeps were also prevalent along this reach. Slumping and other erosion was occurring at these locations".

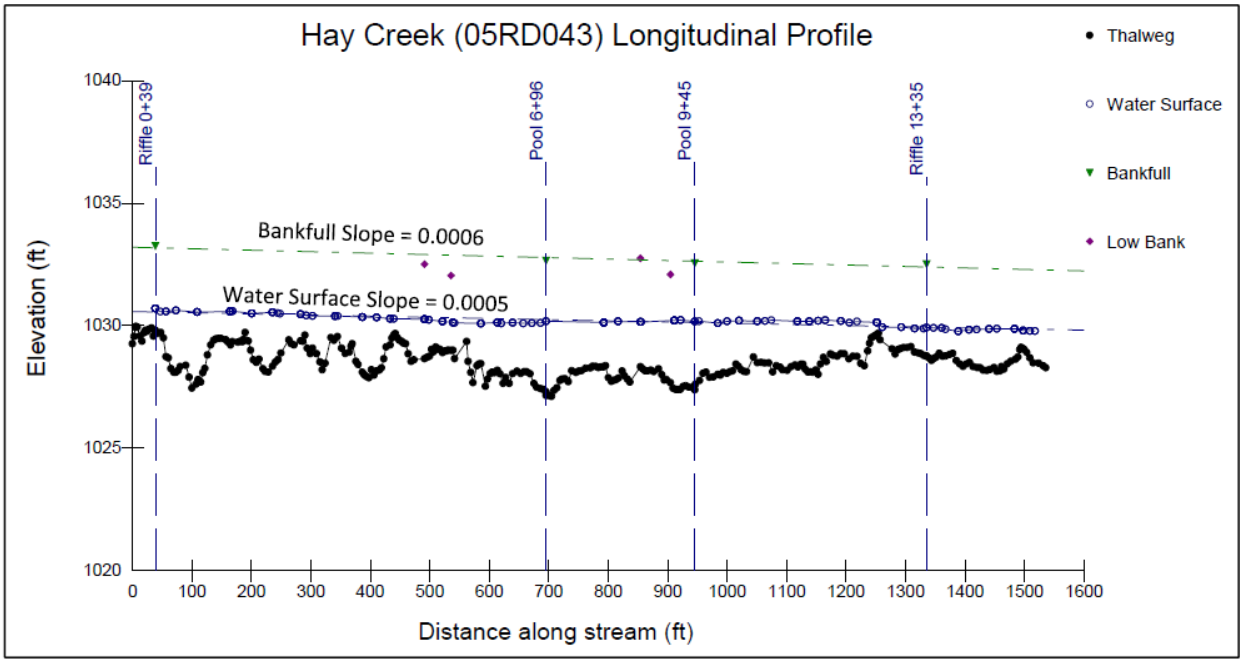
"Within this study location, Hay Creek has been channelized. While the pools were deeper than the riffles, both cross-section types were similar in area. The measured riffles were entrenched and did not have access to a floodplain, which was creating in-channel erosion. Fine sediments were observed on the riffles among the gravel and cobble-sized particles. The bottom substrate was also fairly bright, indicating a mobile channel bed during floods. Intensifying the potential for in-channel erosion is the presence of groundwater seeps in banks that are composed of finer sediment. It would be beneficial to monitor Hay Creek for further entrenchment and identify upstream sediment sources."

On July 10, 2017, DNR staff evaluated Station 05RD043. The stream type at this location was estimated to be a B5c/C5c- (moderate to high width-to-depth ratio, slightly too moderately entrenched, sand bed stream). The site yielded a Pfankuch stability rating of 108 (moderately unstable). Below are excerpts from the assessment summary for Station 05RD043:

"A bankfull bench was observed on some of the cross-sections, while on others, mass erosion or excessive deposition may have impacted the elevation of the top of the channel. Some of the cross-sections were constricted enough at the flood-prone elevation to be considered a B stream type, while at riffle 13+35 [Figure 12], the flood-prone width was wide enough to be considered a C stream type. In-channel bank erosion and excessive deposition on the channel bed were concerns at this location."

"The constructed channel, at bankfull and below, was over wide. Excessive deposition was occurring in the form of mid-channel bars, side bars, and fine deposition on the riffles. The source of the fine sediment may be from within the study area, or it could be from upstream upland/off-channel sources. Groundwater seeps were also present on the low banks. With cutting already occurring, saturation of the bank could exacerbate the bank erosion."

Figure 12. Longitudinal profile for Station 05RD043 along Hay Creek.



In summary, the MSHA data suggest that the physical habitat of Hay Creek is primarily limited by the embeddedness of coarse substrate and poor channel morphology characteristics. Clark and Vinje (2017) identified areas of the stream that exhibited poor habitat including bank slumping and in-channel erosion, deposition of fine sediments, embedded riffles, and an over-widen stream channel. These deficiencies can be attributed to the effects of past channelization and recent ditch maintenance.

Biological response: Fish

Loss of instream zone stability and channel morphology can limit the potential for lithophilic spawners and benthic insectivores (Frimpong et al., 2005; Aadland and Kuitunen, 2006). According to Table 18, the upstream station (05RD084) yielded scores above the statewide averages, with the exception of a below statewide average insectivorous fish species score. However, the downstream station (05RD043) had several indices that failed to meet the statewide average, indicating progressive downstream degradation due to channelization. Furthermore, several of the 2005 scores for Station 05RD043 indicate recent degradation of in-stream habitat (i.e., RiffleTxPct, SLithopTxPct, Insect-TolPct, BenInsect-TolTxPct, and DarterSculpTxPct) the available data ***strongly supports*** the case for insufficient physical habitat as a stressor to the fish community of Hay Creek.

Table 18. Summary of biological indices for Hay Creek compared with the statewide Class 6 streams (A – upstream Station 05RD084) and Class 5 streams (B- downstream Station 05RD043) that support a healthy fish community.

***A**: 05RD084*

Metric	Description	Statewide score[1] [mean ± SD]	Hay Creek score [mean ± SD]	Station (score)	*Station (2005 score[2])*
RiffleTxPct	Relative abundance (%) of taxa that predominately utilize riffle habitats	9 ± 7	9	05RD084 (9)	*05RD084 (7)*
SLithopTx Pct	Relative abundance (%) of taxa that are simple lithophilic spawning species	20 ± 11	45	05RD084 (45)	*05RD084 (36)*
Insect-TolPct	Relative abundance (%) of individuals that are insectivorous excluding tolerant species	22 ± 17	10	05RD084 (10)	*05RD084 (21)*
BenInsect-TolTxPct	Relative abundance (%) of taxa that are benthic insectivores, excluding tolerant species	11 ± 9	27	05RD084 (27)	*05RD084 (21)*
DetNWQT xPct	Relative abundance (%) of taxa that are detritivorous	18 ± 8	9	05RD084 (9)	*05RD084 (14)*
DarterScul pTxPct	Relative abundance (%) of taxa that are darters and sculpins	10 ± 8	18	05RD084 (18)	*05RD084 (14)*

[1] Statewide score includes stations that provide General Use habitat within the same IBI class and meet or exceed the applicable IBI threshold.

[2] 2005 data were not used for the purposes of assessment; data were outside of 10-year assessment window.

[15] 2015 sampling event at Station 05RD043 occurring on August 19, 2015.

[16] 2016 sampling event at Station 05RD043 occurring on August 16, 2016.

Good: Score for the impaired reach met or was equal to the statewide average.

Fair: Score for the impaired reach failed to meet the statewide average but was within the standard deviation range.

Poor: Score for the impaired reach failed to meet the statewide average and was outside the standard deviation range.

***B**: 05RD043*

RiffleTxPct	Relative abundance (%) of taxa that predominately utilize riffle habitats	18 ± 10	6 ± 0	05RD043[15] (6) 05RD043[16] (6)	*05RD043 (10)*
SLithopTx Pct	Relative abundance (%) of taxa that are simple lithophilic spawning species	32 ± 12	31 ± 0	05RD043[15] (31) 05RD043[16] (31)	*05RD043 (40)*
Insect-TolPct	Relative abundance (%) of individuals that are insectivorous excluding tolerant species	32 ± 25	50 ± 4	05RD043[15] (53) 05RD043[16] (47)	*05RD043 (71)*
BenInsect-TolTxPct	Relative abundance (%) of taxa that are benthic insectivores, excluding tolerant species	27 ± 9	19 ± 0	05RD043[15] (19) 05RD043[16] (19)	*05RD043 (30)*
DetNWQT xPct	Relative abundance (%) of taxa that are detritivorous	13 ± 7	22 ± 4	05RD043[15] (25) 05RD043[16] (19)	*05RD043 (30)*
DarterScul pTxPct	Relative abundance (%) of taxa that are darters and sculpins	18 ± 7	13 ± 0	05RD043[15] (13) 05RD043[16] (13)	*05RD043 (20)*

[1] Statewide score includes stations that provide General Use habitat within the same IBI class and meet or exceed the applicable IBI threshold.

[2] 2005 data were not used for the purposes of assessment; data were outside of 10-year assessment window.

[15] 2015 sampling event at Station 05RD043 occurring on August 19, 2015.

[16] 2016 sampling event at Station 05RD043 occurring on August 16, 2016.

Good: Score for the impaired reach met or was equal to the statewide average.

Fair: Score for the impaired reach failed to meet the statewide average but was within the standard deviation range.

Poor: Score for the impaired reach failed to meet the statewide average and was outside the standard deviation range.

Biological response: Macroinvertebrate

Loss of physical habitat will limit the streambed composition and morphology, overall affecting the species adapted for specific microhabitats. The effects of erosion and sedimentation will decrease the species that cling onto hard surfaces, while promoting burrower, legless, and sprawler taxa (Gore et al., 2001). According to Table 19, Hay Creek has a higher abundance of clinger and sprawler taxa compared to the statewide averages, indicating the availability of hard-aerated surfaces (e.g., riffles). Additionally, Hay Creek supports a higher abundance of burrower and legless individuals compared to the statewide averages indicating fine sediments for midge taxa. The available data ***somewhat supports*** the case for insufficient physical habitat as a stressor to the macroinvertebrate community of Hay Creek.

Table 19. Summary of biological indices for Hay Creek (Stations 05RD084 and 05RD043) compared with the statewide Class 3 streams that support a healthy macroinvertebrate community.

Metric	Description	Statewide score[1] [mean ± SD]	Hay Creek score [mean ± SD]	Station (score)	*Station (2005 score[2])*
Burrower Pct	Relative abundance (%) of burrower individuals	9 ± 9	15 ± 12	05RD084[15] (22) 05RD084[16] (9) 05RD043[15] (27) 05RD043[16] (2)	*05RD084 (5)* *05RD043 (7)*
ClingerPct	Relative abundance (%) of clinger individuals	53 ± 17	58 ± 33	05RD084[15] (17) 05RD084[16] (74) 05RD043[15] (47) 05RD043[16] (94)	*05RD084 (42)* *05RD043 (20)*
LeglessPct	Relative abundance (%) of legless individuals	38 ± 18	60 ± 37	05RD084[15] (96) 05RD084[16] (79) 05RD043[15] (56) 05RD043[16] (10)	*05RD084 (25)* *05RD043 (27)*
SprawlerPct	Relative abundance (%) of sprawler individuals	15 ± 9	3 ± 2	05RD084[15] (1) 05RD084[16] (6) 05RD043[15] (3) 05RD043[16] (1)	*05RD084 (20)* *05RD043 (30)*

[1] Statewide score includes stations that provide General Use habitat within the same IBI class and meet or exceed the applicable IBI threshold.

[2] 2005 data were not used for the purposes of assessment; data were outside of 10-year assessment window.

[15] 2015 sampling events at Stations 05RD084 occurring on August 4, 2015 and 05RD043 on August 19, 2015.

[16] 2016 sampling events at Station 05RD084 occurring August 24, 2016 and 05RD043 on August 17, 2016.

Good: Score for the impaired reach met or was equal to the statewide average.

Fair: Score for the impaired reach failed to meet the statewide average but was within the standard deviation range.

Poor: Score for the impaired reach failed to meet the statewide average and was outside the standard deviation range.

High suspended sediment

Available data

Hay Creek has a new TSS impairment that will be included on the proposed 2018 Impaired Waters List. The MPCA biological monitoring staff collected a discrete water quality sample at Stations 05RD084 and 05RD043 along Hay Creek at the time of each of the six monitoring visits. The samples were analyzed for several parameters, including TSS. The biological monitoring stations had TSS concentrations ranging from 3 to 15 mg/L; which were well below the 30 mg/L standard. Table 20 summarizes all available discrete TSS data for Sites S002-105 (CR 28 crossing) and S002-106 (CSAH 11 crossing); the location of the sites is shown in Figure 10. Collectively, 24% of the values exceeded the standard. The RRW HSPF model estimates that Hay Creek had a TSS concentration in excess of the standard between 5% and 11% of the time during the period of 1995 to 2014. Additionally, the aforementioned MSHA results indicate that the deposition of excess fine sediment caused the “moderate” to “severe” level of embeddedness of coarse substrate documented at Stations 05RD084 and 05RD043. Figure 24 shows images of sediment sources to Hay Creek. Overall, the available data suggest that Hay Creek experiences frequent periods of high suspended sediment.

Table 20. Discrete TSS data for Sites S002-105 and S002-106 along Hay Creek.

Site	Date range	*n*	Min (mg/L)	Max (mg/L)	Mean (mg/L)	Standard exceedances (#)
S002-105	2002-2015	53	2	227	30	12
S002-106	2002-2013	41	1	390	37	11

Figure 13. Images of sediment sources along Hay Creek, including bank erosion caused by cattle access at Station 05RD084 on August 24, 2016 (upper left); a slump at the CSAH 28 crossing on August 2, 2017 (upper right); bank erosion near the 510th Avenue crossing on September 28, 2017 (lower left); and a tributary ditch with no riparian buffer along CSAH 28 on September 28, 2017 (lower right).

Biological response: Fish

Excessive TSS can affect a fish community in various ways depending on the concentration and duration of exposure. High TSS often results in a limited fish community that is dominated by tolerant taxa (EPA, 2012). Sediment deposition fills interstitial space in riffles and coarse substrate that is utilized by sensitive lithophilic spawning fish (Bilotta and Brazier, 2008). The deposited material blocks the pores in the streambed, preventing the exchange within the hyporheic zone (Greig et al., 2005). Sedimentation can also degrade the macroinvertebrate community, which can adversely affect insectivore fish species. According to Table 21, Hay Creek's fish community shows a decline in taxa that are sensitive to TSS relative to the statewide averages. Since the 2005 sampling event, there has been a consistent decline in benthic insectivores taxa indicating degradation of streambed habitat for macroinvertebrates. The available data ***somewhat supports*** the case for high-suspended sediment as a stressor to the fish community of Hay Creek.

Table 21. Summary of biological indices for Hay Creek compared with the statewide Class 6 streams (A – upstream Station 05RD084) and Class 5 streams (B- downstream Station 05RD043) that support a healthy fish community.

***A**: 05RD084*

Metric	Description	Statewide score[1] [mean ± SD]	Hay Creek score [mean ± SD]	Station (score)	*Station (2005 score[2])*
TSS TIV	Mean TSS (mg/L) tolerance indicator value	14 ± 2	14	05RD084 (14)	*05RD084 (13)*
CondProb	Probability of meeting the TSS standard	79 ± 8	78	05RD084 (78)	*05RD084 (83)*
SLithopTx Pct	Relative abundance (%) of taxa that are simple lithophilic spawning species	20 ± 11	45	05RD084 (45)	*05RD084 (36)*
BenInsect Pct	Relative abundance (%) of taxa that are benthic insectivores	8 ± 12	9	05RD084 (9)	*05RD084 (20)*

***B**: 05RD043*

TSS TIV	Mean TSS (mg/L) tolerance indicator value	13 ± 2	14 ± 0.2	05RD043[15] (14) 05RD043[16] (13)	*05RD043 (14)*
CondProb	Probability of meeting the TSS standard	80 ± 7	80 ± 1	05RD043[15] (79) 05RD043[16] (81)	*05RD043 (76)*
SLithopTx Pct	Relative abundance (%) of taxa that are simple lithophilic spawning species	32 ± 12	31 ± 0	05RD043[15] (31) 05RD043[16] (31)	*05RD043 (40)*
BenInsect Pct	Relative abundance (%) of taxa that are benthic insectivores	22 ± 23	43 ± 11	05RD043[15] (51) 05RD043[16] (35)	*05RD043 (70)*

[1] Statewide score includes stations that provide General Use habitat within the same IBI class and meet or exceed the applicable IBI threshold.

[2] 2005 data were not used for the purposes of assessment; data were outside of 10-year assessment window.

[15] 2015 sampling event at Station 05RD043 occurring on August 19, 2015.

[16] 2016 sampling event at Station 05RD043 occurring on August 16, 2016.

Good: Score for the impaired reach met or was equal to the statewide average.

Fair: Score for the impaired reach failed to meet the statewide average but was within the standard deviation range.

Poor: Score for the impaired reach failed to meet the statewide average and was outside the standard deviation range.

Biological response: Macroinvertebrate

Excessive TSS can adversely affect macroinvertebrates in various ways depending on the concentration and duration of exposure. High TSS often results in a limited macroinvertebrate community that is dominated by tolerant taxa (Henley et al., 2000; EPA, 2012; Jones et al., 2012). Sediment suspended in the water column can limit collector species and species that filter using a net-spinning casing. According to Table 22, Hay Creek is limited in species that are intolerant to high TSS and contains a higher abundance of species that are tolerant to TSS compared to the statewide average. Since the 2005 sampling event, there has been a decline in taxa that are intolerant to TSS. The available data ***strongly supports*** the case for high suspended sediment as a stressor to the macroinvertebrate community of Hay Creek (Table 22).

Table 22. Summary of biological indices for Hay Creek (Stations 05RD084 and 05RD043) compared with the statewide Class 3 streams that support a healthy macroinvertebrate community.

Metric	Description	Statewide score[1] [mean ± SD]	Hay Creek score [mean ± SD]	Station (score)	*Station (2005 score[2])*
TSS TIV	Mean TSS (mg/L) tolerance indicator value	13 ± 1	14 ± 2	05RD084[15] (16) 05RD084[16] (14) 05RD043[15] (12) 05RD043[16] (14)	*05RD084 (16)* *05RD043 (17)*
TolTSS	Relative abundance (%) of high TSS tolerant taxa	21 ± 10	23 ± 20	05RD084[15] (53) 05RD084[16] (15) 05RD043[15] (16) 05RD043[16] (8)	*05RD084 (23)* *05RD043 (37)*
InTolTSS	Relative abundance (%) of high TSS intolerant taxa	17 ± 10	1 ± 1	05RD084[15] (0) 05RD084[16] (2) 05RD043[15](0.6) 05RD043[16] (0.7)	*05RD084 (3)* *05RD043 (6)*

[1] Statewide score includes stations that provide General Use habitat within the same IBI class and meet or exceed the applicable IBI threshold.

[2] 2005 data were not used for the purposes of assessment; data were outside of 10-year assessment window.

[15] 2015 sampling events at Stations 05RD084 occurring on August 4, 2015 and 05RD043 on August 19, 2015.

[16] 2016 sampling events at Station 05RD084 occurring on August 24, 2016 and 05RD043 on August 17, 2016.

Good: Score for the impaired reach met or was equal to the statewide average.

Fair: Score for the impaired reach failed to meet the statewide average but was within the standard deviation range.

Poor: Score for the impaired reach failed to meet the statewide average and was outside the standard deviation range.

Low dissolved oxygen

Available data

The MPCA biological monitoring staff collected a combined eight discrete DO measurements at Stations 05RD084 and 05RD043 along Hay Creek at the time of fish and macroinvertebrate monitoring. Measurement values ranged from 7.2 to 11.7 mg/L; all of which were well above the 5.0 mg/L standard. Figure 14 displays all available discrete DO data for Sites S002-105 (2001-2016; *n*=89), S002-106 (2002-2013; *n*=60), and S004-135 (CSAH 12; 2003-2012; *n*=49). Collectively, 4% of the values were below the standard; however, only 17 of the measurements were collected prior to 9:00 a.m., when values are typically lowest. Generally, the lowest DO levels were in the months of June, July, and August. The MPCA conducted continuous DO monitoring at Site W71049003 (CSAH 28 crossing) from August 17, 2017, to August 28, 2017, as well as Site W71054001 (CSAH 12) from August 2, 2017, to August 9, 2017; the locations of the sites are shown in Figure 10. The monitoring results are provided in Table 23, as well as displayed in Figures 15 and 16. None of the values for Site W71049003 fell below the standard. Site W71054001 had 9% of values that were below the standard, with the lowest concentration at 4.4 mg/L on August, 8 at 6:01 a.m. On August 17, 2017 (3:51 p.m. to 5:40 p.m.), MPCA staff conducted a longitudinal synoptic survey along Hay Creek. The DO-related survey results are shown in Figure 17. While all of the sites had a DO concentration above the standard, nearly all of the sites had supersaturated DO levels, which is indicative of excessive aquatic plant growth. Additionally, the RRW HSPF model estimates that Hay Creek had a DO concentration below the standard between 1% and 23% of the time during the period of 1995 to 2014. Overall, the available data suggest that Hay Creek experiences at least occasional periods of low DO.

Figure 14. Discrete DO data for Sites S002-105, S002-106, and S004-135 along Hay Creek.

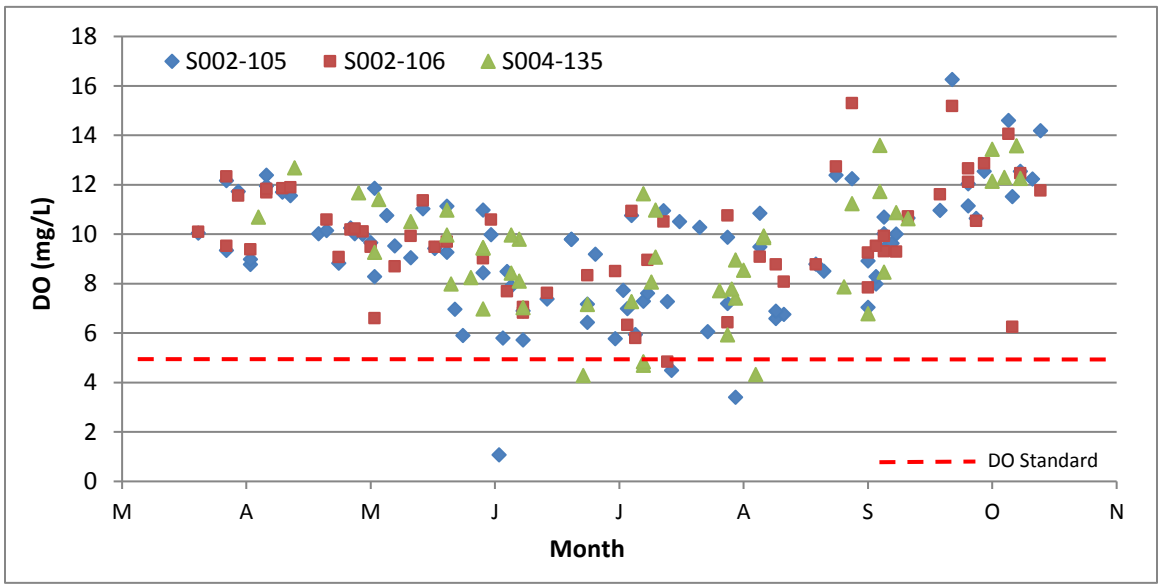


Table 23. Continuous DO data for Sites W71049003 and W71054001 along Hay Creek.

Site	Start date - End date	*n*	Max. (mg/L)	Min. (mg/L)	% Total values below standard	% Daily min. values below standard	Mean daily flux (mg/L)
W71049003	8/17/2017 - 8/28/2017	1043	12.5	5.1	0	0	5.0
W71054001	8/2/2017 - 8/9/2017	679	17.5	4.4	9	83	9.8

Figure 15. Continuous DO data for Site W71049003 along Hay Creek.

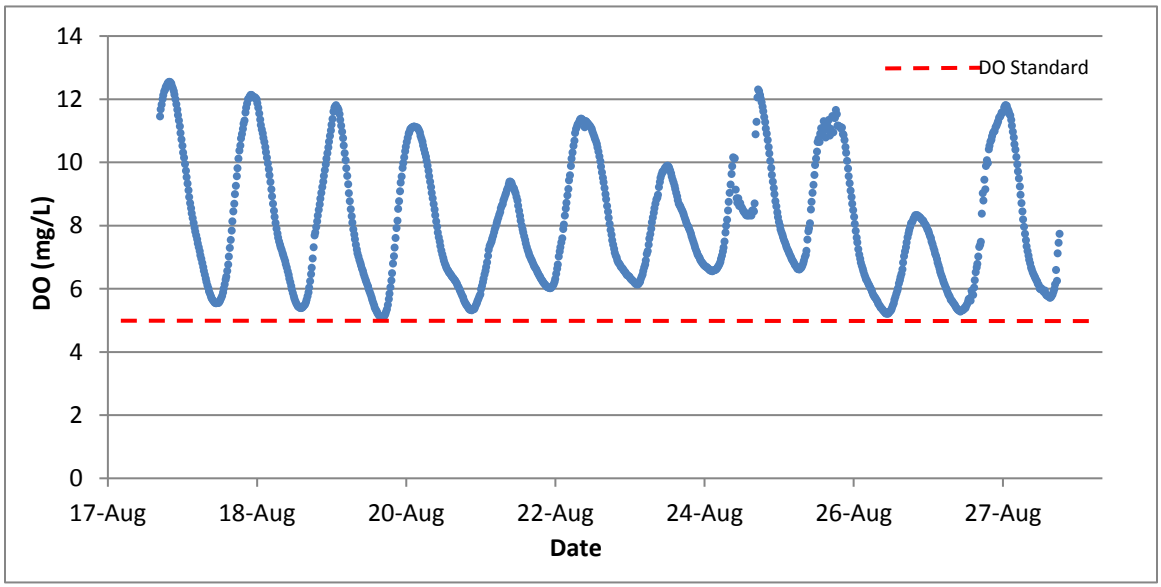


Figure 16. Continuous DO data for Site W71054001 along Hay Creek.

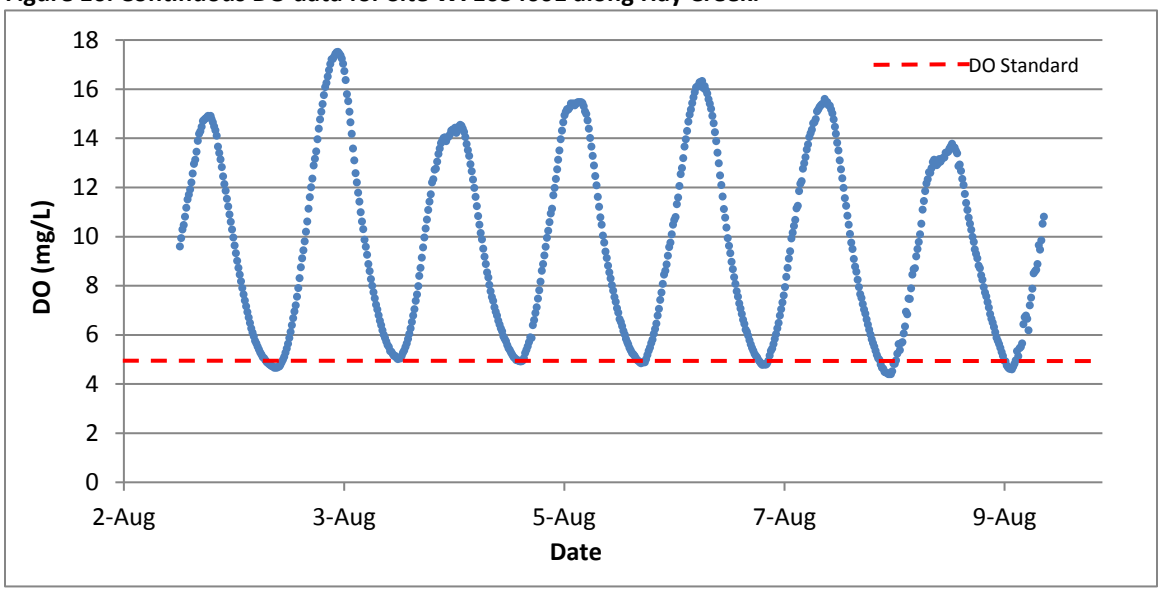
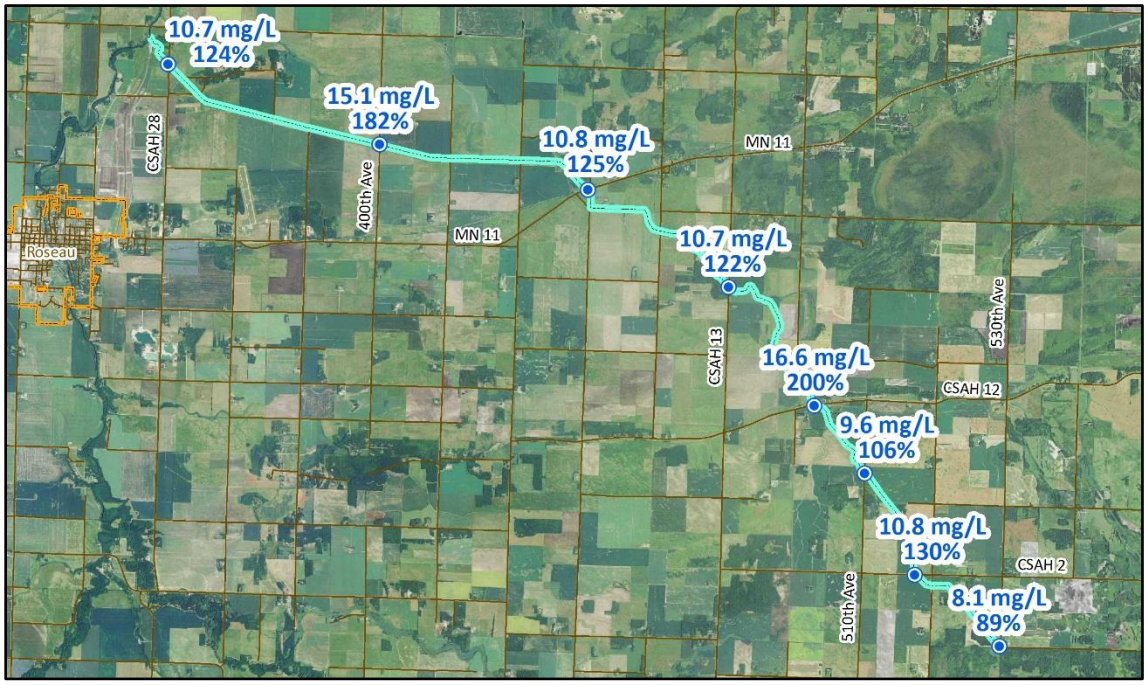


Figure 17. Hay Creek longitudinal DO survey (August 17, 2017) results.



Eutrophication-related data for Hay Creek includes the following parameters: TP and DO flux. The MPCA biological monitoring staff collected a discrete water quality sample at Stations 05RD084 and 05RD043 along Hay Creek at the time of each of the six monitoring visits. The samples were analyzed for several parameters, including TP. The stations had TP concentrations ranging from 19 to 96 µg/L, with three values exceeding the 50 µg/L North River Nutrient Region TP standard. Discrete TP data are also available for Sites S002-105 (2001-2015; *n*=57), S002-106 (2002-2013; *n*=42), and S004-135 (2003-2012; *n*=50). Collectively, the mean TP concentration for the sites was 98 µg/L, while the highest concentration was 786 µg/L and the lowest concentration was 12 µg/L. Approximately 62% of the values exceeded the TP standard. The mean daily DO flux documented during continuous DO monitoring at Sites W71049003 (5.0 mg/L) and W71054001 (9.8 mg/L) was well above the 3.0 mg/L North River Nutrient Region standard. In addition, the MPCA biological monitoring staff noted an excessive amount of algae at

Station 05RD043 during the August 17, 2016, macroinvertebrate monitoring visit, as well as at Station 05RD084 during the August 4, 2015, fish monitoring visit and the August 24, 2016, macroinvertebrate monitoring visit. The MPCA SID staff also documented supersaturated DO levels and excessive algae and aquatic macrophyte growth along Hay Creek during an August 17, 2017, longitudinal synoptic survey. While Hay Creek is prone to high TP concentrations, additional response variable data are needed to determine if eutrophication is adversely affecting the DO regime of Hay Creek.

Biological response: Fish

Dissolved oxygen concentrations can alter the biological community by limiting species that are intolerant of low levels for an extended period of time, along with species that are sensitive to dramatic shifts in concentration (Davis 1975, EPA, 2012). According to Table 24, Hay Creek scored above the statewide average for indices pertaining to dissolved oxygen stressors. The available data ***neither supports nor weakens*** the case for low dissolved oxygen as a stressor to the fish community of Hay Creek (Table 24).

Table 24. Summary of biological indices for Hay Creek compared with the statewide Class 6 streams (A – upstream Station 05RD084) and Class 5 streams (B- downstream Station 05RD043) that support a healthy fish community.

***A**: 05RD084*

Metric	Description	Statewide score[1] [mean ± SD]	Hay Creek score [mean ± SD]	Station (score)	*Station (2005 score[2])*
DO TIV	Mean DO (mg/L) tolerance indicator value	6 ± 1	7	05RD084 (7)	*05RD084 (6)*
CondProb	Probability of meeting the dissolved oxygen standard	25 ± 16	57	05RD084 (57)	*05RD084 (11)*
***B**: 05RD043*					
DO TIV	Mean DO (mg/L) tolerance indicator value	7 ± 1	7 ± 0	05RD043[15] (7) 05RD043[16] (7)	*05RD043 (7)*
CondProb	Probability of meeting the dissolved oxygen standard	40 ± 19	42 ± 0.4	05RD043[15] (42) 05RD043[16] (41)	*05RD043 (54)*

[1] Statewide score includes stations that provide General Use habitat within the same IBI class and meet or exceed the applicable IBI threshold.

[2] 2005 data were not used for the purposes of assessment; data were outside of 10-year assessment window.

[15] 2015 sampling event at Station 05RD043 occurring on August 19, 2015.

[16] 2016 sampling event at Station 05RD043 occurring on August 16, 2016.

Good: Score for the impaired reach met or was equal to the statewide average.

Fair: Score for the impaired reach failed to meet the statewide average but was within the standard deviation range.

Poor: Score for the impaired reach failed to meet the statewide average and was outside the standard deviation range.

Biological response: Macroinvertebrate

Low dissolved oxygen can especially limit the taxa for the orders of, Ephemeroptera, Plecoptera, and Tricoptera (EPT). The EPT individuals favor environments that provide adequate dissolved oxygen, including riffles and swift aerated portions of the stream channel. According to Table 25, Hay Creek is limited in species that are intolerant to low DO and contains a higher abundance of species that are tolerant to low DO compared to the statewide average. The available data ***somewhat supports*** the case for low dissolved oxygen as a stressor to the macroinvertebrate community of Hay Creek.

Table 25. Summary of biological indices for Hay Creek (Stations 05RD084 and 05RD043) compared with the statewide Class 3 streams that support a healthy macroinvertebrate community.

Metric	Description	Statewide score[1] [mean ± SD]	Hay Creek score [mean ± SD]	Station (score)	*Station (2005 score[2])*
DO TIV	Mean DO (mg/L) tolerance indicator value	7 ± 0	6 ± 1	05RD084[15] (5) 05RD084[16] (6) 05RD043[15] (6) 05RD043[16] (8)	*05RD084 (7)* *05RD043 (8)*
TolDO	Relative abundance (%) of low DO tolerant taxa	8 ± 10	17 ± 15	05RD084[15] (9) 05RD084[16] (37) 05RD043[15] (18) 05RD043[16] (3)	*05RD084 (21)* *05RD043 (42)*
InTolDO	Relative abundance (%) of low DO intolerant taxa	24 ± 15	6 ± 8	05RD084[15] (1) 05RD084[16] (8) 05RD043[15] (0) 05RD043[16] (16)	*05RD084 (12)* *05RD043 (1)*

[1] Statewide score includes stations that provide General Use habitat within the same IBI class and meet or exceed the applicable IBI threshold.

[2] 2005 data were not used for the purposes of assessment; data were outside of 10-year assessment window.

[15] 2015 sampling events at Stations 05RD084 occurring on August 4, 2015 and 05RD043 on August 19, 2015.

[16] 2016 sampling events at Station 05RD084 occurring on August 24, 2016 and 05RD043 on August 17, 2016.

Good: Score for the impaired reach met or was equal to the statewide average.

Fair: Score for the impaired reach failed to meet the statewide average but was within the standard deviation range.

Poor: Score for the impaired reach failed to meet the statewide average and was outside the standard deviation range.

Summary of stressors

The evidence suggests that the F-IBI impairment associated with Hay Creek is attributed to insufficient physical habitat and high-suspended sediment stressors, and to a lesser extent, flow regime instability. Additionally, the macroinvertebrate community displays the same trend, as well as some sensitivity to low dissolved oxygen. Additional data are needed to determine if eutrophication is effecting the dissolved oxygen regime. Hay Creek experiences high peak flows; however, the connection to groundwater sustains baseflow and alleviates stressors caused by low-flow and stagnant conditions. Hay Creek is entirely channelized and entrenched with no access to a floodplain during large flood events. These conditions cause in-channel erosion and deposition of fine sediments on the stream bottom. Hay Creek offers riffles with course substrate; however, embeddedness is limiting the habitat utilized by fish and macroinvertebrates. Hay Creek would benefit from re-establishing the natural channel and morphology along with additional water detention/retention over the upland landscape.

3.2.3 Pine Creek (AUID 542)

Physical setting

Pine Creek (AUID 542) (Figure 18) extends from its confluence with an unnamed creek, located near 410th Street, to its confluence with the Roseau River, located within the Roseau Lake Wildlife Management Area; a total length of six miles (herein referred to as "Pine Creek"). Pine Creek has a subwatershed area of 98 square miles (62,714 acres); however, 84% of the area lies in Canada. The United States (US) portion of the subwatershed contains 22 miles of intermittent drainage ditch, five miles of perennial stream (i.e., Pine Creek), two miles of perennial drainage ditch, and one mile of intermittent stream (DNR, 2003). According to the MPCA (2013), 91% of the watercourses in the subwatershed (US only) have been physically altered (i.e., channelized, ditched, or impounded), including 90% of Pine Creek. The NLCD 2011 (USGS, 2011) lists cultivated crops (45%) and wetlands (33%) as the predominant land covers in the subwatershed (US only). Other notable land cover groups in the subwatershed (US only) included hay/pasture (7%), open water (6%), forest (4%), developed (4%), and shrub/scrub (1%).

Figure 18. Map of Pine Creek and associated biological monitoring station and water quality/flow monitoring sites (2013 NAIP aerial image).

Biological impairments

Fish (F-IBI)

On September 2, 2015, and August 16, 2016, the MPCA monitored the fish community of AUID 542 at Station 15RD029 (0.1 mile downstream of the CR 118 crossing). The location of the station is shown in Figure 18. The station was designated as General Use within the Northern Streams F-IBI Class (Class 5). Accordingly, the impairment threshold for the station is an F-IBI score of 47. According to Table 26, both sampling events indicate severe impairment with F-IBI scores of 0 and 29. In 2015, only one common carp was encountered during the sampling period. The 2016 sampling event indicated an improvement in the fish community as only seven species were encountered; however, the IBI score remained well below the threshold, indicating a fish impairment. The Pine Creek subwatershed has been heavily altered and indicates non-support for fish.

Table 26. Summary of fish monitoring data for Station 05RD029 along Pine Creek.

Species	05RD29	
	2015	2016
brook stickleback	X	36
central mudminnow	X	85
common carp	1	X
creek chub	X	2
fathead minnow	X	2
northern pike	X	1
northern redbelly dace	X	2
white sucker	X	1
F-IBI scores	**0**	**29**

Candidate causes

Loss of longitudinal connectivity

Available data

The biological monitoring staff observed a beaver dam while sampling at Station 15RD029 (Figure 19). According to the DNR (2014), there are no man-made dams along Pine Creek. The MPCA SID staff completed a longitudinal survey of Pine Creek on August 9, 17, 28, and September 28, 2017. Staff viewed all of the road crossing on the reach as part of the assessments. No obstructions to connectivity (e.g. perched culverts and beaver dams) were identified. However, staff documented barriers due to flow regime instability through the reduction of baseflow and associated impacts to sediment transport (see flow regime instability section). In addition to the surveys, MPCA SID staff performed a detailed review of a May 8, 2013, aerial photo (courtesy of Google Earth) of Pine Creek. Several private road crossings were identified that could potentially cause a disconnect in biological passage (Figure 19). However, it is unknown whether velocity barriers caused by culverts or private road crossings impede passage along Pine Creek. Overall, Pine Creek periodically experiences a loss of connectivity.

Figure 19. Bottom right photo taken by biological monitoring staff of a beaver dam located at Station 15RD029 on Pine Creek. Photo was captured on September 1, 2015. Top right and left and bottom left photos, created using Google Earth, documenting private road crossings located downstream of Station 15RD029 on Pine Creek. Photos were captured on May 8, 2013.

Biological response: Fish

A waterway that is not longitudinally connected results in an inability for migratory fish to gain access to spawning grounds or different suitable habitats required for certain life history stages (Saunders, 2007). Dams often result in changes to the natural habitat, causing sensitive species to decline in abundance along with the overall diversity (Poole, 2002; Aadland, 2015; Gardner, et al. 2013; Cross et al., 2013). Long-lived and late maturing species require well-connected habitat for various life history stages, including spawning and fixed retreats. According to Table 27, Pine Creek scored a zero for the abundance of late-maturing females, which is below the statewide average and outside the confidence interval. The relative abundance of migratory taxa in Pine Creek was below the statewide average but within confidence interval. The available data ***somewhat supports*** the case for connectivity as a stressor to the fish community of Pine Creek.

Table 27. Summary of biological indices for Pine Creek (Station 15RD029) compared with the statewide Class 5 streams that support a healthy fish community.

Metric	Description	Statewide score[1] [mean ± SD]	Pine Creek score [mean ± SD]	Station (score)
MgrTxPct	Relative abundance (%) of taxa that are migratory	20 ± 8	7 ± 10	15RD029[15] (0) 15RD029[16] (14)
MA>3-TolTxPct	Relative abundance (%) of taxa with a female mature age of equal to or greater than three years, excluding tolerant taxa	17 ± 11	0 ± 0	15RD029[15] (0) 15RD029[16] (0)

[1] Statewide score includes stations that provide General Use habitat within the same IBI class and meet or exceed the applicable IBI threshold.

[15] 2015 sampling event at Station 15RD029 occurring on September 2, 2015.

[16] 2016 sampling event at Station 15RD029 occurring on August 16, 2016.

Good: Score for the impaired reach met or was equal to the statewide average.

Fair: Score for the impaired reach failed to meet the statewide average but was within the standard deviation range.

Poor: Score for the impaired reach failed to meet the statewide average and was outside the standard deviation range.

Flow regime instability

Available data

According to the MPCA (2013), 91% of the watercourses in the subwatershed (US only) have been physically altered (i.e., channelized, ditched, or impounded), including 90% of Pine Creek. On August 17, 2016, the MPCA biological monitoring staff encountered "hardly any flow" at Station 15RD029 (Figure 20). The USGS conducted continuous flow monitoring at Site E71024001 (near 410th Street crossing) between 1928 and 1953; the location of the site is shown in Figure 18. According to Figure 21, there was a discernable increase in mean flow values starting in 1941. Table 28 provides the percentile flow values for the site from 1928 to 1940, as well as 1941 to 1953. The percentile values for the latter period were substantially higher than the earlier period. Over the entire period of monitoring, the data suggests that Pine Creek had a relatively stable flow regime, with ample baseflow. Flow monitoring was discontinued after 1953. In 1953, the Canadian government completed the construction of the eight-mile-long Pine Creek Diversion. The channel, which was built under a joint agreement between the province of Manitoba and the state of Minnesota, diverts flow from approximately the uppermost two-thirds of the Pine Creek Subwatershed, to the Roseau River Wildlife Management Area. The original design plan included a dike across the inlet, with a 36-inch culvert and a control gate to regulate flow into the diversion. In an effort to quantify the impact of the diversion on the discharge of Pine Creek, MPCA staff conducted flow measurements on Pine Creek and the Pine Creek Diversion on October 19, 2017. Contrary to the design plan, there was no dike or control structure at the inlet of the diversion (Figure 22) and the diversion channel was capturing all of the flow from the Canadian portion of Pine Creek. The depth of water in the diversion channel would need to be approximately four feet in order for flow to spill into the original downstream channel of Pine Creek (Figure 22). The diversion channel had mean flow at the Road 1N crossing (0.7 mile downstream of the confluence with Pine Creek) of 16.4 cfs. Comparatively, Pine Creek had a mean flow at CR 118 (6.5 miles downstream of the confluence with the diversion channel) of 7.0 cfs. Therefore, the diversion channel was capturing approximately 70% of the discharge of Pine Creek. In addition, the MPCA SID staff conducted reconnaissance along Pine Creek on four separate dates (i.e., August 2, 2017, August 9, 2017, September 28, 2017, and October 19, 2017) and documented flow conditions. Minimal flow (≈0.1 cfs) was noted at Station 15RD029 on August 2, 2017 (Figure 20) and August 9, 2017. Overall, the available data suggest that Pine Creek is prone to extended periods of minimal to no flow.

Figure 20. Images of low flow conditions along Pine Creek, including Station 15RD029 on August 17, 2016 (left) and Site S004-291 on August 2, 2017 (right).

Figure 21. Standardized departure for annual mean flow values for Site E71024001 (1928-1953) along Pine Creek.

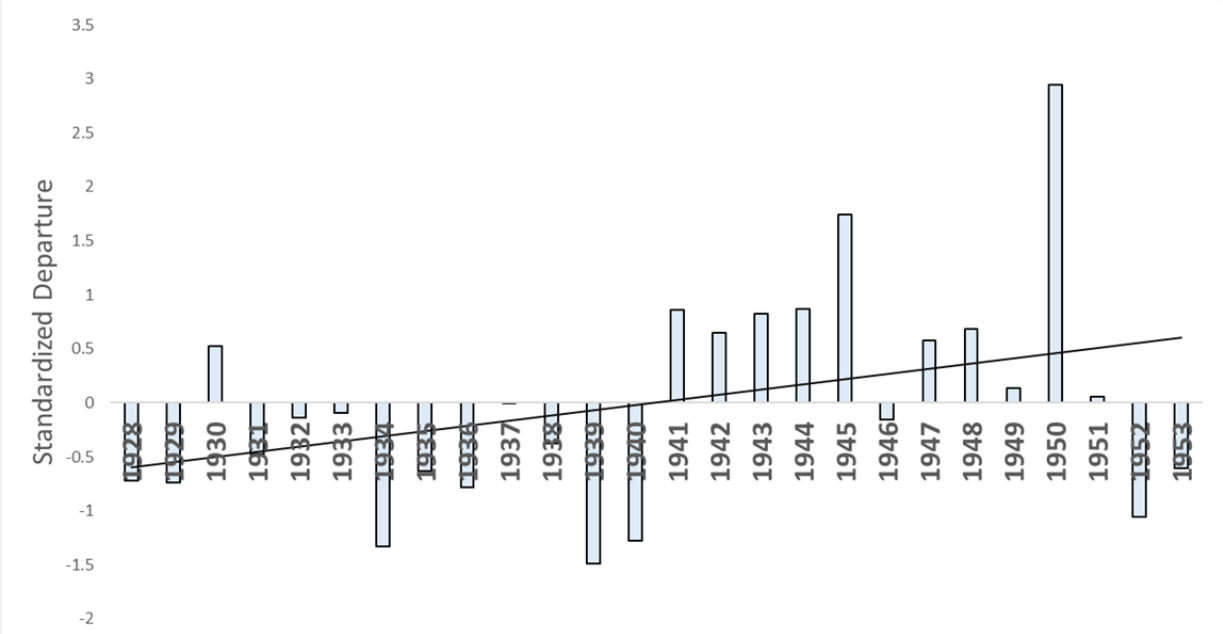


Table 28. Percentile flow values for Site E71024001 along Pine Creek from 1928 to 1940, and 1941 to 1953.

Date range	*n*	Percentile values – Mean daily discharge (cfs)						
		5th	10th	20th	40th	60th	80th	100th
1928-1940	4537	3.2	4.0	5.0	7.0	10.0	22.0	462.0
1941-1953	4659	5.0	6.0	7.4	10.0	17.0	42.0	663.0

Figure 22. Images of Pine Creek (left) and the Pine Creek Diversion (right) on October 19, 2017.

Biological response: Fish

Flow regime instability has been shown to limit species diversity and favor taxa that are generalists, early maturing and short lived, pioneering, and intolerant to disturbances (Aadland et al., 2005; Poff and Zimmerman, 2010). Pine Creek failed to meet the statewide averages in all indices that provide evidence for stressors caused by flow regime instability (Table 29). The available data ***convincingly supports*** the case for flow regime instability as a stressor to the fish community of Pine Creek.

Table 29. Summary of biological indices for Pine Creek (Station 15RD029) compared with the statewide Class 5 streams that support a healthy fish community.

Metric	Description	Statewide score[1] [mean ± SD]	Pine Creek score [mean ± SD]	Station (score)
DomTwoPct	Relative abundance (%) of the two most abundant taxa	61 ± 14	97 ± 4	15RD029[15] (100) 15RD029[16] (94)
GeneralTxPct	Relative abundance (%) of individual that are generalists	25 ± 12	71 ± 40	15RD029[15] (100) 15RD029[16] (43)
MA<2TxPct	Relative abundance (%) of taxa with a female mature age equal to or less than two years	67 ± 12	93 ± 10	15RD029[15] (100) 15RD029[16] (86)
NumPerMeter-Tol	Number of individuals per meter of stream sampled, excluding tolerant species	1 ± 2	0 ± 0	15RD029[15] (0) 15RD029[16] (0)
PioneerTxPct	Relative abundance (%) of taxa that are pioneers	15 ± 6	14 ± 20	15RD029[15] (0) 15RD029[16] (29)
SLvdPct	Relative abundance (%) of individuals that are short-lived	15 ± 19	16 ± 22	15RD029[15] (0) 15RD029[16] (31)
SensitiveTxPct	Relative abundance (%) of sensitive taxa	27 ± 12	7 ± 10	15RD029[15] (0) 15RD029[16] (14)

[1] Statewide score includes stations that provide General Use habitat within the same IBI class and meet or exceed the applicable IBI threshold.

[15] 2015 sampling event at Station 15RD029 occurring on September 2, 2015.

[16] 2016 sampling event at Station 15RD029 occurring on August 16, 2016.

Good: Score for the impaired reach met or was equal to the statewide average.

Fair: Score for the impaired reach failed to meet the statewide average but was within the standard deviation range.

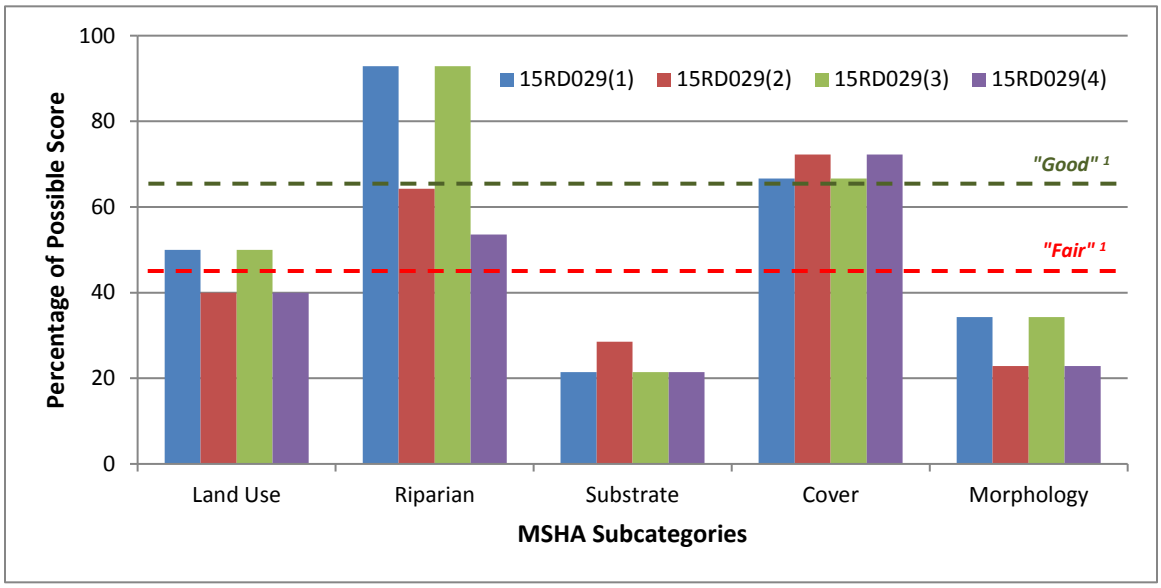
Poor: Score for the impaired reach failed to meet the statewide average and was outside the standard deviation range.

Insufficient physical habitat

Available data

The physical habitat of Pine Creek was evaluated at Station 15RD029 using the MSHA. The station is located along a channelized segment of Pine Creek (MPCA, 2013). The station yielded "fair" MSHA scores (MSHA=46, 40, 37, and 46). Figure 23 displays the MSHA subcategory results for the station. The predominance of agricultural row crops in the immediate vicinity of the station limited its land use subcategory score. While the station had a "wide" to "extensive" riparian zone width, a "heavy" amount of bank erosion was also noted. The station scored uniformly poor in the substrate subcategory due to a lack of riffle habitat and coarse substrate (e.g., cobble and gravel). Conversely, the station scored well in the cover subcategory due to the diversity and "moderate" to "extensive" amount of cover present. Noted cover types included deep pools, logs, macrophytes (emergent, submergent, and floating leaf), overhanging vegetation, and undercut banks. Lastly, the morphology subcategory scores for the station were adversely affected by "moderate" channel stability and "fair" to "poor" channel development.

Figure 23. MSHA subcategory results for Station 15RD029 along Pine Creek.



[1] The minimum percentage of each subcategory score needed for the station to achieve a "fair" and "good" MSHA rating.

On October 25, 2017, Clark and Vinje (2017) completed fluvial geomorphic assessments at Station 15RD029 along Pine Creek. The stream type at this location was estimated to be a B5 (moderate width-to-depth ratio, moderately entrenched, sand bed stream). Based on observations in the field, the potential stream type is likely a E5 (low width-to-depth ratio, slightly entrenched, and bed stream). The station yielded a Pfankuch stability rating of 78 (moderately unstable). Below are excerpts from the assessment summary for Station 15RD029:

> *"During the site visit, the channel appeared to be at bankfull, with very little flow. Small bankfull benches were observed and surveyed near the water surface. On some of the cross-sections, a wider bench was present at a slightly higher elevation. With entrenchment ratios of 2.1 and 1.6 at the riffles, the creek was considered moderately entrenched at this site."*
>
> *"Historically, Pine Creek was likely a highly sinuous E stream type with access to an extensive floodplain; however, channel modifications have cut-off the channel from its historic floodplain and have caused the stream to be confined within a narrow valley made up of spoil piles from where the river was dredged and straightened. Overall, changes in flow regime and channelization have led Pine Creek to become a moderately unstable ditch system that lacks the typical riffle-pool sequences of a meandering stream. Although no longitudinal connectivity issues were observed during the*

geomorphology survey, several private crossings may warrant further inspection to ensure there are no fish passage or stream stability issues associated with them."

In summary, the MSHA data suggest that the physical habitat of Pine Creek is primarily limited by the absence of riffles, lack of coarse substrate, and poor channel morphology characteristics. Clark and Vinje (2017) identified areas of the stream that were unstable and lacked the typical habitat facets of natural meandering stream. These deficiencies can be attributed to the effects of past channelization and flow regime alteration.

Biological response: Fish

Loss of instream zone stability and channel morphology can limit the potential for lithophilic spawners and benthic insectivores (Frimpong et al., 2005; Aadland and Kuitunen, 2006). Pine Creek failed to meet the statewide average in all categories that provide evidence for stressors caused by insufficient physical habitat (Table 30). The available data ***convincingly supports*** the case for insufficient physical habitat as a stressor to the fish community of Pine Creek (Table 30).

Table 30. Summary of biological indices for Pine Creek (Station 15RD029) compared with the statewide Class 5 streams that support a healthy fish community.

Metric	Description	Statewide score[1] [mean ± SD]	Pine Creek score [mean ± SD]	Station (score)
RiffleTxPct	Relative abundance of taxa that predominately utilize riffle habitats	18 ± 10	7 ± 10	15RD029[15] (0) 15RD029[16] (14)
SLithopTx Pct	Relative abundance of taxa that are simple lithophilic spawning species	32 ± 12	7 ± 10	15RD029[15] (0) 15RD029[16] (14)
Insect-TolPct	Relative abundance of individuals that are insectivorous excluding tolerant species	32 ± 25	0 ± 0	15RD029[15] (0) 15RD029[16] (0)
BenInsect-TolTxPct	Relative abundance of taxa that are benthic insectivores, excluding tolerant species	27 ± 9	0 ± 0	15RD029[15] (0) 15RD029[16] (0)
DetNWQT xPct	Relative abundance of taxa that are detritivorous	13 ± 7	64 ± 51	15RD029[15] (100) 15RD029[16] (29)
DarterScul pTxPct	Relative abundance of taxa that are darters and sculpins	18 ± 7	0 ± 0	15RD029[15] (0) 15RD029[16] (0)

[1] Statewide score includes stations that provide General Use habitat within the same IBI class and meet or exceed the applicable IBI threshold.

[15] 2015 sampling event at Station 15RD029 occurring on September 2, 2015.

[16] 2016 sampling event at Station 15RD029 occurring on August 16, 2016.

Good: Score for the impaired reach met or was equal to the statewide average.

Fair: Score for the impaired reach failed to meet the statewide average but was within the standard deviation range.

Poor: Score for the impaired reach failed to meet the statewide average and was outside the standard deviation range.

High suspended sediment

Available data

The MPCA biological monitoring staff collected a discrete water quality sample at Station 15RD029 along Pine Creek at the time of each of three monitoring visits. The samples were analyzed for several parameters, including TSS. The stations had TSS concentrations ranging from 2 to 4 mg/L; which were well below the 30 mg/L standard. The RRW HSPF model estimates that Pine Creek had a TSS concentration in excess of the standard between 27% and 97% of the time during the period of 1995 to 2014. Overall, the available data suggest that Pine Creek experiences at least occasional periods of high suspended sediment.

Biological response: Fish

Excessive TSS can affect a fish community in various ways depending on the concentration and duration of exposure. High TSS often results in a limited fish community that is dominated by tolerant taxa (EPA, 2012). Sediment deposition fills interstitial space in riffles and coarse substrate that is utilized by sensitive lithophilic spawning fish (Bilotta and Brazier, 2008). The deposited material blocks the pores in the streambed, preventing the exchange within the hyporheic zone (Greig et al., 2005). Sedimentation can also degrade the macroinvertebrate community, which can adversely affect insectivore fish species. According to Table 31, the fish community of Pine Creek indicates a decline in taxa that are sensitive to TSS relative to the statewide averages. The available data ***somewhat supports*** the case for high-suspended sediment as a stressor to the fish community of Pine Creek.

Table 31. Summary of biological indices for Pine Creek (Station 15RD029) compared with the statewide Class 5 streams that support a healthy fish community.

Metric	Description	Statewide score[1] [mean ± SD]	Pine Creek score [mean ± SD]	Station (score)
TSS TIV	Mean TSS (mg/L) tolerance indicator value	13 ± 2	26 ± 18	15RD029[15] (39) 15RD029[16] (13)
CondProb	Probability of meeting the TSS standard	80 ± 7	42 ± 58	15RD029[15] (0) 15RD029[16] (83)
SLithopTx Pct	Relative abundance (%) of taxa that are simple lithophilic spawning species	32 ± 12	7 ± 10	15RD029[15] (0) 15RD029[16] (14)
BenInsect Pct	Relative abundance (%) of taxa that are benthic insectivores	22 ± 23	0 ± 0	15RD029[15] (0) 15RD029[16] (0)

[1] Statewide score includes stations that provide General Use habitat within the same IBI class and meet or exceed the applicable IBI threshold.
[15] 2015 sampling event at Station 15RD029 occurring on September 2, 2015.
[16] 2016 sampling event at Station 15RD029 occurring on August 16, 2016.
Good: Score for the impaired reach met or was equal to the statewide average.
Fair: Score for the impaired reach failed to meet the statewide average but was within the standard deviation range.
Poor: Score for the impaired reach failed to meet the statewide average and was outside the standard deviation range.

Low dissolved oxygen

Available data

The MPCA biological monitoring staff collected a discrete DO measurement at Station 15RD029 along Pine Creek at the time of each fish and macroinvertebrate monitoring visit. The DO concentrations were 9.5 mg/L (September 2, 2015), 7.6 mg/L (August 16, 2016), and 7.3 mg/L (August 17, 2016). Figure 24 displays all available discrete DO data for Site S004-291 (CR 118; 2005-2012; *n*=34). Two measurements were below the standard; however, only one of the measurements was collected prior to 9:00 a.m., when values are typically lowest. Generally, the lowest DO levels were in the months of June, July, and August. The MPCA conducted continuous DO monitoring at Site W71024002 (CR 118 crossing) from August 2, 2017, to August 9, 2017; the location of the site is shown in Figure 24. The monitoring results are provided in Table 32, as well as displayed in Figure 25. The site had a substantial proportion (47%) of total values that were below the standard and all of the daily minimum values were below the standard. Additionally, the RRW HSPF model estimates that Pine Creek had a DO concentration below the standard between 90% and 99% of the time during the period of 1995 to 2014. Overall, the available data suggest that Pine Creek likely experiences frequent periods of low DO.

Figure 24. Discrete DO data for Site S004-291 along Pine Creek.

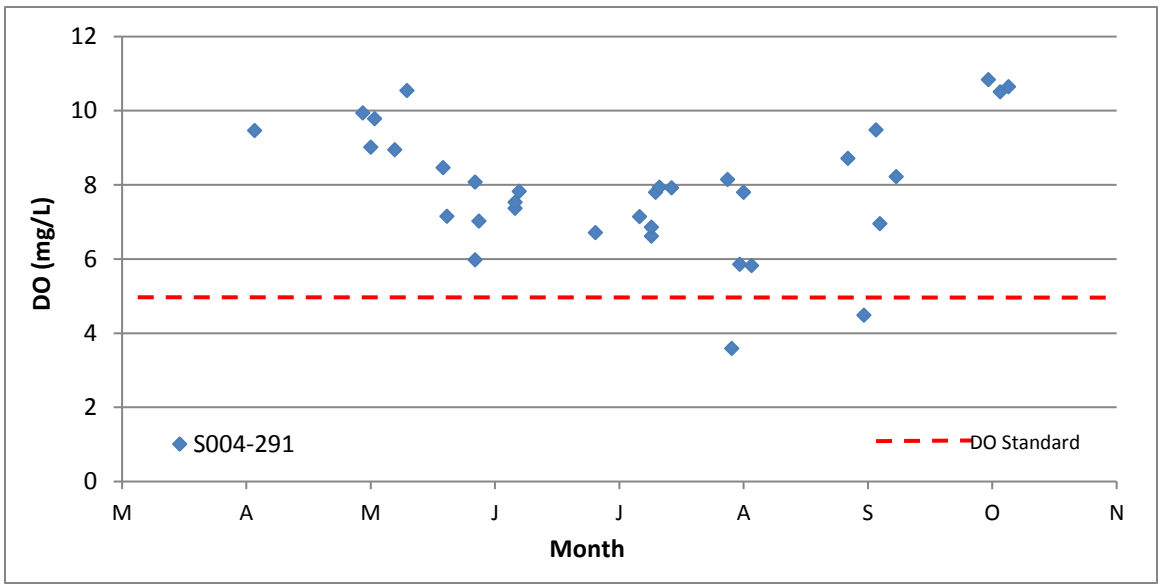
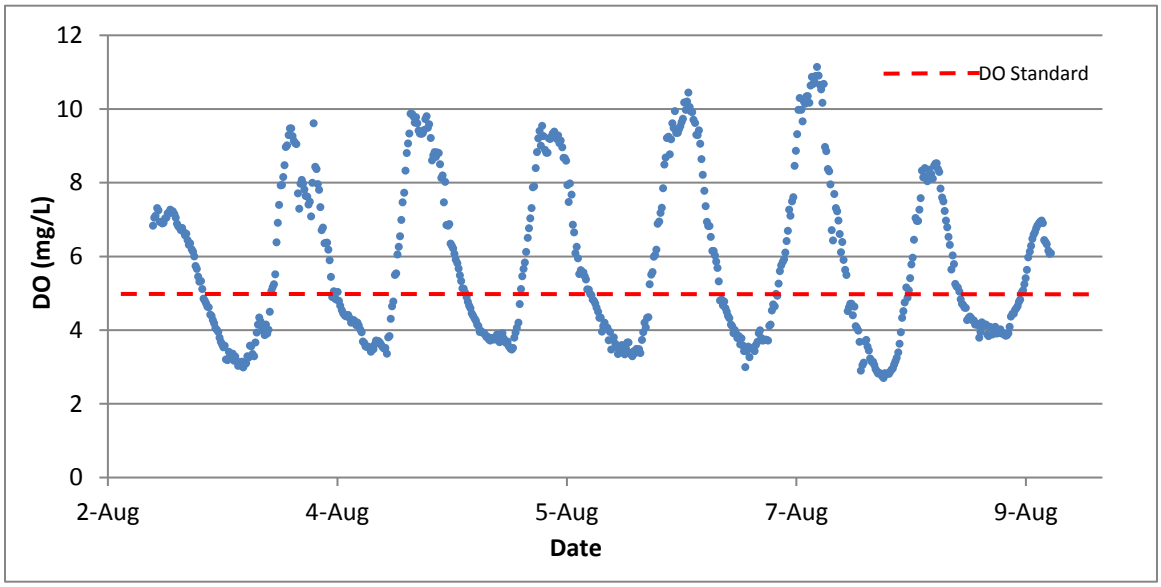


Table 32. Continuous DO data for Site W71024002 along Pine Creek.

Start date - End date	*n*	Max. (mg/L)	Min. (mg/L)	% Total values below standard	% Daily min. values below standard	Mean daily flux (mg/L)
8/2/2017 – 8/9/2017	677	11.1	2.7	47	100	5.8

Figure 25. Continuous DO data for Site W71024002 along Pine Creek.



Eutrophication-related data for Pine Creek includes the following parameters: TP and DO flux. The MPCA biological monitoring staff collected a discrete water quality sample at Station 15RD029 along Pine Creek at the time of each of two fish monitoring visits. The samples were analyzed for several parameters, including TP. The station had TP concentrations of 39 and 61 µg/L; the North River Nutrient Region TP standard is 50 µg/L. Discrete TP data are available for Site S004-291 (2005-2012, *n*=37). The mean TP concentration for the site was 40 µg/L, while the highest concentration was 87 µg/L and the lowest concentration was 15 µg/L. Approximately 30% of the values exceeded the TP standard. The mean daily DO flux documented during continuous DO monitoring at Site W71024002 (Table 32) was 5.8 mg/L, which is well above the 3.0 mg/L North River Nutrient Region standard. In addition, the MPCA biological monitoring staff noted an excessive amount of aquatic vegetation during the August 17, 2016, macroinvertebrate monitoring visit. In addition, MPCA SID staff did not observe any signs of eutrophication (e.g., excessive algal growth) during reconnaissance visits along Pine Creek. While Pine Creek is prone to high TP concentrations, additional response variable data are needed to determine if eutrophication is adversely affecting the DO regime of Pine Creek.

Biological response: Fish

Dissolved oxygen concentrations can alter the biological community by limiting species that are intolerant of low levels for an extended period of time, along with species that are sensitive to dramatic shifts in concentration (Davis 1975, EPA, 2012). Pine Creek failed to meet the statewide average for DO tolerance indicator value and the probability of meeting the dissolved oxygen standard (Table 33). The available data *strongly supports* the case for low dissolved oxygen as a stressor to the fish community of Pine Creek.

Table 33. Summary of biological indices for Pine Creek (Station 15RD029) compared with the statewide Class 5 streams that support a healthy fish community.

Metric	Description	Statewide score[1] [mean ± SD]	Pine Creek score [mean ± SD]	Station (score)
DO TIV	Mean DO (mg/L) tolerance indicator value	7 ± 1	6 ± 1	15RD029[15] (6) 15RD029[16] (5)
CondProb	Probability of meeting the dissolved oxygen standard	40 ± 19	14 ± 12	15RD029[15] (23) 15RD029[16] (5)

[1] Statewide score includes stations that provide General Use habitat within the same IBI class and meet or exceed the applicable IBI threshold.

[15] 2015 sampling event at Station 15RD029 occurring on September 2, 2015.

[16] 2016 sampling event at Station 15RD029 occurring on August 16, 2016.

Good: Score for the impaired reach met or was equal to the statewide average.

Fair: Score for the impaired reach failed to meet the statewide average but was within the standard deviation range.

Poor: Score for the impaired reach failed to meet the statewide average and was outside the standard deviation range.

Summary of stressors

The evidence suggests that the F-IBI impairment associated with Pine Creek is attributed to flow regime instability and insufficient physical habitat and, to a lesser extent, loss of longitudinal connectivity, high-suspended sediment, and low dissolved oxygen. Pine Creek is prone to extended periods of minimal to no flow. This is mainly due to the diversion on the upper portion of Pine Creek that diverts a majority of the flow from Pine Creek into the Roseau River Wildlife Management Area. Pine Creek is prone to low dissolved oxygen caused by the lack of baseflow, especially when exacerbated by connectivity issues (e.g. beaver dams and private road crossings) that further disrupt the flow regime. Soil erosion, caused by the effects of past channelization, has degraded the in-stream habitat causing embeddedness of the streambed and periods of high suspended sediment. Overall, the historical changes in flow regime and

channelization has limited the physical habitat utilized by the fish community of a natural meandering stream. It is recommended to consider the removal of beaver dams and further inspect private road crossing to re-establish longitudinal stream connection and alleviate stressors regarding flow, sediment transport, and low dissolved oxygen. Additionally, with more involvedness, this system would benefit immensely by re-establishing the historical flow regime.

Section 4: Conclusions and recommendations

4.1 Conclusions

Table 34 presents a summary of the stressors associated with the biologically impaired reaches in the RRW. Connectivity barriers (i.e., beaver dams and private road crossings) appear to be adversely affecting fish passage along Pine Creek. Beaver dams have also caused extensive water impoundment along Severson Creek. Each of the biologically impaired reaches are prone to high and quick peak flows and/or prolonged periods of low or no discharge. Historical changes in land cover (e.g., native vegetation to cropland) and drainage patterns (e.g., channelization and ditching) are the primary factors contributing to this flow regime instability. The flow regime of Pine Creek is substantially altered by an upstream diversion located in Canada. Alterations to the natural hydrology of the landscape have also caused the degradation of instream habitat (e.g., loss of facets and embeddedness of coarse substrate) for many of the reaches. The reaches are prone to periods of high suspended sediment. Instream and soil erosion are the primary sources of this sediment. Lastly, low DO is a stressor for Hay Creek and Pine Creek. While the severity of low DO conditions varies amongst the reaches, the lowest concentrations generally occur in the summer, when flow is low and the water temperature is high.

Table 34. Summary of the stressors associated with the biologically impaired reaches in the RRW.

Reach name (AUID suffix)	Biological impairment(s)	Candidate causes[1]				
		Loss of longitudinal connectivity	Flow regime instability	Insufficient physical habitat	High suspended sediment	Low dissolved oxygen
Severson Creek (AUIDs 516, 541)	M-IBI	0	+++	+	+	0
Hay Creek (AUID 505)	F-IBI	0	+	++	+	0
	M-IBI	NE	+	+	++	+
Pine Creek (AUID 542)	F-IBI	+	+++	+++	+	++

[1] **Key:** +++ the available evidence *convincingly supports* the case for the candidate cause as a stressor, ++ the available evidence *strongly supports* the case for the candidate cause as a stressor, + the available evidence *somewhat supports* the case for the candidate cause as a stressor, **0** *neither supports nor weakens* the case for the candidate cause as a stressor, **NE** *no evidence* is available to support the case for the candidate cause as a stressor, and **NA** *not applicable.*

4.2 Recommendations

The recommended actions listed below, as well as included in *The Aquatic Biota Stressor and Best Management Practice Selection Guide* (MPCA, 2016), will help to reduce the influence of or better understand the stressors that are limiting the fish and macroinvertebrate communities of the RRW.

Loss of longitudinal connectivity

- Remove/modify barriers (e.g., dams and private road crossings) that are impeding fish passage.
- Evaluate the potential impact of culverts as velocity barriers to fish passage.

Flow regime instability

- Increase runoff detention/retention efforts to attenuate peak flows and augment base flows.
- Mitigate activities that will further alter the hydrology of the watershed.

Insufficient physical habitat

- Increase runoff detention/retention efforts to attenuate peak flows and augment base flows.
- Establish and/or protect riparian corridors along all waterways, including ditches, using native vegetation whenever possible.
- Reduce soil erosion through the strategic implementation of best management practices (BMPs).
- Incorporate the principles of natural channel design into stream restoration and ditch maintenance activities.

High suspended sediment

- Increase runoff detention/retention efforts to attenuate peak flows and augment base flows.
- Establish and/or protect riparian corridors along all waterways, including ditches, using native vegetation whenever possible.
- Reduce soil erosion through the strategic implementation of BMPs.
- Incorporate the principles of natural channel design into stream restoration and ditch maintenance activities.

Low dissolved oxygen

- Increase runoff detention/retention efforts to attenuate peak flows and augment base flows.
- Reduce soil erosion through the strategic implementation of BMPs.
- Improve agricultural nutrient management.
- Collect additional eutrophication-related data (i.e., TP, Chl-a, and DO flux) for each of the reaches to better understand the relationship, if any, to low DO.

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