Stressor identification

July 2019

Rainy River Headwaters Stressor Identification Report

A study of local stressors limiting the biotic communities in the Rainy River Headwaters Watershed

MINNESOTA POLLUTION CONTROL AGENCY

CLEAN WATER LAND & LEGACY AMENDMENT

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Key terms and abbreviations

ARW	Ash River Watershed
AUID	Assessment unit ID
BANCS	Bank assessment for Non-point source consequences of sediment
BEHI	Bank erosion hazard index
BER	Bank erosion rate
BWSR	Board of Water and Soil Resources
CWLA	Clean Water Legacy Act
DO	Dissolved oxygen
DNR	Minnesota Department of Natural Resources
DRW	Dunka River Watershed
E. coli	*Escherichia Bacteria*
EPA	U.S. Environmental Protection Agency
F-IBI	Fish index of biological integrity
HUC	Hydrological unit code
IBI	Index of biological integrity
IWM	Intensive watershed monitoring
M-IBI	Macroinvertebrate index of biological integrity
MPCA	Minnesota Pollution Control Agency
MPN	Most probable number
MSHA	MPCA Stream Habitat Assessment
NBS	Near bank stress
RRHW	Rainy River Headwaters Watershed
SID	Stressor identification
SWCD	Soil and Water Conservation District
TKN	Total Kjeldahl nitrogen
TMDL	Total maximum daily load
TP	Total phosphorous
TSS	Total suspended solids
USFS	U.S. Forest Service
VNP	Voyageurs National Park
WRAPS	Watershed Restoration and Protection Strategy

Executive summary

Over the past 10 years, the Minnesota Pollution Control Agency (MPCA) has substantially increased the use of biological monitoring and assessment as a means to determine and report the condition of the state's rivers and streams. This basic approach is to examine fish and aquatic macroinvertebrate communities and related habitat conditions at multiple sites throughout a major watershed. From these data, an Index of Biological Integrity (IBI) score can be developed, which provides a measure of overall community health. If biological impairments are found, stressors to the aquatic community must be identified. Stressor Identification (SID) is a key component of the major watershed restoration and protection projects being carried out under Minnesota's Clean Water Legacy Act (CWLA).

This report summarizes SID work in the Rainy River Headwaters Watershed (RRHW). The monitoring and assessment process found no biological impairments on the 64 Assessment Unit IDs (AUIDs) sampled in the RRHW. However, the process identified two aquatic life impairments for TSS (Total Suspended Solids), and one recreational impairment for *Escherichia coli* (*E.coli)* bacteria. Impairments are on the Ash and Blackduck Rivers, located within the Ash River Watershed in St. Louis County near Orr, Minnesota. There are areas within the watershed where land use has the potential to impact stream health. For these reasons, the Ash River Watershed was a priority watershed for SID and pollutant-source assessment work.

The Ash River and the Blackduck River have 2A (Coldwater) Aquatic Life Use Classifications, as do several tributaries to these rivers. The Minnesota Department of Natural Resources (DNR) currently stocks Brown Trout in two tributaries within the Ash River Watershed, providing one of the few recreational trout fisheries for the surrounding community. Stream temperature and biology data available at the time of assessment indicated stream conditions were marginal to support Coldwater fish in given reaches, but adequate to maintain a Coldwater designation. Additional water chemistry data collected during the SID process and further evaluation of the biological communities in lieu of the new water chemistry data suggests that a use classification change to 2B (Warmwater) may be more appropriate in low-gradient and heavily wetland-influenced reaches of the Ash River.

The MPCA also identified the Dunka River HUC-12 watershed as a priority watershed for SID work. Historically designated a Warmwater stream, the biological assessment work found the Dunka River to support Brook Trout in a lower watershed reach. There is interest by the local community and regional resource managers as to whether the headwaters of the Dunka River and its tributaries can also support trout and what elements may be limiting fish movement throughout the system. SID work in the Dunka River aimed to collect additional water chemistry and habitat data to increase our understanding of trout suitability in the Dunka River.

This report summarizes SID monitoring results for the priority watersheds with the goal of informing the Watershed Restoration and Protection Strategy (WRAPS) effort for the RRHW.

1. Report purpose, process, and overview

1.1. Monitoring and assessment

As required by the CWLA, the Minnesota Pollution Control Agency (MPCA) has developed a strategy for improving water quality of the state's streams, rivers, wetlands, and lakes in Minnesota's 81 Major Watersheds. This process is named the Watershed Restoration and Protection Strategy (WRAPS).

A WRAPS is comprised of several types of assessments. The initial phase of WRAPS is called the Intensive Watershed Monitoring (IWM), through which the MPCA and partners characterize the overall health of streams and lakes, and identify impaired waters that do not meet established standards. Results of biological and water chemistry monitoring completed by the MPCA as well as other state, federal, and local organizations are included in this process. This phase of WRAPS occurred between the years of 2014-2016 in the Rainy River Headwaters Watershed (RRHW) and resulted in the completion of the Monitoring and Assessment Report in 2017. An electronic copy of this report can be found by clicking the following link (Link: Rainy River Headwaters Monitoring and Assessment Report).

1.2. Stressor identification

The next phase of WRAPS development is the Stressor Identification (SID) Assessment. This process builds on the results of the IWM, but a greater emphasis is placed on the evaluating various physical and chemical factors that either harm or protect aquatic life in a given stream. Whereas IWM is a non-biased assessment of ecological health, the SID process targets specific locations in a given watershed. The product of the SID process is the identification of the stressor(s) and sources for which a local watershed plan or TMDL may be developed. Most importantly, it can guide potential watershed restoration and protection priorities. More information on the Stressor Identification (SID) process can be found on the U. S. Environmental Protection Agency (EPA) website http://www.epa.gov/caddis/ and the MPCA's "Is your stream stressed?" website. This report is the summary of SID for the RRHW, completed during years 2016-2018.

1.3. Stream health and common stressors

The five major elements of a healthy stream system are hydrology, connectivity, physical form and processes, water chemistry, and stream biology. If one or more of the components are unbalanced, the stream ecosystem may fail to function properly and may result in failure to meet water quality standards or degrade the biological community enough to be listed as an impaired water body. Common stressors to aquatic life include and are not limited to unsuitable stream temperatures or dissolved oxygen (DO), increased or reduced (altered) flow, elevated total suspended solids, and lack of physical habitat. A separate document "Stressors to Biological Communities in Minnesota's Rivers and Streams" has been developed by MPCA describing the various candidate stressors of aquatic biological communities, including where they are likely to occur, their mechanism of harmful effect, and Minnesota's standards for those stressors (MPCA, 2017a). Additional information on Stressor Identification in Minnesota can be found on MPCA's website: https://www.pca.state.mn.us/water/your-stream-stressed.

2. Overview of the RRHW

The RRHW is one of the largest Major Watersheds in Minnesota and is the headwaters of the Rainy River, an important water resource for recreation, water supply, and commerce. The watershed is located within the mixed deciduous and boreal forests of northeast Minnesota along the United States-Canadian border. The Minnesota portion (2954 square miles of drainage area) was assessed through the WRAPS process. An additional 3353 square miles of the watershed, located in Canada, were not assessed through this process. Multiple Minnesota counties are within the watershed border: St. Louis, Cook, Lake, and Koochiching Counties.

2.1. Monitoring and assessment process findings

The MPCA assessed sixty-four stream AUIDs in the RRHW for aquatic life use, recreational use, or both. Although no biological impairments were found based on fish and macroinvertebrate IBI scores, several streams were listed impaired for aquatic life and recreational use based on water chemistry data.

The Ash River Lower (AUID 09030001-818) near Orr, Minnesota, was non-supporting for aquatic life and the nearby Blackduck River (AUID 09030001-820) was non-supporting of both aquatic life and aquatic recreation. More specifically, the Ash River failed to meet the state of Minnesota's water quality standards for total suspended solids (TSS) and the Blackduck River did not meet the standards for TSS or *E.coli* bacteria. Both AUIDS narrowly met the fish IBI threshold for Northern Coldwater streams. Use classifications (Coldwater or Warmwater) for the Ash and Blackduck Rivers were reviewed during the assessment process. The resulting decision was to maintain Coldwater stream designations based on marginal and variable stream temperatures and DNR's interest in managing the watershed for a trout fishery.

Use classifications were also reviewed for the Dunka River, a tributary to Birch Lake that is located in the greater Kawishiwi River Subwatershed. This stream, consisting of two AUIDs, was considered for its viability to support a Coldwater assemblage. A proposed change from Warmwater to Coldwater was recommended for the lower reach of the Dunka River (AUID 09030001-987) based on temperature and biological data. The Dunka River Upper (AUID 09030001-986) remained designated as a Warmwater stream due to the biological community found there. The Dunka River's potential/limitations to support a Coldwater community will be discussed further in this report.

2.2. Stressor identification focus subwatersheds

Typically, the primary focus of MCPA's "stressor identification" monitoring efforts is to identify the cause(s) of impaired stream biological communities (fish/macroinvertebrates). In the RRHW, as well as many of the less impacted areas of Northeast Minnesota, the emphasis of this effort has shifted. Assessing sources of chemistry-based aquatic life and recreational use impairments and investigating stressors that may be limiting (although not impairing) biology were identified as high-priority watershed goals by area natural resource managers. Protecting current conditions to avoid further degradation of the rivers was identified as an equally high priority.

Focus watersheds were selected based on the impaired waters status and input from state (MPCA, DNR, BWSR), federal agency (Voyageurs National Park (VNP), USFS), and local units of government (SWCDs).

Streams impaired for conventional chemistry parameters (Ash and Blackduck Rivers) and marginally meeting fish IBI (F-IBI) thresholds for Northern Coldwater Streams were determined good candidates for focus watersheds. Because this was a watershed approach, SID investigations also focused on upstream reaches and tributaries to impaired AUIDS.

Another focus subwatershed selected was the Dunka River Watershed, located in St. Louis and Lake County, near Babbitt, Minnesota. Although it is not impaired for biology or water chemistry, it supports a native Brook Trout population in the lower reaches that does not extend into the headwaters. Only adult Brook Trout were sampled during the IWM; no young-of-year were found. Evaluating Brook Trout habitat suitability, natural reproduction (spawning areas), and age class distribution in the Dunka River, as well as stressors limiting the migration of Brook Trout into the upper reaches was identified as a priority.

Table 1 summarizes the streams and watersheds evaluated during this study and the primary objective for each specific effort. The location of the study areas are shown in Figure 1. The four primary goals that provided the framework for stressor identification work in the RRHW are listed below.

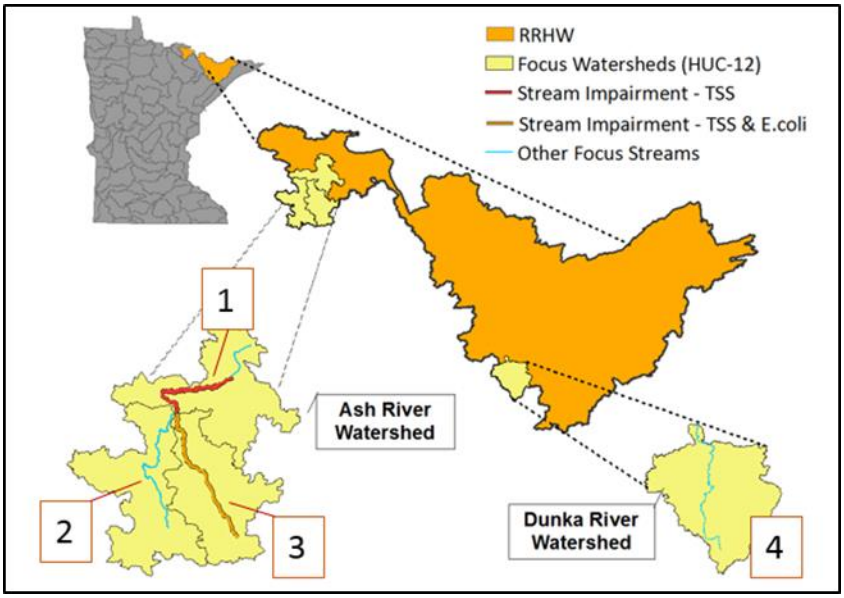
Specific objectives:

1. Evaluate pollutant dynamics and pollutant sources within TSS-impaired and/or *E.coli* impaired watersheds.
2. Evaluate biological response data to determine if there are any symptoms of stress related to increased TSS concentrations in TSS-impaired watersheds.
3. Evaluate current conditions of overall stream health and potential to support a trout fishery.
4. Identify feasible protection and restoration efforts that could sustain or improve stream health.

Table 1. Stressor Identification focus study areas and specific objectives for RRHW.

Focus areas for watershed assessments and problem investigations				
ID	**Stream AUID**	**AUID name**	**Impairments**	**Objective *(see main text)***
1	09030001-818	Ash River Lower	TSS	1,2,3,4
2	09030001-819	Ash River Upper	None	1,2,3,4
3	0903001-820	Blackduck River	TSS, *E.coli*	1,2,3,4
4	09030001-986 and -987	Dunka River	None	3,4

Figure 1. Map of focus watersheds for Stressor identification reporting in the RRHW, which includes 1) Ash River Lower, 2) Ash River Upper, 3) Blackduck River and 4) Dunka River AUIDs.



3. Ash River Watershed

3.1. Ash River Watershed characteristics

The Ash River drains an area of 158 square miles in North St. Louis County, located in Northeast Minnesota north of the city of Orr. The Ash River flows northward 34 miles from the headwaters at Ash Lake to the outlet at Lake Kabetogama in Voyageurs National Park. The river upstream of the lake inlet is divided into four designated stream AUIDs. Ash River Falls, a 35-foot waterfall, marks a divide in the river four miles upstream from the outlet. The MPCA did not monitor the two AUIDs (09030001-821 and -832) located downstream of the falls during the assessment process due to the low-gradient nature of the stream and potential for backwater effects from the lake. The outlet (AUID -832) was monitored for select parameters during the SID process in field season 2017 for more information on the river's water chemistry entering the lake. The two AUIDs (09030001-818 and -819) located upstream of the falls were assessed through the IWM process; they account for 88% of the total river length. We refer to these AUIDs as the Ash River Lower (-818) and the Ash River Upper (-819) respectively.

Tributaries to the Ash River include the Blackduck River, Kinmount, Camp Ninety, Gannon, and numerous other unnamed creeks. The Blackduck River (09030001-820) is the largest tributary and its confluence with the Ash River marks the divide of the Ash River Upper and the Ash River Lower AUIDs. The Blackduck River and the Ash River Upper AUIDs are close to equal in length (16 and 17 miles respectively), have similar drainage areas (50 and 55 mi2 respectively), and flow out of headwater lakes (Blackduck Lake and Ash Lake). The two lakes have similar water chemistry and meet water quality standards. Major tributaries to the Blackduck River are Ninemile Creek and Fawn Creek. The largest tributary to the Ash River Upper AUID is Kinmount Creek.

Because the MPCA uses HUC-12 watershed delineations to define subwatershed boundaries that may or may not align with MPCA stream AUID breaks, the terminology used to identify subwatershed boundaries in this report is defined here. The boundaries are delineated in Figure 1. The Ash River Upper subwatershed refers to the area that drains to the Ash River Upper AUID (09030001-819). The Blackduck River subwatershed refers the area that drains to the Blackduck River AUID (09030001-820). The Ash River Lower subwatershed refers to the area that drains to the Ash River downstream of the Ash River-Blackduck River confluence, including downstream of Ash River falls.

Both lakes and wetlands contribute to hydrological storage in the Ash River Watershed (ARW), occupying 21% of the total watershed area. Most of the storage (86%) is in wetlands. The dominant wetland type is hardwood forest. Coniferous forest, shrub, bog, and marsh wetlands are also present. Total wetland area of the three ARW subwatersheds is close to equal; however, the size and distribution of individual wetlands within the subwatersheds vary. Wetlands in the Ash River Lower tend to be large and closely connected to the stream channels. Conversely, wetlands in the Ash River Upper and Blackduck River subwatersheds are smaller, more abundant, and scattered throughout the drainage. Beaver ponds influence the wetland area within the watershed, producing marsh and wet meadow habitat; they are found in all three subwatersheds, typically on first and second order streams. Although different in design, these hydrologic storage areas are critical features in moderating stream flow and runoff and reducing soil particle transport into streams, particularly in this watershed where soils are highly erosive.

Stream channel slope is a major determinant in stream form and function. For example, it can determine how rapidly a stream can move water and sediment, how often it meanders, and how many riffles and pools there are; all of which relate to stream stability and biological function. Stream slope overall in the Ash River Watershed is low, but there are higher gradient reaches on both the Ash and Blackduck Rivers (Figure 8 and Figure 9). While most of the Ash River Lower is low gradient, slopes of the Blackduck River and the Ash River Upper AUID are more variable. They can be very low (<0.1%) to moderate (>2%) and can alternate between low and moderate multiple time within an AUID.

3.2. Geology and soils in the ARW

Glacial deposits and the underlying bedrock shape the RRHW landscape. Three glacial lobes: the Des Moines, Rainy, and Superior, historically covered the RRHW leaving behind distinct glacial drifts. Drift deposits vary in depth; rock outcrops exposing bedrock are common to the area (Ojakangas et al., 1982). Although most of the RRHW consists of sandy and stony soils of the Rainy and Superior lobes, the Ash River Watershed is mostly covered (84% area) with calcareous, silty-clay soils of the Des Moines lobe (Figure 2). The soil has a high silt content and is highly erodible. Based on DNR's Watershed Health Assessment Framework (WHAF) dataset that uses land slope and soil type in calculating erodibility scores, ARW soils are the most susceptible to erosion in all of the Rainy River Basin (Figure 3). The most erodible soils are found in the Ash River Upper Subwatershed.

Figure 2. Geology of the RRHW and focus subwatersheds. The Ash River Watershed is dominated by fine clays and the Dunka River watershed drains a coarser landscape.

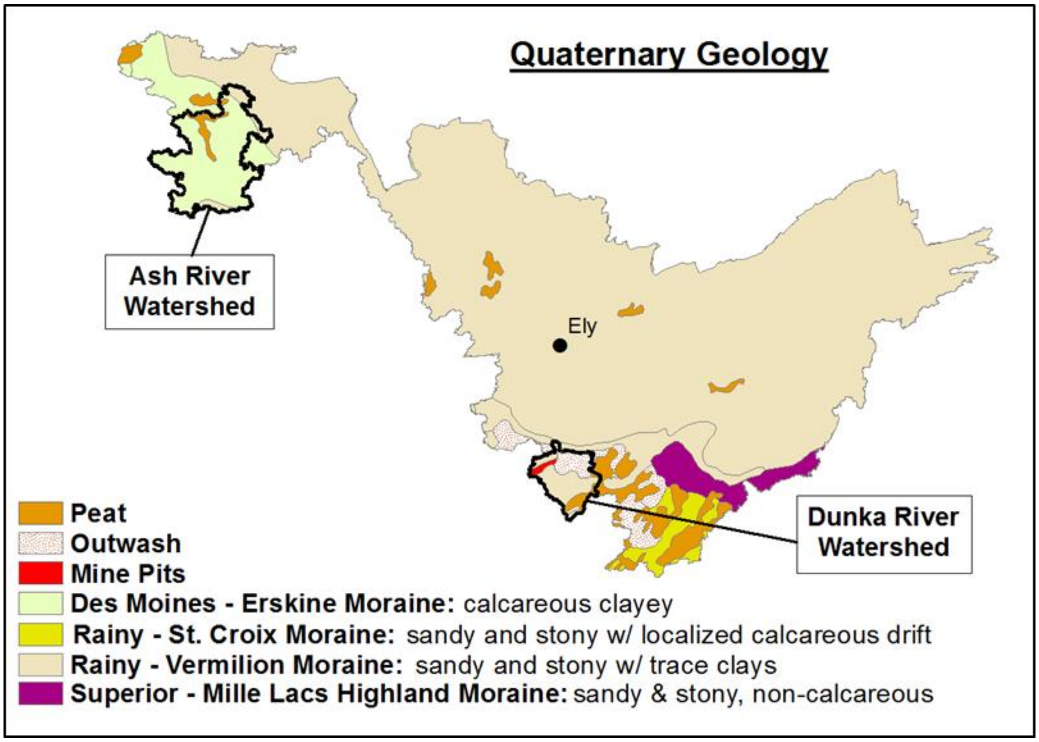
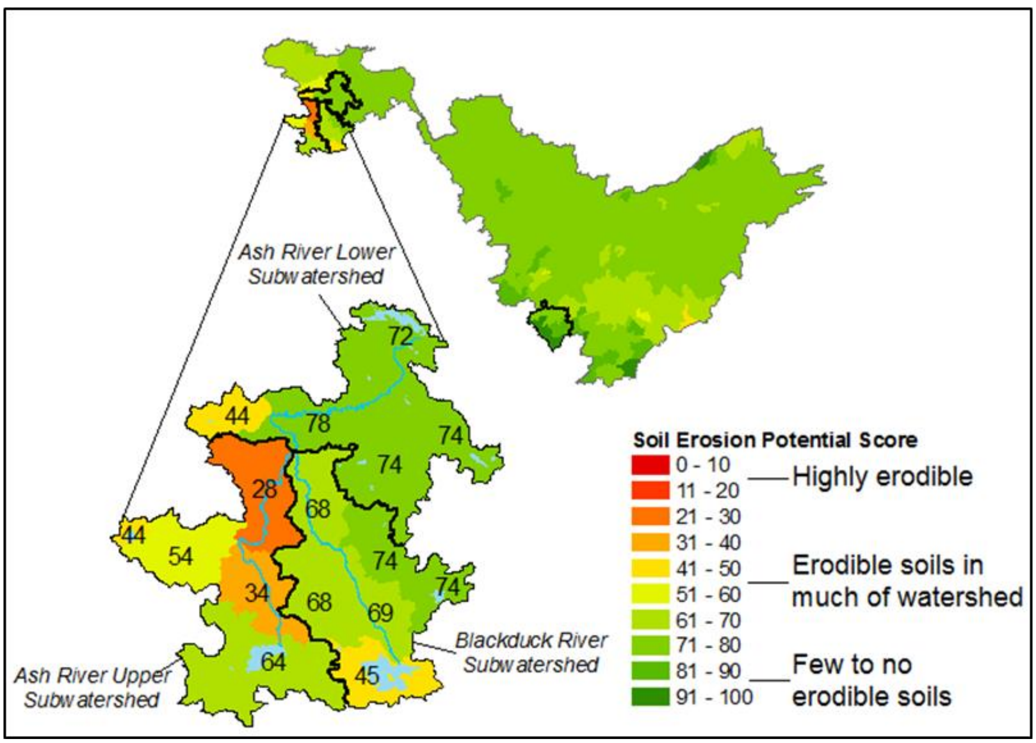


Figure 3. Soil erosion potential map for the RRHW and Ash River (inset), based on Minnesota DNR's Watershed and Health Assessment Framework dataset.



3.3. Land cover and land use in the ARW

Woody wetlands and mixed and deciduous forests cover much of the Ash River Watershed. Flooding of adjacent forests is common, especially where the topography flattens and the stream slope decreases. It is common to find tamarack, cattail, and other plants that tolerate wet conditions mixed within deciduous stands.

Forestry is an active industry in the watershed. A forest change study conducted by the U.S. Park Service (Kirschbaum, 2017) reviewed forest change in eleven RRHW subwatersheds that drain to VNP during years 1995 to 2013, including the ARW. The report found that the ARW had experienced the highest forest disturbance (23% of watershed area) and that harvest was the dominant disturbance agent. The study showed that in the greater VNP drainage, most harvesting had occurred on private and State of Minnesota land, with considerably less harvesting being done on U.S. Forest Service (USFS) land.

Based on St. Louis County parcel data, the Federal government and State of Minnesota own 27% and 36% of land within the ARW respectively. Private ownership accounts for 37% of the land with 25% of that belonging to timber corporations. School trust lands, which is State land set aside to generate revenue for education funding (often from mining and timber harvest) accounts for 7% of the watershed area and is expected to increase to 10% following a land exchange between federal and state governments.

Agricultural land use, primarily in the form of pasture and hay, is found at a small percent (<3%) within the watershed. However, pasture and hay can be found in areas concentrated along stream corridors in the watershed. One of the largest pasture operations in the RRHW is located within the Blackduck River Subwatershed. Cattle graze 1.5 miles of the Blackduck River and over 4 miles of its tributary streams on approximately 1500 acres of mostly cleared land.

3.4. Trout stocking history in the ARW

The Ash River and select tributaries currently support a put-and-take brown trout fishery in some reaches. Historical stocking records prior to 1990 lack detail, but indicate both Brook Trout and Brown Trout were stocked at undocumented locations and varying rates from 1942 to 1989. More recently, the DNR has stocked Brown Trout in two ARW streams: Kinmount Creek (years 2016 and 2018), a tributary to Ash River Upper, and Fawn Creek (annually from years 2013 to 2018), a tributary to the Blackduck River.

The first records of detailed fish population assessments were completed through various efforts by the MPCA and DNR during years 2014-2016. Based on these results, there is no evidence of natural reproduction of trout occurring in the river. Rather, MPCA and DNR data suggest most trout are harvested by anglers or do not survive beyond the stocking year. According to a 2016 DNR population assessment report (DNR, 2016), a stocking of 500 Brown Trout in Kinmount Creek in spring of 2016 resulted in a fall sampling catch of 10 Brown Trout in Kinmount Creek and Ash River. Although catch rates were low, the survey results showed that the fish spread through at least six miles of stream. The same year, Fawn Creek was stocked with 500 Brown Trout; two Brown Trout were captured in the fall season sample (DNR2, 2016). The Fawn Creek stocking site is a popular angling destination, accounting for the low catch rate.

3.5. Overview of biological data in the ARW

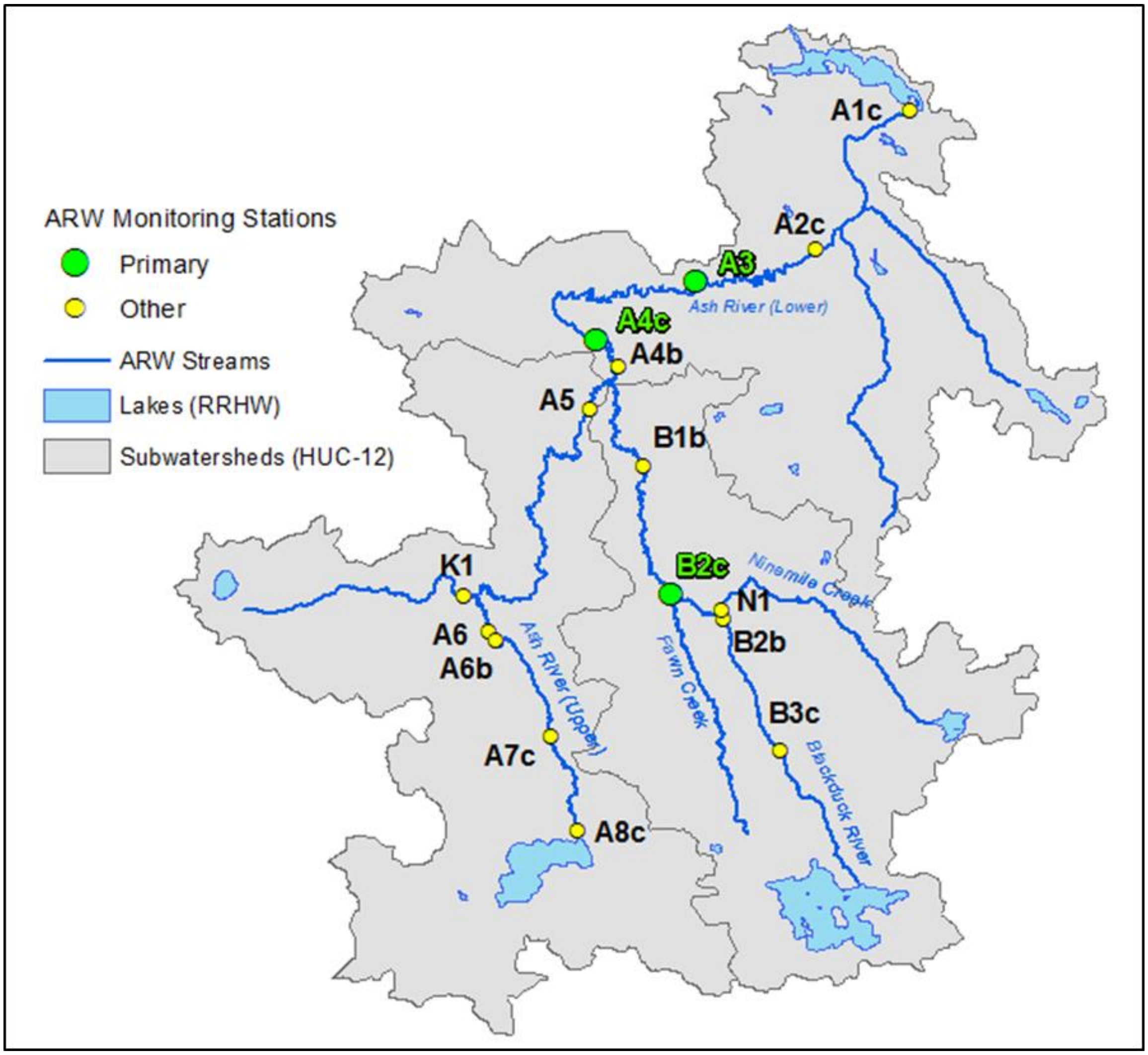
The MPCA assessed six AUIDs for biology in the ARW based on data from eight biological monitoring stations. Two additional stations were surveyed outside of the 10-year assessment period and were considered only for supporting the assessment. The biological assessment results are summarized below. Fish IBI results based on the biological samples are shown in Table 2 for AUIDs assessed as Northern Coldwater Streams. The table reports Warmwater IBI scores as a comparison to Coldwater scores to initiate discussion on stream chemistry expectations in relation to the aquatic communities sampled. Locations of biology and chemistry sampling for the Monitoring and Assessment and SID efforts are shown in Figure 4.

Table 2. Fish-IBI scores under the designated Coldwater 2A fish classes and the Warmwater (2B) fish classes for comparison. CI = confidence limit, NS = Northern Streams, NH = Northern Headwaters. * indicates reach does not fit well into an IBI Fish Class based on its characteristics.

AUID	Site ID	Biology Station	Visit Date	Coldwater IBI	Threshold +/- CI	Warmwater IBI	Warmwater Fish Class	Threshold +/- CI
Ash River (Lower) -818	A3	14RN001	Jul-15	35.0	35 +/- 10	36.2	*NS**	47 +/- 9
	A4b	05RN043	Aug-05	36.8	35 +/- 10	51.0	*NS**	47 +/- 9
Ash River (Upper) -819	A5	14RN012	Sep-14	35.7	35 +/- 10	47.7	NS	47 +/- 9
	A6	14RN099	Sep-14	50.3	35 +/- 10	90.3	NH	42 +/- 16
	A6b	98NF199	Jul-98	35.3	35 +/- 10	71.6	NH	42 +/- 16
Kinmount Ck -823	K1	14RN014	Jul-14	41.9	35 +/- 10	72.5	NH	42 +/- 16
Blackduck River -820	B1b	14RN017	Sep-14	35.9	35 +/- 10	80.1	NH	42 +/- 16
	B2b	14RN018	Jul-14	24.2	35 +/- 10	57.8	NH	42 +/- 16
	B2b	14RN018	Jul-15	32.8	35 +/- 10	64.8	NH	42 +/- 16
Ninemile Ck - 827	N1	14RN021	Jul-14	17.3	35 +/- 10	69.0	NH	42 +/- 16
	N1	14RN021	Jul-15	29.2	35 +/- 10	64.5	NH	42 +/- 16

Description
Below lower CI
Below threshold but within lower CI
Above threshold but within upper CI
Above upper CI
Exceptional score

Figure 4. Map of biological and stressor identification monitoring stations in the Ash River Watershed. Stations denoted with a "b" were biology-only. Stations denoted with a "c" were chemistry-only stations. Stations without a "b" or "c" were sampled for both chemistry and biology.



3.5.1. Ash River Upper -819 and tributary Kinmount Creek

Fish IBI results varied by location and sample year within the Ash River Upper AUID. Two biological monitoring stations (14RN099, 14RN012), sampled in 2014 passed the Northern Coldwater F-IBI with fair to good scores (Table 2). The dominant fish species were Common Shiner and Creek Chub, species tolerant to marginal temperatures. A low number of Mottled Sculpin were the only Coldwater species found in this AUID; however, enough sculpin combined with coolwater species (Brassy Minnow, Northern Redbelly Dace, and Finescale Dace) were present to meet the Coldwater F-IBI at both sites.

Coldwater macroinvertebrate scores in the Ash River Upper AUID were marginal to fair. Some good taxa that indicate healthy conditions were present, but they are more common in Cool/Warmwater communities than Coldwater. Although a few sensitive taxa (mayfly and stonefly) were found, tolerant species such as snails and mites were the most common taxa and very tolerant species such as mosquito larvae were present. The presence of these taxa in addition to the lack of caddisfly species indicate flows were often slow or stagnant.

Kinmount Creek, the main tributary to this AUID, had a fish and invertebrate community similar to that observed in the Ash River Upper. Warmwater species such as Creek Chub and Common Shiner were dominant. Fewer coolwater and no Coldwater species were present. Invertebrates were also more indicative of a Warmwater community. The DNR has stocked this AUID with several trout species, but there was no evidence of a self-sustaining population.

The biological communities in the Ash River Upper and Kinmount Creek consist largely of species that are not typical of a degraded cold-water stream, but instead indicate healthy Cool/Warmwater communities. Even though these AUIDs passed the Coldwater Fish-IBI, they would score significantly higher under the Cool/Warmwater Fish-IBI (Table 2). Ash River sites A6 and A6b as well as the Kinmount Creek site would score above the exceptional use threshold for fish under a Warmwater designation.

3.5.2. Ash River Lower

Fish IBI scores were fair to marginal in the Ash River Lower. The reach marginally met the Coldwater F-IBI due to the presence of several coolwater species in very low numbers, which decreased longitudinally downstream. The survey found a single Coldwater fish (Mottled Sculpin) at station A4b, located in an upstream reach of the AUID. Dominant fish species included Common Shiner, Creek Chub, White Sucker, and Central Mudminnow. Central Mudminnow is a species tolerant to both warm temperatures and low DO.

Only the upstream station A4b was sampled for macroinvertebrates. There were no strongly associated Coldwater taxa present and only a couple often found in Northern Coldwater Streams (Dragonfly *Boyeria*, and the fishfly *Nigronia*). Several tolerant taxa such as mosquito larvae, slack-water beetles, and true bugs indicate flows were slow to stagnant, as does the lack of caddisfly species.

3.5.3. Blackduck River and tributary Ninemile Creek

Fish IBI scores were poor to fair on the Blackduck River. The poorest score, falling below the confidence limit of the IBI threshold, was not factored into the assessment due to extreme low flows in the AUID in 2014. A repeat sample in 2015 resulted in an improved, yet marginal F-IBI score. Cool/Coldwater species observed included Pearl Dace, Finescale Dace, Brassy Minnow, and Mottled Sculpin. All of these species are common in Cool/Warmwater streams as are the dominant species (Creek Chub, Common Shiner, Sucker, and Hornyhead Chub).

The macroinvertebrate survey at the upstream Blackduck River station B2b showed signs of a Coldwater community, scoring above the upper confidence limit for Northern Coldwater Streams. The community had numerous Coldwater taxa including a variety of sensitive stonefly, caddisfly, mayfly, and dragonfly. The macroinvertebrate community at this station indicates that this AUID has isolated reaches with faster flow velocities and/or groundwater spring influence. The downstream station (B1) did not have Coldwater taxa, but did have several taxa indicating good water quality for a Cool/Warmwater stream. The lack of Coldwater taxa at B1 is likely due to the low-gradient wetland-like conditions in the downstream reaches of the AUID.

Similar to the Ash River Upper, the Blackduck River stations would score higher under the Northern Headwater Streams (Cool/Warmwater) Fish IBI. Upstream station B2 would score fair to good and downstream station B1 would score above the exceptional use threshold for fish.

Ninemile Creek, a tributary that discharges to the Blackduck River near site B2, had the same dominant fish species as Blackduck River station B2b; however, the F-IBI score was lower (below the confidence limit) due to less Cool/Coldwater species and no Mottled Sculpin. The macroinvertebrate score was good although the overall assemblage was less representative of a healthy Coldwater community than Blackduck River site B2b. Biology on this AUID was sampled within the same pastured area as station B2; however, the pastured portions of Ninemile Creek have experienced more drastic riparian area loss than the Blackduck River. In addition, a perched culvert near the confluence of the Blackduck River may be negatively affecting biology at the Ninemile Creek biological station.

3.6. Total suspended solids impairments in the ARW

The Ash River Lower and Blackduck River were listed impaired for Total Suspended Solids (TSS) based on more than 10% of the samples exceeding the Coldwater TSS standard (10 mg/L) at the time of the 2017 watershed assessment. Since then, additional samples were collected. The total number of samples and percent exceedances of each the Coldwater and Warmwater standards is shown in Table 3. During the 2017 assessment process, the Ash River Upper was not listed as impaired based on the marginal number of samples collected and a sample record biased to a single season. The most samples collected in the watershed over the longest record were collected on the two impaired reaches, the Ash River Lower and Blackduck River.

Table 3. TSS exceedances in the Ash River and Blackduck Rivers. Reaches that were assessed as impaired for TSS include the Ash River Lower and the Blackduck River (highlighted orange).

	% Exceedences				
	Site	Equis ID	Coldwater (TSS >10 mg/L)	Warmwater (TSS >15 mg/L)	# Samples (n)
Unassessed-832	A1c	S015-009	0	0	18
Ash River (Lower) - 818	A3	S007-902	55%	34%	29
	A4c	S008-622	90%	28%	32
Ash River (Upper) - 819	A5	S008-602	53%	40%	15
	A6	S008-603	28%	7%	14
Blackduck -820	B2c	S007-904	26%	20%	73

3.6.1. Total Suspended Solids methods

TSS was sampled at various locations in the ARW during years 2014 to 2018. The majority of stations in Figure 4 have had TSS collected at least one time. Ash River Lower stations A3 and A4c and Blackduck River station B2 were sampled most frequently (29-73 samples per station) and were considered "primary stations". The data from these stations were influential in the assessment process that resulted in TSS-impairments in the respective reaches. The other (non-primary) stations were sampled less frequently, ranging from two to eighteen TSS samples per station.

In addition to water quality and biology sampling, continuous stream flow and turbidity data were collected on the Ash and Blackduck Rivers at stations A4c and B2. The gage stations were not located at the outlets of the two rivers, as locations were chosen based on accessibility, channel controls, and channel geometry. The Ash River gage was located fifteen miles upstream of the outlet to Kabetogama

Lake. The Blackduck River gage was located eight miles upstream from the outlet to the Ash River. Stream flow was collected years 2017-2018 (and currently through 2019) at both stations.

Turbidity (a surrogate parameter for TSS) was collected during the same years for the Ash River Lower gage (station A4c); however, was only collected during 2017 on the Blackduck River (station B2) due to equipment issues in 2018. Turbidity was measured using a DTS-12 turbidity sensor, an in-stream meter that stores an average of turbidity readings every 15 minutes. The flow and turbidity data in addition to TSS sample collection provided a more in-depth analysis of sediment dynamics in the impaired reaches through development of TSS- load duration curves and comparing flow dynamics to stream turbidity.

A basic model using average TSS concentrations and average flows for each of the five flow regimes provided the flow duration curves (Figures 5 and 6), percent reduction needs (Tables 4 and 5), and lower annual load estimates reported in this Section 3.6. Load duration curves indicate the probability that a flow is exceeded. For example, a 95% exceedance probability would characterize low-flow conditions in a stream, because 95% of all daily mean flows in the record are greater than that amount. Loads were calculated using the average flow and average TSS concentration for each flow regime. When seasonal variability was further incorporated into load computation, annual load estimates increased to the higher values in our reported range. The two different approaches provided a range of TSS loads for each gage. Analysis of seasonal variability and modeling flows to an extended flow period (beyond two years) could result in more precise load calculations for future work.

3.6.2. Review of Total Suspended Solids data

TSS load contributions at the Blackduck River gage were higher than the expected distribution based on upstream drainage areas. Loads at the Ash River flow gage (site A4) were estimated at 692 to 1033 ton/year. Blackduck TSS loads were estimated at 317 to 533 ton/year at the gage (Sheep Ranch Road crossing downstream of B2). The Blackduck River at the gage had 40% of the contributing drainage area, yet contributed 50% of the TSS loads. This did not account for additional loading on the Blackduck River downstream of the Blackduck River gage.

The load duration curves showed different sediment dynamics at the two gage stations (Figure 5 and Figure 6). Coldwater targets for loading were based on the 10 mg/L TSS standard. In 2017, Ash River TSS loads were greater than the Coldwater target for all flow regimes, very low to very high. Contrary, Blackduck River TSS loads were greater than the Coldwater target at high and very high flows (>34cfs) only. At both gages, summer high flows produced higher target exceedances than spring season high flows.

TSS- flow regressions were computed for both gage sites using exponential regression and showed that TSS was most dependent on stream discharge at the Blackduck River gage. There was not a well-defined relationship between TSS and stream flow at the Ash River gage (R^2=0.25). This supports load duration curve findings where TSS was sampled above the Coldwater standard often and across all flow regimes, including low flows. The TSS-flow relationship improved at the Blackduck River gage (R^2=0.53) and further improved (R^2=0.76) when only considering samples collected at discharges greater than 10cfs (75^{th} percentile, low flow regime). For flows less than 10cfs, TSS-flow points clustered in a group, lacking any correlation. This indicates that flows at 10cfs might be a threshold for the Blackduck River to suspend and transport material.

The sediment dynamic differences between the two reaches can also be observed by plotting turbidity and flow data together (Figure 5 and Figure 6) for each site. Turbidity at the Ash River remained at an elevated value relative to the Blackduck River during drier periods. During high flow events, turbidity values were greatest at the Blackduck River gage.

TSS load reduction targets

TSS load reduction targets calculated for the various flow regimes show that different reduction strategies will need to be considered for the two reaches (Table 4 and Table 5). Approximate reductions of 28 to 35% are needed across all flow regimes for the Ash River to meet Coldwater targets. On the Blackduck River, reductions of 32% would be needed to meet high flow targets and 80% would be needed to meet very high flow targets. Because the biology, particularly in the Ash River Lower, indicates that the stream may better support Warmwater biological communities, target reductions for the Warmwater standard (15 mg/L) were calculated as well. To achieve the Warmwater target, only minor reductions (estimated <4%) would be needed on the Ash River Lower, mostly during mid-range flows. The Blackduck River would still need 70% reductions during very high flows.

Figure 5. TSS Load Duration Curve at the Ash River Lower-818 flow gage station for flow and TSS samples collected in year 2017. TSS exceeds the Coldwater target for TSS loading at all flow regimes. For high flows, more exceedances occur during summer months compared to spring. The Warmwater target was also plotted. Continuous turbidity and flow are plotted in the upper right.

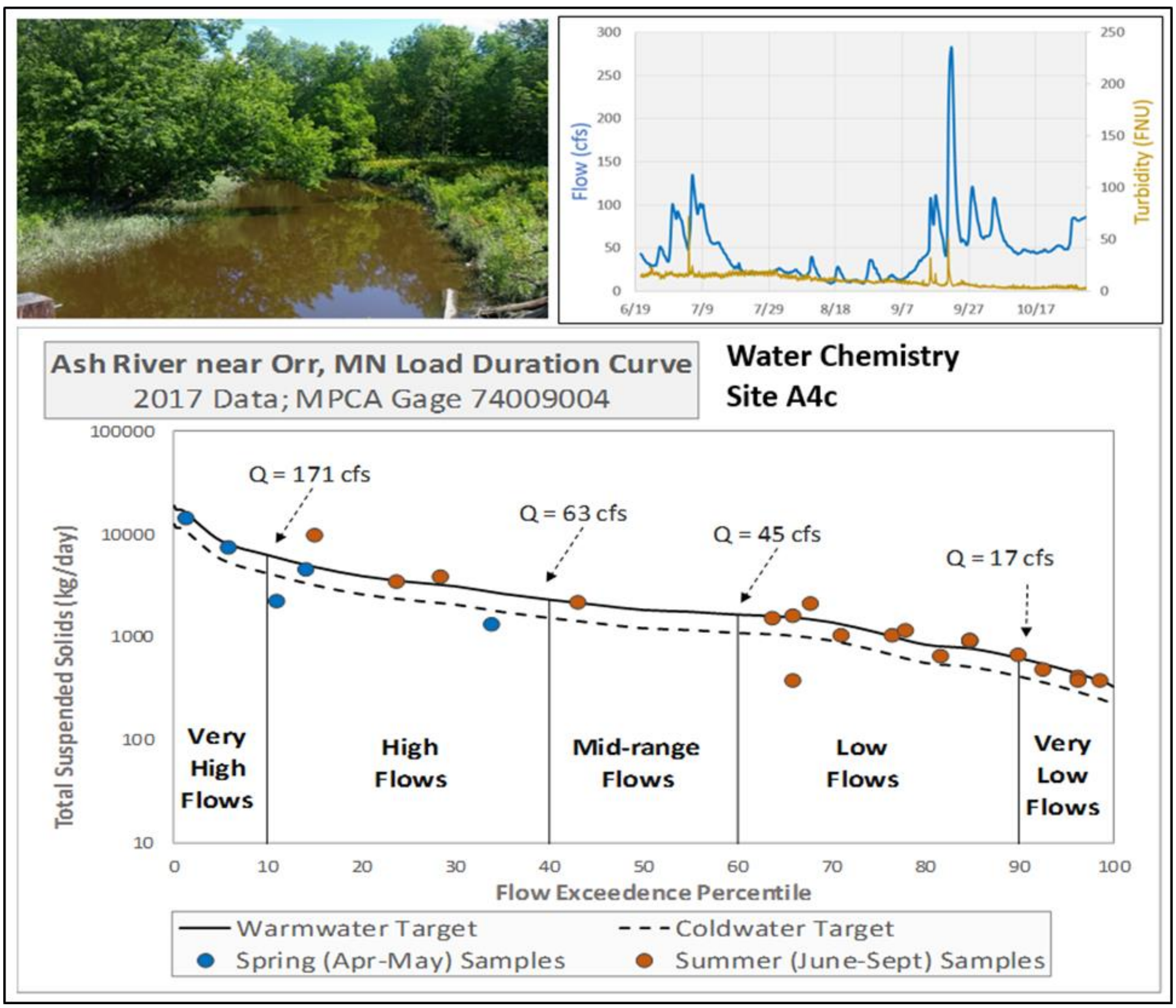


Table 4. Ash River TSS load reduction needs to meet Coldwater and Warmwater Targets. The target was calculated using the average flow for a given regime and the Coldwater and Warmwater TSS standards.

Ash River Gage TSS Load Reduction Needs (%)		
Flow	Coldwater Target	Warmwater Target
Very High	28	0
High	33	0
Mid-Range	35	3.8
Low	33	0.1
Very Low	32	0
*Preliminary, based on 2017 Data Only		

Figure 6. TSS Load Duration Curve at the Blackduck River flow gage station for flow and TSS samples collected in year 2017. TSS exceeds the Coldwater target for TSS loading at high and very high flow regimes. The Warmwater target was also plotted. Continuous turbidity and flow are plotted in the upper right.

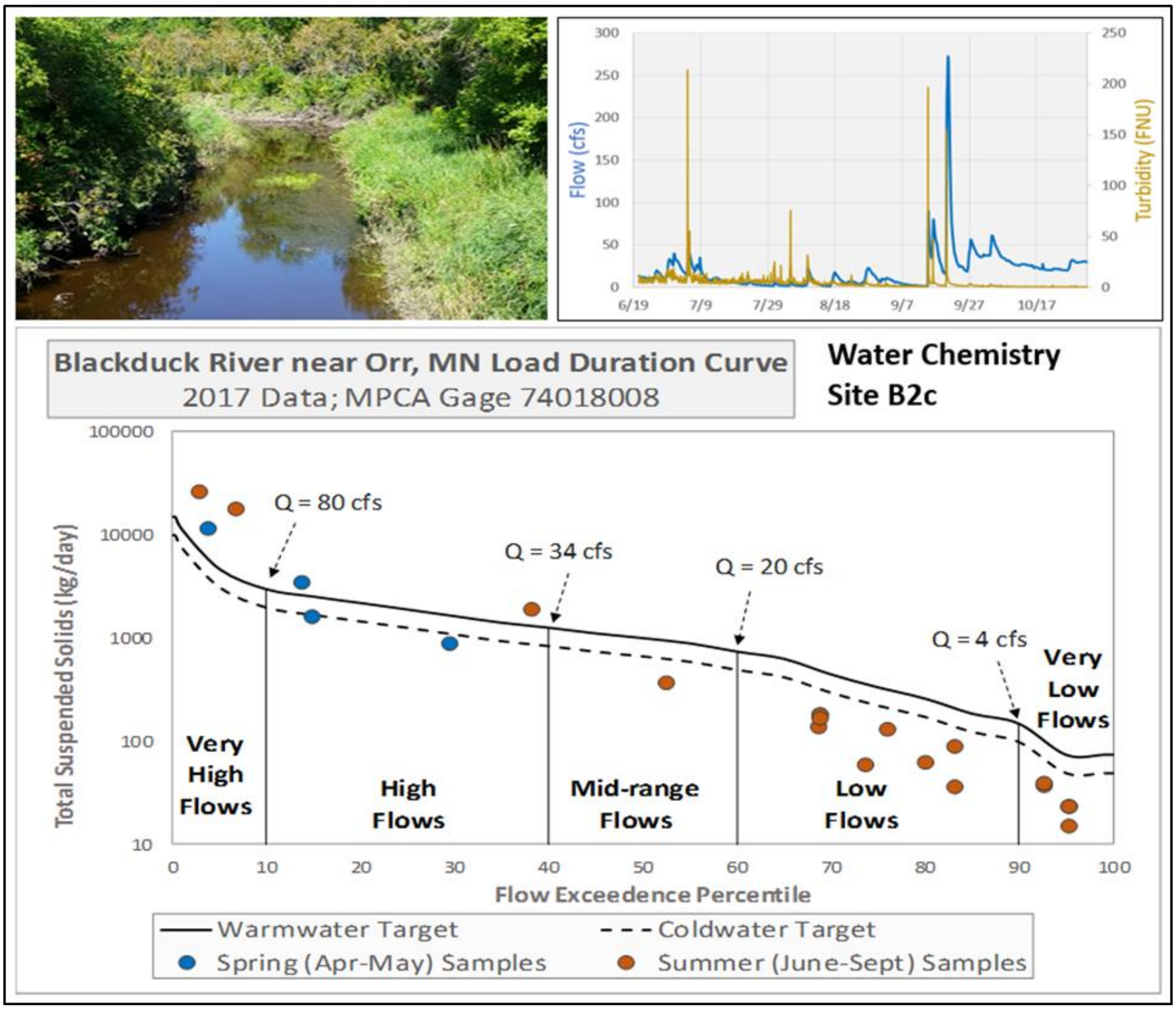


Table 5. Blackduck River TSS load reduction needs to meet Coldwater and Warmwater Targets. The target was calculated using the average flow for a given regime and the Coldwater and Warmwater TSS standards.

Blackduck River Gage TSS Load Reduction Needs (%)		
Flow	Coldwater Target	Warmwater Target
Very High	80	70
High	32	0
Mid-Range	0	0
Low	0	0
Very Low	0	0
*Preliminary, based on 2017 Data Only		

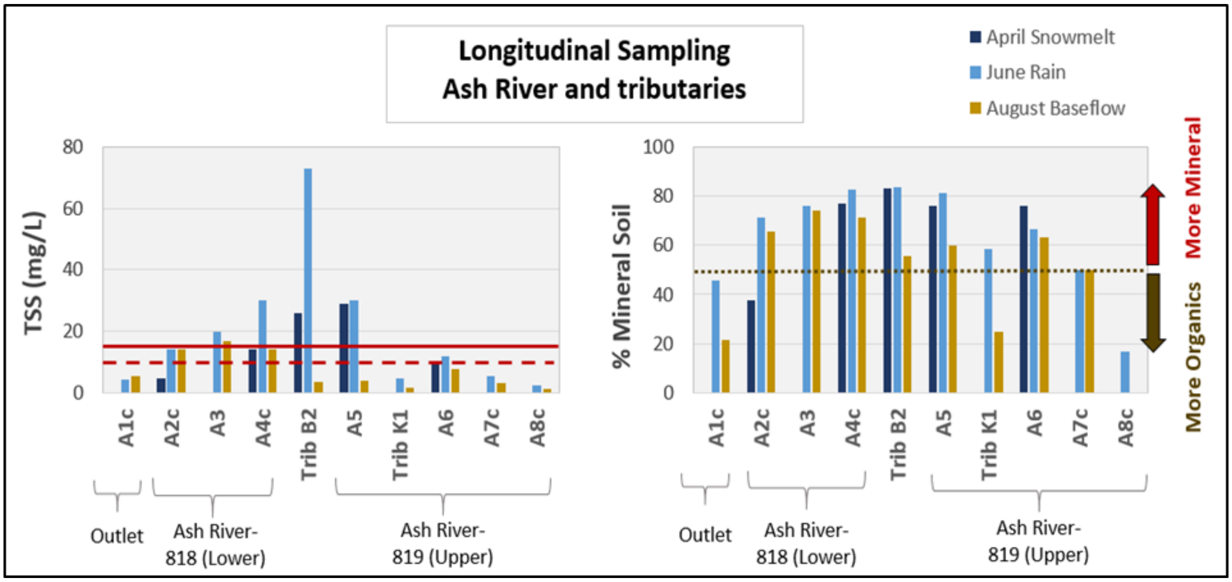
Longitudinal variations in TSS

Changes in TSS concentrations along Ash River were observed through longitudinal sampling of the Ash River and several tributaries. Five to ten water chemistry stations were sampled within a timeframe of a few hours. TSS and Volatile Suspended Solids (VSS) were sampled longitudinally for three flow events (snowmelt, rain, and baseflow). Suspended solid materials were reported as percent mineral soil, calculated as the difference between TSS and VSS divided by TSS. Based on the percent mineral soil, suspended materials were identified as having "more mineral soil" or "more organics."

Most exceedances of the Coldwater TSS standard occurred during the June 2017 rain event. On the Ash River, the Coldwater TSS standard was exceeded downstream of station A5 of the Ash River Upper and all stations in the Ash River Lower AUID. The Blackduck River exceedance was the most severe, with concentrations more than two times greater than reported at other stations. Snowmelt samples exceeded the TSS standard within a shortened reach of the Ash River, between stations A5 and A4c. During baseflow, exceedances of the standard only occurred in the Ash River Lower, across the entire length of the AUID.

In all three scenarios, suspended materials had a higher mineral soil content than organics at locations with exceedances. Data showed that most suspended solids in the ARW were made up of inorganic materials (mineral soil) and that organic material contributed a smaller fraction of the suspended materials. This was particularly apparent at sites located within catchments with highly erodible soils. Organics were higher (>50%) in two reaches: near the outlet of Ash Lake (A7 and A8) and at the outlet of the Ash River (A1). Near the outlet, chemistry may have been influenced by Kabetogama Lake. There, organics were the dominant solid in suspension most (80% of samples) of the 2017 season and TSS concentrations remained below the standard for all flow regimes.

Figure 7. TSS concentrations (left) and percent mineral soil [percentage = (TSS-VSS)/TSS *100] (right) taken longitudinally along the Ash River and on two tributaries during snowmelt, a June rain event, and baseflow of year 2017. The Coldwater (dashed line) and Warmwater (solid line) TSS standards are shown in the left plot. The dashed line in the right plot represents equal proportions (50%) of inorganic/mineral and organic materials.

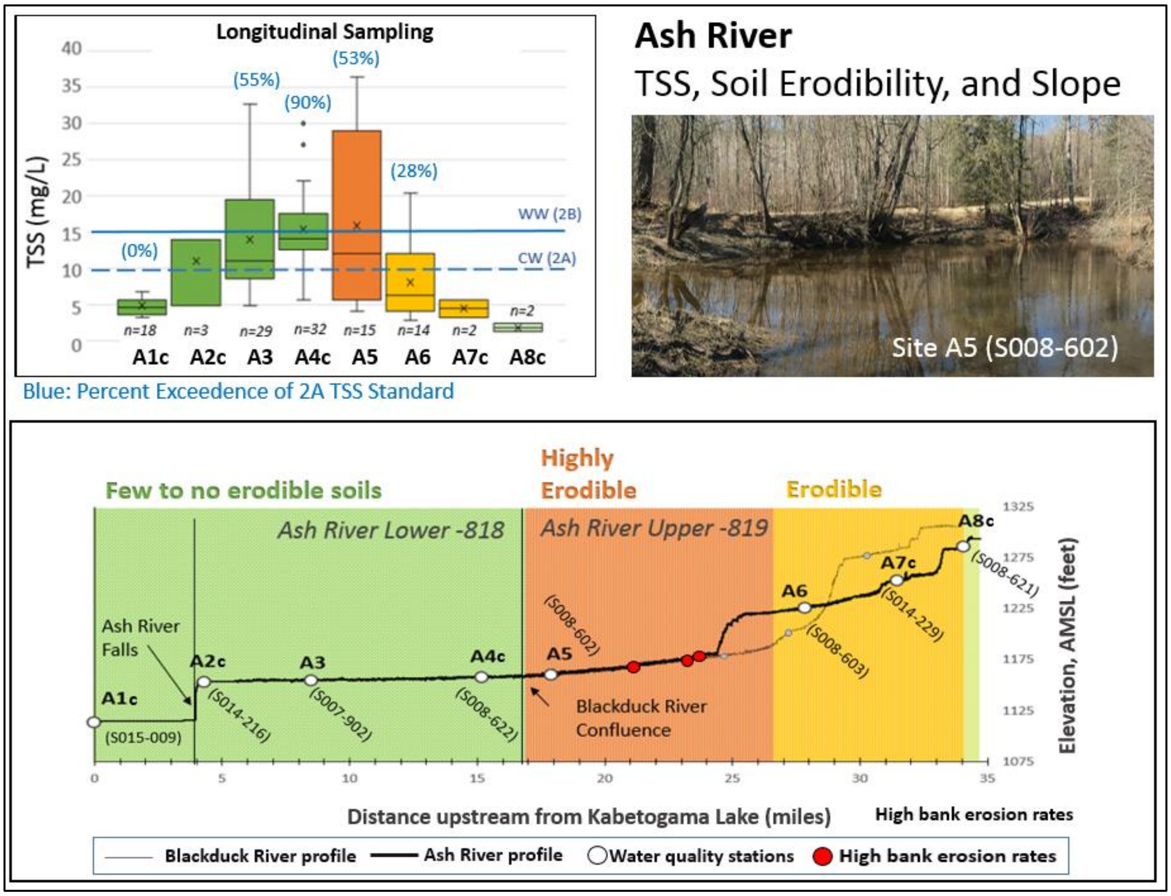


Longitudinal variations in TSS, stream slope, and soils

Stream slope and soil influences on TSS throughout the watershed were evaluated by comparing TSS concentrations to these variables at sampling sites. Soil erodibility was a qualitative value derived from the WHAF soil erosion potential output shown in Figure 3. The stream profile showing slope changes was extracted from LiDAR imagery (1-meter resolution). TSS values in the boxplots of Figure 8 included all available TSS data for each location. Several sites were limited to the data collected for the few longitudinal sampling events described above. Boxplots of TSS and the stream slope profile were color-coded based on soil erodibility.

Stream slope and soil erodibility influences on TSS concentrations along the Ash River are suggested in Figure 8. From the headwaters (site A8c), TSS concentrations increased longitudinally downstream in the Ash River Upper. Soils were most erodible in this AUID and stream slopes were relatively steepened (2% slope). Higher slopes in erodible soils could be a mechanism for increasing erosion or added TSS inputs to the stream. The greatest longitudinal increase in TSS concentrations was observed between sites A6 and A5 where soils were highly erodible and stream slopes were greatest. Several banks with higher erosion rates were located within this reach, which is discussed more in section 3.7.1 of this report. Maximum and average TSS concentrations were greatest among all Ash River sites at station A5.

Figure 8. TSS concentrations (2014-2018) at eight stations along the Ash River (upper left), where it represents the number of samples at each station. The stream profile (bottom) was derived from LiDAR data. The EQuis ID for each station (e.g. S015-009 for station A1) is shown in parenthesis. The graph background colors represent soil erodibility obtained from the soil erosion potential map (Error! Reference source not found.**).**



The highest median TSS concentration and the most TSS exceedances occurred at the gage station (site A4c), located at the upstream end of the Lower Ash River AUID. TSS concentrations declined longitudinally downstream of site A4c; however, the 10mg/L TSS threshold was still exceeded regularly (55%) at downstream station A3. Soils were mapped as “few to no erodible soils” in the Ash River Lower; however, the lower WHAF scores were partly due to the flattened landscape (slope < 0.1%) surrounding this AUID. Quaternary maps and field observations show that the silt content of soils in this area was comparable to soils in the Ash River Upper. Overall, declining precipitation-driven TSS concentrations, low erodibility, and low gradient stream slopes suggest that soils were unlikely eroding in this low-gradient section of the stream.

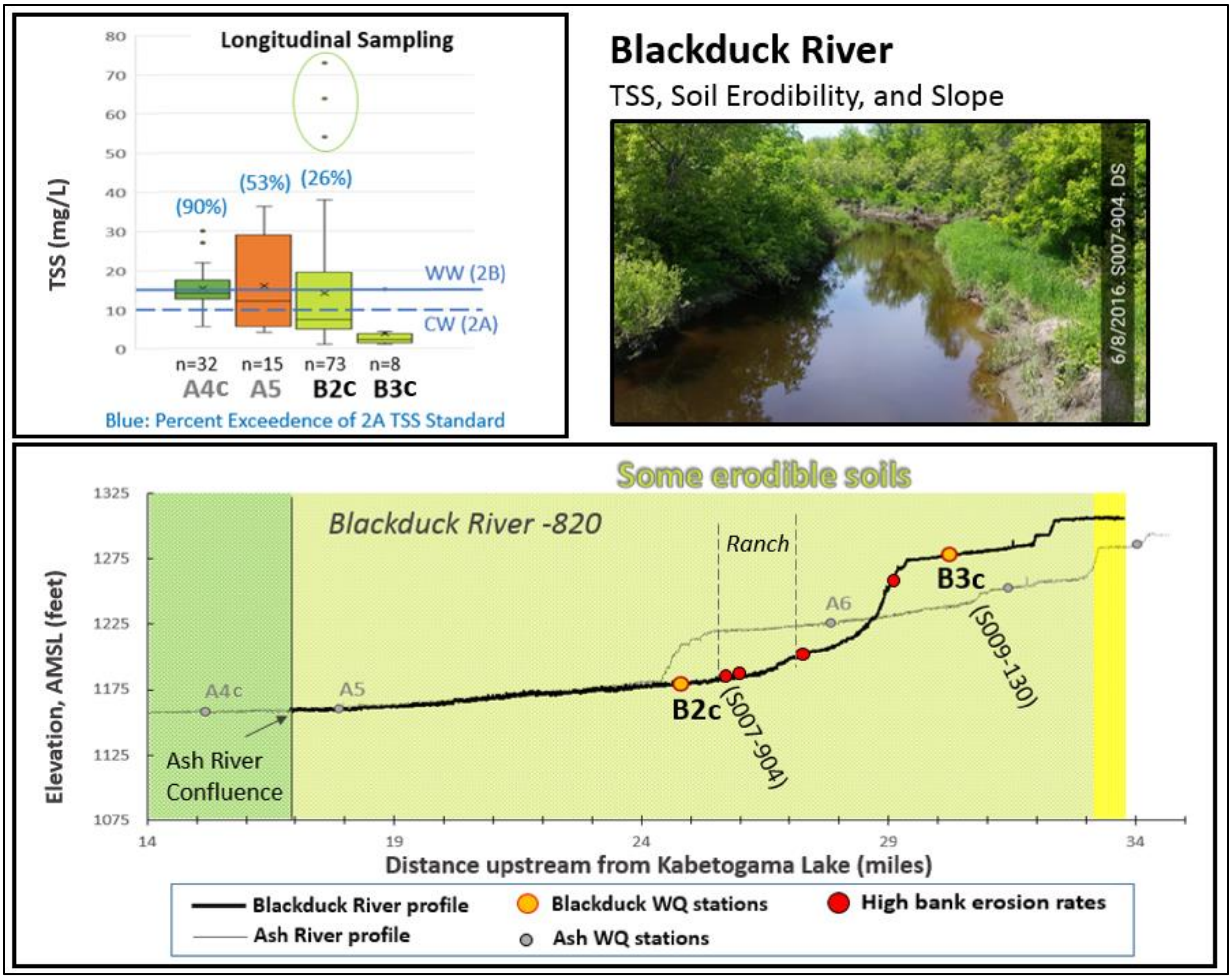


Figure 9: TSS concentrations (2014-2018) at two stations each along the Blackduck River and Ash River (upper left), where n represents the number of samples at each station. The stream profile (bottom) was derived from LiDAR data. The EQuis ID for each station (e.g. S015-009 for station A1) is shown in parenthesis. The graph background colors represent soil erodibility obtained from the soil erosion potential map (Error! Reference source not found.**).**

Elevated exceedances of the TSS standard occurred on the Blackduck River at station B2c on multiple occasions. The site is located at the toe slope of a steepened reach (2% slopes) that extends for several miles through a catchment identified to have "some" erodible soils (Figure 9). Longitudinal sampling in 2017 confirmed that TSS at B2c exceeded by a factor of two other measured concentration in the watershed for that specific rain event. Sampling at upstream station B3 showed that TSS was low across multiple flow regimes in the lower gradient headwaters of the Blackduck River, identifying the reach between B3 and B2c as a reach where high TSS inputs occurred. Several banks within the reach (Figure 9) were identified as having high erosion rates, which is discussed in Section 3.7.2 of this report. The banks were located upstream and within the pastured section of this reach. Compared to the Ash River stations, the Blackduck River B2c site had a lower median value and exceeded the standard less often, as the load duration curves also showed. High TSS loading at this site was mostly isolated to precipitation events.

Suspended solids under low flow conditions

Suspension of sediment in the Ash River Lower during baseflow cannot be conclusively determined through this dataset, but likely, the exceedance was related to several natural variables. These include 1) the fine particle size of solids (silty-clay) remained in suspension for long periods of time, 2) the low-gradient nature of the AUID inhibited downstream transport of materials, and 3) sediment build-up in the stream bed was prone to re-suspension. Both physical disturbance and off gassing of bed material was observed in the Ash River Lower during field visits. Biological factors that may have influenced suspended materials include beavers and other in-stream wildlife activity. There were no rough fish known to disturb bed sediment sampled within the reach.

The longitudinal data indicated that a portion of the suspended sediment generated in the Ash River Upper settled out within the Ash River Lower reach. This infers that particle detachment in the upper river may have contributed to increased siltation and depth of fines in the Ash River Lower, indirectly increasing TSS concentrations under low flow conditions in the Ash River Lower. The banks and bed of the stream at station A4c also had a naturally high silt content (Figure 10).

Based on the reduced TSS concentrations near the outlet of the Ash River at Lake Kabetogama, it appears that dilution from the lake and/or settling of solids improved TSS concentrations just upstream of Lake Kabetogama. All outlet samples were collected in 2017, a normal weather year. It is suspected that during very wet/high flow years; there is opportunity for more of the sediment build-up to pass over the falls and/or move through the lower channel downstream of the falls and enter the lake.

Figure 10. Images of low flow conditions of the Ash River Lower at station A4c show TSS suspended in the stream channel and the exposed silt banks that form the channel.

3.6.3. Biological response to total suspended solids

The MPCA biological monitoring staff has developed a set of Tolerance Indicator Values as a guidance for how tolerant various fish and macroinvertebrate taxa are to certain stressors. The TIV are calculated using the abundance weighted average of each taxon that is present in conjunction with water quality. For example, Central Mudminnow is a very tolerant fish species that has been observed as the dominant fish species in many streams with low DO conditions in Minnesota. As a result, this species has a TIV value for DO that indicates a very high tolerance. Each individual species is assigned a TIV value for a given stressor. Community level TIV have also been developed, which is calculated using the abundance weighted average of the tolerance values of each taxon at a station. Using logistical regression, biologists have also determined the probability of the sampled community being found at a site meeting the TSS and/or DO standards, based on a site's community score compared to all MPCA biological sites sampled to date.

The TIV scores indicated that fish and macroinvertebrate communities in the ARW Coldwater streams show some tolerance to TSS. The regression-based probability of these streams to meet the Coldwater TSS standard was low (<25%) throughout the watershed. Probabilities were slightly improved for macroinvertebrates (33-65%). Compared to other Northern Coldwater Streams, ARW streams ranked poorly (< 30th percentile) for fish based on TIV scores. There was a wider range in macroinvertebrate scores; stations ranked between first and seventieth percentile among Northern Coldwater streams. The Ash River Lower and Blackduck River downstream station B1 ranked particularly low for both fish (9th percentile rank) and macroinvertebrates (1st and 5th percentile rank). These are low gradient reaches with strong wetland connections. Additionally, the Ash River Lower was an AUID that had higher TSS concentrations for longer durations and observed siltation.

In the Ash River Upper AUID, Blackduck River upstream station B2b, and Ninemile Creek, macroinvertebrate community TIV scores were relatively higher and indicated a greater than 50% probability of meeting the Coldwater TSS standard. This indicates that in higher gradient reaches where high TSS concentrations were limited to precipitation events, the macroinvertebrate community showed less tolerance for TSS than lower gradient AUIDs where wetland connectivity is high and/or TSS concentrations remain elevated for longer periods.

3.7. Sediment sources and pathways in the ARW

3.7.1. Stream bank erosion and BANCS model methods

Stream bank erosion is a common source of sediment loading and along with bed and floodplain erosion help shape a stream. While erosion and sedimentation are natural processes that help shape a stream and provide habitat features for aquatic organisms, the processes can be accelerated or depart from a natural state due to poor land use practices.

In September of 2018, DNR staff led an assessment of streambank erosion potential in the ARW using the Bank Assessment for Non-point source Consequences of Sediment (BANCS) model developed by Rosgen (2006). The overall goals of this assessment were to identify sources of sediment, primarily bank erosion, in the Ash and Blackduck Rivers and several major tributaries. Once identified, a further assessment of pathways leading to localized areas of increased erosion was completed. The results were meant to identify natural verses land use disturbance mechanisms for erosion and to inform restoration and protection strategies.

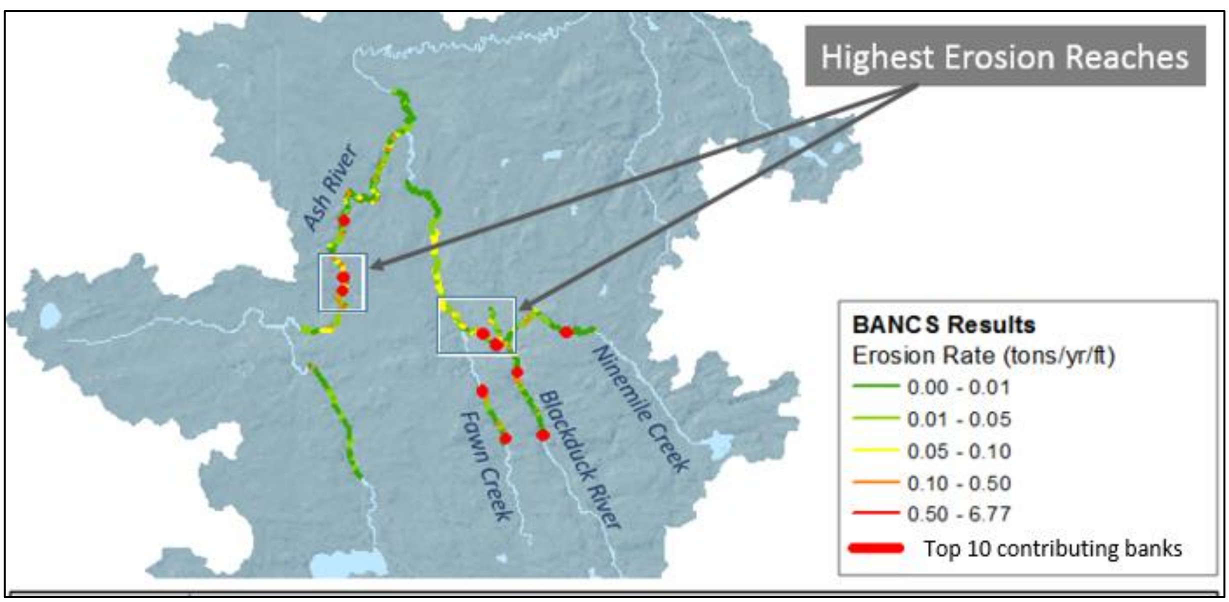
DNR, PCA, and local SWCD staff assessed nearly 30 miles of stream, prioritized by reach characteristics of slope, stream and valley type, and access. Most of the headwater streams in this drainage were low gradient, unconfined streams with frequent beaver dams. Due to their low risk for erosion and poor access, the focus was placed on third and fourth order streams and select tributaries.

The BANCS model predicts annual erosion rates by incorporating field observations of Bank Erosion Hazard Index (BEHI) and Near Bank Stress (NBS). BEHI scores seven bank attributes such as bank height, weighted root density, and bank material to assess the erosion potential of the bank. NBS rates the energy exerted by the stream against the bank from very low to extreme. The combination of the scores provides a predicted annual Bank Erosion Rate (BER in feet/year) based on empirically derived curves from streams in Colorado. Predicted total erosion per reach (tons/year) and a rate per foot (tons/year/feet) is estimated by incorporating bank height, length, and the density of soil. Although not a direct measurement, the predicted BER provides a good comparison of where the most unstable reaches are. Predicted erosion rates (tons/feet/year) were used to identify the largest contributors of sediment since it includes bank height and is a direct comparison to other reaches in the survey. The complete DNR BANCS Summary, which includes more detail on data collection methods and results, is in the Appendix.

3.7.2. BANCS (stream bank erosion) model and channel survey results

The BANCS study found that erosion rate potential in much of the ARW was low compared to other TSS-impaired streams in Northeast Minnesota; however, several reaches in the watershed had rates higher than the rest of the ARW. The highest erosion reaches and banks are shown in Figure 11. High erosion banks were scattered amongst the survey area. They were less than 1% of the total survey length, but contributed 7% of total survey erosion.

Figure 11. BANCS survey results showing erosion rates and identifying the top 10 most erosive banks and the highest erosion reaches in the survey area.



Blackduck River upstream of Sheep Ranch Road

The BANCS model estimated that ten miles of the Blackduck River accounted for 53% of the erosion. Most of the predicted erosion on the Blackduck River came from a 3.3 mile (11% of survey length) reach near Sheep Ranch Road that contributed 30% of the total estimated erosion. To compare, 33% of the survey erosion came from an Ash River reach that was four times longer (13 miles in survey length). Two of the top 10 highest contributing banks were located within this reach and two more were identified within a two mile reach immediately upstream (Figures 9 and 11). Elevated high flow TSS concentrations were identified at water chemistry site B2c, located within the high erosion reach (Figure 9). Lower rates that met the TSS water quality standards were measured several miles upstream at station B3c.

A geomorphic survey was performed by DNR at the stream gage (site B2c) at Sheep Ranch Rd in August of 2018. The DNR survey classified the stream as a stream type E that is highly sinuous, narrow, and deep and dominated by silt and sand. The reach scored poor (unstable) using the Pfankuch Stability Index (Pfankuch, 1975) and geomorphic survey results verified moderate to deep channel incision (mean bank height ratio = 1.33) in the reach. The survey found that channel incision prevented greater than bankfull flows from accessing the floodplain resulting in excess sheer stress on the bed and banks. The resulting accelerated erosion rates led to excess sediment in the channel, particularly during high flows. The channel, only slightly entrenched, allowed small to moderate floods to access the floodplain. Most pools maintained expected depths (greater than two times mean riffle depth) in spite of the excess fine sediments observed.

The initial and primary cause of instability in this reach is likely century-old clearing of the forest and channelization of a 3,750' section of the Blackduck River that occurred prior to 1939. Channelization reduced the stream length by 34% (Figure 12) and increased the slope by an estimated 60%. Although oxbows along the channel indicate a historically active channel, the channel straightening likely destabilized the stream and initiated an acceleration of the processes of channel evolution. The process of channelization typically creates an incised channel that, because of the increased sheer stress caused by the slope increase, will continue to incise (down-cut). Eventually the steep banks will collapse as the stream widens and ultimately evolves to a stable state. During this process, bank and bed erosion rates accelerate significantly and lateral channel migration increases resulting in high sediment loads. The channel evolution process can take decades or longer before a channel returns to a more stable state.

Land use practices in this area over the past 20 years have likely exacerbated the instability by increasing surface runoff (adding more flow volume) to this already unstable reach during snowmelt and rain events. Field observations suggest that land management practices such as clear cutting, loss of riparian area vegetation, improperly sized or aligned culverts, and cattle access are perpetuating instability.

Figure 12. Channelized section (blue line) of the Blackduck River that occurred prior to 1939, reducing the historical stream (yellow line) length by 34% and increasing stream slope by 60%. The photo shows the channelized reach along the roadway.

Ash River downstream of US Highway 53

The BANCS model estimated that 1.75-mile reach of the Ash River accounted for 12% of the total estimated survey erosion. The reach contained two of the top ten highest contributing banks for predicted erosion rates (Figures 8 and 11).The reach is located just downstream of the northernmost U.S. Highway 53 crossing of the Ash River. This area was identified as having highly erodible soils and the water chemistry station (site A5) downstream of the reach had the highest TSS concentrations during sampled runoff events.

Land use in this area is primarily managed forest with small pockets of hay fields. Forest change data shows the greatest recent disturbance in the area was the clearing of 400 acres along the stream corridor during years 2000-2001 due to insect/disease management. Adjacent to this initial disturbance, an additional 300 acres of forest was cut between 2005 and 2009 for the logging industry. Aerial imagery showed that stream corridor buffers were met according to Minnesota's Forest Management Guidelines (MFRC, 2012) when both diseased and planned cuts occurred; however, nearly 30-40% of the mature forest cover within a half-mile perimeter of the reach was cut within a nine-year period. The impacts of this on surface runoff, stream flow dynamics, and erosion are unknown.

A geomorphic survey was not completed in this reach, but was completed downstream at station A4c where stream slope and catchment-scale drainage area slope decreased. The downstream survey results indicated a stable reach that was not incised and had no excess erosion even though it had elevated TSS concentrations. Future geomorphic survey work in the more upstream reach in question could provide additional insight to higher erosion rates and degraded banks in the reach.

3.7.3. Upland Sources – roads, culverts, open land/harvest

Anthropogenic sources of sediment and instability in the watershed identified include channelization, cattle access, and riparian area vegetation removal within a pastured area of the Blackduck River. Less-impactful sources include road crossings, an old railroad grade, remnant bridge pilings left in stream channels, and scattered pockets of logging.

Road networks

Roads add to impervious surface and thereby contribute many secondary effects on flashy flows and related destabilized channels, increased pollutant transport, and other effects (EPA, 2011). An extensive network of gravel and silt roads connects major roads to residences as well as logging and recreational areas in the ARW. Roadside erosion in this gravel road network was visible for several weeks during the spring snowmelt season and following heavy or consecutive summer rain events (Figure 13) during the study period.

During snowmelt, several road-ditches were observed transporting landscape and road runoff into nearby streams, particularly in areas that were clear-cut over the winter season. Erosion of gravel and silt road material surrounding undersized stream crossing culverts and roadway cross-drain culverts resulted in localized gullying to road ditches and directly to streams (Figure 13). Evidence of road failures during the study period and historically were observed (Figure 13). Applying fill to gullies appeared to be a common practice. It is suspected that if no change is made to the placement or sizing of stream crossing and cross-drain culverts, erosion is bound to occur again.

A Wemple, 2013 study found that road grade, measures of slope position, slope steepness and the implementation of best management practices influenced the tendency for erosion to occur on roads. A quick review of road densities within the ARW could be used to direct where more roadway inspections and management may be needed. Road densities were quantified by DNR-delineated drainage catchments. Road density values were calculated as the ratio of road length in miles to watershed area in square miles. Values ranged from 0.47 to 3.57 in the 16 catchments evaluated. This range was similar to findings of a SID study in the Flute Reed River Watershed (MPCA, 2018). The ARW densities were slightly lower because road width was not incorporated into the density calculation, as road widths were highly variable in the ARW.

The highest road densities in the ARW were located in the Ash River Upper watershed (mean=2.7, max = 3.57). Much of the road network in the two Ash River Upper catchments with high road densities were gravel roads that branched off the main highway. The same catchments were identified by the WHAF as having the most erodible soils in the Rainy Basin, due to a steepened landscape in combination with fine soils. These are also the same drainages where TSS data showed increasing concentrations of suspended sediment in the stream channel and the BANCS model estimated high erosion rates. Gravel roads within these two catchments should prioritize high for further roadway and runoff analysis. The Blackduck River watershed had more moderate road densities (mean=1.83, max=2.39) with the higher densities leading from Sheep Ranch Road to a gravel road network east of Ninemile Creek and near Blackduck Lake. Ash River Lower had low road densities (mean=1.02, max=1.43).

In addition to roadway material erosion, roadways can influence stream stability by restricting natural lateral migration of a channel. Aerial imagery shows that U.S. Highway 53 currently restricts movement of the Ash River along the east side of the highway for the majority of stream miles located between stations A7c and A6. Roadway bank slumps and attempted slump restorations align the west side of the highway. Although mass wasting of these banks presumably could have effects on water quality, the BANCS survey and sample data suggests it is not currently affecting stream stability or increasing suspended sediment concentrations, likely because of the low gradient nature of the stream and dense riparian area vegetation.

Stream crossings/culverts

If not properly sized and installed, culverts and bridge crossings cause problems with not only fish passage, but also stream stability. Poor alignment, setting, or sizing of a culvert can cause channel instability. Signs of instability include upstream deposition of sediment; downstream scour pools/incision, lateral erosion around the culvert, and road failures. Incision downstream of undersized or misaligned culverts often causes the culvert to become perched or set above the water surface, reducing or eliminating fish passage. To transport material and water effectively at a rate that is not too fast or too slow and to maintain overall stability, the ideal crossing span should equal bankfull width, the distance between the stream banks at bankfull stage (DNR, 2015). Based on DNR guidance, appropriately sized culverts are those where the total span of the crossing is between 0.8 and 1.5 times the bankfull width of the stream. Crossing spans outside of that range are undersized or oversized, respectively.

Local partners with the help of DNR and MPCA surveyed 66 culverts in the ARW. Culvert size, visual erosion, alignment and perched status were evaluated, along with other variables. The survey found that 74% of culverts were potential fish barriers, 65% were undersized (<0.8 bankfull width), 26% had visible erosion, 18% were improperly aligned, and 18% were perched. The unexpected difference between undersized culverts and visible erosion throughout the watershed may be related to the low-gradient nature of the watershed, where slopes are flat enough that sheer stress on the bed and banks is below the critical threshold to move particles.

The percent of culverts with stability and fish passage problems had a similar distribution in each subwatershed (Figure 13). Ash River Upper had the most culverts (37 surveyed) because US Highway 53 intersects this subwatershed and acts as a main corridor to smaller State, Federal, County, and private roads throughout the drainage. Even though Blackduck River and Ash River Lower watersheds had less (16 and 13 respectively) culverts, the distribution for each category was similar to Ash River Upper.

Forest harvest

An active forestry industry exists in the ARW compared to neighboring watersheds. Much of the forest has been converted from pine to aspen and birch over the past century. Forest harvest can negatively alter runoff and streamflow dynamics when greater than 60% of a drainage area is less than 16 years age (Verry, 2001). The risk of negative effects decreases with a decrease in watershed slope.

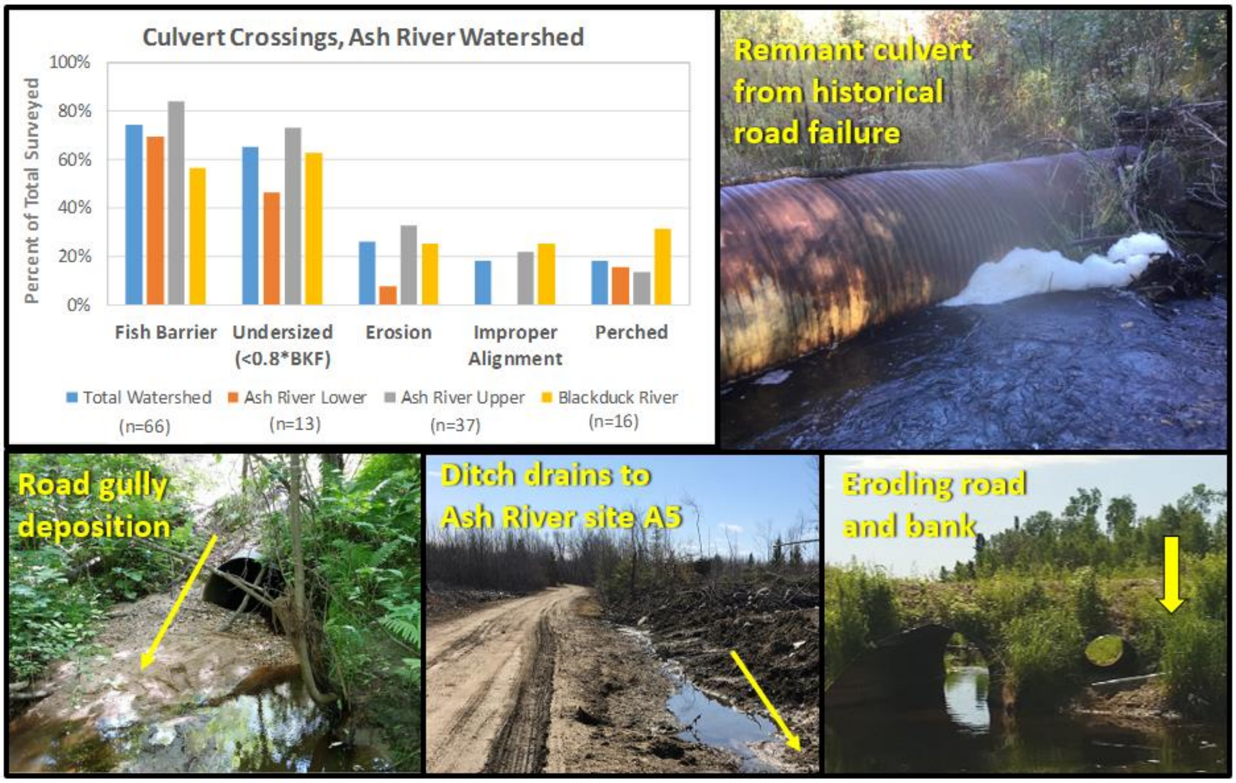
A National Park Service's (NPS) forest change study showed that 25% of the ARW experienced conversion of mature forest to another cover type in the past eighteen years. The NPS study calculated change in land use using change detection methodology described in the Great Lakes Inventory and Monitoring Network Landscape Dynamics monitoring protocol (Kirschbaum, 2017; Kennedy et al. 2010). In this SID study, the same LandTrendr dataset was used to estimate the area of forest conversion over the past eighteen years in each HUC-12 subwatershed and due to what "change agent". It was found that mature forests were harvested for timber on 18% of land in the Ash River Upper, 27% in the Ash River Lower, and 31% in the Blackduck River Subwatershed. Agriculture, development, and insect disease control accounted for an additional 2 to 6% of forest conversion and beaver activity and mortality due to insect and disease accounted for less than 1% in each of the subwatersheds.

The Ash River Lower, having the most land owned by the private timber industry and State of Minnesota, may be under the most pressure for future harvest based on the NPS study findings that private and State of Minnesota land were harvested more than Federal land. Contiguous parcels of State land are found in the upper two watersheds as well. Increases of School Trust lands from 11 to 16 square miles are expected across the ARW, with the most School Trust land located in the Ash River Upper. Continued or increased harvest is expected in these areas.

As reported above, the BANCS survey identified two reaches within the ARW where estimated bank erosion was particularly high. Both reaches experienced forest change in the surrounding drainage area over the past 18 years although the forest management practices between the reaches differed.

Forest harvest had occurred on 40% of the land within a half-mile perimeter of the Ash River Upper reach within a nine-year period. Aerial imagery suggested stream buffers guidelines were met. On the Blackduck River reach, the forest had primarily been converted to pasture. The initial forest was cleared in the early 1900s and additional cuts occurring between 1995 and the current date increased the cleared area from approximately 450 acres to greater than 1500 acres. Harvest practices maintained some trees within a 50-foot buffer along the Blackduck River. Sections of Ninemile Creek and smaller tributaries were mostly cleared of trees up to the streambanks.

Figure 13. Culvert inventory results (Top Left) in the Ash River Watershed identifying the most commonly found problems at stream-road crossings. Photos: Examples of culverts and roadways that have contributed sediment to stream channels in the Ash River Watershed.



Cattle access

Cattle had access to over 3 miles of stream within the ranch including reaches of the Blackduck River, Ninemile Creek, Fawn Creek, and an unnamed tributary. Additionally, smaller ephemeral streams were also being grazed. The total number of cattle varied by season with approximately 500-700 cattle occupying the pasture during summer. While many stream banks remained fully to partially vegetated, cattle access in other areas resulted in trampled banks that were void of vegetation (Figure 14). While overall, the Blackduck River is incised due to historic channelization, areas over-accessed by cattle were widened in localized areas where banks had been trampled. Fine streambed materials were more dominant in highly accessed areas, burying coarser gravel that is desirable to Coldwater fish and invertebrates.

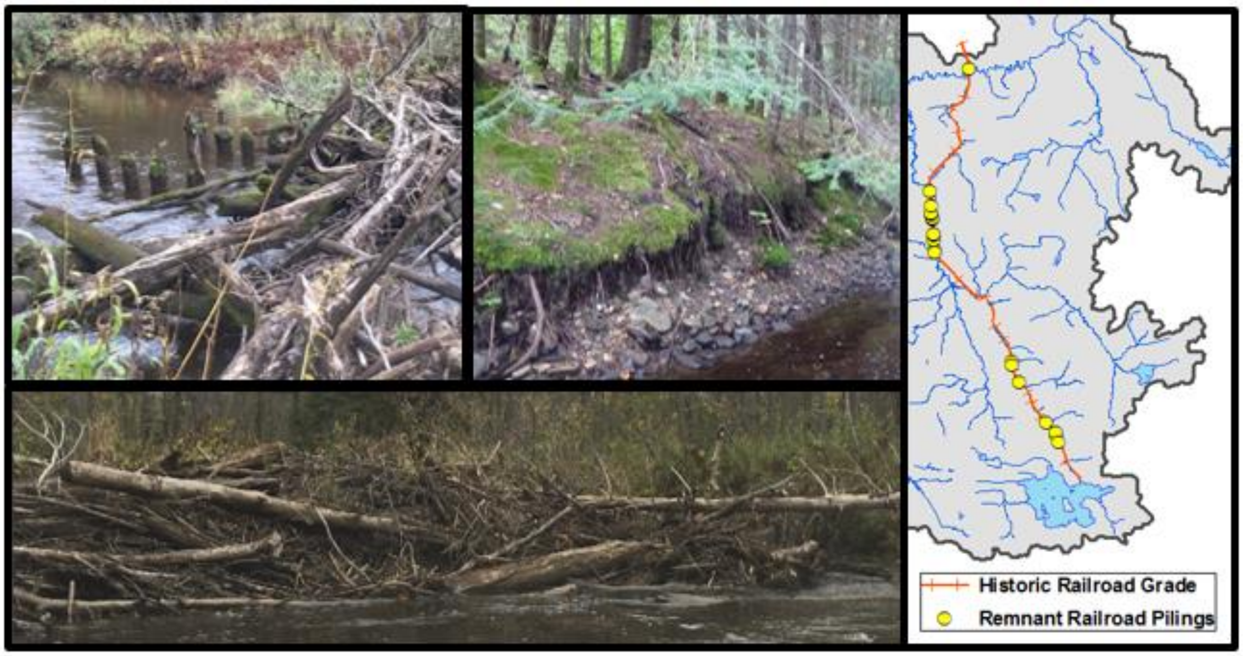
Figure 14. Cattle access areas on the Blackduck River and Ninemile Creek showing trampled banks (top left), sediment deposition (top-right), and steep eroding banks from a combination of streamflow and cattle access (bottom).

Historic railroad grade and remnant grade pilings

The BANCS survey identified old railroad grade and in-channel pilings left behind from remnant railway bridges as sources of erosion in the ARW. The old railroad grade transects the ARW from Blackduck Lake to the Ash River Lower. Visual observations of aerial imagery showed eighteen possible railroad crossings on the Black Duck River. Six of those were confirmed to have pilings. The status of pilings are unknown at the remaining nine locations. Pilings were also present at the Ash River water quality station A3, located in Ash River Lower.

Erosion caused by the old railroad grade and/or pilings was verified in several reaches of the Blackduck River through BANCS survey work. Erosion was observed along longer lengths of streambank (Figure 15) where the stream abutted against the old grade. Erosion at remnant rail pilings appeared to be the result of logjam releases. Logjams of various sizes were observed at all of the verified piling crossings and often bank scour was present at these locations from the continuous cycle of logjams being created and blown out during various sized flow events. In addition to causing erosion, we suspect that the piling-induced logjams prevent large wood from natural placement within the channel. Large wood naturally deposited in stream channels can create beneficial scour pools and overhead cover for fish; whereas logjams created at the pilings often result in blockage of the entire cross-section. The resulting loss of cross-sectional area increases stress on the banks, thus initiating and accelerating bank erosion.

Figure 15. Map (Right) identifying locations where the old railroad historically crossed the Ash and Blackduck Rivers including one location on the Ash River and 18 on the Blackduck River. Pilings remain in the stream at many of these historic crossings causing debris pile-ups (top left and bottom). Bank erosion was identified in the Blackduck River in areas where the old railroad runs parallel with the Blackduck River (Top center).



Beaver dams

Beaver dams, although not anthropogenic, were identified as minor sources of sediment in the ARW, particularly when constructed against valley walls. Beaver dams can also act as local sinks, trapping sediment on the upstream side. In addition to influencing sediment dynamics, beaver dams can have positive and negative effects on other variables critical to the fish community such as temperature and passage. Both positive and negative influences on temperatures can occur depending on the stream, its position in the valley, and the extent of area the beaver dam covers. Beaver dams can be detrimental to brook trout populations in systems with limited and discreet areas of groundwater input due to loss of connectivity. Brook trout will migrate to groundwater during times of thermal stress (heat of summer and during winter) and migrate to spawn. If prevented by beaver dams (or culverts) that act as complete barriers, survival can be reduced. Beaver dams can provide positive ecological services such as wildlife habitat. Defining watershed goals is critical in assessing the effects of beaver dams on an area.

Beaver dam densities, identified by visual observations of aerial imagery, were calculated to see which drainages at the DNR catchment scale contained the most dams. Densities ranged from 1.3 to 5.8 dams per mile of stream. Densities were the greatest on first and second order streams, but also high in some third order streams. Ninemile Creek and Fawn Creek catchments had the highest beaver densities (> 5 dams/mile). Total erosion in the ARW due to beaver dams was not calculated; however, rates on a few of the more erosive banks due to beaver dam activity were calculated.

Overall Fawn Creek had a very low bank erosion rate and low bank heights; however, it contained banks with elevated erosion rates. One of the two highly erosive banks was the result of a beaver dam directing flow at it. The eroding bank was 102 feet long and produced an estimated 42 tons/year of sediment, 0.5% of the total. The BANCS survey found that a reduction in sediment from restoring this bank alone would not be worth a standalone restoration, but done in combination with other highly eroding banks in the subwatershed could reduce bank sediment entering the Blackduck and Ash Rivers.

Beaver meadows in the Ninemile reach generally had low erosion rates because the stream has access to its floodplain and the dense grass root systems held the banks well. Ninemile Creek is 10.2% of the survey length but only contributed 5.95% of the total sediment. The reach is stable and not a large contributor of sediment from its banks. Ninemile Creek had one bank with high erosion rates caused by a beaver dam against a valley wall. The bank was 40 feet long and contributed 0.2% of total sediment. Reductions in sediment from this one bank are not high enough to make this a high priority restoration project unless combined with other projects in the subwatershed.

Because the Fawn and Ninemile Creek banks are remote with limited access, contribute less than 1% erosion in the survey, and are located in a high beaver dam density area where dams are likely to be rebuilt, they are considered low priorities for sediment reduction efforts.

3.8. *E.coli* bacteria impairment in the ARW

The Blackduck River has a recreational impairment for *E.coli* based on data collected at station B2c (S007-904) during years 2014-2016. This AUID had sufficient bacteria data for an assessment of aquatic recreation. Data clearly indicated an impaired condition with six (40%) of the 15 samples exceeding the individual maximum standard (1260 Most probable number (MPN)/100mL). All three-summer months exceed the geometric mean standard (126 MPN/100mL). Four samples were greater than the lab reporting limit
(2419 MPN/100 mL), suggesting a significant source of bacteria to the stream.

3.8.1. *E.coli* methods

In 2017, the MPCA and partner agencies further sampled *E.coli* at this station as well as upstream reaches and various tributaries to the Blackduck River. Six locations in the Blackduck River Subwatershed were sampled weekly (12-15 times) during June through mid-September in 2017. Samples from all stations were collected within a two-hour timeframe of one another on each sample date. Monthly geometric means were not calculated because only one season of data was collected on tributaries, therefore we used the 2017 season mean to show variability between stations.

3.8.2. Review of *E.coli* data

E.coli results shown in Table 6 clearly show that bacteria levels at sites within the ranch were elevated with respect to others for the majority of stations. Three of four streams within the ranch boundary, Ninemile Creek, Blackduck River, and an unnamed tributary to Blackduck River (eastern portion of the ranch) exceeded the individual maximum standard (1260 MPN/100mL) for a high percent (27-67%) of samples. Ninemile Creek had the most standard exceedances. Seasonal means at the three sites were 989 – 1577 MPN/100mL. The mean values were underestimated, as at least one sample was above the reporting limit for each of the stations.

The monthly geometric mean threshold was exceeded during low and very low flows and the individual standard was exceeded during all flow regimes. This suggests that pasture runoff during storm events was not the primary source of *E.coli*. Rather, in-channel or near-channel deposition of feces during low to moderate flows when cattle could safely access the stream was likely a primary source of *E.coli* bacteria to the stream. In addition to acquiring drinking water, access to shade and cooler air temperatures may have encouraged cattle to herd along the stream. Few trees remained on the pasture and those that did, were mostly located immediately along the banks of the Blackduck River.

The Blackduck River immediately upstream of the ranch had zero exceedances of the individual standard and much lower seasonal means, as did Fawn Creek (located in the ranch) and an unnamed tributary (located downstream of the ranch). Seasonal means ranging from 159-307 MPN/100 mL at the three lower reporting stations in the Blackduck River Watershed provide a reference for natural background conditions in this area. The bacteria levels at the three stations were slightly elevated from the monthly geometric mean standard likely due to insufficient samples (less than two years) and/or the influence of beaver dams.

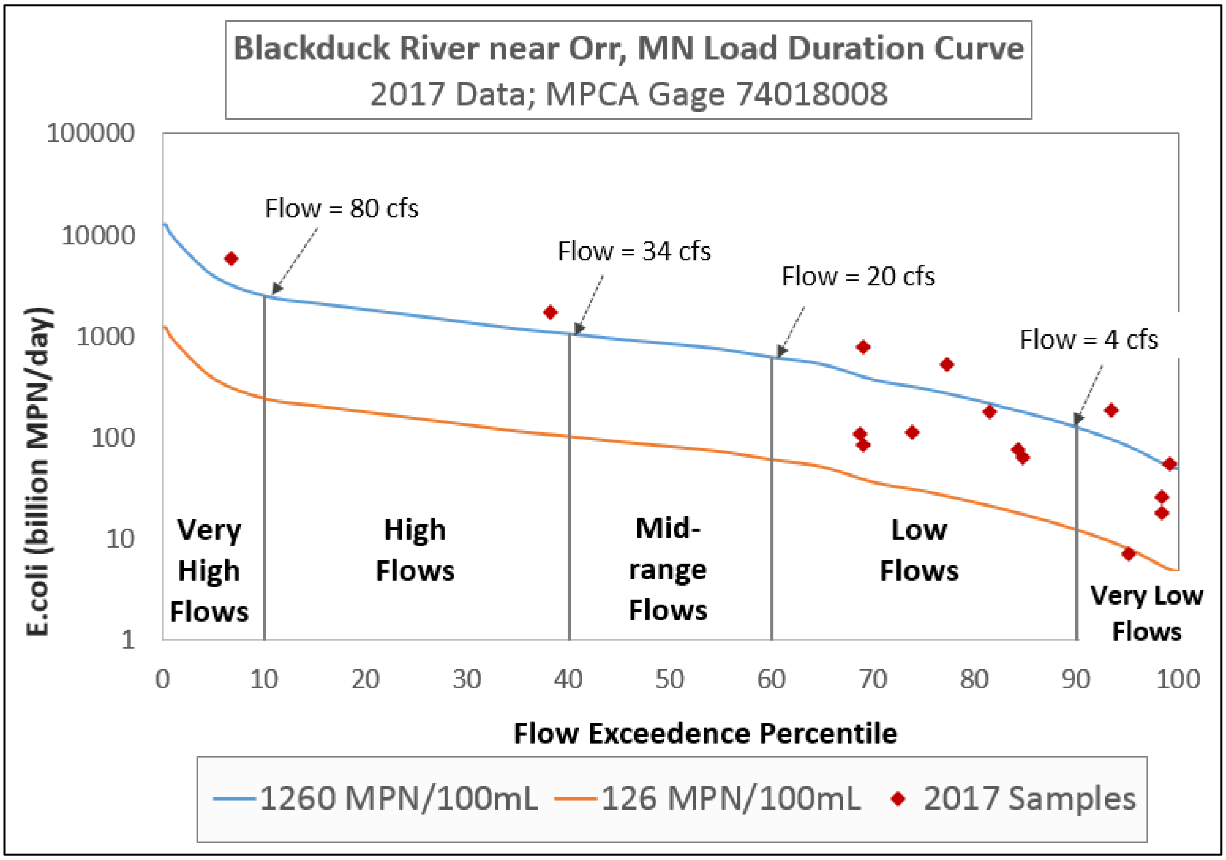
Fawn Creek is located within the ranch, yet had natural background level counts. It is suspected that conditions there were unfavorable for instream wading of cattle. Heavy beaver activity and multiple dams result in deep in-channel pools and wet meadow riparian area. Access there may have been difficult, particularly when improved walking/wading conditions were available in nearby streams such as the Blackduck River and Ninemile Creek.

E.coli levels were lower in the Ash River where no clear impairments were found based on data collected in years 2014-2016. Fifteen *E.coli* samples collected at Ash River station A1 in 2017 were all below the 126 MPN/100mL standard and two were below the lab's detection limit indicating that low to very low levels enter Kabetogama Lake.

Table 6. *E.coli* results for the Blackduck River and tributaries. Green cells identify pasture-influenced reaches. The gray cell is the outlet of the Ash River and does not influence Blackduck River *E.coli* levels. *The upper Reporting Limit (2419.6 MPN/mL) was used in calculating the 2017 Season Mean when it was exceeded, overall underestimating the mean value.

Equis ID	Station Description	2017 Season Mean (MPN/100mL)	% Samples > 1260 MPN/100 mL	# Samples Year 2017
S007-904	Blackduck River *(downstream of ranch)*	1139.9*	33	15
S014-230	Blackduck River *(upstream of ranch)*	159.6	0	12
S008-619	Ninemile Creek *(east side of ranch)*	1577.5*	67	15
S014-231	Unnamed Tributary *(east side of ranch)*	989.6*	27	15
S014-232	Unnamed Tributary *(downstream of ranch)*	218.7	0	15
S014-233	Fawn Creek *(west side of ranch)*	307.5	0	14
S015-009	Ash River (*at Kabetogama Lake)*	13.2	0	15

Figure 16. *E.coli* bacteria Load Duration Curve at the Blackduck River station B2c, year 2017. Target loads are shown for the two *E.coli* standards (individual and geometric mean). *E.coli* exceeds the target loads for all sampled flow regimes. No *E.coli* samples were collected for Mid-range flows.



3.9. Use classifications and impacts on TSS load reduction targets

The majority of streams discussed in the above sections of this report are designated trout streams by the Minnesota DNR and several have been managed as trout streams over the decades, stocked with both Brook Trout and more recently Brown Trout. The MPCA's Coldwater designation is focused on identifying and protecting aquatic communities that can be naturally supported given the natural potential of a stream. This often is dependent on geography, geology, and watershed characteristics. The MPCA operates under a policy that a stream can remain a DNR designated trout stream, yet be assessed as a Warmwater (Class 2B). This particularly occurs when the DNR stocks trout, but natural conditions limit good carryover of trout from one season to the next.

Load reduction targets outlined in Tables 4 and 5 of Section 3.6 show how use class designation of Coldwater (Class 2A) versus Warmwater (Class 2B) affects water quality expectations and reduction needs. Therefore, it is critical that the appropriate use classification is designated for a specific AUID as not to uphold a stream to a water quality expectation that it naturally cannot meet.

The Monitoring and Assessment process identified the ARW stream fish and macroinvertebrate communities as Cool/Warmwater communities not typical of degraded Coldwater communities. Because several streams are managed by DNR for trout, a Coldwater IBI was used to assess the DNR-designated trout streams. All streams passed or marginally passed the Northern Coldwater IBI due to the presence of several Coolwater species and one Coldwater species (Mottled Sculpin). The number of Cool and Coldwater species varied between stations as did stream temperatures indicating that some AUIDs had more potential than others to support trout.

At the time, some stream temperature data and very limited DO data were available. Stream temperatures were not exceptionally cold, but thought to be adequate for Brown Trout, the currently stocked trout species. During the SID process, the MPCA collected additional stream temperature and DO data to validate whether appropriate designations and associated water quality expectations are being applied to ARW streams or whether this needs to be re-evaluated in the next 10-year cycle of the MPCA's WRAPS process. The additional data collected during the SID process is reported in the following two Sections.

3.10. Water temperature in the ARW

Water temperature is a critical factor in shaping the distribution, abundance, and species composition of stream fishes, particularly trout. The temperature ranges to which the MPCA and DNR refer to assess suitability for the growth and Brook Trout and Brown Trout are in Table 7. Criteria used by DNR and MPCA for Brook Trout and Brown Trout growth, stress, and lethal temperatures. Most typically, the 20.0˚C threshold is used in the MPCA assessment process for consideration of whether a stream meets "Coldwater" criteria.

3.10.1. Stream temperature methods

Available summer temperature data (2014-2017) were reviewed from eighteen locations in the ARW to determine whether stream temperatures in the focus subwatershed AUIDs were suitable for trout. Although Brown Trout is the stocked species in the ARW, the temperature thresholds for Brook Trout were used as an indicator of suitable temperatures for the overall Coldwater community and as an indicator of the appropriateness of the current aquatic life use classifications.

ARW temperatures were compared to other RRHW Coldwater streams (Figure 17) by plotting temperature metrics: Percentage Growth (percentage of temperature readings in the growth range for Brook Trout) and Summer Average Temperature (mean temperature recorded June 1 – August 31). MPCA biologists have found these to be strong predictors of trout presence and abundance (Sandberg and Dingmann, 2016, unpublished data). Four temperature regimes initially developed for Lake Superior North streams (MPCA, 2018) were used as a way to describe "typical" fish communities based on temperature data. The regimes (Table 8), developed using temperature and biological data, provide a regional perspective on whether or not thermal conditions in a given stream are comparatively limiting for Coldwater biota.

Table 7. Criteria used by DNR and MPCA for Brook Trout and Brown Trout growth, stress, and lethal temperatures.

	Classification	Temperature Range (°C)	Description
Brook Trout	Growth	7.8 to 20.0 °C	Temperature range favorable for growth
	Stress	>20.0 to 25.0 °C	Stress and avoidance behaviors
	Lethal	>25.0 °C	Mortality can be expected at prolonged exposure
Brown Trout	Growth	5.0 to 23.0 °C	Temperature range favorable for growth
	Stress	23.0 to 26.3 °C	Stress and avoidance behaviors
	Lethal	>26.3 °C	Mortality can be expected at prolonged exposure

Table 8. Temperature regime categories developed based on visual interpretations of the scatterplot results of Northeast Minnesota North Shore trout streams with temperature and fisheries data.

Grouping	% Temperature Reading in Brook Trout Growth Range	Summer Average Temperature (C)
Area 1	<60%	>19 C
Area 2	60-79%	17 – 20 C
Area 3	80-89%	16 – 18 C
Area 4	90 – 100%	<17 C

Grouping	Description
Area 1	Brook Trout and coldwater species sometimes present, more often a mix of cool/warmwater taxa
Area 2	Can support Brook Trout/other coldwater species, often a mix of cold, cool, and warmwater taxa
Area 3	Frequently supports Brook Trout and other coldwater species, lower relative densities
Area 4	Almost always support high relative densities of Brook Trout and/or other coldwater species, low taxa richness

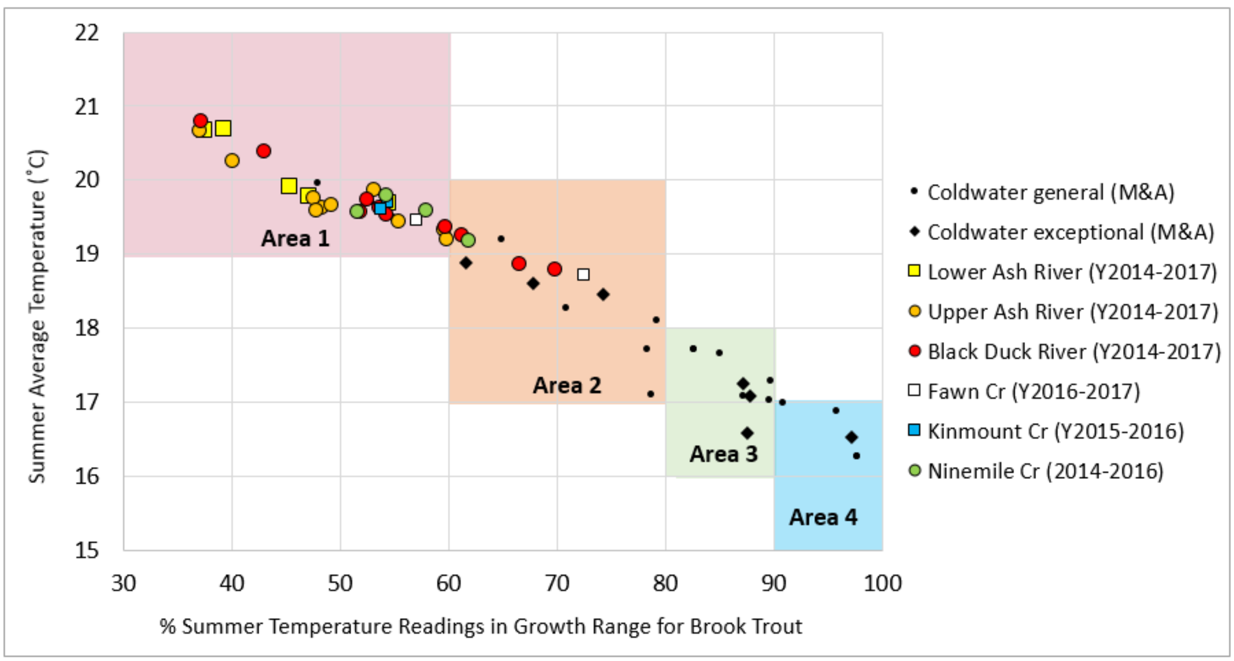
3.10.2. Review of water temperature data

Stream temperature records show that reaches of the Ash River and its tributaries had fair to poor water temperatures for supporting Brook Trout and other Coldwater species. ARW Coldwater streams had some of the warmest temperatures reported in the RRHW. Several of the AUIDs were the only stations to exceed a Summer Average Temperature of 20˚C in the RRHW (Figure 17). Most of the ARW summer temperature records plot in “Area 1”on the scatter-plot, which regionally tend to support Warm/Coolwater communities and are absent of trout. All of the Ash River temperature stations (Ash River Lower and Ash River Upper) plot in “Area 1”.The warmest temperatures in the watershed were recorded in the Ash River Lower, as well as just downstream of the Ash and Blackduck headwater lakes. Warmer stream temperatures at lake outlets is expected. Temperatures at those locations were in the stress range for Brook Trout 45-62% of the summer readings.

Temperatures at the coldest locations were still marginal, reporting within the growth range for Brook Trout for 70% or less of the summer readings. These stations plot in “Area 2” on the graph and include Ninemile Creek, Fawn Creek, and Blackduck River B2c and B2b stations. While Area 2 streams have shown to support wild Brook Trout populations in this region, more often they support a mix of Cold, Cool, and Warmwater taxa.

“Area 2” streams are more likely to support trout when hydrologically connected to colder water that provides a place of refuge for fish during warm periods. An example of this is Mitawan Creek, an exceptional RRHW Coldwater stream located outside of the ARW. The three exceptional use markers in “Area 2” of Figure 17 are multiple year readings on the upper reach. Mitawan Creek plots in “Area 2” of the graph, yet supports a healthy Coldwater community including native Brook Trout. The downstream reach on Mitawan as well as tributary Jack Pine Creek have much colder temperatures that plot in “Area 3” and “Area 4” on the graph. Unlike Mitawan Creek, no colder tributaries to “Area 1” or “Area 2” streams were identified in the ARW.

Figure 17. Plot of Summer Average Temperature vs. Percent of Summer Readings within the growth range for Brook Trout, a regionally native Coldwater trout species. Ash River Watershed stations are shown in colored markers, while all other Rainy River Headwater Watershed Coldwater stations collected during the Monitoring and Assessment (M&A) period are shown in black. Diamonds indicating streams with exceptional Coldwater communities.



3.10.3. Biological response to water temperature

In addition to the F-IBI and M-IBI scores, several Coldwater fish metrics were used to assess Coldwater suitability at the ARW biological station. These included Coldwater-sensitive percent and Coldwater-tolerant percent.

More Coldwater tolerant than sensitive individuals were sampled at all of the ARW biological stations. ARW fish communities had lower percentages (0% to 6.7%) of Coldwater sensitive individuals than the median (7.6%) and lower percentages of Coldwater sensitive taxa (0-9%) than the median (15%) for

Northern Coldwater Streams. Blackduck River station B2b had the highest amount of sensitive species in the ARW, which correlates with the relatively colder (Area 2) temperatures measured at that station. Ninemile Creek measured colder temperatures as well, but had zero Coldwater individuals. This indicates that something other than temperature was limiting Coldwater fish communities at the Ninemile site.

Overall tolerant individuals were abundant compared to Northern Coldwater streams (median < 1%), but particularly in Ash River Lower where some of the warmest temperatures were found. Tolerant individuals were as high as 23% in the Ash River Lower; the average for the ARW was 9%.

3.11. Dissolved oxygen in the ARW

Aquatic organisms require oxygen for respiration; DO levels can affect growth rates and alter fish behavior (Doudoroff, 1965). Low or highly fluctuating DO levels can have detrimental effects on many fish and macroinvertebrate species (Davis, 1975 and Nebeker, 1991). DO levels below 5 mg/L are stressful to most fish and trout tend to avoid waters where DO levels fall below 7mg/L. Wide swings in DO causes its own stress on fish and is often related to eutrophication or excess plant growth in streams. The Minnesota DO standard (as a daily minimum) is 5 mg/L for Warmwater streams and 7 mg/L for Coldwater. DO flux (daily fluctuations in DO) of 3mg/L is used as a threshold for measuring wide swings in dissolved oxygen.

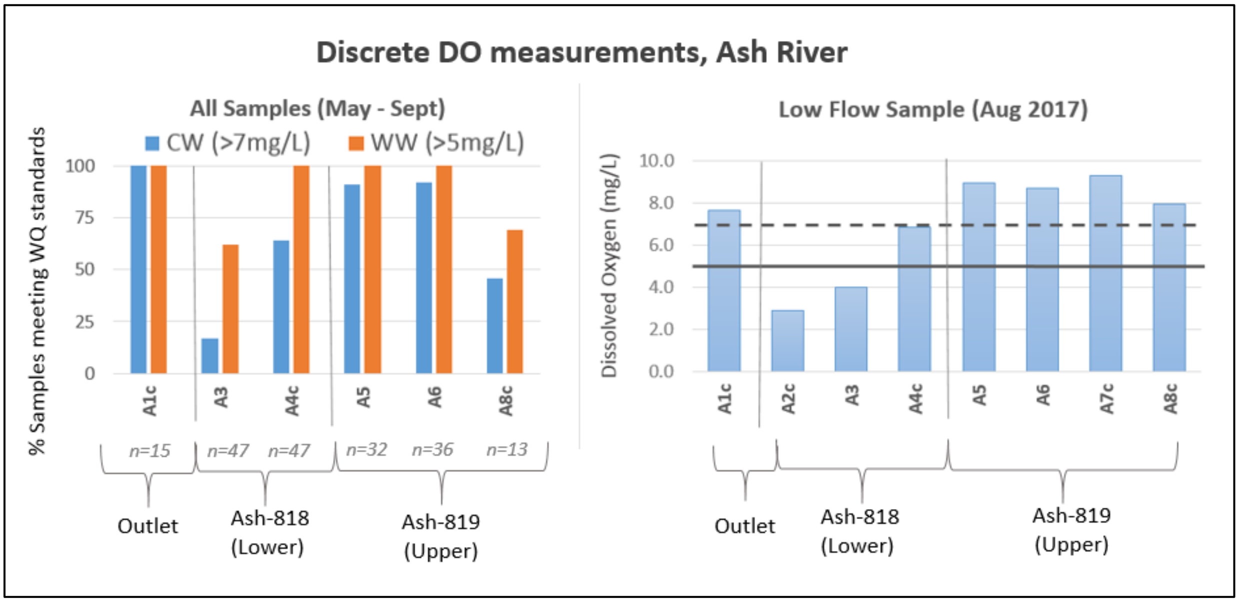
3.11.1. Dissolved oxygen methods

Dissolved Oxygen was measured at various locations between 2014 and 2017 in the ARW. Readings were taken at discrete times when sample collection for other parameters at these locations were collected. *Discrete* measurements were most frequently collected during the day when DO levels are typically on the rise in the normal daily cycle. Because discrete measurements were not taken when DO is typically at its daily minimum (evening to pre-9:00 am), DO loggers were deployed at several locations in the ARW. The loggers collected *continuous* DO at 15-minute intervals from which daily changes in DO levels were observed.

3.11.2. Review of dissolved oxygen data

DO levels in the Ash River Lower were the lowest of stations samples. Levels were most-often unsuitable for trout, and at times were marginal to support a healthy Warmwater community as well. Levels decreased longitudinally downstream in the AUID. DO levels at mid-reach station A3 rarely (17% of discrete measurements) met the Coldwater standard. DO was below the Coldwater standard for the entire 2016 and 2018 continuous deployments and most of the 2017 deployment (Figure 18 and Figure 19). Furthermore, DO in the Ash River Lower was often (38% of discrete measurements) below the Warmwater standard. In 2018, levels below 5mg/L occurred only during the evenings, but loggers recorded consecutive days below the 5mg/L standard in 2016 and 2017. Discrete DO readings measured DO below 3 mg/L during baseflow in this AUID (site A2) and continuous data shows levels at site A3 approaching 3 mg/L briefly in 2017. Levels this low are unsuitable for trout and can cause avoidance by Warmwater fish as well.

Figure 18. Variations in discrete DO measurements in the Ash River between the headwaters at Ash Lake (S008-621) and the outlet to Kabetogama Lake (S015-009) are shown in two plots. Left: graph of % total measurements taken between May and September in years 2014-2017 that pass the Coldwater and Warmwater DO standards. Right: graph of DO (mg/L) during baseflow of August 14, 2017 show variability of DO within the Ash River. The dash line represents the Coldwater DO standard and the solid line represents the Warmwater DO standard.

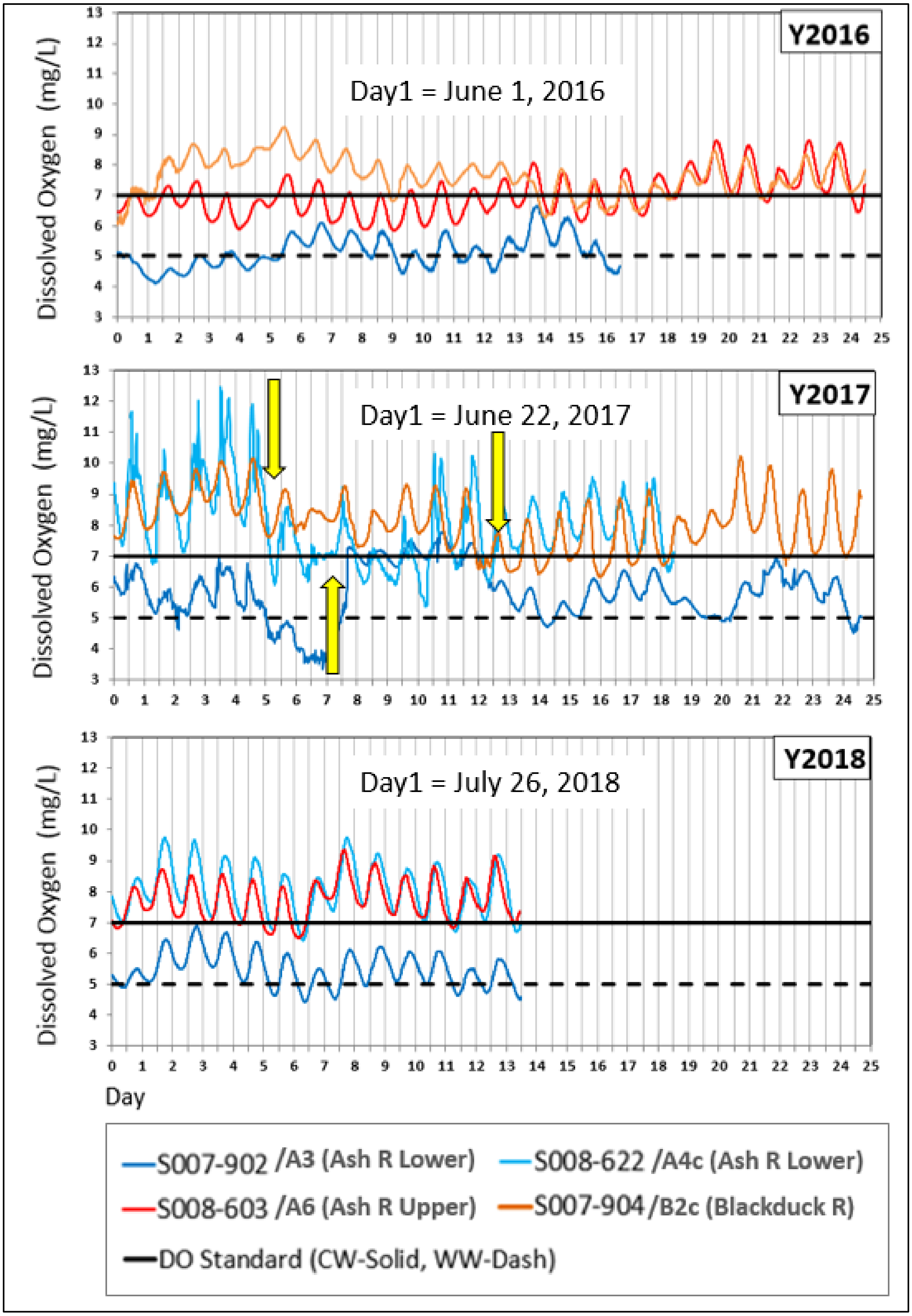


DO levels in the upstream end of the Ash River Lower (Site A4) noticeably improved from the downstream site. The Warmwater DO standard was always met; however, levels were below the Coldwater standard for 36% of discrete measurements. Continuous data showed that DO was lowest in the late evening to morning hours, but occasionally remained below the standard for consecutive days. DO flux was abnormally high (>3 mg/L) at this station for multiple days in 2017, but decreased following a 0.70-inch rain as did base level DO. Two more 1-inch rain events occurred during the deployment; one raised DO levels in the stream whereas the other decreased DO and DO flux. Yellow arrows mark the timing of these rain events in Figure 19.

DO concentrations were higher in the Ash River Upper compared to the Lower AUID, but levels varied annually/seasonally. The Coldwater standard was met greater than 90% of the sample record, however continuous records show summer DO fell below the Coldwater standard more often (53% of the 24-day record in 2016). The Warmwater standard for DO was clearly met in this AUID.

Sustained levels above the Coldwater standard were best met at Blackduck River site B2c. This included 90% of the 77 discrete measurements and 84% of the continuous record greater than 7mg/L. DO flux was elevated during the end of the 2017 deployment, but only exceeded 3 mg/L for one day.

Figure 19. DO levels for reaches of the Ash River and Blackduck River, years 2016-2018.



3.11.3. Biological response to dissolved oxygen

Dissolved oxygen tolerance and TIV scores were used to assess the affect DO was having on stream biota. At all biological sites, there were more DO-tolerant fish than DO-sensitive fish. Fish TIV scores ranked in the lower 31% of all Northern Coldwater Streams in regards to tolerance to DO. Ash River station A4 ranked particularly low (ninth percentile). Regression-based probabilities of meeting the Coldwater DO standard ranged from 43% in the Ash River Lower to 67% in both the Ash River Upper and Blackduck River AUIDs based on the fish community. Generally, these correspond to lower DO measured in the Ash River Lower compared to higher levels measured in the other two AUIDs. DO TIV scores within the Ash River Lower AUID did not correlate with spatial variations of DO within the AUID. Fish TIV scores indicated that DO tolerance decreased longitudinally downstream in the Ash River Lower, which did not correlate with lower DO levels in the downstream reaches of the AUID.

Macroinvertebrate TIV scores indicated less tolerance to low DO in the ARW compared to fish scores. Probabilities of meeting the Coldwater DO standard ranged from 62% to 84% based on macroinvertebrate communities. ARW macroinvertebrate TIV scores for DO ranked mostly in the lower 21% for Northern Coldwater Streams; however the Blackduck River station B2 ranked above the median (54th percentile). Thirty DO-intolerant taxa were found at this station, making up 64% of the total individuals. The macroinvertebrate DO TIV score at this station correlated better with DO records (showing adequate levels) compared to the fish TIV scores (30th percentile). This may indicate that factors other than DO were limiting the Coldwater fish community at this station.

3.12. Eutrophication and total phosphorous in the ARW

In addition to supporting respiration for biota, stable DO levels above 5mg/L are essential for normal chemical reactions that continually occur in rivers and streams. For example, low DO promotes the accelerated release of phosphorus from sediments. Low DO problems often have as their root cause excess nutrients, particularly phosphorus in relation to eutrophication.

Total phosphorus (TP) is often above the North Region River Nutrient Standard (50 µg/L) in the Ash River Lower AUID and as previously shown, DO is periodically below 5mg/L and DO flux is greater than 3mg/L at times. Because of this, we investigated TP and eutrophication in the ARW. It is important to note that headwater lakes, Ash and Blackduck Lakes, currently meet the regional eutrophication criteria for lakes, showing no water quality concerns related to eutrophication. High phosphorus concentrations are potentially a concern for downstream receiving waters, Sullivan Bay of Kabetogama Lake, where high algal productivity produce blooms of blue-green algae in some years (Payne, 1991) and cyanotoxins are present in blooms (Christensen et al., 2011; Christensen et al., 2013).

3.12.1. Eutrophication and total phosphorous methods

The river eutrophication standard is a two-part standard, requiring an exceedance of the causative variable (TP) and a response variable, which indicates the presence of eutrophication. Response variables have region specific standards and for Northern Rivers, they are Chlorophyll-a (7 µg/L), DO flux (3 mg/L), and Biological Oxygen Demand (1.5 mg/L).

TP was sampled at five Ash River stations and one Blackduck River station during years 2014-2017 (Table 9). The number of samples collected varied among stations. Several stations were sampled too infrequently to assess for TP, but serve as an indicator of phosphorous levels. Chlorophyll-a was sampled two times at station A3 where TP levels were greatest. Nitrogen was also collected at several stations. A comparison of TP and nitrogen concentrations can indicate whether one nutrient is limiting in a system.

Table 9. Water quality parameters typically used in analysis of eutrophication within a stream for multiple Ash River Watershed sites. Values in red-print indicate a standard may be exceeded and required more review. Asterix indicate less than ten samples were used to calculate averages and should be used as supporting information only.

AUID	Station (*Equis ID*)	TP (ug/L) June-Sept Average/Maximum	Diel DO Flux (mg/L) Average	# days DO Flux > 3mg/L (% record)	Chlor-a (ug/L) Average	TKN:TP ratio Average	TKN:TP ratio Range
Ash River outlet	A1 (*S015-009*)	42/63				21	(16,35)
Ash River -818 (Lower)	A3 (*S007-902*)	**63/130**	1.12	0	4.58 *	13	(9,21)
	A4c (*S008-622*)	**52/69**	2.5	**6 (20%)**	-	14	(11,22)
Ash River -819 (Upper)	A5 (*S008-602*)	46/78*	-	-	-		-
	A6 (*S008-603*)	37/61*	1.33	0	-		-
Blackduck River -820	B2c (*S007-904*)	46/101	1.09	1	-	14	(8.5,21)

3.12.2. Review of eutrophication indicators

Seasonal average (June-Sept) TP in the Ash River Lower-818 AUID was elevated relative to the region's river nutrient threshold of 50 µg/L, but symptoms of eutrophication were not observed in the river. Two chlorophyll-a samples were collected during the summer 2018 season at station S007-902 when TP was 60 µg/L; both chlorophyll-a samples were below the North Region Standard. Dissolved oxygen levels were between 4 and 7 mg/L during this period and DO flux was well below 3.0 mg/L.

Seasonal mean TP levels were also elevated beyond the standard at Ash River Lower station A4. Chlorophyll-a was not sampled at this station; however DO flux was measured for brief periods of 2017 and 2018. The average DO flux at this station was 2.5 mg/L. There were multiple days in 2017 when DO flux exceeded the 3 mg/L response threshold, but the later part of the 2017 record and the full 2018 record show that DO flux was more often in a normal range.

Nitrogen levels alone and as compared to TP did not indicate eutrophication. Overall, nitrate plus nitrite in the ARW was very low, at levels that were often below the reportable limit by the lab. Because of this, Total Nitrogen was assessed using Total Kjeldahl Nitrogen (TKN), the sum of ammonia-nitrogen and organically bound nitrogen. TKN levels were <1100 µg/L, within a normal range for rivers and streams exhibiting non-eutrophic conditions (Dodds & Smith, 2016). Additionally, Ash River TKN to TP ratios (Table 9) were within a normal range (11:1 to 21:1) for forested streams (Allan, 1995). Mixing of lake and stream water at station A1 (S015-009) near the outlet to Lake Kabetogama would explain the slightly elevated ratios there. Most lakes in the Northern Lakes and Forests Ecoregion including Ash and Blackduck Lakes have a TKN to TP ratio of approximately 30:1.

No signs of filamentous algae were observed in the Ash River Lower; rather macrophytes were the dominant aquatic plant. Overall, the stream regularly appeared gray, rather than green. The high DO flux at station A4 likely was caused by macrophytes growing in the channel. It is suspected that the gray coloration relates to suspended sediment that does not settle out; and influences light penetration through the water column as well as macrophyte photosynthesis, which causes variability in DO flux. DO flux decreased after several rain events in 2017 when water levels would rise. This could be due to low-DO wetland waters flushing into the stream post-rain and/or less sunlight availability for photosynthesis in the deeper more turbid waters. Variability in DO flux did not appear to correlate with sky cover based on weather-records for the area, which further supports the idea that stream turbidity plays a role in macrophyte photosynthesis and resulting DO fluctuations.

Although data did not show clear signs of in-stream eutrophication, the receiving waters (Kabetogama Lake) experiences regular blue-green algal blooms and has shown to have larger nutrient and chlorophyll-a concentrations than other large area lakes (Payne, 1991; Christensen et al., 2004). A 2011 study estimated 34 to 100% of TP loading (years 2008-2009) to Kabetogama Lake came from sources to the south, including contributions from the Ash River (Christensen et al., 2011). TP levels measured for this study at station A1c (Table 9) during 2017 were similar to concentrations (mean = 41 µg/L, max = 74 µg/L) measured by the USGS and VNP in Sullivan Bay of Kabetogama Lake, years 2016-2017 (USGS, 2019). The SID study found slightly higher concentrations above Ash River Falls at station A3. Lower concentrations near the stream outlet that were more similar to lake concentrations indicate that mixing of lake and stream water likely influenced stream samples collected at A1c and that higher levels of TP were being transported from upstream Ash River than were measured at the outlet.

3.12.3. Total phosphorous and low DO sources

TP attached to suspended sediment

Water chemistry data suggests that TP is bound to suspended sediment under certain flow conditions, particularly high flows, in the Blackduck River and reaches of the Ash River. TP-TSS regressions were completed for three stations that had the largest datasets of paired TP and TSS sample results. These included stations A1c, A3, A4c, and B2c.

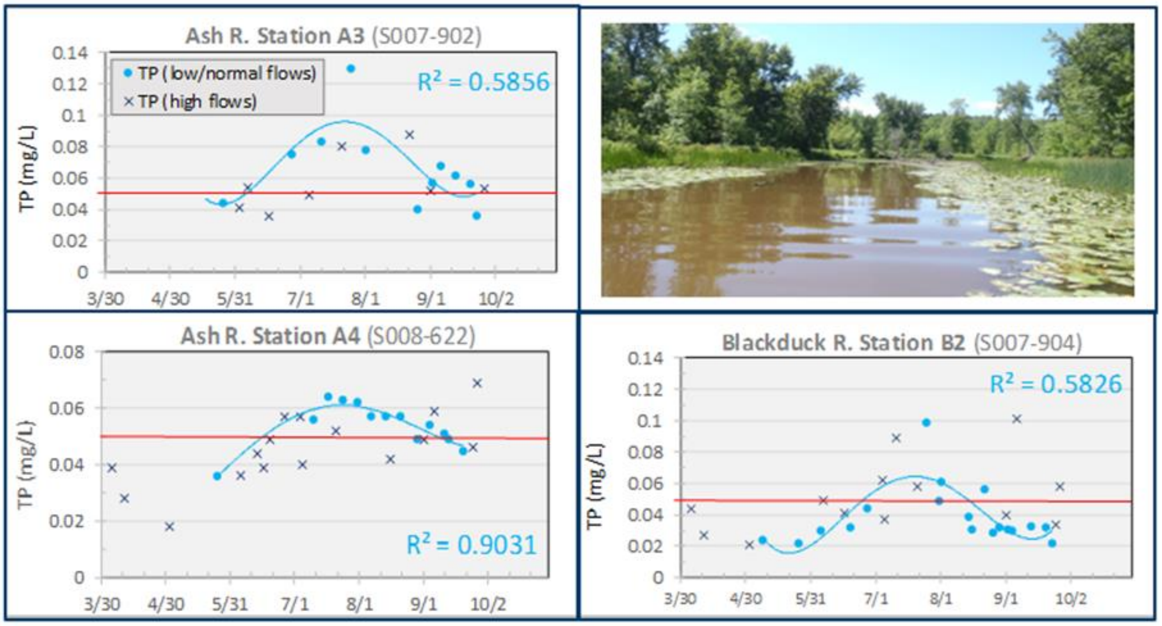
Linear regression found the strongest relationships at stations A4c and B2c, the two gage stations, indicating particle-bound TP was a strong driver of suspended phosphorous at the two stations. When looking at the entire dataset at each station, the regression coefficient (r^2-value) was approximately 0.45. However, when low flows were excluded, the relationships improved to r^2=0.60 at the Ash River gage and r^2=0.72 at the Blackduck River gage and weakened at the two downstream Ash River stations A3 (r^2= 0.30) and A1c (r^2 = 0.16). Under low flow conditions, a weaker TSS-TP relationship was expected on the Blackduck River; however, the weaker relationship at the Ash gage was not as easily explained by TSS concentrations since duration curve analysis shows that TSS levels remain elevated at this station during low flows.

TP released from wetlands

It was found that in addition to suspended sediment, wetlands were a dominant source of TP in the ARW, particularly under normal to low flow conditions. This was observed through seasonal patterns in TP that were plotted (Figure 20) at multiple stations (A3, A4c, B2c), chosen for a high number of low flow TP data points. TP was plotted for "day of year", focusing on low to normal flow conditions, and excluding TP measured during high flow conditions when TP levels are elevated due to the attachment to elevated suspended sediment. Under low to normal flow conditions, TP peaked at all three stations in late July and then slowly decreases into the fall season. A similar pattern of TP in streams sourced from anoxic wetlands has been documented in other Minnesota Northern Streams (MPCA, 2018). This late-July period when TP peaks is the time of the summer when wetland soils are at their warmest and most anoxic condition, more readily releasing TP.

Low flow TP levels were highest at Ash River station A3, which can be explained by the close connectivity to riparian area and bog wetlands near the sampling station. The very low DO signal at station A3 also supports the conclusion of a strong wetland connection at this Ash River Lower station.

Figure 20. Seasonal patterns of TP under low to normal flow conditions plotted for three water chemistry stations. TP peaks in mid to late-July. Low to normal flow TP concentrations were highest at station A3 where there is a close connection to wetlands. Photo: Station A3 under low to normal flow conditions.



3.13. Physical habitat in the ARW

The MPCA Stream Habitat Assessment (MSHA) scores were mostly fair in the ARW, with one poor score on Ninemile Creek. The MSHA scores account for variables such as land use, overhead cover, instream cover, substrate, and channel geomorphology (riffle-pool placement and depths). In Table 10, several habitat variables were reported. In addition, a more detailed list of "limiting factors" were reported for stations with lower scores, categorized as "fair" or "poor." Several natural stream features limited many of the stations, including a lack of riffles, embeddedness, slow uniform velocities, and lack of instream cover. Finer substrates (silt and sand) were dominant substrates. Gravel, critical to healthy Coldwater communities, lacked at most locations.

The Ash River Lower at station A3 scored fair with both natural features and sediment dynamics contributing to the low score. Multiple physical habitat features critical to Coldwater communities were absent including adequate flow velocities, riffle features, and coarse gravels. The riparian area was extensive, but shading was low to moderate. Silt and clay were the dominant substrates. There was evidence of siltation on in-channel features, which correlates with our understanding of TSS in the AUID. SID work found that fines were up to a foot deep in places.

Both stations on Ash River Upper scored fair for physical habitat. Silt and sand were dominant bed materials and riffles were poorly defined. Percent silt and sand increased at downstream station A5, which may be due to the bank erosion identified upstream of the reach (Figure 8), compounded with a decreased gradient to transport fine particles readily. Embeddedness was moderate at both stations.

The results for Kinmount Creek were very similar to the upstream station A6; the stations were located in the same area of the watershed with similar geologic and watershed characteristics.

The Blackduck River scored fair at both stations, but for different reasons. Natural features were most limiting at the downstream station B1, whereas anthropogenic influence on habitat was more limiting at upstream station B2b. Station B1, located in the low-gradient downstream reach, lacked prominent riffle features, had uniform slow velocities, and the bed material was mostly fines. Where gradient increases at station B2b, riffles were prominent and coarser sand and gravels were dominant in both riffles and pools. Variability in flow velocities was also observed. Variables negatively influencing habitat at the site included disturbed riparian area, severe erosion, and embeddedness.

The poor score on Ninemile Creek was negatively impacted by many of the same variables that influenced the Blackduck River score. Shading was further reduced at the Ninemile Creek site where more riparian area tree removal had occurred. Particle size was fine and embeddedness was moderate. A perched and undersized culvert on Ninemile Creek near the confluence of the Blackduck River likely contributed to increased depth of fines, as sediment aggraded upstream of the undersized crossing. Finally, riffles were noted as absent within the Ninemile Creek monitoring site, but were present further upstream within the boundary of the ranch.

Table 10. MSHA (habitat) summary of Ash River Watershed biological sites.

		Dominant Substrate					
AUID	Site ID	Run/Glide	Pool	Embeddedness	Habitat (MSHA) Rating	Shade	Limiting Factors
Ash River Lower	A3 (14RN001)	clay and silt	clay and silt	No coarse substrate	Fair	Low to Moderate	Siltation, no coarse substrate, lacks riffles and large substrate, slow uniform velocities
Ash River Upper	A5 (14RN012)	silt and sand	sand	Moderate	Fair	Substantial	Heavy erosion, embeddedness, lacks riffles and sinuosity, slow uniform velocity
	A6 (14RN099)	sand and gravel	silt and sand	Moderate	Fair	Moderate	Embeddedness, siltation, lacks sinuosity
Kinmount Creek	K1 (14RN014)	silt, sand, gravel	silt and sand	Moderate	Fair	Moderate	Embeddedness, siltation, lacks large substrate, lacks riffles
Blackduck River	B1b (14RN017)	silt and sand	silt	Moderate	Fair	Substantial	Embeddedness, lacks large substrate, lacks riffles and deep pools, slow uniform velocities
	B2b (14RN018)	sand and gravel	sand and gravel	Light	Fair	Moderate	Lacks riparian, severe erosion, embeddedness, lacks large substrate
Ninemile Creek	N1 (14RN021)	silt and sand	silt and sand	Moderate	Poor	Light to Moderate	Lacks riparian and shade, moderate erosion, embeddedness, lacks riffles

3.14. Summary of findings in the ARW

The SID findings in the ARW are summarized below in Table 11. While the TSS and *E.coli* impairments were the focus of the study, other water quality and habitat findings were included. The additional information provides context to the natural potential and/or limitations of these streams and identifies areas where human disturbance has negatively influenced them.

Table 11. Summary of findings in the ARW.

Use Classifications	*1. Use classifications for the ARW AUIDs should be re-evaluated using new and existing data. Knowing this classification is critical because TSS standards and associated target reduction loads are dependent on whether the stream is Coldwater or Warmwater. The re-evaluation process is started below in Table 12 for all Coldwater AUIDs in the ARW by summarizing existing findings and identifying what types of additional information would be helpful. A change from Coldwater to Warmwater is recommended for the Ash River Lower.*
TSS Impairments	2. In the Ash River Lower, TSS was elevated above the Coldwater standard for 90% of samples and beyond the Warmwater standard 55% for of samples for the full data record (2014-2018). During 2017, TSS was elevated above the standard for all flow regimes, indicating that TSS entered the stream during high flows and did not settle out under low flows. Target load reductions were very different depending on whether the Coldwater or Warmwater standard was applied. Reductions of approximately 30% were estimated across the full range of flows to meet the Coldwater target and much lower reduction needs were estimated at low to mid-range flows only to meet the Warmwater target. 3. In the Blackduck River, TSS was elevated beyond the Coldwater standard for 25% of samples and beyond the Warmwater standard 20% of samples for the full data record (2014-2018). During 2017, TSS was only elevated above the standard for high and very high flow regimes, indicating that TSS entered the stream during high flows and moved/settled as flows reduced. Target load reductions were similar depending on whether the Coldwater or Warmwater standard was applied. High TSS reductions (70-80%) were estimated to meet the Coldwater and Warmwater target at flows greater than 80cfs. Additionally, reduced loading is needed at flows between 34 and 80cfs to meet the Coldwater target. 4. Bank erosion and channel instability is a dominant source of TSS in the Blackduck River. Bank erosion and upstream/tributary inputs area dominant source of TSS in the Ash River as low slopes and fine soils that result in longer suspension of fine materials. Sources linked to erosion and instability include channelization, cattle access, culverts, historic railroad grade and in-channel pilings, and isolated beaver dams abutted against valley walls.
E.coli Impairment	5. The primary source of *E.coli* in the Blackduck River is a ranch where cattle access the stream. *E.coli* levels violated the standard during all flow regimes. Outside the influence of the ranch, *E.coli* can be elevated beyond the monthly geometric mean-based standard in high beaver-activity areas. Our data shows that concentrations of 220 MPN/100 mL can occur under natural conditions.

Action for Impairments	6. There is a need to develop/support restoration and protection plans for stream reaches where land-use activities, both historic and present, have contributed to TSS and/or E.coli impairments. These areas and/or activities were identified in the above sections and recommended actions are highlighted below in Section 3.15
Elevated Total Phosphorous Low Dissolved Oxygen	7. TP levels elevated beyond the standard in the Ash and Blackduck Rivers is partly natural due to TP release from anoxic wetland during the summer months. In addition, TP is bound to TSS, which is elevated in the Ash River Lower during all flow regimes, and the Blackduck River during high flows. The former is a natural condition and the latter can be addressed through efforts to reduce TSS inputs to the streams. 8. Low DO levels, often below the 7mg/L standard and sometimes below the 5mg/L standard, appear to be a natural condition of low-gradient streams closely connected to riparian area and bog wetlands. Wetland release of low DO water during large rain events was documented at station A3 in the Ash River Lower through continuous DO monitoring efforts.
Physical Habitat Loss	1. Lack of riffles and lack of gravel and/or embeddedness of gravels is evident throughout much of the ARW. Spawning areas for Coldwater fish and critical habitat for aquatic macroinvertebrates is not optimal in much of the ARW, and may be naturally occurring in many AUIDs. 2. A high percent of culverts in the ARW act as fish barriers for various reasons influenced by an undersized design and/or perched status. 3. Anthropogenic influenced sources of habitat degradation include bank erosion (influencing embeddedness and fine substrates), riparian area loss, and overhead shading loss.

Table 12. Summary of water quality, biological, and resource management data to aid in future use classification discussions. Coloring indicates whether the data indicates Coldwater (blue), Warmwater (beige), or is marginally CW/WW (green). Recommendations for future changes or data collection efforts are included.

	Ash River Lower	Ash River Upper	Blackduck River	Ninemile Creek	Kinmount Creek
Temperature	WW	WW	M	M	WW
Dissolved Oxygen	WW	M	CW	IF	IF
Trout Stocked (Y/N)	N	N	N	N	Y
Trout Recovery (Y/N)	Not Sampled	Y	Not sampled	Not sampled	Not sampled
Coldwater F-IBI Score	marginal to fair *(a single Coldwater fish in survey)*	fair to good	poor to fair	poor to marginal	fair
Warmwater Fish-IBI Score	fair to poor *(does not fit well in IBI-developed Fish classes)*	fair to excellent	fair to excellent	good to excellent	excellent
Macroinvertebrates	No strong Coldwater taxa	taxa represent healthy Cool/Warmwater community	various Coldwater taxa present	some Coldwater taxa present	taxa represent healthy Cool/Warmwater community
Natural (non-human disturbance) Habitat features	No riffles, uniformly slow velocity, fine substrate	No riffles, uniform slow velocity, fine substrate in some reaches	*Lower AUID* : No riffles, uniform slow velocity, fine substrate. *Upper AUID:* has riffles, diverse flows, some gravels	Lacks riffles, but may be result of downstream culvert.	Lacks riffles, mostly fine substrate
Notes	No strong WQ indicators that this AUID supports coldwater fishes. Wide low-gradient reach with wetland characteristics. Reach does not fit well in the current IBI fish classes.	DNR sampled 10 brown trout (231 mm) in Fall, 2016 (stocked in Kinmount Cr tributary June, 2016).	High land-use activity near biological station B2b and water chemistry station B2c.	High land-use activity near biological station. Perched culvert could be negatively affecting F-IBI scores.	The DO logger did not record at this station. MNDNR stocks Brown Trout.
Recommendation	Consider useclass change from CW (2A) to WW (2B)	Resample biology, temperature, and DO in next assessment cycle. Is there carry-over from 2016 and 2018 stocking efforts?	Resample biology, temperature, and DO in next assessment cycle. Consider splitting AUID where slope & flow dynamics change	Resample biology, temperature, and DO in next assessment cycle.	Resample biology, temperature, and DO in next assessment cycle. Is there carry-over from 2016 and 2018 stocking efforts?

3.15. Recommendations for restoring impaired waters

3.15.1. Blackduck River near Sheep Ranch Road

The Blackduck River showed many signs of being unstable including meander cutoffs and oxbows, high rates of bank erosion, and channel incision. While there were several contributing factors, the straightening of 3,300’ of stream prior to 1940 is likely a primary cause of instability. The stream is moderately incised and bankfull flows are unable to access the floodplain. The increased sheer stress will continue to erode the banks and contribute to the TSS impairment until the channel stabilizes at a lower base level. However, this could take decades and would result in continued high sediment loads over that period.

Land management practices such as clear cutting, loss of riparian area vegetation, improperly sized or aligned culverts, and cattle access are perpetuating instability and accelerating the rate of channel evolution. In addition, sample data showed that the *E.coli* levels are highest within the boundaries of the ranch, exceeding the *E.coli* standard in high frequency and magnitude. Several culverts are perched within the boundaries of the ranch, particularly one on Ninemile Creek near the confluence with the Blackduck River, which impedes fish passage between the two streams.

Based on DO, and temperature, the Blackduck River reach that intersects the ranch has the highest natural potential to support a Coldwater community in the ARW, yet fish scores were poor to fair. Stream temperatures monitored were within a range that was regionally shown to support trout and cooler than other streams in the ARW. Dissolved oxygen levels met the Coldwater DO standard 90% of the record. In addition, despite the siltation that has occurred on the streambed, macroinvertebrate scores were good in this reach, scoring above the upper confidence level of the M-IBI. The MSHA found degraded habitat that included no riparian area, severe bank erosion, and moderate shade and instream cover. Instream cover included undercut banks, wood, and deep pools, but lacked features such as boulders, backwaters and slow shallows, root wads, and floating vegetation.

This study suggests implementation to address the TSS and *E.coli* impairments on the Ash and Blackduck systems start in this area. Water quality and channel restoration projects have the potential to improve physical habitat as well. The magnitude and cost of restoration activities varies and is dependent on available funding and landowner interest. Because of this, some options may be more feasible that others to carry forward. Professional guidance on project prioritization including the order of activities or areas of focus is highly recommended to obtain optimal results. For example, planting riparian area vegetation along a reach of stream that is incised without addressing the channel instability will not address and treat the source of the TSS in the stream. However, riparian vegetation restoration will have long-term positive effects conducted on a channel that has been reconnected to its floodplain. Restoration activities to consider within the ranch include:

- Work with the local landowner to provide watering and shade for cattle outside of the riparian zone of the river. This would include a fence or other exclusion to allow the riparian forest vegetation to become re-established and keep the cattle from wading in the stream. Goals: reduce the amount of bed and bank disturbance as well as eliminate the direct introduction of animal waste (*E.coli* bacteria, nutrients, etc.) to the stream.
- Work with the local landowner to develop a grazing management plan that benefits production, the pasture environment, and the stream ecosystem. Goals: increase productivity per unit land area, improve/maintain pasture health (high quality plants per acre), and improve plant cover and litter to prevent soil erosion and provide for water conservation and quality.
- Work with the local landowner to develop a forest management plan. Goals: provide stream canopy to lower/maintain stream temperatures, provide cooling areas other than stream water for cattle, provide fallen wood and leaf litter to the stream channel, and increase bank stability.
- Work with the local landowner to implement stream restoration projects that connect channel to the existing floodplain, while also protecting landowner infrastructure. Connectivity to the floodplain could be achieved through adding gravel, wood, and rock to the existing riffle areas where the pattern of the stream is intact. In areas, consider removing the road from the valley and reconnecting old meander loops to the existing stream where the stream meander pattern

has been truncated, being cautious of old meander loops that have the potential to avulse. This can be accomplished by plugging the ditched channel and adding grade control at the riffles that would include a mixture of gravel and rock substrate. If moving the road were considered not feasible, another option would be to add grade control in the existing ditch in order to raise the channel to the existing floodplain. If these options are chosen, detailed engineering and design will be required to achieve the maximum benefit to the stream and protect existing infrastructure. Additional benefits could be added to the design using gravel riffles and wood, utilized as erosion prevention and habitat enhancement. Goals: connect stream to its floodplain, dissipate stream energy, improve channel stability, and improve stream habitat.

- Work with landowners to replace and/or realign culverts that are causing sedimentation to the stream and/or are impeding fish passage. Goals: restore natural stream flow at crossings, decrease erosion, improve channel stability, decrease road crossing maintenance, and improve fish passage.
- Work with the local landowner to restore vegetation along the streambanks including un-grazed native grasses, forbs, trees, and shrubs. Goals: improve physical habitat, improve channel stability, reduce channel erosion, and reduce pollutants entering the stream through surface runoff.

3.15.2. Roadway and ditch management

Gullying and erosion of road silt and gravel were regularly observed in the ARW during wet conditions (snowmelt and post rain events) within the study period, particularly at culvert stream crossings and around roadway cross-drain pipes. Ditches were observed transporting turbid waters, particularly during the spring season along silt roadways and/or adjacent to previous winter cuts. In addition to gravel roads, several bank stabilization projects have been completed along U.S. Highway 53 in the past several years due to roadway bank failures, which have not shown to impact water quality or stream stability in the Ash River.

Roadway management activities to consider include:

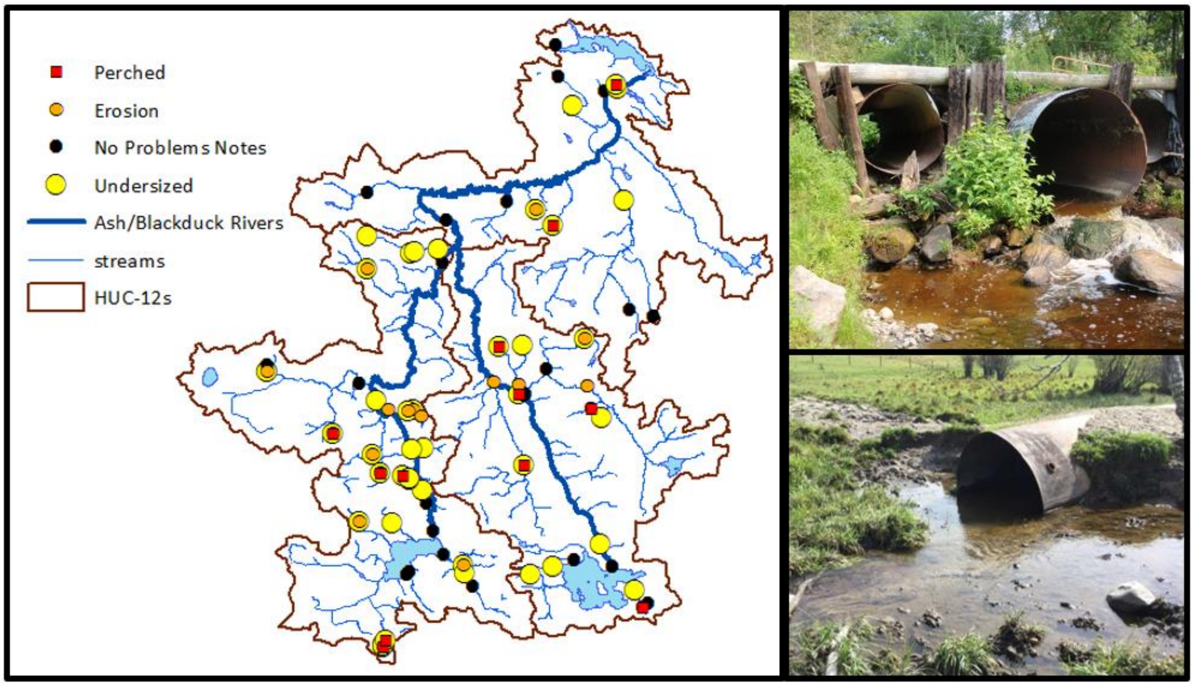
- Conduct thorough roadway and ditch assessments in prioritized areas throughout the ARW. Visual observations of gullying, soil erosion potential maps (Figure 3), and road densities suggest starting in the Ash River Upper subwatershed, particularly the area that drains to the Ash River between station A6 and A4c. Other priority areas include the Fawn Creek, Ninemile Creek, and Blackduck River (upstream of Sheep Ranch Road) drainages.
- Re-size or realigning cross-drain pipes in a way that minimizes roadway and ditch erosion in problem areas. In addition to location recommendations above, prioritize localized areas near streams and on roadways where maintenance and refill regularly occurs.
- Perform proper ditch maintenance using guidelines outlined in the Field Guide for Maintaining Rural Roadside Ditches (link below). http://www.lakesuperiorstreams.org/stormwater/toolkit/contractor/resources/DitchGuide_SeaGrant.pdf
- Continue monitoring bank stabilization projects and future bank failures along the west side of U.S. Highway 53, as well as potential impacts to stream health.

3.15.3. Replace undersized/perched culverts

A high percent of culverts in the ARW are undersized, which can lead to stream instability and erosion as well as impede fish passage. The flatness of the overall watershed may explain why signs of erosion were limited to one-third of undersized culverts in the ARW. Culvert inventories identified crossings with erosion and gullying as well as those that act as fish barriers. These data have been imported into the DNR's culvert inventory database. The culvert inventory map (Figure 21) below shows the location and problem status of culverts surveyed in the ARW. Detailed locations or descriptions of problem culverts can be obtained by contacting DNR Clean Water Specialist staff in the Minnesota Grand Rapids DNR office and/or the authors of this report. Recommendations include:

- Prioritize problem culverts using culvert inventory results, through knowledge of those prone to maintenance or failure, as crossings deteriorate, as roadways are constructed or upgraded, and/or in conjunction with other restoration and protection efforts. A perched culvert on Ninemile Creek (Figure 21) is a good example of a culvert replacement that could enhance other restoration efforts.
- Replace prioritized culverts in a way that simulates the natural stream form, using tools such as MESBOAC design procedure and other guidance published in the report (link below), Best Practices for Meeting DNR General Public Waters Work Permit GP 2004-0001. http://www.dnr.state.mn.us/waters/watermgmt_section/pwpermits/gp_2004_0001_manual.html)
  - **MESBOAC** stands for:
  - **M**atch culvert width to bankfull stream width
  - **E**xtend culvert length through the side slope toe of the road
  - **S**et culvert slope the same as the stream slope
  - **B**ury the culvert
  - **O**ffset multiple culverts
  - **A**lign the culvert with the stream channel
  - **C**onsider head-cuts and cutoffs

Figure 21. Culvert inventory results for the Ash River Watershed (left). Blackduck River culverts that are perched (top right) and causing erosion (bottom right).



3.15.4. Forest management and soil erodibility

Forest harvest was a dominant land use activity in areas identified as having high bank erosion rates, high soil erodibility, and elevated TSS concentrations in streams. Most specifically, the two high erosion reaches identified in the BANCs survey had forest disturbances of 40% land area along the stream corridor. Forested land is owned by state, private, and federal entities in the ARW. Collaboration between agencies and the private industry on the extent of areas cut within an area, can only benefit the environment by keeping percent "young forest" (<16 years) to percentages that are protective of the stream riparian and water quality.

Recommendations to reduce the impact of harvest on flow dynamics and protect stream riparian area and water quality include:

- Maintain or improve collaboration between government agencies and the private industry regarding harvested areas within a drainage, considering "young" (<16 years) and older growth forest at various scales (within a drainage area or stream reach corridor). Management plans should be protective of the stream riparian area and water quality.
- Convert aspen/birch stands to longer-lived tree species in areas.
- Design forest roads using State Forest Management Guidelines and/or in a way that is protective of stream stability and aquatic life. Culvert design is addressed above in 3.15.3.

The best management practices currently used by government and many private industries is detailed at the link below. Adhering to the same guidelines by private property owners is encouraged. In addition, consideration of cumulative impact of total harvest areas (by all parties) on a stream corridor within an area is encouraged in forest management planning.

https://mn.gov/frc/forest-management-guidelines.html

(Updated 2012)

3.15.5. Remove/cut-off remnant railroad pilings

The BANCS survey identified the old railroad grade and in-channel pilings left behind from remnant railway bridges as sources of erosion in the ARW. Wood accrues on these pilings, blocking the channel and interfering with natural wood placement in the stream. Visual observations of aerial imagery show eighteen possible railroad crossings on the Black Duck River and one on the Ash River.

We recommend the following to deal with old railroad pilings in the stream channel:

- Complete inventory of remnant pilings documenting locations, impact on stream stability, impact on aquatic life (fish passage, sedimentation, other), amount of debris trapped, site accessibility, and priority level for removal.
- Research piling removal methods and removal process impacts on the stream channel
- Removal of pilings where priority level is high and accessibility is economically feasible.

4. Dunka River Watershed

The biological assessment work (2014-2015) found the Dunka River to support Brook Trout in a lower watershed reach. There is interest by the local community and regional resource managers as to whether the headwaters of the Dunka River and its tributaries can also support trout and what elements may be limiting survival, reproduction, and movement throughout the system.

4.1. Dunka River Watershed characteristics

The Dunka River drains an area of 58 square miles in Lake and North St. Louis Counties, located on the south side of Birch Lake near Babbitt, Minnesota. The headwaters of the Dunka River starts in a shallow marsh surrounded by bog wetlands and forest. From there, it flows north 17 miles, mostly through forest and wetlands until it reaches the outlet at Birch Lake. The river segment consists of two stream AUIDs, the Dunka River Lower (09030001-987, downstream reach) and the Dunka River Upper (09030001-986, upstream reach). The divide in AUIDs occurs at an unnamed ditch that enters the river at the Scott Road crossing, 1.5 miles upstream of the Peter Mitchel Mine pit.

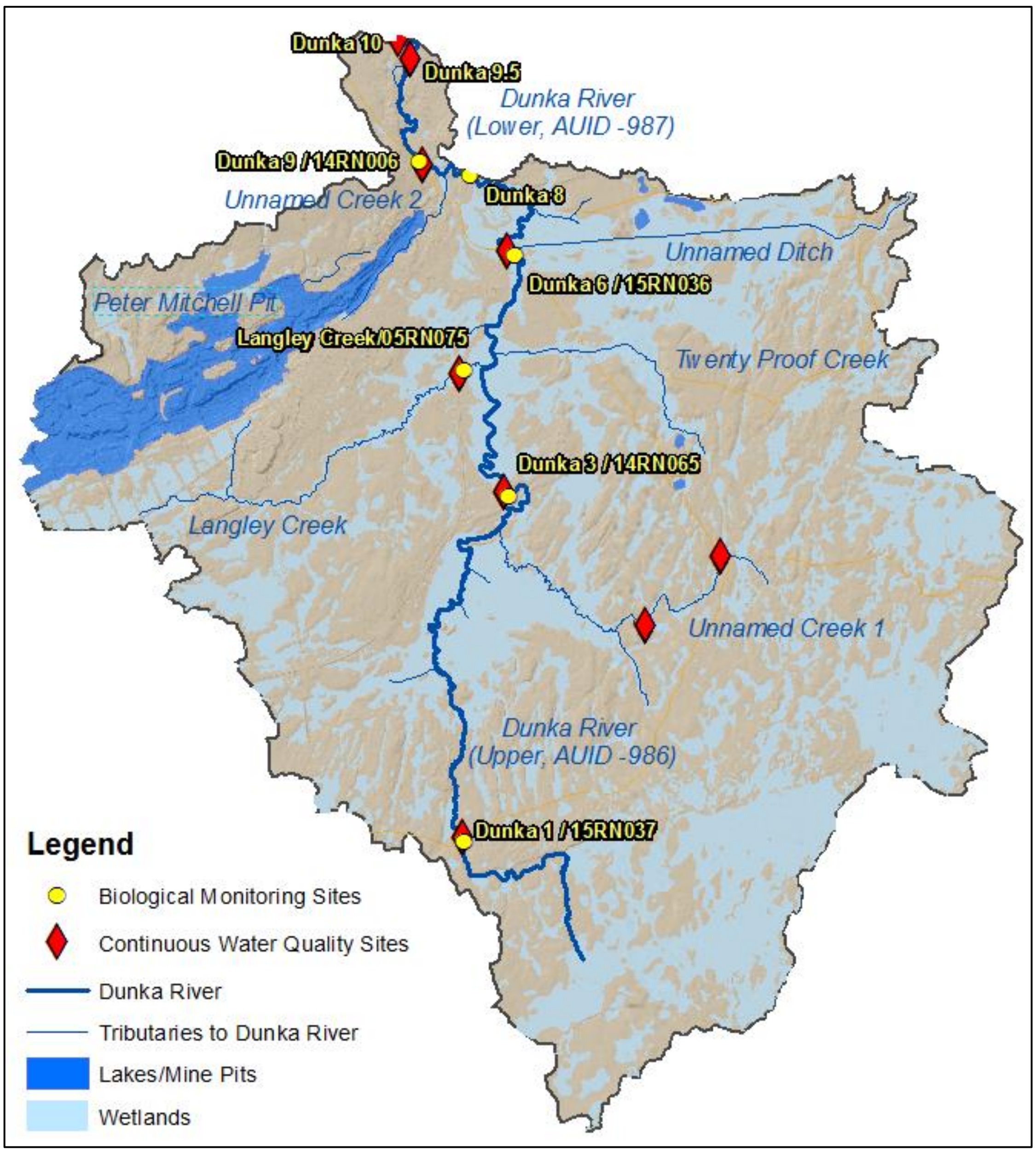
Tributaries to the Dunka River, in order longitudinally from upstream to downstream, include Unnamed Creek (referred to in this report as Unnamed Creek 1), Langley Creek, Twenty Proof Creek, Unnamed Ditch at Scott Rd, and Unnamed Creek (referred to in this report as Unnamed Creek 2) that has severely been altered by the Peter Mitchel Mine (Figure 22).

Wetlands are the primary hydrological storage in the Dunka River Watershed (DRW), occupying 37% of the total watershed area. Bogs are the dominant wetland type in the Dunka River Upper drainage and coniferous wetlands are dominant in the Dunka River Lower drainage. Beaver ponds have some influence on the wetland area within the watershed, producing marsh and wet meadow habitat; they are mostly located in the Dunka River Upper (headwaters) and tributaries. There are no large lakes upstream of Birch Lake in the Dunka River Watershed.

Stream slope in the Dunka River Watershed is variable with low, moderate, and high gradient reaches present in both Dunka River AUID drainages (Figure 26). The headwaters (from mile 12.5 to mile 17) has a moderate slope overall; however, steeper (>4%) forested sections dominated by boulders, as well as very low gradient (<1%) sections surrounded by shrub/meadow, are present. Moderate to high slope reaches tend to alternate with low slope reaches. Lower gradient reaches are mostly controlled by small to moderate-sized beaver dams. Downstream of mile 12.5, Dunka River Upper is mostly flat (<0.1% slope) and flows through shrub/meadow wetlands. There is one moderate-sloped boulder riffle at station Dunka_3, formed within a narrowing of the valley.

The Lower Dunka AUID has the highest stream gradients; although the upper portion of the AUID features very low slopes similar to those described in the Dunka River Upper. Moderate (>2%) to steep (>4%) slopes are present in the three-mile reach just upstream of the outlet to Birch Lake. This downstream-most section of the river features long riffles and cascading boulder/bedrock reaches with frequently spaced deep pools in associated step/pool bed geomorphology.

Figure 22. Map of Dunka River Watershed showing streams, lakes, wetlands, and monitoring locations.



4.2. Geology and soils in the DRW

Most of the DRW consists of Rainy Lobe - Vermilion moraine soils, which are sandy and stony with trace clays and boulders. Outwash deposits of sand and gravel are mapped in the downstream third of the watershed, and are likely mixed with Rainy lobe till. Finer peat deposits are located in the far headwaters. Areas of drift have been removed in the Dunka River Lower where the underlying Biwabik iron formations are currently being mined. Bedrock outcrops are scattered through the watershed.

4.3. Land cover and land use in the DRW

Woody wetlands and mixed forests cover much of the Dunka River Subwatershed. The US FS and the DNR Division of Forestry own 48% and 21% of land within the Dunka River Subwatershed respectively. Private ownership (primarily corporate timber and mining) accounts for the remaining 31% of land.

Forestry is active in the watershed, but more moderate than in the ARW. Forest change data collected by the DNR indicated that a fraction (low estimate of 2%) of mature forest had been converted to another cover type over the past 10-years, indicating that forest harvest was not resulting in major land disturbance during that period.

Besides forest management, the other major industry in the watershed is mining. A portion of the Peter Mitchel Mine lies within this subwatershed and crosses the hydrological boundary between the Rainy River and Lake Superior basins. This is an actively working pit with 1722 acres (4% of the subwatershed area) located within the Dunka River Subwatershed. Pit water from the Peter Mitchell pit is discharged to tributaries Langley Creek and Unnamed Creek 2 just upstream of their confluences with the Dunka River. Pit water enters the Dunka River through tributary flow between stream miles two and five upstream of Birch Lake.

Broader mineral exploration continues within the Dunka River Watershed including exploration and testing of copper-nickel containing ore. Changes to the existing operation upon mine closure are also forecasted (approximately year 2070), which will alter the hydrology of the Dunka River and its tributaries. The mine closure plan includes adding drainage area to Unnamed Creek 2 that will receive pit overflow from the Peter Mitchell pit. A Barr, 2008 study estimated this will increase the current flows in Unnamed Creek 2 by a factor of six (>500% increase). Other hydrological changes include a flow increase in the Dunka River by 32% and decrease in Langley Creek flows by 60% from current conditions.

Land use pressure including timber management and mining are likely with an expected increase in School Trust Lands, as these state lands are managed by the DNR to generate revenue for education funding (often from mining and timber harvest), including lease or sale of land. They account for 4% of the watershed area and is expected to increase to 15% following a land exchange between federal and state governments. The new School Trust lands are densely located in the lower and mid-watershed in the area of Unnamed Ditch, Twenty Proof Creek, and Langley Creek. Large parcels of existing School Trust land are located in the headwaters of Unnamed Creek1 and around the Peter Mitchel pit.

4.4. Overview of biological data in the DRW

The MPCA collected fish and macroinvertebrate community samples at five locations on the Dunka River over a two-year period (2014-2015). Table 13 lists the stations sampled, IBI results, and criteria used to assess the stream for biology at locations identified in Figure 22. The Dunka River Lower AUID was assessed using Coldwater standards and is currently in the processes of a use classification change from Warmwater (2B) to a Coldwater (2A) based on the biological communities sampled there. Dunka River-Upper is a Warmwater (2B) stream and MPCA biologists assessed it accordingly. Both AUIDs passed the fish and macroinvertebrate IBIs.

Table 13. Fish and Macroinvertebrate IBI scores for the DRW biological sites. CI = Confidence limit, NC = Northern Coldwater, LG = Low Gradient, NH = Northern Headwaters.

				Fish				Macroinvertebrates		
AUID	**Site ID**	**Biology Station**	**Use Class**	**Visit Date**	**F- IBI**	**Threshold +/- CI**	**Fish Class**	**Visit Date**	**M-IB I**	**Threshold +/- CI**
Dunka River Lower-987	Dunka 9	14RN006	2A	Jul-14	**41.9**	35 +/- 10	NC	-	-	-
	Dunka 9	14RN006	2A	Aug-14	**40.6**	35 +/- 10	NC	Aug-14	**33.5**	32 +/- 12.4
	Dunka 9	14RN006	2A	Sep-15	**55.4**	35 +/- 10	NC	Aug-15	**40.8**	32 +/- 12.4
	Dunka 8	15RN035	2A	Jun-15	**49.7**	35 +/- 10	NC	Aug-15	**31.6**	32 +/- 12.4
Dunka River Upper -986	Dunka 6	15RN036	2B	Oct-15	**51.5**	42 +/- 10	LG	Aug-15	**62.5**	51 +/- 13.6
	Dunka 3	14RN065	2B	Aug-14	**82.8**	42 +/- 16	NH	-	-	-
	Dunka 1	15RN037	2B	Sep-15	**51.3**	42 +/- 16	NH	Aug-15	**66.3**	53 +/- 12.6

Description
Below lower CI
Below threshold but within lower CI
Above threshold but within upper CI
Above upper CI
Exceptional score

4.4.1. Dunka River Lower -987

Both stations in this AUID scored above the general use thresholds for Northern Coldwater Streams in respect to fish, with 2015 season samples scoring higher than 2014. The number of fish species and individuals varied between the stations and visits, but the overall fish composition was similar. The most abundant species were Creek Chub, Blacknose Dace, Common Shiner, White Sucker, and Longnose Dace. Numerous sensitive species (Brook Trout, Blacknose Shiner, and Mottled Sculpin) were also present. Adult Brook Trout (128-370mm) were sampled at every visit to Dunka 9. No young-of-year Brook Trout were captured. Because Brook Trout have not been stocked in the area since the 1970s, the current population is likely both natural reproducing and self-sustaining.

No young-of-year Brook Trout were captured during sampling. It is suspected that rearing of young trout is occurring in another reach within the AUID. Additional habitat and water chemistry data was collected during the Stressor ID process to investigate where conditions might be supportive of rearing young Brook Trout. The results of those investigations are found in the following sections of this report.

Macroinvertebrates passed the Northern Coldwater M-IBI at both stations with fair scores. The macroinvertebrate communities differed somewhat between the two stations. Good Coldwater taxa including stonefly, mayfly, and caddisfly were present at Dunka 8, where stream slope steepens and bed material is primarily boulders and cobble. The downstream station Dunka 9 is in a lower-gradient reach of the AUID and had a mix of Coldwater and low-gradient wetland taxa.

Figure 23. Adult Brook Trout sampled in the Dunka River Lower AUID. Photo courtesy of MPCA Biological Unit.

4.4.2. Dunka River Upper -986

All three biological monitoring stations (Dunka 6, Dunka 3, and Dunka 1) passed the Warmwater F-IBI for their associated fish classes. Two stations (Dunka 6 and Dunka 1) reported fair scores just below the upper confidence limit for general use, while the middle station (Dunka 3) scored extremely well, above the exceptional use standard.

Species richness varied between the stations with 15 species captured between the three stations. The most dominant species were Common Shiner, Creek Chub, White Sucker, and Northern Redbelly Dace, with numerous sensitive species (Mottled Sculpin, Pearl Dace, and Blacknose Shiner) present. The site with the highest F-IBI score had slightly more species and significantly more individuals than the other two stations.

Stations Dunka 1 and Dunka 6 were sampled for macroinvertebrates, both scoring above the standards set for their respective Warmwater fish class. The macroinvertebrate communities differed between stations and were reflective of the habitat types at each site. The sample at the lower-gradient downstream station (Dunka 6) was a mix of Coldwater taxa as well as snails and small freshwater clam that typically indicate a wetland-type environment. The higher-gradient upstream station (Dunka 1) reported a large number of Coldwater individuals and a fair number of Coldwater taxa including strongly Coldwater-oriented species of caddisfly, stonefly, and mayfly.

4.5. Water temperature in the DRW

Continuous temperature was collected in the Dunka River and several tributaries June through August of years 2015 and 2017. Results were plotted in Figure 1 using the methods outlined in Section 3.10., as well as summarized below and in the stream profile of Figure 26.

4.5.1. Review of water temperature data

Most reaches of the Dunka River recorded marginal to fair water temperatures for supporting Brook Trout and other Coldwater obligate species. Data from nine locations within the DRW were analyzed. Based on all monitoring years, stations had an average summer water temperature (June-August) between 18.1 and 19.8˚C, with 26-51% of summer temperature readings exceeding the “stress” threshold for Brook Trout (>20˚C).

Warmer temperatures in the watershed were recorded in the Dunka River Lower including the Dunka 9 station where adult Brook Trout were sampled over three summer visits in 2017. The majority of temperature records within the Dunka River Lower plotted on the regional temperature curve (Figure 24) as “Area 1” streams, which typically indicates conditions more appropriate for

Cool/Warmwater fish. Cooler temperatures were recorded in the downstream-most mile of Dunka River Lower below a steep gradient reach at station Dunka 9.5. This station plotted as an "Area 2" stream in Figure 24. "Area 2" streams regionally have proved to support Brook Trout if other habitat and water chemistry conditions are suitable.

The Dunka River Upper stations overall recorded cooler temperatures than the Lower AUID. All three stations in this AUID plotted in "Area 2" for data collected in 2015 and 2017. Headwater station Dunka_1 had the coldest temperatures in this AUID with 74% of the summer record within the growth range for Brook Trout.

Tributaries Unnamed Creek 1 and Langley Creek reported the coldest temperatures of monitored locations. Langley Creek plotted in "Area 2". Flow in Langley Creek is sourced from both watershed drainage and mine pit dewatering of groundwater inflow to the pit. Temperature records from pit discharge to Langley Creek ranged from 9 to 18 degrees Celsius during the summer months when loggers were deployed in years 2015-2017, which was cooler than stream temperatures measured in Langley Creek. Headwater stream Unnamed Creek 1 plotted in "Area 4" and "Area 3" respectively upstream and downstream of a wetland complex. Temperatures in this range are regionally good to excellent for supporting trout, but other trout habitat conditions in the wetland streams may be lacking. It is suspected that both of these cold tributaries act as critical sources of Coldwater to the Dunka River.

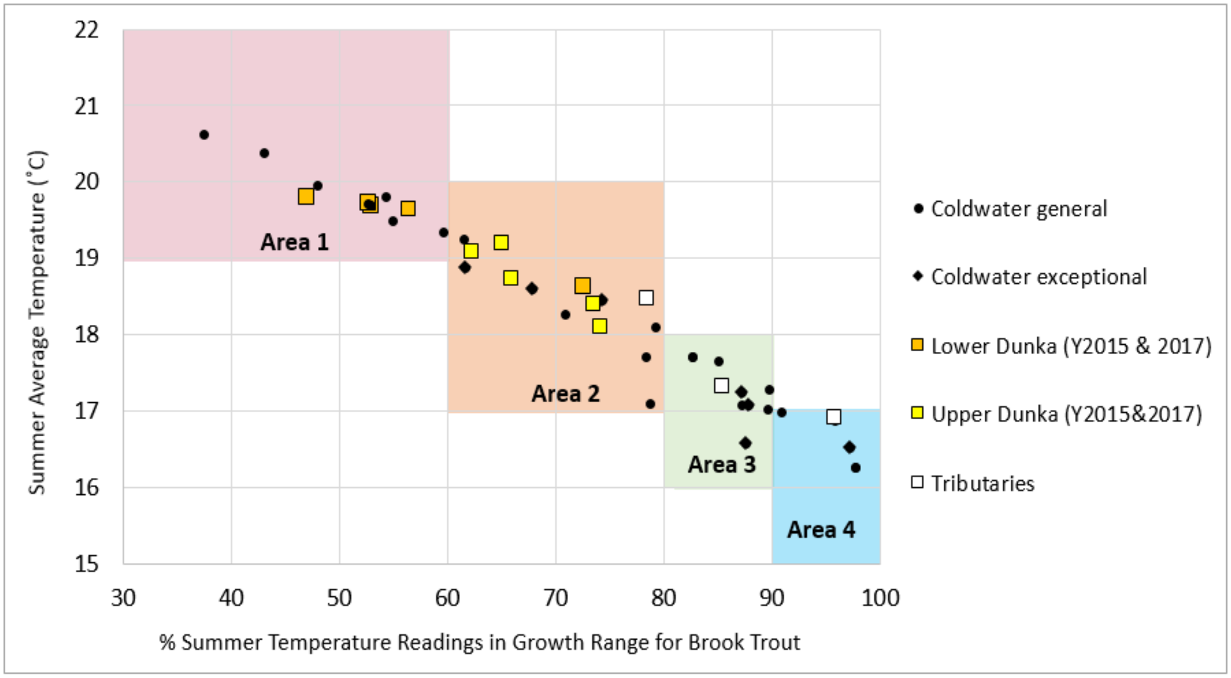
Unnamed Creek 2 was not monitored for temperature. The majority of flow in Unnamed Creek 2 is sourced from mine pit dewatering of groundwater inflow to the pit. Temperature records from pit discharge to Unnamed Creek 2 ranged from 12 to 18 degrees Celsius during the summer months when loggers were deployed in the Dunka River (years 2015-2017). Pit discharge to Unnamed Creek 2 was cooler than average monthly temperatures measured in the Dunka River (Dunka 9) just downstream of the confluence with Unnamed Creek 2.

4.5.2. Biological response to water temperature

Brook Trout presence did not correlate exactly with the temperature observations in the Dunka River Lower, but some explanations of why are provided below. Brook Trout were sampled multiple times at station Dunka 9 where marginal to poor temperatures (Area 1) were recorded. During a late summer visit in September of 2015, percent individual Coldwater fishes at the biological station was 8.8% (> 7.6% median for Northern Coldwater Streams) and percent Coldwater taxa was 22% (>15% median for Northern Coldwater Streams). During July and August visits when stream temperatures were warmer, percent Coldwater individuals and taxa decreased, ranking lower than the median for Northern Coldwater Streams. Dunka_9 was the only "Area 1" biological station in the RRHW where trout were sampled.

It is suspected that cooler temperatures in the reach were undetected by the temperature sensors isolated from pockets of colder water. Brook Trout in this reach likely were able to escape stressful temperatures in colder microhabitats such as the bottom of deep pools, against undercut banks, and/or near springs. Brook trout generally are prone to moving to find cool water during times of thermal stress, including small seeps within a warmer reach and are capable of utilizing reaches that are marginal during the spring and fall months of most years. Dunka 9 has numerous deep pools and is located immediately downstream of the confluence of Unnamed Creek 2 where temperatures were below 18 degrees Celsius during the deployment period. Although minimal surficial inputs from Unnamed Creek 2 to Dunka River were observed during field visits, subsurface flow from the tributary likely provides Coldwater inputs to the reach in addition to surficial inputs. Slightly colder water (Area 2 regime) was recorded 1.6 miles downstream at station Dunka 9.5 where visual observations of groundwater seeps along the banks were noted.

Figure 24. Plot of Summer Average Temperature vs. Percent of Summer Readings within the growth range for Brook Trout. The Dunka River temperature stations are shown in colored markers and tributaries to the Dunka in white. All other RRHW Coldwater station data are shown in black, with diamonds indicating streams with exceptional Coldwater communities.



4.6. Dissolved oxygen in the DRW

Continuous DO was collected in the Dunka River and Unnamed Creek1 June through mid-August. Results were plotted in Figure 25, summarized both below and in the stream profile of Figure 26.

4.6.1. Review of dissolved oxygen data

Dissolved oxygen levels varied within the Dunka River with higher DO levels in high-gradient reaches and lower DO in lower gradient reaches. Monitoring locations with higher gradients included the headwaters stations, Dunka 1 and Dunka 9.5 of the Lower AUID. Both stations had DO levels greater than the 7 mg/L Coldwater standard for greater than 90% of the deployment record. Levels at both stations briefly dropped below the threshold around August 1, 2017 when air temperatures reached 85˚F. DO rebounded as air temperatures cooled over the following days.

Dunka 9 also had a daily DO average greater than 7 mg/L, but remained above the threshold for only 76% of the record. The sensor recorded DO levels below 5mg/L one evening during the deployment. The stream gradient is flatter compared to downstream station Dunka 9.5 where DO levels remained above 7mg/L more often.

Extremely low DO levels were recorded in the flatwater sections of the Dunka River Upper at station Dunka 3. The average DO (June through mid-July) was 4.1 mg/L with less than 80% of the readings meeting the 5 mg/L Warmwater standard. Accuracy of the logger diminished in mid-July and data extending beyond that time was not evaluated. The drastic difference in DO signal pattern of this site compared to the others suggests that wetland-connection, rather than daily oscillations in air temperature, most influences DO at this station.

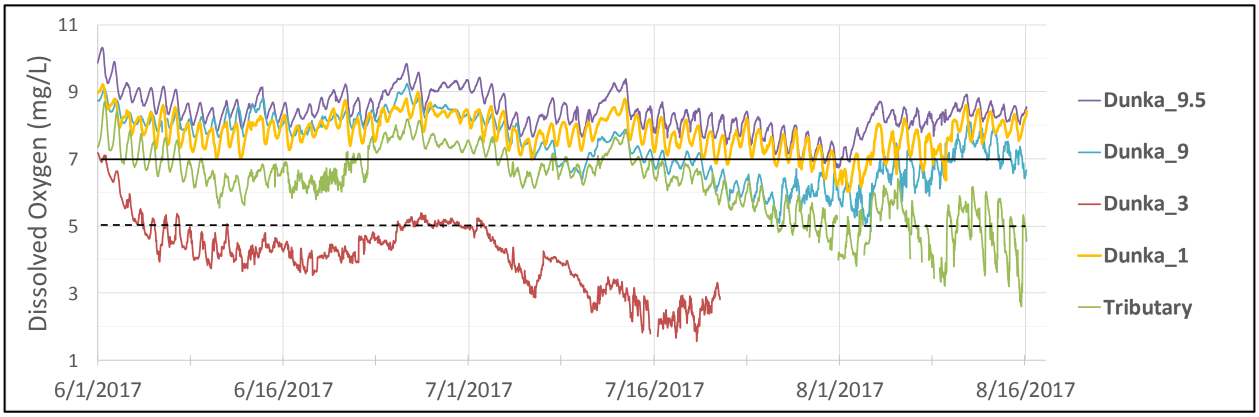
The headwater tributary, Unnamed Creek 1, had moderate DO levels with an average DO (June to mid-August) of 6.3 mg/L. Readings were below the 7mg/L Coldwater standard 64% of the record and below the 5 mg/L Warmwater standard 7% of the record. This suggests that DO is mostly adequate to support a healthy Warmwater community, but not adequate to support trout or other DO-intolerant species. There is negligible human disturbance to this tributary indicating that low DO is a result of wetland connectivity.

4.6.2. Biological response to dissolved oxygen

Dissolved oxygen tolerance and TIV scores were used to assess the affect DO was having on stream biota. Results for years 2014 and 2015 varied greatly, as 2014 was a very dry year with low water levels. As a result, DO levels were low that year as was observed in the TIV scores. In 2015, a normal water year, the highest percent DO sensitive fish (34%) and macroinvertebrates (33%) were sampled in the Dunka River Lower. There were less than 6% of DO tolerant fish and macroinvertebrate individuals. The regression-based probability of meeting the Coldwater DO standard was approximately 80% for each fish and macroinvertebrates. The resulting TIV scores ranked near the median for Northern Coldwater Streams and below the median for macroinvertebrates. DO was frequently above the Coldwater standard in this reach as the biology suggested.

In the Dunka River Upper, the regression-based probability of meeting the Warmwater standard was 30-53% based on fish and 51-85% based on macroinvertebrates. Compared to all streams in their respective fish classes, only Dunka 3 ranked below the median for fish. Macroinvertebrates were not sampled there. Extremely low DO levels were recorded there. The fish community had excellent F-IBI scores for a Northern Headwaters stream; however 40% of the individual fish sampled were DO-tolerant species and less than 1% were DO-sensitive. Northern Redbelly Dace, often found in low DO water, were present in high numbers. DO sensitive fish such as Mottled Sculpin were also present, but in low numbers. Because the fish community overall was higher quality than DO levels would suggest, it is suspected that DO is variable in this reach.

Figure 25. Continuous DO records collected in field season 2017 show the variability of DO in the Dunka River Watershed.



4.7. Physical habitat in the DRW

MPCA Stream Habitat Assessments were completed at the five biological stations on the Dunka River. The MSHA scores account for variables such as land use, riparian area, instream cover, substrate, and channel geomorphology (riffle-pool placement and depths).

4.7.1. MSHA results in the Dunka River Watershed

The majority of MSHA surveys on the Dunka River returned "good" ratings, with the exception of one "fair" rating on the Dunka River Upper AUID (Table 14). Channel morphology and substrate were two categories limiting the Dunka 6 rating compared to the other reaches assessed for habitat. Channel facets (riffles, runs, pools) were lacking; defined riffles were absent in this reach and flow was uniformly slow within the channel. There were no deep pools, undercut banks, root wads, or eddies to provide cover. Although gravels were present and only slightly embedded, larger substrate were lacking. Instream cover and flow were more diverse at the other stations. Dunka River Lower stations had areas of slow to fast flow, deep pools, eddies, undercut banks, and overhanging vegetation. Dunka River Upper stations upstream of Dunka 6 also had more instream cover, deep pools, and variety in flow dynamics.

Table 14. MSHA Habitat summary of Dunka River Watershed biological sites.

		Dominant Substrate					
AUID	Station ID	Run/Glide	Pool	Shading	Embeddedness	Habitat (MSHA) Rating	Limiting Factors
Dunka River Lower	Dunka 9 (14RN006)	gravel/sand	gravel/silt	Moderate to Substantial	Light	Good	
	Dunka 8 (15RN035)	boulder/cobble	boulder/cobble	Heavy	None	Good	
Dunka River Upper	Dunka 6 (15RN036)	gravel/sand	gravel/sand	Substantial	Light	Fair	riffles absent, moderate instream cover, lacks large substrate, uniform slow velocities
	Dunka 3 (14RN065)	boulder/cobble	boulder/cobble	Substantial	Light	Good	
	Dunka 1 (15RN037)	boulder/cobble	gravel/sand	Heavy	Moderate	Good	

4.7.2. SID trout habitat observations in the DRW

MSHA scores were rated good at several biological stations where F-IBI scores were fair and/or where trout were not present. This included the Dunka 1 station where temperature and DO sensors recorded adequate levels to support Coldwater fish. Because of this, SID staff conducted field visits in October of 2018 and further reviewed notes and photos from the 2014-2015 biological visits to investigate trout habitat conditions in various reaches. Water levels were unexpectedly high for that time of year which affected stream wadability and clarity adversely affecting our ability to complete a thourough trout suitability survey. A summary of our observations are below. Additionally, Figure 27 includes photographs from various locations in the watershed that show how habitiat features change longitudinally from the headwaters to the outlet in the Dunka River.

Stream Miles 0 to 4.5 (trout habitat and recommendations for future sampling)

Stressor ID staff floated or hiked most of this reach starting just downstream of Dunka 6 and moving towards the outlet of Birch Lake. Channel geomorphology and other habitat characteristics changed longitudinally throughout this reach.

The upper portion of this reach lacked many of the same habitat features identified in the MSHA at Dunka 6. These included lack of riffles, deep pools, flow variability, and instream habitiat. Beaver dams were present, but appeared passable by trout. Dams became more frequent as flow velocities increased nearing the high gradient reach at station Dunka 8. These beaver dams were not included in Figure 26, as locations were not marked and they were not high enough to act as fish barriers or affect channel geometry. The gradient drop at Dunka 8 contained many cobbles and boulders, but gravel substrates were limited or non-existent in this area. A large pool filled with gravel was present at the base of the Dunka 8 riffle and habitat appeared suitable to support trout.

The presence of gravel, good instream cover, deep pools, and good riffle pool spacing increased at downstream station at Dunka 9, where adult Brook Trout were surveyed multiple times. Gravels were abundant and not embedded by fine substrates. Temperature and DO data showed conditions sometimes less than ideal for trout, especially in July and August. However, Brook Trout have been previously sampled at this station during both months.

Biological sampling did not occur downstream of mile 1.0, but visible observations suggest mile 0.25 to mile 1.0 offers suitbale habitat to support young-of-year trout as well as adults. We recommend future sampling in the reach to validate or invalidate the presence of trout. Streamflow moves down cascading step-pools downstream of mile 1.0 and into a a large gravel pool with side channels and eddies. There the stream split into two narrowed channels where side pools, eddies, gravels, and deep pools were present. Channel shading and instream cover were good with many in-channel microhabitats available (Figure 27, photo 9). The split merged just upstream of station Dunka 9.5 forming a long wide riffle that eventually entered slack water near the mouth of the river. Water temperature and DO recorded at the Dunka 9.5 riffle showed these parameters were adequate to support trout. Additional biological sampling of this reach is planned for the 2019 summer.

Stream Miles 4.5 to 12 (unsuitable trout habitat)

Stressor ID staff did not further investigate this reach. Water chemistry data indicated that DO levels were below the Coldwater threshold for most or all of the summer months. Based on the presence of a few sculpin, it is suspected that DO was higher in the high-gradient riffle on the upstream side of the Dunka 3 station. MSHA data and photos indicated the riffle was dominated by cobble and boulders and summer water levels were well below the tops of large substrate. The reach is highly connected to riparian area wetlands and the gradient is extremely low for several miles downstream of Dunka 3. Station Dunka 6, located at the downstream end of this reach lacked riffles, deep pools, flow variability, and instream habitiat. The lack of physical habitat combined with low DO for miles of stream may deter trout from migrating through the reach from the Dunka River Lower to the headwaters.

Stream Miles 12-17 (habitat limited by lack of gravels and meadows)
The headwaters segment of the Dunka River Upper includes station Dunka 1 where temperature, DO, and MSHA data indicated generally adequate conditions to sustain trout. SID investigations found the upper watershed had higher gradient sections with adequate instream cover, however; much of the headwaters lacked gravel. Boulders and cobble were dominant bed materials in riffles. This may explain why Common Shiner and dace were present in the fish samples, but no trout. The upper watershed alternated between low-gradient meadows and high gradient boulder/cobble reaches. Low-gradient sections were primarily controlled by beaver dams that formed upstream ponds and open riparian area meadows. A higher percentage of detritus was found behind dams, further limiting clean gravels. Figure 26 shows how beaver dam frequency increased 0.25 miles downstream and 0.5 miles upstream of the Dunka 1 station. Substrate might be the most limiting factor in the reach, although hiking the headwaters during baseflow might result in the detection of more gravel areas.

4.8. Summary and recommendations

Biological sampling, MSHA, and SID observations indicated that the Dunka River Lower AUID has the most potential to support trout. Adult Brook Trout were sampled multiple times (years 2014-2015) in the upper reaches of the AUID. No young-of-year Brook Trout were sampled although the population is sustained by natural reproduction. Trout habitat improves downstream of the biological sampling location where the presence of side pools, eddies, gravels, and deep pools were noted and stream temperatures were colder.

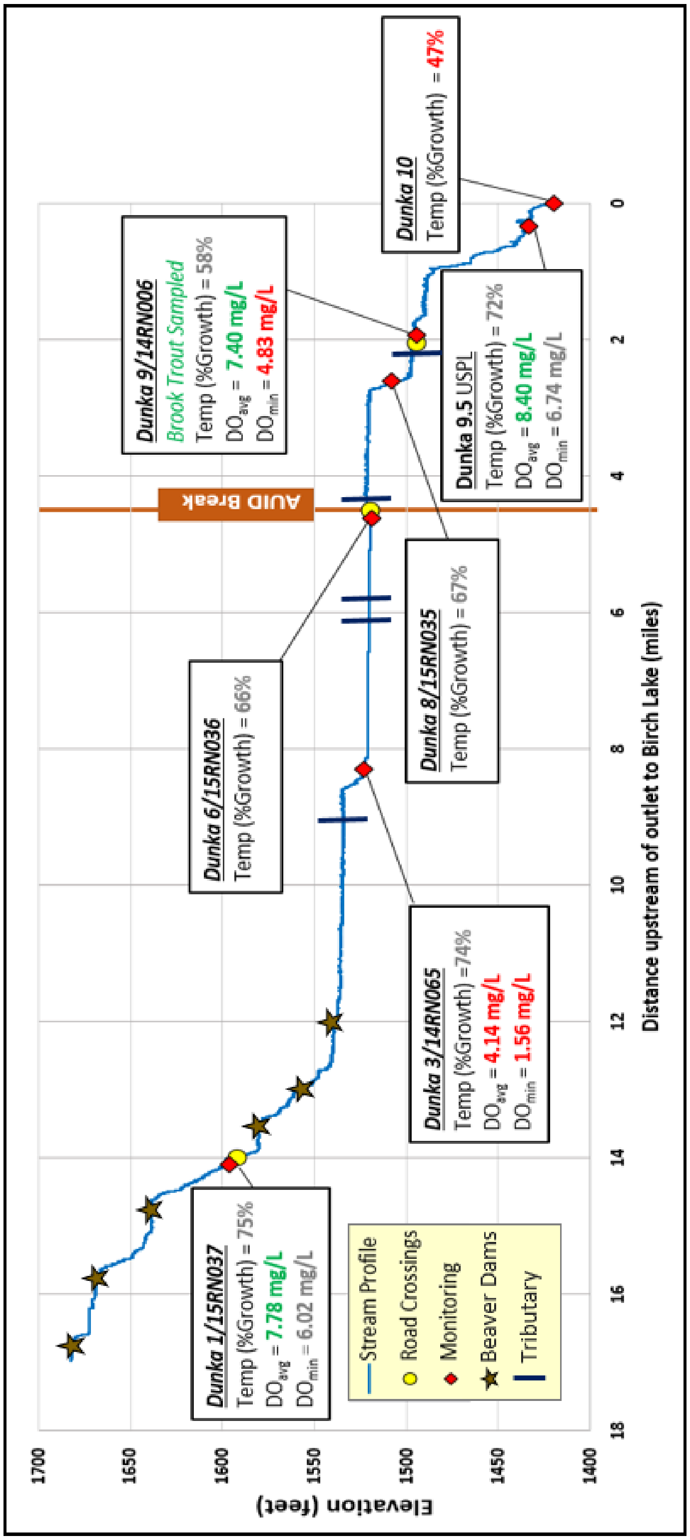
Stream temperature and DO data identified the headwaters reach that includes Dunka 1 as having water chemistry to support trout; however, physical habitat, including lack of gravel and large beaver meadows, may limit their ability to spawn. Other Coldwater species were sampled in the upper reach. Headwater tributaries to the Dunka River had temperatures suitable for trout, but the habitat was not ideal in the anastomosing wetland channels where DO levels were below 7mg/L for much of the summer season and detritus covered much of the stream bottom. Over seven miles of wetland-influenced low DO waters separated the headwaters from the Dunka River Lower, which may deter trout passage through the middle reaches of the river.

Future land use pressures in the watershed include increased mining and forestry activity. An increase of School Trust lands is expected in the watershed, which is land dedicated to generate revenue. Mine exploration continues and there is potential to mine for copper-nickel in the lower watershed, just upstream of the Dunka River Lower AUID. A mine closure plan for an existing taconite ore facility, projected for sometime around 2070, will change the hydrology of Dunka River, Unnamed Creek 2, and Langley Creek from current conditions due to changes in drainage areas and mine pit outflow upon pit closure. Predicted changes in stream temperature, sheer stress on the channels, and water chemistry have not been reported.

Recommendations to protect the Dunka River Watershed streams and prevent degradation of the aquatic community and water quality from changes expected on the landscape include:

- Improve the understanding of the aquatic community in the Dunka River Lower. Continue biological sampling in the Dunka River Lower, adding sample stations downstream of Dunka 9. Identify areas in need of protection, including areas that are critical to spawning and supportive of different age classes of Brook Trout and protective of other Cool/Warmwater species both in the Dunka River Lower and Dunka River Upper.
- Through monitoring and/or modeling, characterize the contributions of tributaries including Langley Cr and Unnamed Cr 2 to healthy trout habitat in the Dunka River. This includes continued temperature and flow monitoring of the Dunka River and its tributaries.
- Investigate impacts to stream temperature from the existing mine closure plan to prevent material increases in temperature that could lead to a stream impairment. Temperature impacts from pit outflow could be investigated at a broad-scale using the existing HSPF watershed model. Those results would represent average conditions over a large reach, not characterizing localized shading or small-scale Coldwater refugia. If more detail is required, a finer-scale stream temperature model could be developed. Such a model could also examine impacts to stream conductivity.
- Examine potential hydrologic impacts of changes in flows (and drainage areas) estimated for post-mine pit closure (Barr, 2008). This includes increased flows to Unnamed Creek 2 and the Dunka River and decreased flows to Langley Creek. Additional mine pit discharges could increase the intensity, duration, and frequency of high flows in the Dunka River Lower with the capacity to alter the stream channel. Hydrologic impacts could be examined within the framework of the existing HSPF watershed model, whereas impacts on shear stress, sediment transport and channel stability could be examined using a hydraulic model coupled with sediment transport and bank erosion models.

Figure 26. Longitudinal profile of the Dunka River showing monitoring locations and water chemistry results. Water chemistry and stream slope vary from the headwaters of the Dunka River to the outlet at Birch Lake. Green text indicates suitable conditions, red indicates unsuitable conditions, and black indicates marginal to poor conditions for Brook Trout.



Mainstem Monitoring Locations

Mile	Name
0.0	**Dunka 10**, walking bridge
0.3	**Dunka 9.5**, US powerline
1.9	**Dunka 9**, DS of Constantine Rd
2.6	**Dunka 8**, US of taconite pits
4.6	**Dunka 6**, US of Scott Rd
8.3	**Dunka 3**, gage Station
14.1	**Dunka 1**, US of FR113

Figure 27. Photos showing physical habitat variations from the headwaters to the mouth on the Dunka River.

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Appendix - DNR RRHW BANCS Summary

Ash River Watershed BANCS Summary

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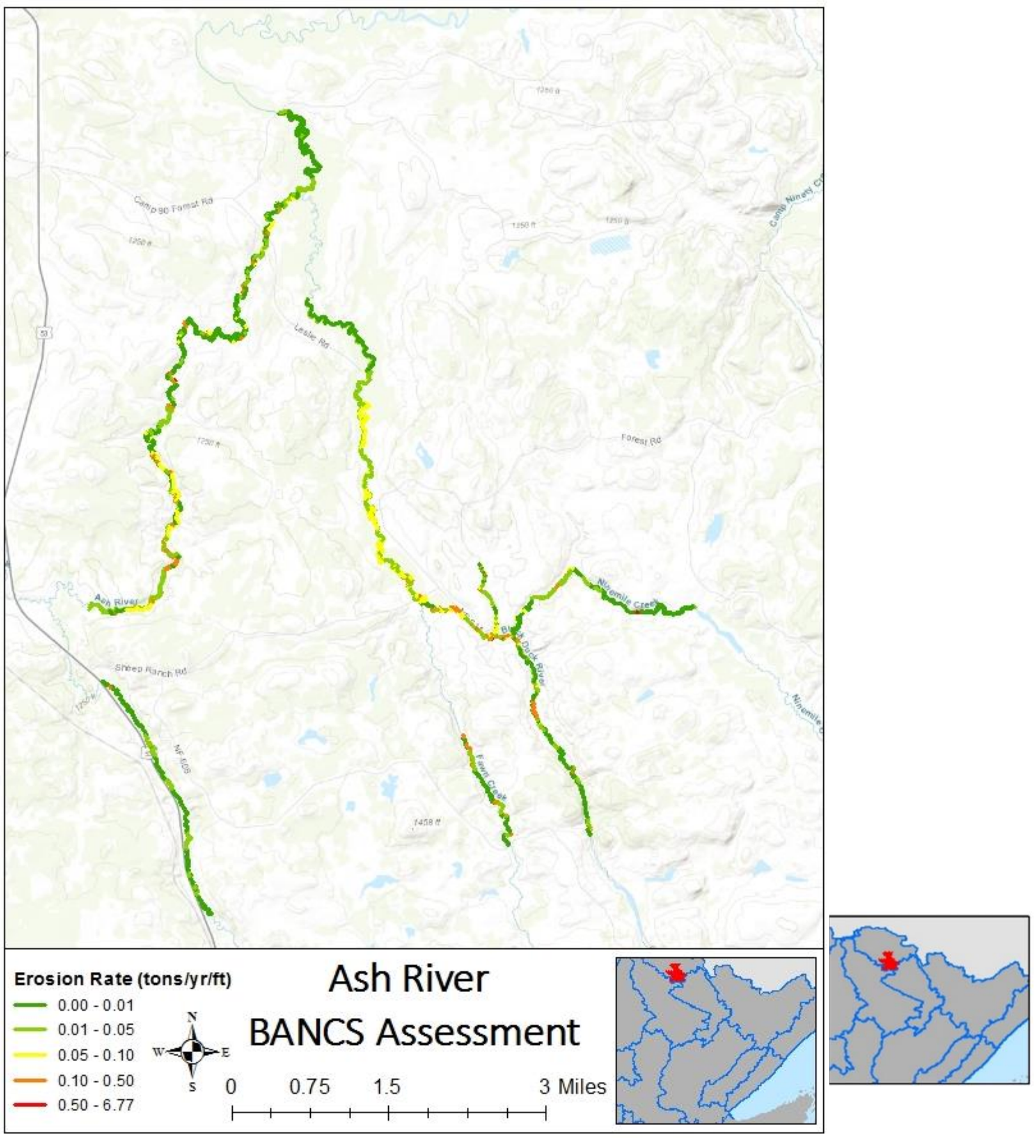
DEPARTMENT OF NATURAL RESOURCES

CLEAN WATER LAND & LEGACY AMENDMENT

Introduction

The Rainy River Headwaters (RRHW) Watershed Restoration and Protection Strategies (WRAPS) identified the Blackduck River and the lower Ash River as impaired for total suspended solids (TSS). DNR Clean Water staff led efforts to identify causes and quantify the impacts to the watershed. As part of the study, DNR, PCA, and local SWCD staff assessed nearly 30 miles of stream, using the Bank Assessment for Non-point source Consequences of Sediment (BANCS) model (Rosgen 2001), inventoried local culverts, and performed Level II surveys at stream gages. This document summarizes the BANCS work in the Ash River Subwatershed.

Figure 28. Map showing extent of reaches assessed and erosion rates.



Methods

The BANCS model predicts annual erosion rates by incorporating field observations of Bank Erosion Hazard Index (BEHI) and Near Bank Stress (NBS). BEHI scores seven bank attributes such as bank height, weighted root density, and bank material to assess the erosion potential of the bank. NBS rates the energy exerted by the stream against the bank from very low to extreme. The combination of the scores provides an annual Bank Erosion Rate (BER)(ft/yr) based on empirically derived curves from streams in Colorado. By incorporating bank height, length, and the density of soil, you get total erosion per reach (tons/yr) and a rate (tons/yr/ft) per linear foot of stream that allows reaches to be compared.

Due to limited staff and availability, only priority reaches were assessed and prioritization was based on prior field visits, access, stream and valley type, and slope. Most of the headwater streams in the drainage are low gradient, unconfined streams with frequent beaver dams. Due to their low risk for erosion and poor access, mainly third and fourth order streams were assessed along with select tributaries. Reach breaks were not predetermined and were broken by changes in BEHI and NBS ratings, resulting in varied reach lengths. This means total erosion (tons/yr) from different reaches cannot be directly compared. Similarly, bank erosion rates (BER)(ft/yr) does not provide a complete picture because it does not factor in bank height. BER can provide a good comparison of where the most unstable reaches are, but the erosion rate (tons/ft/yr) should be used to identify the largest contributors of sediment since it includes bank height and the value and is a direct comparison to other reaches in the survey. In areas where BEHI or NBS ratings changed frequently or ratings merely changed back and forth between outside and inside meanders, reaches were extended for efficiency. One set of BEHI and NBS ratings would be carried on left bank while right bank carried the other set. This method allowed for quicker field assessment, but created final images that do not accurately depict where the ratings occurred on the landscape. Lastly, the BANCS method does not provide accurate measurements of bank erosion and sediment supply but rather identifies area of proportionately high sediment contributions and thus areas for BMP's or restoration.

Figure 29. Summary of Ash River Subwatershed BANCS and erosion data. Total length includes length of both left and right banks.

	BEHI Avg	NBS Avg	Height Avg (ft)	BER Avg (ft/yr)	Total Length (ft) [% of total]	Erosion Rate Avg (tons/yr/ft)	Total Erosion (tons/yr) [% of total]
Blackduck Trib	2.5	3.2	2.10	0.219	9,784.3 [3.2]	0.024	237.7 [2.8]
Fawn Creek	1.8	2.8	2.24	0.109	15,927.5 [5.2]	0.024	384.3 [4.3]
Ninemile Creek	1.7	2.9	2.68	0.101	31,246.3 [10.2]	0.017	533.2 [6.0]
Blackduck River	2.5	3.0	4.12	0.186	109,584.8 [35.9]	0.044	4,815.7 [53.7]
Ash River	1.9	2.6	3.47	0.097	138,708.2 [45.4]	0.022	2,995.5 [33.4]

Results and discussion

Unnamed tributary

An unnamed tributary to the Blackduck River flows from the north and meets the Blackduck River on the ranch. The tributary has an average erosion rate of 0.024 tons/yr/ft for a total of 237.7 tons/year. The erosion rate is low, typically a sign of stable banks. However, the stream is significantly smaller than the others in the assessment and the banks are heavily degraded from cattle access. In fact, the stream has the highest average BER (0.22 ft/yr) and only maintains a low erosion rate due to its low bank heights. The tributary's 2.1' average bank height is the lowest of any assessed stream. Visual observations upstream of the ranch suggest much more stable banks and significantly lower erosion rates. The stream contributes 2.75% of overall survey erosion, and constitutes 3.2% of survey length. Even though this reach is not contributing comparably large amounts of sediment, it will continue to be an unstable reach as long as cattle have access. Better grazing management and BMP's such as improving riparian area vegetation could significantly decrease the sediment load coming from this reach's banks.

Fawn Creek

Fawn Creek, a Blackduck tributary, has a low average erosion rate of 0.024 tons/yr/ft for a total of 384.3 tons/yr. Only a portion of Fawn Creek was surveyed since it was lower priority. Beaver dams dominate the stream and the surveyed reach is in a confined valley. This means the stream is near or against the valley, wall more frequently and beaver dams are more likely to abut the valley wall. The stream has unconfined reaches elsewhere, but they were not surveyed. Overall, it has very low BER and low bank heights. Its 384.3 tons/yr is only 4.29% of the total erosion and constitutes 5.2% of the total survey length. Even though Fawn Creek has low average erosion rates, two of the top ten banks with the highest erosion rates occur in Fawn Creek. One bank is located where an outside meander is up against the valley wall and the other is at an old beaver dam causing flows to cut around and into the banks. The bank against the valley wall is 102' long and produces an estimated 42.2 tons/yr of sediment, 0.47% of the total. The reduction in sediment from restoring these two banks alone would not be worth a standalone restoration, but done in combination with other highly eroding banks in the subwatershed could significantly reduce bank sediment entering the Blackduck and Ash Rivers.

Ninemile Creek

Ninemile Creek is a major tributary to the Blackduck River and has an average erosion rate of 0.017 tons/yr/ft, the lowest average rate for any stream in this survey, and a total of 533.2 tons/yr. The Ninemile reach is 10.2% of the survey length but only contributes 5.95% of the total sediment. The reach is stable and not a large contributor of sediment from its banks. It is mostly an unconfined low gradient stream with slopes of <1%, but has three short reaches with slopes of >2% in confined valleys. The upper portion of the reach has several beaver dams. Beaver meadows generally have low erosion rates because the stream has access to its floodplain and the dense grass root systems hold the banks well. However, beaver dams can contribute high sediment loads when they are up against valley walls or fail and release large amounts of sediment in one event. Ninemile Creek does have one of the top 10 erosion rate banks due to a beaver dam against a valley wall. The bank is only 40' long and contributes 0.22% of total sediment. It is not a good candidate for bank stabilization or restoration unless combined with other isolated projects in the subwatershed.

Figure 30. The banks with the top 10 highest erosion rates.

Top 10 Banks - Erosion Rate							
Stream	BEHI	NBS	BER (ft/yr)	Length (ft)	Height (ft)	Erosion Rate (tons/yr/ft)	Total Erosion (tons/yr) [% of total]
Ash	6	5	7.03	38.54	20	6.77	260.8 [2.9]
Ash	4	6	1.32	35.57	7	0.45	15.8 [0.2]
Ash	3	6	1.16	80.61	8	0.45	35.9 [0.4]
Fawn	4	5	0.87	140.73	10	0.42	59.1 [0.7]
Ninemile	4	5	0.87	39.62	12	0.50	20.0 [0.2]
Blackduck	4	5	0.87	196.83	12	0.50	99.2 [1.1]
Blackduck	4	5	0.87	110.86	10	0.42	46.5 0.5]
Fawn	4	4	0.58	101.57	15	0.42	42.2 [0.5]
Blackduck	4	4	0.58	110.69	15	0.42	46.0 [0.5]
Blackduck	3	4	0.42	74.49	20	0.40	30.1 [0.3]

Ash River

On the Ash River, 13.14 miles were surveyed and had an average erosion rate of 0.022 tons/yr/ft for a total of 2,995.48 tons/yr. The low erosion rate signifies mostly stable banks and confirms field observations. The length of the Ash survey constitutes 45.4% of the total survey length, yet only contributes 33.41% of the total erosion.

To provide a more comprehensive analysis and see if more bank erosion was occurring in the impaired AUID, gaps in the assessment were filled using data from similar stream and valley types. This allowed us to compare erosion rates in the AUID's above and below (impaired) the Ash's confluence with the Blackduck River. With modelling, 26.3 miles of the Ash were assessed. The exercise lowered the overall average erosion rate to 0.014 tons/yr/ft, but raised the total erosion to 3,985.99 tons/yr. This is not surprising because much of the lower Ash is a very low gradient stream in an unconfined valley, conditions that generally produce low erosion rates. The impaired reach has a very low erosion rate so other sediment sources are likely causing the impairment.

When comparing the upstream and downstream Ash AUID's using the model, the upstream reach has the higher average erosion rate. The upstream reach has an average erosion rate of 0.02 tons/yr/ft, a low erosion rate. However, the total erosion was 3,092.8 tons/yr due to some isolated unstable banks. In total, the upper reach contributed 78% of the total sediment for the modelled Ash River, while only accounting for 55% of its length. The lower Ash had an erosion rate of 0.007 tons/yr/ft, even though it has higher average bank heights of 3.7'. It contributes 893.2 ton/yr, only 22% of the assessed Ash, even though it is 45% of the length.

Figure 31. Summary of modelled Ash River BANCS and erosion data. Total length includes length of both left and right banks.

	BEHI Avg	NBS Avg	Height Avg (ft)	BER Avg (ft/yr)	Total Length (ft) [%]	Erosion Rate Avg (tons/yr/ft)	Total Erosion (tons/yr)	% of Total Ash Erosion
Upstream Ash	1.9	2.8	3.34	0.094	153,371.7 [55]	0.020	3,092.8	78.0
Downstream Ash	1.9	2.2	3.70	0.040	124,638.5 [45]	0.007	893.2	22.0

The highest contributing eroding reaches on the Ash River are isolated cases of the stream eroding a high bank at a meander or valley wall. Three of these banks are in the top ten for highest contributing erosion rates and percent of total erosion. Combined, they account for 3.5% of total erosion from only 155'. Stabilizing these banks could reduce total erosion from the Ash but access presents an issue and other banks might provide better bang for the buck. In addition to the isolated banks, a two-mile stretch downstream of Hwy 53 has elevated average erosion rates of 0.06 tons/yr/ft. It contributes 12.6% of total erosion from only 19,087' of bank.

Blackduck River

Ten miles of the Blackduck River were assessed. It had the second highest average BER, the highest average bank height at 4.12', and by far the highest average erosion rate at 0.044 tons/yr/ft. Its erosion rate is nearly double the next highest stream. These factors contribute to its 4,815.7 total tons/yr sediment contribution, which is 53.71% of the total survey erosion, though only from 35.9% of the total length. A closer look at the stream around the ranch illuminates an area of high average erosion rates. The continuous stretch of 3.3 miles (11.4% of the survey total) starting on the ranch and continuing well past Sheep Ranch Rd, has an average BER of 0.291 ft/yr, bank height of 4.78', and a resulting erosion rate of 0.077 tons/yr/ft, nearly double the entire Blackduck rate. The total erosion from this stretch is 2,695.5 tons/yr, 30.1% of erosion from the entire survey. This highlighted reach only contains two of the top ten highest contributing banks for erosion rates, but has the highest average bank erosion rate, erosion rate, and bank height. We did not assess banks all the way downstream to the confluence with the Ash River due to time constraints, but it is apparent that the banks stabilized by that point and have returned to more baseline erosion rates. Erosion rates for the stretch from the end of the survey to the confluence with the Ash River were estimated using attributes from similar stream and valley type conditions, but were not included in this analysis. Overall, four of the highest contributing ten reach erosion rates are on the Blackduck.

Above the ranch on the Blackduck, erosion rates are generally low, but there are isolated banks with high erosion rates due to the stream eroding valley walls in confined sections. There are also areas of elevated erosion rates in unconfined valleys where current and abandoned beaver dams are creating braided channels and bank instability. Overall, these isolated erosion hot spots are not major drivers of the impairment. Once on the ranch, poor land management practices such as clear cutting, loss of riparian area vegetation and cattle access are perpetuating instability but are not the primary cause. Further research shows that a 3,750' section of the Blackduck was straightened prior to 1939, reducing the stream length by 34%. The resulting lack of sinuosity and estimated 60% slope increase destabilized the stream by increasing shear stress on the banks. The stream is now continuing through the process of channel evolution where a stream will down cut, widen, and lose access to its floodplain at bankfull flows. Eventually the stream should develop a new floodplain and stabilize at a lower base level.

The straightened reach is likely the driver of instability and excess bank erosion downstream of the ranch. Implementing land use and riparian area BMP's, bank stabilization or channel restoration projects, or reconnecting the stream to its old meander pattern have good potential to reduce bank erosion in this reach. Implementation to address the TSS impairments on the Ash and Blackduck systems should start in this area.

Figure 32. BANCS and erosion data from the highlighted Blackduck River reach. Total length includes length of both left and right banks.

	BEHI Avg	NBS Avg	Height Avg (ft)	BER Avg (ft/yr)	Total Length (ft) [%]	Erosion Rate Avg (tons/yr/ft)	Total Erosion (tons/yr)	% of Total Survey Erosion
Worst Blackduck	2.9	3.1	4.78	0.291	34,789.3 [11.4]	0.077	2,695.5	30.1

Comparison

Another way to look at the results is to compare them to other recently completed BANCS assessments. The comparison is not perfect since the specialists performing the assessments may visually rate bank parameters differently and the streams are in areas with different hydrologic and geologic conditions. The Flute Reed, Sucker, and Lester Rivers are impaired for total suspended solids (TSS).

Figure 33. Erosion rates from several BANCS assessments. (MPCA 2018) (SSL SWCD 2018).

	Erosion Rate (tons/yr/mile)
Blackduck Tributary	128.3
Fawn Creek	127.4
Ninemile Creek	90.1
Entire Blackduck River	232.0
Worst Blackduck Section	409.1
Ash River	114.0
Flute Reed River	145.6
Flute Reed Tributaries	88.3
Sucker River	215.7
Woods Creek	149.6
Lester River	829.0

Conclusions

Overall, erosion rates in the Ash River subwatershed are low. Major sediment sources can be attributed to isolated beaver dams, locations where the stream abuts the valley wall and a stretch of the Blackduck River starting on the ranch. Besides the ranch, anthropogenic sources of sediment and instability are limited to road crossings, an old railroad grade, remnant bridge pilings, and scattered pockets of logging. Field observations show that they are contributing minimal sediment. Stream channels could also still be adjusting to the effects from historic logging, but it would be challenging to make a direct connection. Stabilizing or restoring the banks with the highest erosion rates would be difficult due to access and provide only small sediment reductions per bank. However, by stabilizing all of the banks that have the top ten highest erosion rates, you could reduce total erosion by 7.3%. In addition to the isolated banks, the 6.5 mile reach of the Blackduck from the ranch to well below Sheep Ranch Road is unstable and likely a large contributor to the impairment. The reach has a high average erosion rate of 0.077 tons/yr/ft and produces 30% of the total erosion. You could significantly reduce bank erosion by implementing BMP's and/or holistic restoration in this reach.

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