Watershed

March 2020

Upper Iowa River and Mississippi River–Reno Watershed Restoration and Protection Strategy Report

MINNESOTA POLLUTION CONTROL AGENCY

CLEAN WATER LAND & LEGACY AMENDMENT

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Key terms

Assessment Unit Identifier (AUID): The unique waterbody identifier for each river reach comprised of the U.S. Geological Survey (USGS) eight-digit HUC plus a three-character code unique within each HUC.

Aquatic life impairment: The presence and vitality of aquatic life is indicative of the overall water quality of a stream. A stream is considered impaired for impacts to aquatic life if the fish Index of Biotic Integrity (IBI), macroinvertebrate IBI, dissolved oxygen, turbidity, or certain chemical standards are not met.

Aquatic recreation impairment: Streams are considered impaired for impacts to aquatic recreation if fecal bacteria standards are not met. Lakes are considered impaired for impacts to aquatic recreation if total phosphorus and either chlorophyll-a or Secchi disc depth standards are not met.

Hydrologic Unit Code (HUC): A HUC is assigned by the USGS for each watershed. HUCs are organized in a nested hierarchy by size. For example, the Mississippi River–Upper Iowa Rivers watershed is assigned a HUC-4 of 0706 and the Upper Iowa River Watershed is assigned a HUC-8 of 07060002.

Impairment: Waterbodies are listed as impaired if water quality standards are not met for designated uses including aquatic life, aquatic recreation, and aquatic consumption.

Index of Biotic Integrity (IBI): A method for describing water quality using characteristics of aquatic communities, such as the types of fish and invertebrates found in the waterbody. It is expressed as a numerical value between 0 (lowest quality) to 100 (highest quality).

Protection: This term is used to characterize actions taken in watersheds of waters not known to be impaired to maintain conditions and beneficial uses of the waterbodies.

Restoration: This term is used to characterize actions taken in watersheds of impaired waters to improve conditions, eventually to meet water quality standards and achieve beneficial uses of the waterbodies.

Source (or pollutant source): This term is distinguished from 'stressor' to mean only those actions, places or entities that deliver/discharge pollutants (e.g., sediment, phosphorus, nitrogen, pathogens).

Stressor (or biological stressor): This is a broad term that includes both pollutant sources and non-pollutant sources or factors (e.g., altered hydrology, dams preventing fish passage) that adversely impact aquatic life.

Total Maximum Daily Load (TMDL): A calculation of the maximum amount of a pollutant that may be introduced into a surface water and still ensure that applicable water quality standards for that water are met. A TMDL is the sum of the wasteload allocation for point sources, a load allocation for nonpoint sources and natural background, an allocation for future growth (i.e., reserve capacity), and a margin of safety as defined in the Code of Federal Regulations.

Abbreviations and acronyms

1W1P	One Watershed, One Plan
AFO	animal feeding operation
AUID	assessment unit identification
BMP	best management practice
BWSR	Board of Water and Soil Resources
CAFO	concentrated animal feeding operation
DNR	Department of Natural Resources
EPA	U.S. Environmental Protection Agency
GHG	greenhouse gas
HSPF	Hydrological Simulation Program-FORTRAN
HUC	hydrologic unit code
IBI	index of biotic integrity
ITPHS	imminent threats to public health and safety
IWM	Intensive watershed monitoring
MDA	Minnesota Department of Agriculture
MDH	Minnesota Department of Health
MPCA	Minnesota Pollution Control Agency
MRR	Mississippi River-Reno
MSHA	Minnesota stream habitat assessment
N	nitrogen
N BMP Tool	University of Minnesota Agricultural BMP Scenario Tool for nitrogen
NPDES	national pollutant discharge elimination system
NRCS	Natural Resources Conservation Service
P	phosphorus
P BMP Tool	University of Minnesota Agricultural BMP Scenario Tool for phosphorus
SDS	State Disposal System
SID	stressor identification
SSTS	subsurface sewage treatment system
SWCD	soil and water conservation district
TMDL	total maximum daily load

TN	total nitrogen
TSS	total suspended solids
UIR	Upper Iowa River
USDA	U.S. Department of Agriculture
WASCOB	water and sediment control basin
WRAPS	watershed restoration and protection strategy
WWTP	wastewater treatment plant

Executive summary

The State of Minnesota has adopted a watershed approach to address the state's 80 major watersheds. This watershed approach incorporates water quality assessment, watershed analysis, public participation, planning, implementation, and measurement of results into a 10-year cycle that addresses both restoration and protection. The scientific findings regarding water quality conditions and strategies for addressing them are incorporated into a Watershed Restoration and Protection Strategy (WRAPS) report. This WRAPS report addresses the Minnesota portion of the Upper Iowa River (UIR) and Mississippi River–Reno (MRR) watersheds, which spans 401 square miles in the southeastern corner of the state. The watersheds are located in the Driftless Area and Western Corn Belt Plains ecoregions. Land cover is predominantly row crop (corn and soybean) and agricultural. Forested areas are more prevalent in the MRR Watershed.

Geology in the UIR and MRR watersheds and much of southeastern Minnesota is characterized by karst features. Karst features are found in areas with soluble bedrock (e.g., limestone) and are known for depressions in the ground, sink holes, springs, caves, steep and highly erodible hills, and a strong surface and groundwater connection, creating challenges for groundwater and drinking water protection.

This WRAPS report is unique for southeastern Minnesota because a comprehensive watershed management plan (i.e., One Watershed, One Plan [1W1P]) for the area has previously been developed. The Root River 1W1P (Root River Planning Partnership 2016) addresses the Minnesota portions of the UIR and MRR watersheds. As part of the 1W1P planning process, partner and public engagement and input activities were conducted. This WRAPS report does not aim to redo existing analyses or planning efforts. Instead, the WRAPS aims to focus on and highlight new information in the project area that can be used to enhance the existing 1W1P when it is updated, expected in 2021.

New information provided in this WRAPS report was summarized and supported by many efforts including the UIR and MRR Watersheds TMDL Report (Tetra Tech 2019), the Minnesota Pollution Control Agency's (MPCA) monitoring and assessment report (MPCA 2018a) and SID reports (MPCA 2018b and 2018c), simulated pollutant loads from the 2018 re-calibration of the watershed model (Tetra Tech 2018), geomorphic and stream crossing/culvert assessment results and recommendations, and information and support from organizations within the Iowa portion of the watersheds.

Thirty-six stream assessment units in the watersheds were assessed by the MPCA reaches for aquatic recreation and/or aquatic life within the UIR and MRR watersheds. Of the reaches evaluated for aquatic recreation, all 9 were not meeting water quality standards and are impaired due to high levels of bacteria. Of the 36 stream reaches evaluated for aquatic life, 11 were not meeting water quality standards and are impaired to fish and/or macroinvertebrate communities. Numerous stream reaches did not have sufficient data to assess for these uses. The most common stressors to aquatic life in the watersheds are nitrate, altered hydrology, and lack of habitat. In addition, high levels of turbidity have led to aquatic life impairment in Winnebago Creek.

All impaired streams require restoration activities; all waters in the watershed require protection in some capacity, including those listed as impaired. Restoration and protection strategies listed in section 3.4 provide examples of the types of changes needed to achieve water quality goals in the UIR and MRR watersheds. When appropriate, the WRAPS references existing plans for implementation strategies.

Rather than duplicate previous work, strategies focus on and highlight new information in the project that can be used to expand existing restoration and protection efforts through the adaptive management process. Examples of strategies provided in this WRAPS report include habitat and stream connectivity management, feedlot runoff controls, pasture management, septic system improvements, and others.

A working group of local, regional and state resource management agency staff participated in the WRAPS process and provided valuable input that was used to develop protection and restoration strategies.

What is the WRAPS Report?

Minnesota has adopted a watershed approach to address the state's 80 major watersheds. The Minnesota watershed approach incorporates **water quality assessment, watershed analysis, public participation, planning, implementation, and measurement of results** into a 10-year cycle that addresses both restoration and protection (Figure 1).

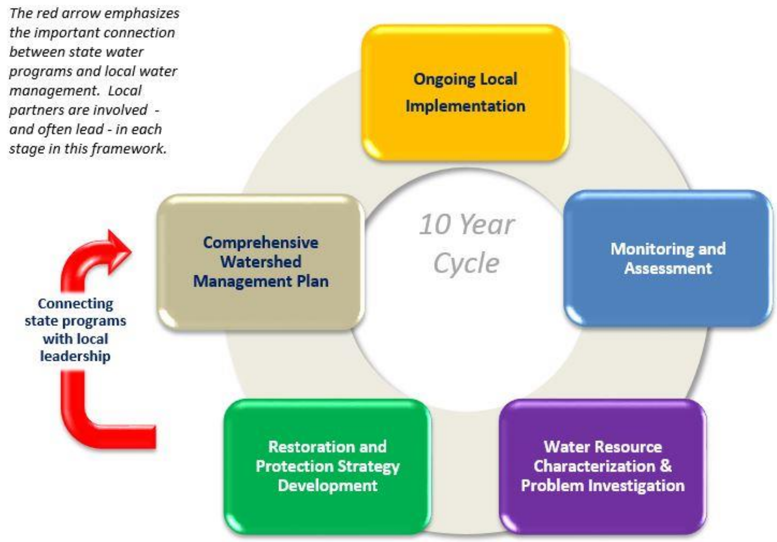


Figure 1. Minnesota's Watershed Approach

The watershed approach process facilitates a more cost-effective and comprehensive characterization of multiple water bodies and overall watershed health, including both protection and restoration efforts. A key aspect of this effort is to develop and use watershed-scale models and other tools to identify strategies for addressing point and nonpoint source pollution that will cumulatively achieve water quality targets. For nonpoint source pollution, this report informs local planning efforts, but ultimately the local partners decide what work will be included in their local plans. This report also serves as the basis for addressing the U.S. Environmental Protection Agency's (EPA) Nine Minimum Elements of watershed plans to help qualify applicants for eligibility for Clean Water Act Section 319 implementation funds.

Along with the watershed approach, the MPCA developed a process to identify and address threats to water quality in each of these major watersheds. This process is called WRAPS development. WRAPS reports address impaired waters with strategies for restoration and waters that are not impaired with protection strategies. Waters not meeting state standards are identified as impaired and total maximum daily load (TMDL) studies are developed for them prior to WRAPS development. The findings and outcomes in the TMDLs are incorporated into the WRAPS report.

This WRAPS report is unique for southeastern Minnesota because a comprehensive watershed management plan (i.e., 1W1P) for the area has previously been developed. The Root River 1W1P (Root River Planning Partnership 2016) addresses the Minnesota portions of the UIR and MRR watersheds (Figure 2). As part of the 1W1P planning process, partner and public engagement and input activities were conducted. This WRAPS report does not aim to redo existing analyses or planning efforts. Instead, the WRAPS aims to focus on and highlight new information in the project area that can be used to enhance the existing 1W1P when it is updated, expected in 2021. New information provided in this WRAPS report includes:

- Information from the recently completed UIR and MRR Watersheds TMDL report (Tetra Tech 2019).

- Identification of priority protection waters within the watersheds.
- New data including those from the MPCA's monitoring and assessment report (MPCA 2018a) and SID reports (MPCA 2018b and 2018c).
- Simulated pollutant loads from the 2018 re-calibration of the Hydrologic Simulation Program–FORTRAN (HSPF) watershed model (Tetra Tech 2018).
- Information and support from organizations within the Iowa portion of the watersheds. Geomorphic and stream crossing/culvert assessment results and recommendations.

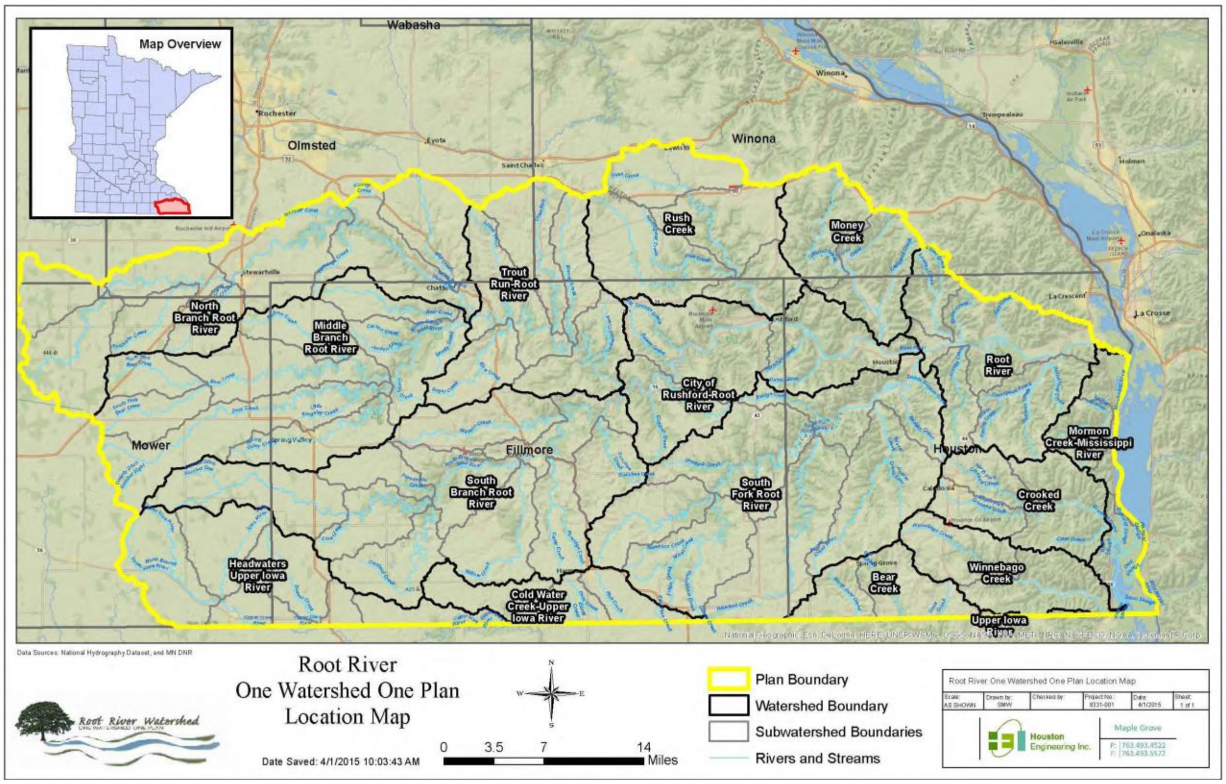


Figure 2. Root River 1W1P planning area.

Purpose	• Support local working groups and jointly develop scientifically-supported restoration and protection strategies to be used for subsequent implementation planning
	• Summarize Minnesota watershed approach work done to date including the following reports:
	  • *Root River One Watershed, One Plan*
	  • *Upper Iowa River, Mississippi River–Reno, Mississippi River–La Crescent Watersheds Monitoring and Assessment Report*
	  • *Upper Iowa River Watershed Stressor Identification Report*
	  • *Mississippi River Reno Stressor Identification Report*
	  • *Upper Iowa River and Mississippi River–Reno Total Maximum Daily Load*

Scope	• Impacts to aquatic recreation and aquatic life in streams • Protection of high quality resources • Protection of downstream uses
Audience	• Local working groups (local governments, SWCDs, watershed management groups, etc.) • State agencies (MPCA, DNR, BWSR, etc.)

1. Watershed background and description

This WRAPS report addresses the Minnesota portion of the UIR and MRR watersheds, which spans 401 square miles in the southeastern corner of the state. While some areas located in Iowa drain into the Minnesota portion of the watersheds (Figure 3), they are outside of Minnesota's authority and are not specifically addressed by this report. Restoration and protection activities in the Iowa areas that drain to Minnesota waterbodies, however, will be important to achieving the goals of this WRAPS, and collaboration between the two states is encouraged.

The UIR begins in southeast Mower County, and flows through southern Fillmore County and southwest Houston County, before flowing into Iowa. The entire watershed, including drainage in Iowa and Minnesota, drains approximately 1,001 square miles, eventually flowing to the Mississippi River in northeastern Iowa. Approximately 21%, or 217 square miles, of the UIR Watershed is located within Minnesota; the remainder is in Iowa. The watershed is recognized by the EPA as a "Priority 1 Watershed" in need of restoration (The UIR Watershed Project 2005). This is the highest designation recognized by the EPA; therefore, despite the relatively small portion of the watershed within Minnesota, the restoration of the UIR Watershed is of high importance in the state of Iowa. For the purposes of this report, the "Upper Iowa River Watershed" or "UIR Watershed" from this point on refers to the portion of the UIR Watershed within Minnesota.

The MRR Watershed is located to the east of the UIR Watershed and includes several small, direct tributaries to the Mississippi River and Mississippi River backwaters. The Minnesota portion of this watershed covers 184 square miles and is located entirely in Houston County. For the purposes of this report, the "Mississippi River–Reno Watershed" or "MRR Watershed" from this point on refers to the portion of the MRR Watershed within Minnesota.

Geology in the UIR and MRR watersheds and much of southeastern Minnesota is characterized by karst features (Figure 4). Karst features are found in areas with soluble bedrock (e.g., limestone) and are known for depressions in the ground, sink holes, springs, caves, steep and highly erodible hills, and a strong surface and groundwater connection. Limestone bedrock dissolved over time from rainwater infiltration. This infiltration can result in hidden and direct pathways between the surface and groundwater, creating challenges for groundwater and drinking water protection from surface pollution. Many of the streams in the MRR Watershed are spring fed coldwater systems as a result of the strong interaction between surface and ground water.

The watersheds are located in the Driftless Area ecoregion in the east and the Western Corn Belt Plains ecoregion in the west (Figure 3). Unlike much of the state, the Driftless Area was not impacted during the last glaciation and therefore retains bedrock bluffs and steep valleys that were leveled by glaciers elsewhere.

Land cover in the UIR and MRR watersheds differs between the western and eastern portions of the area (Figure 5). In the UIR Watershed, land cover is predominantly row crop (corn and soybean) and agricultural. Forested areas become more frequent in the Houston County portions of the watershed. Prior to European settlement, the area was predominantly oak savannah, forests, and wetlands. Tile drains are common to allow for cultivation in the low lying, wet areas found predominantly in the western portion of the watershed. In the MRR Watershed, steep topography limits cropland to flatter areas. Pasture is common in the valleys where it is too steep to operate the farm machinery typically used in cropland areas. Overall, the eastern portion of the project area remains largely forested, especially in areas near the Mississippi River where the steep slopes present obstacles to conducting agricultural activities. Row crop agricultural activities are mostly limited to the upper reaches of the tributaries. Prior to European settlement, the area was largely big hardwoods (i.e., oak, maple, basswood, and hickory) along the streams and valleys, with oak openings and prairie in the flatter areas (Root River Planning Partnership 2016).

Several existing studies and planning efforts have been conducted in the project area and are summarized and referenced throughout the report. Instructions on where to locate these existing studies and planning efforts are provided in Appendix B.

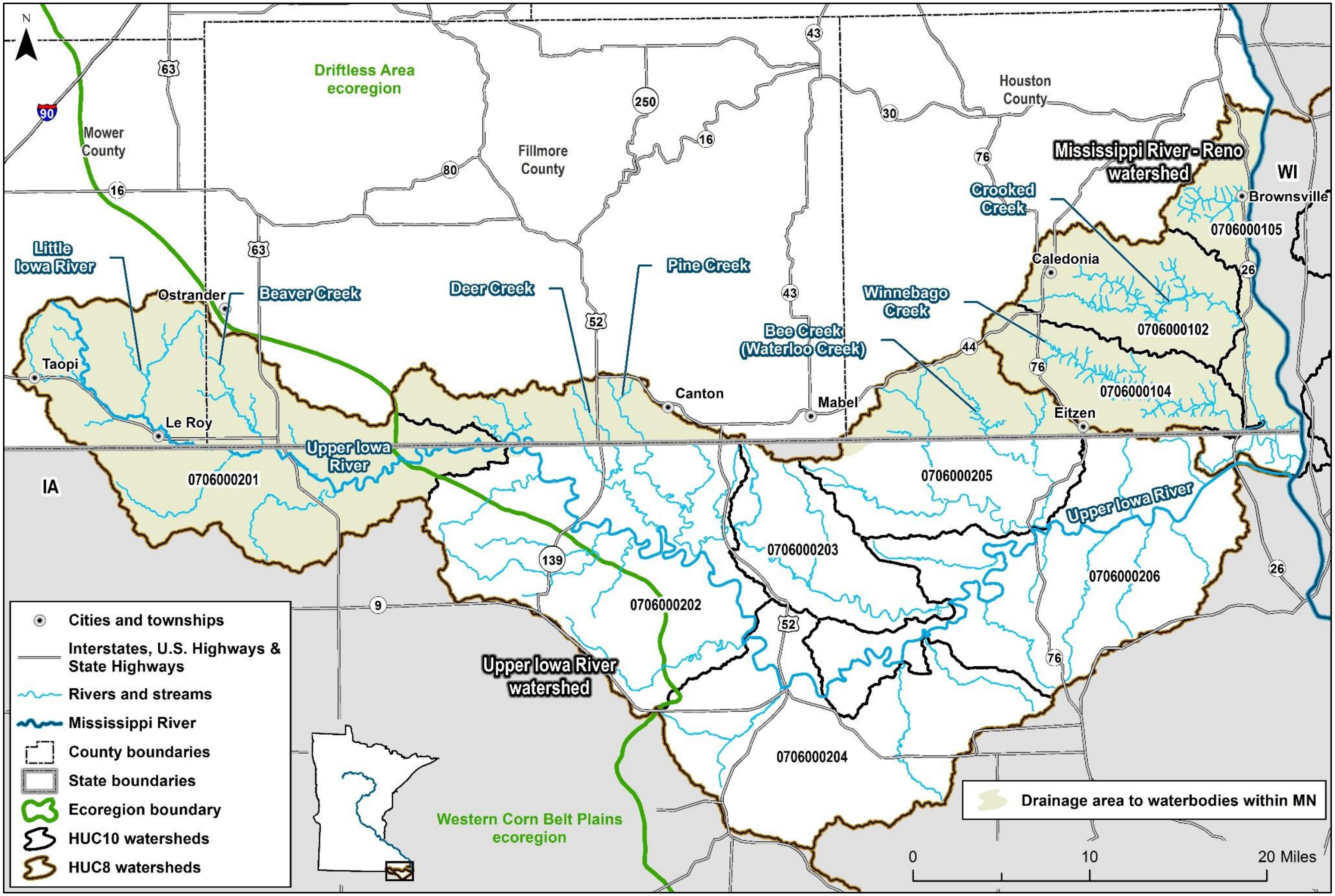


Figure 3. Areas draining to the Minnesota portion of the UIR and MRR watersheds.

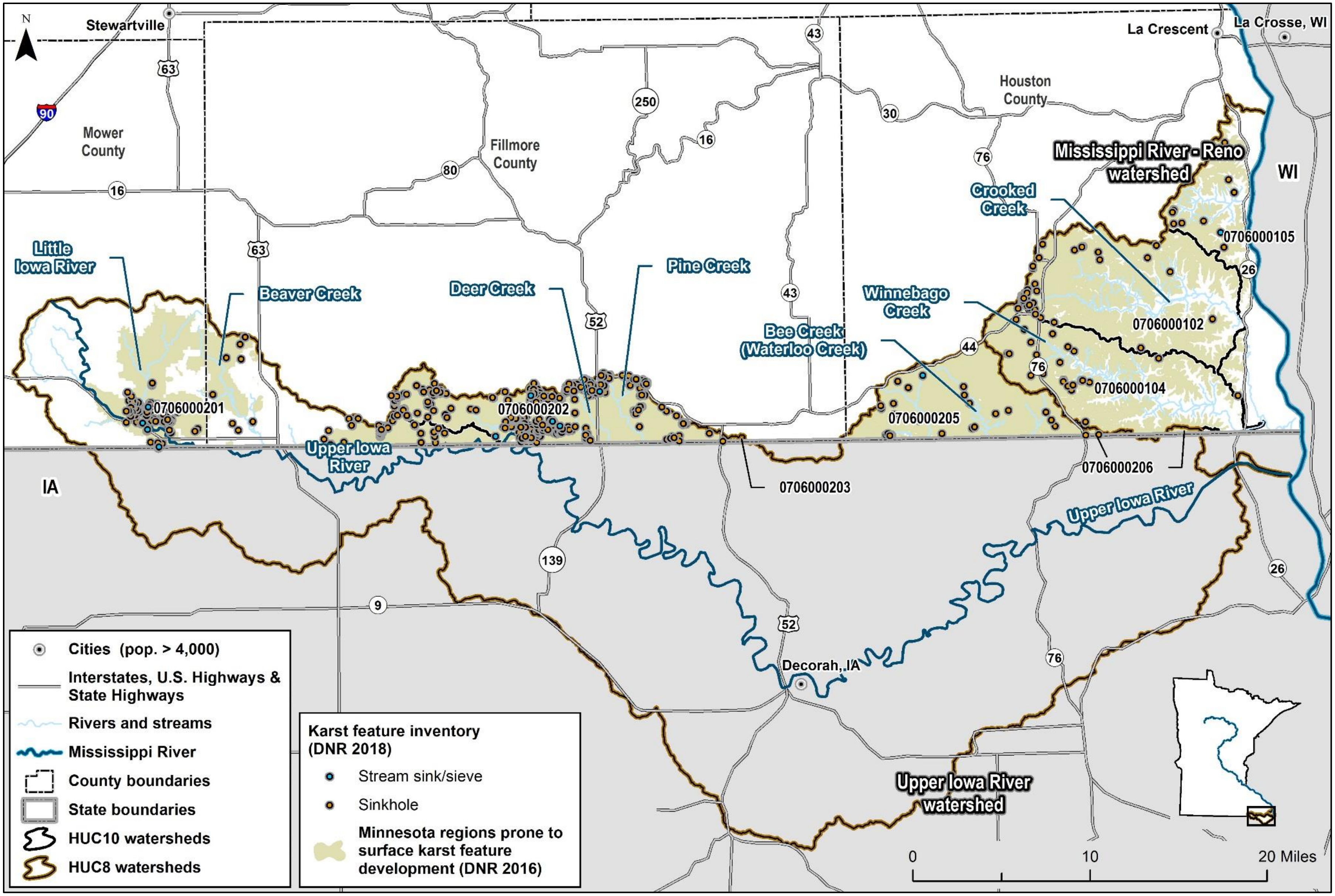


Figure 4. Karst features in the Minnesota portion of the watersheds.

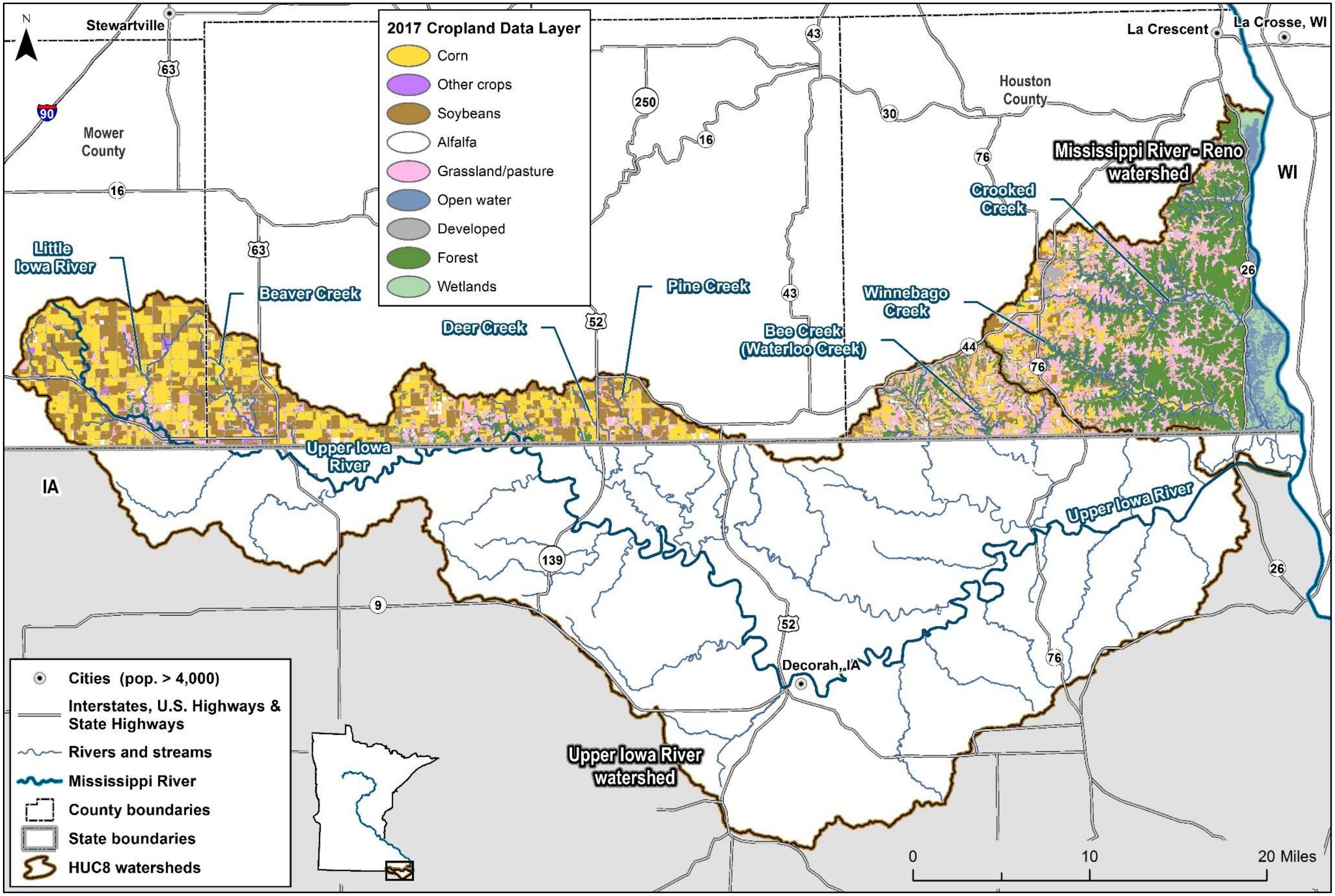


Figure 5. Land cover in the UIR and MRR watersheds.

2. Watershed conditions

Water quality and conditions of the UIR and MRR watersheds are important to the downstream conditions of the Iowa River and Mississippi River, and the states through which they flow. Several of the streams within the UIR and MRR watersheds are not meeting water quality standards and are impaired (Figure 6). However, the streams remain popular for trout fishing and canoeing, and the unique geology and topography of the Driftless Area draws tourists from around the country. In addition, excess nutrients pose a potential threat to surface and groundwater quality in the area. The UIR Watershed was identified as a high nitrogen reduction priority and both watersheds were identified as high phosphorus reduction priorities at the state scale in the Minnesota Nutrient Reduction Strategy (NRS; MPCA 2014). Additional information on the watersheds' conditions can be found in the Root River 1W1P (Root River Planning Partnership 2016) and on the MPCA's webpage for each watershed.

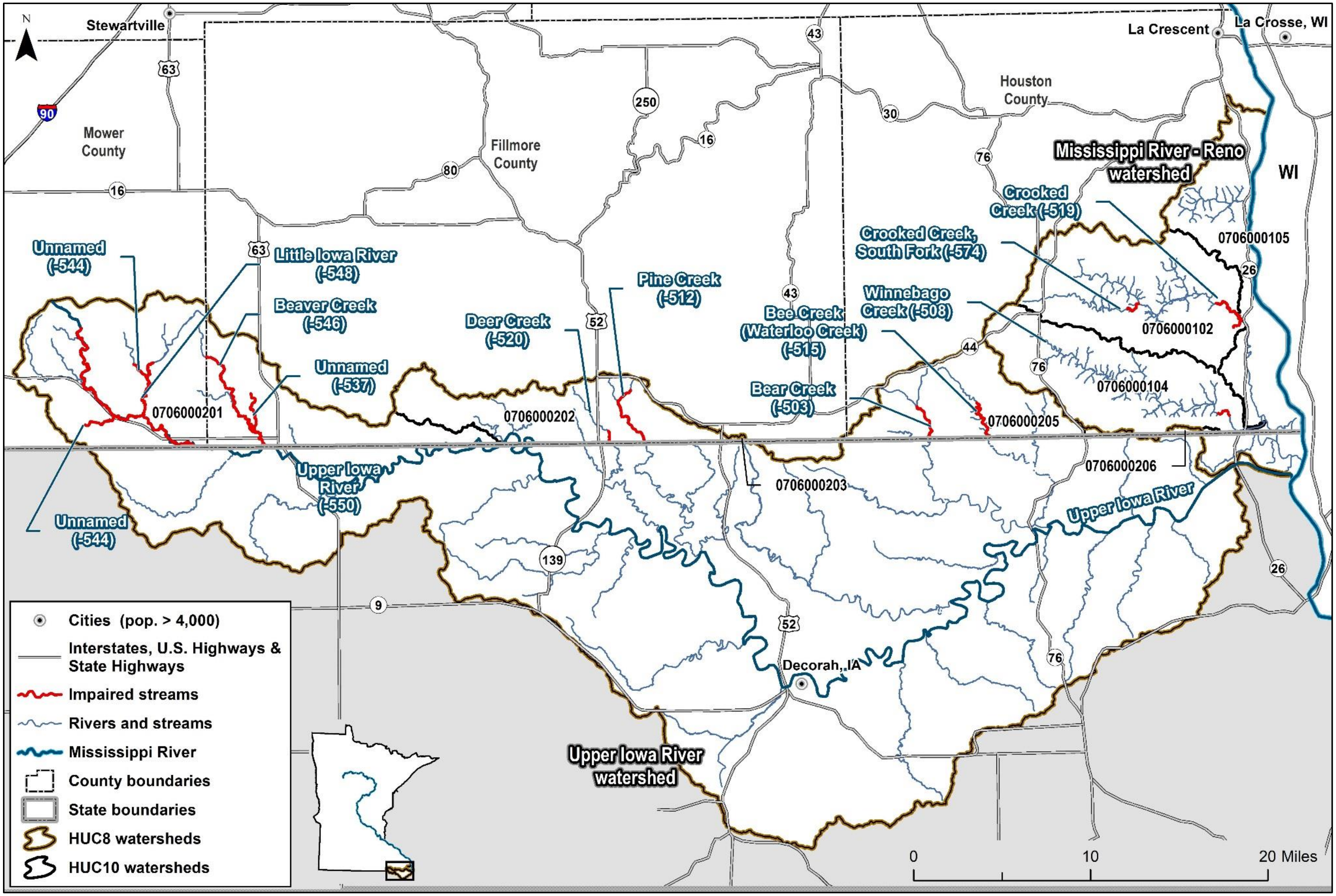


Figure 6. Impaired waters in the UIR and MRR watersheds.

2.1 Condition status

Beginning in 2015, the MPCA undertook an intensive watershed monitoring (IWM) effort of the surface waters in the UIR and MRR watersheds. The MPCA assesses the water quality of streams and lakes based on each waterbody's ability to support a variety of uses, including aquatic life, aquatic recreation, drinking water, and aquatic consumption. Data from waterbodies are compared to state standards and targets. Waterbodies that do not meet the targets are considered to be impaired and require restoration; waterbodies that meet targets are considered to be fully supporting and are the focus of protection efforts. Waters that are not yet assessed continue through a process of data collection and evaluation and can be candidates for protection work. The UIR, MRR, Mississippi River–La Crescent Watersheds Monitoring and Assessment Repor*t* (MPCA 2018a) summarizes each waterbody's ability to support aquatic life (e.g., fish and macroinvertebrates) and aquatic recreation (e.g., fishing and swimming). Findings from this report are summarized below.

2.1.1 Streams

The monitoring and assessment report (MPCA 2018a) evaluated 36 stream reaches for aquatic recreation and/or aquatic life within the UIR and MRR watersheds. All 9 of the reaches evaluated for aquatic recreation were not meeting water quality standards due to high levels of bacteria. Of the 36 stream reaches evaluated for aquatic life, 11 were not meeting water quality standards. Numerous stream reaches did not have sufficient data to assess for these uses. A summary of the stream assessment is provided in Figure 7 and Table 1.

Several of the reaches on the border have been assessed by the Iowa Department of Natural Resources (IADNR). Only one has a potential impairment for aquatic life. The reach (01-UIA-242: From confluence with Silver Cr to Winneshiek/Howard Co line) is partially supporting.

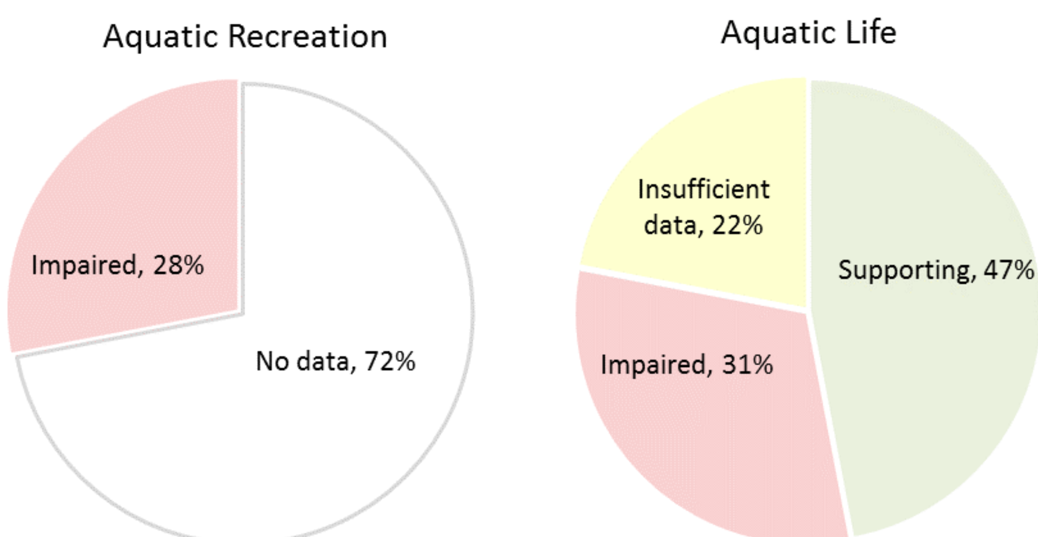


Figure 7. Stream assessment results in the UIR and MRR watersheds.

Table 1. Assessment status of stream reaches in the Upper Iowa River and Mississippi River–Reno watersheds.

					Aquatic Life										Aquatic Recreation
HUC-8 Watershed	HUC-10 Subwatershed	AUID (Last 3 digits)	Stream	Reach Description	Fish IBI	Macroinvertebrate IBI	Dissolved Oxygen	Turbidity/TSS	Secchi Tube	Chloride	pH	Ammonia	Pesticides	Eutrophication	Bacteria (*E. coli*)
Upper Iowa River (07060002)	Headwaters to Upper Iowa (0706000201)	509	Upper Iowa River	Little Iowa River to Beaver Creek (MN)	SUP	SUP	SUP	IF	SUP	SUP	SUP	SUP	–	IF	IMP
		526	North Branch Upper Iowa River	Unnamed creek to Unnamed creek	SUP	SUP	IF	IF	IF	IF	SUP	IF	–	IF	–
		536	Unnamed Creek	Unnamed creek to MN/IA border	–	–	IF	–	IF	–	IF	–	–	–	–
		537	Unnamed Creek	Unnamed creek to Beaver Creek	SUP	IMP	IF	IF	IF	–	SUP	IF	–	IF	–
		539	Unnamed Creek	Unnamed creek to Little Iowa River	–	–	IF	–	IF	–	IF	–	–	–	–
		540	Unnamed Creek	Unnamed creek to Little Iowa River	SUP	IMP	IF	IF	IF	–	SUP	IF	–	IF	–
		541	Unnamed Creek	Unnamed creek to Unnamed creek	–	–	IF	–	IF	–	IF	–	–	–	–
		542	Unnamed Creek	Unnamed creek to Upper Iowa River	–	–	IF	–	–	–	IF	–	–	–	–
		543	Unnamed Creek	Headwaters to North Branch Upper Iowa River	–	–	IF	–	IF	–	IF	–	–	–	–
		544	Unnamed Creek	Unnamed creek to Upper Iowa River	SUP	IMP	IF	IF	IF	–	SUP	IF	–	IF	–

HUC-8 Watershed	HUC-10 Subwatershed	AUID (Last 3 digits)	Stream	Reach Description	Aquatic Life										Aquatic Recreation
					Fish IBI	Macroinvertebrate IBI	Dissolved Oxygen	Turbidity/TSS	Secchi Tube	Chloride	pH	Ammonia	Pesticides	Eutrophication	Bacteria (*E. coli*)
Upper Iowa River (07060002)	Headwaters to Upper Iowa (0706000201) (cont.)	545	Beaver Creek	Headwaters to Mower-Fillmore Rd	–	–	IF	IF	IF	–	IF	–	–	IF	–
		546	Beaver Creek	Mower-Fillmore Rd to Upper Iowa River	SUP	IMP	IF	IF	IF	–	SUP	IF	–	IF	IMP
		547	Little Iowa River	Headwaters to 770th Ave	–	–	IF	–	IF	–	SUP	–	–	–	–
		548	Little Iowa River	770th Ave to Upper Iowa River	SUP	SUP	IF	IF	SUP	–	SUP	SUP	–	IF	IMP
		549	Upper Iowa River	Headwaters to -92.5901, 43.5985	–	–	IF	–	IF	–	IF	–	–	–	–
		550	Upper Iowa River	-92.5901, 43.5985 to Little Iowa River	SUP	IMP	IF	IF	IF	–	SUP	IF	–	IF	IMP
		552	Unnamed Creek	-92.4338, 43.5416 to Beaver Creek	SUP	SUP	IF	IF	IF	–	SUP	IF	–	IF	–
	Coldwater Creek (0706000202)	505	Unnamed Creek	Headwaters to Pine Creek	NA	NA	IF	IF	IF	–	SUP	IF	–	IF	–
		506	Upper Iowa River	Beaver Creek (IA) to Pine Creek	SUP	SUP	IF	IF	IF	–	IF	IF	–	IF	–
		512	Pine Creek	T101 R10W S24, north line to MN/IA border	–	–	SUP	–	–	–	SUP	SUP	–	–	IMP
		520	Deer Creek	Headwaters to MN/IA border	IMP	SUP	IF	IF	IF	–	SUP	IF	–	IF	–

HUC-8 Watershed	HUC-10 Subwatershed	AUID (Last 3 digits)	Stream	Reach Description	Aquatic Life										Aquatic Recreation
					Fish IBI	Macroinvertebrate IBI	Dissolved Oxygen	Turbidity/TSS	Secchi Tube	Chloride	pH	Ammonia	Pesticides	Eutrophication	Bacteria (*E. coli*)
Upper Iowa River (07060002)	Coldwater Creek (0706000202) (cont.)	521	Elliot Creek	Headwaters to MN/IA border	NA	NA	IF	IF	IF	–	SUP	IF	–	IF	–
	Bear Creek (0706000205)	503	Bear Creek	Unnamed creek to MN/IA border	–	–	SUP	–	–	–	SUP	SUP	–	–	IMP
		515	Bee Creek (Waterloo Creek)	T101 R6W S29, north line to MN/IA border	SUP	SUP	IF	IF	IF	–	IF	IF	–	IF	IMP
		535	Unnamed Creek	Unnamed creek to MN/IA border	SUP	IMP [a]	IF	IF	IF	–	SUP	IF	–	IF	–
Mississippi River–Reno (07060001)	Crooked Creek (0706000102)	507	Crooked Creek,	South Fork Crooked Creek to T102 R4W S28, east line	SUP	SUP	IF	IF	IF	–	IF	IF	–	IF	–
		518	Unnamed Creek	Unnamed creek to Crooked Creek	SUP	SUP	IF	IF	IF	–	IF	IF	–	IF	–
		519	Crooked Creek	T102 R4W S27, west line to Bluff Slough	SUP	IMP	IF	SUP	SUP	SUP	SUP	SUP	–	IF	IMP
		520	North Fork Crooked Creek	T102 R5W S21, north line to Crooked Creek	SUP	SUP	IF	IF	IF	–	IF	SUP	–	IF	–
		524	Clear Creek	T102 R4W S34, south line to Bluff Slough	NA	IMP	IF	IF	IF	–	IF	IF	–	IF	–

HUC-8 Watershed	HUC-10 Subwatershed	AUID (Last 3 digits)	Stream	Reach Description	Aquatic Life										Aquatic Recreation
					Fish IBI	**Macroinvertebrate IBI**	**Dissolved Oxygen**	**Turbidity/TSS**	**Secchi Tube**	**Chloride**	**pH**	**Ammonia**	**Pesticides**	**Eutrophication**	**Bacteria (*E. coli*)**
Mississippi River–Reno (07060001)	Crooked Creek (0706000102) (cont.)	574	South Fork Crooked Creek	T102 R5W S26, west line to Crooked Creek	IMP	IMP	IF	IF	IF	–	IF	IF	–	IF	–
	Winnebago Creek (0706000104)	508	Winnebago Creek	Unnamed creek to T101 R4W S28, east line	SUP	SUP	IF	IF	IF	–	IF	IF	–	SUP	–
		685	Unnamed Creek	T101 R6W S12, west line to Unnamed creek	SUP	SUP	IF	IF	IF	–	IF	IF	–	IF	–
		687	Unnamed Creek	T101 R5W S14, north line to Unnamed creek	NA	NA	–	–	–	–	–	–	–	–	–
		693	Winnebago Creek	T101 R4W S27, west line to south line	SUP	IMP	IF	IMP	IMP	SUP	IF	SUP	–	SUP	IMP
	Mormon Creek (0706000105)	516	Wildcat Creek	Unnamed Creek to Mississippi River	SUP	SUP	IF	IF	IF	–	IF	IF	–	IF	–

SUP = found to meet the water quality standard, IMP = does not meet the water quality standard and therefore is impaired,
IF = the data collected were insufficient to make a finding, NA = not assessed, –: No data

a. AUID 07060002-535 is identified in MPCA (2018a) as not meeting its aquatic life use based on the macroinvertebrate IBI. The reach is currently classified as class 2Bg but is undergoing a use class change to class 2Ag and may be listed as impaired in the 2020 impaired waters list after the use class change is completed.

2.1.2 Lakes

Louise Mill Pond or “Lake Louise” (50-0001-00) is a reservoir within Lake Louise State Park and is the only lake located in the UIR and MRR watersheds. It was not assessed by the MPCA because its residence time is too short, meaning water doesn’t stay in the reservoir long enough to make it “lake-like” and as such, lake and reservoir water quality standards do not apply.

2.2 Water quality trends

The MPCA typically completes trend analysis using transparency data from lakes and streams across the state. However, there are insufficient transparency data to conduct a trend analysis in these watersheds as part of MPCA’s monitoring and assessment program. In addition, there are no Watershed Pollutant Load Monitoring Network sites located in the UIR nor MRR watersheds.

Long-term fish monitoring data collected by the Minnesota Department of Natural Resources (DNR) were evaluated for evidence of trends for Bee Creek and Winnebago Creek. Bee Creek, proposed in October 2019 for an exceptional use class stream for both fish and macroinvertebrates, is a coldwater stream that supports popular fish for anglers, and is a designated trout stream that is actively managed by the DNR. Winnebago Creek is another high quality fishery and popular trout stream. Winnebago Creek is managed by the DNR and plays and important outdoor educational and recreational role for a recreational camp, Winnebago Springs, in Houston County.

The data show varied counts over time of brown trout adults and recruits[1] (Figure 8 and Figure 9); there is no clear trend in fish monitoring data. The number of recruits each year is typically driven by the timing and intensity of spring snowmelt, as high peak flows in spring can be a major determining factor in the mortality of trout fry.

[1] Recruits are defined as the youngest year class of a specific species in a sampled fish population. Sampling Brown/Brook Trout in spring yields older recruits (typically 1+ years old) since fish within the youngest year class are too small for capture. Fall sampling, after the youngest year class has grown over the year, captures all year classes of trout.

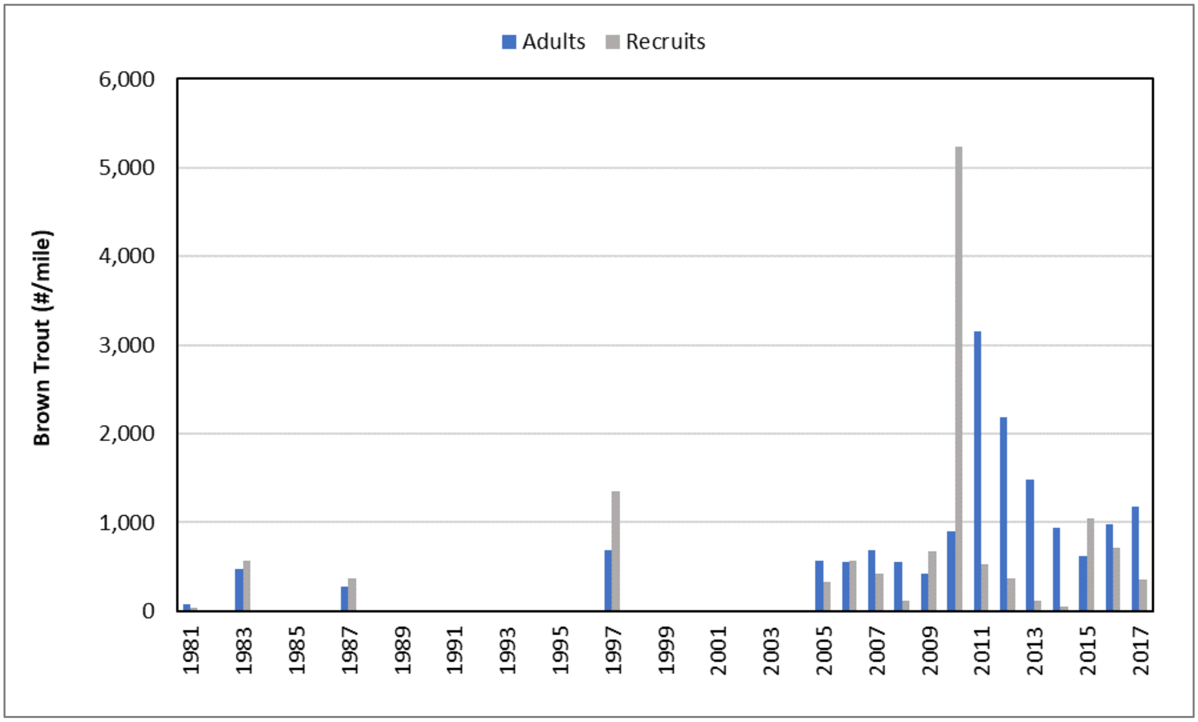


Figure 8. DNR brown trout monitoring (0.21 miles from stream mouth), Bee Creek (Waterloo Creek) (1981–2017).

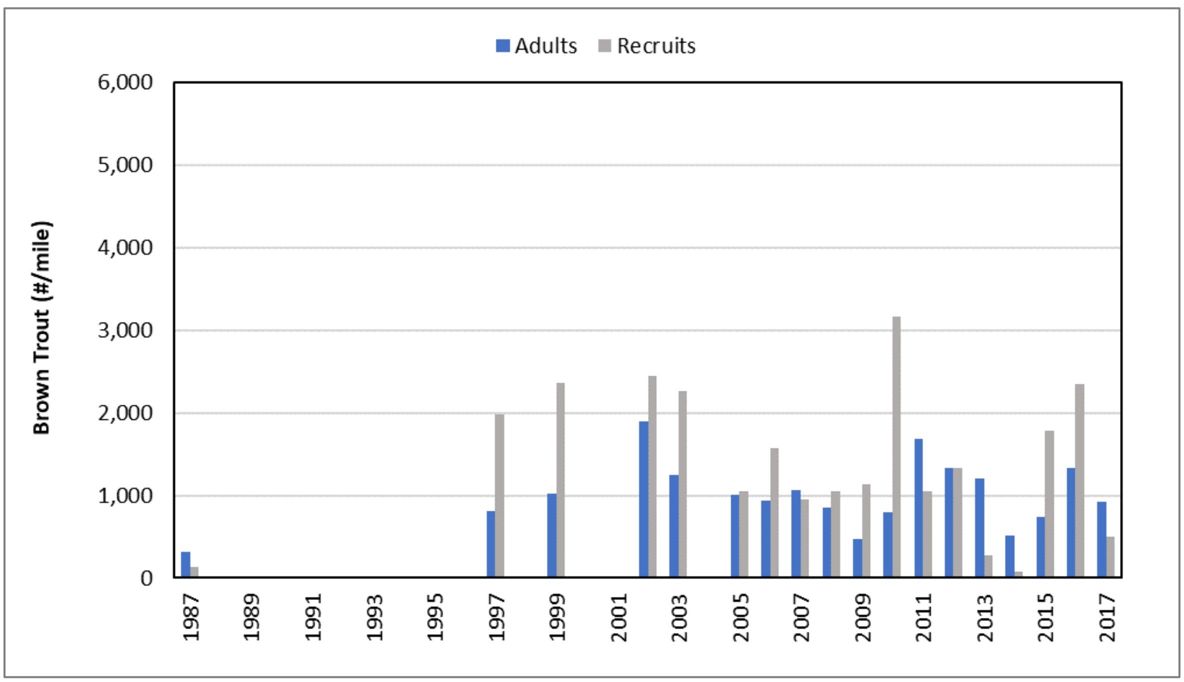


Figure 9. DNR brown trout monitoring (14.48 miles from stream mouth), Winnebago Creek (1987–2017).

2.3 Stressors and sources

In order to develop appropriate strategies for restoring or protecting waterbodies, the stressors and/or sources impacting or threatening the waterbodies must be identified and evaluated. Stressors to waterbodies with either fish or macroinvertebrate impairments are determined through a biological SID process. SIDs evaluate both pollutant and non-pollutant-related (e.g., altered hydrology, fish passage, habitat) factors as potential stressors. If a non-pollutant stressor is linked to a pollutant (e.g., habitat issues driven by total suspended solids (TSS) or low dissolved oxygen (DO) caused by excess phosphorus), a TMDL is required. Non-pollutant stressors are not subject to load quantification and therefore do not require TMDLs. Streams determined to be stressed by degraded habitat and other non-pollutant stressors are not addressed by TMDLs but are still priorities for restoration efforts.

Different from stressors, sources of pollutants are determined through a pollutant source assessment. A source assessment for pollutant related impairments is provided in the UIR and MRR TMDL Report (Tetra Tech 2019). A full pollutant source assessment was conducted for the UIR and MRR WRAPS project area for pollutants of concern and is provided below.

2.3.1 Stressors of biologically-impaired stream reaches

Stressors of biologically impaired stream reaches were determined in the UIR and MRR Watersheds SID Reports (MPCA 2018b and MPCA 2018c). The most common stressors identified in the SID reports are nitrate, altered hydrology, and lack of habitat (Table 2). More information on the SID process can be found in the SID reports (MPCA 2018b and MPCA 2018c). Biological monitoring results (macroinvertebrate index of biotic integrity [mIBI] and fish index of biotic integrity [fIBI]) for all stream reaches in the UIR and MRR watersheds can be found in Appendix 3.2 and 3.3 of the monitoring and assessment report (MPCA 2018a).

Biologically-impaired stream reaches and monitoring stations in the UIR Watershed are provided in Figure 1010. In addition, the UIR SID Report (MPCA 2018b) provides conclusions from the UIR Watershed SID evaluation:

- **Channelization and loss of wetlands** due to agricultural tile drainage systems are the primary cause of altered hydrology in UIR the watershed. Hydric soils, which indicate historic wetlands, make up 21.8% of the watershed, but existing wetlands only make up 1.7%, indicating significant wetland loss. In contrast, the MRR Watershed has retained much of its historic wetlands. Within the UIR and MRR watersheds, 18.6% streams are natural, 64.9% are altered, 0.8% are impounded and 15.7% do not have a definable channel (Figure 11).
- **Fine sediment river bed substrate** is a primary cause of poor macroinvertebrate habitat.
- **A perched culvert** at County Road A14 **and low stream flows** located just below the Minnesota and Iowa border are limiting fish passage on Deer Creek (assessment unit identification [AUID] 07060002-520).
- **Higher nitrogen levels were observed in the western portion** of the UIR Watershed compared to the central and eastern portions.
- **High phosphorus levels were observed throughout** the watershed; however, limited data resulted in phosphorus as an inconclusive stressor.
- DO **levels were overall sufficient** to support aquatic life throughout the UIR.
- **Lack of data from the unnamed tributary to Bear Creek (AUID 07060002-535) led to several inconclusive determinations on stressors.**
- **Bee Creek was recommended as a priority for protection efforts** due to its exceptional fish and macroinvertebrate communities (see Section 3.2.6 for more information).

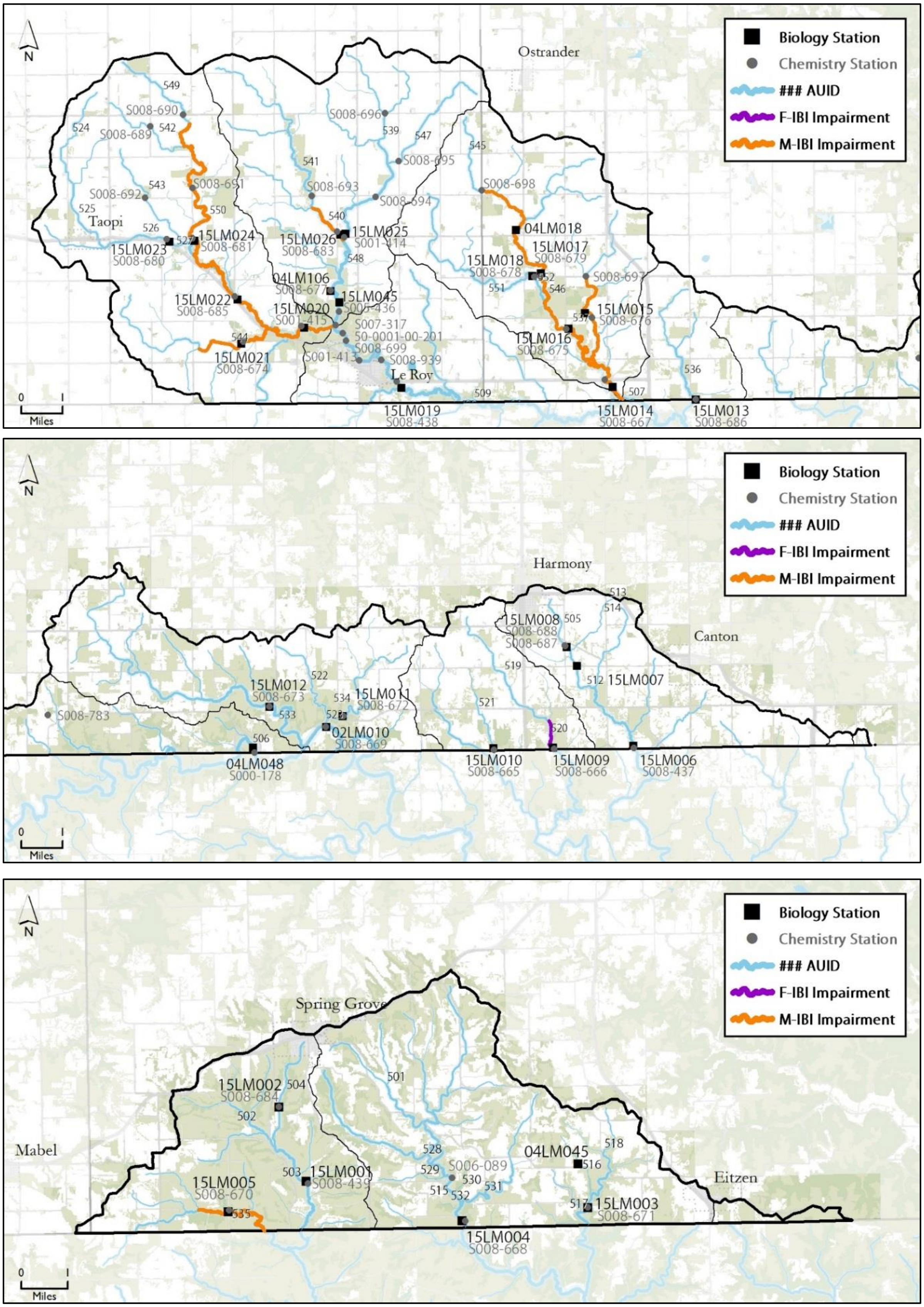
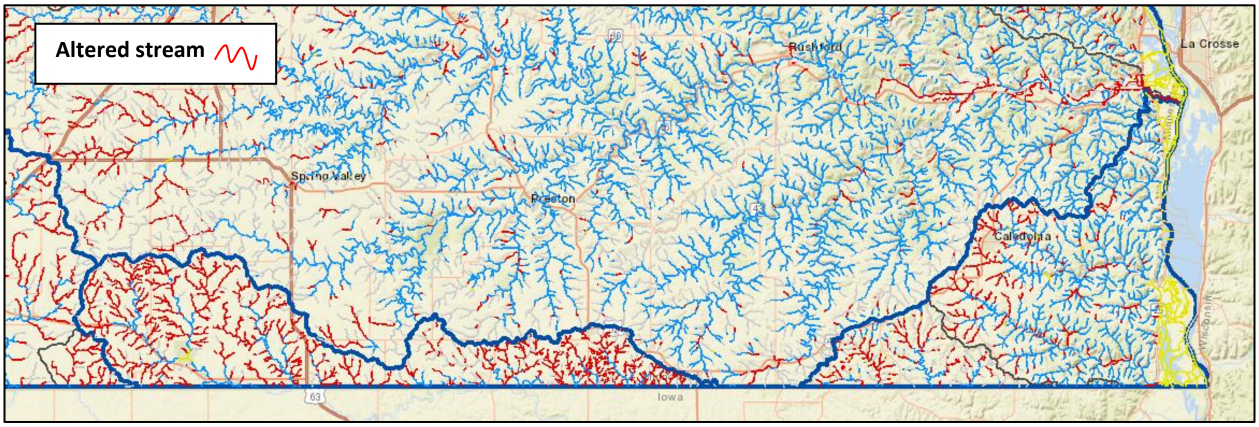


Figure 10. Biologically impaired stream reaches and monitoring stations in the UIR Watershed.



Key: Blue = Natural, Red = Altered, Yellow = Impounded, Gray = No definable channel

Figure 11. Altered streams in the UIR and MRR watershed (Minnesota DNR Watershed Health Assessment Framework 2019).

Biologically-impaired stream reaches and monitoring stations in the MRR Watershed are provided in Figure 12. The Mississippi River Reno SID Report (MPCA 2018c) provides conclusions from the MRR Watershed SID evaluation:

- **The R-3 reservoir (located upstream of the R-3 dam on Figure 12) is negatively impacting DO levels, increasing temperatures, and causing eutrophic conditions in South Fork Crooked Creek (574).** The R-3 dam was built as a flood control structure and has since impacted the downstream cold water resources**.** The R-3 reservoir, however, is currently managed by the DNR as a warm water fishery, and is a popular fishing location that allows anglers access to different games species not found in the cold water dominated watershed.
- **Excessive siltation, poor substrate conditions, and poor riparian land uses** are negatively impacting habitat conditions on Clear Creek (524).
- **Bank erosion is common in the downstream portions Winnebago Creek** and is a source of excess TSS.
- **TSS, temperature, and habitat are high priority stressors** to address in the MRR Watershed.
- **Lack of diverse habitat types, sedimentation, and natural stream slope limitations** are negatively impacting habitat conditions on Crooked Creek (519).
- **Wildcat Creek is a priority for protection efforts** as it is at risk for impairment (see Section 3.2.6 for more information).

Figure 12. Biologically impaired stream reaches and monitoring locations in the MRR Watershed.

Table 2. Stressors to aquatic life in biologically impaired reaches in the UIR and MRR watersheds.

HUC-10	AUID (Last 3 digits)	Stream	Reach Description	Biological Impairment	Stressor(s)							
					Dissolved Oxygen	Temperature	Nitrate	Eutrophication/ Phosphorus	Turbidity/TSS	Fish Passage	Altered Hydrology	Habitat
Headwaters to Upper Iowa (0706000201)	550	Upper Iowa River	-92.5901, 43.5985 to Little Iowa R	Macro-invertebrate	–	–	●	○	○	–	●	●
	546	Beaver Creek	Mower-Fillmore Rd. to Upper Iowa River	Macro-invertebrate	–	–	●	○	○	–	●	○
	544	Unnamed Creek	Unnamed creek to Upper Iowa River	Macro-invertebrate	–	–	●	○	○	–	●	●
	540	Unnamed Creek	Unnamed creek to Little Iowa River	Macro-invertebrate	○	–	●	○	○	–	●	●

HUC-10	AUID (Last 3 digits)	Stream	Reach Description	Biological Impairment	Stressor(s)							
					Dissolved Oxygen	Temperature	Nitrate	Eutrophication/ Phosphorus	Turbidity/TSS	Fish Passage	Altered Hydrology	Habitat
	537	Unnamed Creek	Unnamed creek to Beaver Creek	Macro-invertebrate	–	–	●	○	○	–	●	●
Coldwater Creek (0706000202)	520	Deer Creek	Unnamed creek to MN/IA border	Fish	○	–	○	○	○	●	○	●
Bear Creek (0706000205)	535	Unnamed Creek	Unnamed creek to MN/IA border	Macro-invertebrate	○	–	○	○	●	–	○	○
Crooked Creek (0706000102)	519	Crooked Creek	T102 R4W S27, west line to Bluff Slough	Macro-invertebrate	–	–	–	–	–	–	NA	●
	574	South Fork Crooked Creek	T102 R5W S26, west line to Crooked Creek	Fish and Macro-invertebrate	●	●	–	●	○	○	NA	–
	524	Clear Creek	T102 R4W S34, south line to Bluff Slough	Macro-invertebrate	–	○	–	–	○	–	NA	●
Winnebago Creek (0706000104)	693	Winnebago Creek	T101 R4W S27, west line to south line	Macro-invertebrate	–	–	○	–	●	–	NA	○

○: inconclusive stressor ●: stressor NA: not assessed –: not a stressor

2.3.2 Pollutant sources

Based on the results of the monitoring and assessment report and the SID reports, the primary pollutants causing aquatic life and aquatic recreation impairments include *E. coli*, sediment, nitrogen, and phosphorus. Low DO levels in South Fork Crooked Creek are primarily due to the influence of the R-3 reservoir (MPCA 2018c).

Sources of sediment, phosphorus, and nitrogen in the UIR and MRR watersheds were quantified with the MPCA's HSPF model application for the area (Tetra Tech 2018), along with additional studies where available. HSPF is a comprehensive model of watershed hydrology and water quality that allows the integrated simulation of point sources, land and soil contaminant runoff processes, and in-stream hydraulic and sediment-chemical interactions. Within each subwatershed, the upland areas are separated into multiple land use categories. The model evaluated both permitted and non-permitted sources of sediment, phosphorus, and nitrogen, including watershed runoff, near channel sources, and wastewater point sources. HSPF was also used to quantify upland loading rates for TSS, TP, and TN by model catchment. Upland loads include rill, sheet, and gully erosion, but do not include near channel sources of TSS. Model development and calibration is based on the best available information, but uncertainties do exist. Model documentation contains additional details about the model development and calibration (Tetra Tech 2018).

Potential sources of *E. coli* in the watersheds are described in the Revised Regional TMDL Evaluation of Fecal Coliform Bacteria Impairments in the Lower Mississippi River Basin in Minnesota (MPCA 2006) and the Upper Iowa MRR TMDL (Tetra Tech 2019). These studies form the basis of the source assessment for *E. coli* provided below.

Permitted (NPDES or SDS) sources

Potential sources of pollution within the UIR and MRR watersheds that are permitted under the National Pollutant Discharge Elimination System (NPDES) or State Disposal System (SDS) include municipal and industrial wastewater, stormwater (industrial and construction), and some animal feeding operations ([AFOs]e.g., CAFOs) (Table 3). There are no permitted Municipal Separate Storm Sewer Systems in the watersheds. Current permit conditions for these point sources are sufficient to meet wasteload allocations of the Upper Iowa MRR TMDL (Tetra Tech 2019).

Concentrated animal feeding operations (CAFOs) are defined by the EPA based on the number and type of animals. The MPCA currently uses the federal definition of a CAFO in its permit requirements of animal feedlots, along with the definition of an animal unit (AU). In Minnesota, the following types of livestock facilities are required to operate under a NPDES Permit or a state issued SDS Permit: a) all federally defined CAFOs that have had a discharge, some of which are under 1,000 AUs in size; and b) all CAFOs and non-CAFOs that have 1,000 or more AUs.

CAFOs and AFOs with 1,000 or more AUs must be designed to contain all manure and manure contaminated runoff from precipitation events of less than a 25-year 24-hour storm event. Having and complying with an NPDES permit allows some enforcement protection if a facility discharges due to a 25-year 24-hour precipitation event (approximately 5.3" in 24 hours) and the discharge does not contribute to a water quality impairment. Large CAFOs permitted with an SDS permit or those not covered by a permit must contain all runoff, regardless of the precipitation event. Therefore, many large CAFOs in Minnesota have chosen to have a NPDES permit, even if discharges have not occurred in the past at the facility. A current manure management plan that complies with Minn. R. 7020.2225, and the respective permit, is required for all CAFOs and AFOs with 1,000 or more AUs.

CAFOs are inspected by the MPCA in accordance with the MPCA NPDES Compliance Monitoring Strategy approved by the EPA. All CAFOs are inspected by the MPCA on a routine basis with an appropriate mix of field inspections, offsite monitoring and compliance assistance. Facilities that are permit compliant are not considered to be a substantial pollutant source to surface waters.

Pollutant loading data from wastewater treatment facilities (2000 through 2018) are provided in Appendix C.

Table 3. NPDES-permitted point sources in the UIR and MRR watersheds.
Current permit conditions of all point sources are sufficient to meet TMDL wasteload allocations (Tetra Tech 2019).

HUC-8 Watershed	HUC-10 Subwatershed	Point Source		
		Name	Permit #	Type
Upper Iowa River (07060002)	Headwaters to Upper Iowa (0706000201)	Baarsch Farms LLC – Field	MNG440066	Animal feeding operation
		Baarsch Farms LLC – Hollyhock	MNG440684	
		Baarsch Farms LLC – Pass	MNG440067	
		Koch Inc – Quarry 3	MNG490112	Industrial wastewater
		Le Roy WWTP	MN0021041	Municipal wastewater
		LeRoy Site	MNG441983	Animal feeding operation
		M & R Pork Farm – Site 1	MNG440541	Animal feeding operation
		M & R Pork Farm – Site 2		
		Bruening Rock Products Inc. - Harmony	MNG490115	Industrial stormwater
		Croell Inc.	MNG490540	
		Koch Inc. - Quarry 3 (multiple sites)	MNG490112	
	Coldwater Creek (0706000202)	Harmony WWTP	MN0022322	Municipal wastewater
	Bear Creek (0706000205)	Scott Sanness Farm – Sec 26	MNG441121	Animal feeding operation
		Spring Grove WWTP	MN0021440	Municipal wastewater
		Wiebke Feedlot LLC – Main Feedlot	MNG440906	Animal feeding operation
		Bruening Rock Products Inc. - Harmony	MNG490115	Industrial stormwater
		Croell Inc.	MNG490540	
	Various [a]		MNR100001	Construction stormwater
Mississippi River–Reno (07060001)	Crooked Creek (0706000102)	Caledonia WWTP	MN0020231	Municipal wastewater
		Houston County Airport	MNR0538VG	Industrial stormwater
		Bonanza Grain Inc. /Kruckow Rock & Redimix (multiple sites)	MNG490087 and MNR053BTK	
		Mathy Construction – Aggregate	MNG490081	
	Winnebago Creek (0706000104)	Eitzen WWTP	MN0049531	Municipal wastewater
		Bruening Rock Products Inc – Harmony	MNG490115	Industrial stormwater
	Mormon Creek (0706000105)	Brownsville WWTP	MN0053562	Municipal wastewater
		Bruening Rock Products Inc – Harmony (multiple sites)	MNG490115	Industrial stormwater
		Mathy Construction – Aggregate	MNG490081	

HUC-8 Watershed	HUC-10 Subwatershed	Point Source		
		Name	Permit #	Type
	Various construction sormwater[a]		MNR100001	Construction stormwater

a. Refers to the facilities regulated under the general construction stormwater permit. Due to the temporary nature of construction permits, current construction permit information is not provided.

Total suspended solids

TSS are materials suspended in the water column that are not dissolved. TSS materials are primarily sediment but also includes algae and other solids. TSS directly affects aquatic life by reducing visibility, clogging gills, and smothering substrate; which limits reproduction. Excessive TSS indirectly affects aquatic life by reducing the penetration of sunlight, limiting plant growth, and increasing water temperatures.

HSPF simulations indicate that cropland and near channel sources of sediment account for the majority of loading in the UIR Watershed whereas near channel and pasture sources are the largest contributors in the MRR Watershed (Figure 13 and Figure 14). The MRR watershed has a higher percentage of pastureland, therefore pastureland has a more significant effect on total loads. Soils in the watershed also transition from west to east from silty and loamy mantled firm till plain in the west to Driftless Loess hills and bedrock in the east (MPCA 2018a). As described by MPCA (2018):

> *The till plains are described as having well drained soils often used for cropland and pastureland. The soils are often silty material over loamy till with bedrock underneath (NRCS 2007). The loess hills are characterized by silty soils over bedrock. They are well to medium well drained.*
>
> *Soils in the MRR Watershed are well to moderately well drained and consist of silty soils over bedrock. This area is also characterized by alternating hills and valleys. Steep slopes are often forested (NRCS 2008).*

Modeled upland sediment loading rates by HSPF model catchment are provided in Figure 15. Sediment loading from wastewater treatment facilities (2000 through 2018) is provided in Appendix C.

A 2012 through 2015 study on erosion and sediment dynamics in the Root River Watershed indicates that agricultural soil erosion and streambank erosion are substantial sediment sources, with agricultural soil erosion representing 60% to 70% of overall sediment loading at small watershed scales (Belmont et al. n.d.). Results from this research were used to inform the calibration of the HSPF model of the Root River, UIR, and MRR watersheds. The findings from Belmont et al. (n.d.) are comparable to the source assessment results derived from the HSPF model. Differences between the HSPF model outputs and findings from Belmont et al. (n.d.) could be attributed to factors including precipitation intensity/frequency, soil type, slope, upland transport distance to the stream network, and differences in tillage and manure application practices in these areas.

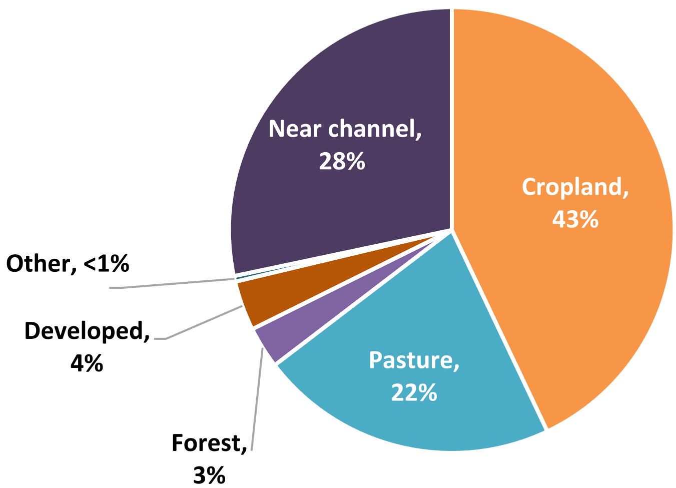


Figure 13. Sources of TSS in the UIR Watershed.
Loads are long-term average annual (1993–2015) simulated in the HSPF model (Tetra Tech 2018).

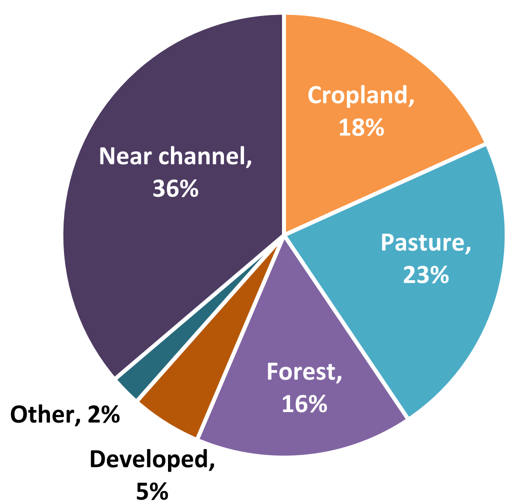


Figure 14. Sources of TSS in the MRR Watershed.
Loads are long-term average annual (1993–2015) simulated in the HSPF model (Tetra Tech 2018).

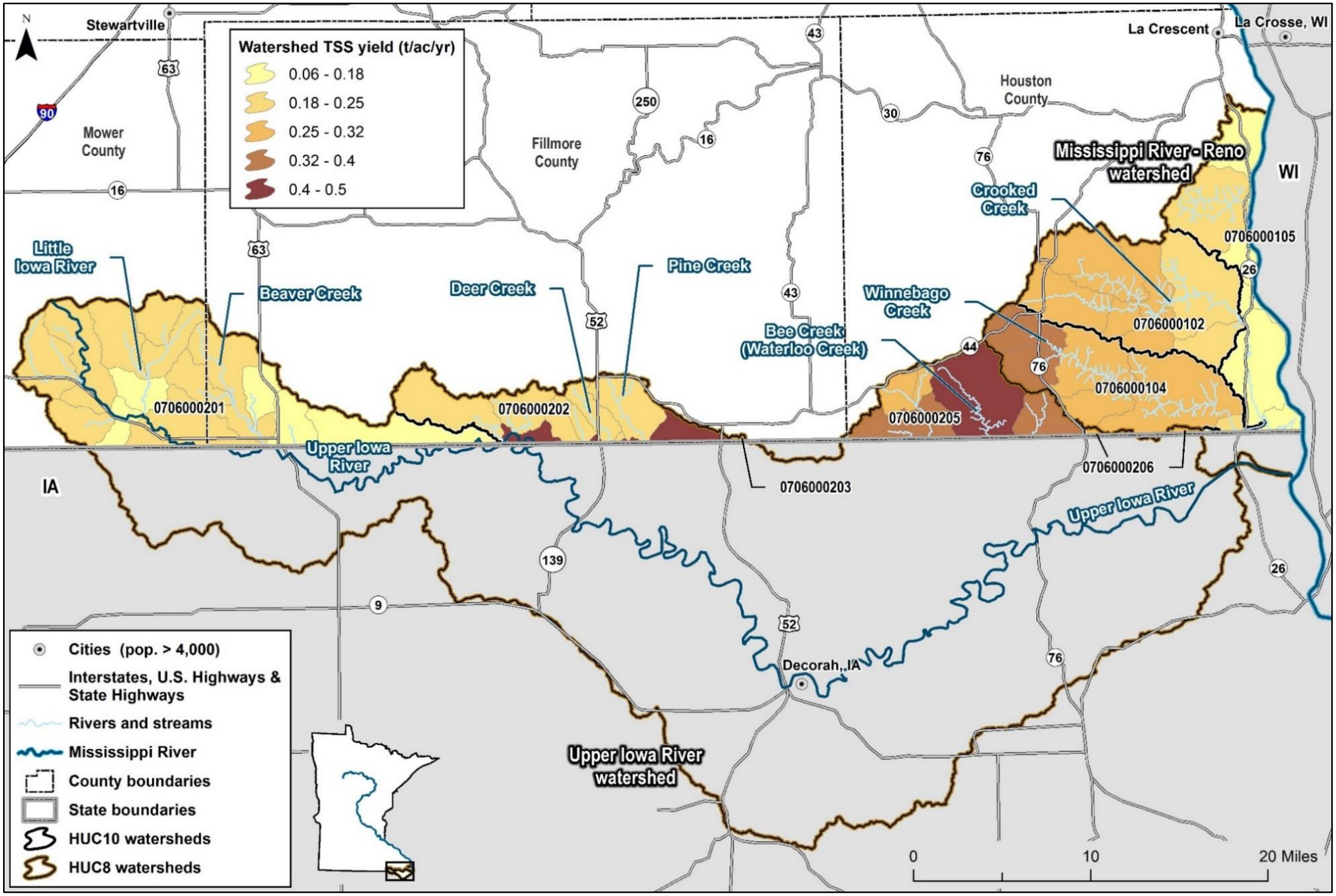


Figure 15. Upland loading rates for TSS (tons/ac/yr) per HSPF model catchment (Tetra Tech 2018).
TSS yield includes gully, sheet and rill erosion. Near channel sources of sediment are not represented.

Phosphorus

Phosphorus is a nutrient that fuels algae and plant growth. While not directly harmful to aquatic life, excess phosphorus can lead to excessive algae growth and eutrophication. These responses to excess phosphorus affect aquatic life by changing food chain dynamics, affecting fish growth and development, and decreasing DO when algae/plants decompose. A major pathway of phosphorus to surface waters is through sedimentation. Molecular bonds adhere phosphorus to sediment and allow movement of phosphorus in stormwater runoff during precipitation events or snowmelt. Phosphorus is also commonly applied to cropland as a supplemental fertilizer; in the form of animal manure or commercial fertilizer. Phosphorus from cropland can enter surface waters through two general pathways: surface runoff during precipitation/snowmelt and subsurface (drain tile) discharge.

Minnesota's NRS was completed in 2014. The NRS outlines goals and milestones for phosphorus reductions and strategies that will be used to meet the reductions. To address downstream impacts, the NRS set a goal of reducing phosphorus loading by 45% by 2025.

HSPF simulations indicate that agricultural lands (cropland and pasture) are the largest upland source of phosphorus loading in both watersheds. Not all agricultural lands contribute the same amounts of phosphorus to a system. For example, well maintained and properly managed pastures can be considered a working lands BMP if adequate vegetation exists for runoff treatment. Point sources contribute only a small fraction of the total phosphorus load in both watersheds. During low flows, however, point sources can be significant contributors of phosphorus to waterbodies (Figure 16 and Figure 17). Upland loading rates by HSPF model catchment are provided in Figure 18. Total phosphorus loading from wastewater treatment facilities (2000 through 2018) is provided in Appendix C.

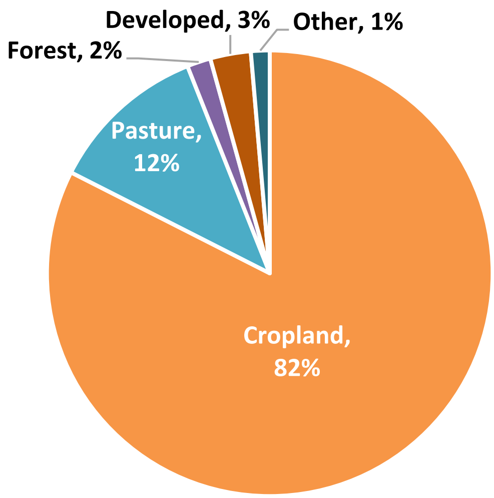


Figure 16. Upland sources of TP in the UIR Watershed.
Loads are long-term average annual (1993–2015) simulated in the HSPF model (Tetra Tech 2018).

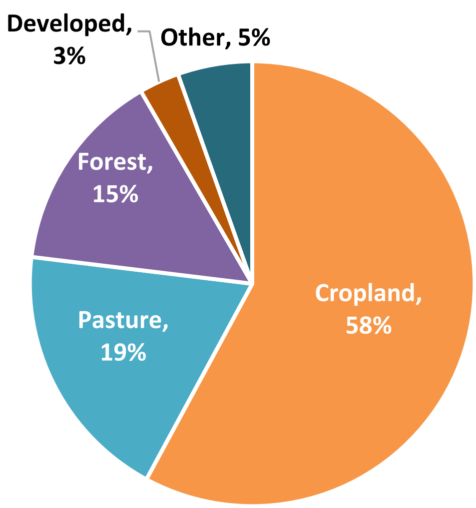


Figure 17. Upland sources of TP in the MRR Watershed.
Loads are long-term average annual (1993–2015) simulated in the HSPF model (Tetra Tech 2018).

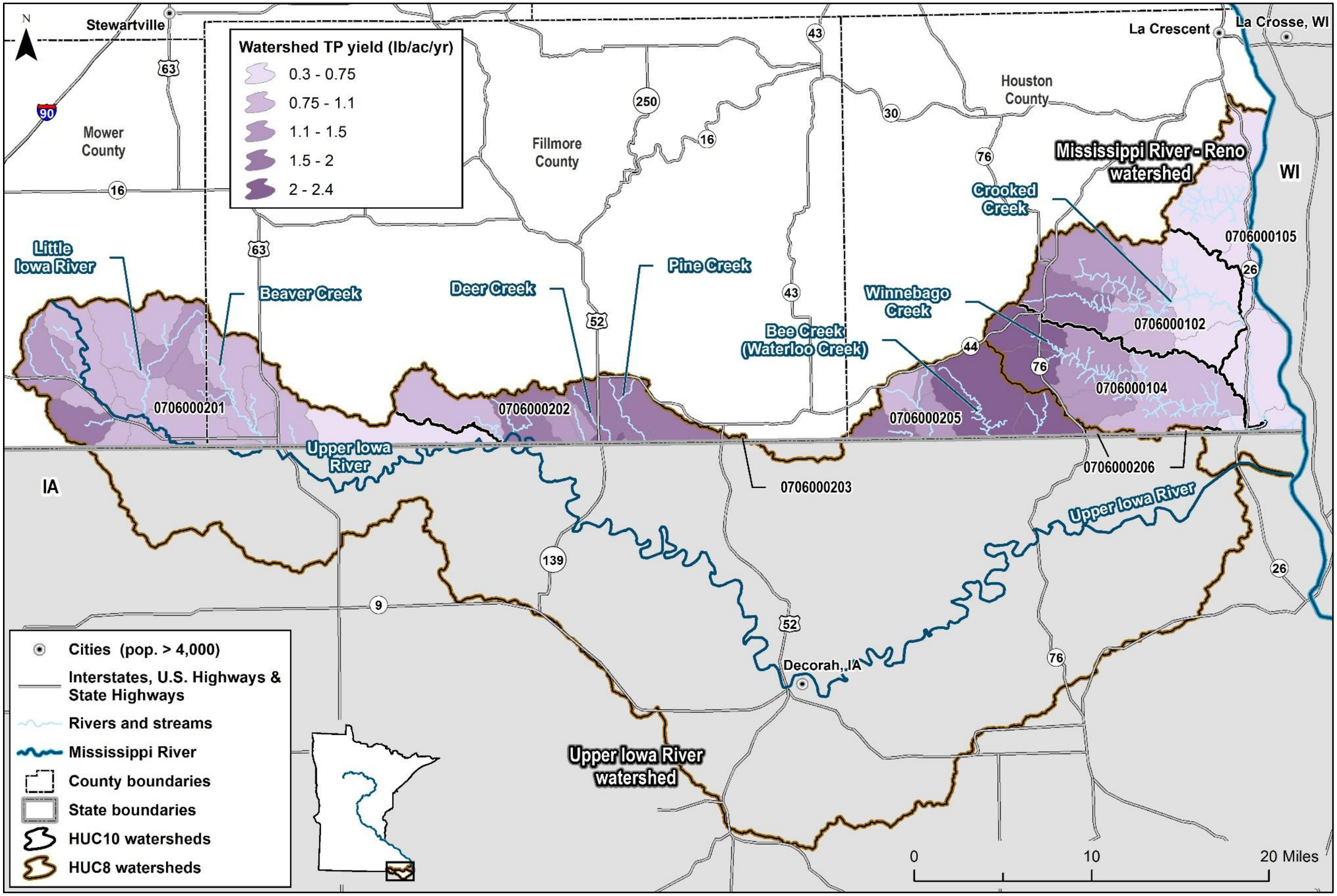


Figure 18. Upland loading rates of total phosphorus (lbs/ac/yr) per HSPF model catchment (Tetra Tech 2018).

Nitrogen

The State of Minnesota has diligently studied nitrogen (N) and its impact to the environment. Minnesota contributes the sixth highest nitrogen load to the Gulf of Mexico and is 1 of 12 member states serving on the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force. The NRS states that cropland nitrogen losses through agricultural tile drainage and agricultural groundwater (leaching loss from cropland to local groundwater) make up the majority of nitrogen sources in Minnesota. To address downstream impacts, the NRS set a goal of reducing nitrogen loading by 20% by 2025 and 45% by 2040.

Nitrogen exists in the environment and water in numerous forms, including ammonia, nitrite and nitrate. Organic nitrogen exists naturally in the environment as soil organic matter and/or decaying plant residue. The nitrogen cycle is the process in which nitrogen changes from one form to another; allowing particular forms of nitrogen to move easier within the environment (Figure 19). Nitrate is the form of nitrogen of most concern in water. Nitrates pose risks to humans in drinking water such as the risk of methemoglobinemia (i.e., "blue baby syndrome") in infants and susceptible adults, are toxic to aquatic life in large quantity, and have contributed to low oxygen, or hypoxic conditions, in coastal areas such as the Gulf of Mexico. Transformations among the different forms of nitrogen occur constantly in the water cycle. Because of this constant cycle, nitrogen it is often considered in totality as "total nitrogen (TN)".

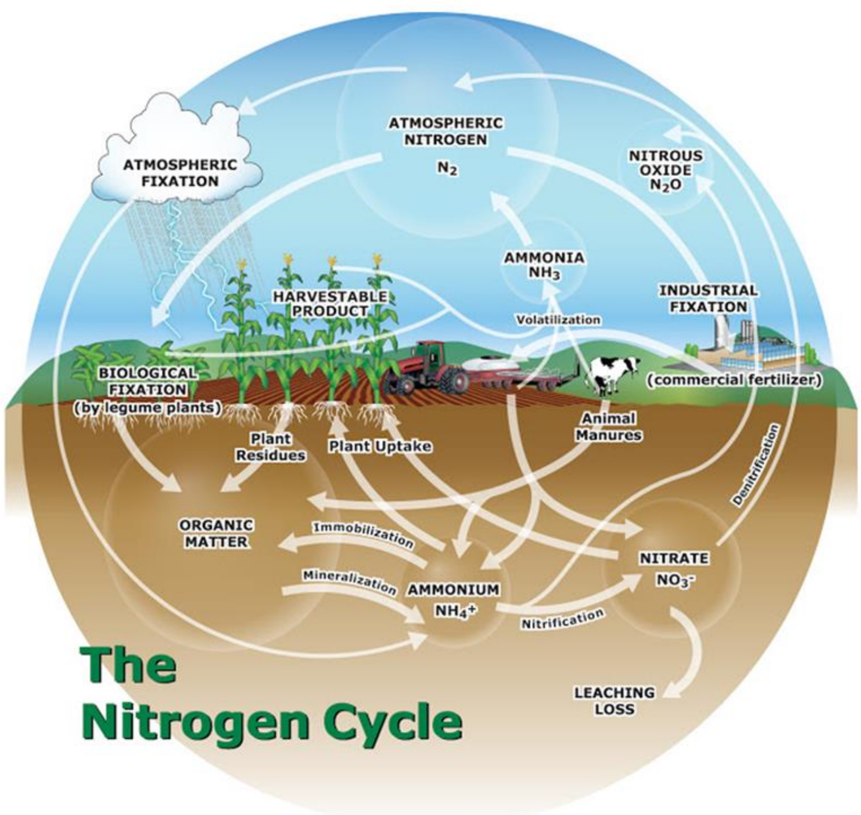


Figure 19. The nitrogen cycle (Cates 2019).

The scientific foundation of information for the nitrogen component of the NRS is the statewide nitrogen study, *Nitrogen in Surface Waters* (MPCA 2013), which identified sources of nitrogen to surface waters in each major basin in Minnesota. Nitrogen loading in the Lower Mississippi River major basin, which is a larger watershed that contains both the UIR and MRR watersheds, is predominantly from agricultural sources. These documents will be useful as the MPCA and other state and federal organizations further their nitrogen-related work, and also as local governments consider how high nitrogen levels might be reduced in their watersheds.

Agricultural sources of nitrogen come from two main avenues: animal manure and commercial nitrogen fertilizer. The State of Minnesota regulates animal manure by using land application rate recommendations and location restrictions though Feedlot Rules (Minn. R. ch. 7020). Minnesota Department of Agriculture's (MDA) Groundwater Protection Rule (GWPR), approved in 2019, aims to minimize the impact of nitrogen from commercial nitrogen fertilizer. The GWPR restricts the fall application of nitrogen fertilizer in vulnerable groundwater areas, and includes a process to reduce the severity of nitrogen contamination in public water supply wells with elevated nitrates. Implementation of the GWPR will begin in January 2020.

Although there is a strong correlation between agriculture land use and elevated nitrogen, non-agricultural areas can have elevated nitrogen as well. For instance, in forested areas, where nitrate levels are very low, organic nitrogen is typically higher than nitrate.

HSPF simulations indicate that cropland is the largest contributor of nitrogen loading in the UIR and MRR watersheds (87% and 66% respectively), followed by pasture (9% and 14% respectively) (Figure 20 and Figure 21). Upland nitrogen loading rates by HSPF model catchment are provided in Figure 22. TN loading from wastewater treatment facilities (2000 through 2018) is provided in Appendix C.

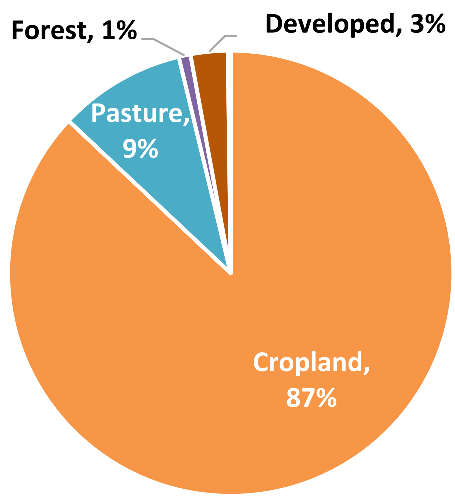


Figure 20. Sources of nitrogen in the UIR Watershed.
Loads are long-term average annual (1993–2015) simulated in the HSPF model (Tetra Tech 2018).

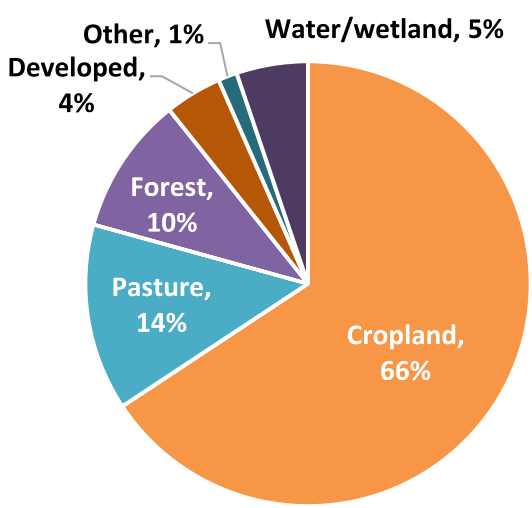


Figure 21. Sources of nitrogen in the MRR Watershed.
Loads are long-term average annual (1993–2015) simulated in the HSPF model (Tetra Tech 2018).

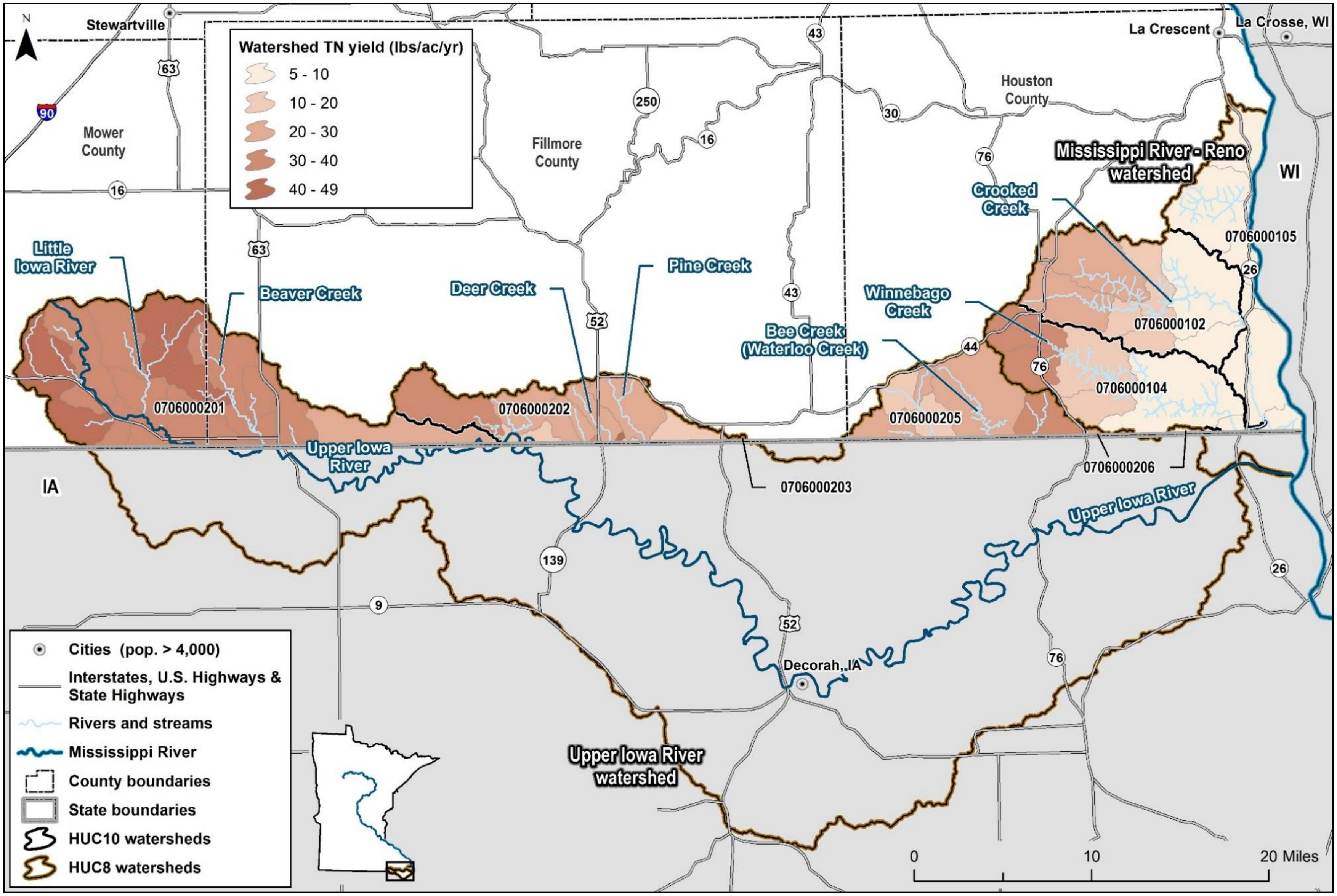


Figure 22. Upland loading rates of total nitrogen (lbs/ac/yr) per HSPF model catchment (Tetra Tech 2018).

E. coli

The following text, which provides an overview of nonpoint sources of fecal coliform and *E. coli* bacteria and associated pathogens, is excerpted and adapted with new information from the Revised Regional TMDL Evaluation of Fecal Coliform Bacteria Impairments in the Lower Mississippi River Basin in Minnesota (MPCA 2006). At the time the 2006 MPCA study was conducted, Minnesota's water quality standard was based on fecal coliform as indicators of fecal pathogens; the standard has since changed and is now based on *E. coli* counts.

The relationship between land use and fecal coliform concentrations found in streams is complex, involving both pollutant transport and rate of survival in different types of aquatic environments. Intensive sampling at numerous sites in southeastern Minnesota shows strong positive correlations among stream flow, precipitation, and fecal coliform bacteria concentrations. In the Vermillion River Watershed, storm-event samples often showed concentrations in the thousands of organisms per 100 mL, far above non-storm-event samples. A study of the Straight River Watershed divided sources into continuous (failing subsurface sewage treatment systems [SSTS], unsewered communities, industrial and institutional sources, wastewater treatment facilities) and weather-driven (feedlot runoff, manured fields, urban stormwater) categories (Baxter-Potter and Gilliland 1988). The study hypothesized that when precipitation and stream flows are high, the influence of continuous sources is overshadowed by weather-driven sources, which generate extremely high fecal coliform concentrations. However, the study indicated that during low flow conditions, continuous sources can generate high concentrations of fecal coliform. Besides precipitation and flow, factors such as temperature, livestock management practices, wildlife activity, days manure is on landscape before rain, and channel and bank storage also affect fecal bacterial concentrations in runoff (Baxter-Potter and Gilliland 1988).

Despite the complexity of the relationship between sources and in-stream concentrations of fecal coliform, the following can be considered major source categories in the UIR and MRR watersheds.

Animal feeding operations and manure application as a source of *E. coli*

AFOs are potential sources of fecal bacteria to streams in the UIR and MRR watersheds, particularly when direct animal access is not restricted and/or where feeding structures are located adjacent to riparian areas. AFOs that are permitted under a NPDES Permit or a state issued SDS Permit are discussed under the Permitted sources section.

AFOs under 1,000 AUs and those that are not federally defined as CAFOs do not operate with operating permits. However, the facilities must operate in compliance with applicable portions of Minn. R. 7020. Animal waste from non-permitted AFOs can be delivered to surface waters from failure of manure containment, runoff from the AFO itself, or runoff from nearby fields where the manure is applied. While a full accounting of the fate and transport of manure was not conducted for this project, a large portion of it is ultimately applied to the land surface and, therefore, this source is of concern. Minn R. 7020.2225 contains several requirements for land application of manure; however, there are no explicit requirements for *E. coli* or bacteria treatment prior to land application.

Solid manure left on the surface and not incorporated into the soil prior to a rainfall or a runoff event presents an elevated risk for contaminated runoff. Winter application of manure presents a higher risk for contaminated runoff. Discovery Farms program of Wisconsin and Minnesota has estimated that late winter, February and March timeframe, manure application can increase phosphorus loss in snowmelt by two to four times when compared to early winter applications (Discovery Farms 2019). One study completed by Discovery Farms Wisconsin provides a visual picture of the difference between early and late winter application of manure from two adjacent fields with similar slope and tillage practices (Figure 23). One field (bottom image) only had manure applied in November while the other field (top image) had manure applied in February.

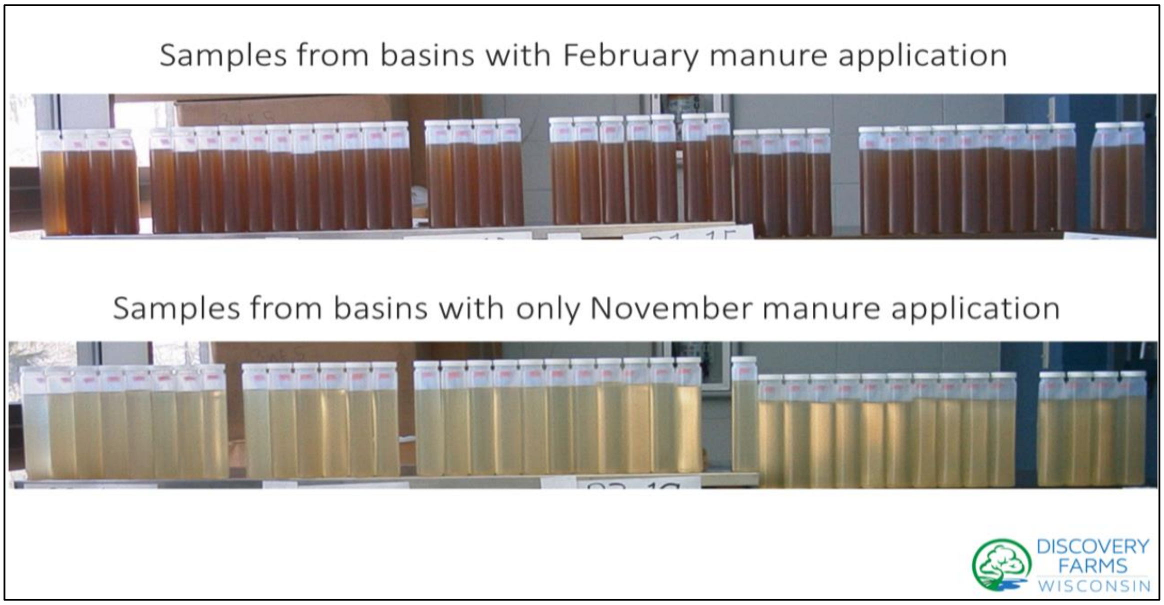


Figure 23. Comparison of runoff when manure is applied in early winter and late winter (photo from Discovery Farms).

The MDA has recently developed an interactive model to assist livestock producers to evaluate the potential runoff risk for manure applications, based on weather forecasts for temperature and precipitation along with soil moisture content. The model can be customized to specific locations. It is advised that all producers applying manure utilize the model to determine the runoff risk, and use caution when the risk is "medium" and avoid manure application during "high" risk times. For more information and to sign up for runoff risk alerts from the MDA Runoff Risk Advisory Forecast, please see the MDA website.

Inspection and compliance data are useful in determining potential sources of *E. coli* (in addition to nutrients) to surface waters. On-site feedlot inspections are conducted by compliance staff to verify compliance with state feedlot rules. Much of this work is accomplished through a delegation of authority from MPCA to county government. Feedlot compliance status may frequently change as updates are made. County staff are responsible for non-compliance follow up in this project area.

The MPCA provided the feedlot locations and numbers and types of animals in registered feedlots. Of the 179 active feedlots located with the MRR Watershed, compliance staff conducted 74 inspections since 2003. During that time, compliance staff deemed 8 feedlot facilities with minor non-compliance for failing to keep adequate manure application records, and 11 major non-compliance for not meeting water quality discharge standards.

Of the 316 active feedlots within the UIR, compliance staff conducted 99 feedlot inspections since 2007. During that time, compliance staff deemed 13 feedlot facilities minor non-compliance and 5 major non-compliance.

In addition, information on feedlots enrolled in open lot agreements, with pastures, and liquid manure storage areas within the UIR and MRR watersheds was available from the MPCA (MPCA 2019a) and is provided in Table 4. Cattle and swine are the most predominant animal type in the UIR and MRR watersheds with the majority of cattle operations located in Houston County and the majority of swine operations in Mower and Fillmore counties (Figure 24).

Table 4. Feedlot information from MPCA Tableau as of August 2019 (MPCA 2019a).

	Feedlots enrolled in open lot agreements		Feedlots with pasture area(s)		Feedlots with liquid manure storage	
HUC-8 Watershed	**number**	**percent (%)**	**number**	**percent (%)**	**number**	**percent (%)**
Upper Iowa River (07060002)	13	7%	144	78%	70	38%
Mississippi River–Reno (07060001)	80	51%	128	82%	33	21%

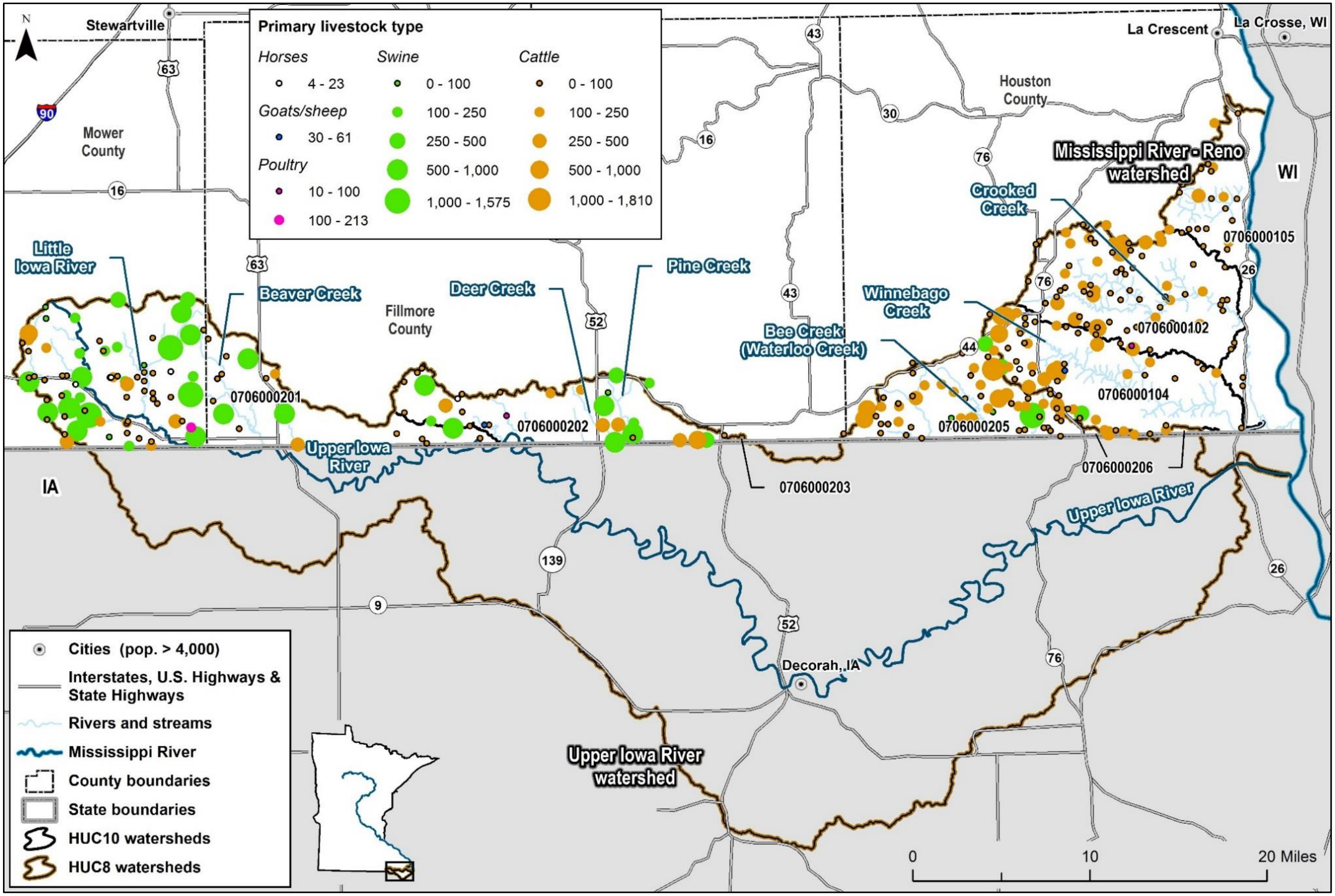


Figure 24. Primary animal types in registered feedlots in the UIR and MRR watersheds.

Humans as a source of *E. coli*

SSTSs that are failing can contribute *E. coli* to nearby waters. SSTSs can fail for a variety of reasons, including excessive water use, poor design, physical damage, and lack of maintenance. Common limitations that contribute to failure include seasonal high water table, fine-grained soils, bedrock, and fragipan (i.e., altered subsurface soil layer that restricts water flow and root penetration). Septic systems can fail hydraulically through surface breakouts or hydrogeologically from inadequate soil filtration. The communities of Eitzen, Brownsville, Caledonia, Spring Grove, Harmony, and Le Roy are served by wastewater treatment facilities (Table 3); all other residents in the watersheds are using SSTSs. Most SSTS systems within the UIR and MRR watersheds are used for individual homes and residences; however, some larger systems are also present.

Septic systems that discharge untreated sewage to the land surface or directly to streams are considered imminent threats to public health and safety (ITPHS). Average County-wide estimated percentages of ITPHS are low, ranging from 3% to 5% of total systems (Table 5). ITPHS typically include straight pipes, effluent ponding at ground surface, effluent backing up into home, unsafe tank lids, electrical hazards, or any other unsafe condition deemed by certified SSTS inspector. Therefore, it should be noted that not all of the ITPHSs discharge pollutants directly to surface waters.

Septic systems with inadequate soil filtration are considered to be failing to protect groundwater from pollutants (Minn. R. 7080.1500, subp. 4B). Due to the unique geology in karst areas where groundwater and surface waters are highly connected, SSTSs that are failing to protect groundwater are also potential sources of *E. coli* and other pollutants to impaired streams. In Houston and Mower counties, 45% and 40% of SSTSs are estimated to be failing to protect groundwater, respectively (Table 5). Without location information and knowledge of the specific hydrogeologic conditions at each SSTS drain field, the extent of these SSTSs as a source of *E. coli* to impaired streams is unknown.

Table 5. Estimated ITPHS and facility SSTSs by county.
Data from MPCA (2017; direct correspondence with Brandon Montgomery on October 25, 2018). These percentages are reported as estimates by local units of government for planning purposes and general trend analysis. These values may be inflated due to relatively low total SSTS estimated per jurisdiction. Additionally, estimation methods for these figures can vary depending on local unit of government resources available.

County	Estimated Percentage ITPHS (%)	Estimated Percentage of SSTS Failing to Protect Groundwater (%)
Fillmore	3	5
Houston	5	45
Mower	5	40

The MPCA (MPCA 2019b) tracks repair and replacement of SSTSs throughout the state. Since 2002, Mower County has repaired or replaced 940 SSTSs, Fillmore County has repaired or replaced 457 SSTSs, and Houston County has repaired or replaced 381 SSTSs.

Stormwater runoff as a source of *E. coli*

Stormwater runoff acts as a delivery mechanism of multiple *E. coli* sources including wildlife and domestic pets. Impervious areas (such as roads, driveways, and rooftops) can directly connect the location where *E. coli* is deposited on the landscape to points where stormwater runoff carries *E. coli* into surface waters. For example, there is a greater likelihood that uncollected pet waste in an urban area will reach surface waters through stormwater runoff than it would in a rural area with less impervious surface. Wildlife, such as birds and raccoons, can be another source of *E. coli* in stormwater runoff (Wu et al. 2011, Jiang et al. 2007).

Permitted wastewater as a source of *E. coli*

Permitted wastewater is a potential source of *E. coli*. Wastewater dischargers that operate under NPDES permits are required to disinfect wastewater to reduce fecal coliform concentrations to 200 organisms/100 mL or less as a monthly geometric mean prior to discharge. Like *E. coli*, fecal coliform are an indicator of fecal contamination. Wastewater that meets the fecal coliform permit limit is not considered a significant source. Wastewater dischargers are summarized in Table 3.

Coldwater Creek microbial source tracking

The UIR Watershed Partnership conducted a microbial source tracking study in Coldwater Creek (HUC-10 0706000202) located in Iowa (Skopec et al. 2004). The study area included the Minnesota portion of the Coldwater Creek Subwatershed, which includes Pine Creek (-512); listed as impaired by *E. coli*. Results from this study can be used to determine appropriate strategies for addressing the bacteria impairment in this area. This study used *E. coli* ribotyping on nine water samples collected at the discharge of the Coldwater Creek Subwatershed during the fall, spring, and summer seasons to determine the presence or absence of *E. coli* from cattle, human, and other animal sources. Cattle indicators were present in the fall, spring, and summer seasons. Other animal fecal identifications were present in the fall and spring. Human fecal indicators were only present in the fall (Figure 25).

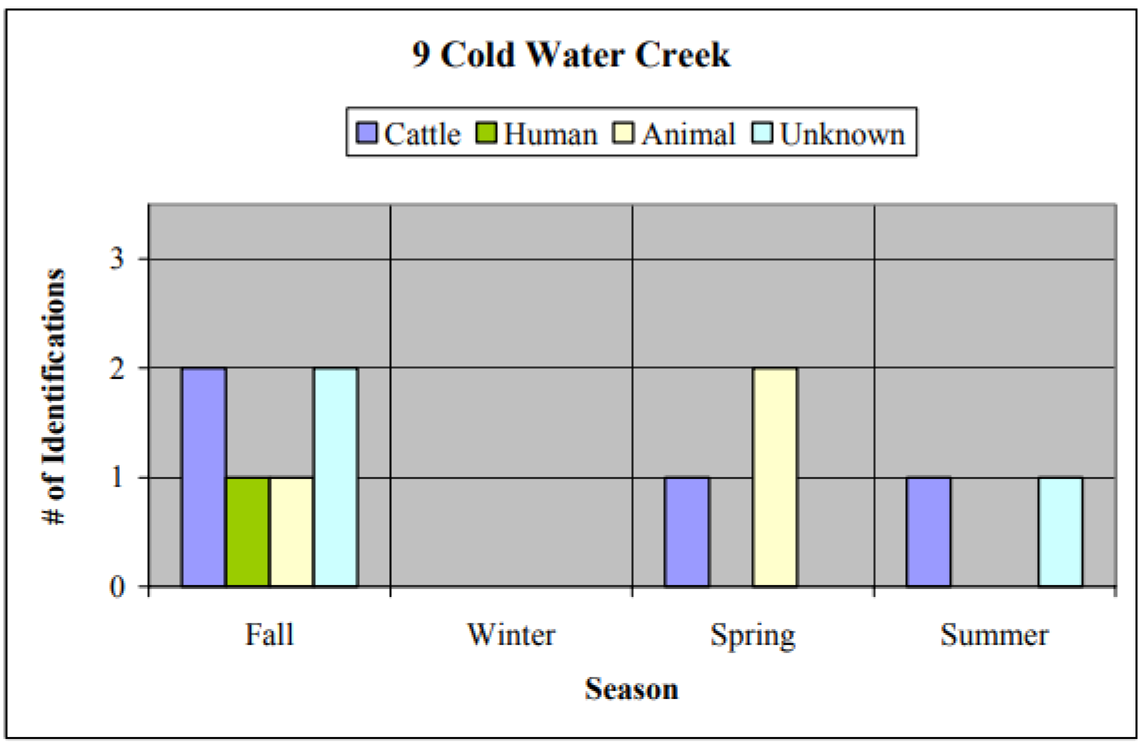


Figure 25. Microbial source tracking results for Cold Water Creek (Skopec et al. 2004).

Natural growth of *E. coli*

When evaluating sources of *E. coli* in the UIR and MRR watersheds, it is important to recognize the natural growth of *E. coli* in soil and sediment. Research in the last 15 years has found the persistence of *E. coli* in soil, beach sand, and sediments throughout the year in the north central United States without the continuous presence of sewage or mammalian sources. An Alaskan study (Adhikari et al. 2007) found that total coliform bacteria in soil were able to survive for six months in subfreezing conditions. A study of coldwater streams in southeastern Minnesota completed by the MPCA staff found the resuspension of *E. coli* in the stream water column due to stream sediment disturbance. A recent study near Duluth, Minnesota (Ishii et al. 2010) found that *E. coli* were able to grow in agricultural field soil. A study by Chandrasekaran et al. (2015) of ditch sediment in the Seven Mile Creek Watershed in southern Minnesota found that strains of *E. coli* had become naturalized to the water−sediment ecosystem. Survival and growth of fecal coliform has been documented in stormsewer sediment in Michigan (Marino and Gannon 1991).

In addition, hydrogeological features in southeastern Minnesota may favor the survival of fecal coliform bacteria. Cold groundwater, shaded streams, and sinkholes may protect fecal coliform from light, heat, drying, and predation (MPCA 1999). Sampling in the South Branch of the Root River Watershed, just north of the UIR and MRR watersheds, showed concentrations of up to 2,000 organisms/100 mL coming from springs, pointing to a strong connection between surface water and groundwater (Fillmore County 1999 and 2000). The presence of fecal coliform bacteria has also been detected in private well water in southeastern Minnesota. However, many detections have been traced to problems of well construction, wellhead management, or flooding, not from widespread contamination of the deeper aquifers used for drinking water. Finally, fecal coliform survival appears to be shortened through exposure to sunlight.

The growth and persistence of *E. coli*, which has been studied and documented in our region and beyond, greatly complicates the clear identification of sources of pathogens to surface waters. As such, the information provided in this section includes the most likely sources based on the best available information. While there is more to be learned about the natural growth of *E. coli* in the environment, it is not believed to be the cause of impairments within the UIR and MRR watersheds.

2.4 TMDL summary

The Clean Water Act and EPA regulations require that TMDLs be developed for waters that do not support their designated uses (fishable, swimmable, consumable). A TMDL is a report on how restore and maintain water quality standards in waters that are not currently meeting them. Waterbodies with impairments determined to be caused from a pollutant are addressed with the development of a TMDL; waterbodies determined to be impaired from a non-pollutant stressor do not require the development of a TMDL.

The UIR and MRR watersheds TMDL (Tetra Tech 2019) addresses waterbodies that have impaired aquatic life, aquatic recreation, and limited resource value designated uses. These types of TMDLs address “conventional pollutants” such as excessive nutrients, fecal bacteria, turbidity, or stressors not related to aquatic consumption designated uses. Table 10 provides a summary of the TMDLs.

In addition, the Mississippi River, that flows adjacent to the MRR Watershed, has aquatic consumption impairments due to high levels of mercury and polychlorinated biphenyls in fish tissue. Because the focus of the watershed condition assessment is the aquatic life, aquatic recreation, and limited resource value designated uses, the aquatic consumption impairments are not addressed here. For more information on mercury impairments, see the Minnesota Statewide Mercury TMDL (MPCA 2007).

Table 6. Impairments in the UIR and MRR watersheds (2018 303(d) List).

HUC8	Waterbody Name	Reach Description	AUID (HUC8-)	Use Class [a]	Year Added to List	Affected Use	Proposed Category [b]	Impaired Waters Listing	Pollutant or Stressor	TMDL Developed in this Report
Mississippi River–Reno (07060001)	Crooked Creek, South Fork	T102 R5W S26, west line to Crooked Creek	574	1B, 2Ag	2018	Aquatic Life	4C	Aquatic macroinvertebrate bioassessments	Temperature Dissolved oxygen/eutrophication	**No:** non-pollutant stressor **No**: dissolved oxygen stressor not conclusively linked to phosphorus load
							4C	Fishes bioassessments	Temperature Dissolved oxygen/eutrophication	**No:** non-pollutant stressor **No**: dissolved oxygen stressor not conclusively linked to phosphorus load
	Crooked Creek	T102 R4W S27, west line to Bluff Slough	519	2Bg	2018	Aquatic Recreation	4A	*E. coli*	*E. coli*	**Yes:** *E. coli*
						Aquatic Life	4C	Aquatic macroinvertebrate bioassessments	Habitat	**No:** non-pollutant stressor
	Clear Creek	T102 R4W S34, south line to Bluff Slough	524	2Bg	2018	Aquatic Life	4C	Aquatic macroinvertebrate bioassessments	Habitat	**No:** non-pollutant stressor
	Winnebago Creek	T101 R4W S27, west line to south line	693	1B, 2Ag [c]	2018	Aquatic Recreation	4A	*E. coli*	*E. coli*	**Yes:** *E. coli*
						Aquatic Life	4A	Aquatic macroinvertebrate bioassessments	TSS	**Yes**: TSS
							4A	TSS	TSS	
Upper Iowa River (07060002)	Unnamed Creek	Unnamed creek to Upper Iowa River	544	2Bg	2018	Aquatic Life	5 (no change)	Aquatic macroinvertebrate bioassessments	Nitrate Habitat Flow alteration	**No:** water quality standard not established **No**: non-pollutant stressor **No:** non-pollutant stressor
	Upper Iowa River	-92.5901, 43.5985 to Little Iowa River	550	2Bg	2018	Aquatic Recreation	4A	*E. coli*	*E. coli*	**Yes:** *E. coli*

HUC8	Waterbody Name	Reach Description	AUID (HUC8-)	Use Class [a]	Year Added to List	Affected Use	Proposed Category [b]	Impaired Waters Listing	Pollutant or Stressor	TMDL Developed in this Report
Upper Iowa River (07060002) (continued)	Upper Iowa River (continued)	-92.5901, 43.5985 to Little Iowa River	550	2Bg	2018	Aquatic Life	5 (no change)	Aquatic macroinvertebrate bioassessments	Nitrate Habitat Flow alteration	**No:** water quality standard not established **No**: non-pollutant stressor **No:** non-pollutant stressor
	Unnamed Creek	Unnamed creek to Little Iowa River	540	2Bg	2018	Aquatic Life	5 (no change)	Aquatic macroinvertebrate bioassessments	Nitrate Habitat Flow alteration	**No:** water quality standard not established **No**: non-pollutant stressor **No:** non-pollutant stressor
	Little Iowa River	770th Ave to Upper Iowa River	548	2Bg	2018	Aquatic Recreation	4A	*E. coli*	*E. coli*	**Yes:** *E. coli*
	Upper Iowa River	Little Iowa River to Beaver Creek (MN)	509	2Bg	2018	Aquatic Recreation	4A	*E. coli*	*E. coli*	**Yes:** *E. coli*
	Unnamed Creek	Unnamed creek to Beaver Creek	537	2Bg	2018	Aquatic Life	5 (no change)	Aquatic macroinvertebrate bioassessments	Nitrate Habitat Flow alteration	**No:** water quality standard not established **No**: non-pollutant stressor **No:** non-pollutant stressor
	Beaver Creek	Mower-Fillmore Rd to Upper Iowa River	546	2Bg	2018	Aquatic Recreation	4A	*E. coli*	*E. coli*	**Yes:** *E. coli*
						Aquatic Life	5 (no change)	Aquatic macroinvertebrate bioassessments	Nitrate Flow alteration	**No:** water quality standard not established **No:** non-pollutant stressor
	Deer Creek	Unnamed cr to MN/IA border	520	2Bg	2018	Aquatic Life	5 (no change)	Fishes bioassessments	Fish passage Flow alteration	**No**: non-pollutant stressor **No:** non-pollutant stressor
	Pine Creek	T101 R10W S24, north line to MN/IA border	512	7	2018	Limited Resource Value	4A	*E. coli*	*E. coli*	**Yes:** *E. coli*

HUC8	Waterbody Name	Reach Description	AUID (HUC8-)	Use Class [a]	Year Added to List	Affected Use	Proposed Category [b]	Impaired Waters Listing	Pollutant or Stressor	TMDL Developed in this Report
Upper Iowa River (07060002) (continued)	Bear Creek	Unnamed cr to MN/IA border	503	7	2018	Limited Resource Value	4A	*E. coli*	*E. coli*	**Yes:** *E. coli*
	Bee Creek (Waterloo Creek)	T101 R6W S29, north line to MN/IA border	515	1B, 2Ag	2018	Aquatic Recreation	4A	*E. coli*	*E. coli*	**Yes:** *E. coli*

a. Use classes—1B: domestic consumption (requires moderate treatment); 2Ag: aquatic life and recreation—general cold water habitat (lakes and streams); 2Bg: aquatic life and recreation—general warm water habitat (lakes and streams); 7: limited resource value water.

b. All waters in the watershed are currently classified as category 5 in the 2018 303(d) list. Category 5 indicates an impaired status and no TMDL plan has been completed. Proposed categories are provided for those listings that have now been further assessed and are proposed for recategorization as either 4A or 4C:

Category 4a: A water is placed in Category 4a when all TMDLs needed to result in attainment of all applicable water quality water quality standards have been approved or established by EPA.

Category 4c: A water is placed in Category 4c when the state demonstrates that the failure to meet an applicable water quality standard is not caused by a pollutant, but instead is caused by other types of pollution. Segments placed in Category 4c do not require the development of a TMDL.

c. This reach is currently classified as class 2Bg but is undergoing a use class change to class 2Ag.

3. Prioritizing and implementing restoration and protection

The Clean Water Legacy Act requires that WRAPS reports summarize tools and data that are useful in targeting actions to improve water quality and identifying point sources and nonpoint sources of pollution. In addition, the Act requires examples of strategies and actions that are capable of cumulatively achieving needed pollution load reductions for point and nonpoint sources. An in-depth prioritization effort was conducted for the Root River 1W1P. As such, this section of the report does not re-prioritize efforts within the UIR and MRR watersheds, but provides additional information that may be used by local stakeholders to refine prioritization efforts as part of future 1W1P updates.

The implementation strategies and associated scales of adoption provided in this section are the result of watershed modeling efforts, existing planning documents, and professional judgment based on what is known at this time and therefore should be considered approximate. In addition, many strategies are predicated on additional funding being secured. As such, the proposed actions outlined are subject to adaptive management—an iterative approach of implementation, evaluation, and course correction.

3.1 Implementation partners

Because many of the nonpoint source strategies outlined in this section rely on voluntary implementation by landowners, land users, and residents of the watershed, it is imperative to create social capital (trust, networks, and positive relationships) with those who will be needed to voluntarily implement best management practices (BMPs). Effective locally-led ongoing civic engagement is therefore important to the overall plan for moving forward. Achieving the goals of this WRAPS will require partnerships and collaboration, in addition to financial resources. Governmental units with primary implementation responsibility include the following entities:

- Soil and Water Conservation Districts (SWCDs; Fillmore, Mower, and Root River)
- Counties (Fillmore, Mower, and Houston counties)
- Municipalities
- MPCA
- MDA
- DNR
- Minnesota Department of Health (MDH)
- Board of Water and Soil Resources (BWSR)

These and other agencies will work with private landowners and other agencies and project partners to support implementation of this WRAPS. In addition, many other partners are anticipated to participate with implementation including:

- Root River Planning Partnership and Root River 1W1P Workgroups and Committees
- Non-profits (e.g., Trout Unlimited)
- Universities

- Business owners

3.2 Targeting of geographic areas

Extensive geographic targeting was conducted during the development of the Root River 1W1P. The primary purpose of this section, therefore, is to provide new information for the UIR and MRR watersheds that may be used by local stakeholders to refine targeting efforts as part of future 1W1P updates. Determining areas in which to target early implementation can be completed in several ways; this section contains a variety of information on potential geographic areas within the watershed in which to focus implementation and to leverage local interest and momentum in the watershed. Information provided in the pollutant sources (Section 2.3.2) may also be useful in determining areas in which to target early implementation.

3.2.1 Minnesota Stream Habitat Assessment rating

As part of the analysis conducted for the monitoring and assessment report, the MPCA summarized the Minnesota Stream Habitat Assessment (MSHA) scores in the UIR and MRR watersheds. The MSHA score is composed of five scoring categories including adjacent land use, riparian zone, substrate, fish cover, and channel morphology, which are summed for a total possible score of 100 points. The average MSHA rating for each HUC-12 watershed are provided in Table 7. More information is provided in Appendix 5 of the monitoring and assessment report including individual station and stream reach MSHA ratings. Streams with fair watershed habitat scores can be targeted for restoration while streams with good scores can be the focus of protection efforts.

Table 7. MSHA ratings indicating watershed health.

HUC-8	HUC-12	Average Stream Habitat Assessment Score						
		Land Use (0-5)	**Riparian (0-15)**	**Substrate (0-27)**	**Cover (0-17)**	**Channel Morphology (0-36)**	**MSHA Score**	**Average MSHA Rating**
Upper Iowa River (07060002)	Headwaters to Upper Iowa River	0.7	7.6	13.7	10.5	16.8	54.7	Fair
	Bear Creek	1.3	7.9	19.8	13.4	26.5	68.9	Good
	Coldwater Creek	0.7	7.6	13.7	10.5	16.8	49.3	Fair
Mississippi River – Reno (07060001)	Crooked Creek	3.0	6.8	14.2	11.0	19.2	54.1	Fair
	Winnebago Creek	2.4	9.2	16.3	10.6	20.1	58.5	Fair
	Mormon Creek	2.5	10.2	17.3	11.7	21.7	63.3	Fair

3.2.2 Geomorphology assessment

The DNR completed geomorphic assessments on several streams within the UIR and MRR watersheds in June of 2015 and 2016 (DNR 2018a and DNR n.d. a-f). The reach-level assessments included information on watershed characteristics, channel stability and erosion rates, potential problem areas and sources of erosion and recommendations for improving conditions along the reach. A summary of the information provided in each geomorphic assessment report is provided in Table 8. Full geomorphology reports are provided in Appendix D.

Table 8. DNR geomorphology assessment work in UIR and MRR watersheds.

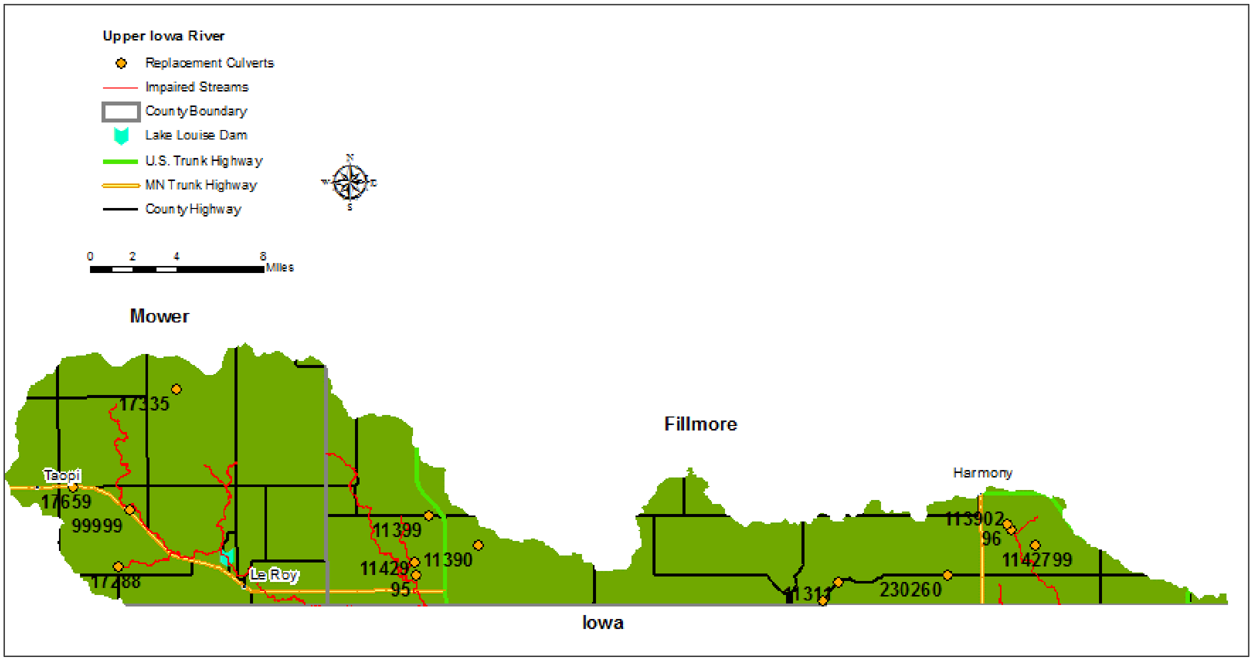
Stream Name (AUID)	DNR Biological Monitoring Station	Stream Channel Stability Rating (Pfankuch 1975)	Average Erosion Rate Estimate and Streambank Erosion Stability Rating (tons/yr/ft; Rosgen 2014)	General Description	Recommendations
Mississippi River – Reno (07060001)					
Crooked Creek (507, 519)	15LM027, 15LM037	Poor	0.0196 to 0.055, moderately unstable to unstable	Visible sediment aggradation along reach indicates excess sediment from upstream sources. Stream banks are bare through several pasture areas along the lower portion of reach, resulting in a higher estimated erosion rate.	Decrease sediment inputs to reach. Investigate grazing impacts on channel erosion and upstream sources of sediment.
Wildcat Creek (516)	15LM038	Fair	0.016, moderately unstable (5 actively eroding banks observed)	Steep and undercut banks contributed to fair Pfankuch rating along survey reach, however, dense vegetation along the riparian corridor provides stabilization in many areas.	Maintain existing riparian areas and reduce grazed areas to protect riparian corridor.
Clear Creek (524)	15LM036	Fair	0.0173, moderately unstable (8 actively eroding banks observed)	Channel is mostly stable with some steep banks contributing to fair Pfankuch rating. Well established vegetation in riparian corridor is a major factor in overall channel stability.	Maintain existing riparian corridor and investigate impacts of over widened channel at culvert crossing.
Crooked Creek, South Fork (574)	15LM033	Good	0.0004, stable	Channel is stable throughout reach. R3 pool impoundment upstream of survey reach negatively impacts sediment input, flow and water temperature.	None
Winnebago Creek (693)	15LM028	Fair	0.0133, moderately unstable (2 actively eroding banks observed)	Extensive fine sediment deposits along reach contributed to fair Pfankuch rating. Reach is partially within a wildlife management area, but vegetation is impacted by grazing outside of the management area.	Improve pasture management to protect riparian corridor and reestablish natural channel through straightened reaches.

Stream Name (AUID)	DNR Biological Monitoring Station	Stream Channel Stability Rating (Pfankuch 1975)	Average Erosion Rate Estimate and Streambank Erosion Stability Rating (tons/yr/ft; Rosgen 2014)	General Description	Recommendations
				Upstream erosion may be a source of sediment as well as incision caused by historic straightening of the channel.	
Upper Iowa River (07060002)					
Unnamed Creek (537)	15LM015	Poor	0.044, unstable (10 actively eroding banks observed)	Deeply incised channel contributes to poor Pfankuch rating and an unstable streambank erosion stability rating. Cause of active downcutting is unknown.	None
Unnamed Creek (540)	15LM026	Fair	0.0038, stable (4 actively eroding banks observed)	Fine sediment deposits contribute to a fair Pfankuch rating, however, well vegetated banks throughout the reach and a well-established riparian corridor resulted in a stable streambank erosion stability rating. A downstream pasture area and over widened road crossing may result in future problems along the reach.	None
Beaver Creek (546)	15LM016	Fair	0.026, moderately unstable (8 actively eroding banks observed)	The reach is located within the Beaver Creek Wildlife Management Area. Fine sediment deposits along reach contributed to fair Pfankuch rating. Historic aerial imagery analysis indicates a change from row crop to a more natural riparian corridor from 1991 to 2015. The channel will continue to stabilize if the riparian corridor is maintained.	None
Upper Iowa River (550)	15LM024	Poor	0.083, highly unstable (5 actively eroding banks observed)	Fine sediment deposits and undercut banks contribute to a poor Pfankuch rating. Stream erosion stability rating is highly unstable; however, historic aerial imagery	None

Stream Name (AUID)	DNR Biological Monitoring Station	Stream Channel Stability Rating (Pfankuch 1975)	Average Erosion Rate Estimate and Streambank Erosion Stability Rating (tons/yr/ft; Rosgen 2014)	General Description	Recommendations
				analysis indicates little to no movement of the channel from 1991 to 2015. Over widened road crossing is a sediment source and cause of local channel instability, but the crossing was recently replaced in 2013.	

3.2.3 DNR Upper Iowa River Watershed Culvert Inventory and Prioritization Report

The DNR recently conducted an inventory of culverts throughout the UIR Watershed (DNR 2018b). Sixteen of the 52 culverts in the inventory were recommended for replacement (Figure 26). The majority of all culverts included in this study were found to be contributing to downstream incision and/or reducing channel stability, potentially impacting sediment loading in the watershed. A private dam in the Bee Creek Subwatershed was also recommended for replacement, due to its history of damage during flood events, its known contribution to channel scouring and bank erosion downstream, and channel widening upstream of the structure. The inventory report also noted that the impoundment that forms Lake Louise is likely blocking fish passage, but was not inventoried because it will likely remain an impoundment. Despite the 16 culverts identified for replacement, there is only one fish impairment in the entire watershed. Culverts are one of many potential stressors to fish community and may result in future impairments. The full report is provided in Appendix E.



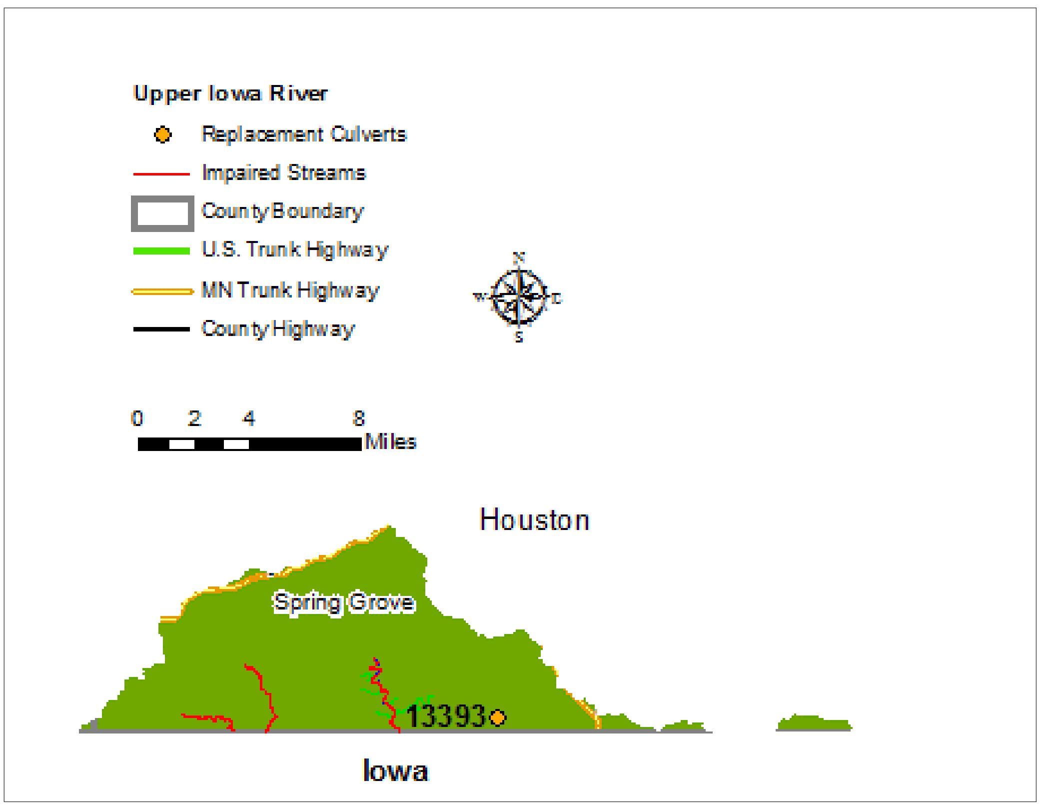


Figure 26. Culverts identified for replacement in the Upper Iowa River Watershed Culvert Inventory and Prioritization Report (DNR 2018b).

Note, only measured culverts included.

3.2.4 Drinking water supply vulnerability

The MPCA guidance document *Incorporating Lake Protection Strategies into WRAPS Reports* (MPCA 2017) states that: “[t]he susceptibility of a surface water source to contamination is considered high because there is no practical means of protecting all potential contaminant releases into surface waters.

Source water protection is critical to ensuring safe drinking water supplies and to minimizing the expense of water treatment. A growing body of evidence suggests that contamination in lakes and streams can affect groundwater used for drinking water through groundwater-surface water interactions". In karst areas such as southeast Minnesota, groundwater and surface water interactions can occur very quickly. To determine the vulnerability of drinking water supplies, the MDH conducts a vulnerability assessment for each public water supply that follow the standards set in the Minn. R. 4720.5550. A public well is considered vulnerable if:

- The well water contains 10 milligrams per liter or more nitrate plus nitrite nitrogen;
- The well water contains quantifiable levels of pathogens as defined in Minn. R. 7040.0100, subp. 26, or chemical compounds that indicate groundwater degradation as defined in Minn. Stat. § 103H.005, subd. 6;
- The well water contains one tritium unit or more when measured with an enriched tritium detection method; or
- An enriched tritium analysis of the well water has not been performed within the past 10 years; and
    - Information on the well construction is not available; or
    - The geological material from the land surface to where the groundwater enters the public water supply well is:
        a. Fractured bedrock;
        b. Solution weathered bedrock;
        c. Sandstone bedrock;
        d. Unconsolidated material 0.062 millimeters (fine sand) or larger; or
        e. A combination of the materials specified in units (a) to (d).

The drinking water supply management areas located within the UIR and MRR watersheds and their associated vulnerability are provided in Figure 27.

In addition to public water supplies, private well vulnerability is evaluated through the MDAs Township Testing Program. The MDA has identified townships that are vulnerable to groundwater contamination and have significant row crop agriculture and works with SWCDs and counties to coordinate nitrate testing in the identified townships. Results from townships within Fillmore County are provided in Figure 28. Initial results from townships within Houston County are provided in Figure 29. Results from Mower County have not yet been published. More information on the Township Testing Program can be found on the MDA website.

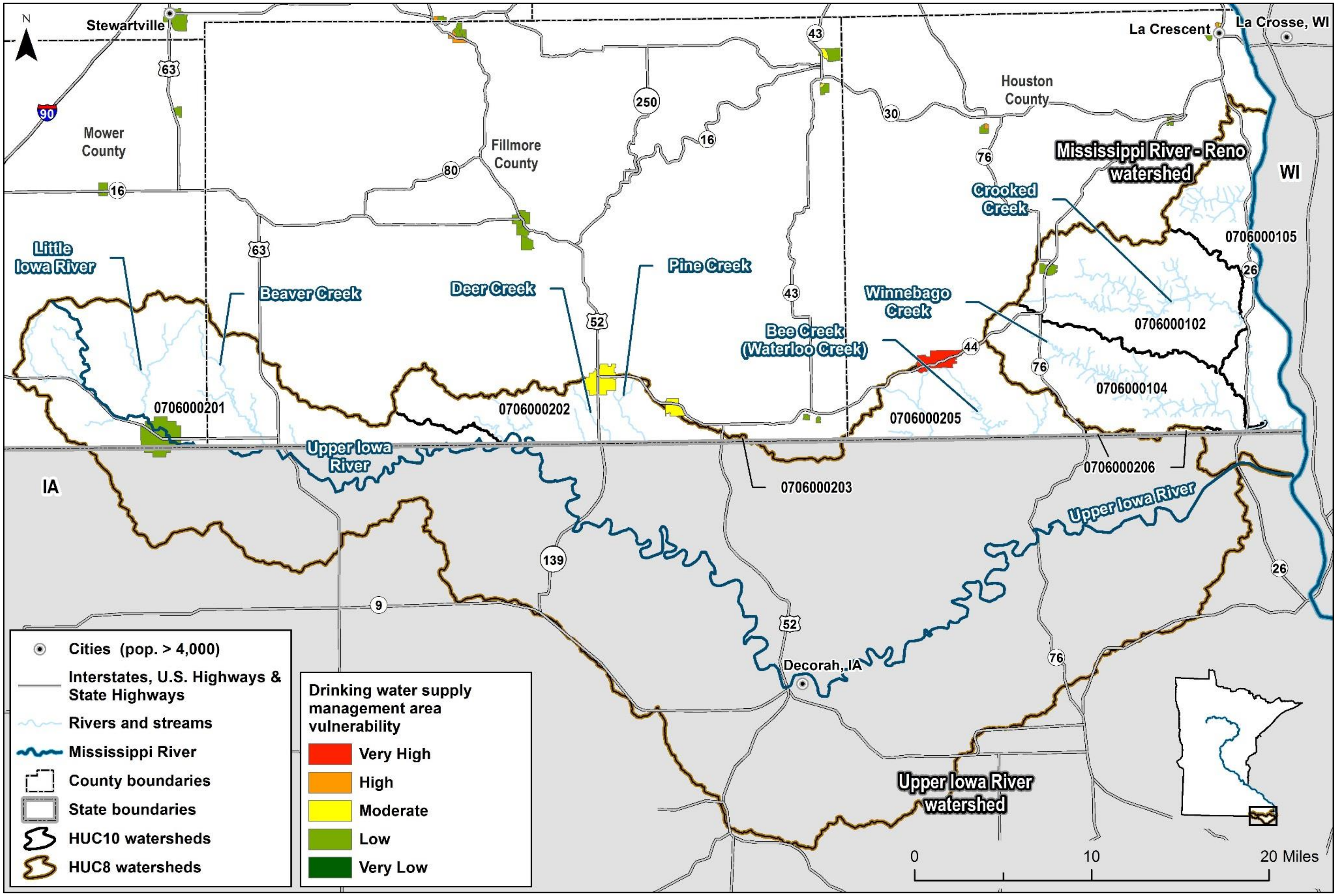


Figure 27. Drinking water supply management area vulnerability (MDH vulnerability assessment).

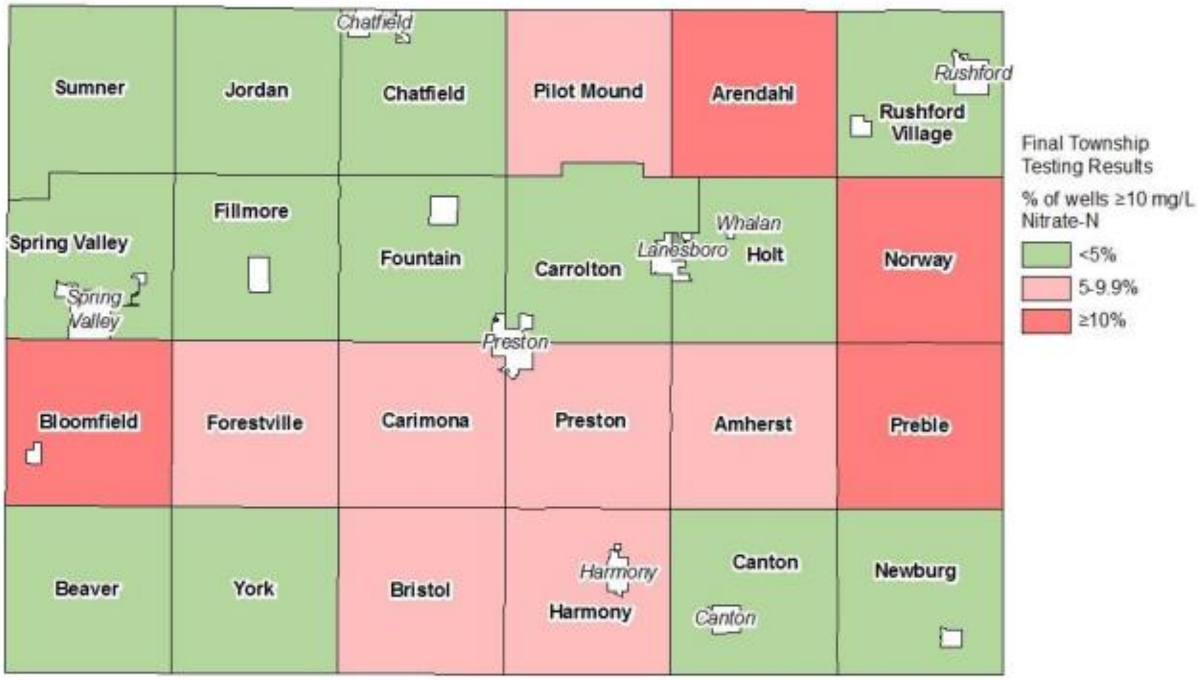


Figure 28. Final results of nitrate levels in private wells in Fillmore County (figure from MDA 2019a).

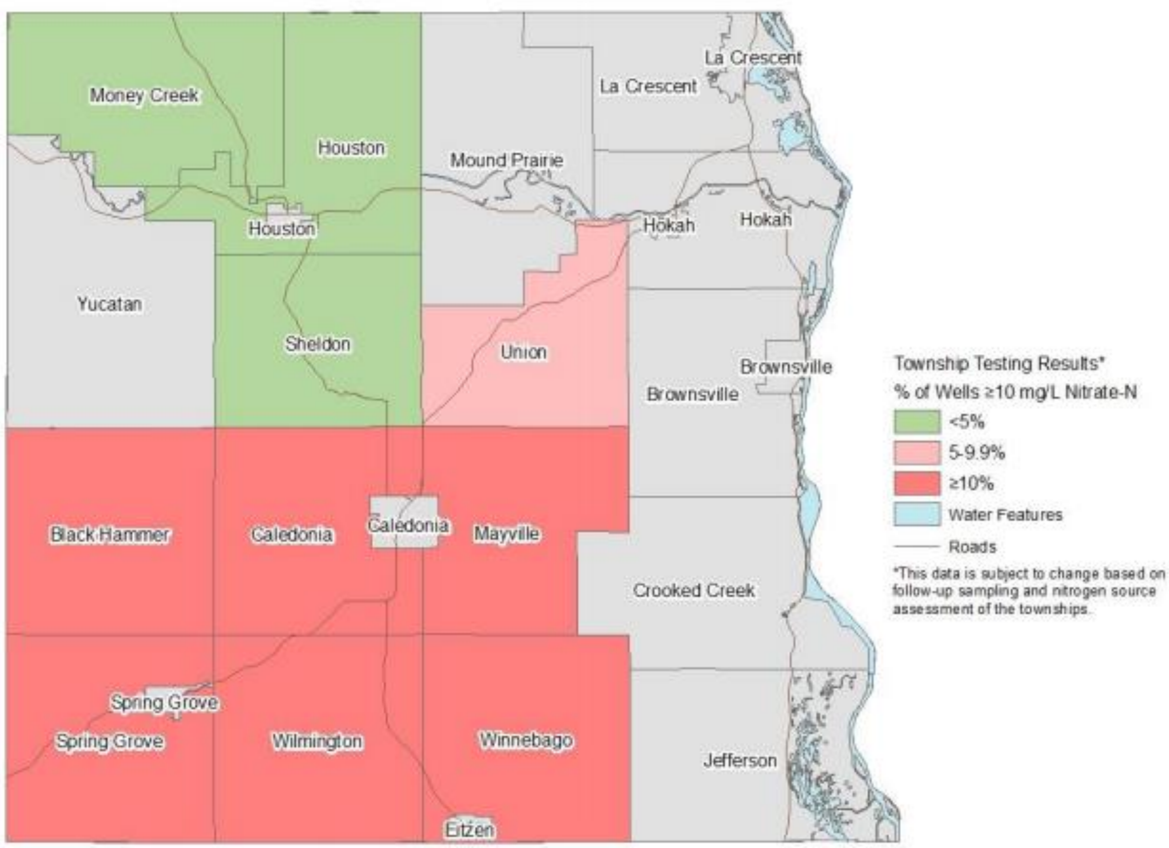


Figure 29. Initial well dataset map for Houston County (figure from MDA 2019b).

3.2.5 Existing BMP inventories

Existing BMPs can help to better target geographic areas for implementation in the UIR and MRR watersheds. For example, areas with a higher percentage of existing BMPs may be targeted for BMP inspection and areas with fewer BMPs may be targeted for BMP installation. The MPCA has developed a system to track the actions taken within the state to achieve healthier watersheds (See the MPCA "Healthier Watersheds" webpage, https://www.pca.state.mn.us/water/best-management-practices-implemented-watershed). Actions taken to reduce polluted runoff from agricultural and rural lands from 2004 to 2018 are provided in Figure 30 for the UIR Watershed and Figure 31 for the MRR on a subwatershed scale. These numbers represent only the BMPs that have been funded through federal and state programs and reported to the MPCA. Actual implementation is likely higher.

In addition, the Iowa State University has been conducting a state-wide mapping effort in Iowa of BMPs on the landscape during circa 2007 through 2010. The goal of the project is to provide a baseline set of existing BMPs for use in watershed modeling, document historic occurrence, and guide future practice tracking. Existing BMPs that are being mapped include: terraces, water and sediment control basins (WASCOB), grassed waterways, pond dams, contour strip cropping, and contour buffer strips. BMPs are mapped and digitized using LiDAR data and aerial photography. While the project is focused on Iowa's major watersheds, BMPs within the Minnesota portion of the UIR Watershed were also mapped (Figure 32). These BMPs were provided by Iowa State University, but have not undergone the verification process that is typically completed for the areas within Iowa. These BMPs provide an initial understanding of the level of existing BMPs in the UIR Watershed, but should be verified if used beyond this initial understanding.

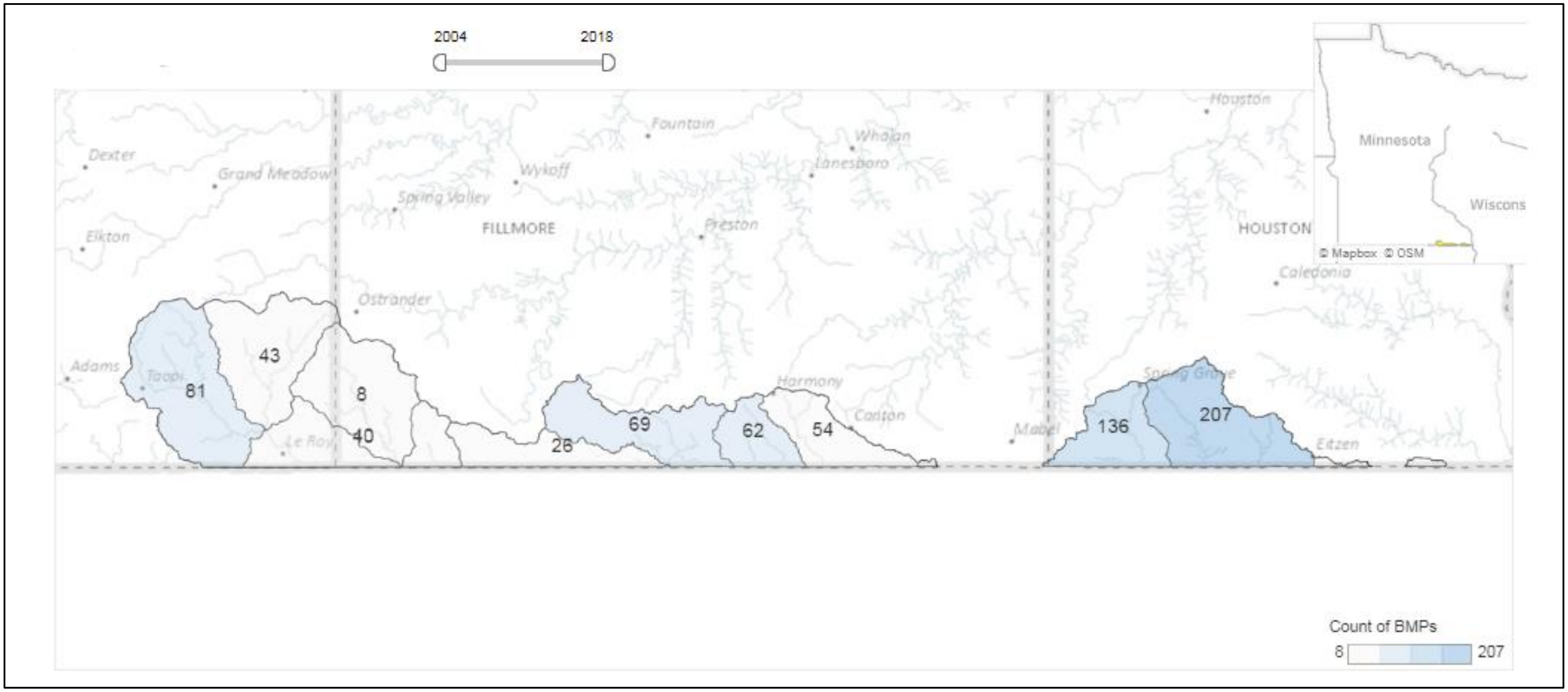


Figure 30. BMPs funded through federal and state programs from 2004-2018 in the UIR Watershed as reported to the MPCA.

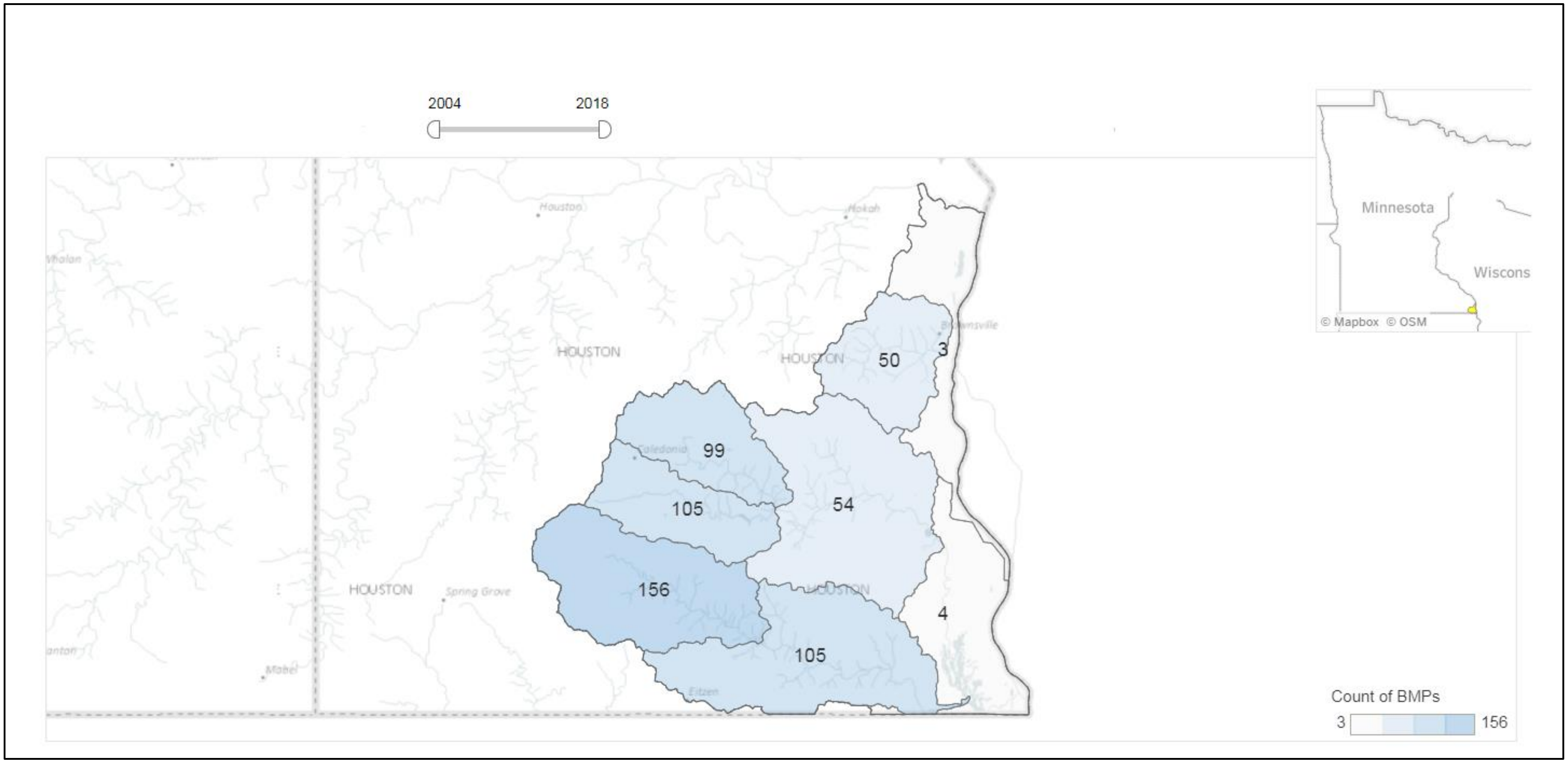


Figure 31. BMPs funded through federal and state programs from 2004-2018 in the MRR Watershed as reported to the MPCA.

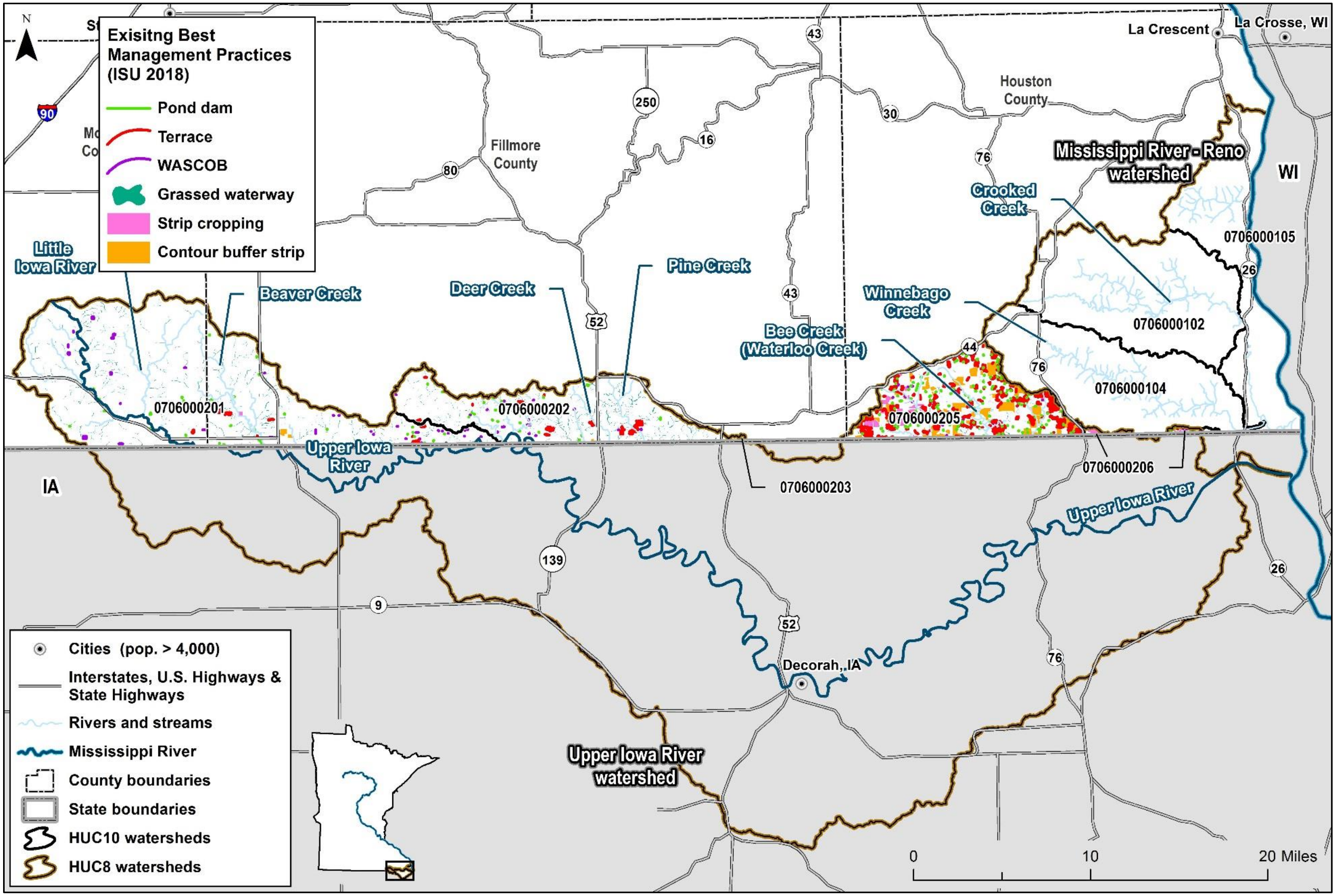


Figure 32. Existing BMPs in the UIR Watershed (ISU 2018). Note, mapping project was not conducted in the MRR Watershed.

3.2.6 Protection considerations

All waters in the URI and MRR watersheds require protection in some capacity, including those listed as impaired and those with insufficient data. It is important to prioritize areas for protection, to better focus implementation of the WRAPS. For example, waters that are particularly threatened or vulnerable may be considered at risk for further degradation and impairment and prioritized for protection efforts. Alternatively, or in addition, unique and high value resources that exhibit the highest biological, cultural, and social significance in the region may also be prioritized for protection in order to ensure their continued quality. This section provides an overview of existing protection related efforts and conclusions from previous studies that can be used when considering protection efforts during WRAPS implementation.

An interagency effort among the MPCA, DNR, and the BWSR conducted a protection prioritization of streams in all of Minnesota that are meeting water quality standards for fish and macroinvertebrate communities—i.e., streams that are fully supporting aquatic life. Protection prioritization was based on 1) the results of water quality assessments, 2) the level of protection already in place in the watershed, and 3) the level of risk posed from the contributing watershed and nearshore areas. While all streams require protection, top priority, or “priority A” streams, are summarized in Table 9 and Figure 33. Fish and/or macroinvertebrate community “nearly impaired” indicates if the index of biotic integrity (IBI) scores (macroinvertebrates or fish) are on average within five points of the assigned threshold (and therefore close to it). Riparian risk is based on road density and disturbed land use within the riparian area. Watershed risk is based on road density and disturbed land use throughout watershed. Current level of protection is based on percentage of public and easement protected land in the watershed area. A similar effort was conducted at the state level for lakes; however, there are no lakes within the UIR or MRR watersheds that were included in this effort.

Additional information on the protection needs of Bee Creek and Wildcat Creek is provided in the SID and monitoring assessment reports. Located southeast of Spring Grove in the UIR Watershed, Bee Creek (AUID 07060002-515) is recommended for protection in the SID report (2018b) and monitoring and assessment report (MPCA 2018a), due to the high quality of the stream as a resource. In addition to being prioritized for protection by state agencies, the protection of Bee Creek is supported by local residents and users of the stream, especially the area’s anglers.

Wildcat Creek (AUID 07060001-516), located in the MRR Watershed, is also recommended for protection in the MRR SID Report (MPCA 2018c). The monitoring and assessment report (MPCA 2018a) identifies Wildcat Creek as at risk of impairment based on its low IBI scores. To ensure excess sediment in the watershed does not cause fish or macroinvertebrate impairments in the future, the report recommends good pasture management, restricting cattle access to the stream, and soil conservation practices in the uplands to control flow and flooding.

Table 9. Summary of highest priority stream protection in the UIR and MRR watersheds (streams with class A protection priority in MPCA, DNR, and BWSR stream protection and prioritization effort).
Lower scores are higher priority.

HUC-8	Stream Name	Stream AUID	Rank	Nearly Impaired	Riparian Risk Rank	Watershed Risk Rank	Current Level of Protection	Protection Priority Rank	Protection Priority Class
Upper Iowa River (07060002)	Upper Iowa River	506	2	one	1	1.5	1	7	A
	Upper Iowa River	509	2	one	1.5	1	1.5	8	A
	Bee Creek (Waterloo Creek)	515	3	neither	1	1	1.5	10.5	A
	Upper Iowa River, North Branch	526	3	neither	1	1	1.5	10.5	A
	Little Iowa River	548	2	one	1	1	1.5	7	A
	Unnamed creek	552	1	both	1	1	1.5	3.5	A
Mississippi River – Reno (07060001)	Crooked Creek	507	2	one	1	1	2	8	A
	Wildcat Creek	516	2	one	1	1	1.5	7	A
	Unnamed creek	518	2	one	1	1.5	1.5	8	A
	North Branch, Crooked Creek	520	3	neither	1.5	1	2	13.5	B
	Unnamed creek (Winnebago Creek Tributary)	685	3	neither	1.5	1	1	10.5	A

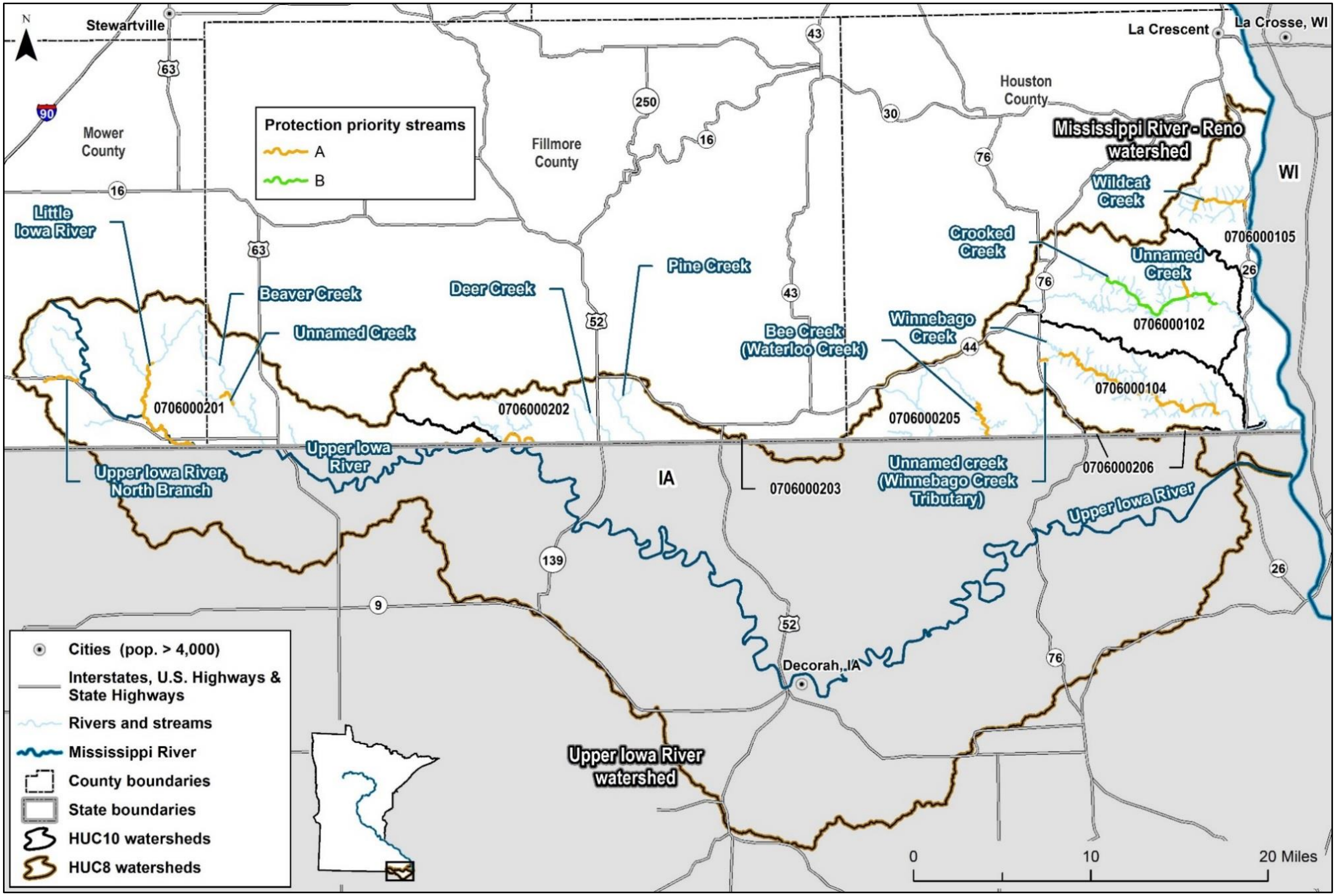
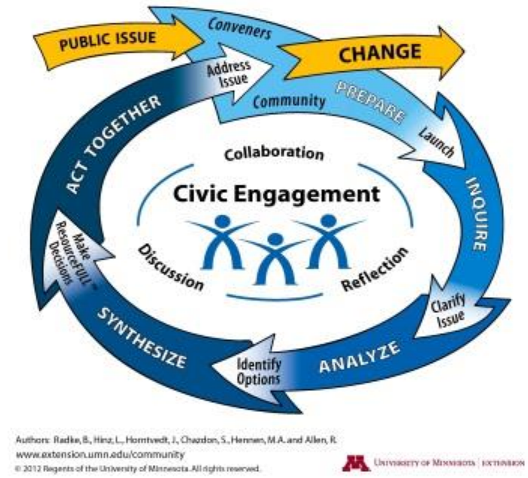


Figure 33. Protection priority streams in the UIR and MRR watersheds.

3.3 Civic engagement



A key prerequisite for successful strategy development and on-the-ground implementation is meaningful civic engagement. This is distinguished from the broader term 'public participation' in that civic engagement encompasses a higher, more interactive level of involvement. The MPCA has coordinated with the University of Minnesota Extension Service for years on developing and implementing civic engagement approaches and efforts for the watershed approach. Specifically, the University of Minnesota Extension's definition of civic engagement is "Making 'resourceFULL' decisions and taking collective action on public issues through processes that involve public discussion, reflection, and collaboration." Extension defines a resourceFULL decision as one based on diverse sources of information and supported with buy-in, resources (including human), and competence. Further information on civic engagement is available at: http://www.extension.umn.edu/community/civic-engagement/.

3.3.1 Accomplishments and future plans

Significant civic engagement was conducted in the UIR and MRR watersheds as part of the 1W1P development prior to the development of the WRAPS report. Because of this prior engagement, civic engagement efforts during the development of the UIR and MRR WRAPS report was conducted on a smaller, more targeted scale. The focus of civic engagement for the UIR and MRR WRAPS was to highlight the relationship between the planning documents: TMDLs, monitoring and assessment, SID, WRAPS, 1W1P, and other existing plans and programs in local communities.

One Watershed, One Plan development and implementation

Prior to the development of the UIR and MRR WRAPS, three committees were formed for the development of the 1W1P: planning, advisory, and policy committees. These committees included representatives from SWCDs, municipalities, state and federal agencies, local governments, agricultural groups, conservation groups, and county commissioners. The committees met regularly to discuss plan development.

In addition to the committee meetings, several public outreach events were held to identify and prioritize resource concerns and applicable actions to address those concerns. More information on civic engagement activities during the 1W1P process, including their stakeholder engagement plan, is available in the 1W1P document.

WRAPS and TMDL reports

During the development of the WRAPS and TMDLs, several meetings were held with local government stakeholders:

- Throughout March and April of 2019, the MPCA attended four meetings with local stakeholders in the watersheds. These meetings provided a summary of the impairment status of streams and the identified stressors and pollutants impacting those streams, and an overview of the TMDL and WRAPS process. Stakeholders included SWCD staff and board supervisors from Mower and Houston county, and Fillmore county staff and township officials.

- The MPCA also attended a Root River 1W1P Advisory Committee meeting on March 19, 2019, to provide a project update. In attendance were advisory committee members including staff from BWSR, Fillmore SWCD, Root River SWCD, Winona SWCD, Nature Conservancy, and DNR.
- WRAPS working group meetings were held on May 17, 2019, at the Mabel Community Center in Mabel, Minnesota. Each of two meetings were focused on staff from counties in the watersheds (Houston County and Mower and Fillmore counties). These meetings provided an overview of the MPCA Watershed Assessment cycle and provided local implementers the opportunity to review and discuss restoration and protection activities. Representatives from each county were able to evaluate implementation scenarios using a tool developed by University of Minnesota. Description of the toll and the final scenario tables are provided in Section 3.3.

3.3.2 Public notice for comments

An opportunity for public comment on the draft WRAPS report was provided via a public notice in the *State Register* from December 20, 2019 through January 29, 2020. There was one comment letter received and responded to as a result of the public comment period.

3.4 Restoration and protection strategies

The WRAPS strategy tables (Table 14 through Table 19) provide examples of the types of changes for both restoration and protection needed to achieve water quality goals in the UIR and MRR watersheds. When appropriate, the table references existing plans for implementation strategies. Rather than re-iterate and duplicate previous work, the strategy tables focus on and highlight new information in the project that can be used to expand existing restoration and protection efforts through the adaptive management process.

Subsequent local planning steps (i.e., the 1W1P update) can take these general examples and describe more specific planning elements for each such as intended projects and efforts, resource needs, who will be involved, and project timeframes. The WRAPS strategy tables are organized by HUC-10. The following sections outline the contents of the UIR and MRR WRAPS strategy tables and are organized by strategy table column.

3.4.1 Waterbody and location

Table 14 through Table 19 provide waterbody specific BMPs for all impaired streams in the UIR and MRR watersheds. Strategies for impaired segments, or restoration strategies, are shown in light red cells. Watershed wide strategies, or strategies for “all” waterbodies, impaired and non-impaired, are shown in the white cells at the top of each table. No waterbody specific BMPs are provided for non-impaired streams with the exception of Wildcat Creek (516), which was given specific strategy recommendations in the MRR SID. Protection strategies are shown in light green cells.

3.4.2 Water quality goals

Waterbody specific goals are set for the individual impairments in the watersheds and are reflected in the strategy tables. Final water quality goals for TSS and *E. coli* impaired streams are identified in the UIR and MRR TMDL (Tetra Tech 2019). Final water quality goals for biota impairments were determined using the applicable fish biocriteria (mIBI and/or fIBI score) necessary to obtain the aquatic life use goals for each waterbody. Goals for biota impairments are supported by the SID reports.

The watershed wide pollutant reduction goals for nitrogen (20% of existing load by 2025) and phosphorus (12% of existing load by 2025) were derived from the Minnesota's NRS milestones and goals (MPCA 2014). Example BMP scenarios that meet these reductions including the cost and estimated scale of adoption of BMPs were developed with local stakeholders in order to attain the interim goal for nitrogen and the final goal for phosphorus. Lastly, the UIR and MRR WRAPS supports the achievement of the goals outlined in the Root River 1W1P.

The final water quality goal year (2040) aligns with the estimated schedule of the UIR and MRR TMDL (Tetra Tech 2019). The NRS has additional goals for nitrogen that extend until 2040 (45% reduction from existing); however, only the 20% reduction milestone was considered in the BMP scenarios. Many factors may influence the final water quality goal year; however, this date provides a reasonable timeframe in which to achieve water quality goals of the UIR and MRR WRAPS.

3.4.3 Strategies to achieve final water quality goals

The UIR and MRR watersheds are located in an active region for water resource restoration and protection activities. The numerous plans, studies, and stakeholder engagement efforts that have been conducted previously in the area, combined with the newer information in the recently completed TMDL, SID reports, and other reports, provide the basis for the restoration and protection strategies in this UIR and MRR WRAPS. Several common themes, recommended BMPs, and other implementation strategies are included in these plans and are summarized below:

- Agricultural BMPs to reduce nutrients and sediment (nutrient management, cover crops, grassed waterways, WASCOBs, and cattle restriction).
- Flood storage and water detention (wetland restoration, tile drain control and inspection, ditch control improvement).
- Septic system maintenance, replacement, and inspection.
- Improve stream health (connectivity, aquatic habitat, sediment source control).
- Improve coordination (interagency, across state lines, within community).
- Education and outreach (support behavioral changes through education and engagement, show and reward positive work).

The strategies implemented in the UIR and MRR WRAPS will maximize the impacts of BMPs whenever possible in order to achieve multiple benefits in water quality, soil health, flood management, habitat improvement, and others. Strategies are provided to address both impaired and unimpaired waterbodies in the UIR and MRR watersheds. Core strategies were provided in the SID reports, the UIR and MRR TMDL (Tetra Tech 2019), implementation strategies in the Revised Regional TMDL Evaluation of Fecal Coliform Bacteria Impairments in the Lower Mississippi River Basin in Minnesota (MPCA 2006), and the Root River *1W1P*. In addition, strategies specific to nitrogen and phosphorus reductions were derived from working group meetings that were held with representatives from each county.

Strategy adoption amount, unit and estimated reduction

Estimated scales of adoption of nitrogen and phosphorus-related BMPs were determined using the University of Minnesota Agricultural BMP Scenario Tools for nitrogen and phosphorus (N and P BMP Tools). The N and P BMP Tools were developed by the University of Minnesota to assist resource managers in better understanding the feasibility and cost of various BMPs in reducing nutrients from Minnesota cropland.

Estimated scales of adoption for TSS-related BMPs were determined using removal efficiencies estimated in existing reports, or as provided in the Spreadsheet Tool for Estimating Pollutant Load developed by the EPA, when possible. A similar tool to estimate scale of adoption specific to *E. coli*-related BMPs in Minnesota is not currently available, therefore a qualitative approach based on the source assessment for the UIR and MRR TMDL (Tetra Tech 2019) was used to determine scales of adoption for *E. coli* BMPs. Strategies for many of the biota impairments were also done in a qualitative fashion because they do not have a specific pollutant load reduction from a TMDL, or the stressor (e.g., degraded habitat) does not have an associated pollutant. Adaptive management can be used to determine scale of adoption necessary to achieve *E. coli* reductions and address non-pollutant-based stressors.

As part of the engagement component of the UIR and MRR WRAPS process, working group meetings were held with representatives from each county to discuss and formulate examples of how to best meet statewide nutrient reduction goals for phosphorus and nitrogen for specific HUC-10 subwatersheds within their counties. Table 10 through Table 13 summarize example combinations of practices that were developed by SWCD and county personnel using the N and P BMP Tools to meet a 20% reduction goal for nitrogen and 12% reduction goal for phosphorus. The tool also translates “percent adoption rates” for specific BMPs into numbers of “acres treated” based on the number of acres suitable for the practice. Counties could utilize these acre and adoption goals for grants and other incentives for landowners to implement these practices. Estimated adoption rates in Table 10 through Table 13 represent the cumulative adoption rates of BMPs to achieve water quality goals.

WASCOBs are popular BMPs in the watersheds but are not modeled in the BMP Tools; therefore, impacts from WASCOBs are provided separately. WASCOBs predominantly target phosphorus and sediment from agricultural land but have also been found to remove a small amount of nitrogen through the dissipation of ammonia (Lenhart et al. 2017). Because of this nitrogen removal, WASCOBs were also included in the N BMP Tool. Costs and reductions for WASCOBS were determined using local information and reductions provided in the Minnesota Agricultural BMP Handbook (Lenhart et al. 2017).

Table 10. Summary of estimated scale of adoption to achieve nitrogen reduction of 20% in the UIR Watershed.

Estimate scales of adoption were determined using the N BMP Tool with stakeholders in the watershed. Some nitrogen BMPs are represented in both the N and P BMP tool. These BMPs are color coded between both tables. Costs for these BMPs are only accounted for in the N BMP Tool tables to avoid double counting.

	Upper Iowa River											
	Headwaters to Upper Iowa River (0706000201)				Coldwater Creek (0706000202)				Bear Creek (0706000205)			
Nitrogen (N) BMPs	% suitable	acres suitable	% adopted	acres adopted	% suitable	acres suitable	% adopted	acres adopted	% suitable	acres suitable	% adopted	acres adopted
Corn acres receiving target N rate, no inhibitor or timing shift	53%	34,273	90%	30,846	58%	14,354	83%	11,914	55%	7,530	75%	5,647
Fall N target rate acres receiving N inhibitor	4%	2,926	90%	2,634	4%	910	80%	728	3%	443	80%	354
Fall N applications switch to spring, % of fall acres	4%	2,926	90%	2,634	4%	910	80%	728	3%	443	80%	354
Fall N application switch to split/side dressing, % of fall acres	4%	2,926	90%	2,634	4%	910	80%	728	3%	443	5%	22
Restored wetlands	7%	4,721	6%	283	2%	455	0%	-	1%	72	0%	-
Tile line bioreactors	5%	3,055	6%	183	1%	265	0%	-	0%	33	0%	-
Controlled drainage	5%	3,055	6%	183	1%	265	0%	-	0%	33	0%	-
Saturated buffers	5%	3,055	6%	183	1%	265	0%	-	0%	33	0%	-
Riparian buffers 50 feet wide	2%	1,255	60%	753	3%	621	50%	310	3%	470	40%	188
Corn grain & soybean acres with cereal rye cover crop	91%	59,070	20%	11,814	82%	20,323	20%	4,065	72%	9,851	23%	2,266
Short season crops planted to a rye cover crop	4%	2,298	40%	919	5%	1,117	40%	447	6%	765	3% [e]	23
Perennial crop % of corn and soybean area (all corn & soybean, marginal area first)	92%	60,045	7%	4,203	85%	21,058	5%	1,053	6%	774	30%	232
WASCOBs [a]	*86%*	*56,015*	*30%*	*16,805*	*81%*	*20,058*	*30%*	*6,017*	*72%*	*9,818*	*30%*	*2,945*
Calculated N load reduction from WASCOBs [b]				*0.8%*				*0.7%*				*3.1%*
Total calculated cost of WASCOBs [c]			*$ 3,360,916*				*$ 1,203,482*				*$ 589,077*	
N load reduction (%) without WASCOBs			19.2%				19.3%				16.9%	
Treatment cost before fertilizer cost savings and corn yield impacts ($/year). Does not include WASCOB cost.			$ 1,345,011				$392,667				$ 177,899	
N fertilizer cost savings and corn yield impacts ($/year)			$ (275,817)				$ (122,756)				$ (67,617)	
Net BMP treatment cost ($/year). Does not include WASCOB cost.			$ 1,069,194				$ 269,911				$ 110,282	
Total N load reduction (%)			**20%**				**20%**				**20%**	
Total BMP treatment cost ($/year)			**4,430,194**				**1,473,393**				**699,359**	

a. WASCOBs are a common BMP in the watersheds but are not modeled in the BMP Tools. Suitable acres for WASCOBs were estimated by subtracting the suitable acres for tile drains (e.g., for controlled drainage) from the suitable acres for cover crops. This equation should result in those cropland acres that have higher slopes (>1%).

b. Reductions for WASCOBs were calculated using recommended reductions in the recommended default reductions (85% for surface pathways) for the Scenario Application Manager tool (RESPEC 2017).

c. Costs were calculated using information provided by local stakeholders.

Table 11. Summary of estimated scale of adoption to achieve phosphorus reduction of 12% in the UIR Watershed.

Estimate scales of adoption were determined using the P BMP Tool with stakeholders in the watershed. Some phosphorus BMPs are represented in both the N and P BMP tool. These BMPs are color coded between both tables. Costs for these BMPs are only accounted for in the N BMP Tool tables to avoid double counting.

	Upper Iowa River											
	Headwaters to Upper Iowa River (0706000201)				Coldwater Creek (0706000202)				Bear Creek (0706000205)			
Phosphorus (P) BMPs	**% suitable**	**acres suitable**	**% adopted**	**acres adopted**	**% suitable**	**acres suitable**	**% adopted**	**acres adopted**	**% suitable**	**acres suitable**	**% adopted**	**acres adopted**
Adopt BMP P_2O_5 Rate (Apply U of MN recommendations)	94%	61,368	0%	-	86%	21,440	17%	3,645	78%	10,616	50%	5,308
Fall corn and wheat fertilizer to preplant/starter	3%	1,712	0%	-	3%	720	0%	-	3%	378	0%	-
Use reduced tillage on corn, soy, and small grain >2% slopes	37%	24,159	0%	-	32%	7,938	10%	794	27%	3,636	30%	1,091
50 ft buffers, permanent and intermittent streams, 100 ft treated	4%	2,816	60%	1,689.61	7%	1,694	50%	847	10%	1,420	40%	568
Perennial crop % of corn and soybean area (marginal area only) [e]	5%	3,041	100%	3,040.86	5%	1,312	80%	1,050	5%	727	30%	218
Corn grain & soybean acres with cereal rye cover crop	89%	57,815	20%	11,562.95	79%	19,702	20%	3,940	69%	9,380	23%	2,157
Short season crops planted to a rye cover crop	4%	2,298	40%	919.22	5%	1,117	40%	447	6%	765	3%	23
Controlled drainage	5%	3,055	6%	183.28	1%	265	0%	-	0%	33	0%	-
Alternative tile intakes	16%	10,494	0%	-	2%	519	0%	-	0%	2	0%	-
Inject or incorporate manure	7%	4,239	0%	-	10%	2,524	10%	252	12%	1,591	30%	477
WASCOBs [a]	*84%*	*54,760*	*30%*	*16,428.02*	*78%*	*19,437*	*30%*	*5,831*	*69%*	*9,348*	*30%*	*2,804*
Calculated P load reduction from WASCOBs [b]			*0.8%*				*0.7%*				*0.6%*	
Total calculated cost of WASCOBs [c]				*no additional cost*				*no additional cost*				*no additional cost*
P load reduction (%) without WASCOBs			17% [d]				11.3%				11.3%	
Treatment cost before fertilizer cost savings and corn yield impacts ($/year). Does not include WASCOB cost.			$ - [d]				$ 4,430.53				$ 172,091	
P and N fertilizer and tillage cost savings			$ - [d]				$ (59,526)				$ (93,728)	
Savings from reduced tillage			$ - [d]				$ (12,426)				$ (15,205)	
Net BMP treatment cost ($/year)			**$ - [d]**				**$ (67,521)**				**$ 63,158**	
Total P load reduction (%)			**17.8% [d]**				**12%**				**12%**	

a. WASCOBs are a common BMP in the watersheds but are not modeled in the BMP Tools. Suitable acres for WASCOBs were estimated by subtracting the suitable acres for tile drains (e.g., for controlled drainage) from the suitable acres for cover crops. This equation should result in those cropland acres that have higher slopes (>1%).
b. Reductions for WASCOBs were calculated using recommended reductions in the recommended default reductions (82% for surface pathways) for the Scenario Application Manager tool (RESPEC 2017).
c. Costs for WASCOBS in the UIR Watershed are provided in Table 10.
d. Estimated phosphorus reductions from the BMPs that are also included in the N BMP Tool were sufficient to achieve the phosphorus goal reduction goal of 12%. No further P BMPs were needed.
e. Stakeholders in the UIR Watershed choose to model this BMP on all applicable corn and soy area, beginning with marginal cropland areas, in order to achieve nitrogen reduction goals (see Table 10). The option to select marginal cropland is not provided in the P BMP Tool. Percent adoption rates were modified in the P BMP tool to obtain adopted acreage as close to that in the N BMP scenario but remain slightly different between the two scenarios.

Table 12. Summary of estimated scale of adoption to achieve nitrogen reduction of 20% in the MRR Watershed.

Estimate scales of adoption were determined using the N BMP Tool with stakeholders in the watershed. Some nitrogen BMPs are represented in both the N and P BMP tool. These BMPs are color coded between both tables. Costs for these BMPs are only accounted for in the N BMP Tool tables to avoid double counting.

Nitrogen (N) BMPs	Mississippi River Reno											
	Crooked Creek (0706000102)				Winnebago Creek (0706000104)				Mormon Creek (0706000105)			
	% suitable	acres suitable	% adopted	acres adopted	% suitable	acres suitable	% adopted	acres adopted	% suitable	acres suitable	% adopted	acres adopted
Corn acres receiving target N rate, no inhibitor or timing shift	56%	6,021	85%	5,118	55%	6,479	85%	5,507	52%	850	73%	620
Fall N target rate acres receiving N inhibitor	3%	354	85%	301	3%	381	85%	324	3%	49	80%	40
Fall N applications switch to spring, % of fall acres	3%	354	85%	301	3%	381	85%	324	3%	49	80%	40
Fall N application switch to split/side dressing, % of fall acres	3%	354	20%	71	3%	381	20%	76	3%	49	20%	10
Restored wetlands	1%	78	0%	-	1%	94	0%	-	1%	9	0%	-
Tile line bioreactors	0%	42	0%	-	0%	47	0%	-	0%	6	0%	-
Controlled drainage	0%	42	0%	-	0%	47	0%	-	0%	6	0%	-
Saturated buffers	0%	42	0%	-	0%	47	0%	-	0%	6	0%	-
Riparian buffers 50 feet wide	3%	367	40%	147	4%	414	40%	166	4%	67	40%	27
Corn grain & soybean acres with cereal rye cover crop	73%	7,901	31%	2,449	72%	8,430	31%	2,613	66%	1,075	30%	323
Short season crops planted to a rye cover crop	6%	606	20%	121	6%	670	20%	134	6%	105	20%	21
Perennial crop % of corn and soybean area (marginal area only)	6%	650	30%	195	6%	726	30%	218	6%	102	30%	31
WASCOBs [a]	*73%*	*7,859*	*30%*	*2,358*	*71%*	*8,383*	*30%*	*2,515*	*66%*	*1,069*	*30%*	*321*
Calculated N load reduction from WASCOBs [b]			*0.7%*				*0.6%*				*0.6%*	
Total calculated cost of WASCOBs [c]			*$ 471,550*				*$ 502,962*				*$ 64,129*	
N load reduction (%) without WASCOBs			19.3%				19.4%				19.4%	
Treatment cost before fertilizer cost savings and corn yield impacts ($/year). Does not include WASCOB cost.			$ 179,139				$ 194,475				$ 25,906	
N fertilizer cost savings and corn yield impacts ($/year)			$ (58,114)				$ (63,737)				$ (8,431)	
Net BMP treatment cost ($/year). Does not include WASCOB cost.			$ 121,024				$ 130,737				$ 17,475	
Total N load reduction (%)			**20%**				**20%**				**20%**	
Total BMP treatment cost ($/year)			**592,574**				**633,700**				**81,604**	

a. WASCOBs are a common BMP in the watersheds but are not modeled in the BMP Tools. Suitable acres for WASCOBs were estimated by subtracting the suitable acres for tile drains (e.g., for controlled drainage) from the suitable acres for cover crops. This equation should result in those cropland acres that have higher slopes (>1%).

b. Reductions for WASCOBs were calculated using recommended reductions in the recommended default reductions for the HSPF Scenario Application Manager tool (RESPEC 2017).

c. Costs were calculated using information provided by local stakeholders.

Table 13. Summary of estimated scale of adoption to achieve phosphorus reduction of 12% in the MRR Watershed.

Estimate scales of adoption were determined using the P BMP Tool with stakeholders in the watershed. Some phosphorus BMPs are represented in both the N and P BMP tool. These BMPs are color coded between both tables. Costs for these BMPs are only accounted for in the N BMP Tool tables to avoid double counting.

	Mississippi River Reno											
	Crooked Creek (706000102)				Winnebago Creek (706000104)				Mormon Creek (706000105)			
Phosphorus (P) BMPs	% suitable	acres suitable	% adopted	acres adopted	% suitable	acres suitable	% adopted	acres adopted	% suitable	acres suitable	% adopted	acres adopted
Adopt BMP P_20_5 Rate (Apply U of MN recommendations)	79%	8,507	50%	4,254	78%	9,100	50%	4,550	72%	1,180	55%	649
Fall corn and wheat fertilizer to preplant/starter	3%	302	0%	-	3%	325	0%	-	3%	42	0%	-
Use reduced tillage on corn, soy, and small grain >2% slopes	27%	2,935	15%	440	26%	3,104	17%	528	23%	381	15%	57
50 ft buffers, permanent and intermittent streams, 100 ft treated	10%	1,100	40%	440	11%	1,253	40%	501	13%	209	40%	84
Perennial crop % of corn and soybean area (marginal area only)	6%	622	30%	186	6%	680	30%	204	6%	95	30%	28
Corn grain & soybean acres with cereal rye cover crop	73%	7,901	31%	2,449	68%	8,015	31%	2,485	62%	1,008	30%	302
Short season crops planted to a rye cover crop	6%	606	20%	121	6%	670	20%	134	6%	105	20%	21
Controlled drainage	0%	42	0%	-	0%	47	0%	-	0%	6	0%	-
Alternative tile intakes	0%	2	0%	-	0%	2	0%	-	0%	0	0%	-
Inject or incorporate manure	11%	1,245	20%	249	11%	1,346	20%	269	12%	199	20%	40
WASCOBs [a]	*73%*	*7,859*	*30%*	*2,358*	*68%*	*7,968*	*30%*	*2,391*	*61%*	*1,002*	*30%*	*301*
Calculated P load reduction from WASCOBs [b]			*0.7%*				*0.6%*				*0.6%*	
Total calculated cost of WASCOBs [c]				*no additional cost*				*no additional cost*				*no additional cost*
P load reduction (%) without WASCOBs			11.3%				11.4%				11.4%	
Treatment cost before fertilizer cost savings and corn yield impacts ($/year). Does not include WASCOB cost.			$ 3,946				$ 428				$ 600	
P and N fertilizer and tillage cost savings			$ (72,688)				$ (7,808)				$ (11,311.93)	
Savings from reduced tillage			$ (6,747)				$ (807)				$ (847.94)	
Net BMP treatment cost ($/year)			**$ (75,489)**				**$ (8,187)**				**$ (11,558.76)**	
Total P load reduction (%)			**12%**				**12%**				**12%**	

a. WASCOBs are a common BMP in the watersheds but are not modeled in the BMP Tools. Suitable acres for WASCOBs were estimated by subtracting the suitable acres for tile drains (e.g., for controlled drainage) from the suitable acres for cover crops. This equation should result in those cropland acres that have higher slopes (>1%).

b. Reductions for WASCOBs were calculated using recommended reductions in the recommended default reductions for the Scenario Application Manager tool (RESPEC 2017).

c. Costs for WASCOBS in the MRR Watershed are provided in Table 12.

Table 14. Restoration and protection strategies for the Headwaters to Upper Iowa River Watershed (0706000201).

Waterbody and Location			Water Quality			Strategies to Achieve Final Water Quality Goal					
HUC-10 Subwatershed	**Waterbody (ID)**	**Location and Upstream Influence Counties**	**Pollutant/ Stressor**	**Current WQ Conditions** (conc./load/ biota score)	**Final WQ Goal Year: 2040** (%/load to reduce/biota score threshold)	**Strategy Type**	**EXAMPLE Best Management Practice (BMP) Scenario**				**Notes**
							BMP [NRCS Code]	**Amount**	**Unit**	**Estimated reduction (lbs/yr and %)**	
Headwaters to Upper Iowa River (0706000201)	All	Mower, Fillmore	All			Implement strategies and recommendations in the Root River 1W1P					
						Evaluate information from the UIR and MRR WRAPS at the 5-year review period for the Root River 1W1P and incorporate if necessary					
						Evaluate prioritization and targeting implementation of the Root River 1W1P based on the UIR and MRR WRAPS at the 5-year review period, update if necessary					
						NPDES and general permit compliance: wastewater facilities, CAFOs, construction sites, industrial stormwater sites					
			Nitrogen /nitrate	-	20% of existing load	See Table 17 for N BMP scenarios			Percent of existing load	20%	
			Phosphorus	-	12% of existing load	See Table 18 for P BMP scenarios			Percent of existing load	12%	
	Upper Iowa River (509)	Mower, Fillmore	Bacteria/*E. coli*	Maximum monthly geomean 270 org/100 mL	Maximum monthly geomean 126 org/100 mL; 53% reduction	Feedlot runoff controls	Feedlot runoff reduction/treatment [635, 784]	High	-	unknown	
							Feedlot manure/runoff storage addition [313, 784]	High	-	unknown	
							Rainwater diversions at feedlots [362, 367]	High	-	unknown	
							Manure incorporation and injection	High	-	unknown	
						Pasture management	Livestock access control [472]	High	-	unknown	
						Septic system improvements	Septic system improvement [126M]	Low	-	unknown	
						Urban stormwater runoff control	Bioretention/biofiltration/rain garden (urban) [567M, 712M]	High	-	unknown	
							Pet waste management	High	-	unknown	
						Coordinate with Iowa regarding implementation in the Iowa portion of the subwatershed					
						See applicable strategies in the Regional Fecal Coliform TMDL (MPCA 2006)					
	Unnamed Creek (537)	Mower, Fillmore	Biota nonpollutant stressors: Habitat /connectivity and altered hydrology	mIBI 24.77	mIBI 43	Habitat and stream connectivity management					BMPs selected based on analyses provided in the UIR stressor identification report.
			Biota pollutant stressor: Nitrates								

Waterbody and Location			Water Quality			Strategies to Achieve Final Water Quality Goal					
							EXAMPLE Best Management Practice (BMP) Scenario				
HUC-10 Subwatershed	**Waterbody (ID)**	**Location and Upstream Influence Counties**	**Pollutant/ Stressor**	**Current WQ Conditions** (conc./load/ biota score)	**Final WQ Goal Year: 2040** (%/load to reduce/biota score threshold)	**Strategy Type**	**BMP [NRCS Code]**	**Amount**	**Unit**	**Estimated reduction (lbs/yr and %)**	**Notes**
Headwaters to Upper Iowa River (0706000201)	Unnamed Creek (540)	Mower, Fillmore	Biota nonpollutant stressors: Habitat /connectivity and altered hydrology	mIBI 31.81	mIBI 37	Drainage ditch modifications					
			Biota pollutant stressor: Nitrates								
	Unnamed Creek (544)	Mower, Fillmore	Biota nonpollutant stressors: Habitat /connectivity and altered hydrology	mIBI 33.33	mIBI 43	Agricultural tile drainage water treatment					
			Biota pollutant stressor: Nitrates								
	Beaver Creek (546)	Mower, Fillmore	Biota nonpollutant stressor: Altered hydrology	mIBI 29.59 - 43.62	mIBI 37	See applicable nitrogen strategies in Table 17					
			Biota pollutant stressor: Nitrates								
	Beaver Creek (546)	Mower, Fillmore	Bacteria /*E. coli*	Maximum monthly geomean 608 org/100 mL	Maximum monthly geomean 126 org/100 mL; 81% reduction	Feedlot runoff controls	Feedlot runoff reduction/treatment [635, 784]	High	-	unknown	
							Feedlot manure/runoff storage addition [313, 784]	High			
							Rainwater diversions at feedlots [362, 367]	High			
							Manure incorporation and injection	High			
						Pasture management	Livestock access control [472]	High			
						Septic system improvements	Septic system improvement [126M]	Low			
						See applicable strategies in the Regional Fecal Coliform TMDL (MPCA 2006)					
	Little Iowa River (548)	Mower, Fillmore	Bacteria /*E. coli*	Maximum monthly geomean 406 org/100 mL	Maximum monthly geomean126 org/100 mL; 69% reduction	Feedlot runoff controls	Feedlot runoff reduction/treatment [635, 784]	High	-	unknown	
							Feedlot manure/runoff storage addition [313, 784]	High			
							Rainwater diversions at feedlots [362, 367]	High			
							Manure incorporation and injection	High			
						Pasture management	Livestock access control [472]	High			
						Septic system improvements	Septic system improvement [126M]	Low			
						See applicable strategies in the Regional Fecal Coliform TMDL (MPCA 2006)					

Waterbody and Location			Water Quality			Strategies to Achieve Final Water Quality Goal					
HUC-10 Subwatershed	**Waterbody (ID)**	**Location and Upstream Influence Counties**	**Pollutant/ Stressor**	**Current WQ Conditions** (conc./load/ biota score)	**Final WQ Goal Year: 2040** (%/load to reduce/biota score threshold)	**Strategy Type**	**EXAMPLE Best Management Practice (BMP) Scenario**				**Notes**
							BMP [NRCS Code]	**Amount**	**Unit**	**Estimated reduction (lbs/yr and %)**	
Headwaters to Upper Iowa River (0706000201)	Upper Iowa River (550)	Mower, Fillmore	Biota nonpollutant stressors: Habitat /connectivity and altered hydrology	mIBI 29.35 - 40.49	mIBI 37	Agricultural tile drainage water treatment					BMPs selected based on analyses provided in the UIR stressor identification report.
						Drainage ditch modifications					
			Biota pollutant stressor: Nitrates			See applicable nitrogen strategies in Table 17					
	Upper Iowa River (550)	Mower, Fillmore	Bacteria /*E. coli*	Maximum monthly geomean 1,007 org/100 mL	Maximum monthly geomean 126 org/100 mL; 87% reduction	Feedlot runoff controls	Feedlot runoff reduction/treatment [635, 784]	High	-	unknown	
							Feedlot manure/runoff storage addition [313, 784]	High			
							Rainwater diversions at feedlots [362, 367]	High			
							Manure incorporation and injection	High			
						Pasture management	Livestock access control [472]	High			
						Septic system improvements	Septic system improvement [126M]	Low			
						See applicable strategies in the Regional Fecal Coliform TMDL (MPCA 2006)					

Table 15. Restoration and protection strategies for the Coldwater Creek Watershed (070600202).

Waterbody and Location			Water Quality			Strategies to Achieve Final Water Quality Goal					
HUC-10 Subwatershed	**Waterbody (ID)**	**Location and Upstream Influence Counties**	**Pollutant/ Stressor**	**Current WQ Conditions** (conc./load/biota score)	**Final WQ Goal Year: 2040** (%/load to reduce/biota score threshold)	**Strategy Type**	**EXAMPLE Best Management Practice (BMP) Scenario** – **BMP [NRCS Code]**	**Amount**	**Unit**	**Estimated reduction (lbs/yr and %)**	**Notes**
Coldwater Creek (0706000202)	All	Fillmore	All			Implement strategies and recommendations in the Root River 1W1P					
						Evaluate information from the UIR and MRR WRAPS at the 5-year review period for the Root River 1W1P and incorporate if necessary					
						Evaluate prioritization and targeting implementation of the Root River 1W1P based on the UIR and MRR WRAPS at the 5-year review period, update if necessary					
						NPDES and general permit compliance: wastewater facilities, CAFOs, construction sites, industrial stormwater sites					
			Nitrogen/nitrate	-	20% of existing load	See Table 17 for N BMP scenarios			Percent of existing load	20%	
			Phosphorus	-	12% of existing load	See Table 18 for P BMP scenarios			Percent of existing load	12%	
	Pine Creek (212)	Fillmore	Bacteria/*E. coli*	Maximum monthly geomean 993 org/100 mL	Maximum monthly geomean 126 org/100 mL; 87% reduction	Feedlot runoff controls	Feedlot runoff reduction/treatment [635, 784]	High	-	unknown	
							Feedlot manure/runoff storage addition [313, 784]	High			
							Rainwater diversions at feedlots [362, 367]	High			
							Manure incorporation and injection	High			
						Pasture management	Livestock access control [472]	High			
						Septic system improvements	Septic system improvement [126M]	Low			
						Urban stormwater runoff control	Bioretention/biofiltration/rain garden (urban) [567M, 712M]	Low			
							Pet waste management	Low			
						See applicable strategies in the Regional Fecal Coliform TMDL (MPCA 2006)					
	Deer Creek (520)	Fillmore	Biota nonpollutant stressors: Fish passage and habitat/connectivity	fIBI 50.76 - 72.93	fIBI 55	Update perched culvert at County Road A14					BMPs selected based on analyses provided in the UIR stressor identification report.
						Habitat and stream connectivity management					
						Drainage ditch modifications					
						Investigate low flows and remedy, if feasible					

Table 16. Restoration and protection strategies for the Bear Creek Watershed (0706000205).

Waterbody and Location			Water Quality			Strategies to Achieve Final Water Quality Goal					
							EXAMPLE Best Management Practice (BMP) Scenario				
HUC-10 Subwatershed	**Waterbody (ID)**	**Location and Upstream Influence Counties**	**Pollutant/ Stressor**	**Current WQ Conditions** (conc./load/biota score)	**Final WQ Goal Year: 2040** [a] (%/load to reduce/biota score threshold)	**Strategy Type**	**BMP [NRCS Code]**	**Amount**	**Unit**	**Estimated reduction (tons/yr or %)**	**Notes**
Bear Creek (0706000205)	All	Houston	All			Implement strategies and recommendations in the Root River 1W1P					
						Evaluate information from the UIR and MRR WRAPS at the 5-year review period for the Root River 1W1P and incorporate if necessary					
						Evaluate prioritization and targeting implementation of the Root River 1W1P based on the UIR and MRR WRAPS at the 5-year review period, update if necessary					
						NPDES and general permit compliance: wastewater facilities, CAFOs, construction sites, industrial stormwater sites					
			Nitrogen /nitrate	-	20% of existing load	See Table 17 for N BMP scenarios			Percent of existing load	20%	
			Phosphorus	-	12% of existing load	See Table 18 for P BMP scenarios			Percent of existing load	12%	
	Bear Creek (503)	Houston	Bacteria/*E. coli*	Maximum monthly geomean 1,488 org/100 mL	Maximum monthly geomean 126 org/100 mL; 92% reduction	Feedlot runoff controls	Feedlot runoff reduction/treatment [635, 784]	High	-	unknown	
							Feedlot manure/runoff storage addition [313, 784]	High			
							Rainwater diversions at feedlots [362, 367]	High			
							Manure incorporation and injection	High			
						Pasture management	Livestock access control [472]	High			
						Septic system improvements	Septic system improvement [126M]	Low			
						Urban stormwater runoff control	Bioretention/biofiltration/rain garden (urban) [567M, 712M]	Low			
							Pet waste management	Low			
						See applicable strategies in the Regional Fecal Coliform TMDL (MPCA 2006)					
	Bee Creek (Waterloo Creek) (515)	Houston	Bacteria/*E. coli*	Maximum monthly geomean 3,728 org/100 mL	Maximum monthly geomean 126 org/100 mL; 97% reduction	Feedlot runoff controls	Feedlot runoff reduction/treatment [635, 784]	High	-	unknown	
							Feedlot manure/runoff storage addition [313, 784]	High			
							Rainwater diversions at feedlots [362, 367]	High			
							Manure incorporation and injection	High			
						Pasture management	Livestock access control [472]	High			
						Septic system improvements	Septic system improvement [126M]	Low			
						See applicable strategies in the Regional Fecal Coliform TMDL (MPCA 2006)					

Table 17. Restoration and protection strategies for Crooked Creek Watershed (0701000102).

Waterbody and Location			Water Quality			Strategies to Achieve Final Water Quality Goal					
							EXAMPLE Best Management Practice (BMP) Scenario				
HUC-10 Subwatershed	**Waterbody (ID)**	**Location and Upstream Influence Counties**	**Pollutant/ Stressor**	**Current WQ Conditions** (conc./load/biota score)	**Final WQ Goal Year: 2040** (%/load to reduce/biota score threshold)	**Strategy Type**	**BMP [NRCS Code]**	**Amount**	**Unit**	**Estimated reduction (lbs/yr and %)**	**Notes**
Crooked Creek (0701000102)	All	Houston	All			Implement strategies and recommendations in the Root River 1W1P					
						Evaluate information from the UIR and MRR WRAPS at the 5-year review period for the Root River 1W1P and incorporate if necessary					
						Evaluate prioritization and targeting implementation of the Root River 1W1P based on the UIR and MRR WRAPS at the 5-year review period, update if necessary					
						NPDES and general permit compliance: wastewater facilities, CAFOs, construction sites, industrial stormwater sites					
			Nitrogen /nitrate	-	20% of existing load	See Table 15 for N BMP scenarios			Percent of existing load	20%	
			Phosphorus	-	12% of existing load	See Table 16 for P BMP scenarios			Percent of existing load	12%	
	Crooked Creek (519)	Houston	Biota nonpollutant stressor: Habitat /connectivity	mIBI 15.01 - 24.09	mIBI 43; maintain fIBI threshold	Implement the recommendations in the Crooked Creek WARSSS report (DNR 2019) to address erosion rates and incision of stream				140 tons	Load reduction estimated in the Crooked Creek WARSSS report. Full WARSSS report is provided in Appendix F of the UIR and MRR WRAPS.
						Aim to re-establish quality riparian corridor buffers to increase woody debris, course particulate organic matter inputs, and stream shading.					Strategy was provided in Table 17 of the MRR stressor identification report to address habitat.
			Bacteria/*E. coli*	Maximum monthly geomean 1,270 org/100mL	Maximum monthly geomean 126 org/100mL; 90% reduction	Feedlot runoff controls	Feedlot runoff reduction/treatment [635, 784]	High	-	unknown	
							Feedlot manure/runoff storage addition [313, 784]	High			
							Rainwater diversions at feedlots [362, 367]	High			
							Manure incorporation and injection	High			
						Pasture management	Livestock access control [472]	High			
						Septic system improvements	Septic system improvement [126M]	Low			
						Urban stormwater runoff control	Bioretention/biofiltration/rain garden (urban) [567M, 712M]	Low			
							Pet waste management	Low			
						See applicable strategies in the Regional Fecal Coliform TMDL (MPCA 2006)					
	Clear Creek (524)	Houston	Biota nonpollutant stressor: Habitat /connectivity	mIBI 30.12	mIBI 43	Aim to re-establish quality riparian corridor buffers to increase woody debris, course particulate organic matter inputs, and stream shading.					Strategy was provided in Table 17 of the MRR stressor identification report to address habitat.

Waterbody and Location			Water Quality			Strategies to Achieve Final Water Quality Goal					
							EXAMPLE Best Management Practice (BMP) Scenario				
HUC-10 Subwatershed	**Waterbody (ID)**	**Location and Upstream Influence Counties**	**Pollutant/ Stressor**	**Current WQ Conditions** (conc./load/biota score)	**Final WQ Goal Year: 2040** (%/load to reduce/biota score threshold)	**Strategy Type**	**BMP [NRCS Code]**	**Amount**	**Unit**	**Estimated reduction (lbs/yr and %)**	**Notes**
Crooked Creek (0701000102)	South Fork Crooked Creek (574)	Houston	Biota nonpollutant stressor: Temperature	mIBI 34.81 - 43.62	mIBI 43	Protect spring sources; etc. Improve near channel riparian cover and reduce sedimentation.					Strategies were provided in Table 17 of the MRR stressor identification report to address temperature. R-3 reservoir is likely also impacting temperature.
						Reduce sedimentation. Focus on reducing sediment input from riparian corridor (cattle pastures/row crops/increased fencing) and immediate stream channel (including possible stream bank restoration).					
						Reduce sedimentation. Control runoff from upland areas. Use soil conservation practices; practices that reduce flows, include CRP, grassed waterways, WASCOBs, etc.					
						Reduce sedimentation. Address gullies that may be contributing sediment to the stream.					
			Biota pollutant stressors: Dissolved oxygen and phosphorus/ eutrophication			Improve nutrient management and reduce soil erosion through implementation of BMPs (See applicable phosphorus strategies in Table 16).					Strategies were provided in Table 17 of the MRR stressor identification report to address dissolved oxygen and phosphorus/eutrophication. R-3 reservoir is likely also impacting dissolved oxygen and eutrophication.
						Collect additional information on DO and eutrophication where necessary.					
						Consider studying eutrophication dynamics of R-3 reservoir to better understand impacts and sources of nutrients to the reservoir.					

Table 18. Restoration and protection strategies for the Winnebago Creek Watershed (0701000104).

Waterbody and Location			Water Quality			Strategies to Achieve Final Water Quality Goal					
HUC-10 Subwatershed	Waterbody (ID)	Location and Upstream Influence Counties	Pollutant/ Stressor	Current WQ Conditions (conc./load/biota score)	Final WQ Goal Year: 2040 (%/load to reduce/biota score threshold)	Strategy Type	EXAMPLE Best Management Practice (BMP) Scenario: BMP [NRCS Code]	Amount	Unit	Estimated reduction (tons/yr and %)	Notes
Winnebago Creek (0701000104)	All	Houston	All			Implement strategies and recommendations in the Root River 1W1P					
						Evaluate information from the UIR and MRR WRAPS at the 5-year review period for the Root River 1W1P and incorporate if necessary					
						Evaluate prioritization and targeting implementation of the Root River 1W1P based on the UIR and MRR WRAPS at the 5-year review period, update if necessary					
						NPDES and general permit compliance: wastewater facilities, CAFOs, construction sites, industrial stormwater sites					
			Nitrogen /nitrate	-	20% of existing load	See Table 15 for N BMP scenarios			Percent of existing load	20%	
			Phosphorus	-	12% of existing load	See Table 16 for P BMP scenarios			Percent of existing load	12%	
	Winnebago Creek (693)	Houston	Biota pollutant stressor: Sediment /TSS	mIBI 30.12 12,600 ton/yr from HSPF model output	mIBI 43; 77% reduction; 9,700 ton reduction	Focus on reducing sediment input from riparian corridor (cattle pastures/row crops/increased fencing) and immediate stream channel (including possible stream bank restoration).					Strategies were provided in Table 17 of the MRR stressor identification report to address sediment/TSS.
						Control runoff from upland areas. Use soil conservation practices; practices that reduce flows, include CRP, grassed waterways, WASCOBs, etc.					
						Address gullies that may be contributing sediment to the stream.					
						Stream banks, bluffs and ravines protected/restored	Streambanks/shoreline - stabilized or restored [580]	4	miles	2,800-3,800 tons/yr	Sediment load reductions were estimated using removal efficiencies provided in the Spreadsheet Tool for Estimating Pollutant Load developed by the US EPA.
						Pasture management	Livestock access control [472]	TBD	-	TBD	
						Forestry Management	Forestry management and improvement [147M, 490, 666]	TBD	-	TBD	
							Riparian zone forestry management	TBD	-	TBD	
						NPDES compliance: wastewater facilities					
									Total tons reduced/ year	**2,800-3,800**	
	Winnebago Creek (693)	Houston	Bacteria/*E. coli*	Maximum monthly geomean: 990 org/100 mL	Maximum monthly geomean: 126 org/100 mL; 87% reduction	Feedlot runoff controls	Feedlot runoff reduction/treatment [635, 784]	High	-	unknown	
							Feedlot manure/runoff storage addition [313, 784]	High			
							Rainwater diversions at feedlots [362, 367]	High			
							Manure incorporation and injection	High			
						Pasture management	Livestock access control [472]	High			
						Septic system improvements	Septic system improvement [126M]	Low			
						See applicable strategies in the Regional Fecal Coliform TMDL (MPCA 2006)					

Table 19. Restoration and protection strategies for the Mormon Creek Watershed (0706000105).

Waterbody and Location			Water Quality			Strategies to Achieve Final Water Quality Goal					
							EXAMPLE Best Management Practice (BMP) Scenario				
HUC-10 Subwatershed	Waterbody (ID)	Location and Upstream Influence Counties	Pollutant/ Stressor	Current WQ Conditions (conc./load/biota score)	Final WQ Goal Year: 2040 (%/load to reduce/biota score threshold)	Strategy Type	BMP [NRCS Code]	Amount	Unit	Estimated reduction (lbs/yr and %)	Notes
Mormon Creek (0706000105)	All	Houston	All			Implement strategies and recommendations in the Root River 1W1P					
						Evaluate information from the UIR and MRR WRAPS at the 5-year review period for the Root River 1W1P and incorporate if necessary					
						Evaluate prioritization and targeting implementation of the Root River 1W1P based on the UIR and MRR WRAPS at the 5-year review period, update if necessary					
						NPDES and general permit compliance: wastewater facilities, CAFOs, construction sites, industrial stormwater sites					
			Nitrogen /nitrate	-	20% of existing load	See Table 15 for N BMP scenarios			Percent of existing load	20%	
			Phosphorus	-	12% of existing load	See Table 16 for P BMP scenarios			Percent of existing load	12%	
	Wildcat Creek (516)	Houston	All	mIBI 46.5; fIBI 54-61	maintain mIBI and fIBI greater than or equal to 43 and 50	Address the dry run tributary just upstream of the Cork Hollow Road crossing and areas of stream bank failure					BMPs selected based on assessments provided in the UIR stressor identification report.
						Upland soil conservation practices to control flow and flooding					
						Livestock access control					
						Pasture management. Reduce number and intensity of grazed areas to improve riparian vegetation and improve channel stability					

3.4.4 Climate protection co-benefit of strategies

Many agricultural BMPs, which reduce the load of nutrients and sediment to receiving waters also act to decrease emissions of greenhouse gases (GHGs) to the air. Agriculture is the third largest emitting sector of GHGs in Minnesota. Important sources of GHGs from crop production include the application of manure and nitrogen fertilizer to cropland, soil organic carbon oxidation resulting from cropland tillage, and carbon dioxide emissions from fossil fuel used to power agricultural machinery or in the production of agricultural chemicals. Reduction in the application of nitrogen to cropland through optimized fertilizer application rates, timing, and placement is a source reduction strategy; while conservation cover, riparian buffers, vegetative filter strips, field borders, and cover crops reduce GHG emissions as compared to cropland with conventional tillage. Additional information about GHG emission reduction from agricultural BMPs is summarized in this MPCA report: https://www.pca.state.mn.us/air/agriculture-and-climate-change-minnesota.

The U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) developed Comet Planner, a ranking tool for cropland BMPs that can be used by local units of government to consider ancillary GHG effects when selecting BMPs for nutrient and sediment control (http://www.comet-planner.com/). Practices with a high potential for GHG avoidance include: conservation cover, forage and biomass planting, no-till and strip-till tillage, multi-story cropping, nutrient management, silvopasture establishment, other tree and shrub establishment, and shelterbelt establishment. Practices with a medium-high potential to mitigate GHG emissions include: contour buffer strips, riparian forest buffers, vegetative buffers and shelterbelt renovation. The following cropland BMPs with ancillary GHG benefits were selected for implementation in the UIR and MRR WRAPS:

- Conservation cover
- No-till and strip-till tillage
- Nutrient management
- Contour buffer strips
- Riparian buffers

A longer, more detailed assessment of cropland BMP effects on GHG emission (NRCS et al. no date) can be found at http://comet-planner.nrel.colostate.edu/COMET-Planner_Report_Final.pdf.

4. Monitoring plan

Monitoring is also a critical component of an adaptive management approach and can be used to help determine when a change in management is needed. This section describes existing and recommended monitoring activities in the watershed.

Future monitoring in the UIR and MRR will be accomplished according to the watershed approach's IWM. IWM uses a nested watershed design allowing the aggregation of watersheds from a coarse to a fine scale. The foundation of this comprehensive approach is the 80 major watersheds within Minnesota. IWM occurs in each major watershed once every 10 years (MPCA 2012). The UIR and MRR watersheds were monitored in 2015 through 2016 for the first cycle of IWM; second cycle IWM will occur in 2025 to 2035. The monitoring and assessment report for the UIR and MRR provides detailed discussion of IWM and how it will be applied going forward. DNR Fisheries staff also collect various data in support of fishery management and monitoring. It is anticipated that these data will be collected into the future.

There are many other project-specific monitoring efforts throughout the watersheds. For example, annual water quality data are collected throughout the UIR Watershed by the UIR Watershed Management Authority, located in the Iowa portion of the watershed. These data are available at their website: https://data.upperiowariver.org/.

It is the intent of the implementing organizations in this watershed to make steady progress in terms of pollutant reduction. Factors that may mean slower progress include limits in funding or landowner acceptance, challenging fixes (e.g., unstable bluffs and ravines, invasive species) and unfavorable climatic factors. Conversely, there may be faster progress for some impaired waters whose watersheds do not have these factors.

As implementation activities are conducted in the watershed, an evaluation of the before and after conditions can be useful to aid in future project planning. Implementation of BMPs is tracked on MPCA's Healthier Watersheds webpage: https://www.pca.state.mn.us/water/best-management-practices-implemented-watershed. In addition to flow and water quality monitoring, a broader assessment of ecological function and restoration could be used to assess various components of the stream system and overall effectiveness of the implementation activity. Additional monitoring efforts and recommendations can be found in the Root River 1W1P and other existing planning documents (see Appendix B for full list).

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6. Appendices

Appendix A. EPA's Section 319 Nine Elements Summary: Guidance for WRAPS Template

EPA requires that 319 grant applications be based on watershed plans that address the nine elements described below. This information is from guidance found on EPA's website at: https://www.epa.gov/nps/handbook-developing-watershed-plans-restore-and-protect-our-waters and

http://water.epa.gov/polwaste/nps/upload/2008_04_18_NPS_watershed_handbook_ch02.pdf

Element #	Element description	WRAPS section where addressed	Notes
A	An identification of the causes and sources or groups of similar sources that will need to be controlled to achieve the load reductions estimated in this watershed-based plan (and to achieve any other watershed goals identified in the watershed-based plan), as discussed in item (b) immediately below. Sources that need to be controlled should be identified at the significant subcategory level with estimates of the extent to which they are present in the watershed (e.g., X numbers of dairy cattle feedlots needing upgrading, including a rough estimate of the number of cattle per facility; Y acres of row crops needing improved nutrient management or sediment control; or Z linear miles of eroded streambank needing remediation).	**Section 2.3 Stressors and sources** should provide the general source ID information needed. **Section 3.3 Restoration & protection strategies** provides more source specific subcategory type of information.	EPA guidance states that the plan should include a map "that locates the major causes and sources of impairment." Guidance also states, "If a TMDL exists, this element may be adequately addressed."
B	An estimate of the load reductions expected for the management measures.	**Section 3.3 Restoration & protection strategies** should provide source specific reduction information.	
C	A description of the NPS management measures that will need to be implemented to achieve the load reductions under paragraph (b) above (as well as to achieve other watershed goals identified in this watershed-based plan), and an identification (using a map or a description) of the critical areas in which those measures will be needed to implement this plan.	**Section 3.3 Restoration & protection strategies and Section 3.1 Targeting of geographic areas** should provide this via the strategies table and supporting maps/GIS tools showing critical areas.	

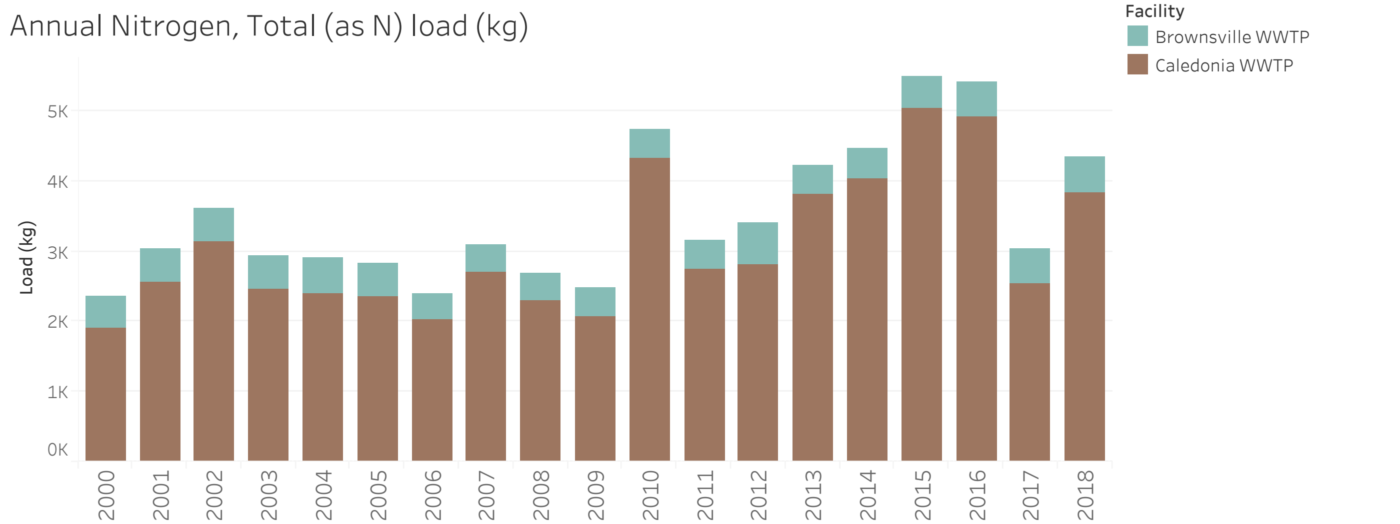
D	An estimate of the amounts of technical and financial assistance needed, associated costs, and/or the sources and authorities that will be relied upon to implement this plan.	**Section 3 Prioritizing and implementing restoration and protection** should address this. Reference to cost estimates in TMDLs should also be cited.	Based on one recent EPA-approved plan (Bad Axe River, MI), it appears acceptable to focus narrative on the available funding sources and organizations that could provide technical assistance.
E	An information/education component that will be used to enhance public understanding of the project and encourage their early and continued participation in selecting, designing, and implementing the NPS management measures that will be implemented.	**Section 3.2 Civic engagement**	
F	A schedule for implementing the NPS management measures identified in this plan that is reasonably expeditious.	**Section 3.3 Restoration & protection strategies**	
G	A description of interim, measurable milestones for determining whether NPS management measures or other control actions are being implemented.	**Section 3.3 Restoration & protection strategies**	
H	A set of criteria that can be used to determine whether loading reductions are being achieved over time and substantial progress is being made towards attaining water quality standards.	**Section 4 Monitoring**	EPA guidance indicates using water quality “benchmarks or waypoints to measure against through monitoring (e.g., direct measures like fecal coliform concentrations or indirect measures like # of beach closings).” This generally translates to listing the parameter, implementation phases/years and parameter concentration to be achieved (e.g., TP: year 10 = 80 µg/L; year 20 = 70 µg/L; etc.). This could get unwieldy given the many parameters covered and varying starting points for the many waterbodies in a watershed. Therefore, see the alternative approach/narrative in Section 4. This element is to be integrated with element I below.

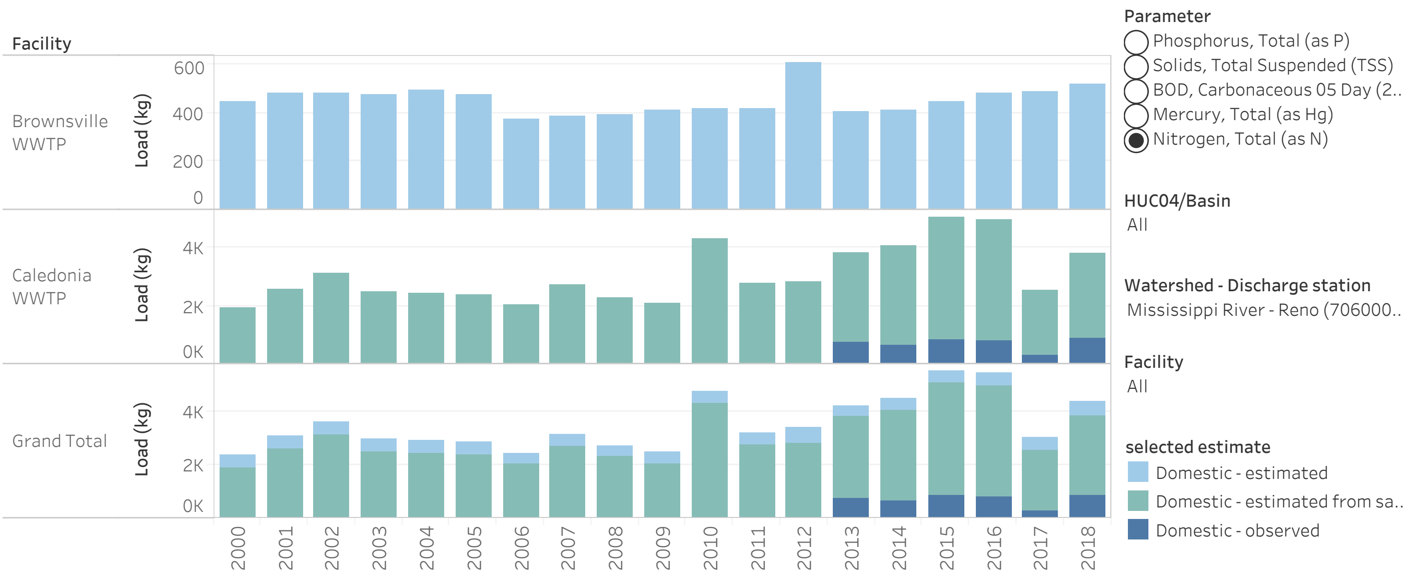
I	A monitoring component to evaluate the effectiveness of the implementation efforts over time, measured against the criteria established under item (h) immediately above.	**Section 4 Monitoring**	Per EPA guidance, this is intended to be watershed-scale monitoring and not monitoring for individual BMPs. Both local and PCA-led monitoring (i.e., HUC-8 pour point continuous monitoring and 10-year IWM cycle) should be described.

Appendix B. Summary of Existing Planning Efforts

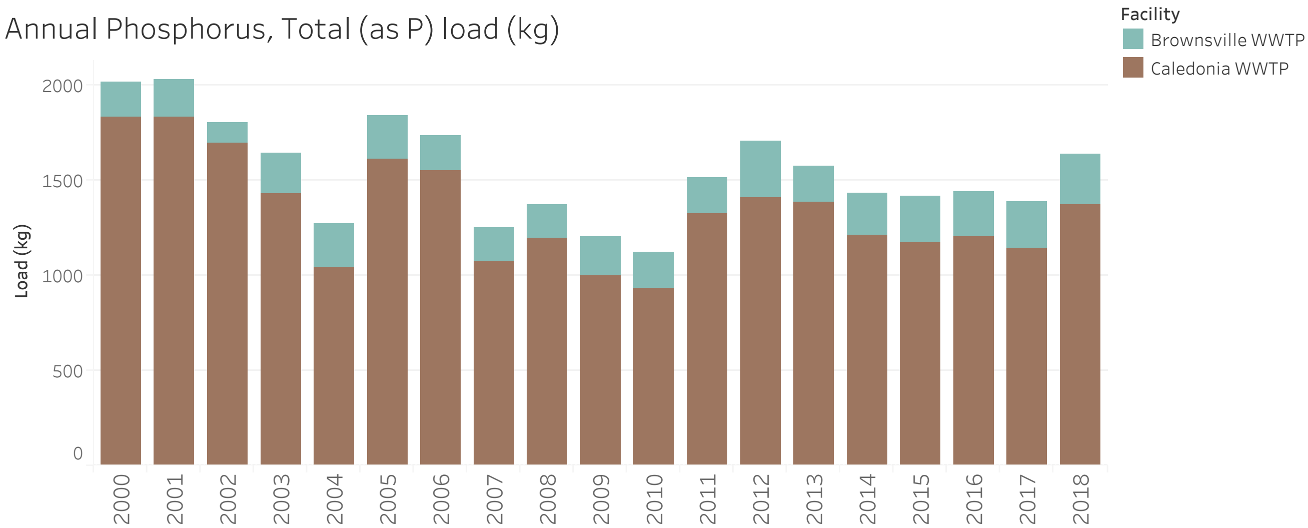
Existing Study or Planning Document	Location
Upper Iowa River, Mississippi River–Reno, Mississippi River–La Crescent Watersheds Monitoring and Assessment Report	MPCA website. See Upper Iowa River, Mississippi River–Reno Watershed pages.
Upper Iowa River Watershed Stressor Identification Report	MPCA website. See Upper Iowa River Watershed page.
Mississippi River Reno Stressor Identification Report	MPCA website. See Mississippi River–Reno Watershed page.
Upper Iowa River and Mississippi River–Reno Watersheds Total Maximum Daily Load.	MPCA website. See Upper Iowa River, Mississippi River–Reno Watershed pages.
Root River One Watershed, One Plan	Fillmore County website.
Revised Regional TMDL Evaluation of Fecal Coliform Bacteria Impairments in the Lower Mississippi River Basin in Minnesota	MPCA website. See Total Maximum Daily Load page, Approved, Lower Mississippi River Basin TMDL: Regional Fecal Coliform
Upper Iowa River Watershed Assessment and Management Strategies	Upper Iowa River Alliance website. See publications page.
Geomorphology Reports	See Appendix D
Minnesota DNR Upper Iowa River culvert inventory and prioritization report	See Appendix E
Watershed Assessment of River Stability and Sediment Supply of Crooked Creek Watershed	See Appendix F

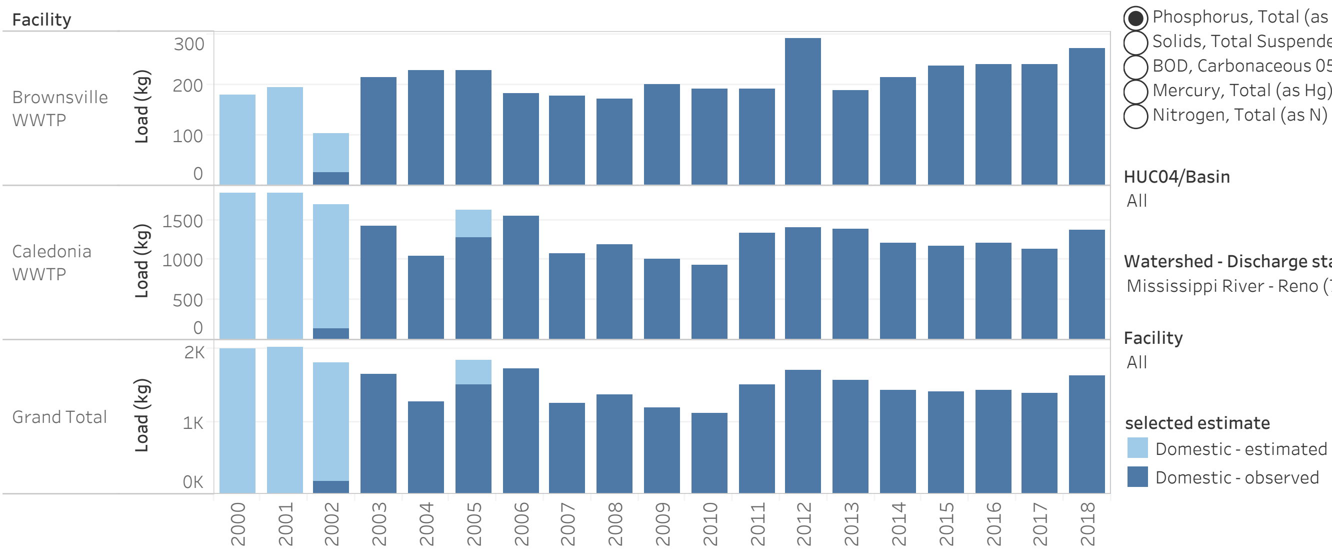
Appendix C. WWTP pollutant discharges





Annual Phosphorus, Total (as P) load (kg)





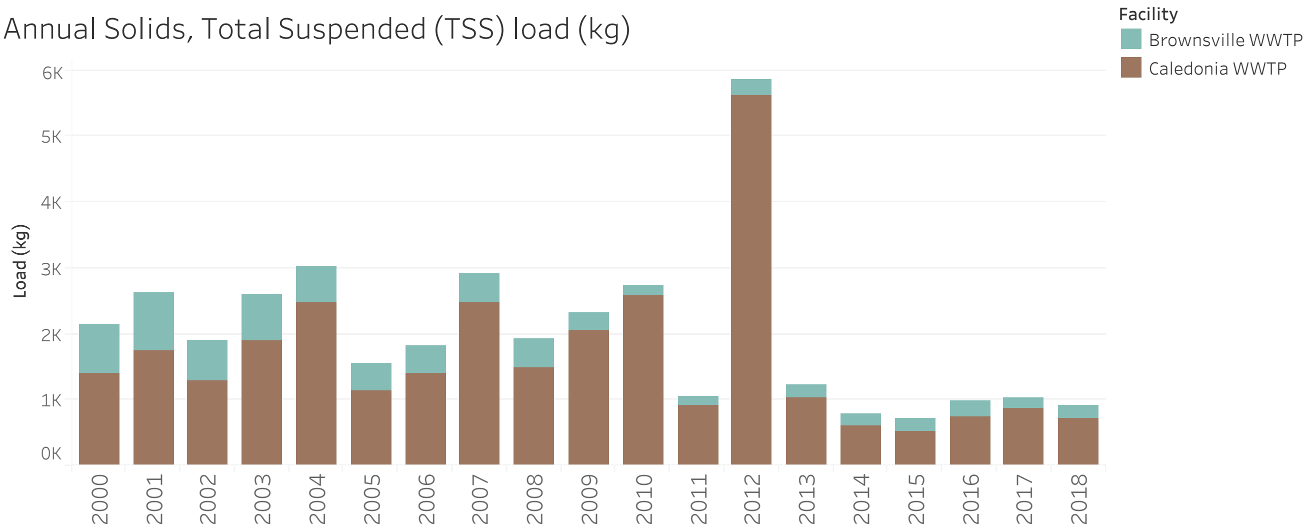
Parameter
- Phosphorus, Total (as P)
- Solids, Total Suspended (TSS)
- BOD, Carbonaceous 05 Day (2..
- Mercury, Total (as Hg)
- Nitrogen, Total (as N)

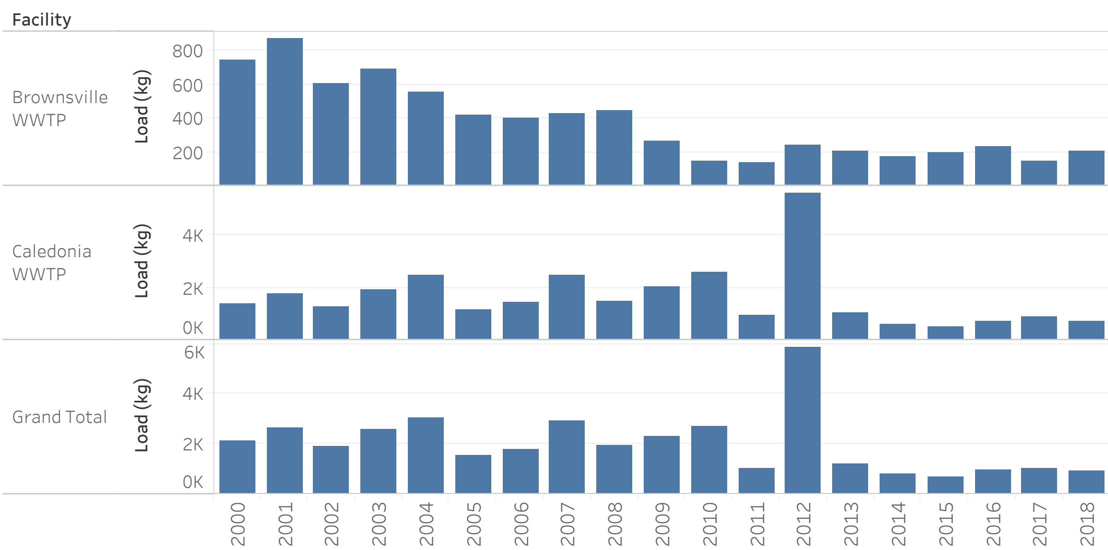
HUC04/Basin
All

Watershed - Discharge station
Mississippi River - Reno (706000..

Facility
All

Annual Solids, Total Suspended (TSS) load (kg)





Parameter
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- Solids, Total Suspended (TSS)
- BOD, Carbonaceous 05 Day (2..
- Mercury, Total (as Hg)
- Nitrogen, Total (as N)

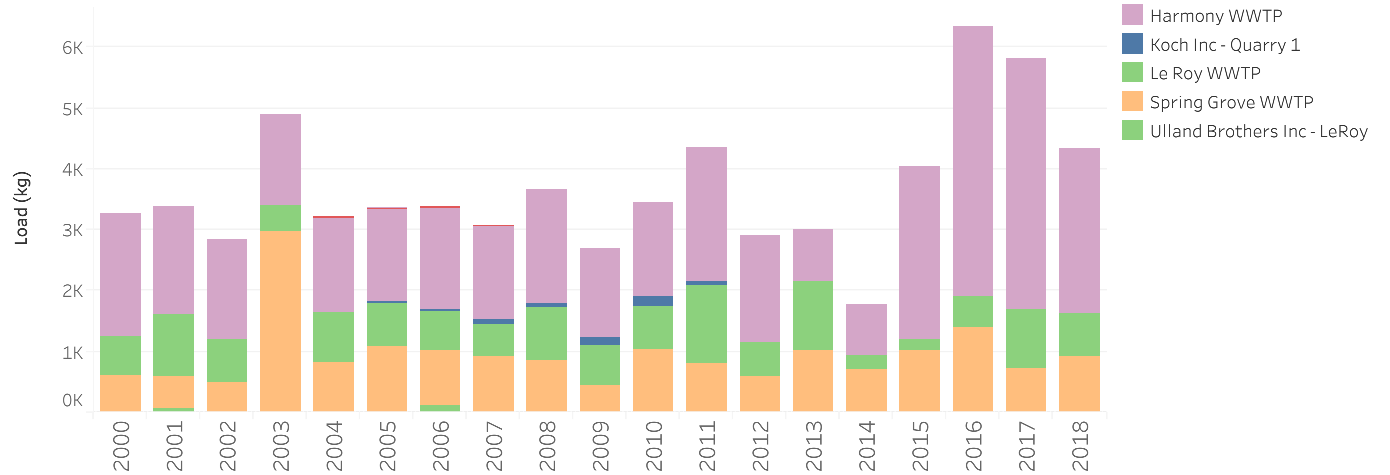
HUC04/Basin
All

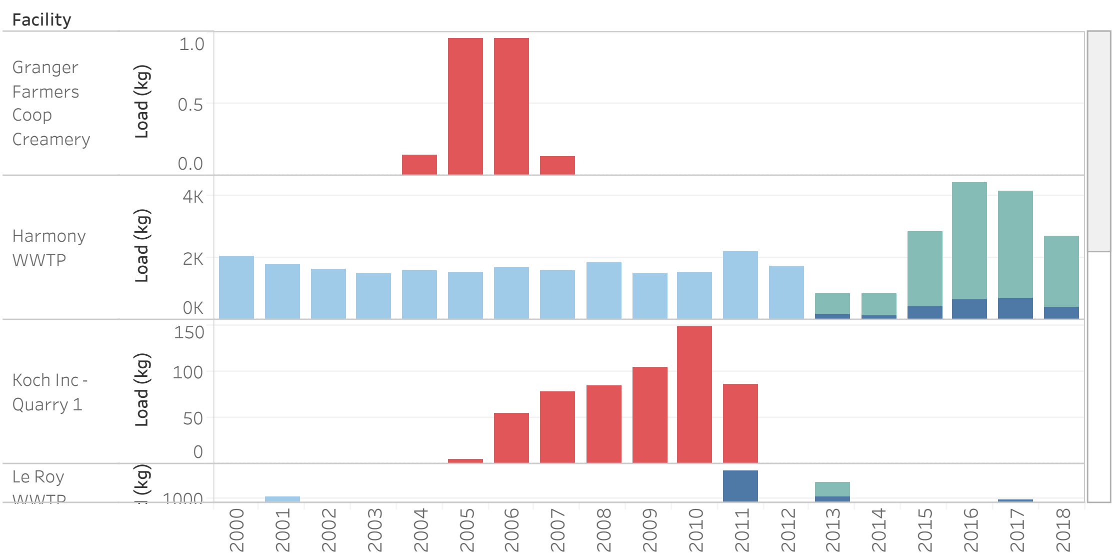
Watershed - Discharge station
Mississippi River - Reno (706000..

Facility
All

selected estimate
Domestic - observed

Annual Nitrogen, Total (as N) load (kg)





Parameter

- Phosphorus, Total (as P)
- Solids, Total Suspended (TSS)
- BOD, Carbonaceous 05 Day (2..
- Mercury, Total (as Hg)
- Nitrogen, Total (as N)

HUC04/Basin
All

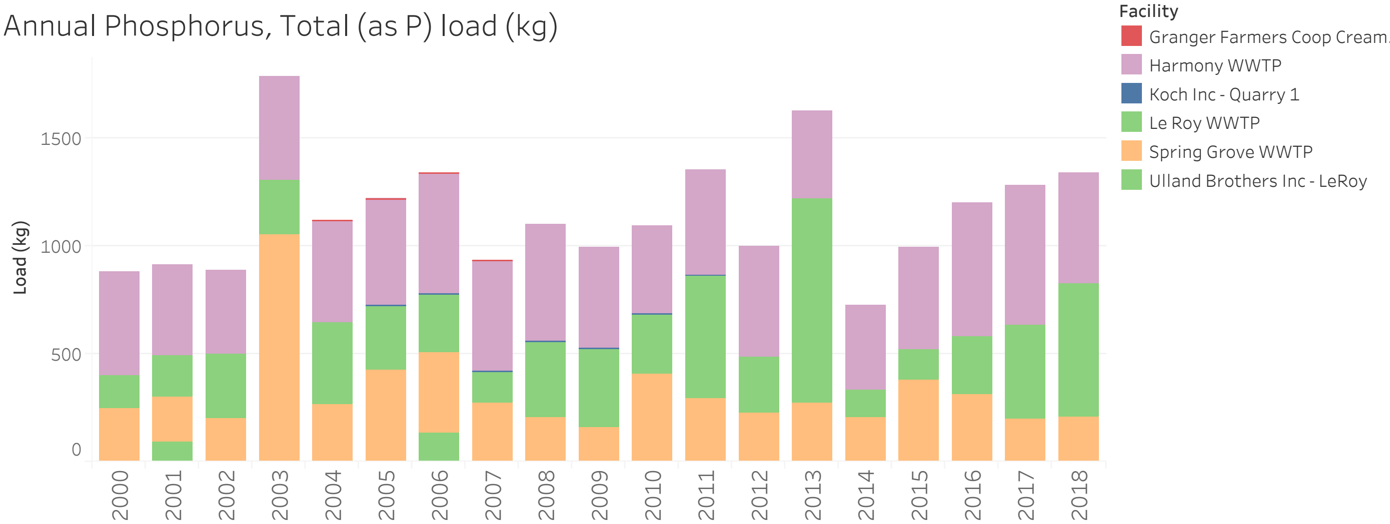
Watershed - Discharge station
Upper Iowa River (7060002)

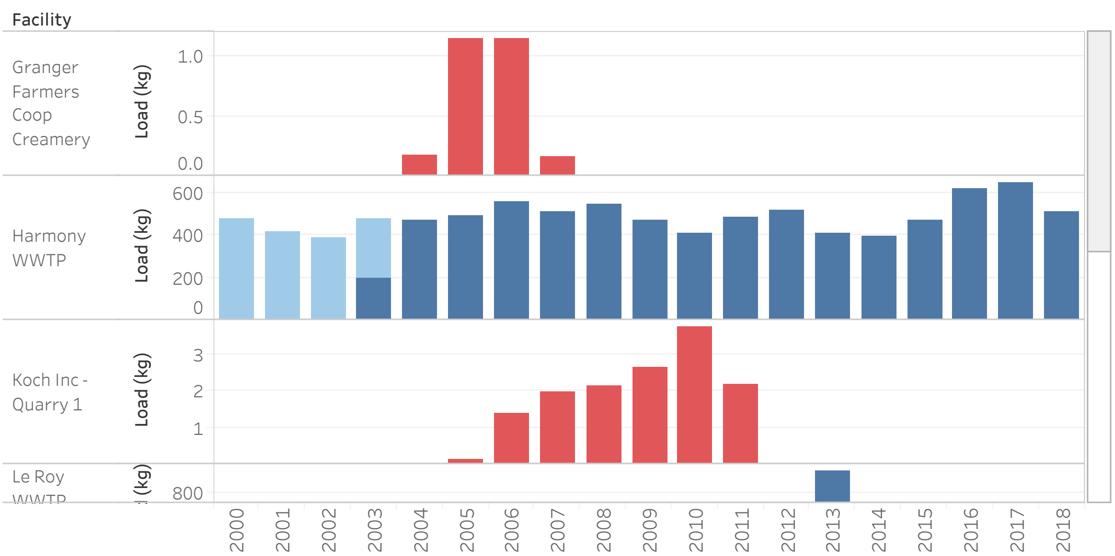
Facility
All

selected estimate

- Domestic - estimated
- Domestic - estimated from sa..
- Domestic - observed
- Industrial - estimated

Annual Phosphorus, Total (as P) load (kg)





Parameter
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- Solids, Total Suspended (TSS)
- BOD, Carbonaceous 05 Day (2..
- Mercury, Total (as Hg)
- Nitrogen, Total (as N)

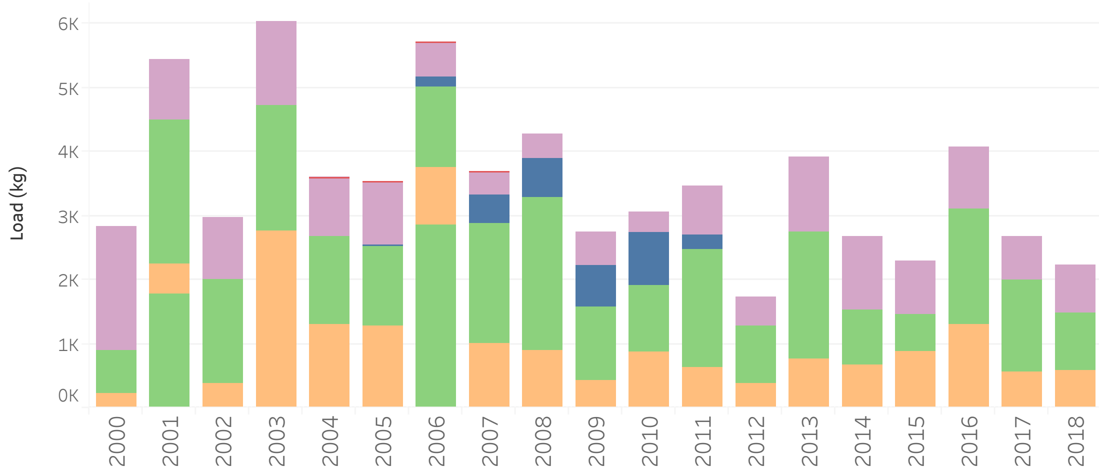
HUC04/Basin
All

Watershed - Discharge station
Upper Iowa River (7060002)

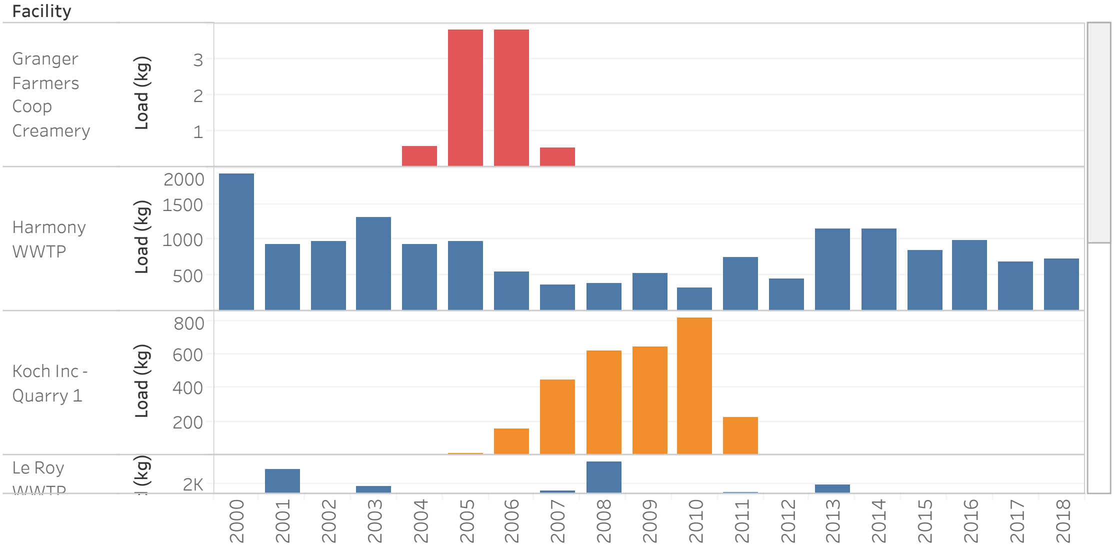
Facility
All

selected estimate
- Domestic - estimated
- Domestic - observed
- Industrial - estimated

Annual Solids, Total Suspended (TSS) load (kg)



Facility
Granger Farmers Coop Cream..
Harmony WWTP
Koch Inc - Quarry 1
Le Roy WWTP
Spring Grove WWTP
Ulland Brothers Inc - LeRoy



Parameter
Phosphorus, Total (as P)
Solids, Total Suspended (TSS)
BOD, Carbonaceous 05 Day (2..
Mercury, Total (as Hg)
Nitrogen, Total (as N)

HUC04/Basin
All

Watershed - Discharge station
Upper Iowa River (7060002)

Facility
All

selected estimate
Domestic - estimated
Domestic - observed
Industrial - estimated
Industrial - observed

MNDNR Geomorphology Site Level Summary for Wildcat Creek

Geomorphic survey near 15LM038

Wildcat Creek geomorphic survey near MPCA biological site 15LM038 occurred June 2016, is located west of County Road 3 in Brownsville at Lat. 43°41'21.04"N Long. 91°17'53.50"W (Figure 1). The geomorphic site is roughly 3,500 feet downstream of the biological site. The site has a drainage area of 8 mi² with major land use consisting of 56.3% forested and 37.5% cultivated (StreamStats 4.0, 2017). The channel is classified as an E4 stream type with a median pebble size of 14.19 mm at the riffle, or gravel substrate (Table 1). The stream has a water surface slope of 0.00253 and sinuosity of 1.3 within the section surveyed. A Pfankuch rating of fair was observed, close to a poor rating. Dominant characteristics negatively affecting the rating include steep upper banks, moderated deposition of new, coarse sand, and significant undercutting of the banks. Elements contributing to stability within the reach includes low debris jam potential and dense diverse vegetation along the channel.

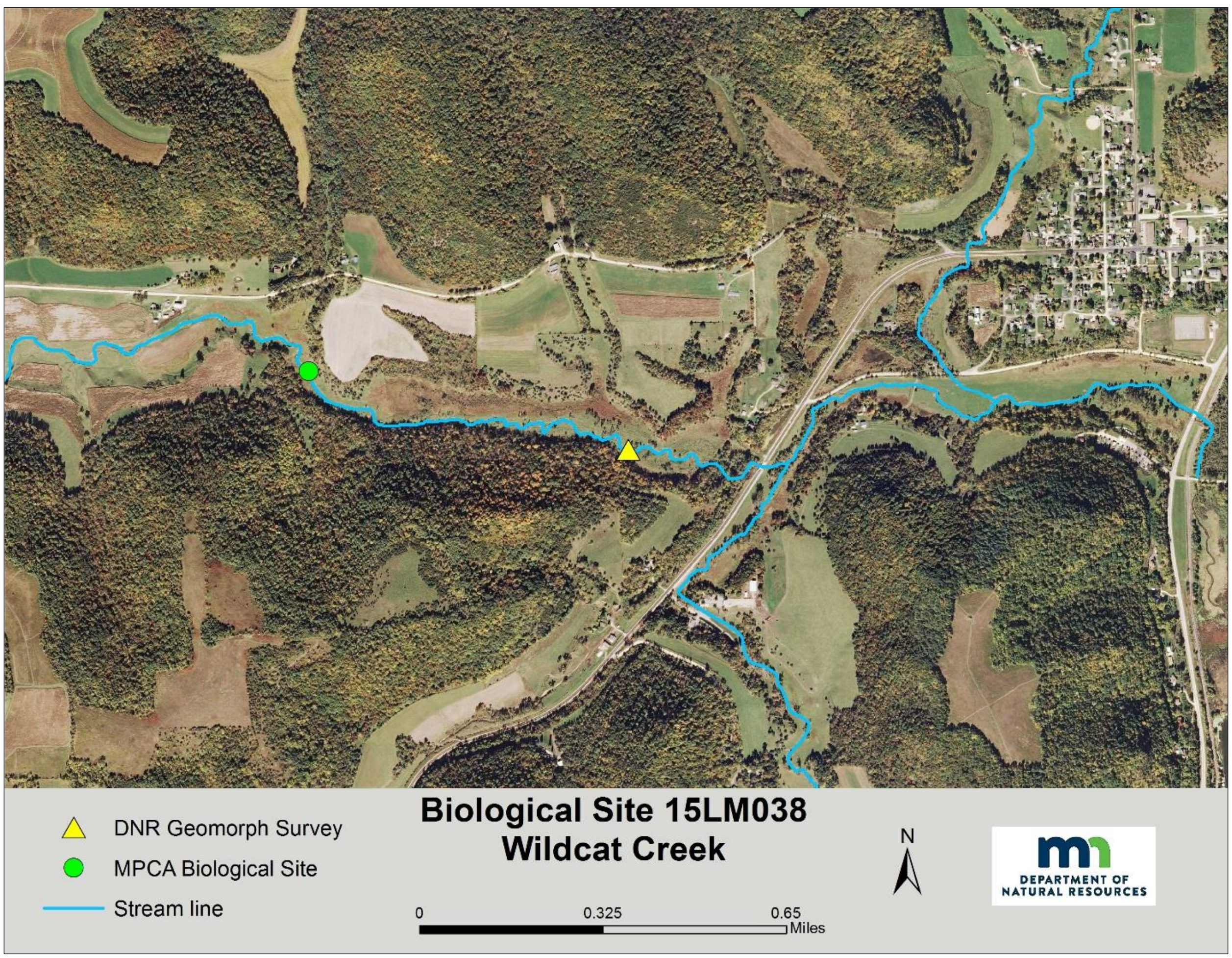


Figure 1. Location of DNR geomorphic survey and MPCA biological site

Table 1. Geomorphic summary for survey on Wildcat Creek

Survey Results			
Stream Type	E4	**Velocity (fps)**	3.2
Valley Type	U-AL-FD	**Discharge (cfs)**	74.8
Sinuosity	1.3	**Riffle D50 (mm)**	14.19
Water Slope	0.00253	**Mean Riffle Depth (ft)**	1.95
Bankfull Width	11.99	**Max Pool Depth (ft)**	3.59
Entrenchment Ratio	2.45	**Bank Erosion Estimates (tons/yr/ft)**	0.016
Width/Depth Ratio	6.15	**Pfankuch Stability Rating**	Fair
Bankfull Area (ft^2)	23.37	**Competence Condition**	NA

Incision is the process of a stream abandoning an active floodplain and is measured by dividing the lowest bank height by the maximum depth at bankfull (Bank height ratio). The bank height ratio of the surveyed riffle is 1.33, classified as *moderately incised*. The lower base levels are lead to a narrowing of the floodplain; although, the reach is still considered as not entrenched.

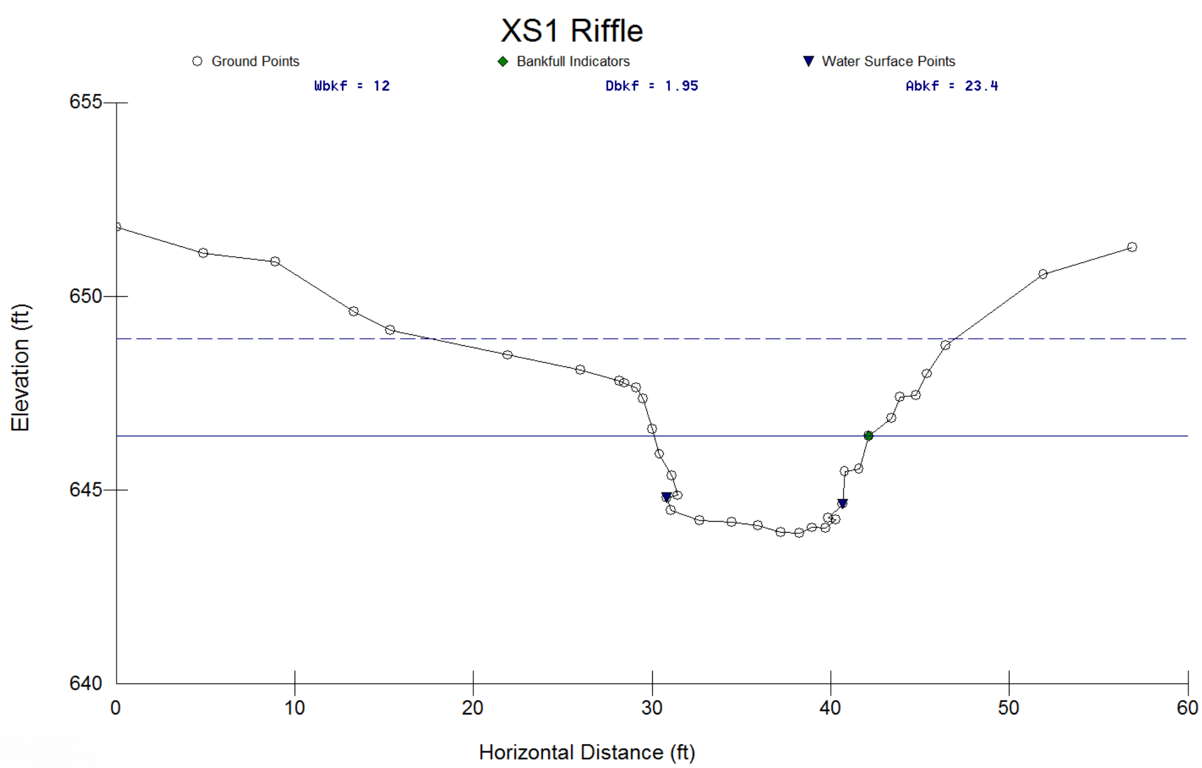


Figure 2. Cross section of riffle showing bankfull elevation (solid line) and floodprone elevation (dashed line)

The longitudinal profile is 311 feet long and contains four riffles and four pools (Figure 3). Pool spacing and riffles are typical of E stream types in the area, but the profile indicates some deposition in pools (also noted in the Pfankuch rating).

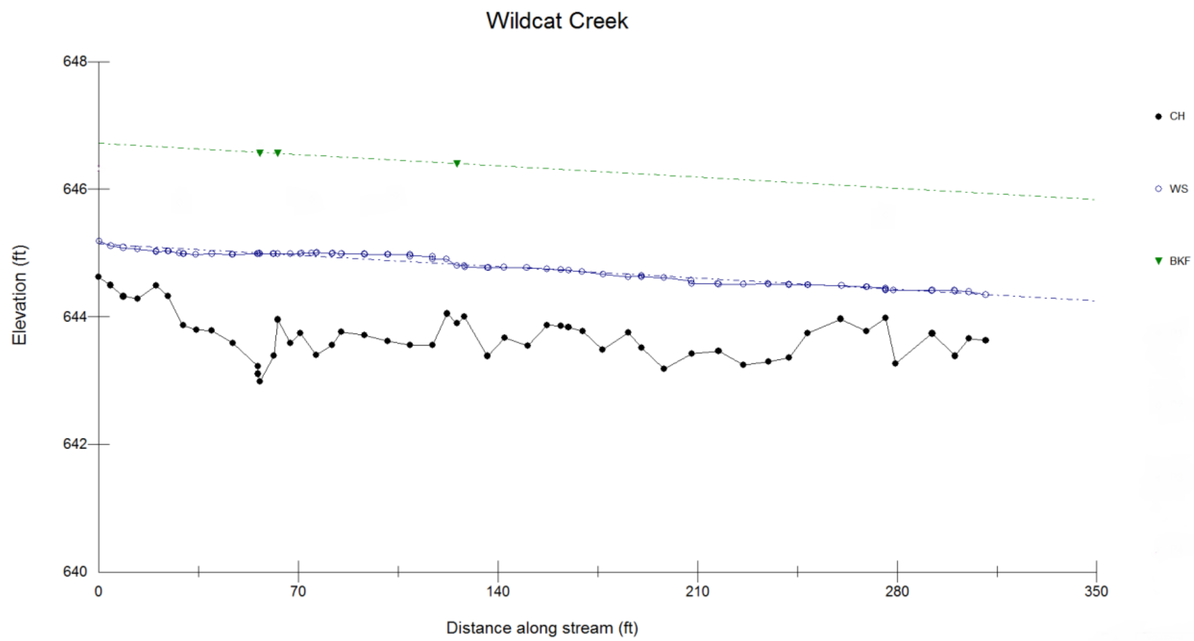


Figure 3. Longitudinal profile of survey

Pebble count at the riffle cross section has a slight bi-modal distribution. Median particle size is 14.19mm, with distribution peaks at 0.125mm and 22.6mm. This indicates fine sediment inundating the interstitial spaces of the gravel.

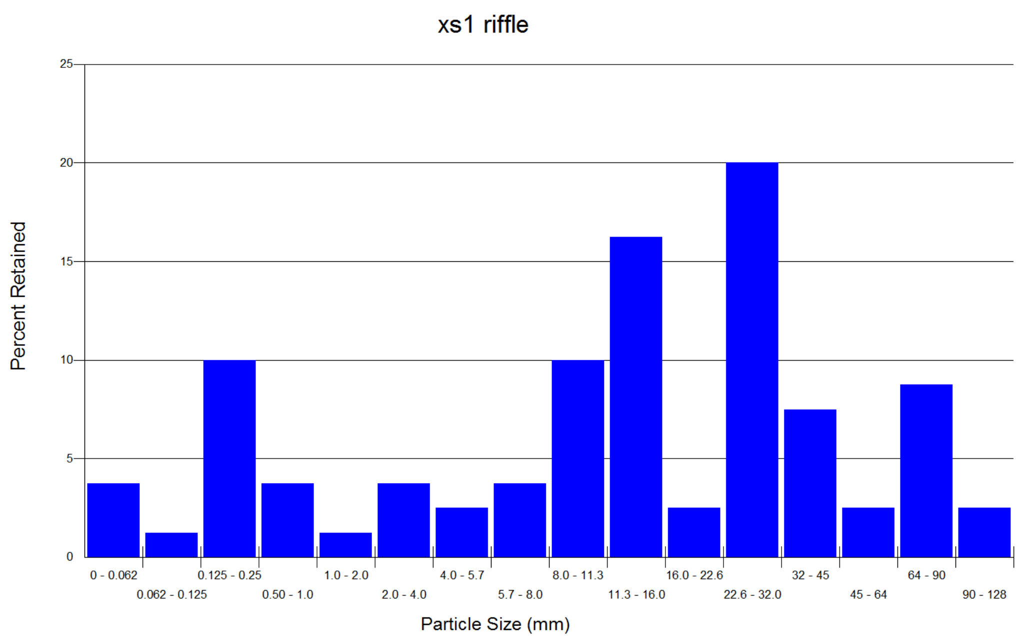


Figure 4. Particle distribution at riffle cross section

A total of 5 banks were observed contributing sediment to the stream in this 311 ft. survey. The erosion rate of the reach is categorized as *moderately unstable*; total erosion is estimated to be 0.016 tons/yr/ft, or 5 tons/yr. (Table 2). Dense and diverse vegetation in the riparian area is stabilizing the streambank and reducing erosion.

Table 2. Streambank erosion stability categories, adapted from Rosgen 2014

	Stable	Moderately Unstable	Unstable	Highly Unstable
Streambank Erosion Rate (tons/yr/ft)	<0.006	0.006 - 0.04	0.041 - 0.07	> 0.07

SID Implications

E stream types are low width to depth channels with high sediment transport capacity, but in the surveyed reach incision and fine sediment build up are indications of instability. Incision may be a result of past land use changes, but the effects are mitigated by the access to a narrow floodplain and dense vegetation protecting banks. Fine sediments are likely from upstream sources, as the reaches above and below the surveyed site have little streambank erosion. Potential sources are areas upstream with intense grazing along the channel that show signatures of higher sediment input (Figures 5 and 6).

Figure 5. Example of a grazed area of the stream with signatures of erosion

Figure 6. Example of a grazed area of the stream with signatures of erosion

Overall, evidence points to the Wildcat Creek being in a moderately stable condition. In addition, the MPCA biological station just upstream of the geomorphic survey has an index of biological integrity score of *fair* for both fish and invertebrates. In this case, riparian vegetation management would be the recommended strategy for protection of Wildcat Creek. Protection efforts would likely be most effective by focusing on reducing the number and intensity of grazed areas to maintain and improve riparian vegetation and channel stability.

References

Rosgen, Dave. 2014. River Stability Field Guide. Second Edition. Wildland Hydrology. Fort Collins, CO.

United States Geological Survey. StreamStats 4.0. Accessed April 20, 2017 from https://streamstatsags.cr.usgs.gov/streamstats/

Wildcat Creek. Google Earth. Accessed April 12, 2018

Crooked Creek Geomorphic Summary for Stressor Identification Support

DEPARTMENT OF NATURAL RESOURCES

ECOLOGICAL AND WATER RESOURCES – CENTRAL REGION

June 2018

Introduction

To support the Minnesota Pollution Control Agency's efforts in developing a Watershed Restoration and Protection Strategies (WRAPS) framework, a muli-year geomorphic sudy was started in 2015. Many geomporhic study sites were established, with multiple sites repeated over a 3 year span (Figure 1). This report will act as a summary of findings, and to address specific biological impairments within Crooked Creek (within Mississippi River Reno) only. There are three biological impairments to be addressed in this watershed. A more robust watershed asessment report will be completed at a later date utililizing the Watershed Assessment of River Stability and Sediment Supply (WARSSS) framework.

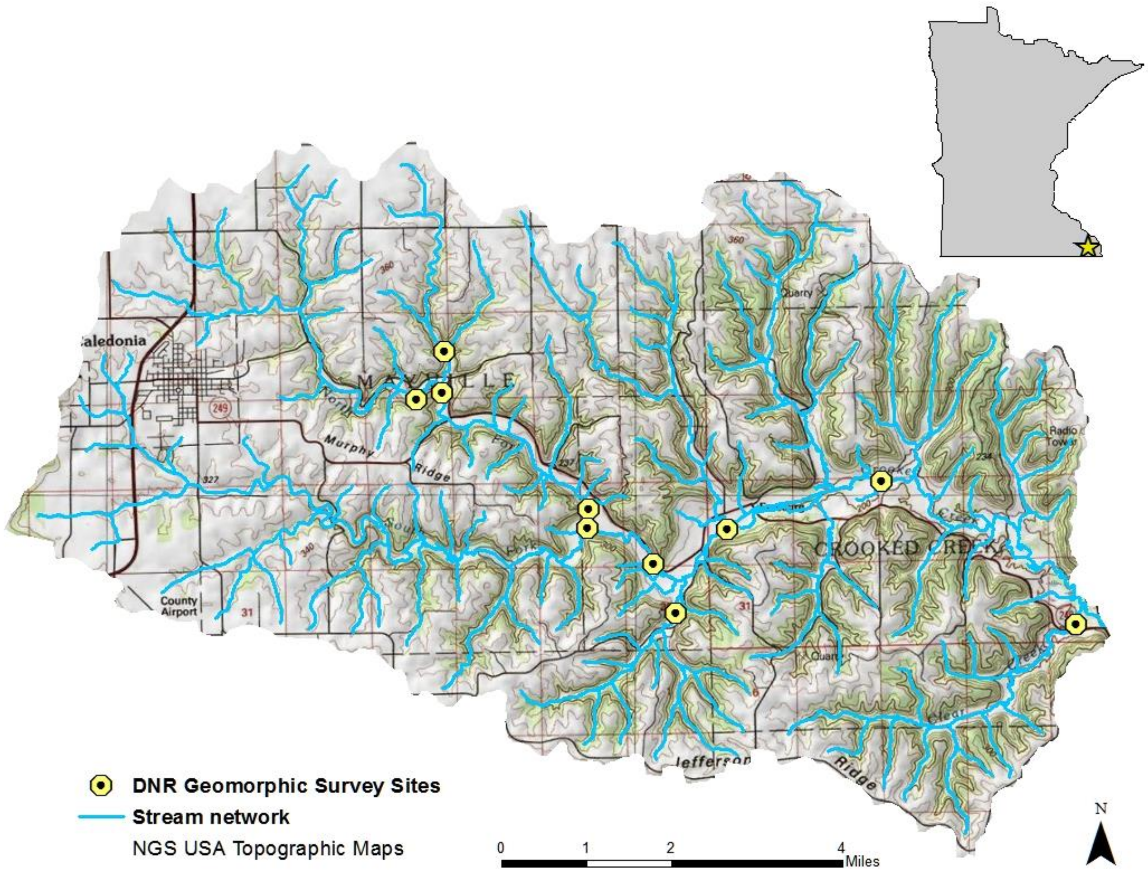


Figure 1. Crooked Creek geomorphic study sites and location of watershed within the state

Clear Creek

Clear Creek is a 5.8mi² tributary to Crooked Creek, near the confluence with the Mississippi River near Reno (Figure 2). Majority of the land use in the catchment is forest (55%) followed by shrub and herbaceous (35%). Only 4% is in cultivation and another 4% in hay and pasture. The perennial channel begins at a spring, then runs through a straightened section of about 2,500 feet in length. Utilizing LiDAR, there appears to be a berm or levee along this straightened section to contain flows, presumably to protect one of the few areas of row crop in the catchment before flowing through pasture until the confluence with Crooked Creek. The geomorphic survey took place in June 2015, just downstream of the County Road 249 crossing in a rotationally grazed area. At the survey reach, the stream is classified as an E6 stream type with a median particle size of 0.14 mm (Table 1). The particle materials are silt and sand, which is consistent with the parent soil materials of the catchment being silt loam. Pfankuch rating of *fair* was observed, with dominant negative characteristics being more than 50% of the bottom in state of change nearly yearlong and significant cuts into the banks. In some cases, imbedded fine particles is a sign of instability, however in this case small fine particles of the channel substrate are likely the natural materials from the catchment, according to soil layer information.

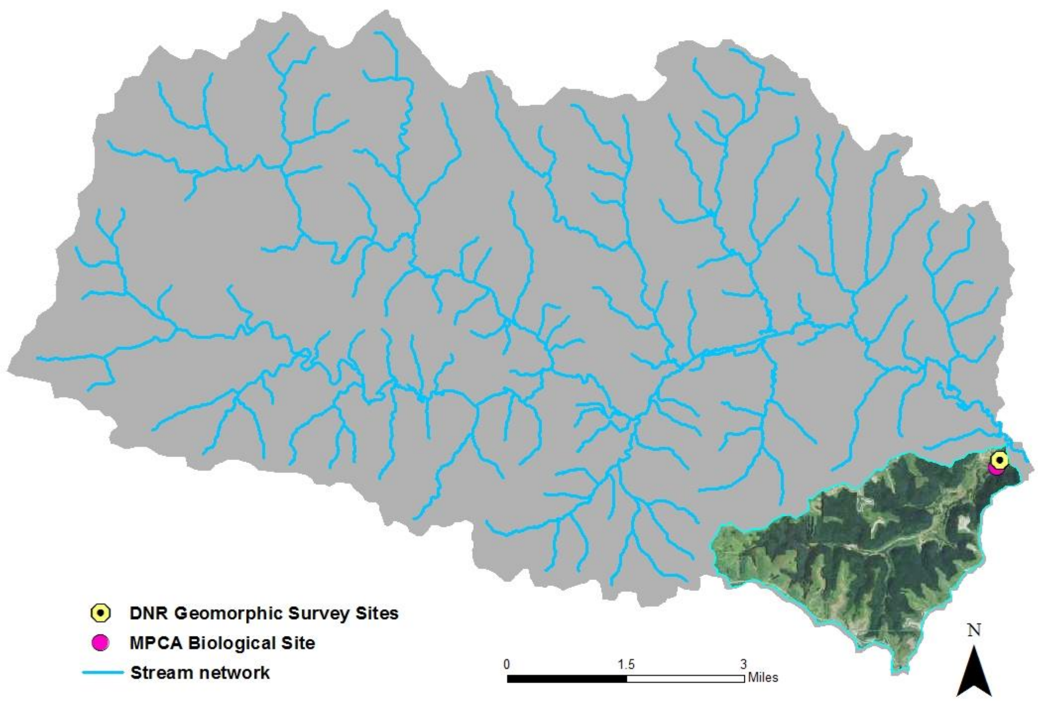


Figure 2. Clear Creek sub-watershed with location of MPCA biological site and DNR geomorphic site, in reference to entire Crooked Creek watershed

Table 1. Geomorphic data for survey located on Clear Creek

Survey Results			
Stream Type	E6	**Bankfull velocity (fps)**	2.06
Valley Type	U-AL-FD	**Bankfull discharge (cfs)**	40.85
Sinuosity	1.4	**Riffle D50 (mm)**	0.14
Water Slope	0.0022	**Mean Riffle Depth (ft)**	1.81
Bankfull Width	10.95	**Max Pool Depth (ft)**	3.61
Entrenchment Ratio	42.92	**Bank Erosion Estimates (tons/yr/ft)**	0.0173
Width/Depth Ratio	6.05	**Pfankuch Stability Rating**	Fair
Bankfull Area (ft^2)	19.81	**Competence Condition**	NA

Incision is a lowering of the channel elevation which increases the risk for accelerated bank erosion. Bank height ratio is the lowest bank height divided by the maximum depth at bankfull, which is a measure of incision. Figure 3 illustrates the amount of incision. Averaging the the entire bank height ratio of the profile is 1.27, or falls within the category of *slightly incised*. Floodprone width describes the amount of flooplain at elevations 2x bankfull depth. At this elevation clear creek has access to 470 feet of floodplain, which reduces streambank sheer stress by allowing the stream to spread out during flood events.

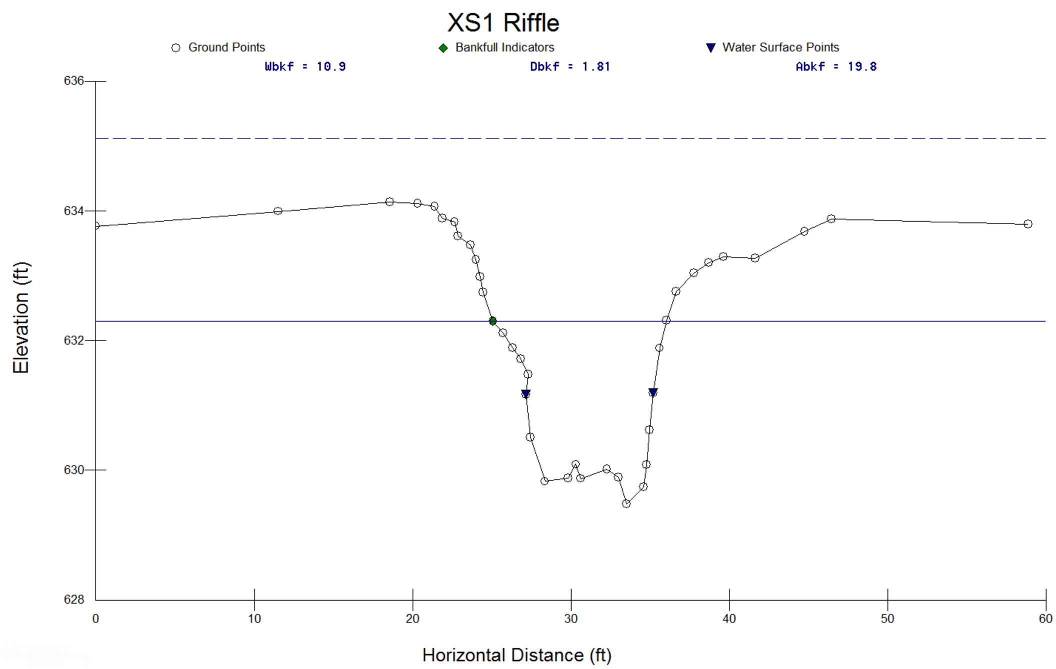


Figure 3. Cross section of riffle showing bankfull elevation (solid line) and flood prone elevation (dashed line)

A total of 8 eroding banks were observed in this reach. The erosion rate is categorized as *moderately unstable*, at a rate of 0.0173 tons/yr/ft (Table 2). Bank erosion is exacerbated by the incision mentioned above, but reduced by thick vegetation along channel.

Table 2. Streambank erosion stability categories, adapted from Rosgen 2014

	Stable	Moderately Unstable	Unstable	Highly Unstable
Streambank Erosion Rate (tons/yr/ft)	<0.006	0.006 - 0.04	0.041 - 0.07	> 0.07

SID Implications

Invertebrates at the biological station were not meeting the biological standards. As part of the larger Watershed Assessment of Crooked Creek, the geomorphic site at Clear Creek overall stability rating was completed utilizing lateral, vertical and channel enlargement categories. The overall stability rating is *moderate*, meaning the channel is relatively stable unless further alterations occur. Although the channel at the geomorphic site is relatively stable, there are items to be considered for the low biological index score. The channel bed is dominated by the natural soil materials of fine sand and silt, which in E stream types minimizes the habitat diversity for macroinvertebrates. In between the MPCA and DNR site is County 249, a four culvert crossing with the upstream side concreted in. The overall width of the crossing is 35 feet, while the bankfull width of the channel is around 11 feet, leading to over widening of the channel near the crossing. Unfortunately pictures and notes for the crossing were lost, but the four culvert overwide set-up may have potential to inhibit biological connectivity. This could prevent fish and invertebrates traveling from Mississippi River and Crooked Creek from reaching further upstream of Clear Creek at low flows.

South Fork Crooked

South Fork Crooked Creek drains approximately 16mi² with land use of 40% cultivated, 23% shrub and herbaceous, 19% forested and 7% hay and pasture. There is a large impoundment on this tributary, known as R3 Pool which holds water back for the upper 14.5 mi². There is approximately 1.4 miles of stream below the impoundment to the confluence with Crooked Creek. A geomorphic survey took place on this stretch, at the same location of the biological site, in June 2015 (Figure 4).

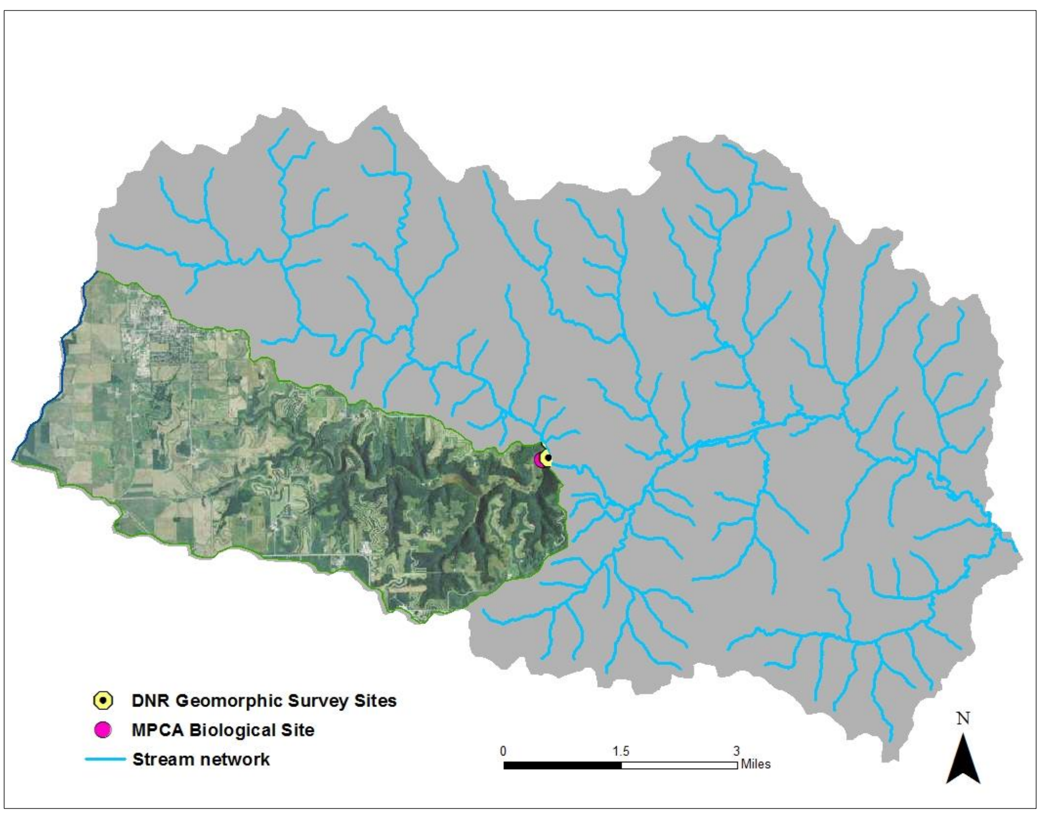


Figure 4. Location of DNR geomorphic survey and MPCA biological site in south Fork Crooked, in reference to entire Crooked Creek watershed

The channel is classified as a C3 stream type with a median pebble size of 88mm, or cobble size (Table 3). Water surface slope is 0.005 with a sinuosity of 1.15. A Pfankuch rating of *good* was observed. All stability categories within the Pfankuch rating were in the excellent and good categories. Erosion rate is considered to be *stable*, with an estimated rate at 0.0004 tons/yr/ft.

Table 3. Geomorphic summary for survey at South Fork Crooked

Survey Results			
Stream Type	C3	**Bankfull velocity (fps)**	1.95
Valley Type	U-AL-FD	**Bankfull discharge (cfs)**	37.34
Sinuosity	1.1	**Riffle D50 (mm)**	88
Water Slope	0.005	**Mean Riffle Depth (ft)**	1.07
Bankfull Width	17.96	**Max Pool Depth (ft)**	2.62
Entrenchment Ratio	3.91	**Bank Erosion Estimates (tons/yr/ft)**	0.0004
Width/Depth Ratio	16.79	**Pfankuch Stability Rating**	Good
Bankfull Area (ft^2)	19.14	**Competence Condition**	NA

Incision is a lowering of the channel elevation, potentially increasing the risk for accelerated bank erosion. Bank height ratio is a measure of channel incision, calculated by dividing the lowest bank height by the maximum at bankfull. The ratio of this survey is 1.0, which represents one aspect of channel stability and represents good connectivity to the floodplain for bankfull flows (Figure 5).

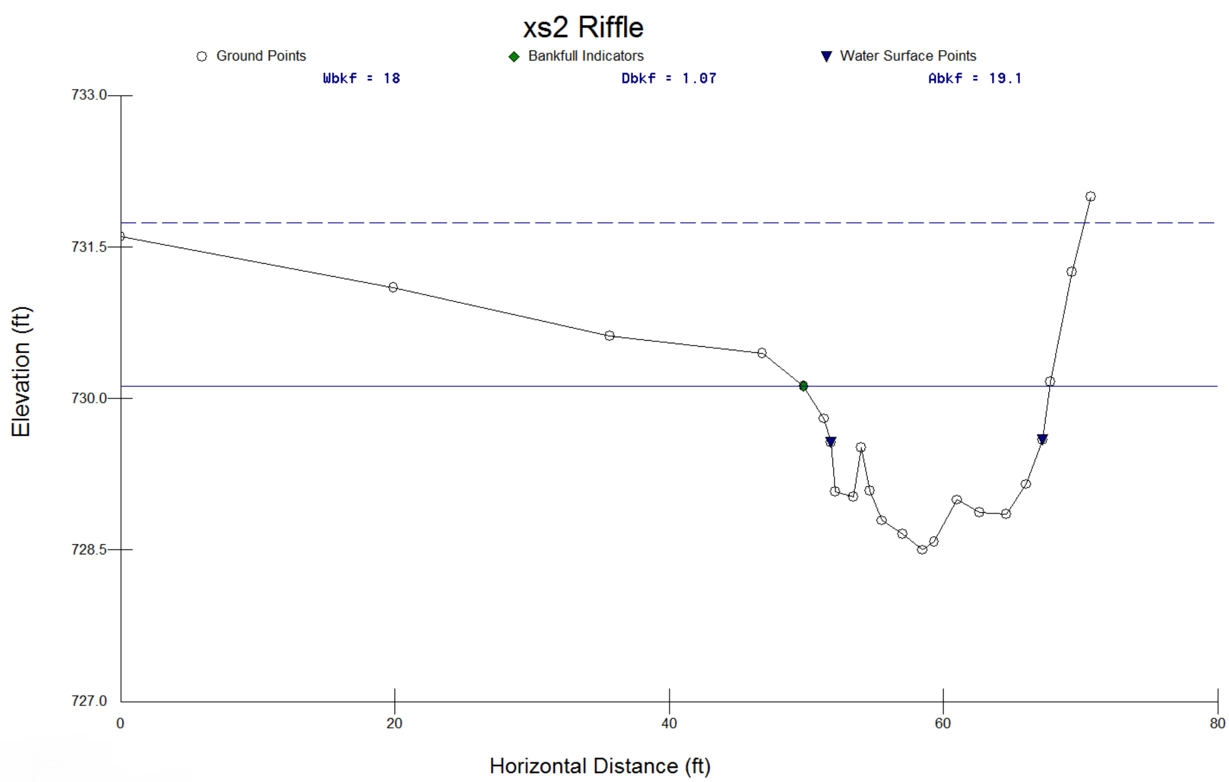


Figure 5. Cross section of riffle showing bankfull elevation (solid line) and flood prone elevation (dashed line) demonstrating the stable bank height ratio

SID Implications

Fish and macroinvertebrate biological score are not meeting standards at this reach. Evidence points to the reach being in a geomorphic stable condition and not a contributor to the biological impairments. Riffles and pools of this reach, along with large particles and aquatic vegetation aid in channel stability while also providing potentially good habitat Coarseness of the particles may however negatively impact fish habitat for spawning. An influence on this reach is the large R3 impoundment upstream. The impoundment is estimated to reduce 1,400 tons of sediment per year, and holds large amounts of water which creates a warm water fisheries. Flow alterations and water warming downstream likely have an impact on this reach.

Lower Main Stem Crooked Creek

The MPCA biological site drains approximately 60mi². Upstream land use primarily consists of 38% forest, 30% hay and pasture, and 20% cultivated. The closest geomorphic site is approximately 2 miles upstream, with the biological site having a larger drainage area by 6mi² (Figure 6). The sites however have very similar characteristics and in a similar place in the watershed.

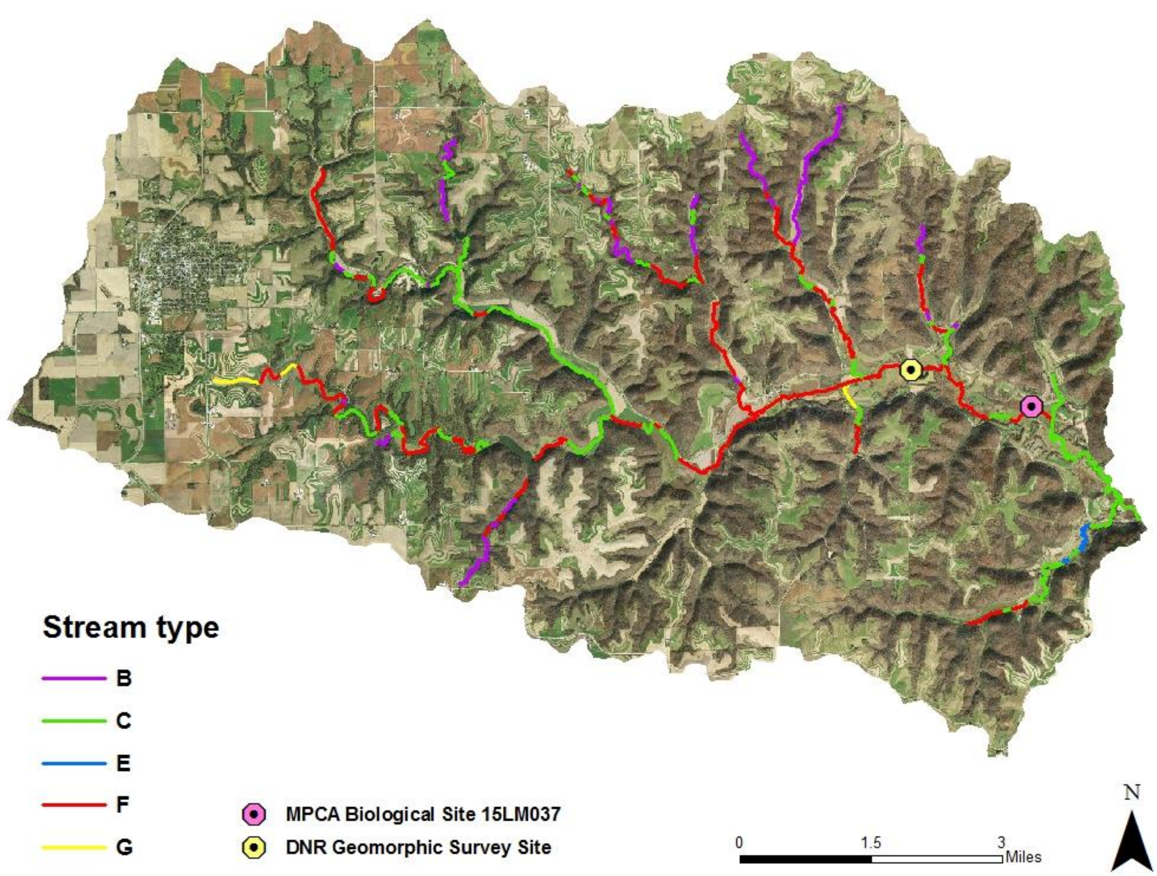


Figure 6. Lower main stem biological and geomorphic site, with stream typing of entire watershed

The channel at the geomorphic site is in a transition state and has ratios that conform to different stream types, pointing to some form of instability. Figure 7 highlights the current state and the likely physical changes the channel will take once the cause of channel instability has abated. The biological site is currently an F stream type.

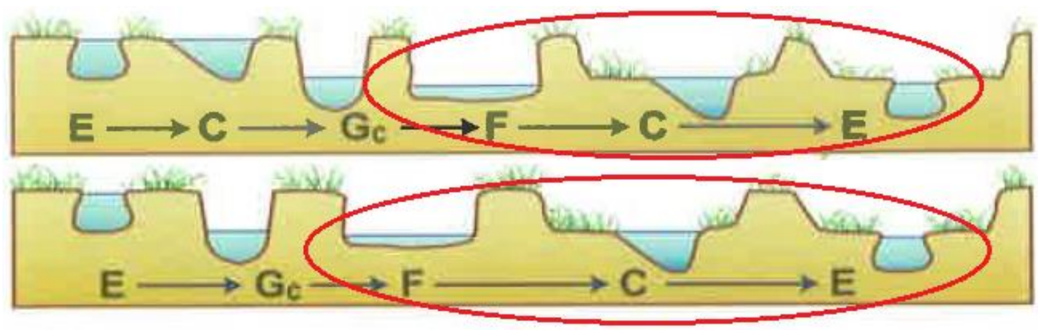


Figure 7. Possible stream succession scenarios and the current conditions highlighted in red

For both sites the channel materials are dominated by coarse sand. Entrenchment of the stream is categorized as *moderately entrenched* with deep incision, meaning flood flows are contained within the channel banks. The reach near the biological site is similar, however the bank heights are slightly lower, leading to a less incised state. Both sites go through pasture areas, with the geomorphic site appearing to be rotationally grazed and the biological site being more intensely grazed. Field estimated stream bank erosion rate of the geomorphic reach is 0.0196 tons/yr/ft, or a *moderately unstable* rate. Although the streambanks are lower in the biological reach, the grazing intensity exposes more bare streambanks leading to a higher predicted rate of 0.055 tons/yr/ft, considered an *unstable* rate. A Pfankuch rating of *poor* was observed, with excess deposition of fine particles, and channel bottom particles being in constant flux. These negative categories are related to the channel bottom particles being primarily coarse and fine sand.

There are two ways to determine if the channel is able to handle the sediment passing through the reach; competence and capacity. Competence determines if the stream has the ability to move the largest particle made available from upstream. In this case, the sand bed stream is assumed to be mobile at all flows. Flowsed/Powersed are models that predict sediment transport capacity based on channel dimensions, profile, sediment curves and bankfull flow. Flowsed/Powersed predicts aggradation of the streambed in the geomorphic reach, which would be very similar to the biological reach. LiDAR profile of Crooked Creek also supports the sediment transport prediction, as the sites are in the flattest part of the stream where there is less power to transport (Figure 8).

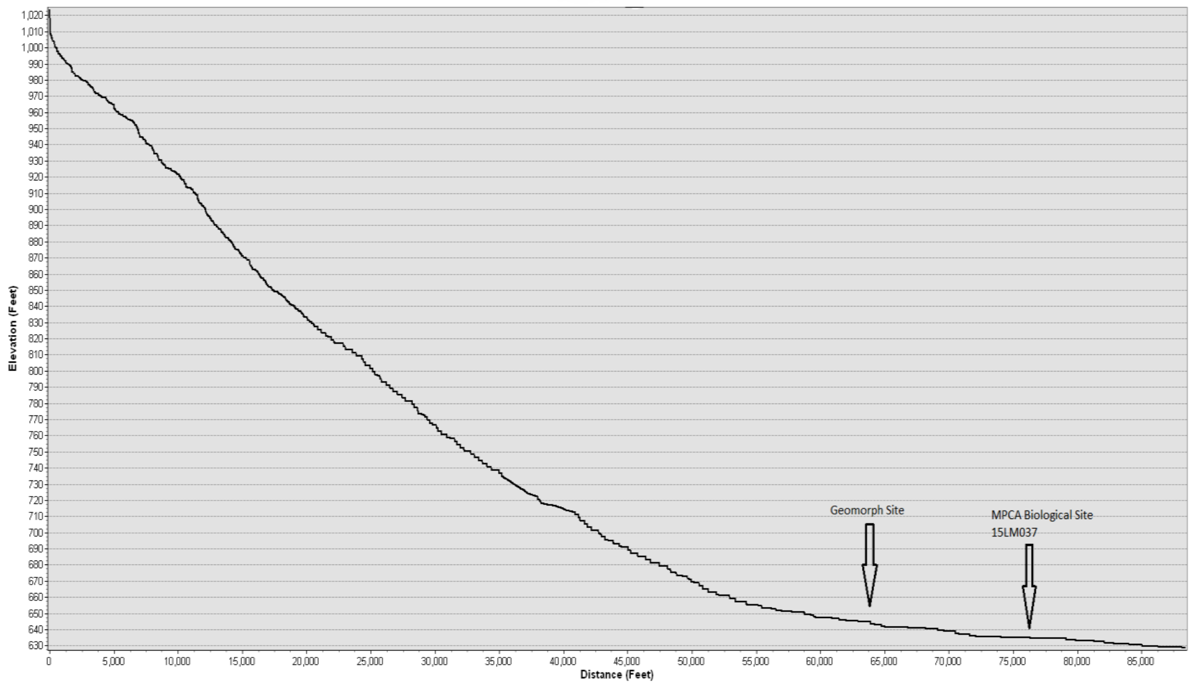


Figure 8. Crooked Creek longitudinal profile, with geomorphic and biological sites

SID Implications

The biological site is on the lower end of Crooked Creek, so it is important to look at the upstream condition and sediment contributions to the stream. As part of the larger WARSSS study, erosion rates were estimated for the different stream types and Pfankuch stability ratings. These rates were applied to like stream types and condition throughout the watershed to obtain streambank erosion estimates (Figure 9). To estimate surface erosion from the watershed an HSPF model created by Tetra Tech for MPCA was used, and estimates 12,033 tons/yr. The sediment supply sources for both hillslope and channel processes are shown in Table 4.

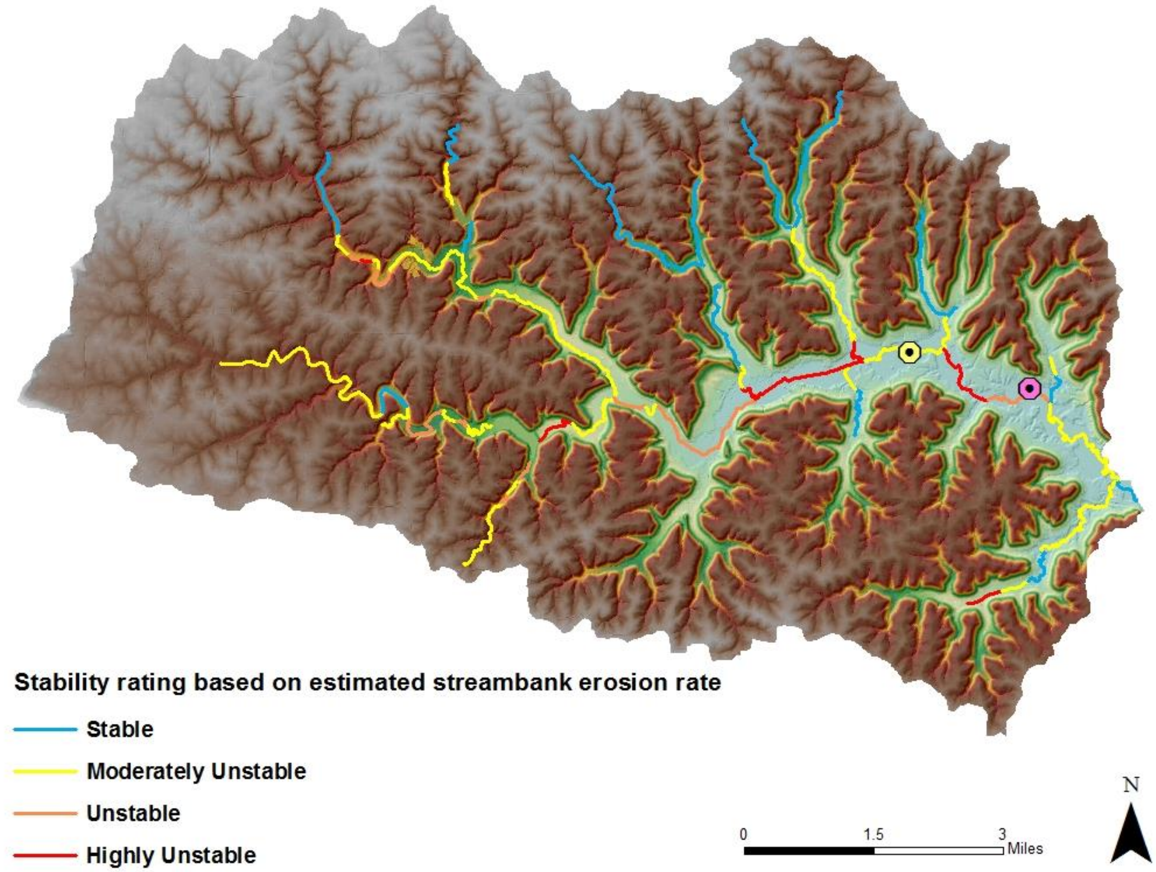


Figure 9. Streambank erosion rate stability categories

Table 4. Annual sediment sources and contribution for entire Crooked Creek watershed

Sediment Supply Process	Total Annual sediment (tons/yr)	Percent of Total Sediment Supply
Roads	20	0%
Streambanks	6,705	36%
Surface Erosion (HSPF)	12,033	64%

Sand dominated F channel stream types do not typically provide good diversity of habitat for macroinvertebrates. At the biological site (15LM027) upstream of 15LM033, channel conditions are similar, however the upstream site also contains downed woody material which likely contributes to more diversity of habitat for macroinvertebrates, thus no impairment (Figure 10).

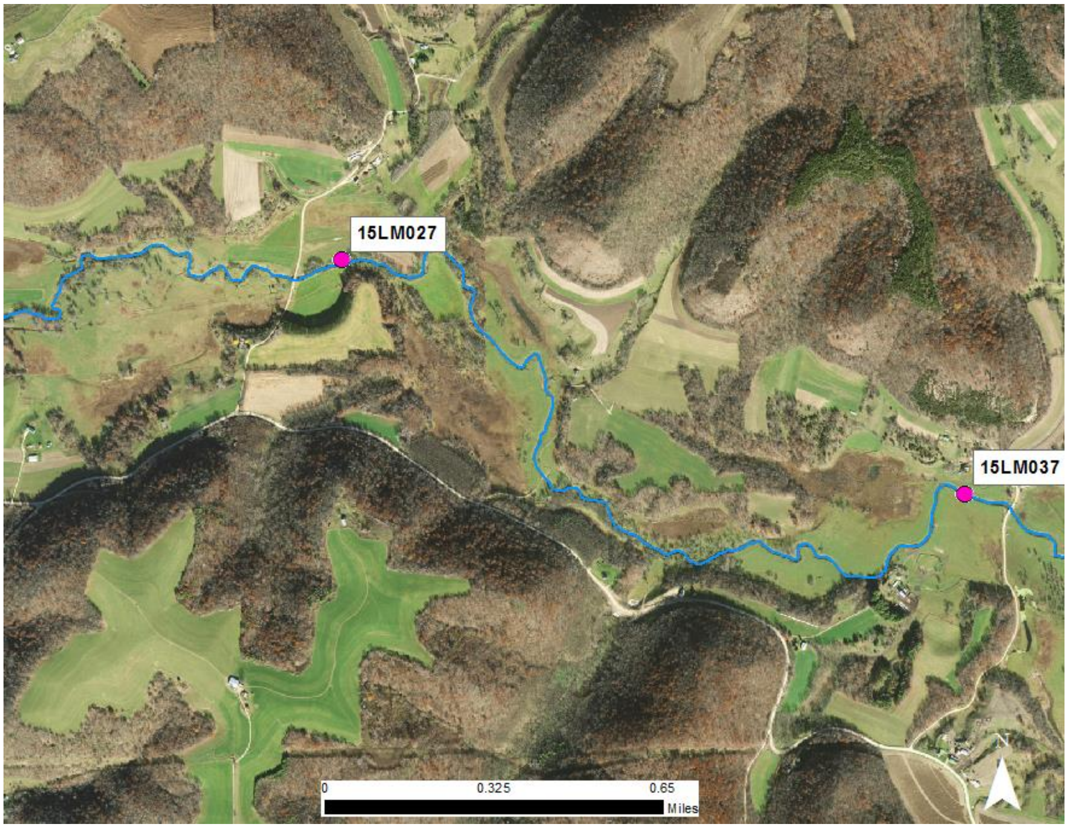


Figure 10. Location of biological sites, 15LM037 is not meeting macroinvertebrate standards while 15LM027 is supporting

Macroinvertebrate habitat could be improved by limiting upstream sources of excess sediment. Recovery of the channel or restoration could also improve the efficiency of sediment transport, as current dimensions are leading to sediment aggradation. The Mississippi River backwater may also have an effect on the biological reach. These effects are unknown, aside from a temperature transition from cold to warm water near the biological site.

References

Rosgen, Dave. 2014. River Stability Field Guide. Second Edition. Wildland Hydrology. Fort Collins, CO.

MNDNR Geomorphology Site Level Summary for Unnamed Creek; A tributary to Beaver Creek

Geomorphic survey near 15LM015

A geomorphology survey (June 2016) was performed near MPCA biological site 15LM015. The site was on a tributary of Beaver Creek in a section of Beaver Creek WMA, located just north of 120th Street in Fillmore County at Lat 43°31'53.55"N Long 92°24'0.76"W (Figure 1). Initial biological monitoring shows the macro invertebrates not meeting the threshold. The stream has a drainage area of 4.2mi² with approximately 78% cultivated, 8% shrub and herbaceous, 8% developed and 5% forested (MN WHAF tool 2017). The channel is classified as an F5 stream type with a median pebble size of 1.98 mm at the riffle (Table 1). Median pebble size and "5" in F5 refer to the dominate material of coarse sand. The reach has a water surface slope of 0.0015 and a sinuosity of 1.5. A Pfankuch rating of *poor* was observed. Dominant characteristics affecting the rating include deposits of predominately fine particles, lack of stable materials in the channel bottom, and scouring and deposition.

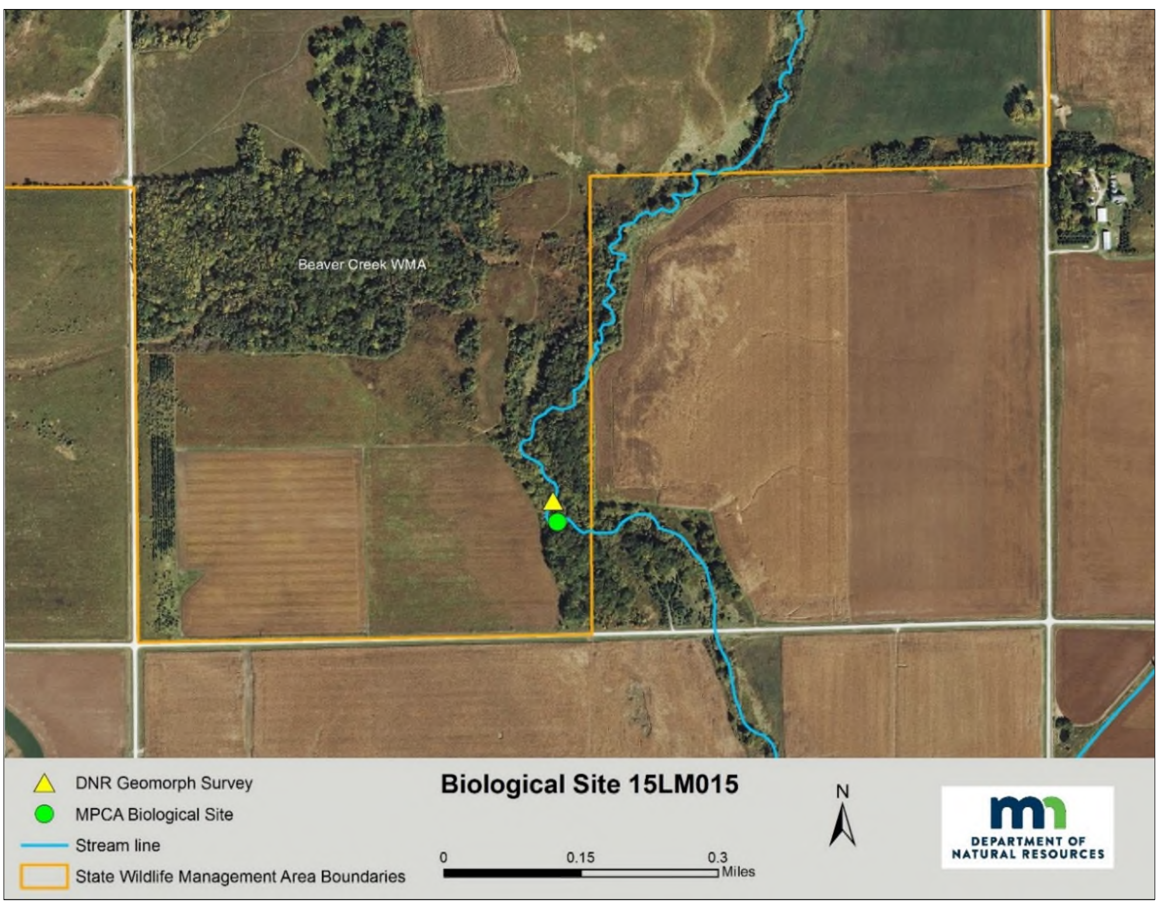


Figure 1. Location of DNR geomorphic survey and MPCA biological site

Table 1. Geomorphic data summary for survey

Survey Results			
Stream Type	F5	**Velocity (fps)**	2.13
Valley Type	C-AL-FD	**Discharge (cfs)**	43.95
Sinuosity	1.5	**Riffle D50 (mm)**	1.98
Water Slope	0.0015	**Mean Riffle Depth (ft)**	1.06
Bankfull Width	19.47	**Max Pool Depth (ft)**	2.76
Entrenchment Ratio	1.13	**Bank Erosion Estimates (tons/yr/ft)**	0.044
Width/Depth Ratio	18.37	**Pfankuch Stability Rating**	Poor
Bankfull Area (ft^2)	20.61	**Competence Condition**	NA

Bank height ratio is the lowest bank height divided by the maximum depth at bankfull, which is a measure of incision. Figure 2 shows this ratio of 2.4 at the riffle with the reach averaging 1.9, for a rating of *deeply incised*. Flows contained within the banks creates higher shear stress and may contribute to higher streambank erosion. Entrenchment ratio (floodplain width/bankfull width) of 1.13 shows that at flood flows the channel is not connected to the floodplain.

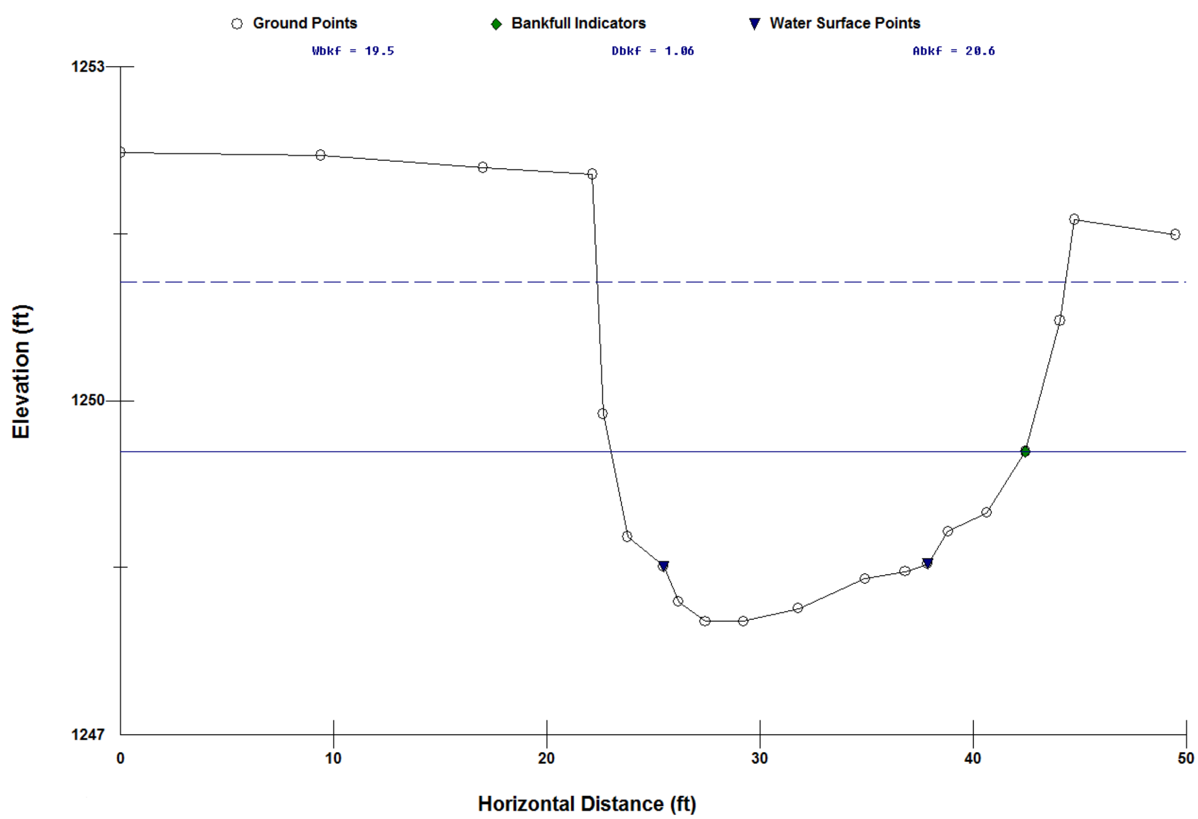


Figure 2. Cross section of riffle, showing bankfull (solid line) and flood prone elevations (dashed line)

The longitudinal profile is 410 feet and contains 4 riffles and pools (Figure 3). The maximum depth of pools to mean depth at the riffle is greater than 2. Reference pool depth ratios are usually 2 or greater, showing evidence of good pool habitat. Slope immediately upstream (measured from LiDAR) is about 0.003, or twice the surveyed reach slope, which may be supplying stream power to maintain pools.

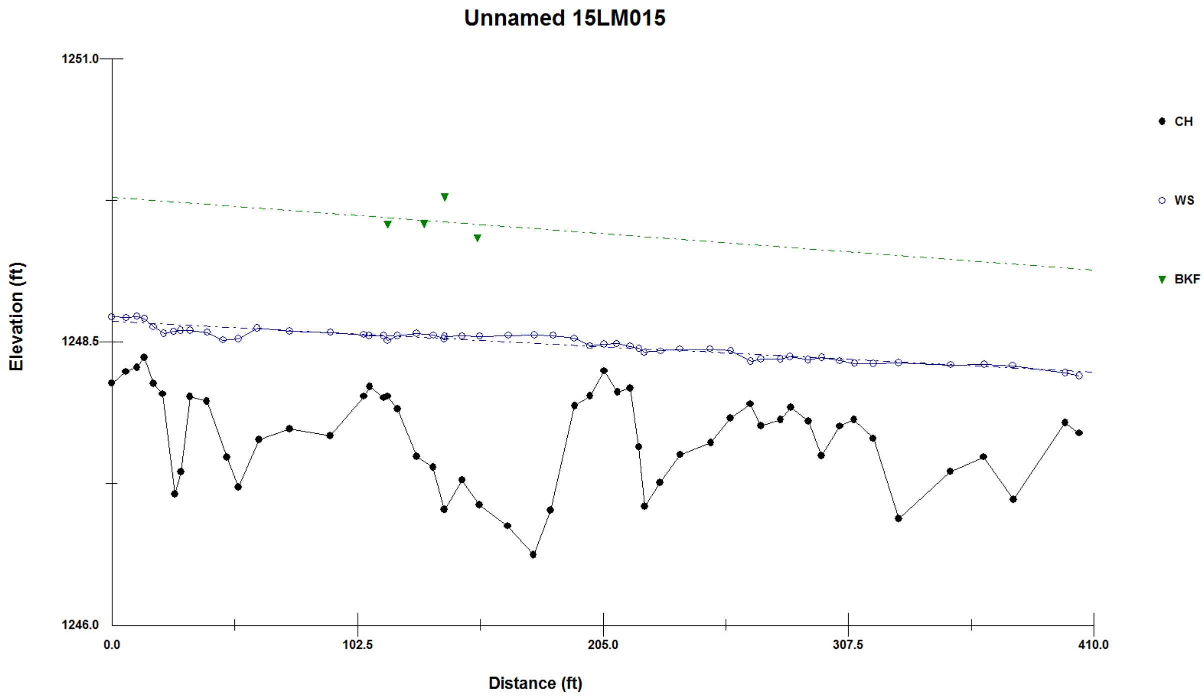


Figure 3. Longitudinal profile of survey

A total of 10 eroding banks were observed in this 410ft. survey. The erosion rate on this reach is categorized as *unstable*, at a rate of 0.044 tons/yr/ft (Table 2 and Figure 4). Bank erosion is high due the incision seen in Figure 2, and the instability of an F stream type in this valley type.

Table 2. Streambank erosion stability categories, adapted from Rosgen 2014

	Stable	Moderately Unstable	Unstable	Highly Unstable
Streambank Erosion Rate (tons/yr/ft)	<0.006	0.006 - 0.04	0.041 - 0.07	> 0.07


Figure 4. Eroding bank within the surveyed reach

SID Implementations

The instability of the stream is likely a contributing factor in the macroinvertebrate impairment found at this site. Utilizing LiDAR, there appears to be a transition from a narrow steep stream, to a wider and flatter slope just above the geomorphic survey location (Figure 5). Seen in the longitudinal profile from LiDAR, it is indicative of a head cut moving upstream through the survey location at about 1,200 feet (Figure 6).

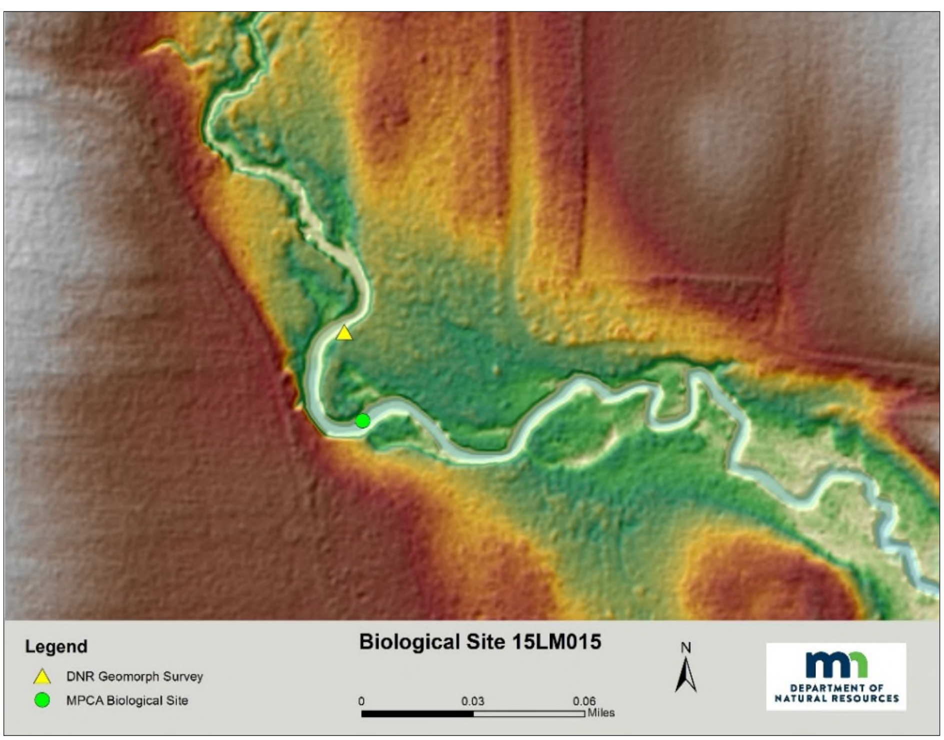


Figure 5. LiDAR image showing transitioning from narrow to wide channel

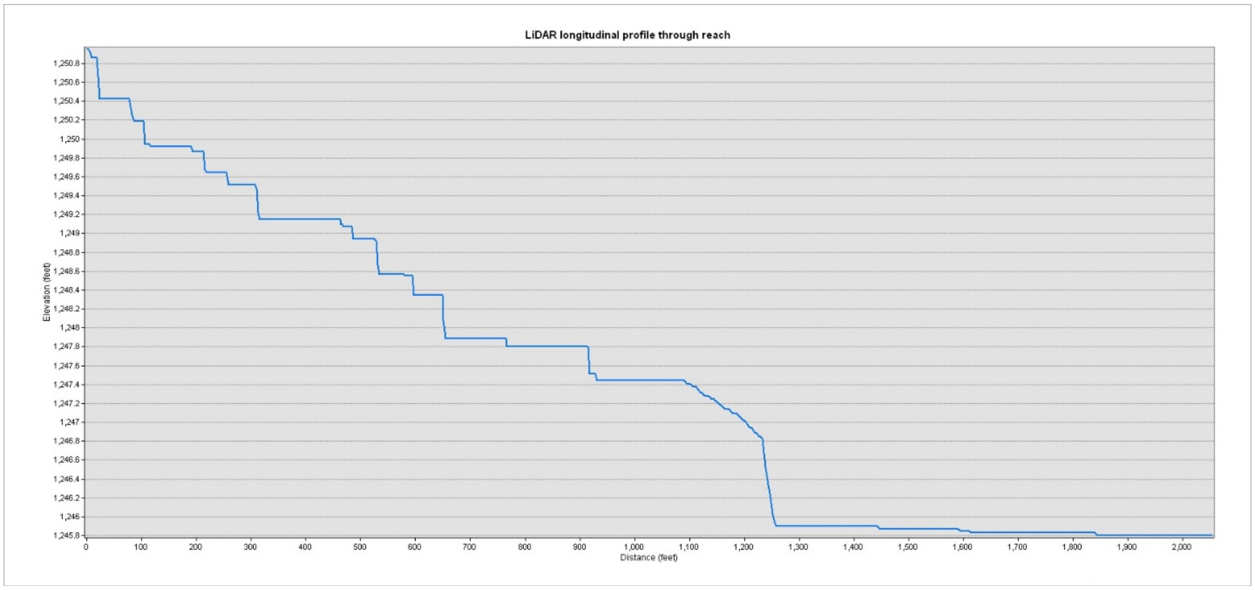


Figure 6. Longitudinal profile from LiDAR, roughly corresponding to stream distance seen in figure 4 with showing gradient changes corresponding with widening of stream

There are two stream succession scenarios that apply to this situation (Figure 7).

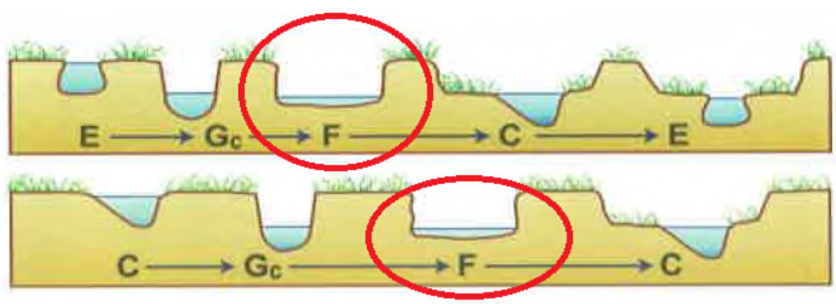


Figure 7. Stream succession scenarios and current stream type

The stream above the survey reach is possibly a stable E or C stream, then down cutting to the unstable F seen in the survey. Final stable stream type is an E or a C, but in either scenario the channel currently in an unstable form. In this unstable form, as a function of width to depth, the channel is unable to effectively transport sediment. This causes fine sediment build-up, contributing to lack of habitat for macroinvertebrates. The channel will continue to adjust until the more stable C and E stream types are reached. The cause of the down cutting would need to be understood to recommend management strategies.

References

Minnesota Department of natural resources. Watershed Health Assessment Framework. Accessed 3/28/17 http://www.dnr.state.mn.us/whaf/index.html

Rosgen, Dave. 2014. River Stability Field Guide. Second Edition. Wildland Hydrology. Fort Collins, CO.

Beaver Creek: MNDNR Geomorphology Site Level Summary

Geomorphic survey near 15LM016

Beaver Creek (tributary to Upper Iowa River) geomorphic survey near MPCA biological site 15LM016 occurred June 2016 within Beaver Creek Wildlife Management Area, just east of 121st Avenue in Fillmore County at Lat. 43°31'32.53"N Long. 92°24'26.41"W (Figure 1). Initial findings show no impairment based off of biological sampling. The site has a drainage area of $18mi^2$ and is part of a watershed with land use that consists of 80% cultivated, 9% shrub and herbaceous, 4% forest, and 6% developed. The channel is classified as an E4 stream type with a median pebble size of 6.6 mm at the riffle, or small gravel (Table 1). Water surface slope of 0.0012 and a sinuosity of 1.7. The stream has access to a floodplain with diverse vegetation. A Pfankuch rating of fair was observed, close to a poor rating. Dominant characteristics affecting the rating include deposits of fine material and scouring and deposition at obstructions with some filling of pools.

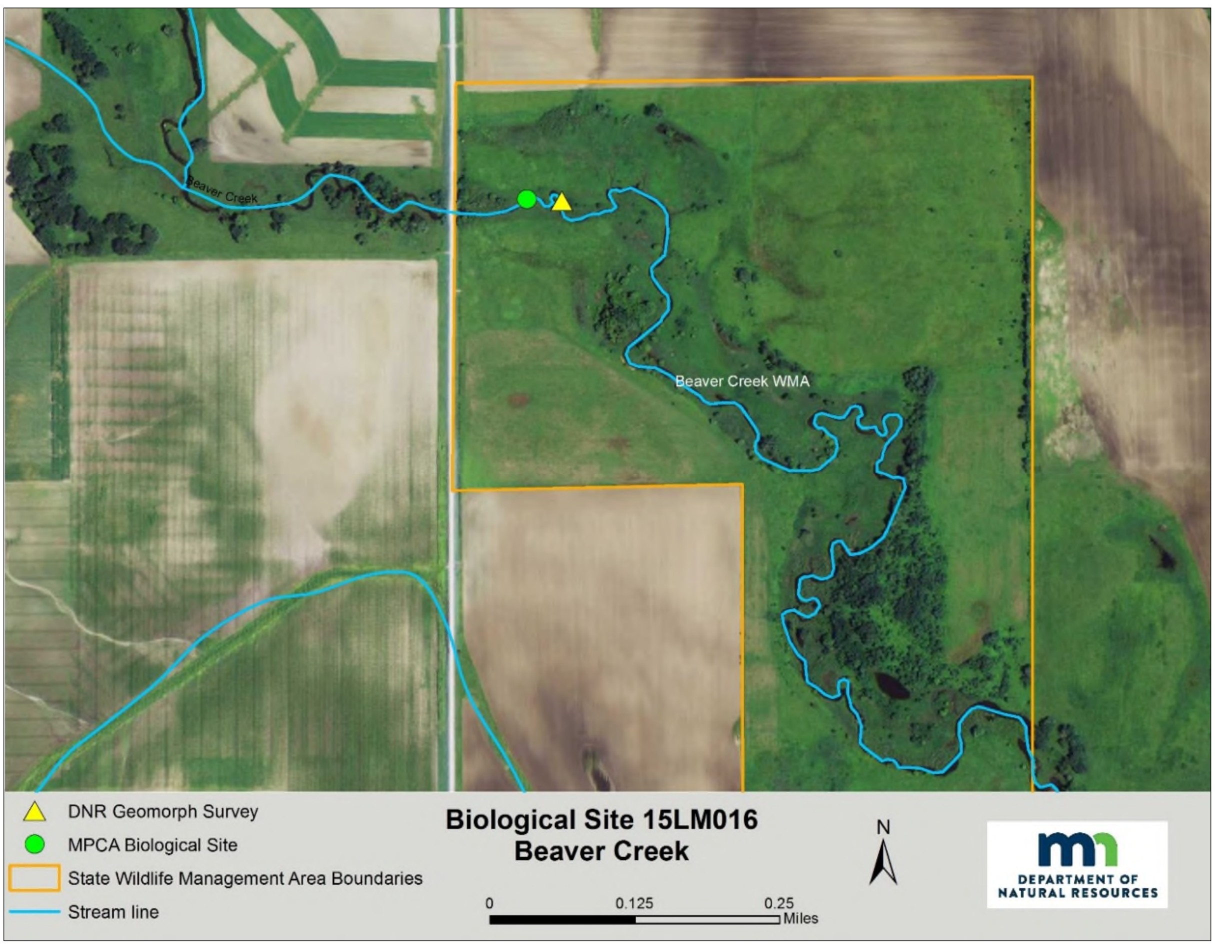


Figure 1. Location of DNR geomorphic survey and MPCA biological site

Table 1. Geomorphic data summary for survey on Beaver Creek

Survey Results			
Stream Type	E4	**Velocity (fps)**	3.14
Valley Type	U-AL-FD	**Discharge (cfs)**	99.36
Sinuosity	1.7	**Riffle D50 (mm)**	6.6
Water Slope	0.0012	**Mean Riffle Depth (ft)**	2.15
Bankfull Width	14.75	**Max Pool Depth (ft)**	3.52
Entrenchment Ratio	8.14	**Bank Erosion Estimates (tons/yr/ft)**	0.026
Width/Depth Ratio	6.86	**Pfankuch Stability Rating**	Fair
Bankfull Area (ft^2)	31.68	**Competence Condition**	NA

Bank height ratio is the lowest bank height divided by the maximum depth at bankfull, which is a measure of incision. Figure 2 shows a bank height ratio of 1.1, or *slightly incised*. Floodprone width describes the amount of flooplain at elevations 2x bankfull depth. At this elevation the stream has access to a broad floodplain of 120 feet, allowing the stream to spread out stream power onto its floodplain.

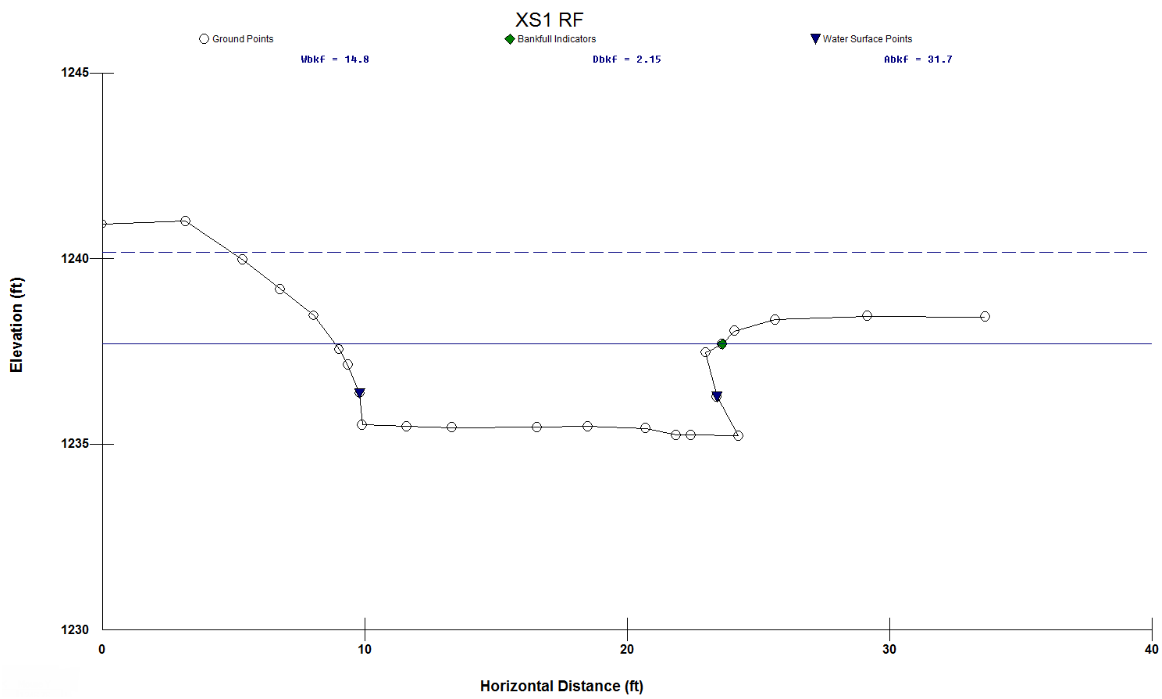


Figure 2. Cross section of riffle showing bankfull elevation (solid line) and flood prone elevation (dashed line)

The longitudinal profile is 511 feet and contains 4 riffles and 4 pools (Figure 3). Pool depths and spacing between pools is within range for stable dimensions for the stream type.

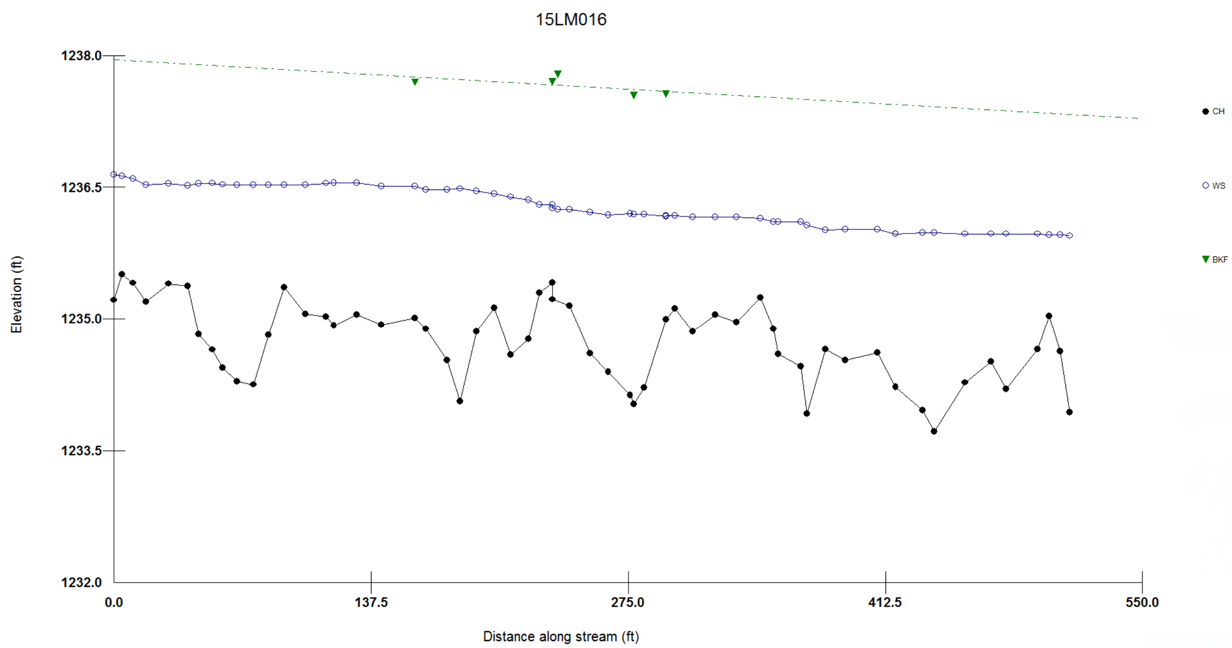


Figure 3. Longitudinal profile of survey

Pebble count at the riffle cross section reveals a bi-modal distribution. Although there is a median particle size of 6.6mm, there is distribution peaks at 16mm and 1mm (Figure 4). This points to gravel size materials being inundated by finer particles.

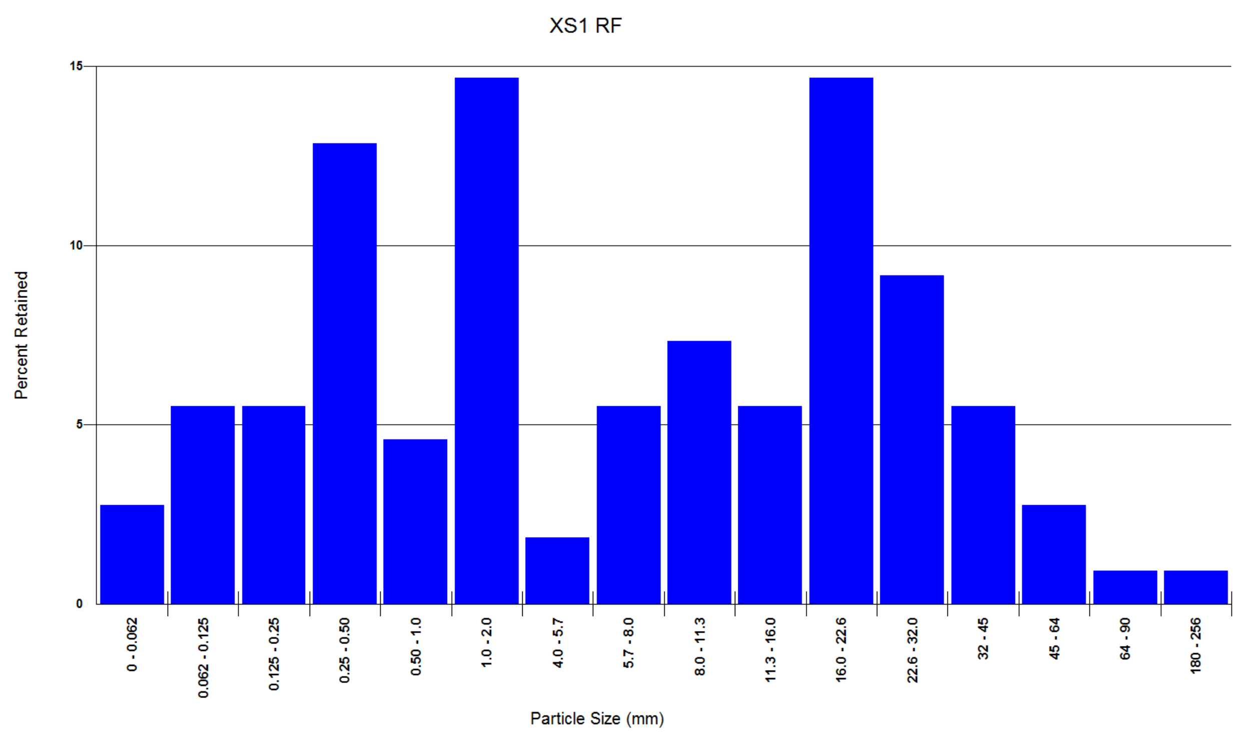


Figure 4. Particle distribution at riffle cross section

A total of 8 banks were observed to be contributing sediment to the stream in this 511 ft. survey. The reach is categorized as *moderately unstable*; total erosion rate is estimated to be 0.026 tons/yr/ft (Table 2). Stream banks are stabilized by dense vegetation. Aerial photo comparison from 1991 to 2015 support the lower erosion rate, showing very little movement (Figure 5). Riparian and upland vegetation have expanded from row crop to a more natural state since 1991, enhancing protection of the stream.

Table 2. Streambank erosion stability categories, adapted from Rosgen 2014

	Stable	Moderately Unstable	Unstable	Highly Unstable
Streambank Erosion Rate (tons/yr/ft)	<0.006	0.006 - 0.04	0.041 - 0.07	> 0.07

Figure 5. 1991 (left) and 2013 (right) aerial photograph, showing little stream movement and increase in perennial cover

SID Implications

Geomorphic evidence of a stable reach supports the initial biological monitoring showing no impairment. E4 stream types have low width to depth ratios resulting in high sediment transport abilities. These stream types are also resistant to change unless vegetation, sediment supply, or streamflow alterations occurs. In this case, dense vegetation is aiding the stream in maintaining a low width to depth. Although Pfankuch Stability Rating and pebble counts show signatures of fine sediments, the stream reach contains deep pools and has no build-up of bars. As long as vegetation remains intact, and streamflow and sediment supply remain static, this stream reach should remain stable to moderately stable.

References

Rosgen, Dave. 2014. River Stability Field Guide. Second Edition. Wildland Hydrology. Fort Collins, CO.

Upper Iowa River: DNR Geomorphology Site Level Summary

Geomorphic survey near 15LM024

A geomorphology survey was performed (June 2016) downstream of macro-invertebrate impaired MPCA biological site 15LM024, south of 140th street and about 1 mile east of Highway 56 at Lat. 43°33'27.98"N Long. 92°35'15.19"W (Figure 1). The site has a drainage area of 8.6mi². Major land use consists of 89% cultivated and 1% forested (StreamStats 4.0, 2017). Within the reach surveyed, the channel is classified as an E6 stream type with a median particle size of 0.06mm at the riffle (Table 1). Particles are comprised of silt and sand material, consistent with floodplain alluvium soil layer, as described in Minnesota Surficial Geology (2017). This means that the sand/silty material present, is what should be expected given the soils in the area. The reach has a water surface slope of 0.00078 and a sinuosity of 1.4, typical of "meandering E" stream types. Dominant channel characteristics include continuous cuts and overhangs, deposition of fine particles and lack of stable materials, resulting in a poor Pfankuch rating.

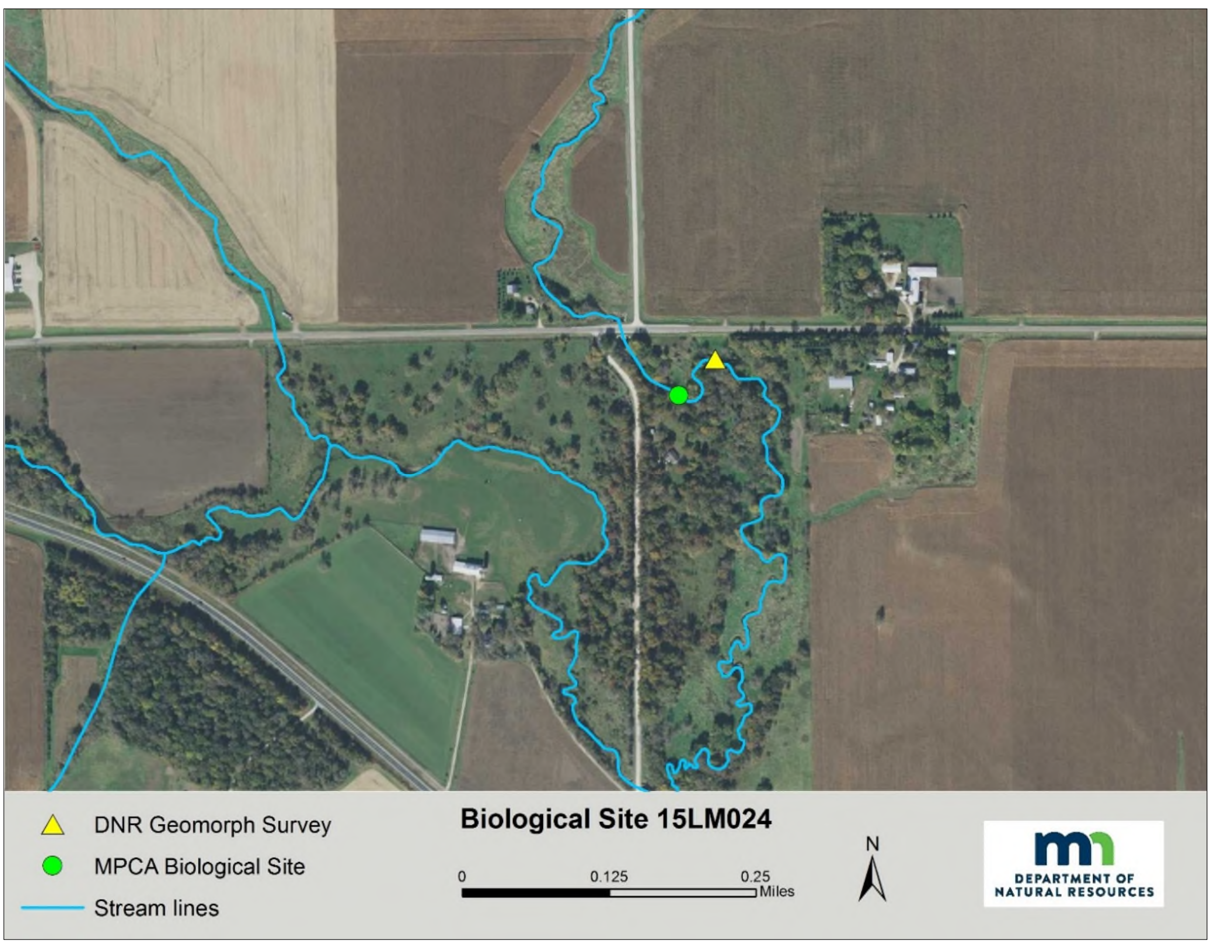


Figure 1. Location of DNR geomorphic survey and MPCA biological site

Table 1. Geomorphic survey data summary.

Survey Results			
Stream Type	E6	**Velocity (fps)**	2.5
Valley Type	U-AL-FD	**Discharge (cfs)**	65.3
Sinuosity	1.4	**Riffle D50 (mm)**	0.06
Water Slope	0.00078	**Mean Riffle Depth (ft)**	2.07
Bankfull Width	12.66	**Max Pool Depth (ft)**	4.35
Entrenchment Ratio	3.5	**Bank Erosion Estimates (tons/yr/ft)**	0.083
Width/Depth Ratio	6.12	**Pfankuch Stability Rating**	Poor
Bankfull Area (ft^2)	26.16	**Competence Condition**	NA

Bank height ratio is the lowest bank height divided by the maximum depth at bankfull, which is a measure of incision. The riffle cross section shows a bank height ratio of 1.2 while the reach has an average of 1.3 (Figure 2). The ratio rates on the border of *slightly* and *moderately incised.* Flows contained within the banks creates higher shear stress and may contribute to higher streambank erosion. Because of the incision, the bankfull call on the cross section was dependent on regional curves and very few bankfull signatures upstream. Entrenchment ratio (flooplain width/bankfull width) of 3.5 shows that at flood flows there is connectivity to the floodplain.

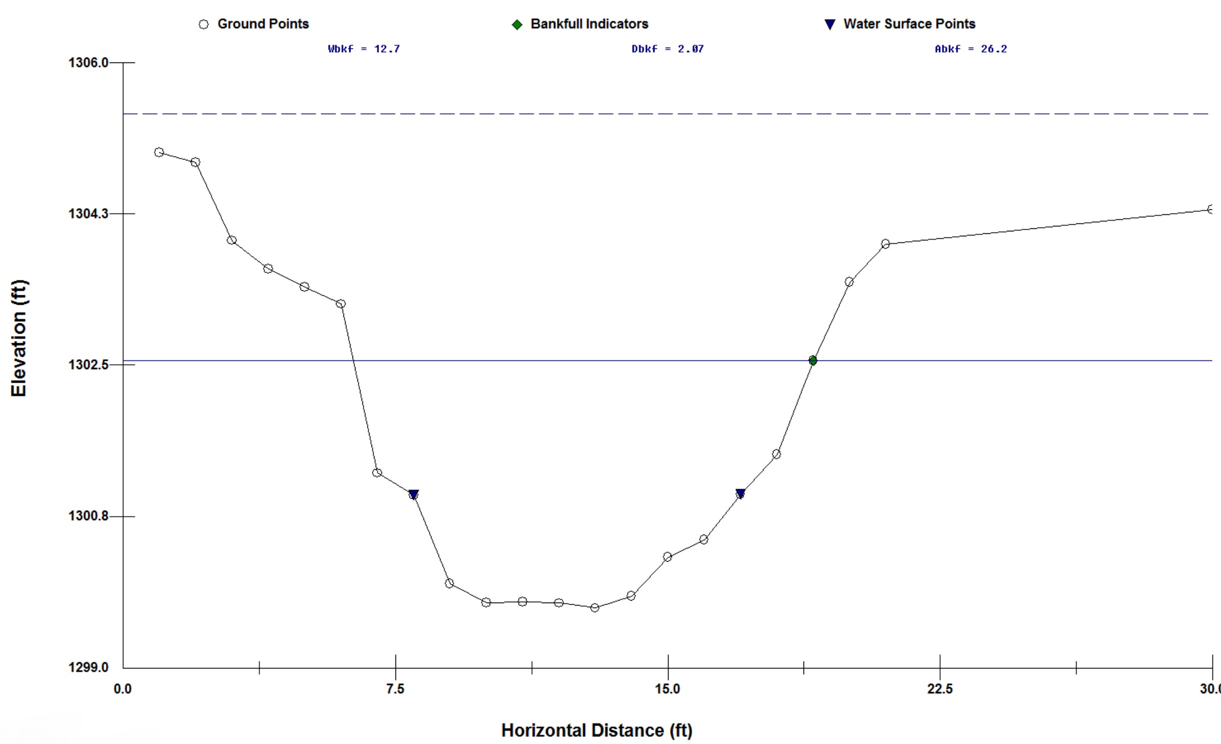


Figure 2. Cross section of riffle, showing bankfull (solid line) and flood prone elevations (dashed line)

Longitudinal profile shows three riffles and three pools (Figure 3). Although there is an excess sediment supply, diverse habitat is seen with pools that are well defined and relatively deep, while riffles show a range of depths.

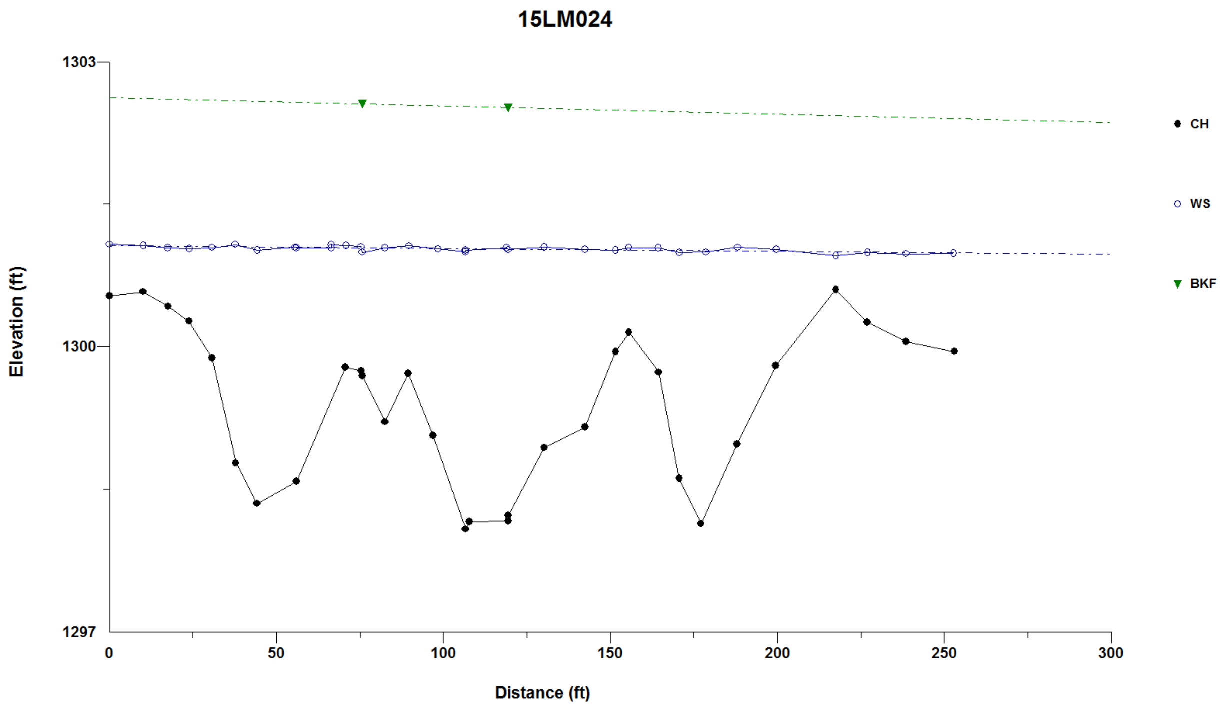


Figure 3. Longitudinal profile of survey

A total of 5 eroding banks were observed in this 230ft. survey. The estimated erosion rate of 0.083 tons/yr/ft. in this reach is categorized as *highly unstable* (Table 2).

Table 2. Streambank erosion stability categories, adapted from Rosgen 2014

	Stable	Moderately Unstable	Unstable	Highly Unstable
Streambank Erosion Rate (tons/yr/ft)	<0.006	0.006 - 0.04	0.041 - 0.07	> 0.07

SID Implications

The narrow and relatively deep channels of E stream types allow for efficient sediment transport. In this reach however there were documented point bars and side bars developing, indicating instability and inadequate sediment transport. This excess sediment deposition is likely limiting macroinvertebrate habitat.

Utilizing aerial photos, upstream of 140th street and downstream of the survey site appears stable and in good condition (Figure 4). The historical photo with the current streamline shows that the stream has moved very little. What is important to note is that although there is some movement, the stream has maintained the narrow width and good pattern.

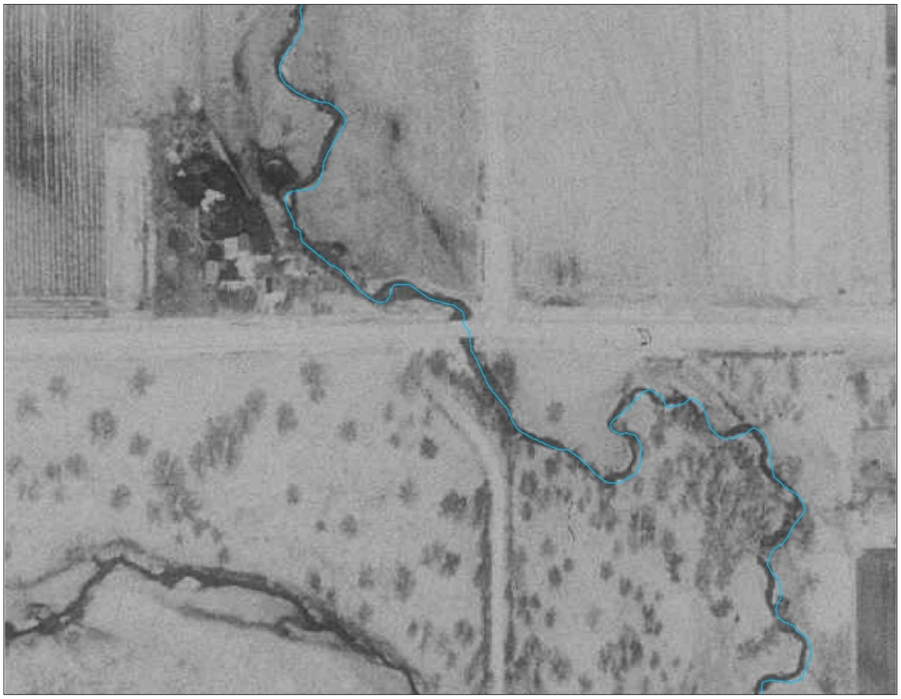


Figure 4. 2015 stream line overlaying 1991 aerial photo

Comparing historical and current aerial photos indicates the stream upstream and downstream continues to have a fair amount of riparian vegetation. The stressor that stands out as causing instability is a pair of box culverts approximately 800 feet upstream. The box culverts have a measured total span of 50 ft., while the stream upstream and downstream bankfull widths are only 13 ft. LiDAR shows over widening immediately downstream of crossing, with recovery occurring near the geomorphic site (Figure 5). The current stream is about 15 feet wider than it was in 1991 immediately downstream of the crossing.

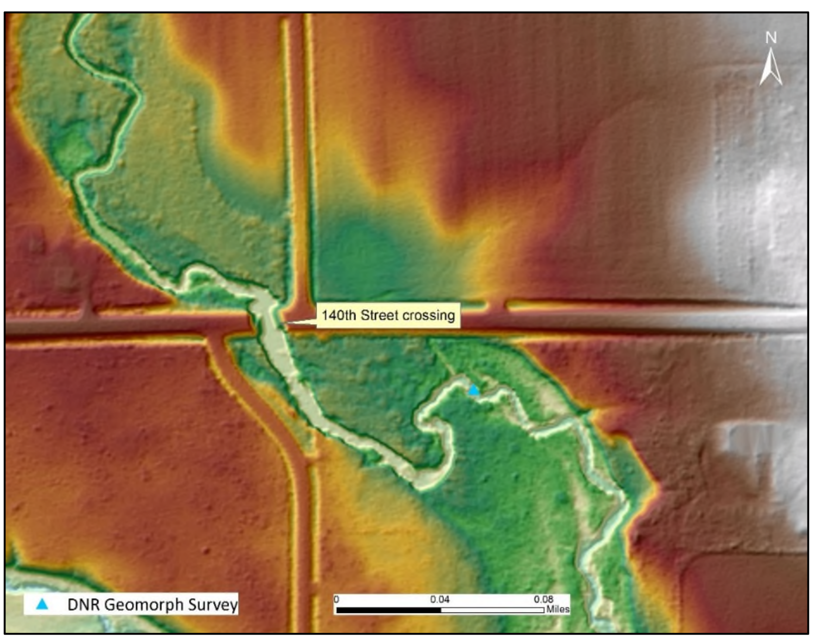


Figure 5. LiDAR image of effect of 140th Street crossing, water flow runs from upper left to lower right

A Google Earth photo captures the moment the crossing is being replaced in August 2013 (Figure 6). The recent disturbance and widening of the crossing is probably playing a large role in instability. The over-wide crossing reduces stream power, resulting in decreased sediment transport and channel aggradation through deposition of sediment. The stream is adjusting laterally to compensate for excess deposition and causing high rates of bank erosion.

Figure 6. Google Earth image showing crossing replacement

Given how recent the disturbance is and the good recovery potential of E6 stream types, the reach may recover. It is also possible that stream may begin succession out of a stable type into more unstable form (Figure 7).

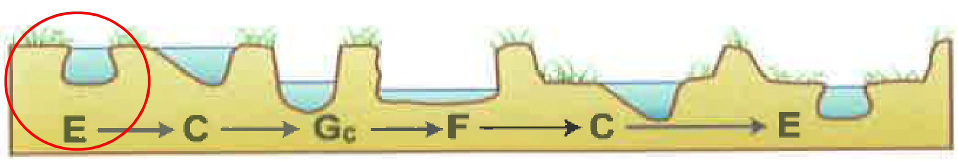


Figure 7. Stream succession scenario

Without the benefit of a re-visit, it is difficult to predict both the potential and the rate of recovery.   In the case of crossing impacts, floodplain culverts and matching bankfull dimensions for the primary (on channel) culvert would have been an improvement by more efficiently transporting sediment and water.

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University of Minnesota. Minnesota Geological Survey, Surficial Geology. Retrieved March 20, 2017 from http://www.mngs.umn.edu/service.htm

Upper Iowa River. 43°33'27.98"N and 92°35'15.19"W. Google Earth. Accessed April, 17, 2017.

Tributary to Little Iowa River: DNR Geomorphology Site Level Summary

Geomorphic survey near 15LM026

A geomorphic survey on a tributary to Little Iowa River near biological site 15LM026 occurred June 2016. The location is near the intersection of 140th Street and 765th Avenue in Mower County at Lat. 43°33'41.09"N Long. 92°31'18.12"W (Figure 1). The riparian area used to be pastured, however within the last several years livestock have been removed. The site has a drainage area of 9.5mi². Land use is 87% cultivated, 8% shrub and herbaceous and 3% developed (MN WHAF Tool). The channel is classified as an E5 stream type with a median pebble size of 1.5mm at the riffle, or course sand material (Table 1). Water surface slope is 0.0013 with a sinuosity of 1.3. A Pfankuch rating of *fair* was observed. The stream has a well vegetated corridor, but is negatively affected by deposition of fine materials.

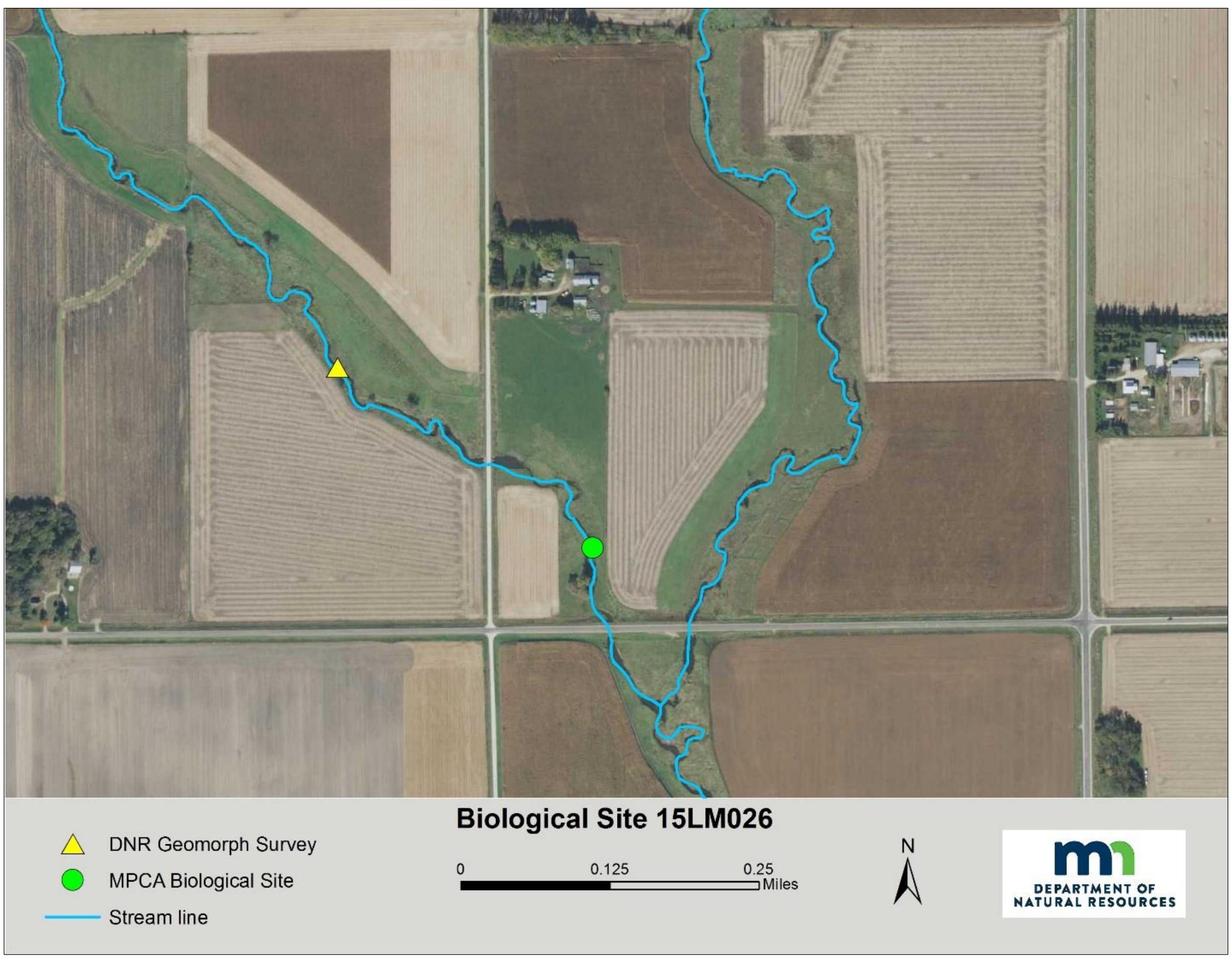

Figure 1. Location of DNR geomorphic survey and MPCA biological site

Table 1. Geomorphic data summary

Survey Results			
Stream Type	E5	**Velocity (fps)**	2.5
Valley Type	U-AL-FD	**Discharge (cfs)**	70.3
Sinuosity	1.3	**Riffle D50 (mm)**	1.53
Water Slope	0.0013	**Mean Riffle Depth (ft)**	1.82
Bankfull Width	15.73	**Max Pool Depth (ft)**	3.46
Entrenchment Ratio	4.5	**Bank Erosion Estimates (tons/yr/ft)**	0.0038
Width/Depth Ratio	8.64	**Pfankuch Stability Rating**	Fair
Bankfull Area (ft^2)	28.62	**Competence Condition**	NA

Regional curve data and very few bankfull signatures were used to determine the bankfull call at the riffle (Figure 2). Flood prone flow narrowly escapes the channel allowing access to a small flood plain, which explains the smaller entrenchment ratio. Any further incision of the stream would cause abandonment of the floodplain.

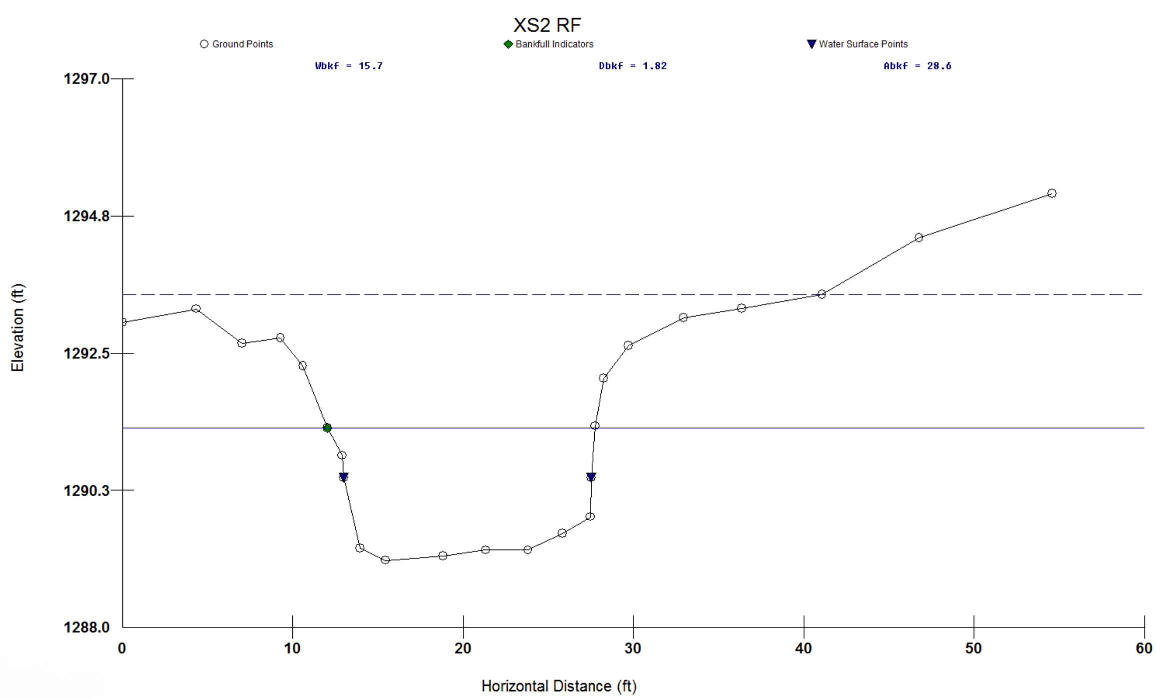

Figure 2. Cross section of riffle showing bankfull (solid line) and flood-prone elevations (dashed line)

Pebble count data at the riffle shows a dominance of fine particles, with a smaller presence of gravel and cobble (Figure 3). According to the Minnesota Geological Survey (2015), the stream runs through floodplain alluvium and is typically silty sand over sand with gravel present in places. This is confirmed in the pebble count.

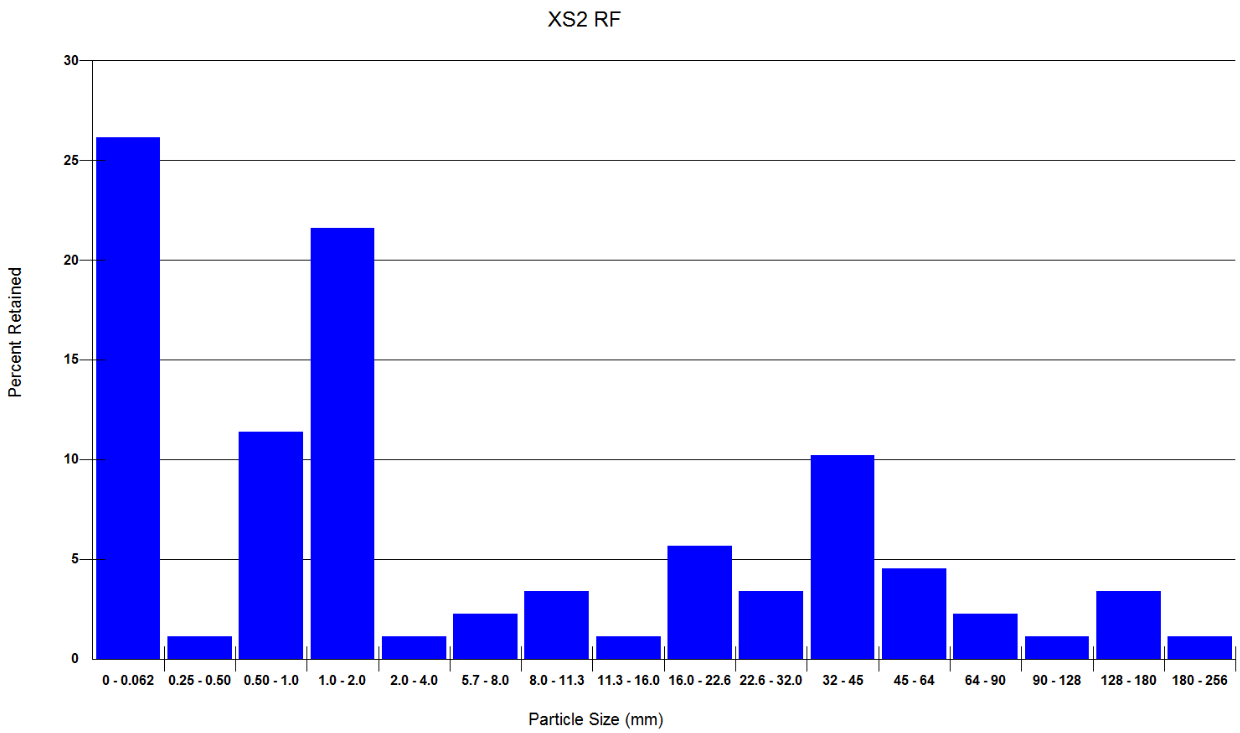

Figure 3. Pebble count information at the riffle cross section

Bank height ratio is the lowest bank height divided by the maximum depth at bankfull, which is a measure of incision. The longitudinal profile shows the low bank and bankfull lines, of which the level of incision is easily measured (Figure 4). In this case incision ranges from 1.1 to 1.2, for a rating of *slightly incised*. Of note is the long and steep riffle roughly in the middle of the profile, indicative of a head-cut.

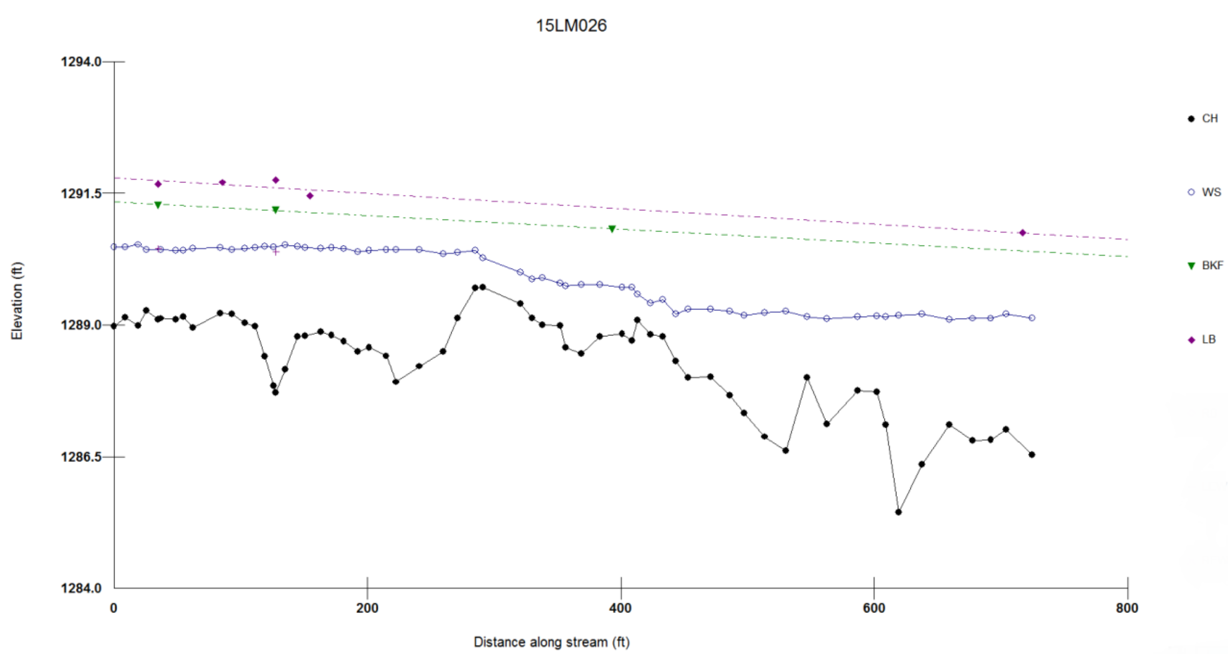

Figure 4. Longitudinal profile with bankfull (green) and lowbank (purple) slopes

A total of 4 eroding banks were observed in this 725ft survey. The erosion rate in this reach is categorized as *stable* at a rate of 0.0038 tons/yr/ft. The banks are protected by thick vegetation (Figure 5). Historical aerial photos reveal the reach has moved very little.

Table 2. Streambank erosion stability categories, adapted from Rosgen 2014

	Stable	Moderately Unstable	Unstable	Highly Unstable
Streambank Erosion Rate (tons/yr/ft)	<0.006	0.006 - 0.04	0.041 - 0.07	> 0.07

Figure 5. View of surveyed reach

SID Implications

Information gathered from the survey show signs of stability, however preliminary IBI scores show invertebrates not meeting thresholds. Although the surveys are showing measures of channel stability, concerns over incision exists. As seen in Figure 3, bankfull elevation is below low bank elevation, a 1.15 average bank-height ratio categorized as *slightly incised*. Also seen in Figure 3, there is an elongated steep riffle, indicative of a head cut. Below this head-cut is a higher bank-height ratio, indicating that the source is downstream and advancing head ward. Incision is a lowering of the water level, leading to an abandonment of the floodplain. Flows above bankfull would be contained within the channel leading to increased bank erosion. Aerial photos, Pfankuch rating and low erosion points to the stream having potential resiliency to change, with the possibility of improvement.

A potential localized stressor on the reach is the crossing located 250ft. downstream of the survey. The crossing measures about 25ft across while the bankfull width of the stream is 15ft. From Figure 6, there is a clear downstream pool and upstream widening of the stream, likely from road prism reducing floodplain. The effect of the overwide channel crossing is a reduction in sediment transport capability. In addition, it's likely the cause of the head-cut moving upstream captured in the longitudinal profile. Another localized stressor is livestock. The biological site is in an actively pastured reach, while the geomorphic site was upstream and no longer in pasture.

Figure 6. Over wide crossing downstream of survey, a potential stressor (Google Earth)

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Minnesota Department of natural resources. Watershed Health Assessment Framework. Accessed 4/6/2017 from http://www.dnr.state.mn.us/whaf/index.html

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Tributary to Little Iowa River. 43°33'37.32"N and 92°31'9.53"W. Google Earth. Accessed April 24, 2017.

Appendix E. Minnesota DNR Upper Iowa River Culvert Inventory and Prioritization Report

UPPER IOWA RIVER WATERSHED

CULVERT INVENTORY AND PRIORITIZATION REPORT

"75% of culverts are impacting stream channel stability while 31% are barriers to fish passage"

Watershed Information

- **The Upper Iowa River watershed lies along the Minnesota: Iowa border in the southeast corner of Minnesota. The watershed is 217 sq. miles in area and is dominated by agricultural land use.**
- **There are three HUC-10 subwatersheds which include the Upper Iowa Headwaters, Coldwater Creek, and Bear Creek.**
- **A total of 52 culverts were measured and 16 were recommended for replacement.**

Stream Crossing Assessment

Figure 1 - Culvert on the Upper Iowa River

Figure 2 - Poorly Aligned Culvert on Pine Creek.

A total of 52 culvert sites were visited in the Upper Iowa River watershed in Minnesota. All of the culverts had flowing water and were measured to determine if they were a barrier to fish passage. Bridges were not measured as they were assumed to provide fish passage. A dam is present in Leroy, MN which forms Lake Louise, an impoundment on the Upper Iowa River. The dam is an obvious complete fish barrier and was not measured for barrier parameters. Most culverts were cement box culverts, however there were several older culverts including one made of creosote wood ties.

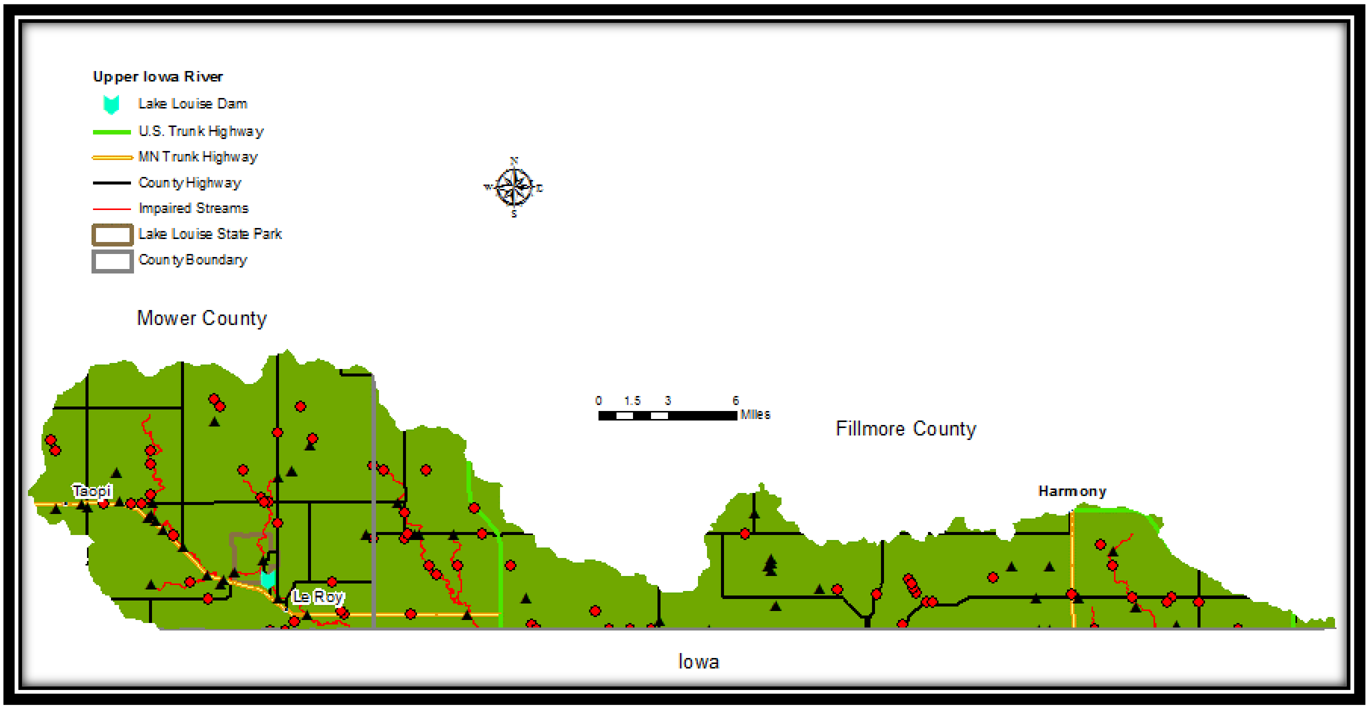

Figure 3 - Culvert and Bridge Locations in Mower and Fillmore Counties

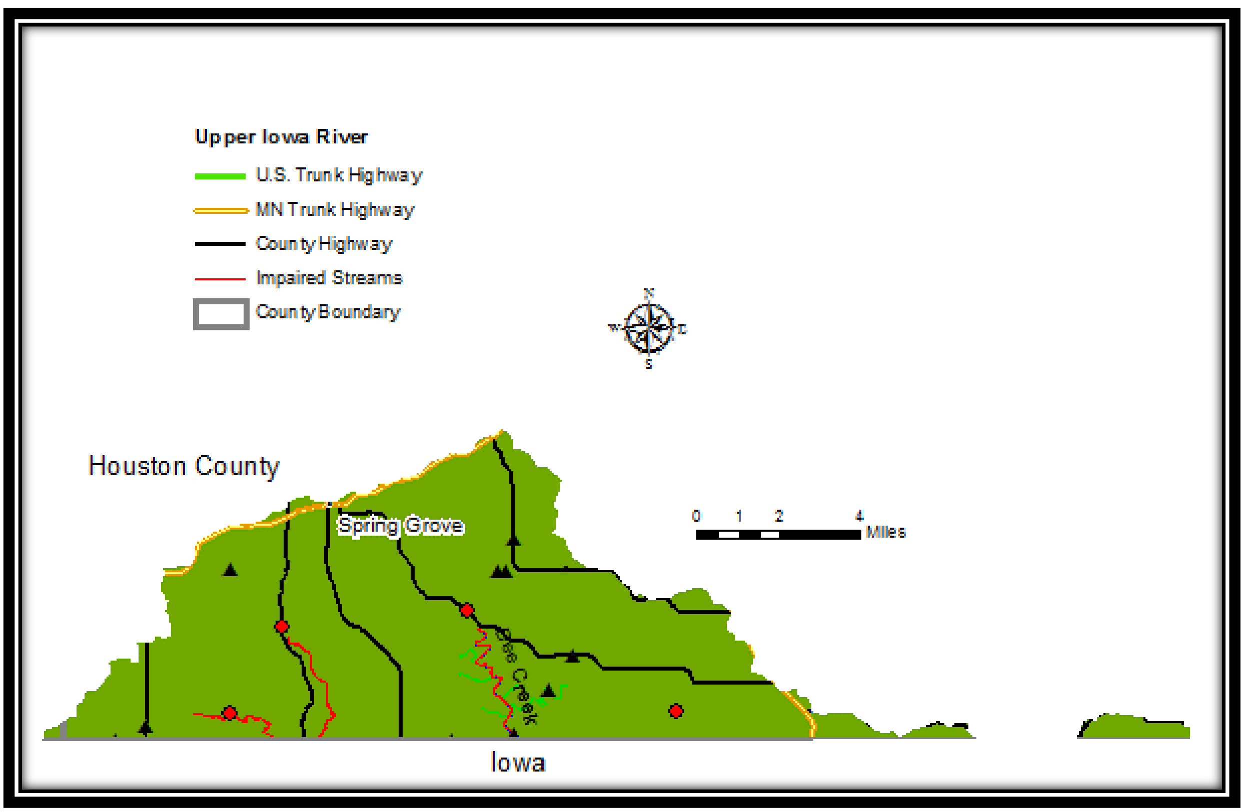

Figure 4 - Culvert and bridge locations in Houston County

Table 1
Parameters Measured and Percent Occurrence

Barrier Ranking Parameters	% of Culverts
Downstream Incision	71
Perched 0.5 ft.	4
Countersunk	2
Culvert Slope >1%	23
Bed Slope >1%	42
Water Surface Slope >1%	10
Water Depth <0.2 ft.	0
Backwatered	27
Scour	54
Upstream Bars	40
Channel Stability Impact	75
Aligned with Channel	48
Fish Barrier	31

Table 2
Barrier Ranking Levels and Number of Culverts to Replace

Barrier Ranking Level	Number of Culverts Measured	Number of Culverts to Replace
Level 1 (complete Barrier)	0	0
Level 2 (significant barrier)	25	13
Level 3 (seasonal barrier)	15	3
Level 4 (passable)	12	0

Figure5 – Wooden culvert on Fillmore County Highway 1

Figure 6 – Concrete arch culvert on 111th avenue, Fillmore County

Examples of Culverts Exceeding Barrier Ranking Criteria

Number 11356 Pine Creek

Number 17288 Tributary to Pine Creek

Number 17335 Tributary to Pine Creek

Number WP95

Number WP96 Tributary to Pine Creek

Number 17659 Upper Iowa River North Branch

Culverts Identified for Replacement

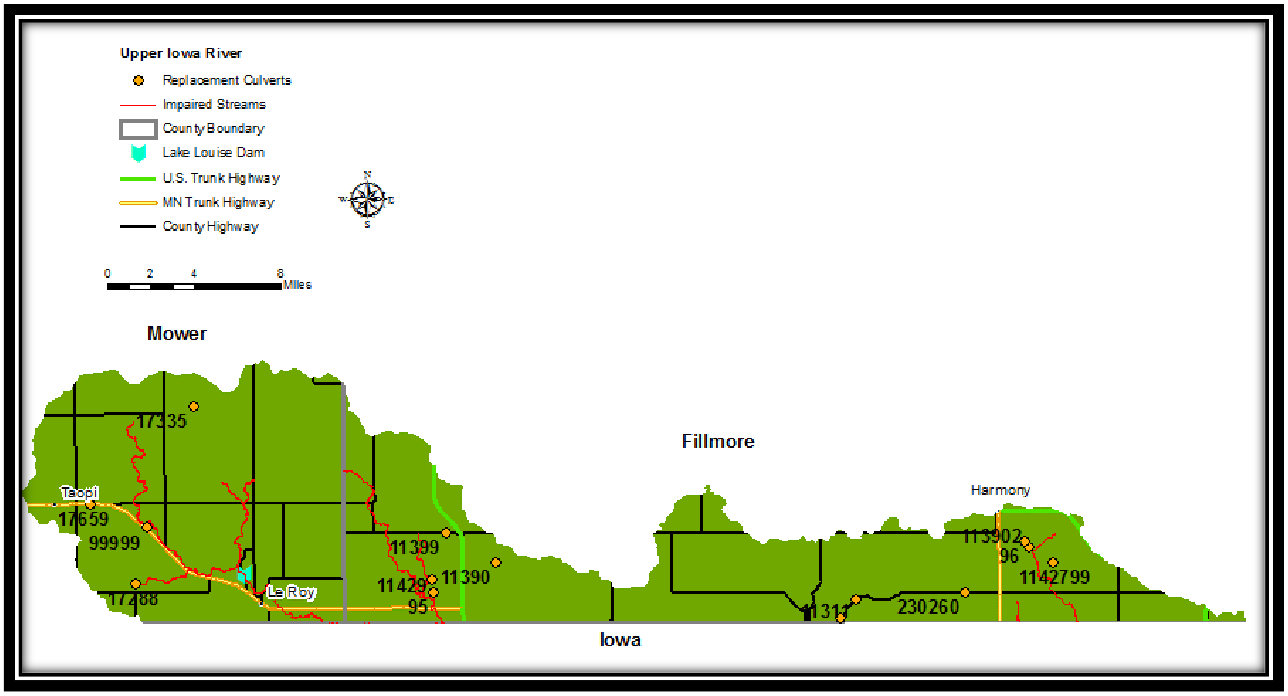

Figure 4 - Locations of culverts recommended for replacement in Mower and Fillmore counties.

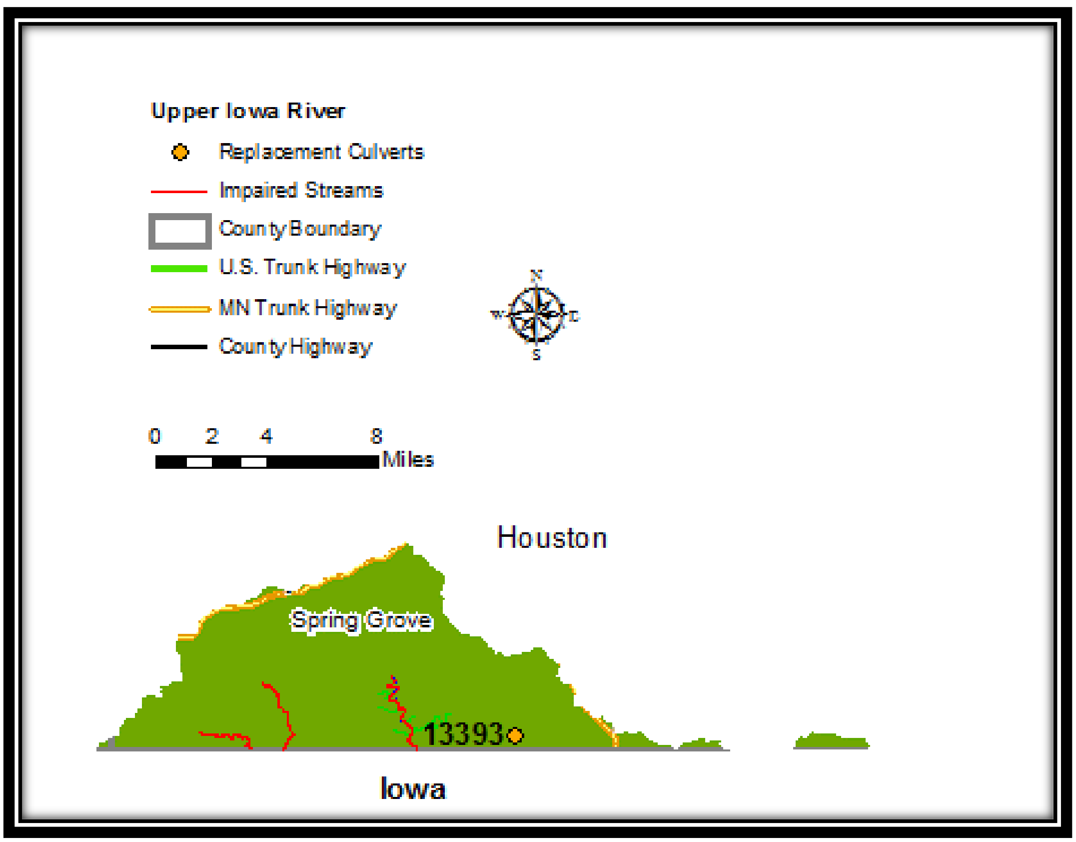

Figure 5 - Locations of culverts recommended for replacement in Houston County.

All of the culverts recommended for replacement in the Upper Iowa River watershed are on tributaries or the main stem of impaired streams. Seventy-five percent of the culverts measured were impacting stream channel stability. Channel instability can cause downstream channel incision (71% of culverts), scour (54%), and formation of sediment bars upstream from culverts (40%). Channel bed slopes exceeding 1% occurred on 42% of culverts measured. Slopes exceeding this threshold increase water velocity to levels that can prevent fish from swimming through a culvert. Excessive slope also contributes to downstream bed scour and channel incision.

Nearly half of the culverts measured were not in alignment with the stream channel. When culverts are correctly aligned bank erosion is reduced and the stability of the road crossing is maintained. When improperly aligned, bank erosion occurs, sediment may be deposited upstream of the culvert, and road crossing stability may be impacted. Additional culvert maintenance may be required to maintain structure stability. There are some newly installed culverts in the watershed that are poorly aligned. The Department of Natural Resources has begun collaborating with county highway departments to improve sizing and placement of culverts to ensure fish passage is maintained, stream habitat is protected, and crossing stability is maximized over time.

Of the 17 culverts recommended for replacement, 13 were level 2 barriers and 4 were level 3 barriers to fish movement. Level 2 barriers are considered significant and can prevent fish passage at most stream discharges. Level 3 barriers can block fish movement at low and/or high discharges or may be slightly perched (<0.5 ft). Just 4% of the culverts studied were perched from 0.5 to 2.0 ft. Fish, particularly trout, may pass through perched culverts if a plunge pool is present immediately downstream of the culvert. Trout are able to gain enough swimming momentum and can leap into a culvert provided it is not high above the water surface. Smaller, nongame fish species likely lack the swimming ability necessary to leap into a perched culvert and are prevented from moving upstream.

The only fish impairment in the Upper Iowa River watershed is on Deer Creek, in the Coldwater Creek subwatershed. Therefore it appears that culverts are not having an impact on the fish community in the Upper Iowa River watershed.

A private culvert structure on Bee Creek (number 17) was not measured but was identified as a candidate for replacement. This stream crossing consists of a cement, low water ford crossing with three small culverts. There have been long standing issues with this stream crossing and it is well known to Department of Natural Resources staff. The crossing is having little impact on the Brown Trout population in Bee Creek as an excellent trout population is present upstream. But the crossing has a history of being damaged by flood events, causes increased channel width upstream while increasing bank erosion and scour downstream. It is unlikely that the landowner would agree to replace the crossing with a bridge due to the high cost.

Watershed Assessment of River Stability and Sediment Supply (WARSSS) of Crooked Creek Watershed

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Ecological and Water Resources Division

2019

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BANCS Bank Assessment for Non-point source Consequences of Sediment

BEHI Bank Erosion Hazard Index

BHR Bank Height Ratio

CCWD Crooked Creek Watershed District

CFS Cubic Feet per Second

DNR Minnesota Department of Natural Resources

EPA Environmental Protection Agency

GIS Geographic Information System

HSPF Hydrological Simulation Program-FORTRAN

HUC Hydrologic Unit Code

LiDAR Light Detection and Ranging

MNDOT Minnesota Department of Transportation

MPCA Minnesota Pollution Control Agency

NBS Near-Bank Stress

NRCS Natural Resources Conservation Service

PLA Prediction Level Assessment

RLA Reconnaissance Level Assessment

RRISSC Rapid Resource Inventory for Sediment and Stability Consequence

SWAT Soil and Water Assessment Tool

USGS United States Geological Service

WARSSS Watershed Assessment of River Stability and Sediment Supply

W/D Width to Depth

Introduction

A geomorphic assessment of Crooked Creek watershed was completed following the Watershed Assessment of River Stability and Sediment Supply (WARSSS) framework developed by D. Rosgen (2009), an approved method by the Environmental Protection Agency (EPA) to assess sediment impairments. This framework is a systematic and repeatable way of analyzing stream channel stability and sedimentation, which are critical in developing prioritized restoration and protection management strategies. WARSSS identifies and quantifies sediment by three erosional processes: hillslope, hydrological, and channel. The erosional processes are assessed in three levels of investigation: Reconnaissance Level Assessment (RLA), Rapid Resource Inventory for Sediment and Stability Consequence (RRISSC), and Prediction Level Assessment (PLA) (Figure 1). RLA rapidly identifies places in the watershed that likely represent sources of instability and sediment using readily available data and historical review. RRISSC level is designed to provide a finer level of analysis to further assess potential impacts by erosional processes. PLA provides a detailed assessment of areas identified as high risk for sediment and stability issues with intensive field investigation and analysis. WARSSS assessments establish the source of sediment impairments and help to identify areas of restoration and develop strategies for the improvement of the overall health of the watershed.

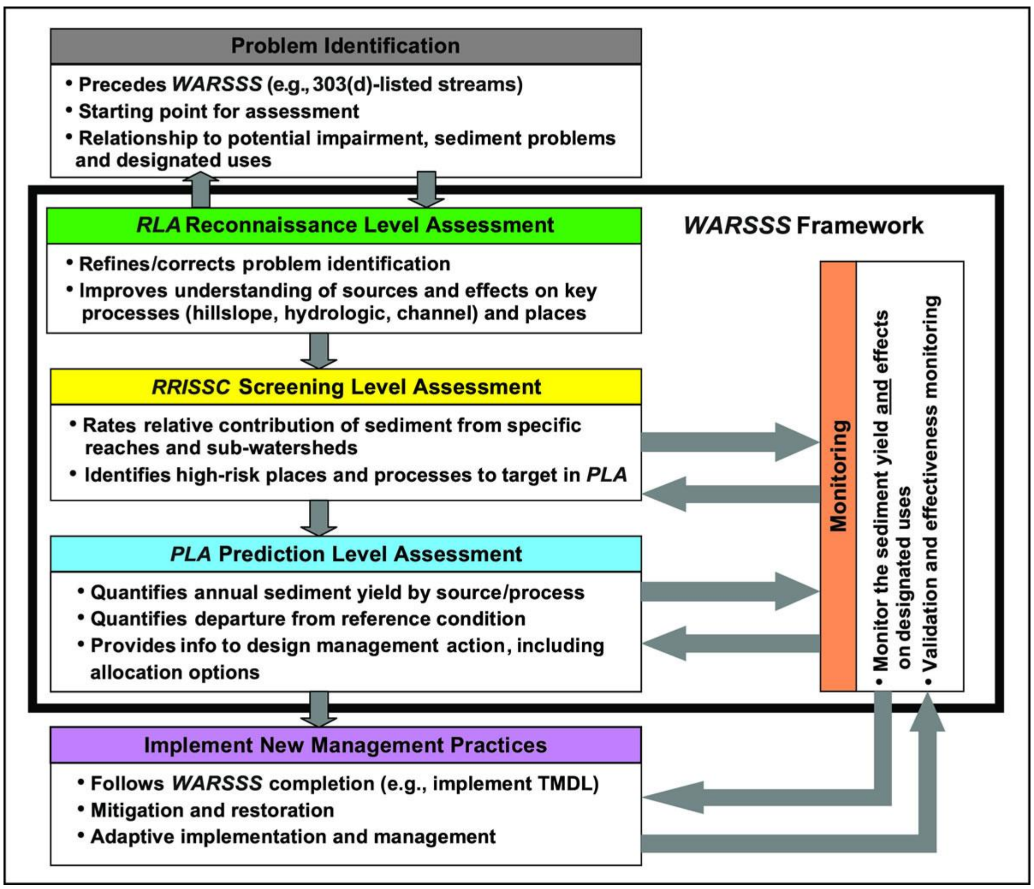

Figure 1. WARSSS phased approach flowchart (Rosgen 2009).

The goal of this process is to provide understanding and target restoration and protection areas, as to improve the watershed and to support aquatic life. Not only does this process allow for management recommendations, it also aids in the Minnesota Pollution Control Agency's (MPCA) Stressor Identification program in which biological and chemical assessments are conducted. When aquatic life impairments are found, geomorphic information helps understand and isolate sediment and habitat issues.

Study Area

Crooked Creek is classified as a cold-water trout stream and the largest of three major streams within the Mississippi River – Reno watershed (HUC: 07060001) (Figure 2). Located in Houston County, the stream begins near Caledonia, MN and drains approximately 70 mi² or 38% of the Mississippi River – Reno watershed and discharges into the Mississippi River just above U.S Lock and Dam #8.

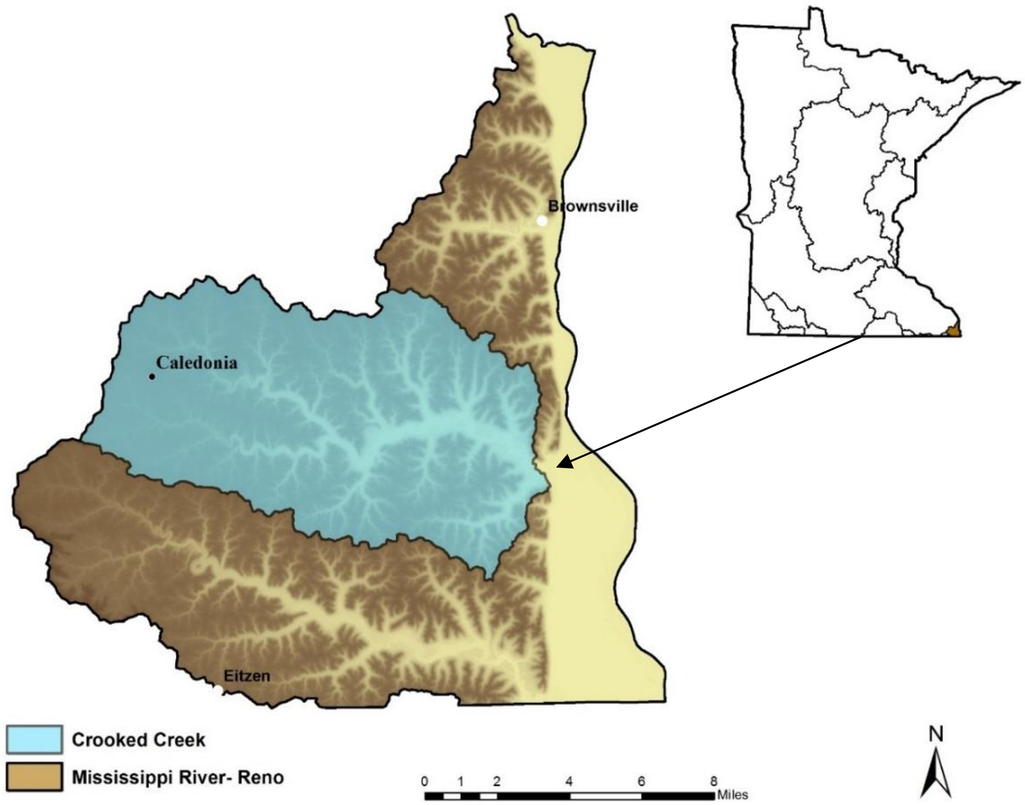

Figure 2. Minnesota major river watersheds and location of Crooked Creek, within Miss. River – Reno.

Reconnaissance Level Assessment (RLA)

Process

To gain an understanding of how past land use activities and changes have impacted the watershed and stream channel, historical accounts, literature, and reports were reviewed. In addition, Geographic Information System (GIS) was used to view current and historical aerial maps, Light Detection and Ranging (LiDAR) images, land cover, hydrology, soil, and geological maps. The tools and information allow rapid assessment of the watershed for obvious sediment sources and processes. To support the rapid-style assessment, Crooked Creek was divided into smaller hydrological units (Figure 3). Delineating the catchments in this way and utilizing the various tools allows for rapid evaluation of low and high risk areas for sediment and channel stability issues, and it also identifies which ones need further analysis based on the specific erosional processes.

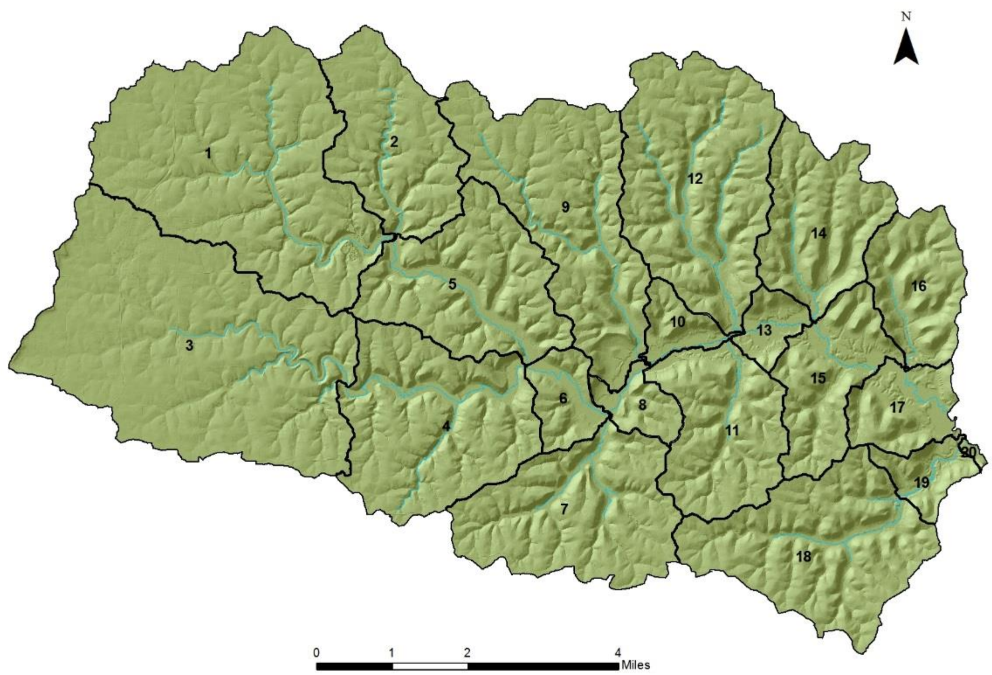

Figure 3. Crooked Creek sub-catchments.

Historic Land Use Change and Effects

Crooked Creek watershed is part of the blufflands subsection of the Eastern Broadleaf Forest Province. The watershed is also part of the unglaciated Driftless Area of the Upper Midwest. Prior to European settlement, the vegetation was described as follows:

> *Tallgrass prairie and bur oak savanna were major vegetation types on ridge tops and dry upper slopes. Red oak-white oak-shagbark hickory-basswood forests were present on moister slopes, and red oak-basswood-black walnut forests in protected valleys. Prairie was restricted primarily to broader ridge tops, where fires could spread, but also occurred on steep slopes with south or southwest aspect (MN DNR Website).*

The first settler in the Crooked Creek area was in 1852 (Curtiss-Wedge 1919). Land conversion to agriculture, primarily wheat in the beginning, quickly followed. Southeast Minnesota began as the first agriculture area in the state. As discussed in the Minnesota Historic Farm Study (2005), by the late 1920s, tractors became common allowing farmers to plant and harvest larger fields. This land conversion and subsequent geomorphic alteration in the Driftless Area has been studied (Beach 1994, Faulkner 1998, Knox 2006, Stout et al. 2014, and Trimble 2009) and results show that conversion to agricultural land use greatly accelerated soil erosion. Much of this erosion was deposited on the valley floodplains adjacent to the channels, as illustrated in Figure 4.

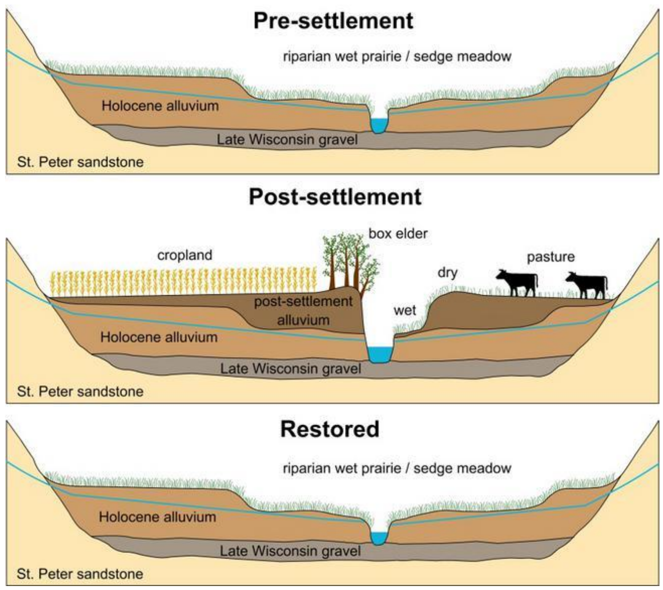

Figure 4. Diagram of floodplain change in Driftless area and one of many restoration options, from Booth and Loheide (2010).

In a watershed just west of Crooked Creek, Beach (1994) found floodplain alluvium deposit depths of 50 cm up to 2.5 m, with variation dependent on floodplain width. Human-accelerated sedimentation, associated with overbank floods, led to higher stream bank heights and deeper, high energy flows during floods (Knox 2006). Trimble (2009) argued the 1920s and 1930s was a period of maximum erosion. Direct anecdotal evidence of floodplain deposition in Crooked Creek is recorded in History of Houston County (1982), stating a big flood in 1946 caused the closure of the post office, depot, and the filling of a swimming hole with sediment in Freeburg, MN. This floodplain sedimentation potentially created incised channels, which in turn created unstable channels and triggered channel succession through unstable forms to ultimately reach a new equilibrium once again.

Fortunately, by the 1930s, soil conservation became an influencing factor in reducing soil erosion. Crooked Creek watershed shows high levels of adoption of these practices (Figure 5). In addition to contour farming, the 2007 Tillage Transect Survey found 41% of crop acres in conservation tillage. In response to flooding, Crooked Creek Watershed District (CCWD) was formed in 1959. The

District built several large earthen dams placed on tributaries to slow the flow in the 1960s. A total of seven dams are in the inventory, of which six are owned by CCWD and were built between 1966 and 1968. Four of these dams are large earthen dams whose purpose is to provide flood control in the watershed. These dams are very large, and range from 40-45 feet high. The largest dam has a permanent pool of 30 acres, and grows to 90 acres during significant flooding events. The other dams are for grade control. The drainage area impounded by these structures is 26.6 mi^2 or 38% of the Crooked Creek watershed. These dams can impact channel stability by creating sediment hungry water downstream and increase lateral meandering upstream, both of which have sediment consequences. In addition, they reduce longitudinal connectivity. One other potentially large impact was a railroad line that ran through the main stem valley; it was constructed in 1879 and abandoned sometime in the 1930s or 1940s.

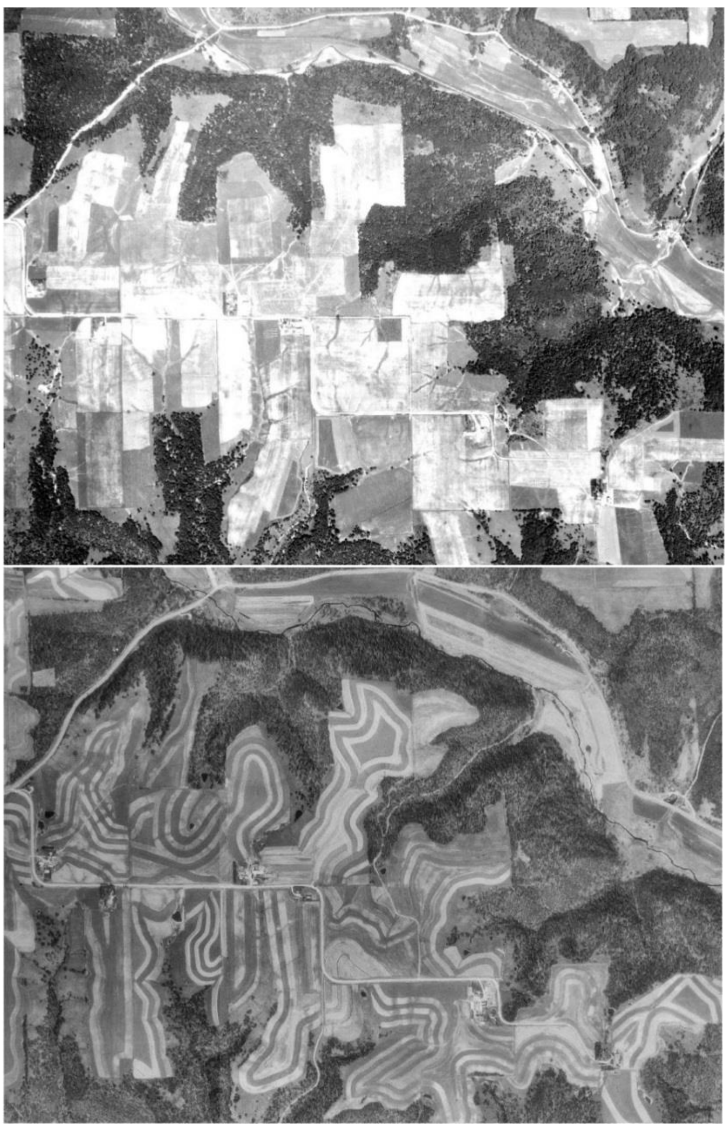

Figure 5. 1937 (above) and 1991 (below) demonstrating the adoption of conservation practices.

Current Land Use and Soils

Currently, the majority of land use in the watershed is classified as forested at 38%, followed by hay/pasture (29%), and cultivated crops (20%) (Figure 6). Land use can play an important role in stream health. Within the Crooked Creek watershed, there is a low amount of natural depressions resulting in lower precipitation retention and increased runoff in this area. The only development within the watershed is the town of Caledonia, found in the upper part of the watershed. This is also where most of the cultivated crop activity is located.

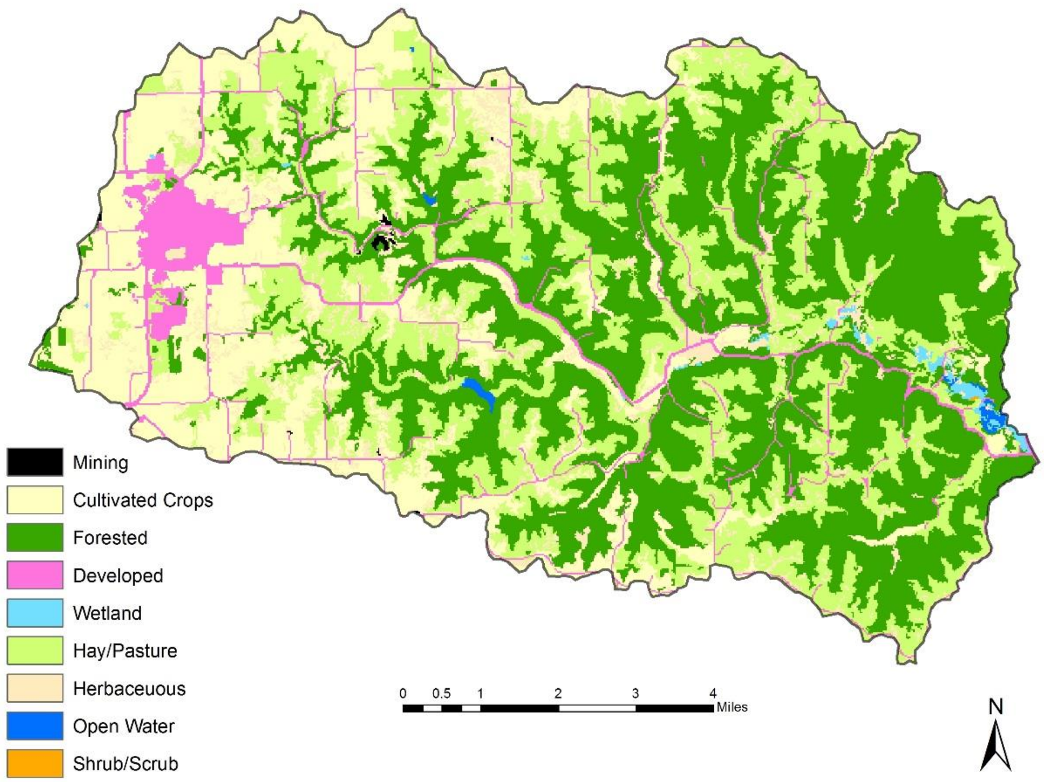

Figure 6. 2011 Land use in Crooked Creek watershed.

Channel and Valley Classification

Stream and valley type classification assists with the assessment of stream flow changes and channel processes related to erosion potential within the RLA. In addition, these classifications are useful throughout the WARSSS process including aiding in targeting field sampling. Utilizing desktop LiDAR analysis, valley and stream typing is determined for well-defined stream channels with either ephemeral or perennial flows. Subsequent field visits and geomorphology surveys validated stream classifications where possible. Broad-level stream classifications are based on morphological features associated with stream patterns, shape (width/depth ratio) and vertical containment (entrenchment ratio) (Rosgen 2009) (Figure 7).

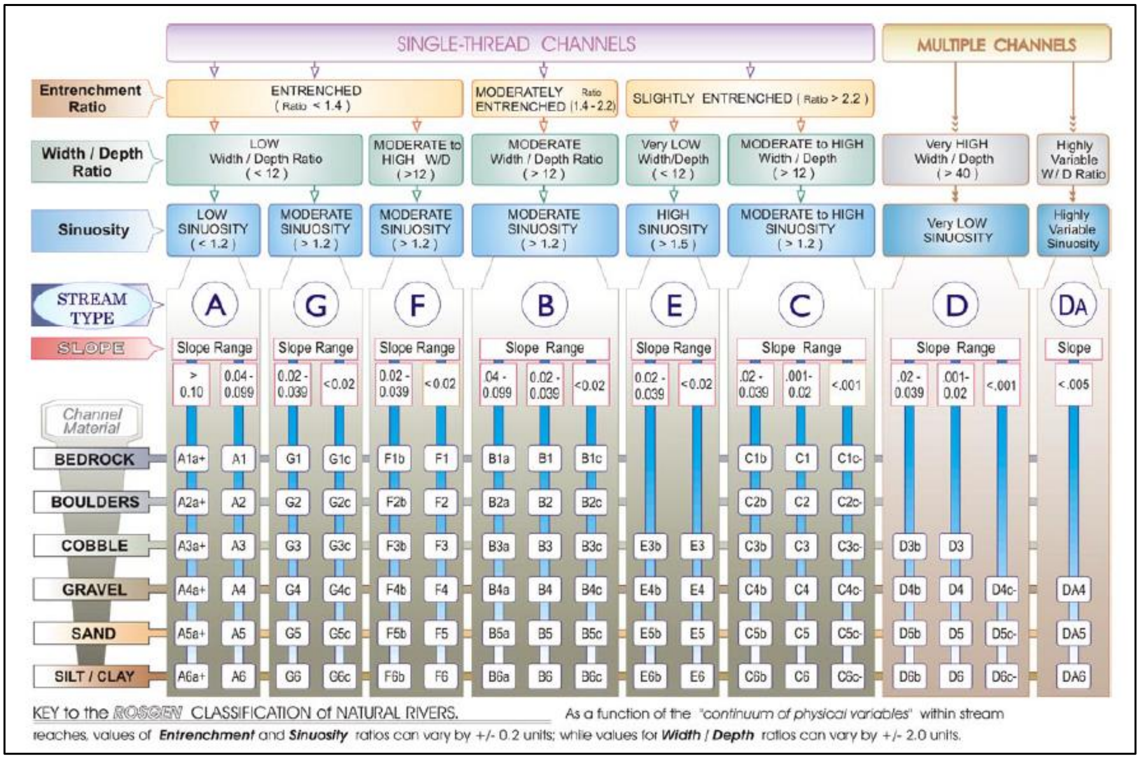

Figure 7. Characteristics of the different stream types and ranges of values (Rosgen 1994).

Delineation of valley types, as described in Rosgen (2014), is based on confinement, origin and associated boundary materials, gradient and shape. By understanding the geology and associated soils, it is possible to understand the substrate and particle sizes that are available to the stream (Figure 8). Also seen in Figure 8, stream type coupled with valley type combinations give the ability to broadly characterize stability of reaches.

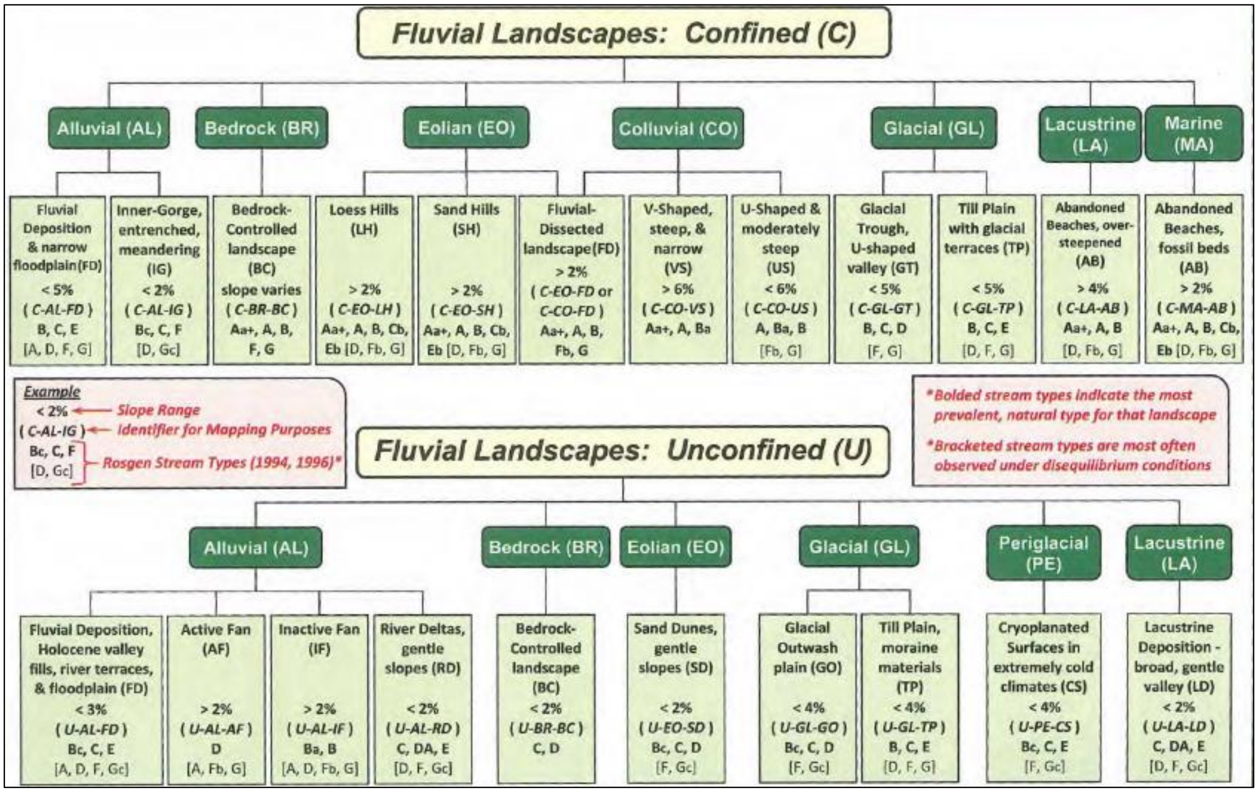

Figure 8. Hierarchical delineation of fluvial landscapes and associated possibility of stable or unstable stream types (Rosgen 2014).

The main stem of Crooked Creek alternates between C4 and F4 stream types of roughly equal total lengths (Figure 9). Valley type delineation along the main stem is categorized as unconfined alluvial floodplain. C stream types in this valley are prevalent and considered natural in this landscape. F4 stream types occurring in incised alluvial valleys can result in the abandonment of floodplains (Rosgen 1996). Tributaries in this watershed begin as steep confined alluvial floodplains with B stream types, which are considered a relatively stable stream/valley type combination. In the less steep areas of the tributaries, the valley opens slightly into unconfined alluvial floodplains where the stream alternates between C and F stream types. F stream types are considered unstable in these areas. One such tributary, Clear Creek, begins as an F4 stream type in unconfined alluvial floodplain and recovers to stable E and C stream types near the confluence with Crooked Creek.

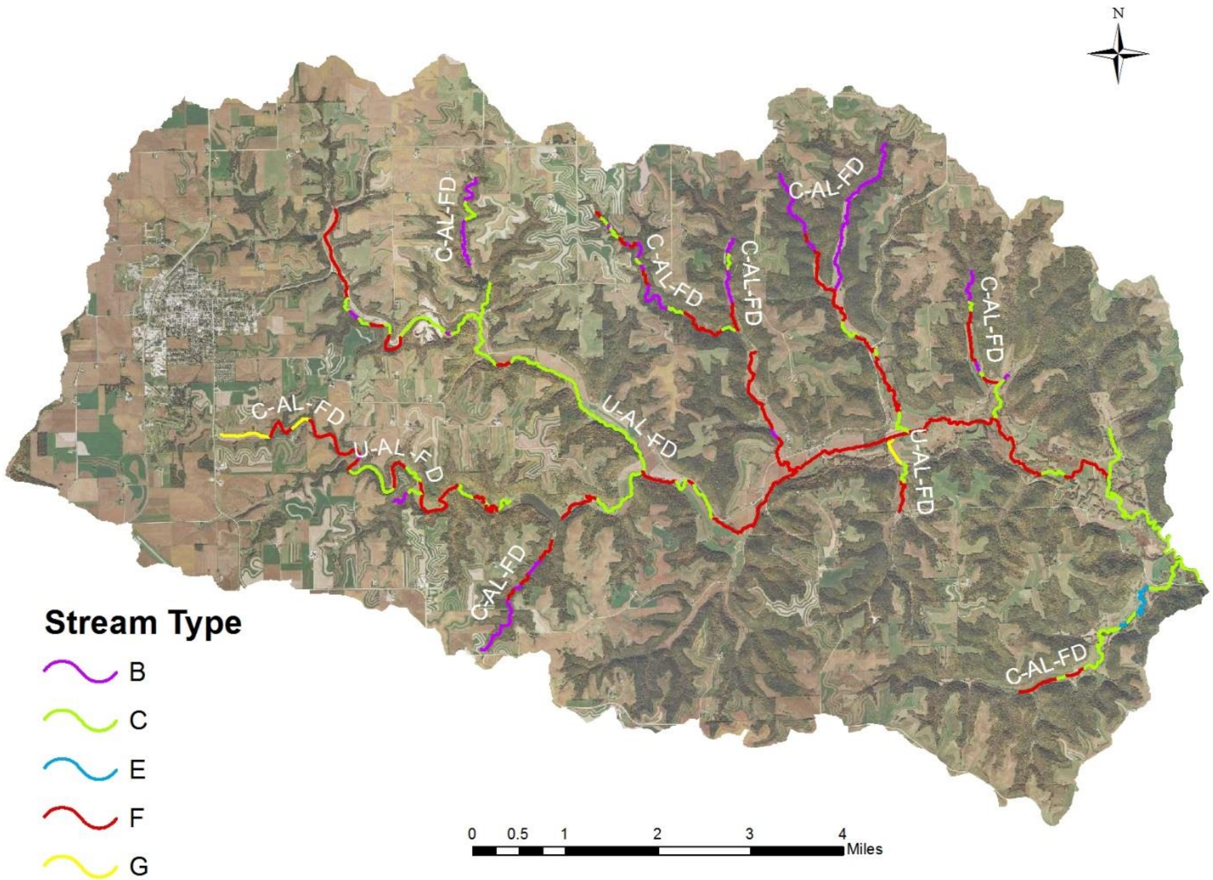

Figure 9. Stream classification with valley type of Crooked Creek.

Hillslope Processes

Surface Erosion

In general, the watershed is covered by loess soils that have been eroded by flowing streams and rivers. Hillslopes are colluvium while the valley bottom along the main branch Crooked Creek is floodplain alluvium. Predominant soil associations, from the Natural Resources Conservation Service (NRCS) GIS layer Soils of Minnesota, are Seaton-Blackhammer-Southridge occurring on tops of ridges, and Lamoille-Lacrescent Associations occurring on steep slopes. In the Seaton-Blackhammer-Southridge Association, “Gullies develop easily unless drainage ways crossing the slopes are maintained as grassed waterways” (USDA 1984). Contour farming and conservation tillage are effective strategies for mitigating gully erosion. Maintaining pastures in good condition and preventing over grazing are the main concerns in the Lamoille-Lacresent Association (USDA 1984). Aerial review using multiple sources did not discover obvious surface erosion areas. Although surface erosion is benefitting greatly from strong adoption of conservation practices such as contour farming and conservation tillage, aerial photos are at a yearly scale and may not capture all conditions. A more consistent approach is to look at

Soil K Factor. Values were averaged by sub catchment, and all values greater than 0.33 were determined to be high risk (Figure 10). The areas where the bluffs steepen tend to have higher risks than the riparian areas. It will be critical to determine if the higher risk areas result in sediment reaching the stream or if they are circumvented by practices or geography.

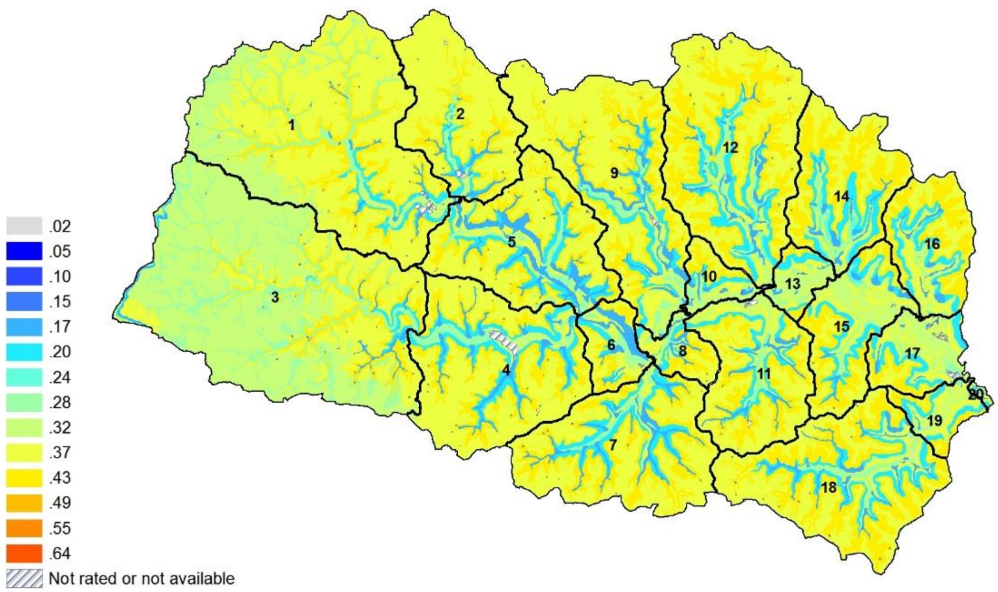

Figure 10. Soil K Factor values, separated by sub-catchment.

Mass Erosion

Mass erosion, with the potential to influence channel dimensions and sediment supply, occurs near stream channels. Examples include large streambank slumps and where the channel is against terraces or bluffs creating geotechnical failures. If mass erosion is found, determinations of potential delivery to streams needs to be made. Two locations of mass slumping were identified on aerial photographs within the watershed. Field visits verified the presence and extent of erosion. After further review, these areas were deemed to be point source specific and not systemic in nature. For this reason, these areas did not warrant further catchment assessment, but they were documented for future reference for specific stabilization efforts.

Hydrologic Processes

Streamflow Change

Six criteria are used in determining if hydrologic processes (altered hydrology) are a factor in sediment delivery and advance to RRISSC. The first considers the percentage of impervious surface if in an urban area, while the second considers the percentage of bare ground in conjunction with specific stream type if within a more rural landscape. The third one is the length of time since the last significant change in vegetative cover occurred in the watershed, with emphasis on the riparian area. The next two criteria assess the impacts of reservoirs, diversions, and changes in water yield by using scale, location within the watershed and age of structure. The final criteria used to evaluate hydrologic processes are road densities within first and second order streams and roads which traverse highly dissected slopes. Of the six criteria, only the unknown impact of the large reservoirs is in need of further analysis.

Channel Processes

Channel Processes

The guidance criteria for channel processes are numerous and utilize primarily aerial photo analysis as well as stream and valley type classifications to determine if a catchment will need further evaluation. Other obvious signs of aggradation, degradation, excess bank erosion, avulsion and enlargement are also included.

The most common criteria seen as potential sediment issues were unstable stream and valley type combinations (Figure 11) and obvious aggradation (Figure 12). The stream type/valley type delineations (Figure 8) help identify the potential mismatches. Two stream types commonly found in disequilibrium are F and G; although, these stream types can be stable in certain valley types such as confined bedrock control. After a review of catchments 3 and 4, mismatches shown are in ephemeral, not well defined channels, and were dismissed as needing further investigation.

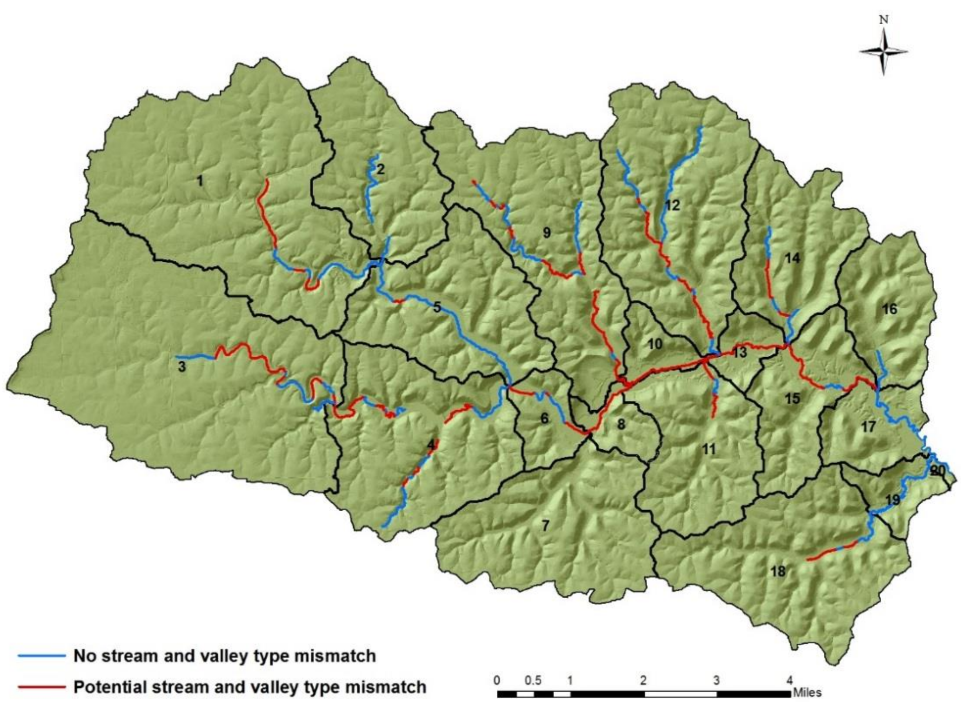

Figure 11. Potential stream type and valley type mismatches.

Figure 12. Areas of stream with visible aggradation.

Direct Channel Impacts

Detrimental effects to dimension, pattern and profile from direct impacts must be analyzed in further detail. These direct impacts include straightening, impacts due to encroachment of row cropping, livestock grazing within the floodplain, dams, gravel mining, and roads.

Road crossings and drainage ways can affect stream stability and sediment supply through changes in stream flow, velocity, and slope. Undersized crossings can temporarily impound water upstream, causing a decrease in slope and a reduction in sediment transport capacity, leading to aggradation which increases sinuosity, lateral migration, and accelerates streambank erosion. Downstream scour pools and widening of the channel occurs due to the sediment starved water and increased velocities. There are a total of 12 known Minnesota Department of Transportation (MNDOT) bridges and 5 culverts within the watershed. Aerial photos and LiDAR were utilized to locate two more private crossings on the main stem.

Livestock production can impact stream channel stability in two ways. Heavy grazing of livestock within the riparian area reduces vegetative abundance and hoof sheer can physically sluff off portions of streambank. Especially in the lower end of watershed, impacts from heavy grazing are easily seen from aerial photographs.

Alterations directly tied to stream pattern in this watershed are from roads and a historic rail road line. In only two short instances does the stream run directly along a road. This has potential negative impacts to the pattern. Sediment input from the road prism, considering this is a gravel road, also draws the need for further analysis. Utilizing historic aerial photos and LiDAR, digitization was completed of the old rail line (Figure 13). It is unclear if the stream was straightened due to the railroad; however, the extreme straight section of stream is going to have negative impacts on channel stability.

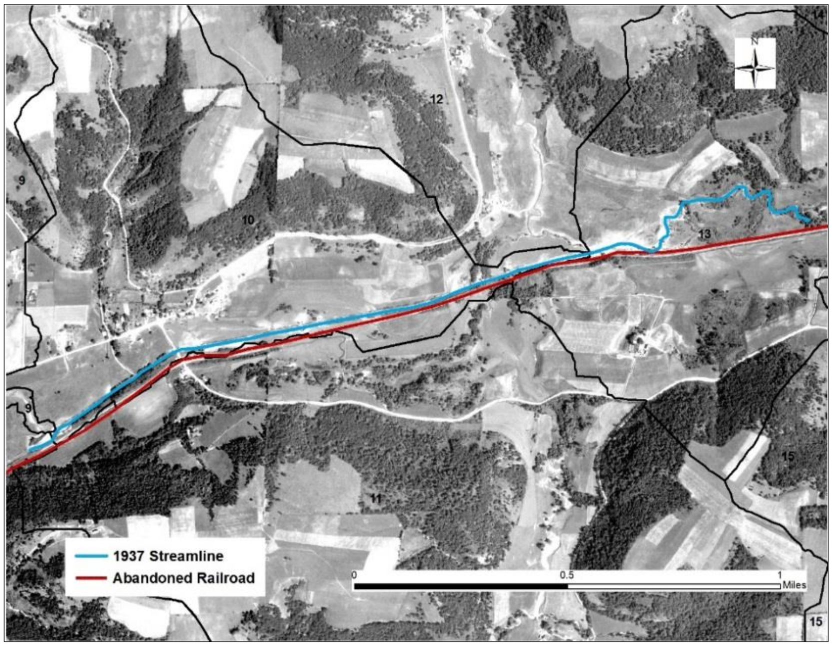

Figure 13. Abandoned railroad and straight section of stream in 1937.

Rock and gravel quarries can also have direct channel impacts and affect the dimension, pattern, and profile of an adjacent stream; they also provide the potential for sediment load to enter the stream. There is one such quarry within the watershed, which is located in the upper reach of the watershed (Figure 14).


Figure 14. Quarry adjacent to stream.

The information described above is used to identify sub-catchments and reaches for further advancement in the WARSSS process. Worksheets are filled out and flagged items indicate the areas of concern to further analyze in the RRISSC phase of the assessment (Table 1). Guidance criteria to complete this table are from Rosgen (2009).

Table 1. Summary guidance of criteria to be further investigated in RRISSC as indicated in red, worksheet 3-1 (Rosgen 2009).

Sub-watershed/ Reach Location ID	Step 7: Surface Erosion		Step 8: Mass Erosion		Step 10: Streamflow Change			Step 11: Channel Processes		Step 12: Direct Channel Impacts		Step 15
	Circle Selected Guidance Criteria Number (Table 3-3)*	Reason for Exclusion	Circle Selected Guidance Criteria Number (Table 3-4)*	Reason for Exclusion	Circle Selected Guidance Criteria Number (Table 3-5)*	Roads	Reason for Exclusion	Circle Selected Guidance Criteria Number (Table 3-6)*	Reason for Exclusion	Circle Selected Guidance Criteria Number (Table 3-7)*	Reason for Exclusion	Check Location Selected for Advance-ment to *RRISSC***
1. 1	**(1) (2) (3) (4)**		(1) (2) (3) (4) (5)		(1) (2) (3) (4) **(5)**	(6)		(1) **(2)** (3) **(4)** (5) (6)		**(1)** (2)		Y
2. 2	(1) (2) (3) (4)		(1) (2) (3) (4) (5)		(1) (2) (3) (4) **(5)**	(6)		(1) (2) (3) (4) (5) (6)		(1) (2)		Y
3. 3	**(1) (2) (3) (4)**		(1) (2) (3) (4) (5)		(1) (2) (3) (4) (5)	(6)		(1) (2) (3) (4) (5) (6)		(1) (2)		Y
4. 4	**(1) (2) (3) (4)**		(1) (2) (3) (4) (5)		(1) (2) (3) (4) **(5)**	(6)		(1) **(2)** (3) **(4)** (5) (6)		(1) (2)		Y
5. 5	**(1) (2) (3) (4)**		(1) (2) (3) (4) (5)		(1) (2) (3) (4) (5)	(6)		(1) (2) (3) **(4)** (5) (6)		**(1)** (2)		Y
6. 6	**(1) (2) (3) (4)**		(1) (2) (3) (4) (5)		(1) (2) (3) (4) (5)	(6)		(1) **(2)** (3) (4) (5) (6)		**(1)** (2)		Y
7. 7	**(1) (2) (3) (4)**		(1) (2) (3) (4) (5)		(1) (2) (3) (4) (5)	(6)		(1) (2) (3) **(4)** (5) (6)		**(1)** (2)		Y
8. 8	**(1) (2) (3) (4)**		(1) (2) (3) (4) (5)		(1) (2) (3) (4) (5)	(6)		(1) (2) **(3)** (4) (5) (6)		**(1)** (2)		Y
9. 9	**(1) (2) (3) (4)**		(1) (2) (3) (4) (5)		(1) (2) (3) (4) **(5)**	(6)		(1) (2) **(3)** **(4)** (5) (6)		(1) (2)		Y
10. 10	(1) (2) (3) (4)		(1) (2) (3) (4) (5)		(1) (2) (3) (4) (5)	(6)		(1) (2) **(3)** **(4)** (5) (6)		**(1)** (2)		Y
11. 11	**(1) (2) (3) (4)**		(1) (2) (3) (4) (5)		(1) (2) (3) (4) (5)	(6)		(1) (2) **(3)** (4) (5) **(6)**		(1) (2)		Y
12. 12	**(1) (2) (3) (4)**		(1) (2) (3) (4) (5)		(1) (2) (3) (4) (5)	(6)		(1) (2) **(3)** **(4)** (5) (6)		(1) (2)		Y
13 13	**(1) (2) (3) (4)**		(1) (2) (3) (4) (5)		(1) (2) (3) (4) (5)	(6)		(1) (2) **(3)** **(4)** (5) (6)		(1) (2)		Y
14. 14	**(1) (2) (3) (4)**		(1) (2) (3) (4) (5)		(1) (2) (3) (4) (5)	(6)		(1) (2) (3) (4) (5) (6)		(1) (2)		Y
15. 15	**(1) (2) (3) (4)**		(1) (2) (3) (4) (5)		(1) (2) (3) (4) (5)	(6)		(1) (2) **(3)** **(4)** (5) (6)		**(1)** (2)		Y
16. 16	**(1) (2) (3) (4)**		(1) (2) (3) (4) (5)		(1) (2) (3) (4) **(5)**	(6)		(1) (2) (3) (4) (5) (6)		(1) (2)		Y
17. 17	(1) (2) (3) (4)		(1) (2) (3) (4) (5)		(1) (2) (3) (4) (5)	(6)		(1) (2) (3) **(4)** (5) (6)		**(1)** (2)		Y
18. 18	**(1) (2) (3) (4)**		(1) (2) (3) (4) (5)		(1) (2) (3) (4) (5)	(6)		(1) (2) (3) **(4)** (5) (6)		**(1)** (2)		Y
19. 19	(1) (2) (3) (4)		(1) (2) (3) (4) (5)		(1) (2) (3) (4) (5)	(6)		(1) (2) (3) (4) (5) (6)		(1) (2)		N
20. 20	(1) (2) (3) (4)		(1) (2) (3) (4) (5)		(1) (2) (3) (4) (5)	(6)		(1) (2) (3) (4) (5) (6)		(1) (2)		N

RLA Summary

The RLA determined that 18 out of 20 sub-catchments required further assessment in the RRISSC phase (Figure 15). Channel processes, along with surface erosion risk, were the leading criteria for sub-watershed advancement. The presence of large earthen dams within the watershed provides potentially complex impacts on channel stability and requires a more detailed assessment. Direct impacts of cattle and channel straightening provided additional support for further detailed assessment in sub-watersheds.

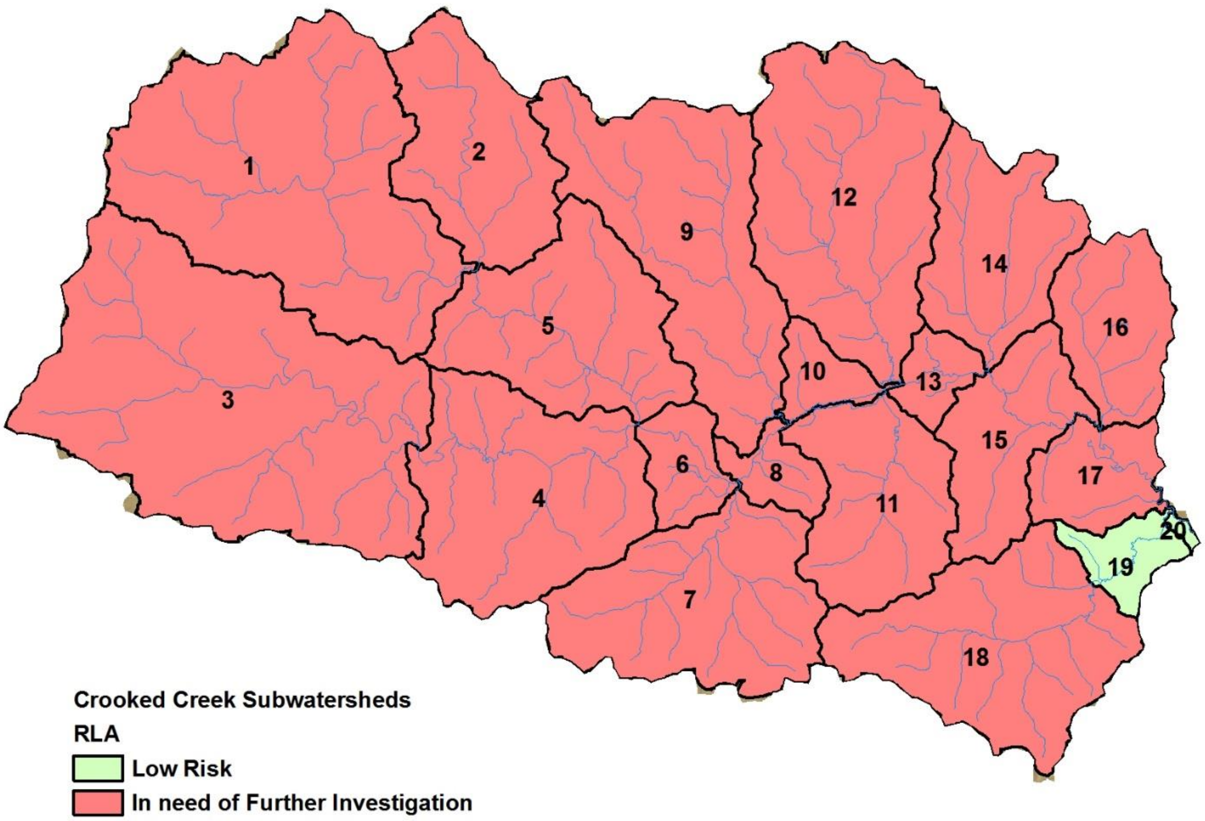

Figure 15. Sub-watersheds in need of further assessment in the RRISSC, or deemed low risk.

Rapid Resource Inventory for Sediment and Stability Consequence (RRISSC)

Process

The RRISSC phase provides a detailed assessment of the processes identified within each catchment categorized as needing further assessment from the RLA analysis. This results in unique combinations and numbers of catchments to be analyzed for each of the steps below. Potential areas of concern, processes, and land use activities are all examined in detail regarding their impact on stream stability utilizing desktop tools, process relations and field verification. Generalized process relations are used to complete worksheets, as described in Rosgen (2009), to provide a consistent, repeatable analysis over large areas and help locate key areas for assessment in the PLA phase. Risk rating summaries are created for hillslope, hydrologic, and channel processes. Individual process ratings of high or very high are assessed further in the PLA phase. Anything at or below a moderate risk rating is excluded from further investigation, but may be considered in management strategies.

Hillslope Processes

Mass Erosion Risk

No catchments needed further assessment for mass erosion risk.

Road Impact Risk

Roads have the potential to deliver sediment from road surfaces and road fill or to cause direct disturbance at stream crossings. A total of five crossings occur on the main stem of Crooked Creek. All crossings are span bridges and appear to have no adverse impacts on stream stability. Sub-watershed 6 was flagged as needing investigation for road impacts. Using LiDAR, sediment input from road surface and fill was calculated by analyzing relationships between road area disturbance, slope and distance to stream. This analysis resulted in a moderate risk rating of sediment potential from roads; however, because the stream is straightened along the road, this impact was also assessed under channel processes. No other sub-watershed were flagged for road impacts.

Surface erosion risk

When assessing surface erosion risk in RLA, soil K Factor was used; however, K Factor only considers erosion potential, and not sediment delivery to the stream. To assess sediment delivery, it is dependent on relationships of drainage density, slope gradient, ground cover and stream buffer. Utilizing these established relationships, surface erosion was found to be a low risk in all sub-catchments. Although for the purpose of RRISSC, surface erosion potential was deemed low, it is a very important aspect in the total sediment budget of a watershed and will be assessed in PLA by using Hydrologic Simulation Program-FORTRAN (HSPF).

Hydrologic Processes

Streamflow Change

Altered streamflow causes changes in volume, timing, connectivity and flow rates. Streamflow change ratings are separated into rural and urban conditions, with adjustments based on increased or decreased bankfull discharge. Land use has changed drastically since pre-settlement vegetation conditions. Settlement in the late 1800s, and subsequent conversion of land to agriculture and pasture, created streamflow changes. The following 80 years since has allowed the stream to adjust to the altered streamflow by land conversion. Recent stream changes can also be attributed to other localized factors. All “rural” sub-watersheds rated very low, based on acres cleared or harvested. Sub-watershed 1 was assessed using the urban watershed category. This watershed contains part of the city of Caledonia, and the urbanization results in a rating of moderate. Five sub-watersheds (1, 2, 4, 9, and 16) have large earthen dams retaining water (Figure 16). CCWD owns four of these for the purpose of flood control (BWSR 2004). The dams create large pools behind the impoundments and release water from outlets with constant flow. The outlets are not monitored for flow; as a result, discharge effects and reductions of bankfull flows are not known. Potential for reductions in natural sediment supply causing sediment “starved” water, reduction in spawning gravel, and altered bed-material size distributions are all reasons the rating score was rated as very high for sub-watersheds 1, 2, 4, 9, and 16 (Figure 17).

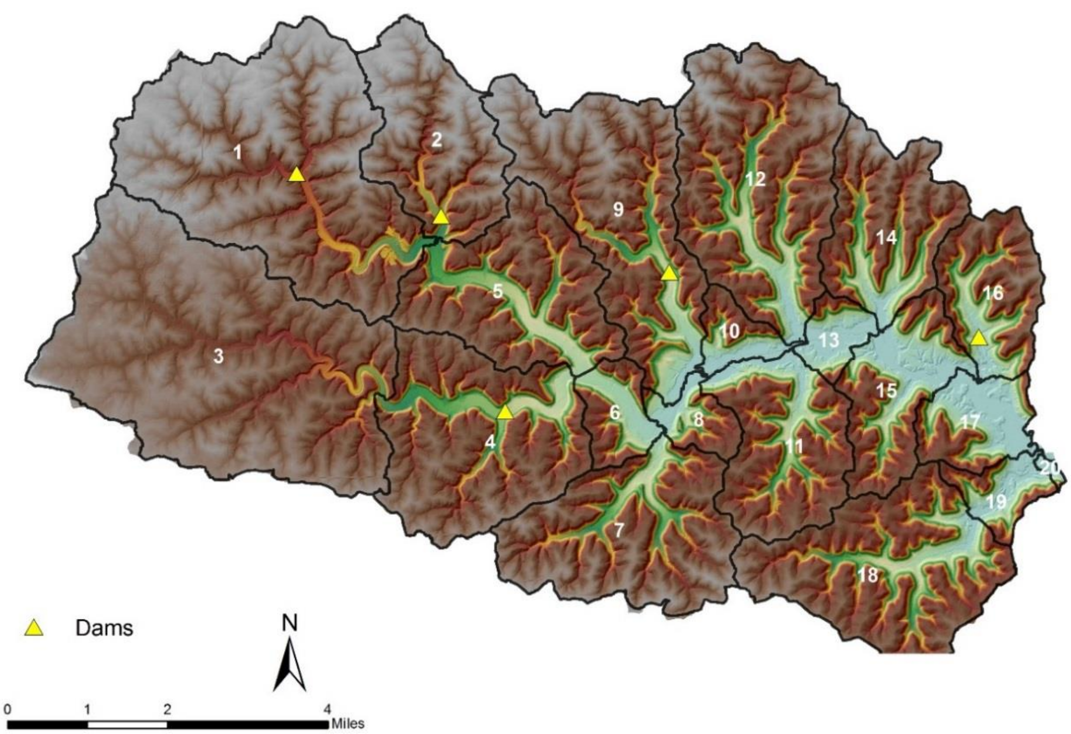

Figure 16. Locations of large earthen dams within sub-catchments.

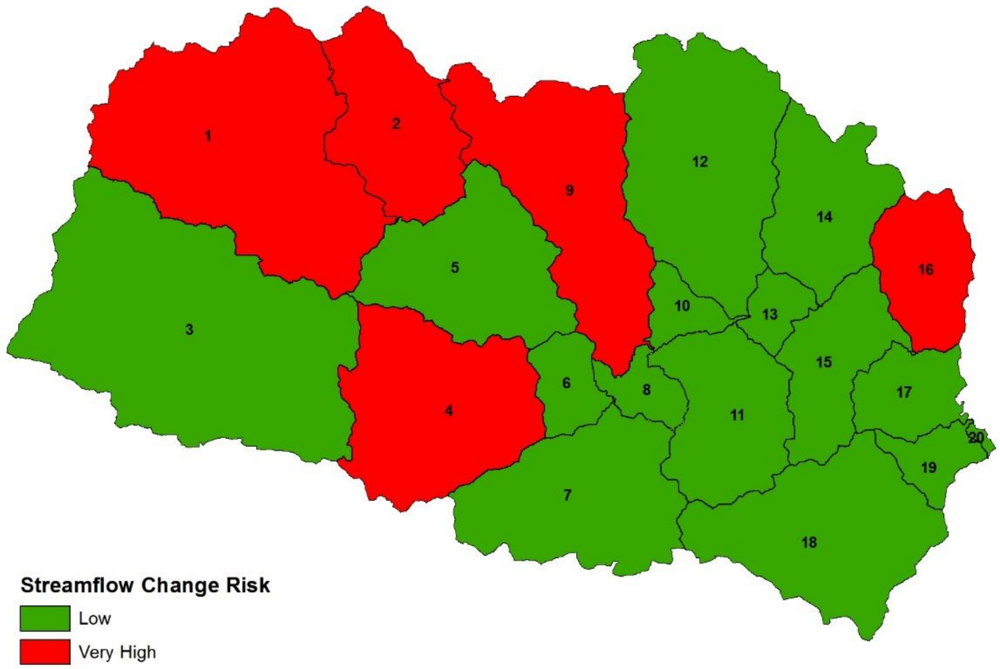

Figure 17. Streamflow change potential risk rating

Channel Processes

Streambank Erosion Risk

Streambank erosion by lateral migration and widening of channels often are a major contributor of sediment to river systems. Although a natural process, accelerated erosion is an indication of channel instability. For the RRISSC assessment, lateral erosion for the main channel was estimated by measuring the movement of the stream in a 20 year span (1991 to 2011), coupled with bank height measurements utilizing LiDAR. This method is a desktop version of the Bank Assessment for Non-point source Consequences of Sediment (BANCS) procedure (Rosgen 2009). Erosion rates were assigned a risk rating based on streambank erosion unit rate ratings from Rosgen (2014) Lateral Stability Categories worksheet. Areas with dense forest canopy and areas where stream digitization was difficult were assigned streambank erosion risk ratings by following the procedure as outlined in Rosgen (2009). This method consists of analyzing vegetation composition, channel dimensions and pattern measurement from LiDAR. A more in-depth accounting for streambank erosion rates utilizing calibrated field derived assessments can be found in the PLA.

RLA revealed channel processes as a leading risk category in this watershed. Stream type and valley type mismatches, along with instability signatures, have the potential of causing high erosion rates. However, for the majority of stream length, the channel has moved little in the 20 year span (Figure 18). From these methods, 5 sub-catchments were assessed further for streambank erosion risk (Figure 19).

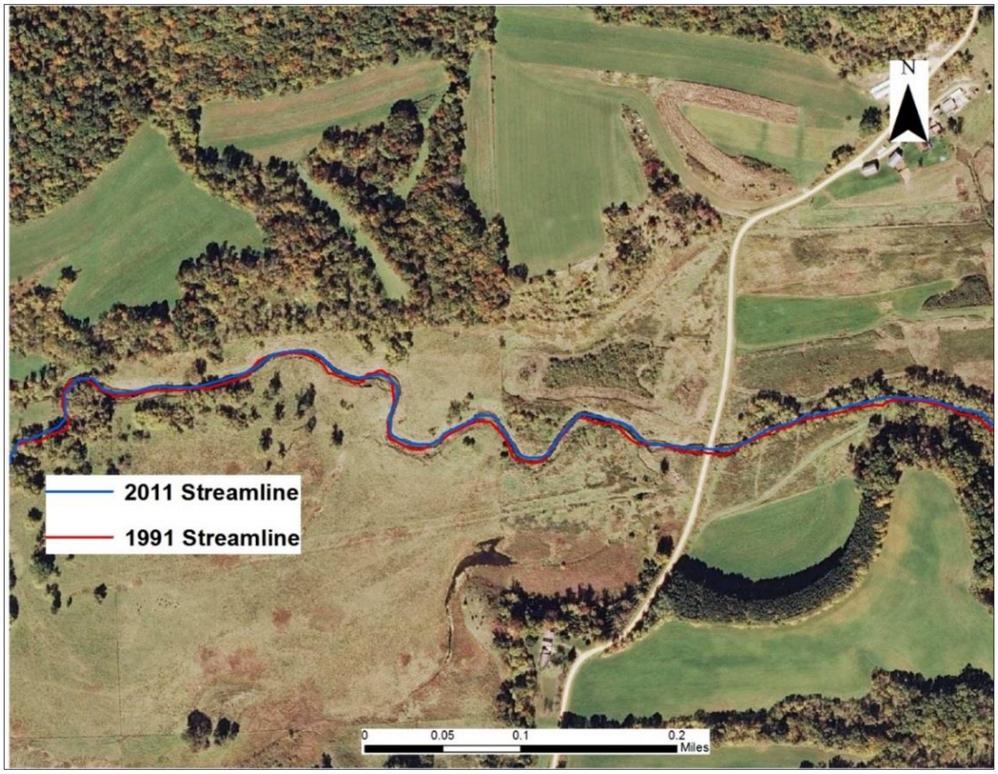

Figure 18. Comparison of stream over a 20 year span showing little movement.

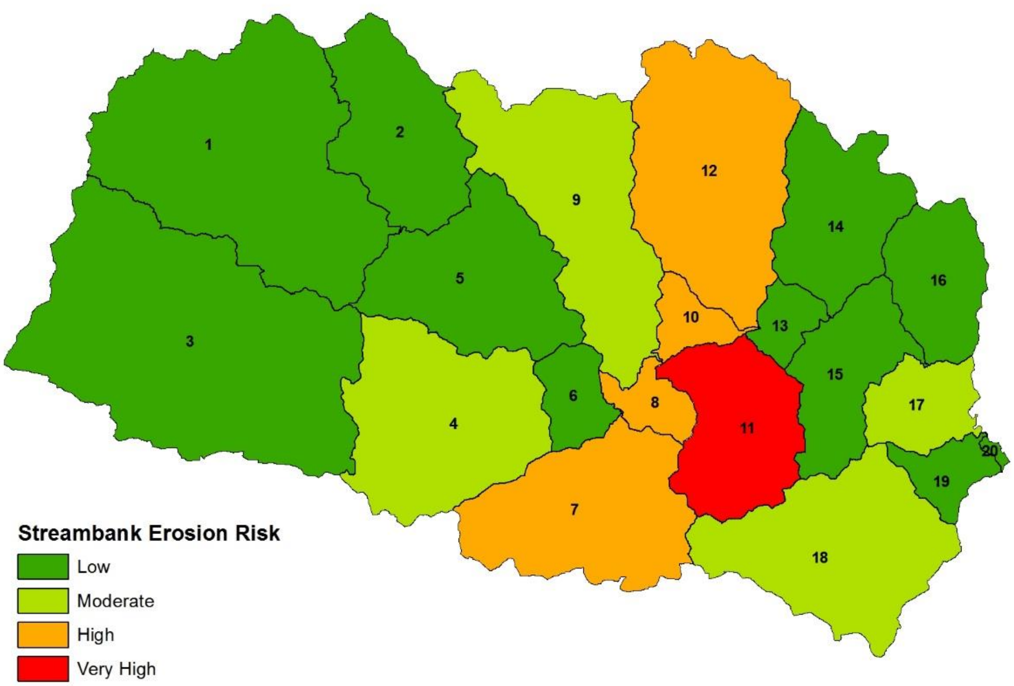

Figure 19. Streambank erosion potential risk rating.

Direct Channel Impacts

Direct channel impact examples are based on disturbances, such as vegetative conversions, heavy grazing, straightening, mining impacts and clearing vegetation. The lengths of disturbances are related to stream type to determine a risk factor. The predominant disturbances in this watershed are heavy grazing and straightening. Measured lengths of disturbance are compared to total length of stream length within each sub-catchment to develop a rating. Channel straightening due to a railroad resulted in high and very high ratings in sub-watersheds 8 and 10, respectively. Heavy grazing was flagged in sub-watersheds 5, 7, 15, 17 and 18 (Figure 20). No debris blockages were observed in aerial photos.

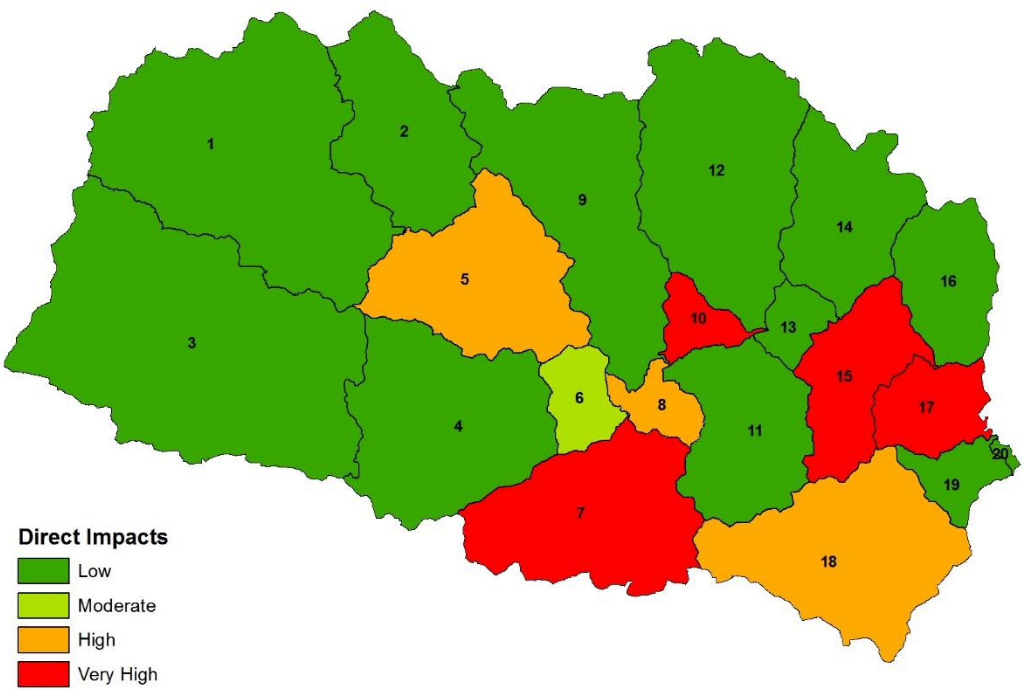

Figure 20. Direct impacts potential risk rating.

Channel Enlargement Risk Potential

Channel enlargement risk rating is an aggregate summary of previous relationships. Streamflow changes, streambank erosion risk, in-channel mining and direct channel impacts ratings are combined with dominant stream type to determine the overall channel enlargement risk. Six watersheds rated high to very high and require further assessment in the PLA phase (Figure 21).

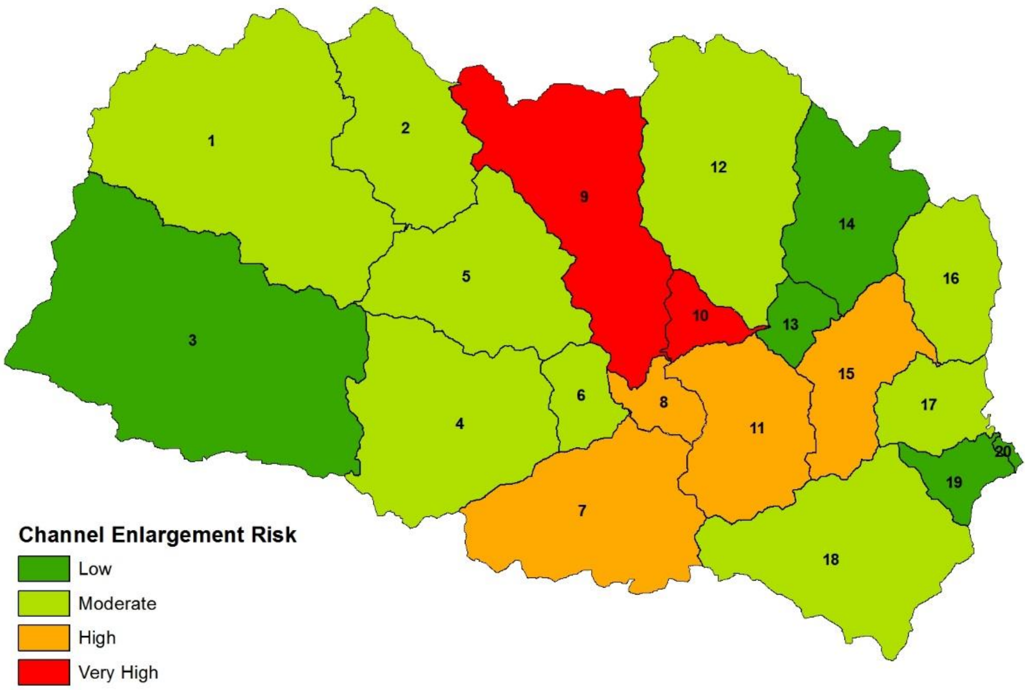

Figure 21. Channel enlargement potential risk rating.

Aggradation/Excess Sediment Deposition Risk

Aggradation/excess sediment deposition risk is a rating dependent on an aggregate of several previously calculated ratings: mass erosion, road impact, surface erosion risk, channel enlargement risk, and streambank erosion. In addition, width-to-depth ratio departure analysis aids in determining the risk rating. For example, increases in width-to-depth ratio effect sediment competency and capacity, which can result in channel aggradation. Ratings adjustments are determined largely through aerial photography interpretation of obvious excess deposition/depositional patterns, filling of pools, and deposition of sand or larger material on the floodplain. Thirteen sub-watersheds rated high or very high and advance to PLA (Figure 22).

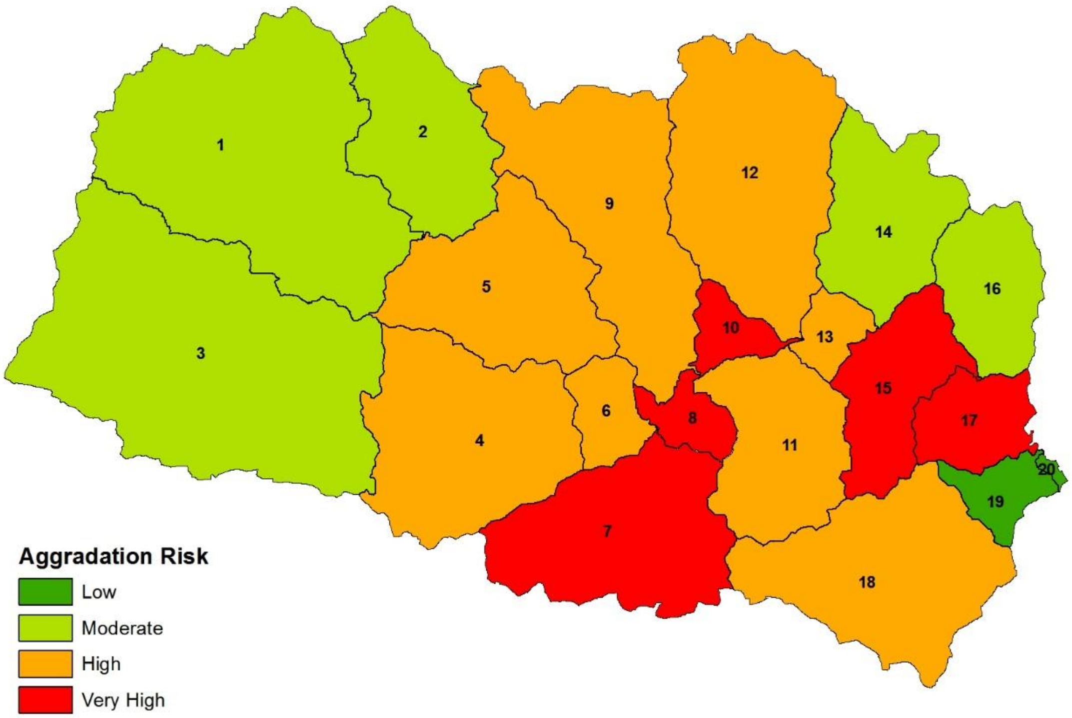

Figure 22. Aggradation potential risk rating.

Degradation Risk

Degradation risk is an aggregated summary rating based on streamflow change, channel evolution, road crossing and direct channel impact ratings. Channel evolution assessment uses stream succession to assign risk based on where the channel is within a given succession scenario and whether it's in a stable or unstable channel state. Figure 23 demonstrates one example of a succession scenario and the impacts, where an alteration to channel or landscape caused disequilibrium and the stream shifts toward recovery to a stable state once again. One sub-watershed was rated as high due to a downstream section of G stream type, which is almost always an unstable form. Thirteen total sub-watersheds rated as high or very high, advancing to PLA (Figure 24). Five of the catchments advanced solely due to the streamflow changes rating as high, from the large earthen dams. These dams do not have flow monitoring; as a result, the effects of flow change are unknown.

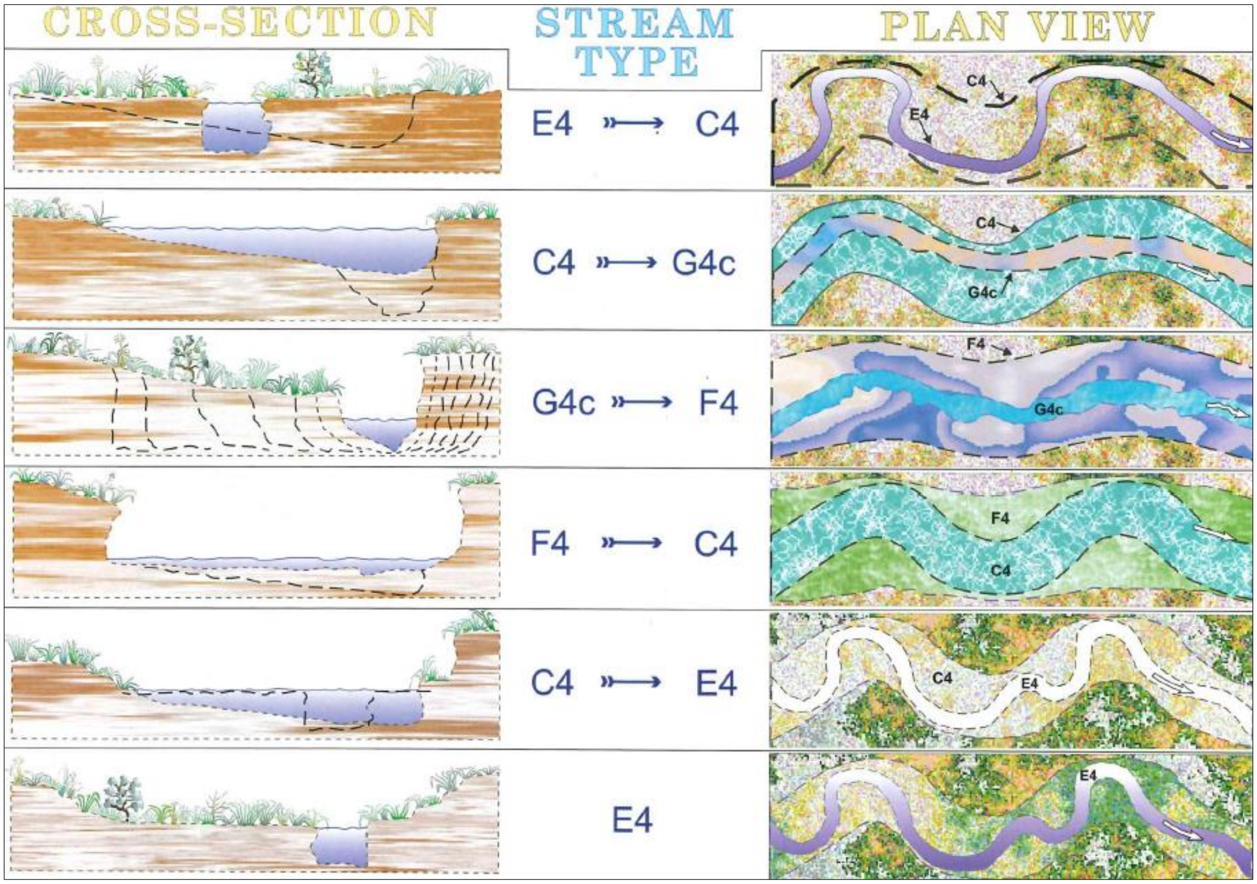

Figure 23. Example of stream succession after channel change and back towards stability.

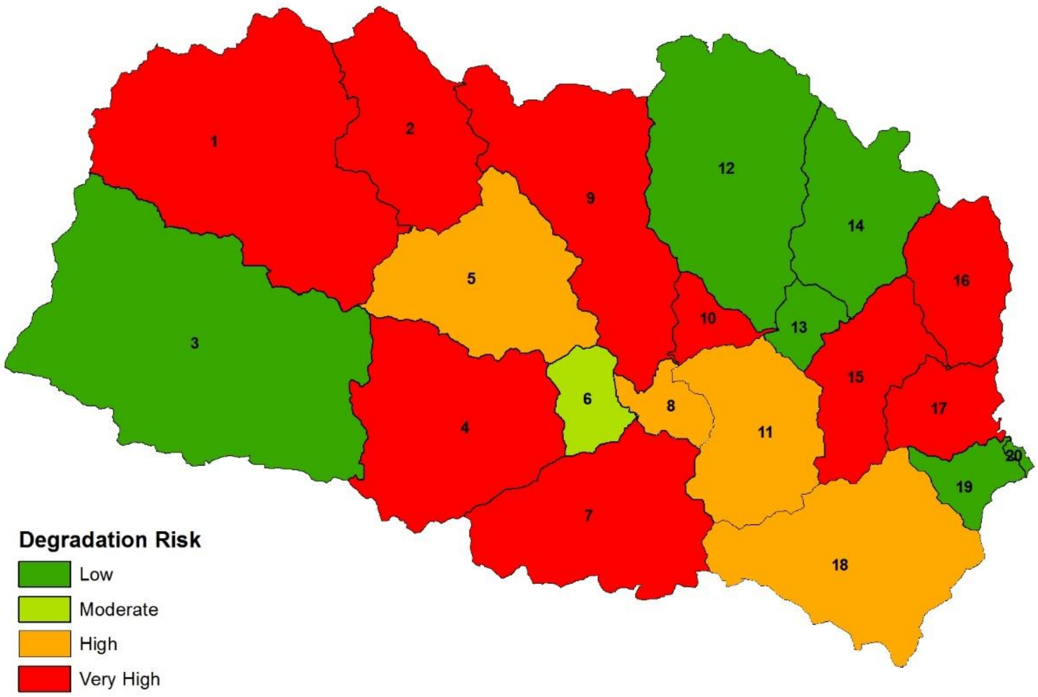

Figure 24. Degradation potential risk rating.

Overall Risk Rating Summary

Seventeen of eighteen sub-watersheds were identified with individual processes triggering advancement to the more detailed PLA phase (Figure 25 and Figure 26). The number of identified processes per sub-catchment illustrates areas of greater concern as identified by RRISSC (Figure 27). Sub-watershed 5 has the potential for reference conditions and the presence of stable streams for departure analysis. Aggradation/excess sediment and degradation are the most frequent processes causing further assessment. Width-to-depth ratio departure and channel enlargement appear to be the leading reason for high ratings for aggradation. Much of Crooked Creek appears to be over-widened, reducing stream power and the ability to transport sediment. Degradation ratings are most influenced by streamflow changes and direct channel impacts and is the most prevalent issue in the watershed.

The effects of the large, un-monitored earthen dams on streamflow are unknown and should be investigated further. Straightening and heavy grazing are potentially affecting the pattern, dimension and profile of the stream. Channel evolution and sediment processes will be investigated further in the PLA, so that an understanding of the processes responsible for channel instability can help with prioritizing management strategies.

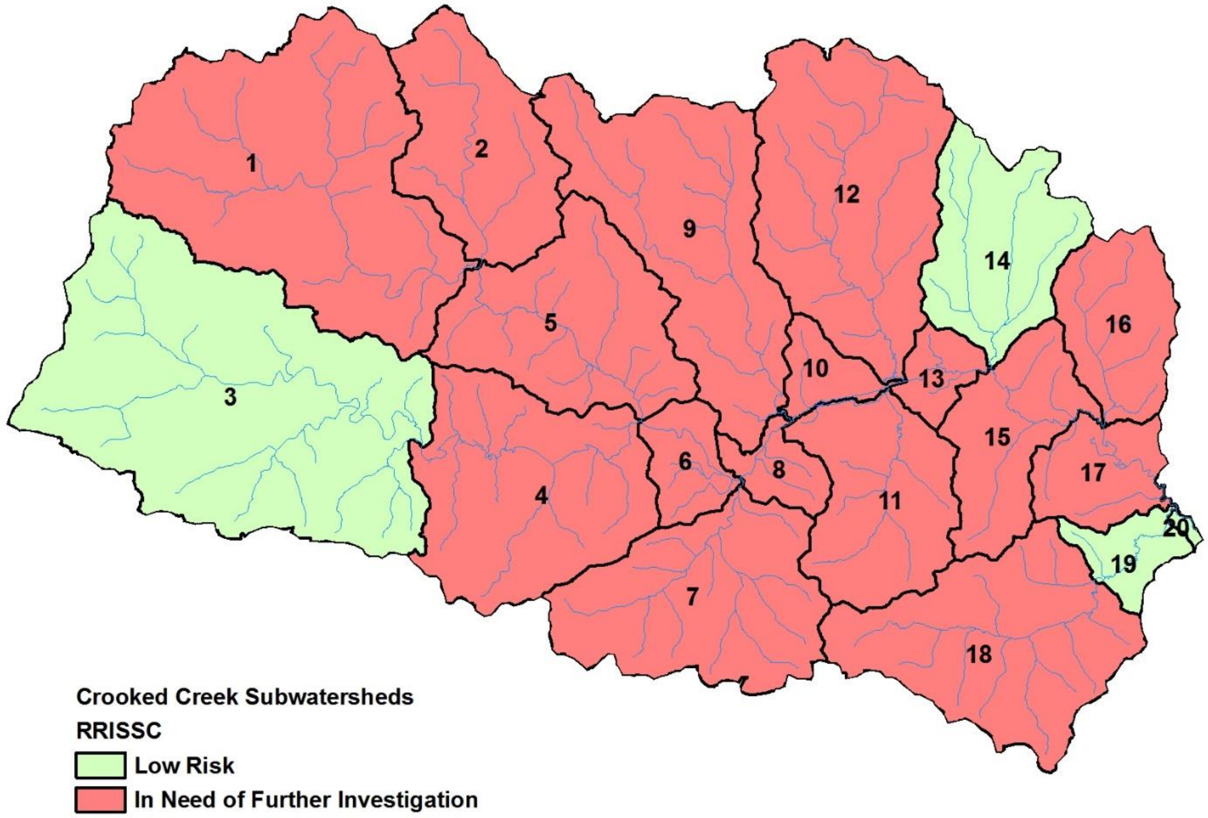

Figure 25. Sub-catchments in need of further investigation in the PLA.

	Geographic Location				Stream Type Location								
Location Code/ River Reach I.D.	**Step 6:** Mass Erosion **(Worksheet 4-3)**	**Step 7:** Roads **(Worksheet 4-4)**	**Step 8:** Surface Erosion **(Worksheet 4-5)**	**Step 10:** Streamflow Change **(Worksheet 4-6)**	**Step 13:** Streambank Erosion **(Worksheet 4-7)**	**Step 14:** In-Channel Mining **(Worksheet 4-8)**	**Step 15:** Direct Channel Impacts **(Worksheet 4-9)**	**Step 16:** Channel Enlargement **(Worksheet 4-10)**	**Step 17:** Aggradation/ Excess Sediment **(Worksheet 4-11)**	**Step 18:** Channel Evolution/ Succession States **(Table 4-5)**	**Step 19:** Degradation **(Worksheet 4-12)**	**Processes Identified by Step for Advancement to *PLA***	**Check Location Selected for Advance-ment to *PLA***
1	Very Low	Very Low	Low	Very High	Low	Very Low	Low	Moderate	Moderate	Low	Very High	10, 19	X
2	Very Low	Very Low	Low	Very High	Low	Very Low	Very Low	Moderate	Moderate	Low	Very High	10, 19	X
3	Very Low	Very Low	Low	Low	Low	Low	Low	Low	Low	Low	Low		
4	Very Low	Very Low	Low	Very High	Moderate	Very Low	Very Low	Moderate	High	Low	Very High	10, 17, 19	X
5	Very Low	Very Low	Low	Very Low	Low	Very Low	High	Moderate	Moderate	Low	High	15, 19	X
6	Very Low	Moderate	Low	Very Low	Low	Very Low	Moderate	Moderate	High	Low	Moderate	17	X
7	Very Low	Very Low	Low	Very Low	Low	Very Low	Very High	High	Very High	Low	Very High	15, 16, 17, 19	X
8	Very Low	Very Low	Low	Very Low	High	Very Low	High	High	Very High	Low	High	13, 15, 16, 17, 19	X
9	Very Low	Very Low	Low	Very High	Moderate	Very Low	Very Low	Very High	High	Low	Very High	10, 16, 17, 19	X
10	Very Low	Very Low	Low	Very Low	High	Very Low	Very High	High	Very High	Low	Very High	13, 15, 16, 17, 19	X
11	Very Low	Very Low	Low	Very Low	Very High	Very Low	Very Low	High	High	High	High	13, 16, 17, 18, 19	X
12	Very Low	Very Low	Low	Very Low	High	Very Low	Very Low	Moderate	High	Low	Low	13, 17	X
13	Very Low	Very Low	Low	Very Low	Low	Very Low	Very Low	Low	High	Low	Low	17	X
14	Very Low	Very Low	Low	Very Low	Low	Low	Low	Low	Low	Low	Low		
15	Very Low	Very Low	Low	Very Low	Low	Very Low	Very High	High	Very High	Low	Very High	15, 16, 17, 19	X
16	Very Low	Very Low	Low	Very High	Low	Very Low	Very Low	Moderate	Moderate	Low	Very High	10, 19	X
17	Very Low	Very Low	Low	Very Low	Moderate	Very Low	Very High	Moderate	Very High	Low	Very High	15, 17, 19	X
18	Very Low	Very Low	Low	Very Low	Moderate	Very Low	High	Moderate	Very High	Low	High	15, 17, 19	X

Figure 26. Overall RRISSC rating summary for sub-catchments, worksheet 4-2 (Rosgen 2009).

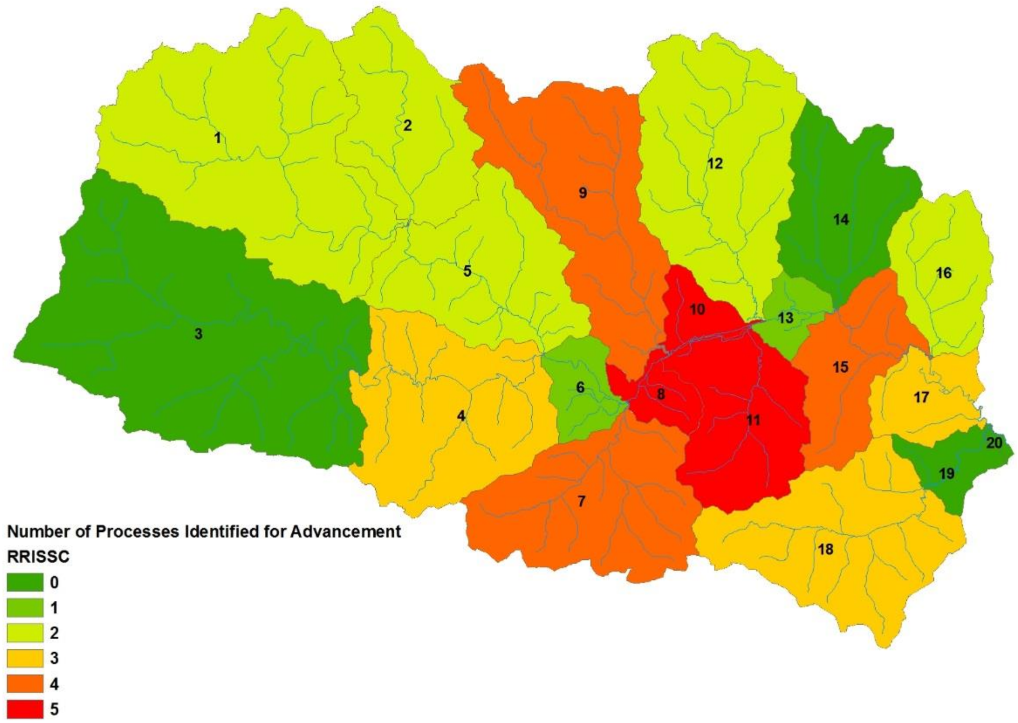

Figure 27. Number of processes identified from RRISSC by sub-catchment.

Prediction Level Assessment

Hydrology and Bankfull Discharge

It is important to understand how timing, intensity, and duration of hydrologic inputs have changed over time and how they have influenced channel forming flows and stream stability. Hydrology in the watershed has historically been driven by a combination of rain and snowmelt. Through the analyzation of precipitation records and discharge data, a narrative can be formed through multiple lines of evidence on how human influences, such as land use conversion and climate, are impacting the watershed.

Karst is a defining feature of the watershed that affects hydrology. It is a geological landform comprised of near-surface carbonate bedrock lacking protective soil layers. The underlying bedrock is subject to dissolution caused by acidic waters percolating down through the soils, over time leading to the formation of sinkholes, caverns, and underground streamflow (MPCA 2015). Watersheds with karst features often have increased interaction between surface water and sub-surface flows. Flow contributions can be lacking on some reaches and over-abundant in others, such as where springs or other groundwater inputs exist.

Seven large water retention structures constructed in the 1960s have also likely impacted watershed hydrology and are shown in Figure 28. Each structure has the ability to hold 1 to 2 inches of precipitation over the contributing watershed area if empty, but most of them hold water year round so that volume is lower than the estimates presented in Table 2. The net result of these structures is the lowering of peak flows and the extension of high flows over a longer duration.

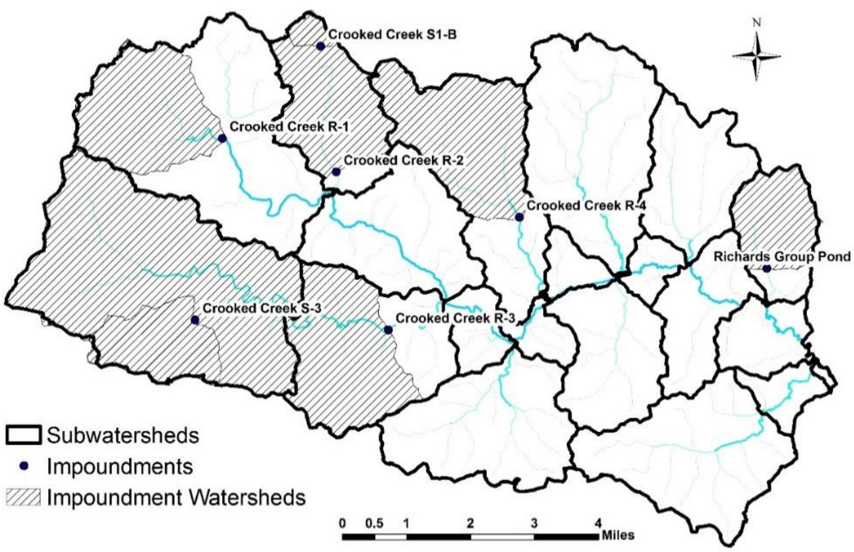

Figure 28. Retention structures in Crooked Creek watershed and the affected upstream areas.

Table 2. Retention structure characteristics.

Dam	Year Completed	Drainage Area (mi^2)	Contributing Watershed Mean Slope (%)	Max. Reservoir Storage Volume (acre-ft)	Max. Reservoir Storage as Precipitation Runoff (inches)
Crooked Creek R-1	1967	3.45	5.1	363	1.97
Crooked Creek R-2	1966	3	8.2	202	1.26
Crooked Creek R-3	1968	12.8	6.76	510	0.75
Crooked Creek R-4	1967	3.95	10.28	450	2.14
Crooked Creek S1-B	1966	0.25	3.45	37	2.78
Crooked Creek S-3	1967	1.94	4.08	240	2.32
Richards Group Pond	1959	1.69	15.05	25	0.28

Historical land use in the watershed in the form of cropping has also played an important role in hydrology in the watershed. The increase in row cropping, through conversion of natural and pasture lands, changes the timing and the volume of precipitation that makes it to the stream from overland and subsurface flow. Significant increases in row crop acreage in the 1970s and 1990s likely has had impacts of increased runoff to Crooked Creek (Figure 29).

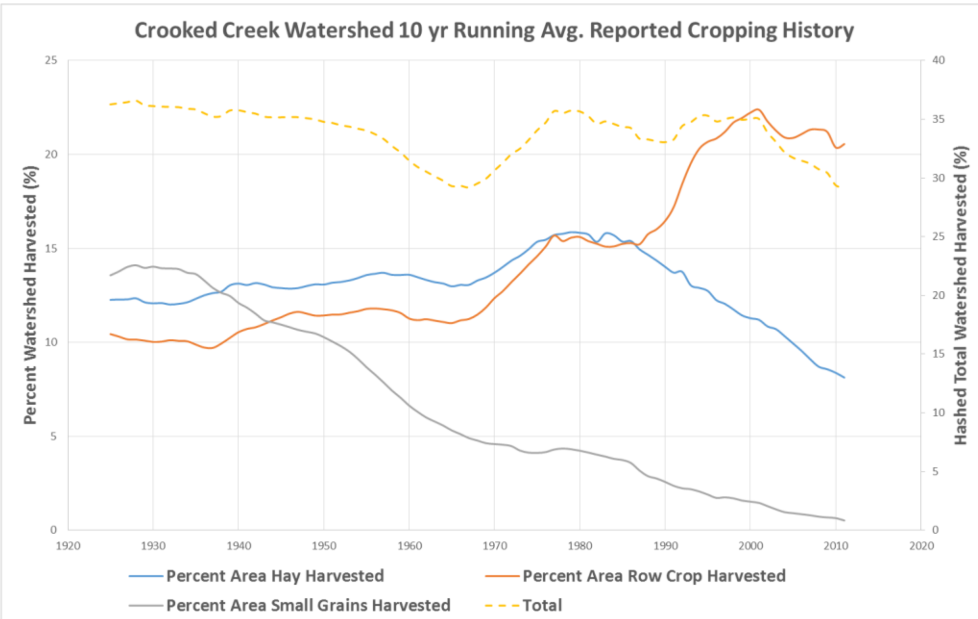

Figure 29. Cropping history of Crooked Creek watershed.

Daily precipitation data is available for the watershed for the past 125 years. Figure 30 shows the annual average precipitation along with a running 7-year average, percentiles (25^{th} and 75^{th}), and the average for the period of record. It appears that precipitation has been increasing over the last 50 to 60 years from around 30 inches per year to near 40 inches currently.

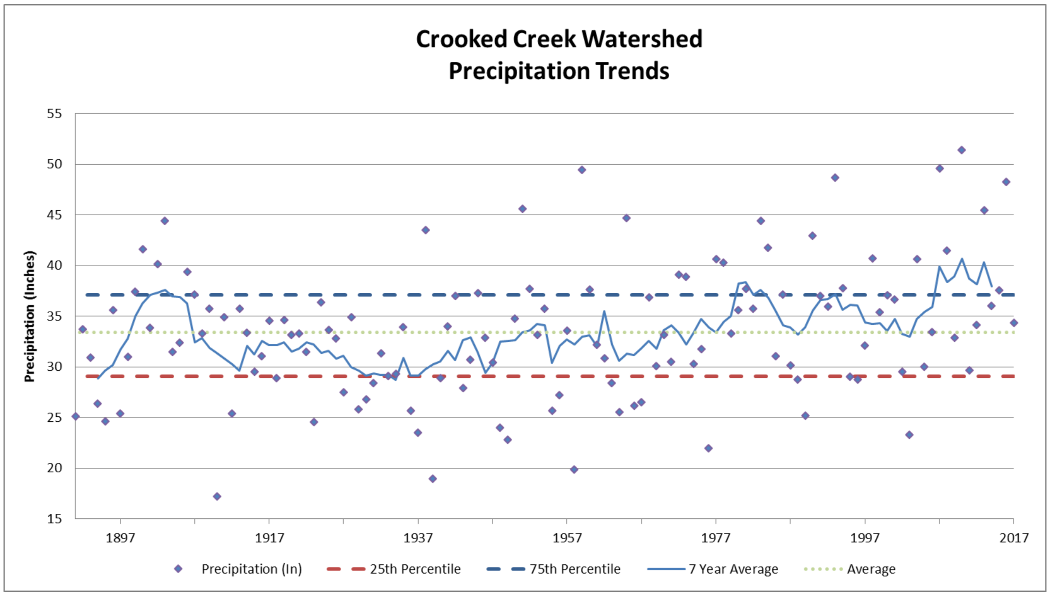

Figure 30. Watershed annual precipitation analysis.

To further validate the precipitation changes, the assessment of persistence using the Hurst Coefficient is shown in Figure 31. The coefficient, with values typically ranging from 0 to 1, is derived from the cumulative departure from the mean value of the dataset. Values above 0.5, moving towards 1, show increase in persistence, and values below 0.5 indicate randomness. The coefficient for the watershed was 0.73, indicating fairly strong persistence; this is supported by the graph showing a negative trend away from the mean from the 1900s to the 1970s and then switching to the positive direction from around 1976 to the present.

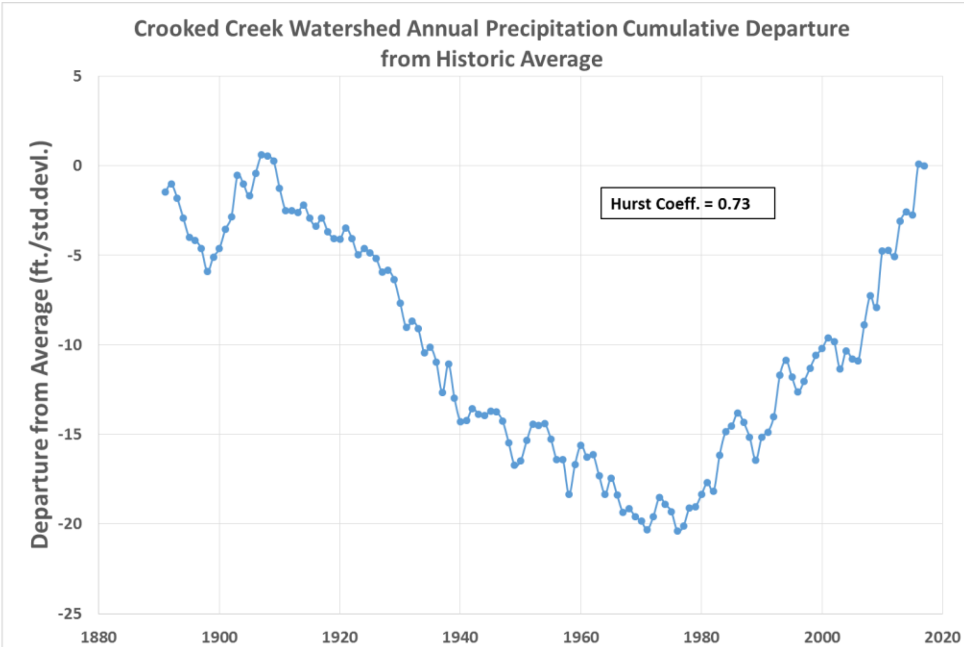

Figure 31. Hurst Coefficient and cumulative departure from mean.

Precipitation timing shown in Figure 32 depicts bi-monthly precipitation averages broken into 30-year increments. Precipitation increased during the 6-month period of March through August, from the first time period to the latest, by 3.2 inches or nearly 17 percent; it decreased by half an inch in the other months of September through February.

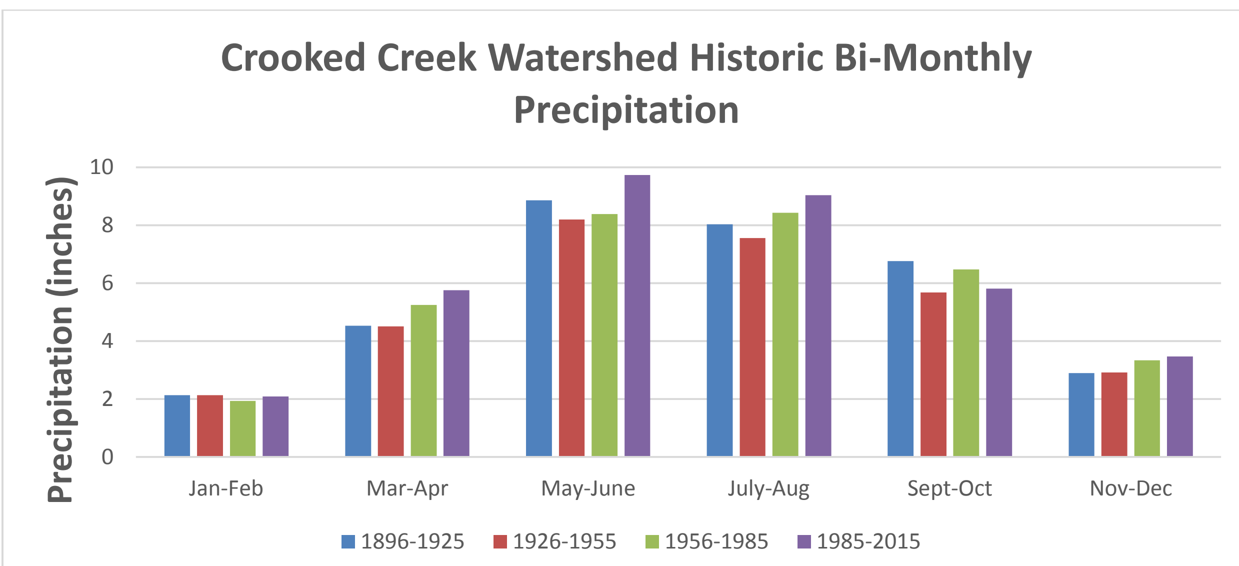

Figure 32. Historic bi-monthly precipitation.

Precipitation intensity in Table 3 shows the number of occurrences of different intensities of 24-hour storms in the same 30-year time periods as the graph of bi-monthly precipitation. Increases in the

1-2” and 2-3” storm events appear to be considerable, while the larger 3” plus events appear to seldom happen but with similar frequency as in the past.

Table 3. Rain event tabulation for Crooked Creek watershed.

Time Period	1-2" Rain Event in 24-hr Period	2-3" Rain Event in 24-hr Period	3-4" Rain Event in 24-hr Period	4-5" Rain Event in 24-hr Period	5+" Rain Event in 24-hr Period
1896-1925	281	34	4	1	1
1926-1955	276	29	11	1	2
1956-1985	284	35	10	2	0
1985-2015	321	40	8	2	1
Total	1162	138	33	6	4

Distribution of flows over time are shown in Figure 33 and utilize annual peak flows from the United States Geological Survey (USGS) gauge at Freeburg, MN (5387030). Separated by decades, data is available beginning in the 1980s and shows similar flow distributions in the 1980s and 1990s, while there is an increase at all flow regimes for the 2000s and an increase in the middle to upper flows in the 2010s. Annual peak flows have occurred in several different months, and over the last 40 years have averaged out in the month of May, but only one year has actually had peak flow occur during that month (Figure 34). There is an equal number of annual peak flows earlier, during the months of February to April, compared to after, during the months of June to October. This indicates that the system has likely been driven by an even mixture of snow melt and large rain storms.

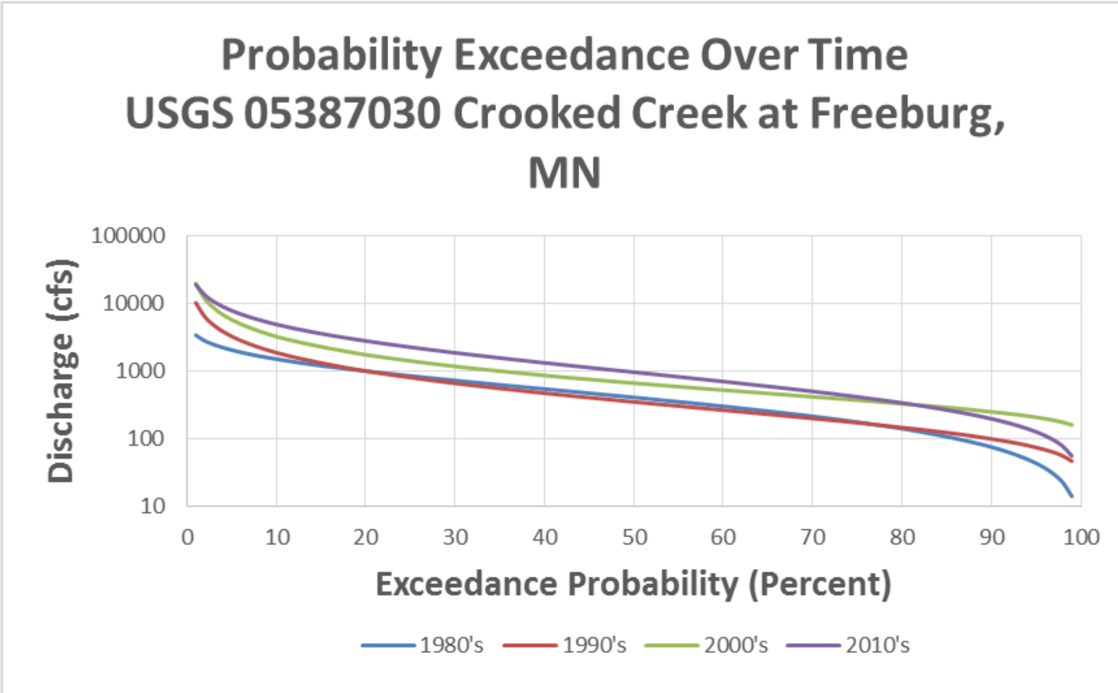

Figure 33. Exceedance probability at USGS gauge 05387030 Crooked Creek Freeburg, MN.

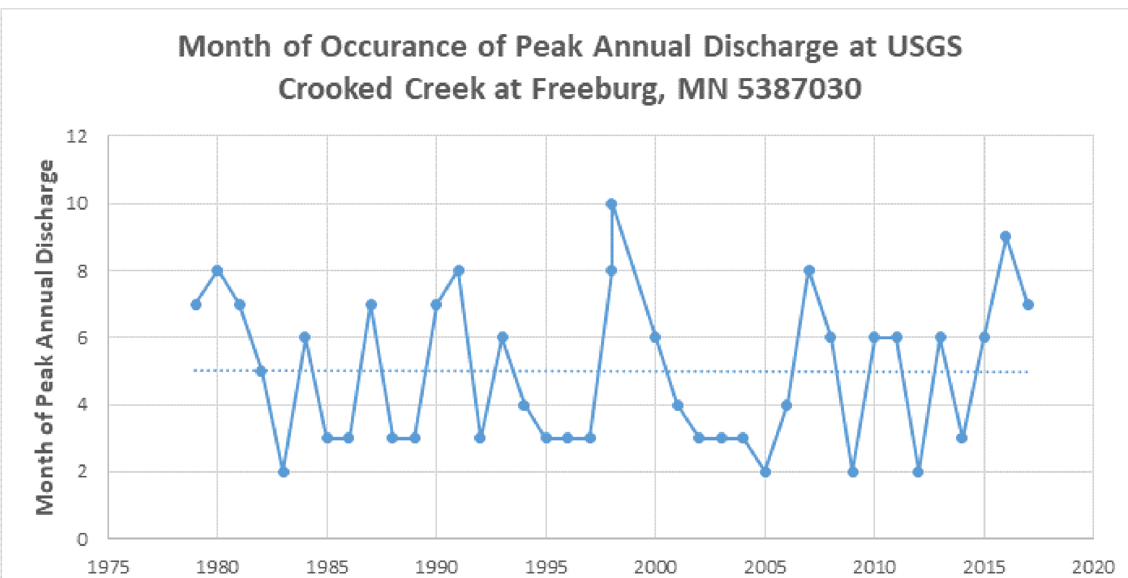

Figure 34. Month of peak annual discharge at USGS gauge 05387030 Crooked Creek at Freeburg, MN.

An analysis of annual peak flows allows for the estimation of return intervals and related discharge estimates. As described in Rosgen (2014), bankfull return intervals have a nominal range of 1.2 to 1.8 years, with an approximate average of 1.5 years. A much larger range in values exist depending on watershed conditions, ranging from rural to urban. Experience in southeast Minnesota shows return intervals between 1.2 to 1.5 years, but much closer to 1.2 years. Analyzing USGS gauge (05387030) Crooked Creek at Freeburg, MN, estimates the 1.2 year return interval discharge is 125cfs, and the 1.5 year return interval is 265 cfs. When the peak flow gauge analysis is coupled with regional curves of drainage area versus bankfull area, the bankfull determinations at field survey sites fall within these existing relationships. The bankfull flow from the gauge also allows for a continuity check for surveys throughout Crooked Creek.

Channel Processes

Stream classification completed to this point has been completed using a desktop method which relies heavily on a few geomorphic relationships. These were used to target field survey locations of representative and references of each stream/valley type within the watershed. Not only were specific combinations of stream/valley types pursued, but also field surveys were targeted to capture the conditions of each sub-catchment that has progressed to the PLA. This method of using representative reaches by stream and valley type, along with a Pfankuch stability ranking, increases the efficiency of the intensive field work required to capture watershed conditions. Once the sites were chosen, field reconnaissance was critical to confirm the locations were indeed representative and fit the targeted criteria (Figure 35).

Field surveys included site specific measurements of dimension, pattern, and profile. These measurements are an integral component of departure analysis. Departure analysis is the way of determining relative instability of unstable channels (representative) compared to more stable reaches (reference) of the same stream type and valley type. Once the cause of the instability is determined, management recommendations can be formed.

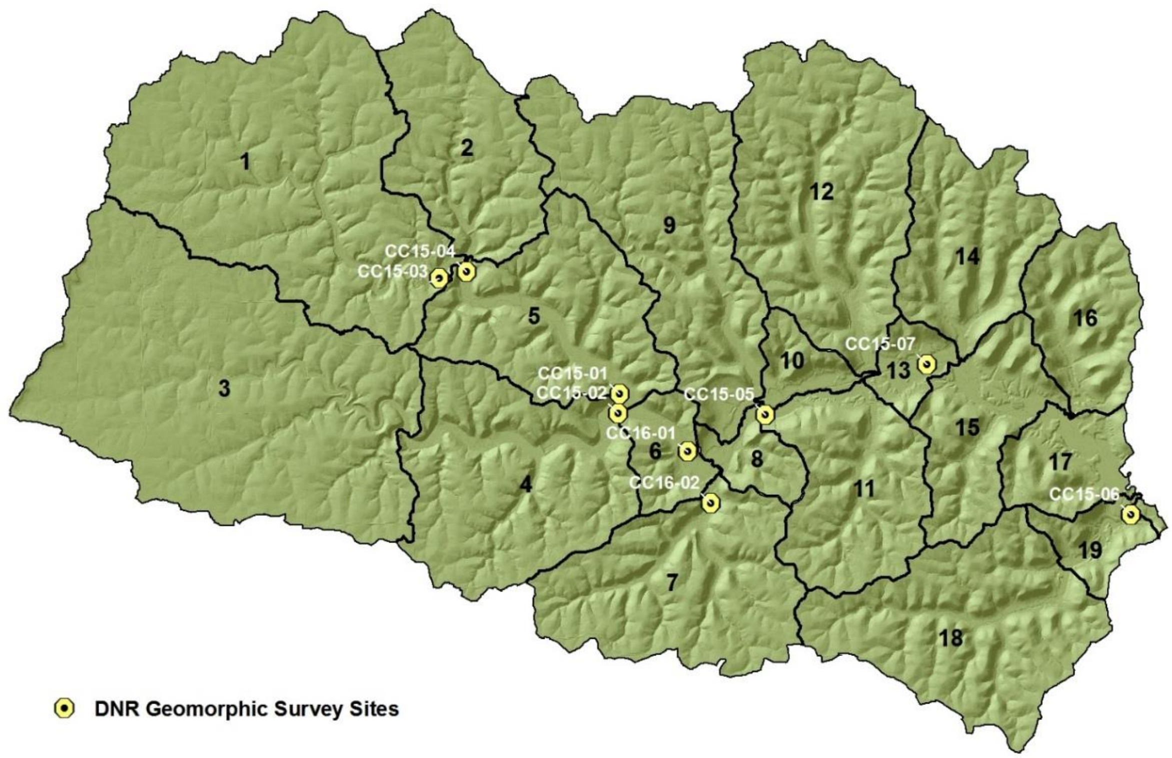

Figure 35. Location of field geomorphic survey sites.

The few confined alluvial tributaries were located through field reconnaissance and found to be ephemeral with limited channel definition or disconnected from main branch due to impoundments. These tributaries had no completed detailed field surveys because they are unlikely to be a source of impactful sediment reaching the perennial flowing channels. Field survey focus was on unconfined alluvial valleys, which is the majority of catchments advanced through the process. For departure analysis, one reference C stream type was located within Crooked Creek; however, there were no E stream type references located. To complete the analysis, two E references were surveyed in nearby watersheds within the same valley type and hydro-physiographic province. A total of three reference sites and eight representative sites were surveyed (detailed information shown in Appendix).

Three reference sites:

1. Crooked Creek site CC15-03: C4 Unconfined Alluvial Floodplain
2. Little Cannon site LC14-01: E4 Unconfined Alluvial Floodplain
3. Vermillion River Site 1: E4 Unconfined Alluvial Floodplain

Eight representative sites:

1. CC15-01: C4 Unconfined Alluvial Floodplain (Potential C) in catchment 5
2. CC15-02: C3 Unconfined Alluvial Floodplain (Potential C) in catchment 4
3. CC15-04: C4 Unconfined Alluvial Floodplain (Potential E) in catchment 5
4. CC15-05: F4 Unconfined Alluvial Floodplain (Potential C) in catchment 8
5. CC15-06: E6 Unconfined Alluvial Floodplain (Potential E) in catchment 9
6. CC15-07: B5c Unconfined Alluvial Floodplain (Potential C or Bc) in catchment 13
7. CC16-01: C3 Unconfined Alluvial Floodplain (Potential C) in catchment 6
8. CC16-02: C4 Unconfined Alluvial Floodplain (Potential C) in catchment 7

Bankfull cross sectional area of all sites in Crooked Creek are based on field bankfull calls reinforced by discharge estimates that are consistent with the gauge analysis and regional curves. Drainage area versus bankfull cross-sectional area of Crooked Creek sites are seen in (Figure 36).

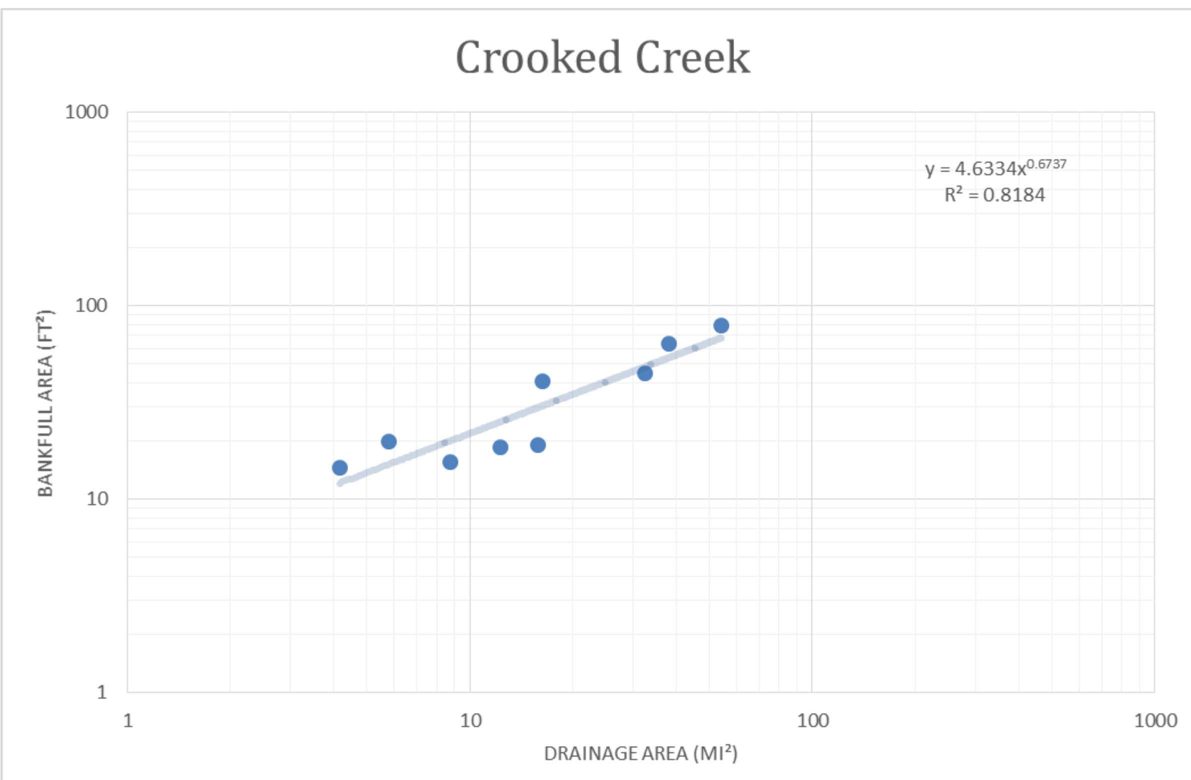

Figure 36. Bankfull cross-sectional area versus drainage area for surveyed sites in Crooked Creek.

Stream stability indices are summarized in Table 4 for surveyed representative and reference reaches located in Crooked Creek. The right side of the table is the departure analysis utilizing process-based channel metrics. The departure analysis shows a general adjustment of representative reaches from reference and provides clues in how best to mitigate the departure from stability. It is important to note that although some representative reaches are currently at the stable stream type, the w/d ratio and degree of incision are not, and this indicates channel instability. In general, there appears to be a trend of upper watershed reaches having no incision to slight incision and becoming more incised at the more downstream reaches. From the previously discussed history, floodplain aggradation is likely a large component for the cause of incision. Influence from the Mississippi River may also have an unknown effect due to backwatering, especially after the construction of the lock and dam system.

Table 4. Stream stability indices (Rosgen 2009) with riparian vegetation column removed.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Reach Location	Stream Type **(Worksheet 5-3)**	**b.** Flow Regime **(Worksheet 5-7)**	**c.** Stream Order/Size **(Worksheet 5-8)**	**d.** Meander Patterns **(Worksheet 5-9)**	**e.** Deposi-tional Patterns **(Worksheet 5-10)**	**f.** Channel Blockages **(Worksheet 5-11)**	**g.** Degree of Channel Incision **(Worksheet 5-12)**	**h.** Width/ Depth Ratio State **(Worksheet 5-13)**	**i.** Degree of Channel Confinement **(Worksheet 5-14) MWR**	**j.** Pfankuch Channel Stability Rating **(Worksheet 5-15)**
CC15-01	**C4**	**P 1, 2**	**S-4**	**M1, M3**	**B4**	**D2**	**1.27 (Slightly Incised)**	**1.1 (Stable)**	**0.2 (Confined)**	**Fair**
CC15-02	**C3**	**P 1, 2, 7**	**S-4**	**M1**	**B4**	**D2, D10**	**1.0 (Stable)**	**1.07 (Stable)**	**.61 (Moderately Unstable)**	**Good**
CC15-03 Reference	**C4**	**P 1, 2**	**S-4**	**M3, M4**	**B1, B4**	**D3, D4**	**1.1 (Slightly Incised)**	**1 (Stable)**	**1.0 (Stable)**	**Fair**
C15-04	**C4**	**P 1, 2**	**S-4**	**M1, M3**	**B1, B2**	**D1**	**1.07 (Stable)**	**1.7 (Highly Unstable)**	**1.0 (Stable)**	**Good**
CC15-05	**F4**	**P 1, 2**	**S-5**	**M1, M3**	**B2, B4**	**D3**	**1.55 (Deeply Incised)**	**1.6 (Unstable)**	**0.23 (Confined)**	**Fair**
CC15-06	**E6**	**P 1, 2**	**S3**	**M1, M3**	**None**	**D1**	**1.28 (Slightly Incised)**	**1.06 (Stable)**	**1.0 (Stable)**	**Fair**
CC15-07	**B5c**	**P 1, 2**	**S-4**	**M1**	**B1, B4**	**D2**	**1.6 (Deeply Incised)**	**0.58 (Unstable)**	**.79 (Moderately Unstable)**	**Fair**
CC16-01	**C3**	**P 1, 2**	**S-4**	**M1, M3, M4**	**B1, B4**	**D3**	**1.7 (Deeply Incised)**	**1.2 (Stable)**	**0.42 (Unstable)**	**Fair**
CC16-02	**C4**	**P 1, 2**	**S-4**	**M3, M4**	**B1, B2, B4**	**D2**	**1.4 (Moderately Incised)**	**1.9 (Highly Unstable)**	**1.3 (Moderately Unstable)**	**Fair**

Streambank Erosion

Bank erosion was estimated using the Bank Erosion Hazard Index (BEHI) and Near-Bank Stress (NBS) ratings as part of the BANCS Model and performed at every field survey site. Estimates of erosion are predicted in lateral erosion (ft/yr), total tons (tons/yr), and unit erosion rate (tons/yr/ft). Following Lateral Stability Prediction Summary Worksheet (Rosgen 2014), unit erosion rates are placed into categories of stable, moderately unstable, unstable, and highly unstable. Stable rates are less than 0.006 tons/yr/ft, moderately unstable rates are 0.006-0.04 tons/yr/ft, unstable rates are 0.041-0.07 tons/yr/ft and highly unstable rates are greater than 0.07 tons/yr/ft. Several of the sites had permanent cross sections set up to monitor and measure actual erosion. These efforts helped validate and apply corrections as needed to the estimated erosion rates of surveyed reaches. Streambank erosion estimates, as well as further discussion, is addressed in the Sediment Delivery from Streambank Erosion section.

FLOWSED/POWERSED Sediment Yield Prediction

Stability of a reach depends on the capacity to move the bedload and suspended sediments made available to the stream. FLOWSED/POWERSED sediment transport models can be used to assess this ability in many ways. In this instance, FLOWSED/POWERSED is used to compare sediment transport as a function of width to depth ratios to reference condition. All representative sites in Crooked Creek were analyzed based on their potential stable stream type. By comparing the sediment transport ability of representative reaches to reference reaches, a determination of stable, aggrading or degrading can be made.

Items needed to complete FLOWSED/POWERSED analysis are dimensionless flow duration curve, bankfull discharge, dimensionless bankfull bedload and suspended sediment curve, and bankfull bedload and suspended sediment measurements. The dimensionless flow duration curve is based on mean daily discharge. The USGS operates a gauging site on Crooked Creek at Freeburg. Unfortunately, the gauge has only 2 years of daily discharge data. The closest gauge within the same hydro-physiographic region which meets the recommended 10 years of data is in the Whitewater River Watershed. The Middle Fork Whitewater River at St. Charles has 11 years of daily discharge data. The flow duration curve is made dimensionless by relating to bankfull discharge at the gauge. As part of a USGS Minnesota Department of Natural Resources (DNR) partnership, sediment rating curves have been developed for the State of Minnesota. However, there are no sediment measurements on Crooked Creek. As a result, sediment measurement curves were used from Cascade Creek, which is near Rochester, MN and has a drainage area of 18mi^2. Based on the use of outside sediment measurements, specific transport numbers are not shown because they would not represent accurately the sediment loads in Crooked Creek. However, using these surrogates, the catchments can be a prioritization tool. The capacity ratings used are stable, aggrading, or degrading and includes a percent departure (Table 5). It is important to recognize that FLOWSED/POWERSED has, on average, an error of 5-10%.

Table 5. Transport capacity rating from FLOWSED/POWERSED for each surveyed reach.

Reach	Overall Sediment Transport Capacity Stability Rating	Suspended Sediment Transport	Bedload Transport
CC15-03 Reference	**Stable**	NA	NA
CC15-04	**Aggrading**	-21%	-40%
CC15-01	**Stable**	-1%	-5%
CC15-02	**Stable**	NA	NA
CC16-01	**Stable***	+6%	+14%
CC16-02	**Aggrading**	-17%	-37%
CC15-05	**Aggrading**	-8%	-31%
CC15-07	**Aggrading**	-10%	-30%
CC15-06	**Aggrading**	-12%	-11%

Negative value is a reduction in transport capacity compared to reference, while positive value is an increase in transport capacity compared to reference

*Although bedload indicates degradation, suspended sediment load is considerably more at this site and is therefore weighted towards stability

Sediment Competence

FLOWSED/POWERSED analyzes sediment capacity, while competence evaluates the ability of the stream to move the largest particle made available to the stream. In essence, competence is the stream power for current conditions. For a stream reach to maintain stability, both the capacity for transport and competence of particles must be met.

Bar samples were collected at surveyed sites to determine the largest particle available. Along with particle size, stream slope and mean depth at bankfull is needed to rate sediment competence (Table 6). In some locations in Crooked Creek, bars and channel bottom were composed entirely of sand particles. In these cases, all particles are considered to be able to move at bankfull flows, and thus for the purpose of competence, are considered stable.

Table 6. Sediment competence rating of representative and reference sites.

Reach	Sediment Competence Rating
CC15-03	**Stable**
CC15-04	**Stable**
CC15-01	**NA**
CC15-02	**Stable**
CC16-01	**Stable**
CC16-02	**Aggrading**
CC15-05	**Aggrading**
CC15-07	**Stable**
CC15-06	**Stable**

Channel Stability Ratings

Overall channel stability rating is a prediction based on multiple processes. The processes looked at are stream channel succession stage shift, lateral stability, vertical stability and channel enlargement. These various categories allow for channel stability prediction and document items that would need to be addressed for channel stabilization. A summary containing rating summaries for each process can be seen in (Table 7). This summary rating gives the ability to pinpoint disproportionate sediment supply related to specific processes and locations

The ratings for each category are derived from comparisons of the measured current conditions to reference. The stream stability indices discussed above play a heavy role in the ratings, with the addition of the cumulative effects from pattern, profile, and dimension characteristics. Stream successional stage shift is the one exception to this.

Table 7. Channel stability rating summary and overall sediment supply rating.

Reach	Sediment Transport Capacity Stability Rating	Sediment Competence	Successional Stage Shift	Lateral Stability Rating	Vertical Stability for Excess Deposition/Aggradation	Vertical Stability for Channel Incision/Degradation	Channel Enlargement Prediction	Overall Sediment Supply Rating
CC15-03 Reference	**Stable**	**Stable**	**Stable**	**Stable**	**No Deposition**	**Not Incised**	**No Increase**	**Low**
CC15-04	**Aggrading**	**Stable**	**Stable**	**Unstable**	**Moderate Deposition**	**Not Incised**	**Slight Increase**	**Moderate**
CC15-01	**Stable**	**NA**	**Stable**	**Moderately Unstable**	**No Deposition**	**Slightly Incised**	**Slight Increase**	**Moderate**
CC15-02	**Stable**	**Stable**	**NA**	**NA**	**NA**	**Not Incised**	**NA**	**NA**
CC16-01	**Stable**	**Stable**	**Stable**	**Unstable**	**No Deposition**	**Slightly Incised**	**Slight Increase**	**Moderate**
CC16-02	**Aggrading**	**Aggrading**	**Unstable**	**Unstable**	**Excess Deposition**	**Slightly Incised**	**Moderate Increase**	**High**
CC15-05	**Aggrading**	**Aggrading**	**Stable**	**Unstable**	**Excess Deposition**	**Slightly Incised**	**Moderate Increase**	**High**
CC15-07	**Aggrading**	**Stable**	**Moderately Unstable**	**Unstable**	**Moderate deposition**	**Slightly Incised**	**Moderate Increase**	**High**
CC15-06	**Aggrading**	**Stable**	**Stable**	**Moderately Unstable**	**No Deposition**	**Slightly Incised**	**Slight Increase**	**Moderate**

Stream Channel Successional Stage

Channel succession is the response of a stream channel to disturbance and the following stages the channel will take to reach a dynamic equilibrium. Stream channel succession rating is based on the current stream state and predicting the future stable state based on documented succession scenarios (Figure 37). Historic aerial photographs and LiDAR are used to determine the rate and changes in stream type and valley characteristics over time. The results can inform channel stability, rate at which the system is changing, and erosion potential.

Stream:	Stream Type:
Location:	Valley Type:
Observers:	Date:
Stream Type Changes due to Successional Stage Shifts (Figure 5-52)	**Stability Rating (Check Appropriate Rating)**
Stream Type at Potential, (C→E), (F_b→B), (G→B), (F→B_c), (F→C), (D→C)	☐ Stable
(E→C), (C→High W/d C)	☐ Moderately Unstable
(G→F), (F→D), (C→F)	☐ Unstable
(C→D), (B→G), (D→G), (C→G), (E→G)	☐ Highly Unstable

Figure 37. Stream channel successional stage shift ratings, worksheet 5-24 (Rosgen 2009).

Starting in the upper watershed main channel and working downstream, site CC15-03 in the upper area is currently in the stable C stream type (Figure 38). Analysis of historic aerial photos, combined witha lack of terrace signatures on LiDAR, leads to a possible succession scenario in Figure 39.

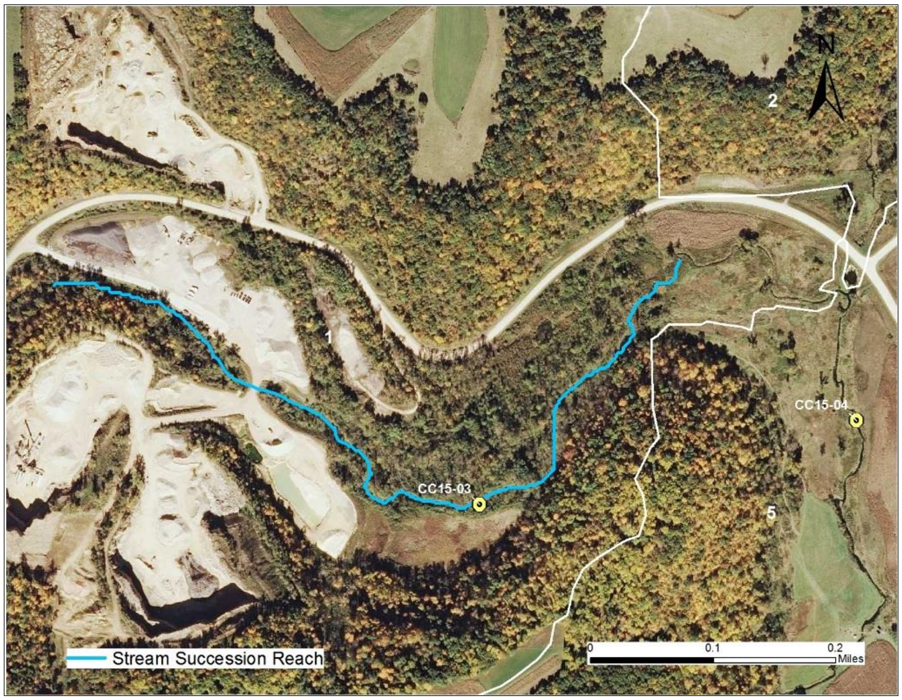

Figure 38. Reach with same succession scenario throughout, near survey site CC15-03.

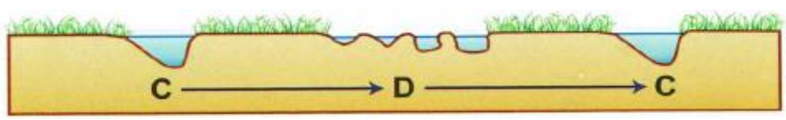

Figure 39. Likely stream succession scenario near site CC15-03.

Continuing downstream is site CC15-04. This site is representative of a stretch where the wide valley would favor an E stream type (Figure 40). Historic photo shows signatures of large sediment aggradation and a poorly defined channel (Figure 41). Coupling this with a lack of terrace features, the likely scenario for this stretch is seen in (Figure 42). Current state at this site is a very low w/d ratio C stream type, indicating likely stability in near future.

Figure 40. Reach with same succession scenario throughout, near survey site CC15-04.


Figure 41. 1937 aerial photograph near site CC15-04, demonstrating large sediment accretion.

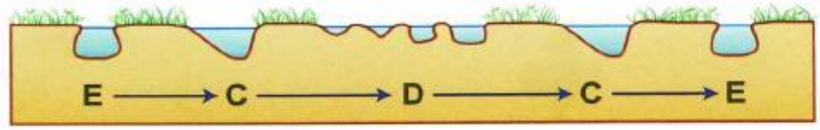

Figure 42. Likely stream succession near site CC15-04.

South Fork Crooked Creek, below impoundment R-3, contains the survey reach CC15-02 (Figure 43). The large upstream impoundment plays a prominent role and complicates the stream successional stages. The reach is currently a C stream type, its most likely stable form.

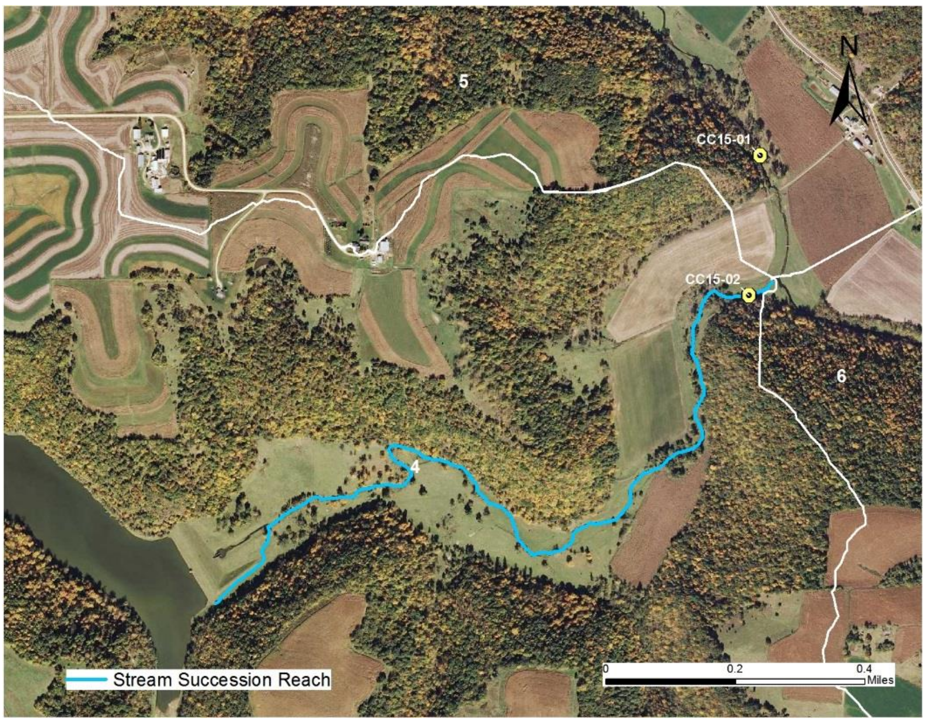

Figure 43. South Fork Crooked Creek, below R-3 impoundment.

Two surveys represent the next long stretch of stream on the main channel (Figure 44). Both survey reaches are in the final stable successional stream type of a C. The upper site (CC15-01) in this reach is only slightly incised while lower site CC16-01 is highly incised. This site is in the “transition” area with the presence of a terrace on the outside of the valley (Figure 45). Not seen is a terrace immediately alongside the channel.

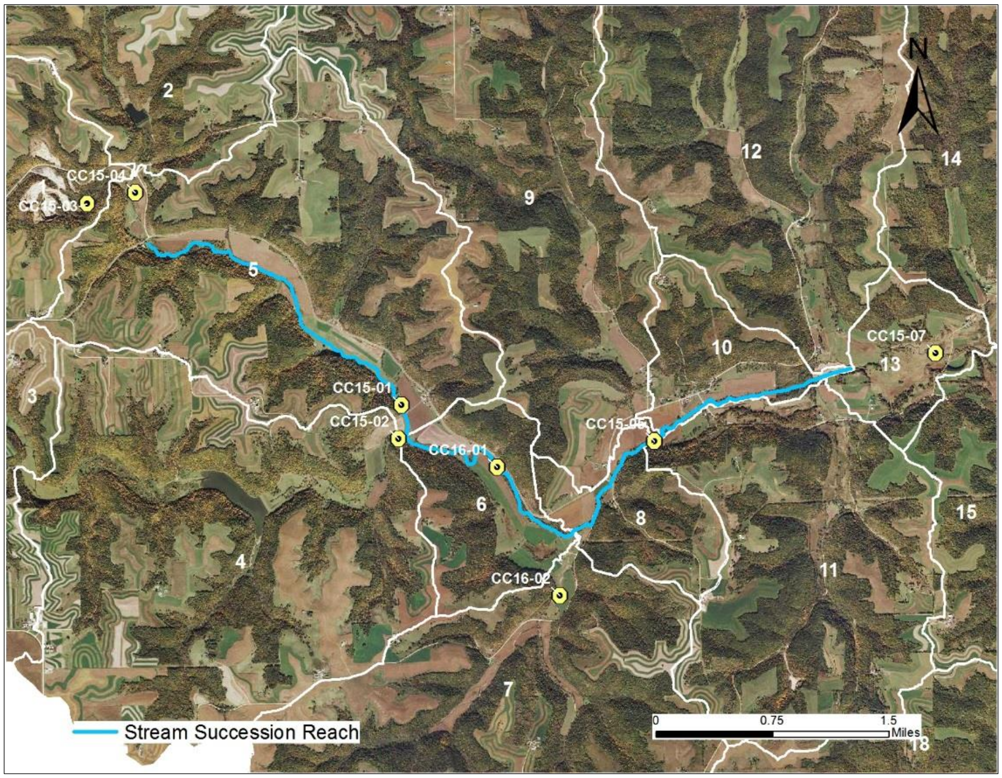

Figure 44. Reach with similar succession scenarios from survey site CC15-01 through CC15-05, to upstream of CC15-07.

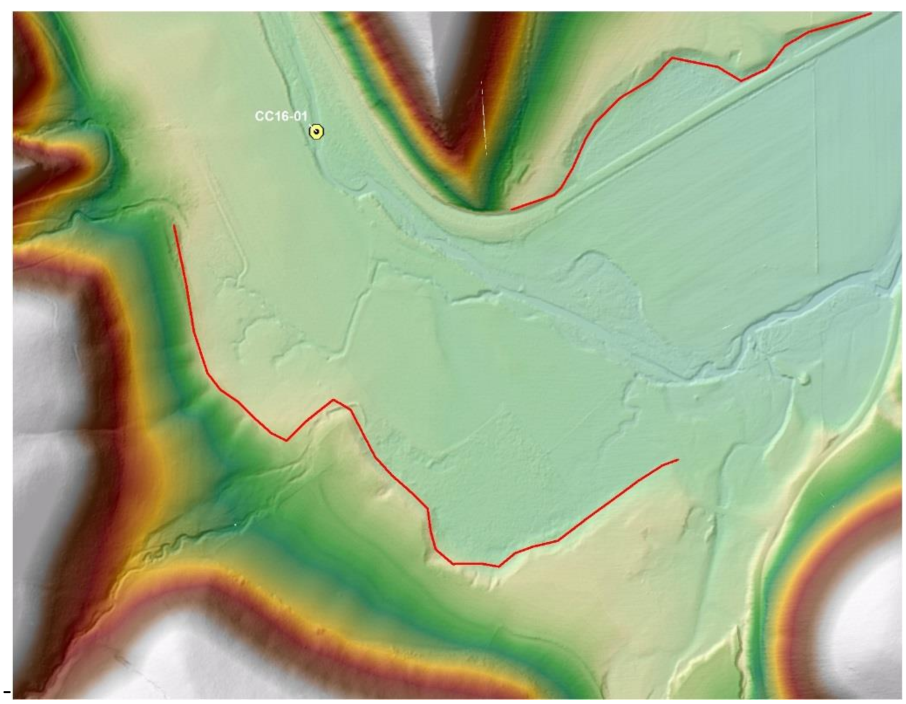

Figure 45. Transition zone of terrace development on outside of valley, demonstrated by the red lines.

Strong evidence points to successional scenarios seen in Figure 46 as the likely stage shifts. Multiple terraces in this reach could be from not only down cutting (lower scenario in Figure 46), but also from floodplain/valley aggradation as was discussed previously (upper scenario in Figure 46).

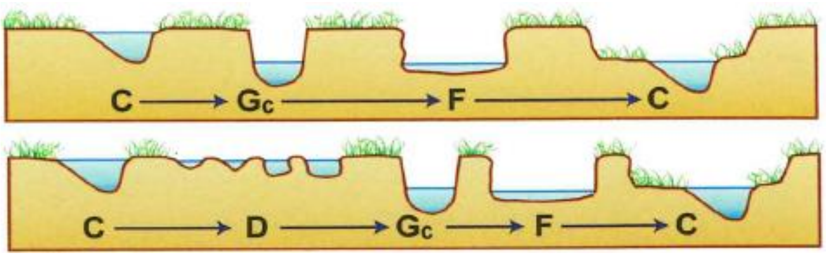

Figure 46. Succession scenarios for site CC16-01.

The section that runs through the town of Freeburg, roughly in the middle of the watershed, follows the same scenario as Figure 46. As demonstrated by the F stream type at site CC15-05, this reach has yet to reach the final stable successional stage. The reach is at its widest, which reduces the channels ability to move sediment. In order to reach its stable state of a C stream type, the channel would need to create more floodplain and develop a channel within the overwide channel, or the channel itself would need to aggrade as a result of its inability to move excess bedload.

Near the lowest surveyed reach on the main channel (CC15-07), channel evolution is more difficult to interpret (Figure 47).

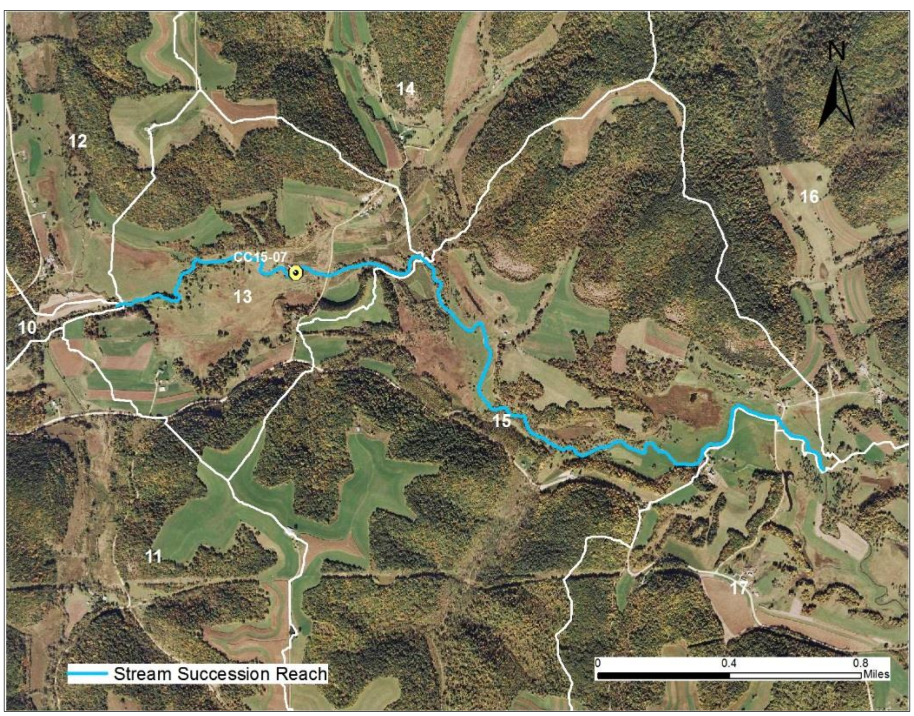

Figure 47. Reach near survey site 15-07 with similar succession scenarios.

Compounding influences of down-cutting, floodplain aggradation and possible Mississippi River influence affect this area. Under pre-European settlement, final successional stage may have been an E or C stream type. Under current conditions, the final stage is a C, or possibly a Bc, through this reach (Figure 48). The C stream type is more probable than an E due to the high sand bedload moving through the system at this point of the watershed. The current stream type at Site CC15-07 contains delineative criteria for several stream types. The stream type most fitting of the criteria is a Bc, meaning the geomorphology of a B stream type but at a lower slope of a C. Considering the channel has very little lateral erosion and good vegetation, it may be possible that the new ending evolution may be a Bc. Once below this reach and to the confluence with the Mississippi River, the flatter profile along with a wide valley and wetland areas, E stream type is likely the stable form (Figure 49).

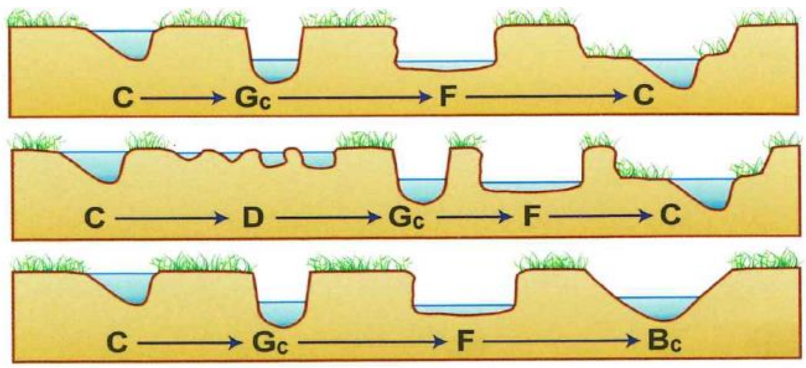

Figure 48. Stream succession scenarios for reach near site CC15-07.

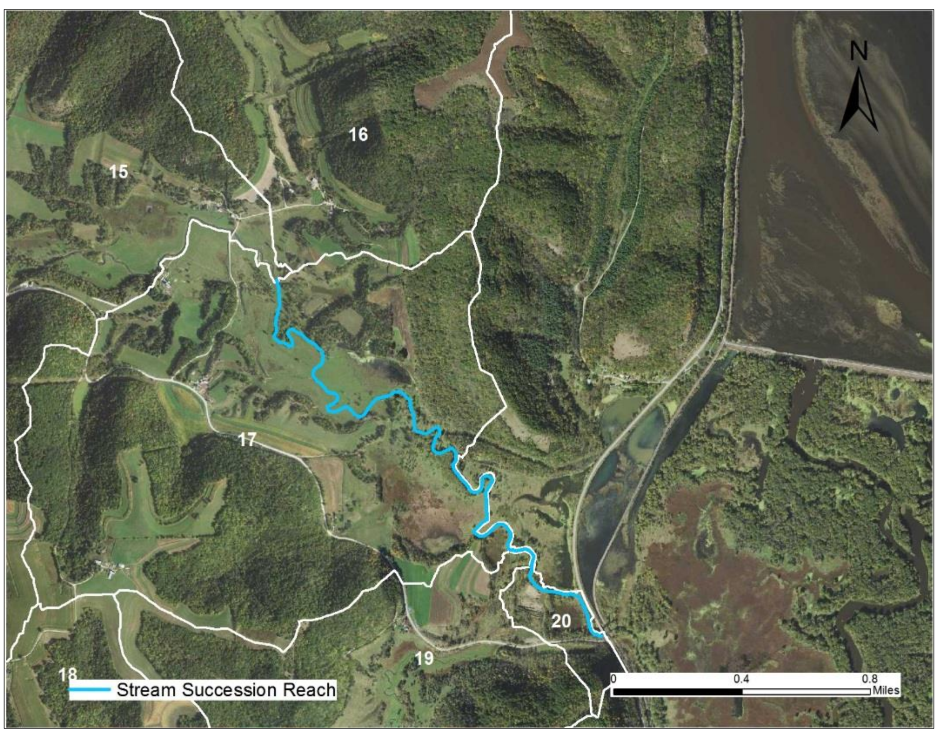

Figure 49. Reach at the confluence with same stable E stream type.

Clear Creek is a tributary that joins main stem Crooked Creek near the confluence with the Mississippi River (Figure 50). The survey site CC15-06 is within this tributary reach. Fine cohesive soils and a wide, low sloped valley means current E stream type is the final stable successional stage. This reach is influenced by the Mississippi River, which has mitigated to some degree the accelerated lateral channel migration which can increase streambank erosion and sediment inputs.

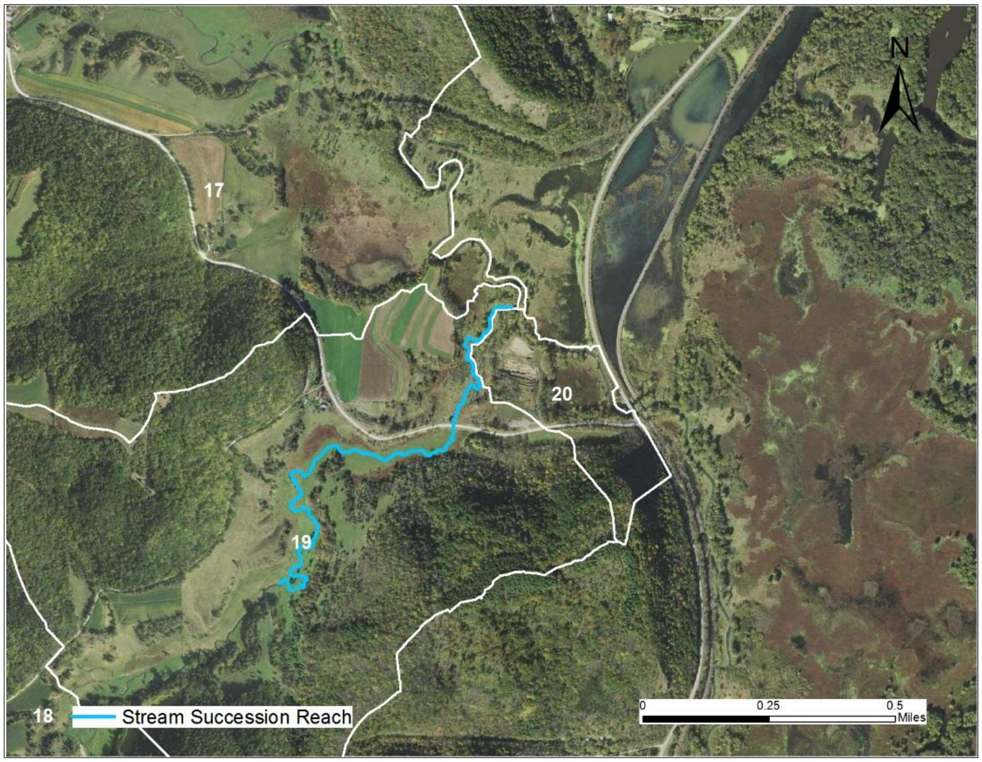

Figure 50. Clear Creek reach with same stable E stream type.

Channel Processes Summary

Reaches rated as high for excess sediment supply are good candidates for targeted restoration, although they may not be the first priority as instability upstream may undermine restoration attempts in these areas. All of these high rated reaches are rated as aggrading, due to widened stream channels, which leads to a reduction in stream power and capability to move the sediment supply. Excess sediment also increases the risk of lateral channel migration in order to accommodate the sediment towards a more stable state. Lateral stability concern is also seen in four other reaches, which may necessitate bank protection or other management strategies.

Sediment Delivery Estimates

Sediment Delivery from Roads

Annual sediment yield from roads was calculated using the Road Impact Index from Rosgen (2009) (Figure 51). Sediment yield from roads is calculated from the number of stream crossings and the road type at the intersection with the river. In Crooked Creek, the number of crossings in each sub-catchment was relatively low. Mitigation reduction adjustments were made to older and paved roads. The low number of crossings and mitigation adjustments resulted in low sediment input from roads, less than 1% of total sediment load for the watershed.

Stream:	**Crooked Creek**					Location:					
Observers:						Date:					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Sub-watershed Location ID#	Total Acres of Sub-watershed (*Step 1*)	Total Acres of Road (*Step 3*)	Number of Stream Crossings (*Step 4*)	Road Impact Index **[(3)/(2)X(4)]** (*Step 5*)	Dominant Slope Position (lower, mid or upper slope) (*Step 6*)	Sediment Yield (tons/acre of road) (**Fig. 5-42**, *Step 7*)	Total Tons **[(3)X(7)]**	Erosion Rate Recovery (% from **Fig. 5-43**, *Step 9*) (convert to decimal)	Total Tons per Year **[(8) - (8)×(9)]**	Mitigation Adjustments (*Step 10*)
1.	**1**	**5554**	**88**	**11**	**0.17**	**Lower**	**8.67**	**763.10**	**0.95**	**38.15**	**1.91**
2.	**2**	**2199**	**18**	**2**	**0.02**	**Lower**	**2.35**	**42.39**	**0.95**	**2.12**	**0.11**
3.	**3**	**6807**	**205**	**2**	**0.06**	**Upper**	**0.03**	**5.47**	**0.95**	**0.27**	**0.02**
4.	**4**	**3278**	**15**	**1**	**0.00**	**Lower**	**1.88**	**28.25**	**0.95**	**1.41**	**1.41**
5.	**5**	**2629**	**28**	**9**	**0.10**	**Lower**	**5.53**	**154.96**	**0.95**	**7.75**	**0.39**
6.	**6**	**636**	**5**	**0**	**0.01**	**Lower**	**2.03**	**10.78**	**0.95**	**0.54**	**0.03**
7.	**7**	**2918**	**17**	**3**	**0.02**	**Lower**	**2.40**	**40.78**	**0.95**	**2.04**	**2.04**
8.	**8**	**474**	**8**	**2**	**0.03**	**Lower**	**3.05**	**24.40**	**0.95**	**1.22**	**0.06**
9.	**9**	**3499**	**28**	**6**	**0.05**	**Lower**	**3.62**	**101.38**	**0.95**	**5.07**	**2.83**
10.	**10**	**452**	**1**	**3**	**0.01**	**Lower**	**1.97**	**1.97**	**0.95**	**0.10**	**0.00**
11.	**11**	**2016**	**21**	**8**	**0.08**	**Lower**	**5.03**	**105.70**	**0.95**	**5.29**	**3.97**
12.	**12**	**3778**	**28**	**6**	**0.04**	**Lower**	**3.48**	**97.40**	**0.95**	**4.87**	**3.63**
13.	**13**	**434**	**4**	**1**	**0.01**	**Lower**	**2.07**	**8.27**	**0.95**	**0.41**	**0.41**
14.	**14**	**1928**	**1**	**2**	**0.00**	**Lower**	**1.74**	**1.74**	**0.95**	**0.90**	**0.90**
15.	**15**	**1523**	**6**	**2**	**0.01**	**Lower**	**2.02**	**12.09**	**0.95**	**0.60**	**0.65**
16.	**16**	**1373**	**5**	**1**	**0.00**	**Lower**	**1.85**	**9.22**	**0.95**	**0.47**	**0.47**
17.	**17**	**1372**	**11**	**2**	**0.02**	**Lower**	**2.34**	**25.76**	**0.95**	**1.29**	**1.29**
18.	**18**	**3198**	**4**	**1**	**0.00**	**Lower**	**1.75**	**7.00**	**0.95**	**0.35**	**0.35**
19.	**19**	**529**	**4**	**1**	**0.01**	**Lower**	**2.00**	**8.00**	**0.95**	**0.40**	**0.40**
20.	**20**	**44**	**1**	**0**	**0.00**	**Lower**	**1.70**	**1.70**	**0.95**	**0.09**	**0.09**
							Total Road Sediment Yield (tons/year):			**73**	**21**

Figure 51. Annual sediment yield calculation based on Road Impact Index, worksheet 5-21 (Rosgen 2009).

Sediment Delivery from Surface Erosion

Surface erosion yield estimates were made via HSPF, which was completed by Tetra Tech for the Minnesota Pollution Control Agency (Tetra Tech 2018). The HSPF model for the Crooked Creek watershed simulates overland sediment transport through two separate processes. The first focuses on detachment of soil particles from meteorological processes, such as rainfall and wind, and scour from overland flow. Interception by ground cover, crop management practices, and soil erodibility coefficients are all factored into this process as well. The second process drives the transport of detached particles and re-attachment through slope, distance to receiving body, and a roughness coefficient that is the equivalent of a Manning's N number. The slopes, coefficient, and distances are all calculated by averaging values within groups of land that have similar properties, such as land use, soil type, slope, and position on the landscape. These variables allow for an estimated amount of sediment that is actually delivered to the stream, instead of general erosion rates.

Sub-catchment boundaries used for channel processes do not match HSPF sub-catchment boundaries (Figure 52). Therefore, WARSSS sub-catchments were combined where needed for the purpose of illustrating surface sediment input. Sub-catchment 20 was outside the boundary of the HSPF model, but it is very small and likely negligible. Sediment yield estimates are seen in Table 8.

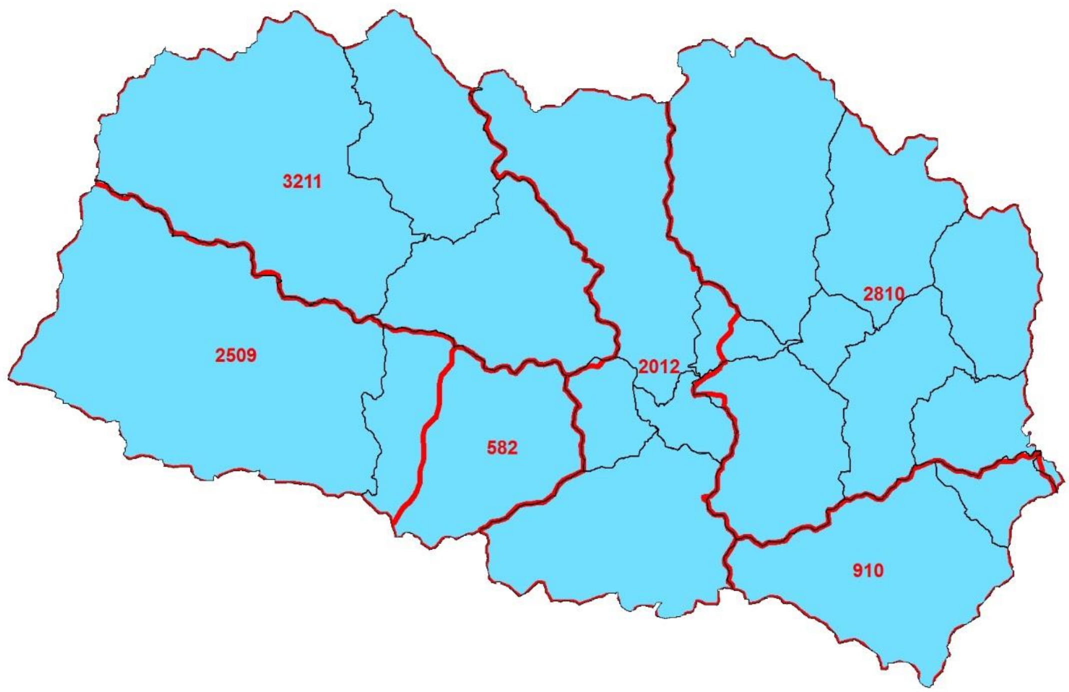

Figure 52. HSPF boundaries (red) and surface sediment input (tons/yr) with geomorphic sub-catchment boundaries (black).

Table 8. Surface erosion sediment yield per sub-catchment.

Sub-watershed Location ID (#)	Introduced Surface Sediment Supply from HSPF Model (tons/yr)	Yield (tons/acre/yr)
1	3,211	0.3065
2		
5		
3	3,091	0.3041
4		
6	2,012	0.2564
7		
8		
9		
10*	2,810	0.2288
11		
12		
13		
14		
15		
16		
17		
18	910	0.2425
19		
20**	0	0.0000
Total	**12,033**	**0.2677**

* Catchment is split between two HSPF catchments
** Outside model boundary

Sediment delivered to the stream ranges from a low of 0.2288 tons/acre/yr near the lower end of the watershed, to a high of 0.3065 tons/acre/yr at the upper part of the watershed. For comparison, a completed WARSSS in nearby Whitewater River estimated sediment yields ranged from 0.24 to 0.29 tons/acre/yr, depending on the fork of river (Whitewater WARSSS 2018) (Figure 53). Two other nearby watersheds in the Driftless region, Zumbro River and Root River, were also modeled via HSPF. Average sediment yields for Root River is 0.20 tons/acre/yr and Zumbro is 0.24 tons/acre/yr. Little Cannon River watershed was modeled using Soil and Water Assessment Tool (SWAT), which estimated surface erosion at 0.29 tons/acre/yr. All of these watersheds are in the same region with very similar drainage densities. However, Crooked Creek watershed has the higher average slope gradient.

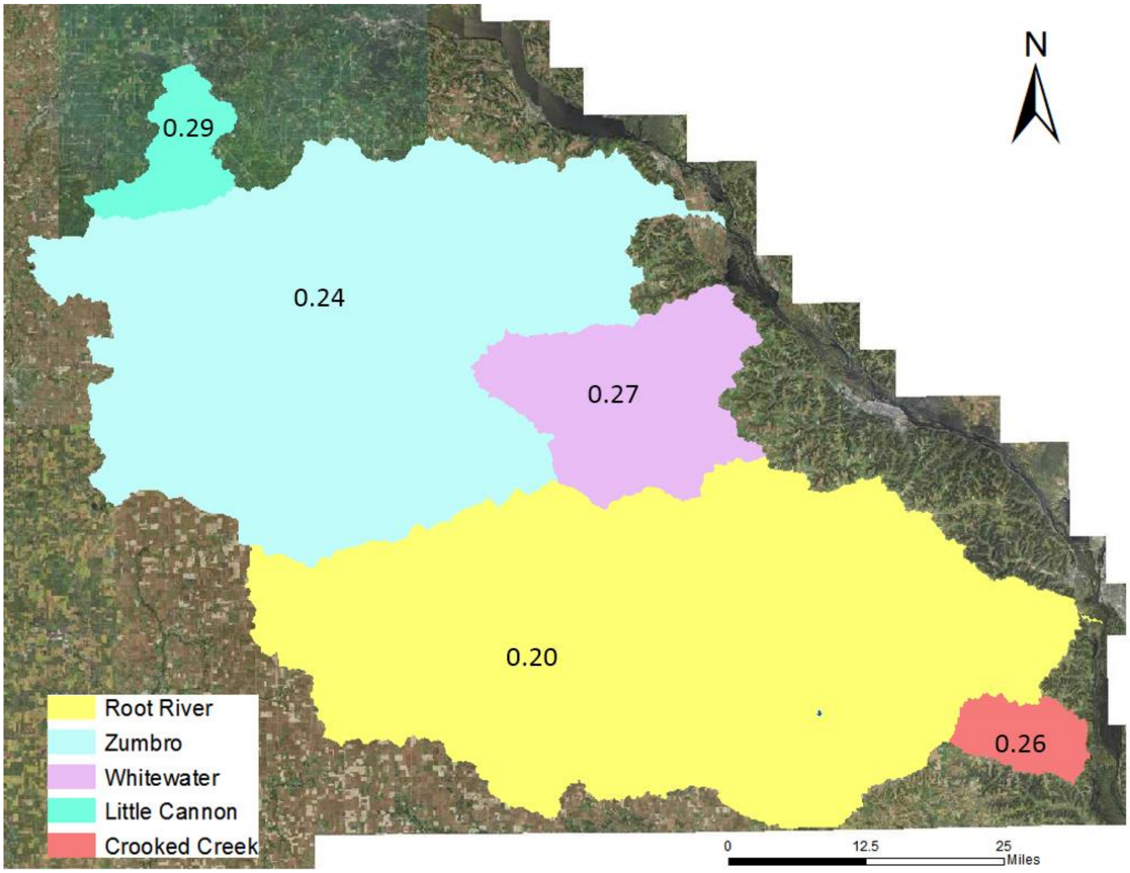

Figure 53. Locations of comparable watersheds for surface erosion, units in tons/acre/yr.

Sediment Delivery from Streambank Erosion

To extrapolate surveyed erosion rates to un-surveyed reaches of similar condition and stream/valley type, bank measurements were made from LiDAR. However, LiDAR does not penetrate the water's surface and therefore may underestimate bank heights. To validate bank heights, LiDAR measurements were compared to nearby surveyed reaches, and it was determined that the estimated heights were good surrogates. With this validation, measured erosion rates were then multiplied by LiDAR bank heights to obtain unit erosion rate in each reach (Figure 54). Overall, the streambank erosion rate for the entire watershed was rated as Moderately Unstable.

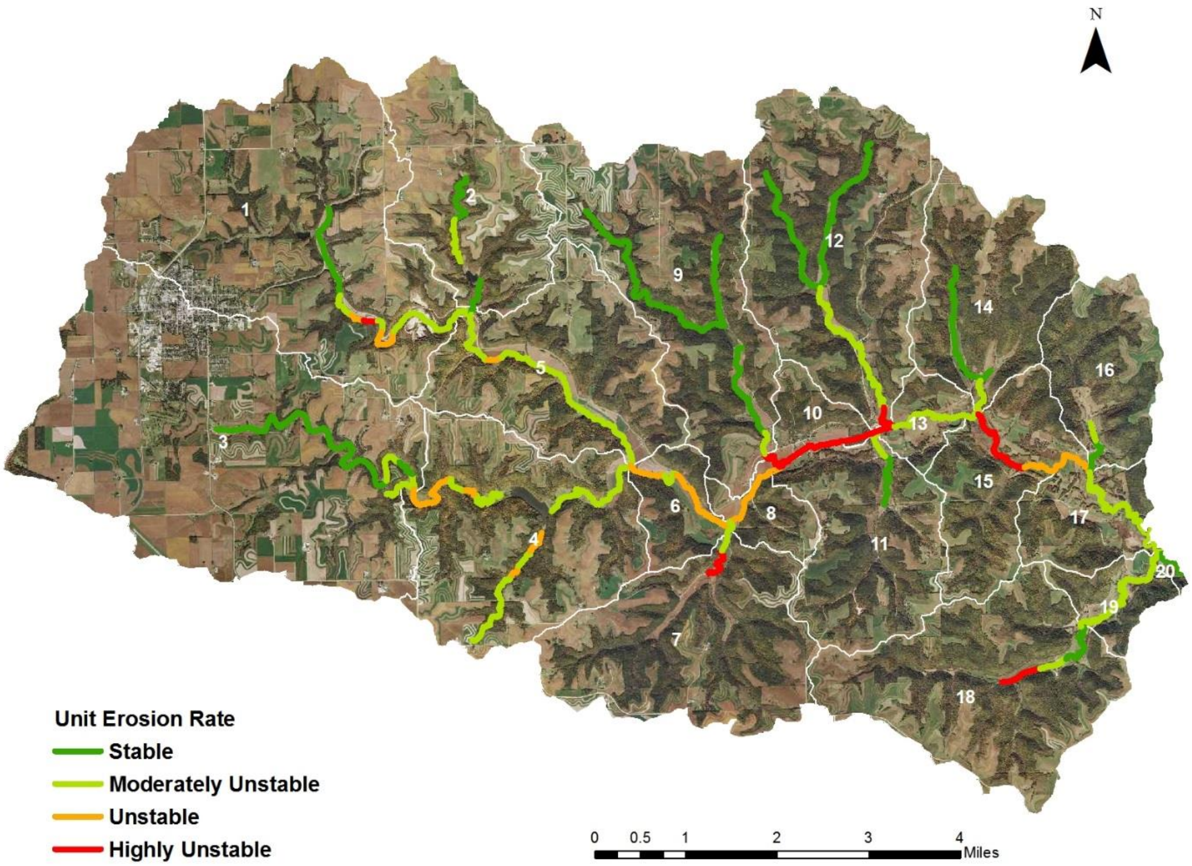

Figure 54. Unit erosion rates in tons/yr/ft by reach.

Total tons contributed to watershed by sub-catchment provides an initial analysis but may be misleading. Total sediment does not take into account the length of stream assessed in each sub-catchment and may be misinterpreted. What should be looked at is the erosion rate per foot (Table 9). This standardizes the catchments where separations of stable and unstable can then occur. Those catchments with Unstable and Highly Unstable rates of streambank erosion contribute a disproportionately high amount of sediment (Figure 55).

Table 9. Streambank erosion rates and contributions by sub-catchment.

Sub-watershed Location ID (#)	Sub-watershed Size (acres)	Stream Length Assessed (miles)	Introduced Sediment supply (tons/yr)	Average in-channel Erosion Rate (tons/yr/ft)	Erosion Rate Rating
1	5,558	3.7	377	0.0193	Moderately Unstable
2	2,199	1.8	44	0.0045	Stable
3	6,807	4.6	55	0.0023	Stable
4	3,283	5.4	748	0.0265	Moderately Unstable
5	2,629	3.3	191	0.0111	Moderately Unstable
6	637	1.7	502	0.0559	Unstable
7	2,917	0.8	540	0.1334	Highly Unstable
8	475	1.0	265	0.0504	Unstable
9	3,500	5.5	225	0.0078	Moderately Unstable
10	453	1.6	1,013	0.1230	Highly Unstable
11	2,017	1.1	59	0.0095	Moderately Unstable
12	3,780	6.6	484	0.0139	Moderately Unstable
13	434	1.2	160	0.0245	Moderately Unstable
14	1,929	1.9	20	0.0020	Stable
15	1,523	2.1	732	0.0655	Unstable
16	1,373	0.7	44	0.0124	Moderately Unstable
17	935	2.2	267	0.0234	Moderately Unstable
18	3,198	1.5	296	0.0365	Moderately Unstable
19	529	2.0	183	0.0173	Moderately Unstable
20	45	0.4	12	0.0058	Stable
Sum of sub-watersheds	44,221	49	6,217	0.032 average	

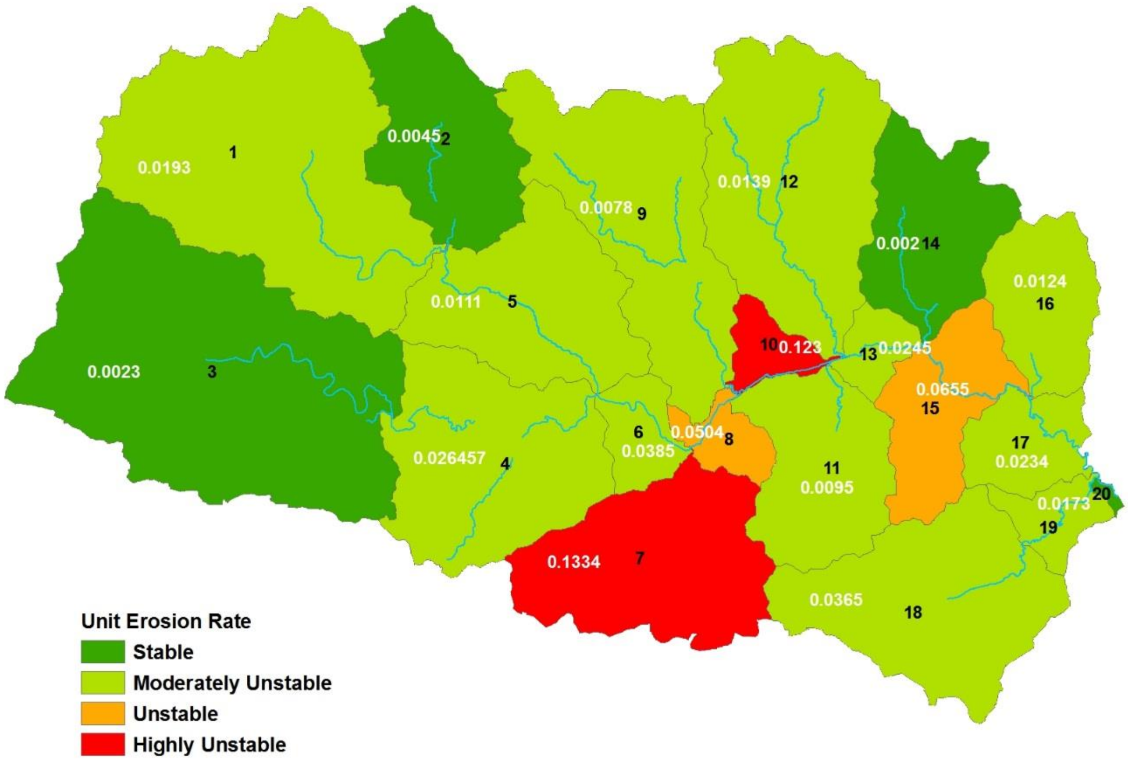

Figure 55. Unit erosion rate and rating by sub-catchment.

Mass Wasting

Based on professional judgment, specifically for Crooked Creek watershed, it was determined that mass erosion is point source specific and not a systemic nature on a yearly basis. Because of this, calculations were not completed for these areas. Instead, the immediate streambank areas were included in the streambank estimates.

Total Sediment Budget

The complete estimated sediment budget for Crooked Creek is seen in Table 10. As indicated earlier, roads contribute an insignificant amount of sediment. In other watersheds in Minnesota with sediment budgets (Little Cannon River, Whitewater River), streambank erosion has been estimated as the largest contributor of sediment, but in this case it is estimated that surface erosion is the largest contributor.

Table 10. Complete estimated sediment budget for Crooked Creek watershed.

Sediment Supply Process	Total Annual sediment (tons/yr)	Percent of Total Sediment Supply
Roads	21	0%
Streambanks	6,217	34%
Surface Erosion (HSPF)	12,033	66%
Total Sediment	**18,271**	**100%**

Unfortunately, because of the different catchment borders for HSPF, a complete breakdown of sub-catchment sediment sources is not possible. However, by grouping by the HSPF boundary, it is possible to see the major sediment source by each group (Table 11).

Table 11. Sediment source amounts by process, grouped by HSPF catchment boundaries.

Sub-watershed Location ID (#)	Sediment Yield (tons/yr)		
	Roads	Streambank Erosion	Surface Erosion
1	1.91	377	3,211
2	0.11	44	
5	0.02	55	
Total	**2.03**	**476**	**3,211**
3	1.41	748	3,091
4	0.39	191	
Total	**1.80**	**939**	**3,091**
6	0.03	502	2,012
7	2.04	540	
8	0.06	265	
9	2.83	225	
Total	**4.96**	**1,532**	**2,012**
10*	0.00	1013	2,810
11	3.97	59	
12	3.63	484	
13	0.41	160	
14	0.90	20	
15	0.65	732	
16	0.47	44	
17	1.29	267	
Total	**11.33**	**2,779**	**2,810**
18	0.35	296	910
19	0.40	183	
Total	**0.75**	**479**	**910**
20	0.09	12	0
Watershed Totals	**21**	**6,217**	**12,033**

* Catchment is split between two HSPF catchments

Surface erosion yield is the major contributor for all catchments, ranging from 50 percent to 87 percent of sediment contribution. Streambank erosion yield ranges from 13 percent to 50 percent of sediment contribution.

Management Strategies

MPCA has conducted a Stressor Identification Study in Crooked Creek and found three reaches not meeting current water quality standards for aquatic life (MPCA 2018) – two for macroinvertebrates and one for both fish and macroinvertebrates. Two of the reaches have unique circumstances influencing the biological community. One impaired reach, below the R3 impoundment, is heavily impacted by the reservoir, reducing dissolved oxygen and increasing water temperatures. The main stem impairment occurs lower in the watershed and is heavily influenced by the Mississippi River, creating a mixture of warmwater/coldwater along with lack of habitat from excess sediment. The third impaired reach is Clear Creek, a tributary near the mouth of Crooked Creek, which is experiencing the same warming impacts from the Mississippi River. Other than these impaired reaches, the majority of Crooked Creek is supporting a diverse biological community. According to the MPCA Monitoring and Assessment Report (2018), the supporting biological communities range from far above thresholds, to near thresholds, and varies with fish and macroinvertebrates. Crooked Creek does not have a turbidity impairment, but a few suspended sediment samples exceeded standards; however, those observations occurred during or immediately after significant rainfall events. Although not impaired for turbidity, the WARSSS process has identified catchments with geomorphic issues related to sediment and localized stressors, such as cattle impacts. The WARSSS process provided a consistent and documentable process to form management strategies based on sediment sources, processes and adverse influences. The management strategies are based on the above information in sequenced steps to improve stability and habitat in selected stream segments. The primary focus of this work is to provide protection from further degradation and keep water courses within the watershed off the impaired list. A large network of angling easements in the watershed provides an opportunity to complete these management strategies.

In general, the channels in the upper catchments of Crooked Creek are stable. The lower reaches are somewhat unstable, while the greatest channel instability can be found in the middle catchments. Following basic watershed science, working from upstream to downstream, the prioritized catchments below represent a sequenced, systemic way of identifying where in-stream restoration can be the most beneficial and when phased correctly will reduce risk of project failure due to upstream conditions. The proposed strategies are meant to highlight trouble areas and provide potential solutions with design concepts based on natural channel design principles. These are not complete restoration designs. If projects are pursued, the DNR is able to provide further planning and assistance.

Cost estimates are also included to assist in future planning and grant applications. The goal of this work is to improve channel stability and reduce excess sediment, which have associated ecosystem benefits but are not as easily quantified. The estimates included in this report do not integrate those other benefits. The estimates were derived from reviewing past projects and determining a range of cost on a per foot basis. The range mostly seen is $100 to $200 per lineal foot for the complete restoration (Proulx 2019). It is possible for restorations in Crooked Creek to cost less or more than the ranges given, depending on the amount of earthwork needed. To give an indication of this, cut and fill estimates were given, where applicable, by using reference dimensions and the earthwork needed to connect to an adequately sized floodplain. The earthwork estimates are considered a worst case scenario in terms of quantities, given the assumption the channel will remain at its current elevation for flood level and agricultural purposes. In ideal situations, restorations call for raising the channel bed to re-connect the floodplain, thereby reducing the amount of excavation needed. Hence, costs could decrease if the restoration included elevating the channel.

Step I

Catchment 6

Although catchment 6 had an overall sediment supply rating of moderate, erosion rates (0.0385 tons/yr/ft) and slight incision are cause for concern, mainly towards the lower end of the catchment. Most importantly, catchment 6 leads into the middle watershed area, which contains the highest erosion rates and channel instability issues (Figure 27 and Figure 55). At the end of survey CC16-01 begins a head cut, or increase in sedimentation of the floodplain; this inflection point can be seen in Figure 56 and in the surveyed profile. Grade control structures and reconnecting the floodplain are important to prevent the instability from moving upward and de-stabilizing catchment 6.

Potential Strategy:

- Stabilize head cut with properly sized and placed grade control (i.e., constructed riffles)
- Reconnect floodplain and increase belt width from just below survey reach CC16-01 to the confluence with catchment 7 (Goetzinger Tributary) to increase stability and decrease bank erosion (Figure 57). The incision near the bottom of survey reach 16-01 continues roughly 2,500 feet to where the stream is less incised, just upstream of the confluence with Goetzinger Tributary.
- Current stream type is a C, but it is slightly over-wide and incised. Reference dimensions would be a narrower C stream type with no incision (Figure 46). Cut and fill estimates using current channel dimensions with reference channel dimensions and floodplain excavation, without raising bankfull, would have an excess of 7,000 yd^3 of sediment (Figure 58).
- Remaining stream length in Catchment 6 is less incised and close to having floodplain access. Look for passive restoration opportunities if there are erosion issues due to localized stressors.
- Restoration has potential to reduce 140 tons/yr from streambank erosion
- Total cost ranging from \$250,000 to \$500,000

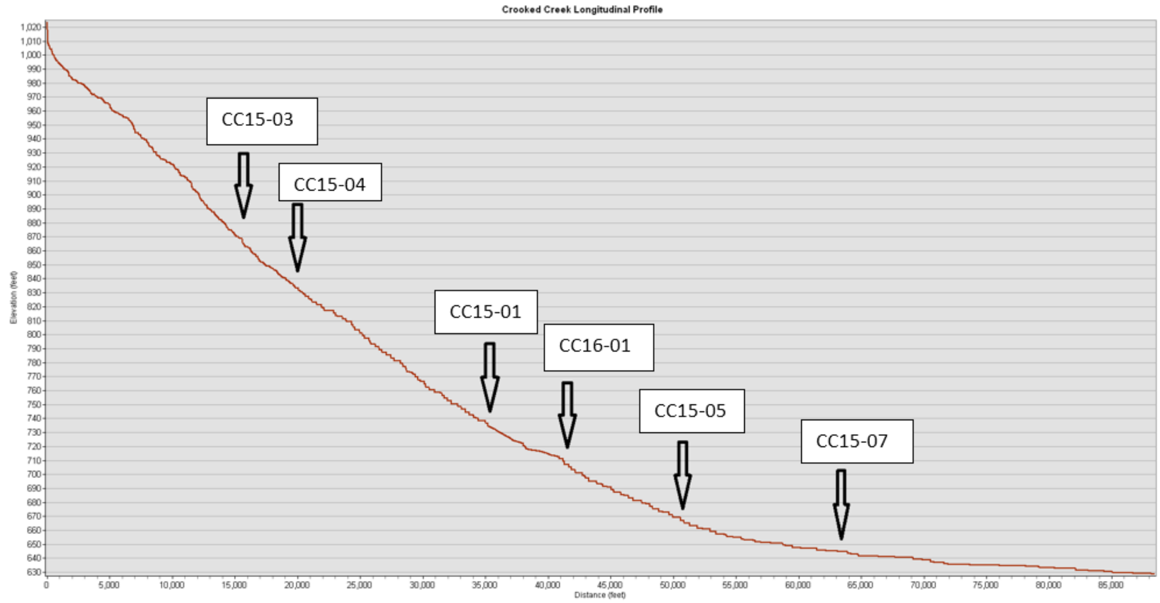

Figure 56. Longitudinal profile (LiDAR) of main stem Crooked Creek. Survey locations are indicated on profile.

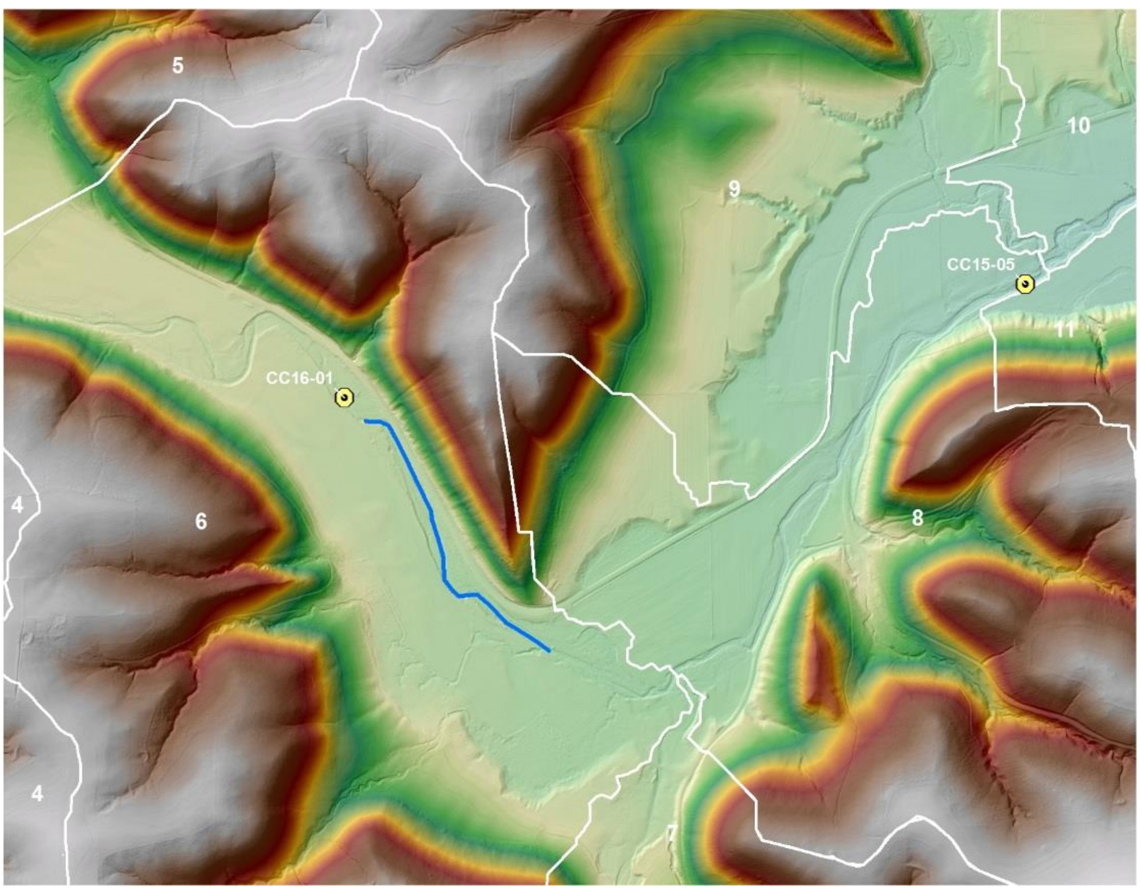

Figure 57. Catchment 6 proposed stream restoration location and effective length (blue).

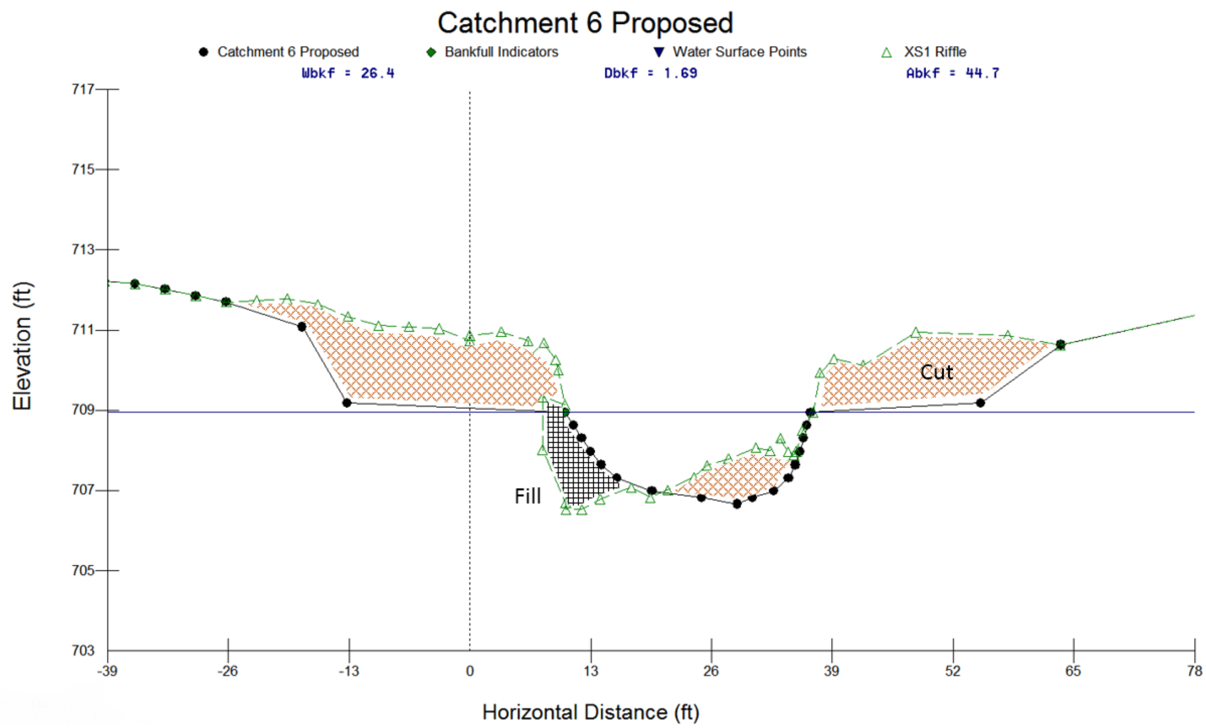

Figure 58. Proposed bankfull channel (below solid line) and floodplain cross-section design for Catchment 6.

Catchment 7

Catchment 7, a tributary (Goetzinger Tributary) with confluence with Crooked Creek in the middle of the watershed, has high overall sediment supply rating and high erosion rates (0.1334 tons/ft/yr). The tributary also has documented large particle sedimentation issues per visits and communication with landowner.

Sequence:

1. Upstream Whitetail Drive
   - Stabilize ephemeral channel south of Whitetail Drive. This reach is supplying large amounts of sediment and increasing downstream sheer stress. Could leverage previous abandoned channel along with using the grade control of the existing road crossing on Whitetail Drive.

2. Downstream Whitetail Drive to confluence
   - Once upstream area is stabilized, the downstream reach, from Whitetail Drive to the confluence with Crooked Creek, can be phased into stream restoration using natural channel design principles (Figure 59).

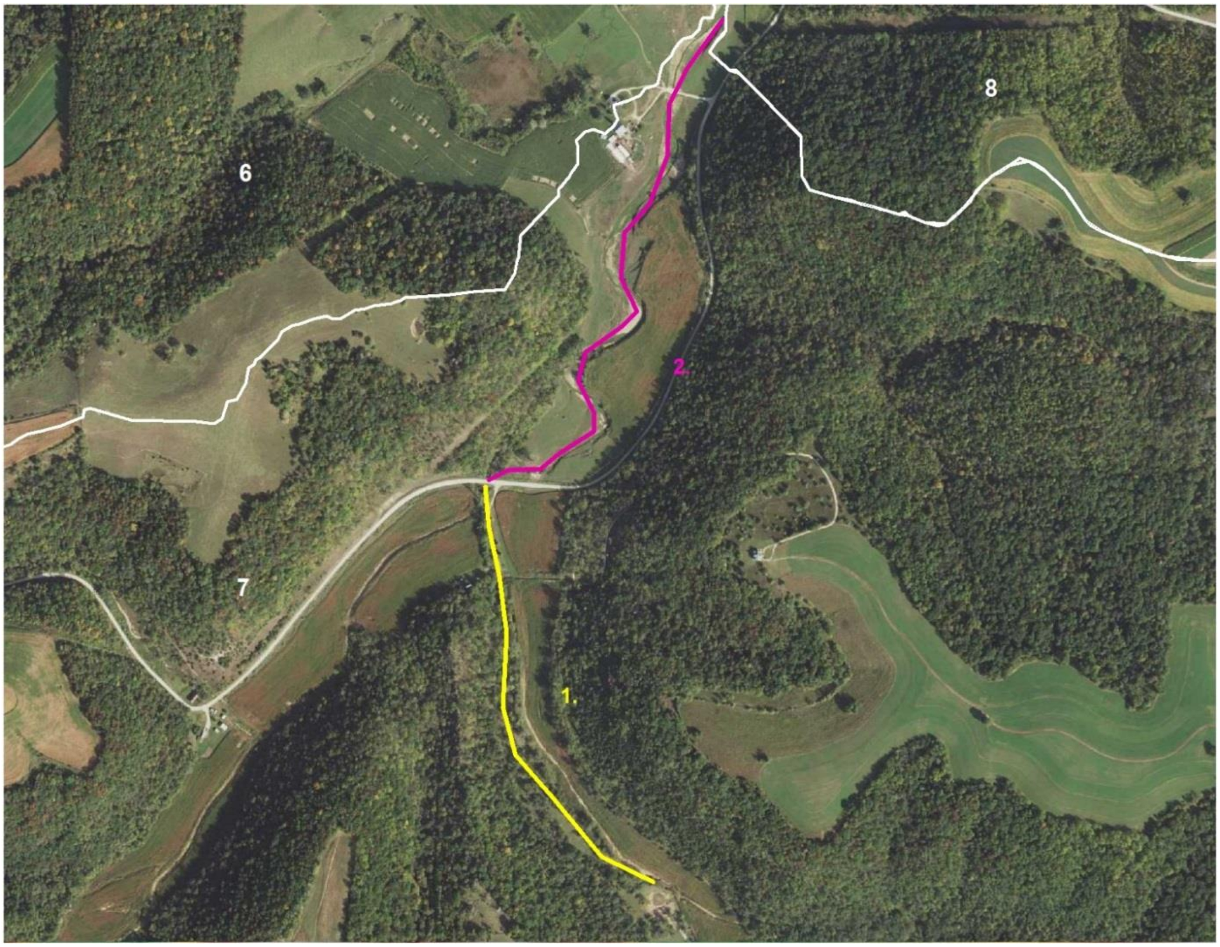

Figure 59. Catchment 7 proposed sequenced restoration steps.

1. Potential Strategy for upstream Whitetail Drive:
    - Re-route water into abandoned channel
    - Narrow valley and steep slope likely means stable stream type is a B, which the channel should be designed as a B stream type
    - From LiDAR, current stream type in abandoned channel is a B, so some channel shaping and cutting off multiple channel access is needed (Figure 60)
    - Roughly 2,600 feet of restoration
    - Due to channel abandonment and flows creating a new channel, coupled with the ephemeral nature of the channel, erosion rates were not estimated
    - Potential restoration strategy cost is likely less than the estimated range of $260,000 to $520,000, due to the minimal earthwork need
    - As of the production of this report, a project is moving forward to construct a retention structure at the top of this reach, routing flow into portions of previous channel

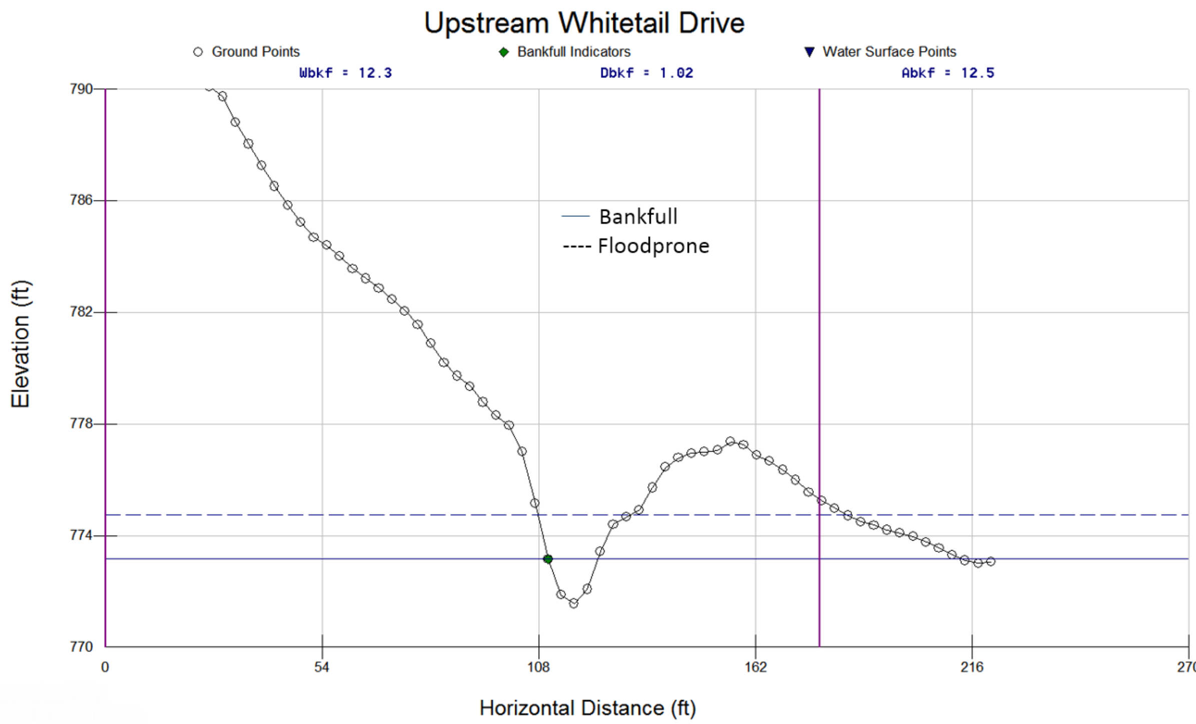

Figure 60. Cross-section of upper reach is currently a B stream type, which was determined to be the stable type in this reach.

2. Potential Strategy for downstream Whitetail Drive to confluence with Crooked Creek
    - The current channel alternates between a C and F stream type. The C stream type is the stable form for this valley and should be the goal using reference channel dimension, pattern, and profile.
    - Reference dimension cross-section shown in Figure 61, when extrapolated to the confluence with Crooked Creek (~ 4,300 feet), would create an excess cut of 2,700 yd^3.
    - Along with channel and floodplain restoration, some banks would need to be cut to create a lesser slope
    - Result of restoration would reduce approximately 520 tons/yr from streambank erosion
    - Cost of restoration ranges from $430,000 to $860,000

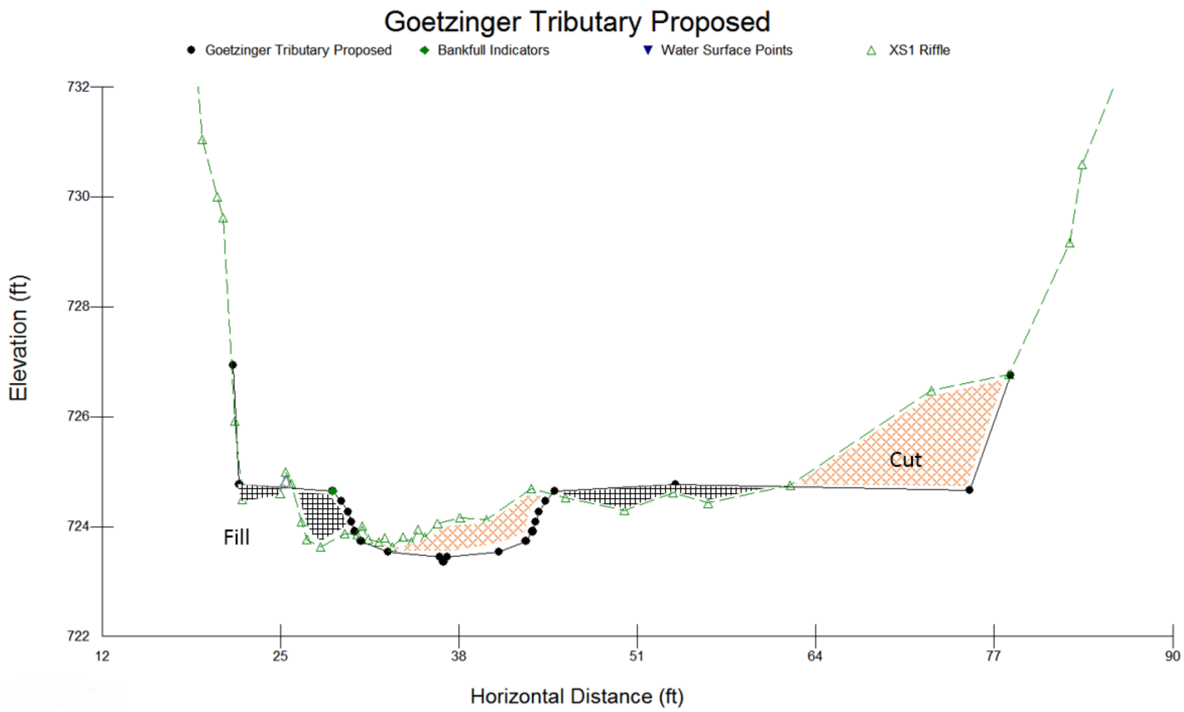

Figure 61. Goetzinger Tributary proposed design, downstream of Whitetail Drive.

Catchment 8, 9 and 10

These three catchments are lumped together as they are adjacent to each other and located in the middle of the watershed (Figure 62). The sections proposed in this area have similar channel characteristics as survey CC15-05, which is considered to have a high overall sediment supply rating. All these catchments had multiple issues as outlined in the RRISSC (Figure 27). The average erosion rates in this section were found to be high, with an average of 0.084 tons/yr/ft.

Potential Strategy:

- Explore effects of Whitetail Drive crossing on the main stem Crooked Creek, and explore options to improve longitudinal connectivity with properly sized crossings and lateral connectivity with floodplain access
- Main stem channel is currently overwide with minimal floodplain and high bank erosion. Restore F stream type to the stable C stream type and increase floodplain access
  - Beginning in Catchment 8 and continuing into Catchment 10, until the town of Freeburg and the County Road 249 crossing, which amounts to a 3,500 foot long restoration, would result in roughly 19,000 yd^3 of excess cut (Figure 63)
  - Sinuosity and belt width would need to be increased
  - Within Catchment 10, upstream of town and carrying through the town of Freeburg, restrict or reduce cattle impact on stream
  - Restoration would reduce 300 tons/yr from streambank erosion
  - Estimated cost of restoration ranges from $350,000 to $700,000

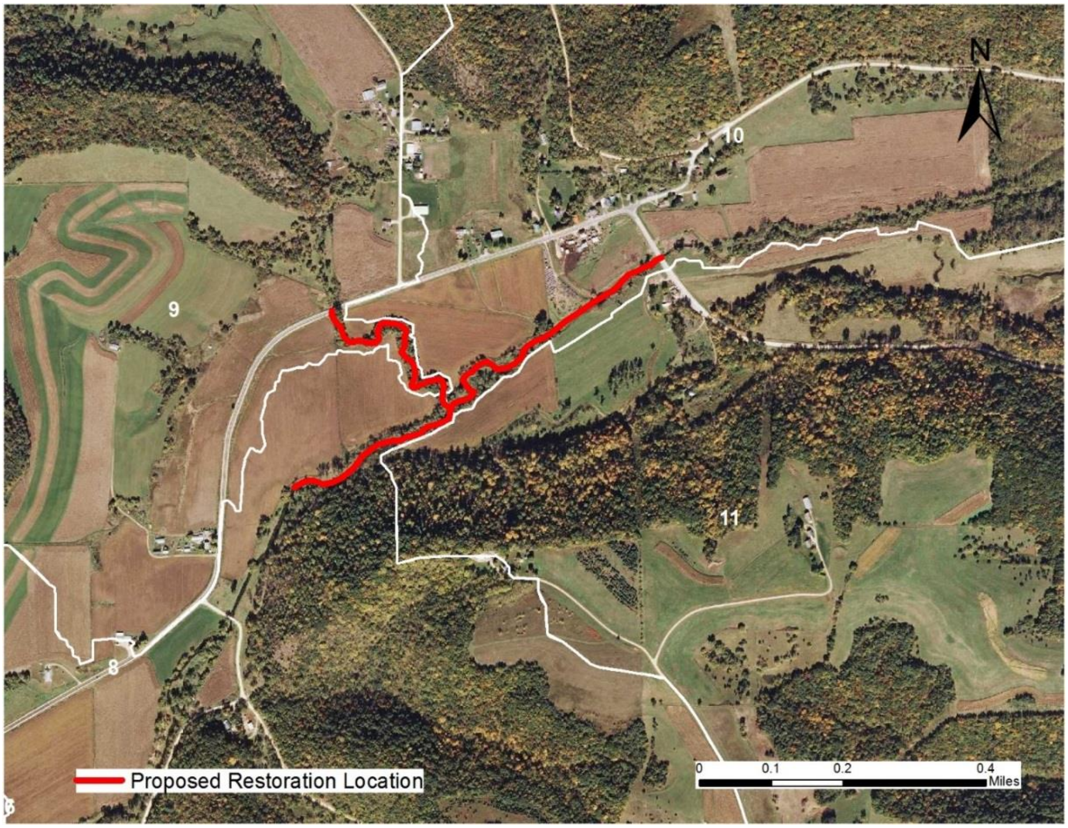

Figure 62. Proposed restoration reaches upstream of Freeburg (including Ball Park tributary) located in catchments 8, 9, and 10.

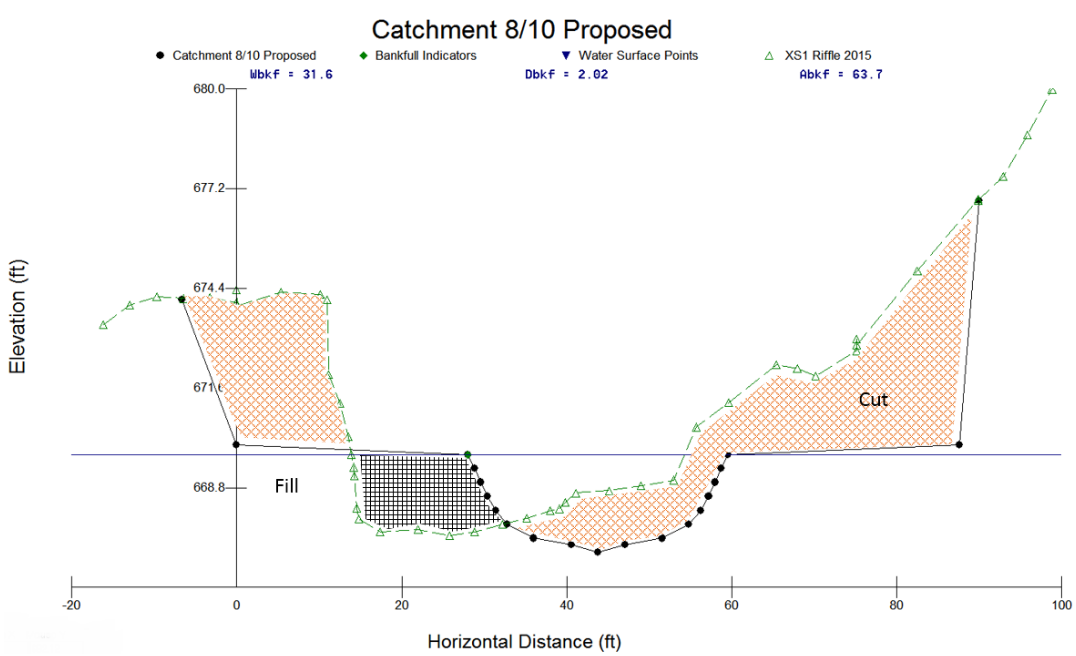

Figure 63. Proposed bankfull channel (below solid line) and floodplain cross-section for catchments 8 and 10.

- Catchment 9 (Ball Park Tributary) incision should be addressed at the same time as Catchment 8/10 project. Ball Park Tributary is incised from downstream of the crossing on County Road 249 to the confluence with main stem Crooked Creek. This tributary is noted as an important cold water source and spawning habitat.
    - Current stream type is an F; however, considering slope, sinuosity, and valley position, stable stream type is a C
    - Channel restoration to reference channel dimensions, as well as floodplain excavation, would be over roughly 1,900 feet and would result in 10,000 yd^3 of excess cut (Figure 64)
    - Restoration would reduce an estimated 140 tons/yr of streambank erosion
    - Estimated cost of restoration ranges from $190,000 to $380,000

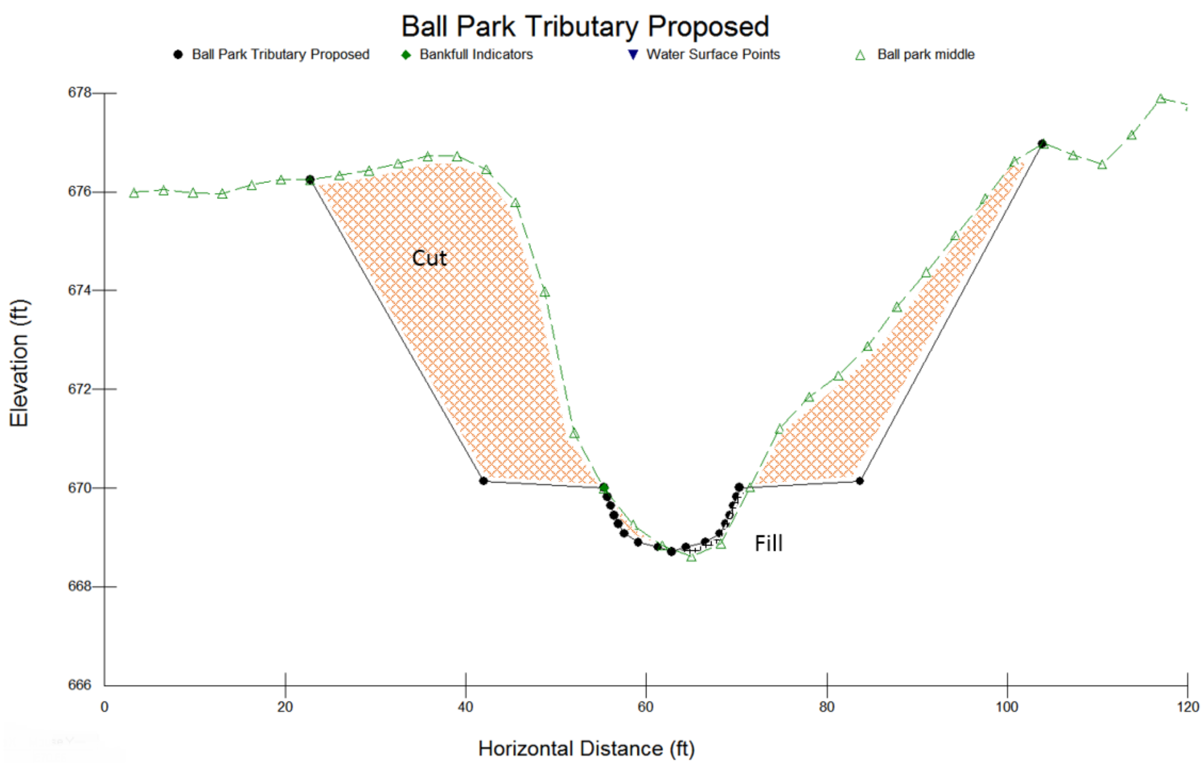

Figure 64. Ball Park Tributary channel restoration.

- Main stem Crooked Creek downstream of Freeburg
    - Conditions immediately downstream of Freeburg appear very similar to the upstream catchment 10 reach; unfortunately, this area was not investigated (Figure 65). Possible restoration needed of an additional 4,500 feet with similar cut and fill as Figure 63
    - Restoration would reduce an estimated 526 tons/yr from streambank erosion
    - Estimated cost ranges from $450,000 to $900,000

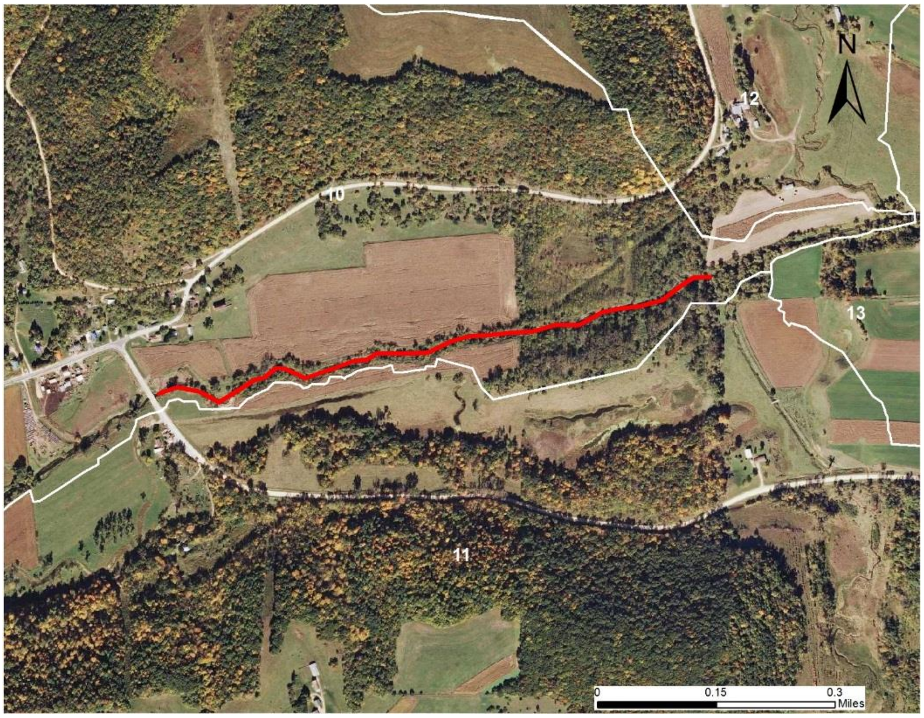

Figure 65. Proposed restoration location (red line) downstream of Freeburg.

Step II

Catchment 5, 15 and 17

These catchments rated high for direct impacts. The direct impacts are related to the effects of cattle grazing on streambank and channel stability

- Pursue riparian grazing plans and other management strategies to reduce impact on streambanks
- In catchment 15, investigate impacts of a private crossing, which was considered a fish passage barrier in the MPCA Stressor Identification Report (2018) (Figure 66). Explore alternate crossing design
- Streambank stabilization with toe-wood on large eroding bank in catchment 5, immediately upstream of County Road 249 bridge. Stream does have floodplain access on left bank, and has not moved in decades. The stream is stable; however, flow is directed at the bluff
- Due to the influence from the Mississippi River and the natural flattening of the stream longitudinal profile in the lower section of catchments 15 and 17, full channel restoration may not be cost effective.

Figure 66. Fish barrier crossing in catchment 15.

Catchment 1

Although a reference site was located downstream of Mathy Gravel mine, evidence of sediment input into the stream was visible.

- Improve stream protection from overland input from gravel mine

Clear Creek, catchments 18 and 19

The upstream catchment (18) was identified in the RRISSC as having direct channel impacts from straightening and spoil piles adjacent to the channel, in effect incising the stream. Due to the remoteness and difficulty in accessing this section of stream, field verification did not occur. Downstream in catchment 19, no processes were identified as issues. Slight incision from the survey in catchment 19 could be from an aggrading floodplain in the early 20th century. As noted in the MPCA Stressor Identification report, macroinvertebrates are impaired due to lack of habitat. The Mississippi River likely influences the hydraulic regime at this location.

- Improve shading of stream

- Address overwide crossing on County Road 249
- Streambank stabilization with toe-wood on large eroding bank in catchment 18, just upstream of catchment 19 (Figure 67). Stream appears stable with floodplain access
- Reduce cattle grazing impacts

Figure 67. Eroding bank in catchment 18, looking downstream.

Step III

Surface erosion yield has been estimated as the highest contributor of sediment to the stream network of Crooked Creek. Questions may arise then why surface erosion is in the third level of priorities. An impactful discussion of the reasoning comes from Trimble (1999), discussing a sediment budget of a watershed within the Driftless region. A take away is "sediment yield monitoring can lead to erroneous conclusions about erosional processes within a basin" (Trimble 1999). Although there has been a drastic reduction in gross surface erosion, it is possible sediment yield remains around the same has it has always been. That is not to say that good land management is not important, as excess sediment can reduce channel bottom diversity and limit aquatic life habitat. During the heavy conversion and farming of lands, much of the erosion was deposited in valleys instead of reaching watershed mouths; the effects of this were discussed in the beginning of this report in Sediment Delivery from Surface Erosion. Surface erosion yield is very similar to other watersheds in the area, which are either exceeding turbidity standards or excess sediment is a stressor to aquatic life. In these watersheds, it has been estimated that streambank erosion contributes the majority of the sediment. At least in these areas, sediment impairment may be driven by in-channel sources.

It is important to consider the sediment yield, but also consider visual evidence of surface erosion and adoption of best management practices. There is a lack of surface erosion signatures from aerial photos. There is also currently a vast adoption of agricultural best management practices (BMPs). Continuation of these practices is important, as well as future investigation of new BMP locations.

Management Strategy Locations and Cost Breakdown

The active restoration cost estimates were included in each step description; however, Table 12 allows for a comparison of estimated costs for the entire watershed. Locations for proposed restoration can be seen in Figure 68. Passive restoration strategies of grazing management are not easily assigned a cost, which depends on size of operation and length along stream, among other considerations. Therefore, cost estimates are not included for passive restoration strategies.

Table 12. Active restoration cost breakdown for proposed strategies.

Catchment	Location	Length	Estimated Cost (Low)	Estimated Cost (High)	Streambank erosion reduction (tons/yr)	Cost Per Ton Reduced (Low)	Cost Per Ton Reduced (High)
6	Below survey 16-01	2,500	$250,000	$500,000	140	$1,786	$3,571
7	Upstream Whitetail Drive	2,600	$260,000	$520,000	Unknown	NA	NA
7	Downstream Whitetail Drive	4,300	$430,000	$860,000	520	$826.92	$1,653.85
8/10	Main stem near Freeburg	3,500	$350,000	$700,000	300	$1,166.67	$2,333.33
9	Ball Park Tributary downstream Cty. 249	1,900	$190,000	$380,000	140	$1,357.14	$2,714.29
10	Main stem downstream of Freeburg	4,500	$450,000	$900,000	526	$855.51	$1,711.03

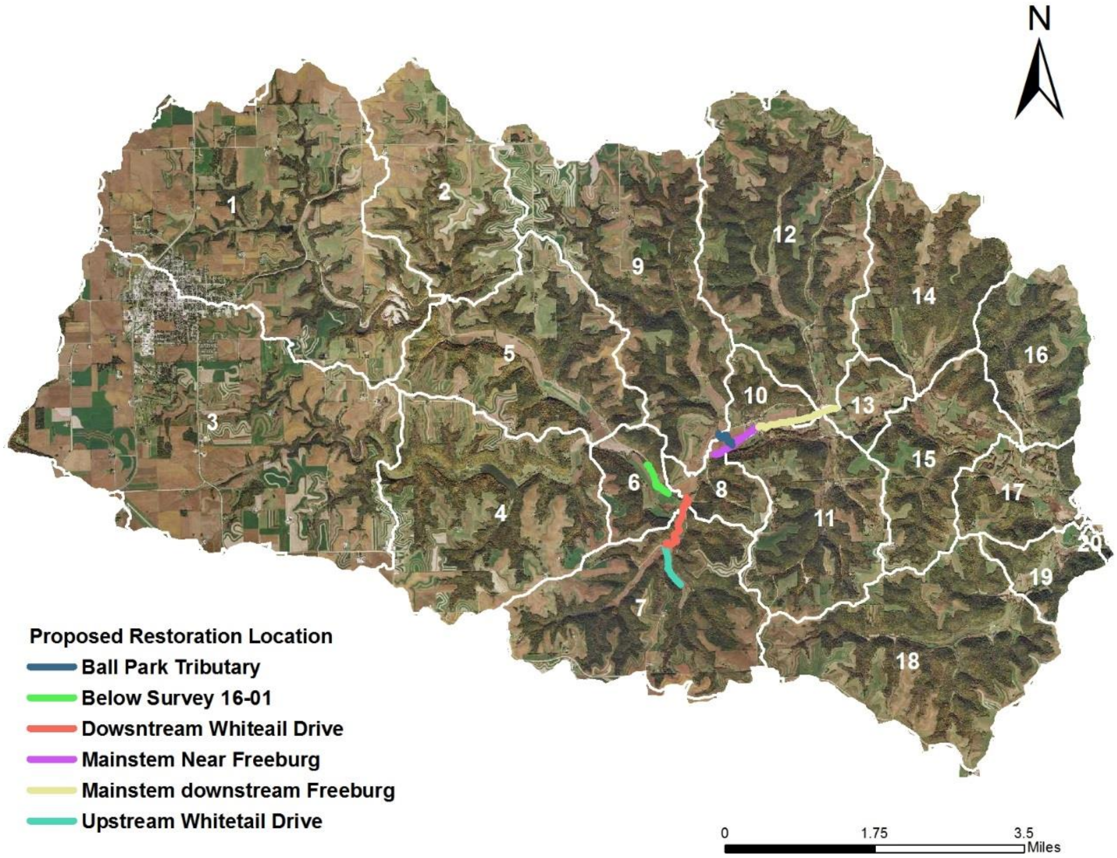

Figure 68. Watershed location of proposed active restorations.

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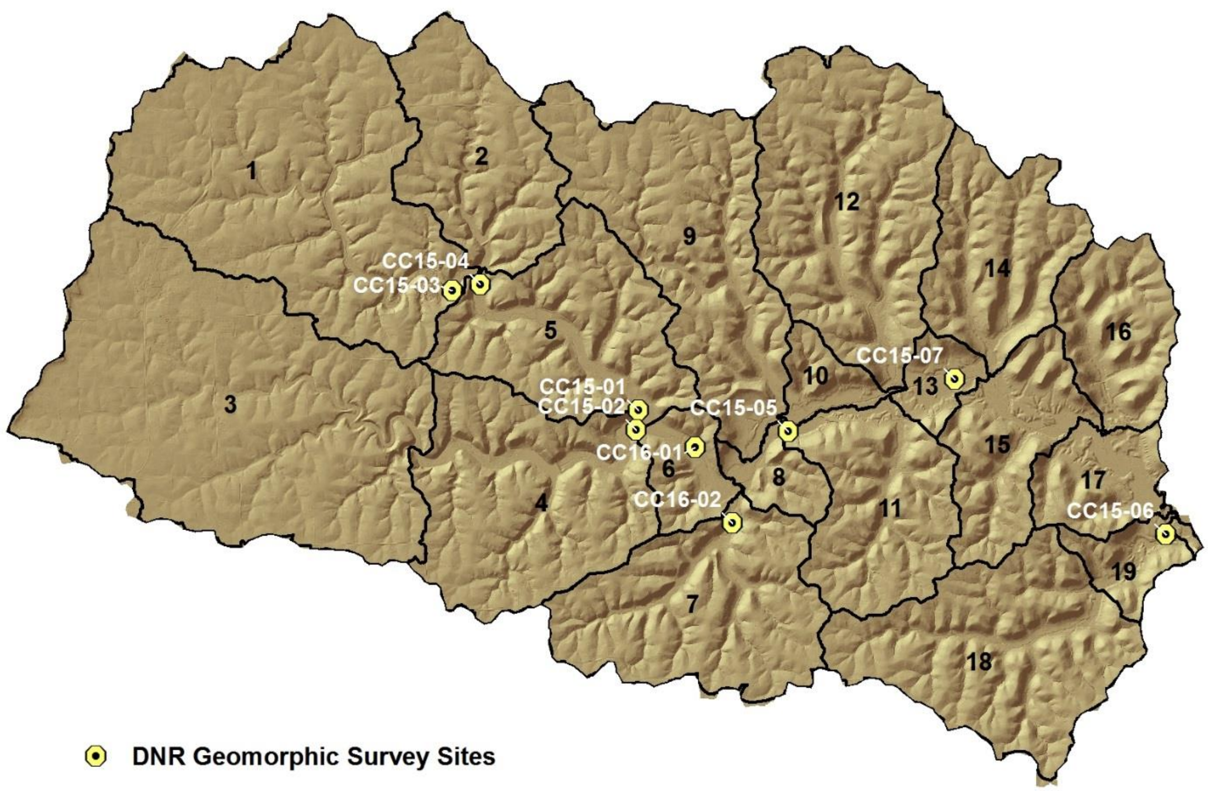
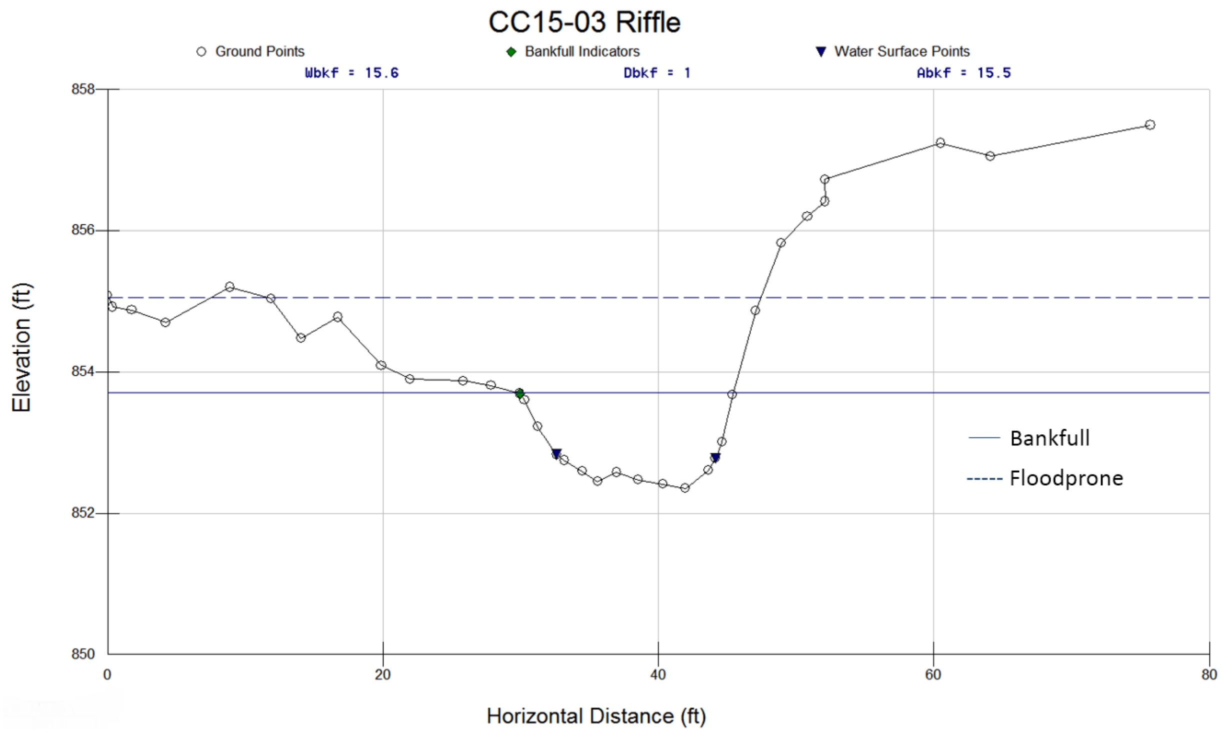
Appendix

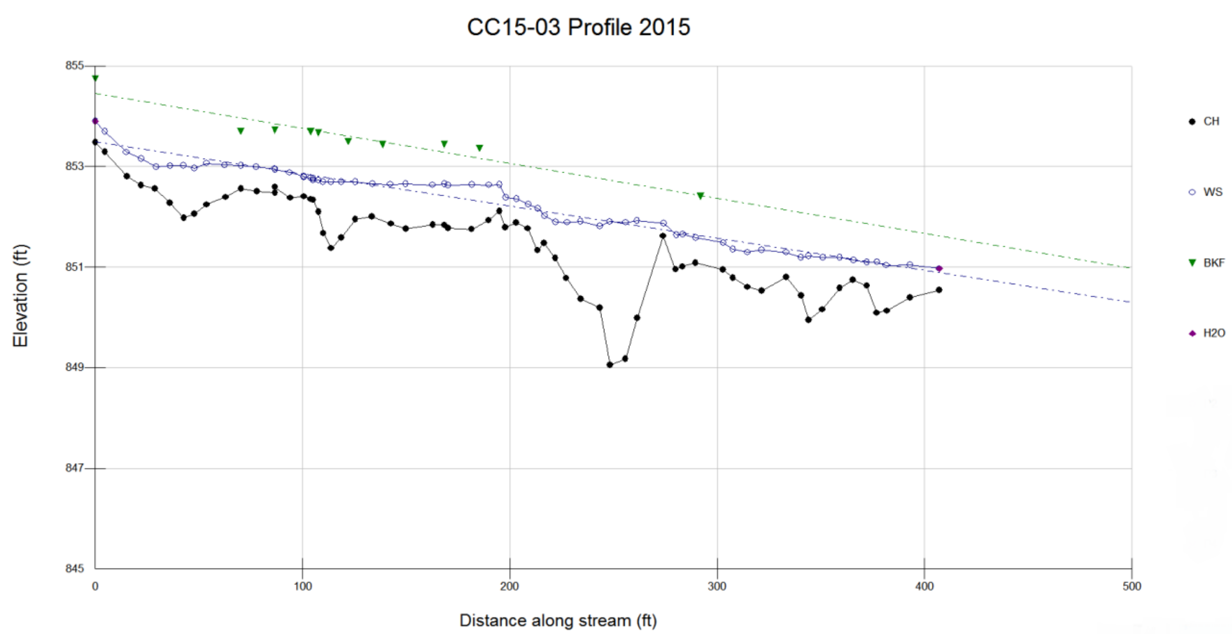
Geomorphic Sites Within Crooked Creek Watershed



Survey Site CC15-03: Reference

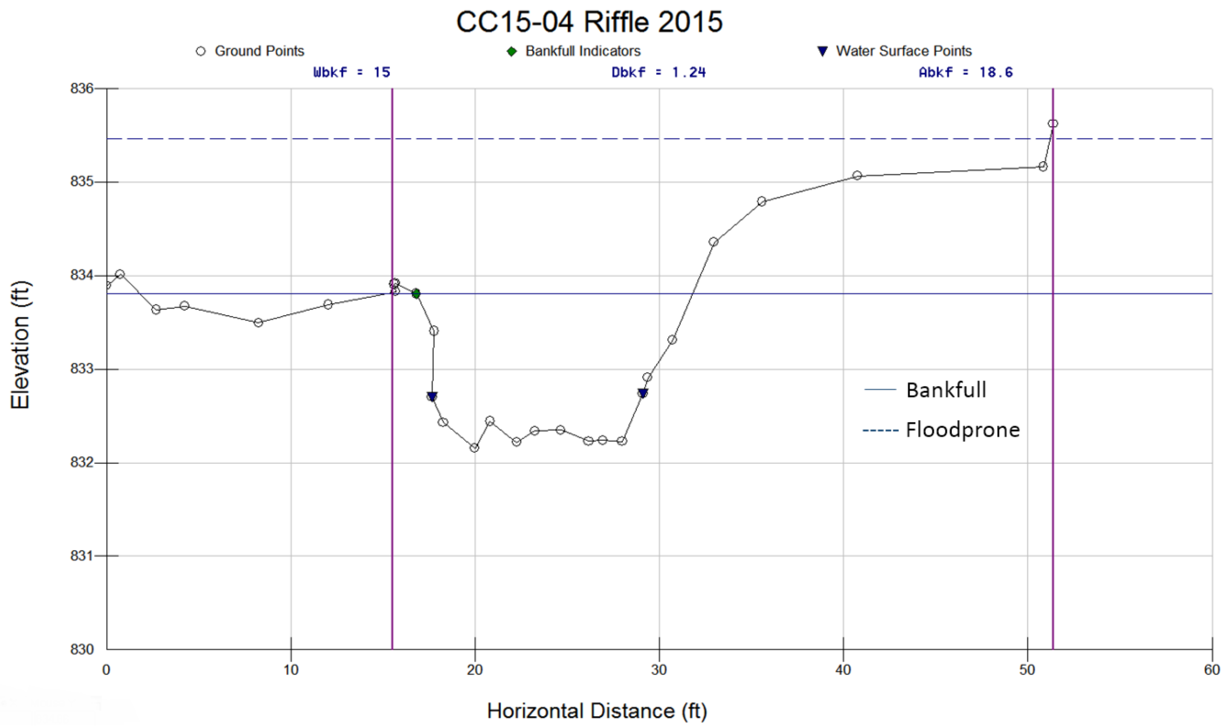
2015 CC15-03 Survey Results (Surveyed 2015, 2016, and 2017)			
Stream Type	C4	**Riffle D50 (mm)**	13.16
Valley Type	U-AL-FD	**Riffle D84 (mm)**	68.61
Bankfull Width (ft)	15.57	**Sinuosity**	1.2
Mean Riffle Depth (ft)	1.0	**Water Slope**	0.006
Width/Depth Ratio	15.57	**Bank Height Ratio**	1.1
Entrenchment Ratio	2.78	**Bank Erosion Estimate (tons/yr/ft)**	0.0092
Bankfull Area (ft²)	15.5	**Pfankuch Stability Rating**	Fair

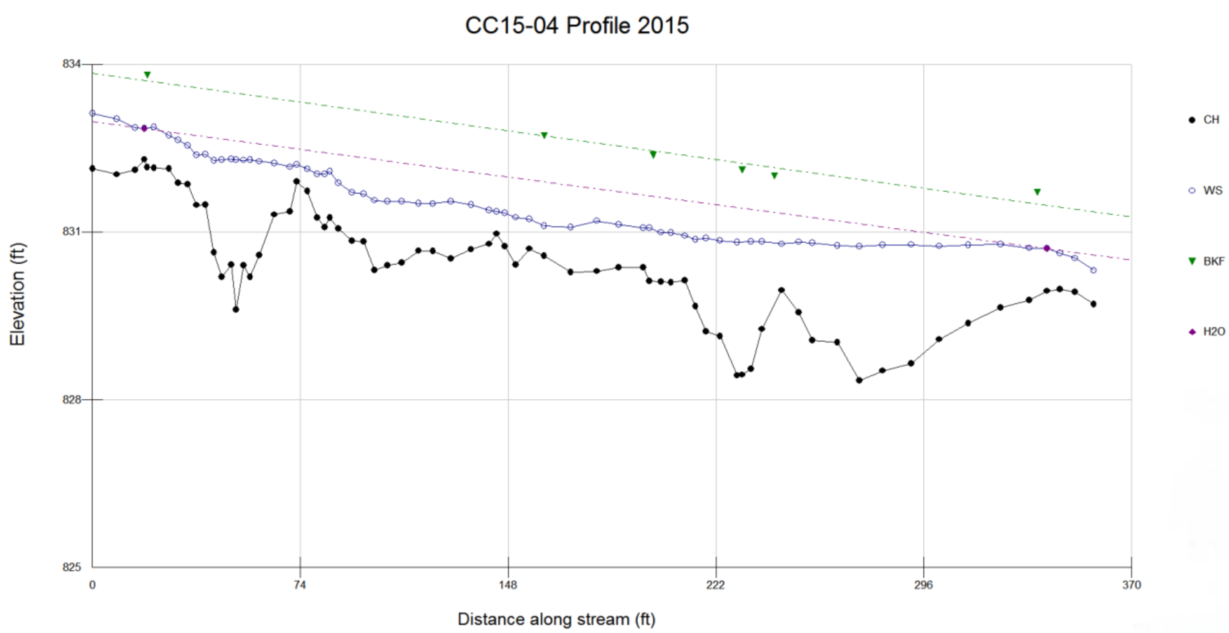

CC15-03 Riffle
Ground Points
Bankfull Indicators
Water Surface Points
Wbkf = 15.6
Dbkf = 1
Abkf = 15.5
Elevation (ft)
Horizontal Distance (ft)
Bankfull
Floodprone
858
856
854
852
850
0
20
40
60
80


CC15-03 Profile 2015
Elevation (ft)
Distance along stream (ft)
CH
WS
BKF
H2O
855
853
851
849
847
845
0
100
200
300
400
500

Survey Site CC15-04: Representative

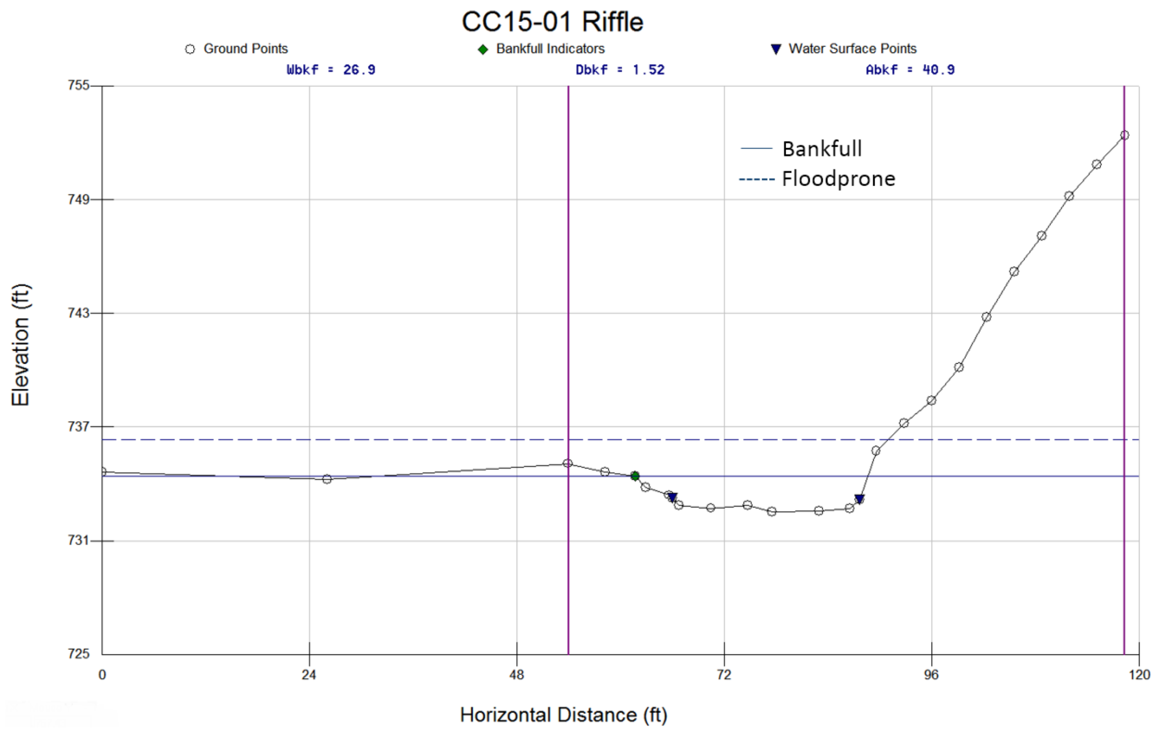
2015 CC15-04 Survey Results (Surveyed in 2015, 2016, and 2017)			
Stream Type	C4	**Riffle D50 (mm)**	16.37
Valley Type	U-AL-FD	**Riffle D84 (mm)**	59
Bankfull Width (ft)	15	**Sinuosity**	1.1
Mean Riffle Depth (ft)	1.24	**Water Slope**	0.0067
Width/Depth Ratio	12.1	**Bank Height Ratio**	1.07
Entrenchment Ratio	16.67	**Bank Erosion Estimate (tons/yr/ft)**	0.0086
Bankfull Area (ft^2)	18.56	**Pfankuch Stability Rating**	Good


CC15-04 Riffle 2015
Ground Points
Bankfull Indicators
Water Surface Points
Wbkf = 15
Dbkf = 1.24
Abkf = 18.6
Bankfull
Floodprone
Elevation (ft)
Horizontal Distance (ft)
836
835
834
833
832
831
830
0
10
20
30
40
50
60

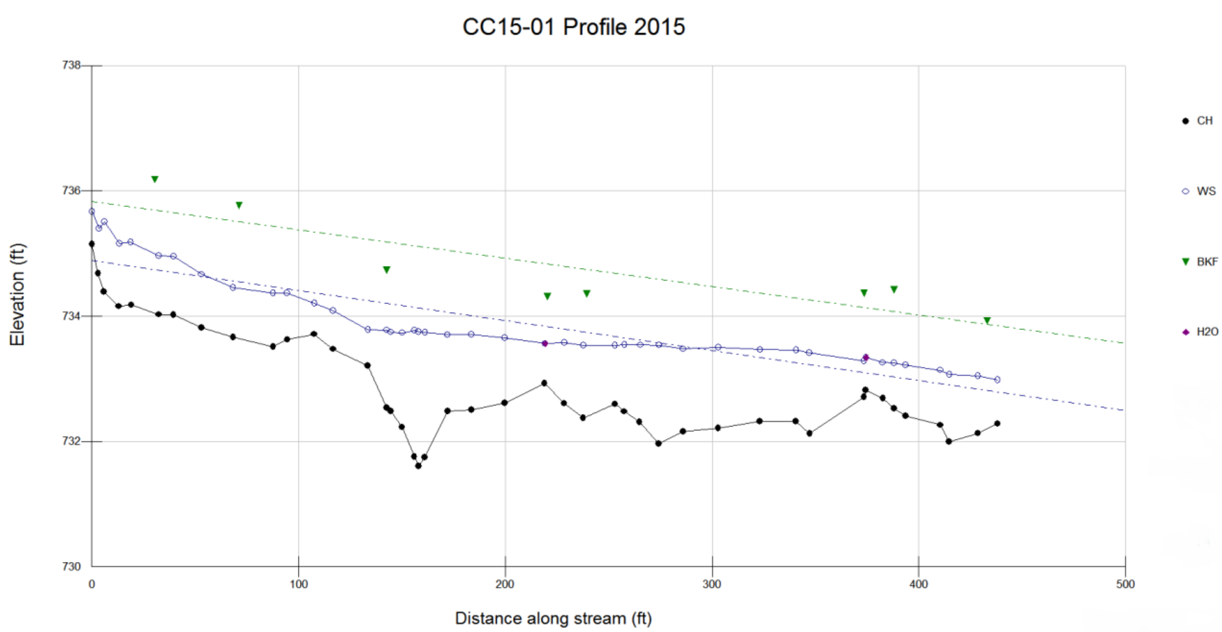

CC15-04 Profile 2015
Elevation (ft)
Distance along stream (ft)
834
831
828
825
0
74
148
222
296
370
CH
WS
BKF
H2O

Survey Site CC15-01: Representative

2015 CC15-01 Survey Results			
Stream Type	C4	**Riffle D50 (mm)**	25.49
Valley Type	U-AL-FD	**Riffle D84 (mm)**	67.86
Bankfull Width (ft)	26.91	**Sinuosity**	1.1
Mean Riffle Depth (ft)	1.52	**Water Slope**	0.004
Width/Depth Ratio	17.7	**Bank Height Ratio**	1.2
Entrenchment Ratio	4.65	**Bank Erosion Estimate (tons/yr/ft)**	0.01
Bankfull Area (ft^2)	40.89	**Pfankuch Stability Rating**	Fair



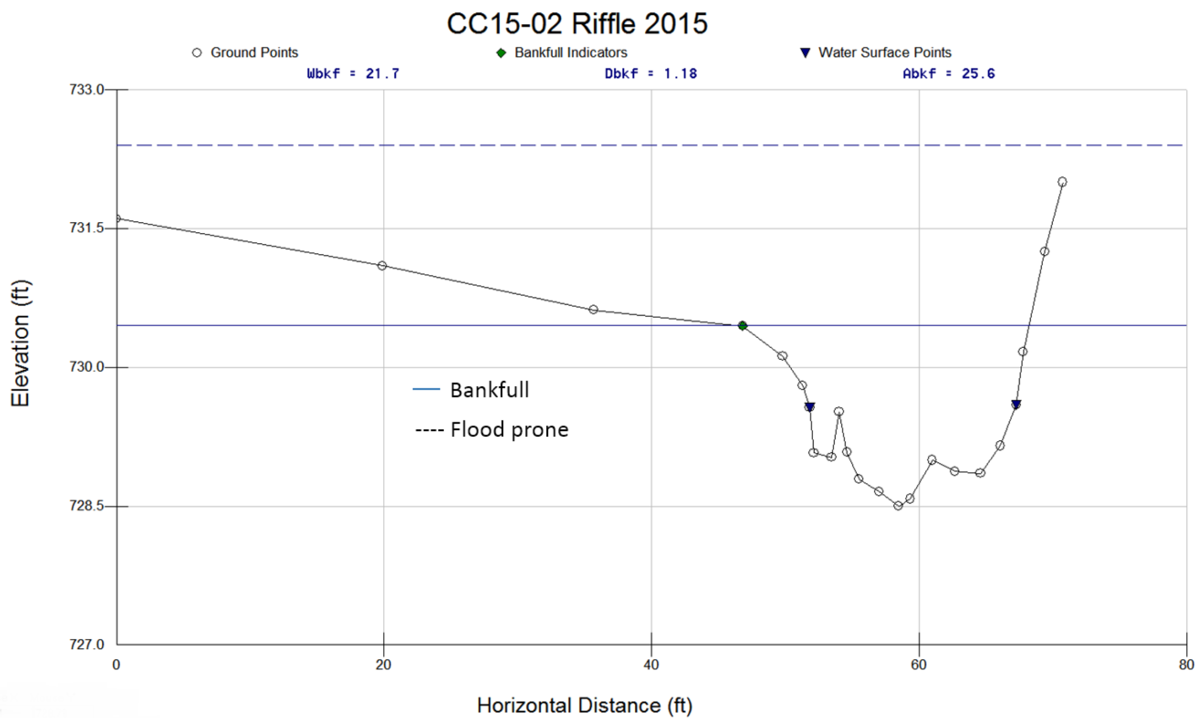
CC15-01 Riffle
Ground Points
Bankfull Indicators
Water Surface Points
Wbkf = 26.9
Dbkf = 1.52
Abkf = 40.9
Bankfull
Floodprone
Elevation (ft)
755
749
743
737
731
725
0
24
48
72
96
120
Horizontal Distance (ft)

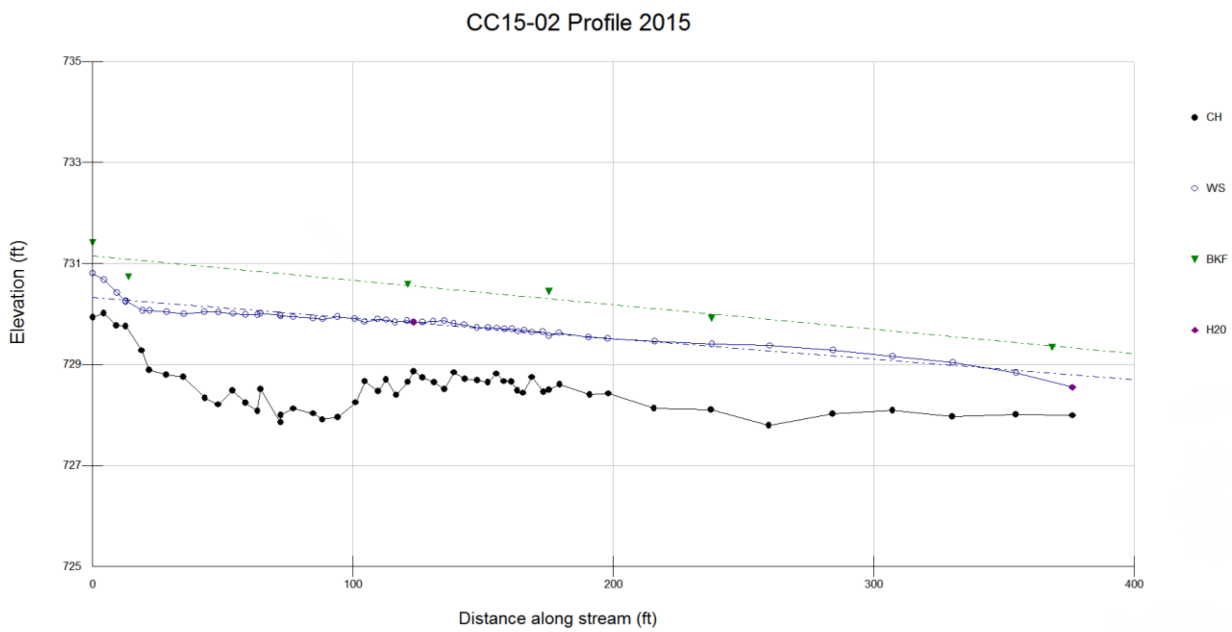


CC15-01 Profile 2015
Elevation (ft)
738
736
734
732
730
0
100
200
300
400
500
Distance along stream (ft)
CH
WS
BKF
H2O

Survey Site CC15-02: Representative

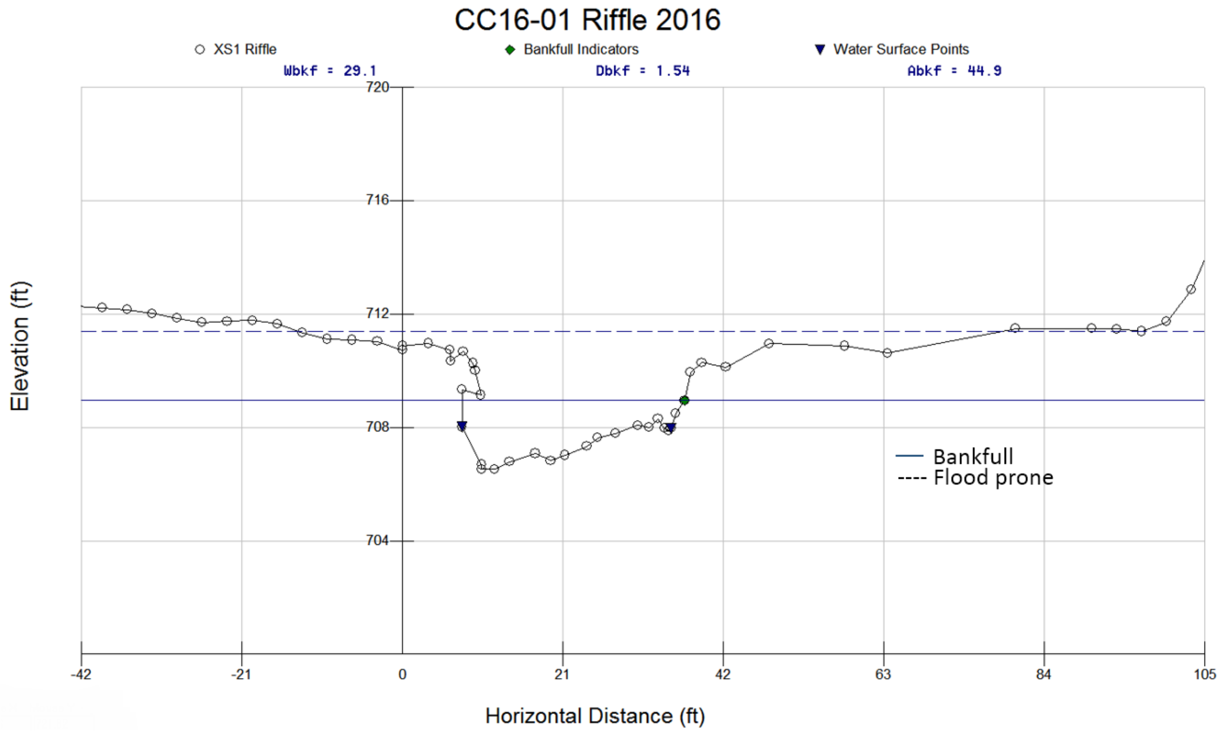
2015 CC15-02 Survey Results			
Stream Type	C3	**Riffle D50 (mm)**	88
Valley Type	U-AL-FD	**Riffle D84 (mm)**	166.67
Bankfull Width (ft)	21.74	**Sinuosity**	1.04
Mean Riffle Depth (ft)	1.18	**Water Slope**	0.005
Width/Depth Ratio	18.42	**Bank Height Ratio**	1.0
Entrenchment Ratio	5.06	**Bank Erosion Estimate (tons/yr/ft)**	Minimal
Bankfull Area (ft^2)	25.64	**Pfankuch Stability Rating**	Good


CC15-02 Riffle 2015
Ground Points
Bankfull Indicators
Water Surface Points
Wbkf = 21.7
Dbkf = 1.18
Abkf = 25.6
733.0
731.5
730.0
728.5
727.0
0
20
40
60
80
Elevation (ft)
Horizontal Distance (ft)
Bankfull
---- Flood prone

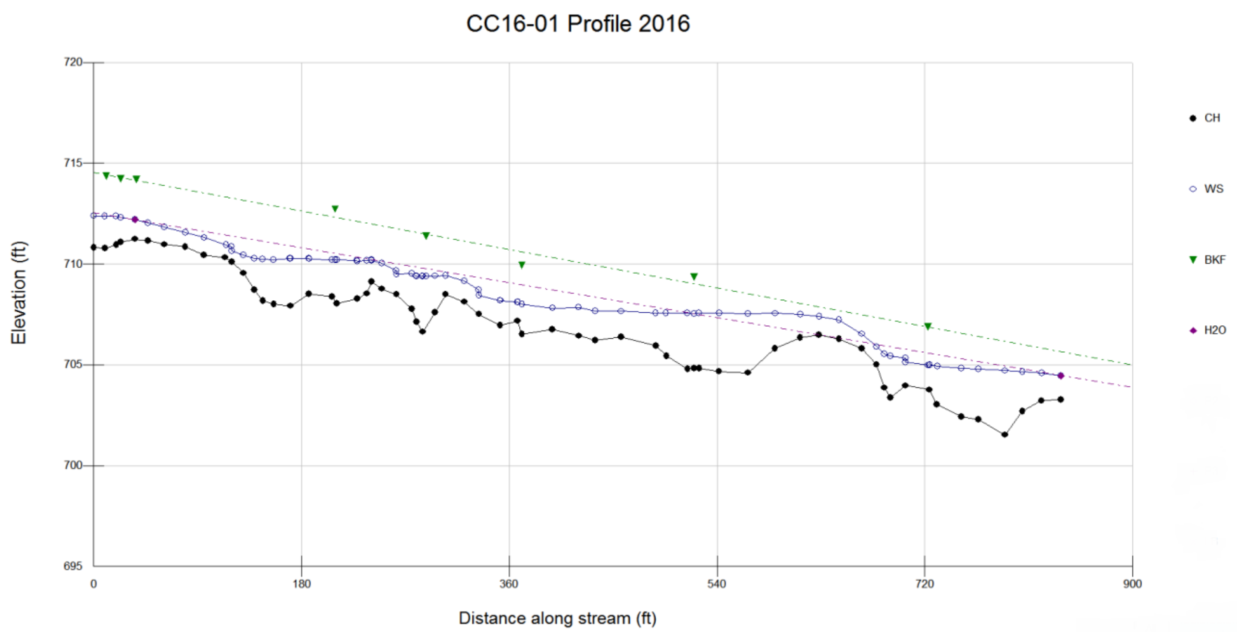

CC15-02 Profile 2015
735
733
731
729
727
725
0
100
200
300
400
Elevation (ft)
Distance along stream (ft)
CH
WS
BKF
H20

Survey Site CC16-01: Representative

2016 CC16-01 Survey Results			
Stream Type	C3	**Riffle D50 (mm)**	74.64
Valley Type	U-AL-FD	**Riffle D84 (mm)**	190.25
Bankfull Width (ft)	29.11	**Sinuosity**	1.1
Mean Riffle Depth (ft)	1.54	**Water Slope**	0.008
Width/Depth Ratio	18.9	**Bank Height Ratio**	1.5
Entrenchment Ratio	8.24	**Bank Erosion Estimate (tons/yr/ft)**	0.0618
Bankfull Area (ft^2)	44.89	**Pfankuch Stability Rating**	Fair



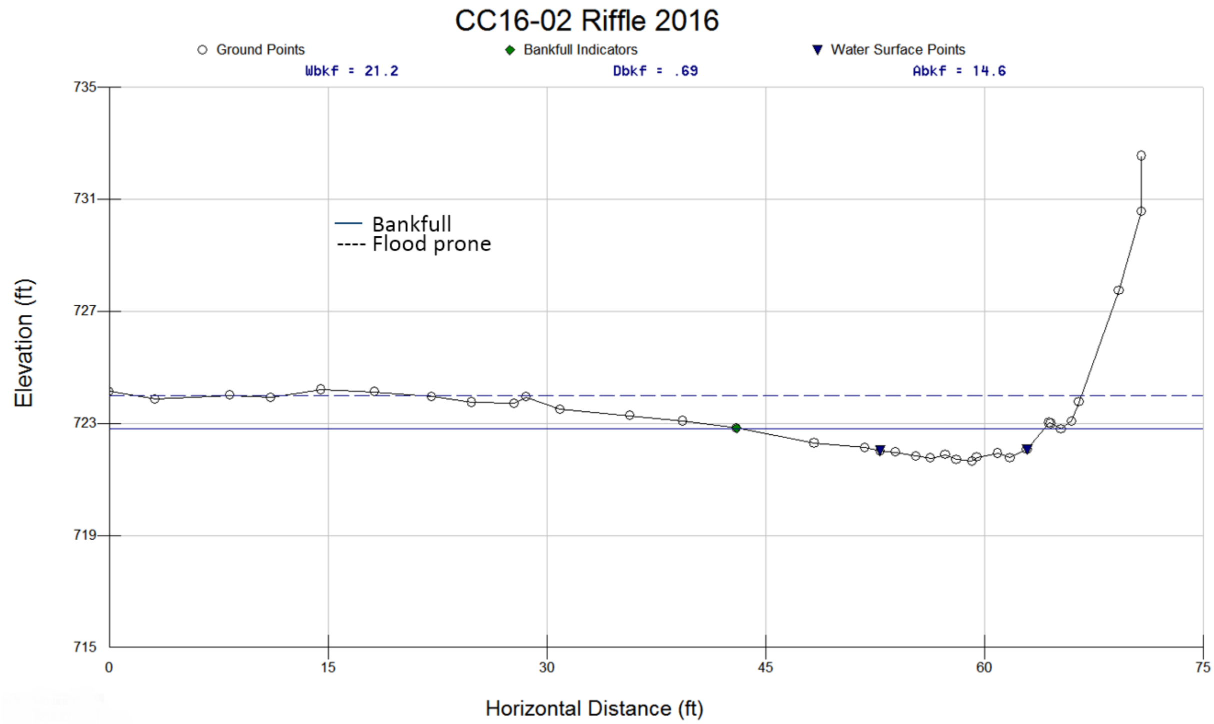
CC16-01 Riffle 2016
XS1 Riffle
Bankfull Indicators
Water Surface Points
Wbkf = 29.1
Dbkf = 1.54
Abkf = 44.9
Bankfull
---- Flood prone
Elevation (ft)
Horizontal Distance (ft)
720
716
712
708
704
-42
-21
0
21
42
63
84
105

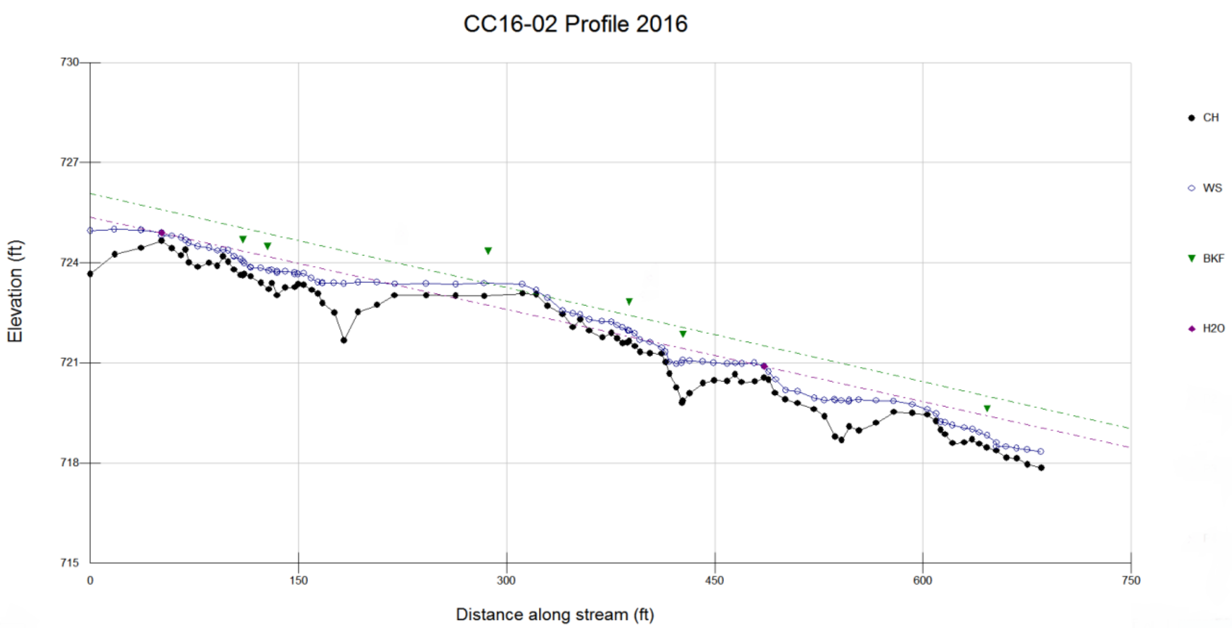


CC16-01 Profile 2016
CH
WS
BKF
H2O
Elevation (ft)
Distance along stream (ft)
720
715
710
705
700
695
0
180
360
540
720
900

Survey Site CC16-02: Representative

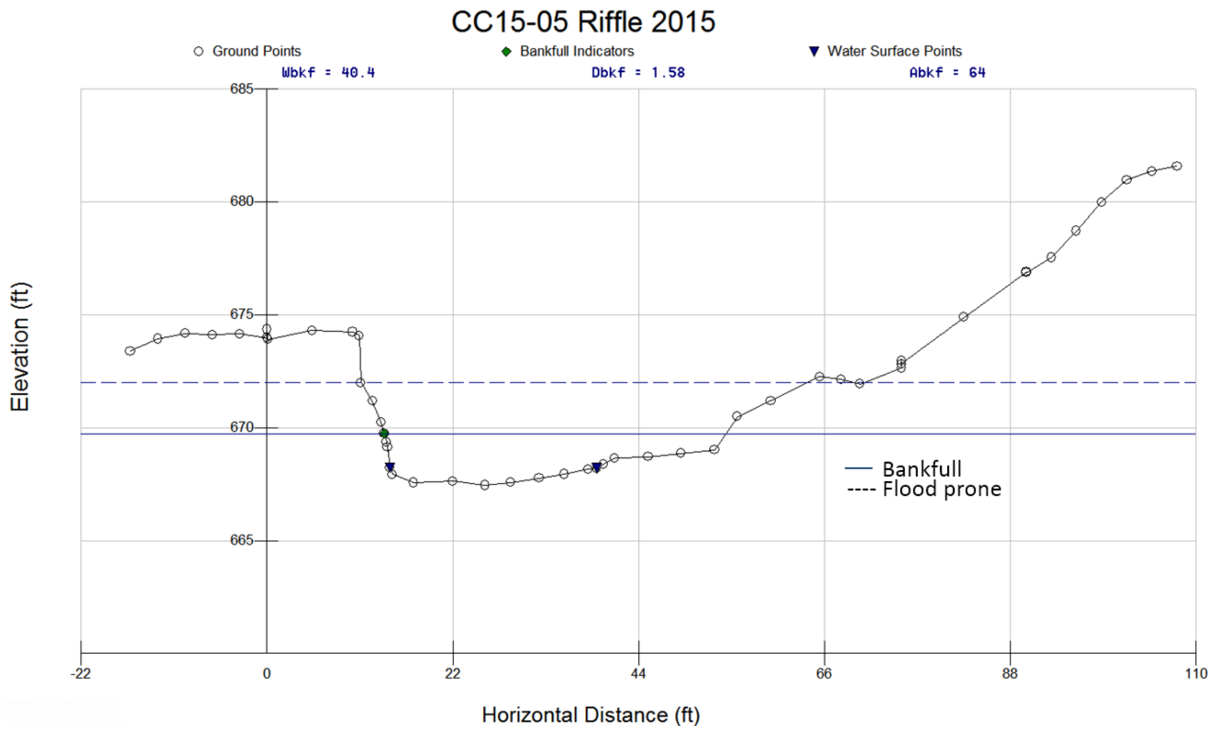
2016 CC16-02 Survey Results			
Stream Type	C4	**Riffle D50 (mm)**	41.75
Valley Type	U-AL-FD	**Riffle D84 (mm)**	73.75
Bankfull Width (ft)	21.22	**Sinuosity**	1.3
Mean Riffle Depth (ft)	0.69	**Water Slope**	0.009
Width/Depth Ratio	30.75	**Bank Height Ratio**	1.4
Entrenchment Ratio	2.63	**Bank Erosion Estimate (tons/yr/ft)**	0.203
Bankfull Area (ft^2)	14.59	**Pfankuch Stability Rating**	Fair

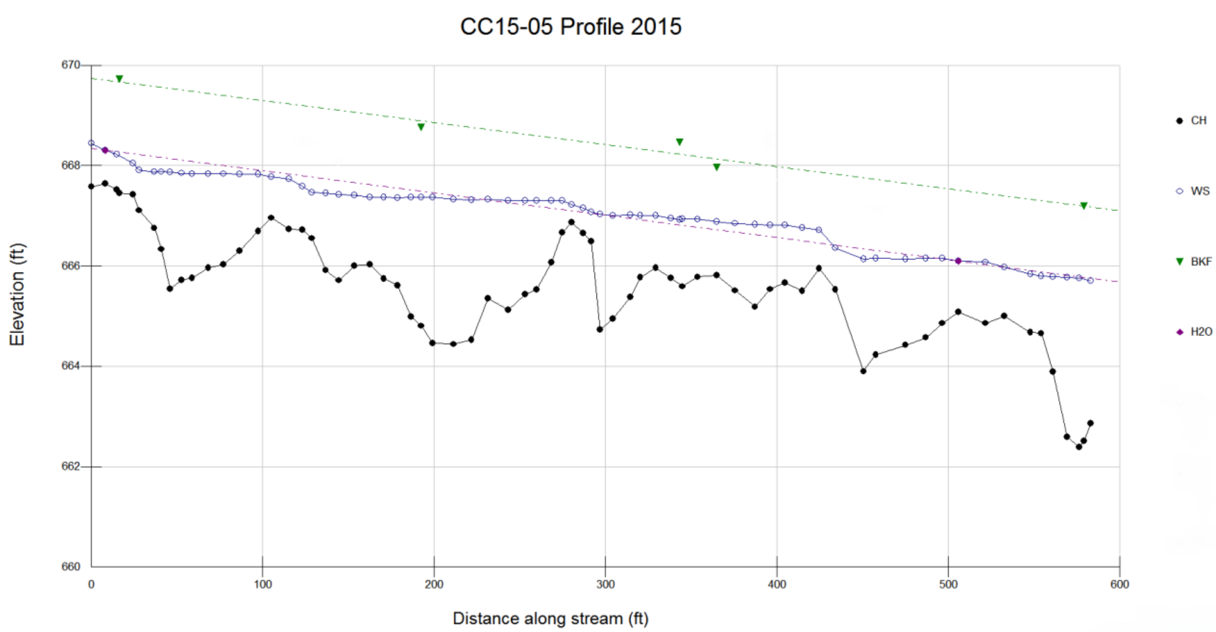

CC16-02 Riffle 2016
Ground Points
Bankfull Indicators
Water Surface Points
Wbkf = 21.2
Dbkf = .69
Abkf = 14.6
Bankfull
---- Flood prone
Elevation (ft)
735
731
727
723
719
715
0
15
30
45
60
75
Horizontal Distance (ft)


CC16-02 Profile 2016
Elevation (ft)
730
727
724
721
718
715
0
150
300
450
600
750
Distance along stream (ft)
CH
WS
BKF
H2O

Survey Site CC15-05: Representative

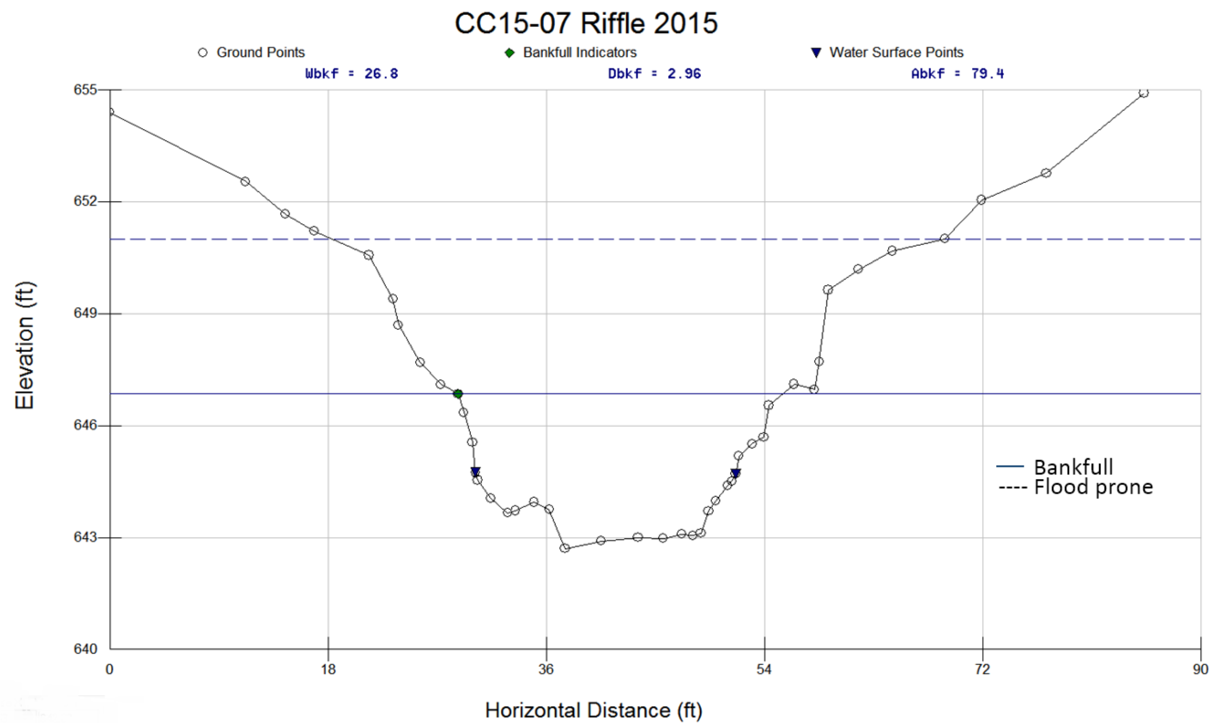
2015 CC15-05 Survey Results (Surveyed 2015, 2016, and 2017)			
Stream Type	F4	**Riffle D50 (mm)**	39.2
Valley Type	U-AL-FD	**Riffle D84 (mm)**	72.32
Bankfull Width (ft)	40.41	**Sinuosity**	1.1
Mean Riffle Depth (ft)	1.58	**Water Slope**	0.004
Width/Depth Ratio	25.58	**Bank Height Ratio**	1.55
Entrenchment Ratio	1.34	**Bank Erosion Estimate (tons/yr/ft)**	0.0875
Bankfull Area (ft^2)	64.01	**Pfankuch Stability Rating**	Fair

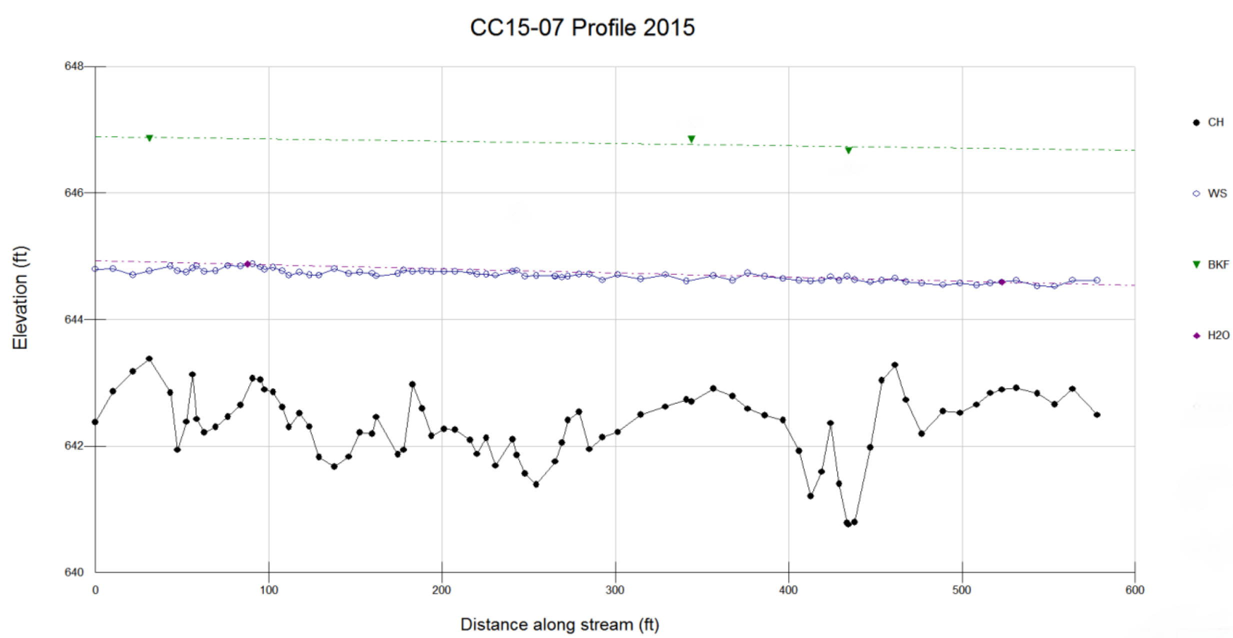

CC15-05 Riffle 2015
Ground Points
Bankfull Indicators
Water Surface Points
Wbkf = 40.4
Dbkf = 1.58
Abkf = 64
685
680
675
670
665
Elevation (ft)
-22
0
22
44
66
88
110
Horizontal Distance (ft)
Bankfull
---- Flood prone


CC15-05 Profile 2015
670
668
666
664
662
660
Elevation (ft)
0
100
200
300
400
500
600
Distance along stream (ft)
CH
WS
BKF
H2O

Survey Site CC15-07: Representative

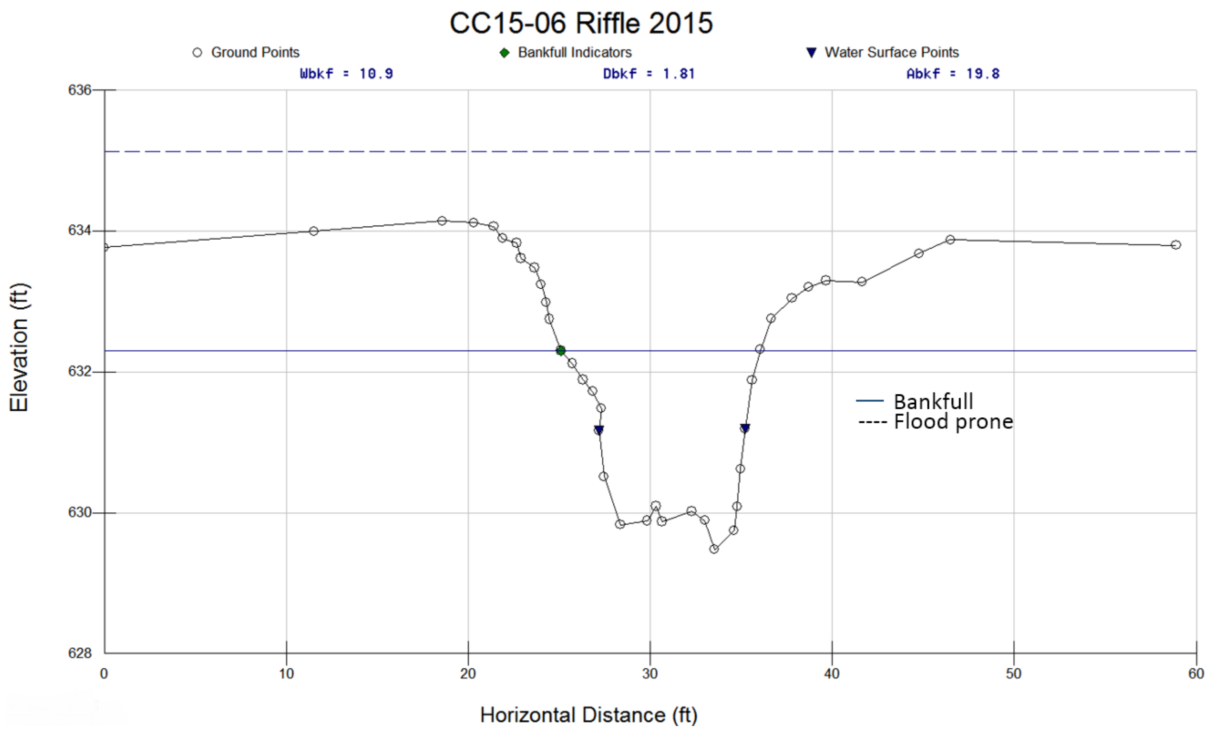
2015 CC15-07 Survey Results (Surveyed 2015 and 2016)			
Stream Type	B5	**Riffle D50 (mm)**	0.17
Valley Type	U-AL-FD	**Riffle D84 (mm)**	0.22
Bankfull Width (ft)	26.78	**Sinuosity**	1.3
Mean Riffle Depth (ft)	2.96	**Water Slope**	0.0006
Width/Depth Ratio	9.05	**Bank Height Ratio**	1.6
Entrenchment Ratio	1.88	**Bank Erosion Estimate (tons/yr/ft)**	0.0196
Bankfull Area (ft^2)	79.38	**Pfankuch Stability Rating**	Poor

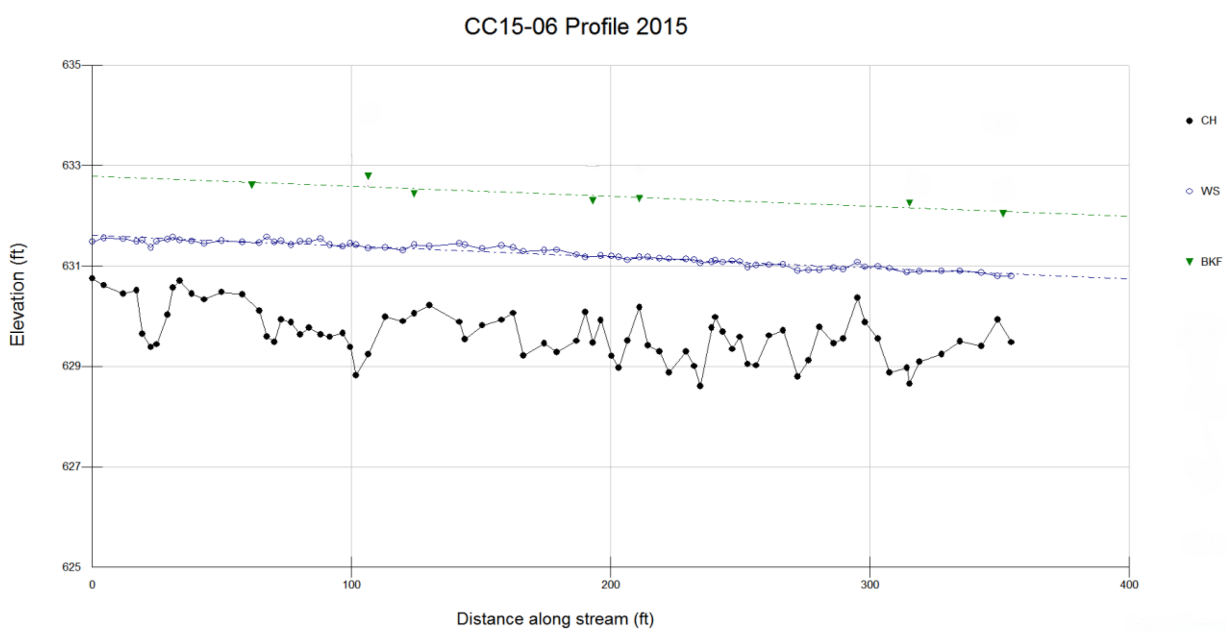

CC15-07 Riffle 2015
Ground Points
Bankfull Indicators
Water Surface Points
Wbkf = 26.8
Dbkf = 2.96
Abkf = 79.4
Elevation (ft)
Horizontal Distance (ft)
Bankfull
Flood prone


CC15-07 Profile 2015
CH
WS
BKF
H2O
Elevation (ft)
Distance along stream (ft)

Survey Site CC15-06: Representative

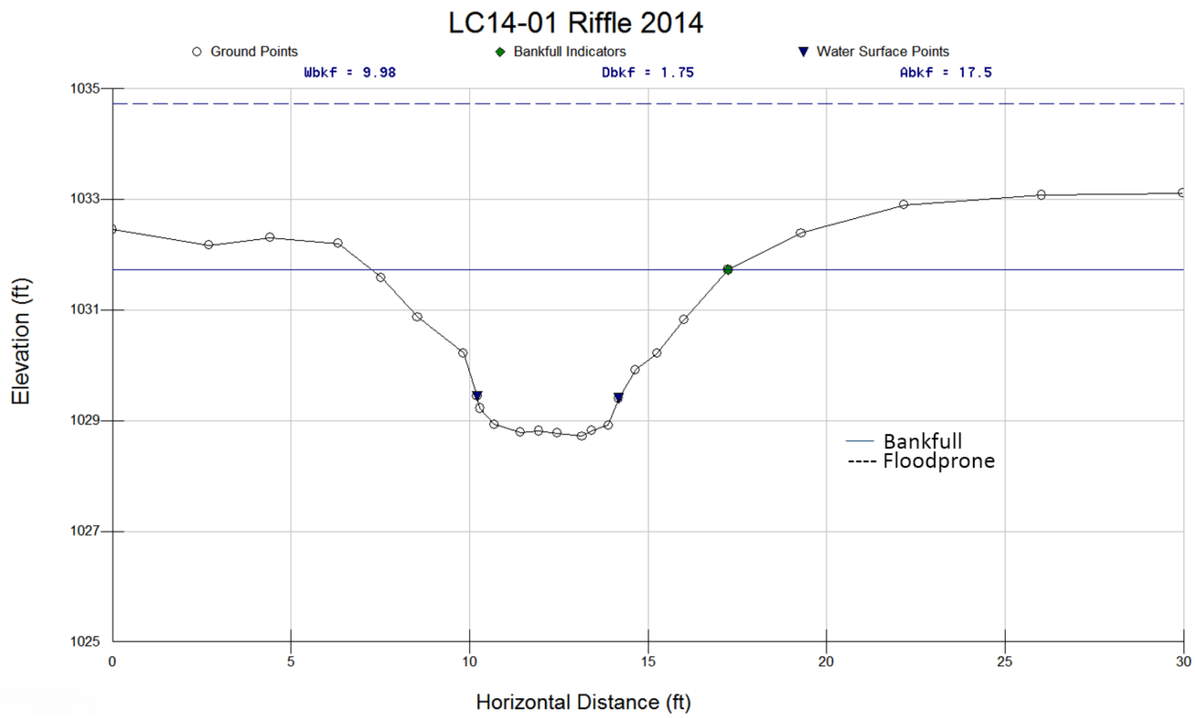
2015 CC15-06 Survey Results			
Stream Type	E6	**Riffle D50 (mm)**	0.14
Valley Type	U-AL-FD	**Riffle D84 (mm)**	0.23
Bankfull Width (ft)	10.95	**Sinuosity**	1.3
Mean Riffle Depth (ft)	1.81	**Water Slope**	0.002
Width/Depth Ratio	6.05	**Bank Height Ratio**	1.3
Entrenchment Ratio	42.94	**Bank Erosion Estimate (tons/yr/ft)**	0.0173
Bankfull Area (ft^2)	19.81	**Pfankuch Stability Rating**	Fair

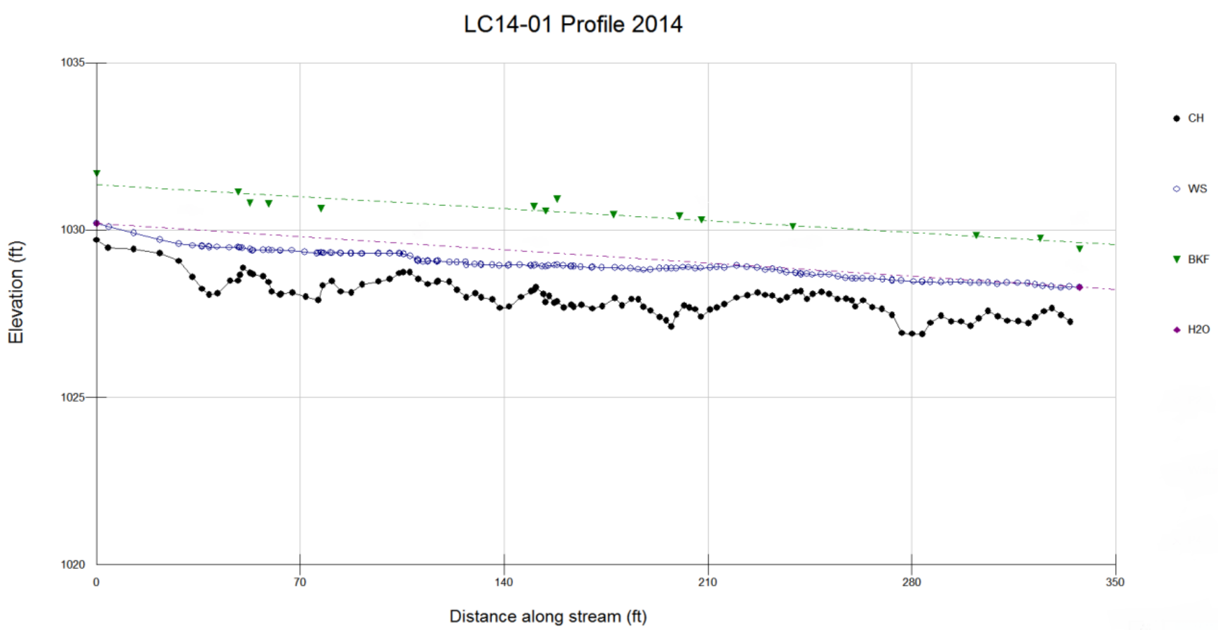

CC15-06 Riffle 2015
Ground Points
Bankfull Indicators
Water Surface Points
Wbkf = 10.9
Dbkf = 1.81
Abkf = 19.8
Bankfull
Flood prone
Elevation (ft)
Horizontal Distance (ft)


CC15-06 Profile 2015
CH
WS
BKF
Elevation (ft)
Distance along stream (ft)

Little Cannon River Survey Site LC14-01: Reference

2014 LC14-01 Survey Results			
Stream Type	E4	**Riffle D50 (mm)**	10.61
Valley Type	U-AL-FD	**Riffle D84 (mm)**	20.74
Bankfull Width (ft)	9.98	**Sinuosity**	1.9
Mean Riffle Depth (ft)	1.75	**Water Slope**	0.0058
Width/Depth Ratio	5.7	**Bank Height Ratio**	1.1
Entrenchment Ratio	25	**Bank Erosion Estimate (tons/yr/ft)**	0.03
Bankfull Area (ft^2)	17.49	**Pfankuch Stability Rating**	Fair


LC14-01 Riffle 2014
Ground Points
Bankfull Indicators
Water Surface Points
Wbkf = 9.98
Dbkf = 1.75
Abkf = 17.5
Bankfull
---- Floodprone
Elevation (ft)
Horizontal Distance (ft)


LC14-01 Profile 2014
CH
WS
BKF
H2O
Elevation (ft)
Distance along stream (ft)

Vermillion River E1: Reference

2014 Survey Results			
Stream Type	E4	**Riffle D50 (mm)**	10
Valley Type	U-AL-FD	**Riffle D84 (mm)**	Unknown
Bankfull Width (ft)	17.41	**Sinuosity**	1.5
Mean Riffle Depth (ft)	2.45	**Water Slope**	0.001
Width/Depth Ratio	7.11	**Bank Height Ratio**	1
Entrenchment Ratio	45.95	**Bank Erosion Estimate (tons/yr/ft)**	Unknown
Bankfull Area (ft^2)	42.63	**Pfankuch Stability Rating**	Good