South Branch Vermillion River: Minnesota Department of Natural Resources Geomorphic Overview

DEPARTMENT OF NATURAL RESOURCES

Ecological and Water Resources Division, Clean Water Team - Central Region

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Introduction

The purpose of this report is to provide a geomorphic overview to help inform the potential causes of the aquatic life impairments for fish and invertebrate communities in the lower portion of the South Branch Vermillion River (MPCA 2012). Though not impaired for turbidity (TSS), sediment is suspected to be one of the main stressors for fish and invertebrates (MPCA 2013). This report will place the role of channel stability and in-channel sediment sources in context with the aquatic life impairments.

The geomorphic assessment included desktop analysis, review of current and historical aerial photographs, land use changes, and generalized stream and valley type classification of reaches using Geographic Information System (GIS) tools. Part of the background work included a watershed reconnaissance observing channel conditions near crossings and confirming aspects of the desktop analysis such as stream and valley type. From desktop analysis, two representative reaches were selected to be surveyed within the lower portion of the 32 square mile watershed (Figure 1).

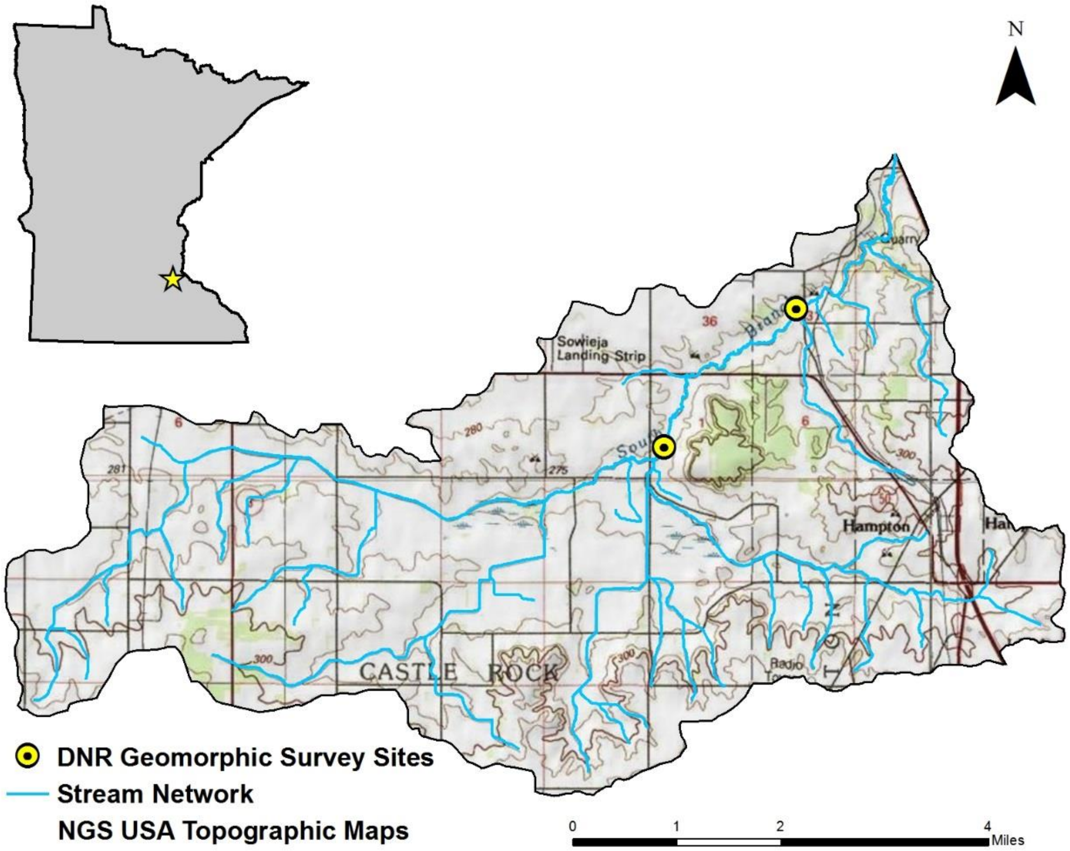

Figure 1. South Branch Vermillion River geomorphic survey sites and location of watershed within the state.

Background

Land-use

The quality of water is often a product of the historic and current land use of its watershed. Knowing past changes may lead to better understanding of the current conditions and potential sediment sources, as well as allow for more effective management planning. Prior to European settlement, prairie made up 75% percent of the land cover in the South Branch Vermillion watershed. The remaining land cover was oak openings (8%), aspen oak-lands (6%), open water (5%), and wet prairie (5%). Significant land use changes occurred shortly after European settlement as agricultural activities increased. Currently, according to the National Land Cover Dataset (2016), land use is dominated by cultivated crops (68%); followed by pasture/hay (14%), forested/grassland (10%), developed (5%), and wetland (3%). Although difficult to quantify, georeferenced historical aerial photos show a large improvement in riparian vegetation from crops to perennial plants, throughout the watershed since the turn of the century (Figure 2).

Figure 2. Comparison of riparian vegetation improvement from 1937 (left) to 2017 (right).

Altering land use and vegetation composition towards more agriculture can lead to increases in sediment. In addition to land use change, looking at surface erosion susceptibility can further the understanding of potential for sediment input. Utilizing the Watershed Health Assessment Framework (WHAF 2020), Figure 3 shows the soil erosion susceptibility of the watershed. This index takes into account the soil type K-factor and the slope of the landscape, but not does not take into account land use. According to this index, erosion potential is predicted to be relatively low. It is important to understand that this is not the current level of erosion, but an indication of how inherently vulnerable the landscape is to erosion (WHAF 2020).

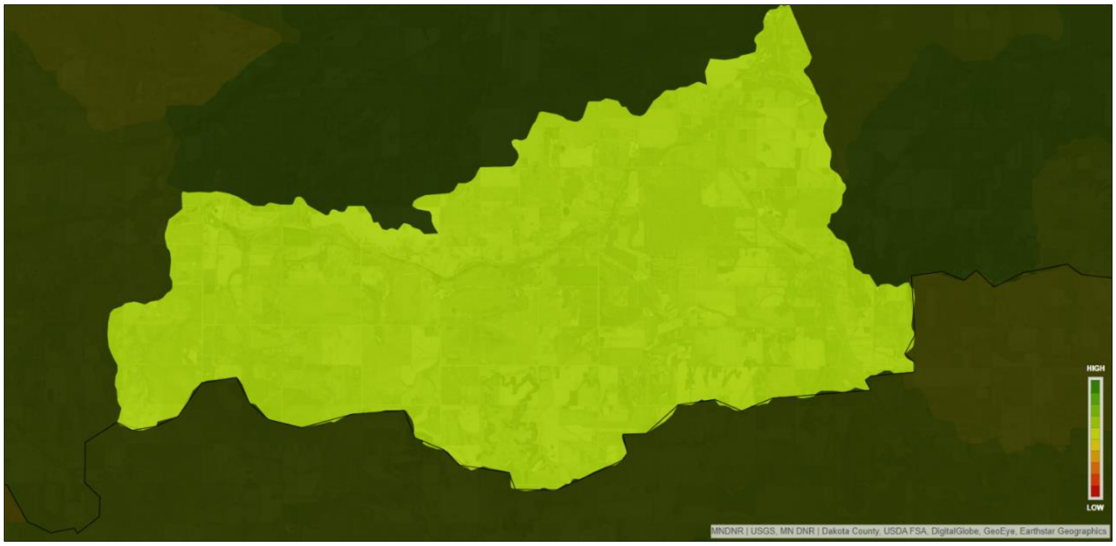

Figure 3. WHAF soil erosion susceptibility index.

Hydrologic Conditions

Hydrology is a driving factor for sediment transport and stream stability within a watershed and when tracked over time identifies shifts in the relationships between precipitation and runoff. Increases in runoff often correlate to increases in sediment from both over land and in-channel sources, and using long-term data along with statistically sound data analysis makes it possible to increase understanding of when and how conditions changed.

There are two stream gages used in this analysis collecting continuous discharge data (Figure 4). The first is the South Branch Vermillion River at Empire stream gage (H38034002), located near the outlet of South Branch Vermillion River. The site has been in operation since 2000 with seasonal continuous data collected through 2014 and year round data collected from 2015 to present. The second gage is the United States Geologic Survey (USGS) stream gage site, Vermillion River near Empire, MN (05345000). This site is located on the main branch of the Vermillion River roughly four miles upstream of the confluence with the South Branch. Data collection for this site has been ongoing since 1975.

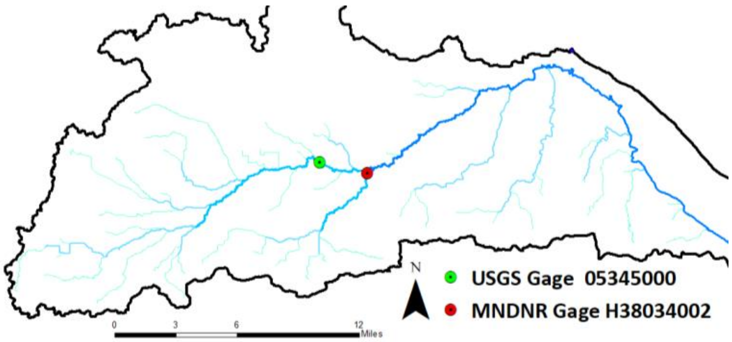

Figure 4. Map of the locations for the stream flow gages in the hydrologic analysis.

While the South Branch Vermillion watershed is being assessed in this report the longer record of the USGS stream gage in an adjacent watershed will be used to assess changes in hydrologic relationships over time. Conditions affecting the two stream flow gages may differ, but similarities in the major drivers of land use and climactic influences are likely to affect hydrology similarly. Annual watershed averaged precipitation records for the greater Vermillion River watershed are used to assess the long term relationship between precipitation and runoff in these watersheds with records going back to the 1920's.

Comparing single mass curves of cumulative annual discharge for the South Branch Vermillion River gage and the USGS gage records identified similar break points between the 2003 and 2004 records as well as around mid-August 2010 (Figure 5). These break points have not been assessed for statistical significance, but have been identified to show the similar responses between the two adjacent watersheds to bring validity to assessing long-term trends on the main stem and relating those to the South Branch Vermillion watershed. These break points may reflect changes in hydrology, data collection/management, or other factors. A similar mass curve was also constructed using data from a baseflow separation analysis on the South Branch Vermillion data set using the University of Purdue's Web-based Hydrograph Analysis Tool (WHAT) (Kim et. al 2005). The baseflow curve showed the same break points as the other mass curves and was not included in Figure 5. These gage comparisons demonstrate the similarities between the adjacent watersheds and supports the case that there is utility in using the longer term USGS gage data set to help understand changing hydrology in the South Branch Vermillion.

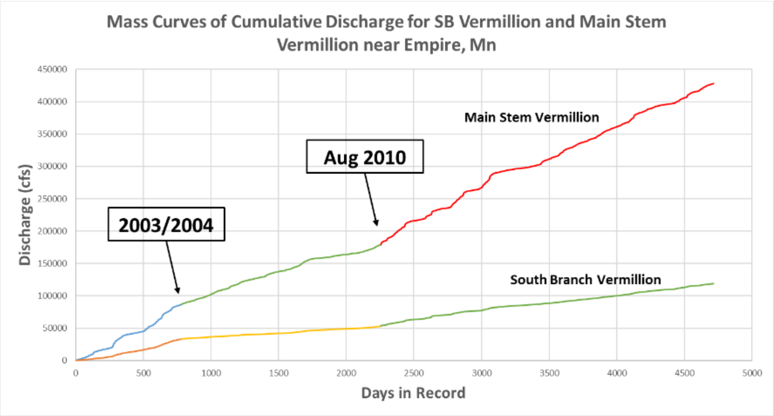

Figure 5. Mass curves of daily South Branch and Main Branch Vermillion River.

A double-mass curve analysis was completed looking at the relationship of precipitation and runoff on the USGS site's 45-year annual average stream flow record and annual gridded watershed averaged precipitation. The curve identified a significant break point at the year 1991 showing an increase in the volume of runoff per volume of precipitation when comparing conditions before and after the break point (Figure 6). Based on the single mass curves from Figure 5, there is an assumption that a break point of nonstationarity also occurred in the South Branch Vermillion Watershed.

Statistical tests on annual instantaneous peak runoff values using the Army Corps of Engineers Nonstationarity Detection Tool (Friedman et. al. 2018) did not show significant breaks in the USGS gage record over the same period indicating that annual peak discharge did not experience the same break in nonstationarity as the entire flow record. Additionally, both runoff and precipitation records in a cumulative departure from average graph identified the shift in 1991 runoff but not in the precipitation record (Figure 7).

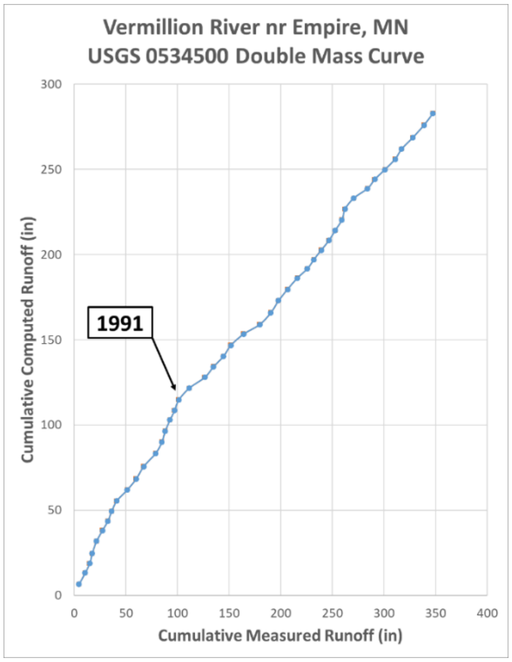

Figure 6. Double Mass Curve.

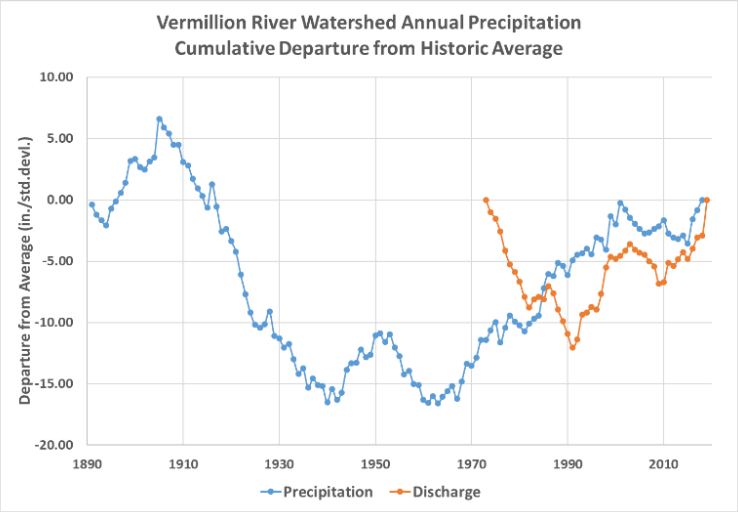

Figure 7. Cumulative departure from average.

A shift in the hydrologic relationship between precipitation and runoff in the Vermillion watershed created two unique time periods, before and after 1991. This shift is not the result of changes in annual precipitation volumes, though timing of precipitation may have been a factor. Though there appears to have been a shift towards more runoff in the watershed per unit of precipitation, which likely holds true for the South Branch Vermillion watershed as well. Lack of long-term continuous discharge data collection in the South Branch limits the certainty of this conclusion, but when comparing recent data in the watershed with the USGS long term gage the two watersheds appear to be reacting similarly. With more runoff occurring in these watersheds it is possible sediment capacity has also increased. Stream channels, which are not connected to an active floodplain (incised) and/or have changes to their boundary condition (lack of deep rooted perennial riparian vegetation), tend to have stream instability issues including an increase in bank erosion.

Stream Classification

General characterizations of the valley and stream are key to understanding the processes influencing a watershed. Following Rosgen (2009), “Broad-level stream classifications are based on patterns, profiles, shapes, and morphological features commonly observed in streams.” Valley classifications are based on the shape, slope, width, and landforms a stream flows through (Figure 8). Broad level classification of the valley and stream channel provides an initial clue into the condition and stability of a stream by identifying stream and valley type mismatches. Certain stream and valley type combinations are more likely than others to be unstable. Stream stability is defined as “the ability of a stream, over time, in the present climate, to transport the sediment and flows produced by its watershed in such a manner that the stream maintains its dimension, pattern and profile without either aggrading nor degrading” (Rosgen 1996).

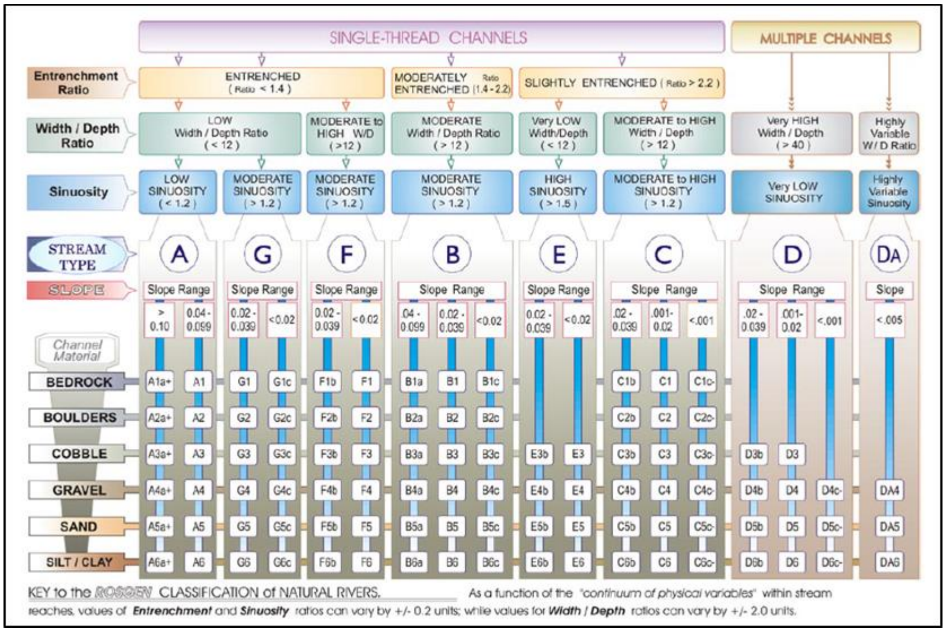

Figure 8. Characteristics of the different stream types and ranges of values (Rosgen 2009).

The geomorphic surveys are chosen using combinations of stream and valley types to represent the watershed. The information collected from these surveys can be extrapolated to like stream and valley types with similar boundary and stability conditions that were not sampled. This approach allows characterization of the watershed without having to conduct intensive surveys throughout. In the South Branch Vermillion watershed, the valley landscape is unconfined glacial outwash and till plains. The stream types most often stable in this valley landscape are B, C, and E. Light Detection and Ranging (LiDAR) derived digital elevation modeling was used to estimate channel and valley dimensions to quickly classify large lengths of stream and valleys with verification by aerial photos and field visits. This desktop method indicated large segments of potentially stable C and E stream types (Figure 9). A few reaches of unstable F stream type were also identified but were limited to crossing impacts and tributaries.

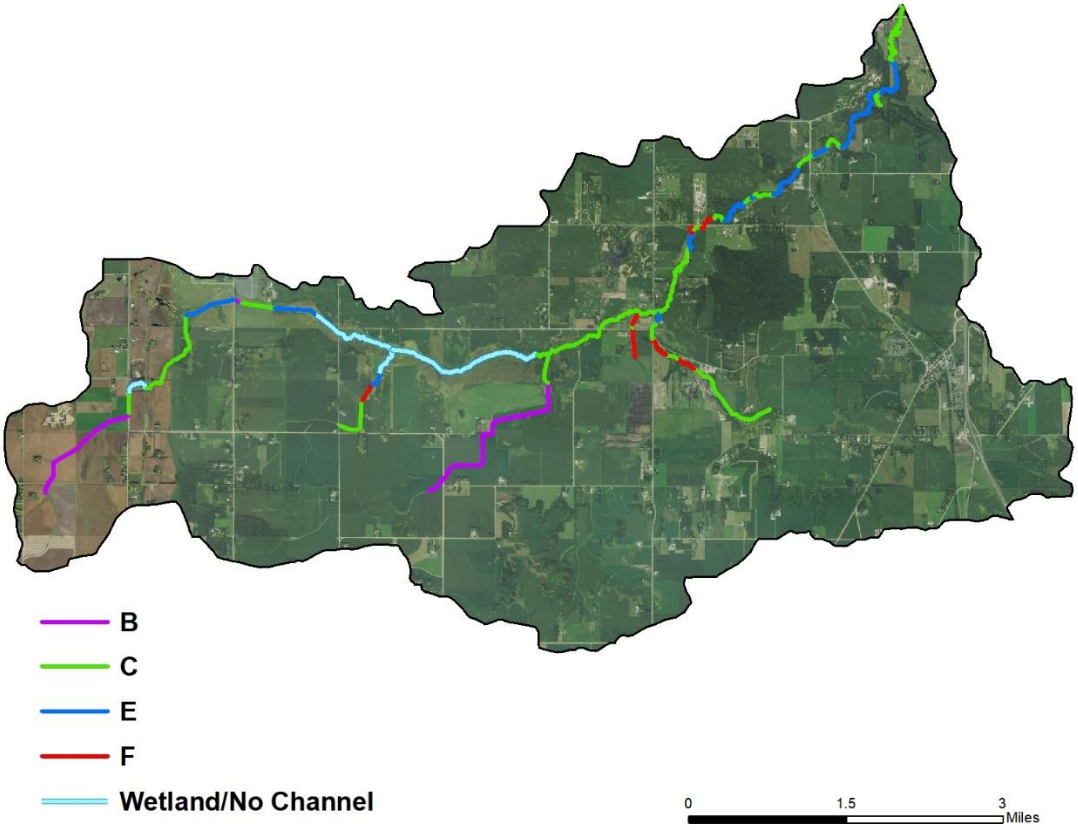

Figure 9. Stream type classifications of South Branch Vermillion.

Typically, ditches are not stable due to the lack of sinuosity and floodplain connectivity, though if left alone can slowly stabilize on their own This can be a long process (years to decades) due to the lack of slope and sediment supply. Soils also play a significant role in determining how unstable a channel can be when ditched. Cohesive soils such as clays can hold the steep bank of a ditch better than sand and silt materials. In the South Branch Vermillion many of the ditched segments were well vegetated and have created enough of a small floodplain (gradually sloped sides) to have less streambank erosion compared to other ditched systems. Although there appears to be low streambank erosion in the ditch segments, the channel bed is usually uniform and provides little habitat diversity for fish and invertebrates, especially when there is high width to depth ratios resulting in shallow depths. Although this analysis did not look at water temperature, it is possible the shallow depths can lead to warming of the water.

Geomorphic Survey Results

Geomorphic Site 19-01

Desktop analysis and dashboard investigations identified the wetland complex near Audrey Avenue through the South Branch Vermillion Aquatic Management Area as the segment to focus field surveys on. However an active restoration, roughly one mile in length, through the management area was under construction and access was limited. The upstream survey (19-01) was chosen instead to take advantage of a historic DNR Fisheries geomorphic survey conducted in 1998, providing the opportunity to document change over time (Figure 10).

The current channel is classified as a C5 stream type with sand and silt substrate (Table 1). The width to depth ratio is very close to E type dimensions, meaning the sediment transport efficiency is greater than the average C stream type, because of the greater depth. The reach has a water surface slope of 0.00135 and a sinuosity of 1.3. Taking into account the condition of the upper banks, lower banks, and channel bottom the Pfankuch stability rating for the reach was rated as fair. Access to a wide floodplain and very low bank erosion positively influenced the score.

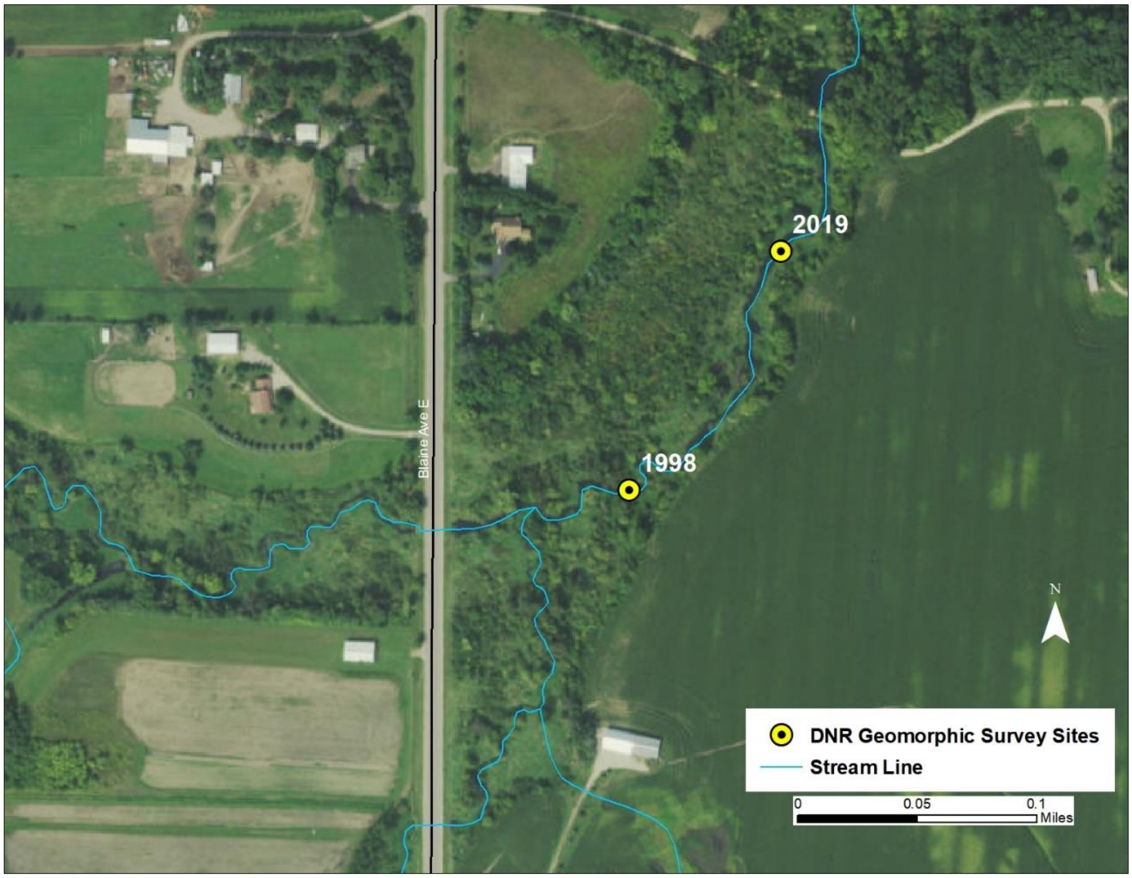

Figure 10. Locations of DNR geomorphic surveys and year completed.

Table 1. Geomorphic data summary for survey 19-01.

Survey Results 19-01			
Stream name	SBV	**Entrenchment Ratio**	16.41
Stream Type	C5	**Water Slope**	0.00135
Valley Type	U-GL-GO	**Riffle D50 (mm)**	Sand
Drainage Area (mi^2)	23	**Bankfull Discharge (cfs)**	67.5
Bankfull Area (ft^2)	47.48	**Bank-Height Ratio**	1.1 (Stable)
Bankfull Width (ft)	24.4	**Sinuosity**	1.3
Mean Riffle Depth (ft)	1.95	**Erosion Estimate**	Minimal
Width/Depth Ratio	12.5	**Pfankuch**	Fair

Lowering of the channel elevation, also known as incision, is a strong indicator of channel instability and accelerated rates of bank erosion. Incision is measured by bank height ratio (BHR), where the lowest bank height is divided by the maximum depth at bankfull (Figure 11). The average bank height ratio of the survey is 1.1, considered not incised. A measured entrenchment ratio of 16.41 shows that at flood flow levels the stream has access to a wide floodplain (Figure 12).

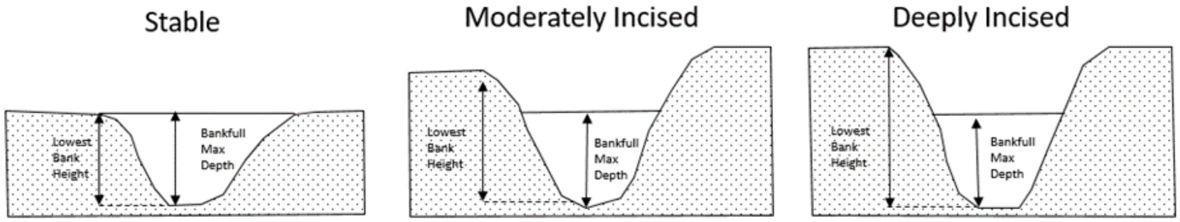

Figure 11. Bank-height ratio measurement and incision rating examples.

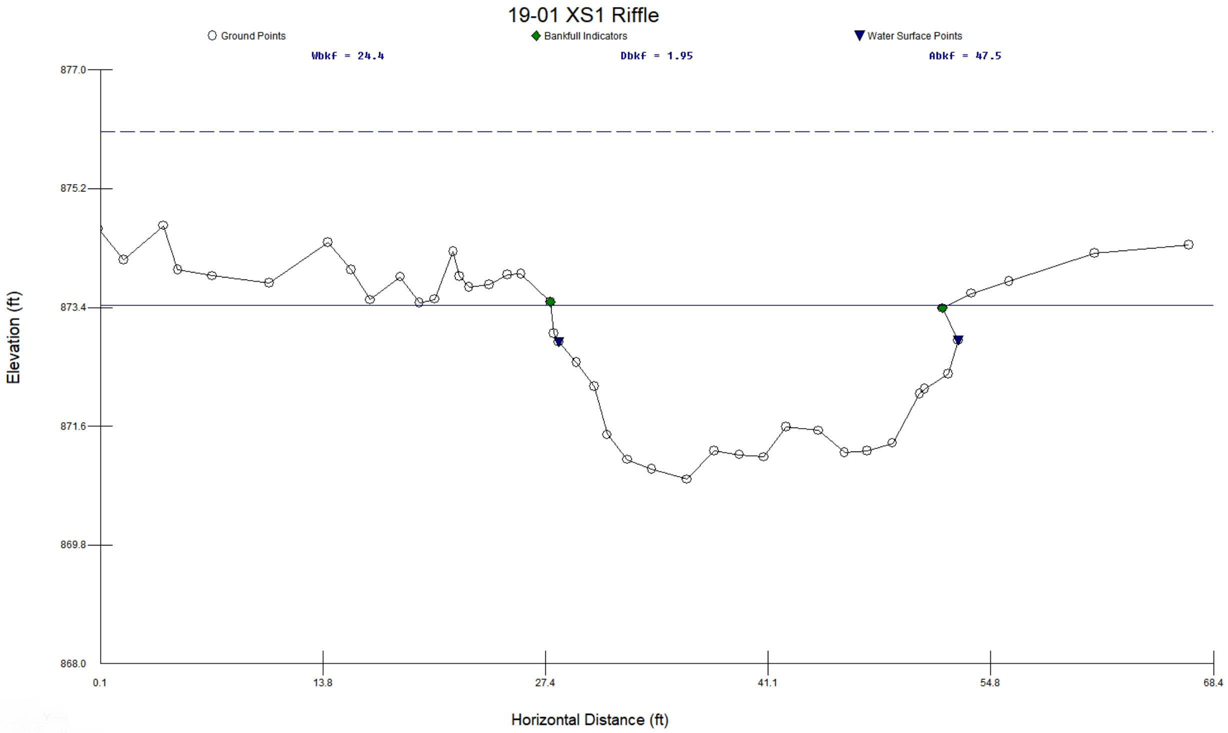

Figure 12. Cross section of riffle, showing bankfull (solid line) and flood-prone elevation (dashed line).

The longitudinal profile is 250 feet long with one representative riffle cross section. The profile shows little differentiation between riffles and pools, a characteristic of E stream types in this region (Figure 13). However the stream did have diverse scour pools associated with vegetation and over-hanging woody material, fairly typical of low width to depth systems in this area.

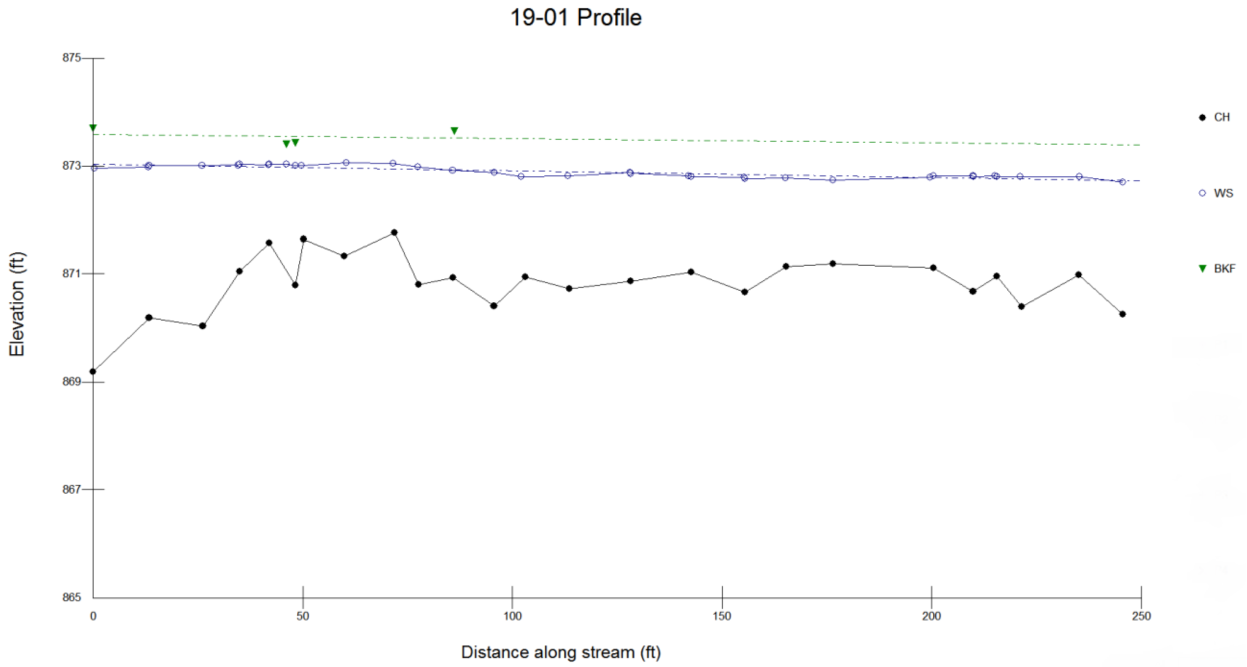

Figure 13. Longitudinal profile of survey 19-01.

No bank erosion was observed in this reach. Low stream bank heights and dense vegetation help to stabilize the surveyed reach (Figure 14)

Figure 14. Photo of stream just upstream of profile of survey 19-01.

Comparison to 1998 survey

Survey 19-01 site was chosen to replicate a survey completed in 1998. However, due to influence of downed trees and a beaver dam, survey 19-01 began roughly 500 feet downstream of the 1998 survey. Since the surveys did not overlap, comparisons can only made through changes in dimension (Table 2).

Table 2. Dimension comparison between 1998 and 2019 19-01 surveys.

	2019	1998
Bankfull Area (ft^2)	47.48	36.43
Bankfull Width (ft)	24.4	20.36
Mean Riffle Depth (ft)	1.95	1.79
Width/Depth Ratio	12.5	11.37
Entrenchment Ratio	16.41	19.65
Stream type	C5	E4/5
Particle D50 (mm)	Silt/Sand	8

Although classified as different stream types, there is not much change in the width to depth ratio. Width-to-depth ratios below 12 are classified as E stream type and above 12 are C stream types. Notable is the change in bankfull area, increasing by more than 11 square feet from 1999. Though because the cross sections were surveyed at different locations, the difference may be due to normal ranges in channel dimensions. The differences could also point to a potential increase of discharge, as noted in the previous hydrology section. The particle D50 for the 1998 riffles averaged 8mm, whereas current particles are silt and sand, indicating an increase in fine sediment deposition.

Geomorphic Site 19-02

The second geomorphic survey was conducted upstream of Darson Avenue/County 81 (Figure 15). The channel is classified as a C5 with predominately sand and silt substrate (Table 3). Again, the width/depth ratio is close to an E stream type, meaning the channel is deeper than an average C channel.

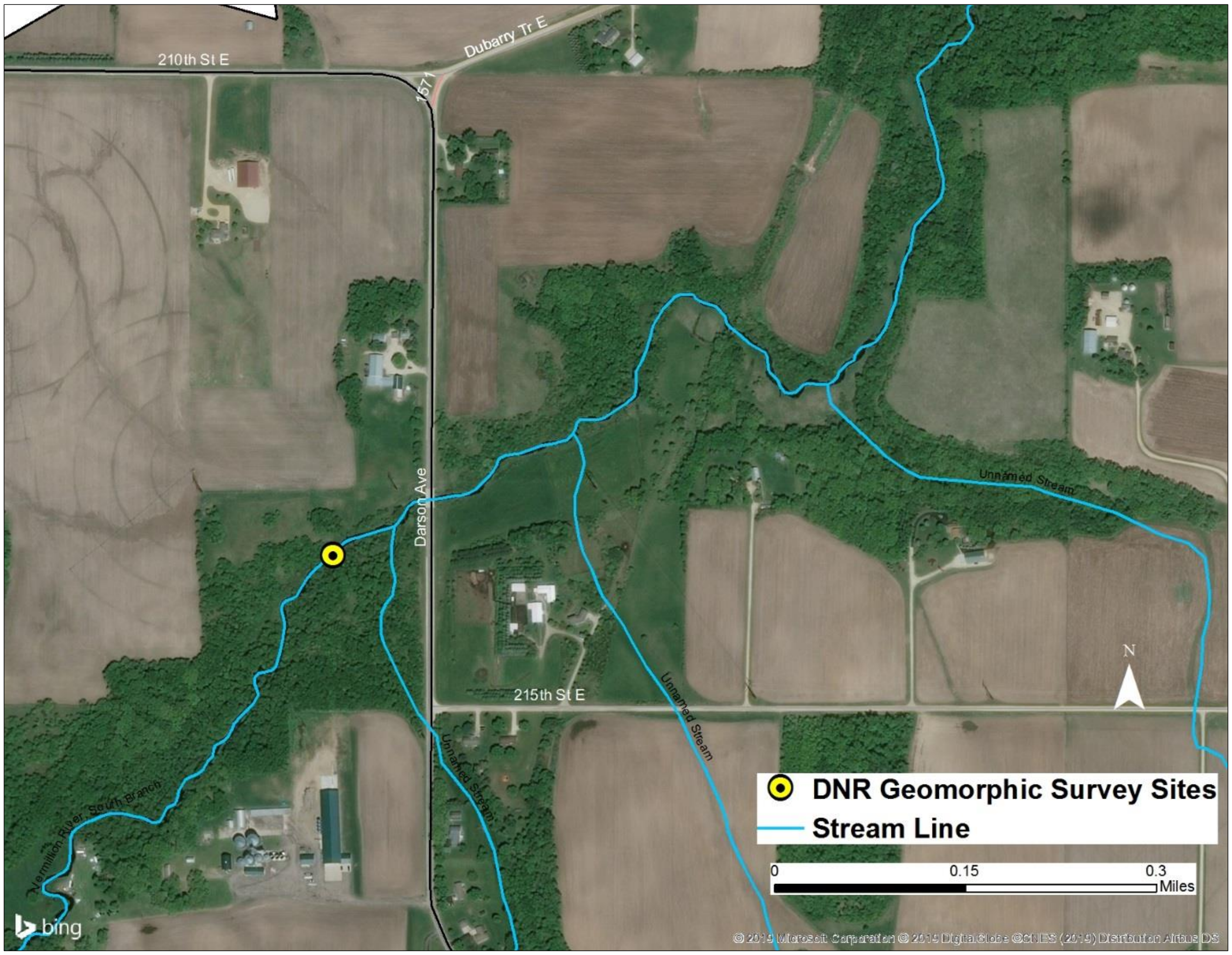

Figure 15. Location of DNR geomorphic survey 19-02.

Table 3. Geomorphic data summary for survey 19-02

Survey Results 19-02			
Stream name	SBV	**Entrenchment Ratio**	5.49
Stream Type	C5	**Water Slope**	0.0005
Valley Type	U-GL-GO	**Riffle D50 (mm)**	Sand
Drainage Area (mi²)	28	**Bankfull Discharge (cfs)**	84.8
Bankfull Area (ft²)	57.02	**Bank-Height Ratio**	1 (stable)
Bankfull Width (ft)	29.13	**Sinuosity**	1.1
Mean Riffle Depth (ft)	1.96	**Erosion Estimate**	Minimal
Width/Depth Ratio	14.86	**Pfankuch**	Good

The average bank-height ratio for the survey is 1.0, considered stable. A measured entrenchment ratio of 5.49 shows the stream is connected to the floodplain during flood flows (Figure 16).

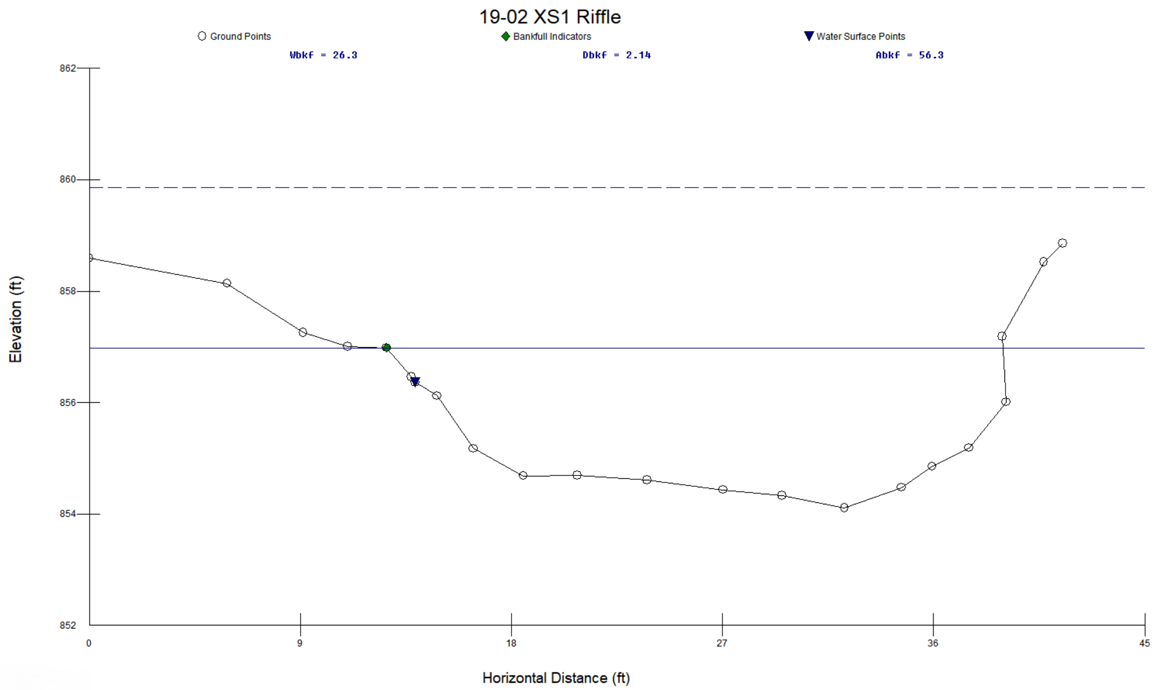

Figure 16. Cross section of riffle, showing bankfull (solid line) and flood-prone elevation (dashed line).

The longitudinal profile is 500 feet long with one representative riffle cross section. The profile shows three riffles and three pools within the surveyed reach (Figure 17). The shallow riffle at approximately 400 feet, is caused by a culvert outlet of unknown beginning. The pools are deep lateral scour pools associated with outside curves, unlike the pools caused by downed woody material in the upstream surveyed reach.

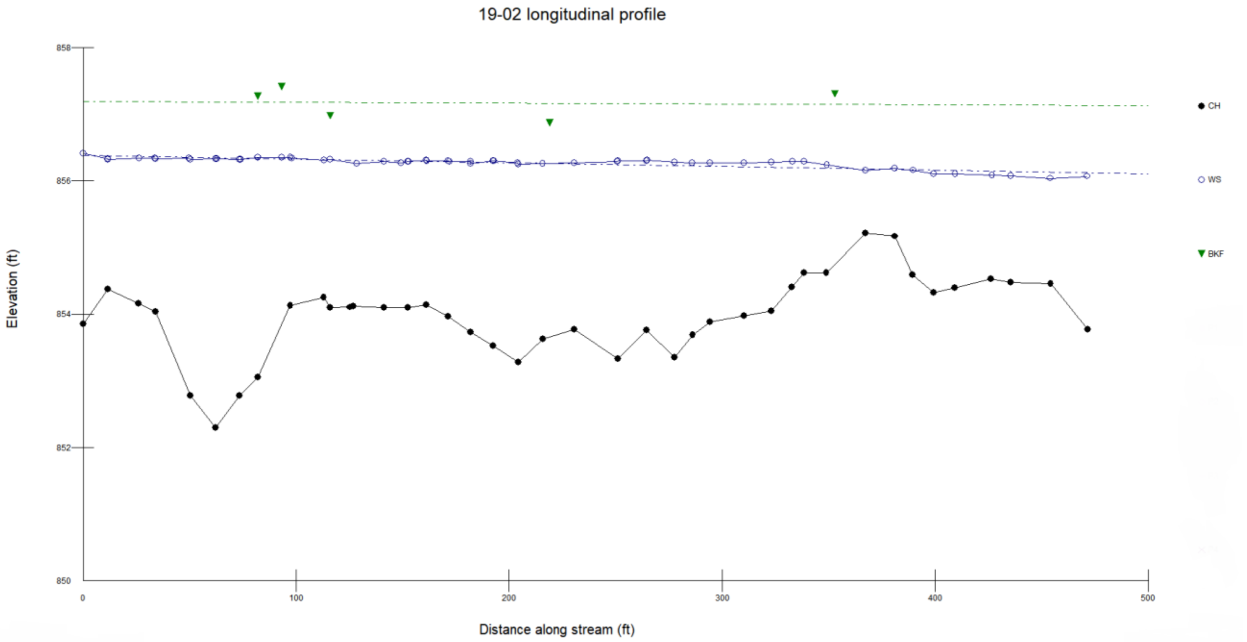

Figure 17. Longitudinal profile of survey 19-02.

No measureable eroding banks were observed in this reach due to low stream banks and dense vegetation stablizing the banks (Figure 17).

Figure 18. Photo of survey reach 19-02, showing dense vegetation along stream channel.

Culvert Inventory

The DNR River Ecology Unit conducted a culvert assessment in this watershed. Two private crossings were identified as undersized on the main branch (Figure 19). Undersized culverts negatively affect channel stability causing water back up and reducing the channels ability to transport sediment, leading to upstream aggradation. The upstream aggradation flattens channel slope and increases lateral channel migration, resulting in streambank erosion. Downstream undersized culverts are scour pools, caused by an increase in exit velocity. One crossing (Crossing 1) has a total width of 14 feet and the other crossing (Crossing 2, was scheduled to be replaced in 2018, but it is unknown if it was replaced) has a width of 5 feet (Figure 18). Survey 19-01 was immediately upstream of these crossings and identified a bankfull width of roughly 25 feet. It is important to match bankfull width and area when designing culverts, discussed in further detail in Conclusions and Recommendations section.

Figure 19. Location of undersized private crossings along main branch of South Branch Vermillion River.

Conclusions and Recommendations

The two geomorphic sites surveyed captured the conditions of the river downstream of the wetland complex (between Biscayne Avenue and Audrey Avenue). As predicted by stream typing, the channel in the surveyed reaches alternates between E and C stream types, allowing for the conditions found at these sites to be applied throughout the lower section of South Branch Vermillion. These sites exhibit very low streambank erosion, due to low slope (lower stream power) and dense riparian vegetation. The stream is connected to the floodplain during flood flows allowing sediment to spread out and maintain stream stability. Pools created by stream bends and scouring around downed woody material provide good habitat. Woody material does not always have a positive impact on streams however. Seen at some crossings in South Branch Vermillion, where downed material fills most of the stream cross sectional area, causes widening and sediment aggradation. Sand and silt in the riffles may be reducing the quality and quantity of spawning habitat. Overall, channel stability in the lower river section is in good to fair condition.

This report provides a geomorphic summary of the South Branch Vermillion watershed to address the aquatic life impairments (both fish/invertebrates) and inform the cause of the impairments. Although there are items of concern, channel stability does not appear to be the primary driver of impairment. To address the concerns, consider protection of the watershed by addressing stream crossings and locations of surface erosion.

Crossing Improvement

To reduce the negative impacts of previously identified crossings, they should be altered to match the pattern, shape, and profile of the adjacent upstream section of stream documented in Survey 19-01. According to the Minnesota Department of Transportation Report (MNDOT 2019), when designing culverts;

1. *Design the culvert slope to match stream channel slope*
2. *Place the culvert to best match stream alignment*
3. *Design the culvert opening to bankfull channel width or slightly greater*
4. *Provide culvert flow depth comparable to channel flow depth for aquatic organism passage (not over-wide and too shallow)*
5. *Provide a continuous sediment bed with roughness similar to the channel*
6. *Maintain continuity of sediment transport and debris passage, similar to adjoining reaches*
7. *Design for safety to the general public, longevity, and resilience*

In addition to the MNDOT recommendations, the (DNR 2014) provides best practices for design of structures impacting Public Waters. In addition, it is also important to match bankfull cross sectional area for the primary culvert. A design should also consider additional culverts to allow floodplain continuity through the road prism. Above and below the actual culvert or span bridge, grade control measures are beneficial in reducing the risk of head cuts, as well as protecting the infrastructure of the culvert.

Surface Erosion Reduction

Although soil erosion susceptibility is low, there are areas of possible surface erosion that can be improved. Rill erosion, caused by concentrated water running through fields, is the most common form of surface erosion in the watershed. The erosion directly enters a drainage system, where the sediment could then be transported downstream. An aerial photo review identified signatures of surface erosion at locations within the watershed (Figure 19).

Figure 20. Example of rill erosion occurring on agricultural field.

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