Geomorphic Monitoring Plan for the Fargo-Moorhead Metropolitan Area Flood Risk Management Project

Attachment B of the Draft Adaptive Management and Mitigation Plan

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1 GEOMORPHIC MONITORING PLAN OVERVIEW

The Fargo-Moorhead Metropolitan Area Flood Risk Management Project (FMM Project) will directly alter the hydrology of the Red River and tributaries in the FMM Project vicinity by partially diverting high flows. This change in hydrology has the potential to affect the geomorphic characteristics of the streams in the vicinity of the FMM Project. Therefore, this Geomorphic Monitoring Plan (GMP) was developed to monitor the geomorphic characteristics over time to allow for a data-driven evaluation of any changes in the FMM Project vicinity and, if detrimental geomorphic impacts relative to the pre-project dynamics of the system and the reference reaches occur and are attributable to the FMM Project, to implement beneficial corrective actions.

This GMP was developed collaboratively by experts representing local, state, and federal organizations referred to herein as the Geomorphic Monitoring Team (GMT). The GMP will follow the adaptive management framework as outlined in the FMM Project's Adaptive Management and Monitoring Plan (AMMP), which was developed and will be managed by the Adaptive Management Team (AMT). The scope of this GMP is reflective of the complexity and uncertainty associated with sediment and hydrologic channel interactions in a large system with many driving variables that are not completely understood. The nature of FMM Project operation (which may not occur for years or may occur multiple years in a row), and the fact that impacts in river systems (e.g., to channels, riparia, and biota) can occur abruptly are examples of the stochasticity inherent in the system which make monitoring essential in the absence of validated predictability.

For the purposes of this GMP, pre-FMM Project is defined as the time period prior to and during construction activities. Post-FMM Project is defined as the time period following construction completion of all the FMM Project features (currently anticipated to begin in 2027).

The US Army Corps of Engineers (USACE) is responsible for ensuring adherence to and execution of the GMP until 24 October 2024 with the non-Federal sponsors (Metro Flood Diversion Authority, City of Fargo, North Dakota, and City of Moorhead, Minnesota) responsible for this after this date.

The GMP shall govern if the AMMP and GMP language is in conflict, unless otherwise agreed to by the AMT.

2 GEOMORPHIC MONITORING PLAN GOALS

Monitoring how the geomorphic characteristics of each river reach in the FMM Project vicinity change through time provides necessary empirical data for assessment of the FMM Project's impacts. The first goal of the GMP is to understand what the natural and adaptive range of geomorphic changes is for each river reach and to recognize and measure changes over time. Pre-FMM Project surveys and other supporting data allow for the establishment of these baseline ranges.

The second goal of the GMP is identifying measured geomorphic change triggers that, if exceeded, would be considered to be outside the natural and adaptive ranges. The trigger exceedance cause may or may not be attributable to the FMM Project. Identifying contributing factors other than those due to the FMM Project may require obtaining additional data beyond the data specified in this GMP, such as land use records, drainage change information, and precipitation and runoff data. Evaluating the contributing factors against FMM Project influences may also require modifications to the GMP and its triggers over time based on interpretation of additional gathered data. In the event that trigger exceedance is attributable to the FMM Project and if the changes are deemed to be detrimental, this GMP guides the process for development of corrective actions.

The third goal of this GMP is to outline a framework to maintain clear and effective communication between the non-Federal sponsors, other AMMP work groups, regulatory agencies, and stakeholders/ affected parties for sharing information specific to the geomorphic aspects of adaptive management, monitoring, and corrective action taking.

3 PRE- AND POST-FMM PROJECT CONDITIONS

3.1 Pre-FMM Project Conditions

USACE has contracted with WEST Consultants, Inc. (WEST) to conduct three separate pre-FMM Project geomorphic assessments in the vicinity of the FMM Project. The first assessment was completed in 2012 using survey and field data collected in 2010 and 2011. The second assessment was completed in 2019 using survey and field data collected in 2018. Survey and field data for the third assessment was collected in 2020, with bankfull flow hydraulic models (containing bankfull top widths and bankfull flow depths) and bank line locations delineated using aerial imagery provided to USACE on 15 June 2021 for use in establishing natural ranges of variability. The full set of results and report from this third assessment were provided in October 2021.

WEST presented a global overview of the current river system condition in Section 10.6 of the 2012 report as follows:

> "Results of the geomorphic assessment indicate that the involved study reaches are not prone to significant change in morphology over short or even moderate periods of time. Channel migration rates are on the order of a few inches per year. The erosion resistant nature of the cohesive glacial lake bed soils and the very flat gradient of the channels prevent significant changes in channel cross section geometry and results in very low rates of lateral migration. Further, the sediment supply from upstream and the surrounding landscape is generally composed of silt-and clay sized material with only minor amounts of sand-sized material. The study streams appear to have sufficient capacity to transport nearly all of the sediment supplied to them in suspension as wash load…"

Additional GMT observations of pre-FMM Project conditions in the for specific areas in the vicinity of the FMM Project features are noted in the following sections.

3.1.1 Staging Area

The Red River in the proposed FMM Project staging area is generally the starting point of taller stream banks compared to the stream banks within the proposed benefitted area. These taller stream banks are more susceptible to rotational failures due to their height and when fail contribute more sediment to the channel and result in larger changes to the riparian area. Structures crossing the Red River, such as the Cass County Highway 18 bridge, tend to induce bank failure near the structures due to concentrated flows and higher velocities during flood events. Additionally, a Red River meander cutoff appears imminent near Oxbow, ND, which will drive a geomorphic response due to the riverine slope increase.

The Wild Rice River exhibits a number of major rotational failures throughout the proposed FMM Project staging area. These failures contribute large amounts of sediment and cause changes to the riparian areas, including the collapse of large trees into the Wild Rice River channel. Some reaches of the Wild Rice River become unnavigable by boat during normal flow conditions due to the abundance and concentration of woody debris.

3.1.2 Benefitted Area

The area proposed to benefit from the FMM Project (i.e., north of the dam and east of the diversion channel) generally consists of shorter bank heights and more abundant vegetation than within the proposed staging area. These two factors have resulted in less overall bank slumping and rotational failures within the proposed benefitted area.

3.1.3 Tributaries

Long stretches of both the Rush River and Lower Rush River have been channelized to increase flow capacity over the past few decades. These anthropogenic changes have resulted in geomorphic characteristics that deviate significantly from streams considered to be fully functioning.

In 2018, the Buffalo-Red River Watershed District began a large stream restoration effort on Wolverton Creek. As of 2021, Wolverton Creek from the upstream extent of the geomorphic monitoring area downstream to 28th Street South has been restored. Restoration has not occurred between 28th Street South and Wolverton Creek's confluence with the Red River.

The Maple River and Buffalo River are both generally considered to be stable streams with little lateral movement over the pre-Project period. Some bank collapses were observed within the Maple River reaches but these did not appear to influence the stream stability or to be the result of widespread stream instability.

The Sheyenne River is similar to the Wild Rice River, in that its tall banks are susceptible to rotational failure and collapse, impacting the riparian area. Landowner concerns with bank collapse and channel movement have been noteworthy enough to be reported on by local news organizations (https://www.inforum.com/news/science-and-nature/1356423-Flooding-effects-Homeowners-along-Sheyenne-River-in-West-Fargo-watching-yards-trees-wash-away). Normal to low flows in the Sheyenne River have also been artificially increased by pumping of Devil's Lake flows. According to a 2020 USACE white paper on the subject, the 50 percent annual exceedance flow has increased from 330 cfs to 560 cfs for the portion of the Sheyenne River above the Sheyenne River Diversion near Horace, ND for the period of time that the Devil's Lake pumping has occurred. The increase of low to normal flows may have an impact on the Sheyenne River geomorphic characteristics due to channel banks being saturated at higher levels and for longer periods of time.

3.2 Possible Post-FMM Project Conditions

The 2012 WEST report presented a global overview of post-FMM Project conditions predictions as follows:

> "Bank stability and riparian vegetation density are expected to slightly increase in the reaches that are protected from high flows by the proposed diversion alignment. Conversely, bank stability and riparian vegetation density are expected to slightly decrease in the staging areas upstream of the diversion alignment as a result of more frequent overbank inundation and sedimentation."

The 2019 WEST report echoed a similar tone, with the following language:

> "Because [project operations] are expected to occur on an infrequent basis, they are not expected to result in significant changes in the channel morphology over the long-term."

While the WEST reports do not predict notable changes globally in the FMM Project vicinity, the reports do state it is possible that localized impacts may occur. Potential types and locations of impacts, including some not listed in the WEST reports, are outlined below.

3.2.1 Local Bed Aggradation

Increased bed aggradation may occur downstream of the Maple River and Sheyenne River aqueduct structures, with it more likely to occur downstream of the Sheyenne River aqueduct due to the prevalence of sand-sized material transported by the Sheyenne River (compared to clay- and silt-sized material transported by the Maple River). Bed aggradation may occur as water from the top of the water column (which typically has a lower sediment concentration) is diverted into the Diversion Channel at the aqueduct structures while water from the bottom of the water column (containing proportionally more sediment) continues across each aqueduct and into the natural river channel downstream of each aqueduct. The ability of the rivers to transport sediment will be reduced, but the proportion of sediment will not be proportionally reduced, indicating a potential for sediment deposition.

Increased bed aggradation may also occur in the vicinity of the Red River Structure and Wild Rice River Structure for the periods of time the structures are not operating, due to the increased cross-sectional area of the engineered channels and structure width, which potentially will result in lower velocities and thus, sediment deposition. It is also possible that during operation of these structure that the high flow velocities through the Red River Structure and Wild Rice River Structure will move this deposited material and some native material from the downstream portion of the engineered channel and deposit it further downstream where velocities are closer to those occurring under pre-FMM Project conditions.

3.2.2 Local Overbank Deposition and Bank Slumping

Additional overbank sedimentation on the floodplain near the Wild Rice River and Red River channels upstream of the dam is possible due to the increased flood durations and depths in this area. Any deposited material is likely to deposit on or near the stream banks, which has the potential to decrease bank stability. Less sedimentation is anticipated further away from the rivers and is not anticipated to result in geomorphic concerns.

3.2.3 Local Bed Degradation

Localized bed degradation is possible upstream of the Sheyenne River and Maple River aqueducts due to the possibility that both the aqueducts and the spillways diverting flow into the Diversion Channel are more hydraulically efficient than the existing river channels, thus reducing backwater levels and increasing velocities in the portions of the rivers upstream of the aqueducts. These increased velocities have the potential to erode the streambed, resulting in localized bed degradation.

3.2.4 Local Bank and Bed Erosion

Increased flow velocities immediately downstream of the Red River Structure and Wild Rice River Structure during operation of these structures has the potential to result in small amounts of erosion of the engineered channel and its banks and, for events less frequent than the 1/1,000 annual exceedance probability event (commonly referred to as the 1,000-year event), erosion of the natural channel bed and banks downstream of the structures.

4 GEOMORPHIC MONITORING STATION SELECTION

The GMT has adaptively managed the selection of each Geomorphic Monitoring Station (GMS) over the course of the pre-FMM Project timeframe to ensure both reference reaches that are not anticipated to be impacted by the FMM Project as well as areas that may show post-FMM Project impacts are included. Of the geomorphic monitoring stations shown in Figure 4-1, the following stations are currently defined as reference sites: RU01, LR01, MA03, SH08, WR07, WR08, RE10, and WC04. Depending on the flood size, sites closer to the Southern Embankment (such as WR06 and RE09) may also function as reference sites to assist in evaluating geomorphic changes post-FMM Project. The sampling locations support Rosgen Classification (Rosgen, 2006) and other geomorphic assessment methods with sampling locations in stratified valley types, stream types, and in-stream habitat types represented by crossings/riffles and pools. Post-FMM Project, it may be needed to add additional GMS locations beyond those currently specified in this GMP if geomorphic changes become evident or if continued local concerns are raised to the GMT and AMT.

> ***Terminology Note:*** The Red River exhibits a Crossing and Pool pattern of in-channel features where the crossings represent the zone where the direction of current crosses the channel center point as it flows in a meandering pattern from one bank to the other. Because the term “riffle” is used in classification systems of rivers with coarser bed material that cause “riffles” in the water surface at crossings, the term “crossing” and “riffle” might be used somewhat interchangeably. On the Red River and fine grained tributaries, “crossing” is used as being more descriptive of the actual river feature.

Additional detail on each GMS and its permanent, monumented cross sections is provided in the following sections.

4.1 Geomorphic Monitoring Stations Recommended for Pre- and Post-FMM Project

This section describes each of the 39 GMSs with a total of 244 monitoring cross sections that have been used for pre-FMM Project monitoring and is recommended for use in post-FMM Project monitoring. The location of each pre-FMM Project GMS is shown in Figure 4-1 and a summary of the number of cross sections in each GMS is provided in Table 4-1. Table 4-2 lists information on whether data was collected at each GMS for each WEST assessment; if the GMS is referred to in the WEST report using a different GMS identifier, this is noted as well.

4.2 Red River

- **RE01** - Farthest downstream GMS. Contains seven cross sections. Important monitoring GMS just downstream of all FMM Project features.

- **RE02** - Covers the area immediately downstream of the FMM Project's Diversion Channel outlet. Contains six cross sections (5 existing and 1 new). The previous RE02 was extended across the Diversion Channel outlet into the Red River. Therefore, to improve monitoring following Diversion Channel construction, the GMS was split into two GMSs. The portion of the previous RE02 located upstream of the Diversion Channel outlet is now RE02A (see next bullet item).
- **RE02A** - Was formally part of RE02 and is located upstream of the Diversion Channel outlet. Contains six cross sections (5 existing and 1 new)
- **RE03** - This GMS is located adjacent to Trollwood Park, just downstream of Edgewood Golf Course, and upstream of Broadway. Contains six cross sections.
- **RE04** - Located just downstream of Interstate 94, bounded on the west by Lindenwood Park in Fargo and Gooseberry Mound Park in Moorhead. Contains six cross sections.
- **RE05 -** Located near Briarwood, ND. Contains six cross sections.
- **RE06** - This GMS is located just downstream of the Wild Rice River confluence. Contains six cross sections. It is noted that RE06 was defined in the WEST (2019) assessment to contain both the cross sections for this updated RE06 and the updated RE06A defined below.
- **RE06A** - This GMS is located just upstream of the Wild Rice River confluence. Contains six cross sections. It is noted that the cross sections for this GMS were contained within RE06 in the WEST (2019) assessment.
- **RE07** – Located downstream of the dam and just upstream of 110th Ave S in Fargo. Contains six cross sections.
- **RE08** – Formerly located partially within the footprint of the Red River Structure dam, RE08 is now located entirely upstream of the dam. Contains nine cross sections. The three most upstream cross sections in the previous RE08 were combined with the six cross sections in RE08A to form a new GMS named RE08. RE08A no longer exists.
- **RE09** - GMS is located in upper staging area. Contains six cross sections.
- **RE10** - This is the furthest upstream GMS and is located just downstream of Abercrombie, ND. Contains six cross sections. Not anticipated to be impacted by FMM Project operations and therefore serves as a reference reach.

4.3 Wild Rice River

- **WR01** – Most downstream Wild Rice River GMS upstream of its confluence with the Red River. Contains six cross sections.
- **WR02** - This GMS is located downstream of 100th Ave S. Contains six cross sections.
- **WR03** - Located downstream of the Wild Rice River dam. Contains six cross sections.
- **WR04** - Located within the staging area. Contains six cross sections.
- **WR05** - This GMS is located in the upper retention footprint. Contains six cross sections.
- **WR06** - Upstream of staging area footprint. Contains six cross sections.
- **WR07** - Located upstream of County Road 28. Contains six cross sections. Not anticipated to be impacted by FMM Project operations and therefore serves as a reference reach. The GMT should consider removing this GMS or WR08 from future assessments, as both serve as a reference reach.
- **WR08** - Located upstream of County Road 4. Contains seven cross sections. Not anticipated

to be impacted by FMM Project operations and therefore serves as a reference reach. The GMT should consider removing this GMS or WR07 from future assessments, as both serve as a reference reach.

4.4 Sheyenne River

- **SH01** - Located upstream of the confluence with the Red River, this is the farthest downstream GMS on this river. Contains seven cross sections.
- **SH02** - Located between the Rush River's and Lower Rush River's confluences with the Sheyenne River. Contains six cross sections.
- **SH03** - Located just downstream of the Maple River confluence. Contains six cross sections.
- **SH04** - Located downstream of existing West Fargo Diversion. Contains six cross sections.
- **SH05** - Located in West Fargo upstream of the Main Avenue crossing and downstream of the existing West Fargo Diversion. Contains six cross sections.
- **SH06A** – Located near the 64th Avenue South crossing and downstream of the existing Horace to West Fargo Diversion. Contains six cross sections. Note that this GMS was not included in the WEST (2019) geomorphic assessment, but it was included in the other two WEST (2012 and 2021) assessments. Survey data was collected in this GMS by WEST in 2012 and by USACE in 2019.
- **SH06** - Located close to the USGS sediment monitoring site just downstream of Wall Street in Horace and downstream of the existing Horace to West Fargo Diversion. Contains six cross sections.
- **SH07** - Located just upstream of the FMM Project Diversion Channel and Sheyenne River Aqueduct. Contains eight cross sections.
- **SH08** - Furthest upstream Sheyenne River GMS. Contains six cross sections. Not anticipated to be impacted by FMM Project operations and therefore serves as a reference reach.

4.5 Maple River

- **MA01** - Most downstream Maple River GMS located between the Maple River's confluence with the Sheyenne River and the Maple River Aqueduct. Contains a total of seven cross sections.
- **MA02** - Located just upstream of FMM Project Diversion Channel and Maple River Aqueduct. Contains six cross sections.
- **MA03** - Near Mapleton, this is the furthest upstream GMS on the Maple River. Contains six cross sections. Not anticipated to be impacted by FMM Project operations and therefore serves as a reference reach.

4.6 Lower Rush River

- **LR01** - Located upstream of FMM Project Diversion Channel. Contains six cross sections. LR01 is the only GMS on the Lower Rush River. Not anticipated to be impacted by FMM Project operations and therefore serves as a reference reach.

4.7 Rush River

- **RU01** - Located upstream of FMM Project Diversion Channel. Contains seven cross sections. RU01 is the only GMS on the Rush River. Not anticipated to be impacted by FMM Project operations and therefore serves as a reference reach.

4.8 Wolverton Creek

- **WC01** – Downstream-most GMS located between 130th Ave S and 3rd St S. GMS was not surveyed as part of the WEST effort in 2019 but was surveyed as part of the WEST efforts in 2012 and 2021. Contains six cross sections.

- **WC02** - Located downstream of Highway 75 and upstream of 130th Ave S. GMS was not surveyed as part of the WEST effort in 2019 but was surveyed as part of the WEST efforts in 2012 and 2021. Contains six cross sections.
- **WC03** – Located just downstream of the FMM Project dam. Contains six cross sections.
- **WC04** –Located upstream of the FMM Project dam. Contains six cross sections. Not anticipated to be impacted by FMM Project operations and therefore serves as a reference reach.

4.9 Buffalo River

- **BU01** - Only GMS located on the Buffalo River located on the western edge of Georgetown, Minnesota, downstream of Mason Street. GMS was not surveyed as part of the WEST effort in 2019 but was surveyed as part of the WEST efforts in 2012 and 2021. Contains six cross sections.

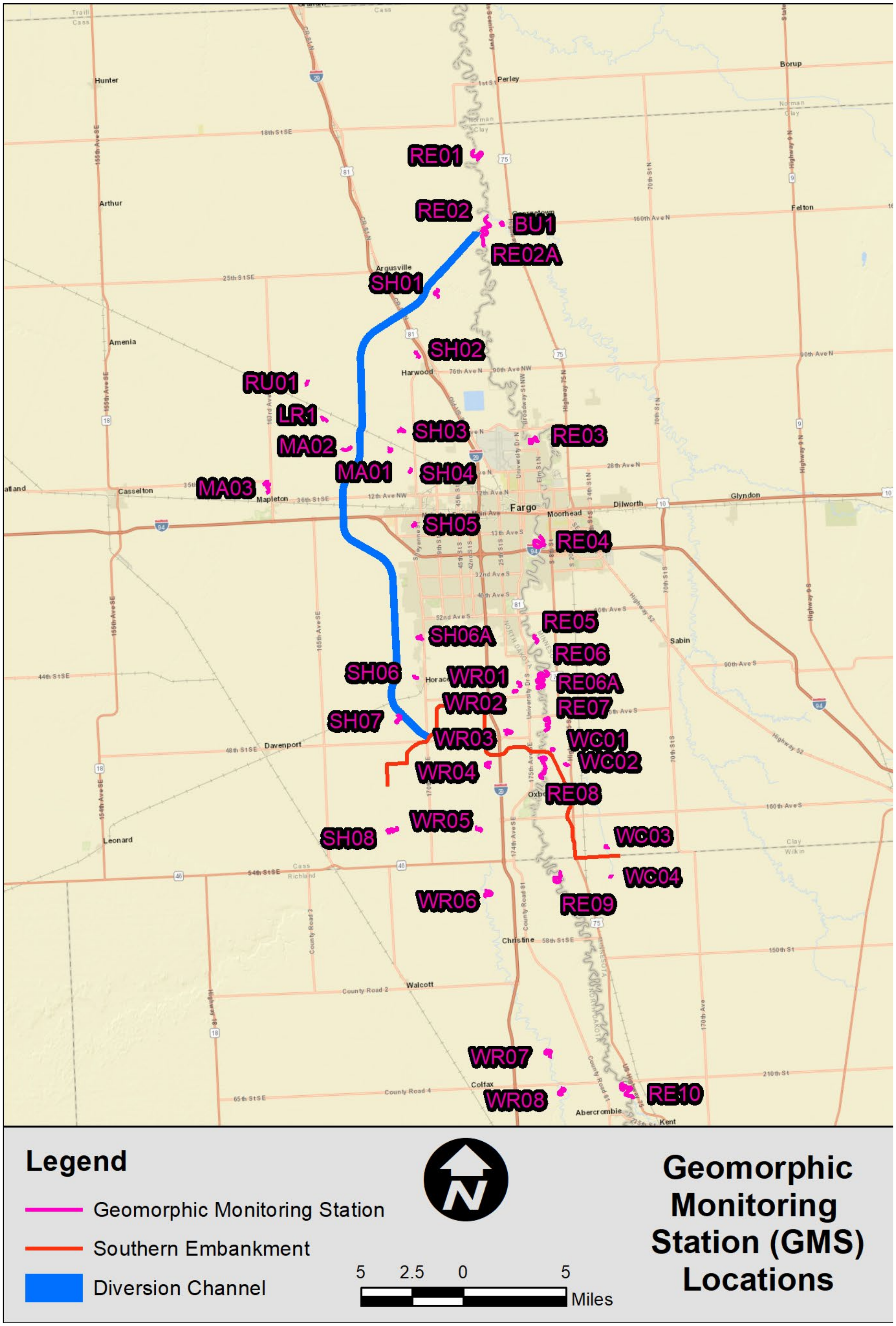


Figure 4-1: FMM Project Geomorphic Monitoring Station Locations

Table 4-1: FMM Project Geomorphic Monitoring Station Cross Section Count

#	GMS	Cross Sections
1	RE01	7
2	RE02	6
3	RE02A	6
4	RE03	6
5	RE04	6
6	RE05	6
7	RE06	6
8	RE06A	6
9	RE07	6
10	RE08	9
11	RE09	6
12	RE10	6
13	WR01	6
14	WR02	6
15	WR03	6
16	WR04	6
17	WR05	6
18	WR06	6
19	WR07	6
20	WR08	7
21	SH01	7
22	SH02	6
23	SH03	6
24	SH04	6
25	SH05	6
26	SH06	6
27	SH06A	6
28	SH07	8
29	SH08	6
30	MA01	7
31	MA02	6
32	MA03	6
33	LR01	6
34	RU01	7
35	WC01	6
36	WC02	6
37	WC03	6
38	WC04	6
39	BU01	6
	TOTAL	**244**

Table 4-2: Geomorphic Monitoring Station Changes throughout Pre-FMM Project Geomorphic Assessments by WEST

GMS	2012 WEST Assessment	2019 WEST Assessment	2021 WEST Assessment	Future Assessments
RE01	Referred to as Red River – 1 – 410.65	Part of assessment	Part of assessment	Part of assessment
RE02	Part of what was referred to as Red River – 2 – 419.14	Part of assessment	Part of assessment	Revised limits and added one cross section
RE02A	Part of what was referred to as Red River – 2 – 419.14	Part of assessment (was part of RE02)	Part of assessment (was part of RE02)	Revised limits and added one cross section
RE03	Referred to as Red River – 3 – 440.57	Part of assessment	Part of assessment	Part of assessment
RE04	Referred to as Red River – 4 – 452.52	Part of assessment	Part of assessment	Part of assessment
RE05	Referred to as Red River – 5 – 463.56	Part of assessment	Part of assessment	Part of assessment
RE06	Not part of assessment	Included both RE06 and RE06A under the heading of RE06 in this assessment	Part of assessment	Part of assessment
RE06A	Referred to as Red River – 6 – 470.23		Part of assessment	Part of assessment
RE07	Not part of assessment	Part of assessment	Part of assessment	Part of assessment
RE08	Not part of assessment	Part of assessment	Part of assessment	Will include both RE08 and RE08A under the heading of RE08
RE08A	Not part of assessment	Not part of assessment	Part of assessment	
RE09	Referred to as Red River – 7 – 492.47	Part of assessment	Part of assessment	Part of assessment
RE10	Referred to as Red River – 8 – 521.18	Part of assessment	Part of assessment	Part of assessment
WR01	Referred to as Wild Rice River – 1 – 3.01	Part of assessment	Part of assessment	Part of assessment
WR02	Referred to as Wild Rice River – 2 – 4.23	Part of assessment	Part of assessment	Part of assessment
WR03	Not part of assessment	Part of assessment	Part of assessment	Part of assessment
WR04	Not part of assessment	Part of assessment	Part of assessment	Part of assessment
WR05	Referred to as Wild Rice River – 3 – 17.52	Part of assessment	Part of assessment	Part of assessment
WR06	Referred to as Wild Rice River – 4 – 22.94	Part of assessment	Part of assessment	Part of assessment
WR07	Referred to as Wild Rice River – 5 – 38.49	Part of assessment	Part of assessment	Part of assessment
WR08	Referred to as Wild Rice River – 6 – 42.36	Part of assessment	Part of assessment	Part of assessment
SH01	Referred to as Sheyenne River – 1 – 4.20	Part of assessment	Part of assessment	Part of assessment

GMS	2012 WEST Assessment	2019 WEST Assessment	2021 WEST Assessment	Future Assessments
SH02	Referred to as Sheyenne River – 2 – 11.56	Part of assessment	Part of assessment	Part of assessment
SH03	Referred to as Sheyenne River – 3 – 18.15	Part of assessment	Part of assessment	Part of assessment
SH04	Referred to as Sheyenne River – 4 – 22.27	Part of assessment	Part of assessment	Part of assessment
SH05	Referred to as Sheyenne River – 5 – 26.47	Part of assessment	Part of assessment	Part of assessment
SH06	Not part of assessment	Part of assessment	Part of assessment	Part of assessment
SH06A	Referred to as Sheyenne River – 6 – 35.82	Not part of assessment; survey data collected by USACE in summer 2019 for use in future assessments	Part of assessment	Part of assessment
SH07	Referred to as Sheyenne River – 7 – 43.27	Part of assessment	Part of assessment	Part of assessment
SH08	Referred to as Sheyenne River – 8 – 55.75	Part of assessment	Part of assessment	Part of assessment
MA01	Referred to as Maple River – 1 – 0.78	Part of assessment	Part of assessment	Part of assessment
MA02	Not part of assessment	Part of assessment	Part of assessment	Part of assessment
MA03	Referred to as Maple River – 2 – 11.39	Part of assessment	Part of assessment	Part of assessment
LR01	Referred to as Lower Rush River – 2 – 6.03	Part of assessment	Part of assessment	Part of assessment
RU01	Referred to as Rush River – 2 – 6.15	Part of assessment	Part of assessment	Part of assessment
WC01	Referred to as Wolverton Creek – 1 – 0.64	Not part of assessment	Part of assessment	Part of assessment
WC02	Referred to as Wolverton Creek – 2 – 2.02	Not part of assessment	Part of assessment	Part of assessment
WC03	Not part of assessment	Not part of assessment	Part of assessment	Part of assessment
WC04	Not part of assessment	Not part of assessment	Part of assessment	Part of assessment
BU01	Referred to as Buffalo River – 1 – 1.19	Not part of assessment	Part of assessment	Part of assessment

4.10 Diversion Channel

This section describes an additional 3 GMSs with a total of 18 monitoring cross sections along the Diversion Channel that are recommended for post-FMM Project monitoring. Monitoring of these GMSs will inform sediment delivery from watercourses intersected by the Diversion Channel and will also inform whether native material from the Diversion Channel is being eroded and potentially delivered to the Red River. All 3 GMSs should include three pool and three riffle cross sections, and a longitudinal profile that follows the thalweg of the meandered low flow channel within the Diversion Channel.

- **DC01** – Downstream-most Diversion Channel GMS. Recommended to be located above confluence with Red River and downstream of Rush River and Highway 29.
- **DC02** - Middle Diversion Channel GMS. Recommended to be located just below Drain 14, downstream of Interstate 94, and upstream of the Maple River aqueduct.
- **DC03** - Upstream-most Diversion Channel GMS. Recommended to span both upstream and downstream of the Sheyenne River aqueduct.

The GMT should also consider adding GMSs immediately downstream of the Sheyenne River aqueduct, immediately downstream of the Maple River aqueduct, upstream of the Rush River inlet to the Diversion Channel, and upstream of the Lower Rush River inlet to the Diversion Channel. These are all areas not currently being monitored but were identified as locations that may experience changes in Section 3.2.

5 GEOMORPHIC MONITORING METHODS

Monitoring for geomorphic changes in the FMM Project vicinity generally follows the Before-After Control-Impact (BACI) (Smith, 2002) accounting method. The BACI sampling framework compares the *before* (pre-FMM Project condition using baseline data) condition to the *after* (post-FMM Project) condition of the area. To account for changes that may occur within the system that are natural changes, the area of impact is compared to another area, which is referred to as a reference site. This is a site that is not expected to be impacted by FMM Project operations but is within close proximity of the FMM Project components and is representative of the reach/site in which changes may be observed due to the FMM Project. To establish baseline conditions, sampling is carried out on a number of occasions before FMM Project operation and a number of occasions following. The sampling design has incorporated BACI methods by recommending sampling areas both inside and outside the potential impact areas. Sampling has occurred three times before FMM Project construction and will occur for a minimum of three times after FMM Project construction as well. This approach allows for comparisons for assessing if an impact occurs.

The following sections describe the monitoring efforts that are recommended for all FMM Project geomorphic assessments. The Scope of Work that outlined the WEST (2021) work effort, developed and approved by the GMT, is included as Appendix A and is the general recommended approach for any future geomorphic monitoring effort.

5.1 Field Data Collection

Field-collected data is a core component of this GMP. Pre-FMM Project data has been collected in 2010/2011, 2018, and 2020 (it is noted that longitudinal profiles are only available for the Red River for 2010/2011). The following sections list specific types of field data that has been and is recommended to continue to be collected as part of each geomorphic assessment.

5.1.1 Cross Sections

Collection of data at cross sections is an important GMP component. Each GMS is comprised of permanent cross sections that allow for replicate data collection to evaluate whether the stream is aggrading, degrading, depositing, or eroding laterally at a specific location. The end of each cross section has a permanent monument that has been installed at or below the existing ground grade to assist in the collection of replicate cross sections. Pre-FMM Project cross section data were collected and are documented in the WEST reports (2012, 2019, and 2021). The WEST reports contain ArcGIS shapefiles and maps noting the location of each cross section. Post-FMM Project cross-sectional surveys shall try to survey the exact locations of the WEST cross sections to allow for appropriate comparisons. The GMT should also leverage any other bathymetric data collected in the FMM Project vicinity, as available. The non-Federal project sponsors have already acquired property easements to allow for geomorphic assessments for a number of the properties covering the GMS locations and are in the process of obtaining the easements for the remaining locations. All easements are anticipated to be obtained by 2022 or 2023.

In addition to collecting cross-sectional overbank and bathymetric survey data at each cross section, the following tasks shall also be conducted:

1. Field-stake points corresponding to top-of-bank elevation (channel bank) and water surface elevation at time of field observation, both along a straight line of sight trajectory from monument end to monument end for each cross section as well as along a "hydraulic modeling" trajectory. Extend geomorphic investigation beyond the top of bank to capture the riparian area and possible overbank deposition, slumping, vegetation surveys, etc. using field stakes indicating needed survey extent.
2. In the event that significantly large geomorphic changes have occurred in the GMS since the previous field investigation, the bankfull elevation shall be identified and staked where appropriate field indicators are present. It is preferred that the bankfull stakes be located at existing cross sections but can also be placed between cross sections if needed and land ownership or easement status allows it. The determination of what is considered "significantly large" geomorphic change will be determined in the future by the GMP and will be incorporated into the scoping of future task orders.
3. Make a qualitative description of riparian vegetation types and how that would impact bank stability.
4. Estimate percentage of banks slumping within each GMS based on field observations.
5. Document any erosion or deposition features and significant sources of sediment.
6. Look for, identify, and document contributing factors (e.g., land use changes, obvious drainage changes, etc.) other than those due to the FMM Project that may be affecting the channel morphology and stability since the most recent geomorphic assessment.
7. Obtain field data needed for Rosgen (2006) Level II (all worksheets) and Level III (only worksheets 3-1, 3-5, 3-6, and 3-10).
8. Continue collecting photos at long-term photo stations for monitoring change at each cross section to add to the electronic photographic record of field investigations. Take photos upstream, downstream, and of both banks; include the entire channel cross-section with a vertical survey rod in the frame. If possible, show a survey team member pointing to the bankfull elevation. If sediment samples are obtained, photographs of sediment samples and

a survey team member collecting the sample shall also be taken. Use a wide-angle lens to show the relative extent of floodplain or confinement on both sides of the channel. These are complimentary to the cross section measurements and provide additional contextual information on the location.

5.1.2 Longitudinal Profiles

Longitudinal profiles collect bed topography data in the down-channel direction and provide additional points to capture changes in the thalweg and channel slope that might otherwise be missed between the monumented cross sections and is a cost effective way of capturing that data. Longitudinal profiles could be sampled with acoustic Doppler current profilers coupled with GPS-grade survey gear covering multiple paths (following the thalweg or in the case of deeper water using a zig-zag pattern or point cloud sampling approach from which the thalweg could be picked out of). It is critical that horizontal and vertical control be established and be the same as for the cross sections and other monitoring efforts.

For the purposes of this GMP, longitudinal profiles are collected from the upstream most cross section to the downstream most cross section for each of the GMSs listed. If additional bathymetric data is collected in the FMM Project vicinity, this data should be leveraged as possible.

5.1.3 Sediment Sampling

Sediment sampling related to the geomorphology of rivers was conducted in the stream bed, bars, banks, and overbanks. Pre-FMM Project stream bed, bar, bank, and overbank samples were collected for each GMS by WEST and are documented in the 2012, 2019, and 2021 reports. For post-FMM Project sampling, it is recommended that stream bed, bar, bank, and overbank samples be collected for any new GMS. Post-FMM Project sediment sampling within established GMSs is not considered necessary unless observations (such as photographic comparisons with pervious sampling efforts) indicate changes in sediment type or size.

5.1.4 Rosgen (2006) Assessments

Rosgen Level II assessments have been conducted for each of the WEST (2012, 2019, and 2021) assessments and shall continue to be conducted. Data shall also be collected for Rosgen Level III worksheets 3-1, 3-5, 3-6, and 3-10 to help track the changes in the system over time.

5.2 Hydrology Assessment

USGS gages provide a long-term record of stage-discharge rating curves. Changes in stage for the same discharge can be used as an indicator of channel aggradation or degradation. As part of post-FMM Project hydrology assessments, it is recommended that the geomorphic assessment team obtain stage-discharge rating curve data from the USGS and update the specific gage analysis for each gage within the FMM study area to analyze gage changes over time working from the WEST (2021) (or subsequent) analysis forward.

5.3 Stability Analysis using Survey Data

Field-collected survey data allows for direct, repeatable comparisons of channel geometry at a specific location as well as along longitudinal profiles over time. As part of any future survey data-based stability analysis, the following tasks are recommended:

- Evaluate changes in surveyed cross section geometry for all historic data reported in WEST (2021) and all subsequent survey data. The data shall be summarized electronically in a spreadsheet listing the station and elevation information (in the Project datum) for each cross section. The data shall also be plotted in a cross-sectional format to show any changes compared to all available historic data.
- Evaluate surveyed longitudinal profile. The data shall be summarized electronically in a spreadsheet listing the station and elevation information (in the Project datum) for each GMS. The data shall also be plotted in a profile format so changes in bed elevation along the profile can be viewed and compared to all available historic data.

5.4 Stability Analysis using Aerial Imagery

Aerial imagery is useful for observing changes and to provide early information highlighting possible changes. It is especially useful for capturing surface changes during and after major flood events that might not be recognizable at the ground level. The primary goal of the aerial imagery analysis in this GMP is to locate areas where obvious lateral shifts in the bank location or vegetation type/density have occurred compared to previous data sets and to flag these areas for further investigation. Pre-FMM Project high-resolution aerial imagery has been collected by the FMM Project's non-Federal sponsors every three years beginning in 2008 and spanning through 2020. Post-FMM Project imagery shall also be collected by the FMM Project's non-Federal sponsors. This imagery collection ideally will occur when water levels in the FMM Project vicinity are within their banks to allow for accurate bank delineation to occur. Aerial imagery shall be collected at the minimum interval specified by the GMT and AMT (see Section 8) as well as after a flood event resulting in FMM Project operation.

As part of post-FMM Project stability analyses using aerial imagery, the following tasks are recommended:

- Delineate bank lines throughout the project area using the protocols established in Section 7.1.4.
- Locate, measure, and document where lateral shifts in the bank line locations have occurred compared to those locations identified in the WEST (2021) report or other subsequent assessments. The WEST (2021) report contains the delineated bank line locations in ArcGIS shapefiles and/or geodatabases.
- Determine sinuosity, channel (meander) migration and erosion rates, and meander amplitude and frequency.
- Evaluate trends in sedimentary features (in-stream sediment bars), changes in large woody debris (LWD), and changes in riparian vegetation type using the aerial imagery.
- Evaluate the degree of incision. If channel is incised, then the influence of contained flow may increase channel erosion.

6 TRIGGERS AND RESPONSES

The Red River and tributaries are dynamic river systems and are expected to show movement of their mobile boundaries. Sites that already show changes in response to existing processes need to be monitored as well as sites that are expected to show change in response to the FMM Project construction and operation. Reference sites outside of the FMM Project impact area will also be monitored to help establish rates of change and natural variability in response to drivers other than the FMM Project. Getting reference and pre-FMM Project data will help establish reference ranges of change rather than singular thresholds for delineating accelerated change outside of the range of norms. A first step for evaluating the system and rates of change is to use pre-FMM Project data collected as part of the WEST (2012, 2019, and 2021) assessments to determine observed types of change and what types and scales of change would trigger a need for action.

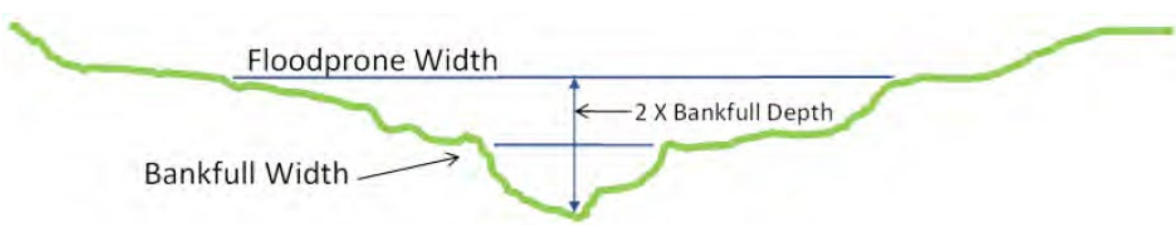
6.1 Triggers

Parameters for defining triggers warranting additional action were discussed with the AMT and GMT during a series of meetings spanning April through June 2021. Three variables were identified for use as triggers during the discussions: Entrenchment Ratio, Bank Height Ratio, and Aerial Image-Derived Bank Line Location. The use of the Rosgen Bank Erosion Hazard Index (BEHI) / Near-Bank Stress (NBS) ratings was considered by the GMT for use as a threshold but was ultimately dismissed because its use may not be entirely applicable to the Red River system and because the aerial image-derived bank line location approach would serve as a similar trigger. Additionally, measured change in bankfull cross-sectional area was also considered for use as a threshold but was ultimately dismissed because this data is a main component in the Entrenchment Ratio and Bank Height Ratio calculations and because this type of approach does not appear to have been used in practice or discussed in literature. However, during the November 2021 and February 2022 GMT workshops, it was decided to further evaluate the addition of a trigger based on changes in cross section geometry. The trigger will be based on specified percentage change of a specific metric such as cross-sectional area.

It is noted that as part of the adaptive management and monitoring component of this GMP, the GMT should consider and provide recommendations to the AMT whether triggers should be added, adjusted, or removed based on additional data, information, and/or observed detrimental impacts that are not covered by the triggers established herein.

6.1.1 Entrenchment Ratio

According to Rosgen (1994), a stream's Entrenchment Ratio is a quantitative expression of the "interrelationship of the stream to its valley and/or landform features" and "distinguishes whether the flat adjacent to the channel is a frequent floodplain, a terrace (abandoned floodplain) or is outside of a flood-prone area." Rosgen (1994) defined the Entrenchment Ratio as the flood-prone width divided by the bankfull width, with the flood-prone width "defined as the width measured at an elevation which is determined at twice the maximum bankfull depth." Additionally, Rosgen (1994) stated that "field observation shows this (flood-prone) elevation to be a frequent flood (50 year return period) or less, rather than a rare flood elevation." Figure 6-1 shows an example of these variables.



$$ER = \frac{Flood\ Prone\ Width}{Bankfull\ Width}$$

Figure 6-1: Entrenchment Ratio Example Graphic

6.1.1.1 *Entrenchment Ratio Action Triggers*

The development of the Entrenchment Ratio action triggers for this AMMP relied on triggers established in literature as well as data collected during the pre-FMM Project geomorphic assessments.

The Minnesota Stream Quantification Tool (MN SQT) Steering Committee developed a scientific support document for the MN SQT, in which Entrenchment Ratio performance standards are provided. According to the scientific support document, an Entrenchment Ratio of greater than 2.2 is considered to indicate a fully functioning stream for the Rosgen C and E stream types, which according to the WEST (2019) report are the Rosgen stream classifications for all of the geomorphic monitoring stations within the FMM Project study area. Therefore, the first step in the Entrenchment Ratio trigger establishment considered whether a stream that previously had an Entrenchment Ratio of greater than 2.2 transitioned to a stream with an Entrenchment Ratio of 2.2 or less.

The second part of the trigger establishment evaluated the Entrenchment Ratios determined using the datasets collected by WEST in 2012, 2019 and 2021, with the methodology that was followed in calculating these Entrenchment Ratios defined in Section 7.1. The observed Entrenchment Ratios for these datasets for each GMS are summarized in Table 6-1. As shown in the table, most Entrenchment Ratios far exceed the value of 2.2, which indicates that most of the streams are considered fully functioning, primarily due to the well-developed floodplains prevalent in the FMM Project vicinity. It is noted that these values differ from values reported in a previous version of the GMP due to the change in calculation method, as recommended by the GMT.

Table 6-1: Observed Entrenchment Ratios by GMS

GMS	Entrenchment Ratio	GMS	Entrenchment Ratio	GMS	Entrenchment Ratio
BU01[1/]	2.8 – 2.9	RE07[2/]	9.2 – 9.3	SH08	10.8 – 11.9
LR01	7.4 – 7.6	RE08[2/]	7.0 – 7.3	WC01[1/]	2.0 – 2.2
MA01	8.4 – 9.0	RE09	8.8 – 9.1	WC02[1/]	4.4 – 5.0
MA02[2/]	13.0 – 13.3	RE10	8.3 – 9.3	WC03[1,2/]	3.0
MA03	11.3 – 12.1	RU01	16.9 – 18.5	WC04[1,2/]	5.2
RE01	3.9 – 4.1	SH01	7.3 – 7.5	WR01	3.8 – 4.0
RE02[2/]	3.3	SH02	8.0 – 8.3	WR02	6.0 – 6.2
RE02A	4.2	SH03	7.2 – 7.4	WR03[2/]	5.6
RE03	7.9 – 8.5	SH04	10.7 – 11.6	WR04[2/]	3.6 – 3.7
RE04	7.6 – 7.9	SH05	12.8 – 13.5	WR05	2.7 – 2.9
RE05	8.1 – 8.2	SH06A[1/]	10.6 – 11.7	WR06	3.2 – 3.7
RE06[2/]	10.2	SH06[2/]	10.0 – 11.0	WR07	8.2 – 8.5
RE06A	11.2 – 11.7	SH07	9.9 – 10.8	WR08	5.3 – 5.6

[1/] GMS not evaluated in WEST (2019)

[2/] GMS not evaluated in WEST (2012)

In defining an appropriate trigger based on the observed Entrenchment Ratios, it was deemed appropriate and consistent with the Rosgen (1994) paper to allow the trigger to be 0.2 Entrenchment Ratio units less than the minimum observed Entrenchment Ratio value. Therefore, this second step in the Entrenchment Ratio trigger establishment considered the lowest observed Entrenchment Ratio for each stream, then subtracted 0.2 off that value for each stream.

The final trigger establishment was to set the trigger for each stream at the lesser of either 2.2 (based on the MN SQT) or the lowest observed Entrenchment Ratio minus 0.2, with the trigger values provided in Table 6-2.

Table 6-2: Entrenchment Ratio Action Triggers by GMS

GMS	Action Trigger	GMS	Action Trigger	GMS	Action Trigger
BU01	<2.3	RE07	<2.3	SH08	<2.3
LR01	<2.3	RE08	<2.3	WC01	<1.8
MA01	<2.3	RE09	<2.3	WC02	<2.3
MA02	<2.3	RE10	<2.3	WC03	<2.3
MA03	<2.3	RU01	<2.3	WC04	<2.3
RE01	<2.3	SH01	<2.3	WR01	<2.3
RE02	<2.3	SH02	<2.3	WR02	<2.3
RE02A	<2.3	SH03	<2.3	WR03	<2.3
RE03	<2.3	SH04	<2.3	WR04	<2.3
RE04	<2.3	SH05	<2.3	WR05	<2.3
RE05	<2.3	SH06A	<2.3	WR06	<2.3
RE06	<2.3	SH06	<2.3	WR07	<2.3
RE06A	<2.3	SH07	<2.3	WR08	<2.3

It is noted that these Entrenchment Ratio action triggers will be re-evaluated by the AMT and GMT if any additional pre-FMM Project geomorphic assessments are completed (which would only happen if a flood occurred in the pre-FMM Project timeframe). The methodology that shall be used to calculate Entrenchment Ratios using any additional pre-FMM Project datasets for the purposes of supplementing and/or adjusting the action triggers is outlined in Section 7.1.

In the event an Entrenchment Ratio trigger is exceeded, the GMT and AMT shall consider whether the reference reaches have also shown changes in the Entrenchment Ratio when working to establish whether the Entrenchment Ratio trigger exceedance is attributable to the FMM Project construction.

It is also noted that Wolverton Creek sites WC03 and WC04 were part of a large stream restoration project completed by the Buffalo-Red River Watershed District between 2018 and 2020. The data collected as part of the 2021 effort was collected after the restoration project was completed in these portions of Wolverton Creek. The GMT and AMT should take this into consideration when evaluating any Entrenchment Ratio triggers on Wolverton Creek.

6.1.1.2 Entrenchment Ratio Investigation Triggers

For most of the GMSs, a considerable amount of geomorphic change would have to occur for the Entrenchment Ratio to change from its current value to that of the Action Trigger values listed in Table 6-2. Therefore, Investigation Triggers are established for each GMS to help detect significant changes to channel morphology that would otherwise not prompt any action on the part of the GMT and AMT. The Investigation Trigger is based on a percent difference in the Entrenchment Ratio from its current value. The selected percent difference varies by GMS based on maximum observed changes between the three previous WEST (2012, 2019, and 2022) field investigations rounded up to the nearest 5%. The Investigation Trigger values provided in Table 6-3 are intended to help preclude initiating an investigation based on the observed natural variability while at the same time not allow for potential notable geomorphic changes from going undetected.

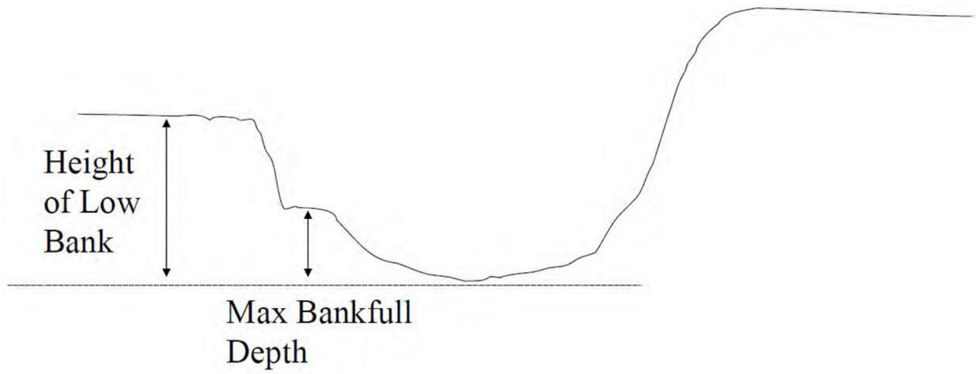
Table 6-3: Entrenchment Ratio Percent Difference and Investigation Trigger Values by GMS

GMS	Percent Difference	Trigger	GMS	Percent Difference	Trigger	GMS	Percent Difference	Trigger
BU01	5	<2.7	RE07	5	<8.7	SH08	10	<10.6
LR01	5	<7.2	RE08	5	<6.7	WC01	10	<1.8
MA01	10	<8.1	RE09	5	<8.5	WC02	15	<4.3
MA02	5	<12.6	RE10	15	<7.1	WC03	5	<4.6
MA03	10	<10.9	RU01	10	<16.3	WC04	5	<5.3
RE01	10	<3.5	SH01	5	<7.1	WR01	10	<3.6
RE02	5	<3.1	SH02	5	<7.8	WR02	5	<5.9
RE02A	5	<4.0	SH03	5	<6.8	WR03	5	<5.3
RE03	10	<7.2	SH04	10	<9.6	WR04	5	<3.4
RE04	5	<7.5	SH05	5	<12.2	WR05	5	<2.6
RE05	5	<7.7	SH06A	15	<9.0	WR06	15	<2.7
RE06	5	<9.7	SH06	10	<9.9	WR07	5	<7.8
RE06A	5	<10.9	SH07	10	<8.9	WR08	10	<4.8

As previously noted, Wolverton Creek sites WC03 and WC04 were part of a large stream restoration project completed by the Buffalo-Red River Watershed District between 2018 and 2020. The data collected as part of the 2021 effort was collected after the restoration project was completed in these portions of Wolverton Creek, thus there is no previous calculation of Entrenchment Ratio from which to evaluate natural variability. Therefore, a value of 5% is suggested as an initial conservative trigger. The GMT and AMT will consider revising this value based on future investigations.

6.1.2 Bank Height Ratio

According to the MN SQT, a stream's Bank Height Ratio "is a measure of channel incision and indicates whether a stream is or is not connected to an active floodplain or bankfull bench." Rosgen (1996) defined the Bank Height Ratio as "the depth from the top of the low bank to the thalweg divided by the depth from the bankfull elevation to the thalweg." Figure 6-2 shows an example of these variables.



$$BHR = \frac{Low\ Bank\ Height}{Dmax}$$

Figure 6-2: Bank Height Ratio Example Graphic

6.1.2.1 Bank Height Ratio Action Triggers

Similar to the Entrenchment Ratio action triggers, the development of the Bank Height Ratio action triggers for this AMMP relied on triggers established in literature as well as data collected during the pre-FMM Project geomorphic assessments.

The Minnesota Stream Quantification Tool (MN SQT) Steering Committee developed a scientific support document for the MN SQT, in which Bank Height Ratio performance standards are provided. According to the scientific support document, a Bank Height Ratio of less than 1.3 is considered to indicate a fully functioning stream. Therefore, the first step in the Bank Height Ratio trigger establishment considered whether a stream that previously had a Bank Height Ratio of less than 1.3 transitioned to a stream with a Bank Height Ratio of 1.3 or greater.

The second part of the trigger establishment evaluated the Bank Height Ratios determined using the datasets collected by WEST in 2012, 2019 and 2021, with the methodology that was followed in calculating these Bank Height Ratios defined in Section 7.1. The observed range of Bank Height Ratios for these datasets for each GMS are summarized in Table 6-4. The Bank Height Ratios generally are in the fully functioning or partially functioning category, which indicates moderate levels of incision on a number of streams in the FMM Project vicinity.

Table 6-4: Observed Range of Bank Height Ratios by GMS

GMS	Bank Height Ratio	GMS	Bank Height Ratio	GMS	Bank Height Ratio
BU01[1/]	1.2 – 1.3	RE07[2/]	1.1	SH08	1.3 – 1.4
LR01	1.2 – 1.2	RE08[2/]	1.2	WC01[1/]	1.7 – 1.9
MA01	1.1 – 1.2	RE09	1.2	WC02[1/]	1.3 – 1.5
MA02[2/]	1.2	RE10	1.1	WC03[1,2/]	1.0
MA03	1.1	RU01	1.3	WC04[1,2/]	1.0
RE01	1.1 – 1.2	SH01	1.3	WR01	1.1
RE02[2/]	1.3	SH02	1.5	WR02	1.1
RE02A	1.2	SH03	1.3 – 1.4	WR03[2/]	1.1
RE03	1.1	SH04	1.4	WR04[2/]	1.1
RE04	1.0	SH05	1.5	WR05	1.1

GMS	Bank Height Ratio	GMS	Bank Height Ratio	GMS	Bank Height Ratio
RE05	1.0	SH06A[1/]	1.2 – 1.3	WR06	1.1 – 1.3
RE06[2/]	1.1	SH06[2/]	1.1 – 1.2	WR07	1.2
RE06A	1.0	SH07	1.2 – 1.3	WR08	1.4 – 1.5

[1/] GMS not evaluated in WEST (2019)

[2/] GMS not evaluated in WEST (2012)

In defining an appropriate trigger based on the observed Bank Height Ratios, it was deemed appropriate to allow the trigger to be 0.1 Bank Height Ratio units less than the minimum observed Bank Height Ratio value due to the fact that the Bank Height Ratio relies on rounding to the nearest 0.1 units. Therefore, this second step in the Bank Height Ratio trigger establishment considered the highest observed Bank Height Ratio for each GMS, then added 0.1 to that value for each GMS.

The final trigger establishment was to set the trigger for each GMS at the greater of either 1.2 (based on the MN SQT) or the highest observed Bank Height Ratio plus 0.1, with the trigger values provided in Table 6-5.

Table 6-5: Bank Height Ratio Action Triggers by GMS

GMS	Action Trigger	GMS	Action Trigger	GMS	Action Trigger
BU01	>1.4	RE07	>1.2	SH08	>1.5
LR01	>1.3	RE08	>1.4	WC01	>2.0
MA01	>1.3	RE09	>1.3	WC02	>1.6
MA02	>1.3	RE10	>1.2	WC03	>1.2
MA03	>1.2	RU01	>1.4	WC04	>1.2
RE01	>1.3	SH01	>1.4	WR01	>1.2
RE02	>1.4	SH02	>1.6	WR02	>1.2
RE02A	>1.3	SH03	>1.5	WR03	>1.2
RE03	>1.2	SH04	>1.5	WR04	>1.2
RE04	>1.2	SH05	>1.6	WR05	>1.2
RE05	>1.2	SH06A	>1.2	WR06	>1.3
RE06	>1.2	SH06	>1.3	WR07	>1.3
RE06A	>1.2	SH07	>1.4	WR08	>1.6

It is noted that these Bank Height Ratio action triggers will be re-evaluated by the AMT and GMT if any additional pre-FMM Project geomorphic assessments are completed (which will only happen if a flood occurs in the pre-FMM Project timeframe). The methodology that shall be used to calculate Bank Height Ratios using any additional pre-FMM Project datasets for the purposes of supplementing and/or adjusting the action triggers is outlined in Section 7.1.

In the event a Bank Height Ratio trigger is exceeded, the GMT and AMT shall consider whether the reference reaches have also shown changes in the Bank Height Ratio when working to establish whether the Bank Height Ratio trigger exceedance is attributable to the FMM Project construction.

It is also noted that Wolverton Creek sites WC03 and WC04 were part of a large stream restoration project completed by the Buffalo-Red River Watershed District between 2018 and 2020. The data collected as part of the 2021 effort was collected after the restoration project was completed in these portions of Wolverton Creek. The GMT and AMT should take this into consideration when evaluating any Bank Height Ratio triggers on Wolverton Creek.

6.1.2.2 Bank Height Ratio Investigation Triggers

For some GMSs a considerable amount of geomorphic change would have to occur for the Bank Height Ratio to change from its current value to that of the Action Trigger values listed in Table 6-5. Therefore, Investigation Triggers are established for each GMS to help detect significant changes to channel morphology that would otherwise not prompt any action on the part of the GMT and AMT. The Investigation Trigger is set to the 2021 Bank Height Ratio plus 0.1 for all GMSs. It is noted that the Investigation Triggers for many of the GMSs are the same value as the Action Trigger. However, the Investigation Trigger values provided in Table 6-6 are intended to help reduce the potential for notable geomorphic changes from going undetected at those GMSs that have current Bank Height Ratios of less than 1.1 or where the 2021 value is less than the values determined for 2012 or 2019.

Table 6-6: Bank Height Ratio Investigation Trigger Values by GMS

GMS	Investigation Trigger	GMS	Investigation Trigger	GMS	Investigation Trigger
BU01	>1.4	RE07	>1.2	SH08	>1.5
LR01	>1.2	RE08	>1.4	WC01	>1.8
MA01	>1.3	RE09	>1.3	WC02	>1.4
MA02	>1.3	RE10	>1.2	WC03	>1.1
MA03	>1.2	RU01	>1.4	WC04	>1.1
RE01	>1.3	SH01	>1.4	WR01	>1.2
RE02	>1.4	SH02	>1.6	WR02	>1.2
RE02A	>1.3	SH03	>1.4	WR03	>1.2
RE03	>1.2	SH04	>1.5	WR04	>1.2
RE04	>1.1	SH05	>1.6	WR05	>1.2
RE05	>1.2	SH06A	>1.2	WR06	>1.2
RE06	>1.2	SH06	>1.2	WR07	>1.3
RE06A	>1.1	SH07	>1.4	WR08	>1.6

6.1.3 Bankfull Cross-Sectional Area Investigation Triggers

Following meetings in November 2021 and February 2022, the GMT decided to add an additional phase of investigation to monitor cross section geometry changes such as cross sectional area. It was previously thought that the Entrenchment Ratio and Bank Height Ratio Triggers would be sufficient to detect significant cross section geometry changes since bankfull depth and bankfull width, components used in calculating these ratios, are derived from the cross section data. However, since one of the outcomes of the November 2021 and February 2022 GMT meetings was to use a fixed bankfull elevation to determine values for Entrenchment Ratio and Bank Height Ratio, significant changes in geometry could occur without exceeding either the Investigation or Action Triggers. These might include changes in channel bed elevation due to aggradation, degradation, or slumping that don't change the bankfull width (resulting in no change to the Entrenchment Ratio) or do not change the thalweg elevation enough to change the Bank Height Ratio by greater than 0.1. Also, since the Entrenchment Ratio and Bank Height Ratio calculations are only conducted for riffle (crossing) sections, significant changes in geometry in the pool sections may otherwise go undetected.

Since the use of cross-sectional area as a geomorphic monitoring trigger does not appear to have been used in practice or discussed in literature, it will be used only as an Investigation Trigger. The Investigation Triggers values were developed for each GMS using the datasets collected by WEST in 2012, 2019 and 2021 using the methodology described below. The values of the observed annualized percent change in cross sectional area for each GMS are summarized in Table 6-7.

The bankfull cross sectional area shall be determined per the method described in Section 7.1.4. The value for each cross section is then subtracted from the value determined from the previous survey to determine the change in cross sectional area. The result could either be a positive value, representing an increase in cross sectional area, or a negative value, representing a decrease in cross sectional area. The percent increase or decrease in cross sectional area is then determined. The absolute value of each percent increase or decrease is then calculated and averaged by GMS to determine the percent change in cross sectional area since the previous survey was conducted for each GMS. This value is then divided by the number of years between the current and previous survey to estimate an annualized percent change. The calculated annualized percent change value is then compared to the Cross Sectional Area Investigation Trigger values provided in Table 6-8.

Table 6-7: Range of observed annualized percent change in cross section area by GMS

GMS	Annualized % Change			GMS	Annualized % Change		
	2018-2020 (2 years)	2011-2018 (7 years)	2011-2020 (9 years)		2018-2020 (2 years)	2011-2018 (7 years)	2011-2020 (9 years)
BU01[1/]	--	--	1.17	SH03	4.62%	1.09%	1.93%
LR01	2.08	2.19	2.07	SH04	5.00%	1.46%	0.62%
MA01	1.53	0.95	0.85	SH05	7.06%	1.20%	1.97%
MA02	1.51	0.62	0.46	SH06A	0.81%	0.46%	0.33%
MA03	1.78	0.66	0.63	SH06[2/]	3.89%	--	--
RE01	2.88	0.42	0.51	SH07	5.36%	1.51%	0.53%
RE02[2/]	0.55	--	--	SH08	5.22%	1.56%	0.60%
RE02A	1.36	0.74	0.33	WC01[1/]	--	--	4.47%
RE03	0.65%	0.71%	0.59%	WC02[1/]	--	--	9.93%
RE04	0.54%	0.27%	0.27%	WC03[3/]	--	--	--
RE05	1.53%	0.47%	0.40%	WC04[3/]	--	--	--
RE06[2/]	0.96%	--	--	WR01	1.51%	0.82%	0.70%
RE06A	1.25%	1.00%	0.63%	WR02	1.94%	0.50%	0.67%
RE07[2/]	1.06%	--	--	WR03[2/]	2.59%	--	--
RE08	0.96%	0.03%	0.18%	WR04	1.97%	0.16%	0.38%
RE09	1.13%	0.57%	0.62%	WR05	1.84%	1.01%	1.15%
RE10	2.50%	1.30%	0.91%	WR06	1.90%	0.85%	0.58%
RU01	3.39%	1.91%	1.51%	WR07	0.98%	0.80%	0.76%
SH01	1.77%	0.65%	0.30%	WR08	0.78%	0.35%	0.29%
SH02	1.52%	0.71%	0.37%				

[1/] Not surveyed for WEST 2019 study
[2/] Not surveyed for WEST 2012 study
[3/] Stream restoration work invalidated available cross section data prior to WEST 2021 study

It is recognized that geomorphic changes are often episodic and associated with large and infrequent flood events. As a result, significant changes in morphology can occur over relatively short periods of time, such as during a single flood season. When monitoring occurs at longer intervals, such as every 5 or 10 years, the observed changes may be considered less significant because they are averaged over longer periods of time, resulting in a relatively low annualized rate of change that does not exceed the trigger value. Therefore, the Cross Sectional Area Investigation Triggers were developed for both shorter (1-4 years) and longer (≥5 years) durations between monitoring surveys.

Table 6-8: Cross-Sectional Area Investigation Trigger Values by GMS

GMS	Annualized % Change		GMS	Annualized % Change		GMS	Annualized % Change	
	1-4 years	≥5 years		1-4 years	≥5 years		1-4 years	≥5 years
BU01[1/]	>1.4	>1.3	RE07[3/]	>1.2	>1.0	SH08	>6.4	>3.5
LR01[2/]	>2.4	>2.4	RE08	>1.1	>0.6	WC01[1/]	>5.4	>4.9
MA01	>1.8	>1.3	RE09	>1.3	>0.9	WC02[1/]	>12	>11
MA02	>1.8	>1.1	RE10	>3.0	>2.0	WC03[4/]	--	--
MA03	>2.1	>1.3	RU01	>4.0	>2.8	WC04[4/]	--	--
RE01	>3.4	>1.8	SH01	>2.2	>1.2	WR01	>1.8	>1.2
RE02[3/]	>0.6	>0.5	SH02	>1.9	>1.1	WR02	>2.3	>1.4
RE02A	>1.7	>1.0	SH03	>5.3	>3.3	WR03[3/]	>2.8	>2.3
RE03[2/]	>0.8	>0.8	SH04	>6.1	>3.3	WR04	>2.3	>1.2
RE04	>0.6	>0.4	SH05	>8.2	>4.7	WR05	>2.1	>1.6
RE05	>1.8	>1.1	SH06A	>1.0	>0.7	WR06	>2.3	>1.4
RE06[3/]	>1.1	>0.9	SH06[3/]	>4.3	>3.5	WR07	>1.1	>1.0
RE06A	>1.5	>1.1	SH07	>6.6	>3.5	WR08	>0.9	>0.6

[1/] Limited historic data available: 1-4 year value set to 120% of measured value, ≥5 year value is set to 110% of the measured value.

[2/] No correlation: 1-4 year and ≥5 year value is set to 110% of the maximum measured value.

[3/] Limited historic data available: 1-4 year value set to 110% of measured value, ≥5 year value is set to 90% of the measured value.

[4/] Insufficient historic data available due to stream restoration project – investigation triggers may be developed at a later date following additional monitoring efforts.

6.1.4 Bank Line Location

Defining quantitative action triggers for aerial imagery-derived bank line movement is inherently difficult, as every stream naturally moves and adjusts its location in response to a variety of causes and because of the uncertainty in the bank line delineation process due a variety of factors such as differing water levels and delineator judgments. Pre-FMM Project geomorphic assessments have included the delineation of bank line locations using aerial imagery, with these delineations creating information that can be used to assess channel movement outside of the surveyed cross section locations. The WEST (2012) report delineated bank line locations spanning from 2010 to as early as 1939 for some streams in the study area. The WEST (2019) report delineated bank line locations spanning from 2018 to 2010. The WEST (2021) report includes re-delineated bank line locations using only high-resolution aerial imagery collected between 2008 and 2020 and using a larger scale (1:1,000 vs. 1:3,000 previously) during bank line delineation to determine bank line location changes more clearly.

Triggers that would require the GMT and AMT to take further action are listed below:

- In the event any member of the GMT or AMT receives complaints from the public stating that the FMM Project is causing increased bank line movements in areas not within the immediate vicinity of a monitored cross section, the GMT shall meet to evaluate the complaint and compare the observed bank line movement that resulted in the complaint against historically observed movement within the same area. The GMT shall then provide a consensus-based response to the AMT stating the following:
    - Whether the GMT judges the observed bank line movement that resulted in the complaint to be inside or outside the range of natural variability for that reach of the stream
    - If outside the range of natural variability, whether the GMT judges the observed bank line movement to be the result of the FMM Project
    - If the result of the FMM Project, the recommended corrective action
- Post-FMM Project construction geomorphic assessments will evaluate bank line locations and any associated movement and apply judgment to highlight areas that may fall outside of normal ranges (referring to the WEST 2012, 2019, and 2021 reports as background). These areas shall be further investigated by the GMT. The GMT shall then provide a consensus-based response to the AMT stating the following:
    - Whether the GMT judges the observed bank line movement that resulted in the complaint to be inside or outside the range of natural variability for that reach of the stream
    - If outside the range of natural variability, whether the GMT judges the observed bank line movement to be the result of the FMM Project
    - If the result of the FMM Project, the recommended corrective action

The GMT and AMT shall consider whether the reference reaches have also shown changes in bank line locations when working to establish whether this trigger has been exceeded and whether the trigger exceedance is attributable to the FMM Project construction.

6.2 Trigger Exceedance Response

In the event that any of the Investigation Triggers or Action Triggers identified in Section 6.1 are exceeded or if it is the GMT's judgment that other significant changes are occurring throughout the system and are not being captured by the currently established triggers, the following process shall be followed by the GMT and the findings provided to the AMT within the timelines established in Section 8.

6.2.1 GMT Investigations Due to Investigation Trigger Exceedance

The Investigation Triggers were established to help limit the amount of geomorphic change that might occur before an Action Trigger is exceeded. This will allow the GMT sufficient time to develop and implement an appropriate plan for conducting a more detailed investigation of the GMSs that appear to be experiencing changes that exceed the pre-project variability observed over the previous monitoring efforts. The details of the investigation plan will be developed by the GMT and provided to the AMT prior to implementation.

6.2.2 GMT Investigations Due to Action Trigger Exceedance

First, the GMT shall provide a recommendation to the AMT as to whether the trigger exceedance is attributable to the FMM Project and, if possible, to what degree. Probable and possible causes for the exceedances should be detailed with documented data by the GMT for the AMT. The GMT should evaluate aerial imagery, LiDAR data, hydrology records, and any other available data sources as part of the attribution effort. One important component of this effort is to evaluate the reference reaches that were unimpacted by FMM Project operations to see if those reaches are showing similar geomorphic patterns. If those reaches are not showing similar geomorphic trends, it is possible (though not certain) that the FMM Project is the primary driver of the trigger exceedance. It is possible that some trigger exceedances will be easily verifiable as being principally caused by the FMM project or some other driver, such as changes in land use, drainage patterns, or precipitation. There are a number of reasons for trigger exceedances that may not be in any way influenced by the FMM Project, including but not limited to hydrology change, sediment load change, stream slope change, land use change, and standard geomorphic responses to large flood events that may have occurred both with and without the FMM Project. It is also possible that trigger exceedances may have a mix of drivers contributing to the exceedance or that they may initially appear to be indeterminant. In the cases where identifying the relative impact of multiple drivers is challenging, the AMT and GMT should consider engaging third-party facilitation to help articulate important criteria for making recommendations and for identifying follow-up actions to ultimately reach a recommendation.

Second, if the GMT concludes that the trigger exceedances were fully or in part attributable to the FMM Project, the GMT shall provide a recommendation to the AMT as to whether the impact is detrimental from the stakeholder perspective. In this instance, stakeholders include (but are not limited to) local, state, and federal agencies as well as local landowners. An example of a clearly detrimental impact is FMM Project-induced erosion that is threatening the stability of a bridge crossing.

Third, if the GMT concludes that the trigger exceedances were fully or in part attributable to the FMM Project and that the impacts are detrimental, the GMT shall provide one or more recommended corrective actions, commensurate with the detrimental level of impact and with the level of attribution to the FMM Project, for consideration to the AMT. A list of geomorphic issues grouped into themes that may be experienced in the FMM Project vicinity and a list of associated potential corrective actions is provided in Section 6.2.2.

6.2.3 List of Themes and Potential Corrective Actions for GMT Consideration

Issues potentially requiring corrective actions can be grouped into themes related to the physical processes that cause them. This can be helpful in treating the root cause of a trigger exceedance rather than just the appearances or symptoms. Treating the symptom instead of the cause may simply result in the same impacts reoccurring over time if the causes remain untreated. Cause determination will require the GMT to thoughtfully analyze the data and use their combined experience and expertise to attribute the issue(s)/symptom(s) to the actual cause(s). It is important to note that streams adapt to some changes over time. Therefore, the GMT shall consider the current stream condition state in relation to its ongoing and evolving geometry before determining the recommended corrective action(s).

A list of themes of geomorphic-related issues and associated potential corrective actions is included in this Section to support early discussions and facilitate a more rapid response when the GMT is recommending that corrective actions are needed. This list is not considered to be all-inclusive or contain any of the specificity required for actual design or implement of the ideas and will be modified over time as new techniques and structural corrective measures are developed. Within the list are references to texts with more information and examples of actions already implemented in the region that can inform discussion. Extensive, expert work will be required to bring contextual ideas to meaningful application based on the specific and unique characteristics of each area being evaluated and what the AMT and GMT determine is beneficial.

Five documents are supplied as appendices B through F to this GMP that give a thorough description of stream bed and bank issues and corrective actions. The appendices are:

B. Resource Sheet 1: Streambank Erosion and Restoration (Minnesota DNR)
C. Resource Sheet 2: The Value and Use of Vegetation (Minnesota DNR)

D. Stream Restoration: Toe Wood-Sod Mat (Minnesota DNR)
E. Chapter 11 of National Engineering Handbook 654 (Natural Resources Conservation Service)
F. Chapter 14 of National Engineering Handbook 654 (Natural Resources Conservation Service)

6.2.3.1 Theme: Increased Bank Erosion and/or Channel Migration Rate

All natural streams have meander patterns that gradually migrate in a downstream direction with time, which requires some degree of erosion and deposition. Locations with increased rates of bank erosion, meander migration, and meander pattern change have often been destabilized due to hydrologic and hydraulic changes and/or changes in vegetation. Bank erosion/collapse in one location can produce sediment that is transported and deposit in downstream reaches, thereby producing a shallower channel in those areas. This, in turn, can destabilize those banks as the river tries to widen to handle the flows, resulting in a feedback cycle of destabilization throughout a system.

One potential corrective action is to reduce the flow velocity near the eroding bank. This can be done through the staking of live cuttings of deep-rooted woody vegetation that naturally occurs within the Red River valley ecosystem or the planting of willows, shrubs, grasses, and rooted forbes, among other vegetation, as this vegetation can significantly lower near-bank velocities. An example of willow plantings is shown in Figure 6-3.

Figure 6-3: Willow Plantings on the Mississippi River

Another potential corrective action is to install toe wood with a sod mat along the bank toe. This stabilizes the bank toe with both the toe wood and with the dense sod mat vegetation. It also has the added benefit of providing aquatic and terrestrial habitat. Toe wood-sod mats are sometimes an additional practice to the restoration of bank vegetation while other times just bank restoration is needed. Figure 6-4 shows the toe wood-sod mat concept while Figure 6-5 shows project examples where this technique has been used.

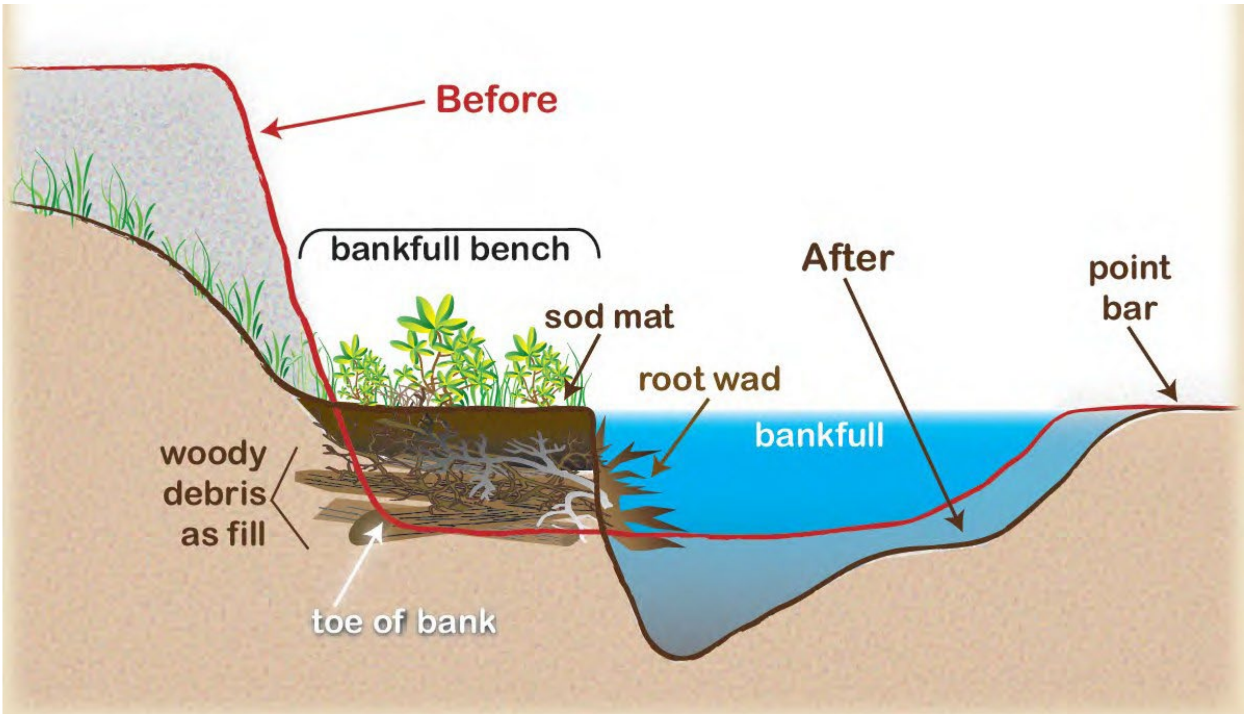


Figure 6-4: Toe Wood-Sod Mat Conceptual Example (source: Minnesota DNR)

Toe Wood-Sod Mat: Construction Examples

Spruce Creek

Unstable bank encroaching on a picnic shelter. Toe of bank is eroding causing slumping and stream is overwide.

Construction of bankfull bench. A layer of woody debris and fill was placed along the bank toe then covered with live willow cuttings (in foreground).

Collection of local dogwood and willow sod mats with very dense root mats.

Placement of final layer of sod mats on the constructed bench at bankfull elevation.

Finished bank stabilization project: Vegetated bankfull bench and a graded streambank protected with erosion control blankets.

Buffalo River

Unstable bank and failing flood control dike protecting a mobile home park. The project started with the placement of woody debris and insertion of root wads.

The completed woody debris layer with incorporated root wads. The upper bank was regraded with a more gentle slope.

Dirt was added as fill and rooting material to the woody debris layer.

Locally collected red-osier dogwood and willow sod mats were placed on the constructed bench at bankfull elevation.

Project was completed with a vegetated bankfull bench and a re-graded upper bank seeded with native seed mix. New growth was thriving the next summer.

Figure 6-5: Toe Wood-Sod Mat Construction Examples (source: Minnesota DNR)

A third potential corrective action is to construct J-hook vanes "designed to reduce bank erosion by reducing near-bank slope, velocity, velocity gradient, stream power and shear stress" (Rosgen, 2001). As flow passes over the length of the J-hook vane, the turbulence dissipates the flow energy and directs it toward the channel thalweg. Multiple J-hook vanes can be implemented, or toe-wood can be put between J-hook vanes on long outside bends. Figure 6-6 shows a generic plan, profile, and cross-sectional view of the J-hook vane.

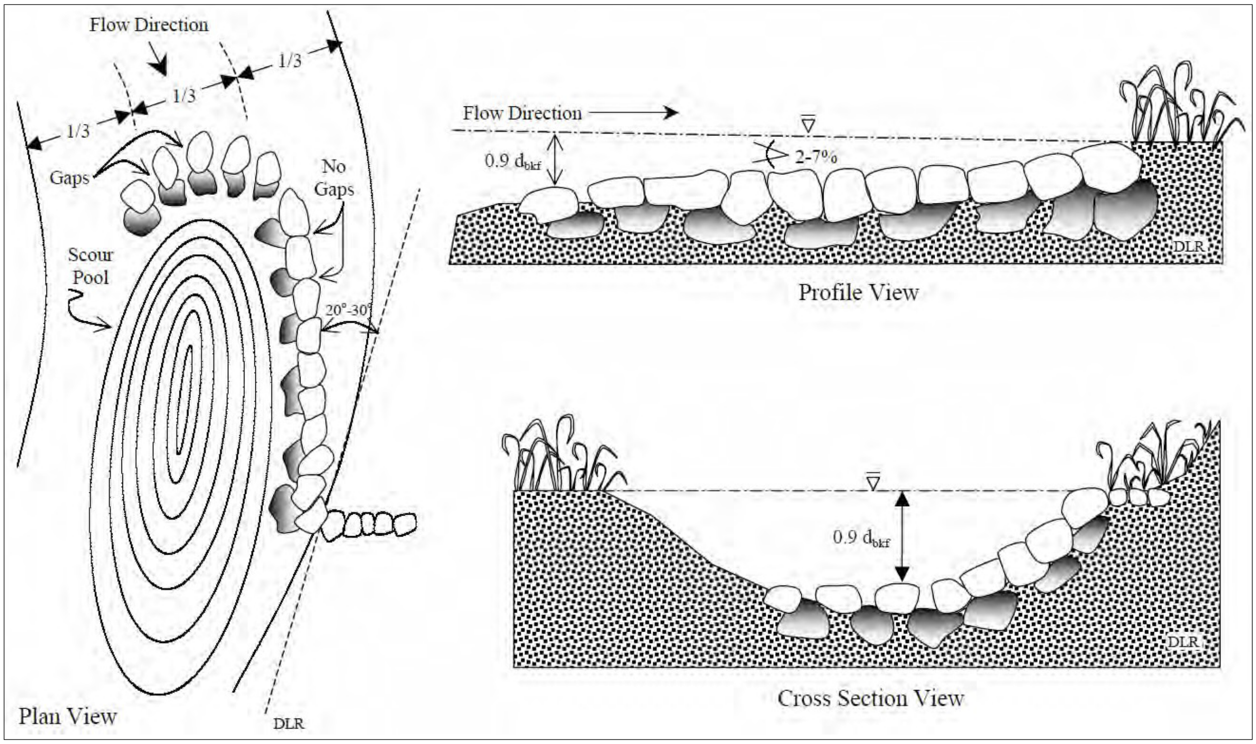


Figure 6-6: Generic J-Hook Vane Plan, Profile, and Cross-Sectional View Detail

A fourth potential corrective action for areas exhibiting bank erosion and channel migration is to add a longitudinal stone toe. This is similar to the toe wood-sod mat technique but has rock at the base of the toe. The use of rock over natural toe wood limits habitat for transitional aquatic species and transfers energy downstream, potentially resulting in erosion downstream of the corrective action area; therefore, this corrective action should primarily be considered only where the feature is protecting something of high value (roads, homes, etc.) where the tolerance to risk of failure is low. Figure 6-7 and Figure 6-8 show an example of a 'longitudinal stone toe' without bank re-shaping or creation of a berm behind the rock. The feature traps sediment from the eroding bank and produces a more stable slope that can be naturally vegetated. This corrective action is considered to be a last-resort remedy when infrastructure or residences are being threatened by erosion.

Figure 6-7: Longitudinal Stone Toe - Immediately After Construction (No Bank re-shaping)

Figure 6-8: Longitudinal Stone Toe – One Year After Construction (No Bank Re-shaping)

6.2.3.2 *Theme: Channel Bed Degradation*

Degrading channels are typically the result of either increases in reach discharge/velocity typically due to local drainage infrastructure or river crossings, reductions in sediment from upstream reaches or other sources (potentially due to perched crossings or, in the case of the FMM Project, the Sheyenne River and Maple River aqueducts), and/or increases in the river water surface slope due to the removal of downstream constrictions that increase the velocity and sediment transport capability of a reach. Channel degradation results in deeper water along the banks, which can cause bank sloughing into the stream. Deeper and faster water along the banks makes them more likely to fail due to the undercutting of material along the bank toe.

One potential corrective action for river reaches that have experienced or are experiencing channel degradation is adding riffles to increase roughness and dissipate energy to prevent further degradation. An elliptically-shaped riffle can also be used to focus velocities away from the banks and direct them toward the pool portion of the stream. Generic plan, profile, and cross-sectional view details with generic dimensions are shown in Figure 6-9, Figure 6-10, and Figure 6-11, respectively.

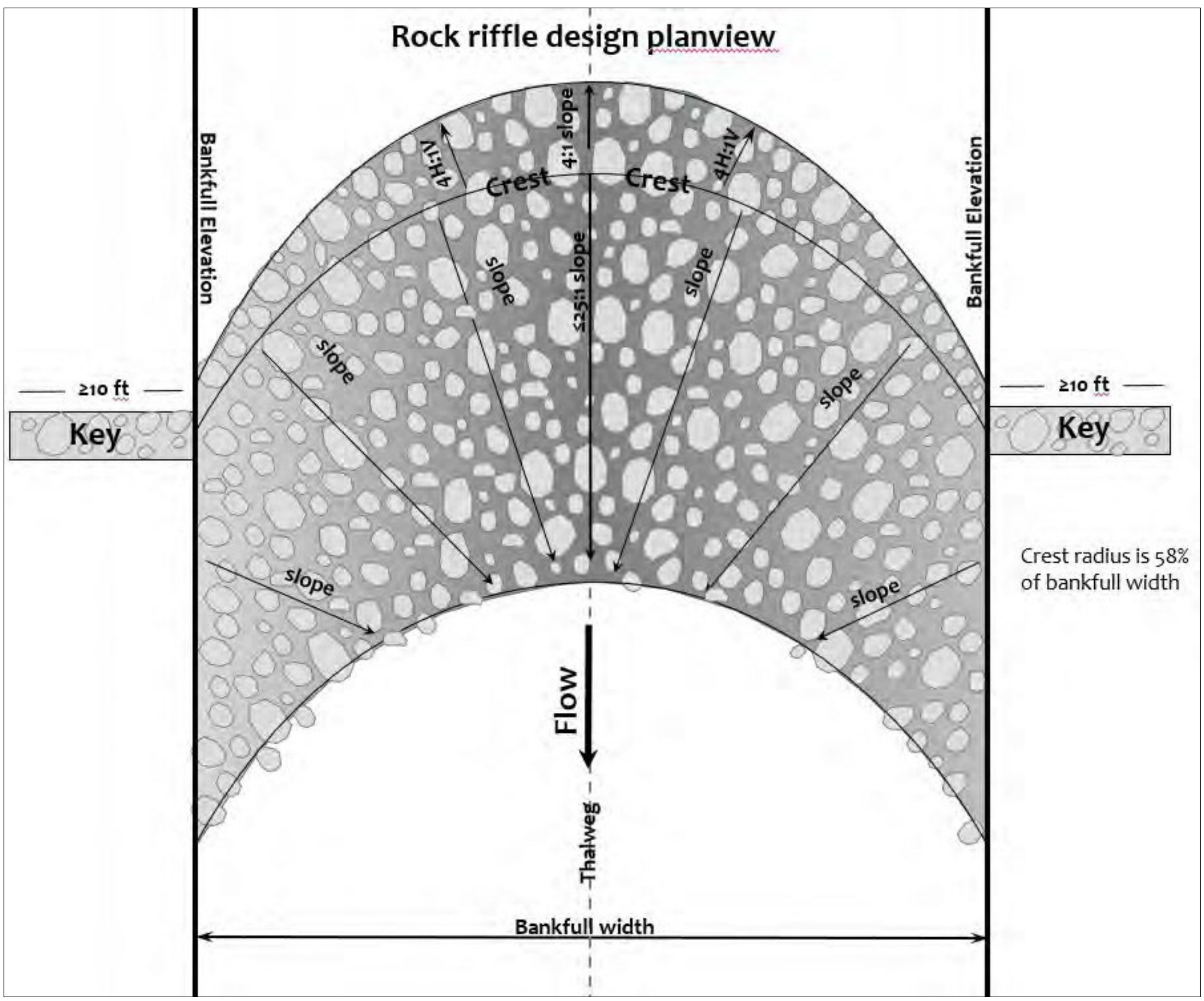


Figure 6-9: Generic Riffle Plan View Detail (Minnesota DNR)

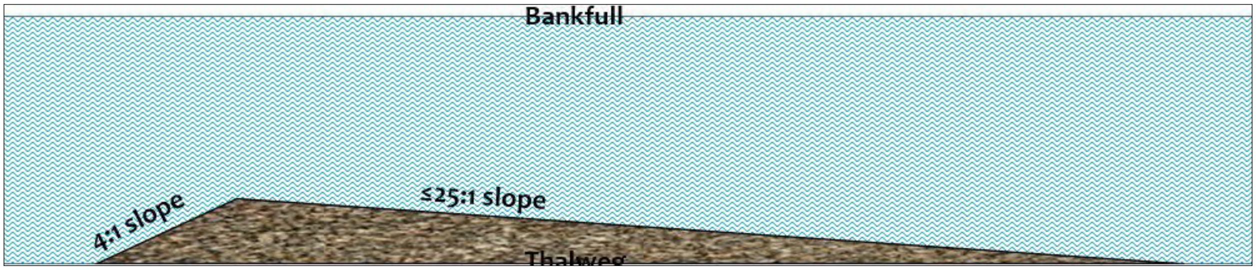


Figure 6-10: Generic Riffle Longitudinal Profile View Detail (Minnesota DNR)

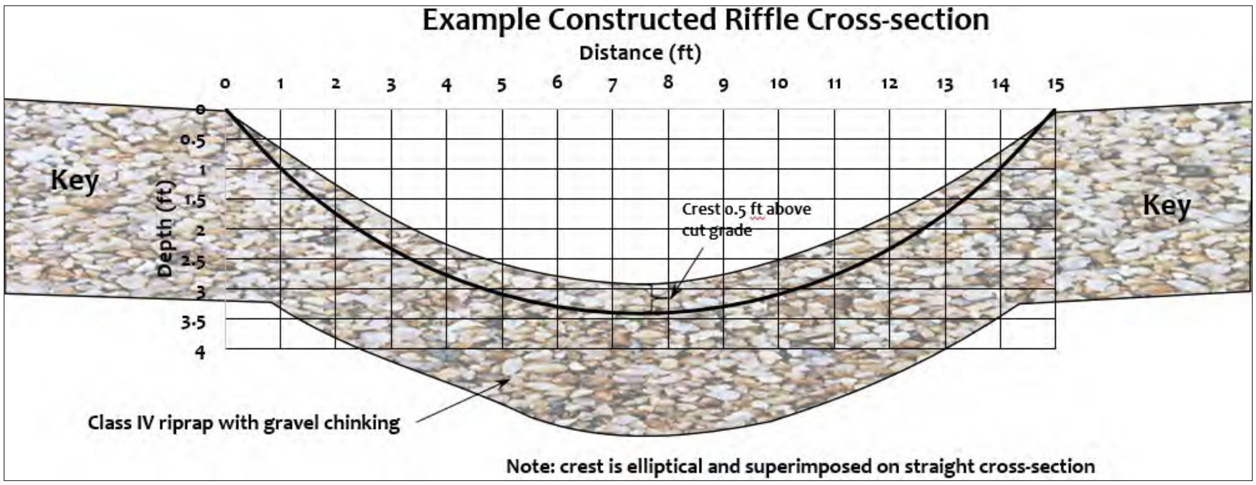


Figure 6-11: Generic Riffle Cross-Sectional View Detail (Minnesota DNR)

Another potential corrective action for a degrading stream bed is to add channel length through greater channel sinuosity and the addition of meanders, in concert with appropriate bed features with riffles at the cross-over and pools in the outside bends. Figure 6-12 shows a re-meandered section of Wolverton Creek near the town of Wolverton, Minnesota.

Figure 6-12: Re-meandered Segment of Wolverton Creek (source: Houston Engineering, Inc.)

A third method of reducing channel degradation is to lengthen the flood flow path of streams through the use of cut-off blockages. Toe wood-sod mat plugs (previously discussed in Section 6.2.2.1) and other similar woody debris/root wad configurations have been used to block cut-off areas along channels. It is noted that this method is most appropriate when there is enough land between the cut-off meanders. If the cut-off distance is too small, it has a high potential of cutting off again. Detailed and careful analysis by the GMT is necessary when considering this corrective action. Figure 6-13 shows a constructed toe wood-sod mat plug aimed at preventing channel cut-off.

Figure 6-13: Plug of Cut-Off Channel using Toe Wood-Sod Mat on the Pomme de Terre River in Minnesota

A fourth method to reduce bed degradation is the installation of J-hook vanes. The J-hook vane concept was previously discussed in Section 6.2.2.1.

6.2.3.3 Theme: Channel Bed Aggradation

Channel aggradation is oftentimes the result of a channel widened through bank erosion (thus reducing flow velocities and encouraging sediment deposition through the aggrading section), changes to upstream sediment supply (such as channel bank collapses and any resulting change in material sizes/characteristics), and/or flattening of the river surface slope due to a permanent downstream constriction (such as a new bridge or a road raise).

Bank collapse resulting in either a widened channel at the aggrading site or an increased sediment supply to the aggrading site can be addressed through the corrective actions discussed in Section 6.2.3.1.

A flattened water surface slope can be addressed by increasing the capacity of the river crossing resulting in the issue. It is noted that the Diversion Channel and associated infrastructure features are proactively being designed to minimize backwater increases and the associated flattened river water surface slopes, which minimizes the potential for these features to result in channel aggradation of the Rush River, Lower Rush River, Maple River, Sheyenne River, and the various drains and ditches intersected by the Diversion Channel.

6.2.3.4 *Theme: Unstable Bank Slopes due to Sediment Deposition*

In some situations, increases in overbank sediment deposition could increase the potential for slope stability problems. Unstable bank slopes can also result in slumping or collapse of riverbanks into the rivers. This is exacerbated in areas with a large amount of clay in floodplain sediments (such as the Red River and most of its tributaries) but can happen anywhere where the bank slope exceeds stable thresholds.

A potential corrective action is to increase slope stability by re-grading the channel banks in the affected area to slopes that are more stable and able to withstand any additional sediment deposition. Grading the channel banks to create a more trapezoidal cross section is considered to be a last-resort remedy when infrastructure or residences are being threatened by the unstable bank slopes.

Another potential corrective action is to determine whether changes in the FMM Project's operating plan would decrease the sediment supply to the channel banks. Any changes to the operating plan would need to be balanced with the FMM Project's operational goals and if those goals result in additional environmental, economic, social, or cultural impacts beyond those disclosed in the FMM Project's NEPA documentation, additional corrective action would also be required to remedy those impacts. Any operational change shall be formally approval by the appropriate regulating agencies, including the US Army Corps of Engineers.

6.2.3.5 *Theme: Localized Erosion*

Erosion problems can also be locally based due to the presence of gated structures (such as the Red River Structure and Wild Rice River Structure), flow eddies, debris jams, bridges, elevated roadways, and other generally localized phenomena. A potential corrective action to localized erosion due to local hydraulics is to provide natural or non-natural erosion protection measures, such as large woody debris (natural) or riprap (non-natural). Other potential corrective actions for this theme could include modifications to or removal of the local cause of the erosion-inducing issue, such as reshaping of the channel banks or removal of debris jams.

7 PROTOCOLS AND STANDARDS

Rigor and consistency of data collection techniques and standards is critical for quality assurance and verifiable quantification of change. Discussing protocols and keeping them up to date with changing contractors and agency personnel is critical for ensuring accuracy and comparability of data sets over time. Therefore, reviewing and discussing sampling protocols shall occur in advance of scheduled field work, in the event of a flood event sampling situation, when there is a change in organizations/contractors conducting the sampling, and when there is a change in protocol or technologies. These discussions may include joint field visits of GMT members and the sampling organization/contractors to go over field methodologies and other protocols.

The following sections describe the protocols and data management/storage/exchange standards that shall be used. Any deviations to specific protocols developed for this GMP requires GMT and AMT approval, with text added to the GMP to describe this protocol change/deviation.

7.1 Protocols for Geomorphic Trigger Evaluation

This section prescribes the methods that shall be used for calculating/determining the Entrenchment Ratio (ER), Bank Height Ratio (BHR), cross sectional area, and bank line locations for the purpose of determining whether an Investigation or Action Trigger has been exceeded.

7.1.1 Entrenchment Ratio Calculation Prescription

The Entrenchment Ratio is calculated for riffle (crossing) sections and is defined as the ratio between the floodprone width and the bankfull width. A close evaluation of the data from the three years of pre-FMM Project monitoring (WEST 2012, 2019, and 2021) indicates that the Entrenchment Ratio can vary substantially because small changes in the floodprone elevation can result in dramatic changes in the floodprone width due to the extremely wide floodplain for streams in the FMM Project vicinity. An example of this is shown in Figure 7-2.

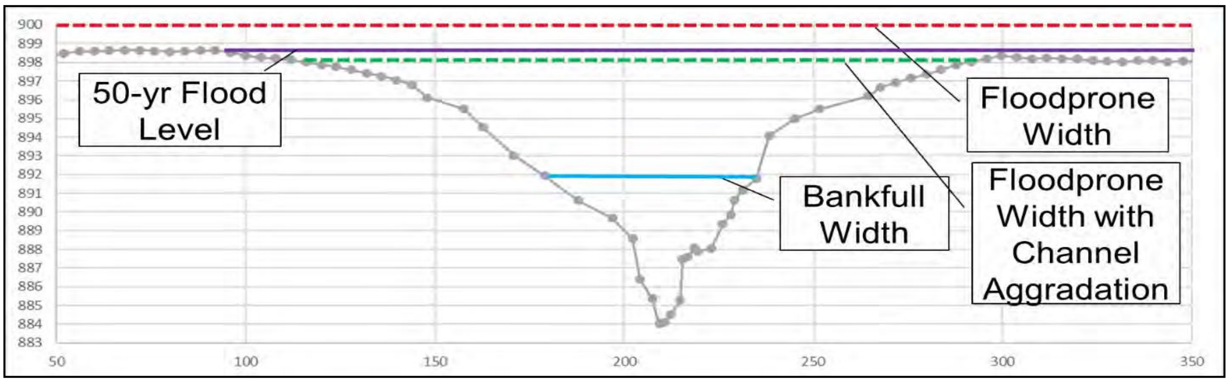


Figure 7-1: Comparison of Floodprone Widths with Small Changes in Floodprone Elevations

Because of the influence on floodprone width in the Entrenchment Ratio calculation, the floodprone width that shall be used for all past and future Entrenchment Ratio calculations completed for the purposes of evaluating trigger exceedance was set to a specified value typically equal to that determined by WEST (2019), with small adjustments at select locations, for each riffle monitoring cross section in the FMM Project vicinity. The specified floodprone widths are shown in Table 7-2. It is noted that in the event the floodprone width exceeded 1,000 feet for all streams besides the Red River, the floodprone width was set to a width of 1,000 feet. For the Red River, the maximum floodprone width threshold was set to 1,500 feet. This ensured that Entrenchment Ratios remained in a reasonable range while also resulting in generally high Entrenchment Ratios that did not approach the low end of the "fully functioning" (per the MN SQT) Entrenchment Ratio threshold.

All Entrenchment Ratio calculations completed for the purposes of evaluating trigger exceedance shall use the fixed bankfull elevations shown in Table 7-2. By using fixed values for both the floodprone width and the bankfull elevation, the potential for error due to geomorphic investigator interpretation and judgment is significantly reduced. However, this approach assumes that only changes in bankfull width will account for changes to the Entrenchment Ratio. Further, because this approach does not account for changes to channel bed elevation, which is possible due to sedimentation, nor does it account for changes at pool sections, a comparison of current and previous cross section geometry should also be conducted to confirm the findings of the Entrenchment Ratio analysis. The method for conducting this comparison is described in Section 7.1.3.

Table 7-1: Floodprone Widths and Bankfull Elevations for Riffle Monitoring Cross Sections

Cross Section	Floodprone Width (ft)	Bankfull Elevation (ft, NAVD88) 1/	Cross Section	Floodprone Width (ft)	Bankfull Elevation (ft, NAVD88) 1/
BU01X01 2/	253	858.93	SH02X01	1,000	877.51
BU01X04 2/	233	859.10	SH02X03	1,000	877.68
BU01X06 2/	196	859.21	SH02X04	1,000	877.81
LR01X01	1,000	895.33	SH02X06	1,000	877.95
LR01X03	1,000	895.38	SH03X01	412	881.98
LR01X06	222	895.46	SH03X02	1,000	882.08
MA01X01	1,000	887.38	SH03X05	1,000	882.30
MA01X03	473	887.49	SH04X01	1,000	888.18
MA01X05	645	887.60	SH04X03	1,000	888.31
MA01X06	417	887.67	SH04X05	1,000	888.57
MA02X01	1,000	891.33	SH05X01	1,000	891.55
MA02X03	1,000	891.54	SH05X03	1,000	891.55
MA02X06	1,000	892.02	SH05X06	1,000	891.55
MA03X01	1,000	897.67	SH06AX02 2/	1,000	907.87
MA03X04	1,000	898.05	SH06AX04 2/	1,000	908.12
MA03X06	1,000	898.28	SH06AX05 2/	1,000	908.21
RE01X01	768	854.04	SH06X02	1,000	908.98
RE01X03	559	854.36	SH06X03	1,000	909.08
RE01X05	850	854.48	SH06X05	1,000	909.16
RE01X07	530	854.56	SH07X01	1,000	913.59
RE02X01	540	857.96	SH07X02	1,000	913.72
RE02X03	547	858.18	SH07X03	1,000	913.83
RE02X06	596	858.53	SH07X04	1,000	913.93
RE02AX01	726	858.87	SH07X05	1,000	913.96
RE02AX03	720	859.14	SH07X08	1,000	914.13
RE02AX06	485	859.44	SH08X01	1,000	925.65
RE03X01	1,037	873.46	SH08X06	1,000	926.28
RE03X03	980	873.76	WC01X03 2/	61	890.01
RE03X05	1,395	873.89	WC01X05 2/	91	890.93
RE03X06	1,325	873.99	WC01X06 2/	51	891.02
RE04X01	765	881.72	WC02X02 2/	84	898.74
RE04X03	1,500	881.96	WC02X04 2/	120	899.14
RE04X05	1,500	882.25	WC02X06 2/	122	899.49
RE05X02	1,500	886.83	WC03X01 2/	142	912.63
RE05X04	1,406	886.89	WC03X04 2/	142	912.88
RE05X06	942	887.08	WC03X06 2/	157	913.22
RE06X01	1,500	889.29	WC04X02 2/	180	915.12
RE06X02	1,500	889.40	WC04X04 2/	144	915.19
RE06X03	1,500	889.56	WC04X06 2/	157	915.33

Cross Section	Floodprone Width (ft)	Bankfull Elevation (ft, NAVD88)	Cross Section	Floodprone Width (ft)	Bankfull Elevation (ft, NAVD88)
RE06X05	1,500	889.78	WR01X01	444	889.37
RE06AX01	1,500	890.07	WR01X03	383	889.50
RE06AX04	1,500	890.26	WR01X06	328	889.68
RE06AX06	1,500	890.36	WR02X02	1,000	890.42
RE07X01	1,087	891.43	WR02X04	338	890.55
RE07X03	1,500	891.57	WR02X06	287	890.73
RE07X06	1,171	891.72	WR03X01	295	895.75
RE08X01	1,109	892.23	WR03X04	289	895.95
RE08X03	1,104	892.32	WR03X06	611	896.07
RE08X05 [2/]	645	890.02	WR04X02	331	898.77
RE08X07 [2/]	478	890.10	WR04X03	359	898.85
RE08X09 [2/]	1,500	890.29	WR04X04	270	898.91
RE09X02	1,500	897.83	WR04X06	288	899.00
RE09X03	495	897.91	WR05X01	240	900.77
RE09X05	1,075	898.03	WR05X03	215	900.84
RE09X06	1,500	898.19	WR05X06	218	900.90
RE10X01	1,167	915.14	WR06X01	239	903.76
RE10X03	1,282	915.69	WR06X02	282	903.86
RE10X05	1,500	916.06	WR06X04	215	904.07
RE10X06	1,210	916.65	WR06X06	353	904.23
RU01X01	1,000	891.72	WR07X01	696	914.63
RU01X02	1,000	891.82	WR07X03	842	914.76
RU01X04	1,000	891.90	WR07X05	468	914.84
RU01X07	249	892.06	WR07X06	510	914.86
SH01X01	859	868.30	WR08X01	447	916.30
SH01X03	920	868.45	WR08X05	503	916.47
SH01X05	798	868.71	WR08X07	361	916.61
SH01X07	439	868.91			

1/ Bankfull elevations from WEST (2019)

2/ Bankfull elevations from WEST (2021)

Once the Entrenchment Ratios for each monitoring cross section are calculated using the methodology listed above, the average Entrenchment Ratio of the riffle monitoring cross sections within each geomorphic monitoring station shall then be averaged to determine the geomorphic monitoring station Entrenchment Ratio, which is the basis for comparison to the trigger values.

Using the Entrenchment Ratio calculation process listed above, the Entrenchment Ratios for each geomorphic monitoring station were calculated based on the 2012, 2019, and 2021 assessment survey data. The results of these calculations are shown in Table 7-3. The Entrenchment Ratio values in these tables were then used to establish the maximum and minimum pre- FMM Project Entrenchment Ratio for each stream for trigger setting purposes. In the event additional pre-FMM Project data is collected, the triggers shall be adjusted (as necessary) in the event the range of pre-FMM Project data increases compared to the data set provided in the tables below. It is noted that the calculated Entrenchment

Ratio values for trigger identification purposes may differ from those presented in the WEST (2012, 2019, and 2021) reports because it was not possible for WEST to use a constant floodprone width or bankfull flow for each geomorphic monitoring cross section over the course of the three assessment years.

Table 7-2: Entrenchment Ratios using 2012, 2019, and 2021 Survey Data and the Calculation Methodology Outlined in this Section

GMS	2012 Entrenchment Ratio	2019 Entrenchment Ratio	2021 Entrenchment Ratio
BU-01	2.9	-	2.8
LR-01	7.4	7.4	7.6
MA-01	8.4	8.9	9.0
MA-02	-	13.0	13.3
MA-03	11.7	11.3	12.1
RE-01	4.1	3.9	3.9
RE-02	-	3.3	3.3
RE-02A	4.2	4.2	4.2
RE-03	8.5	7.9	8.0
RE-04	7.6	7.9	7.9
RE-05	8.2	8.1	8.1
RE-06	-	10.2	10.2
RE-06A	11.7	11.2	11.5
RE-07	-	9.3	9.2
RE-08	-	7.3	7.0
RE-09	9.1	8.8	8.9
RE-10	9.3	8.4	8.3
RU-01	18.5	16.9	18.1
SH-01	7.3	7.3	7.5
SH-02	8.0	8.3	8.2
SH-03	7.3	7.4	7.2
SH-04	11.6	11.1	10.7
SH-05	13.5	13.2	12.8
SH-06A	11.7	-	10.6
SH-06	-	10.0	11.0
SH-07	10.8	10.0	9.9
SH-08	11.9	10.8	11.8
WC-01	2.2	-	2.0
WC-02	4.4	-	5.0
WC-03	-	-	3.0
WC-04	-	-	5.2
WR-01	3.8	3.8	4.0
WR-02	6.2	6.0	6.2
WR-03	-	5.6	5.6

GMS	2012 Entrenchment Ratio	2019 Entrenchment Ratio	2021 Entrenchment Ratio
WR-04	-	3.7	3.6
WR-05	2.9	2.7	2.7
WR-06	3.7	3.5	3.2
WR-07	8.5	8.3	8.2
WR-08	5.6	5.4	5.3

Note: Values may differ from WEST 2012, 2019, & 2021 since a constant bankfull elevation could not be used for these studies.

7.1.2 Bank Height Ratio Calculation Prescription

The Bank Height Ratio (BHR) is calculated for riffle (crossing) sections and is defined as the ratio between the low bank height and maximum bankfull depth. A close evaluation of the data from the three years of pre-FMM Project monitoring (WEST 2012, 2019, and 2021) indicates that the Bank Height Ratio can vary substantially due to different interpretations of low bank height by the geomorphic investigator. An example of this is shown in Figure 7-3.

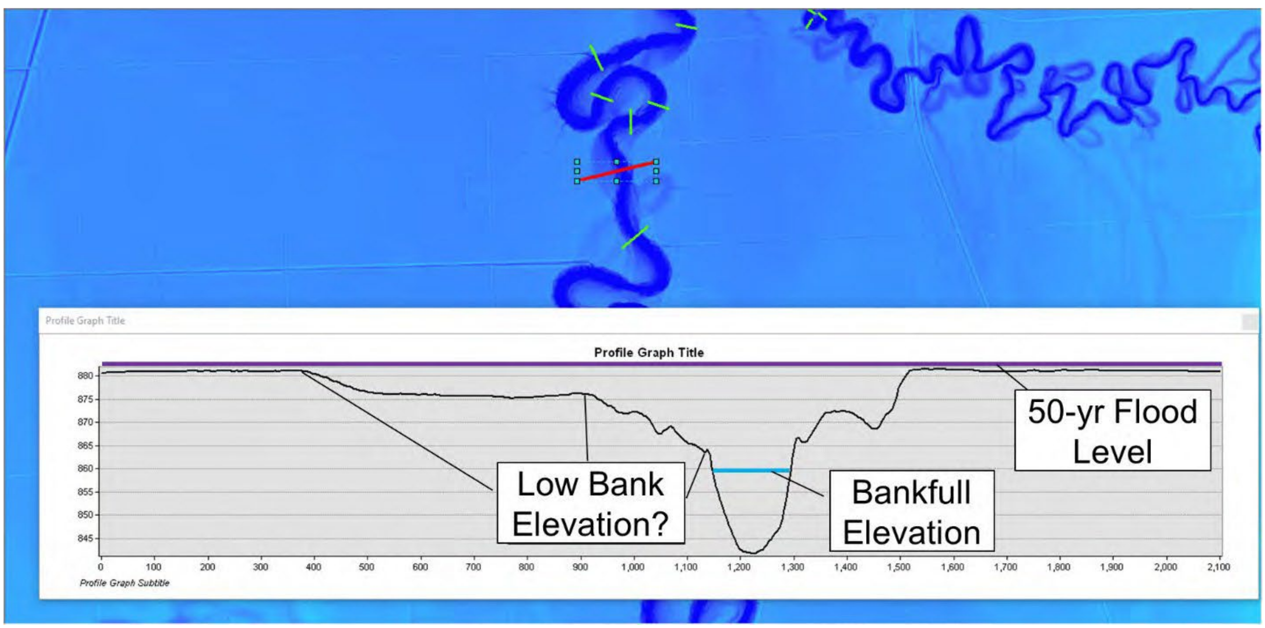


Figure 7-2: Comparison of Low Bank Height Possibilities

Because of the influence of the low bank elevation in the Bank Height Ratio calculation, the low bank elevation that shall be used for all past and future Bank Height Ratio calculations completed for the purposes of evaluating trigger exceedance was set to a specified value typically equal to that determined by WEST (2019), with small adjustments at select locations, for each riffle monitoring cross section in the FMM Project vicinity. The specified low bank elevations are shown in Table 7-4.

The Bank Height Ratio calculations completed for the purposes of evaluating trigger exceedance shall use the bankfull elevations shown in Table 7-4, which are the same as the bankfull elevations shown in Table 7-2. By using fixed values for both the low bank elevation and the bankfull elevation, the potential for error due to geomorphic investigator interpretation and judgment is significantly reduced. However, this approach assumes that only changes in thalweg elevation will account for changes to the Bank Height Ratio. Further, because this approach does not account for changes to low bank height, which are possible due to either sedimentation or slumping, a comparison of current and previous cross section geometry should also be conducted to confirm the findings of the Bank Height Ratio analysis. The method for conducting this comparison is described in Section 7.1.4.

Table 7-3: Low Bank and Bankfull Elevations for Riffle Monitoring Cross Sections

Cross Section	Low Bank Elevation (ft NAVD88)	Bankfull Elevation (ft NAVD88)	Cross Section	Low Bank Elevation (ft NAVD88)	Bankfull Elevation (ft NAVD88)
BU01X01 2/	859.8	858.93	SH02X01	884.2	877.51
BU01X04 2/	862.9	859.10	SH02X03	883.9	877.68
BU01X06 2/	862.1	859.21	SH02X04	886.0	877.81
LR01X01	896.1	895.33	SH02X06	884.5	877.95
LR01X03	896.6	895.38	SH03X01	889.3	881.98
LR01X06	895.7	895.46	SH03X02	886.8	882.08
MA01X01	888.7	887.38	SH03X05	884.6	882.30
MA01X03	889.0	887.49	SH04X01	894.0	888.18
MA01X05	890.8	887.60	SH04X03	893.9	888.31
MA01X06	889.7	887.67	SH04X05	893.3	888.57
MA02X01	897.4	891.33	SH05X01	897.3	891.55
MA02X03	892.9	891.54	SH05X03	893.3	891.55
MA02X06	892.2	892.02	SH05X06	896.5	891.55
MA03X01	899.8	897.67	SH06AX02 2/	908.3	907.87
MA03X04	898.4	898.05	SH06AX04 2/	911.6	908.12
MA03X06	898.7	898.28	SH06AX05 2/	908.9	908.21
RE01X01	857.6	854.04	SH06X02	911.3	908.98
RE01X03	857.7	854.36	SH06X03	911.6	909.08
RE01X05	854.9	854.48	SH06X05	910.6	909.16
RE01X07	860.3	854.56	SH07X01	918.3	913.59
RE02X01	862.9	857.96	SH07X02	915.1	913.72
RE02X03	861.8	858.18	SH07X03	917.2	913.83
RE02X06	862.2	858.53	SH07X04	918.8	913.93
RE02AX01	859.6	858.87	SH07X05	918.5	913.96
RE02AX03	864.0	859.14	SH07X08	919.3	914.13
RE02AX06	863.3	859.44	SH08X01	928.4	925.65
RE03X01	875.7	873.46	SH08X06	932.6	926.28
RE03X03	875.0	873.76	WC01X03 2/	892.0	890.01
RE03X05	874.3	873.89	WC01X05 2/	894.2	890.93
RE03X06	874.9	873.99	WC01X06 2/	896.0	891.02
RE04X01	881.9	881.72	WC02X02 2/	899.4	898.74
RE04X03	882.8	881.96	WC02X04 2/	901.2	899.14
RE04X05	883.6	882.25	WC02X06 2/	901.1	899.49
RE05X02	887.7	886.83	WC03X01 2/	912.4	912.63
RE05X04	888.2	886.89	WC03X04 2/	913.0	912.88
RE05X06	887.2	887.08	WC03X06 2/	913.1	913.22
RE06X01	890.7	889.29	WC04X02 2/	915.1	915.12
RE06X02	889.7	889.40	WC04X04 2/	915.2	915.19

Cross Section	Low Bank Elevation (ft NAVD88)	Bankfull Elevation (ft NAVD88)	Cross Section	Low Bank Elevation (ft NAVD88)	Bankfull Elevation (ft NAVD88)
RE06X03	891.4	889.56	WC04X06 2/	915.0	915.33
RE06X05	899.7	889.78	WR01X01	890.5	889.37
RE06AX01	890.6	890.07	WR01X03	889.9	889.50
RE06AX04	891.0	890.26	WR01X06	891.8	889.68
RE06AX06	890.4	890.36	WR02X02	891.7	890.42
RE07X01	893.2	891.43	WR02X04	891.0	890.55
RE07X03	894.7	891.57	WR02X06	891.6	890.73
RE07X06	892.2	891.72	WR03X01	897.6	895.75
RE08X01	900.8	892.23	WR03X04	896.6	895.95
RE08X03	894.1	892.32	WR03X06	896.6	896.07
RE08X05 2/	894.6	890.02	WR04X02	900.0	898.77
RE08X07 2/	893.1	890.10	WR04X03	899.1	898.85
RE08X09 2/	896.8	890.29	WR04X04	899.5	898.91
RE09X02	900.9	897.83	WR04X06	900.0	899.00
RE09X03	900.9	897.91	WR05X01	901.8	900.77
RE09X05	903.1	898.03	WR05X03	902.0	900.84
RE09X06	901.0	898.19	WR05X06	902.2	900.90
RE10X01	917.1	915.14	WR06X01	906.1	903.76
RE10X03	917.1	915.69	WR06X02	904.2	903.86
RE10X05	917.0	916.06	WR06X04	905.2	904.07
RE10X06	918.3	916.65	WR06X06	905.2	904.23
RU01X01	893.4	891.72	WR07X01	918.0	914.63
RU01X02	894.0	891.82	WR07X03	920.5	914.76
RU01X04	894.0	891.90	WR07X05	916.4	914.84
RU01X07	893.6	892.06	WR07X06	915.7	914.86
SH01X01	872.1	868.30	WR08X01	923.5	916.30
SH01X03	871.0	868.45	WR08X05	923.5	916.47
SH01X05	873.3	868.71	WR08X07	917.1	916.61
SH01X07	875.3	868.91			

1/ Bankfull elevations from WEST (2019)

2/ Bankfull elevations from WEST (2021)

Once the Bank Height Ratios for each monitoring cross section are calculated using the methodology described above, the average Bank Height Ratio of the riffle monitoring cross sections within each geomorphic monitoring station shall then be averaged to determine the geomorphic monitoring station Bank Height Ratio, which is the basis for comparison to the trigger values.

Using the Bank Height Ratio calculation process described above, the Bank Height Ratios for each geomorphic monitoring station were calculated based on the 2012, 2019, and 2021 assessment survey data. The results of these calculations are shown in Table 7-5. The Bank Height Ratio values in these tables were then used to establish the minimum and maximum pre- FMM Project Bank Height Ratio for each stream. In the event additional pre- FMM Project data is collected, the triggers shall be adjusted (as necessary) in the event the range of pre- FMM Project data increases compared to the data set provided in the tables below. It is noted that the calculated Bank Height Ratio values for trigger identification purposes may differ from those presented in the WEST (2012, 2019, and 2021) reports because it was not possible for WEST to use a constant low bank elevation or bankfull flow for each geomorphic monitoring cross section over the course of the three assessment years.

Table 7-4: Bank Height Ratios using 2012, 2019, and 2021 Survey Data and the Calculation Methodology Discussed in this Section

GMS	2012 Bank Height Ratio	2019 Bank Height Ratio	2021 Bank Height Ratio
BU-01	1.2	-	1.3
LR-01	1.1	1.2	1.1
MA-01	1.1	1.2	1.2
MA-02	-	1.2	1.2
MA-03	1.1	1.1	1.1
RE-01	1.1	1.2	1.2
RE-02	-	1.3	1.3
RE-02A	1.2	1.2	1.2
RE-03	1.1	1.1	1.1
RE-04	1.0	1.0	1.0
RE-05	1.0	1.0	1.0
RE-06	-	1.1	1.1
RE-06A	1.0	1.0	1.0
RE-07	-	1.1	1.1
RE-08	-	1.2	1.3
RE-09	1.2	1.2	1.2
RE-10	1.1	1.1	1.1
RU-01	1.3	1.3	1.3
SH-01	1.3	1.3	1.3
SH-02	1.5	1.5	1.5
SH-03	1.1	1.1	1.1
SH-04	1.4	1.3	1.3
SH-05	1.5	1.5	1.5
SH-06A	1.1	-	1.1
SH-06	-	1.2	1.1
SH-07	1.2	1.3	1.3
SH-08	1.3	1.3	1.4
WC-01	1.9	-	1.7
WC-02	1.5	-	1.3
WC-03	-	-	1.0
WC-04	-	-	1.0
WR-01	1.1	1.1	1.1
WR-02	1.1	1.1	1.1
WR-03	-	1.1	1.1
WR-04	-	1.1	1.1

GMS	2012 Bank Height Ratio	2019 Bank Height Ratio	2021 Bank Height Ratio
WR-05	1.1	1.1	1.1
WR-06	1.2	1.1	1.1
WR-07	1.2	1.2	1.2
WR-08	1.4	1.5	1.5

Note: Values may differ from WEST 2012, 2019, & 2021 since a constant bankfull elevation could not be used for these studies.

7.1.3 Bankfull Cross-Sectional Area Calculation Prescription

The bankfull cross-section area is determined at both pool and riffle (crossing) sections. It is defined as the wetted area, in square feet, of the portion of the cross section located below the bankfull elevation. One method of determining the wetted cross sectional area is by forcing a specific water surface elevation for each cross section in an HEC-RAS hydraulic model. Other methods are also available but are not described herein. However, whichever method is chosen, it should be compared to previous calculations methods to ensure consistency in the results. The HEC-RAS method is done in the flow file by selecting “Options” then “Set Changes in WS and Eg…”. This will bring up a table where the known bankfull water surface elevations can be entered for each cross section. After running the model using a small dummy flow, the flow area is obtained from the Profile Output Table – Standard Table 1. The bankfull elevations that are to be used in the hydraulic models for this calculation are provided in Table 7-6, which are the same as the bankfull elevations shown in Table 7-2 and Table 7-4.

Table 7-5: Bankfull Elevations Used for Calculating Cross Sectional Area

Cross Section	Bankfull Elevation (ft NAVD88) [1/]	Cross Section	Bankfull Elevation (ft NAVD88) [1/]	Cross Section	Bankfull Elevation (ft NAVD88) [1/]
Buffalo River – 01 [2/]		**Red River – 08**		**Wolverton Creek – 01** [2/]	
BU01X01	858.93	RE08X01	892.23	WC01X01	889.75
BU01X02	858.99	RE08X02	892.27	WC01X02	889.81
BU01X03	859.04	RE08X03	892.32	WC01X03	890.01
BU01X04	859.10	RE08X04[2/]	890.02	WC01X04	890.47
BU01X05	859.15	RE08X05[2/]	890.02	WC01X05	890.93
BU01X06	859.21	RE08X06[2/]	890.06	WC01X06	891.02
Lower Rush River – 01		RE08X07[2/]	890.10	**Wolverton Creek – 02** [2/]	
LR01X01	895.33	RE08X08[2/]	890.18	WC02X01	898.49
LR01X02	895.35	RE08X09[2/]	890.29	WC02X02	898.74
LR01X03	895.38	**Red River – 09**		WC02X03	899.00
LR01X04	895.40	RE09X01	897.72	WC02X04	899.14
LR01X05	895.41	RE09X02	897.83	WC02X05	899.27
LR01X06	895.46	RE09X03	897.91	WC02X06	899.49
Maple River – 01		RE09X04	897.97	**Wolverton Creek – 03** [2/]	
MA01X01	887.38	RE09X05	898.03	WC03X01	912.63
MA01X02	887.44	RE09X06	898.19	WC03X02	912.76
MA01X03	887.49	**Red River – 10**		WC03X03	912.82
MA01X04	887.55	RE10X01	915.14	WC03X04	912.88
MA01X05	887.60	RE10X02	915.58	WC03X05	913.05

Cross Section	Bankfull Elevation (ft NAVD88) [1/]	Cross Section	Bankfull Elevation (ft NAVD88) [1/]	Cross Section	Bankfull Elevation (ft NAVD88) [1/]
MA01X06	887.67	RE10X03	915.69	WC03X06	913.22
MA01X07	887.74	RE10X04	915.93	**Wolverton Creek – 04 [2/]**	
Maple River – 02		RE10X05	916.06	WC04X01	915.06
MA02X01	891.33	RE10X06	916.65	WC04X02	915.12
MA02X02	891.47	**Rush River – 01**		WC04X03	915.16
MA02X03	891.54	RU01X01	891.72	WC04X04	915.19
MA02X04	891.77	RU01X02	891.82	WC04X05	915.25
MA02X05	891.93	RU01X03	891.86	WC04X06	915.33
MA02X06	892.02	RU01X04	891.90	**Wild Rice River – 01**	
Maple River – 03		RU01X05	891.93	WR01X01	889.37
MA03X01	897.67	RU01X06	891.95	WR01X02	889.41
MA03X02	897.80	RU01X07	892.06	WR01X03	889.50
MA03X03	897.97	**Sheyenne River – 01**		WR01X04	889.53
MA03X04	898.05	SH01X01	868.30	WR01X05	889.61
MA03X05	898.15	SH01X02	868.41	WR01X06	889.68
MA03X06	898.28	SH01X03	868.45	**Wild Rice River – 02**	
Red River – 01		SH01X04	868.56	WR02X01	890.41
RE01X01	854.04	SH01X05	868.71	WR02X02	890.42
RE01X02	854.18	SH01X06	868.87	WR02X03	890.51
RE01X03	854.36	SH01X07	868.91	WR02X04	890.55
RE01X04	854.43	**Sheyenne River – 02**		WR03X05	890.64
RE01X05	854.48	SH02X01	877.51	WR02X06	890.73
RE01X06	854.53	SH02X02	877.57	**Wild Rice River – 03**	
RE01X07	854.56	SH02X03	877.68	WR03X01	895.75
Red River – 02		SH02X04	877.81	WR03X02	895.78
RE02X01	857.96	SH02X05	877.91	WR03X03	895.90
RE02X02	858.06	SH02X06	877.95	WR03X04	895.95
RE02X03	858.18	**Sheyenne River – 03**		WR03X05	896.02
RE02X04	858.30	SH03X01	881.98	WR03X06	896.07
RE02X05	-- [3/]	SH03X02	882.08	**Wild Rice River – 04**	
RE02X06	858.53	SH03X03	882.15	WR04X01	898.67
Red River – 02A		SH03X04	882.17	WR04X02	898.77
RE02AX01	858.87	SH03X05	882.30	WR04X03	898.85
RE02AX02	859.10	SH03X06	882.48	WR04X04	898.91
RE02AX03	859.14	**Sheyenne River – 04**		WR04X05	898.98
RE02AX04	-- [3/]	SH04X01	888.18	WR04X06	899.00
RE02AX05	859.33	SH04X02	888.23	**Wild Rice River – 05**	
RE02AX06	859.44	SH04X03	888.31	WR05X01	900.77
Red River – 03		SH04X04	888.41	WR05X02	900.81
RE03X01	873.46	SH04X05	888.57	WR05X03	900.84
RE03X02	873.59	SH04X06	888.66	WR05X04	900.86
RE03X03	873.76	**Sheyenne River – 05**		WR05X05	900.87
RE03X04	873.82	SH05X01	891.55	WR05X06	900.90

Cross Section	Bankfull Elevation (ft NAVD88) [1/]	Cross Section	Bankfull Elevation (ft NAVD88) [1/]	Cross Section	Bankfull Elevation (ft NAVD88) [1/]
RE03X05	873.89	SH05X02	891.55	**Wild Rice River – 06**	
RE03X06	873.99	SH05X03	891.55	WR06X01	903.76
Red River – 04		SH05X04	891.55	WR06X02	903.86
RE04X01	881.72	SH05X05	891.55	WR06X03	903.99
RE04X02	881.89	SH05X06	891.55	WR06X04	904.07
RE04X03	881.96	**Sheyenne River – 06A** [2/]		WR06X05	904.16
RE04X04	882.08	SH06AX01	907.76	WR06X06	904.23
RE04X05	882.25	SH06AX02	907.87	**Wild Rice River – 07**	
RE04X06	882.37	SH06AX03	907.96	WR07X01	914.63
Red River – 05		SH06AX04	908.12	WR07X02	914.69
RE05X01	886.83	SH06AX05	908.21	WR07X03	914.76
RE05X02	886.83	SH06AX06	908.39	WR07X04	914.82
RE05X03	886.86	**Sheyenne River – 06**		WR07X05	914.84
RE05X04	886.89	SH06X01	908.96	WR07X06	914.86
RE05X05	886.97	SH06X02	908.98	**Wild Rice River – 08**	
RE05X06	887.08	SH06X03	909.08	WR08X01	916.30
Red River – 06		SH06X04	909.16	WR08X02	916.35
RE06X01	889.29	SH06X05	909.16	WR08X03	916.40
RE06X02	889.40	SH06X06	909.21	WR08X04	916.43
RE06X03	889.56	**Sheyenne River – 07**		WR08X05	916.47
RE06X04	889.68	SH07X01	913.59	WR08X06	916.52
RE06X05	889.78	SH07X02	913.72	WR08X07	916.61
RE06X06	889.88	SH07X03	913.83		
Red River – 06A		SH07X04	913.93		
RE06AX01	890.07	SH07X05	913.96		
RE06AX02	890.12	SH07X06	914.04		
RE06AX03	890.14	SH07X07	914.09		
RE06AX04	890.26	SH07X08	914.13		
RE06AX05	890.32	**Sheyenne River – 08**			
RE06AX06	890.36	SH08X01	925.65		
Red River – 07		SH08X02	925.83		
RE07X01	RE07X01	SH08X03	925.96		
RE07X02	RE07X02	SH08X04	925.97		
RE07X03	RE07X03	SH08X05	926.15		
RE07X04	RE07X04	SH08X06	926.28		
RE07X05	RE07X05				
RE07X06	RE07X06				

[1/] Except where noted, all bankfull elevations from WEST (2019)
[2/] Bankfull elevations from WEST (2021)
[3/] Proposed new cross sections for 2022 – bankfull elevations not established yet

7.1.4 Aerial-Image Derived Bank Line Locations

Identification of bank line locations using aerial imagery is dependent on many factors, including scale, process, and judgment. The following protocol has been used by WEST in their geomorphic assessments and is recommended for use in future assessments for trigger comparison purposes. For demonstration purposes, the protocol described below uses the year 2020, which is the most recent year for which bank line locations were delineated by WEST in their 2021 report. The actual year in the protocol will change and should be based on the most recent year for which bank line locations have been delineated.

1. Load the 2020 aerial imagery and 2020 delineated bank line shapefile into GIS.
2. Set the scale in GIS to 1:1,000, which is the scale at which the WEST (2021) assessment delineated bank line locations.
3. Compare the delineated 2020 bank line locations with the 2020 aerial imagery to understand and the general judgment process used for delineating the 2020 bank line locations so it can be replicated for determining the current year bank line locations.
4. Make a copy of the 2020 bank line locations shapefile, rename it to the current year being evaluated, and load it into GIS.
5. Load the current year aerial imagery into GIS.
6. Compare the copied/renamed 2020 bank line locations shapefile with the current year aerial imagery. If bank line locations have notably moved at the 1:1,000 scale, edit the copied/renamed 2020 bank line locations shapefile to reflect the change.

In the event multiple years of aerial imagery are to be evaluated during one assessment, the use of the most recent year of delineated bank lines should still be used. For example, if conducting an assessment using 2023 and 2026 aerial imagery, the 2020 bank line shapefile should be the one edited to define the 2023 bank line locations, while the newly created 2023 bank line shapefile should be the one edited to define the 2026 bank line locations, always working in sequential order from oldest to newest imagery.

If channel sinuosity, meander amplitude, or meander frequency metrics are desired, the following process shall be used:

1. Create stream centerline shapefiles using the delineated left and right bank line shapefiles and the "Collapse Dual Lines to Centerline" tool in ArcGIS's ArcToolbox (or similar tool for a different GIS program). Centerlines obtained from the "Collapse Dual Lines to Centerline" tool are very similar and for the most part identical to what would be obtained if the stream centerline were digitized separately.
2. Use the methodology described in Heo et al. (2009) to find the centroid and radius of an imaginary circle best fit to the data points along the digitized bank line that represents the bend line.

7.2 Protocols for Other Work

7.2.1 Survey Data

Cross-sectional survey data below the top of bank shall be collected with no more than 10 feet between each point, with at least 5 points along the channel bottom and 3 points along each channel bank, as well as points at every notable slope change location. Between the cross-section monuments and top of bank, data shall be collected with no more than 20 feet between each point and at every notable slope change location. Longitudinal profile data shall be collected with no more than a 10 foot spacing between each point along the profile.

7.2.2 Sediment Sample Analysis

All sediment samples shall be assessed by identifying the classification (following ASTM D2488), particle size distribution (following ASTM D7928), particle density (following ASTM D854, Method B), and organic content analysis (following ASTM D2974, Method C). A photograph and the northing and easting location for each sample collected shall also be collected.

7.2.3 Rosgen Assessments

All Rosgen assessments and worksheets shall be conducted and completed in accordance with those processes outlined in Watershed Assessment of River Stability and Sediment Supply (Rosgen, 2006). All field assessment crew leads shall have at least 10 years of experience in riverine geomorphic assessments, measurements, and analysis. If more than one field crew is deployed at the same time, the field crew lead for each team shall meet this requirement. It is also recommended, though not required, that all geomorphic assessment field crew leads have Rosgen training through the Level III channel stability assessment.

7.3 Data Management

The RIVERMorph data management software package (www.rivermorph.com) associated with the Rosgen stream assessments should be part of the data management and analysis package. Surveyed cross-sectional data, field-observed bankfull elevations, longitudinal profile data, sediment size data, roughness parameters, and riparian vegetation characteristics shall be entered into the software for each cross section. If field-observed values (such as bankfull elevation calls) are manually changed or altered due to additional/outside analysis (such as HEC-RAS or other modeling), the Contractor shall include a list of the changes as well as the explanation for each change. This list shall include both the field-estimated values as well as the adjusted values.

Other data, such as survey data, hydraulic models, spreadsheets analyses, and GIS data, shall be provided in an electronic format as an attachment to the geomorphic assessment report.

7.4 Data Storage and Exchange

The data will need to be accessible and shared for redundancy and analysis purposes as well as stored as part of the monitoring record and for future data needs. The FMM Project's non-Federal sponsors shall manage and host the official repository of all of the data sets and completed analysis related to the FMM Project into perpetuity and make this data accessible via a web interface. Data from the watershed districts and others may be included in this data base. At present, the Aconex site (https://us1.aconex.com/Logon) serves as the repository for all reports and associated electronic data. The FMM Project's non-Federal sponsors shall provide access to this site for all members of the GMT and AMT upon request.

Raw data shall be shared within 2 months of the end of the data collection or as soon as possible. Post-processed data shall be shared with all GMT and AMT members within 2 weeks of finalization. Results shall be shared to AMT members at least 6 months prior to the next anticipated field geomorphic monitoring effort.

8 GEOMORPHIC MONITORING SCHEDULE AND GMP UPDATES

8.1 Pre-FMM Project

A total of three pre-FMM Project geomorphic assessments have been completed and are documented in WEST (2012, 2019, and 2021). All three sets of monitoring results were analyzed by the GMT during working meetings that occurred in November 2021 and February 2022. Any changes that were deemed significant by the GMT were discussed at these meetings. The working meetings for interpreting the analyzed data with regards to geomorphic stability were open and scheduled for participation by all of the interested agencies. It is noted that external facilitation was used and found to be a beneficial approach for reaching consensus decisions. As a result of the meetings, the GMT provided a summary of the interpretation and a list of recommended GMP updates to the AMT in May 2022. The GMT considered the following in their recommendations:

- the magnitude and rate of the noted changes and the significance of the potential consequences resulting for those changes, including whether triggers should be added, removed, or adjusted
- whether each geomorphic assessment component is providing relevant and valuable information and, if it is not, recommend additions/subtractions/alterations to the AMT to ensure the appropriate data is being gathered
- whether the monitoring schedule for different reaches is appropriate, and if not, identify what frequency of sampling is needed (for example, if the Red River is deemed to be more stable than the tributaries, the tributaries may need more frequent monitoring than the Red River)
- whether aerial imagery collection can be reduced to once every 5 years post FMM-Project, with data collected the year prior to the next scheduled geomorphic assessment so that the data is available for the assessment (also ensuring that it is consistent with the initial schedule for the post-FMM Project geomorphic monitoring)

The AMT was ultimately responsible for determining appropriate responses and actions based on the GMT recommendations. Those responses and actions were incorporated into this GMP.

Additional pre-FMM Project sampling events may occur during construction if a large flood event occurs that would have resulted in operation of the Red River and Wild Rice River structures if the Project construction was complete, which is currently defined as an event causing the combined flows at the USGS gages on the Red River at Enloe and the Wild Rice River at Abercrombie to exceed 21,000 cfs. In the event of multiple successive years of project operation floods, the GMT will meet to recommend whether the second or later events are monitored and at what level of detail based on the data collected from the previous event(s). After successive events close in time, the GMT will meet to see if it can identify criteria for supporting the decision-making process related to future assessments. Any information collected during FMM Project Construction will be compared to information presented in the 2012, 2019, and 2021 reports to provide a baseline for comparisons to post-FMM Project conditions.

8.2 Post-FMM Project

Post-FMM Project, data for field data-based investigations (see Section 5.1) shall be collected within one year of FMM Project completion and a report summarizing the geomorphic monitoring efforts (see Sections 5.2 through 5.4) finalized within 2 years to establish baseline post-FMM Project conditions. Two additional Post-FMM Project geomorphic assessments shall also be completed: one 5 years after this initial post-FMM Project assessment and one 10 years after the initial assessment.

It is noted that the total cost of each pre-FMM Project geomorphic assessment was approximately $1,000,000 for the combined survey and geomorphic assessment effort. Therefore, to ensure taxpayer funds are used in an efficient, effective, and appropriate manner, the GMT shall convene and provide a recommendation to the AMT about reducing the geomorphic assessment frequency to every 10 years (or some other frequency), especially if no significant changes in the channel morphology are noted. As part of its recommendation to the AMT, the GMT shall also consider whether future assessment efforts should only be focused on any areas exhibiting significant changes.

For each of the areas flagged for further investigation by the aerial imagery-based stability analysis, a site-specific field reconnaissance and survey may need to be conducted to understand the local conditions of the site and to help understand the causation for the noted changes.

The first three sets of post-FMM Project monitoring results shall be analyzed by the GMT during working meetings following receipt of the third round of post-FMM Project monitoring (e.g., 10 years after the initial post-FMM Project geomorphic monitoring), noting any changes deemed significant by the GMT. These meetings shall be initiated within 90 calendar days of the finalization of the third post-FMM Project report. The working meetings for interpreting the analyzed data with regards to geomorphic change should be open and scheduled for participation by all of the interested agencies. It is noted that external facilitation might be a beneficial approach, especially if it is anticipated that reaching consensus decisions may be difficult. As a result of the meetings, the GMT shall then provide a summary of the interpretation and a list of recommended GMP updates (if any) to the AMT within 180 calendar days of the finalization of the third post-FMM Project report. At a minimum, the GMT should consider the following in their recommendations:

- the magnitude and rate of the noted changes and the significance of the potential consequences resulting for those changes, including whether triggers should be added, removed, or adjusted
- whether each geomorphic assessment component is providing relevant and valuable information and, if it is not, recommend additions/subtractions/alterations to the AMT to ensure the appropriate data is being gathered
- what future post-FMM Project monitoring schedule is needed (for example, once every 10 years, only after the FMM Project operates, etc.), taking into consideration that the monitoring schedule may differ for different reaches
- what future aerial imagery collection schedule is needed, with data collected the year prior to the next scheduled geomorphic assessment so that the data is available for the assessment

8.3 Flood Event

If a flood occurs that would have resulted or did result in operation of the Red River and Wild Rice River structures, either before or after the project is operational, another geomorphic assessment shall occur. The field investigation portion of the geomorphic assessments shall be completed either by the end of the calendar year in which the operation occurred or within 6 months after flows recede to below bankfull flow levels, whichever is later. The final flood event report shall be provided within 1 year of the completion of the field investigation effort.

In the event of multiple successive years of project flood operations, the GMT shall meet during or soon after the second flood to recommend whether the second or later events should be monitored and at what level of detail based on the data collected from the previous event(s). After successive events close in time, the GMT shall meet to see if it can identify criteria for supporting the decision-making process.

The GMT shall be provided an opportunity to provide input to and review the flood event scope of work prior to the field assessment being conducted. All comments shall be provided by the GMT to USACE or the non-Federal sponsors, as appropriate, within 21 calendar days of scope of work receipt.

The GMT shall provide a recommendation to the AMT whether a flood event assessment can be used as a substitute for any regularly-scheduled geomorphic assessment.

8.4 Trigger Timelines

When triggers are known to be exceeded, likely either a result of public/agency notification and subsequent review or as a result of a post-FMM Project geomorphic assessment, GMT meeting(s) will be held within 30 calendar days of notification for the purpose of making recommendations to the AMT in accordance with the process outlined in Section 6.2. The GMT shall then provide recommendations to the AMT for action / no action supported by data, analysis, and discussion by the experts within the next 30 calendar days for a total of 60 calendar days from notification to recommendation. The GMT shall remain responsive to the AMT, providing additional information and clarifications when requested and may need to call additional meeting(s) if further recommendations are required to achieve a rated consensus.

As part of the AMT's consideration of the GMT's recommendations, for effective adaptive management, the AMT, GMT, and other monitoring teams shall meet together to discuss the inter-related impacts of the changes in the system and potential corrective actions. Near bank vegetation and habitat both in and out of the stream are tied to the geometric and geomorphic characteristics of a stream.

9 GEOMORPHIC MONITORING TEAM COMMUNICATON PLAN AND DECISION PROCESS

To successfully implement a GMP will require coordinated communication and clear decision rules for the collaborative work of the agencies and stakeholders in planning, funding, and executing the GMP. The AMMP contains much of the structure needed to support GMT; therefore, the communication plan described herein is in addition to the structure outlined in the AMMP. Requests from GMT members to schedule meetings to discuss specific concerns (i.e., meetings that not regularly scheduled) shall be addressed within 30 calendar days of the request being made.

9.1 Communication Plan and Meetings

Regularly scheduled annual or more frequent communication shall be established with GMT members, any interested AMT member(s), representatives from agencies, and other interested stakeholders (including but not limited to the USDA-NRCS, college extension services, farming co-ops and local landowners, irrigation and drainage districts, etc.). Such communication efforts will allow for real or perceived changes in channel morphology to be documented and flagged for further evaluation. Regular communications will help focus the monitoring efforts and allow for concerns to be documented and appropriately addressed.

Prior to each of the post-FMM Project geomorphic assessments, coordination between the identified technical experts/organizations shall be done at least 6 months in advance of the actual field work to allow for schedule adjustments or GMP modifications. It is acknowledged that the AMT will be sent the recommended schedule and any deviations based on the geomorphic needs. In turn, the AMT shall be informed at least 6 months in advance of the field season and provided the opportunity to suggest changes or necessary deviations based on other criteria like funding or changes in FMM Project operation and other unanticipated changes. The advance notice is needed to allow time for changes in scope to be negotiated with the geomorphic assessment team (or contractors) after review and input from the GMT.

After each individual geomorphic assessment, a summary of findings shall be presented to the GMT. The GMT members shall also be provided with an opportunity to review each geomorphic assessment report. All GMT member review comments will be due to either USACE or the non-Federal sponsors, as appropriate, within 21 calendar days of report receipt.

As discussed in greater detail in Section 8, working meetings shall also be held to evaluate the three pre-FMM Project geomorphic assessments and the first three post-FMM Project geomorphic assessments with the purpose of determining GMP modification recommendations, as appropriate.

All AMT members shall be informed of and invited to GMT meetings to provide for the opportunity for AMT members to observe and participate in these meetings. GMT members are responsible for informing the AMT of upcoming personnel changes and providing an agency-authorized alternate or replacement upon retirement or reassignment.

The GMT shall be notified by the AMT and/or non-Federal sponsors of geomorphic issues or concerns identified outside of the regular monitoring process and hold a meeting to identify next steps within 45 calendar days of initial notification to the AMT and/or non-Federal sponsors.

9.2 Decision Process

The GMT is charged with providing expert technical advice and recommendations to the AMT for their consideration. The GMT will use a consensus-based approach for providing recommendations to the AMT. One approach for reaching and documenting consensus that the GMT has used successfully is a 5-point rating that helps distinguish the level of buy in by the participants on a specific recommendation. The 5-point scores are ratings that are not to be added to form an overall score for a specific proposal and does not constitute a vote. Rather, the 5-point scores serve as expert elicitation that can be attributed to specific GMT members if helpful for the AMT consideration.

9.2.1 5-Point Consensus Rating Scale

The following bullets represent descriptions of each of the 5 ratings:

- 5 – Fully support idea, would endorse and/or help to implement
- 4 – Good idea, maybe not exactly as would have chosen, but good enough
- 3 – Meets expectations, can “live with it” but have some questions and/or reservations
- 2 – Needs improvement and/or have some serious questions or suggestions for revision
- 1 – Poor and/or cannot support in current form at all

9.2.2 5-Point Consensus Rating Process

The 5-Point consensus process is a rapid way of checking in with a team on their level of buy-in on an idea and to daylight both enthusiasm and issues or concerns with its potential implementation in a documentable format. There are a few steps to the process:

- Formulate recommendation statement
- Participants ask clarifying questions about the recommendation
    - It is important that individuals are clear on what they are rating.
    - At this point, wait to have in-depth discussion of support or concerns until after the rating.
- Each individual rates the recommendation using the 5-point rating scale
    - In a face to face meeting this can start with everyone just raising a hand with the number of fingers raised to indicate their rating and the meeting facilitator can do a quick hand count of the groups rating.
    - On a virtual meeting the scores may be entered into a chat feature, spoken by the attendees, or using a polling tool or white board for people to indicate on the 5-point

scale their rating.

- For any scores 3 and below: the individual shall share what it would take to raise the score to a 4
    - The very process of choosing a score helps an individual identify why they believe their rating is correct. The individual will have a sense of what prevents it from having a higher score and why it does not deserve a lower score, which will allow benefits and concerns to be captured and discussed.
    - Sharing that insight with the team helps identify a path forward through discussion or needed actions for issue resolution.
- If all scores rise to a score of 3 or higher the GMT recommendation shall be carried forward to the AMT.
    - Ask for and document any remaining questions or issues or endorsements for the recommendation that the GMT experts would like the AMT to consider in their decisions.
- If scores remain below 3 then the recommendation can be dropped, or specific tasks defined to resolve remaining issues for future consideration by the GMT.
- Finally, document the recommendations with a tally of the ratings and statements of support, issue consideration and resolution, and outstanding questions for future consideration to forward to the AMT. This provides the AMT with a complete understanding of the level of consensus and details that may help the AMT's decision process.

10 REFERENCES

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